PERFORMANCE OF BIOCLIMATIC DESIGN STRATEGIES AT RESIDENTIAL COLLEGE BUILDINGS IN UNIVERSITY OF MALAYA

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ABSTRACT

Preliminary studies of twelve residential colleges located in the University of Malaya campus, Kuala Lumpur were conducted to evaluate the effectiveness of their current implementation of bioclimatic design strategies, as well as their performance in terms of electricity usage. It was found that residential college buildings designed with an internal courtyard and balconies for each room achieve the most efficient electricity use, within a range of between 24 to 33 kWh/m^2/year, while other residential college buildings recorded annual electricity use of between 40 to 125 kWh/m^2/year.

One of them, 5th residential college (5th RC) was selected for the case study due to its best implementation of bioclimatic design strategies that encourage efficient energy use. Furthermore, its uniform building layout minimises uncontrolled variables in further field investigation and evaluations.

The satisfaction and perception surveys show that a majority of respondents at 5th RC are at a comfortable level. This is based on findings from all performance indicators of functional elements, thermal comfort and indoor air quality, as well as, visual comfort and landscape elements. The 5th RC is capable to provide a comfortable living space with indoor temperatures ranging from 28°C to 30°C with 70% to 78% relative humidity. Different locations have different effects on room conditions and higher temperatures were recorded at rooms on the top level of the building compared to rooms at the lower levels. There were no significant differences detected owing to different orientation of rooms which are largely due to the effects of the green landscape. Higher values of daylight intensity were recorded in the corridor compared to the daylight intensity in the rooms which even varies in amount at different areas within the same room. Further analysis show that night ventilation provides better thermal comfort for residents compared to other ventilation options like full-day and daytime ventilation or no ventilation at all.

The living behaviour assessment reveals that residents of 5th RC have adapted well to maintain the comfort level in their rooms. Only light activities were conducted in the rooms which reduces the metabolic heat production. Ceiling fans were fully utilized at the maximum speed of five for maintaining air circulation in the rooms where the operable windows are closed most of the time due to the safety issues. Light clothing was worn at most times, especially on sunny days. In fulfilling the need for privacy, curtains have been overused and leading to the use of artificial lighting.

The study concludes, residential college buildings that implement the appropriate bioclimatic design strategies, particularly to address natural ventilation and daylighting issues tend to achieve a desired comfort level and efficient electricity usage. With a well-planned design improvement, better results can be achieved without sacrificing the needs and comfort level of the residents.

ABSTRAK

Kajian awal di dua belas buah kolej kediaman yang terletak di dalam kampus Universiti Malaya, Kuala Lumpur telah dijalankan bagi menilai keberkesanan terhadap pelaksanaan semasa strategi reka bentuk bioiklim, serta prestasi penggunaan tenaga elektrik. Didapati kolej-kolej kediaman yang direka dengan halaman dalaman dan beranda di setiap bilik mencapai tahap penggunaan elektrik yang paling cekap iaitu di dalam lingkungan 24 hingga 33 kWh/m^2/tahun. Manakala, antara 40 dan 125 kWh/m^2/tahun penggunaan elektrik telah direkodkan di lain-lain bangunan kolej kediaman.

Salah satu daripadanya, iaitu Kolej Kediaman Kelima (KK 5) telah dipilih sebagai kajian kes berdasarkan kepada pengadaptasian terbaik strategi reka bentuk bioiklim yang mendorong kepada penggunaan tenaga elektrik yang lebih cekap. Seterusnya, susun atur bangunan yang seragam meminimakan pembolehubah tidak terkawal bagi siasatan dan penilaian lanjutan.

Tinjauan kepuasan dan persepsi menunjukkan bahawa majoriti responden di KK5 berada pada tahap yang selesa. Ini berdasarkan kepada penemuan daripada kesemua petunjuk prestasi yang terdiri daripada elemen seni bina, keselesaan terma dan kualiti udara dalaman, keselesaan visual dan landskap. KK 5 dapat menyediakan ruang tamu yang selesa dengan suhu dalaman antara 28°C hingga 30°C, serta kelembapan relatif antara 70% hingga 78%. Lokasi berlainan memberikan keadaan yang berbeza di mana suhu dalaman yang lebih tinggi direkodkan di aras atas bangunan berbanding dengan aras yang lebih rendah. Tiada perbezaan keadaan yang ketara berdasarkan kepada orientasi bilik disebabkan oleh pengaruh landskap hijau dipersekitaran bangunan. Nilai keamatan cahaya yang lebih tinggi telah direkodkan di koridor berbanding di dalam bilik dan terdapat perbezaan pada nilai yang dicatatkan walaupun di dalam bilik yang sama. Analisis selanjutnya menunjukkan pengudaraan semulajadi di waktu malam memberikan lebih keselesaan terma kepada penginap berbanding lain-lain strategi pengudaraan; pengudaraan sepanjang hari, pengudaraan di waktu siang dan tiada langsung pengudaraan.

Penilaian tingkah laku penghuni mendedahkan bahawa penginap di KK5 telah dapat menyesuaikan diri dengan baik dalam mengekalkan tahap keselesaan mereka di dalam bilik. Hanya aktiviti ringan dilakukan di dalam bilik bagi mengurangkan pengeluaran haba metabolik. Kipas siling telah digunakan sepenuhnya pada kelajuan maksimum; iaitu lima, untuk mengekalkan peredaran udara di dalam bilik apabila tingkap ditutup sepenuhnya pada kebanyakan masa disebabkan oleh isu-isu keselamatan. Pakaian yang nipis dipakai pada kebanyakan masa terutama pada hari yang cerah. Dalam memenuhi keperluan privasi, langsir telah digunakan secara berlebihan dan memaksa penggunaan cahaya tiruan.

Penyelidikan merumuskan bahawa bangunan-bangunan kolej kediaman yang mengaplikasikan reka bentuk bioiklim yang bersesuaian terutamanya berkaitan pengudaraan dan pencahayaan semulajadi dapat mencapai tahap keselesaan yang diingini dan penggunaan tenaga elektrik yang lebih cekap. Dengan penambahbaikan yang dirancang secara rapi, keadaan yang lebih baik boleh dicapai tanpa perlu mengorbankan keperluan dan tahap keselesaan penginap.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	percentage
Δt_{pr}	:	asymmetry of thermal radiation
°C	:	degree Celsius (unit of temperature)
µm	:	micrometre
a.m.	:	*Ante Meridiem*/before noon
ASHRAE	:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BBC	:	Bâtiment de basse consommation énergétique
BCA	:	Building and Construction Authority
BEE	:	Building Environmental Efficiency
BEI	:	Building Energy Index
BERNAMA	:	Berita Nasional Malaysia
BOD	:	Biochemical oxygen demand
BREEAM	:	Building Research Establishment Environment Assessment Method
CASBEE	:	Comprehensive Assessment for Building Environmental Efficiency
CETREE	:	Centre for Education, Training and Research in Renewable Energy and Energy
CH_4	:	methane
clo	:	unit of thermal insulation of clothing
cm	:	centimetre
CO_2	:	carbon dioxide
CO_2e	:	carbon dioxide equivalent
DDT	:	dichlorodiphenyltrichloroethane (synthetic insecticides)
DF	:	Daylight Factor
DR	:	Draught Rating
E	:	east
EE	:	energy efficient
EEI	:	Energy Efficiency Index
EPU	:	Economic Planning Unit
ET	:	effective temperature
Fig.	:	figure
FiT	:	Feed-in-Tariff
ft	:	feet
g	:	gram
GBCA	:	Green Building Council Australia
GBCI	:	Green Building Council Indonesia
GBI	:	Green Building Index
GEF	:	Global Environmental Facility
GEO	:	Green Energy Office
GF	:	ground floor
GHGs	:	Green house gasses
GLC	:	Government-Linked Company
GWP	:	Global Warming Potential
h	:	hour
HVAC	:	Heating, Ventilation and Air Conditioning
Hz	:	hertz (unit of frequency)
IEA	:	International Energy Agency
IES	:	Illuminating Engineering Society
INC/FCCC	:	Intergovernmental Negotiating Committee for Framework Convention on Climate Change
IPCC	:	Intergovernmental Panel on Climate Change
ISO	:	International Standard Organization
K	:	Kelvin
KLCC	:	Kuala Lumpur City Centre

kWh : kilowatt hour
LAI : Leaf Area Index
LEED : Leadership in Energy and Environmental Design
LEO : Low Energy Office (LEO) Building
lumen : unit of luminous flux
lux : unit of illuminance
lx : lux
m/s : metre per second
m^2 : metre square metre
met : unit of metabolic rate
mm : millimetre
mmBTU : million metric British Thermal Units
MoHE : Ministry of Higher Education
N : north
N_2O : nitrous oxide
NFPEs : Non-Financial Public Enterprises
NKRA : National Key Economic Area
NO_x : nitrogen oxides
O_3 : ozone
OTTV : Overall Thermal Transfer Value
p.m. : *Post Meridiem*/after noon
Pa : unit of relative humidity
PJ : petajoule
PMV : Predicted Mean Vote
POE : Post Occupancy Evaluation
PPD : Predicted Percentage of Dissatisfied
PTM : Pusat Tenaga Malaysia
PV : photovoltaic
Q_g : heat conduction through glass windows
Q_w : heat conduction through opaque walls
R&D : Research and Development
RC : residential college
RE : renewable energy
RETV : Residential Envelope Transmittance Value
RH : relative humidity
RIBA : Royal Institute of British Architects
RM : Ringgit Malaysia
RTTV : Roof Thermal Transfer Value
S : south
SBS : Sick Building Syndrome
SC : shading coefficient
SD : standard deviation
SEAI : Sustainable Energy Authority of Ireland
SET : Standard Effective Temperature
SF : solar factor (Wm^{-2})
Sig. : Significant
SIRIM : Standards and Industrial Research Institute of Malaysia
SO_x : sulphur oxides
sp. : species
SPSS : Statistical Package for the Social Sciences (computer program)
t_a : air temperature
T_c : comfort temperature
t_{eq} : equivalent temperature
T_i : mean indoor air temperature
T_m : mean monthly dry bulb temperature
T_n : thermal neutrality
$T_{n,i}$: neutral temperature based on mean indoor air temperature

$T_{n,o}$	:	neutral temperature based on mean outdoor air temperature
TNB	:	Tenaga Nasional Berhad
T_o	:	outdoor air temperature
t_o	:	operative temperature
t_{pr}	:	plane radiant temperature
t_r	:	mean radiant temperature
T_{sens}	:	thermal sensation
TSV	:	thermal sensation votes
Tu	:	turbulence intensity
Uf	:	U-value of the opaque part of the fenestration
UK	:	United Kingdom
UM	:	University of Malaya
UN	:	United Nation
UNEP	:	United Nations Environmental Programme
UNFCCC	:	United Nations Framework Convention on Climate Change
UPM	:	Universiti Putra Malaysia
USA	:	United States
U-value	:	overall heat transfer coefficient
Uw	:	U-value of the opaque part of the wall
V_a	:	local mean air velocity
V_a	:	air velocity
W	:	watt (unit of power)
W	:	west
WI	:	Well Index
WMO	:	World Meteorological Organization
WWR	:	Window Wall Ratio

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CHAPTER 1
Introduction

1.1 Research background

The depletion of natural resources especially fossil fuels has increased the price of energy steadily around the world. The price of energy in Malaysia is still competitively quite low due to fuel subsidies. As a Government-Linked Company (GLC), Petronas supplies natural gas to Tenaga Nasional Berhad (TNB); which is the main electricity provider in Peninsular Malaysia, at a discount price of 76% less than international market rates (Chan, 2009a). New tariff rates were announced effective June 1st, 2011 where the average tariff has been increased by 7.12% of which 5.12% increment is due to 28% upward revision of natural gas price to the power sector from RM 10.70 per million metric British Thermal Units (mmBTU) in the last tariff adjustment in March 2009 to RM 13.70 per mmBTU, while the other 2.0% increment is due to higher electricity supply cost since June 2006 (TNB, 2011).

Approximately, 65% of power stations are relying on natural gas and if gas were supplied at international rates, electricity tariffs would increase by 25% (Chan, 2009a; Rahman, 2009). Any increase in fuel price means higher costs to generate electricity which are then passed on to consumers (Berita Nasional Malaysia, 2010). According to Pusat Tenaga Malaysia (2008), Malaysia will become a net importer of energy by 2015. Wasteful energy uses lead to greenhouse gas emissions and ultimately contribute to climate change (Saidur et al., 2007; United Nations, 1992). Thus, the energy reserves that we have today should be conserved through efficient use in a sustainable manner to mitigate the impact on the environment and avoid energy shortages.

The building sector was identified as a good start in energy conservation due to it being the third largest energy consumer in Malaysia (Economic Planning Unit, 2006).

This sector contributes to 40 % of the world total greenhouse gasses (GHGs) emissions and up to 80 % of emissions in the city area (Atkinson, 2009). These findings are supported by Al-Mofleh et al. (2009) who reported that commercial and residential buildings alone account for about 13% of total energy consumption and 48% of electricity consumption in Malaysia. This figure can be decreased by constructing energy efficient buildings, which however also simultaneously increase construction costs by up to 15% higher than conventional designs (Al-Mofleh et al., 2009).

The increase of construction costs will be paid off by the long term benefits of the energy efficient buildings. Energy efficient buildings would protect jobs in the building sector, stimulate new job growth, lead to better health, productivity and quality of workers, reduce or even avoid the need to invest in energy infrastructure whether for the maintenance and upgrading of existing infrastructure, or for building new power plants (Atkinson, 2009). According to Levine et al. (2007), energy efficient buildings can improve indoor and outdoor air quality, social welfare and improve energy security.

At present, other than the term 'bioclimatic design', terms like 'sustainable building', 'green building', 'eco design' and many more have become popular in the building sector. Although the literal meanings of the terms are different, but their aims are similar in promoting efficient use of natural resources especially energy and water, as well as the application of renewable energy in running the functions of buildings so as to create a healthier environment. These design approaches can significantly reduce or even eliminate negative environmental impacts and improve existing unsustainable designs, constructions and operation practices (Tiyok, 2009).In fact, these approaches have already been adopted in many traditional/vernacular architecture of the past, which fully utilises the concepts of natural ventilation, daylight, massive walls, light exterior surfaces, etc. (Tantasavasdi et al., 2001; Lechner, 2009). All of these concepts have turned out to be the focus of attention recently, due to climate change issues.

In the equatorial region, there are three main elements of building services (Omer, 2008). Which are; the conditioning for thermal comfort, lighting for visual comfort, and ventilation for indoor air quality. Ventilation provides clean air to a space for the purpose of meeting the metabolic requirements of occupants and to dilute and remove pollutants emitted within a space. Unfortunately, poor building design could lead to higher than necessary electricity usage for lighting and cooling load in order to obtain the ideal comfort level in buildings. This may have a major impact on the wastage of energy through artificial lighting and mechanical cooling. Consequently, how well we design our buildings will be reflected in how much energy will be required to run them.

The sun, heat and high humidity of the Malaysian climate are key elements to be considered. According to Nugroho et al. (2007), a good house design keeps the indoor environment favourable and comfortable during most of the year without the use of any mechanical devices and also with sufficient airflow through the building that dehumidifies the high humidity percentages of the indoor climate. The use of day lighting as a passive solar source can contribute to the reduction of energy consumption where effective uses of daylighting directly reduce the energy required for heating, cooling and lighting to condition buildings. In the long run, the implementation of passive design can reduce operating costs, enhance building marketability, reduce potential liability from indoor air quality problems and increase worker productivity (Tiyok, 2009). Thus, the provision for air circulation and daylighting as a passive solar source must be given high priority as the most important considerations in building design, even if electricity demand remains a crucial element to meet sustainability requirements of passive and low energy systems and also while achieving the required comfort level in a building.

The residential college building; which is also known as a multi-residential building, in the equatorial region, is the best option to provide accommodation facilities for a large number of students when land spaces are an issue. A multi-residential building typically plays the role of students' halls of residence, key worker accommodation, care homes and shelter houses which contain catering facilities, lounges, dining rooms, health and leisure area, offices, meeting rooms and other support areas like laundry facilities (Building Research Establishment Environment Assessment Method, 2010). With regards to the residential colleges in Kuala Lumpur, most of the activities in a student room are sedentary activities including sleeping, relaxing, studying and class preparation.

There are only a small number of studies that have been done on a residential college building specifically in the equatorial region (Dahlan et al., 2009) compared to studies that have been conducted for the temperate climate (Balaras et al., 2000; Oseland, 1994; Ghisi & Massignani, 2007; Pfafferott et al., 2007). Most of the reported studies in the equatorial region focus on common residential buildings like single and double storey houses, flat houses and apartments (Wong et al., 2002; Ghisi & Massignani, 2007; Indraganti, 2010; Mohit et al., 2010) which are quite different in terms of building layout, services provided and occupant activities.

Dahlan et al. (2009) conducted a study on indoor comfort perceptions in the typical Malaysian multi-storey hostel, which is possibly the first study done on multi-storey hostel buildings in Malaysia. Unfortunately, this study does not represent multi-residential buildings in Malaysia as a whole because the building that was studied, like most other existing multi-storey hostels in Malaysia, especially those built in 1990's and earlier are classified as low-rise buildings with four levels and below in terms of building height. In addition to that the number of respondents for the subjective measurements was quite small; approximately 95 respondents for each case study.

Therefore they do not directly represent the selected high rise multi-storey hostels as a whole due to the number of residents which exceeds 2000 people.

In the University of Malaya (UM) campus, there are twelve residential colleges that can accommodate up to 12,000 students (UM, 2009). These figures directly demonstrate the quantity of energy needed for the buildings to function. Most of the residential colleges can be classified as old buildings. The first residential college was built in 1959 and is known as the Tunku Abdul Rahman Residential College, and the most recent is the Raja Dr. Nazrin Shah Residential College which was established in 2002. The design and capacity of each residential college building vary due to the available space during the time of construction. The Ibnu Sina Residential College was built in 1967 to provide accommodation for clinical students whereas the Raja Nazrin Shah Residential College which has the highest capacity is able to comfortably accommodate 2990 students at any one time as the university expands. This shows that there is a need for bigger capacity residential colleges to provide comfortable accommodation for students when other residential colleges are no longer sufficient and with the increasingly limited space in which to develop them. This claim was supported by Kamaruzzaman and Edwards (2006) who said that building services are normally fitted according to functional and aesthetic values without taking into account energy efficiency matters.

The bioclimatic design strategies which were firstly introduced in the 1950s have gone out of fashion and are overshadowed by recent ‘green building’ concepts. However, there is still no specific benchmark of comfort and Energy Efficiency Index (EEI) for residential college or multi-storey residential buildings in Kuala Lumpur. Referring to Iwaro and Mwasha (2010); energy use in residential buildings are usually 10 to 20 times lower compared to office buildings.

Thus, the electricity usage in residential buildings in Malaysia amount to approximately 10 to 25 kWh/m^2/year while the electricity use of office buildings in Malaysia is in the range of 200 to 250 kWh/m^2/year (Chan, 2009a). Unfortunately, this figure is only a general assumption and does not apply to residential college buildings of different form configurations, layout plan, functions, services and activities. The benchmarks of other countries may not be applicable in regions where the situation is different, especially in terms of climate (Sapri & Muhammad, 2010). Therefore, there is a need for studies to contribute to the establishment of a comfort benchmark and EEI for this region by focusing on the implementation of bioclimatic design strategies.

The proposed research will examine building design according to the recent practice of bioclimatic design strategies; particularly involving uses of daylight and natural ventilation, the efficiency of electricity usage and prospective energy conservation at the twelve residential colleges of the UM campus. Moreover, the building performance in achieving ideal comfort conditions, including thermal and visual comfort, will be evaluated at selected residential college buildings through survey and field measurements. The findings of this research will contribute to appropriate design recommendations for residential college refurbishments and new designs by tertiary education institution building developers and policy makers. It is also targeted that this document will increase the awareness on the wastage of energy due to poorly designed buildings. As a result, it will encourage better use of building resources, significant operational savings especially on energy usage, and an elevated comfort level.

1.2 Research questions

Main research question

Do current residential college buildings in the UM campus designers apply the appropriate bioclimatic design strategies, particularly in their consideration for natural ventilation and daylighting to achieve the desired comfort level and efficient electricity usage?

Sub research questions

i. How do current implementations of natural ventilation and daylighting in the bioclimatic design strategies, influence the efficiency of electricity use and comfort levels of student rooms in selected residential college buildings?

ii. What are the residents' perceptions and degree of acceptance on the quality of currently implemented natural ventilation and daylighting designs in the selected residential college buildings?

iii. How efficient are the selected residential college buildings, in providing a comfortable habitable space with the current implementation of bioclimatic design strategies?

iv. What are the living behaviour of residents that allows them to adapt or achieve a comfortable state with regards to the currently implemented bioclimatic design strategies?

v. What are the possible bioclimatic design strategies that can assist in achieving optimal electricity usage in the residential colleges of higher learning institution campuses, particularly those that can be implemented by improving natural ventilation and daylighting?

1.3 Research aim, purpose and objectives

The research aim is to define the impact of implementing daylighting and natural ventilation by focusing on temperature and relative humidity on the comfort of identified student rooms in the UM campus, with the purpose of justifying the effectiveness of applying these bioclimatic design strategies for residential college buildings in the UM campus. In realising this aim and purpose, five objectives were decided as listed below;

i. To identify the residential college building in UM campus with the best practice of bioclimatic design strategies in regards to natural ventilation and daylighting, as well as with the best performance in the Energy Efficiency Index (EEI) (*see Chapter 4*).

ii. To evaluate the comfort level of student's rooms in identified residential college buildings through a survey on the satisfaction level and perceptions of the adopted bioclimatic design strategies, particularly in the design of natural ventilation and daylighting (*see Chapter 5.2.1*).

iii. To evaluate building performance of the current implemented bioclimatic design strategies at identified residential college buildings through field measurements of temperature, relative humidity and light intensity by using scientific measuring equipment (*see Chapter 5.2.2*).

iv. To determine the residents living behaviour and adaptations to achieve a state of comfort in their rooms with regards to the implemented bioclimatic design strategies (*see Chapter 5.2.3*).

v. To identify bioclimatic design strategies for natural ventilation and daylighting that are applicable to similar residential college buildings in order to reduce energy consumptions whilst keeping the thermal and visual comfort of residents at optimum levels (*see Chapter 7*).

1.4 Significance of research

Rapid urbanisation increases the demand for energy which directly boosts the generation of greenhouse gasses (GHGs). The application of bioclimatic design strategies can help to reduce the generation of these GHGs and in a larger perspective, ease the effects of climate change. The significance of conducting research in this area of interest is due to possible contributions identified and explained in the following,

i. Identifying the range in comfort levels of student's rooms in a selected residential college building with the highest implementations of bioclimatic design strategies.

ii. Offering new knowledge on how the energy efficiency of student rooms in residential college buildings can be achieved through optimising the applications of bioclimatic design strategies, particularly on daylighting and natural ventilation in building design for the tropics.

iii. Contribute to the establishment of comfort level index and EEI specifically for residential college buildings.

iv. Contribute to the establishment of design guidelines and best practices for renovation or retrofitting strategies of residential college buildings or multi-storey residential buildings to move towards low energy buildings.

1.5 Research approach

There were three phases in the research approach as shown in the following research structure in Figure 1.1. Phase 1 started with the definition of issues on the impact of bioclimatic design strategies applied in residential college buildings in the UM campus on achieving the desired comfort level and efficient electricity usage. This is followed by the identification of problems and research statements.

The literature review considered six topics related to the aspects of bioclimactic design which are; climate change and energy usage in Malaysia, energy conservation and comfort of building architecture in the equatorial climate region, thermal comfort, natural ventilation, daylighting, and post occupancy evaluation (POE). Based on the knowledge gaps shown in the literature reviews, the research objectives were critically formulated. The most ideal and appropriate research methodologies to achieve the research objectives were developed based on previous recognised studies which have been done by other researchers. All of the methods are explained and elaborated in chapter 3.

The scope of research was selected by giving extensive considerations on the limitation and variables that are involved in this study. The research covers ventilation and lighting systems while ignoring the acoustic element at low-rise residential college buildings in the UM campus area. A low rise residential college building is usually three to four storeys high and has more than ten residential units on each floor; with one big shared bathroom, washroom and toilet. Each residential unit; referred to as a student room in this research, has a floor area of $10m^2$ to $20m^2$ and is able to accommodate two to four residents at one time. The rooms are accessible via corridors and each floor is connected to a staircase.

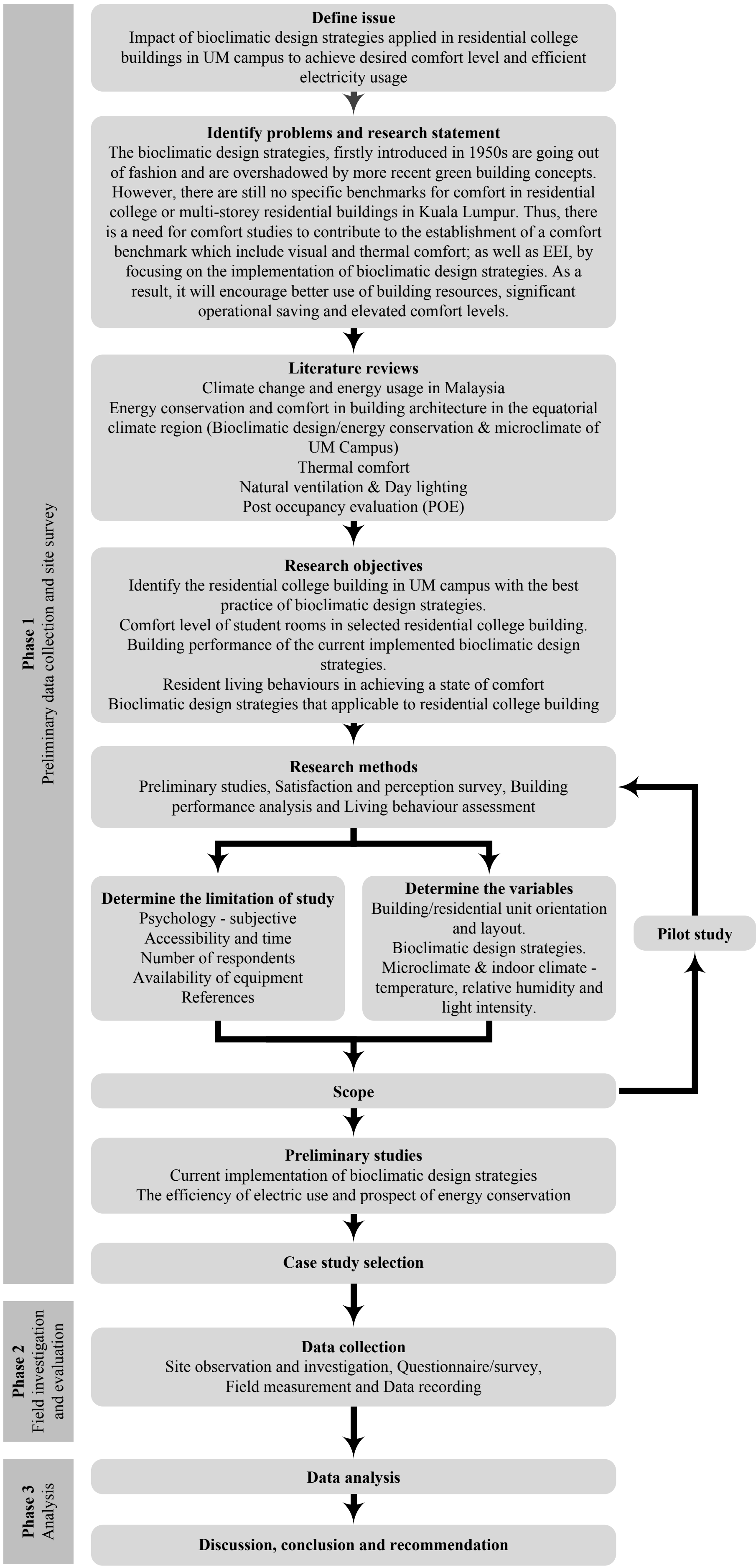


Figure 1.1: Research structure

One pilot study was done for testing the research methods that were defined earlier. Consequently, there have been some improvements made during the field investigation and evaluation especially in the satisfaction and perception survey, as well as in the site measurement for building performance analysis.

Preliminary studies were done on all twelve residential colleges in the UM campus through drawings and site visits, with a focus on the existing implementation of bioclimatic design strategies as well as, the efficiency of electricity usage for a five year duration to learn the energy efficiency index (EEI) and prospect of energy conservation of each residential college. From the preliminary studies, the residential college with the best practice of bioclimatic design strategies particularly of natural ventilation and daylighting in building design, lower EEI and with the least number of uncontrollable variables by considering the homogeneity of building design (especially on the student room and floor plan) was selected as a case study.

The field investigation and evaluation were done in Phase 2 by implementing site observation and investigation, questionnaire/survey, field measurement and data recording; which are extensively explained in Figure 1.2. Simultaneously, secondary data were collected from sources comprising of books, journals, newspaper articles and materials on the World Wide Web; which were also done during literature reviews.

All of the findings from the primary data; from methodological triangulation of POE that employed satisfaction and perception survey, building performance evaluation and living behaviour assessment, and secondary data were critically analysed in Phase 3. The correlation between these three analyses will show the impact of bioclimatic design concepts that would reflect the energy performance and comfort level of the residential college. Thus, the comfort level benchmarks and EEI for the residential college building were recognised; as well as the best design and ‘must apply’ bioclimatic design strategies towards 'low energy' buildings.

Phase 2
Field investigation and evaluation

Building investigation

Further analysis of building layout including a typical student room and the floorplan of each residential block of selected residential colleges. Also included, the performance of electricity consumption and usage pattern. Moreover, the landscape setting where the diversity of plants was identified and the integration between landscape and buildings were critically observed, especially on shading effects.

Satisfaction and perception survey

Evaluation of occupants' perception and acceptance on existing implementation of bioclimatic design concepts to understand the mutual interaction process between the building and users' needs in a general manner. The evaluation was particularly on natural ventilation and daylighting which directly influences thermal, visual and overall comfort level. Also the funtional elements, landscape and acoustic elements.

The questionnaire was revised and various improvements have been made after the pilot study. Number of questions and elements have been added in order to get more accurate responses and information. The questionnaire sheets were distributed to the all residents with the minimum number of feedbacks with a 95% reliabilty or confidence level and ±5% margin of error from the overall population.

Building performance evaluation

Building performance evaluation through field measurement by using instruments. Three parameters were collected including air temperature, relative humidity, and light intensity in selected student rooms, which represent numerous best and worst case scenarios.

The field measurement took 31 days, covering 24 hours duration with one hour interval. Different conditions were introduced each day with regards tothe opening or closing of all operable windows while exposing the student room with no curtains. Then, the presence or absence of an operated ceiling fan at different speeds on different days.

Initially, a pilot study was conducted for 29 days before the actual study started with different conditions were introduced each day. The distribution of daylight in the student room was also examined manually. As a results, data collection plans were refined with respect to the both content of data and the procedures to be followed.

Living behaviour assessment

Further experiment focusing on living behaviour will be done for two weeks with the rooms fully occupied. All the data loggers are placed in the same setting as in the building performance analysis, without determining the condition of openings (windows), fan speed and curtains. All the occupants are asked to record the time, garment worn,activities, weather, condition of openings, and electrical appliances that are used including the fan and lamps. Moreover, the perception of the residents itself regarding on the visual comfort, ventilation, thermal comfort and the comfort level of the room at that moment.

Figure 1.2: Details of Phase 2

1.6 Thesis structure

The introduction of this thesis is given in Chapter 1. It starts with a research background that focuses on the issues, problem statements and the need for the studies. The research questions containing one main and five sub research questions are also provided in the same chapter. These are followed by the research aims, purpose and objectives, significance of research, research approach and thesis structure.

Chapter 2 consists of a compilation of literature reviews in seven sub-topics. The first subtopic; 2.1, discusses the relationship between climate change and built environment, as well as the current energy usage trends in Malaysia. Then, a detailed description of the sustainable building architecture is included in subtopic 2.2, together with aspects of energy conservation. The principles of bioclimatic design strategies were clarified and available world building performance assessment tools were identified. Two of these rating tools, tailored to the equatorial climate region known as the Green Building Index (GBI) and the Green Mark, are comprehensively explained with respect to the area of residential building construction. The ideas and benefits of energy conservation in the building environment were also presented based on previous studies. These are followed by a critical review of the microclimate in the UM campus. Subtopic 2.3, discusses the theory of thermal comfort which includes standards, evaluation instruments, models, principles and strategies in optimising thermal comfort in residential buildings. The dynamic qualities of natural ventilation and daylighting in building architecture were discussed in subtopic 2.4 and 2.5 respectively. The systems, principles, strategies and effectiveness of these passive design strategies were well documented in each subtopic. Subtopic 2.6 covers the theories of POE, current implementation, as well as the relevance of this evaluation approach in both, the worldwide and the Malaysian environment. Subtopic 2.7 contains the conclusion of Chapter 2.

Chapter 3 presents the research methods which are divided into three phases. Phase 1 is the preliminary data collection and site survey for case study selection, while Phase 2 is the field investigation and evaluation that involves further analysis of selected case studies. There are building investigation and POE which employs satisfaction and perception survey, building performance evaluation and living behaviour assessment. Each evaluation and assessment is extensively explained. All results and findings from Phase 2 were critically analysed in Phase 3. The limitations of the studies and reasons for choosing each method are clearly explained at the beginning of the chapter.

Chapter 4 illustrates the results of preliminary studies, by describing the characteristics of student rooms and residential college building designs of twelve residential colleges, focusing on the implementation of bioclimatic design strategies. This is then, followed by the measurement of the efficiency of electricity usage and prospects for energy conservation which is a main criteria of the case study selection.

The core of the thesis is Chapter 5 which deals with all results and findings from the field investigations and evaluations. These entail the satisfaction and perception surveys, building performance evaluation and living behaviour assessment. This chapter also clarifies reason for the inclusion of selected case studies based on building description and landscape design, which are put at the beginning of the chapter.

Further analysis and correlations of all the findings in Chapter 5 are interpreted in Chapter 6. Chapter 7 covers discussions of research objectives and their respective conclusion, based upon the preliminary studies, as well as field investigation and evaluations. The chapter ends with a final conclusion based on the research questions and recommendations to improve the research methodology for further studies.

CHAPTER 2
Literature review

2.1 The issues of climate change and energy usage in Malaysia

The industrial revolution started in England about 230 years ago from the 18th to the 19th century when the world economy changed from an agrarian and handicraft economy to industry and machine manufacture (Levy, 2006). In other words, from the manual labour and draft animal based economy towards the machine-based manufacturing; which started with the mechanization of the textile industries, the development of iron-making techniques and the increased use of refined coal (Roger, 1999). This revolution then spread to other parts of the world and was recognized as a major development in world history. The all-metal machine tools were developed for other industries to increase the production capacity (Meier & Rauch, 2000) and massive changes in society was identified as an impact from this revolution (Brown, 2003). These are clearly shown from the change of intellectual paradigms and criticism namely capitalism, Marxism, and romanticism.

The invention of steam-powered ships and railways marked the beginning of the second industrial revolution around the 1850s. These followed by the development of the internal combustion engine and the electrical power generation in the 19th century, resulted in the world economies being dominated by the capitalist (Lucas, 2004). These also include the growth of chemical industries, petroleum refining and distribution which directly lead to the emergence of great factories with higher consumption of coal and fossil fuels. As consequences, this revolution has given rise to the unprecedented air pollution and large volume of industrial chemical being discharged (Fleming & Knorr, 1999); although at the beginning, it seemed to be the new age of human civilization.

Therefore, environmentalism has taken precedence as a social movement which definitely contradicts the economist in order to protect natural resources and ecosystems which focuses on ecology, health and human rights.

According to Hall (2008), the popular environmental movement began in the 1960's when Rachel Carson published her revolutionary work, Silent Spring in 1962. This book received great attention and leads to so much controversy especially within the chemical industry and ended with the ban of DDT (pesticides) in 1972. As a consequence, Arne Naess published an article introducing the phrase 'deep ecology' a year after. According to Naess (1973), deep ecology is an integrated concept of preservation, ecology and spirituality which was based on eight tenets which are listed below,

- All life has its own intrinsic value.
- Diversity of life has intrinsic value.
- Human interference is excessive.
- Human has no right to reduce diversity.
- Human life can survive with a substantial decrease in population which is necessary for non-human life.
- This requires change in policies and a much different state of affairs.
- The ideological change involves appreciating life quality.
- Those who subscribe to the foregoing points have an obligation to implement necessary change.

Although the concern about environmental protection had already started during the industrial revolution, the issue of climate change only came to attention in the 1980's when scientific evidence on global climate change became a public concern. This led to the United Nations Environmental Programme (UNEP) and World Meteorological Organization (WMO) to establish an intergovernmental working group known as the Intergovernmental Panel on Climate Change (IPCC) in the 1990's.

Prior to this, Intergovernmental Negotiating Committee for Framework Convention on Climate Change (INC/FCCC) was set up as a result from the United Nations General Assembly in the 1990 session. After five sessions of meetings between February 1991 and May 1992; which was participated by over 150 countries, the United Nations Framework Convention on Climate Change (UNFCCC) has been selected to be adopted on May 9, 1992 at the United Nations (UN) headquarters in New York (Climate Change Secretariat, 2002).

The UNFCCC was introduced in June 1992 at the Rio 'Earth Summit' and received 155 signatures and was set to be enforced on March 21, 1994, 90 days after the 50th ratification (Carpenter et al., 1995). Malaysia as a third world country signed the Convention on June 9, 1993 and ratified it on July 13, 1994, while gazetted to be enforced on October 11, 1994 (Malaysia Meteorological Service, 1996). Decades after its adoption, 186 governments; including the European Community, are now Parties to the convention and it is approaching universal membership (Climate Change Secretariat, 2002). For countries that signed the convention, they will seek to achieve the ultimate objective of stabilising greenhouse gas (GHGs) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. This objective was mentioned clearly under the Article 2 of the UNFCCC convention (UN, 1992) that stated,

> *"The conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threaded and to enable economic development to proceed in a sustainable manner".*

While, under the Article 1 of the UNFCCC (UN, 1992), climate change is defined as,

> *"A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in additional to natural climate and variability observed over comparable time periods"*

This convention was continued with the Kyoto Protocol, an international and legally binding agreement that linked to the UNFCCC. The major feature of this protocol is the reduction of GHGs emissions especially for 37 industrialized countries and the European community for an average of five per cent against 1990 level over the five year period (2008-2012) (UN, 1998). This protocol was adopted in December 1997 and was enforced in February 2005; where 184 parties of the convention had ratified its protocol to date. By the end of the first commitment period in 2012, a new international framework will have been ratified which is a more stringent emission reductions of GHGs (UNFCCC, 2010).

As a kick start in fulfilling the objectives of the UNFCCC, many activities have been programmed and established by the Malaysian Government. These were started with capacity building in human resource and institutional development; which in the long term, will help the country to develop the research and development (R&D) sector in national climate scenarios. Therefore, in 1994, a project on the 'Enhancement of Technical Capacity to Develop National Response Strategies to Climate Change' was submitted to the Global Environmental Facility (GEF) for funding for the purpose of enhancing and developing the local expertise in preparation of GHGs inventories, climate modelling, impact assessments, education and public awareness, formulation of policies, strategies and measures to reduce climate change (Malaysia Meteorological Service, 1996).

The commitment of the Malaysian government in handling this issue is clearly shown from the establishment of the Ministry of Energy, Green Technology and Water (KeTTHA) on April 9, 2009. This ministry is responsible to formulate the policies and regulate the services for energy, green technology and water to ensure the availability of high quality, efficient and safe services at a reasonable price to consumer throughout the country. Whilst, the Energy Commission and the Communication and Multimedia Commission are the two bodies undertaking the regulatory function of the ministry (KeTTHA, 2009a). As a continuous dedication to sustain the environment, National Green Technology Policy was launched on July 24, 2009 (KeTTHA, 2009b) with the policy statement that states;

> *"Green Technology shall be a driver to accelerate the national economy and promote sustainable development"*

Furthermore, the initial reduction in the rate of increase of GHGs emission and the subsequent progression towards reduction in the annual GHGs emission has been stated as a national key indicator to measure the success of the policy and its initiatives. Referring to the objective of the UNFCCC convention, GHGs has been pointed out as the ultimate sources that contribute to climate change and was given high priority in the convention. Under Article 1 of the UNFCCC (UN, 1992), GHGs mean,

> *"those gaseous constituents of the atmosphere, both natural and anthropogenic that absorb and re-emit infrared radiation".*

However, the GHGs actually are not really dangerous although they are the ultimate sources that contribute to climate change. All living creatures are relying on the GHGs whereby generally, it plays a role as a thermal blanket to keep the right temperature for animals, plants and humans to survive at 60°F / 16°C (Yusoff, 2007). However, due to the increasing amount of GHGs, this natural thermal blanket gets thicker and resulted in too much heat being kept in the earth's atmosphere.

Thus, the earth's capability to reflect out the CHGs to space again was denied. This situation causes global warming as a whole of the planet which directly leads to the climate change phenomenon.

The climate change has already begun since the industrial revolution when the global average temperature had been recorded to increase by 0.6°C ± 0.2°C since the late 19^{th} century (UNEP & UNFCCC, 2002). The mean of sea level has risen by 10cm to 20cm and snow cover has declined by some 10% since the late 1960s in the mid and high latitudes of the Northern Hemisphere. Then, there is more precipitation in many regions of the world while some parts of Africa and Asia are faced with drought which is in the worst frequency and intensity.

Nowadays, the effects are more perceptible. Even a 1°C increase of world surface temperature, will drastically lead to extreme changes of weather especially in wind patterns, the amount and type of precipitation with greater frequency of severe weather events that may be expected to occur (Yusoff, 2007). For example, the areas which previously were wet might get less rain and other areas might get more. In the temperate areas, places might be colder or warmer than usual and season might get longer or shorter (Ahmad, 2007); as what happened in the winter season of early 2006 when Asia, Russia and parts of Eastern Europe faced extremely cold conditions.

The recent Hurricane Katrina which hit the United States in August 2005 and Typhoon Durian which caused great damage to Philippine in late 2006 are other prime examples of the phenomenon. The El Nino phenomenon has become more common which brings along heat waves especially in the temperate countries during summer. Besides that, a slight rise in ocean temperature resulted from the melting polar ice will affect the underworld ecological systems starting with the bleaching of coral that plays a role as nursery to various marine lives. To broaden perceptions; it will affect the protein sources in the world.

In Malaysia, this extreme weather clearly can be illustrated more clearly through the monsoon floods that affected the state of Perlis and Kedah in December 2005; and Johor, Pahang, Sabah and Sarawak in December 2006 and January 2007; in scales that were not experienced before. This directly affects the food and water security, biodiversity, public health and socioeconomic well-being. Then, the impact of climate change to agricultural practice in Malaysia is generally seen to be connected with one another in an interesting and circular way; for example, reduction in productivity and change of harvesting and sowing seasons (Siwar et al., 2009). As reported by Minderjeet (2007), Malaysia can expect higher temperatures which will cause heat waves, flooding, droughts, tropical storms and surges in sea levels that will become more frequent, more widespread and more intense by 2025. This is supported by the IPCC (2007) through the Fourth Assessment Report that was formally approved in February 2007 that mentioned,

- The global surface temperature during the past 100 years (1906-2005) has risen by 0.74°C, larger than the corresponding temperature rise for 1901-2000 given in the Third Assessment Report (TAR), 2001 of 0.6°C.
- The warming over the last 50 years is nearly twice that for the last 100 years.
- Eleven of the last twelve years (1995-2006) rank amongst the 12 warmest years in the instrumental record of global surface temperature (since 1850).

Recently, Ibrahim (2010) reported the freak storm incidents that happened within the same month; August at three different locations, namely, Kedah, Melaka and the Klang Valley. The storm was described as tornado-like which tore the rooftop of flats and crashed onto the parked vehicles below in the Klang Valley, while two traders and a passerby were killed by flying debris at the Jasin Ramadan Bazaar, Malacca. Then, the four hour storm caused hundreds of houses in 28 villages in Sik and Baling, Kedah to be inundated by flash floods.

Before that, UNEP and UNFCCC (2002) had presented the way how global warming will change the world climate. Based on the current climate models, global warming is predicted at about 1.4°C to 5.8°C between 1990 and 2100. These figures were projected based on a wide range of assumptions including the population growth and technological advancement. Therefore, the average sea level is predicted to rise by 9cm to 88cm by 2100, resulting from the thermal expansion of the upper layers of the ocean with some role attributed to the melting of glaciers. Regional and seasonal warming are much more uncertain and inland regions are projected to warm faster than oceans and coastal zones.

Furthermore, the global precipitation is predicted to increase but at the local level trends are much less certain. More rain and snow will mean wetter soil conditions in high latitude winter seasons but higher temperatures may mean drier soils in summer. In addition, the frequency and intensity of extreme weather events are likely to change, which lead to rapid and unexpected climate transitions where the most dramatic change resulted from the collapse of the West Antarctic ice sheet (UNEP & UNFCCC, 2002).

In local perspective; by using Atmosphere-Ocean General Circulation Model (AOGCMs), the projected temperature increase from 2001 to 2099 for Malaysia was from 1.0°C to 3.6°C and for the same duration, projection of seasonal temporal rainfall variation is the largest (-60% to 40%) during the months of December, January and February; due to change of the Northern Monsoon wind circulation strength while the minimal (-15% to 25%) variation is during the months of September, October and November (Malaysian Meteorological Department, 2009).

The main GHGs that are released into the atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), sulphur oxides (SO_x), and ozone (O_3); where CH_4 has Global Warming Potential (GWP) 25 times more than CO_2 in warming up the earth's atmosphere (Lou & Nair, 2009).

For each ton of fuel oil used, 3.24 tonnes of CO_2 are released into the atmosphere followed by coal (2.43 tonnes), while natural gas is the least; 2.13 tonnes CO_2 per tonne utilized (Ahmad, 2007).

The increase of GHGs in the atmosphere is mostly contributed by human activities that include combustion activities for generating the energy from fossil fuels (Saidur et al., 2007). Different activities will produce different rate and type of GHGs emissions. Other examples are urbanization that altered the urban climate in various ways (Sani & Sham, 2007); wastewater treatment plant where the overall on-site emission were 1952, 1992, and 2435 kg CO_2ed, while the off-side emissions were 1313, 4631, and 5205 CO_2ed for the aerobic, anaerobic and hybrid treatment systems, respectively when treating a wastewater at 2000kg BOD/d (Shahabadi et al., 2009); and forest logging which resulted in the increase of CH_4 and N_2O for at least 1 year after logging (Yashiro et al., 2008).

In addition, the landfill as a major anthropogenic sources of CH_4 emission worldwide through decomposition and life cycle activities process (Ritzkowski & Stegmann, 2007; Lou & Nair, 2009); agriculture sector that contributes approximately 10% of the total European anthropogenic GHGs; mainly CH_4 from livestock activities and inefficient use of nitrogen in agricultural soils (N_2O) (Neftel et al., 2006); nuclear reactor which the mean value of emission over the course of the lifetime is 66g CO_2e/kWh due to reliance on existing fossil-fuel infrastructure for plant construction, decommissioning, and fuel processing along with the energy intensity of uranium mining and enrichment (Savacool, 2008); and also the building sector which is responsible for over a third of global energy-related CO_2 emission (Ürge-Vorsatz & Novikova, 2008).

Looking deeply into urbanization, the alteration of the urban climate can be started with changes of land physical surface, urban man and his activities; which directly produce a significant amount of heat climatically including the function of cities itself that introduce a great quality of pollutants including GHGs. From a study done by Sani and Sham (2007), the average annual magnitude of climate change for a large city can be summarized in Table 2.1.

Table 2.1: Annual magnitude of climate changes resulted from urbanization

Parameter	Annual changes
Solar radiation	-22%
Air temperature	+1%
Relative humidity	-6%
Visibility (frequency)	-25%
Fog (frequency)	+60%
Wind speed	-25%
Cloudiness (frequency)	+8%
Rainfall (amount)	+14%
Thunderstorm (frequency)	+16%
Air pollution (volume)	+>1000%

Note:

- Average changes are expressed in percent of rural conditions.

Source: Sani and Sham (2007)

Referring to Table 2.1, urbanization can give a bigger impact to the climate especially fog and air pollution; whereby these two parameters stated the higher percentage as compared to other parameters. As a main structure in a large city, the buildings and the services offered could have significant impacts in reducing the climate change effects if it is well managed starting from the plan and design stage. It must be considered in the context of mitigation, meaning, low running costs in carbon terms; that is related with energy consumption while comfort is maintained. However, the success of building designs to cope with the effects of climate change; where the warmer weather, extreme wet weather and flood risk, requiring measures for both resistance for initial protection and resilience for rapid recovery especially in the building sectors those large in number and occupancy; homes, offices and schools, will not be achievable if the behaviour of individuals; including gender, age and socio demographic condition, are not handled appropriately first (Robert, 2008).

The changes of climate directly increase the demand for energy. As presented by UNEP and UNFCCC (2002), at mid and high latitudes and altitudes there would be a decline on heat requirements but the cooling requirements would be increased. Malaysia which is located in the equatorial region is not excluded. There has been a significant increase in the average surface temperature that correlates to El Nino events especially in Peninsular Malaysia, which directly increases the cooling requirements. Moreover, the year 1963, 1997 and 2002 were recorded as the driest years in Peninsular Malaysia (Malaysian Meteorological Department, 2009). Therefore, energy supply systems will be vulnerable as the situation becomes worse when the increase of water deficits leads to less winter snowfall to fill summer streams; and by the higher demand for fresh water supplies definitely affect the hydropower production.

This is linear with world energy consumption that was reported by the International Energy Agency (2000a). The total final consumption increased from the year 1971 to 2010 and is expected to reach 9,117 million tonnes in 2020 as shown in *Appendix A - World energy consumption and demand*. The energy from oil stated the highest consumption as compared to renewable energy which had a lesser effect on the climate change. However, the world primary energy demand scenario is expected to change where renewable energy will get more demands although fossil fuels which are coal, oil and gas still lead the list.

By narrowing the scenario, Malaysia also stated the same figure where the petroleum products lead the list of energy demand for the duration of 2000 to 2010, and expected to grow annually in an average of 1.6% from 5.7% in the 8th Malaysia Plan to 6.4% in the 9th Malaysia Plan (Economic Planning Unit, 2006).

The total energy demand for the five year duration increased from 1,243.7 PJ in 2000 to 1,631.7 PJ in 2005 and is expected to increase to 2,217.9 PJ in 2010. As a consequence, oil and gas has been put on the top of the National Key Economic Area (NKRA) list as a driver of economic activity that has a potential to directly and materially contribute a quantifiable amount of economic growth to the Malaysian economy (Economic Planning Unit, 2010).

The commitment of the Malaysian government in energy matters can be described more through the Malaysia Plan which focuses on sustainable development of the energy sector to enable it to continuously support the economic growth, enhance the competitiveness as well as contribute towards achieving a balanced development; where the Federal Government will provide an allocation of RM 1.8 billion for the development of energy sector while in the investment expenditure by the Non-Financial Public Enterprises (NFPEs) will total RM 71.7 billion (Economic Planning Unit, 2006).

The New Energy Policy has been introduced into the 10^{th} Malaysia Plan to emphasize energy security and economic efficiency as well as the environmental and social consideration (Economic Planning Unit, 2010). There are five strategic pillars behind this policy which are initiatives to secure and manage reliable energy supply, measures to encourage energy efficiency, adoption of market based energy pricing, stronger governance and managing change. Then, five objectives have been listed based on environmental, economic, and social elements in which to minimize growth of energy consumption while enhancing economic development is listed as the first objective. The other four objectives are, to facilitate the growth of the Green Technology industry and enhance its contribution to the national economy, to increase national capability and capacity for innovation in Green Technology development and enhance Malaysia's competitiveness in Green Technology in the global arena, and to ensure sustainable development and conserve the environment for future generations.

Lastly, to enhance public education and awareness on Green Technology and encourage its widespread use.

Under the 9th Malaysia Plan and earlier, other renewable energy is not listed due to the price of existing sources that are still cheaper as compared to the application of renewable technology that required a long payback period. In other words, it is not economical. Fortunately, the 10th Malaysia Plan has listed renewable energy as part of developing a climate resilient growth strategy by creating stronger incentives for investments in renewable energy through the introduction of a Feed-in-Tariff (FiT) and the establishment of a renewable energy fund from the FiT; adjacent to promoting energy efficiency to encourage productive use of energy (Economic Planning Unit, 2010). Referring back to the 9th Malaysia Plan which was also reported by Economic Planning Unit (2006), residential and commercial building stated the third largest demand after the industrial and transport for the final commercial energy demand by sector for the years 2000-2010. The overall average annual growth rate was expected to increase 0.7% from 5.6% in the 8th Malaysia Plan to 6.3% in the 9th Malaysia Plan.

Therefore, energy efficiency and energy conservation are keywords in tackling the climate change issues that are ultimately caused by the GHGs. Energy efficiency and energy conservation in the buildings seem a right combination in enhancing the efforts to reduce GHGs emissions when building sectors are responsible for over a third of global energy-related CO_2 emission (Ürge-Vorsatz & Novikova, 2008). Moreover, the stabilization of building related CO_2 emissions level from 2004-2030 would cancel the approximately 3°C temperatures increase (Ürge-Vorsatz & Novikova, 2008), as projected before by the researches around the world (UNEP & UNFCCC, 2002; Malaysian Meteorological Department, 2009).

Thus, climate change issues needs to be handled in a holistic manner starting at the source rather than at the end of the pipe. In the built environment, it should be started at the design and planning stage. The use of non-renewable energy in the buildings including the services offered needs to be minimized while the use of renewable energy must be optimized. Directly, it will ensure that the building is managed in a sustainable manner where it meets the needs of the present without compromising the ability of future generations to meet their own needs, as mentioned in the Brundtland Report (World Commission on Environment and Development, 1987).

2.2 Sustainable and energy conservation in building at the equatorial climate region

2.2.1 Bioclimatic design strategies

Bioclimatic elements in the building were introduced by Olgyay during the 1950s and were developed as a process of design during the 1960s; which included the disciplines of human physiology, climatology and building physics (Olgyay, 1963). It became a starting point for the integration between building design and climate which is primarily for low and medium scale buildings. These types of buildings are very bioclimatically interactive compared to large scale development due to issues of complexity, the density in an urban context, in which these buildings are located and the availability of cheap energy for cooling and providing comfort (Hyde & Røstvik, 2008).

This is supported by Pedrini (2003) who claimed that design professionals often remain sceptical of the bioclimatic approach to large scale projects due to the lack of workable bioclimatic models of large scale buildings and the cost of additional design work; such as simulation modelling, to demonstrate proof of concept, cost effectiveness and the comfort of these types of buildings. In addition, building decisions have long-term consequences, particularly for the environment and the consumption of energy (Ryghaug & Sørensen, 2009).

According to Niu (2004), there are six significant environmental issues in high-rise residential buildings in the urban areas of Asian countries including facade design; reducing insolation while providing good view, providing a window vent and envelope insulation, provision of the balcony, the use of natural ventilation, the centralization of heating and cooling systems, building material selection and the micro-environment design.

There are two main values of bioclimatic design for passive and low energy building. First of all, it seeks to provide a comfortable environment by virtue of passive features of the design. Second of all, to apply the hybrid system in order to create an integrated solution for climate control this produces an integrated approach for design (Hyde & Sunaga, 2008). According to Hyde (2000), the principle behind bioclimatic design is the understanding of the climatic factors of a site by analysing the influence of microclimate; including solar radiation, sunshine, temperature, humidity, rainfall, wind velocity and direction. Then, it is followed by bioclimatic comparative analysis in assessing the climate data in relation to thermal comfort and finally ends with the selection of climate responsive modification strategies to meet design strategies.

Climate can be defined as the broad meteorological conditions pertaining to a region (Hyde, 2000) and climate can be generally considered at two scales. There are macroclimate which is a regional scale including hundreds of square miles in area, while microclimate is a site scale (Moore, 1993). Referring to Benites (2005), a microclimate is a climate of a small and specific place, few meters across and frequently much smaller, within an area as contrasted with the climate of the entire area. Moreover, the temperature, rainfall, wind, humidity, soil moisture, vegetation index and topography may be subtly different as compared to the prevailing conditions over the area as a whole.

The exploration of site potential, in terms of its macro and microclimate is an important stage in development to establish the appropriate building response to the climate especially in vernacular architecture; when there is a strong relationship between site, climate and the elements of the building in the generation of the building form which are the building elements and materials used in the building and associated landscaping of the site (Hyde, 2000).

As part of climate classification, there is mesoclimate which is placed between macro and microclimate. The mesoclimate is the climate of small areas of the earth's surface, refers to from tens to hundreds of meters across (Benites, 2005). Also acknowledged as site climate, mesoclimate may not be representative of the general climate of the district that is created by the elevation differences and slope aspect (mesoclimate, 2011). By narrowing down the scale, indoor climate is a specific part of the environment which is formed with agencies representing energy and mass flows in between the two environments (Zuzana & Petr, 2009). The indoor climate consists of temperature (54%), humidity (23%) and speed of air flow (23%), which is mainly influenced by building constructions and heating/cooling systems (Jokl, 1993). Whilst, in microclimate, these three components are significantly influenced by natural features such as earth forms, vegetation and water (Moore, 1993). This is supported by Konya and Vandenberg (2011) who stated topography, water, ground surface, vegetation and wind breaks are the most important factors which may cause local variations of site climate.

In conjunction with the current update, new definitions and concepts that incorporate wider diversity of approaches and priorities; including social, ecological and economical can be found in a range of built environment. There are 'Green Design', 'Green Building', 'Sustainable Design', 'Sustainable Architecture', 'Eco Design', and 'Eco Innovation'.

All these different concepts share the same aim and objective; to eliminate negative environmental impact completely through skilful, sensitive design (McLennan, 2004). In referring to Architecture Malaysia (2009), Green Building has three main intentions which are to;

- save energy and resources, recycle materials and minimize the emission of toxic substances throughout its life cycle.
- harmonize with the local climate, traditions, culture and surrounding environments.
- sustain and improve the quality of human life whilst maintaining the capacity of the ecosystem at local and global levels.

As a consequence, better use of building resources, significant operational savings, and increased workplace productivity sends the right message about a company or organization that it is responsibly well run and committed to the future (Architecture Malaysia, 2009). In integration with climate change issues, zero energy building came out as a part of the solution to account for carbon neutral target. The zero energy building is an ideal concept where no fossil fuels are used and sufficient electricity is generated from natural sources to meet the service needs of the occupants (Gilijamse, 1995) or in other words, a building with the capability to create sufficient power from renewable sources on site which can balance power drawn from non-renewable sources supplied by the electricity grid. Theoretically, according to Hyde and Røstvik (2008), the zero dwelling concepts can be achieved by simultaneous actions of;

- reducing the energy demand (increasing energy efficiency) of dwellings through various energy conservation measures
- utilizing the solar energy incident on the wall surface, roof and ground surfaces surrounding the house for electricity generation and for satisfying the dwelling's heating requirement.

However, the implementation of these actions entails the careful assessment of economic feasibility, benefits for the environment and human comfort. Therefore, in assessing the building performance towards sustainability environment, building performance assessment tools have been introduced all around the world and directly it becomes sustainable building guidelines. Several environmental methodologies and methods for evaluating environmental performance of buildings are being currently developed. These are Building Research Establishment Environment Assessment Method (BREEAM) for UK, Leadership in Energy and Environmental Design (LEED) for USA, Comprehensive Assessment for Building Environmental Efficiency (CASBEE) for JAPAN, GRENNSTAR for Australia, Green Mark for Singapore and Green Building Index (GBI) for Malaysia (Sinou & Kyvelou, 2006).

Each assessment tools have different rating classifications, benchmarks and weights to suit with local interests and conditions as shown in Table 2.2. BREEAM, LEED and GREENSTAR listed nine assessment criteria while Green Mark and GBI only stated five and six assessment criteria respectively. Each criterion assessment will be divided into certain items where certain points are allocated to each item. The total points will define the rating classification of the assessed building. Poles apart to CASBEE whereby the assessment criteria is divided into two concepts namely, Environmental quality and performance of the building (Q) and Reduction of building environmental loadings (L); where each of these criteria consists of three items for assessment as shown in Table 2.2. From these two assessment criteria, the overall result of the environmental assessment will be defined as Q/L which is based on the concept of eco-efficiency, known as BEE (Building Environmental Efficiency) (Sinou & Kyvelou, 2006).

Table 2.2: Assessment criteria and rating classification of assessment tools

METHOD	BREEAM	LEED	CASBEE	GREEN STAR	Green Mark	GBI
Country	United Kingdom	United States	Japan	Australia	Singapore	Malaysia
Assessment criteria	1. Energy 2. Management 3. Health & Wellbeing 4. Transport 5. Water 6. Materials 7. Waste 8. Land Use 9. Pollution 10. Ecology	1. Sustainable Site 2. Water Efficiency 3. Energy & Atmosphere 4. Materials & Resources 5. Indoor Environmental 6. Location & Linkages 7. Awareness & Education 8. Innovation in Design 9. Regional Priority	*Environment Quality & Performance of the Building* 1. Indoor Environment 2. Quality of Service 3. Outdoor Environment on Site *Reduction of building environmental loads* 1. Energy 2. Resources & Materials 3. Off-site Environment	1. Management 2. Transport 3. Ecology 4. Emissions 5. Water 6. Energy 7. Materials 8. Indoor Environmental Quality 9. Innovation	1. Energy Efficiency 2. Water Efficiency 3. Environmental Protection 4. Indoor Environmental Quality 5. Other Green Features	1. Energy Efficiency 2. Indoor Environmental Quality 3. Sustainable Site Planning & Management 4. Materials & Resources 5. Water Efficiency 6. Innovation
Rating classification	Outstanding Excellent Very Good Good Pass	Platinum Gold Silver Certified	S (excellent) A (average) B+ (average) B- (average) C (poor)	6 Star (World Leadership) 5 Star (Aus Excellent) 4 Star (Best Practice)	Platinum Gold Plus Gold Certified	Platinum Gold Silver Certified
Source	BREEAM (2009a)	Sinou and Kyvelou (2006)	Sinou and Kyvelou (2006)	Green Building Council Australia (2010)	Building and Construction Authority (2008)	GREENBUILDING INDEX (2009a)

In regards to Horvat and Fazio (2005), all the assessment methods are sophisticated as they consider the environmental performance of the building and its impact on the surrounding; from resources' use and contextual fit to indoor climate and recyclability. Additionally, the level of priorities and importance of specific issues is established by introducing the weighting of the scores. This is also mentioned by Sinou and Kyvelou (2006) who concluded that all the assessment methods seem to be focusing on issues regarding energy, landscape-site, resources and quality of the indoor environment. Unfortunately, the economic and social factors as well as the comfort which is directly involved in the sustainability are assessed only by some of the tools presented. Later, some of the performance evaluation models for residential buildings appeared to be difficult and complicated to use when there are too many questions required to be answered and related documents that need to be submitted (Kim et al., 2005). Thus, this lessened the interest of residence or building owners to participate in green/sustainable building campaigns.

Based on the available data, benchmarking study that included BREEAM and LEED has concluded that the certified buildings are in the top 25% of market positions, while the buildings with excellent energy performance belong to top 5% in the market (Lee & Burnett, 2008). Unfortunately, Paul and Taylor (2008) came up with the closing argument when they found no evidence that green buildings are more comfortable compared to conventional buildings. Conversely, this finding is not representative of the most efficient of all assessment tools as there is insufficient evidence in particularly with respect to aesthetics, serenity, lighting, ventilation, acoustics and humidity. The assessment tools should cover wider areas and aspects.

The same findings were also reported by Newsham et al. (2009), where on average, LEED certified buildings used 18-39% less energy per floor area than conventional buildings but 28-35% of LEED buildings used more energy than conventional buildings. These findings directed Scofield (2009) to make an argument where these findings are not related to the total energy used by those buildings when particular definition of the mean energy intensity of a collection of buildings are not related to the total energy used by those buildings. Moreover, it is crucial to understand that GHGs emission associated with building operation when the consideration of site energy does not account for the energy consumed off-site in generating and delivering electric energy to the building.

Therefore, the development of complete tools which include as many parameters as possible and would apply at a macro-regional scale should be done (Sinou & Kyvelou, 2006). The concept of sustainable design may be extended beyond environmental metrics to include other subjective assessments of building impacts such as quality of life, working conditions, dependence on foreign goods, or cultural and historical continuity when current guidelines do not address extension of the building life span; while the expected useful life span of a building may be critical in determining its true sustainability (Bunz et al., 2006).

There are four main perceptions that impede the private sector to participate with green building projects. These are perceived higher upfront cost, lack of education, lack of awareness and lack of fiscal incentives from the government. Moreover, the development of knowledge and technology amongst the industry and awareness programs could be the most efficient strategies to increase the participation of all stakeholders when rising energy cost, government regulation/building codes, lower life cycle cost of green building and worsening environmental conditions became the main favourable factors in promoting green building business (Chan et al., 2009).

As a consequence, some of the assessment tools are improving from time to time when specific tools were established for specific buildings. For example, in BREEAM, there are schemes that range from starter homes to opera houses that include courts, sustainable homes, Eco homes, healthcare, industrial, multi-residential, prisons, offices, retail, education, communities, and domestic refurbishment (BREEAM, 2009b). Then, the older versions are also being replaced with new versions when some of the standards are included to make the assessment tools more stringent (BCA, 2008).

For equatorial climate regions, the Malaysian GBI and the Singaporean government's Green Mark are the only rating tool that are established (Architecture Malaysia, 2009), while in Indonesia, the rating system is going to be developed by Green Building Council Indonesia (GBCI) (Tiyok, 2009). On the surface, Malaysian GBI is quite similar to Green Mark as it became a reference during the development of GBI (Architecture Malaysia, 2009). However, in regards to local issues and interest, the current state of Malaysian development and existing resources, some arrangement has been made for making sure the GBI is suitable to the Malaysian condition.

Malaysian GBI is still new as it was just launched in early 2009, four years after Green Mark was launched in 2005 (BCA, 2006). A lot of amendments have been made to improve the tools especially when the Green Mark for Residential Building is already at Version 3.0 whilst the Residential New Construction of GBI is still at Version 1.0 (GREENBUILDINGINDEX, 2009a; BCA, 2008). The Malaysian GBI certification process starts with an assessment of the building design by a certifier appointed by Greenbuildingindex Sdn. Bhd. (Li, 2009). A provisional award is then issued when the completed building has been verified according to the design and to maintain the award, the building is reassessed every three years. Under GBI, there are two categories which are residential and non-residential. Buildings will be awarded based on six key criteria in which the points distribution can be summarized as in Table 2.3.

Table 2.3: GBI rating – residential and non-residential

Item	Maximum Points	
	Residential	Non Residential
Energy Efficiency (use of renewable energy, lighting zoning and low energy consumption)	25	35
Indoor Environmental Quality (mould & air pollutions prevention, thermal comfort, natural lighting, volatile organic compounds-free paints and formaldehyde-free composite wood, particle boards and plywood)	10	21
Sustainable Site Planning & Management (site selection, access to public transport, community services, open space and landscaping, redevelopment of existing sites and brownfields (abandoned land or former industrial sites), avoidance of environmentally sensitive sites, construction management (proper earthworks and pollution control) and storm water management)	39	16
Material & Resources (use of environment-friendly, recycled materials and sustainable timber, storage and collection of recyclables, construction waste management, and reuse of construction formwork).	10	11
Water Efficiency (rainwater harvesting, water recycling and water-saving fittings).	7	10
Innovation (innovative design and initiatives)	9	7
TOTAL SCORE	100	100

Source: Li (2009)

The building will be awarded one of the four types of rating according to the point of Certified (50 to 65 points), Silver (66 to 75 points), Gold (76 to 85 points) or Platinum (86+ points). Different emphasis is given in GBI for residential and non-residential but the energy aspect is given a higher priority due to the high Building Energy Index (BEI) especially for office buildings; in the range of 250kWh/m2/year, which is higher than the national guideline of 150kWh/m^2/year (Chan, 2009a). This rating system will provide an opportunity for developers to design and construct sustainable buildings that can provide efficient use of energy and water, healthier indoor environment, better management of site planning with competent use of materials and innovative design.

By making comparisons between GBI (Residential New Construction) and Green Mark (Residential Building), in regards to assessment criteria and point allocation of both assessment tools, energy efficiency is given more attention in Green Mark due to the higher point allocation (65 exclude bonus points) and placed under specific category (Table 2.4 and Table 2.5). Vice versa, sustainable site planning and management (39 points) is given more attention in GBI then followed by energy efficiency (23 points) in regards to the point allocated. Overall, Green Mark is more stringent as compared to GBI because there are mandatory requirements under current building control regulations that should be fulfilled before proceeding with an elective requirement for energy improvement and other areas; that include water efficiency, environmental protection, indoor environmental quality and other green features. The mandatory requirements that should be fulfilled are building envelope-Residential Envelope Transmittance Value [RETV], roof-U value, air-conditioning system, air tightness and leakage, artificial lighting, ventilation, electrical sub-metering and luminance level.

The accomplishment of fulfilling the mandatory requirements will directly enable the building to be awarded with Green Mark Certification (BCA, 2008). Additionally, there are also pre-requisite requirements that need to be fulfilled specifically for Green Mark Gold^{Plus} and Platinum rating as shown below,

Pre-requisite requirements for BCA Green Mark Gold^{Plus} Rating

- Building envelope design with RETV of 22W/m^2 or lower.

Pre-requisite requirements for BCA Green Mark Platinum Rating

- Building envelope design with RETV of 20W/m^2 or lower.
- Use of ventilation simulation software or wind tunnel testing to identify the most effective building design and layout and has implemented the recommendations derived to ensure good natural ventilation.

Table 2.4: Assessment criteria and score summary of GBI for residential new construction

PART	CRITERIA	ITEM	POINTS	TOTAL
1	EE	ENERGY EFFICIENCY		23
	EE1	Minimum EE Performance	3	
	EE2	Renewable Energy	5	
	EE3	Advanced EE Performance based on OTTV & RTTV	10	
	EE4	House Office & Connectivity	2	
	EE5	Sustainable Maintenance	3	
2	EQ	INDOOR ENVIRONMENTAL QUALITY		11
	Air Quality, Lighting, Visual & Acoustic Comfort			
	EQ1	Minimum IAQ Performance	2	
	EQ2	Daylighting	2	
	EQ3	Sound Insulation	2	
	EQ4	Good Quality Construction	1	
	EQ5	Volatile Organic Compounds	1	
	EQ6	Formaldehyde Minimisation	1	
	Verification			
	EQ7	Post Occupancy Evaluation : Verification	2	
3	SM	SUSTAINABLE SITE PLANNING MANAGEMENT		39
	Site Planning & Transport			
	SM1	Site Selection	1	
	SM2	Public Transportation Access	12	
	SM3	Community Services & Connectivity	8	
	SM4	Open Spaces, Landscaping & Heat Island Effect	4	
	Site & Construction Management			
	SM5	Construction System & Site Management	3	
	SM6	Storm water Management	3	
	SM7	Re-development of Existing Sites & Brownfield Re-development	4	
	SM8	Avoiding Environmentally Sensitive Areas	2	
	SM9	Building User Manual	2	
4	MR	MATERIAL & RESOURCES		9
	Reused & Recycle Materials			
	MR1	Storage & Collection of recyclables	2	
	MR2	Materials Reuse and Selection	2	
	MR3	Construction Waste Management	2	
	Sustainable Resources			
	MR4	Recycled Content Materials	1	
	MR5	Regional Materials	1	
	MR6	Sustainable Timber	1	
5	WE	WATER EFFICIENCY		12
	Water Harvesting & Recycling			
	WE1	Rainwater Harvesting	4	
	WE2	Water Recycling	2	
	Increased Efficiency			
	WE3	Water Efficient Landscaping	2	
	WE4	Water Efficient Fittings	4	
6	IN	INNOVATION		6
	IN1	Innovation in Design & Environmental Design Initiatives	5	
	IN2	Green Building Index Facilitator (GBIF)	1	
			TOTAL POINTS	100

Source: GREENBUILDINGINDEX (2009a)

Table 2.5: Assessment criteria and score summary of Green Mark for residential building

		CATEGORY	POINTS	TOTAL
(I)		Energy Related Requirements		
Maximum Cap of 50 points	Minimum 30 points	Part 1 : Energy Efficiency		65 (excluding bonus points)
		1-1 Building Envelope – RETV	15	
		1-2 Dwelling Unit Indoor Comfort	16	
		1-3 Natural Ventilation in Common Areas	2	
		1-4 Lighting	15	
		1-5 Ventilation in Car parks	8	
		1-6 Lifts	2	
		1-7 Energy Efficient Features	7	
Bonus 20 points		1-8 Renewable Energy *(Bonus Points)*	20	
(II)		Other Green Requirements		
Maximum Cap of 50 points	Minimum 20 points	Part 2 : Water Efficiency		
		2-1 Water Efficient Fittings	10	13
		2-2 Water Usage	1	
		2-3 Irrigation System	2	
		Part 3 : Environmental Protection		
		3-1 Sustainable Construction	12	29
		3-2 Greenery	6	
		3-3 Environmental Management Practice	9	
		3-4 Public Transport Accessibility	2	
		Part 4 : Indoor Environmental Quality		
		4-1 Noise Level	1	6
		4-2 Indoor Air Pollutants	3	
		4-3 Waste Disposal	1	
		4-4 Indoor Air Quality in Wet Areas	1	
		Part 5 : Other Green Features		
		5-1 Green Features & Innovations	7	7
			Total Points Allocated	120
			Total Point Allocated (Include BONUS points)	140
			Green Mark Score (Max)	100 + Bonus 20 points

Source: BCA (2008)

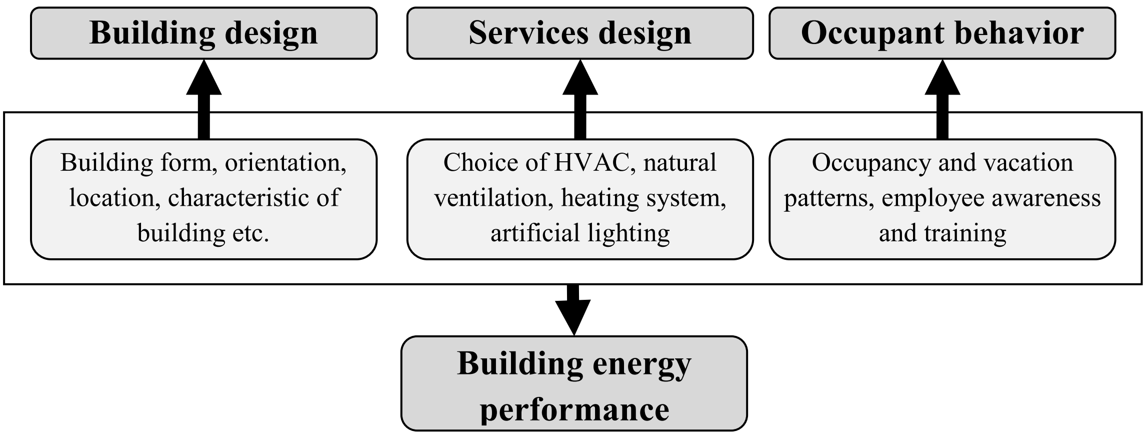
Vice versa to GBI, the rating classification is directly from the assessment and there is no mandatory or pre-requisite requirement for each rating. In a holistic perspective, the Green Mark is more advanced as compared to GBI. However, it is a good start for learning and to improve the performance of residential buildings. Any weakness that arises from the early years of implementation should be noted to ensure that the GBI is not left behind and remains relevant with the passing of time as technological advances are being made on a daily basis.

Furthermore, the energy efficiency should be given more or equal priority in the assessment. In the long term, specific tools for specific buildings should be considered to be developed when different buildings will have different services and functions where some of the criteria will not be applicable to be implemented.

2.2.2 Energy conservation in building

Generally, energy conservation can be achieved by the efficient use of energy whereby electricity is used wisely in order to accomplish the same tasks (Centre for Education, Training and Research in Renewable Energy and Energy Efficiency, 2006). In other words, paying less as the usage of electricity is reduced while at the same time enjoying the same amount of amenities for the purpose of protecting the environment. Directly, it can also minimize the utilization of non-renewable energy sources, pollution, and energy consumption whilst maintaining comfort, health and safety of the occupants (Kannan, 2006). According to Omer (2008), nearly half of the world's energy use is associated with providing environmental conditioning in the buildings and about two thirds of this is for heating, cooling and mechanical ventilation. In addition, buildings represent approximately 40% of onshore energy usage (Ryghaug & Sørensen, 2009).

Energy conservation in a building can be achieved in many ways but in the holistic manner, it should be started from the source itself; building's design and structure. According to Al-Mofleh et al. (2009), building's design is one of the interrelated factors in achieving building energy performance, besides service design and occupant behaviour (Figure 2.1); as these two factors are not easy to be controlled and maintained.



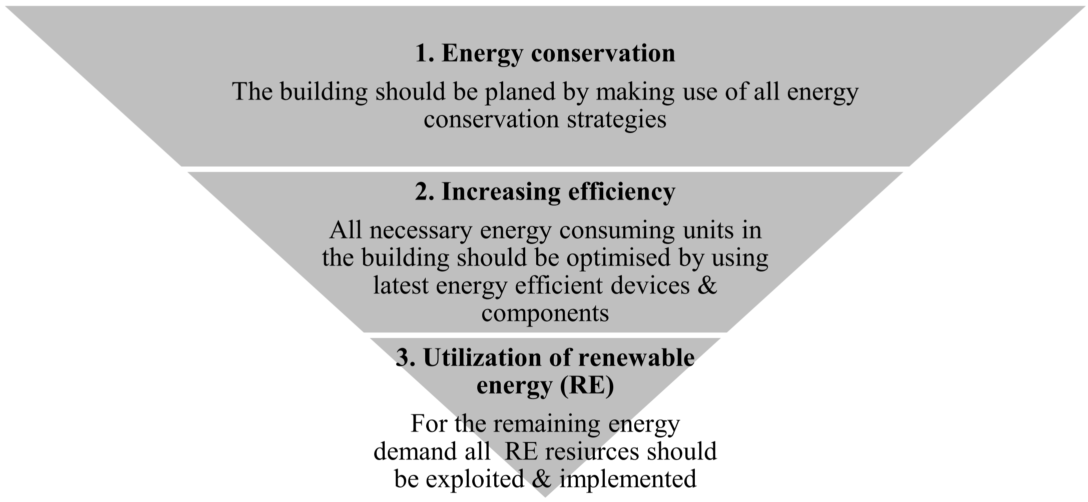
Source: Al-Mofleh et al. (2009)

Figure 2.1: Interrelated factors in achieving building energy efficiency

In the equatorial region, there are three main elements related to building services that becomes an energy liability as 60-70% of total energy are used in non-industrial buildings (Omer, 2008). The three main elements are conditioning (for thermal comfort), lighting (for visual comfort), and ventilation (for indoor air quality). To achieve indoor air quality, the building is ventilated by providing clean air to a space in order to meet the metabolic requirements of the occupants, and to dilute and remove pollutants emitted within a space. As such, three main approaches in building design principles for conserving energy has been proposed by Hyde and Røstvik (2008). The three main approaches are the reduction of energy demand in houses; the use of mechanical equipment and appliances (the level of service provided and energy used) and the reduction in the use of energy from fossil fuels. In regards to the reduction of energy demand in houses approach, it can be achieved by using energy from the ambient air and the ground, and by minimizing the energy demand and rational energy used (Omer, 2008).

This is supported by Hasse and Amato (2006) who came up with the Energy Triangle Approach in developing a new building design which contributes directly to a sustainable development.

In reference to Figure 2.2, the energy conservation is stated as the first approach, in which with proper planning in an early stage, it will cost nothing and passive design building (without mechanical and electrical) can be developed appropriately.



Source: Hasse and Amato (2006)

Figure 2.2: Energy triangle approach for a new building design

This has been mentioned by Davis et al. (2006) who claim that energy saving over the lifetime of the building can equal the original construction cost. For example, when fitting a bungalow with air conditioning systems; which needs to be replaced every 10 years and to pay the probable electricity bills over the next 30 years, the sum of money needed far exceeds the initial cost of an old bungalow.

Then, it is followed by the increase of efficiency through the use of the latest energy efficient devices and components. According to Al-Mofleh et al. (2009), this approach will increase the construction cost up to 15% higher than conventional designs; however it can help to reduce 13% of total energy consumption and 48% of electricity consumption in the commercial and residential sector. In addition, the aforementioned author also came out with the technical specification of lighting fixtures (Table 2.6) which can show how much electricity consumption can be reduced while the construction cost is increasing.

Table 2.6: Technical specification of lighting fixtures

Type	Lumen/watt	Life time (h)	Relight time (minute)	Energy saved (%)
Tungsten	12-25	800	0	0
Mercury	35-63	16,000	3.5	58-76
Fluorescent conventional	25-65	18,000	0	40-77
Fluorescent compact	`40-81	18,000	0	62-81
Metal halide	80-100	7,500	10-15	81-85
High presser sodium	80-140	20,000	<1	81-89

Source: Al-Mofleh et al. (2009)

Nowadays, the latest types of lighting devices such as compact fluorescent lamps are very expensive which cost six times as much as conventional bulbs (Lavelle, 2007). However, in the long term, they have longer lifetime and result in higher percentage of energy saved. As a comparison, compact fluorescent lamps showed higher energy saved in the range of 62% to 81% while the conventional fluorescent lamps only stated 40% to 77%; although both have the same lifetime duration, 18,000 hours. The same result was also reported by Trifunovic et al. (2009) where considerable reduction in electricity consumption and power demand can be achieved by the replacement of energy inefficient incandescent lamps with energy efficient light sources.

The utilization of renewable energy becomes the last approach due to its relatively high cost of installation coupled with its unproven track record in Malaysia. In a global perspective, this technology has been implemented widely especially in European countries and the United States (Rahman, 2009). Unfortunately, only big organizations can afford the installation due to the cost constraints. In addition, the building design has also become a part of the limiting factors as well when energy production is more applicable at specific characteristics of the building; a 15m deep building has a better potential than deeper buildings while a high rise building which is more than five floors has low potential for electricity production due to lower solar exposure on horizontal surfaces (Haase & Amato, 2006).

In addition to the Energy Triangle Approach, Al-Mofleh et al. (2009) proposed three tools to achieve energy conservation in Malaysia. These are, the use of efficient electrical equipment; the application of passive energy technology in a building such as insulation, evaporative cooling, ventilation and solar heating; and support tools such as public awareness, energy codes, regulations, energy information and databases.

This is supported by Aries and Newsham (2008) who claim, the energy use in residence could be reduced more effectively through traditional energy conservation programs such as using more efficient lighting system, HVAC equipment and insulation. Comparatively, these three elements are more relevant in achieving sustainable energy in existing buildings rather than the Energy Triangle Approach by Hasse and Amato (2006) which focuses more on designing new buildings. Therefore, the integration between the two ideas can improve the energy conservation efforts for both existing and new buildings.

According to Balaras et al. (2000), energy consumption of a specific building depends mainly on the building type, climatological conditions, building construction, annual hours of use, installation for heating and cooling, production of domestic hot water and lighting. In regards to energy conservation programmes at existing residential buildings within equatorial regions, four aspects must be fully considered. These four aspects are climatological conditions, building type, cooling and lighting.

Located in the equatorial region, Malaysia has a high potential in energy conservation because she only has a little seasonal variation with a consistent annual average of temperature and humidity. The climate in Kuala Lumpur is hot and humid all year long and is only affected by the weaker Southeast monsoon from April to September.

The average temperature is 23-32°C and the average rainfall reaches up to 190mm. The wind direction is mainly from the north-west to the south-west throughout the year. The Malaysian climate is generally described by Ahmad (2008) as the following;

- The daytime maximum temperature of 30-35°C, warm all year around.
- The range of average monthly temperature is about 1-3°C.
- The average diurnal temperature variation is about 8°C.
- The annual mean temperature is about 27°C.
- The annual precipitation is greater than 1500mm.
- Coastal area high with the wind when inland areas are wingless, leads to thermal stress during the day.
- Solar radiation intensity varies widely with cloudy conditions.
- Only have two seasons, a wet season and a dry season.

Consequently, daylight can be fully optimized while natural ventilation can be freely exploited for sustaining thermal comfort in the buildings; rather than using mechanical devices like artificial lamps and air conditioning systems. This is supported by Srivajana (2003) who claims that energy saving opportunity is even much greater in the countries where hot and humid climates are common all year around rather than countries with cold climates.

The building type and climatological condition of local areas are two interrelated aspects that illustrate how the building should be designed appropriate to the local climate. This has been proven by Chan (2009a) who claims solar radiation and its heating effects on walls and rooms facing different directions are the most significant effect on energy consumption in the tropic regions. Referring to the daily solar gain for some typical residential building in Malaysia in Table 2.7, the house with east-west fronting type resulted in higher total solar gains in both, roof and wall as compared to the north-south fronting types in the range of 14% to 29%.

Table 2.7: Solar heat gains in typical residential building in Malaysia

Type of residential building	Single storey terrace	Double storey terrace	Five storey flats	Eight storey apartments
Gross Floor Area	880	1,408	60,500	81,680
Unit Floor Area	880	1,408	75`0	850
Volume	14,080	18,304	665,500	898,480
Roof Area	1,012	792	12,100	10,210
Wall Area	484	968	28,050	47,872
Envelope Area	1,496	1,760	40,150	58,082
Roof/Envelope Area	*68%*	*45%*	*30%*	*18%*
Wall/Envelope Area	*32%*	*55%*	*70%*	*82%*
North-South Fronting				
Roof Solar Gains	30	24	363	306
North-Solar Wall Solar Gains	5	10	198	356
East-West Wall Solar Gains	0	0	165	246
Total Solar Gains (kWh/day)	35	34	726	908
Total Solar Gains (kWh/m^2)	0.04	0.02	0.01	0.01
Roof Solar Gains/Total Solar Gains	*86%*	*71%*	*50%*	*34%*
North-South Wall Solar Gains/Total Solar Gains	*14%*	*29%*	*27%*	*39%*
East-West Wall Solar Gains/Total Solar Gains	*0%*	*0%*	*23%*	*27%*
East-West Fronting				
Roof Solar Gains	30	24	363	306
North-Solar Wall Solar Gains	0	0	83	123
East-West Wall Solar Gains	10	19	396	711
Total Solar Gains (kWh/day)	40	43	842	1,141
Total Solar Gains (kWh/m^2)	0.46	0.31	0.14	0.14
Roof Solar Gains/Total Solar Gains	*75%*	*56%*	*43%*	*27%*
North-South Wall Solar Gains/Total Solar Gains	*0%*	*0%*	*10%*	*11%*
East-West Wall Solar Gains/Total Solar Gains	*25%*	*44%*	*47%*	*62%*
Increase Solar Gains (%)	14%	29%	16%	26%

Source: Chan (2009a)

This directly increases the total energy demand in the building for cooling purposes and rejects the statement by Li et al. (2002) who claim that the heat gained through the roof is generally small. Then, the listing of cooling and lighting as two aspects that must be fully considered in energy conservation programmes at existing residential buildings within the equatorial region; adjacent to climatological conditions and building type, is definitely right. The cooling and lighting becomes a prominent contributor to energy used in the buildings when about 30-35% of total energy is consumed by lighting and other appliances alone, except air conditioning (Bellarmine & Turner, 1994).

This is supported by Aries and Newsham (2008) who state that the electric lighting is one of the world's biggest end-uses of electricity and a major contributor to the peak demand for electrical power. Thus, lighting should be the priority in the energy conservation programme, because it is believed that by reducing lighting energy consumption, cooling load could be reduced as well (Kamaruzzaman & Edwards, 2006). This statement is in line with the findings of Hasse and Amato (2006), in which nearly 45% of cooling loads is determined by the internal heat sources and even the best building envelope design cannot avoid the resulting internal cooling load of which 55% of the peak cooling loads are influenced by the building envelope design itself. Therefore, the internal heat sources that are contributed by electrical appliances like artificial lamps should be avoided when the building envelope design itself; which is quite difficult to be controlled especially for existing buildings, contributes higher cooling load in the buildings.

In handling cooling load and lighting issues, natural ventilation and daylighting are two well-known strategies in reducing building energy consumption. A lot of studies have been reported regarding the amount of energy that can be conserved through the exploitation of these strategies. The peak-cooling load; that determines the maximum demand of energy, and annual electricity consumption can be reduced substantially by 10% and 13% through the applications of daylighting (Li et al., 2002). In warm humid climates, approximately 50% of energy used for ventilation in buildings can be conserved and by making the right decision in determining the building's characteristics; including the building length, depth and height, the efficient use of electricity can be improved in the buildings.

This has been proven by Haase and Amato (2006) who revealed that shallow buildings with optimal orientate and maximum 5 floors are more applicable for daylight and wind can be exploited for natural ventilation.

As a result, about 60% or more of carbon emission which is equivalent to 1.36 billion tonnes of carbon can be reduced through efficient building structure as well as the building envelope and artificial lighting that indirectly help to conserve conventional energy sources (Markis & Paravantis, 2007). Good daylighting of spaces helps to promote efficient productivity, and simultaneously increases the sense of well-being (Omer, 2008). The ability to control air movement can save energy up to 20% on heating and cooling costs while improving comfort as at air speeds of between 0.5-1.0m per second and the body can feel 2-3°C cooler inside 25°C air (Sustainable Energy Authority Victoria, 2002). Moreover, approximately 43% of energy reduction can be achieved by using a combination of well-established technologies such as glazing, shading, insulation, and natural ventilation while the building itself is designed according to the climate of the site (Omer, 2008).

All these achievements can be contributed by well-planned strategies which consider various aspects. This is supported by (Cândido et al., 2010) who state that natural ventilation combined with solar protection is the most efficient building design strategy to achieve thermal comfort without resorting to mechanical cooling. Moreover, the occupants should be able to control the air flow inside the buildings according to their preferences. Al-Temeemi (1995) recommended two design guidelines for reducing cooling energy consumption in Kuwaiti houses that can be adapted in the equatorial region. Reasoning that radiation on a flat roof is greater than on a vertical wall, he succeeded in minimizing solar heat gains and reducing conductive heat flow. These can be achieved via changing all major window exposures to face north or south and ensuring that they are shaded, painting the roof white in colour to reduce heat absorption and good insulation of the building envelope to lessen the conduction. By implementing all these strategies, heat gains from radiation, air filtration and conduction can substantially be reduced.

In regards to higher energy demand due to the increase of total solar gains at existing east-west fronting type buildings, Chan (2009a) came out with simple ideas to solve this problem which are to;

- Orientate larger wall areas in the north-south direction.
- Locate service areas such as staircases, storerooms and service ducts in the east-west external walls.
- Place as many service rooms on the roof top of flats as possible to reduce the solar gain through the roof.
- Ensure sky lights are not used. If roof ventilation is required, use a jack up roof facing the north.
- Shade east-west facing walls with large roof overhangs or plant shading trees in front of them.
- Use lighter coloured roofing or better still slightly reflective type roofing.
- Apply aluminium foil insulation under the roof tile to reduce radiant heat gained by the roofing from being radiated to the ceiling.
- Ventilate the loft area above the ceiling and below the roof tiles. Measurements taken in this loft area have been found to go as high as 45°C for outside air temperature of 35°C for not insulated roofs.
- Apply a layer of rock wool insulation immediately above the ceiling to prevent the heat from the loft area from being radiated and conducted in the living area immediately below the ceiling.

As far as shading devices are concerned, Gutierrez and Labaki (2007) found the most significant response was to use the horizontal concrete louver on north façade as compared to vertical fins and eggrate typologies. In spite of better insulation properties of wood, the concrete devices presented the best result. Then, the typological solution sets for hot and humid climate (Table 2.8) that was introduced by Ahmad (2008), was identified as a comprehensive and holistic approach towards energy efficiency in the building sector. These sets cover three types of houses and all the important aspects that influence energy consumption in the buildings that was mentioned before by Balaras et al. (2000).

Table 2.8: Typological solution sets for a hot humid climate

Strategies	Type of House		
	Detached house	Row house	Multi-family apartment house
Form	compact for air conditioning to minimize surface area of envelope; spread-out building for natural ventilation	row of terraced houses	block
Floors	two to three maximum	one to three maximum	four to five maximum
Dimensional ratio (length/width)	1-3 maximum	0.3-1 maximum (single house cluster)	1.6-2.5
Orientation	(0° = south) : 0° and 180°	(0° = south) : 0° and 180°	(0° = south) : 0° and 180°
Roofing	pitched, ventilated attic, reflective foil under roof, separate and insulated ceiling	pitched, ventilated attic, reflective foil under roof, separate and insulated ceiling	pitched, ventilated attic, reflective foil under roof, separate and insulated ceiling
Solar protection	façade-shadowing systems	façade-shadowing systems	façade-shadowing systems
Active systems	photovoltaic (PV) collectors on roof	photovoltaic (PV) collectors on roof	photovoltaic (PV) collectors on roof
Passive systems	cross-ventilation, shading, orientation	internal courtyards	'double-skin' bioclimatic system
Glazed/opaque surfaces ratio	south and north 30%	south and north 30%	south and north 30%
Thermal time lag	>8 hours	>8 hours	>8 hours
Ambient air exchange	10 in summer (V x hour)	10 in summer (V x hour)	10 in summer (V x hour)
Max. yearly heating energy consumption	0 kWh/m^2	0 kWh/m^2	0 kWh/m^2
Reference U value	0.3-0.6 W/m^{2}K	0.3-0.6 W/m^{2}K	0.3-0.6 W/m^{2}K
Living-room orientation	south and north	south and north	south and north

Source: Ahmad (2008)

In addition to the typological solution sets in reducing energy consumption in the buildings, rooftop gardens which are commonly known as green roof can also be adopted. Studies done by Wong et al. (2003) revealed that green roof at five-storey buildings are able to save 1-15% of annual energy consumption, 17-79% in space cooling load including 17-79% in the peak space load and these figures can be optimized by using shrubs that help to absorb the radiation and clay soil (dry) as a base case which plays a role to transmit the solar heat when the simulation results showed a reduction of 17-81% in the peak of Roof Thermal Transfer Value (RTTV), the similar concept to OTTV where the maximum value that has been set in MS1525 is 25 Wm^{-2} (Kannan, 2006). Research done by Kumar and Kaushik (2005) revealed, the application of green roof combined with solar thermal shading in buildings provided a cooling potential of 3.02kWh per day and the reduction of 5.1°C to maintain 25.7°C of average indoor air temperature. Moreover, it can be improved by using a plant with larger Leaf Area Index (LAI) which directly cuts the penetrating flux by nearly $4W/m^2$.

Therefore, the installation of rooftop gardens is a good alternative to be considered for the purpose of reducing energy consumption in the building especially in equatorial regions. Looking at a bigger perspective, it can help to elevate the air quality and storm water through the natural filters resulting from the use of the shrub and clay soil as a base case (Wong et al., 2003). Moreover, it can also reduce the volume of storm water that contributes to flash flood especially in city areas. Unfortunately, this strategy is limited to the buildings with flat roofs which usually are the multi storey buildings.

In spite of the achievements and well planned strategies toward energy efficiency which has been discussed before, there still are objections to it.

According to Ryghaug and Sørensen (2009), there are three interrelated problems that failed the energy efficient construction in the building industry which are,

- deficiencies in public policy to stimulate energy efficiency *where this is closely related to tenant-owner dilemma; builders and building owners tend not to be so concerned with future energy cost, energy use and related aspects of the indoor environment because they will not use the building themselves.*
- limited governmental efforts to regulate the building industry *when the authorities primarily focused on energy-economizing that energy should be used in an economically optimal way where deciding to increase energy standards when prices increase* and,
- a conservative building industry *where there are only focusing on short-term costs, lack of research and development, contract practices, the communication challenges of interdisciplinary coordination of building projects, and architects unsupportive attitude towards energy efficiency.*

In addition, abundant resources and inexpensive energy which is still reliable and affordable to the consumer make the issues of energy savings over a lifetime cost of a building have little meaning while the developers' philosophy of reducing initial cost and fast profit recovery often puts a full stop to the effort of energy conservation in building industry (Horvat & Fazio, 2005). However, these three interrelated problems can be solved through the introduction of new policies, better regulations and reformed practices in the industry itself (Ryghaug & Sørensen, 2009). Besides that, proper maintenance has to be carried out to fine tune the performance of the building while the occupants should continually be made aware of energy efficiency practices and do their part endlessly (Kannan, 2006). The introduction of building energy efficiency labelling programme should be also considered which indirectly can encourage developers, building owners, architects and engineers to adopt best practices in the conceptualization, design and construction, as well as in the operation and management of the buildings (Lee & Rajagopalan, 2008).

Consequently, the energy performance of a building is significantly influenced by the human factor when the system and policy are taken into account. In addition, the microclimate also has a very important impact on both energy and environmental performance of a building which includes building design, services and occupant behaviour. As a front line in the building environment, the architects can play a role in achieving energy conservation in the buildings while the quality of human life is able to be sustained and improved. Thus, thermal comfort is a key element that should be borne in mind either during designing a new building or retrofitting existing buildings to achieve energy conservation and efficiency that are highly considered microclimate aspects.

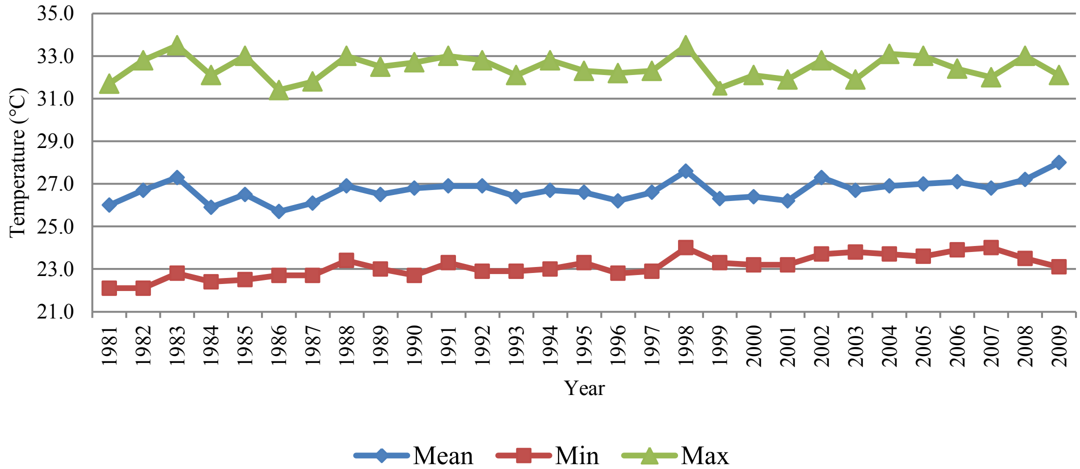
2.2.3 Microclimate of the UM campus

As the principle behind bioclimatic design is the understanding of the climatic parameters in which the building is situated (Hyde, 2000), the climate condition of the UM campus was analysed from 1981 until 2009. All the meteorological data were collected from the UM weather station which is located within the campus and managed by the Malaysian Meteorological Department. The UM weather station is located at 3°07' N latitude, 101°39'E and 104.0m of height above mean sea level. As an auxiliary weather station, only certain parameters are measured including temperature (°C), relative humidity (%), rainfall (mm), evaporation (mm) and surface wind (m/s), as completely compiled in *Appendix B - Climate data of the UM weather station for the period 1981 to 2009*. The climate data was only available for the years of 1981 until 2009; since this station had to be closed in 2010 for maintenance works. Moreover, most of the data on evaporation and wind speed are not completed as some of the data in certain months are not available due to technical errors.

As it is located in the equatorial region, the UM campus has a typical tropical climate, little seasonal variation with a constant annual average. The climate is hot and humid all year around with uniform temperature, high humidity and heavy rainfall. It is extremely rare to have a full day with a completely clear sky; even during periods of drought, and a stretch of a few days with completely no sunshine except during the northeast monsoon seasons. Moreover, the UM campus is only affected by the weaker Southeast monsoon from April to September and winds are generally light.

a) Air temperature

The temperature profile of the UM area for the period of 1981 until 2009 is presented in Figure 2.3; in which there are uniform temperatures throughout the year. The monthly and annual variations of temperatures are narrow, less than 2°C (Figure 2.3 and Table 2.9). Monthly mean temperatures are between 25.6°C and 29.0°C, where the lowest and highest mean values are recorded in December, 1991 and May, 2009 respectively. Annually, the mean temperatures are in the ranges of 26.3°C and 27.6°C as documented in the year 1984 and 2006 respectively. However, the daily range of temperature is large; from 8°C to 12°C, when the days are frequently hot and the nights are reasonably cool everywhere.



Source: Malaysian Meteorological Department

Figure 2.3: Monthly 24 hours mean temperature (°C) for the period 1981-2009

Table 2.9: Annual 24 hour mean, max and min temperature (°C) for the period 1981-2009

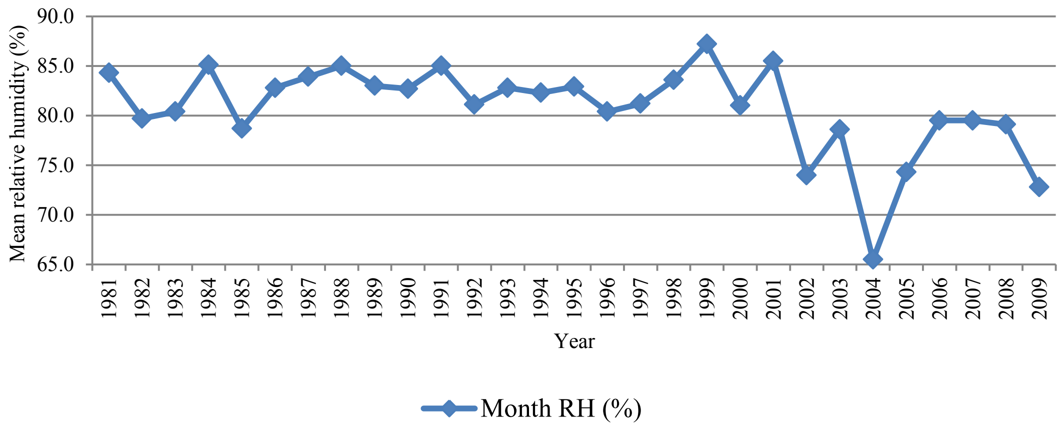
Year	Mean	Max	Min	Year	Mean	Max	Min	Year	Mean	Max	Min
1981	27.0	33.4	22.9	1991	26.7	32.4	23.4	2001	27.1	32.4	23.7
1982	26.8	32.9	22.8	1992	26.8	32.8	23.3	2002	27.4	32.9	23.9
1983	27.2	33.3	23.3	1993	26.6	32.5	23.2	2003	26.8	32.5	23.8
1984	26.3	32.5	22.8	1994	26.6	32.6	23.2	2004	26.9	32.9	23.7
1985	26.4	32.7	23.0	1995	26.7	32.7	23.5	2005	27.3	33.1	23.9
1986	26.5	32.5	23.1	1996	26.7	32.4	23.4	2006	27.6	33.2	24.1
1987	26.8	32.8	23.4	1997	26.9	32.7	23.6	2007	27.1	32.6	23.8
1988	26.7	32.5	23.4	1998	27.6	33.3	24.1	2008	27.2	32.5	23.5
1989	26.7	32.6	23.1	1999	26.6	32.3	23.4	2009	N.A	32.6	23.6
1990	27.2	33.1	23.5	2000	26.7	32.4	23.5				

Note:
- N.A. - not available

Source: Malaysian Meteorological Department

b) Relative humidity

The levels of humidity are high throughout the year as presented in Figure 2.4.



Source: Malaysian Meteorological Department

Figure 2.4: Monthly 24 hours mean relative humidity (%) for the period 1981-2009

The monthly variation of relative humidity is much greater than the annual variation when most time of the month, the mean relative humidity levels are above 80%. The minimum and maximum mean relative humidity is 65.5% and 89.9%; as recorded in January, 2004 and April, 1991 respectively. Every year, the months of October and November show higher mean relative humidity compared to other months. Annually, the mean relative humidity varies between 74.3% and 87.0% when the minimum was in 2004 and the maximum was in 1991, as shown in Table 2.10.

Table 2.10: Annual 24 hours mean relative humidity (%) for the period 1981-2009

Year	%	Year	%	Year	%	Year	%	Year	%
1981	82.2	1987	85.1	1993	85.5	1999	84.2	2005	80.2
1982	84.5	1988	86.2	1994	85.2	2000	85.2	2006	82.3
1983	84.0	1989	85.3	1995	83.6	2001	80.7	2007	79.8
1984	85.0	1990	84.2	1996	83.6	2002	78.4	2008	77.4
1985	83.1	1991	87.0	1997	84.5	2003	75.9	2009	N.A.
1986	83.8	1992	84.7	1998	83.6	2004	74.3		

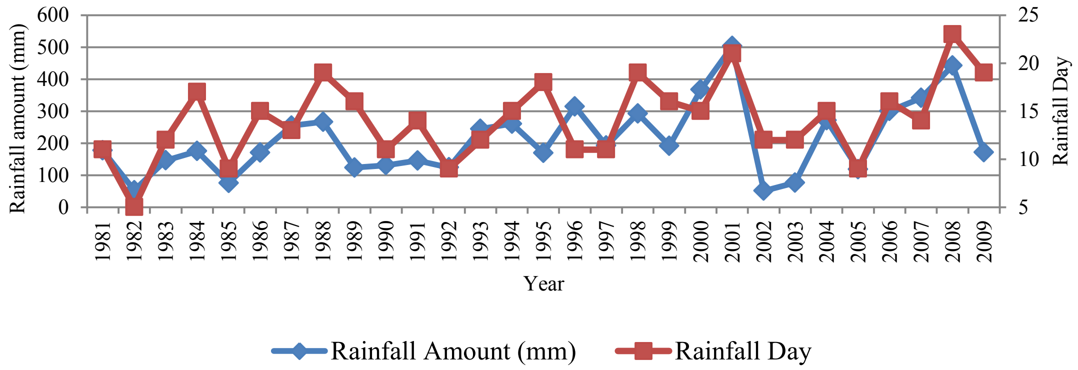
Note:
- N.A. - not available

Source: Malaysian Meteorological Department

It is observed that there are some declines after the year 2000 when the recorded percentage was below 85%. The significant reductions are shown by monthly mean relative humidity started in the year 2007; when most of the percentage values were dropping below than 80%.

c) Rainfall

Since located in the tropical climate region, there is rainfall throughout the year when more than 150 rain days are recorded in each year (Figure 2.5).



Source: Malaysian Meteorological Department

Figure 2.5: Rainfall amount (mm) and rainfall day for the period 1981-2009

The year 2000 and October, 1987 are acknowledged as the wettest with highest annual and monthly rainfall amount; 3435.6mm and 648.2mm respectively. In regards to annual rain days as shown in Table 2.11, 2003 stated the highest with 215 of raining days.

Table 2.11: Annual rainfall amount (mm) for the period 1981-2009

Year	mm	Year	mm	Year	mm	Year	mm	Year	mm
1981	2728.0	1987	2850.5	1993	3151.6	1999	3096.8	2005	N.A.
1982	3104.5	1988	3183.8	1994	2897.6	2000	3435.6	2006	N.A.
1983	2466.4	1989	2498.2	1995	3012.6	2001	2652.0	2007	3225.0
1984	2624.0	1990	2156.7	1996	3266.3	2002	N.A.	2008	N.A.
1985	2491.3	1991	N.A.	1997	3360.7	2003	2655.6	2009	N.A.
1986	2388.9	1992	2714.2	1998	N.A.	2004	3072.2		

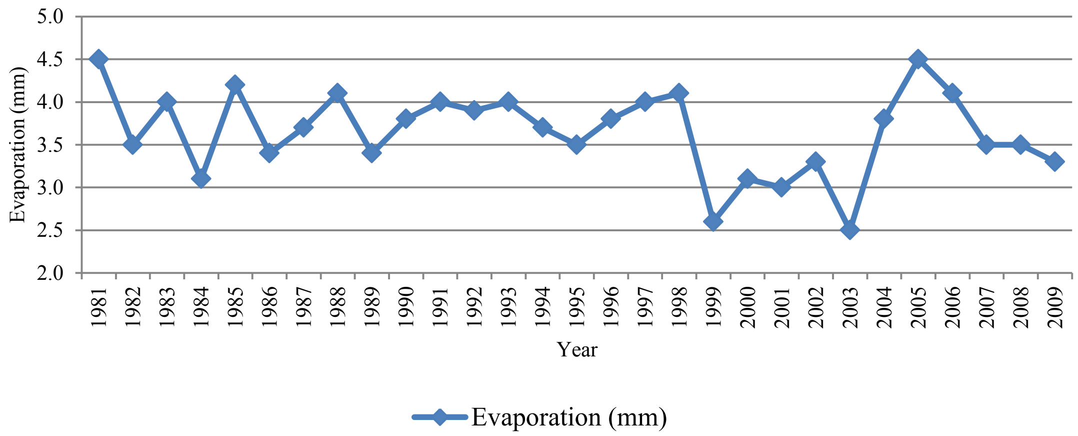
Note:
- N.A. - not available

Source: Malaysian Meteorological Department

As affected with early morning "Sumatras" from May to August, October and November are the months with maximum rainfalls; which result in higher mean relative humidity, while February is the month with minimum rainfall. The March, April and May rainfall are the maximum, as well as the June and July minimum rainfall is absent or indistinct. Consequently, there are more rainy days recorded in October and November in each year.

d) Evaporation

Initially, cloudiness and temperature are two of the most important factors which are interrelated in affecting the rate of evaporation. Similar to air temperature, both of the monthly and annual ranges of evaporation are small (Figure 2.6).



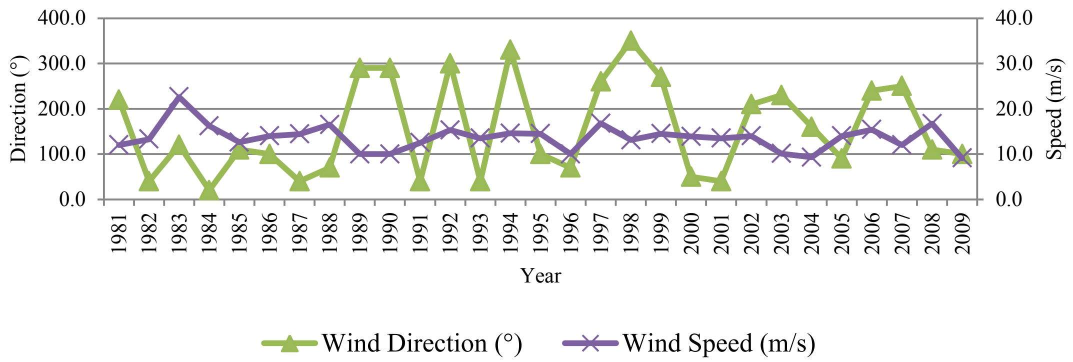
Source: Malaysian Meteorological Department

Figure 2.6: Evaporation amount (mm) for the period 1981-2009

The monthly mean of daily evaporation is in the range of 2.1mm and 5.1mm; as recorded in December, 1991 and September, 2005 respectively. Whilst, the annual minimum and maximum values are 2.8mm in the year 1999 and 4.0mm in the year 1986. Generally, higher mean daily evaporation was documented in the first six months compared to the last six months in a year; as January to June are considerably hotter and drier than the last six months.

e) Surface wind

The wind over the UM area is generally light and variable, with uniform periodic changes in the wind flow patterns. This is influenced by south-west monsoon season which is usually established in the latter half of May or early June and ends in September. The maximum surface wind speed and direction is shown in Figure 2.7.



Source : Malaysian Meteorological Department

Figure 2.7: The maximum surface wind speed (m/s) and direction (°) for the period 1981-2009

Referring to *Appendix B - Climate data on the UM weather station for the period 1981 to 2009*, most of the extreme surface winds were recorded in September. The prevailing wind flow is generally south-westerly and light; where the annual mean surface wind speed was 1.0 m/s. The average of monthly maximum surface wind in UM is 15.1 m/s. Whilst, the lowest and highest maximum surface wind speed which was recorded for 29 years is 8.6m/s in February, 2008, and 34.6m/s in September, 1989 respectively.

2.3 Thermal comfort in building

Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004). Thermal comfort is not the feeling of a man in the room temperature but the energy that is lost from the body as a waste of cellular metabolism and muscular work; in ensuring the body's core temperature is kept at approximately 37°C (Davis et al., 2006) in fulfilling the first comfort condition, thermal neutrality; a person feels neither too warm nor too cold. Then, the second condition which is balancing the body's energy where the heat produced by metabolism should be equal to the amount of heat lost from body to atmosphere; steady state (INNOVA, 1996). In addition, it should be reminded that thermal comfort and thermal sensation are not the same whereby thermal comfort depends on the desired physiological state; uncomfortable through comfortable, while thermal sensation depends on the skin temperature; cold through hot (Hedge, 2010).

This is explained more by Zain et al. (2007) who claim that the human body has intelligent behaviour, ability to learn through acclimatization and adaptation process to cope with hyperthermia and hypothermia situations. The hyperthermia is a situation when the body loses insufficient heat while excess heat loss results in body cooling called hypothermia. In addition, these two phenomena could be influenced by the dry bulb temperature, relative humidity and air flow; the main factors that influence the human thermal comfort.

Thermal comfort is very complex to evaluate as many physical parameters that are also known as environmental conditions need to be considered namely; air temperature (°C), relative humidity (%), air velocity (m/s) and mean radiant temperature (°C). All these conditions directly affect the body simultaneously and allow the heat to be lost.

The effect of these conditions to create thermal comfort of the environment are clearly explained by Lechner (2009) where,

- Air temperature (°C): *It will determine the rate at which heat is lost to the air, mostly by convection where the flow reverses and the body will gain heat from the air when the temperature exceeds 37°C.*
- Relative humidity (%): *It directly affects the evaporation of skin moisture where dry air can readily absorb the moisture from the skin and leads to rapid evaporation that effectively cools the body.*
- Air velocity (m/s): *The rate of heat loss through convection and evaporation increase when the air velocity becomes higher.*
- Mean radiant temperature: *This parameter should be maintained close to ambient air temperature where the cause of the great difference from these two conditions should be considered.*

In addition, Srivajana (2003) clearly shows the interactions among these environmental conditions that resulted from her surveys. For the purpose of increasing personal thermal comfort in hot and humid climate area, preferred air velocity; as shown in Table 2.12, should be considered when most of the respondents preferred a slightly higher air velocity as the relative humidity increased; between 60 to 80%, and felt no draught or no disturbance if air velocity was not greater than approximately 0.9 m/s.

Table 2.12: Preferred air velocity (m/s) in hot and humid climate area regarding to the temperature (°C) and relative humidity (%).

Relative humidity (%)	Temperature (°C)			
	26	28	30	32
50	0.39	1.03	1.72	1.81
60	0.41	1.05	1.68	1.95
70	0.58	1.22	1.70	2.18
80	0.75	1.31	1.82	2.27
	Air velocity (m/s)			

Source: Srivajana (2003)

Referring to ASHRAE (2004), the indoor air speed in hot climate should be set between 0.2-1.5m/s. This is supported by Cândido et al. (2010) who states that higher air speeds are desirable in order to improve the subjects' thermal comfort whereby acceptable indoor air speed in hot humid climates should range from 0.2 to 1.5 m/s and operative temperatures above 24°C; while draft risk is definitely not the main complaint in relation to a hot and humid climate until air speeds exceed 1m/s. In addition, the occupants should be able to control the airflow inside the buildings due to their preferences including the constant regulation of fans and the closing/opening of the windows.

In thermal comfort research, standard methodology directly defines a good practice. Thus, there are two main references on thermal comfort namely the International Standard Organization (ISO) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) which is clearly described by Orosa (2009a) as listed below;

- ISO 11399 : 1995 Ergonomics of the thermal environment - *Principles and application of relevant International Standards*
- ISO 7730 : 2005 Ergonomics of the thermal environment - *Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*
- ISO 9920 : 2007 Ergonomics of the thermal environment - *Estimation of thermal insulation and water vapour resistance of a clothing ensemble*
- ISO 8996 : 2004 Ergonomics of the thermal environment - *Determination of metabolic rate*
- ISO 7726 : 1998 Ergonomics of the thermal environment - *Instruments for measuring physical quantities*
- ISO 7933 : 2004 Ergonomics of the thermal environment - *Analytical determination and interpretation of heat stress using calculation of the predicted heat strain*

- ISO 11079: 2007 Ergonomics of the thermal environment - *Determination and interpretation of cold stress when using required clothing insulation (IREQ) and a local cooling effect.*
- ISO 9886 : 2004 Ergonomics of the thermal environment - *Evaluation of thermal strain by physiological measurements*
- ISO 10551 : 1995 Ergonomics of the thermal environment - *Assessment of the influence of the thermal environment using subjective judgment scales*
- ASHRAE 55-2004 *Thermal environmental conditions for human occupancy*

According to Parsons (2002), ISO standards provide the best internationally agreed methods and the data available are valid *(concerned with whether the assessment or prediction accurately represents the phenomenon of interest)*, reliable *(concerned with whether a standard used would give the same prediction if repeatedly used to assess exactly the same conditions)*, and usable *(concerned whether the users of the standard can use it correctly)* with sufficient scope for practical application. However, it should be noted that, reliability does not imply validity but validity does imply reliability.

In addition to these standards, there are evaluation instruments to evaluate the building in all phases of the life cycle of a building including programming, design, building construction, building operation, and finally demolition (Bunz et al., 2006). The evaluated building will be awarded with certification or rating according to the index classification from the overall evaluations. Some of the evaluation instruments are already established, namely BREEAM for United Kingdom, LEED for USA, CASBEE for JAPAN, and GRENNSTAR for Australia. In Malaysia, GBI was launched in 2009 and it is Malaysia's first comprehensive rating system for evaluating the environmental design and performance that specifically caters for the Malaysian tropical weather, environmental and developmental context, cultural and social needs (GREENBUILDING INDEX, 2009a).

Besides that, the Singaporean government's Green Mark is also a rating system that is specific for tropical zones (Architecture Malaysia, 2009) while the Indonesian rating system is going to be developed by GBCI (Tiyok, 2009).

Under all these evaluation instruments (*Appendix C - Minimum requirements/standards for thermal comfort, natural ventilation & daylighting of various evaluation instruments for residential buildings*), thermal comfort is a core element of the assessment whereby the minimum requirement or standards have been set up. Under GBI, the minimum requirement for residential building is quite loose when compared to non-residential buildings (*Appendix D - Minimum requirements/standards for thermal comfort, natural ventilation & daylighting of Green Building Index (GBI) for non-residential new construction*). As compared to Green Mark, this evaluation instrument is better in achieving a good thermal comfort in equatorial climate perspective when the minimum requirements are more specific to building layout and dwelling unit design. Moreover, the use of ventilation simulation software is compulsory to identify the most effective design and layout. Therefore, the minimum requirement or standard that has been set for non-residential buildings in GBI should also be implemented in residential buildings while Green Mark and BREEAM become a prominent reference in improving the thermal comfort level at residential college buildings.

Globally, as a pioneer in evaluation instruments which was established in 1990, BREEAM has gone further by introducing the schemes in assessing the environmental performance of any type of buildings either new or existing buildings. The schemes are specified due to the type of buildings where one of the schemes is BREEAM Multi-residential that includes student halls of residence, key worker accommodation, care homes, sheltered residential and other multi-residential buildings which contain a mix of residential accommodation and communal area (BREEAM, 2010).

For the purpose of adopting this scheme for evaluating the residential college buildings in Malaysia, it is probably not suitable due to the differing climate factors. The BREEAM is designed for temperate climate while Malaysia is located in the equatorial climate region. This is different to Green Star; that also introduced a rating tool specifically for Multi-Unit Residential (GBCA, 2010) due to the Australian climate which is quite similar to the Malaysian climate in certain areas (Bureau of Meteorology, 2010).

Besides all these standards and evaluation instruments, Davis et al. (2006) have also introduced the term 'Thermal Discomfort'. When referred to the Malaysian climate, it is a very useful concept; it quantifies and characterizes both the indoor and outdoor environments in human terms. One unit of thermal discomfort is defined as experienced by a person wearing light clothing and resting inside a building or outdoors in the shade when subjected to a temperature of 1°C above the upper thermal comfort level; 28°C. Results from various studies on an enormous amount of Malaysian meteorological data, Malaysian Thermal Discomfort Units (every 3 days) are shown in Table 2.13.

Table 2.13: Malaysian Thermal Discomfort Units

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1 to 3	26	23	38	21	21	38	20	23	20	12	11	18
4 to 6	24	14	*48*	28	18	25	37	23	14	16	10	16
7 to 9	29	33	46	28	29	28	28	15	18	10	6	14
10 to 12	32	31	37	19	29	30	18	20	4	18	14	14
13 to 15	25	21	31	28	21	22	20	9	19	23	14	17
16 to 18	15	24	29	25	28	20	20	23	17	14	15	3
19 to 21	13	20	21	27	32	32	24	20	26	20	9	4
22 to 24	21	16	30	31	42	34	18	30	5	28	9	5
25 to 27	28	15	33	19	35	17	17	18	11	19	13	19
28 to 31	11	10	28	23	45	22	22	29	20	13	11	19
Mean	22.41	20.65	33.84	24.84	30.09	26.87	22.39	20.95	15.27	17.31	11.09	12.78

Source: Davis et al. (2006)

Through these units, true seasonality of Malaysia revealed the maximum and minimum temperatures as weather forecast that gives the impression that Malaysia has an extremely even climate throughout the year.

Besides, it directly contributes useful knowledge for planning new buildings that is suitable with local climate and sustains the thermal comfort of the occupants. Referring to Table 2.13, the 4th to 6th March was revealed as the hottest day throughout the year when thermal discomfort is 48 units which had 16 times more heat stress than the coolest days which was on the 16th to 18th December. Davis et al. (2006) have made a conclusion that the first six months of the year are considerably hotter than the last six months.

Generally, thermal comforts in residential building are affected by occupants' activity to the air temperature and relative humidity. This includes the type and design of the rooms itself. The relationship between the design of the room and thermal comfort clearly can be seen through the size and numbers of windows which are the main elements in providing natural ventilation, as well as the number of walls that are directly exposed to the outdoors which had an impact on the indoor air temperature resulted from radiation and absorbent effects.

According to Rajapaksha et al. (2003), overheating of building interior in warm humid tropics are common due to solar penetration through the buildings envelope and windows; where more number of windows resulted in a hotter interior. Unfortunately, Zain-Ahmed et al. (2005) reported bungalow type of houses showed higher indoor air quality compared to semidetached bungalow and terrace houses, even though all sides of the bungalow are directly exposed to the outdoors. The overheating problems that are caused by solar penetration are reduced when spacious area within the bungalow allows more air flow and circulation through natural ventilation. A study done by Zain et al. (2007) found that the passive cooling strategy is limited to the rural areas and thermal comfort cannot be achieved through natural ventilation. There are also some issues that need to be considered.

This is supported by Yeang (2008), who stated that the natural ventilation requires frequent maintenance especially vents, windows and any automated actuators, as dusty air in hot climates cannot be easily filtered.

However, thermal comfort can be achieved in the urban area through a design strategy for building that complies with the locality of the building. This includes enough microclimate strategies within the surrounding areas of the building, such as cross ventilation in the attic, facilitate air flow and insulated wall (Zain et al., 2007). In equatorial climate region, hot and humid weather are an uncomfortable when high humidity limits the skin evaporation and the effectiveness of evaporative cooling strategies in achieving thermal comfort. This will then lead to thermal stress.

As mentioned by Davis et al. (2006), a scientific random household survey showed that on a hot day inside a terrace house which is housed by 70% of the urban population, approximately 62% suffered from headaches, 36 % get angry and 34% get sick. These are the basic symptoms of heat/thermal stress. In addition, two major problems of overheated houses are proved to be the small kitchen area and roof leakage. As a consequence, there is a need to reduce internal temperatures, maximize ventilation rates to increase the effectiveness of sweat evaporation and provide protection from sun, rain and insects in the design. Six strategies have been highlighted by Ahmad (2008) to minimize the thermal stress as listed below,

i. Keep out direct sunshine and heat by,
   - *Using large overhangs to protect internal spaces from solar radiation*
   - *Ensuring that east and west elevations have few or no windows admitting low sun, and that wall on these elevations are reflective and well insulated*
   - *Using low thermal mass materials to minimize heat storage*
   - *Using shading devices to minimize solar gain*

ii. Maximize natural ventilation by ensuring that,
   - *North and south walls have large openings for ventilation*
   - *Double-banking of rooms is avoided, if possible*
   - *Rooms are arranged to aid cross-ventilation*
   - *Plans are open and free spaces between buildings are wide*
   - *Large volumetric ventilation is provided is provided to remove internal heat*
   - *Spacing of building optimizes access to breezes*
   - *In freestanding houses, elevated construction is used, where possible to improve wind exposure*

iii. Use orientation to best effect,
   - *The best orientation is for long facades to face north and south*
   - *Orientation of buildings should respond to available cooling winds as well as to the sun*
   - *Conflict between sun and breeze orientation should always be resolved to control the sun, with the design of both building and landscaping modified to deflect available winds.*

iv. A roof should be pitched to facilitate water drainage

v. Mean radiant temperature should be kept as low as possible by using reflective roof, ventilated air space and reflective foil above ceilings, as well as insulating ceilings.

vi. For row houses, courtyards and air wells on the ground floor, encourage cross-ventilation and daylighting into the internal spaces

This is supported by Davis et al. (2006) who has stated seven design principles to cool Malaysian houses two years ago. These can be integrated in optimizing the thermal comfort in residential buildings which includes,

i. Highly insulated roof - *on a hot day, it can reduce the temperature in the attic from 48°C to 35°C as 80% of heat gain in a residential building comes through the roof. In addition, the colour of the roof should be considered, as the light colour reflects heat while dark colour absorbs heat and the temperature of white surface is 11°C cooler compared to a black surface.*

ii. Night time mechanical ventilation - *the outside air can help to cool down the concrete structure of the house and it is effective when the ventilation rate are between 14 to 28 air changes per hour.*

iii. Wall shading - *which can be achieved through 1.5m awning that can protect a single storey wall from around 95% of direct sunlight. Bamboo blinds, and verandas is the most cost effective overhang to shade the walls.*

iv. High thermal mass walls and floor - *which is commercially available; lightweight 'BT Drywall' and lightweight insulated 'Rapid wall'. However, it should be reminded that the concrete also effectively stores coolness as well as heat if other factors are properly considered.*

v. Orientation - *where the buildings should be built in any orientation to the sun by minimizing the heating effect.*

vi. Double glazing - *which has a cooling effect that is most negligible in a tropical climate. From the computer simulation, it's only around 0.1°C compared to other climate where the year round maximum and minimum temperature range can be 40°C.*

However, one of the strategies which is not listed above is very contradicting to the six strategies that have been highlighted by Ahmad (2008) before in minimizing the thermal stress. There is the reduction of the natural ventilation rate from the usual 3 or more air changes per hour to the minimum value 0.5, that is required to keep the air in a room fresh for human breathing, due to daytime ventilation (7am to 6pm) is undesirable and only heats up the house drastically (Davis et al., 2006; Kannan, 2006). This is supported by Orosa and Garcia-Bustelo (2009) who claimed natural ventilation is difficult to implement in urban locations when the indoor temperature and relative humidity values are higher than expected. This means, natural ventilation is only to cool down the house with hot air. This statement is supported by scientific studies that have been done at Universiti Putra Malaysia (UPM) 'Cool Bungalow' as shown in Table 2.14.

Table 2.14: The unit of thermal discomfort in UPM 'Cool Bungalow'*

VENTILATION STRATEGIES	UNIT OF THERMAL DISCOMFORT				
Daytime ventilation	23	35	42	50	57
24hr ventilation	23	19	18	21	23
Night ventilation	23	9	4	1	0
AIR CHANGES PER HOUR VIA MECHANICAL VENTILATION	0	7	14	28	56

Note:
- * - on the hottest day of the year
- Unit of Thermal Discomfort : One unit of thermal discomfort defined as experienced by a person wearing light clothing and resting inside a building or outdoors in the shade when subjected to a temperature 1°C above the upper thermal comfort level; 28°C.

Source: Davis et al. (2006)

The night ventilation (6pm to 7am) shows the lowest units of thermal discomfort compared to day ventilation which should be avoided when it only makes the house hotter, either naturally or mechanically. Although the 24 hours ventilation strategies showed the best results compared to daytime ventilation, it does not have the overall beneficial effect as running the electric ventilation fans continuously just leads to a wastage of energy (Davis et al., 2006).

Furthermore, if the mechanical ventilation is required for night ventilation, only at the rate of 14 air changes per hour is needed, which is 50 cents extra on the electricity bill per night to run a whole house ventilation system (Davis et al., 2006). The application of night ventilation in residential buildings may decrease the cooling load up to 40 kWh/m^2/year with an average contribution close to 12 kWh/m^2/year (Santamouris et al., 2010).

Unfortunately, as a prominent researcher in thermal comfort, Nicol and Humphrey (2002) suggested that the building should give occupants the chance to control and adjust the conditions to suit themselves as the temperatures in free-running naturally ventilated buildings are constantly changing in line with outdoor conditions. This is clearly influenced by the presence of green landscape, water fountain and other man built elements surrounding the buildings.

According to Monteiro and Alucci (2009), the tree canopy provides better environments than open sky in terms of thermal sensation when tending more to cooler situation and neutral sensation at urban spaces. In addition, the spaces with openings to the outdoors as well as courtyard will experience better thermal conditions. In order to lessen the influences of solar radiation which will penetrate into the building through the internal courtyard especially around noon and afternoon hours, suitable shading devices as well as suitable materials for its walls are suggested (Sadafi et al., 2008).

A further discussion about the courtyard has been highlighted by Rajapaksha and Rajapaksha (2008) who claimed that courtyards within the building can offer a substantial potential for indoor thermal comfort as the ability of a courtyard is to act as cool sink for the surrounding built spaces involving shading and ventilation aspect. In a different situation, the courtyards create different pressure fields along the wind-flow axis and thus, making the building an air funnel which promotes cross-ventilation, assists stack effect by thermal buoyancy and Venturi effects, and removes warm air away from the courtyards. In addition, the incorporation of a courtyard into a building offers a microclimate or buffer zone between the outdoor and indoor environments of the building, which promotes natural ventilation and daylighting when the air flow effect encourages cooling of occupants, structural cooling, controlling of overheating and removal of solar heat out of the building interior. These can be enhanced through the introduction of semi enclosed courtyard that functions as an air funnel that regulates the heat transfer between the courtyard, its adjacent servant spaces and the outdoor environment (Rajapaksha & Hyde, 2005).

Unfortunately, all of the benefits behind the courtyard can be achieved if the overheating by solar gain that reduces comfort to adjacent occupied spaces can be avoided through airflow effect, roofing, shading and thermal mass.

The climate condition and courtyard configuration also influence the amount of heat gain through radiation (Muhaisen & Gadi, 2006). Therefore, to optimize indoor environments in a building, criteria of sustainability should be considered.

Prior to all this, the first serious study on the local thermal comfort has been done by Kerka and Humpreys in 1956. They found that the intensity of the odour goes down slightly with some increase in atmospheric humidity Orosa (2009b). Then, further studies with more variables added and this resulted in a number of models and empirical equations. The thermal comfort model can be classified into the general thermal comfort model and the alternative thermal model in determining the conditions for achieving human internal thermal neutrality with minimal power consumption. In other words, to provide comfort to the occupants by removing or adding heat and humidity of the occupied space while fulfilling the requirement of sustainable buildings.

2.3.1 General thermal comfort model

According to Orosa (2009b), comfort equation obtained by Fanger (1970) is too complicated to be solved through manual procedures. Research by Srivajana (2003) showed Fanger model cannot correctly predict thermal sensation at high air velocity when the increased heat loss from the skin surface under high air velocity had been neglected. As consequences, a lot of studies were done by researchers to define the heat balance of a person which can be figured out from operative temperature, air velocity and relative humidity as shown in Table 2.15.

In addition, Standard Effective Temperature (SET) was introduced by ASHRAE (1992) which approach assumed air and radiant temperatures are similar and also incorporate different levels of activity and clothing.

Table 2.15: Methods to calculate general thermal comfort indexes

Method 1	Air velocity (V_a) *Field measurement*	Air temperature (t_a) *Field measurement*	Mean radiant temperature (t_r) *Calculation*	Humidity (P_a) *Field measurement*
Method 2	Air velocity (V_a) *Field measurement*	Operative temperature (t_o) *Calculation*		Humidity (P_a) *Field measurement*
Method 3		Equivalent temperature (t_{eq}) *Field measurement*		Humidity (P_a) *Field measurement*
Method 4	Air velocity (V_a) *Field measurement*	Effective temperature (ET) *Calculation*		

Note :

- Mean radiant temperature (t_r) defined as the uniform temperature of an imaginary black enclosure which would result in the same heat loss by radiation from the person as the actual enclosure.
- The Globe Temperature, air temperature (t_a) and air velocity (V_a) at a point can be used as input for t_r calculation.
- Operative temperature (t_o) is the temperature at which must be the walls and the air of an equivalent compound that experiments the same heat transfer to the atmosphere by convection and radiation than in a enclosure where such temperatures are different.
- Equivalent temperature (t_{eq}) can be calculated from the dry heat loss and by definition is the uniform temperature of a radiant black enclosure with zero air velocity in which an occupant would have the same dry heat as the actual non-uniform environment.
- The operative temperature (t_o), equivalent temperature (t_{eq}) and effective temperature (ET) are resulted from the integration of parameters that influence on the heat loss of the single parameters as shown below;
  - t_o integrated effect of $t_a + t_r$
  - t_{eq} integrated effect of $t_a + t_r + V_a$
  - ET integrated effect of $t_a + t_r + P_a$
- The ET and t_{eq} values are relying on the persons level of activity and clothing whereas the value t_o is normally independent of these parameters.

Source: Orosa (2009b); INNOVA (1996)

Then, some improvement has been made where correction for skin wittedness is incorporated and symbolized as ET* which is equivalent to SET for sedentary activity (1.1 met), light clothing and low air speed (Hedge, 2010).

A study done by Srivajana (2003) found a range of design air velocities applicable to most people (80% or more) is between Modified SET*; 23.0°C and 26.3°C while the best value as resulted from the survey is at Modified SET*; 24.3°C when all of them felt not draughty and not disturbed if air velocity was not greater than approximately 0.9 m/s.

There are four issues of local thermal discomfort namely draught, asymmetry of thermal radiation (Δt_{pr}), vertical air temperature difference and uncomfortable floor temperature.

Draughts happen in air-conditioned buildings, vehicles and air planes when convection cooling of the body especially in unclothed parts of the body including face, hands and lower legs. The average air velocity, turbulence in airflow, temperature of the air and fluctuation of the skin temperature influence the amount of heat loss from skin caused by draught. This was clearly expressed by INNOVA (1996) where a high turbulent airflow is felt to be more annoying than a low turbulent airflow and fluctuation with a frequency of 0.5 Hz are most uncomfortable, while frequencies above 2 Hz are not felt. In evaluating the draught rate, the following equation can be implemented,

$$DR = (34 - t_a) * (V_a - 0.05)^{0.62} * (37 * SD + 3.14)$$

where, DR - Draught Rating (%), t_a - Air Temperature (°C), V_a - Local Mean Air Velocity (m/s), *SD* - Standard Deviation of air velocity. As a result from studies comprising 150 subjects, this equation is appropriate for people at light mainly sedentary activity with an overall thermal sensation close to neutral (INNOVA, 1996). Turbulence Intensity (Tu) is used to describe how fluctuating is the air velocity in the percentage unit as shown in equation below,

$$Tu = 100 * (\mathrm{SD}/V_a)$$

Asymmetry of thermal radiation (Δt_{pr}) is an uncomfortable conditions due to a non-uniform radiant heat effect when excessive warm front and high cooling on the opposed side of the example (Orosa, 2009a). Another variation of asymmetry thermal radiation is the conditions caused by warm roofs and cold windows which produce the greatest impact of dissatisfaction. Thus, Δt_{pr} could define as the difference between Plane Radiant Temperature (t_{pr}) of the two opposite sides of a small plane element and the frequent change of position can reduce the asymmetry of thermal radiation effects when more uniform heating resulted.

According to INNOVA (1996), there are two methods can be used in determining this parameter including measurement in two opposite directions by using a transducer to capture radiation that affects small plane from the corresponding hemisphere. While another method is obtain temperature measurements from all surrounding surfaces and calculating the Δt_{pr} by employed the equations below,

$$t_{pr} = 4\sqrt[4]{\sum_{1}^{n} F_{pl-i} * (t_i + 273)^4}$$

where t_i is surface temperature of surface no. i (°C) and is angle factor between a small plane and surface.

As results from radiation or convection, around the head become warm whilst around the feet is being cold which has directly led to vertical air temperature differences. This phenomenon creates unpleasant comfort where 3°C air temperature differences between head and feet gave a 5% dissatisfaction level which has been chosen as the ISO 7730 acceptance level for a sitting person at sedentary activity (INNOVA, 1996). In addition, the vertical air temperature difference is expressed as the difference between the air temperature at ankle and neck level.

The uncomfortable floor temperatures usually cause by too high or too low of floor temperature as a result of conductivity and the heat capacity of the floor material, as well as type of covering worn on the feet. The optimal temperature is 29°C for a marble floor and 26°C for a hard linoleum with wood which still in the range of ISO 7730 standards; comfort levels ranging from 19°C to 29°C at sedentary activity to 10% of dissatisfaction.

2.3.2 Alternative thermal model

Generally, there have three alternative thermal models namely Predicted Mean Vote (PMV) index, operative temperature model and adaptive model.

a) Predicted Mean Vote (PMV) Index

The PMV index is a model that capable to predict the mean value of the subjective ratings of a group of people in a given environment in purpose to find out how perfect the thermal comfort is and what the limits of temperature and humidity should be maintained to enable reasonable thermal comfort. There have seven points of thermal sensation (T_{sens}) scale ranging from -3 to +3 where 0 represents the thermally neutral sensation; 3 (hot), 2 (warm), 1 (slightly warm), 0 (natural), -1 (slightly cold), -2 (cold) and -3 (cold) (ASHRAE, 2004).

In purpose to predict how many people are dissatisfied with a given thermal environment, Predicted Percentage of Dissatisfied (PPD) index can be implemented where people who vote -3, -2, +2, and +3 on the PMV index scale are regarded as thermally dissatisfied. Referring to ISO 7730 and 7726, the identification of the PMV and PPD in classification of environments is regarding to the degree of thermal comfort with an adaptation concept in assessing facilities and indoor environments. The PPD based on the PMV admissible is shown in Table 2.16.

Table 2.16: PPD based on the PMV

Comfort	PPD	Range of PMV
A	<6	-0.2 < PMV < 0.2
B	<10	-0.5 < PMV < 0.5
C	<15	-0.7 < PMV < 0.7

Source: Fanger (1970)

Furthermore, natural temperature can be predicted through PMV but limited to a margin error of 1.4°C that defined by the thermal sensation equation.

This erroneous is contributed by metabolic activity and the index of clo, or the incapability to include the isolation of the seat. Thus, Berglund (1978) has developed thermal sensation model which takes into account the effect of the clo as shown below,

$$T_{sens} = 0.305 \cdot T + 0.996 \cdot \text{clo} - 8.08$$

where there thermal sensation values are defined as 3 (warm), 2 (heat), 1 (soft), 0 (natural), -1 (soft freshness), -2 (freshness) and -3 (cold) (Orosa, 2009b).

Unfortunately, PMV is not able to predict thermal sensation correctly at high air velocity when Srijavana (2003) found the thermal sensation vote obtained from the experiment was much less than the value predicted by PMV although with higher air velocity, cloth insulation and skin moisture can be decreased. Therefore, modification to decrease clo value due to air velocity is necessary especially when the relative humidity increased between 60 to 80%.

Referring to ASHRAE (2004), recommended acceptable thermal comfort where at least 90% of occupants feel thermally satisfied are shown in Table 2.17.

Table 2.17: ASHRAE 55-2004 Standard

Season	Operative Temperature	Acceptable range
Winter	22°C	20-23°C
Summer	24.5°C	23-26°C

Source: ASHRAE (2004)

Unfortunately, according to Hussein and Rahman (2009) due to higher heat tolerance of a Malaysian who lives in equatorial region, the neutral temperature of 28.4°C with a comfort range of 26.0°C to 30.7°C was obtained by regression analysis of Thermal Sensation Votes (TSV) on operating temperature; which is exceeding the acceptable thermal condition set by the ASHRAE standard as mentioned above. Thus, it directly shows the respondents have capabilities to adapt the environment that they used to.

b) Operative temperature model

Different with an operative temperature model, the activity and clothing are considered in determines the temperature (Brager & deDear, 1998). The equation of this model is shown below,

$$t_{oac} = t_{osed} - 3(1 + Clo)\ (Met - 1.2)$$

This equation is valid with met value in the range of 1.2 to 3 met with minimum t_{oac} of 15°C (Orosa, 2009b). The operative temperature conditions for a sedentary activity in summer and winter are,

Terms of summer: $t_{osed} = 24.5 \pm 1.6$°C and Terms of winter: $t_{osed} = 21.8 \pm 1.8$°C

The Clo is a unit for measuring clothing's insulation where 1.0 Clo is equivalent to 0.155m^2°C/W. The Clo value can be determined by summing the Clo values of each individual garment dressed by a person as shown in *Appendix E - Clo values regarding to the garment dressed*. For example, a naked person has a Clo value of 0.0 while someone wearing a typical business suit has a Clo value of 1.0. Similar to determining the Clo value, Met value is the measurement of human metabolism with regards to the amount of muscular activity, which can be referred to in *Appendix F - Met values regarding to the activities*. 1.0 Met is equivalent to 58.15W/m^2 where approximately 100W will be lost by a normal adult that has 1.7m^2 of surface area.

An average person at rest records 0.8 Met while a sportsperson generally records the highest Met values, valuing approximately 10 Met is frequently recorded. Taking into consideration the human body's heat capacity imprint of the past hour's activity level, the average value of the activity performed within the last hour is important in evaluating the human metabolic rate. Then, external factors such as the upholstered seats, car seats and beds must be included in the overall calculation of the ability to reduce the heat loss from the body.

c) Adaptive model

The adaptive model is most useful to define the neutral temperature as a function of outdoor, indoor or both temperature with regards to the interaction between the subject and the buildings or other environment that was occupied. In certain conditions, it is able to achieve a higher accuracy level of neutral temperature and this adaptive model is standing under the principle, *if the change occurs such as to produce discomfort, people react in ways which tend to restore their comfort*, that clearly demonstrates the tendency of humans to adapt to changing conditions in their environment (Nicol & Humphreys, 2002).

There have three contextual variables in defining the adaptive model namely, indoor and outdoor climates, the nature of the buildings and its services and time where the human activity and responses take place in a time frame (Nicol & Humphreys, 2002). As a consequence, Orosa (2009b) mentions some of the conditions that need to be given attention to before applying this adaptive model. The occupants must be engaged in near sedentary activity (1.0 -1.3met) and is free to adapt their clothing; neither a heating system nor a mechanical cooling system can be in operation; and windows must be the principal way of controlling the thermal conditions. From the research on general thermal comfort, Orosa (2009b) listed the equations of adaptive models introduced by the prominent researchers in the thermal comfort area including Nicol, Roaf, Humphreys Auliciems and deDear,

$T_{n,o} = 17 + 0.38T_o$

$T_{n,1} = 2.6 + 0.831T_i$

$T_{n,o} = 11.9 + 0.534T_o$

$T_{n,i} = 5.41 + 0.731T_i$

$T_{n,o} = 17.6 + 0.31T_o$

$T_{n,i,o} = 9.22 + 0.48T_i + 0.14T_o$

ASHRAE : $T_c = 17.8 + 0.31T_o$

where T_c is the comfort temperature, T_o is the outdoor air temperature, T_i is the mean indoor air temperature, $T_{n,i}$ is the neutral temperature based on mean indoor air temperature and $T_{n,o}$ is the neutral temperature based on mean outdoor air temperature.

Prior to that, Nicol and Humphreys (2002) carried out a research on thermal comfort and relying on the massive body of data now available from comfort studies in the field from throughout the world and finally found the almost exact comfort temperature equation to be:

$$T_c = 13.5 + 0.54T_o$$

where T_o is the monthly mean of outdoor air temperature and the correlation coefficient r for the relationship was 0.97 for 1978 data and 0.97 for ASHRAE database. In addition, the range of conditions which will be acceptable at any one time is in the region of ±2°C and the buildings' occupants would need to adjust the conditions to suit themselves as discomfort is increased if control is not provided, ineffective, inappropriate or unusable. Then, changes in clothing, activity, posture and the promotion of air movement will also affect the comfort of its occupants.

This is different with South East Asia where there are no enunciated seasons such as summer and winter but consistent hot and wet weather throughout the year. As a result of the thermal response survey in South East Asia, acceptability for thermal comfort can be estimated from thermal neutrality T_n which is based on the mean monthly dry bulb temperature T_m,

$$T_n = 17.6 + 0.31\ T_m$$

For 90% acceptability for thermal comfort suggested value is T_n ± 2.5K while 80% acceptability for comfort suggests T_n ± 3.5K (Aynsley, 1999).

Eighteen years prior, Auliciems (1981) revealed the comfort band in the Klang Valley area for all types of building to be between 23.6°C and 28.6°C, with a neutrality temperature of 26.1°C; where there is not much of a difference with the empirical equation introduced by Aynsley (1999). In addition, Zain-Ahmad et al. (2005) presented various studies on range of comfort for Malaysia, which can be concluded in the Table 2.18.

Table 2.18: The various studies on range of comfort for Malaysians

Source	Temperature range, t (°C)	Relative air humidity (%)	Air velocity, v (m/s)
ASHRAE	23.0 – 25.0	20 – 60	-
Abdulmalik	25.5 – 29.5	45 – 90	-
Department of Standards Malaysia	22.0 – 26.0	30 – 70	-
Abdul Rahman	23.4 – 31.5	54 – 76	≥ 0.20
Zain-Ahmed	24.5 – 28.0	~73	-
Institute of Environmental Epidemiology	22.5 – 25.5	≤ 70	~0.25

Sources:

- ASHRAE. (1981). American Society of heating Refrigerating and Air Conditioning Engineers. Thermal environment conditions for human occupancy. ASHRAE Standards 55-1081. Atlanta.
- Abdulmalik, A. (1993). Thermal comfort as an aid to determine energy saving in Malaysia. In Proceedings of ENERGEX '93. Vol.II., Soul, Korea. pp 261-267
- Department of Standards Malaysia. (2007). MS 1525:2007 - Code of practice for energy efficiency and use of renewable energy for non residential buildings. Malaysia: SIRIM
- Abdul Rahman, S. (1997). A study of thermal comfort in naturally ventilated classrooms : Toward new indoor temperature standards. In Proceeding of the Asia-Pacific Conference on the Built Environment. Kuala Lumpur.
- Zain-Ahmed, A., Abdul Rahman, S., Shahrani, S. (2004). Indoor air quality in a Malaysian middle class home. In Proceedings of Conference on Scientific and Social Research. CSSR 2004. Sarawak, 19-22 May.
- Institute of Environmental Epidemiology. (1996). Guidelines for good indoor air quality in office premises.1st ed. Singapore Ministry of the Environment.

Source: Zain-Ahmad et al. (2005)

Most of the researchers are more concerned with the relative air humidity (%) versus air velocity (m/s) in influencing the temperature range (°C) of comfort for Malaysians. Then, the ranges of comfort for Malaysians are discovered to be constantly rising with relative humidity. Consequently, to achieve energy conservation in thermal comfort strategy, understanding the solar radiation behaviour and building envelope characteristics will facilitate the necessary measures required to control and manage the heat effectively.

In other words, to flush out the excess heat from the building while eliminating the wastage of energy while ensuring comfort is not compromised.

According to Zain et al. (2007), most of the town areas in Malaysia tend to receive solar radiation of more than 5.0 $kWhm^{-2}$ per day and the maximum heat that goes into a building space is after 4.00 pm due to the heat capacity or thermal mass of a building as presented in Table 2.19.

Table 2.19: The average dry bulb temperature (DBT), wet bulb temperature (WBT), relative humidity (RH) and solar radiation for a period of five from 1996 to 2000 for Subang, Malaysia

Time	DBT (°C)	WBT (°C)	RH (%)	Sol (W/m^2)	Time	DBT (°C)	WBT (°C)	RH (%)	Sol (W/m^2)
1	25	24	90	0	13	30	26	70	749
2	25	24	91	0	14	30	26	70	714
3	25	24	92	0	15	30	26	71	587
4	25	24	92	0	16	30	26	73	416
5	25	24	92	0	17	29	26	75	220
6	24	24	92	0	18	28	25	79	53
7	25	24	92	41	19	28	25	82	0
8	26	25	86	195	20	27	25	84	0
9	28	25	80	372	21	27	25	85	0
10	29	26	74	535	22	26	25	87	0
11	30	26	71	644	23	26	25	88	0
12	30	26	70	717	24	26	24	90	0

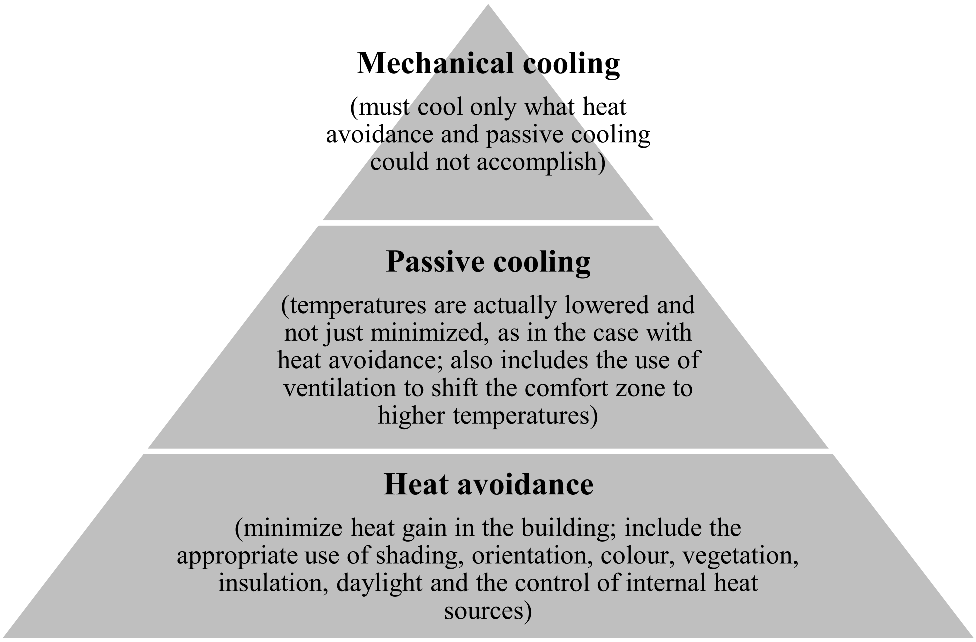
Source: Zain et al. (2007)

In overall, thermal standards for specifications of the indoor climate in the building do not seem to be critically necessary. This is supported by Nicol and Humphreys (2002) who came out with the statement that optimal indoor environments in a building are a function of its form, the services it provides and the climate in which it is placed. In terms of controls and building management, standards that came out of the relationship between characteristics of a building and local climate are more sufficient and meaningful when likely to be occupied.

2.4 Dynamics of natural ventilation in equatorial climate region

2.4.1 Passive cooling systems

The passive cooling strategy came of interest in 1980s although the use of air conditioning systems was already a part of the standard procedure in most warm climate countries. This was due to the concern of depletion of natural resources which had an effect of increased fossil fuels price and environmental damages that lead to climate change. Passive cooling is much more dependent on climate than passive heating and it is placed after heat avoidance in the three-tier design approach for building cooling needs (Lechner, 2009) as shown in Figure 2.8 below,



Source: Lechner (2009)

Figure 2.8: Three-tier design approach for cooling needs of buildings

Besides climate, building type also influences the effectiveness of passive cooling (Norford, 2006) and according to Soebarto and Ribeiro (2008); Givoni (1994), passive cooling comprises any cooling strategy that may sink the inner temperature of a building through the use of heat sinks that are available in nature and natural energy sources under the limit of the annual average outer temperature as listed in the next page.

Comfort ventilation / daytime ventilation

This strategy is the most common passive cooling strategy utilized, which is the use of outdoor air during daytime to remove heat gains in the room. The passage of air across the occupants' bodies is manipulated as the heat sink. There are five aspects that influence the effectiveness of comfort ventilation that enhances the convection and evaporative heat transfer between the occupants and the room air, namely; spatial planning of the building, position of windows, ceiling height, size and type of windows.

Generally, this strategy is only limited to warm and dry region with wind speeds of between 1.5 to 2m per second, with maximum temperature in the range 28°C to 32°C, 70% of maximum relative humidity and daily amplitude of below 10°C. In addition, for very hot and humid climate area, Lechner (2009) highlights the use of fans to supplement the wind, maximize the air flow across the occupants, lightweight construction while passive solar heating is not required, moderate amount of insulation to keep the mean radiant temperature near to air temperature, 20 per cent of the operable window area while the larger window area is needed in tropical and split about equally between windward and leeward walls.

Night cooling ventilation

This strategy is suitable for warm and dry climate when it uses the night's cool air to reduce the building's temperature during the day. Moreover, it can be more effective when buildings are closed during the day and opened at night and mechanical fans are used to create air circulation in the building itself. Moreover, this enhances the heat exchange between occupants and thermal mass.

The combination of high level insulation and thermal mass in building envelope in addition to the building oriented corresponding to the wind direction at night could enhance the effectiveness of this strategy. Concisely, night temperature under 20°C with daily temperature is 30°C to 36°C are necessary. Also, 15% of relative humidity including 12°C to 15°C of daily amplitude and 1.5 to 2.0m per second of wind speed.

Radiant cooling

The building's roof plays a role as a heat radiator; balancing the daily long radiation waves at night, which are limited to buildings with maximum height level of one with fixed mechanical ventilation to draw in cooler air from the roof and located in any regions with clear sky. The whole roof area should be painted white and fully used as the cooling effect is small (Lechner, 2009).

The example of this approach is a massive roof with mobile insulation (highly conductive material such as concrete), skytherm system (consisting of a series of roof ponds) and long-wave radiators (conventional insulation with 5 to 10cm of air space).

Evaporative cooling

This strategy exploits the energy that changes water from a liquid to gas state where the energy comes from the sensible heat in the air, resulting in lowering the temperature of the air itself. This strategy can be adopted only at warm and dry climates where the maximum wet bulb temperature (WBT) in summer is 22 to 24°C and maximum dry bulb temperature (DBT) in summer is 42 to 44°C. There are two types of evaporative cooling, known as direct evaporative and indirect evaporative. In direct evaporative, water is evaporated directly into the air which is circulated to the space being cooled and directly raises the relative humidity of the air and space. Thus, it is not appropriate in humid climates because the cooling effect is low and the humidity was already too high (Lechner, 2009).

However with indirect evaporative evaporation is used to lower the temperature of a medium which is separated from the building air and does not add moisture to the air, or in other words, cooling the indoor air without increasing its humidity level. According to Lechner (2009), the combination of direct and indirect is sometimes the best choice.

Earth cooling

Manipulating the earth as the heat sink when the cold air that is below the normal temperature is blown into the building and it can be enhanced through the shading the earth's surface or mulching the surface soil with pea stone or wood chips and providing moisture for evaporation. Therefore, the condition and the type of the soil itself is the main factor that contributes to the success of this strategy which is generally limited to moderate and warm climates. Also, $1m^2$ of underground area is necessary for every $5m^2$ of the occupied area.

The application of passive cooling strategies according to the climate can be summarized in Table 2.20.

Table 2.20: Strategies for passive cooling according to the climate

		Solar protection		Passive cooling							
Climate	Passive solar systems	Transparent element	Opaque elements	Ventilation (day & night)	Nocturnal radiation	Direct evaporation	Indirect evaporation	Earth cooling	Dehumidification	Air heat exchange (reducing power equipment)	Day lighting
Moderate	X	XX	XX	XX	X	X	X	XX	X	X	XX
Hot day		XX	XX	XX	XX	XX	XX	XX		X	XX
Hot humid		XX	XX	XX	XX			XX	XX	X	XX

Note:
- X - Level of efficiency and appropriateness of adopting the strategies

Source: Calderaro (2008)

In addition to these passive cooling strategies, there are more holistic strategies that are indirectly capable of enhancing the thermal comfort in the buildings. There are five approaches where the elimination of heat source in the building is the core elements of these strategies (Omer, 2008) namely,

- Solar control: protection of the building from direct solar radiation
- Ventilation: expelling and replacing unwanted hot air
- Internal gains minimization: reducing heat from occupants, equipment and artificial lighting.
- External gains avoidance: protection from unwanted heat by infiltration or conduction through envelope.
- Natural cooling: improving the natural ventilation by acting on the external air.

Therefore, based on the criteria of equatorial region; which have little seasonal variation with constant annual average temperature and humidity (Ahmad, 2008), natural ventilation is the best approach among the passive cooling systems for the achievement of thermal comfort, particularly in residential buildings in order to reduce energy consumption.

2.4.2 Natural ventilation strategies in building

Ventilation is defined as the effect of air movement in the building that plays a role as a provision of sufficient quality and quantity of air for people's life processes and activities. This happens by the removal of foul air and moisture, providing occupants with personal cooling by eliminating indoor surplus heat, which is also known as comfort ventilation by reducing the effects of relative humidity above 60%, particularly in a warm humid climate, and cooling the fabric of the building, commonly referred to as structural cooling (Soebarto & Ribeiro, 2008; Aynsley, 2007; Su et al., 2009). The pressure difference that comes from air movement by difference in temperature or by wind in and around the building generates natural ventilation. Ventilation that is driven by temperature is called stack effect when the natural buoyancy leads to air stratification where hotter air rises to the top and is displaced by cooler fresh air at the bottom from outside (Fordham, 2000). The efficiency of stack effect in providing natural ventilation can be improved by increasing the stack height and the temperature difference between the bottom and top of the stack while minimizing the airflow resistance through the stack; minimizing the number of bends, and by ensuring that there is generous radius (Aynsley, 2007). Thus, natural ventilation can be buoyancy-led or wind-driven, or by a combination of both (Su et al., 2009).

There are three types of ventilation approaches that are usually implemented in buildings as mention by Omer (2008) in the list below,

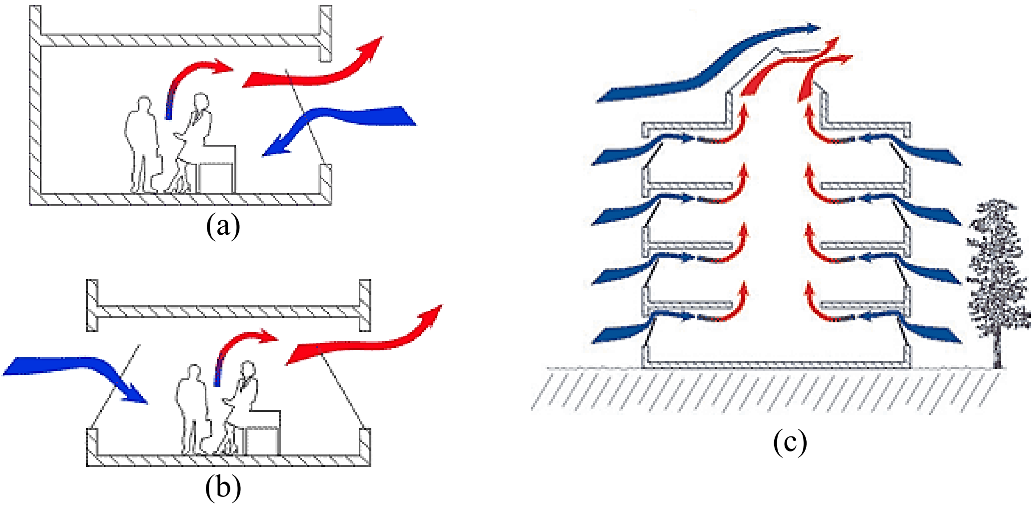
i. Single-sided ventilation [Figure 2.9(a)]
    - Simplest form – window or trickle vent on the wall.
    - Allow outdoor air enter the building and leave out either from the same opening or another opening situated on the same wall.
    - Common and expensive but uncontrollable except in an open or a closed position.
    - Effective over a distance of 6m from the opening itself.
    - Suitable in moderate climates and not suitable for winter ventilation.

ii. Cross-flow/two sided ventilation [Figure 2.9(b)]

- Quite similar to single-sided ventilation but these are installed on two or more opposite walls.
- For spaces of more than 6m deep and suitable for larger heat gains.
- Uncontrollable airflow.

iii. Mixed-flow ventilation [Figure 2.9(c)]

- Suitable for larger spaces with large heat gains (> 30W/m^2 of floor area)
- More complex systems – height of the roof utilized for situating exhaust air openings to provide a large height to increase the effect of buoyancy.
- Located air opening on the floor or on the walls at low level in case of a suspended floor design.
- Very effective but require high ceiling to be viable; in excess of 4m.



(a). Single-sided ventilation, (b). Cross-flow/two sided ventilation, (c). Mixed-flow ventilation

Source: Dyer Environmental Controls (2010)

Figure 2.9: Types of natural ventilation approaches

According to Gratia et al. (2004), single-sided day ventilation can reduce cooling needs by about 30% while day cross ventilation is much less efficient. Moreover, in optimizing single-sided ventilation, one should position the aperture at two openings at different heights and to create a cross ventilation when there is no wind, the window openings on opposite sides of the building have to be at different heights.

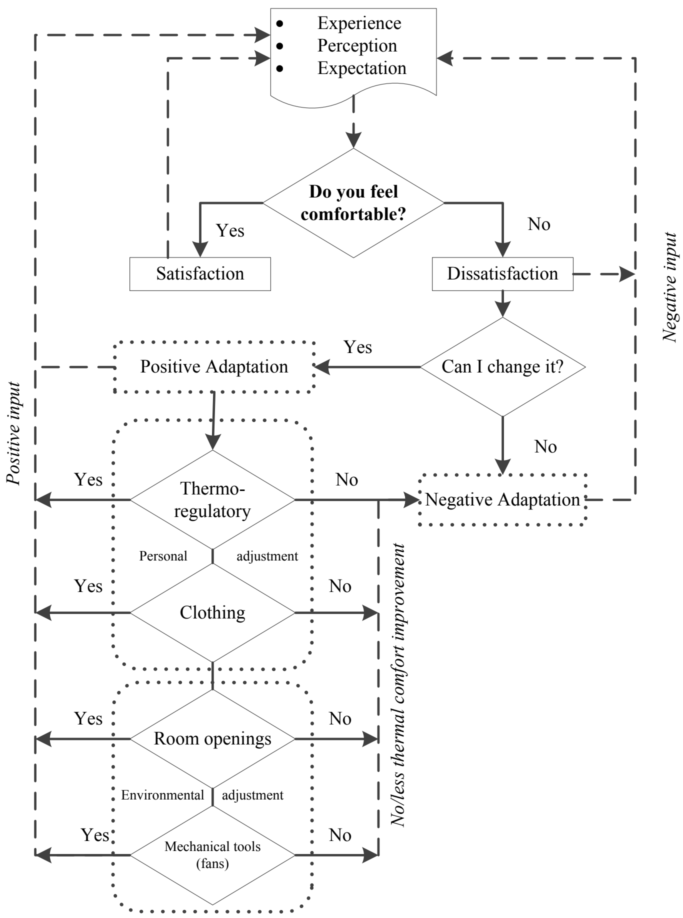
In standard and benchmark perspective, natural ventilation is listed as one of the criteria in worldwide evaluation instruments namely; GBI, Green Mark, Green Star, LEED, BREEAM and CASBEE. This is clearly described in *Appendix C - Minimum requirements/standards on thermal comfort, natural ventilation & daylighting of various evaluation instruments for residential buildings*. By comparing two evaluation instruments of the equatorial region, Green Mark is better than GBI in achieving good natural ventilation in buildings when this particular area is stated in both mandatory and elective requirements. Focusing on the GBI, minimum requirements for non-residential new construction is more appropriate under specific criteria and area of assessment, EQ7-Air change effectiveness (*Appendix D - Minimum requirements/ standards on thermal comfort, natural ventilation & daylighting of Green Building Index (GBI) for non-residential new construction*), compared to evaluation instrument of GBI for residential new construction.

The majority of people spends approximately 90% of their lives indoors and indoor air pollution is one of the top four environmental risks to public health where the sources are from combustion sources. This is supported by Hess-Kosa (2002) where indoor pollution is consistently reported to be around 2 to 5 times higher than outdoor pollutions. This situation becomes more serious when there is inadequate ventilation in the house, either by the design of the building itself or by the actions taken by the occupants (Zain-Ahmed et al., 2005). According to Gupta et al. (2007), the lack of good indoor air quality and thermal comfort have a strong bearing on Sick Building Syndrome (SBS) where the main symptoms prevailing in SBS are headache, lethargy and dryness in body mucus; mostly contributed to by the concentration of CO_2. The effects of SBS will be more apparent with an increased CO_2 concentration.

The heating, ventilation and air conditioning (HVAC) systems is not the ultimate solution to these problems when the mechanical systems which are commonly used to control the temperature, humidity, circulation, ventilation and purification of the air in the building are not firmly providing comfort to the building occupants. As reported by Yau (2008) from his study on University of Malaya buildings, the majority of the occupants were feeling uncomfortable from unpleasant odour inside certain office buildings resulting from return air circulation inside the building itself. This situation is a consequence of design failure in HVAC systems in fulfilling the requirement of unique hot and humid climates. Hence, natural ventilation is the best approach in providing comfort to occupants.

Natural ventilation is less controllable than mechanical ventilation. However, it can provide thermal comfort as well as maintain a healthy indoor environment while being proven to be efficient in reducing running costs in buildings. This is supported by Nicol and Humphreys (2002) who claimed that people have a natural tendency to adapt to changing conditions in their environment. Thus, by increasing the upper limit of the comfort range, it would result in a greater energy saving as Malaysians are acclimatized to hot and humid climates.

According to Wong et al. (2002), occupants in Singapore prefer to employ environmental control by turning on fans and opening the windows first before they resort to personal adjustment due to the fact that a higher wind velocity sensed by the occupants will bring about a higher evaporative cooling of the body thus leading to a feeling closer to the neutral sensation. Personal adjustments include various conscious actions that are related to the human body, such as consuming more liquid, changing clothes, etc. as shown in Figure 2.10.



Source: Wong et al. (2002)

Figure 2.10: Adaptive behaviour and thermal comfort perception

This is in line with Ismail et al. (2009), who claimed clothing strongly modifies the comfort feeling in natural ventilation, and is further supported by Daghigh et al. (2009), who claimed indoor thermal comfort can be improved significantly by personal adjustments such as consuming more liquid, changing clothes and other environmental adjustments such as, window-door opening in accordance with the temporal variations of indoor and outdoor climates.

As a consequence, natural ventilation is better than mechanical ventilation due to the favourable effect on thermal comfort when the fluctuation of natural wind can make people more comfortable and closer to nature, prolonged low speed helps to reduce the feeling of tiredness, and intensifies the heat convection between people and the environment through the larger turbulence and intensity of natural wind (Su et al., 2009).

Recently, Haase and Amato (2009) have analysed the effect of climatic conditions and building location with thermal comfort through natural ventilation in buildings. There are four different climates with specific problems regarding the building design that were listed as a part of their findings,

- Cold climates: where the main problem is the lack of heating
- Temperate climates: where there is a seasonal variation between under heating and overheating
- Hot dry climates: where the main problem is overheating, but the air is dry with a large diurnal temperature variation.
- Warm humid climates: where overheating is not as great as in hot dry areas but it is aggravated by high humidity and small diurnal temperature variation.

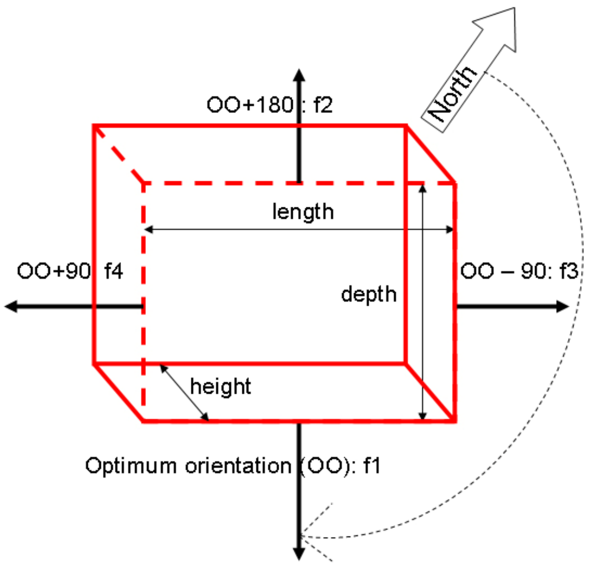
Then, by using selected cities with different climates, these two authors concluded that natural ventilation has a good potential in tropical and temperate climates, but not in subtropical climates (especially in Hong Kong) where during the hottest period (summer), the potential for comfort improvements are very small as shown in Table 2.21.

Table 2.21: Optimum orientation and natural ventilation improvement potential (%) in selected city with different climate

Location	Latitude	Longitude	Climate	Optimum Orientation	Natural ventilation improvement potential (%)
Singapore	1.4	104.0	Warm-humid	165.0	43
Kuala Lumpur	*3.1*	*101.6*	*Warm-humid*	*150.0*	*45*
Bangkok	13.9	100.6	Warm-humid	188.0	36
Manila	14.5	121.0	Warm-humid	170.0	50
Hanoi	21	105.8	Warm-humid	180.0	27
Hong Kong	22.2	114.2	Warm-humid	192.5	24
Guangzhou	23.1	113.3	Warm-humid	175.0	20
Taipei	25.1	121.6	Warm-humid	175.0	29
Kunming	25	102.7	Warm	177.5	14
Shanghai	31.2	121.4	Warm summer cold winter	170.0	12
Beijing	39.8	116.5	Cold	175.0	13
Harbin	45.7	126.7	Severe cold	172.5	13

Source: Haase and Amato (2009)

Conversely, for Kuala Lumpur that located in the equatorial region with the latitude 3.1 and longitude 101.6, the optimum orientation of a building is 150.0 (Figure 2.11) due to warm-humid climate.



Source: Hasse and Amato (2006)

Figure 2.11: Optimum orientation of a building

These findings are very significant towards the successful use of natural ventilation in the buildings where Germano and Roulet (2006) emphasized on the assessment of natural ventilation potential is as important as the potential of the site itself.

Furthermore, Kubota et al. (2009) revealed that majority of occupants have a tendency to apply daytime ventilation as opposed to night ventilation in the Malaysian residential areas. About 80% of the respondents usually open windows from 10 a.m. to 6 p.m. even though night ventilation provides better thermal comfort due to high humidity conditions that reached 70-80% of indoor relative humidity in all ventilation conditions. This includes daytime ventilation, full-day ventilation and night ventilation. These usually occur during the night time, whether with the opening or closing of operable windows. Avoiding insects, security purpose, preventing rain and dust from entering indoor are among the main reasons for not opening windows during the night for night ventilation purposes.

In addition, the implementation of SET* (Standard Effective Temperature) revealed the effects of evaporative heat loss of thermal comfort increase considerably with the rise of ambient air temperature especially in warm condition like in the tropics.

In conclusion, Kubota et al. (2009) stresses that full-day ventilation would be a better option compared with night ventilation and applying ceiling insulation with window shading devices would be effective in reducing operative temperature during the afternoon in Malaysia. The same result was also stated by Liping and Hien (2007) who had carried out a study on the impact of ventilation strategies and facade on indoor thermal environment for naturally ventilated residential buildings in the neighbouring country of Singapore. These two researchers proved that full day ventilation can provide better thermal comfort to the residences when climatic condition and air flow rate during night time were found to have the largest effect on night-time ventilation (Artmann et al., 2008).

Generally, passive cooling through natural ventilation is highly variable and dynamic while the effectiveness of this strategy is reliant on three principal factors (Aynsley, 2007). There are,

- The site and local landscaping features, where it is important to check the local wind conditions and speeds that are influenced by the seasons and topographic features such as hills, ridges and escarpments in addition to water features that provide psychological effect and vegetation that can be used to modify the external wind direction. Thus, enhancing the ventilation as well as cooling the incoming air while the adaptation of fragrant plant species can help to perfume the air flowing through buildings.
- The building form and building envelope, where the building openings are level with wind direction, the horizontal openings near floor level, roof outlets, casement sashes or hinged doors, extending eaves and taking cross walls, elevated rooms above ground level and larger total of air outlet.

With respect to Singapore's condition and perspective, north-south facing facades can provide much comfort while the closed window for daylighting on east-west orientations should be avoided in the design of naturally ventilated buildings for better indoor thermal environment (Liping & Hien, 2007). Moreover, non-isolated construction materials with thermal mass inertia are an ideal choice for naturally ventilated buildings in hot humid climate.

- The internal planning and room design, having large openings for the passage of air minimizes airflow resistance and encourages the jet of air flow through wall openings adjacent to a cross wall.

These three principal factors are already mentioned by Sustainable Energy Authority Victoria (2002), five years ago. Unfortunately, there are additional elements that need to be considered for designing good ventilation in the buildings, which requires the installation of fans in the situation where natural ventilation is not adequate.

The application of mechanical devices such as propeller fan in the building is capable of enhancing the effectiveness of natural ventilation especially in warm and humid regions. This statement supported by Hussein and Rahman (2009) who stated that due to higher heat tolerance of Malaysians, it is convenient for naturally ventilated buildings to use fans instead of air-conditioners to improve the indoor thermal condition. The study done by Haase and Amato (2006) revealed that there is only 45% of annual natural ventilation potential where the use of M&E are needed to support another 55% of ventilation. According to Lechner (2009), there are three quite distinct uses for fans namely; to exhaust hot, humid and polluted air; bring in outdoor air to either cool people (comfort ventilation) or cool the building at night (night-flush cooling) and to circulate indoor air at those times when the indoor air is cooler than outdoor air.

Beside the use of the fan in promoting thermal comfort in residential building, roof wind turbines have been highlighted as a part of M&E to cool down the buildings.

This has been highlighted by Lechner (2009) who claimed that the common wind turbine enhances ventilation about 30 percent more than an open stack. Unfortunately, three years prior, Davis et al. (2006) had revealed the roof wind turbines to have no significant cooling effect as stated in Table 2.22 due to the very low average of our local wind speed, 1.6 kph.

Table 2.22: Units of Thermal Discomfort per 6 hour periods

	Morning		**Afternoon**		**Evening**		**Night**	
	Control	Test house	Control	Test house	Control	Test house	Control	Test house
Roof space	35	38	79	84	19	20	2	2
Bedrooms (means of 3 rooms)	15	10	27	28	22	19	17	12
Downstrairs (means of 3 rooms)	8	7	17	15	14	14	9	8

Note

- Unit of Thermal Discomfort : One unit of thermal discomfort defined as experienced by a person wearing light clothing and resting inside a building or outdoors in the shade when subjected to a temperature 1°C above the upper thermal comfort level, 28°C.
- Control : Intermediate double storey terrace house
- Test house : Neighbour to control house fitted with two 16” wind turbines on roof

Source: Davis et al. (2006)

Compared to hot windy climate areas such as Texas and Australia, the roof wind turbines are really effective when the wind speed exceed 6kph.

By making a comparison with Aynsley (2007), who came out with three principal factors that influence the effectiveness of passive cooling through natural ventilation, Soebarto and Ribeiro (2008) highlighted five aspects that should be considered in making sure the effectiveness of natural ventilation in enhancing the convection and evaporative heat transfer between the occupants and the room air. The five aspects are,

- Spatial planning, to allow air to move through from the windward side to the leeward side to create cross-ventilation.
- Position of windows, where at least two windows are placed on different external walls.
- Ceiling height, approximately 3m to allow air to flow vertically through the bottom of the window and can diffuse through the room and out through the top of the window.

- Size of windows where there is a need for bigger open or equivalent at the higher pressure opening as compared to the lower opening. Unfortunately, there are no guidance for the maximum size of the opening where other practical requirements such as sun control, security and privacy are to be considered (Aynsley, 2007). According to Liping and Hien (2007), the increase of window to wall ratio to 0.24 can improve indoor thermal conditions to a large extent and horizontal shading devices are needed for the four orientations to further improve the indoor thermal comfort.
- Types of window that affect the volume of pressure and airflow pattern inside the building.

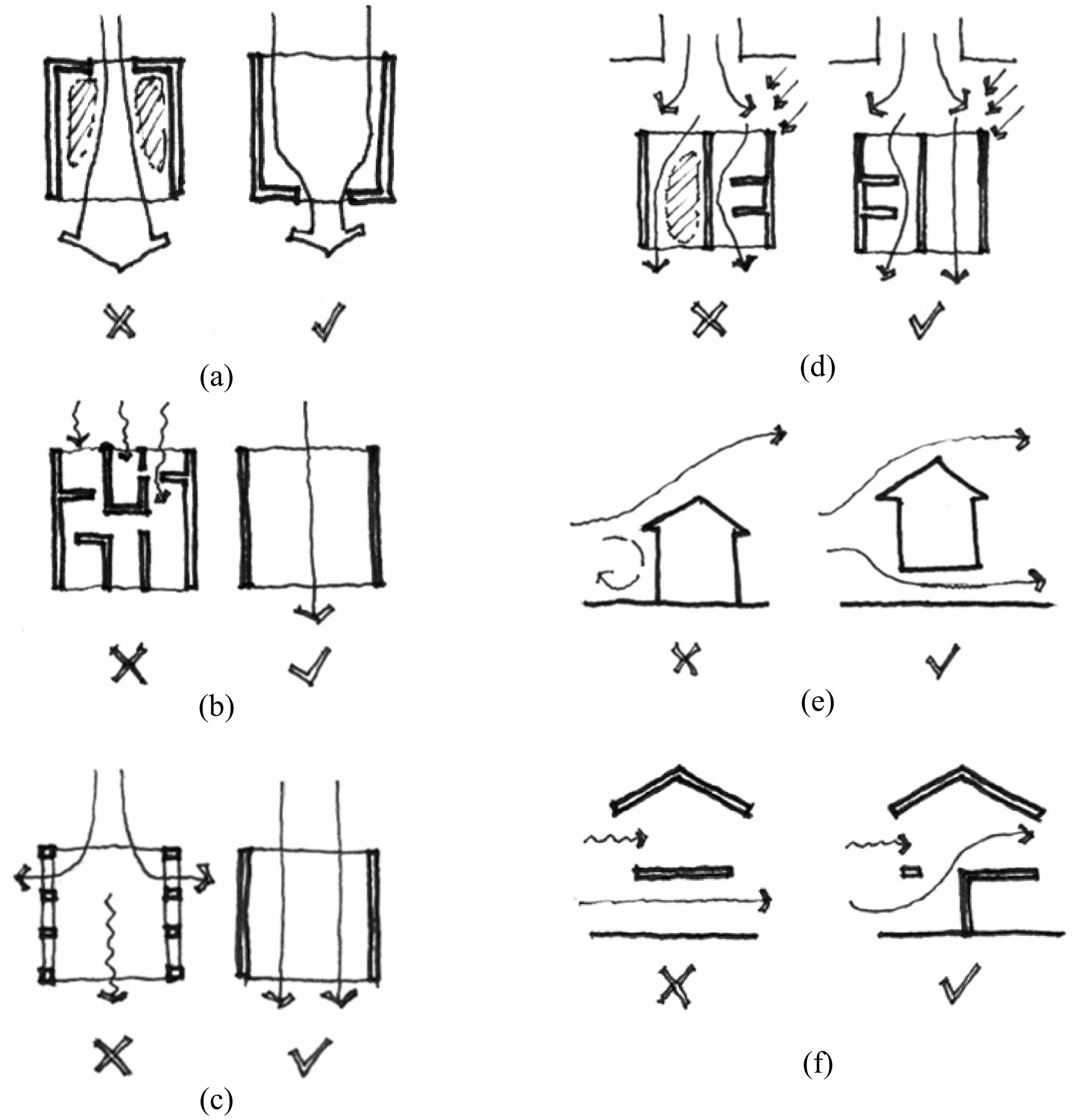
This is in line with Kamaruzzaman and Edwards (2006) who undertook a research on historic buildings in Malaysia. He revealed that natural ventilation approaches were clearly described through louvered windows, full-length windows or French windows, fanlights, air-wells, high ceilings and internal courtyards in giving buildings and occupants a cooling effect; as a result of design for the local climate.

In holistic approaches, Tantasavasdi et al. (2001) have listed measures that are needed to enhance the natural ventilation for houses in Bangkok. These measures most probably can be adapted in Malaysian houses when all the principal factors and aspects that influence the effectiveness of natural ventilation are taken into consideration; as presented by Aynsley (2007) and Soebarto and Ribeiro (2008) in the list below;

- The natural ventilation should provide an indoor air velocity of 0.4 m/s as strong air movement can increase the rate of convective and evaporative heat loss from human skin to the environment.
- The total area of the inlet and outlet apertures should be about 40% [Figure 2.12 (a)].
- Avoid rectangular houses as it is not as good for natural ventilation as square shaped houses
- Using larger inlet than outlet apertures (for example, inlet area of $32m^2$ and an outlet area of $16m^2$, the corresponding ventilation rate is $9.6m^3/s$).

- Keeping the indoor space as open as possible by reducing the number of walls inside the building, so that wind can circulate freely [Figure 2.12 (b)].
- Closing the apertures on the east-facing and west-facing wall to avoid a shortcut [Figure 2.12 (c)].
- Keep long rooms in the east-facing part of the house [Figure 2.12 (d)].
- The elevated floor can allow more wind to flow through the houses [Figure 2.12 (f)] and as an added advantage; a wind scoop on the ground level can be design adequately [Figure 2.12 (e)].
- The buoyancy effect which can generate a maximum air speed of 0.25 m/s at the area close to a heat source.
- A ceiling fan can be used to increase the air velocity if the indoor air velocity is really low.

Regarding the building layout, form and envelope that influence the effectiveness of natural ventilation, Hasse and Amato (2006) revealed a shallow building with optimal orientation and a maximum of five floors is more applicable for exploiting wind for natural ventilation. This is supported by Aynsley (2007) who claimed that natural ventilation in modern buildings is most common in relatively low rise and shallow plan buildings such as residentials, schools and small office unit. This occurs due to inconsistent average wind speed and high air temperature that leads to stack effects becoming a major issue for natural ventilation in high rise buildings, especially an office building in a hot and humid country (Kannan, 2006). As a result, the effectiveness of natural ventilation in achieving thermal comfort at equatorial climate region is heavily influenced by the wind rather than other aspects that have been highlighted before.



Source: Tantasavasdi et al. (2001)

Figure 2.12: Design strategies for enhancing the natural ventilation

This is supported by Candido et al. (2008) who found that the acceptable indoor air speed in hot humid climates should range between 0.2 to 1.5 m/s, which is classified as light air under the Beaufort scale (*Appendix G - Wind speeds: Beaufort scale*), and when the operative temperatures exceed 24°C, air speed up to 1m/s is preferred by the building occupants. Moreover, Tantasavasdi et al. (2001) have mentioned that natural ventilation should provide an indoor air velocity of 0.4 m/s as a measure to enhance the natural ventilation for houses in Bangkok.

Comparatively, all these findings are higher than the range of minimum recommended air velocity rates for interiors by ASHRAE that was presented by Aynsley (2007) in Table 2.23.

Table 2.23: Recommended air velocity rates for interiors (when occupied)

Dry bulb	Met	Clo	Relative Humidity %	Air Max (m/s)	Air Min (m/s)
21	1	0.9	40	0.1	none
21	1	0.9	60	0.1	none
21	1	0.9	80	0.1	none
24	1	0.9	40	0.	0.1
24	1	0.9	60	0.1	0.1
24	1	0.9	80	0.1	0.1
27	1	0.5	30	0.95	0.6
27	1	0.5	50	1.35	0.6
27	1	0.5	75	2.05	0.6

Note;
Met is the metabolic rate. For sedentary person 1 met = 58.1 W/m^2
Clo is unit of thermal insulation of clothing. 1 Clo = 0.155 $m^2.k/W$

Source: Aynsley (2007)

The ventilation rates can be further increased if the indoor air temperature is over 28°C to eliminate the heat (Su et al., 2009). However, the velocity along the body surface should not be over 0.8 m/s.

The application of insect screens at natural ventilation devices are prominent in the equatorial region, particularly in the tropics due to the risk of serious illnesses such as malaria and dengue fever that are spread by insects. This approach indirectly reduces the wind speed through the opening of natural ventilation as presented in Table 2.24, where Aynsley (2007) found that the insect screens which are made from plastic coated with fibreglass resulted in a higher reduction of wind speed. This also supported by Lechner (2009) who claimed that the air flow is decreased about 50 per cent by the use of insect screens. Moreover, higher reduction is also registered by dusty insect screens compared to clean insect screens. Thus, the insect screens need to be chosen properly while maintenance works should be carried out periodically to make sure it is functioning properly to prevent insects from coming into the house while encouraging natural ventilation through openings.

Table 2.24: The effect of insect screens (clean and dusty) on natural ventilation wind speeds through openings

Wind speeds through a clear opening (m/s)	% Wind Speed Reduction			
	Wind speed through bronze wire screen (m/s) 5.5 wires/cm Porosity 80%		Wind speed through plastic coated fibreglass (m/s) 7 threads/cm Porosity 66%	
	Clean	Dusty	Clean	Dusty
0.5	0.25 (50%)	0.18 (64%)	0.10 (80%)	0.08 (84%)
1.0	0.55 (45%)	0.40 (60%)	0.35 (65%)	0.25 (75%)
1.5	1.06 (29%)	0.85 (43%)	0.80 (47%)	0.65 (56%)
2.0	1.50 (25%)	1.30 (35%)	1.15 (43%)	1.00 (50%)
2.5	2.00 (20%)	1.65 (34%)	1.50 (40%)	1.35 (46%)

Source: Aynsley (2007)

By considering all the strategies and approaches, natural ventilation must be done in an appropriate manner as too much or too little outdoor air in a room can cause draughts and discomfort (Omer, 2008). Moreover, it should be capable of being controlled by the occupants and to be integrated with solar protection without considering the uses of mechanical cooling; this has been identified as the most efficient building strategy.

2.5 Dynamics of daylighting in equatorial climate region

2.5.1 Introduction of daylighting

Daylighting is a technique to bring natural light into a building through openings (Fontoynont et al., 2004). This technique has already been implemented in building design especially before the second half of the twentieth century when fluorescent lightings have not yet been introduced and the cost of electricity is very pricy. This is most evident when the majority of the buildings during that time had more windows than walls, high ceilings with high windows, E-, U-, O- or H-shaped floor plans in providing daylighting and natural ventilation (Lechner, 2009).

In equatorial regions where the climate is hot and humid, most of the traditional buildings are light constructions with wide awning or verandas shading large windows which can be opened during day and night throughout the year for ventilation (Edmonds & Greenup, 2002).

Historically, the concerns regarding daylighting were already highlighted earlier in 1784, when Benjamin Franklin wrote a letter to the Journal of Paris about the waste of both candlelight and daylight in his capability as American Minister to France, while in 1907, Briton William Willet published a pamphlet entitled 'The Waste of Daylight' (Aries & Newsham, 2008). They had proposed an idea to solve the wastage of daylight; unfortunately the ideas were not adopted.

Nowadays, daylighting is given attention in building design due to the decrease of energy resources and the contribution of the energy sector to climate change while not compromising visual comfort. There are three major developments that contribute to daylighting interest in building design; the recent discovery of the impact of light on human health, the growing influence of green building rating schemes and the progress on lower cost, reliable, integrated control technologies to provide the responsiveness needed for comfort and energy savings (Reinhart & Selkowitz, 2006).

Regarding green building rating schemes, daylighting has been stated as one of criteria for the assessment in GBI, Green Mark, Green Star, LEED, BREEAM and CASBEE (*Appendix C - Minimum requirements/standards for thermal comfort, natural ventilation & daylighting of various evaluation instruments for residential buildings*). Directly, it will encourage more of daylighting implementation in the building design. Focusing on GBI, minimum requirements/standards on daylighting of GBI for non-residential new construction (*Appendix D - Minimum requirements/standards for thermal comfort, natural ventilation & daylighting of Green Building Index (GBI) for non-residential new construction*) are more detailed and strengthened when it also includes daylight glare control and external views due to the need of better condition for working places. Regarding residential colleges, the residential unit is not only uses as a bedroom, but also uses as a place for the residents for conducting their work, study and social interactions among the residents.

Thus, the minimum requirements/standards of GBI for non-residential new construction should be also adapted for residential college buildings.

Besides these green building rating schemes, the illumination level standard that was established by Illuminating Engineering Society (IES) is also adapted all around the world. In local perspective, there are two recognized standards which are the Standards and Industrial Research Institute of Malaysia (SIRIM) and Public Works Department of Malaysia as shown in Table 2.25.

Table 2.25: Illumination standards for circulation areas and homes

Building area	Illuminating Engineering Society (IES) Standards (lux)	MS 1525:2007 Recommendation (lux)	Public Works Department of Malaysia (lux)
CIRCULATION AREAS			
Corridors, Passageway	100	50	100
Lift	150	100	100
Stairs	150	100	100
Escalator	150	150	100
External Covered Ways	30	50	30
HOMES			
Living room general	50	150	50
Casual reading	150	300-400	150
Sewing darningsrudies desk & protuged	300	-	300
Bedroom general	50	100	50
Bed lead kitchen	150	-	150
Kitchen working areas	-	150-300	-
Bathrooms	100	150	100
Hall and landings	150	-	150
Stairs	100	100	100
Workshops	300	-	200
Garages	50	-	50

Source: IES (2011); Department of Standards Malaysia (2007); Faculty of Engineering, Alexandria University (2008)

By making comparisons between these standards, no significant difference is identified especially for the minimum lux level for homes. However, for circulation area, IES standards needed higher lux level especially at lift and stairs. In general, Malaysian guidelines for energy efficiency in buildings recommended that the interior lighting for offices should be between 200 and 500 lux (Zain-Ahmed et al., 2002a), while the typical illumination level for Malaysian office is 350-400 lux (Kannan, 2006).

Noted as one of the major development towards daylighting interest in building design; lower cost, reliable, integrated control technologies in providing responsiveness needed for comfort and energy savings, studies done by Franzetti et al. (2004) proved that complementing daylight and artificial light in efficient installation or by a better control of use time leads to the reduction of lighting energy consumption. According to Phelan (2002), daylighting approaches involve a great number of design factors that cross the disciplines of site planning, architecture, interior design, lighting design, electrical engineering and mechanical engineering. All these factors have to integrate with occupant characteristics, owner operating requirements, task lighting requirements and the daily and seasonal solar cycles as shown in Table 2.26.

Table 2.26: Daylighting design factors

Discipline	Design factors	
Site	▪ Building orientation	▪ Adjacent buildings or natural features
Architecture	▪ Building shape, mass ▪ Top daylighting ▪ Side daylighting ▪ Window/wall ratio	▪ Glazing characteristics ▪ Interior light shelf ▪ Exterior light shelf ▪ Ceiling tile reflectance
Interior Design	▪ Cubicle layout ▪ Cubicle height	▪ Interior colours
Lighting Design	▪ Task/ambient lighting design ▪ Open office ▪ Enclosed office ▪ Indirect lighting	▪ Direct lighting ▪ Lighting zones ▪ Task lighting ▪ Lamp and fixture type ▪ Lamp colour temperature
Mechanical Design	▪ Building automation system integration	
Occupant	▪ Age	▪ Previous office environment
Task	▪ IES task type ▪ Computer use	▪ Paper tasks
Solar/Weather	▪ Time of year ▪ Time of day	▪ Cloud cover

Source: Phelan (2002)

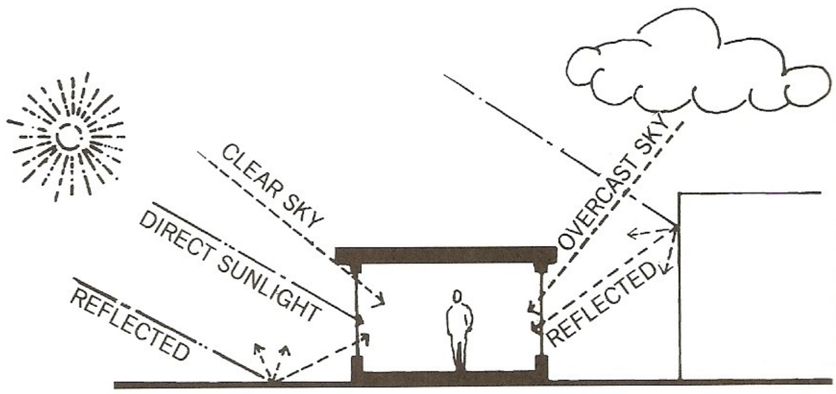
Generally, daylight is the total light from the sky dome that is affected by attenuation due to absorption and scattering in the atmosphere and consists of direct (or beam), diffuse and ground-reflected components (Zain-Ahmed et al., 2002b).

The most important properties of an effective day-lit space is adequate and uniform light distribution in the space, natural shadow projections and colour rendition and avoidance of disabling glare and minimization of contrasting glare (Jughans, 2008). Therefore, the quality and quantity of light are the two most important aspects in daylighting. This is supported by Lechner (2009) who had listed the six goals of daylighting,

- Minimize glare, minimize veiling reflections, avoid excessive brightness ratios and supply fairly even ambient illumination throughout a space.
- Reduce or prevent the severe direct glare of unprotected windows and skylights.
- Prevent excessive brightness ratios, especially those caused by direct sunlight on or near the task.
- Prevent or minimize veiling reflections, especially from skylights and clerestory windows.
- Diffuse the light by means of multiple reflections off the ceiling and walls.
- Use the full aesthetic potential of daylighting and sunlight (limited to spaces which there are few critical visual tasks).

In addition to these six goals of daylighting, Omer (2008) stated four aims of daylighting, which are more simplified; increase daylight levels towards the rear of deep rooms, improve daylight uniformity within a space and hence its appearance, control direct sunlight so that it can be used as an effective working luminance and reduce glare and discomfort for occupants. In other words, to control incoming direct sunlight in order to minimize its potentially negative effect on visual comfort; minimize glare, and to reduce the building's cooling load by reducing heat gain (Yeang, 2008). Consequently, the use of daylight system is adjusted to the building, surrounding climate and matches with the requirements of lighting for specific purposes (Kischkoweit-Lopin, 2002).

The natural light is varied by its amount and direction; that varies during a typical day as the sun moves and the condition of the sky (Dean, 2005). According to Lechner (2009), natural light comes from several sources, including direct sunlight, clear sky, clouds or reflections from the ground and nearby buildings as shown in Figure 2.13.



Source: Lechner (2009)

Figure 2.13: The various sources of daylight

The direct sunlight is very directional and extremely bright which should be excluded from the building due to potential for glare, excessive brightness ratio and overheating (Lechner, 2009). Moreover, it is between 5 and 10 times stronger than diffuse light and casts sharp shadows (Baker & Steemers, 2002). However, direct sunlight is appropriate when renewable energy strategies such as photovoltaic were utilized in the buildings.

The natural light from reflection is particularly relevant in dense urban situations where owing to the closeness of the neighbouring buildings, a view of the sky may be limited or even completely absent for all but the positions closest to the window (Baker & Steemers, 2002). Thus, the light will tend to come from a low angle, close to horizontal and will penetrate deeper into the space than the sky components. Regarding the quality of light, it is much weaker due to the absorption by external obstructions; buildings and trees.

Concerning sky conditions, Jughans (2008) had classified into three types which are, 1). Overcast sky: The light coming from the zenith is triple that coming from the horizon; 2). Clear sky without sun: The light coming from the horizon is brighter than from the zenith; and 3). Clear sky with sun: The intense light from the sun dominates the sky globe. With specific characteristics, each sky condition gives a challenge in terms of quantity and quality to the architect for implementing daylighting strategies in building design. The overcast sky has a relatively low luminance; 5000-20,000 lux but it is ten to fifty times greater than what is needed indoors, while clear sky continually changes direction although it is not extremely bright (Lechner, 2009). Luminance is defined as the energy contained within the visible solar spectrum of wavelengths between 0.39 and 0.78µm in candela/m^2 unit (Zain-Ahmed et al., 2002b).

In equatorial regions, the ratio of direct to diffuse radiation may reach 1:4 when the sky condition is cloudy and hazy during the entire year, while bright when cloud cover diminishes (Grimme & Laar, 2002). Thus manifesting a strong predominance of diffuse radiation in vice versa to arid regions which glare is usually caused by reflection of irradiated surfaces of the ground or other buildings (Jughans, 2008). The diffuse light intensity usually varies from 1,000 to 30,000 lux depending on the degree of overcast and solar altitude (Kim & Kim, 2010). A study done by Zain-Ahmed et al. (2002b), found out Malaysian sky is predominantly intermediate where it is neither clear nor overcast when the hourly indices indicate that 85.6% of the time, the sky is predominantly intermediate (2.3% intermediate overcast, 66.0% intermediate mean and 16.3% intermediate blue) and 14.0% is overcast while the luminance may reach 80,000 lux during the brightest month and exceed 60,000 lux during the cloudy month. This has been supported by Fadzil and Sia (2004) who had stated that Malaysian sky conditions are commonly cloudy to clear days and resulted dull grey sky condition which also comes with heat and glare problems.

Thus, some kind of efficient control is needed and right decision can only be made through research and analysis. In considering the potential for daylighting, the function of the building and its occupancy period has to be considered (Baker & Steemers, 2002).

The natural light from reflections also challenges the architect due to critical reflectance factor on the reflecting surface. Kim and Kim (2010) stated the sunlight reflected from the ground constitutes only 10-15% of the total daylighting reaching a window, but light ground surfaces increase this amount. According to Baker and Steemers (2002), there are three possible processes that can take place when light falls onto a surface or a layer; absorption, reflection and transmission. Moreover, different surfaces have different effects,

- Opaque surface: some light is absorbed and some reflected. Reflection may be diffuse or specular; most real surfaces exhibit both to a varying degree.
- Transparent layer: some light is reflected, some is absorbed in passing through the layer, and some transmitted. Transmission may be diffuse or specular.

Considering reflectance, perfect black would be 0, perfect white would be 1 and all real surfaces lie somewhere in between as shown in Table 2.27. The reflection and transmission at surfaces and layers can modify the composition of white light sufficiently to give the sensation of colour which can be created by a combination of three primary colour lights: red, green and blue; known as the tristimulus principle (Baker & Steemers, 2002). Contrary to absorption aspects, where the colour of the built form's envelope has significant impact on a building's cooling load where colour with higher solar absorption increases heat gain in the buildings (Yeang, 2008) as shown in Table 2.28 and Table 2.29.

Table 2.27: Diffuse reflectance of building surfaces

Surface type	Description	Reflectance
Ceilings	White emulsion paint on a plain plaster surface	0.8
	White emulsion paint on acoustic tile	0.7
	White emulsion paint on no-fines concrete	0.6
	White emulsion paint on wood-wool slab	0.5
Walls	White emulsion paint on a plain plaster surface	0.8
	Tiles: white glazed	0.8
	Brick: white gault	0.7
	Plaster, pink	0.65
	White asbestos cement	0.4
	Brick: concrete, light grey	0.4
	Portland cement, smooth	0.4
	Stainless steel	0.35
	Brick, fletton	0.3
	Concrete, light grey	0.25
	Portland cement, rough (as board marked)	0.25
	Brick, London stock	0.25
	Timber panelling: light oak, mahogany, gaboon	0.25
	Timber panelling: teak, afromosia, medium oak	0.2
	Brick: concrete, dark grey	0.2
	Brick: blue engineering	0.15
	Chalkboard, painted black	0.05
Floors and furniture	Paper, white	0.8
	Cement: screed	0.45
	PVC tiles: cream	0.45
	Carpet: light grey, middle buff	0.45
	Timber: birch, beech, maple	0.35
	Timber: oak	0.25
	PVC tiles: brown and cream marbled	0.25
	Carpet: turquoise, sage green	0.25
Floors and furniture	Timber: iroko, kerning, medium oak	0.2
	Tiles: cork, polished	0.2
	Quarry tiles: red, heater, brown	0.1
	Carpet: dark, "low maintenance"	0.1
	PVC tiles: dark brown	0.1
	Timber: dark oak	0.1
Other	Asphalt	0.07
	Moist earth	0.07
	Slate (dark grey)	0.08
	Gravel	0.13
	Water	0.15
	Grandolite	0.17
	Bluestone, sandstone	0.18
	Macadam	0.18
	Vegetation (average)	0.25
	Cement	0.27
	Dark red glazed brick	0.3
	Green Grass	0.33
	Dark buff brick	0.4
	Light buff brick	0.48
	Concrete	0.05-0.5
	Marble (white)	0.45
	Oak	0.15-0.05
	Old white paint	0.55
	New white paint	0.75
	Old snow	0.64
	New snow	0.74

Table 2.27 (continued)

Surface type	Description	Reflectance
Specular reflectance	Aluminium commercial grade (anodised and polished)	0.7
	Aluminium super-purity (anodised and polished)	0.8
	Surface aluminised glass or plastic	0.94
	Chromium (plate quality)	0.65
	Stainless steel (polished)	0.6
	Steel: white paint glossy (specular only)	0.05

Source: Baker and Steemers (2002)

Table 2.28: Solar absorption of various colours and materials

Materials	Value
Optical flat black paint	0.98
Flat black paint	0.95
Black lacquer	0.92
Dark grey paint	0.91
Black concrete	0.91
Dark blue lacquer	0.91
Black oil paint	0.90
Stafford blue bricks	0.89
Dark olive drab paint	0.89
Dark brown paint	0.88
Dark blue-grey paint	0.88
Azure blue or dark green lacquer	0.88
Brown concrete	0.85
Medium brown paint	0.84
Medium light brown paint	0.80
Brown or green lacquer	0.79
Medium rust paint	0.78
Light grey oil paint	0.75
Red oil paint	0.74
Red bricks	0.70
Uncoloured concrete	0.65
Moderately light buff bricks	0.60
Medium dull green paint	0.59
Medium orange paint	0.58
Medium yellow paint	0.57
Medium blue paint	0.51
Medium Kelly green paint	0.51
Light green paint	0.47
White semi-gloss paint	0.30
White gloss paint	0.25
Silver paint	0.25
White lacquer	0.21
Polished aluminium reflector sheet	0.12
Aluminised mylar film	0.10
Laboratory vapour deposited coatings	0.02

Source: Yeang (2008)

Table 2.29: Solar emittances and absorption of selected materials

Item	Emittance (at 10-40°C)	Absorptance (for solar radiation)
Black non-metallic surfaces (e.g. asphalt, carbon, slate, paint)	0.90-0.98	0.85-0.98
Red brick & tile, concrete & stone, rusty steel & iron, dark paints (red brown, green, etc)	0.85-0.95	0.65-0.80
Yellow & buff brick & stone, firebrick, fireclay	0.85-0.95	0.50-0.70
White or light cream brick, tile, paint or paper, plaster, whitewash	0.85-0.95	0.30-0.50
Bright aluminium paint, gilt or bronze paint	0.40-0.60	0.30-0.50
Polished brass, copper, Monel metal	0.02-0.05	0.30-0.50

Source: Yeang (2008)

The effectiveness of a building design in bringing daylight indoors can be indicated through daylight factor where the quality and the quantity of daylighting design are determined through the ratio of the illumination indoors to outdoors on an overcast day independent of the units used (Lechner, 2009).

$$Daylight\ factor\ (D.F.) = \frac{Indoor\ illumination}{Outdoor\ illumination} \times 100\%$$

According to Ghisi and Tinker (2005); Baker and Steemers (2002), the daylight factor is simply the sum of three components which are,

- The sky component: daylight on the reference point in the room received directly from the sky.
- The external reflected component: daylight on the reference point reflected into the room by any external surfaces.
- The internal reflected component: daylight on the reference point reflected and inter-reflected at the surfaces in the room which the amount is varied according to the distance of the reference point from the window.

In addition, typical minimum daylight factors are shown in Table 2.30 whereby if the daylight factor measured is greater, there will be more than enough daylight for most of the year.

Table 2.30: Typical minimum daylight factors

Type of space	Daylight Factor (%)
Art studios, galleries	4-6
Factories, laboratories`	3-5
Offices, classrooms, gymnasiums, kitchens	2
Lobbies, lounges, living rooms, churches	1
Corridors, bedrooms	0.5

Source: Lechner (2009)

For sufficient circulation, the minimum day light factor in any portion of a space should not drop below 0.5% and the ratio between the minimum and average daylight factor should not be less than 3% (Kim & Kim, 2010).

Located in the equatorial region which has abundant and frequent daylight (Kamaruzzaman & Edwards, 2006), Malaysia has a good potential in implementing daylighting at the buildings which directly provides more effective savings on energy consumptions while avoiding glare and excessive heat gain (Edmonds & Greenup, 2002). Unfortunately, the success of daylighting in buildings will not be achievable when the basic knowledge of daylighting is not understood properly, which includes the properties of daylight, the benefits of utilizing daylighting and effective strategies in maximizing the use of daylighting. Moreover, a daylighted building is saving energy only if the daylighting effectively and reliably displaces electric lighting usage (Yeang, 2008).

2.5.2 The advantages of daylighting from different perspectives

The application of daylighting in the buildings can give a lot of benefits where it can reduce the energy usage for lighting, which represents about 40% of energy usage in the buildings (Lechner, 2009). Thus, there have been a lot of studies done which demonstrated the benefit of daylighting for energy conservation.

Crisp et al. (1998) found out daylighting in a building can reduce the electricity usage for room illumination up to more than 50% while Zain-Ahmed et al. (2002a) proved the adaptation of daylighting as passive solar design in tropical buildings can help to conserve 10% of energy used.

Recently, Ihm et al. (2009) claimed significant savings can be achieved through the utilization of daylighting especially for space that is fully exposed to natural light while the sole application of dimming control strategy can contribute to 60% of annual energy savings in term of lighting. The daylighting aperture; defined as the product of window visible transmittance and window to perimeter floor area ratio, was found to have significant impact on energy savings from daylighting (Krarti et al., 2005). By using computer simulation approaches; DOE-2.1E, Li et al. (2005) found that the application of daylighting can reduce the maximum cooling plant load and building electrical demand for the base case model by 5% and 9.3% respectively.

The significance of daylighting in promoting energy conservation is more clearly described by Lechner (2009) who claimed that approximately 100 of 60 W incandescent lamps would be required to produce same amount of light as $1.35m^2$ (0.9m x 1.5m) window. Then, a calculation of the ratio of the amount of daylight typically available on a sunny day incident on one square foot of horizontal glass to the heat content of that incident sunlight gives an efficacy for daylight that is nearly twice as high as an efficient fluorescent lamp (Dean, 2005).

By lowering the usage of electric lighting in the buildings, it can reduce energy demand for cooling requirement resulted from internal load from the light (Leslie, 2003). In the future, fewer electric power plants need to be built or maybe the existing power plants are sufficient due to the reduction of electricity demand. Thus, decreasing the ultimate source that contributes to climate change; CO_2 which registers the highest emission for a unit electricity generation (Table 2.31).

Table 2.31: Fossil fuel emissions for a unit electricity generation

Fuels	Emission (kg/kWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.1800	0.0139	0.0052	0.0002
Petroleum	0.8500	0.0164	0.0025	0.0002
Gas	0.5300	0.0005	0.0009	0.0005
Hydro	0.0000	0.0000	0.0000	0.0000
Other	0.0000	0.0000	0.0000	0.0000

Source: Mahlia et al. (2005)

In addition, at the same illumination level, daylight is cooler than electric lighting, although light is radiant energy which eventually absorbed and turned into heat. As mentioned by Lechner (2009), the incandescent lamps introduce about six times more heat than daylighting and fluorescent lamps introduce about two times more heat than daylighting; 60 lumens/watt for fluorescent lamps versus 120 lumens/watt for daylighting. These have been explained in detail by Mahlia et al. (2005) where in an incandescent lamp, electricity heats up a wire filament causing it to glow and give the light where 90% of the energy produced is heat, not light.

Furthermore, the benefits of daylighting are not limited to energy conservation. In broader perspective as had been discussed by Leslie (2003), captured daylighting in the buildings is capable of,

- Improved human performance and well-being through daylighting's impact on aesthetics, vision, and photobiology where experimental work indicates that suppression of melatonin, the hormone responsible for regulating the body's internal clock or circadian rhythm is influenced by exposure to light levels typical of daylight.
- Might improve productivity, increased job satisfaction or reduced absenteeism, which also agreed by Phelan (2002).
- Create interesting lighting effects that modulate throughout the day and year, while also provides a broad electromagnetic spectrum with excellent colour rendering.
- Allows the buildings to be lit at higher levels than with electric lighting alone and allows people to continue working on some task during power outages.

Then, Baker and Steemers (2002) highlighted the roles of daylight in architecture which are considered from two basic perspectives; art and science, emotion and quantity, and heavenly and earthly. These can be simplified as fulfilling the personal emotional needs of well-being, comfort and health and the practical communal needs of energy conservation to underpin an environmentally sustainable future.

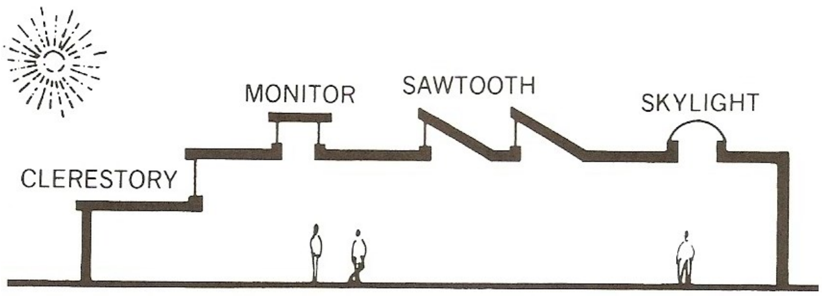
2.5.3 Daylighting strategies in the equatorial climate region

The form and orientation of the buildings; and window designs are the basic strategies that are needed to be given full attention in order to maximize the use of daylighting. This supported by Ihm et al. (2009) who claimed the cost effectiveness of daylighting controls depends on several factors, including the building architectural features (shape, window area, glazing type) as well as the building location. In window design aspects, it includes the size, location, orientation, external condition and the use of light diffusers which directly control the light level, daylight qualities and internal luminance (Jughans, 2008). Therefore, improving the visual comfort while reducing the heat caused by light penetration which can be concluded in four daylighting strategies mention by Omer (2008), 1). Penetration: collection of natural light inside the building; 2). Distribution: homogeneous spreading of light into the focused spaces; 3). Protect: reducing by external shading devices the sun rays penetrating into the building; and 4). Control: control light penetration by movable screens to avoid discomfort.

For equatorial region, north orientation might even be preferable to the south orientation while east and west are the worst orientations. Consequently, larger buildings will have less surface area and larger core area where it receives no daylight.

However, this can be solved by the use of side lighting with 3m of high ceiling, where the 7m room depth of daylighting can be achieved and the use of verandas in the room's design should be considered when 3m of veranda will reduce the daylight penetration by 3m (Jughans, 2008).

For one-storey or the top floor of multi-storey buildings, horizontal openings (skylight) can be implemented where lighting through the roof allows fairly uniform illumination over very large interior areas while daylighting from vertical windows is limited to approximately a 15ft (4.5m) depth. Unfortunately, this strategy confronted by the difficulty to shade horizontal glazing which can be alternated by various possibilities for overhead openings including clerestory, monitor, saw tooth and skylight (Lechner, 2009) as shown in Figure 2.14.



Source: Lechner (2009)

Figure 2.14: The various possibilities for overhead openings for daylighting

For multi-storey buildings, the introduction of the atrium that also known as enclosed courtyard form, can accommodate 100% full daylight including adjoining spaces resulting from the reflection of most of the light reaching these spaces (Littlefair, 2002). The efficiency of the atrium can be in various forms; skylight, clerestory and window wall, which depends mainly on the configuration of the atria (Kim & Kim, 2010). This can be estimated from Well Index as shown below;

$$Well\ Index = \frac{Atrium\ height\ \times (width + length)}{2\ \times Atrium\ length\ \times Atrium\ width}$$

The Well index and balcony depth are the most significant factors in daylighting performance in the atrium spaces with interior balconies where the light attenuation on the position under balcony floor is up to 70%, particularly when the Well index is higher than 1.0 and balcony floor is deeper than 3m. A higher balcony Well Index would generally means deeper balcony floor and thus indicates lower daylighting performance, which can be estimated through equation below;

$$Balcony\ Well\ Index\ (WI') = \frac{Atrium\ height\ \times Balcony\ well\ (width + length)}{2\ \times balcony\ well\ length\ x\ Balcony\ well\ width}$$

Optimistically, each balcony floor might function as overhang of a roof glazing system to the floor below. In local perspective, Zain-Ahmed (2009) revealed there is a significant relationship between daylighting from skylight and indoor thermal comfort in a top-lit atria for controlling the environment and the recent trend of atria becoming very popular in tropical architecture. A study of three sample atria that are incorporated in a large six-storey commercial building found passive solar systems and design applications can reduce the dependence on artificial or mechanical means of lighting when overall illumination provided by the atrium is considered sufficient as it exceeds the minimum intensity for normal vision.

The colour of light for both indoors and outdoors are capable of reflecting more light into the building and beyond into the interior spaces while at the same time reducing dark shadows, glare and excessive brightness ratios when a light coloured interior is able to diffuse the incoming light. This is supported by Jughans (2008) who had stated that the surface of room contributes to the level of reflectance in controlling glare and light distribution in the room. In order to maximize daylighting while maintaining the visual comfort in the building, separate openings for view and daylighting can be implemented where high windows; skylights are positioned for excellent daylighting while low windows at eye level for view (Lechner, 2009).

According to Kannan (2009), better uniform daylight distribution in a room can be achieved by implementing light shelf; the upper part of window will play a role purely as a daylight window where it can contribute to better illumination to the deeper end of the room while the lower part is a vision window which also allows daylight to the zone near the window. This is supported by Yeang (2008) who claimed that light shelf do not enhance the quality of light, but instead ensures a better distribution to the inside of the space. According to Reimann and Plainiotis (2009) who had conducted a scientific study of bamboo house, found that light shelves provide a visually pleasant and basic lighting level in the rooms while with some adjustment of the window blinds, it can give great flexibility of daylight control.

The efficient use of daylighting is achievable when the illumination is greatest inside the window and rapidly drops off to inadequate levels for the most visual task. These can be achieved with the following strategies, which focuses on window designs; as adapted from Lechner (2009) and Leslie (2003), that should be implemented in the building design,

i. Windows should be high on the wall, widely distributed and of optimum area.
   The distribution of daylighting in a space will be more uniformly when windows are horizontal rather than vertical. However, Baker and Steemers (2002) reported that tall windows provide twice as much light as wide windows and this finding is very significant since illuminating the back half of the room is always the critical factor.

ii. If possible, windows are placed on more than one wall.
   Bilateral lighting (windows on two walls) can lead to better light distribution, reduce glare and reduce the contrast between each window and its surrounding walls.

iii. Place windows adjacent to interior walls.
   The reflections from the side wall directly reduce the glare when the brightness ratio between the window and its surrounding wall is decreased.

iv. Splay walls to reduce the contrast between windows and walls.

The glare that form inside the windows are lesser when the splayed or rounded edges create a transition of the brightness. Nevertheless, external shading devices are the most effective strategies for existing buildings in reducing solar heat gains through windows without losing the benefit of daylighting. This is supported by Hassan (2002) who came up with strategies by considering the building orientation; the horizontal shading devices are generally effective against high sun in both east and west orientations while vertical shading is generally successful for south orientations. For all orientations, egg-crate shading devices are the most efficient strategies.

v. Filter and softer daylight.

This can be done by using the trees or by horizontal elements, window blinds, and other non-specula surfaces to distribute and diffuse the light. Regarding window blinds, Galasiu et al. (2004) have made a comparative study between daylight-linked dimming and automatic on/off lighting controls. Various percentages of savings in terms of lighting energy consumption were recorded and more significant saving was achieved through lighting control systems with photo controlled blinds due to the capability of the blinds to adjust their position automatically in direct response to the variable daylight levels.

vi. Shade windows from excess sunlight.

The overhangs can reduce glare problems where it can diffuse the light by reflecting it off the ceiling. According to Soebarto et al. (2008), adjustable vertical shading is advised (external blinds and timber louvers) or fixed horizontal and vertical shading devices for east and west facades due to the low sun angles in early mornings and late afternoons compared to north and south facades, while the north and south facades can simply resolve the glare problem by the use of fixed or adjustable shading devices placed horizontally. This was also agreed by Edmonds and Greenup (2002) who claimed that external shade considerably reduced the daylight penetrating the building while functioning as the simplest and most effective form of controlling heat gain through windows. However, it can be further improved by light-coloured overhangs (especially white) with louvers which can help to reduce the brightness ratio between itself and the sky.

By using computer simulation techniques, Li and Wong (2007) found the shading effects due to nearby obstructions strongly affect the building energy budget when daylighting designs are used; the electricity savings decreased from 40 to 28 kWh/m^2 at individual floor.

vii. Use movable shades.

This strategy can overcome the variations of daylighting especially on east and west exposure. The application of indoor shading devices is simpler, but outdoor shading is more effective. Unfortunately, outdoor shading carries penalties of cost and control which can be avoided by internal devices in the roof of an atrium; remoteness from the occupants (Baker & Steemers, 2002). According to Tzempelikos and Athienitis (2007), the simple on/off (open/close) control of the shade resulted in substantial daylighting saturation, while an integrated approach like automatic control of motorized shading in conjunction with controllable electric lighting systems could contribute to a substantial reduction in energy demand for cooling and lighting in perimeter spaces which are dependent on climate conditions and orientation.

In addition to these strategies, Leslie (2003) had given a suggestion to place critical visual tasks near to the building parameter and to use light colour interior surfaces to reduce the luminance contrast between the windows and surrounding surfaces while increasing visual comfort. Furthermore, workstations and computer screens need to be located perpendicular to the windows to reduce reflected glare in the screens for visual comfort. For multi-storey buildings, the same author suggested to configure the building where the most floor area occupied by the people is within the daylight zone; typically about 5m deep from window wall or the top floor of a building with skylight.

The opening size of window is the most important aspect that affects the daylighting in the building. The solar gains as the window to wall ratio (WWR) increase while the peak gains occur in the southwest facing windows (Zain-Ahmed et al., 2002b).

The optimum window opening for daylighting in Malaysia is 25% WWR; where the illuminance levels in a room do not reach 500 lux before 8.30 a.m. and after 4.30 p.m. for distances less than 1.75m from the window.

As a result of these findings, Ibrahim and Zain-Ahmed (2006) had developed Daylight Factors (DF) distribution table and estimation floor area to determine of window opening sizes in relation to WWR and glass types for making decisions about incorporating daylighting in buildings' design as shown in **Table 2.32**. This table indirectly helps the architects in designing facade design especially to incorporate daylighting strategies with natural ventilation approaches; in conjunction with daylight footprints and illuminance charts, when Aynsley (1999) claimed there is no guidance for the maximum size of the opening when other practical requirements such as sun control, security and privacy should be considered.

Table 2.32: Daylight factors distribution table and estimated floor area

Distance from window	25 WWR	35 WWR	45 WWR	55 WWR	65 WWR
0.25	22.4	25	27.2	31.6	35.4
0.75	11.3	15.7	19	21.2	24.5
1.25	6.6	10	13.5	16.8	18.5
1.75	4.4	6.8	9.5	12.2	14.3
2.25	3.4	5.1	7.5	9.7	11.6
2.75	2.7	4.5	6.3	8.3	9.8
3.25	2.4	3.9	5.6	7.3	8.8
3.75	2.5	3.7	5.5	7.1	8.5
4.25	1.4	2.2	3	3.8	4.5
% of day lit floor area	57	70	90	90	90
% of artificial light needed	43	30	10	10	10

Note
- > 10 DF : adequate to over lit
- < 5 DF, > 2 DF : require
- < 10 DF, > 5 DF : good quality daylight
- < 2DF : require full artificial light

Source: Ibrahim and Zain-Ahmed (2006)

Ghisi and Tinker (2005) came up with the concept of Ideal Window Area which is the effective integration between daylight and artificial lighting system. The analysis of this concept revealed that;

i. The smaller rooms and rooms with greater width have a greater potential for energy savings on lighting due to daylight reaching the working surface through windows.

ii. The Ideal Window Area tends to be larger on the orientations whose energy consumption is lower due to smaller solar thermal loads reaching the facade.

iii. The larger the room and the narrower its width, the larger its Ideal Window Area. Whereas with the larger room, the energy consumption reduces per unit of floor area.

iv. The room with a narrower width have lower energy consumptions due to the lower solar heat gains or losses through windows.

Besides that, Kischkoweit-Lopin (2002) came with more structural strategies when they characterized daylighting systems into shading systems and optical systems as shown in Table 2.33. The abilities of these systems can be described with specific criteria, namely glare protection, view outside, light guiding into the depth of the room, homogeneous illumination, saving potential concerning artificial lighting, the need for tracking and the availability of lighting. The successful implementation of optical systems that include angle selective glazing, light guiding shades, vertical and horizontal light pipes, switchable glazing and angle selective skylight has been proven in small buildings by Edmonds and Greenup (2002). All these optical systems have been critically explained by International Energy Agency (2000b) under Energy Conservation in Buildings and Community System Programme, in conjunction with Solar Heating and Cooling Programme.

The light pipe which is considered as advanced optical daylighting systems reflects sunlight to the ceiling plane and transporting the daylight efficiently by using a relatively small inlet glazing area (Yeang, 2008).

Table 2.33: Daylighting systems

Daylighting System		Description	Example
Shading system (Primarily to block direct sun and admit diffuse light).	1. Shading systems primarily using diffuse skylight	Ultimately block direct sunlight but being transparent for diffuse skylight	1. Prismatic panel *(Climate : All climates)* 2. Prisms & venetian blinds *(Climate : Temperate climates)* 3. Sun protecting mirror elements *(Climate : Temperate climates)* 4. Anidolic zenithal opening *(Climate : Temperate climates)* 5. Directional selective shading system with concentrating HOE *(Climate : All climates)* 6. Transparent shading system with HOE based on total reflection (→ 4.2.3) *(Climate : Temperate climates)*
	2. Shading systems primarily using direct sunlight	Diffuse sunlight or redirect sunlight onto the ceiling or above eye height.	1. Light guiding shade *(Climate :Hot climates, sunny skies)* 2. Louvers & blinds *(Climate : All climates)* 3. Light shelf for redirection of sunlight *(Climate : All climates)* 4. Glazing with reflecting profiles (Okasolar) *(Climate : Temperate climates)* 5. Skylight with Laser Cut Panels *(Climate : Hot climates, sunny skies, low latitude)* 6. Turnable lamellas *(Climate : Temperate climates)*
Optical systems (redirect daylight to area further from the windows or skylight	1. Diffuse light guiding systems	The light from zenith area which much brighter than in horizontal part of overcast sky is redirect into the depth of the room and allows an improvement of daylight utilisation.	1. Light shelf *(Climate : Temperate climates, cloudy skies)* 2. Anidolic Integrated System *(Climate : Temperate climates)* 3. Anidolic ceiling *(Climate : Temperate climates, cloudy skies)* 4. Fish system *(Climate : Temperate climates)* 5. Zenith light guiding elements with Holographic Optical Elements *(Climate : Temperate climates)*
	2. Direct light guiding systems	Redirect and distribute the sun light in a small part of facade while the rest of the facade is closed by conventional shading devices.	1. Laser Cut Panel (LCP) *(Climate : All climates)* 2. Prismatic panels *(Climate : All climates)* 3. Holographic Optical Elements in the skylight *(Climate : All climates)* 4. Light guiding glass *(Climate : All climates)*
	3. Scattering systems	Realise an even lighting distribution	Light diffusing, capillary & frosted glass *(Climate : All climates)*
	4. Light transport	The outside light were collected and guiding it through a light guiding media onto rooms in the depth of the building	1. Heliostat *(Climate : All climates, sunny skies)* 2. Light-Pipe *(Climate : All climates, sunny skies)* 3. Solar-Tube *(Climate : All climates, sunny skies)* 4. Fibres *(Climate : All climates, sunny skies)* 5. Light guiding ceiling *(Climate : All climates, sunny skies)*

Source: Kischkoweit-Lopin (2002)

This system transports the daylight efficient, and is carefully designed to block direct sun, direct source glare and thermal discomfort. Unfortunately, this system is not widely implemented especially in Malaysia due to the higher costs of fibre optic components (Zain-Ahmed, 2009). Besides that, Sulaiman et al. (2005) who had proved that fibre optic daylighting is able to save more than 50% of the total energy consumed proposed the sensible opinion that the total cost savings would be considerably increased as well when the use of fibre optic become popular and price of the fibre optic components is reduced.

Consequently, the availability and quality of daylight in an existing building can be improved by increasing the size of existing apertures or making new apertures or by redistributing the glazing, increasing the transmittance of windows by reducing obstruction due to framing or replacing the glazing material with one of higher transmittance, increasing the external reflected component by treating nearby external surfaces with high-reflectance finishes, increasing the internal reflected component by treating internal room surfaces with high-reflectance finishes and increasing the penetration of light using special elements such as light shelves or prismatic glazing (Baker & Steemers, 2002). Two types of light pollution that have been discussed earlier, glare and trespass result from daylighting which should be reduced and eliminated. Glare is direct light shining from an artificial lighting fixture (luminaire) that causes difficulty in seeing or causes discomfort, while light trespass is intrusive light that reaches into neighbouring properties and become objectionable (Yeang, 2008).

Deletion is not only an energy efficient technology but also an architectural discipline, and a major factor in occupants' perception and acceptance of workspaces in building while successful energy saving from daylighting can only be realized when the building and systems design support broader occupant needs for comfortable and healthy indoor environments (Reinhart & Selkowitz, 2006).

2.6 Post occupancy evaluation

Post occupancy evaluation (POE) is defined as the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time (Preiser, 1995) to understand the mutual interactive process between the building and the user's needs, and also to recommend ways of improving the environment necessary to accommodate user needs (Khalil et al., 2008); or other words, determining the building defects that would lead to increased maintenance and operating costs. According to Zimring and Reizenstein (1980), POE is an effectiveness examination for human users of occupied design environments while Ilesanmi (2010) states that POE is about procedures for determining whether or not design decisions made by the architect are delivering the performance needed by those who are using the building and using occupants as a benchmark in evaluation. Specifically, POE is concentrating on building occupants or users and their requirements (Hassanain et al., 2010). Unfortunately, the buildings are very rarely revisited and reassessed once they are handed over to their users even though they are more expensive than cars and electronic equipment (Mier et al., 2009).

The history of POE development, purpose and benefits are well documented from all around the world, as Hadjri and Crozier (2009) highlighted, there is a significant lack of scientific exploration into successful and failed completed project which have been identified by the Royal Institute of British Architects (RIBA). It was a moment that leads to the introduction of POE and it was realized into practice when 'feedback' was put up as part of the Plan of Work in RIBA's first handbook in 1965 and was known as 'environmental analyses' or 'building appraisals' in the 1960s (Hassanain et al., 2010).

Unfortunately, POE was removed from the plan due to concerns over fees, insurance and liability, but had recently made a comeback with RIBA (Bordass & Leaman, 2005) when it was then endorsed as a useful addition to architectural practices in the USA (Cooper, 2001). From this point onwards, the POE has been improving from year to year to increase the quality and efficiency of building construction. This is clearly shown in the late 1980s, when Preiser et al. (1988) introduced three phases of the POE process (Table 2.34) that is more structural and organized.

Table 2.34: Phases of POE process

	PHASES OF POE PROCESS		
	Planning	Conducting	Applying
Process Outline	▪ Feasibility study ▪ Identify objectives ▪ Review & analyse building performance ▪ Define building's strength & weakness ▪ Identify building users	▪ Collect data on relevant elements ▪ Develop data collection ▪ Interviews, walk-through, observation, questionnaires ▪ Analyse data	▪ Documentation & report findings ▪ Review & determine outcomes ▪ Recommendations for further action ▪ Implement action

Source: Preiser et al. (1988)

The evolution of POE in assessing building performance was clearly illustrated by Wolfgang et al. (2008) which was initially inspired by the evaluation case studies of university dormitories in the late 60s. According to Hadjri and Crozier (2009), POE has progressed from a one dimensional feedback process to a multidimensional process that as an integrated element helps drive the building procurement process forward. This was clearly presented by Cartney (2006) in the development of a standardized POE methodology for Australian health projects, which are sufficiently generic that could well be applied to a range of different project types and to different project procurement environments.

Focusing on the purpose and benefits of POE, Khalil and Husin (2009) claimed that the application of POE was able to indicate satisfaction and comfort level needed by occupants as lessons learned to identify problems in indoor environments, which includes the building defects.

Therefore, situations where corrective action is taken only through ad-hoc preparation and pre-planning programmes before defect or failure occurrence were disregarded can be eliminated. Any problems regarding the building design and structure will be identified for further mitigative actions while building environment and performance are being improved (Vischer, 2002; Hewitt et al., 2005). Thus, the successful design features can be repeated in future development and any redundant or unnecessary building features will be eliminated. In other words, continuous building improvements can be identified by doing POE regularly and it can ensure that the building continues to deliver appropriate levels of satisfaction to the end-user (Turpin-Brooks & Viccars, 2006). This has been supported by Langston and Ding (2001); Jaunzens et al. (2003) who have claimed that the POE should not be a one-off process to confirm that a new building has fulfilled its criteria while Preiser (1995) stressed out the critical evaluation of POE should not only occur in a facility once constructed and occupied, but it should carry out throughout the entire building delivery cycle.

A number of plausible benefits of conducting the POE have been documented by (Whyte & Gann, 2001), which seems to conclude all the discussions about the purpose and benefits of POE by other authors and researchers, Turpin-Brooks and Viccars (2006), Nawawi and Khalil (2008), Hadjri and Crozier (2009), Khalil and Husin (2009). These include more effective application of design skills, improving commissioning process, improving user requirements, improving management procedures, providing knowledge of design guides and regulatory processes and targeting of refurbishment.

Nevertheless, as a pioneer in this field, Praiser (1995) had categorized the benefits of POE into three, short-term benefits include obtaining users' feedback on problems in buildings and the identification of appropriate solutions, medium-term benefits include feed-forward of the positive and negative lessons learned into the next building cycle, and long-term benefits aim at the creation of databases and the update, upgrade and generation of planning and design protocols and paradigms. In recent times, Ilesanmi (2010) highlighted two benefits of POE which are ensuring the sustenance of building performance and understanding the mutual interaction between buildings and users' inspiration when satisfaction, attitudes and preferences are three types of criterion normally used.

As Doidge (2001) reports, the POE is widely acknowledged, but however rarely practiced. According to Meir et al. (2009) who had critically analysed more than 50 studies on POE to assess the evolution and state of the art of POE, revealed the overall sense is that of a field that is at the threshold of maturity, but is not quite there yet when there are lack of agreed-upon protocols, measures and procedures which making comparison difficult. Moreover, the acceptance, consistency and formalization of POE are inevitable. This was supported by Zakaria and Hamzah (2007) who claimed that no systematically collected data is available for various types of building in Malaysia while the aspects of evaluating building performance have not been emphasized widely in Malaysia and term of POE itself is still new in Malaysia. According to Turpin-Brooks and Viccars (2006) and Hadjri and Crozier (2009), the implementation of POE is frustrated by,

i. Ownership - where client and designer refuse to pay an extra charge for carrying out a POE survey and also the cost of implementing the findings even though there are benefits for both if POE is implemented. Moreover, the designers are almost never paid to go back and review the outcomes of their design decisions (Zimmerman & Martin, 2001).

ii. Liability - the POE may uncover problems which may cause the building to be labelled as "under performing" and may directly reduce the value of the building for the client. This was agreed by Copper (2001) who said, professionals are unlikely to offer POE, as part of the standard service during the procurement process, unless the issues of liability can be satisfactorily resolved.

iii. Lack of knowledge - when many people never heard of POE and with the absence of POE on the educational curriculum, human resource and skills become a barrier to POE adoption. According to Zhang and Barrett (2010) who done POE in the UK primary school sector, the occupants are usually simply coping with the given environment rather than actively managing it and from the head teacher's perspective, there are not enough driving forces to carry out POE that would reveal this gap. Thus, the same authors proposed an education programme by the design team should be implemented to ensure that the potential of spaces, design strategies, services are fully realized by the actual users.

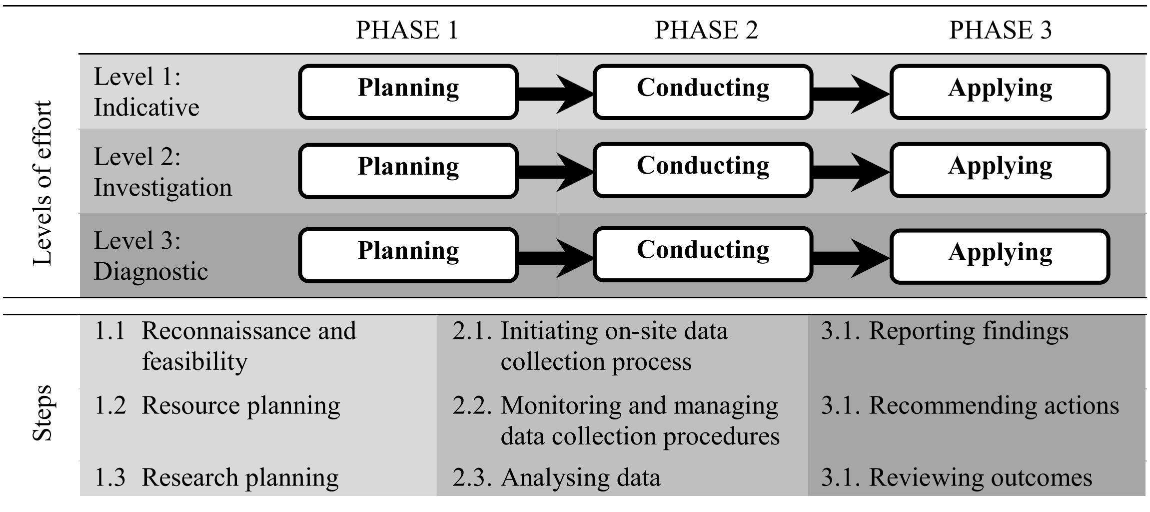
iv. Lack of progress - especially in the development of standard methods where compatible results that can be compared to give indications of improvement is not available. Nawawi and Khalil (2008) have had the same opinion when they conducted a research to propose guidelines to implement POE for public buildings in Malaysia.

In addition, Riley et al. (2010) also highlighted culture as a barrier to the POE process where the occupants may feel that moving into a new working environment is disruptive. All of these inhibitors could be reduced if pragmatic model were available. Discussion of Turpin-Brooks and Viccars (2006) and Hadjri and Crozier (2009), clearly indicate three levels of effort in the POE process as presented in Table 2.35 which is based on POE process model formulated before by Preiser (1995; 2001) in Figure 2.15. The level undertaken will depend on the availability of finance, time, manpower and the required outcome (Turpin-Brooks & Viccars, 2006).

Table 2.35: The level of POE

Level of POE	Aim	Methods	Timescale	Comments
Indicative	Assessment by experienced personnel to highlight POE issues	▪ Walk-through evaluation ▪ Structured interview ▪ Group meetings with end users ▪ General inspection of building performance ▪ Archival document evaluations	Short inspection period	Quick, simple, not too intrusive/disruptive to daily operation of building. Judgmental and overview only.
Investigative	In-depth study of the building's performance and solution to problems	Survey questionnaires & interviews. Results are compared with similar facilities. Report appropriate solutions to problems	From one week to several months	In-depth/useful results. Can be intrusive/time consuming, depending on the number of personnel involved
Diagnostic	Show up any deficiencies (to rectify) and collect data for future design of similar facilities	▪ Sophisticated data gathering and analysis techniques ▪ Questionnaires, surveys, interviews and physical measurements	From several months to several years	Greater value is usability of results. More time consuming.

Source: Turpin-Brooks and Viccars (2006); Hadjri and Crozier (2009)



Source: Preiser (1995)

Figure 2.15: POE process model

In maintaining the effectiveness and efficiency of POE, there is a need for occupants to provide which are easy to compare with other studies, avoid intruding on the respondents' time and patience too much, give good value in terms of quality and content, be relevant in a given situation, be reliable and address the factors that relate to the needs, activities and goals of the people using the building.

Regarding to the methods of POE, Bordass and Leaman (2005) point out five categories portfolio of techniques that can be assessed and utilized where appropriate. There are audit (using quantitative technical assessments), discussion (use discursive techniques such as workshops and interviews), questionnaires, process (techniques that are used to adapt the procurement process to incorporate feedback in an organized manner), and packages (probes). Furthermore, there are numbers of techniques in the data collection process where according to Hadjri and Crozier (2008), each of the techniques has its own pro and cons while the potential to be used in POE can be doubtful as shown in Table 2.36.

As a part of a sustainable approach in building environment, Turpin-Brooks and Viccars (2006) pointed out that the development of POE should result in an adoption of a case study approach when it can provide contextual information (or reality), greater depth of qualitative data, opportunities for benchmarking performance and learning opportunities from each project for all stakeholders involved. Then, it can be also used to validate the method used as a confirmation of repeatability when a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2003).

Table 2.36: Advantages and disadvantages of the data collection techniques considered

Techniques	Advantages	Disadvantages	Potential to use in POE	Comments
1. Walk-through survey	Cheap & simple	Can be too judgmental & subjective	Yes	Essential especially for technological review systems
2. Diary analysis	Detailed data over time	Hard to administer. Respondents' response flags. Data intensive.	Only if no alternative	-
3. Focus group	Cost effective. Pick up detail left out of questionnaires	Need skilled facilitator	Yes	Especially for design team review
4. Individual interviews	Excellent for senior management	Time consuming. Needs skilled interviewer. Note taking & write-up time burdensome	Yes	-
5. Documentary analysis	Essential for building brief	Jargon. Understanding context	Questionable	-
6. Plan analysis	Often excellent data source	Information overload	Yes	-
7. Supplied data	Can be a cheap source of data	Can be poor form or imprecise or hard to interpret without help	Yes	Good for energy data
8. Monitored data	Accurate. Quantitative	Cost. Sampling methods	Questionable	-
9. Questionnaire surveys	Comprehensive coverage. Quantitative & Qualitative	Tend to miss out fine points & contexts	Yes	Essential for base data. Also extremely useful to involve as many people as affordable

Source: Hadjri and Crozier (2008)

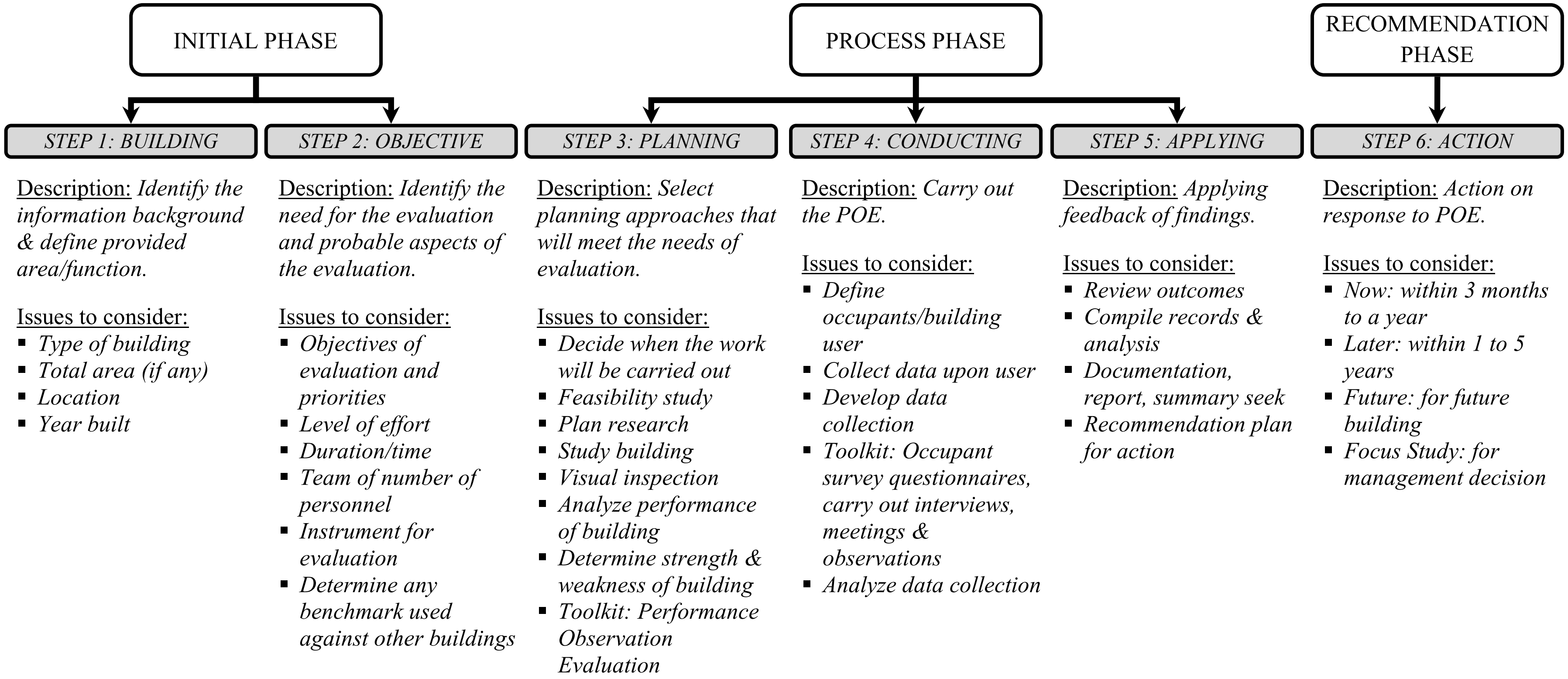
Recently, Hassanain et al. (2010) discussed a framework for evaluating the quality of university family residential facilities which can be well adapted at other type of buildings as the framework was more organized and has diversified its investigation techniques, integrating community participation to ascertain the emerging outcomes and to define the most efficient and feasible interventions. The framework started with a walk-through investigation being carried out to pinpoint the major problematic zones or elements and is documented with photos.

It is then followed by conducting focused group meetings to obtain an initial prescription of the degraded performance of the residential facilities and services, interviewing the executives of campus maintenance and planning departments to be guided by the experienced of such a stakeholder who has encountered various arrays of residential maintenance and planning. Then developing and administering a questionnaire survey to obtain the residences' satisfaction rate of various categories of outdoor and indoor performance requirements (*Appendix H - Indicators of outdoor and indoor performance requirements*). After that, a public hearing session is conducted to evoke the community to express their further concerns and main complains. All the data gathered from the above were analysed which entails analysing and triangulating two types of obtaining data, quantitative and qualitative. The framework is ended by recommending a range of time-phased solutions for residential improvements (Hassanain et al., 2010).

Gossauer and Wagner (2007) pointed out those two main methodical approaches in analysing comfort research through POE, laboratory test in climate chamber and field tests in running buildings, where POE in field studies has a major influence on new understandings when historically it became the dawn of adaptive comfort model. In addition, it also revealed that the occupants' perceptions of the indoor environment are influenced by numerous parameters while laboratory tests still reveals many open questions regarding the definition of the key parameters for overall satisfaction with the workplace, well-being and productivity due to uncontrolled boundary conditions. In other words, climate chamber does not represent actual conditions as in the field, it is influenced by a range of complex factors.

Urged by many building defect complaints in Malaysian public buildings, for example the collapsed ceiling at the parliament building and fungus infection on the walls at Hospital Sultanah Aminah, Johor in 2006, leaking pipes which caused flooding at the new court complex in Jalan Duta, Kuala Lumpur in 2007 and many more, Nawawi and Khalil (2008) have proposed a guideline for POE for government and public buildings in Malaysia as shown in Figure 2.16. This guideline consists six steps that are divided into three phases and it has proven to be effective and relevant for government and public buildings in Malaysia due to very high and high correlations grades scored by a majority of the parameters in a correlation coefficient of building performance and occupants' satisfaction. The score was measured based on the quality of various building elements, services and environment on a scale of 1 to 10 which constitutes a full score (S= 1.0), good is above 6 ($0.6 \leq S \geq 0.9$), medium is 5 (S= 0.5), and poor is below 4 ($S \leq 0.4$).

Different approaches have been taken by Khalil and Husin (2009) in conducting POE towards indoor environment improvement in Malaysia's office building when the three phases are involved, namely: planning, conducting and applying, as adapted from Preiser et al. (1988). A self-administered questionnaire where the format is based on a Likert - scale, scores ranging from 1 to 5, was adapted to focus on six elements, including cleanliness, visual comfort, thermal comfort, air movement, noise pollution and overall comfort (*Appendix I - A self-administered questionnaire format based on Likert-Scale*). As a result, uncomfortable environment in the office is a result of cooling system (73%), natural daylighting (53%), provision of air movement (40%) and quality of indoor ventilation (47%) which lead to the decreased of work productivity, constitute to 47% out of total respondents.



Source: Nawawi and Khalil (2008)

Figure 2.16: Proposed guideline for POE for government and public buildings in Malaysia

By making a comparison between both approaches, guidelines for POE for governments and public buildings in Malaysia could be assumed to be an evolution from the approach taken Khalil and Husin (2009) in conducting POE towards indoor environment improvement in Malaysia's office building. With the combination of these two approaches, a workable POE can be achieved when one of the criteria of success of POE outside academic circles is simple, reliable, and standardized in terms of collecting useful feedback from occupants, not on the entirety of their experience of using the building but on a few, carefully selected and identified indicators of environmental quality (Vischer, 2002). This is also supported by Turpin-Brooks and Viccars (2006) who stated that a combined approach POE with more than one "tool" of assessment can enhance understanding of a building's performance and give clear direction for further investigations of key relationships, as the Eden project case study found.

POE method on residential college buildings by Hassanain (2008) has classified two performance requirements for the performance evaluation of sustainable student residential facilities. These are technical performance requirements and functional performance requirements (*Appendix J - Technical and functional performance requirement*). Based on these two requirements, the degree of satisfaction is obtained from 22 elements of technical performance that derived from five core elements and 26 elements of functional performance, which also originated from five core elements. These holistic approaches are capable of providing a good resource for solving technical and functional problems in the building. There are four degrees of satisfaction for each element of the performance that was adopted,

- 'Strongly Dissatisfied' - mean response is below 1.49,
- 'Dissatisfied' - mean response is between 1.50 and 2.49,
- 'Satisfied' - mean response is between 2.50 and 3.49,
- 'Strongly Satisfied' - satisfaction index is above 3.50.

As a result, Hassanain (2008) found out the overall mean response for the investigated four indoor environmental qualities was 2.80; matching a satisfaction rating of 'satisfied'. Based on the study done by Hassanain (2007) a year earlier, Adewunmi et al. (2010) had conducted an advanced POE of postgraduate hostel facilities which included 29 identified performance criteria under 12 factors, namely bedroom social and place qualities, hostel design, social densities in the hostel, storage and room furnishing, floor levels, hostel maintenance, conveniences, hostel facilities, laundry, balcony, hostel management, and location. The degree of satisfaction for each criterion of performance was quantified based on a graduated scale of 1-5,

- 'Neutral' - mean response is less than or equal to 1.49,
- 'Strongly Dissatisfied' - mean response is between 1.50 and 2.49,
- 'Dissatisfied' - mean response is between 2.50 and 3.49,
- 'Satisfied' - mean response is between 3.50 and 4.49,
- 'Strongly Satisfied' – mean response is between 4.50 and 5.

Although the scales of degrees of satisfaction used by researchers were quite different, the studies are capable to show subsequent design that should be improved in the design and management of new hostel facilities. Moreover, this will guide the university's management with regards to policy formulation, focus on the institution's core and supporting objectives, particularly hostel facilities (Adewunmi et al., 2010). This is in line with Meir et al. (2009) who stated that the nature and goals of POE depended on who is asked, as the prospects and hazards of this tool and approaches are seen differently from the standpoint of each stakeholder. Consequently, it is necessary to focus on the most relevant issues rather than to attempt to analyse everything and risk an overload of data (Hadjri & Crozier, 2009).

The POE studies have the potential to clarify discrepancies, loopholes and problems in different ways, including the problems in the design process, the operation or in the building as a system (Meir et al., 2009). The benefits to be derived from the results of POE do not only promise to improve the quality of facilities, worker morale and work performance (Hassanain et al., 2010), but they may also contribute to significant cost savings (Preiser, 1995), as well as being key in minimizing energy consumption while helping to bring the existing buildings towards zero-carbon targets (Spataru et al., 2010). In addition, the POE is an assessment that integrates the occupant's behaviour, perception and opinion as the building user which allows the researcher to outline the issues to be monitored (Khalil et al., 2008). This was concurred by Ilesanmi (2010) who found that 62% of the physical characteristics of the residences highly correlate with residents' satisfaction.

The integration of POE results into value management process, as an essential component in the organizational learning cycle, ensures that the facilities management decision-making process becomes increasingly well-informed and accountable (Green & Moss, 1998). Finding from Ilesanmi (2010) clearly indicate that the residents' perception of residential environment cannot be ignored at policy, planning, design and implementation levels where satisfaction with the physical environment of residences is the most powerful predictor of residential satisfaction.

2.7 Conclusion

The climate change issues have brought in the 'Green Building' term, which significantly relates to bioclimatic design building, when building sector was identified as one of the largest contributors to GHGs emission that directly leads to global warming phenomenon. The interrelationship between building sector and climate change was critically discussed by UNEP and UNFCCC (2002), Sani and Sham (2007), Ürge-Vorsatz and Novikova (2008), and particularly on energy usage by Economic Planning Unit (2006), Atkinson (2009), and Al-Mofleh et al. (2009). The climate change decreases global heating demand by over 30%, but increases cooling demand by about 70%, and influences the energy demand for residential air conditioning in South Asia, which could increase by around 50% (Isaac & vanVuuren, 2009).

At present, 'Sustainable Building', 'Green Design', 'Eco Design Building', 'Sustainable Architecture', 'Eco Innovation' and many more are becoming popular terms besides of bioclimatic design building itself. Although the terms and meanings are different, the aim remains the same in promoting efficient use of natural resources, especially energy and water, and application of renewable energy in running the function of the buildings for creating a healthier environment. Subsequently aims are to incorporate a wider diversity of approaches and priorities, including social, ecological and economic.

The continuing commitment of world nations in building sectors to climate change issues are clearly described with the introduction of building evaluation instruments. There are BREEAM (UK), LEED (USA), CASBEE (JAPAN), GRENNSTAR (Australia), and GBI (Malaysia) which are identified as rating tools that are principally designed for tropical zones other than Singapore government's Green Mark (Architecture Malaysia, 2009).

Whilst, Indonesia's rating system is going to be developed by Green Building Council Indonesia (GBCI) (Tiyok, 2009). The thermal comfort, natural ventilation and daylighting were defined as the important criteria for residential building in each of these evaluation instruments. In line with the revolution of the building, in terms of type and design, some of these evaluation instruments are revised from time to time where the minimum requirement becomes more particular, while specific instrument were established for specific type of buildings as clearly describe by BREEAM (2009b). In the line with GBI, the government of Malaysia is currently promoting the development of energy efficient (EE) buildings by demonstrating several EE buildings namely Low Energy Office (LEO) Building, Green Energy Office (GEO) Building and Diamond Building (POS Malaysia Philatelic Bureaus, 2009).

Pointed out as one of the important criteria in all building evaluation instruments, energy efficiency in building sector, particularly on existing residential building within equatorial region is influenced by four aspects. These are building type, climatological conditions, cooling and lighting. Principally, building design, services design and occupant behaviours are the three interrelated factors in achieving building energy performance (Al-Mofleh et al., 2009), where the last two factors are not easy to be controlled and maintained, as well as being influenced by the first factor itself; building design. This supported by Spataru et al. (2010), who stated the behaviour of occupant is increasingly important and being responsible for the energy consumption in the building. Thus, how we design our building will reflect how much energy they required to run.

By taking building design as a main factor in reducing energy consumption, a lot of strategies have been discussed by considering the local climate, the need of cooling and lighting including built-form configuration and orientation, enclosure and facade design, solar control devices and landscaping, particularly in the equatorial region (Cândido et al., 2010; Al-Temeemi, 1995; Chan, 2009a; Gutierrez & Labaki, 2007; Ahmad, 2008).

The sun, heat and high humidity are key elements of the Malaysian climate that need to be well thought-out (Chan, 2009b). As a consequence, most of the strategies discussed places emphasis on the minimization of negative impact from the failure of building designs and natures insistences through manipulation of surrounding area approaches including sun path, wind direction, altitude, sunlight penetration and landscaping. Additionally, these strategies were optimized by giving full control of indoor climate to the residences with regards to their needs.

In achieving energy efficiency in building, thermal comfort should not be left behind when this is the key element of satisfaction in micro and indoor climate. In a holistic manner, the integration between building design and climate should be prioritized where it will directly reflect the amount of energy that required for the building in running their services. A good building design keeps the indoor environment favourable and comfortable during most of the year without the use of any mechanical devices and also promotes sufficient airflow through the building for dehumidification resulting from high humidity percentages (Nugroho et al., 2007). To maintain the thermal comfort in buildings, there are four environmental conditions that affect the body simultaneously and causes the heat to be lost. These are air temperature (ºC), relative humidity (Pa), air velocity (m/s) and mean radiant temperature. The interactions among these conditions are clearly described by Srivajana (2003) who came out with a preferred air velocity (m/s) in hot and humid climate area regarding to the temperature (ºC) and relative humidity (%).

Whereas, Davis et al. (2006) introduced Malaysian thermal discomfort units based on various studies on enormous amounts of Malaysian meteorological data which contributed useful knowledge for planning new buildings that is suitable for local climate and sustains the thermal comfort of the occupants.

The study by Liping et al. (2007) reveals that the optimum window to wall ratio is equal to 0.24. and horizontal shading devices are needed for the four orientations for further improvement in indoor thermal comfort, while east and west facing facades should be avoided and if this is not possible due to site limitations, the building can be built up with 45° alignment to the west or east to increase ventilation. In order to avoid thermal asymmetry near to openings, the *U*-value of facade materials for north and south orientation should be less than 2.5 W/m^2 K while less than 2 W/m^2 for east and west orientation (Liping et al., 2007).

As an aid to attain thermal comfort in buildings, there are two models of thermal comfort that are acknowledged as a general thermal comfort model and alternative thermal model, which includes Predicted Mean Vote (PMV) index, operative temperature model and adaptive model. The General thermal comfort model is an evaluation of the comfort equation obtained by Fanger (1970). There are four methodologies to calculate general thermal comfort indexes that can be achieved through field measurement and calculation. Contrary to PMV Index where thermal sensation values are used to predict the mean value of the subjective ratings of a group of people in a given environment, while activity in Met unit and clothing in Clo unit are considered in the determination of the operative temperature model. For adaptive model, three contextual variables are should be considered that is indoor and outdoor climate, the nature of the buildings and its services with time where the human activity and responses take place in a time frame (Nicol & Humphreys, 2002).

As a result, a lot of equations on adaptive model were introduced to define the neutral temperature as a function of outdoor, indoor or both temperature regarding the interaction between the subjects and the buildings or other environment that were occupied.

Subsequently, Gossauer and Wagner (2007) highlighted three classes of thermal comfort studies that have been introduced by Brager and de Dear (1998) which are;

- Class I: All sensors and procedures are in 100 percent compliance with the specifications in ASHRAE 55 and ISO 7730. Measurements at three heights above floor level with laboratory grade instrumentation are required. This procedure allows a careful examination of the effects of non-uniformities in the environment as well as a comparison between buildings.
- Class II: All physical environmental variables necessary for calculating PMV and PPD indices are measured and collected at the same time and place when and where the thermal questionnaires are administered, most likely at one height. This allows an assessment of the impact of behavioural adjustment and control on subjective responses.
- Class III: This is based on simple measurements of indoor temperature and possibly relative humidity at a single height level above the floor. The physical measurements can possibly be asynchronous with subjective measurements (questionnaire with rating scales).

Based on literature, most of the studies conducted have been Class III studies due to good and quick overview over the situation when the quality does not necessarily allow explanatory analyses by extensive statistics (Gossauer & Wagner, 2007).

As one of the passive cooling strategies, natural ventilation is less controllable than mechanical ventilation and is capable of maintaining a healthy indoor environment while being proven to be a good approach to reduce running costs of buildings. Primarily, the elimination of heat source in the buildings is the core element in passive cooling strategies (Omer, 2008).

Three principal factors were highlighted by Aynsley (2007) in optimizing the effectiveness of natural ventilation which are the site and local landscaping features, the building form and building envelope, and the internal planning and room design. In addition to these principles, five aspects that should be considered in enhancing the convection and evaporative heat transfer between the occupants and the room air, which are spatial planning, position of windows, ceiling height, size of windows and types of window (Soebarto & Ribeiro, 2008). Bady et al. (2011) reports, the buildings arrangement and wind direction obviously affect the characteristics of wind flow inside urban domains, which in turn affect the induced natural ventilation. Moreover, the presence of gaps between adjacent buildings is an important factor to be considered when it able to introduce more wind which directly improves the ventilation process.

Furthermore, there are three types of ventilation approaches that are usually implemented in buildings, which are single-sided ventilation, cross-flow/two sided ventilation and mixed-flow ventilation. Then, the suitability application of natural ventilation in tropical and temperate climate has been proved by Haase and Amato (2009) and due to warm-humid climate. These two authors found the optimum orientation of building in Kuala Lumpur that is located in the equatorial region with latitude 3.1 and longitude 10.6, to be 150.0. Unfortunately, the quality of wind becomes an issue when wind speeds up to 1m/s is preferred meanwhile the application of special device for healthiness purpose; insect screen at window opening reduces the wind speeds. Then, security aspects become main barriers for effective adaptation of daytime or night cooling ventilation. As a consequence, natural ventilation must be done in appropriate manner as too much or too little outdoor air in a room can cause draughts and discomfort (Omer, 2008).

As for daylighting, where quality and quantity are the two important aspects where the excessive daylighting in the building increases the potential of negative effect on visual comfort, known as glare, and increases the building's cooling load by increasing the heat gain (Yeang, 2008). The dynamic of daylighting is clearly shown from three possible processes that can take place when light fall onto a surface or a layer; absorption, reflection and transmission (Baker & Steemers, 2002). The surface type, materials and colours of the buildings often play their own roles in influencing the daylighting. Moreover, the dynamics of daylighting as shown from the variability of daylight resulted due to the sky condition and its direction as well. For holistic approaches of daylighting, there are four strategies acknowledged by Omer (2008); penetrations, distribution, protect and control, where these strategies were closely interrelated to the building design aspects especially on facade design, particularly on windows. Findings from Baker and Steemers (2002) clearly indicate that courtyards provide access to daylight by avoiding deep plans in buildings with a large floor area, but without the major climatic modification of the atrium. Additionally, courtyards with surrounding cloisters are reliant on ground-reflected light to penetrate the adjacent rooms.

Nowadays, there are generally two daylight systems implemented in the buildings, which are shading systems that is primarily to block direct sun and admit diffuse light, and optical systems, that redirect daylight to area further from the windows or skylight (Kischkoweit-Lopin, 2002). Daylighting has been acknowledged as an architectural discipline while the success of energy saving from daylighting can be only realized when the building and systems design support broader occupant needs for comfortable and healthy indoor environments (Reinhart & Selkowitz, 2006). As Hwang and Jeong (2011) reports, daylighting could improve the occupants' psychological health and productivity.

In defining the building's performance in fulfilling the occupants' needs, post occupancy evaluation (POE) can be done after it is occupied. Indirectly, the success of bioclimatic design strategies implemented, particularly natural ventilation and daylighting, can be examined. Thus, any problems with regards to the building design and structure can be identified for mitigative actions while building environment and performance can be further improved (Vischer, 2002; Hewitt et al., 2005). Generally, there are three phases of POE beginning with the planning phase, conducting and lastly with applying phase which can be done in three levels. These are indicative, investigative and diagnostic levels that are dependent on the aims and objectives that is to be achieved. For data collection, there are a lot of techniques that can be implemented whereby each of the technique has its own pros and cons. Thus, it gives an option for those that would want to implement POE with respect to the time frame, budget, manpower, and also the objective that listed in the earlier study.

Unfortunately, POE is rarely practiced in Malaysia due to the lack of knowledge and systematic or standard data collection system. Therefore, nobody wants to take a risk to carry out a POE survey when the results from the survey are not applicable for any improvement. In addition, without any constructive database, the comparison cannot be carried out to identify the level of achievement. Globally, there are four major barriers to POE implementation, which are ownership, liability, lack of knowledge and progress. These barriers were clearly explained by Turpin-Brooks and Viccars (2006) and Hadjri and Crozier (2009).

With the new guideline of POE for Malaysian government and public buildings that was proposed by Nawawi and Khalil (2008), it seems to be a good starting point for the implementation of POE in Malaysia. This guideline, which is more structural in nature, is an evolution of the three phases of POE techniques; planning, conducting and applying, which was introduced earlier by Preiser et al. (1988).

Under the proposed guidelines, these three phases are acknowledged as part the six POE steps, beginning with building, objective, planning, conducting, applying and action. All these steps are categorized under three main phases, namely: initial phases, process phases and recommendation phases. Each step describes the main purpose or aim, as well as issues that must be considered. Therefore, a critical POE can be achieved when only most relevant issues are highlighted, rather than attempting to analyse everything and risk an overload of data (Hadjri & Crozier, 2009).

The implementation of passive design strategies in building design is believed to be the best way to reduce climate change effects from the building sector. As holistic approaches go, especially in the equatorial region, natural ventilation should be combined with daylighting strategies due to the interrelationship between these two strategies, especially in sustaining thermal and visual comfort level in the buildings, while drastically reducing the energy for cooling and lighting. It has to be said, the increased efficiency and thus the reduction of electricity usage is not the ultimate victory of implementing strategies when the occupants are tortured with the uncomfortable indoor surroundings, in terms of thermal comfort and visual comfort. Therefore, the POE has been identified as an approach to examine the building performance and the effectiveness of implementing strategies to accommodate comfortable environment to the residences. Then the exact building conditions will be able to be recognized mutually with computer simulation and site survey by using on-site microclimatic measurement sets. In other words, it will play a role as an inclusive action to the all improvement plans and strategies. Hence, any identified problems will mitigate for enhancing the building performance while in the long term, the successful design features will be repeated in future development and any redundant or unnecessary building features will be eliminated.

As a consequence, the building comfort levels can be successfully identified which will contribute to the establishment of thermal comfort benchmark and energy performance index for residential college buildings where before there was only the Code of Practice for Energy Efficiency and Renewable Energy for non-residential buildings (MS1525) that available as a Malaysian Standard. This Code of Practice provides the criteria and minimum standards for energy efficiency in the design of new and existing non-residential buildings (Kannan, 2006).

Then, Daghigh et al. (2009), points out that the international standards for interior comfort, ASHRAE Standard 55-92, are not suitable to be adopted in the naturally ventilated building due to the Malaysian hot and humid tropical climate which may lead to overcooling and energy wastage. Thus, there is a need for a wider thermal range for Malaysia which directly indicates that Malaysia as a nation is acclimatized to much higher environmental temperatures. This is supported by Djongyang et al. (2010) who claimed that the actual standards of thermal comfort help but should not be considered as absolute references when different climatic regions such as the tropics may require different levels of comfort parameters mandated in the standards. Sapri and Muhammad (2010) stated that for improving building energy performance in higher educational institutions, monitoring and targeting of consumption can be employed which directly help the organizations to significantly reduce their energy consumption and cost.

CHAPTER 3
Research methods

3.1 Introduction

This research started with preliminary studies on the characteristic of a typical student room as well as the building design and implementation of bioclimatic design strategies. It was then followed by a study on the efficiency of electricity usage and the prospect of energy conservation. The findings from these preliminary studies were used in the selection of a case study. The bioclimatic design strategies and energy efficiency index (EEI) were part of the main criteria for the case study selection. These criteria will show the best building design with electricity usage performance in mind.

A field investigation and evaluation were made on the selected case study which included building investigation and post occupancy evaluation (POE). For the building investigation, a detailed description was made of the residential college, residential buildings and surrounding landscape setting. The entire findings were used to identify samples of student rooms for subsequent evaluation and assessment. Further study of the electricity consumption performance and usage pattern was also done by considering the efficiency of electricity usage, carbon footprint and electricity cost. This was followed by the POE that involved satisfaction and perception surveys, building performance evaluation, and living behaviour assessment which form the core elements of this research. These three types of evaluation form a methodological triangulation (Denzin, 2006) as shown in Figure 3.1.

As a powerful technique, this triangulation enhances the credibility and persuasiveness of a research account by giving a more detailed and balanced picture of the situation to facilitate the validation of data through cross verification from more than two sources in a study of the same phenomenon (Altrichter et al., 2008).

Moreover, it maps out and explains more fully the richness and complexity of the human behaviour by studying it from more than one standpoint (Cohen & Manion, 2000).

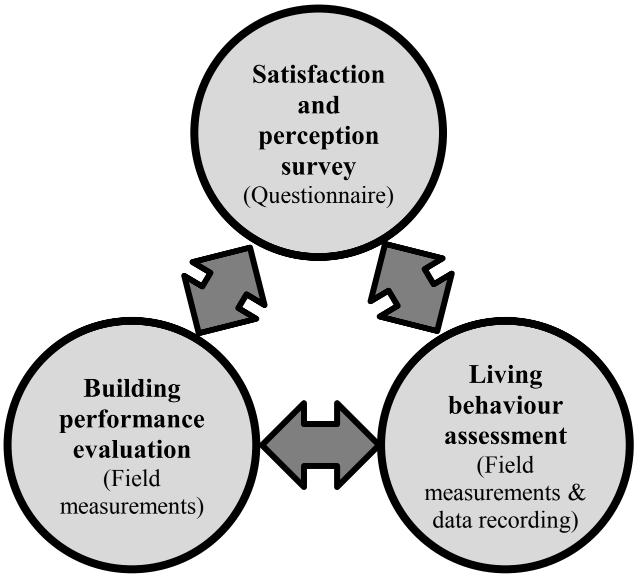


Figure 3.1: Methodological triangulation of POE

A survey on the perception and acceptance of occupants towards existing implementation of bioclimatic design concepts was used in the POE as a subjective measurement tool. This method is recognised as a systematic way and an effective examination method to understand the mutual interaction process between buildings and the user's needs (Preiser, 1995; Khalil et al, 2008; Zimring & Reizenstein, 1980; Hassanain et al., 2010). In other words, it uses the occupants' preferences as a benchmark for determining building performance (Ilesanmi, 2010) in a holistic approach. Then, the focus of the research was narrowed down to obtaining the precise condition for student rooms to provide comfort in a living space. Field measurement using data loggers at specific times and scenarios were applied in selected student rooms during building performance evaluation. This method is already established and widely used in observing micro and indoor climate (Candido et al., 2008; Dahlan et al., 2009; Kubota et al., 2009; Nugroho et al., 2007), which could indirectly give an impression of the general conditions of the residential buildings.

In addition to findings validation and justification, an assessment on living behaviour was used to provide useful information on how room conditions at different moments reach the desired comfort level of occupants. Moreover, it shows the regular changes that occur involving the room and its occupants at a particular time and the necessary conditions of obtaining the optimum level of comfort during these times.

The research flow which started with preliminary studies and ended with analysis of field investigation and evaluation is visualised in Figure 3.2.

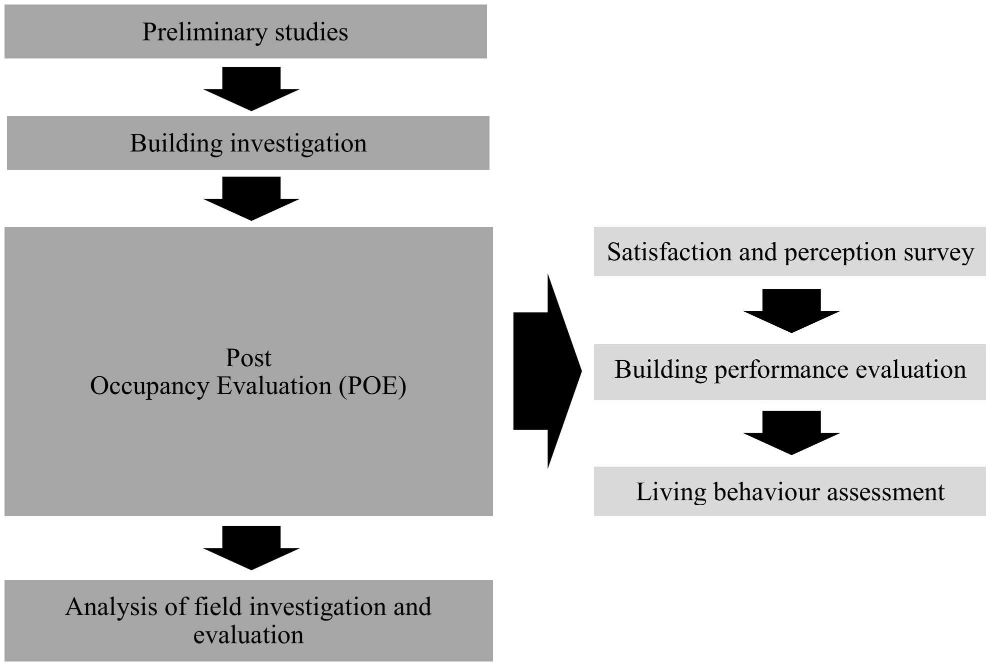


Figure 3.2: Research flow

3.2 Preliminary studies

3.2.1 The description and characteristic of UM residential college

There are twelve residential college buildings within the University of Malaya (UM) campus that are involved in the preliminary studies as listed in Table 3.1. In identifying the selection of residential colleges for the case study, the twelve residential colleges' work drawings, which include the site plan, architectural drawings and structure drawings were critically analysed.

Table 3.1: Residential colleges within the UM campus

Name of Residential College (RC)	Year of established
1st RC (Tunku Abdul Rahman Residential College)	1959
2nd RC (Tuanku Bahiyah Residential College)	1958
3rd RC (Tunku Kurshiah Residential College)	1962
4th RC (Bestari Residential College)	1963
5th RC (Dayasari Residential College)	1966
6th RC (Ibnu Sina Residential College)	1967
7th RC (Za'ba Residential College)	1975
8th RC (Kinabalu Residential College)	1985
9th RC (Tun Syed Zahiruddin Residential College)	1995
10th RC (Tun Ahmad Zaidi Residential College)	1997
11th RC (Ungku Aziz Residential College)	1997
12th RC (Raja Dr Nazrin Shah Residential College)	2002

Source: University of Malaya (2009)

Site visits to each residential college were also carried out in order to gauge actual conditions, since most of the drawings were drawn 30 to 40 years back. Since then, numerous renovations and add-ons have been carried out to increase the occupants' capacities. A study done by Dahlan et al. (2009) on assessing the effects of indoor climate on student occupants in a typical multi-storey hostel in Malaysia, will be used as a primary reference. The elements of tropical bioclimatic design introduced by Yeang (2008) were adapted as matrixes as shown in Table 3.2 for assessing the building's design in implementing bioclimatic design concepts, with focus on the application of natural ventilation and day lighting.

3.2.2 The efficiency of electricity usage and prospects of energy conservation

The efficiency of electricity usage in each residential college was evaluated by adapting methods from Saidur (2009) who estimated energy intensity, EI in kWh/m^2 by using the following equation,

$$EI = \frac{AEC}{TFA}$$

Where, AEC is the annual energy consumption (kWh) and TFA is the total floor area (m^2).

Table 3.2: The matrixes and criteria in case study selection

Internal systems	Characteristics	
Built - form configuration, orientation, site layout planning and features	▪ Form of building : *(Low-rise / Medium-rise / High-rise)* ▪ Building layout : *Linear arrangement / Courtyard arrangement* ▪ Orientation to sun path : *North / North East / East / South East / East / South West / West / North West* ▪ The shape of the building's floor plate : *Circle / Ellipse / Square / Square with patio / Rectangular / Gamuda / Rhombus / Trapezoid* ▪ Wind direction of the locality : *North / North East / East / South East / East / South West / West / North West* ▪ Building location on the ground : *Different altitude / Same altitude* ▪ Floor level (excluding ground floor) ▪ Total Residential College area (m^2) ▪ Total built up area(m^2) ▪ Total floor area (m^2) ▪ Capacity ▪ Density (capacity/total floor area) ▪ The ratio of air conditioned & non air conditioned area	
Typical student room - form, configuration and layout planning	▪ Room dimensions (l) x (w) x (h) ▪ Room's floor area (m^2) ▪ Room volume (m^3) ▪ Typical of corridor width (m)	
Enclosure and façade design	▪ Design : *Solar Screening / Glare Protection / Temporary Thermal Protection / Adjustable Natural Ventilation Options* ▪ Window area (m^2) ▪ Window to wall ratio ▪ Operable window area (m^2) ▪ Operable window to wall ratio ▪ Window design : *Fixed / Sliding / Double or single-hung / Casement / Awning / Hopper / Centre pivot / Jalousie or louvered window / Tilt & turn window / Tilt window / Turn window / French window* ▪ Location : *North / North East / East / South East / East / South West / West / North West*	
Solar-control devices	▪ Horizontal overhangs along the wall with windows ▪ Vertical overhangs along the wall with window	▪ Tinted window glass ▪ Balconies/ Veranda ▪ Deep recesses ▪ Sky courts/ Internal courtyard
Passive daylight	▪ Articulated light shelves ▪ Light pipes	▪ Sky courts/ Internal courtyard ▪ Balconies/Veranda)
Wind & natural ventilation	▪ Window opening with horizontal adjustable/closing devices ▪ Window opening with vertical adjustable/closing devices ▪ High level fixed/adjustable exhaust opening ▪ Low level fixed/adjustable exhaust opening	▪ Horizontal/Vertical wing walls ▪ Transom/fixed opening above residential unit entrance door and wall ▪ Wall opening ▪ Balconies/veranda ▪ Internal courtyard ▪ Location of opening with respect to wind direction.
Landscaping	▪ Ratio of soft and hard surface area	
Others	▪ Corridor *(Open corridor/Closed corridor)* ▪ Staircase area *(Open staircase area/Closed staircase area)*	

Source: Yeang (2008)

Globally, energy use per square metre of floor area is used as energy benchmarks, which are also referred to as energy use indicators that can be used to compare a building's actual energy performance (Action Energy, 2003; Building Research Energy Conservation Support Unit, 2000). Whilst, Kamaruzzaman and Edwards (2006) stated that the energy use per unit floor area can be described as the 'Normalised Performance Indicators' (NPI), which is also known as the energy use index or Building Energy Performance (BEP) by the Electrical and Mechanical Services Department (2007). In addition, if the energy use is in the region of Mega Joule (MJ) per unit floor area, it will be noted as the Energy Utilization Index (EUI).

Consequently, the Energy Efficiency Index (EEI) will be used in this study to indicate the residential colleges' performance in terms of electricity use in the unit of $kWh/m^2/year$ (Ibrahim, 2008; Chou, 2004). Referring to Iwaro and Mwasha (2010), electricity usage in residential buildings are usually 10 to 20 times lower compared to that of office buildings. Thus, the total electricity usage in residential buildings in Malaysia amount of 10 to 25 $kWh/m^2/year$ (Jamaludin et al., 2011), whereas the electricity usage of office buildings in Malaysia are in the range of 200 to 250 $kWh/m^2/year$ (Chan, 2009a).

The five year period energy consumption data, starting from 2005 to 2009 were collected and analysed while the total floor area was calculated from the building design study. On-site measurements were also carried out for the purpose of obtaining accurate facts to minimize errors arising from sources such as outdated drawings due to recent renovations. Further statistical analysis was carried out using a statistical computer software package. Descriptive statistical analysis was performed to analyse the mean, median, mode, standard deviation, variance and range value of data for comparison purposes. The EEI was made a part of the characteristics and criteria for case study selection.

The estimation of electricity savings in residential colleges were identified through the measuring of the difference between average total energy use in a year (kWh) and the minimum electricity usage of residential colleges, using two different calculations.

First, the maximum or total amount of average electricity used in these residential college buildings was calculated by multiplying the average electricity usage of residential buildings in Malaysia, which are in the range of 10 to 25kWh/m^2/year, with the TFA of each residential college building. Thus, the minimum electricity usage of a residential college based on the current average of local consumption or requirement was obtained. Next, the minimum electricity usage was calculated based on the basic electrical appliances in each space: rooms, offices, dining hall etc., for the residential college to run its basic function and services in providing minimal comfort to the residents. The mechanical and electrical (M&E) inventory checking was conducted using data supplied by the administrator of the residential colleges. This was done by a walk-through survey for verification purposes of obtaining the accurate type and number of M&E appliances, since errors may arise from outdated data and recent renovations. These two techniques are suitable for energy studies and are essential for technology review systems (Hadjri & Crozier, 2009). As a consequence, the precise figure of the minimum electricity usage was able to be directly determined.

3.2.3 Case study selection

In the first stage, the case study selection was performed by making comparisons between the residential college buildings particularly based on the matrixes and criteria of bioclimatic design strategies as previously shown in Table 3.2. The process was rather extensive in taking into account the corridor and staircase area that affect the application of day lighting and natural ventilation in student rooms which made them quite predictable.

Then, the energy performance of the twelve residential colleges was also considered in terms of electricity usage and prospective energy conservation through an energy audit. All residential colleges were ranked based on the EEI and other local and established international building energy rating systems for comparison. Additionally, the potential electricity use reduction will clarify the relation between energy performance and bioclimatic design strategies that has been implemented at each residential college.

Thus, specific approaches can be taken in further analyses and experiments to enhance the energy performance of the residential college while sustaining the residents' comfort levels. Moreover, the homogeneity of the building designs, particularly of student rooms and floor plan of the residential colleges, as well as the forms of the buildings were also considered to minimize random variables. This means, only low-rise buildings were short listed for the case study selection. This is so that the selection of student rooms as samples would represent the condition of all the spaces in the residential college so as to streamline the field investigation and evaluation, whilst considering the restrictions due to limited availability of equipment for field measurements and the safety of data loggers used during building performance evaluation and living behaviour assessment.

After all the residential colleges were gauged, the residential colleges with the most effective implementations of bioclimatic design strategies, particularly those applying natural ventilation and day lighting in its building design, with a low EEI and number of uncontrolled variables were selected as a case study.

3.3 Building investigation

The detail description of the building layout and surrounding landscape setting was done on the selected residential colleges. This took into account site and elevation plan, typical sections of the residential buildings, typical elevation of the residential buildings, all floor layouts at each residential building, and a layout of a typical student room. The type and number of student rooms were identified and the bioclimatic design strategies employed were critically examined and explained, particularly the application of daylighting and natural ventilation.

Further analysis of electricity consumption of the selected case study was done from the year 2005 to 2011 by taking into account the efficiency of electricity usage, carbon footprint and electricity cost. Moreover, the pattern of electricity usage was studied by considering three distinct periods of activities in the campus, which are the semester break, examination preparation week and the orientation week for new students.

The surrounding landscape that includes hard and soft surface areas of the site were analysed through drawing studies, site visits and measurements, as they can influence the microclimate of selected case studies (Konya & Vandenberg, 2011). According to the same authors; Konya and Vandenberg (2011), the natural cover of a terrain tends to moderate extreme temperatures and stabilise conditions; as a plant and grassy cover reduces temperatures, while other vegetation also provides protection against glare, dust and erosion. Thus, all the vegetation was identified and the integration between the surrounding landscape and buildings were critically observed, especially to determine the shading effects. The landscape layouts of the selected case studies were re-drawn to illustrate the species and location of the matured/big plants which able to give significant amounts of shading.

Standard normal photographs were also taken in bright daylight to analyse the effects of the landscape as a cover to reduce sunlight radiation and penetration into the buildings. The standard or normal photographs appeared to be more suitable for measuring certain variables in visual landscape assessments rather than in situ landscape and panoramic photographs (Sevenant & Antrop, 2011).

All the findings of these building investigations were used for identifying samples of student rooms for further evaluation that will include building performance evaluation and living behaviour assessment.

3.4 POE

3.4.1 Satisfaction and perception survey

This form of survey method was carried out to gauge the perception and acceptance level of occupants towards existing implementations of bioclimatic design concepts. In other words, it was conducted to understand the interaction between the building and the users' needs in a general manner. Specifically, passive design strategies through natural ventilation and day lighting were acknowledged to directly influence thermal, visual and overall comfort levels. Findings from studies done by Khalil and Husin (2009) on POE of the indoor environment improvement in Malaysia's office buildings, and Srivajana (2003) on the effects of air velocity on thermal comfort in hot and humid climates were adopted in restructuring the questionnaire as shown in *Appendix K - Questionnaire for satisfaction and perception survey*. This questionnaire was formerly revised and various improvements have been made after the pilot study, as presented in *Appendix L - Pilot study of satisfaction and perception survey*. A number of questions and elements were added in order to get a more accurate response and more detailed information.

This includes those concerning the architecture, visual comfort and landscape elements, while the survey on thermal comfort was combined with the indoor air quality element. The day and time are not particularly considered in the survey.

The questionnaire uses a Likert Scale format where each number generally responds to a specific scale as listed in Table 3.3. As adopted from Hassanain (2008) and Adewunmi et al. (2010), the percentage response for each scale will be multiplied by the corresponding weight which are either, "+2" with 5 points, "+1" with 4 points, "0" with 1 point, "-1" with 3 points and "-2" with 2 points.

Table 3.3: Likert Scale used in the satisfaction and perception survey

Likert Scale				
-2	-1	0	+1	+2
too dark	Dark	neither/nor	Bright	very bright
strongly dissatisfied	Dissatisfied	neither	Satisfied	strongly satisfied
too hot	Hot	neither/nor	Cold	too cold
still air	inconspicuous still air	neither/nor	Breezy	very breezy
very poor	Poor	Fair	Good	very good
very uncomfortable	uncomfortable	neither/nor	Comfortable	very comfortable
much decrease	Decrease	no changes	Increase	much increase
never	rarely/occasionally *(in about 25% of chances when I could have)*	sometimes *(in about 50% of chances when I could have)*	frequently/ usually *(in about 75% of chances when I could have)*	every time

Source: Khalil and Nawawi (2008); Khalil and Husin (2009); Ilesanmi (2010); Zambrano et al. (2006)

The sum of the products of multiplication will be divided by 100 to get the mean value and the following calibration was adopted to quantify the degree of satisfaction for each element of performance:

- if the mean response is less than or equal to 1.49, then the respondents are considered "neutral, neither/nor, and no changes"
- if the mean response is between 1.50 and 2.49, then the respondents are considered "strongly dissatisfied, too dark, too hot, still air, very poor, very uncomfortable, and much decreased"
- if the mean response is between 2.50 and 3.49, then the respondents are considered "dissatisfied, dark, hot, inconspicuous still air, poor, uncomfortable, and decreased"

- if the mean response is between 3.50 and 4.49, then the respondents are considered “satisfied, bright, cold, breezy, good, comfortable, and increased”
- if the mean response is between 4.50 and 5.00, then the respondents are considered “strongly satisfied, too bright, very satisfied, too cold, very breezy, very good, very comfortable, and much increased”

Regarding thermal comfort, a detailed survey was done by adopting the ASHRAE 7 point thermal sensation with a scale ranging from -3 to +3 where, -3 means cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, and +3 hot (Singh et al., 2011).

The questionnaires were distributed to all occupants at selected 5th RC with the minimum number of feedbacks relying on 95% confidence level and ±5% margin of error from the overall population at each residential college. The following is a simplified formula introduced by Barlett et al. (2001) and Israel (1992) which was initially based on Yamane (1967) who used to calculate sample sizes.

$$\mathrm{n} = \frac{N}{1 + (e)^2}$$

Where, n is the sample size, N the population size and e is the level of precision, which is 0.05. In order to increase the reliability of this formula, online sample size calculator (Raosoft, 2004) has been used concurrently. Regarding to the case study, the minimum sample size for 847 population size is 265 that relying on 95% confidence level and ±5% margin of error.

All the collected questionnaires were analysed by using a statistical software package to find out the frequency of responses and the intercorrelation between each indoor environmental conditions (Chua, 2006; 2008).

3.4.2 Building performance evaluation

Regarding safety issues which limit the accessibility to certain residential blocks, the building performance evaluation of the selected 5th RC, was only done in Block E for a very short period of time as allowed by the residential college administrators. This block is one of the male residential blocks and is located in the southwest of the residential college area, adjacent to the 'Rimba Ilmu' area. Rimba Ilmu is a tropical botanical garden of over 1,600 species in an area of 80 hectares and established in 1974. It adopted a rainforest garden concept and emphasis on the flora of the Malaysian and Indonesian regions. The location for this evaluation is shown in Figure 3.3.

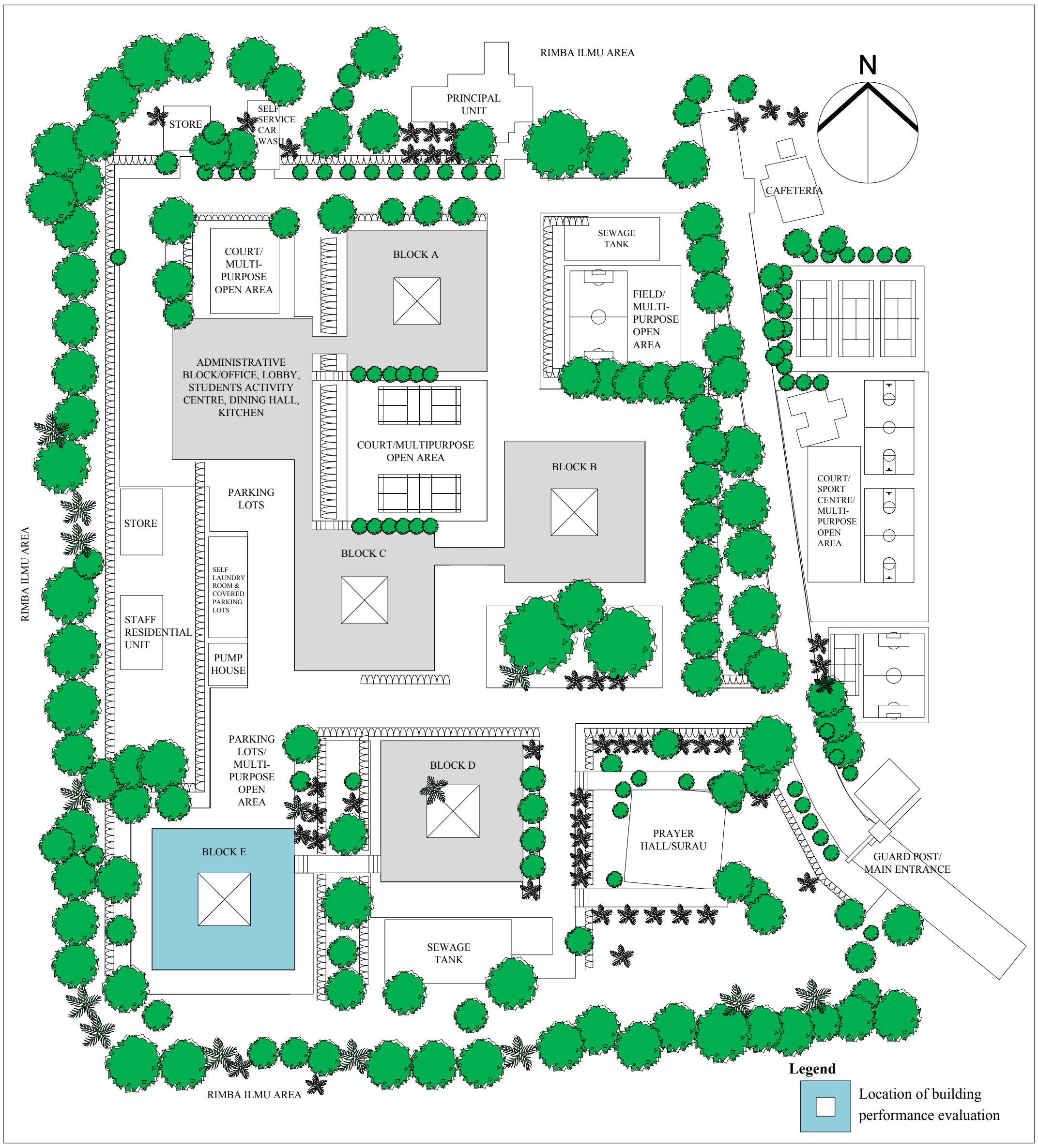


Figure 3.3: Location for building performance evaluation

Some changes and improvements were put into practice based on the findings of the pilot study which was done earlier, as explained in *Appendix M - Pilot study of building performance evaluation*. This pilot study helps to refine data collection plans with respect to both the content of the data and the procedures to be followed (Yin, 2003).

The building performance evaluation was carried out at eight unoccupied student rooms, which were considered the most excellent rooms to represent ten scenarios that concern the level of radiation and penetration of sunlight into the student rooms. All the ten identified scenarios are based on grounded theories according to previous studies done particularly in the tropical region by others before which are extensively explained in Table 3.4. The student rooms were critically chosen based on building investigations which also include a landscape setting analysis to represent each identified scenarios to account for the limited access afforded by the residential colleges' management. Initially, two from eight selected rooms were measured to represent two scenarios.

Two ONSET HOBO U12-012 data logger (*Appendix N*) for indoor climate measurements, were fixed on both sides of the walls as a result of the differential distribution level of daylight in the student room. The measurement of the distribution levels of daylight in the student room were done manually during the pilot study on days with clear sky. A portable lux meter, Luxmeter LX 100 (*Appendix O*) was used in different spots to compute the distribution of daylight in the student rooms.

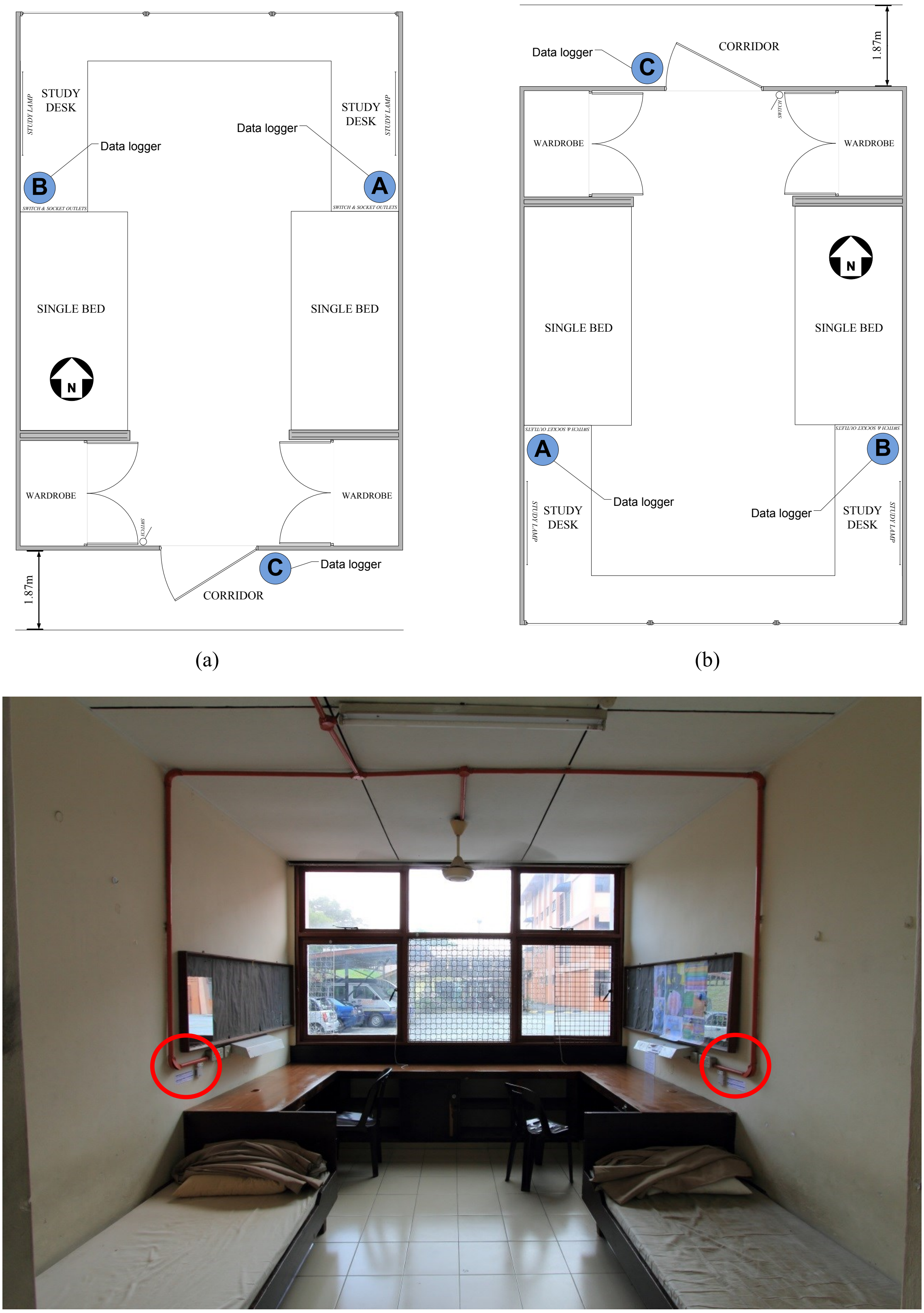
This indoor data logger was fixed on the student room's core area of activity; which is on the study desk at the height of 1.10m above the floor. This height is acknowledged as the typical human body level. The metabolic heat production is assumed as light activity (1met) and the clothing insulation value is 0.55 clo, which is a suitable value for tropical clothing (Nugroho et al., 2007). The location of all three data loggers are shown in Figure 3.4.

Table 3.4: Scenarios for building performance evaluation based on grounded theories

Best scenario of CS-A		Grounded theories based on the previous studies	Worst scenario of CS-A	
B1	▪ Receiving reflected heat radiation and penetration either from the west or east. Whilst, not influenced with direct heat radiation and penetration by man-made surface either on the top or ground. *(Keyword: North orientation)*	▪ Solar radiation and its heating effects on walls and room facing different directions has the most significant effect on energy consumption in the tropic regions where houses with east-west fronting type result in higher solar gains on both roof and walls compared to north-south fronting types by 14% to 29% (Chan, 2009b). ▪ For the equatorial region, north orientation might even be preferable to the south orientation while east and west are the worst orientations (Jughans, 2008). ▪ In minimizing thermal stress, orientation can be fully used where the best orientation is for long facades to face north and south while conflict between sun and breeze orientation should always be resolved to control the sun, with the design of both building and landscaping modified to deflect available winds. Consequently, the best orientation of buildings in hot humid climate is 0° (south) and 180° (Ahmad, 2008). ▪ Placing shorter opaque walls to the east and west (maximum solar heating) and longer transparent walls to the north and south (minimum solar heating) are an optimum strategy (Hyde, 2000).	W1	▪ Receiving direct heat radiation and penetration from east. Whilst, not affected by direct heat radiation and penetration of man-made surface either on the top or ground. *(Keyword: East orientation)*
B2	▪ Receiving reflected heat radiation and penetration either from the west or east. Whilst, not influenced with direct heat radiation and penetration by man-made surface either on the top or ground. *(Keyword: South orientation)*		W2	▪ Receiving direct heat radiation and penetration from the west. Whilst, not affected by directing heat radiation and penetration of man-made surface either on the top or ground. *(Keyword: West orientation)*
B3	▪ Not receiving direct heat radiation and penetration from man-made surfaces on the top, i.e. roof, wall etc. and with north-south building orientation. *(Keyword: Avoiding direct contact with man-made surfaces on the top)*	▪ More than 40% of solar gain by a typical five storey block of flat is through its roof (Chan, 2009b). ▪ Higher temperatures were also recorded by Davis et al. (2006) at the top level of flats and apartments compared to the ground floor which are more affected by heat penetration from the ground/tarmac, especially when there is no tree with a large canopy around. ▪ The radiation on a flat roof is greater than on a vertical wall (Al-Temeemi, 1995) as well as sloping roof (Chan, 2009a).	W3	▪ Receiving direct heat radiation and penetration from man-made surfaces on the top solely, i.e. roof, wall etc. and with north-south building orientation. *(Keyword: Direct contact with man-made surfaces on the top only)*

Table 3.4, continued

Best scenario of CS-A		Grounded theories based on the previous studies	Worst scenario of CS-A	
B4	▪ Not receiving direct heat radiation and penetration from man-made surfaces on the ground, i.e. tarmac, court etc. As well as, direct heat radiation and penetration neither from east nor west. *(Keyword: Avoiding direct contact with man-made surfaces on the ground)*	▪ Concrete paving, white walls and reflective glazing can all reflect intense solar radiation from a window (Lechner, 2009). ▪ Temperatures in and around buildings can be tempered or aggravated by the nature of surrounding surfaces. Plant and grassy cover reduce temperatures and they may be still further reduced by other vegetation, whilst cities and man-made surfaces tend to elevate temperatures and reduce humidity. Additionally, most unpleasant results are to place paved surfaces which store up a great deal more heat, exceeding 50% of radiation and remain hot longer than unpaved or grass surfaces which only store 5% of heat (Konya & Vandenberg, 2011). ▪ Stone, ceramics and concrete have larger thermal mass and so they often react more slowly to changes in temperature (Hyde, 2000). ▪ The air temperatures over grass surfaces are -12.2 to -10°C cooler than over exposed soil while under a tree at midday are often -5°C lower than in comparable unshaded areas (Moore, 1993).	W4	▪ Receiving direct heat radiation and penetration from man-made surfaces on the ground solely, i.e. tarmac, court etc. Whilst, not affected by directing heat radiation and penetration either from east or west. *(Keyword: Direct contact with man-made surfaces on the ground only)*
B5	▪ Shaded by landscape or trees or adjacent buildings and with a north-south building orientation. Whilst, not affected by directing heat radiation and penetration of man-made surface either from the top or ground. *(Keyword: Shaded)*	▪ Shaded east-west facing walls with large roof overhangs or plant shading trees in front of buildings are able to decrease total solar gain of existing east-west fronting type buildings (Chan, 2009a). ▪ Visual comfort is afforded by vegetation in buildings whilst plants can affect the indoor temperature and the cooling load of buildings in several ways including shading and insulation effects. Additionally, plants near a building can lower the air temperature next to the building's skin, thus reducing the conductive and infiltration heat gains (Yeang, 2008). ▪ Tree canopies provide better environments than open sky in terms of thermal sensation when tending more to cooler situations and a neutral sensation of urban spaces (Monteiro & Alucci, 2009). ▪ Water features and vegetation can be used to modify the external wind direction as a strategy of passive cooling through natural ventilation (Aynsley, 2007). ▪ The avoidance of heat gain can also be affected at the site level through shading from the landscape (Hyde, 2000). ▪ A further strategy in preventing solar access into the building is by buffering and environmental shading, which involves placing a screening system of building elements or landscaping around the building to create shade (Hyde, 2000).	W5	▪ Exposed to open spaces and with a north-south building orientation. Whilst, not affected by directing heat radiation and penetration man-made surface either from the top or ground. *(Keyword: Exposed)*



(c)

(a). Scenario B1, B3, B4, B5, W3, W4 and W5, (b). Scenario, B2, W1 and W2, (c). Photograph of the data loggers location in identified room (in red circle).

Figure 3.4: Location of the data loggers

The same device, ONSET HOBO U12-012 data logger was also fixed outside of selected student rooms to examine the climate outside of the rooms as the ONSET HOBO Pendant data logger (*Appendix P*) that was used in the pilot study is suitable for only limited measurement of temperature and light intensity. To reduce the risk of damage caused by rain, the data logger was fixed facing the corridor area. There are three parameters of indoor climate data that were collected including air temperature (°C), relative humidity (%), and light intensity (lumens/ft^2 or lux).

During the primary data collection stage, time became a big concern in building performance evaluation for the findings representing the condition of residential college buildings as a whole. As located in the equatorial region, Malaysia's climatic conditions are uniform throughout the year with only little seasonal variation and a constant annual average temperature and humidity (Ahmad, 2008).

Referring back to climatic analysis and past reviews acquired from literature, not much data variation were found in terms of monthly mean temperature, relative humidity and monthly wind speed. In contrast, there are very distinguishable difference between the minimum and maximum of daily temperature due to day and night factor. Thus, the field measurement can be done on any month in the year, however the sampling period should cover at least a 24-hours duration. Nevertheless, the rainfall and wind direction differ due to the monsoon.

According to the Malaysian Meteorological Department (2012), the north to northeast wind prevails during the northeast monsoon (November to March), which bring more rainfall originating from China and the north Pacific. Whilst, the south wind prevails during the Southeast monsoon (May to September) and less rainfall is recorded, originating from the deserts of Australia. In addition, the transitions between these two monsoons are in March and October.

Therefore, the building performance evaluation is considered to be a case study of the Southeast monsoon which is considered to be a relatively dry season (Kubota et al., 2009).

The measurement was planned for 26 days with different conditions introduced on each day. The first condition was the opening or closing of all operable windows while exposing the student room to sunlight by opening the curtains. The second condition was the presence or absence of an operated ceiling fan at different speeds on different days. Consequently, the effects of facade design and building orientation in providing day lighting and natural ventilation into the ten different scenarios of student rooms can be quantitatively identified. Moreover, the effects of ceiling fans in influencing indoor temperature via air circulation and ventilation can be clearly discerned. This microclimatic measurement set was to cover a 24-hour period with one hour intervals between measurements (Dahlan et al., 2009). Unfortunately, the measurement of the open windows condition and fan speed on three-speeds had to be repeated when some of the student rooms were interrupted for maintenance works on day 18, 19 and 20. Furthermore, on day 14 nets were installed as a requirement for the safety of data loggers during the opening of all operable windows which was started on day 15 as shown in Table 3.5. Therefore, the readings which have been recorded by the data loggers on day 14 starting from 00:00 am until 23:00 pm, and day 18 starting from 9 am until 8 am on day 20 were not representative of normal conditions hence were not taken into account.

All the collected data were initially analysed by using the Hoboware pro software to compare existing international and local standards. A statistical computer software package was used for further statistical analysis that include descriptive analysis to find the differences in the mean measurement values and the intercorrelation between indoor, outdoor and UM's microclimate (Chua, 2006; 2008).

Table 3.5: The schedule of field measurement for building performance evaluation

Day	Room Condition		Date	Note	Day	Room Condition		Date	Note
	Windows	Fan Speed				Windows	Fan Speed		
			14.7.2012	Equipment & data logger installation	15	Open	5	31.7.2012	Start at 12 a.m.
			15.7.2012		16		5	1.8.2012	
			16.7.2012		17		5	2.8.2012	
1	Close	5	17.7.2012	Start at 12 a.m.	18		3	3.8.2012	The rooms have been interrupted
2		5	18.7. 2012		19		3	4.8.2012	
3		5	19.7. 2012		20		3	5.8.2012	
4		3	20.7.2012		21		1	6.8.2012	
5		3	21.7.2012		22		1	7.8.2012	
6		3	22.7.2012		23		1	8.8.2012	
7		1	23.7.2012		24		0	9.8.2012	
8		1	24.7.2012		25		0	10.8.2012	
9		1	25.7.2012		26		0	11.8.2012	
10		0	26.7.2012		27		0	12.8.2012	
11		0	27.7.2012		28		3	13.8.2012	Repeated measurement
12		0	28.7.2012		29		3	14.8.2012	
13		0	29.7.2012		30		3	15.8.2012	
14			30.7.2012	Fixing safety net	31		3	16.8.2012	Stop at 9 a.m.

The indoor condition of residential buildings was found to have a strong relation with recent outdoor temperatures (Peeters et al., 2009). The data on the UM microclimate were taken from the UM weather station, which is located within the campus and managed by the Malaysian Meteorological Department. The UM weather station is located at 3°07' N latitude, 101°39'E and at the height of 104.0m above mean sea level.

3.4.3 Living behaviour assessment

A further assessment that focuses on living behaviour was done for two weeks on fully occupied student rooms. A study done by Lin and Deng (2006), Frontczak et al. (2012), Kamaruzzaman et al. (2011) and Rijal et al. (2007) to assess sleeping thermal environment, factors influencing comfort through indoor environmental quality, the effects of indoor environmental quality on the occupants' perception of performance and the effects of open windows for thermal comfort, were prominently used as reference.

All the data loggers were placed in the same settings as in the building performance evaluation which was done earlier. The condition of openings (windows), fan speed and curtains were not determined.

However, all the residents in these eight rooms which are representing ten different scenarios are asked to record the time, garments worn, activity, weather, condition of openings, and electrical appliances that were used including the fan and lamps. In addition, the perception of the residents itself regarding visual comfort, ventilation, thermal comfort and the general comfort level of the student room at that moment was obtained. In facilitating the residents in recording all these information, one particular form was provided as shown in *Appendix Q - Living behaviour assessment form*.

There was no fixed time determined to complete this form, as the occupants need to attend lectures at their faculty and attend their own off-campus activities. However, this form was required to be completed within any three time periods by the occupants depending on their free time. The three time periods are, from 6 am to 12 pm, 12pm to 6 pm and 6pm to 12 am, everyday. Thus, time would also be recorded for further analysis with data recorded by data loggers.

Consequently, it was possible to recognize the times when the student room conditions reach the desired comfort level for residents. Also it was possible to recognize, the regular changes made in the room by the occupants at a particular time and conditions of obtaining an optimum comfort level during these times (Chiang et al., 1996; Frontczak et al., 2012). Indirectly, this will show the residents' pattern of living behaviour at the residential college buildings with respect to the internal space arrangement. The statistical computer software package will be used for further comprehensive analysis and the intercorrelation between the climate and the pattern of living behaviour (Chua, 2006; 2008).

3.5 Analysis of field investigation and evaluation

In this final stage, all results from the methodological triangulation of the POE namely; satisfaction and perception survey, building performance evaluation and living behaviour assessment were critically analysed. The correlation between results from these three methods of evaluation directly show how the bioclimatic design strategies reflect the efficiency of electricity usage and comfort levels of the residential college buildings.

In other words, the acceptance level and perception of the occupants on the bioclimatic design strategies which were well applied at residential buildings were fundamentally defined. Moreover, a comprehensive description of the precise conditions of student rooms that provide a comfortable living space through the implementation of natural ventilation and day lighting strategies were compiled. Additionally, the living behaviour assessment establishes the living behaviour patterns through analysis of regular changes in the room initiated by the occupants at a particular time as well as the corresponding conditions required to obtain an optimum level of comfort during those times.

3.6 Research limitations

There are a number of limitations in this research, most of which were encountered during the POE specifically in building performance evaluation and living behaviour assessment. They are;

i. The lack of site drawings and floor plans for preliminary studies on old residential college buildings. To overcome this, on site observations took place in order to gauge current conditions of residential colleges due to numerous renovations.

ii. The limited availability of electricity bills of residential colleges due to the practiced standard operating procedure (SOP) where all the utility bills are kept for duration of only three years. Hence, the performance of electricity usage of the twelve residential colleges was only analysed for a five year period; beginning from 2005 to 2009.

iii. The lack of climate data due to some of the parameters such as sunshine and solar radiation as well as cloud cover not being measured at the University of Malaya (UM) weather station. Only important parameters are measured there as it is only an auxiliary weather station. Furthermore, the climate data are only available from 1981 to 2009 as this weather station was closed for maintenance work in 2010. Even then, some of the data are not available in certain months due to technical errors.

iv. The limited of data loggers and devices due to limited of research funding. Therefore, only selected student rooms were evaluated for specific scenarios based on grounded theories from previous studies. Only three parameters were measured namely temperature (°C), relative humidity (%) and light intensity (lux). The microclimate of the UM campus was obtained from the UM weather station due to the lack of equipment for outdoor measurement. Apparently, there is also a lack of microclimate data on certain days due to technical errors.

v. Limited time frame and safety issues of data loggers. Thus, the measurements for building performance evaluation were only taken for 31 days. Different conditions were introduced each day in terms of rooms' openings and the presence of operating ceiling fans at different speeds on different days. For living behaviour assessment, the measurements were only taken for 14 days.

vi. Limited access to certain student rooms and residential blocks on the basis of safety issues by residential college administration. Thus, student room identification for building performance evaluation and living behaviour assessment were only focused on the easily accessible residential blocks.

vii. Reservations of views from residents of the selected student rooms while recording room conditions and in giving their response towards satisfaction and perception level. Thus, the results of living behaviour assessment were presented and discussed from a general point of view.

CHAPTER 4
Preliminary studies

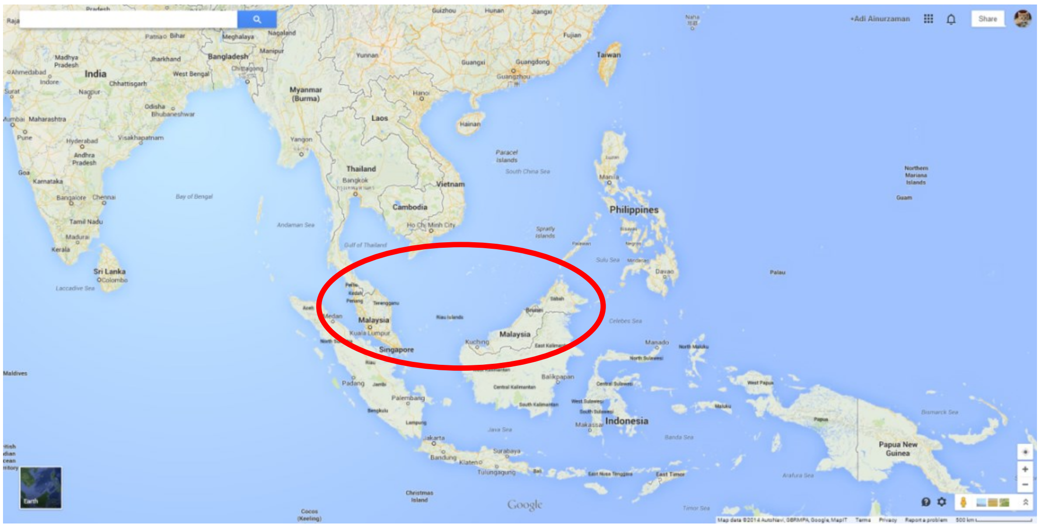
There are two parts of these preliminary studies. First of all are studies on the current design practice of residential college buildings in University of Malaya (UM) campus in Kuala Lumpur, Malaysia that demonstrates bioclimatic design concepts particularly on natural ventilation and daylighting. The location of Malaysia and UM campus is presented in Figure 4.1. The second part involves studies on the efficiency of current electricity usage to obtain the energy efficiency index (EEI) and the prospect of energy conservation for each residential college (RC). The findings of both studies were critically examined for case study selection.

4.1 The description and characteristic of UM residential colleges

4.1.1 History of UM residential colleges

There are twelve residential college buildings within the UM campus. The 2nd RC is the first residential college that was built in 1958 when the UM campus was moved from Singapore to Kuala Lumpur. A year later, 1st RC was built to accommodate third year students from the faculty of arts and faculty of engineering who were previously based in the Singapore campus. In the 1960's, another four residential colleges were built. There was 3rd RC in 1962, 4th RC in 1963, 5th RC in 1966 and 6th RC in 1967. They were followed by the 7th RC in 1975 and 8th RC in 1985. Ten years later, the 9th RC was built after the modular residential college caught fire in 1990. In 1997, the 10th RC and the 11th RC were built, giving students the option of not having meals provided; dissimilar to the other nine residential colleges which were equipped with a dining hall that provide meals for breakfast, lunch and dinner.

The construction of 12th RC was completed in 2002 which is the newest and the biggest residential college in the UM campus. Similar to the 10th and the 11th RC, the 12th RC only provides lodging while cafeterias are provided for the residents' convenience.



(a)

(b)

(a). Location of Malaysia, (b). Location of UM campus

Figure 4.1: Location of study area

The location of twelve residential college buildings in UM campus is presented in Figure 4.2.

Figure 4.2: Location of residential college buildings within UM campus

4.1.2 Building form, height and density

The majority of residential college buildings have a linear arrangement with the rectangular shape of the building's floor plate to maximise the space to accommodate the larger number of residents. All student rooms are positioned facing each other and are attached to a closed corridor. Only two residential colleges were built with an internal courtyard arrangement and a different shape of building floor plates. There is the 5th RC which has a square shape, while the 11th RC was designed with an L-shape. Considering the hilly land's surface, some of the residential colleges were not designed with a north-south orientation which would have helped to eliminate excessive heat from direct sunlight penetration. This can be seen at the 3rd RC, 4th RC, 6th RC, 7th RC, 8th RC and 10th RC. With the L-shape design for the building's floor plate, some of the student rooms at the 11th RC have a west-east orientation.

Five out of twelve residential colleges had their different residential blocks built in different phases. These are the 1st RC, 2nd RC, 3rd RC, 4th RC and 6th RC. Each residential block in each phase has different designs corresponding to the need for a bigger building which can accommodate the large number of students that was continuously increasing with the founding of new faculties in University Malaya campus during that time. The floor plans that are presented in this chapter for these five residential colleges only represent the newest additional residential block which is means it is not a typical floor plan. This is different to other residential colleges which include the 5th RC, 7th RC, 8th RC, 9th RC, 10th RC, 11th RC and 12th RC which had all their residential blocks built within the same phase, where the design of each residential block within the residential college are identical to one another. Thus, the floor plan is typical with repeatable design especially in 1st, 2nd and 3rd floor.

Most of the residential buildings at residential colleges in the UM campus are low-rise buildings with three or four floor levels. Each level is connected with a staircase which located either at the both ends of the floor or in the middle of the building. In contrast, all four residential buildings at 12th RC are high rise buildings with ten floor levels. Other than staircases, each floor is connected by elevators.

In comparison, the 3rd RC is the smallest residential college with a land area of only 18,740.60m^2, total floor area of 7,159.92m^2 and built up area of 4,196.08m^2, on the other hand, the biggest residential college is the 12th RC with a land area of 46,415.84m^2, total floor area of 89,545.91m^2 and a built up area of 30,724.87m^2. Although known as the smallest residential college, the 3rd RC is able to occupy a high number of residents. This residential college has the capacity to house 765 residents at any one time compared to the 2nd RC which is only able to accommodate 611 residents. The 2nd RC is bigger than 3rd RC with a land area of 41,014.10m^2, total floor area of 11,224.71m^2 and a built up area of 7,499.98m^2. In fact, the highest density of residents was recorded in the 3rd RC with 0.107 people/m^2, while the lowest density recorded was in 11th RC with 0.026 people/m^2. The 11th RC is able to provide a comfortable and spacious room with only 897 of the residents. A typical room's floor area in the 11th RC is about 20.0m^2, which is the biggest room area compared to other residential colleges. The smallest typical room's floor area was recorded by the 10th RC with 13.16m^2. Other residential colleges have densities below 0.065 people/m^2 with different capacity, which depend on the number of the rooms.

4.1.3 Building opening - enclosure and façade design

Regarding the enclosure and façade design, all residential college buildings were designed with sun shading devices complete with adjustable and/or fixed natural ventilation options. The locations of the room's windows correspond to the building's orientation. The majority of residential colleges were designed with louver/jalousie windows and only three residential colleges were fitted with different window designs. There are the 5^{th} RC and 7^{th} RC which were had windows with centre pivots and awning/top hang windows, while the 11^{th} RC were fitted with casement window.

The residential buildings at the 1^{st} RC and 3^{rd} RC that have been renovated recently and were installed with casement windows, while other buildings are still fitted with louver/jalousie windows. All the windows at the 2^{nd} RC, 5^{th} RC, 7^{th} RC, 11^{th} RC and 12^{th} RC have been designed in two forms, operable (can be opened or closed) and inoperable (fixed). Only two residential colleges had their rooms designed with effective window to wall (WWR) ratio, 0.24<WWR>0.3 (ASHRAE, 2010). They are the 1^{st} RC with 0.30 and 10^{th} RC with 0.26. However, there still remains controversies and debate based on differing views regarding the percentage amount for an effective WWR. Latest, on January 30, 2012, the ASHRAE 90.1 Standards Committee voted to continue with the current 40% WWR for low-rise buildings with significant changes possible in 2013 and 2016 (US Glass News Network, 2012).

Based on this latest decision, there are six other residential colleges which were designed with effective WWR. They are the 4^{th} RC with 0.32, 7^{th} RC with 0.33, 8^{th} RC with 0.38, 11^{th} RC (Type B) with 0.36 and 12^{th} RC with 0.32. The highest and lowest WWR recorded was the 5^{th} RC and 9^{th} RC with 0.66 and 0.07 respectively. Thus, curtains can be fully utilised at the 5^{th} RC to control excessive daylight penetration inside the room. While, the fluorescent lamp in the room is needed to be switched on during the daytime at 9^{th} RC, especially during cloudy days.

4.1.4 The adaptation of bioclimatic design strategies

All the residential colleges were designed with at least one bioclimatic strategy design concept. The most implemented strategy was the fitting of horizontal overhangs along the wall with windows which acts as solar control devices. The 5th RC and 11th RC showed the highest number of implemented strategies where the most distinguishing strategy is the internal courtyard that was not applied in other residential colleges.

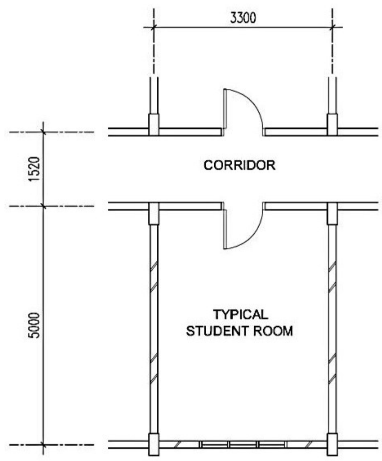
Comparing all the residential colleges, the 5th RC was identified as the residential college with the best implementation of bioclimatic design strategies particularly utilising daylighting and natural ventilation. While the 8th RC and 9th RC were the residential colleges with the minimum number of implemented strategies. Only three residential colleges the 5th RC, 6th RC and 7th RC that were fitted with window openings with both horizontal and vertical adjustable/closing devices, which indirectly give full control to the residents to channel outside wind into the room. Other residential colleges were only designed with one directional window opening, where the horizontal adjustable/closing devices are the most popularly used design. Only the 4th RC and several rooms at the 10th RC were designed with both high and low level fixed/adjustable exhaust opening devices whilst other residential colleges were designed with only high level fixed/adjustable exhaust opening. The evolution of building design can be seen through a transom or fixed opening over the doorway of the student room. This concept was only implemented at the first five residential colleges, which gave more natural light and encourage air circulation inside the room. Without the application of this concept at the 6th RC, 7th RC, 8th RC, 9th RC, 10th RC, 11th RC and 12th RC, the daylight penetration and air circulation inside the room are only dependent on the window opening and the balcony.

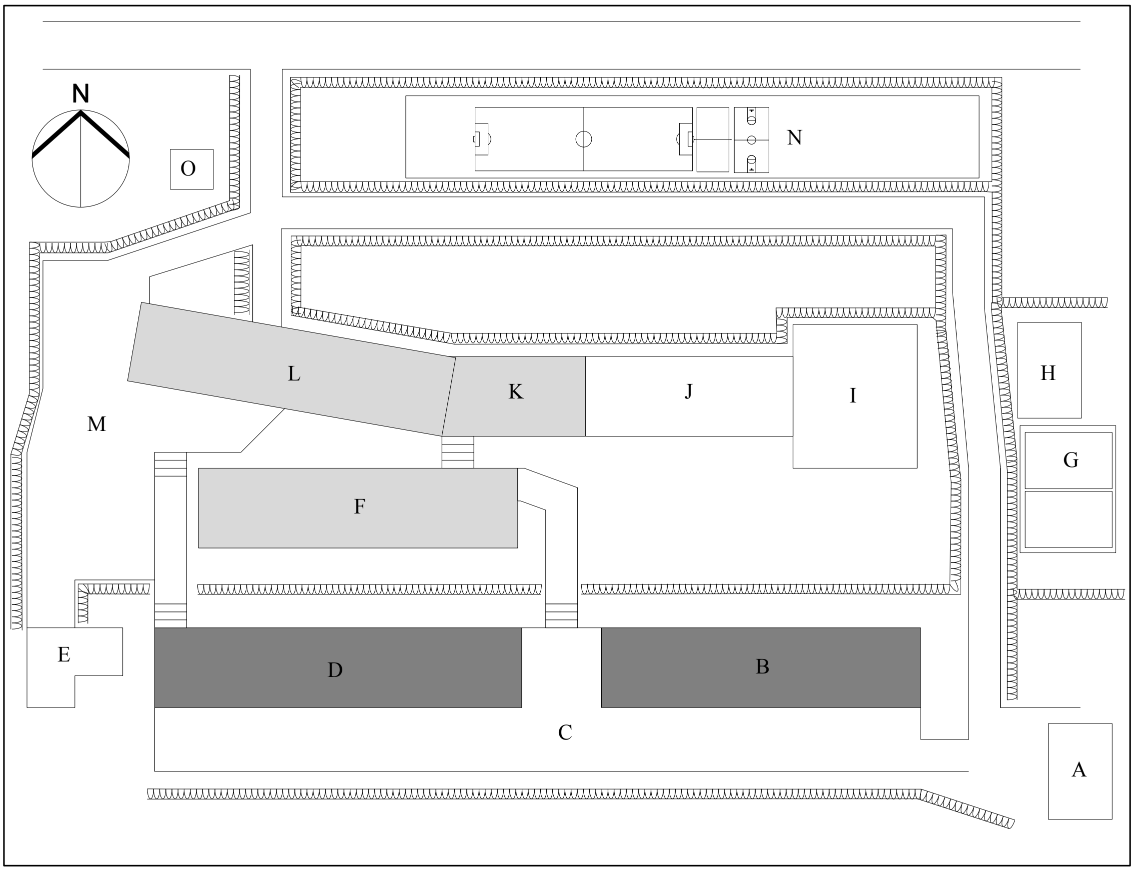
In promoting air circulation and daylight inside the corridor and staircase area, opening devices were introduced with either adjustable or fixed opening especially at residential colleges with linear building layout arrangement. Unfortunately, the area of opening devices is quite small and does not allow sufficient daylight to enter which then force residents to switch on the light even during day time. Exhaust fans were also installed at the both ends of the corridor at 8^{th} RC. As a consequence, this increases the electricity load to sustain the comfort level of the residents.

Regarding the landscape aspect, the majority of the residential colleges have more than 50% of the soft surface area. With the higher soft surface area having been planted with various species of trees, the indoor temperature and the cooling load of buildings can be reduced drastically. Furthermore, they play a role as carbon sinks when 1 hectare of tree stores about 2,600kg of carbon per year (KeTTHA, 2011). The 2^{nd} RC showed the highest ratio but in terms of area in m^2 unit, the 5^{th} RC has the largest soft surface area with 26,214.04m^2. Compared to the others the 3^{rd} RC is the lowest contributor to CO_2 emission with approximately; 9,424.40 kg of CO_2 released when its area of 1.1 acres of green field area were developed into what it is, which is equivalent to 10,000kg of CO_2 emission (KeTTHA, 2011). Whilst, 12^{th} RC being the biggest residential college with a land area of 46,415.84m^2 and a total floor area of 89,545.91m^2, is the highest contributor of CO_2 emission when 69,008.06kg was released from 30,724.87m^2 of its built up area.

The internal system and characteristic of residential college buildings which focused on the adaptation strategies of bioclimatic design are presented in Table 4.1 to 4.12. Some of the points are clearly explained in Figure 4.3 to 4.38 that include site plan and floor plan of each residential college buildings. Moreover, they are also visualized through standard normal photographs that are presented in Figure 4.5, 4.8, 4.11, 4.14, 4.17, 4.20, 4.23, 4.26, 4.29, 4.32, 4.35 and 4.38.

Table 4.1: Internal system and characteristic of 1st RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.1]
	ORIENTATION TO SUN PATH	N - S [Fig. 4.1]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.2]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.1]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	26,152.49
	TOTAL BUILT UP AREA (m^2)	12,530.88
	TOTAL FLOOR AREA (m^2)	12,727.44
	CAPACITY	816
	DENSITY (capacity/total floor area)	0.064
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	3 : 97
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	ROOM DIMENSION (l) x (w) x (h)	5.0 x 3.3 x 2.6 
	ROOM'S FLOOR AREA (m^2)	16.50
	ROOM VOLUME (m^3)	42.90
	CORRIDOR WIDTH (m)	1.52
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.3(a) & (b)].
	WINDOW AREA (m^2)	2.60
	WINDOW TO WALL RATIO	0.30
	OPERABLE WINDOW AREA (m^2)	2.60
	OPERABLE WINDOW TO WALL RATIO	0.30
	WINDOW DESIGN	Louver window/Jalousie & Casement window (depend on phase of building constructed) [Fig. 4.3(b)]
	LOCATION	N - S [Fig. 4.1 & 4.2]
SOLAR CONTROL DEVICES		Large horizontal overhangs along the wall with windows [Fig. 4.3(b)]
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.3(c) & (d)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.3(c)] High-level fixed exhaust opening [Fig. 4.3(c)] Transom/fixed opening over the doorway of residential unit [Fig. 4.3(d)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	52 : 48 (13,621.61 m^2 : 12,530.88 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable & fixed opening devices at the end of the corridor [Fig. 4.3(a) & (e)]
	STAIRCASE AREA	A closed staircase area with fixed opening devices [Fig. 4.3(f)]
ARCHITECT		Chawangan Bangunan, Malaysia Barat
PHASE OF CONSTRUCTION		Various phases
YEAR ESTABLISHED		1959



Legend

Sloping edge | Origin residential block | New additional residential block

A - Cafeteria, B - Residential block (Block D/Male), C - Covered parking lots for motorcycle, Parking lots/ Multipurpose open area, D - Residential block (Block E/Female) & Musollah/Prayer room, E - Principal unit, F - Residential block (Block B/Female), G - Staff residential unit, H - Store, I - Dining hall, Kitchen, Warden office, VVIP room, J - Multipurpose hall, K - Residential block (Block A/Female), L - Residential block (Block C/Male) & Administrative office (Ground floor), M - Parking lots/Multipurpose open area, N - Court/Sports area/Multipurpose open area, O - Guard post/Main entrance

Figure 4.3: Site plan of 1st RC

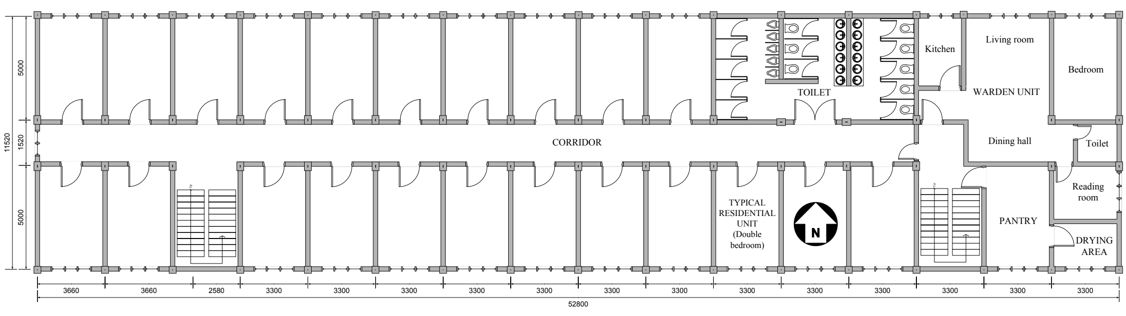


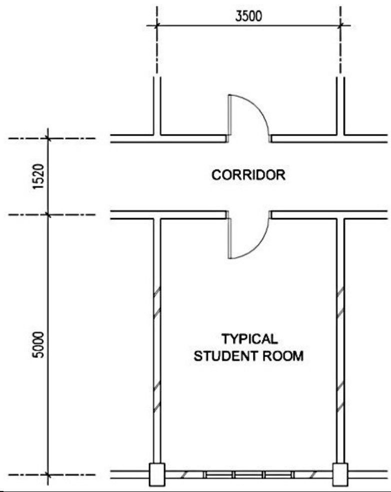
Figure 4.4: Floor plan of 1st RC (new additional residential block - Block D & E)

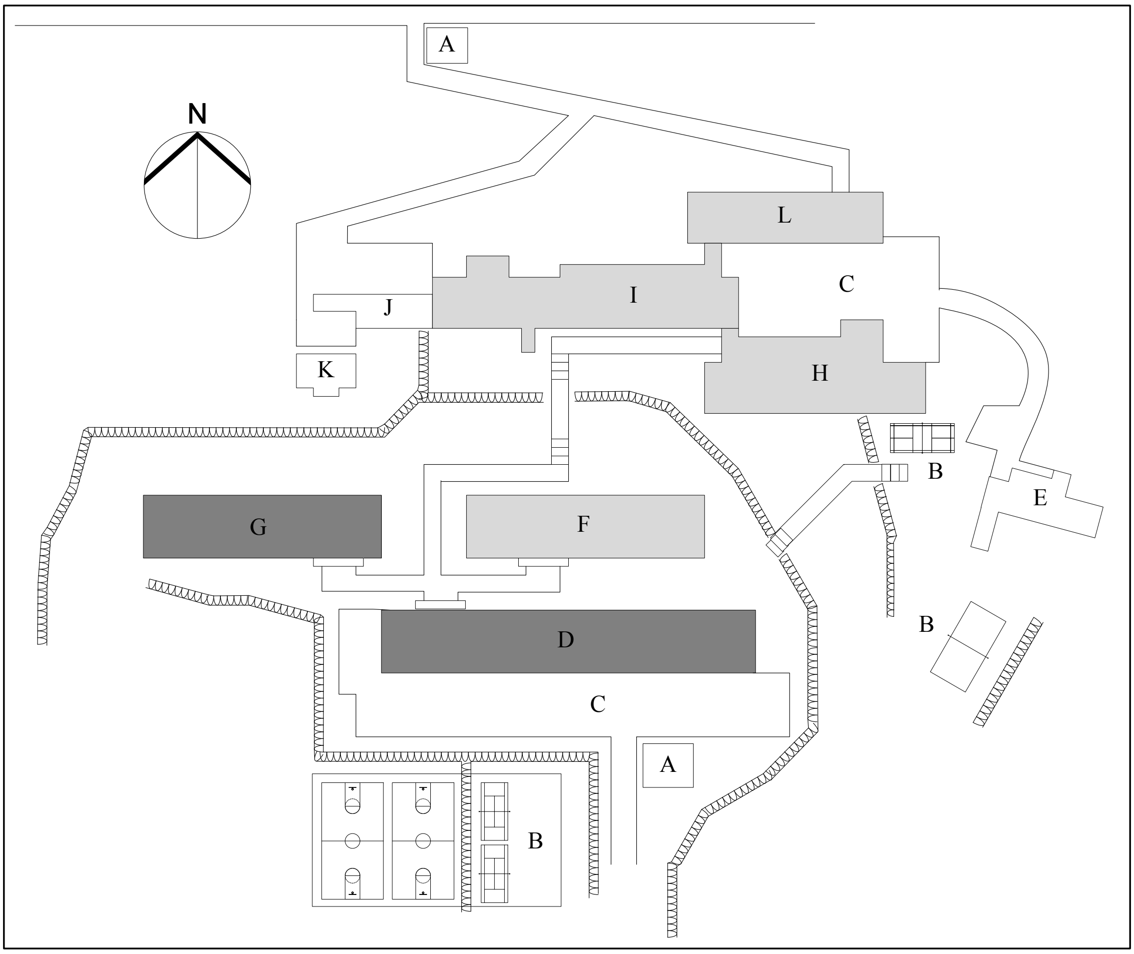
(a) (d) (b) (e) (c) (f)

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design & large horizontal overhangs along the wall with windows, (c). High level fixed exhaust opening & articulated light shelves, (d). Transom/fixed opening over the doorway of residential unit, (e). Closed corridor with adjustable & fixed opening devices at the end of the corridor, (f). A closed staircase area with fixed opening devices - creates wind pressure effects.

Figure 4.5: Internal system and characteristic of 1st RC

Table 4.2: Internal system and characteristic of 2nd RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.4]
	ORIENTATION TO SUN PATH	N - S [Fig. 4.4]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.5]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.4]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	41,014.10
	TOTAL BUILT UP AREA (m^2)	7,499.98
	TOTAL FLOOR AREA (m^2)	11,224.71
	CAPACITY	611
	DENSITY (capacity/total floor area)	0.054
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	2 : 98
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	ROOM DIMENSION (l) x (w) x (h)	5.0 x 3.5 x 2.9 
	ROOM'S FLOOR AREA (m^2)	17.50
	ROOM VOLUME (m^3)	50.75
	CORRIDOR WIDTH (m)	1.52
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.6(a) & (b)]
	WINDOW AREA (m^2)	4.31
	WINDOW TO WALL RATIO	0.42
	OPERABLE WINDOW AREA (m^2)	2.39
	OPERABLE WINDOW TO WALL RATIO	0.24
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.6(b)]
	LOCATION	N - S [Fig. 4.4 & 4.5]
SOLAR CONTROL DEVICES		Large horizontal overhangs along the wall with windows [Fig. 4.6(b)]
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.6(c) & (d)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.6(c)] High-level fixed exhaust opening [Fig. 4.6(c)] Transom/fixed opening over the doorway of residential unit [Fig. 4.6(d)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	82 : 18 (33,514.12 m^2 : 7,499.98 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable & fixed opening devices at the end of the corridor [Fig. 4.6(a) & (e)]
	STAIRCASE AREA	A closed staircase area with fixed opening devices [Fig. 4.6(f)]
ARCHITECT		No information
PHASE OF CONSTRUCTION		Various phases
YEAR ESTABLISHED		1958



Legend

Sloping edge | Origin residential block | New additional residential block

A - Guard post/Main entrance, B - Court/Sport area/Multipurpose open area, C - Parking lots/Multipurpose open area, D - Residential block (Block E/Male), E - Principal unit, F - Administrative block/Office, Cyber cafe, Balai Islam & Study room, G - Residential block (Block D/Male), H - Residential block (Block B/Female), I - Residential block (Block A/Female) & Multipurpose hall/Dining hall, J - Kitchen, K – Staff residential unit, L - Residential block (Block C/Female)

Figure 4.6: Site plan of 2nd RC

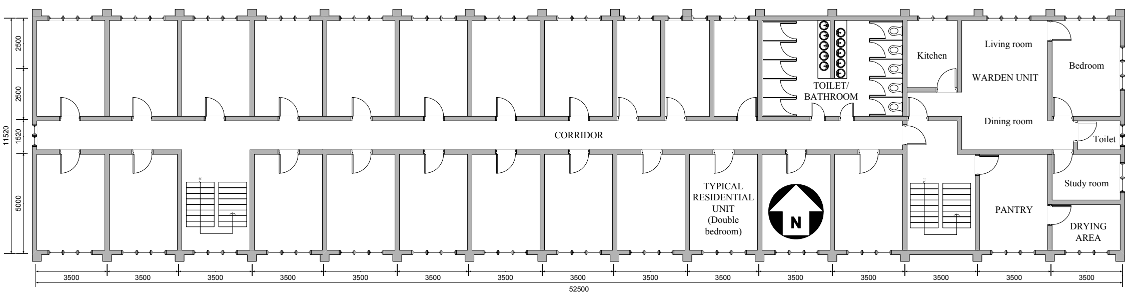
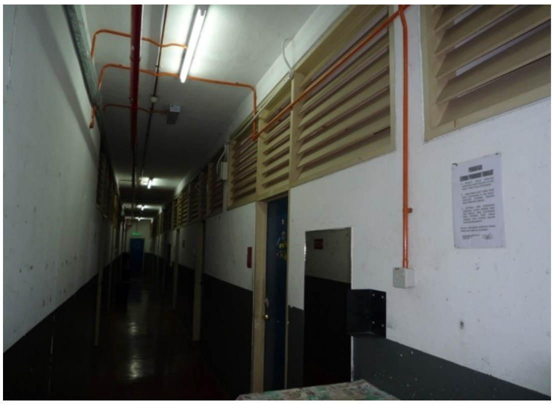


Figure 4.7: Floor plan of 2nd RC (new additional residential block - Block E)

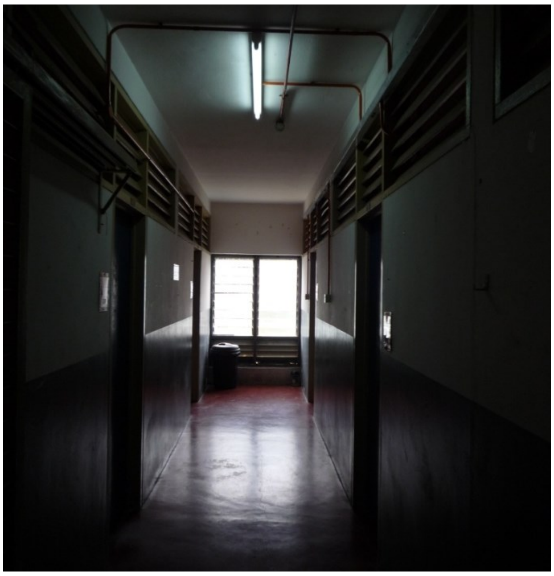
(a)

(b)

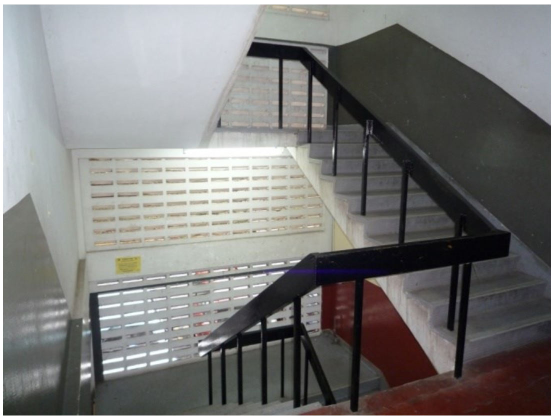
(c)



(d)



(e)

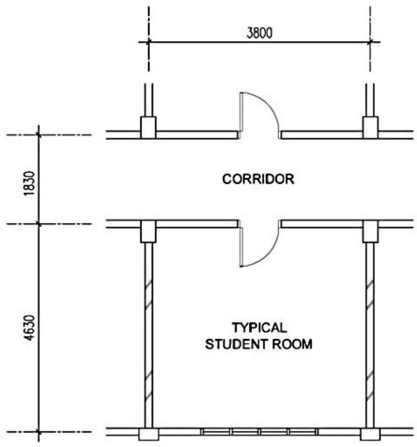


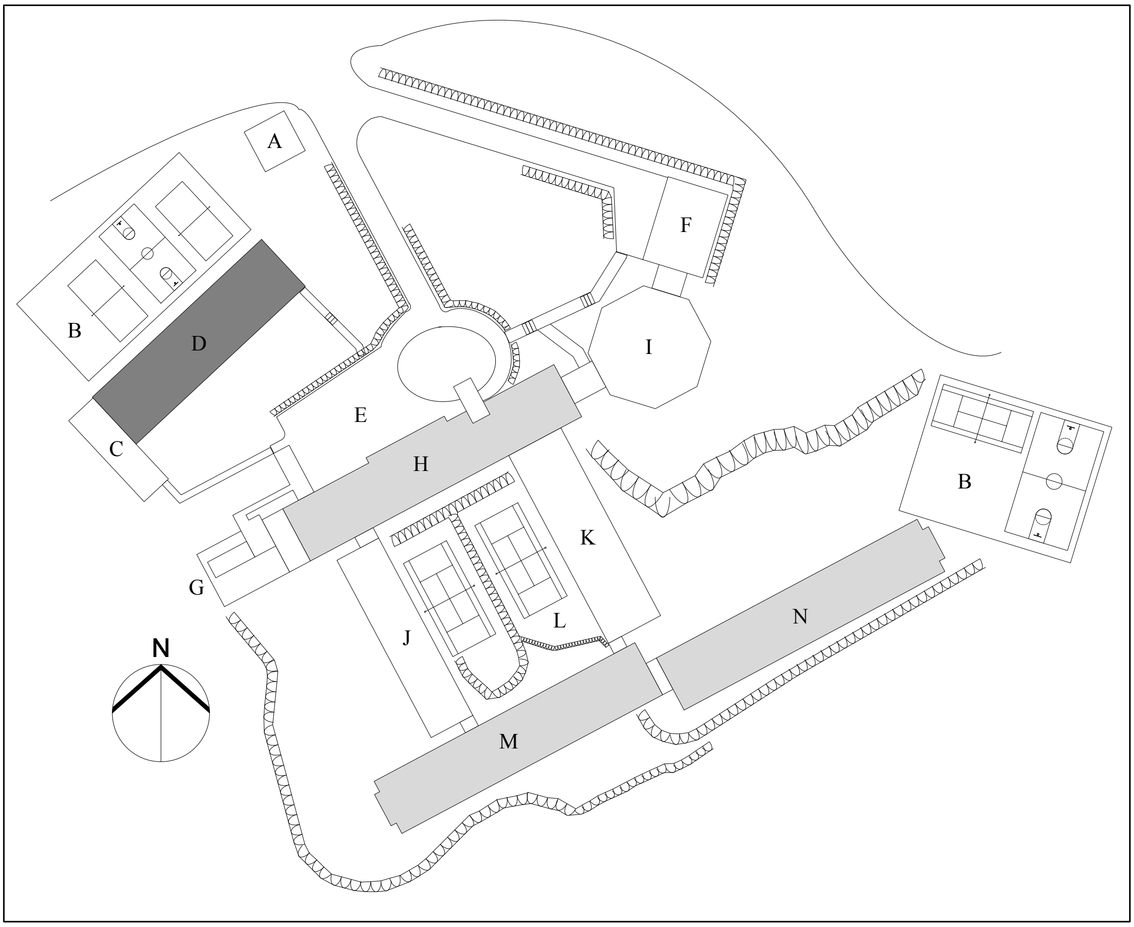
(f)

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design & large horizontal overhangs along the wall with windows, (c). High level fixed exhaust opening & articulated light shelves, (d). Transom/fixed opening over the doorway of residential unit, (e). Closed corridor with adjustable & fixed opening devices at the end of the corridor, (f). A closed staircase area with fixed opening devices - creates wind pressure effects.

Figure 4.8: Internal system and characteristic of 2nd RC

Table 4.3: Internal system and characteristic of 3rd RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.7]
	ORIENTATION TO SUN PATH	NW - SE [Fig. 4.7]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.8]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.7]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	18,740.60
	TOTAL BUILT UP AREA (m^2)	4,196.08
	TOTAL FLOOR AREA (m^2)	7,159.92
	CAPACITY	765
	DENSITY (capacity/total floor area)	0.107
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	5 : 95
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	ROOM DIMENSION (l) x (w) x (h)	4.63 x 3.8 x 2.86 
	ROOM'S FLOOR AREA (m^2)	17.59
	ROOM VOLUME (m^3)	50.32
	CORRIDOR WIDTH (m)	1.83
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection, adjustable & fix natural ventilation option [Fig. 4.9(a) & (b)]
	WINDOW AREA (m^2)	5.76
	WINDOW TO WALL RATIO	0.53
	OPERABLE WINDOW AREA (m^2)	5.76
	OPERABLE WINDOW TO WAL RATIO	0.53
	WINDOW DESIGN	Louver window/Jalousie & Casement window (depend on phase of building constructed) [Fig. 4.9(b) & (c)]
	LOCATION	NE - SW & NW – SE [Fig. 4.7 & 4.8]
SOLAR CONTROL DEVICES		Large horizontal overhangs along the wall with windows [Fig. 4.9(c)]
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.9(c) & (d)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal or vertical adjustable or closing devices to assist in channelling the air flow) [Fig. 4.9(c)] High-level fixed & small exhaust opening [Fig. 4.9(c)] Transom/fixed opening over the doorway of residential unit [Fig. 4.9(d)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	78 : 22 (14,544.52 m^2 : 4,196.08 m^2)
OTHERS	CORRIDOR	Closed corridor with fixed opening devices at the end of corridor [Fig. 4.9(a) & (e)]
	STAIRCASE AREA	A closed staircase area with fixed opening devices [Fig. 4.9(f)]
ARCHITECT		No information
PHASE OF CONSTRUCTION		Various phases
YEAR ESTABLISHED		1962



Legend

Sloping edge | Origin residential block | New additional residential block

A - Guard post/Main entrance, B - Court/Multipurpose open area, C - Warden units, D - Residential block (Block E/Male), E - Parking lots/Multipurpose open area, F - Store room, Support staff room, Kitchen, G - Warden units, H - Residential block (Block C/Female) & Administrative office (Ground floor), I - Dining hall, Student activity centre, J - Musollah/Prayer room, K - Reading room, Conference room, L - Court/Multipurpose open area, M - Residential block (Block B/Female), N - Residential block (Block A/Female)

Figure 4.9: Site plan of 3rd RC

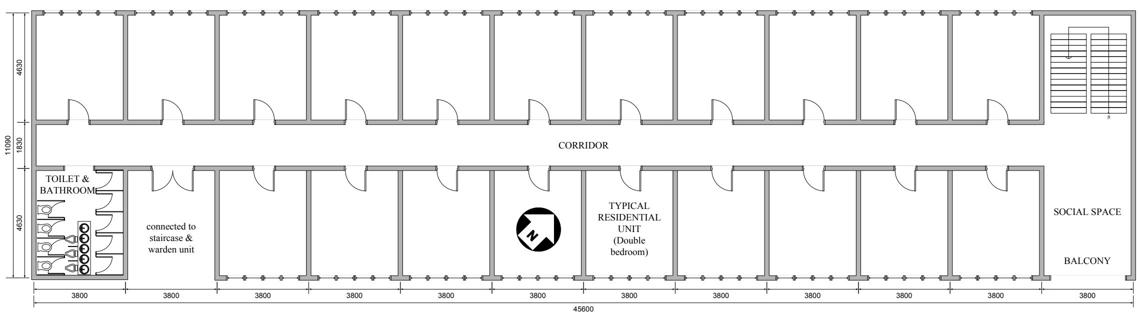


Figure 4.10: Floor plan of 3rd RC (new additional residential block - Block E)

(a)

(d)

(b)

(e)

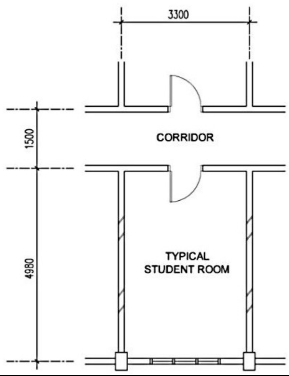
(c)

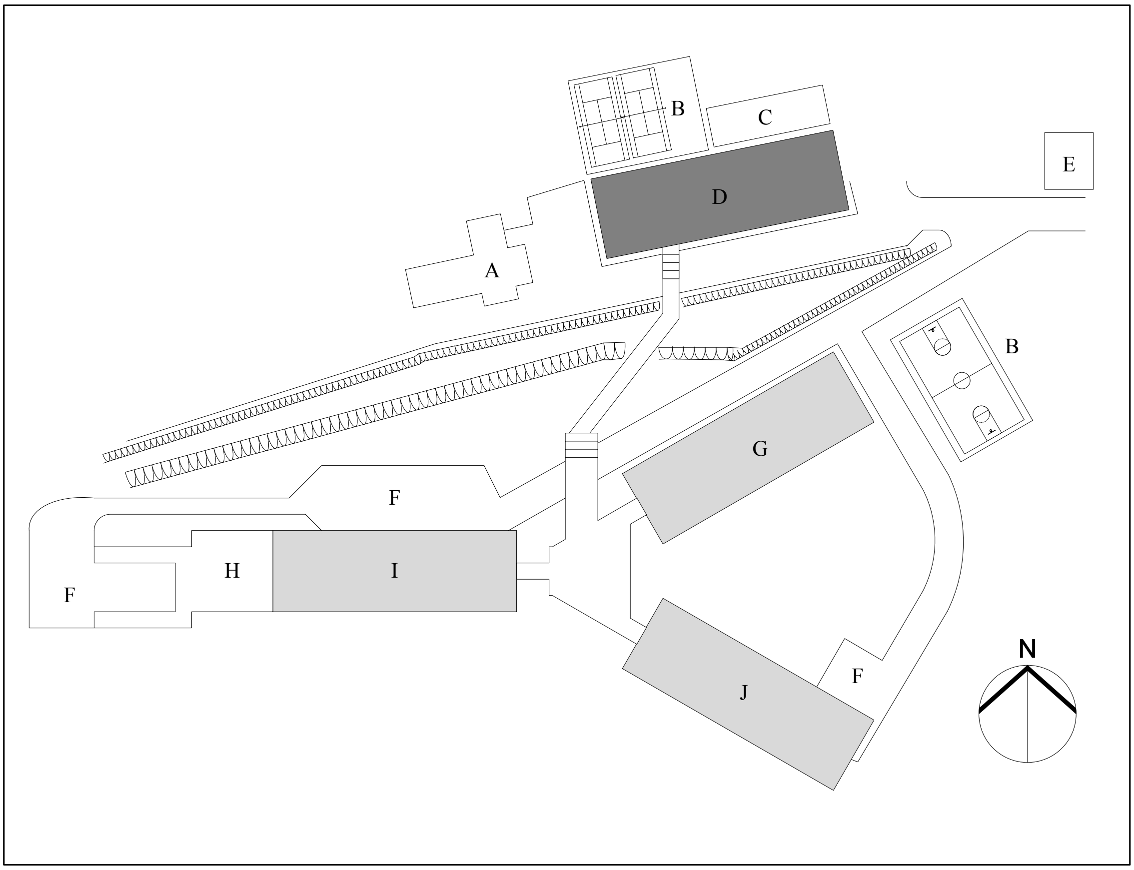
(f)

(a). Built-form configuration, enclosure and facade design, (b). Large horizontal overhangs along the wall with windows & balcony at the end of corridor nearer to staircase area, (c). Louver window/Jalousie window design, high level fixed exhaust opening & articulated light shelves, (d). Transom/fixed opening over the doorway of residential unit, (e). Closed corridor with fixed opening devices at the end of the corridor, (f). A closed staircase area with fixed opening devices - creates wind pressure effects.

Figure 4.11: Internal system and characteristic of 3rd RC

Table 4.4 : Internal system and characteristic of 4th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.10]
	ORIENTATION TO SUN PATH	N - S, NW - SE & NE - SW [Fig. 4.10]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.11]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.10]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	22,199.00
	TOTAL BUILT UP AREA (m^2)	10,599.03
	TOTAL FLOOR AREA (m^2)	11,427.67
	CAPACITY	705
	DENSITY (capacity/total floor area)	0.062
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	2 : 98
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	ROOM DIMENSION (l) x (w) x (h)	4.98 x 3.3 x 2.5 
	ROOM'S FLOOR AREA (m^2)	16.43
	ROOM VOLUME (m^3)	41.09
	CORRIDOR WIDTH (m)	1.50
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection, adjustable & fix natural ventilation option [Fig. 4.12(a) & (b)]
	WINDOW AREA (m^2)	2.60
	WINDOW TO WALL RATIO	0.32
	OPERABLE WINDOW AREA (m^2)	2.60
	OPERABLE WINDOW TO WALL RATIO	0.32
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.12(a)]
	LOCATION	N - S, NW - SE & NE - SW [Fig. 4.10 & 4.11]
SOLAR CONTROL DEVICES		Large horizontal overhangs along the wall with windows and large vertical overhangs at selected buildings and orientation [Fig. 4.12(a) & (b)]
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.12(c) & (d)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal or vertical adjustable or closing devices to assist in channelling the air flow) [Fig. 4.12(c)] High-level fixed exhaust opening [Fig. 4.12(c)] Low-level fixed inlets opening [Fig. 4.12(c)] Transom/fixed opening over the doorway of residential unit [Fig. 4.12(d)] Location of opening with respect to wind direction (certain residential building)
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	52 : 48 (11,599.97 m^2 : 10,599.03 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable & fixed opening devices at the end of the corridor [Fig. 4.12(e)]
	STAIRCASE AREA	A closed staircase area with fixed opening devices [Fig. 4.12(f)]
ARCHITECT		No information
PHASE OF CONSTRUCTION		Various phases
YEAR ESTABLISHED		1963



Legend

Sloping edge | Origin residential block | New additional residential block

A - Principal unit, B - Court/Sport area/Multipurpose open area, C - Covered parking lots, D - Residential block (Block D/Male), E - Guard post/Main entrance, F - Parking lots/Multipurpose open area, G - Residential block (Block C/Female), H - Dining Hall & Kitchen, I - Residential block (Block A/Female), J - Residential block (Block B/Female)

Figure 4.12: Site plan of 4th RC

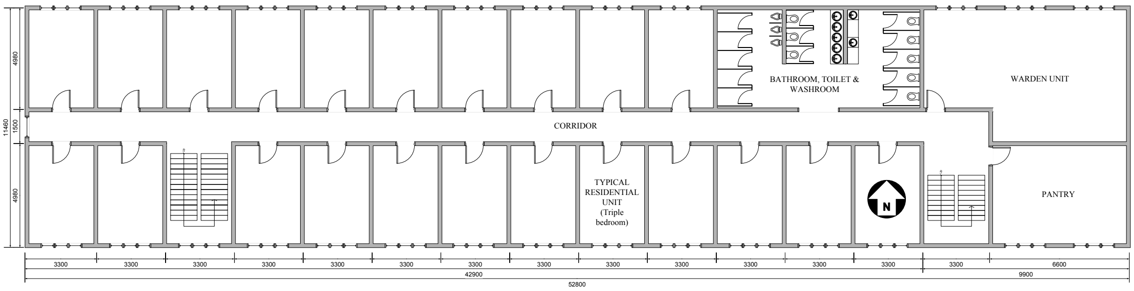


Figure 4.13: Floor plan of 4th RC (new additional residential block - Block D)

(a)

(d)

(b)

(e)

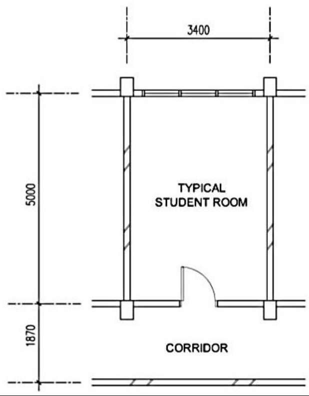
(c)

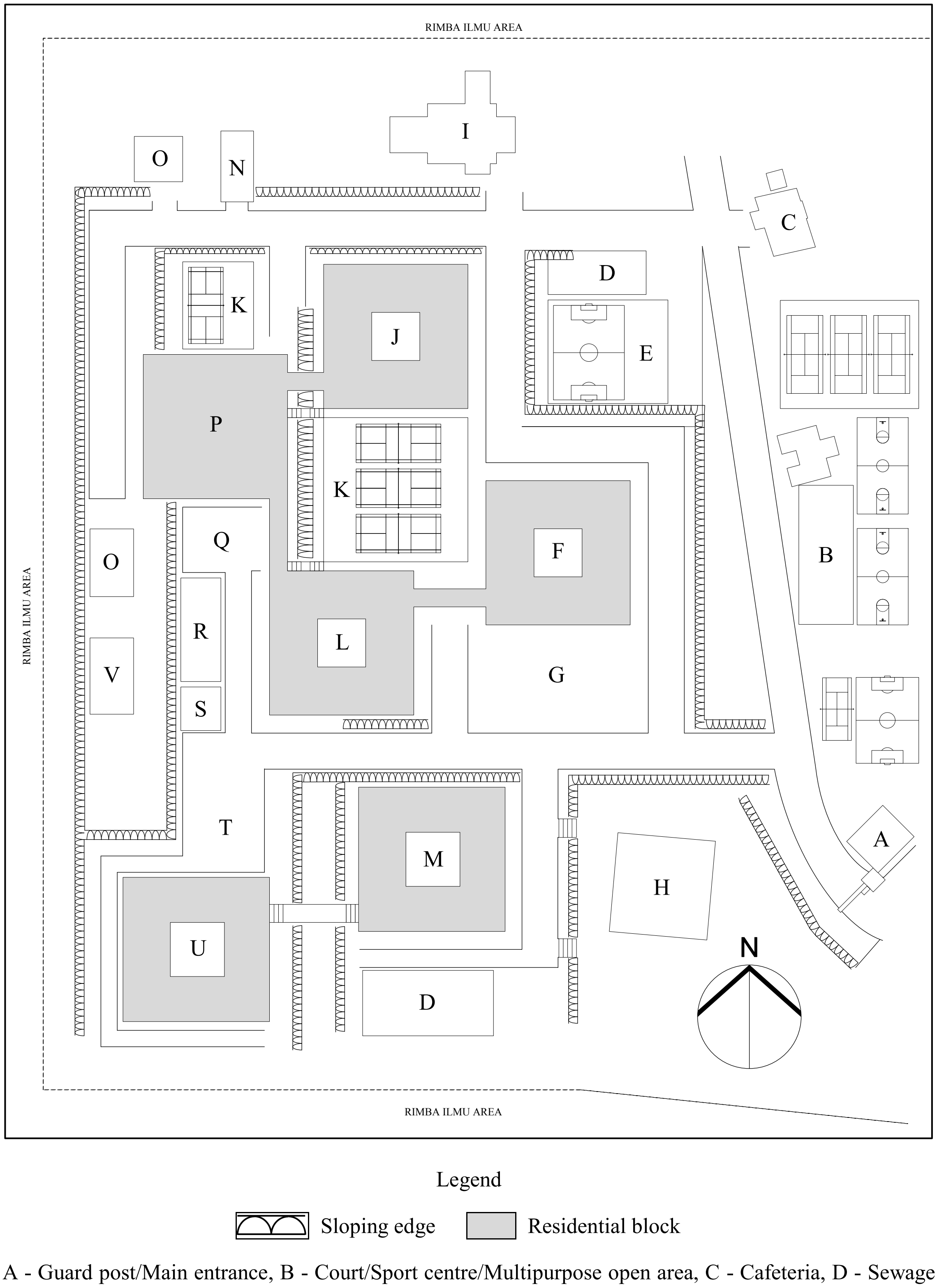
(f)

(a). Built-form configuration, enclosure and facade design; louver window/jalousie window design & large horizontal overhangs along the wall with windows, (b). Large horizontal & vertical overhangs along the wall with windows, (c). High level fixed exhaust opening, low level fixed inlets opening & articulated light shelves, (d). Transom/fixed opening over the doorway of residential unit, (e). Closed corridor with adjustable & fixed opening devices at the end of the corridor, (f). A closed staircase area with fixed opening devices - creates wind pressure effects.

Figure 4.14: Internal system and characteristic of 4th RC

Table 4.5: Internal system and characteristic of 5th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Courtyard arrangement [Fig. 4.13]
	ORIENTATION TO SUN PATH	N - S [Fig. 4.13]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.14]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.13]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	43,185.06
	TOTAL BUILT UP AREA (m^2)	16,971.02
	TOTAL FLOOR AREA (m^2)	18,212.51
	CAPACITY	847
	DENSITY (capacity/total floor area)	0.047
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	1 : 99
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	4.74 x 3.45 x 2.80 
	TYPICAL ROOM'S FLOOR AREA (m^2)	16.35
	TYPICAL ROOM VOLUME (m^3)	45.78
	TYPICAL OF CORRIDOR WIDTH (m)	1.87
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.15(a) & (c)]
	WINDOW AREA (m^2)	6.41
	WINDOW TO WALL RATIO	0.66
	OPERABLE WINDOW AREA (m^2)	4.20
	OPERABLE WINDOW TO WALL RATIO	0.43
	WINDOW DESIGN	Centre pivots & awning [Fig. 4.15(b)]
	LOCATION	N- S [Fig. 4.13 & 4.14]
SOLAR CONTROL DEVICES		Tinted window glass, large horizontal overhangs along the wall with windows on 2nd & 3rd floor, & open corridor [Fig. 4.15(b), (c) & (e)]
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves & sky courts/internal courtyard [Fig. 4.15(b), (c) & (d)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal & vertical adjustable or closing devices to assist in channelling the air flow) [Fig. 4.15(b)] High-level adjustable exhaust opening [Fig. 4.15(b)] Large open corridor & facing to internal courtyard [Fig. 4.15(e)] Transom/fixed opening over the doorway of residential unit [Fig. 4.15(d)] Wall opening (create wind pressure inside the room) Internal courtyard [Fig. 4.15(e)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	61 : 39 (26,214.04 m^2 : 16,971.02 m^2)
OTHERS	CORRIDOR	Open corridor (facing to internal courtyard) [Fig. 4.15(e)]
	STAIRCASE AREA	Open staircase area [Fig. 4.15(f)]
ARCHITECT		No information
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		1966



A - Guard post/Main entrance, B - Court/Sport centre/Multipurpose open area, C - Cafeteria, D - Sewage tank, E - Field/Multipurpose open area, F- Residential block (Block B - Boungainvilla/Female), G - Garden/Green area, H - Prayer Hall/Musollah, I - Principal unit, J - Residential block (Block A - Azalea/Female), K - Court/Multipurpose open area, L - Residential block (Block C - Camellia/Female), M - Residential block (Block D - Dahlia/Male), N - Self car wash, O - Store, P - Administrative block/Office, Lobby, Students activity centre, Dining hall, Kitchen, Q - Parking lots, R - Self-laundry room & Covered parking lots, S - Pump house, T - Parking lots/Multipurpose open area, U - Residential block (Block E - Episcia/Male), V - Staff residential units

Figure 4.15: Site plan of 5th RC

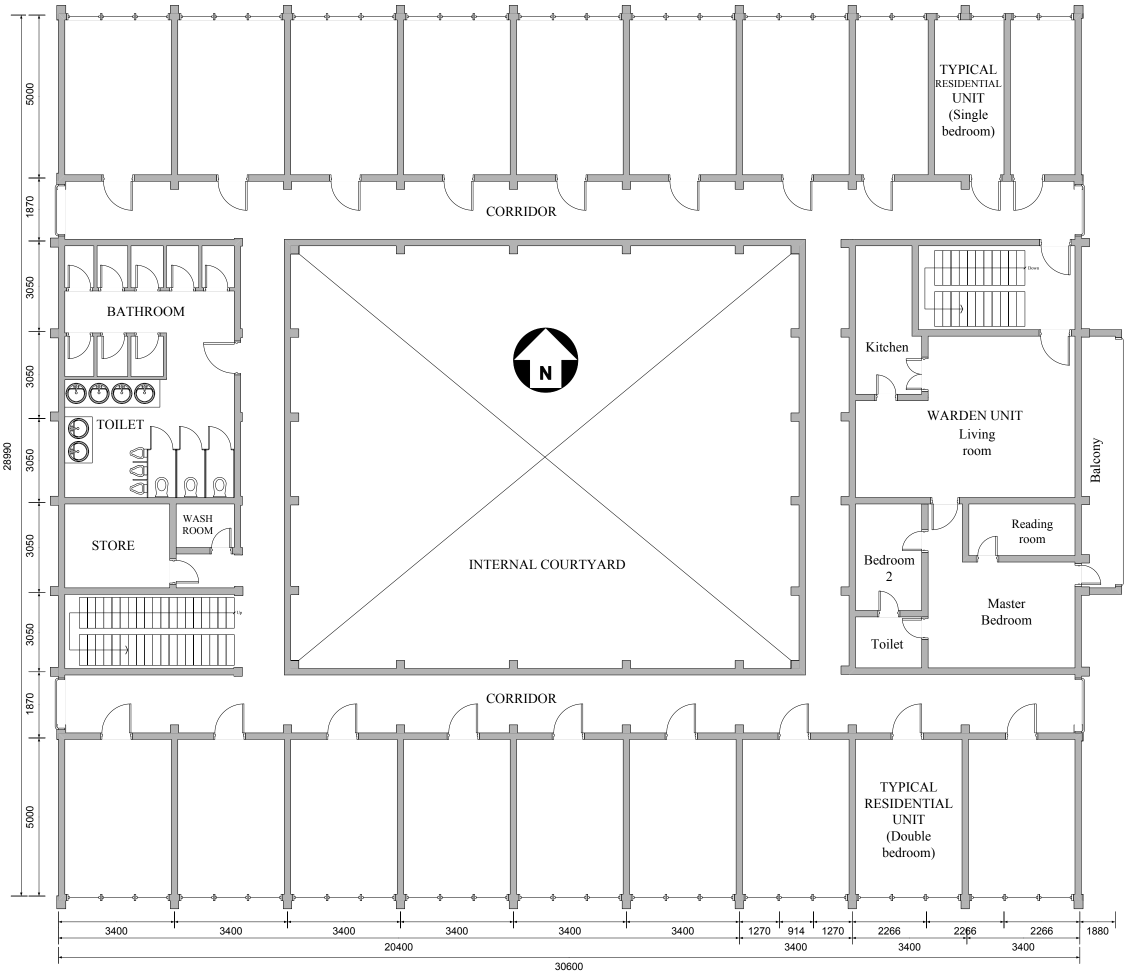


Figure 4.16: Typical floor plan of 5th RC

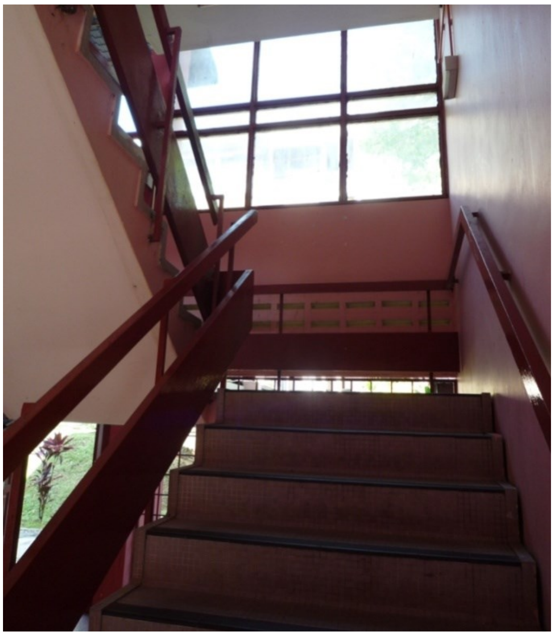
(a)

(d)

(b)

(e)

(c)

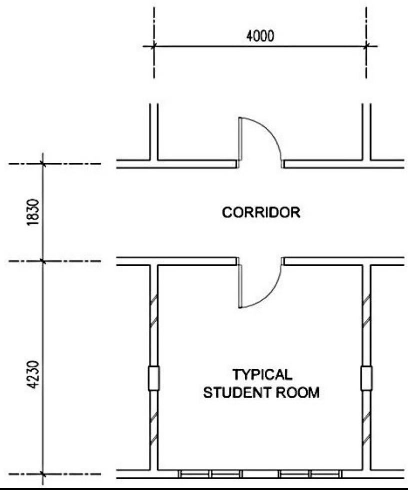


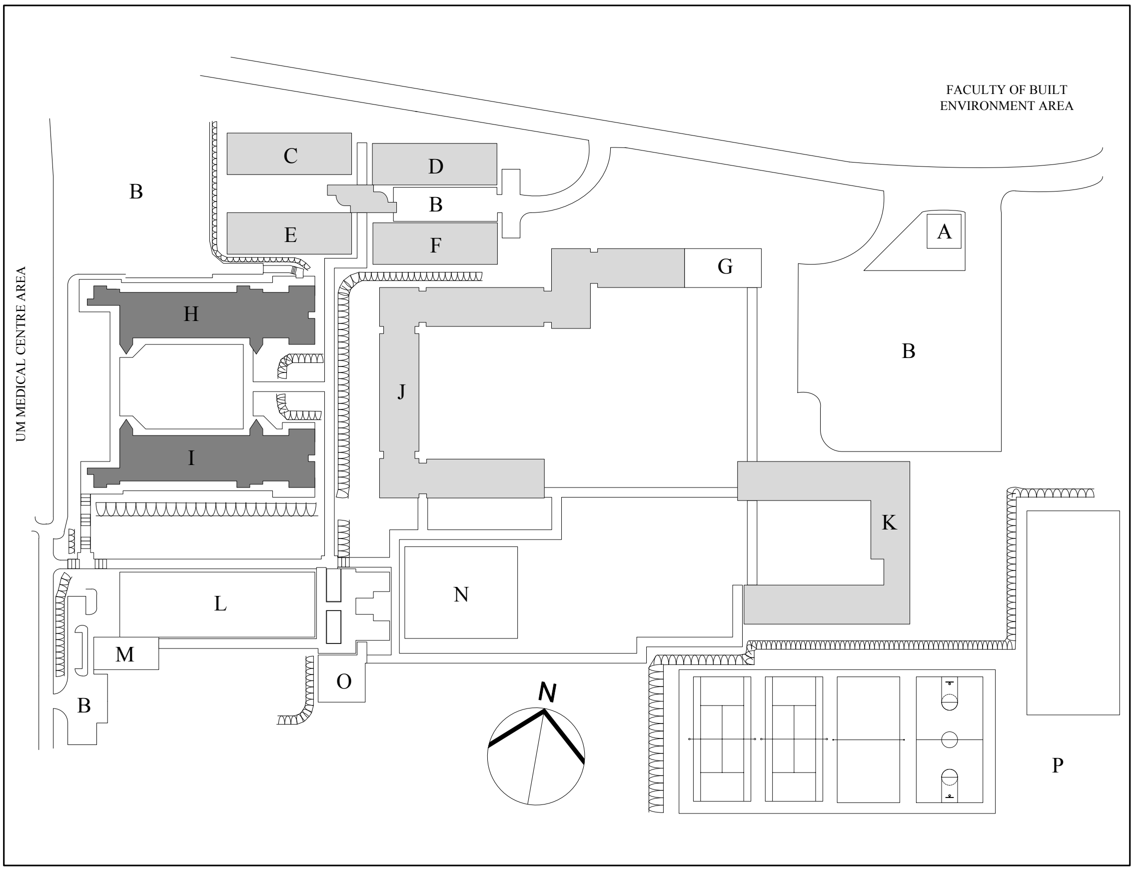
(f)

(a). Built-form configuration, enclosure and facade design, (b). Centre pivots & awning window design with tinted glass and high level adjustable exhaust opening with articulated light shelves, (c). Large horizontal overhangs along the wall with windows, (d). Transom/fixed opening over the doorway of residential unit, (e). Open corridor that faces to internal courtyard, (f). Open staircase area.

Figure 4.17: Internal system and characteristic of 5th RC

Table 4.6: Internal system and characteristic of 6th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.16]
	ORIENTATION TO SUN PATH	N - S, NW - SE & NE - SW [Fig. 4.16]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.17]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.16]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	29,121.64
	TOTAL BUILT UP AREA (m^2)	12,822.28
	TOTAL FLOOR AREA (m^2)	21,148.03
	CAPACITY	630
	DENSITY (capacity/total floor area)	0.030
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	1 : 99
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	ROOM DIMENSION (l) x (w) x (h)	4.23 x 4.0 x 3.0 
	ROOM'S FLOOR AREA (m^2)	16.92
	ROOM VOLUME (m^3)	50.76
	CORRIDOR WIDTH (m)	1.83
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.18(a)]
	WINDOW AREA (m^2)	2.27
	WINDOW TO WALL RATIO	0.19
	OPERABLE WINDOW AREA (m^2)	2.27
	OPERABLE WINDOW TO WALL RATIO	0.19
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.18(b)]
	LOCATION	N - S & W - E [Fig. 4.16 & 4.17]
SOLAR CONTROL DEVICES		Wide horizontal overhangs along the wall with windows and at the a part of windows itself (depend on phase of building constructed) [Fig. 4.18(b)]
PASSIVE DAYLIGHT CONCEPTS		Nil
WIND AND NATURAL VENTILATION		Window opening (with vertical & horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.18(b)] Transom/fixed opening over the doorway of residential unit [Fig. 4.18(c)] High-level adjustable exhaust opening [Fig. 4.18(d)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	56 : 44 (16,299.36 m^2 : 12,822.28 m^2)
OTHERS	CORRIDOR	Closed corridor with fixed opening devices at the end of corridor [Fig. 4.18(e)]
	STAIRCASE AREA	Closed staircase area [Fig. 4.18(f)]
ARCHITECT		Arkitek Kitas Sdn. Bhd.
PHASE OF CONSTRUCTION		Various phases
YEAR ESTABLISHED		1967



Legend

Sloping edge Origin residential block New additional residential block

A - Guard post/Main entrance, B - Parking lots/Multipurpose open area, C - Residential block (Block F - Female), D - Residential block (Block D - Female), E - Residential block (Block E - Female), F - Residential block (Block C - Female), G - Administrative block/Office, Lobby, Students activity centre, H - Residential block (Block G - Female), I - Residential block (Block H - Male), J - Residential block (Block A - Female), K - Residential block (Block B - Male), L - Dining hall, M - Store room, N - Multipurpose open area (Dataran Sentua), O : Prayer Hall/Musollah, P : Court/Sport centre/Multipurpose open area.

Figure 4.18: Site plan of 6th RC

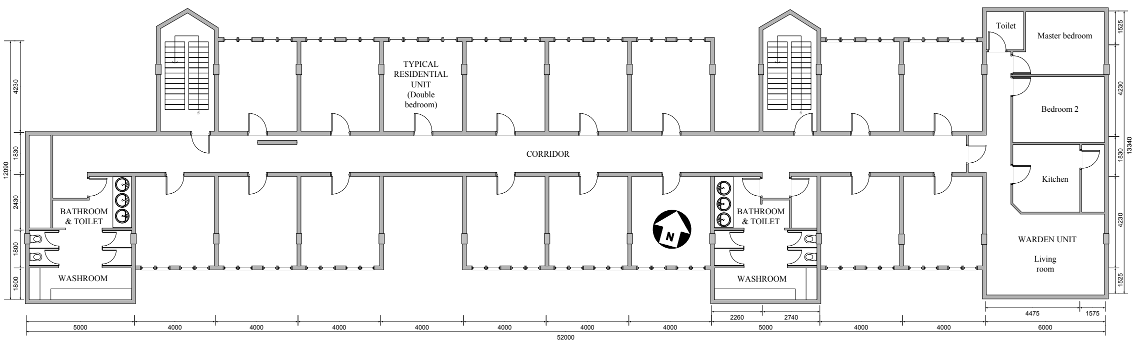


Figure 4.19: Floor plan of 6th RC (new additional residential block - Block H)

(a)

(d)

(b)

(e)

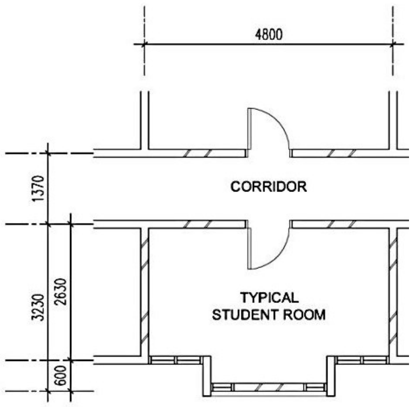
(c)

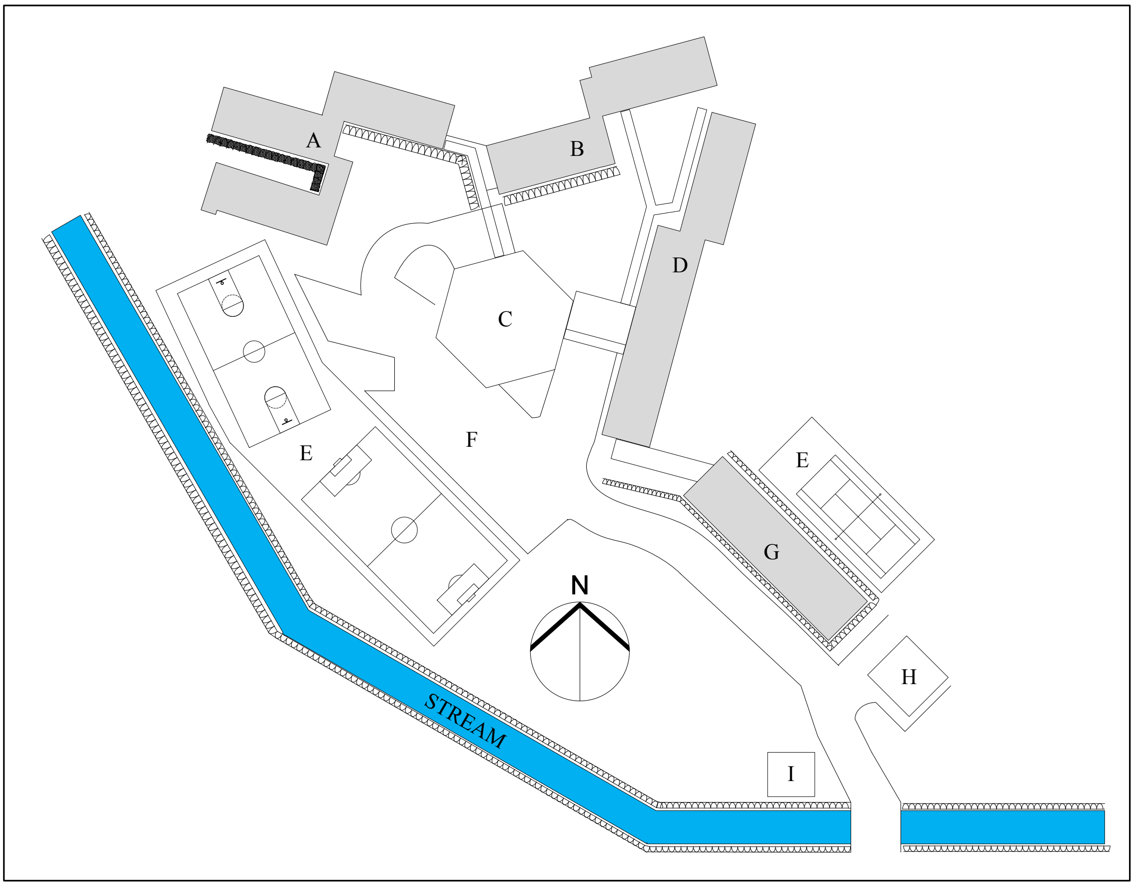
(f)

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design with large horizontal overhangs along the wall with windows; large fixed shading devices against to adjustable window area, (c). Transom/fixed opening over the doorway of residential unit, (d). High level fixed exhaust opening, (e). Closed corridor with adjustable opening devices, (f). Closed staircase area.

Figure 4.20: Internal system and characteristic of 6th RC

Table 4.7: Internal system and characteristic of 7^{th} RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.19]
	ORIENTATION TO SUN PATH	NE- SW & NW - SE [Fig. 4.19]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.20]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.19]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	19,263.41
	TOTAL BUILT UP AREA (m^2)	11,786.98
	TOTAL FLOOR AREA (m^2)	12,989.87
	CAPACITY	798
	DENSITY (capacity/total floor area)	0.061
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	1 : 99
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	3.23 x 4.8 x 3.0
		
	TYPICAL ROOM'S FLOOR AREA (m^2)	15.50
	TYPICAL ROOM VOLUME (m^3)	46.50
	TYPICAL OF CORRIDOR WIDTH (m)	1.37
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.21(a) & (b)]
	WINDOW AREA (m^2)	4.68
	WINDOW TO WALL RATIO	0.33
	OPERABLE WINDOW AREA (m^2)	4.18
	OPERABLE WINDOW TO WALL RATIO	0.29
	WINDOW DESIGN	Casement & Awning window [Fig. 4.21(b)]
	LOCATION	Depending on the building's orientation [Fig. 4.19 & 4.20]
SOLAR CONTROL DEVICES		Tinted window glass [Fig. 4.21(b)]
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.21(a) & (b)]
WIND AND NATURAL VENTILATION		Window opening (with vertical & horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.21(b)] High-level adjustable exhaust opening [Fig. 4.21(b)] Location of opening with respect to wind direction (certain residential building)
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	39 : 61 (7,476.43 m^2 : 11,786.98 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable & fixed opening devices at the end and middle of the corridor [Fig. 4.21(c), (d) & (e)]
	STAIRCASE AREA	A closed staircase area with fixed opening devices [Fig. 4.21(f)]
ARCHITECT		No information
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		1975



Legend

Sloping edge Residential block

A - Residential block (Block A/Male), B - Residential block (Block B/Female), C - Administrative block/Office, Lobby, Kitchen, Dining Hall, Multipurpose hall, D - Residential block (Block C/Female), E - Court/Sport area/Multipurpose open area, F - Covered parking lots, Parking lots/ Multipurpose open area, G - Residential block (Block D/Female), H - Principal unit, I - Guard post/Main entrance

Figure 4.21: Site plan of 7th RC

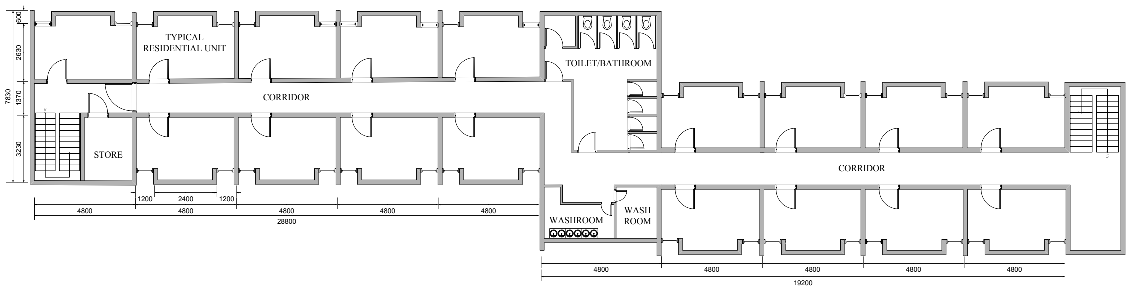


Figure 4.22: Typical floor plan of 7th RC


(a)


(d)


(b)


(e)

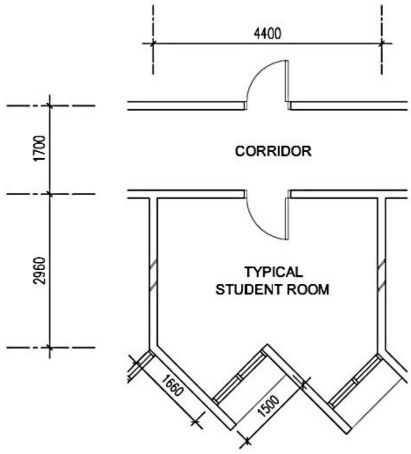

(c)

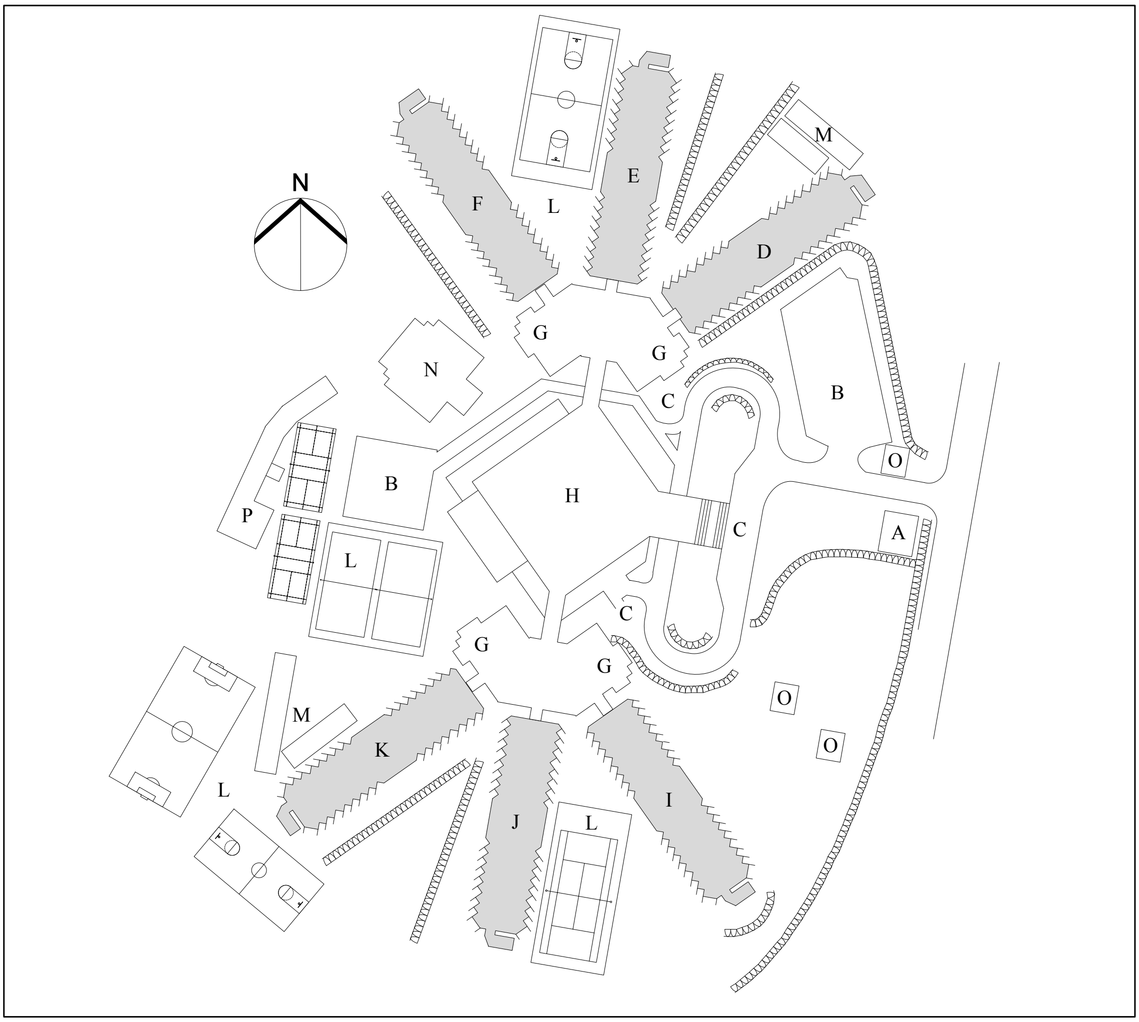
(f)

(a). Built-form configuration, enclosure and facade design, (b). Casement & awning window design with tinted glass and high level adjustable exhaust opening with articulated light shelves, (c). (d). A wall opening with fixed devices at corridor against to washroom - create wind pressure effects, (e). Closed corridor with adjustable & fixed opening devices at the end of corridor, no transom/fixed opening over the doorway of residential unit, (f). A closed staircase area with fixed opening devices - creates wind pressure effects.

Figure 4.23: Internal system and characteristic of 7th RC

Table 4.8: Internal system and characteristic of 8th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.22]
	ORIENTATION TO SUN PATH	W - E, NW - SE & NE - SW [Fig. 4.22]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.23]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.22]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	32,806.00
	TOTAL BUILT UP AREA (m^2)	9,213.63
	TOTAL FLOOR AREA (m^2)	11,274.23
	CAPACITY	694
	DENSITY (capacity/total floor area)	0.062
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	2 : 98
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	(1.52 x 1.52 x 3.20) + (4.27 x 2.92 x 3.20) 
	TYPICAL ROOM'S FLOOR AREA (m^2)	14.78
	TYPICAL ROOM VOLUME (m^3)	47.30
	TYPICAL OF CORRIDOR WIDTH (m)	1.70
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Figure 4.24(a)]
	WINDOW AREA (m^2)	3.34
	WINDOW TO WALL RATIO	0.38
	OPERABLE WINDOW AREA (m^2)	3.34
	OPERABLE WINDOW TO WALL RATIO	0.38
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.24(b)]
	LOCATION	W - E, NW - SE & NE – SW [Fig. 4.22 & 4.23]
SOLAR CONTROL DEVICES		Large horizontal and vertical overhangs along the wall with windows [Fig. 4.24(c)]
PASSIVE DAYLIGHT CONCEPTS		Nil
WIND AND NATURAL VENTILATION		Window opening (with vertical & horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.24(b)] Location of opening with respect to wind direction (certain residential building) Vertical wing wall at window opening [Fig. 4.24(c)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	72 : 28 (23,592.37 m^2 : 9,213.63 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable opening devices at the end of corridor [Fig. 4.24(d), (e) & (f)]
	STAIRCASE AREA	Open staircase area [Fig. 4.24(f)]
ARCHITECT		No information
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		1985



Legend

Sloping edge   Residential block

A - Guard post/Main entrance, B - Parking lots/Multipurpose open area, C - Parking lots, D - Residential block (Block A/Female), E - Residential block (Block B/Female), F - Residential block (Block C/Female), G - Flat, H - Administrative block/Office, Lobby, Students activity centre, Dining hall, Kitchen, Multipurpose hall, I - Residential block (Block F/Male), J - Residential block (Block E/Female - Ground floor & Male - 1st Floor to 3rd floor), K - Residential block (Block D/Female), L - Court/Sport area/Multipurpose open area, M - Covered parking lots, N - Prayer hall/Musollah, O - Wakaf/Hut, P - Cafeteria/Shops.

Figure 4.24: Site plan of 8th RC

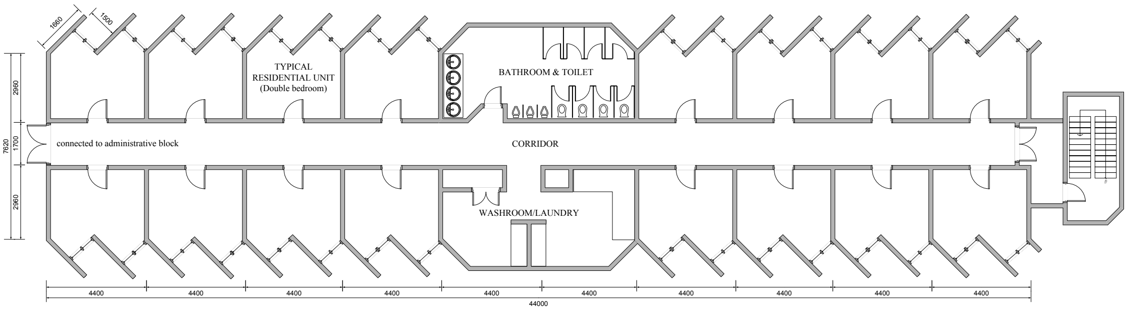


Figure 4.25: Typical floor plan of 8th RC

(a)

(d)

(b)

(e)

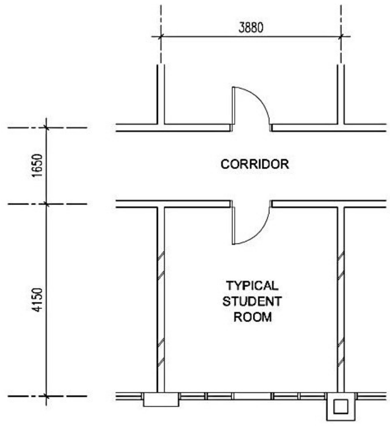
(c)

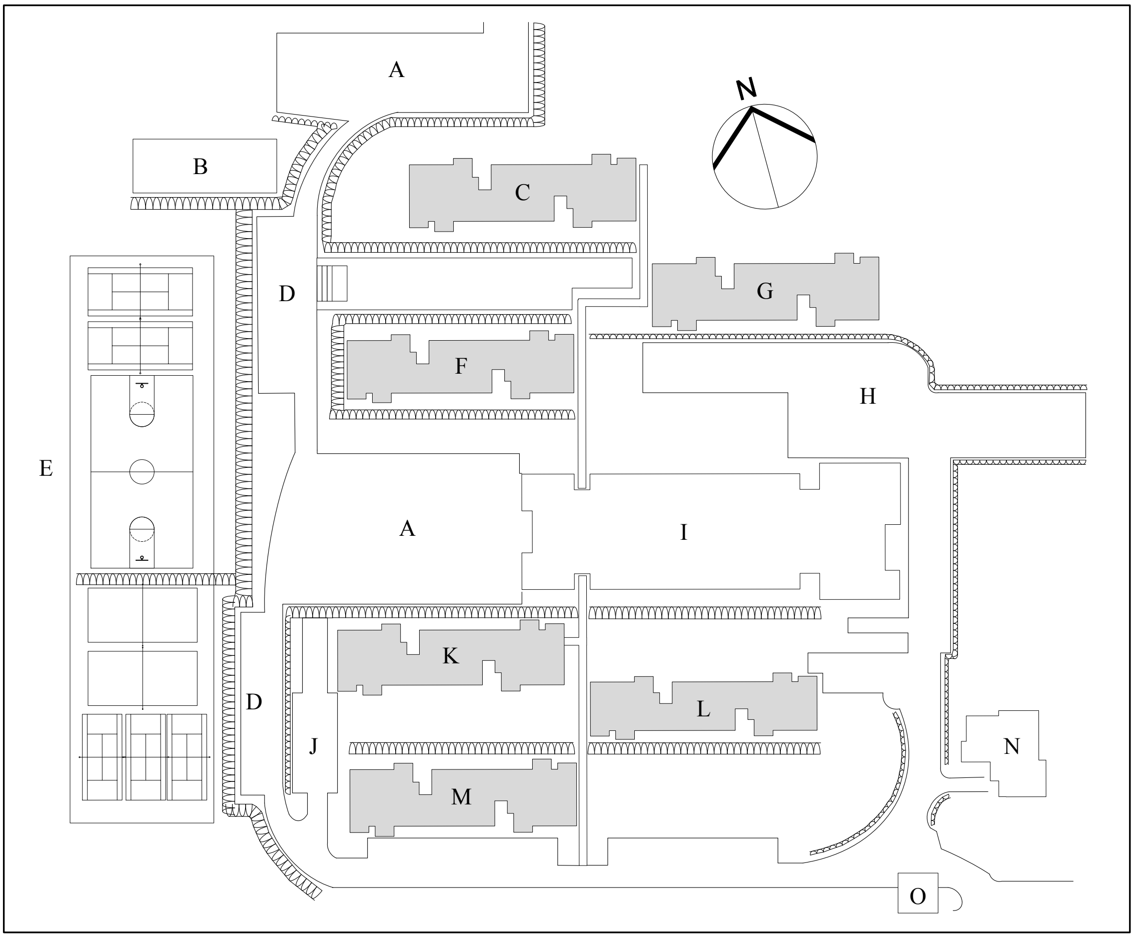
(f)

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design, (c). Large horizontal overhangs and vertical wing walls along the wall with windows, (d). (e). Open ended corridor with adjustable opening devices (door), no transom/fixed opening over the doorway of residential unit, (f). An open staircase area at the end of the corridor - creates wind pressure effects.

Figure 4.26: Internal system and characteristic of 8th RC

Table 4.9: Internal system and characteristic of 9th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.25]
	ORIENTATION TO SUN PATH	N - S [Fig. 4.25]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.26]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.25]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	36,858.00
	TOTAL BUILT UP AREA (m^2)	17,451.85
	TOTAL FLOOR AREA (m^2)	22,288.14
	CAPACITY	1,001
	DENSITY (capacity/total floor area)	0.045
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	1 : 99
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	4.15 x 3.88 x 2.91 
	TYPICAL ROOM'S FLOOR AREA (m^2)	16.10
	TYPICAL ROOM VOLUME (m^3)	46.86
	TYPICAL OF CORRIDOR WIDTH (m)	1.65
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.27(a)]
	WINDOW AREA (m^2)	0.82
	WINDOW TO WALL RATIO	0.07
	OPERABLE WINDOW AREA (m^2)	1.82
	OPERABLE WINDOW TO WALL RATIO	0.07
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.27(b)]
	LOCATION	N - S [Fig. 4.25 & 4.26]
SOLAR CONTROL DEVICES		Wide horizontal awning along the wall with windows (1st to 3rd floor), horizontal overhangs along the wall with windows (ground floor) & corridor opening at the middle of the building at each level [Fig. 4.27(c)] Deep recesses
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.27(b) & (c)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.27(b)] High-level adjustable horizontal exhaust opening [Fig. 4.27(b)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	53 : 47 (19,406.15 m^2 : 17,451.85 m^2)
OTHERS	CORRIDOR	Closed corridor with fixed opening at the end and middle of corridor [Fig. 4.27(d)]
	STAIRCASE AREA	A closed staircase area with adjustable & fixed opening devices [Fig. 4.27(e)]
ARCHITECT		Hijjas Kasturi Associates Sdn. Bhd.
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		1995



Legend

Sloping edge Residential block

A - Parking lots/Multipurpose open area, B - Cafeteria, C - Residential block (Block Sri Seroja/Female), D - Parking lots, E - Court/Sport area/Multipurpose open area, F - Residential block (Block Sri Melor/ Female), G - Residential block (Block Sri Cempaka/Female), H - Covered parking lots, Parking lots/ Multipurpose open area, I - Administrative block/Office, Lobby, Dining hall, Kitchen, Multipurpose hall, Student activity centre, Prayer room/Musollah, J - Covered parking lots/Parking lots, K - Residential block (Block Sri Bakawali/Male), L - Residential block (Block Sri Worawari/Male), M - Residential block (Block Sri Kemboja/Male), N - Principal unit, O - Guard post/Main entrance

Figure 4.27: Site plan of 9th RC

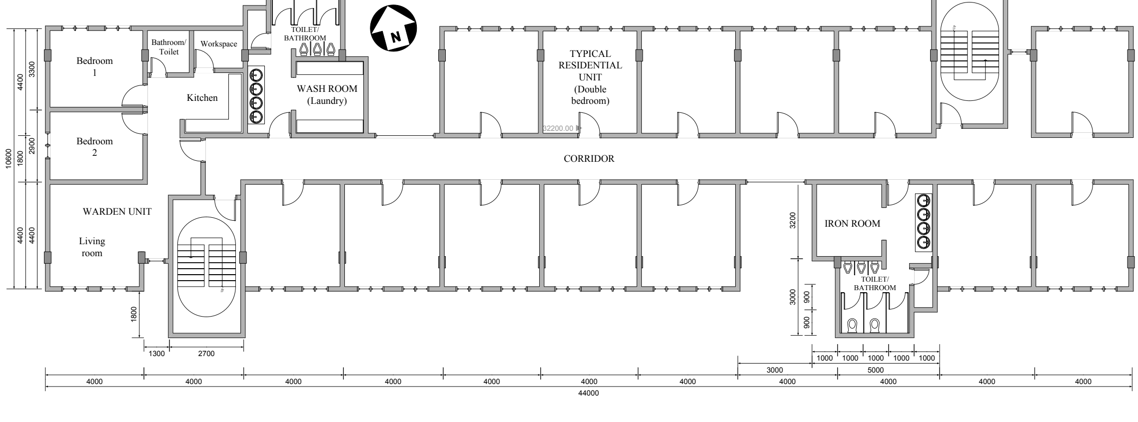
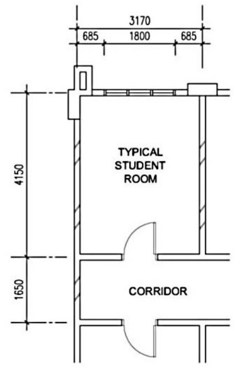


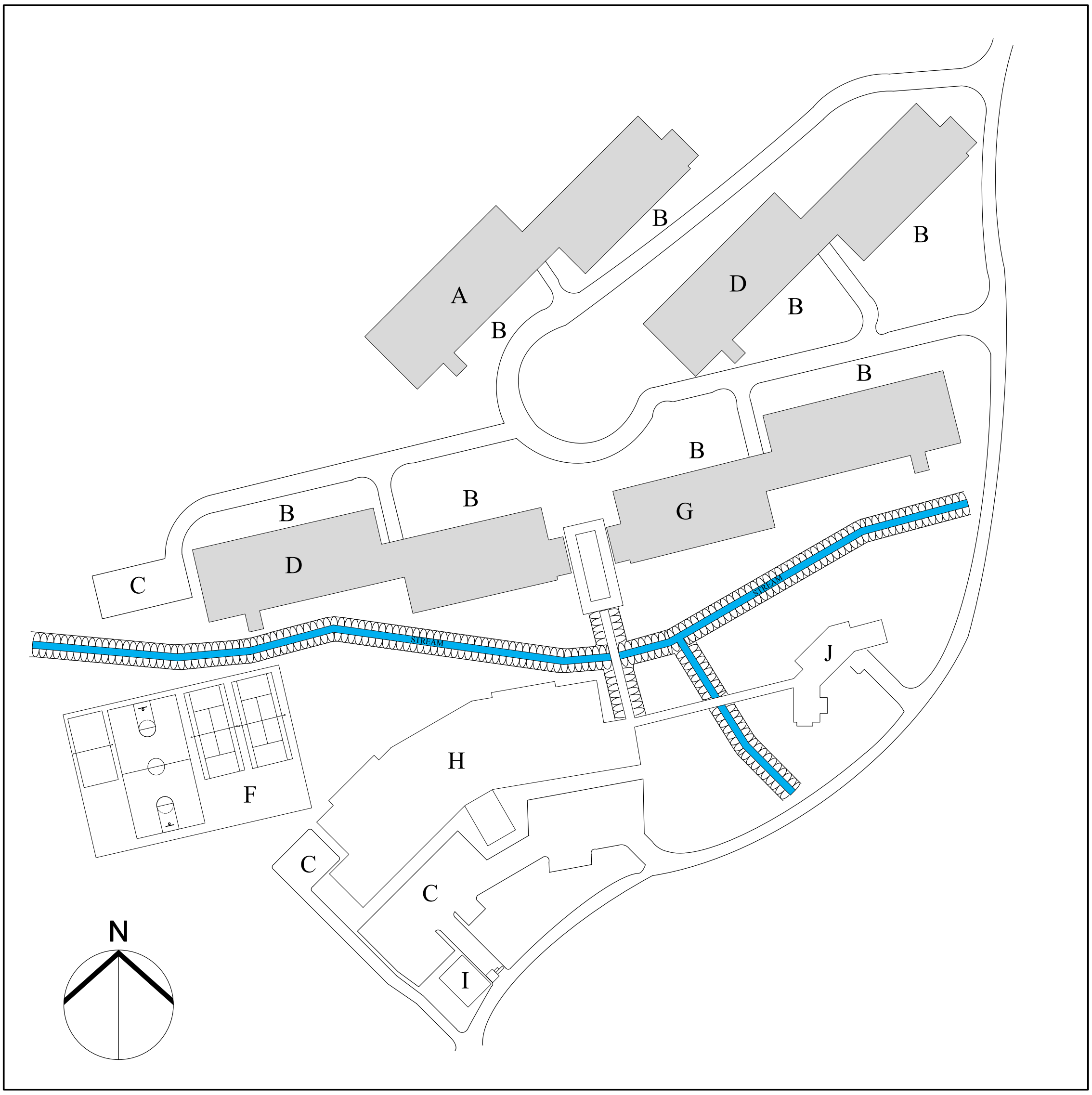
Figure 4.28: Typical floor plan of 9th RC

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design with high level adjustable exhaust opening and articulated light shelves, (c). Wide horizontal awnings and overhangs along the wall with windows, (d). Open corridor in the middle of buildings in each level, no transom/fixed opening over the doorway of residential unit, (e). Open staircase area (view from inside and outside) - creates wind pressure effects.

Figure 4.29: Internal system and characteristic of 9th RC

Table 4.10: Internal system and characteristic of 10th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.28]
	ORIENTATION TO SUN PATH	N - S & NW - SE [Fig. 4.28]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.29, 4.30 & 4.31]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Different altitude [Fig. 4.28]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	24,751.08
	TOTAL BUILT UP AREA (m^2)	7,224.38
	TOTAL FLOOR AREA (m^2)	15,217.02
	CAPACITY	747
	DENSITY (capacity/total floor area)	0.049
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	3 : 97
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	4.15 x 3.17 x 3.0 
	TYPICAL ROOM'S FLOOR AREA (m^2)	13.16
	TYPICAL ROOM VOLUME (m^3)	39.47
	TYPICAL OF CORRIDOR WIDTH (m)	1.65
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.32(a)]
	WINDOW AREA (m^2)	2.52
	WINDOW TO WALL RATIO	0.26
	OPERABLE WINDOW AREA (m^2)	2.52
	OPERABLE WINDOW TO WALL RATIO	0.26
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.32(b)]
	LOCATION	N - S & NW - SE [Fig. 4.28, 4.29, 4.30 & 4.31]
SOLAR CONTROL DEVICES		Balconies at 3rd floor, open corridor at 4th floor & a corridor opening at the middle of the building at each level [Fig. 4.32(c)] Deep recesses
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.32(b)] Balconies/veranda at 3rd floor [Fig. 4.32(c)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.32(b)] High-level adjustable exhaust opening [Fig. 4.32(c)] Low-level fixed inlets (3rd floor only) [Fig. 4.32(c)] Open corridor at the 3rd floor and balcony at 2nd floor [Fig. 4.32(c)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	71 : 29 (17,526.70 m^2 : 7,224.38 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable & fixed opening devices at the end of corridor (ground 1st & 2nd floor), while open corridor at 3rd floor. [Fig. 4.32(c) & (d)]
	STAIRCASE AREA	Open staircase area [Fig. 4.32(e)]
ARCHITECT		Hijjas Kasturi Associates Sdn. Bhd.
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		1997

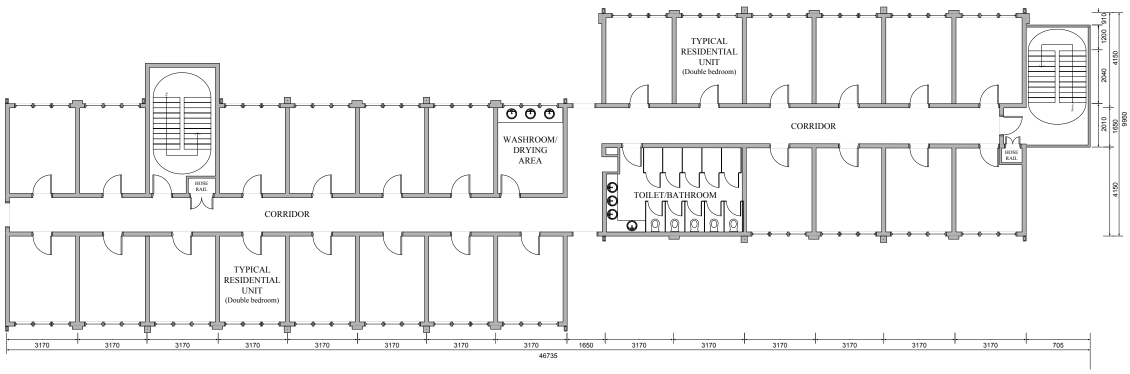


Legend

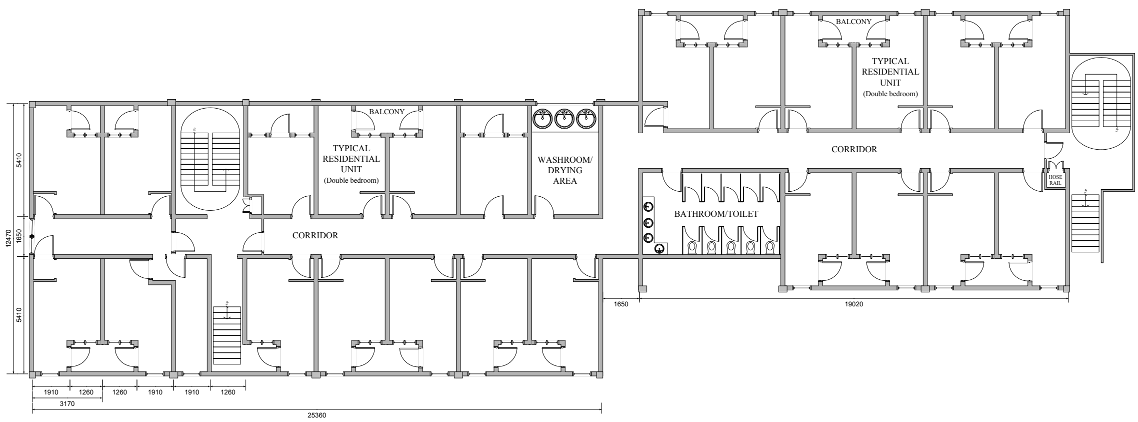
Sloping edge   Residential block

A - Residential block (Kenyalang 2/Female), B - Covered parking lots for motorcycle, C - Parking lots/Multipurpose open area, D - Residential block (Santubong 2/Male), E - Residential block (Santubong 1/Female), F - Court/Sport area/Multipurpose open area, G - Residential block (Kenyalang 1/Female), H - Administrative block/Office, Lobby, Students activity centre, Cafeteria, Multipurpose hall, Musollah/ Prayer room, I - Guard post/Main entrance, J - Principal unit.

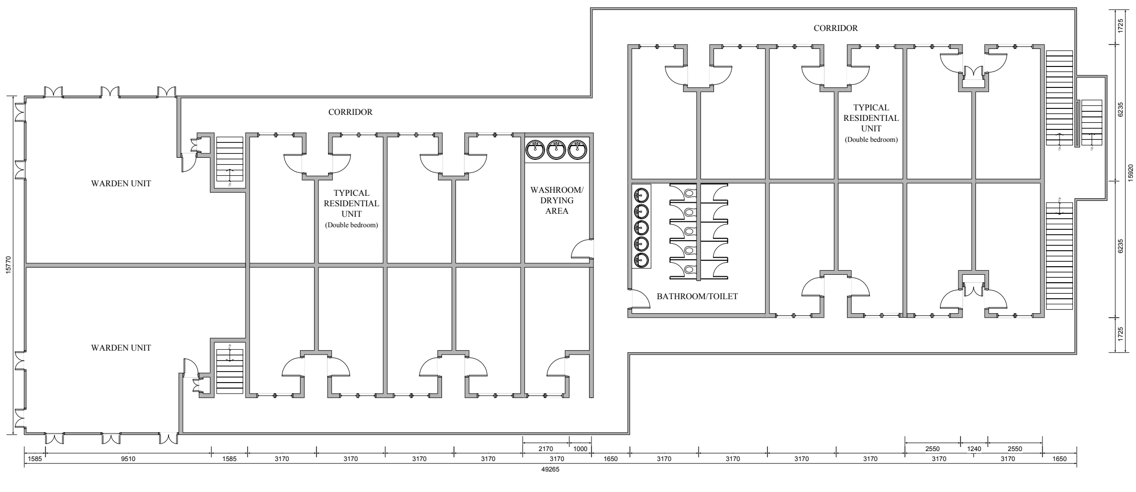
Figure 4.30: Site plan of 10th RC



Ground level and Level 1



Level 2



Level 3

Figure 4.31: Typical floor plan of 10th RC

(a)

(b)

(d)

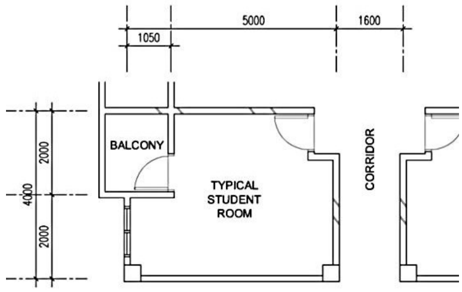
(c)

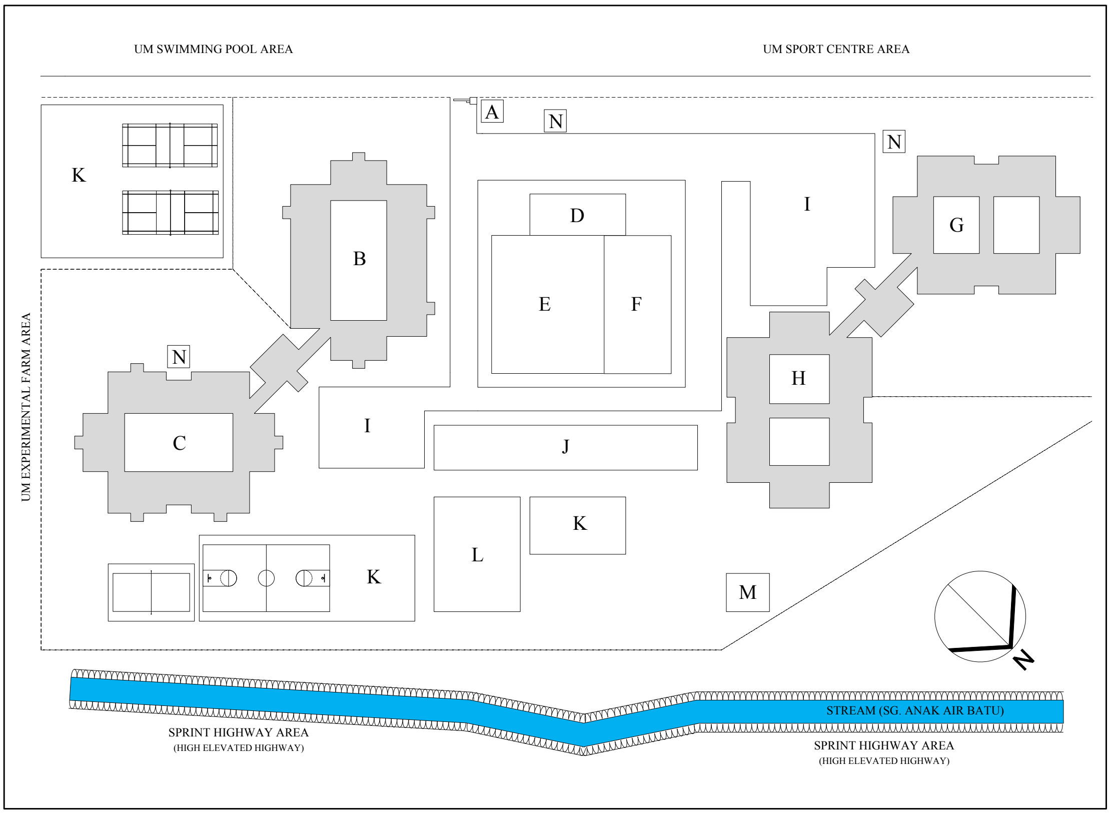
(e)

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design with fixed and adjustable high level exhaust opening, (c). Wide horizontal awnings and overhangs along the wall with windows, Different design or residential unit at different levels; *Ground floor & 1st floor - window opening, 2nd floor – window opening, balcony, low level fixed inlets and high level fixed exhaust opening, 3rd floor - window opening, balcony, low level fixed inlets, high level fixed exhaust opening and open corridor*, (d). Closed corridor with adjustable & fixed opening devices at the end of corridor, no transom/fixed opening over the doorway of residential unit, (e). Open staircase area

Figure 4.32: Internal system and characteristic of 10^{th} RC

Table 4.11: Internal system and characteristic of 11th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	Low-rise
	BUILDING LAYOUT	Courtyard arrangement [Fig. 4.33]
	ORIENTATION TO SUN PATH	N - S & W - E [Fig. 4.33]
	SHAPE OF THE BUILDING'S FLOOR PLATE	L-shape [Fig. 4.34]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Same altitude [Fig. 4.33]
	FLOOR LEVEL (excluding GF)	3
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	26,766.14
	TOTAL BUILT UP AREA (m^2)	11,250.44
	TOTAL FLOOR AREA (m^2)	34,305.32
	CAPACITY	897
	DENSITY (capacity/total floor area)	0.026
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	1 : 99
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	5.0 x 4.0 x 2.87 
	TYPICAL ROOM'S FLOOR AREA (m^2)	20.00
	TYPICAL ROOM VOLUME (m^3)	57.40
	TYPICAL OF CORRIDOR WIDTH (m)	1.60
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.35(a)]
	WINDOW AREA (m^2)	Type A : 1.65 / Type B : 4.12
	WINDOW TO WALL RATIO	Type A : 0.14 / Type B : 0.36
	OPERABLE WINDOW AREA (m^2)	Type A : 1.10 / Type B : 2.75
	OPERABLE WINDOW TO WALL RATIO	Type A : 0.1 / Type B : 0.24
	WINDOW DESIGN	Casement window [Fig. 4.35(b) & (c)]
	LOCATION	N - S & W - E [Fig. 4.33 & 4.34]
SOLAR CONTROL DEVICES		Tinted window glass [Fig. 4.35(b) & 4.35(c)]
		Balconies/veranda [Fig. 4.35(b)]
		Deep recesses
		Sky courts/ Internal courtyard [Fig. 4.35(d)]
PASSIVE DAYLIGHT CONCEPTS		Balconies/veranda [Fig. 4.35(b)]
		Sky courts/ Internal courtyard [Fig. 4.35(d)]
WIND AND NATURAL VENTILATION		Window opening (with vertical adjustable or closing devices to assist in channelling the air flow) [Fig. 4.35(b) & (c)]
		Large balcony (2.1m^2) & facing to the outside area in each living unit [Fig. 4.35(a) & (b)]
		Large open corridor & facing to an internal courtyard [Fig. 4.35(d)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	58 :42 (15,515.70 m^2 : 11,250.44 m^2)
OTHERS	CORRIDOR	Open corridor (facing to internal courtyard) [Fig. 4.35(d)]
	STAIRCASE AREA	Open staircase area [Fig. 4.35(e)]
ARCHITECT		AbRAZ Arkitek
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		1997

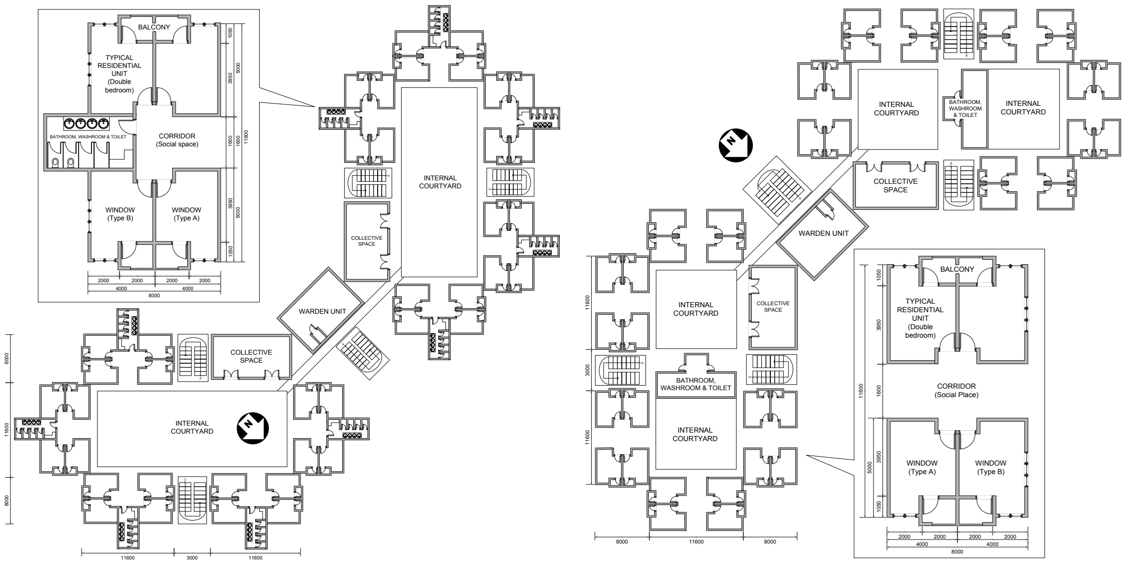


Legend

Sloping edge Residential block

A - Guard post/Main entrance, B - Residential block (Block A - Awana/Female), C - Residential block (Block B - Bayu/Male), D - Administrative block/Office, E - Hall/Student activity centre, F - Student activity centre, G - Residential block (Block C - Flora/Female), H - Residential block (Block D - Impiana/Male), I - Parking lots/Multipurpose open area, J - Cafeteria/Food court, K - Court/Sport area/Multipurpose open area, L - Covered parking lots, M - Store, N - Wakaf/Hut.

Figure 4.33: Site plan of 11th RC



Block A and Block B

Block C and Block D

Figure 4.34: Typical floor plan of 11th RC

(a)

(d)

(b)

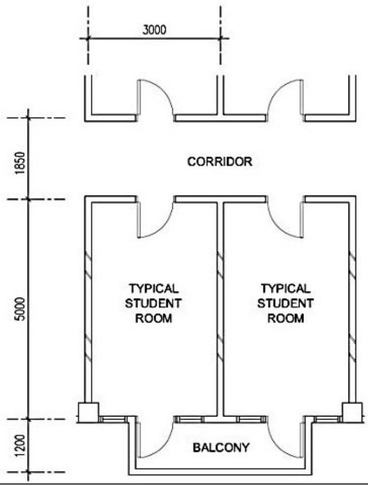
(e)

(c)

(a). Built-form configuration, enclosure and facade design, (b). Casement window design with tinted glass; Large balcony in each residential unit faces to outside areas, (c). Wall opening - create wind pressure in the cubicle, (d). Open corridors face the internal courtyard with lightly vegetated, no transom/fixed opening over the doorway of residential unit (small picture in the box), (e). Open staircase area (view from inside and outside) - creates wind pressure effects.

Figure 4.35: Internal system and characteristic of 11th RC

Table 4.12: Internal system and characteristic of 12th RC

INTERNAL SYSTEMS	CHARACTERISTIC	
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING & FEATURES	FORM OF BUILDING	High-rise
	BUILDING LAYOUT	Linear arrangement [Fig. 4.36]
	ORIENTATION TO SUN PATH	N - S [Fig. 4.36]
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle [Fig. 4.37]
	WIND DIRECTION OF THE LOCALITY	SW
	BUILDING LOCATION ON THE GROUND	Same altitude [Fig. 4.36]
	FLOOR LEVEL (excluding GF)	9
	TOTAL RESIDENTIAL COLLEGE AREA (m^2)	46,415.84
	TOTAL BUILT UP AREA (m^2)	30,724.87
	TOTAL FLOOR AREA (m^2)	89,545.91
	CAPACITY	2,990
	DENSITY (capacity/total floor area)	0.033
	RATIO OF AIR CONDITIONED & NON AIR CONDITIONED AREA	0.3 : 99.7
TYPICAL STUDENT ROOM – FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	5.0 x 3.0 x 3.0 
	TYPICAL ROOM'S FLOOR AREA (m^2)	15.00
	TYPICAL ROOM VOLUME (m^3)	45.00
	TYPICAL OF CORRIDOR WIDTH (m)	1.85
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option [Fig. 4.38(a)]
	WINDOW AREA (m^2)	2.9
	WINDOW TO WALL RATIO	0.32
	OPERABLE WINDOW AREA (m^2)	0.95
	OPERABLE WINDOW TO WAL RATIO	0.11
	WINDOW DESIGN	Louver window/Jalousie [Fig. 4.38(b)]
	LOCATION	N - S [Fig. 4.36 & 4.37]
SOLAR CONTROL DEVICES		Balconies/veranda [Fig. 4.38(b)] Deep recesses
PASSIVE DAYLIGHT CONCEPTS		Articulated light shelves [Fig. 4.38(b)] Balconies/veranda [Fig. 4.38(b)]
WIND AND NATURAL VENTILATION		Window opening (with horizontal adjustable or closing devices to assist in channelling the air flow) [Fig. 4.38(a) & (b)] High-level fixed horizontal exhaust opening [Fig. 4.38(b)] Large balcony & facing to the outside area in each living unit [Fig. 4.38(b)]
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	34 : 66 (15,690.97 m^2 : 30,724.87 m^2)
OTHERS	CORRIDOR	Closed corridor with adjustable opening devices at the end and middle of corridor [Fig. 4.38(c), 4.38(d)]
	STAIRCASE AREA	Open staircase area [Fig. 4.38(e)]
ARCHITECT		Zull.G.Architect
PHASE OF CONSTRUCTION		One phase
YEAR ESTABLISHED		2002

Legend

Sloping edge   Residential block

A - Guard post/Main entrance, B - Parking lots/Multipurpose open area, C - Court/Sport area/ Multipurpose open area, D - Centralize dust bin, E - Residential block (Block D/Female), F - Residential block (Block C/Female), G - Open stage/Student activity centre, H – Café, I - Administrative block/ Office, Lobby, Multipurpose hall, Student activity centre, J - Cafeteria/Food court, K - Pond, L - Principal unit, M - Residential block (Block B/Male), N - Residential block (Block A/Male).

Figure 4.36: Site plan of 12th RC

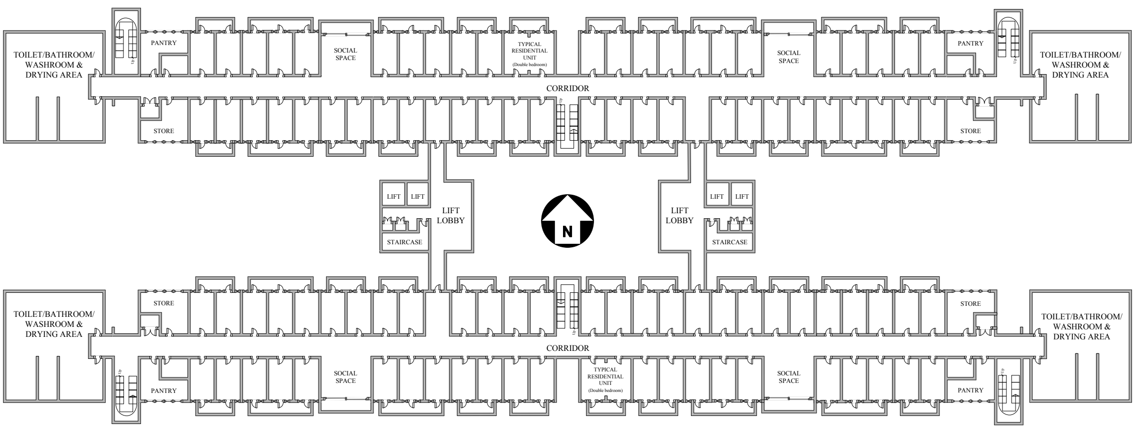


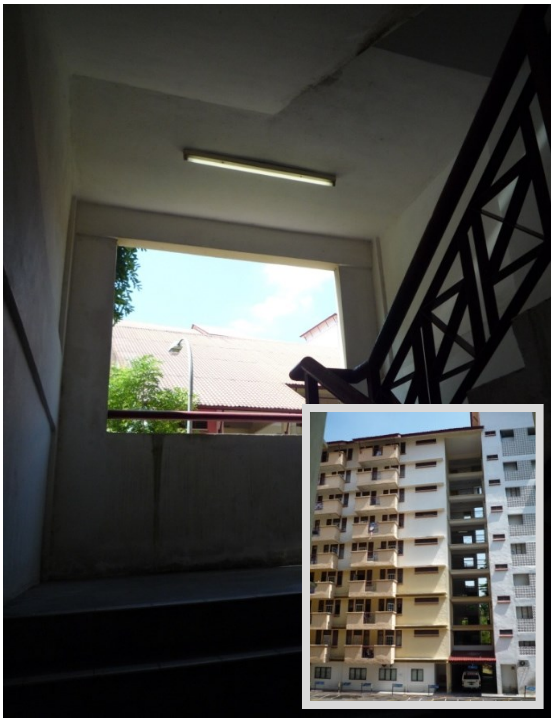
Figure 4.37: Typical floor plan of 12th RC

(a)

(b)

(c)

(d)



(e)

(a). Built-form configuration, enclosure and facade design, (b). Louver window/Jalousie window design with fixed high level exhaust opening and articulated light shelves; large shared balcony in each residential unit faces outside area (c). A large open area with an adjustable sliding door in the middle of buildings (view from inside and outside), (d). Closed corridor with adjustable opening devices at the end and middle of corridor; no transom/fixed opening over the doorway of residential unit (small picture in the box), (e). Open staircase area - create wind pressure (view from inside and outside).

Figure 4.38: Internal system and characteristic of 12^{th} RC

4.2 The efficiency of electricity use and prospective of energy conservation

4.2.1 Energy consumption of UM residential colleges

The monthly and annual mean of electricity consumption, including efficiency of electricity usage in terms of Energy Efficiency Index - EEI (kWh/m^2/year) of the twelve residential colleges (RC) for five years duration, from 2005 to 2009 are presented in Table 4.13. The complete calculations can be referred in *Appendix R - EEI of the UM residential college for 2005-2009*.

Table 4.13: The electricity consumption and efficiency of usage at twelve residential colleges for five years duration (2005-2009)

Residential college	**TFA (m^2)**	**Capacity/No. Of residents**	**The electricity consumption and efficiency of usage for five years duration (2005-2009)**			
			Monthly mean (kWh)	**Annual mean (kWh)**	**kWh/person/year**	**EEI (kWh/m^2/year)**
1st RC	12,727.44	816	64,102	769,230	942.68	60.439
2nd RC	11,224.71	611	57,803	693,631	1135.24	61.795
3rd RC	7,159.92	765	74,547	894,560	1169.36	124.940
4th RC	11,427.67	705	61,307	735,679	1043.52	54.006
5th RC	18,212.51	885	49,956	599,473	677.37	32.915
6th RC	21,148.03	630	74,612	895,339	1421.17	42.337
7th RC	12,989.87	798	58,068	696,818	873.21	53.643
8th RC	11,274.23	694	78,884	946,610	1363.99	83.962
9th RC	22,288.14	1001	79,304	951,643	950.69	42.697
10th RC	15,217.02	747	60,723	728,678	975.47	47.886
11th RC	34,305.32	897	69,282	831,378	926.84	24.235
12th RC	89,545.91	2990	203,738	2,444,858	817.68	27.308

Abbreviations:
- TFA - Total Floor Area (m^2)
- EEI - Energy Efficiency Index (kWh/m^2/year)

Regarding various occupancy densities of the buildings studied (*Appendix S - Comparison of twelve residential buildings particularly in the characteristic of a typical student room, building design and adaptation of bioclimatic design concepts*), the annual electricity consumption has been also normalized by the number of people, as a validation of the EEI. By comparing both; kWh/m^2/year and kWh/person/year, as presented in Table 4.13, the trend of electricity consumption at the twelve residential colleges would obviously be different and unacceptable.

Therefore, energy intensity should be normalized by the floor area (Kamaruzzaman & Edwards, 2006) instead of the number of people where this can be influenced by uncontrolled variables, such as human behaviours. Through the EEI ranking, the 11th RC leads the list with the lowest electricity consumption of 24.235 kWh/m^2/year, while the 3rd RC ranked last in the list due to the highest electricity consumption, reaching 124.940 kWh/m^2/year. The ranking of the EEI values of other residential colleges shows the efficiency of electricity usage in the following order: 11th RC>12th RC>5th RC>6th RC>9th RC>10th RC>7th RC>1st RC>2nd RC>4th RC>8th RC>3rd RC.

Referring to the EEI ranking, the residential colleges with different features of building layout and arrangement, such as a courtyard arrangement with balconies like at the 11th RC, linear arrangement with balconies at the 12th RC and courtyard arrangement at the 5th RC lead the list on the efficiency of electricity usage. Vice versa, buildings built with a linear arrangement showed non efficient electricity usage with higher electricity consumption. This is attributed to their need of having fluorescent lamps switched on continuously in corridors and staircases, even during day time. This situation has been identified at the 1st RC, 2nd RC, 3rd RC, 4th RC, 6th RC, 7th RC, 8th RC, and for certain levels/floors at 10th RC. With open corridors in the centre of the buildings in each level that allows daylight to penetrate into the building, the 9th RC is fifth in the rank.

Increase of both window to wall ratio (WWR) and operable window to wall ratio at the 9th RC, which is the smallest among the residential colleges, is expected improve the situation and significantly reduce the electricity consumption from usage of artificial lighting in the rooms. This has been successfully demonstrated by the 5th RC, which was designed with the largest WWR. A small WWR of a room will force occupants to switch on the light even during day time to obtain visual comfort (Nicol & Humphreys, 2002).

In contrast, the 5th RC and 11th RC, which are built with an internal courtyard arrangement, it does not require fluorescent lamps in the corridor and staircase area to be switched on during daytime. The transoms/fixed opening on the top of the entrance door and wall of each room at the 5th RC was found to be ideal in providing air circulation and daylight of the room interior. As for the 11th RC and 12th RC, balconies designed at each room helps to enhance natural ventilation and day lighting, while at the same time allowing the occupants to control the level of thermal and visual comfort in a natural way.

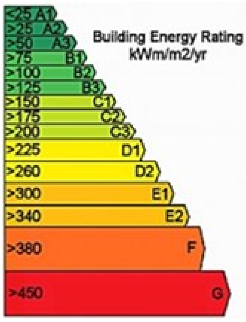
According to Yeang (2008), the use of excessive daylight leads to negative effect which include glare and heat gain inside the building. This implies more cooling demand in the summer. Though, Malaysia is located in the equatorial region; the hot, humid and cloudy with dull grey sky conditions cause heat and glare problems (Fadzil & Sia, 2004; Zain-Ahmed et al., 2002a). Thus, the use of artificial lighting and air conditioning are seen as a solution to overcome heat gain from daylighting. Unfortunately, at the same illumination level, daylight is cooler than electric lighting even though light is a form of radiant energy which is eventually absorbed and turned into heat. These have been explained more by Mahlia et al. (2005) where in an incandescent lamp, electricity heats up a wire filament causing it to glow and give light where 90% of the energy produced is heat not light. As mentioned by Lechner (2009), incandescent lamps introduce about six times more heat than day lighting compared to fluorescent lamps which is about two times more heat than daylighting for 60 lumens/watt of fluorescent lamp, and 120 lumens/watt of daylighting respectively. From a computer simulation; DOE-2.1E, Li et al. (2005) it was found that the application of daylighting was able to reduce the maximum cooling plant load and building electrical demand for the base case model by 5% and 9.3% respectively.

Besides, window design also influences the electricity consumption in terms of cooling (Soebarto & Ribeiro, 2008). The centre pivot and awning window at the 5^{th} RC, and the casement and turn window at the 11th RC, indirectly help residents to channel wind into the room, although the opening locations do not correspond to the wind direction. Furthermore, with the biggest room area ($20.0m^2$) and volume ($57.4m^2$) at 11^{th} RC, the indoor air circulation is drastically increased. Thus, natural ventilation can be fully optimized and directly reduces the cooling load for the buildings (Candido et al., 2010). In contrast to this, the 3^{rd} RC with the highest population density of 0.107 per m^2 (Table 4.3) has a building design which hinders the optimization of daylight and natural ventilation, even though this building has the biggest operable window area ($5.76m^2$) and operable WWR (0.53). The same situation is also encountered at the 4^{th} RC and the 8^{th} RC, where the building's opening to the wind direction denies the optimization of daylight and natural ventilation, particularly in the corridor area.

According to Iwaro and Mwasha (2010), energy use in residential buildings is usually 10 to 20 times lower compared to office buildings. Thus, the electricity usage in residential buildings in Malaysia amounts to approximately 10 to 25 kWh/m^2/year if the electricity use in office buildings in Malaysia is in the range of 200 to 250 kWh/ m^2/year (Chan, 2009a). Agreeing to this assumption, only the 11^{th} RC is below the range, 24.235 kWh/m^2/year, while none of the residential colleges are beyond the MS1525:2011 standard, 130 kWh/ m^2/year (Table 4.14). However, this standard is only applied for non-residential buildings and there is no standard or benchmark specifically for residential buildings in Malaysia.

By making comparisons between all of the residential colleges based on their EEI and an established international building energy rating system (Sustainable Energy Authority of Ireland, 2012) which are implemented in Ireland and widely used by other countries in Europe, only the 11^{th} RC rated as the most efficient building (Table 4.14).

Table 4.14: Comparison between EEI of residential college buildings and established international building energy rating system – SEAI and BBC 2005

EEI (kWh/m^2/year) of UM RC		Sustainable Energy Authority of Ireland (SEAI)		BBC 2005- Bâtiment de basse consommation énergétique (France Low-energy house).	
1st RC	60.44	A3	**MOST EFFICIENCT**	B	**MOST EFFICIENCT**
2nd RC	61.80	A3		B	
3rd RC	124.94	B2		C	
4th RC	64.38	A3		B	
5th RC	34.52	A2		A	
6th RC	42.34	A2		A	
7th RC	53.64	A3		B	
8th RC	83.96	B1		B	
9th RC	42.70	A2		A	
10th RC	47.89	A2		A	
11th RC	24.24	A1		A	
12th RC	27.31	A2	**LEAST EFFICIENT**	A	**LEAST EFFICIENT**

Source: Sustainable Energy Authority of Ireland (2012); Concept BIO (2008)

Vice versa, the 3rd RC rated B3 is the least efficient among the twelve residential colleges, while others were rated either as A2, A3 or B1. This is different to BBC-2005 (Concept BIO, 2008), a rating system which is more stringent where the residential colleges which were rated as A3 under SEAI rating system was rated B. Then the 3rd RC which is the least efficient building was rated C.

The use of these two energy rating system for the comparison purpose due to the basis of benchmarking approach that based on kWh/m^2/year. As compared with other established energy rating systems, the building's elements and features that have an impact on the energy performance such as wall, roofs, floor, windows etc. are also involved (Chartered Institution of Building Services Engineers, 2014; ASHRAE, 2012), which obviously were not considered in this calculation.

4.2.2 The prospective of energy conservation

To find out the prospect of energy conservation, the total savings of electricity in residential colleges were identified through the difference between the average total energy use in a year (kWh) and the minimum electricity usage of the residential college using two different calculations.

With regards to the second method of calculating the minimum electricity usage of the residential colleges, first of all, basic M&E equipment is listed according to the building and area as shown in Table 4.15.

Table 4.15: Estimation electricity usage by each M&E based on regular usage and services offered at all residential college buildings

Building	Area	M&E	Watts	Hour/ Week	Week/ Year	Energy Used (kWh/year)
Residential blocks	Room	Fluorescent light	30	42.0	52	65.52
		Study light	30	28.0	52	43.68
		Fan	70	105.0	52	382.20
	Toilet	Fluorescent light	30	84.0	52	131.04
	Corridor	Fluorescent light	30	84.0	52	131.04
	Student activity centre	Fluorescent light	30	35.0	52	54.60
		Fan	70	35.0	52	127.40
		Air conditioning	750	35.0	52	1365.00
	Warden unit	Fluorescent light	30	35.0	52	54.60
		Fan	70	35.0	52	127.40
		Air conditioning	750	35.0	52	1365.00
	Covered parking lots	Fluorescent light	30	84.0	52	131.04
Administration	Office	Fluorescent light	30	42.0	52	65.52
		Fan	70	42.0	52	152.88
		Air conditioning	750	42.0	52	1638.00
	Toilet	Fluorescent light	30	84.0	52	131.04
	Meeting room	Fluorescent light	30	49.0	52	76.44
		Fan	70	49.0	52	178.36
		Air conditioning	750	49.0	52	1911.00
	Corridor	Fluorescent light	30	168.0	52	262.08
	Covered parking lots	Fluorescent light	30	84.0	52	131.04
	Lobby	Fluorescent light	30	84.0	52	131.04
		Fan	70	84.0	52	305.76
Hall	Main area	Fluorescent light	30	49.0	52	76.44
		Fan	70	49.0	52	178.36
		Air conditioning	750	49.0	52	1911.00
	Corridor	Fluorescent light	30	49.0	52	76.44
Dining hall & kitchen	Main area	Fluorescent light	30	168.0	52	262.08
		Fan	70	168.0	52	611.52
	Corridor	Fluorescent light	30	84.0	52	131.04
Café & kitchen	Main area	Fluorescent light	30	119.0	52	185.64
		Fan	70	119.0	52	433.16
	Corridor	Fluorescent light	30	84.0	52	131.04
Principal house	Main area	Fluorescent light	30	42.0	52	65.52
		Fan	70	105.0	52	382.20
		Air conditioning	750	56.0	52	2184.00
	Corridor	Fluorescent light	30	84.0	52	131.04
Musolla	Prayer hall	Fluorescent light	30	17.5	52	27.30
		Fan	70	17.5	52	63.70
		Air conditioning	750	17.5	52	682.50
	Corridor	Fluorescent light	30	84.0	52	131.04
Miscellaneous	Main area	Fluorescent light	30	35.0	52	54.60
		Fan	70	35.0	52	127.40
		Air conditioning	750	35.0	52	1365.00
	Corridor	Fluorescent light	30	35.0	52	46.80

The fluorescent lights and fans were identified as two of the major basic M&E appliances at the residential colleges, and the wattage of each appliance was adapted from Saidur et al. (2007). The usage duration of each M&E unit was calculated considering the main student activities, which include attending lectures and classes at the faculties during day time and other activities during the weekends. For the administrative offices, the usage duration was based on normal working hours which is 9 a.m. to 5 p.m. during weekdays, while other areas were calculated based on regular usage by residents and staffs as well as services offered. The number of M&E units from the inventory list supplied by the administration and walk-through survey of all twelve residential colleges was multiplied with the energy used in kWh unit for a year, which was estimated and listed in the last column of Table 4.15. Thus, the minimum annual electricity usage of each residential college was derived from the sum of annual usage of all basic M&E appliances as presented in column 6 of Table 4.16.

Table 4.16: The potential of electricity saving at residential colleges

Residential College	Average electricity usage (kWh) for 2005-2009	Estimation of electricity savings					
		1st calculation : TFA x 10kWh/m^2/year			2nd calculation : The inventory of basic M&E x minimum electricity usage by each M&E annually (Table 4.15)		
		Minimum electricity usage (kWh/year)	Potential of electricity saving (kWh/year)	% of electricity saving	Minimum electricity usage (kWh/year)	Potential of electricity saving (kWh/year)	% of electricity saving
1st RC	769,230.00	127,274.40	641,955.60	83.45	362,908.00	406,322.00	52.82
2nd RC	693,631.00	112,247.10	581,383.90	83.82	290,020.64	403,610.36	58.19
3rd RC	894,560.00	71,599.20	822,960.80	92.00	251,036.24	643,523.76	71.94
4th RC	735,679.00	114,276.70	621,402.30	84.47	260,540.28	475,138.72	64.59
5th RC	599,473.00	182,125.10	417,347.90	69.62	359,897.72	239,575.28	39.96
6th RC	895,339.00	211,480.30	683,858.70	76.38	506,214.80	389,124.20	43.46
7th RC	696,818.00	129,898.70	566,919.30	81.36	439,397.14	257,420.86	36.94
8th RC	946,610.00	112,742.30	833,867.70	88.09	525,073.64	421,536.36	44.53
9th RC	951,643.00	222,881.40	728,761.60	76.58	425,343.10	526,299.90	55.30
10th RC	728,678.00	152,170.20	576,507.80	79.12	303,368.52	425,309.48	58.37
11th RC	831,378.00	343,053.20	488,324.80	58.74	370,377.28	461,000.72	55.45
12th RC	2,444,858.00	895,459.10	1,549,398.90	63.37	1,223,993.68	1,220,864.32	49.94

The sum potential of electricity saving for all twelve residential colleges, which were estimated by calculating the difference between average total energy use in a year (kWh) and minimum electricity usage, by the multiplication of TFA with 10kWh/m^2/year and basic M&E inventory, are presented in Table 4.16.

The first calculation revealed a higher percentage of electricity saving potential, exceeding 92% compared to the second calculation which only exceeds 71.94%. The residential colleges with higher EEI will also have a higher percentage of electricity saving respectively.

By taking both first and second calculations into consideration, electricity use of the residential colleges could be reduced to by about 37% to 92% annually. In the 3rd RC, which was identified as the highest annual user of electricity, there is also the highest potential for electricity saving in the range of 70% to 92%, followed by 4th RC with more than 60%. Whilst the 1st RC, 2nd RC, 7th RC and 8th RC were calculated to have the electricity saving potential of more than 80% which indirectly shows unnecessary electricity wastage. Although ranked as the lowest electricity consumer among the twelve residential colleges with 24.235kWh/m^2/year, there is still a big potential for electricity saving at the 11th RC, exceeding 55.45%, as a result of the calculations of the basic M&E inventory list and 58.74% of the first calculation. Higher percentages of electricity saving potential are also deduced from the calculations of the basic M&E inventory lists at 1st RC, 2nd RC, 3rd RC, 4th RC, 9th RC and 10th RC; where the percentages of electricity saving are more than 50%. In contrast the 5th RC, 6th RC, 7th RC, 8th RC and 12th RC reveal a much lower percentage potential for electricity saving.

From the walk through investigation, it was seen that electricity wastage occurs in the corridors and staircase areas, especially at residential colleges with linear arrangement and layout. The fluorescent lamps need to be switched on even during daytime in order to sustain residents' visual comfort.

4.3 Conclusion

The comparison of twelve residential college buildings in University of Malaya particularly on typical student room and building design is presented in *Appendix S - Comparison of twelve residential buildings particularly in the characteristic of a typical student room, building design and adaptation of bioclimatic design concepts.* By ranking all the residential colleges, the residential college buildings with a courtyard arrangement and special features like a balcony / veranda like the 5^{th} RC, 10^{th} RC, 11^{th} RC and 12^{th} RC, lead the list followed by other buildings with linear arrangement. The study shows how the best practice of bioclimatic design strategies was found to be in the following order, 5^{th} RC > 11^{th} RC > 10^{th} RC > 12^{th} RC > 4^{th} RC > 7^{th} RC > 9^{th} RC = 1^{st} RC = 2^{nd} RC = 3^{rd} RC > 6^{th} RC > 8^{th} RC. Thus, the 5^{th} RC was identified to be selected as a case study for further analysis on field investigation and evaluation due to the highest implementation of bioclimatic design concepts particularly on natural ventilation and day lighting in building design.

Additionally, the 5^{th} RC also shows that the largest soft surface area contribute to the high CO_2 stored even when its ratio of soft to hard surface area is smaller compared to other residential colleges. By adopting the estimation of carbon stored by KeTTHA (2011); where 1 hectare of trees stores 2,600 kg or carbon per year, about 6,815.65 kg of carbon are stored at the 5^{th} RC annually. As a natural reservoir, this soft surface area which is dominated by green landscapes is able to remove CO_2 from the atmosphere.

The selection of the 5^{th} RC was quite complicated considering the efficiency of electric use of the 11^{th} RC and 12^{th} RC that also have lower EEI values of 24.235 and 27.308 kWh/m^2/year respectively, compared to the EEI of the 5^{th} RC which indicated 32.915 kWh/m^2/year.

Referring to the analysis on electricity performance as presented in *Appendix R - EEI of the UM residential college for 2005-2009*, the 5th RC is stated to have higher range values of monthly usage that are almost similar to the mean value due to extreme usage of electricity in certain months. Also due to the technical problems of electricity consumption meter which have been reported to occur two times in the year 2005 and 2006. Thus, the median values were referred to when mean values for the performance of electricity consumption meter are far-off from the normal value or regular usage of electricity and do not actually represent the performance of monthly electricity consumption appropriately. By making the comparison of median values among these three residential colleges the 5th RC was found to have the lowest value of EEI (23.909 kWh/m^2/year), which is getting the better of the 11th RC and 12th RC which are stated to be 25.273 kWh/m^2/year and 28.763 kWh/m^2/year respectively. Therefore, the ranking of EEI for a five year duration for the twelve residential colleges based on median value was found to be in the following order, 5th RC > 11th RC > 12th RC > 6th RC > 9th RC > 10th RC > 1st RC > 4th RC > 7th RC > 2nd RC > 8th RC > 3rd RC.

The 5th RC was also recorded as the lowest annual electricity consumer compared to the other residential college which have less number of occupants and total floor area. There are the 1st RC, 2nd RC, 3rd RC, 4th RC, 7th RC, 8th RC and 10th RC which are clearly listed in Table 4.13. Thus, less carbon will be produced annually by the 5th RC, approximately 427,551.36 kg, when 1kWh of electricity used will emit 0.68 kg of CO_2 (KeTTHA, 2011).

As the homogeneity of building design especially in the residential units and the floor plan of the residential college are highly considered, the 10th RC and 11th RC are eliminated due to the need for the same designs to represent the residential college to minimise the uncontrolled variables.

As presented in Figure 4.29 to 4.32, there are different designs of rooms and floor plan at the 10th RC where the rooms on the second level of the residential blocks are designed with balcony and an open corridor on the third level. Whereas the ground level and first level are designed with a closed corridor where each residential unit is facing each other's as presented in Figure 4.29.

The 11th RC is designed with two different floor plans. First, four rooms are joined as one cubicle in Blocks A and B sharing one washroom/bathroom as shown in Figure 4.34(a). Second, the entire floor in Blocks C and D [Figure 4.34(b)] are sharing two big washrooms/bathrooms on every single floor. Additionally, some cubicles have a different orientation to the sun path. Therefore, the dissimilarity of design and layout of the residential college building will increase the number of uncontrolled variables where more equipment is required while the availability and safety of the equipment remains a constrain. Due to the different building forms of the 12th RC it is also eliminated as it is categorised as a high-rise building. As a consequence, the selection of residential units/rooms in representing the whole building for building performance evaluation will be more complicated with higher uncontrolled variables that need to be considered; as well as a great number of equipment for field measurements.

By looking into bioclimatic design aspects, some of the strategies are well adapted in the 12th RC where the presence of balcony facing the outside area provides the occupant control over natural ventilation and day lighting in the residential unit (Figure 4.37 and 4.38). Moreover, the high level of fixed exhaust opening promotes air circulation and daylight distribution when it is also an articulated light shelf. A large open area with an adjustable sliding glass door in the middle of a residential block on each floor lets the daylight in and air circulate inside the corridor area which also gives an impact inside the residential unit.

The presence of fixed opening devices at the bathroom / washroom that are located at the both ends of the building and the open staircase area on each floor enhances the distribution of daylight and air circulation in the corridor area. Unfortunately, the corridor lamps would still need to be continually switched on when these two sections are separated by a door that would be closed recurrently due to security purposes.

As consequences to these reasons, the 5^{th} RC was selected as the case study due to the uppermost implementation of bioclimatic design strategies; particularly of natural ventilation and day lighting with the biggest landscape area, efficient electricity usage, low EEI and most prominently the least number of uncontrolled variables.

CHAPTER 5
Case study - Field investigation and evaluation

5.1 Building investigation

5.1.1 Building description

The 5th RC was selected as a case study in preliminary studies for field investigation and evaluation due to the best practice of bioclimatic design strategies, efficient electricity usage and least number of uncontrolled variables. The 5th RC was built in 1966 with a total floor area of 18,212.51m^2. It consisted of five residential blocks with three floor levels each, excluding a ground floor, providing space enough for 847 residents at any single time. The 5th RC lead the other residential colleges of the UM campus with regards to the implementation of bioclimatic design concepts, which involve the best utilisation of natural ventilation and daylighting as visualized through photographic pictures shown in Figure 5.1. These are supported with the study of site plan and the site elevations of the 5th RC presented in Figure 5.2., as well as the typical plan and sections of the 5th RC residential building which are illustrated in Figure 5.3. These are followed by Figure 5.4 which visualises typical elevations of a residential building at the 5th RC. Whilst, the floor plans of each floor at each residential block are shown in Figure 5.5 to 5.9. The 5th RC adopts the American convention in naming floors, the lowest floor or the floor on the ground at the 5th RC is recognized as the first floor. This is distinct with the British convention; which are used by most buildings in Malaysia, the lowest floor is acknowledged as ground floor while the first floor is assigned for next floor up.

The building layout is based on a courtyard arrangement that allows for the transom on top of entrance doors and walls to fully function in providing air circulation and daylight in the student room [Figure 5.1(a) & (b)]. Moreover, the corridor lamps do not need to be switched on during daytime. The presences of wall openings create wind pressure inside the room [Figure 5.1(c)].

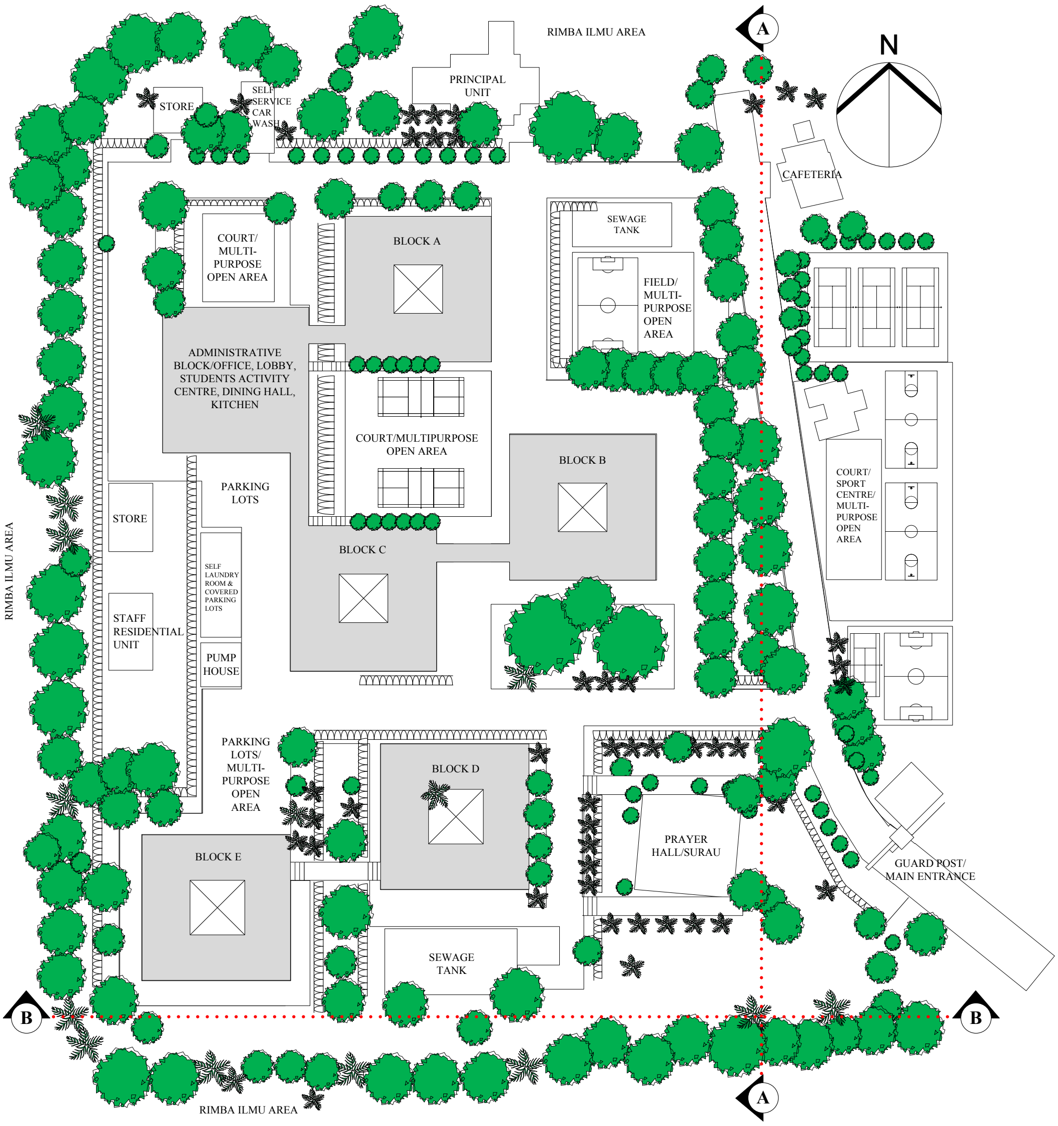
(a) (d)

(b) (e)

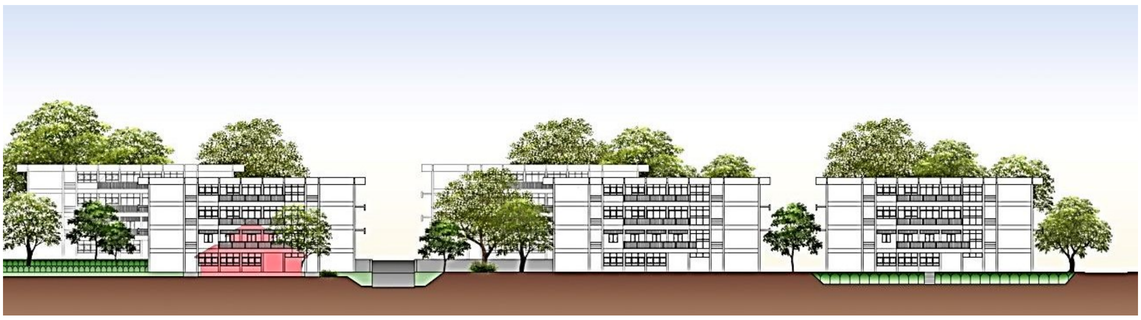
(c) (f)

(a). Internal courtyard in the middle of residential building, (b). Transom/fixed opening over the doorway of residential unit, (c). The wall opening in the residential unit – creates a wind pressure, (d). Open staircase area, (e). Two types of windows, centre pivot and awning with tinted glass, (f). Glare protection and adjustable natural ventilation options.

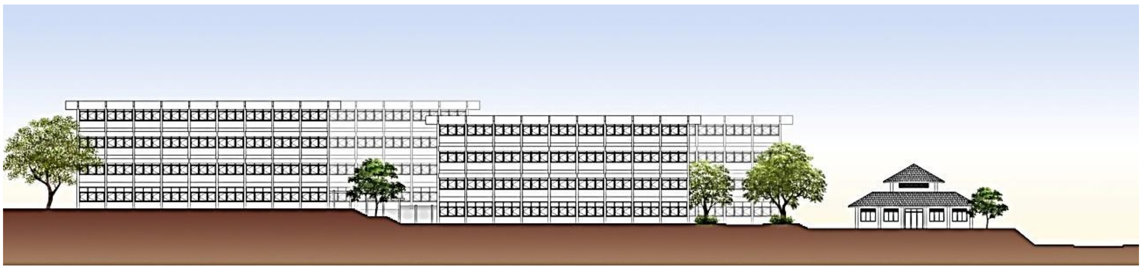
Figure 5.1: Implementation of bioclimatic design strategies at the 5th RC



SITE PLAN



SITE ELEVATION A-A



SITE ELEVATION B-B

Figure 5.2: Site plan and site elevations of 5th RC

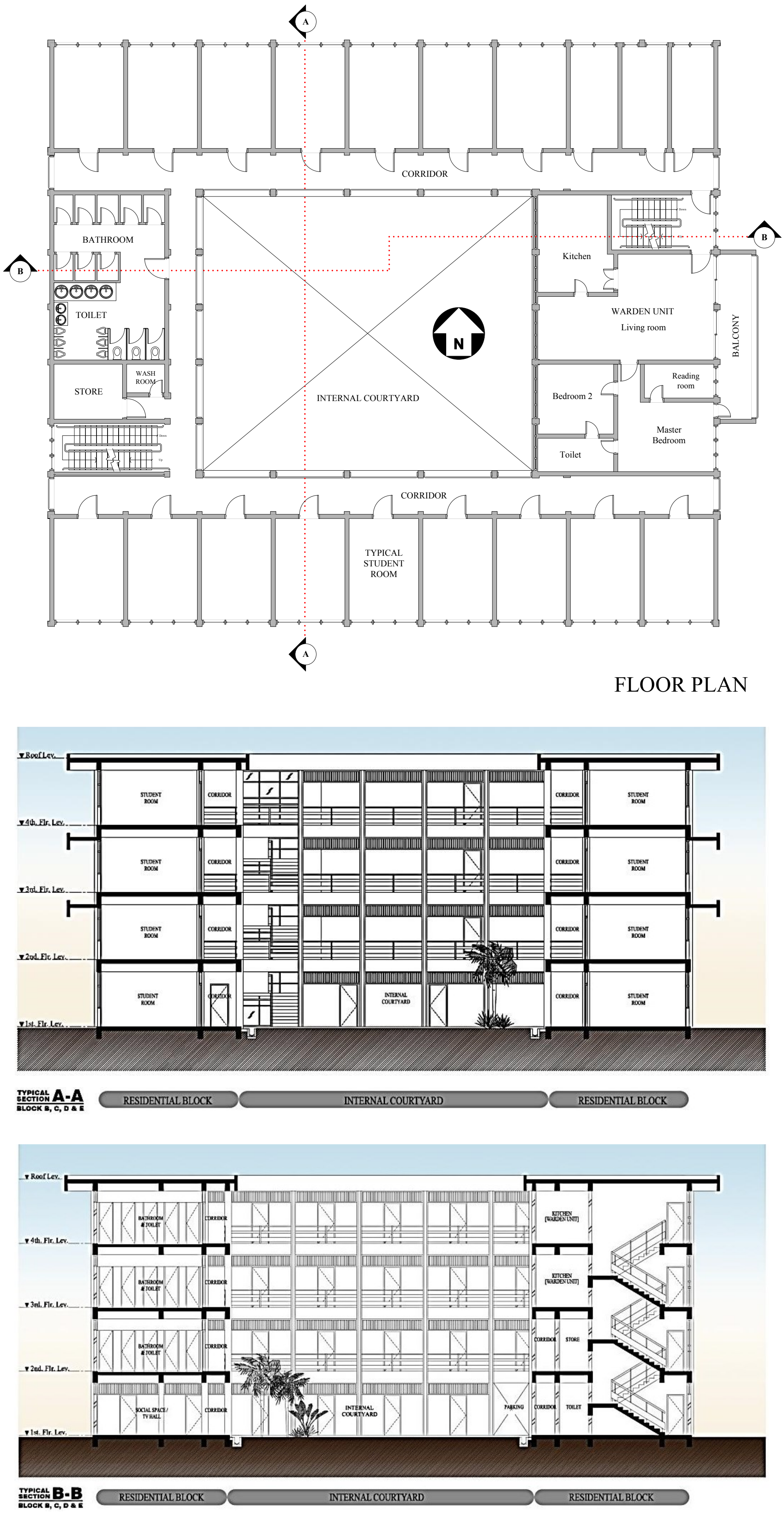
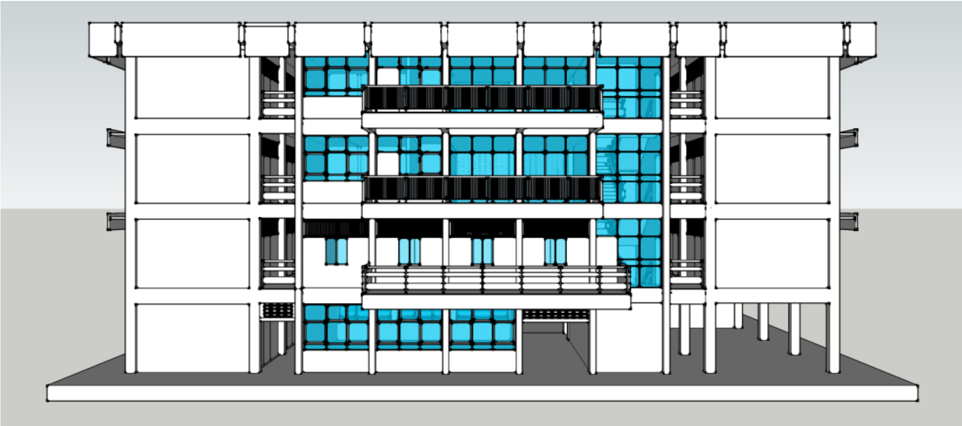
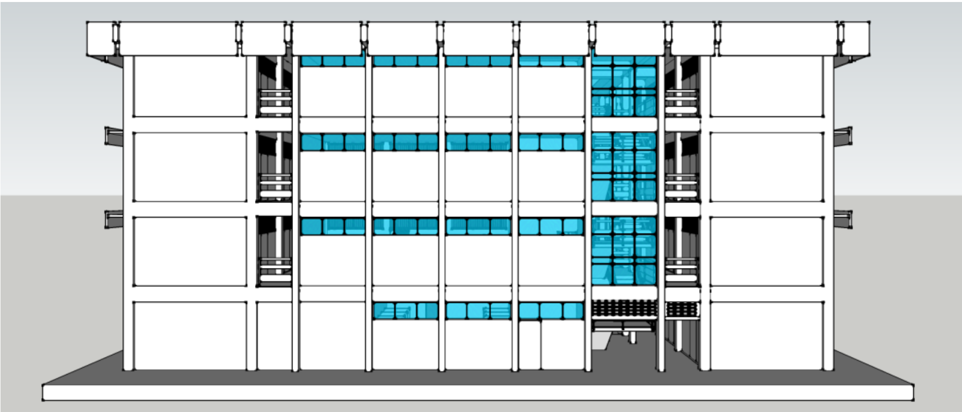


Figure 5.3: Typical floor plan and sections of residential building at the 5th RC

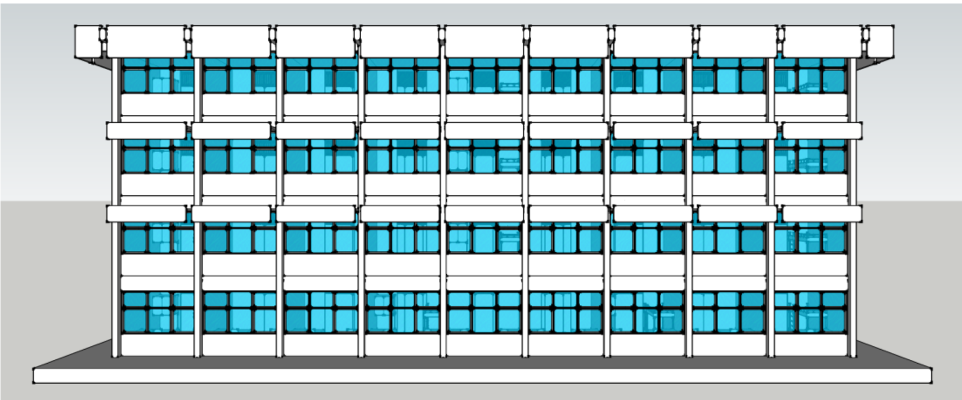


FRONT ELEVATION



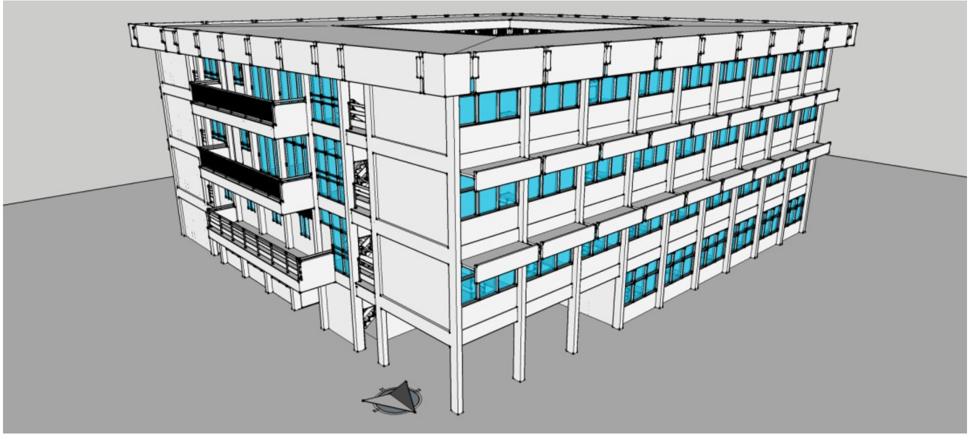
REAR ELEVATION

RIGHT ELEVATION

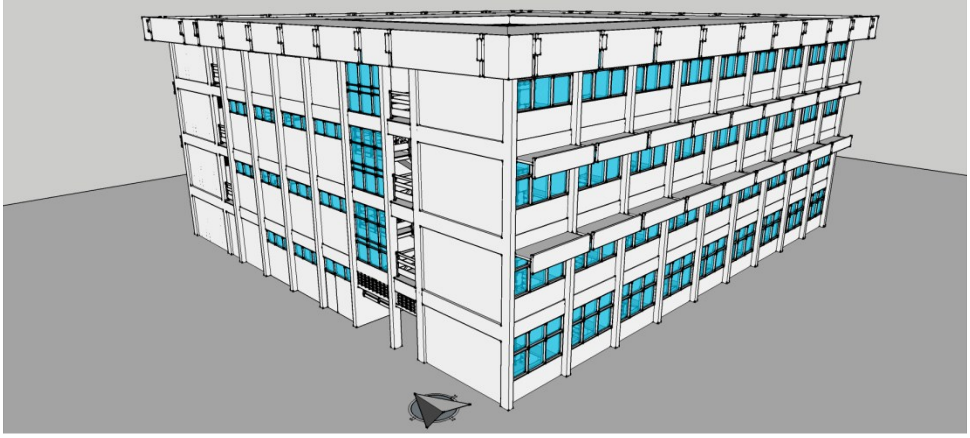


LEFT ELEVATION

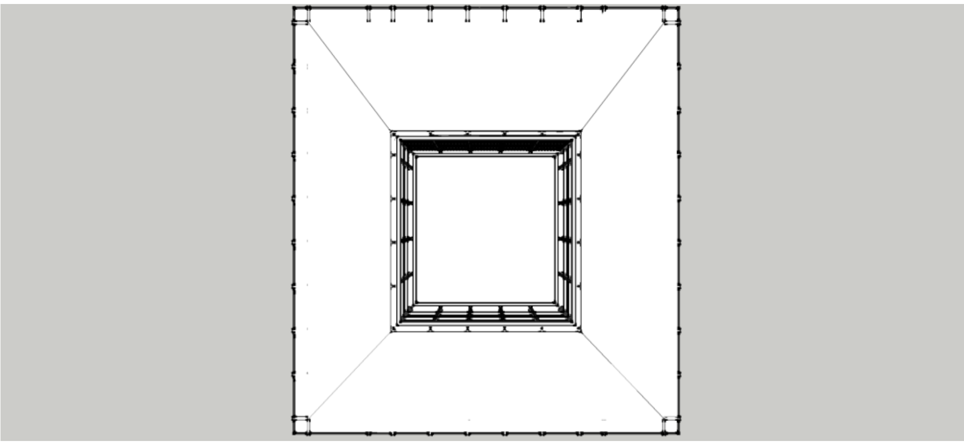
Figure 5.4: Typical elevations of residential building at the 5th RC



FRONT ISOMETRIC ELEVATION

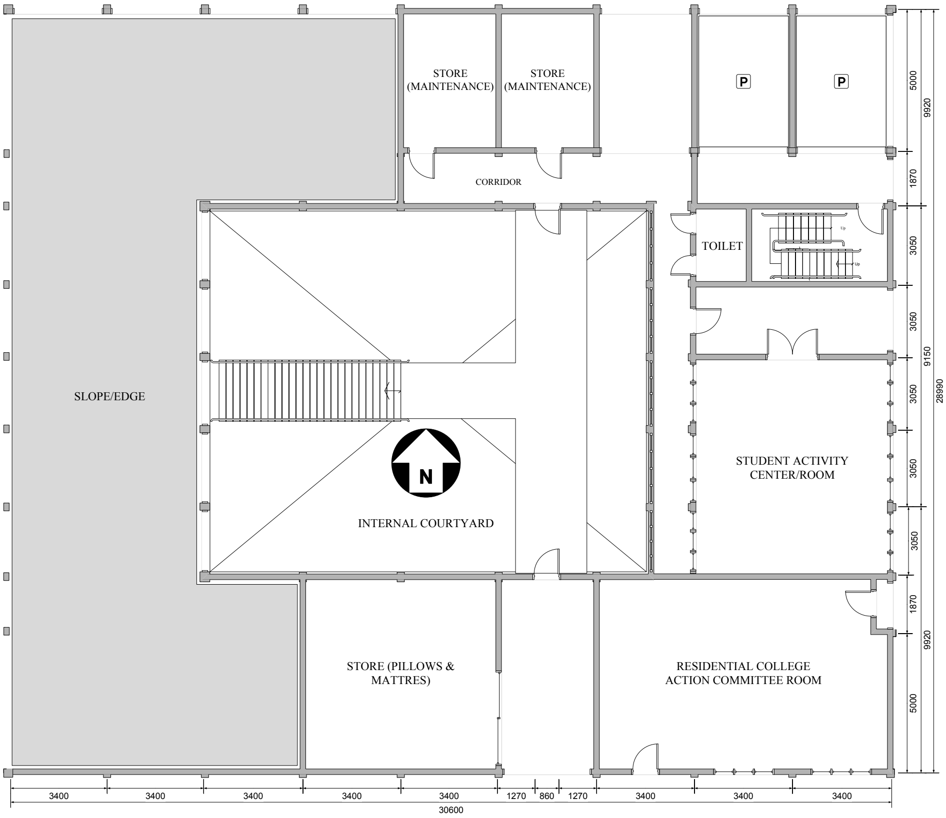


REAR ISOMETRIC ELEVATION

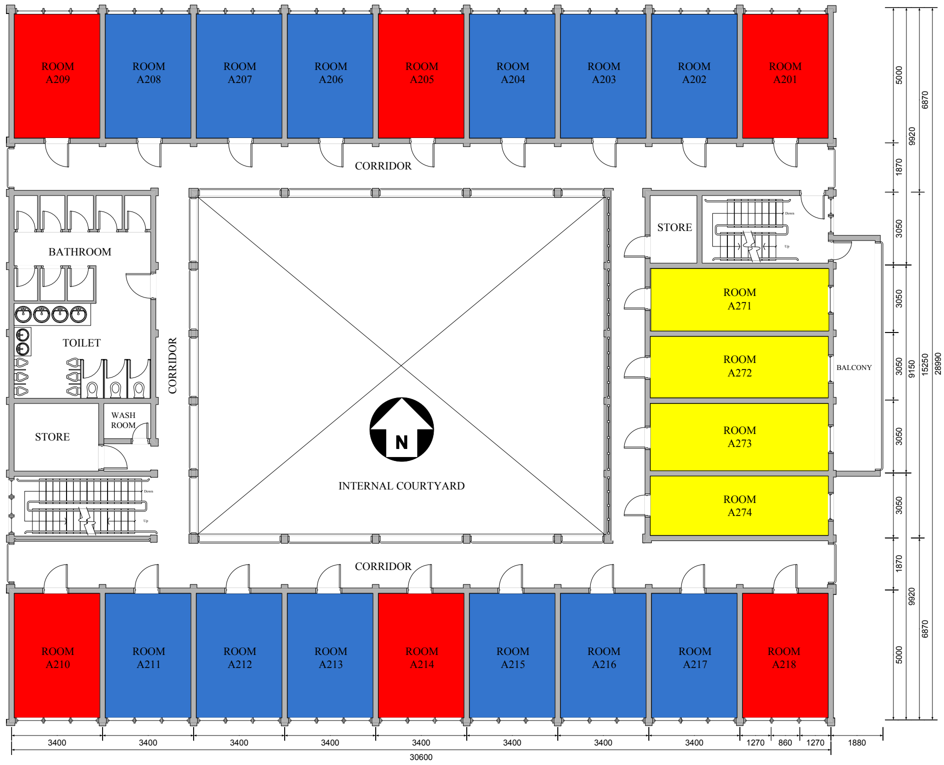


TOP ELEVATION

Figure 5.4, continued



(a)



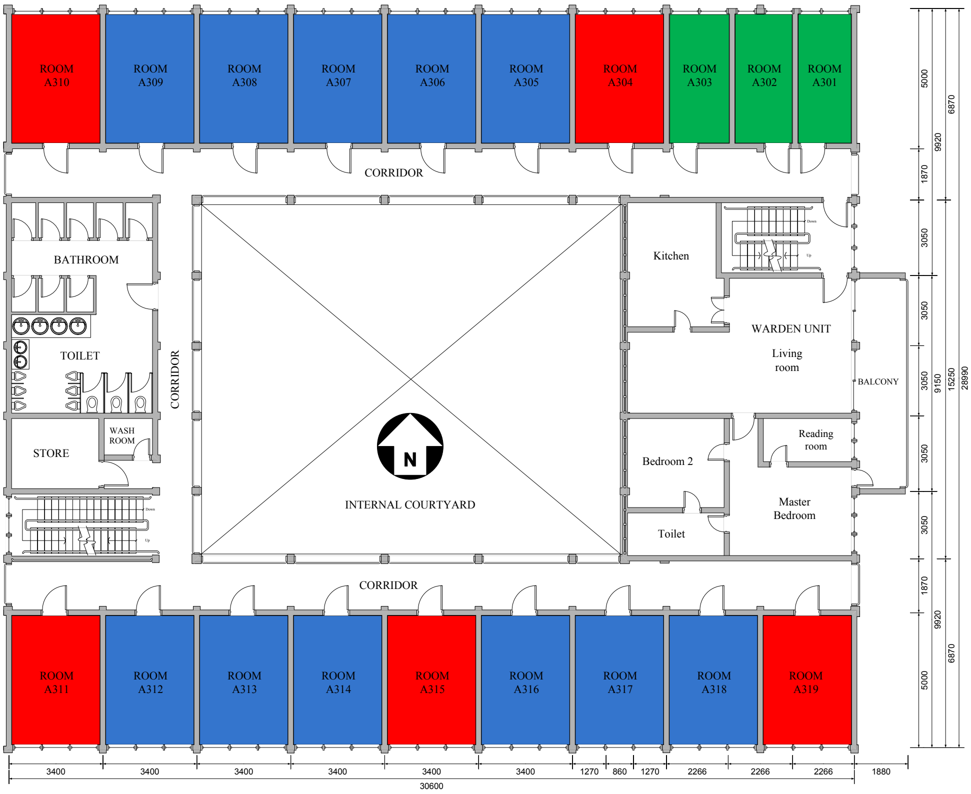
(b)

Legend

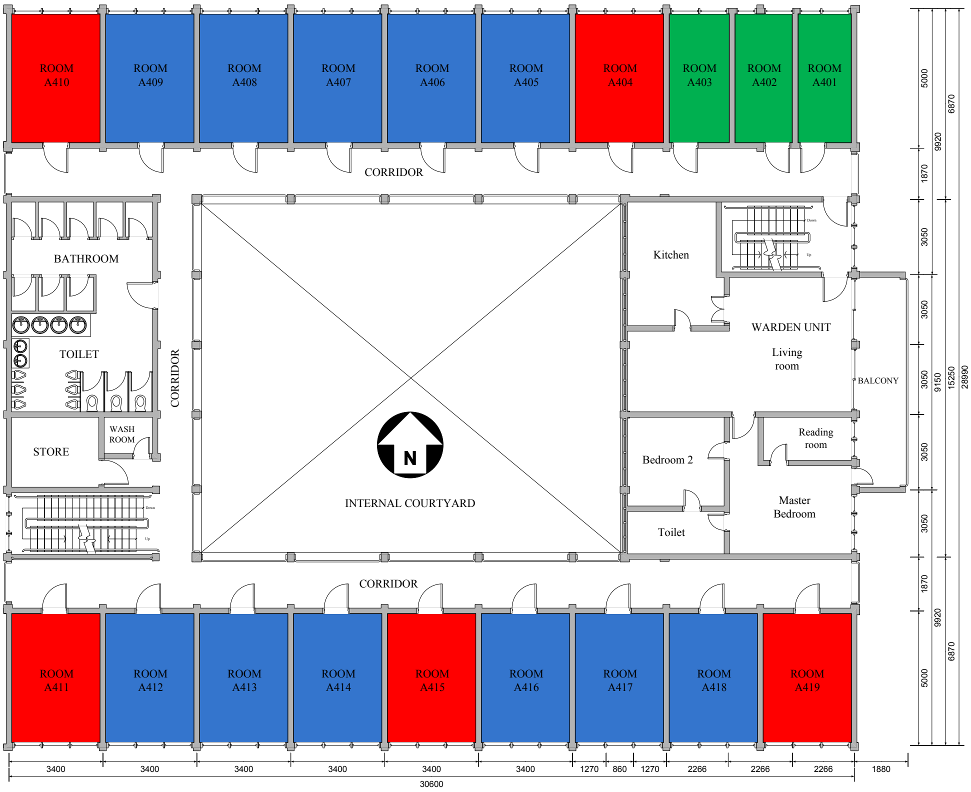
Single room (one single bed)
Double room (two single beds)
Triple room (one single bed & one double decker bed)
Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.5: Floor plan of Block A



(c)



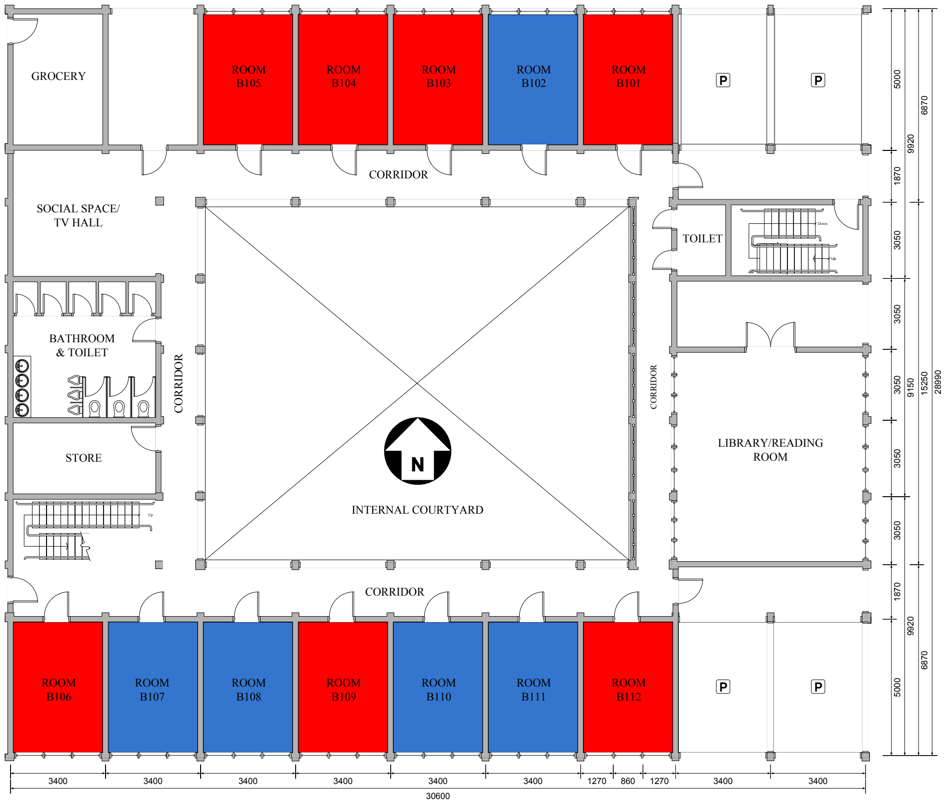
(d)

Legend

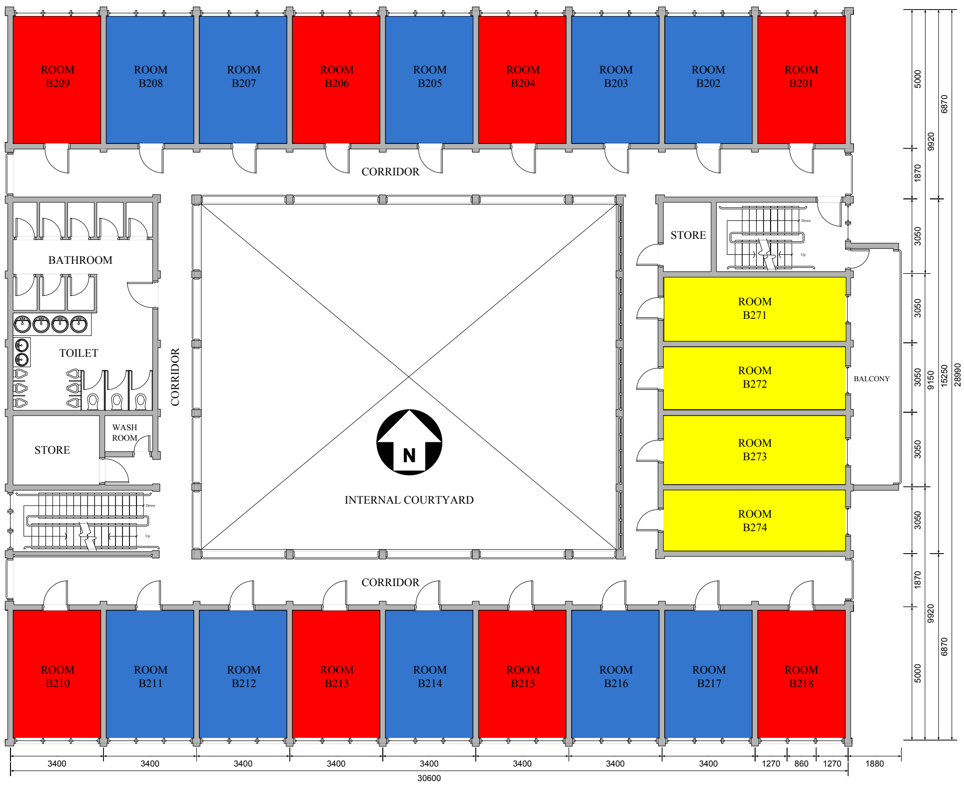
- Single room (one single bed)
- Double room (two single beds)
- Triple room (one single bed & one double decker bed)
- Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.5, continued



(a)



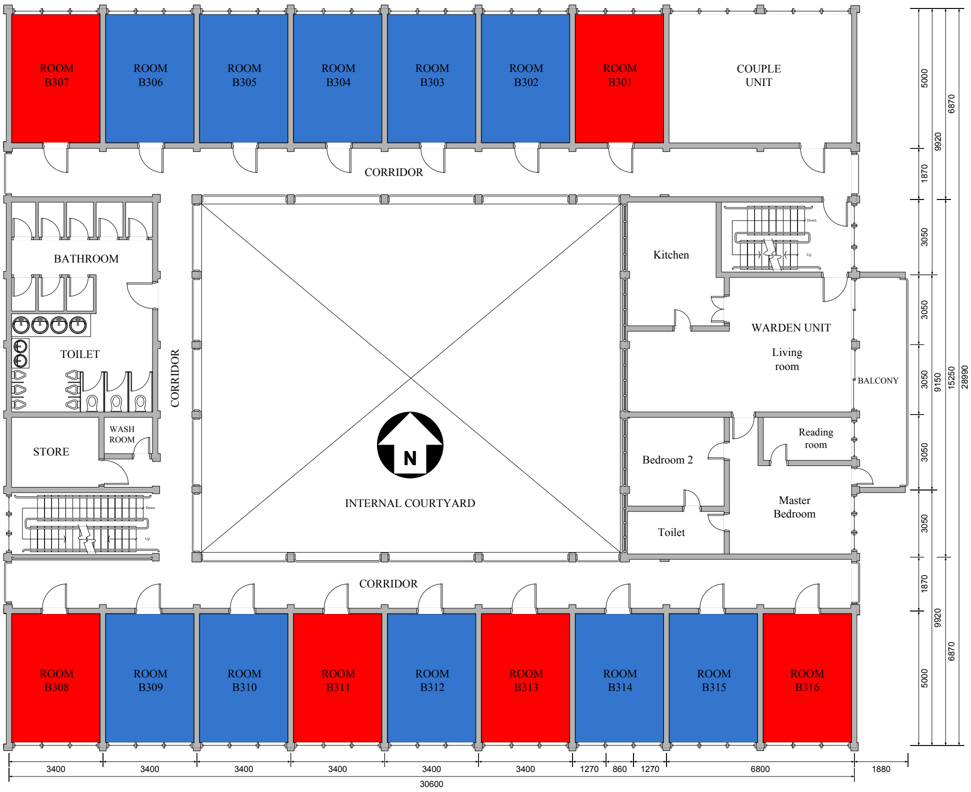
(b)

Legend

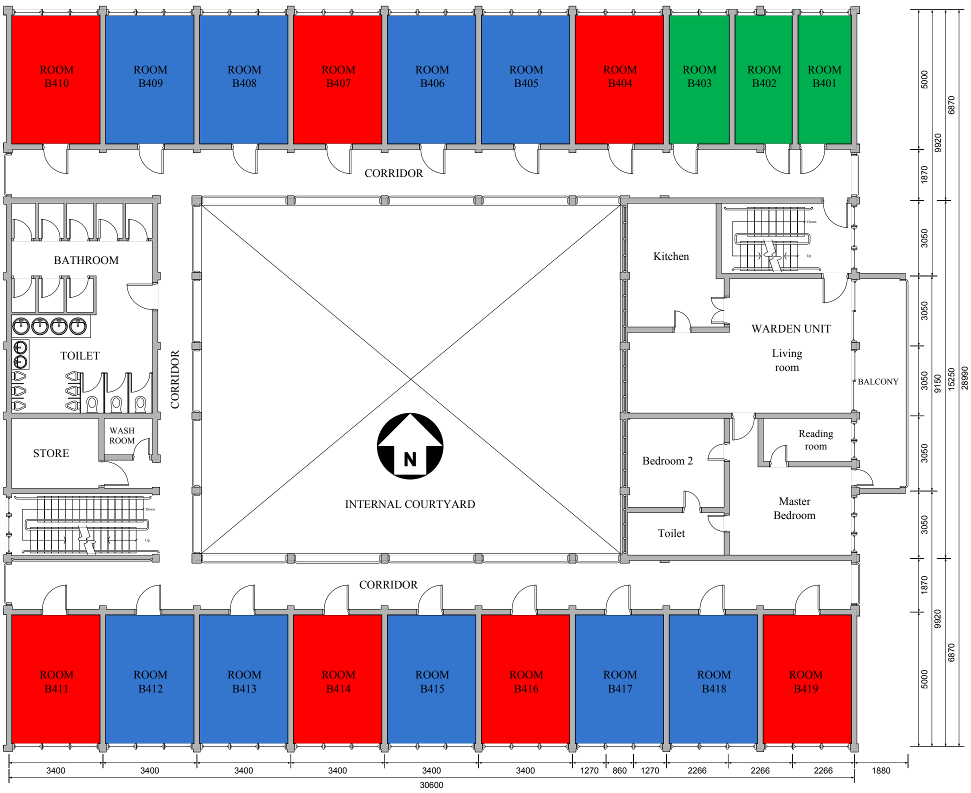
Single room (one single bed)	Double room (two single beds)
Triple room (one single bed & one double decker bed)	Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.6: Floor plan of Block B



(c)



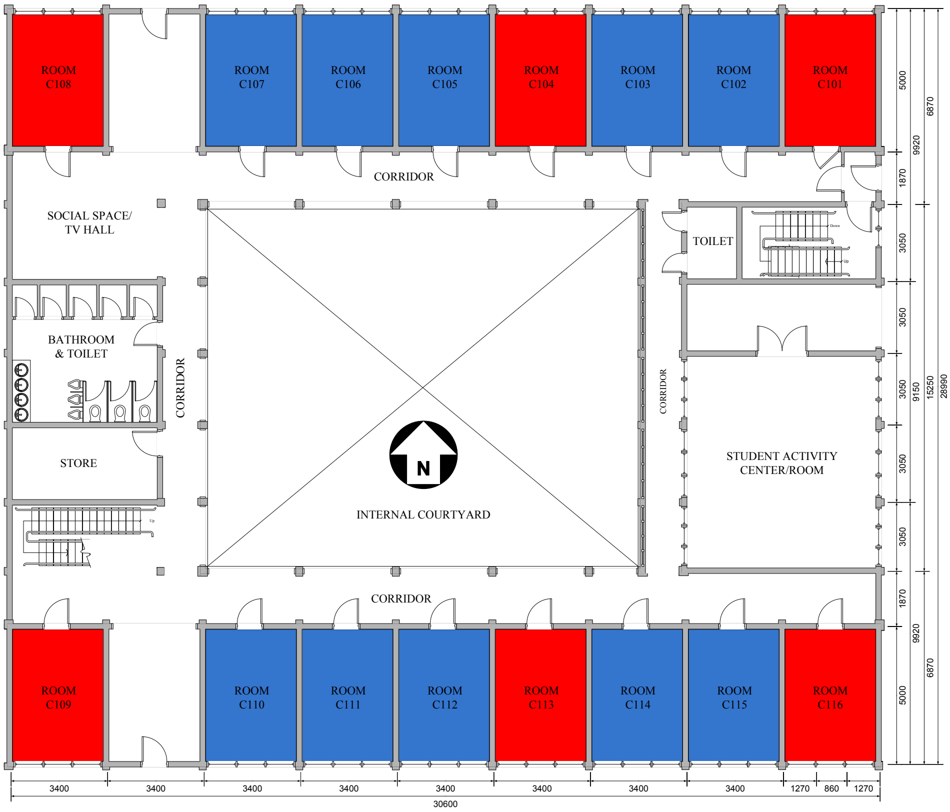
(d)

Legend

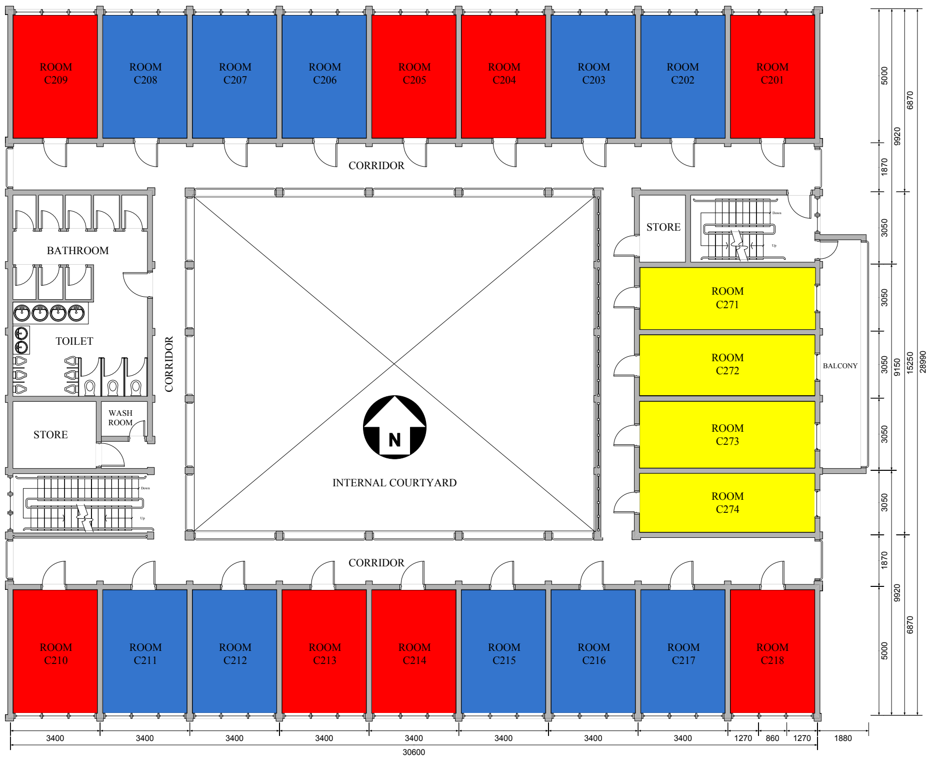
- Single room (one single bed)
- Double room (two single beds)
- Triple room (one single bed & one double decker bed)
- Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.6, continued



(a)



(b)

Legend

Single room (one single bed)

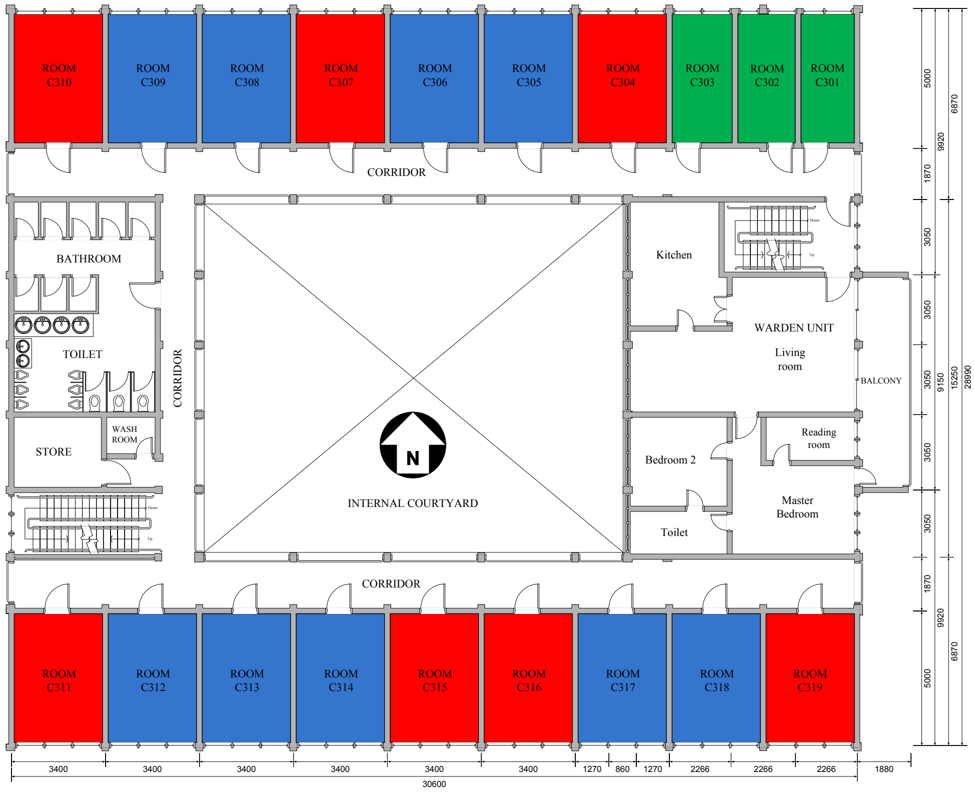
Double room (two single beds)

Triple room (one single bed & one double decker bed)

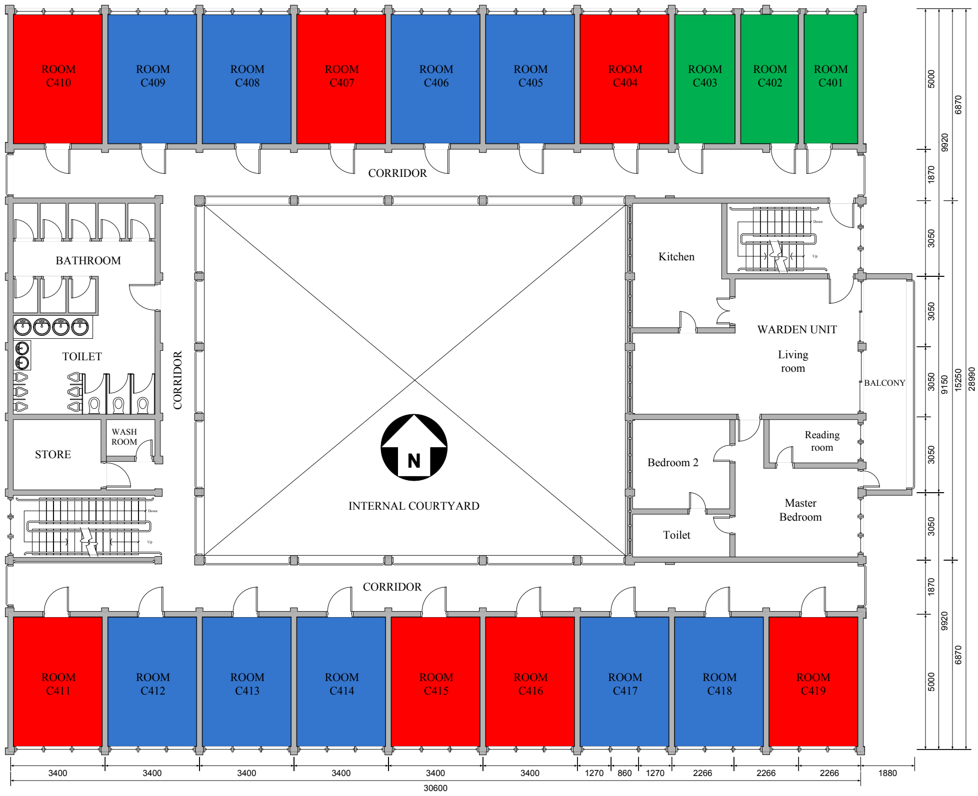
Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.7: Floor plan of Block C



(c)



(d)

Legend

Single room (one single bed)

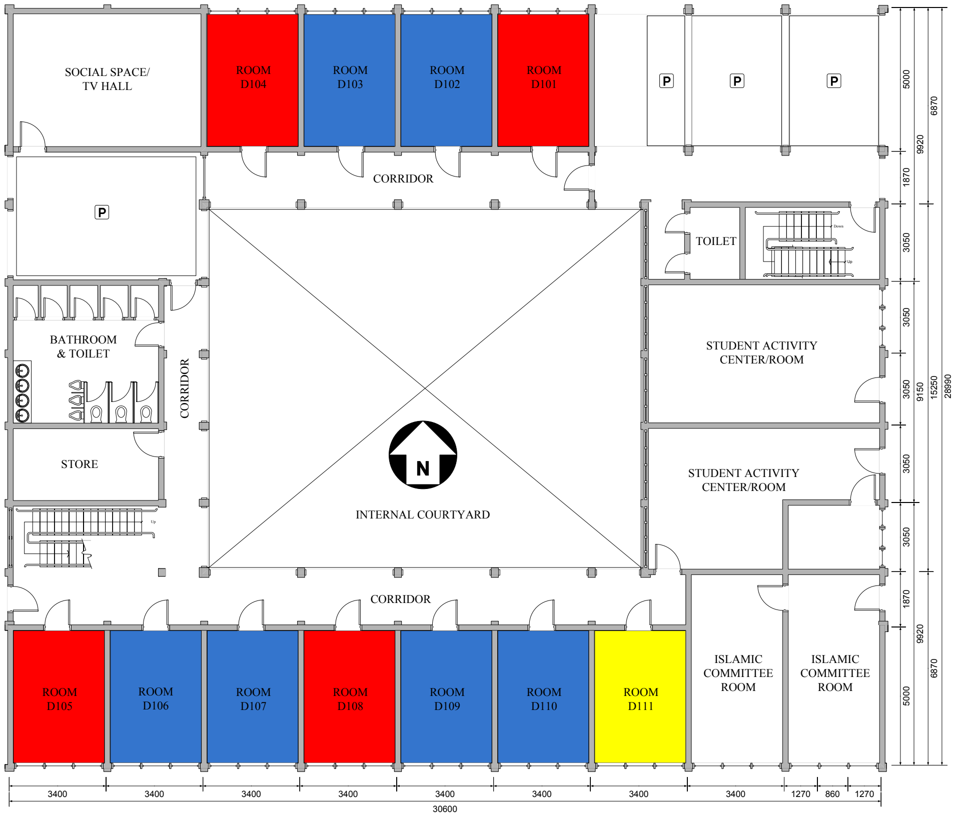
Double room (two single beds)

Triple room (one single bed & one double decker bed)

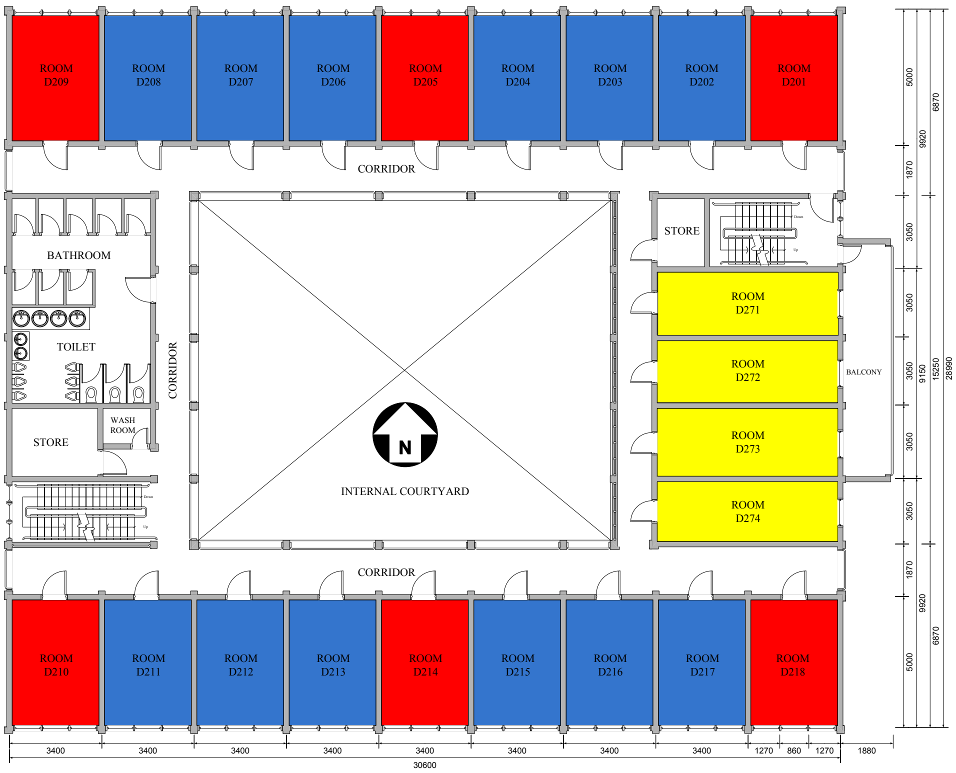
Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.7, continued



(a)



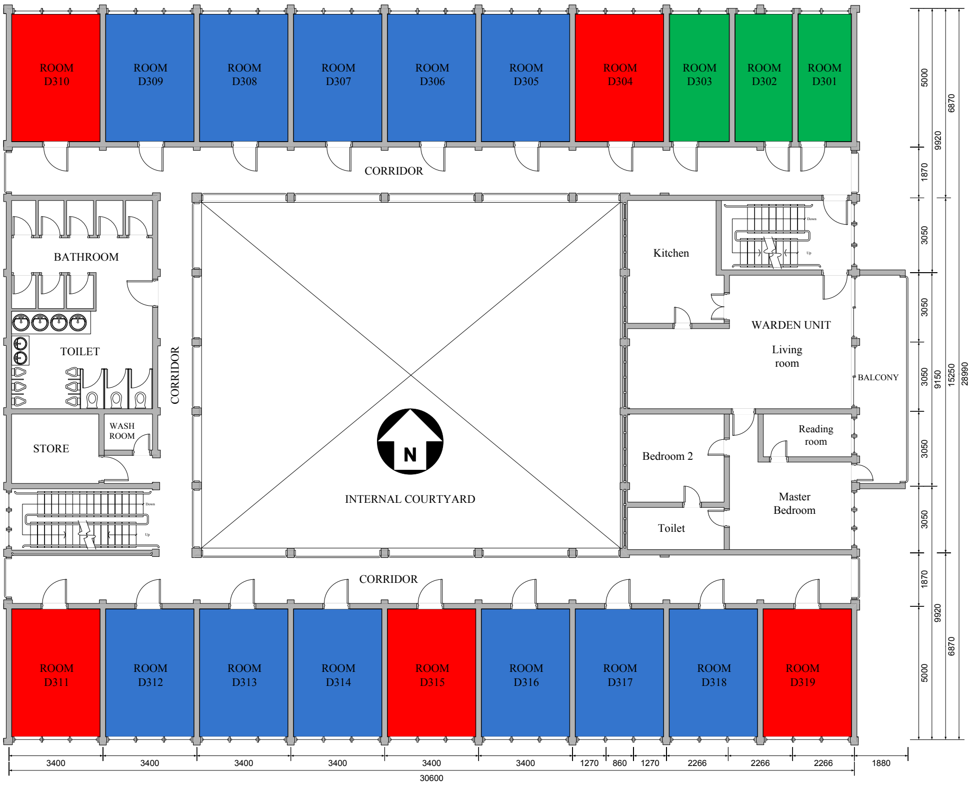
(b)

Legend

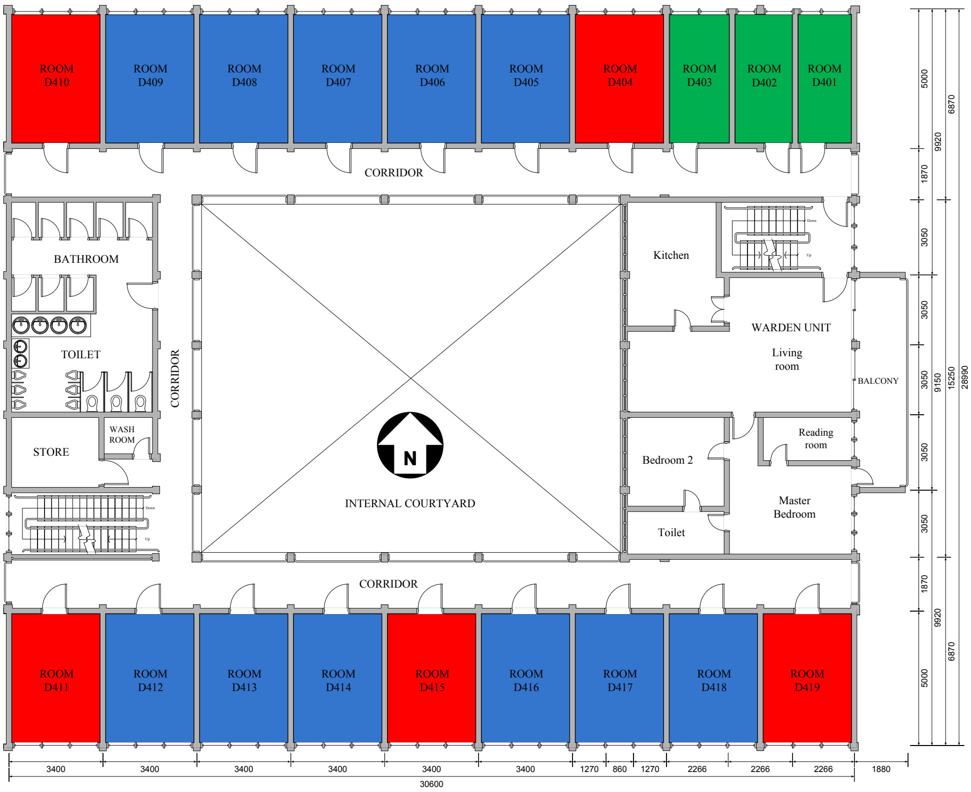
Single room (one single bed)	Double room (two single beds)
Triple room (one single bed & one double decker bed)	Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.8: Floor plan of Block D



(c)



(d)

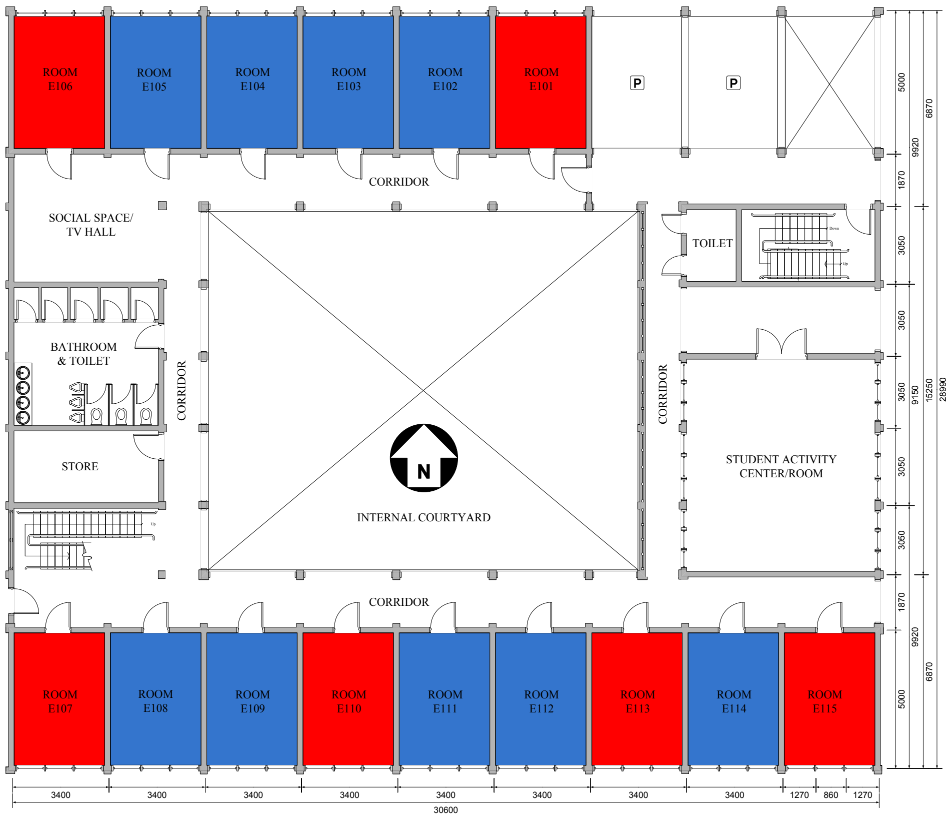
Legend

Single room (one single bed) | Double room (two single beds)

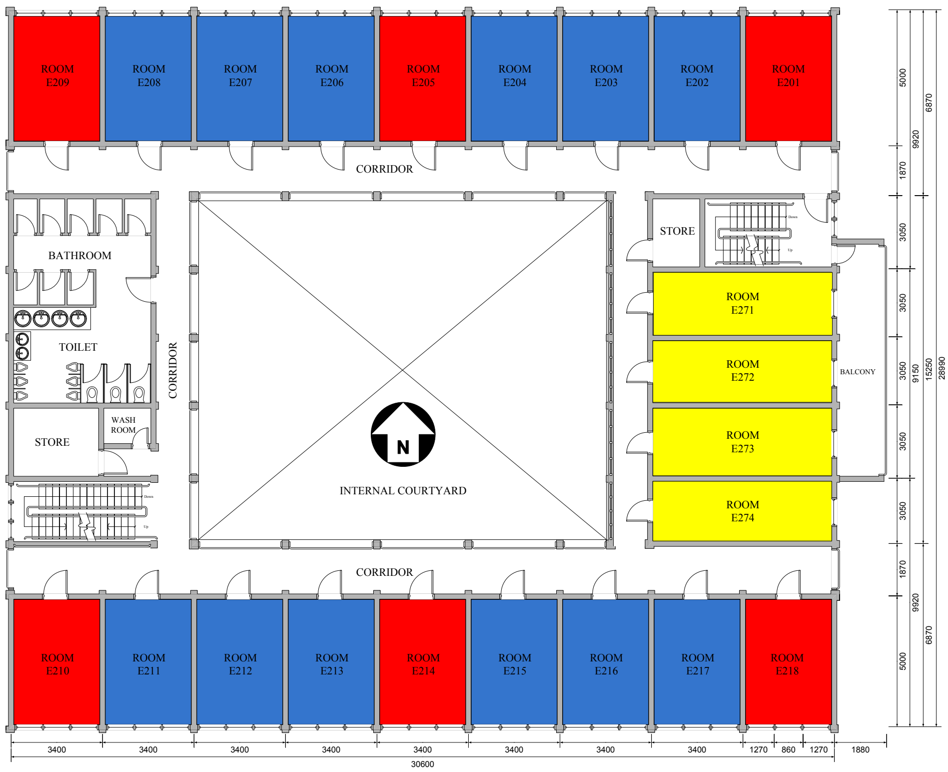
Triple room (one single bed & one double decker bed) | Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.8, continued



(a)



(b)

Legend

Single room (one single bed)

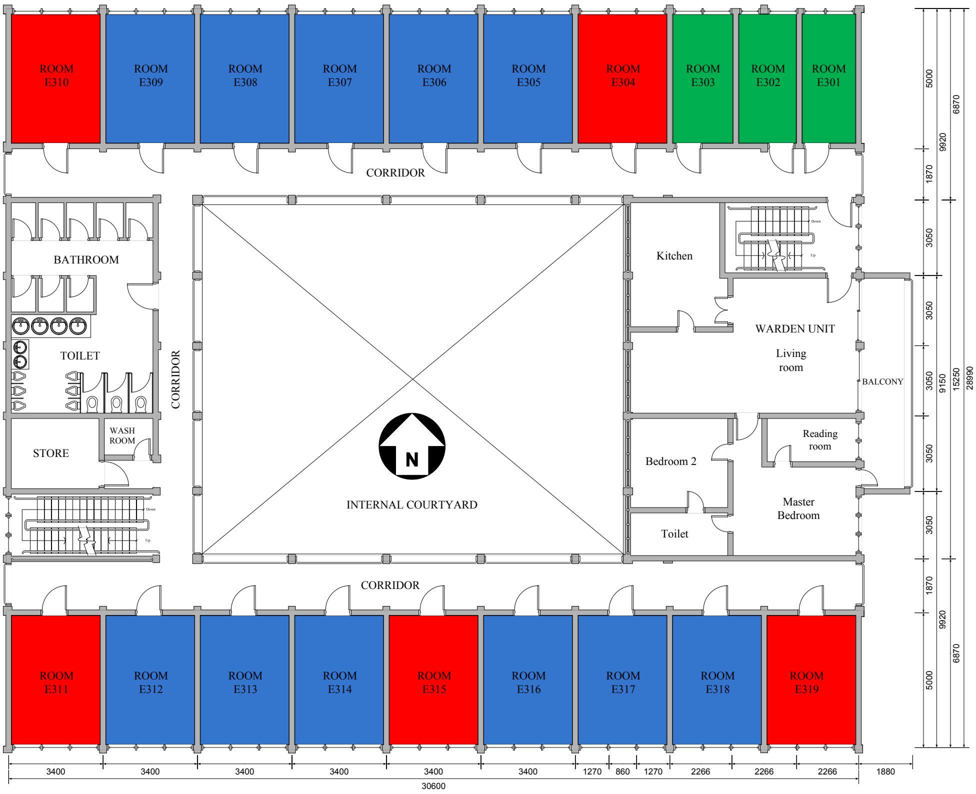
Double room (two single beds)

Triple room (one single bed & one double decker bed)

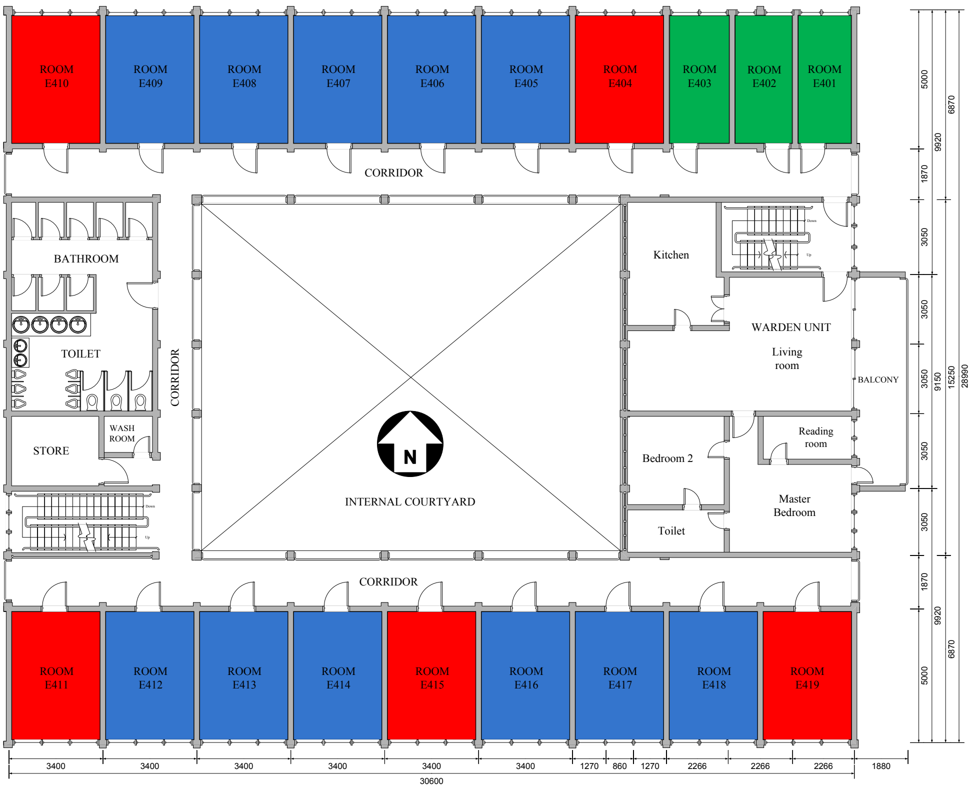
Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.9: Floor plan of Block E



(c)



(d)

Legend

Single room (one single bed) | Double room (two single beds)
Triple room (one single bed & one double decker bed) | Quad room (two double decker beds)

(a). 1st floor, (b). 2nd floor, (c). 3rd floor, (d). 4th floor

Figure 5.9, continued

The main aspect of the layout, the buildings' orientation to sun path, they follow a north-south orientation which directly reduce the thermal effect inside their residential units. Only the common areas such as the toilets, bathrooms, stores, staircases and balconies are built with a west-east orientation (Figure 5.5 to 5.9). The high penetration of sunlight into the toilets and bathrooms helps control the humidity levels in those areas. This way it helps eliminate mould growth, which can be a major contributor to unhealthy buildings and poor indoor air quality. These factors add up to making the 5th RC as the first choice in the case study selection.

Regarding the enclosure and facade design, the 5th RC buildings were designed with special features such as glare protection and adjustable natural ventilation options [Figure 5.1(e)]. The two types of windows, centre pivot and awning, which are also tinted, offer occupants the choice of regulating daylight penetration [Figure 5.1(f)], even though the window to wall ratio (WWR) is relatively high at 0.66, while the window area is 6.41m^2. Furthermore, the operable window area is only 4.20m^2 making the operable window WWR to be 0.43. Although the position of the windows and the building orientation are not in accordance with the wind flow direction, which has a southwest direction, the centre pivot window design is able to channel outside air/wind inside. Meanwhile, the awning windows that are located above the centre pivot directly play the role as a high level exhaust opening. As a consequence, the 5th RC is stated to have one of the lowest EEI (34.52 kWh/m^2/year) compared to other residential colleges, which EEI's are in the range of 40 to 125 kWh/m^2/year.

Even with several differences in floor plans at ground, first and other floors as revealed in Figure 5.5 to 5.9, the effects of uncontrolled variables are still considerably small when compared to effects of differences recognized at other residential buildings, except for the ground floor of Block A. This block is obviously designed with a high consideration for the sloping edge as shown in Figure 5.10.

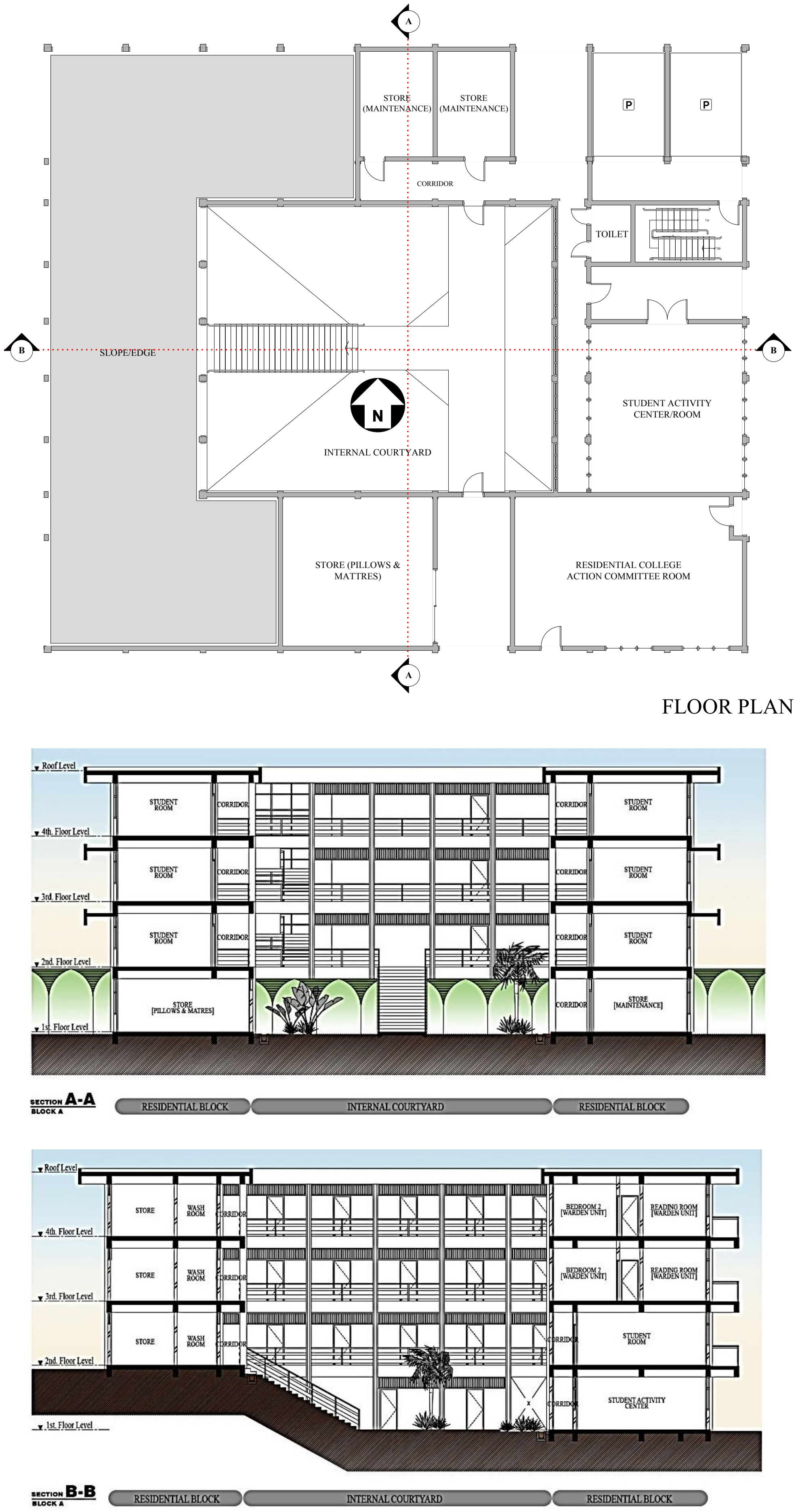


Figure 5.10: Floor plan and section of Block A at 5th RC

However, this exception does not considerably influence the subsequent field investigations and evaluations since there are no student rooms at this level. There is only a store room, toilet, student activity centre/room and the residential college action committee room which is rarely used.

Statistically, there are four types of student room at the 5th RC namely, the single room (one single bed / one person per room), the double room (two single beds / two person per room), the triple room (one single bed and one double decker bed / three person per room) and the quad room (two double decker beds / four person per room). A fundamentally distinct feature of the 5th RC is its availability of double rooms.

Along with the increasing number of students and the demand for single rooms, some renovations have been done. The layouts of double and triple room are similar where one of the single beds has been replaced with a double decker bed. Whilst, three single rooms on the third and fourth floor of each block were rebuilt from two double rooms. Vice versa, the quad rooms have a different layout compared to others and are very limited in number. There are only four to five units on each block, including one on the first floor of the administrative block. These student rooms are specifically for first year students and do not considerably influence the case study. According to the numbers, the typical student room of the 5th RC are double bedrooms as shown in Table 5.1 and the layout of typical room is presented in Figure 5.11.

Table 5.1: Type and numbers of student rooms at 5th RC

Block	Type of student rooms				Capacity (No. of resident)
	Single	Double	Triple	Quad	
A	6	34	16	4	138
B	3	34	28	4	171
C	6	38	28	4	182
D	6	40	20	5	166
E	6	43	22	4	174
F	0	0	0	4	16
Total	27	189	114	25	847

Note:

Block F is Administrative block and not considered in Post Occupancy Evaluation (POE) when the studies are focused on residential building.

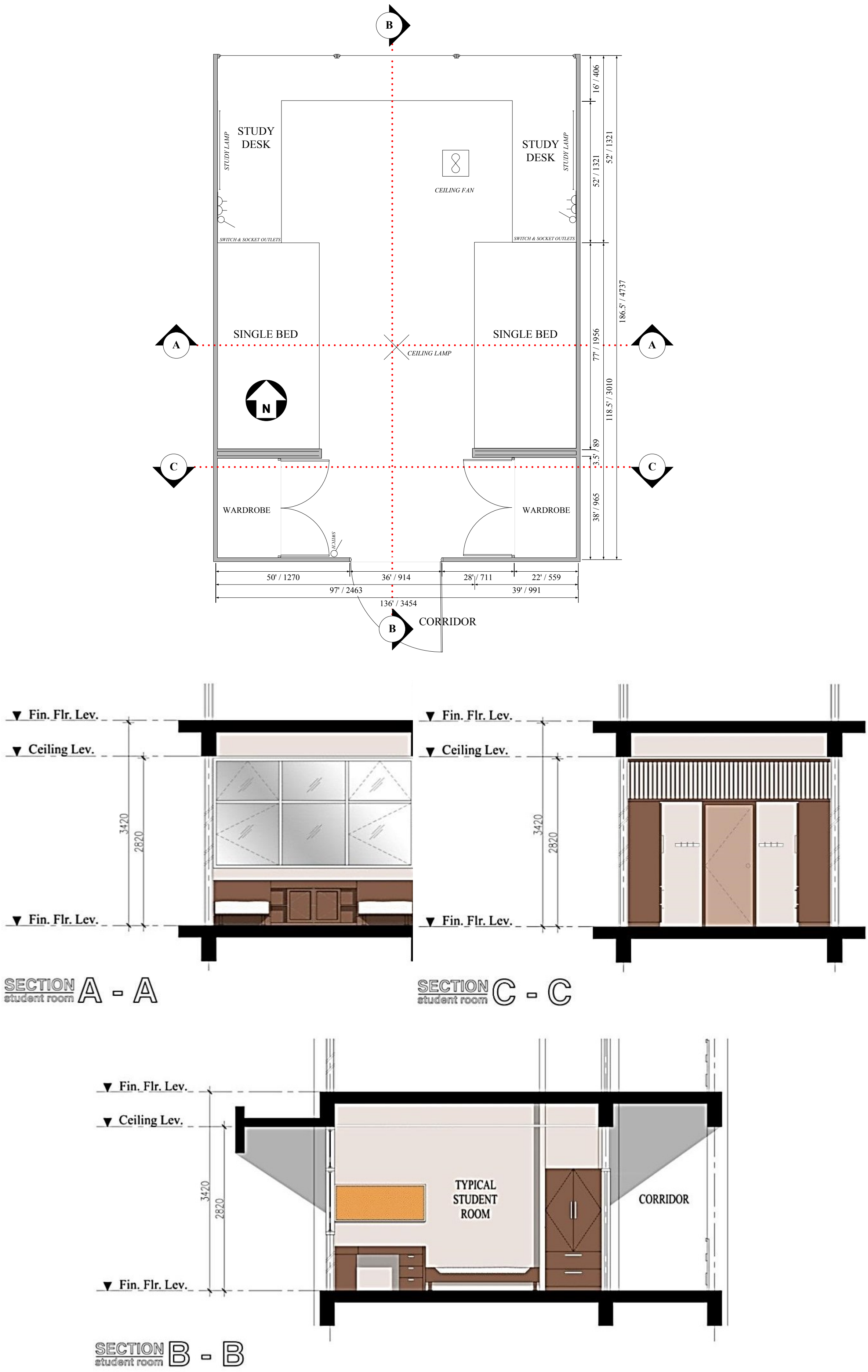


Figure 5.11: Layout and section of typical student room at 5th RC

To accommodate the increasing number of female students, block A was allocated for female residents starting September 2011 in addition to block B, C and F. Block D and E are still maintained for male residents. Therefore, there are 507 female residents and 340 male residents at 100% of occupation rate.

Historically, the 5th RC was only occupied by male residents and only after two years of being established in 1966 was about 98 female residents checked in. At the moment, most of the UM Reserve Officers Training Unit stay at the 5th RC.

5.1.2 The performance of electricity consumption and usage pattern

Further analysis of electricity consumption at the 5th RC was done on data from 2005 until 2011 by taking into account the efficiency of electricity usage, carbon footprint and electricity cost as presented in detail in *Appendix T - The performance of electricity consumption at the 5th RC for seven years' duration (2005-2011).* Generally, the efficiency of electricity usage in terms of the Building Energy Index (BEI) and CO_2 emissions correspond to the value of electricity consumption on each month. Thus, giving the same trends and lines as shown in Figure 5.12. In contrast, the electricity costs are more affected by the electricity tariff. The cost for electricity usage on each month will not reduce correspondingly to the usage when the tariff is progressively increased as shown in Figure 5.13.

The overall performance of electricity consumption for the seven years' duration starting from 2005 until 2011 is presented statistically in Table 5.2. By making comparisons with the five years' duration (2005-2009) of analysis which has been presented earlier as a part of the criteria for case study selection in Table 4.13 (page 220) and *Appendix R - EEI of UM residential college for 2005-2009*, the performance of electricity consumption only increased by approximately 1%. The mean value of the EEI saw an increase from 32.92 kWh/m^2/year to 33.25 kWh/m^2/year.

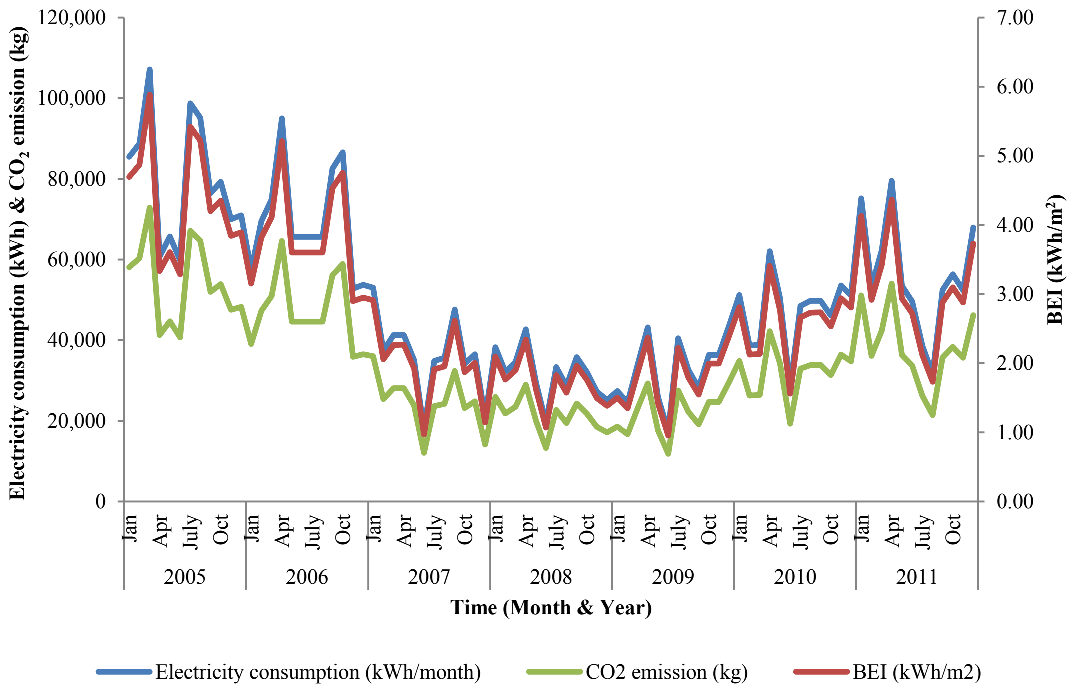


Figure 5.12: The performance of electricity consumption with regards to the efficiency of electricity usage and CO_2 emission for 2005 until 2011

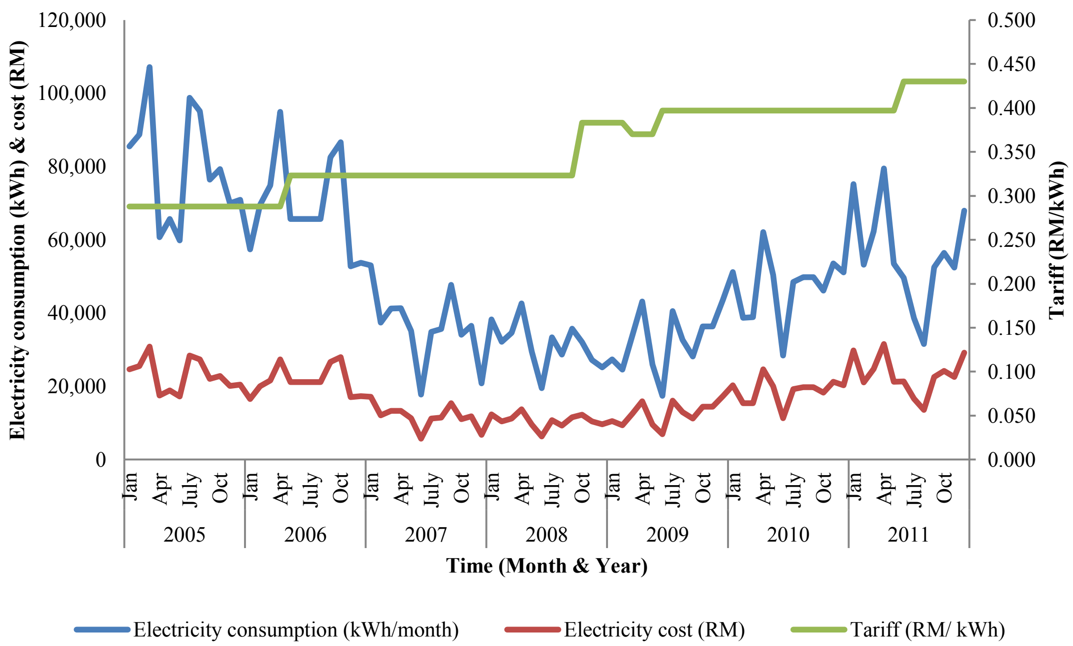


Figure 5.13: The electricity consumption, cost and tariff for 2005 until 2011

Referring to Table 5.2, the mean value of electricity usage from 2005 to 2011 is 50,459 kWh/month with a standard deviation of 20,636.01 and 605,505 kWh/year with a standard deviation of 227,131.10. The highest recorded values of electricity consumption (107,161 kWh/month; 958,107 kWh/year), and carbon footprint (72,869.48 kg CO_2/month; 651,512.76 CO_2/year) were recorded in March 2005 which as clearly visualised in Figure 5.12. These directly influenced the efficiency of electricity usage.

Table 5.2: The statistical analysis of electricity consumption performance at 5th RC for seven years duration (2005-2011)

	Electricity consumption		Efficiency of usage		Carbon footprint [a]		Electricity cost		
Statistical analysis	Monthly (kWh/ month)	Annually (kWh/year)	BEI (kWh/ m^2)	EEI (kWh/m^2 /year)	CO_2 emission (kg)	Annual CO_2 emission (kg)	Rate (RM/ kWh)	Monthly total cost (RM)	Annual total cost (RM)
Mean	50,459	605,505	2.771	33.25	34,311.97	411,743.69	0.365	17,367.97	208,415.69
Median	49,051	568,592	2.693	31.22	33,354.34	386,642.56	0.377	17,178.72	225,731.02
Std. Dev.	20,636.01	227,131.10	1.133	12.47	14,032.49	154,449.15	0.05	6,309.44	66,795.30
Variance	425845093.1	51588536961	1.284	155.530	196910771	23854539491	0.00265817	39809078.1	4461611471
Range	89,742	579,174	4.927	31.801	61,024.56	393,838.32	0.142	25,835.56	151,066.89
Max	107,161	958,107	5.884	52.61	72,869.48	651,512.76	0.430	31,559.12	278,529.97
Min	17,419	378,933	0.956	20.81	11,844.92	257,674.44	0.288	5,723.56	127,463.08

Note: [a] : 1kWh of electricity used emits 0.68 kg of CO_2 (KeTTHA, 2011)
BEI : Building Energy Index
EEI : Energy Efficiency Index

The EEI value exceeded 52.61 kWh/m^2/year, whereas the mean value only showed 33.25 kWh/m^2/year with a standard deviation of 12.47. Moreover, the BEI (5.88 kWh/m^2) showed double the value compared to the mean value which is 2.77 kWh/m^2 whilst, the standard deviation is 1.133. Besides this, the lowest electricity consumption recorded was in the month of June 2009 and the year 2008 with the recorded electricity consumption of 17,419 kWh/month and 378,933 kWh/year respectively. As a consequence, this month and year were discovered to have the most efficient recorded electricity use where the BEI were 0.96 kWh/m^2 and EEI was 20.81 kWh/m^2/year.

The highest recorded value of electricity cost recorded was in April 2011 with RM 31,559.12, which directly contributes to the highest annual electricity cost reaching RM 278,529.97. Regarding on the electricity tariff, the lowest and highest tariffs were RM 0.288/kWh and RM 0.430/kWh respectively.

The monthly and annual performances of electricity consumption at the 5th RC are presented in Table 5.3. On average, the recorded values of electricity consumption gradually decreased within the range of 13% to 48% from 2005 to 2008. Therefore, the efficiency of electricity usage was increased when the values of BEI were prominently decreased from 4.38 kWh/m^2 in 2005, to 1.73 kWh/m^2 in 2008. Whereas, the Energy Efficiency Index (EEI) decreased from 52.61 kWh/m^2/year to 20.81 kWh/m^2/year.

Table 5.3: The monthly and annual performances of electricity consumption at the 5th RC from 2005 until 2011

Year	Electricity consumption (kWh)		Efficiency of electricity usage		CO_2 emission (kg) [a]		Electricity cost (RM)	
	Monthly mean	Annual	Mean of BEI	EEI	Monthly mean	Annual	Monthly mean	Annual
2005	79,842.25	958,107	4.38	52.61	54,292.73	651,512.76	22,994.57	275,934.82
(+/-) [b]	-10,265.92 (-13%)	-123,191 (-13%)	-0.56 (-13%)	-6.77 (-13%)	-6,980.82 (-13%)	-83,769.88 (-13%)	-1,386.96 (-6%)	-16,643.45 (-6%)
2006	69,576.33	834,916	3.82	45.84	47,311.91	567,742.88	21,607.61	259,291.37
(+/-) [b]	-33,289.41 (-48%)	-399,473 (-48%)	-1.83 (-48%)	-21.93 (-48%)	-22,636.81 (-48%)	-271,641.64 (-48%)	-9,886.94 (-46%)	-118,643.28 (-46%)
2007	36,286.92	435,443	1.99	23.91	24,675.10	296,101.24	11,720.67	140,648.09
(+/-) [b]	-4,715.17 (-13%)	-56,510 (-13%)	-0.26 (-13%)	-3.10 (-13%)	-3,202.23 (-13%)	-38,426.80 (-13%)	-1,098.75 (-9%)	-13,185.01 (-9%)
2008	31,571.75	378,933	1.73	20.81	21,472.87	257,674.44	10,621.92	127,463.08
(+/-) [b]	+925.58 (+3%)	+11,035 (+3%)	+0.05 (+3%)	+0.60 (+3%)	+625.32 (+3%)	+7,503.80 (+3%)	+1,987.37 (+19%)	+23,88.36 (+19%)
2009	32,497.33	389,968	1.78	21.41	22,098.19	265,178.24	12,609.29	151,311.44
(+/-) [b]	+14,885.34 (+46%)	+178,624 (+46%)	+0.82 (+46%)	+9.81 (+46%)	+10,122.02 (+46%)	+21,464.32 (+46%)	+6,201.63 (+49%)	+74,419.58 (+49%)
2010	47,382.67	568,592	2.60	31.22	32,220.21	386,642.56	18,810.92	225,731.02
(+/-) [b]	+8,665.58 (+18%)	+103,987 (+18%)	+0.48 (+18%)	+5.71 (+18%)	+5,892.60 (+18%)	+70,711.16 (+18%)	+4,399.91 (+23%)	+52,798.95 (+23%)
2011	56,048.25	672,579	3.08	36.93	38,112.81	457,353.72	23,210.83	278,529.97

Note:
[a] : 1kWh of electricity used emits 0.68 kg of CO_2 (KeTTHA, 2011)
[b] : The difference value and percentage between the current and previous year. The increment noted as + and reduction noted as -
BEI : Building Energy Index (kWh/m^2)
EEI : Energy Efficiency Index (kWh/m^2/year)

Furthermore the levels of annual CO_2 emission were also drastically decreased from 651,512.76 kg in 2005 to 257,674.44 kg in 2008. Vice versa, the mean recorded values of electricity consumption were marginally increased by 3% in 2009 and more noticeably by 46% in the following year. In 2011, about 17% growth was recorded in electricity consumption, directly reducing the efficiency of electricity use to 36.93 kWh/m^2/year. The same trend was also seen in the recorded values of CO_2 emission.

Nevertheless, the electricity consumption, efficiency of electricity usage and CO_2 emission that were recorded in 2011 were not very high compared to the recorded values of 2005, except the electricity cost.

Regarding electricity costs, the percentages of reduction within the same period (2005 to 2008) were quite smaller, in the range of 6% to 46%. The electricity tariff during this time was revised upwards two times and show- first from RM 0.288/kWh to RM 0.323/kWh in May 2006 and then to RM 0.383/kWh in October 2008, the. In March 2009, the electricity tariff was reduced to RM 0.370/kWh.

This rate only lasted for three months until it was fixed at RM 0.397/kWh in June 2009. After two years, the tariff was increased to RM 0.430/kWh. As a consequence, the annual electricity cost for 672,579 kWh of energy in 2011 was RM 278,529.97, whereas the annual electricity cost for 2005 was only RM 275,934.82 for a higher amount of electricity usage exceeding 958,107 kWh. In the seven years' duration, the pricing and tariff for the residential college have been revised five times by the Department of Development & Estate Maintenance of UM and has recorded a total increment of 49% from RM 0.288 per kWh in 2006 to RM 0.430 per kWh in June 2011.

With this increment, the annual electricity consumption showed some reduction when electricity saving measures were implemented holistically by the residential college administration to reduce the maintenance cost. These include reminder stickers and daily reminder announcements to switch off electrical appliances when they are not in use. The floor representative and cleaning staff have been given the responsibility of ensuring that all lamps at corridors, toilets, washrooms and stores are switched off during the day. As a consequence, the annual electricity usage has been reduced to 60% in 2008 and with slight increases in the following years.

Furthermore, the electricity usage pattern was studied by considering the three main activities conducted in the campus which are also presented in *Appendix T*. There are semester breaks, examination preparation week and orientation week for new students, which influence the number of occupants who stay in the residential college. During the semester break, all students leave the residential college for their hometown. Thus, the electricity consumption were reduced drastically especially during the long term semester break. Unfortunately, the electricity consumption was still high and at times exceeding the mean value or normal usage as shown in March 2005, April 2006 and December 2009. These were due to some students who continue to occupy the residential college and in campus activities. Moreover, the residential college was also open for the short term rental by government agencies and private companies who have their own activities either in the UM campus or in nearby locations.

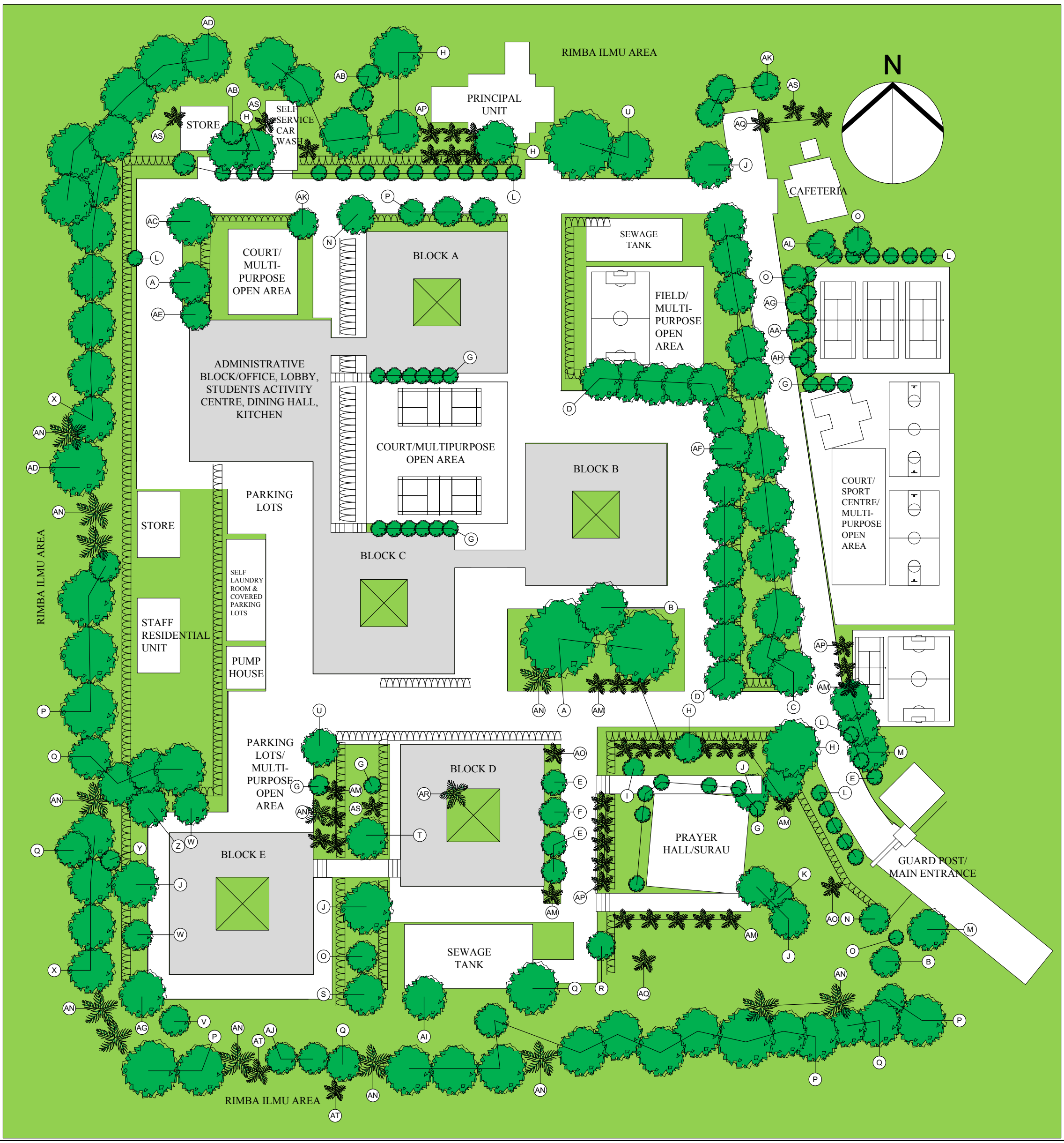
The electricity consumption also increased during the examination preparation week when most of the students stayed up during the night for their revisions, finalising assignments and group discussions. An increase in electricity consumption was also discovered in the month during which the orientation week, where many activities were conducted until late at night. On the contrary, some reductions were noticed during the exam preparation week due to some students who returned to their hometown for revision.

5.1.3 The landscape setting

The 5th RC has a smaller ratio of soft to hard surface area compared to other residential colleges as shown in *Appendix S - Comparison of twelve residential buildings particularly in the characteristic of a typical student room, building design and adaptation of bioclimatic design concepts*. Nevertheless, most of the trees in the 5th RC landscape are well matured with leaf canopies that are capable of providing coverage to the ground and shading for the residential building from maximum sunlight penetration.

The 5th RC is surrounded by highly vegetated area with a high diversity of plants as it is located next to the foothill of Rimba Ilmu, a tropical botanical garden as shown in Figure 5.14. The presence of wild trees like cinnamon (*Cinnamomum sp.*), jackfruit (*Artocarpus cempeden*), rambutan (*Nephelium lappaceum*), Ashoka trees (*Polyalthia longifolia*), simpoh ayer (*Dillenia suffruticosa*), Singapore rhododendron (*Melastoma malabathricum*) and elephant's ear (*Macaranga gigentea*) significantly reduces the late afternoon solar radiation to Block E by filtering, reflecting and scattering the sunlight [Figure 5.15(a)]. Whereas, the presence of a row of Borneo mahogany (*Calophyllum inophyllum*) and purple millettia (*Milletia atropurpurea*) shades Block B from excessive morning sunlight [Figure 5.15(b)]. The same situation also noticed for Block D with the presence of coconut trees (*Cocos nucifera*), blue junipers (*Juniperus chinensis*), bottlebrush (*Callistemon lanceolatus*) and sealing wax palm (*Cyrtostachys lakka*) [Figure 5.15(c)].

Unfortunately, these trees only cover certain levels and mainly areas close to the ground floor and balcony. On the other hand Block C, which is located at a higher altitude, has an east wall which is freely exposed to morning sunlight even with a green area in front of it [Figure 5.15(d)].

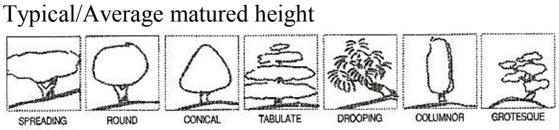


NO.	BOTANICAL NAME	COMMON NAME	HEIGHT (m)*	FORM**	SYMBOL
Trees					
1.	*Pterocarpus indicus*	Angsana, Sena	30	Spreading	A
2.	*Ficus benjamina*	Waring, Beringin, Ara Beringin, Weeping Fig, Benjamin's Fig, Ficus Tree	24	Dropping	B
3.	*Calophyllum inophyllum*	Penaga Laut, Paku Achu, Borneo-mahogany	18	Round	C
4.	*Milletia atropurpurea*	Tulang Daeng, Jenaris, Purple Millettia	30	Conical	D
5.	*Juniperus chinensis*	Blue Juniper	10-15	Conical	E
6.	*Callistemon lanceolatus*	Bottlebrush	< 10	Conical	F
7.	*Thuja orientalis*	Thuja, White Cedar, Yellow Cedar	< 10	Conical	G
8.	*Durio zibethinus*	Durian	25	Spreading	H
9.	*Syzgium samarangense*	Jambu Air, Wax Apple, Love Apple, Java Apple, Water Apple, Mountain Apple	12	Conical	I
10.	*Nephelium lappaceum*	Rambutan	15	Spreading	J
11.	*Microcos blattaefolia*	Chenderai, Bunsi	-	Spreading	K
12.	*Mesua ferrea*	Penaga, Penaga Lilin, Ironwood Tree, Lenggapus,Ceylon Ironwood	20	Conical/Round	L

Figure 5.14: Landscape plan of 5th RC

NO.	BOTANICAL NAME	COMMON NAME	HEIGHT (m)*	FORM**	SYMBOL
Trees					
13.	*Peltophorum pterocarpum*	Batai Laut, Yellow Flame	20	Spreading	M
14.	*Lagerstroemia floribunda*	Bungar, Bungor, Kedah Bungor	18	Conical	N
15.	*Shorea sp.*	Temak, Seraya, Meranti Sarang Punai, Kepong, Meranti Sengkawang	30-50	Round	O
16.	*Bambusa sp.*	Buluh, Bamboo	12-30	-	P
17.	*Macaranga gigentea*	Telinga Gajah, Kubin, Elephant's Ear, Giant Mahang	20	Spreading	Q
18.	*Alstonia angustifolia*	Pulai	25	Spreading	R
19.	*Garcinia manggostana*	Manggis, Mangosteen, Mesetor, Sementah, Semetah	18	Conical	S
20.	*Hopea odorata*	Merawan Siput Jantan, Chengal Pasir, Chengal Kampung	30	Conical	T
21.	*Mimusops elengi*	Tanjong, Mengkulah, Mengkulang, Bakul, Spanish Cherry, Medlar, Bullet Wood.	12	Round	U
22.	*Sambucus javanica*	Kerak Nasi, Javanese Elder	5	Spreading	V
23.	*Artocarpus cempeden*	Cempedak, Jackfruit	15	Conical	W
24.	*Dillenia suffruticosa*	Simpoh Ayer	15	Round	X
25.	*Melastoma malabathricum*	Senduduk, Singapore Rhododendron	5	Spreading	Y
26.	*Polyalthia longifolia*	Mempisang, Ashoka Tree, Cemetery Tree	18	Conical	Z
27.	*Michelia alba*	Cempaka Putih, White Chempaka	23	Conical	AA
28.	*Phyllanthus acidus*	Ceremai, Chermai, Otaheiti Gooseberry, Malay Gooseberry	10	Spreading	AB
29.	*Hymenaea courbaril*	West Indian Locust Tree, South American Locust, Stinking Toe, Old Man's Toe	33	Round	AC
30.	*Hevea brasiliensis*	Getah, Rubber Tree	44	Round	AD
31.	*Artocarpus heterophyllus*	Nangka, Jackfruit	17	Conical	AE
32.	*Adananthera pavonina*	Saga, Suga	20	Round	AF
33.	*Cinnamomum sp.*	Kayu Manis, Medang Wangi, Wild Cinnamomum	12-15	Round	AG
34.	*Mangifera indica*	Mangga, Mempelam, Pauh, Indian Mango	27	Conical	AH
35.	*Melia sp.*	Sentang, Setan, Setang, Nim Tree, Mindi Kecil, Persian Lilac, China Berry	10-50	Spreading/ Round	AI
36.	*Piper aduncum*	Spiked Pepper, Menuda,	7	Spreading	AJ
37.	*Ravenala madagascariensis*	Pisang Kipas, Traveller's Tree, Traveller's Palm	7	-	AK
38.	*Xanthophyllum sp.*	Minyak Berok, Sesyor, Minyak Berok Laut	25-30	Spreading	AL
Palms					
39.	*Areca catechu*	Pinang, Betelnut Palm	>9	-	AM
40.	*Elaeis guineensis*	Kelapa Sawit, African Oil Palm	>9	-	AN
41.	*Cocos nucifera*	Kelapa, Coconut	> 9	-	AO
42.	*Cyrtostachys lakka*	Pinang Merah, Sealing Wax Palm	3-9	-	AP
43.	*Caryota mitis*	Rabok, Beridin, Dudok, Clustered Fish Tail Palm	3-9	-	AQ
44.	*Licuala grandis*	Palas Kipas, Fan Palm	<3	-	AR
45.	*Chrysalidocarpus lutescens*	Butterfly Palm	<3	-	AS
46	*Calameae sp.*	Rotan, Rattan	1-2	-	AT

Note:
* Typical/Average matured height
**



References: Said et al. (2004); LaFrankie (2010); Jabatan Perangkaan Bandar dan Desa (1995).

Figure 5.14, continued

Furthermore, a row of yellow flame (*Peltophorum pterocarpum*), and bungor (*Lagerstroemia floribunda*) at the north orientation of Block A [Figure 5.15(e)], a line of purple millettia (*Milletia atropurpurea*) [Figure 5.15(f)] and a dense canopy of angsana (*Pterocarpus indicus*) [Figure 5.15(g)] at the north and south orientation of Block B, directly moderate the solar radiation reflected off of the tarmac. The other benefits of the landscape, they provide a recreational ground for the residential community and provide shelter for the wildlife like the common myna (*Acridotheses tristis*), monkey (*Macaca fascicularis*) and junglefowl (*Gallus gallus*) as well as shrubs to grow under their canopies. The higher populations of wildlife and plant diversity are visible in the north, south, and west of the 5th RC which are dominated by bamboo (*Bambusa sp.*), elephant's ear gajah (*Macaranga gigente*), African oil palm (*Elaeis guineensis*), simpoh ayer (*Dillenia suffruticosa*), and rattan (*Calameae sp.*)[Figure 5.15(h) & (i)].

Although there is a row of trees consisting of rambutan (*Nephelium lappaceum*), seraya (*Shorea sp.*), and manggosteen (*Garcinia manggostana*), the height and canopy of these trees are not able to provide shade in reducing solar radiation at the eastern orientation of Block E especially at the higher levels [Figure 5.15(j)]. The same condition is also seen at Block A where the shade of the Borneo mahogany (*Calophyllum inophyllum*) trees only covers the adjacent field [Figure 5.15(k)]. Besides, with the only thuja (*Thuja orientalis*) trees at the border between the court and Block A and C, the solar radiation due to the direct reflection of sunlight from the court could not be ignored especially during the afternoon [Figure 5.15(l)].

(a)

(b)

(c)

(d)

(e)

(f)

(a). The presence of wild cinnamon (*Cinnamomum sp.*), jackfruit (*Artocarpus cempeden*), rambutan (*Nephelium lappaceum*), Ashoka tree (*Polyalthia longifolia*), simpoh ayer (*Dillenia suffruticosa*), Singapore rhododendron (*Melastoma malabathricum*) and elephant's ear (*Macaranga gigentea*) at the west of Block E, (b). A row of Borneo mahogany (*Calophyllum inophyllum*) and purple millettia (*Milletia atropurpurea*) at the east of Block B, (c). A row of coconut tree (*Cocos nucifera*), blue juniper (*Juniperus chinensis*), bottlebrush (*Callistemon lanceolatus*), and sealing wax palm (*Cyrtostachys lakka*), (d). Block C is freely exposed to morning sunlight, (e). A row of yellow flame (*Peltophorum pterocarpum*) and bungor (*Lagerstroemia floribunda*) at north orientation of Block A, (f). A line of purple millettia (*Milletia atropurpurea*).

Figure 5.15: Landscape of 5th RC

(g)

(j)

(h)

(k)

(i)

(l)

(g). A dense canopy of angsana (*Pterocarpus indicus*) (h)(i). The higher plant diversity which dominated by bamboo (*Bambusa sp.*), elephant's ear (*Macaranga gigente*), African oil palm (*Elaeis guineensis*) simpoh ayer (*Dillenia suffruticosa*) and rattan (*Calameae sp.*), (j). The low height and small canopy of rambutan (*Nephelium lappaceum*), seraya (*Shorea sp.*) and mangosteen (*Garcinia manggostana)* are not able to be a shelter in reducing solar radiation at the east orientation of Block E especially at the higher level, (k). The shadow of Borneo mahogany (*Calophyllum inophyllum*) is only covering the adjacent field; not reaching to Block A, (l). A row of thuja (*Thuja orientalis*) as a border between court and Block A; as well as Block C

Figure 5.15, continued

5.2 POE

5.2.1 Satisfaction and perception survey

This form of survey method was done to gauge residents' satisfaction and perception on existing implementation of bioclimatic design concepts at the 5th RC, with a focus on natural ventilation and daylighting approaches. The landscape element is also included as it is part of the bioclimatic design concept. The day and time are not particularly specified during this evaluation as the questionnaires were distributed randomly for a month. Thus, the mutual interaction processes between the building and the users' needs were understood in a general manner.

A total of 266 out of 847 responses were retrieved fully filled by the respondents of which 39.6% are male and 60.4% are female residents. The numbers of respondents exceed the minimum number of feedbacks required for a reliable 95% of confident level with a ±5% margin of error from the overall population. About 15.4% of respondents occupy the first/ground floor, 31.7% on the second floor, 30.9% on the third floor, while 22.0% occupied the fourth floor. The majority of respondents; 74.9% are new residents of the 5th RC who have had a shorter period of stay which were about less than six months when the surveys were conducted, and also who frequently spend time in their rooms (40.1%), as well as at their table for studying and working (45.5%) in the day. The results obtained are more reliable as the new residents are generally more honest in participating in the survey and in giving their perception and opinions compared to existing residents. Also, they were found to be more able to describe the real condition of the rooms and residential building in a holistic way.

The results of the satisfaction and perception survey of residents at the 5th RC are presented in Table 5.4.

Table 5.4: The result of satisfaction and perception survey

The performance indicators	Likert scale / *Residents' responses (%)*					Mean	Overall rating*
	-2	-1	0	+1	+2		
Architectural elements							
The residential building layout (internal courtyard with open corridor)	Very poor	Poor	Fair	Good	Very good	3.17	Poor
	0.4	*8.7*	*28.7*	*50.2*	*12.1*		
The residential building is an environmental friendly with efficient energy usage	Strongly disagree	Disagree	Undecided	Agree	Strongly agree	3.35	Disagree
	0.4	*7.2*	*23.8*	*54.3*	*14.3*		
The importance of the buildings is built in an environmentally friendly way	Not at all	Slightly important	Moderate	Very important	Extremely important	3.93	Very important
	0.0	*3.0*	*14.0*	*45.7*	*37.4*		
The overall quality of the residential building	Very poor	Poor	Fair	Good	Very good	3.18	Poor
	1.1	*6.0*	*28.7*	*52.1*	*12.1*		
The general room layout	Very poor	Poor	Fair	Good	Very good	3.22	Poor
	1.5	*7.5*	*27.2*	*50.2*	*13.6*		
The room is fulfil the needs	Strongly disagree	Disagree	Undecided	Agree	Strongly agree	3.22	Disagree
	1.1	*11.4*	*25.5*	*49.8*	*12.2*		
The provision of privacy in the room	Very poor	Poor	Fair	Good	Very good	3.11	Poor
	3.0	*17.0*	*26.4*	*40.8*	*12.8*		
The feeling of safety in the room and building	Very unsafe	Unsafe	Neither	Safe	Very Safe	3.32	Unsafe
	0.8	*6.1*	*26.1*	*49.2*	*17.8*		
The overall comfort level of the room	Very uncomfortable	Uncomfortable	Neither	Comfortable	Very comfortable	3.19	Uncomfort able
	0.8	*4.5*	*29.1*	*53.6*	*12.1*		
The influence of overall room conditions on the degree of work productivity	Much decreased	Decreased	No changes	Increased	Much increased	3.32	Decreased
	0.8	*4.5*	*26.8*	*49.4*	*18.5*		
Thermal comfort and indoor air quality							
The thermal comfort/indoor air temperature at the room	Very poor	Poor	Fair	Good	Very good	3.05	Poor
	3.4	*11.7*	*29.7*	*43.6*	*11.7*		
The ventilation and air quality of the room	Very poor	Poor	Fair	Good	Very good	3.03	Poor
	1.9	*13.4*	*29.8*	*46.2*	*8.8*		
The control of the ventilation of the room	Very poor	Poor	Fair	Good	Very good	2.78	Poor
	1.1	*14.2*	*37.5*	*39.8*	*7.3*		
The air movement in the room (without the aid of mechanical fan)	Still air	Inconspicuous still air	Neither	Breezy	Very breezy	2.77	Inconspicu ous still air
	13.7	*22.1*	*26.7*	*30.9*	*6.5*		
The provision of air movement in the room	Very dissatisfied	Dissatisfied	Neither	Satisfied	Very satisfied	2.67	Dissatisfied
	3.1	*17.6*	*39.3*	*31.7*	*8.4*		
Visual comfort							
The adequacy of natural daylight in the room	Too Dark	Dark	Neither	Bright	Too Bright	2.85	Dark
	4.2	*12.0*	*34.4*	*40.9*	*8.5*		
The control of the daylight in the room	Very poor	Poor	Fair	Good	Very good	2.85	Poor
	1.5	*9.5*	*37.4*	*42.4*	*9.2*		
The adequacy of artificial light in the room	Too Dark	Dark	Neither	Bright	Too Bright	2.93	Dark
	1.1	*8.8*	*35.1*	*46.2*	*8.8*		
The control of the artificial light in the room	Very poor	Poor	Fair	Good	Very good	2.94	Poor
	0.4	*8.9*	*35.3*	*45.7*	*9.7*		
The effectiveness of curtains in controlling the level of lighting	Very poor	Poor	Fair	Good	Very good	3.43	Poor
	0.4	*6.5*	*23.8*	*48.3*	*21.1*		
The satisfaction with the quality of the lights in the room	Very dissatisfied	Dissatisfied	Neither	Satisfied	Very satisfied	3.16	Dissatisfied
	1.5	*7.7*	*28.8*	*48.5*	*13.5*		
The view out of the room from the inside	Very poor	Poor	Fair	Good	Very good	3.16	Poor
	0.4	*11.1*	*30.3*	*39.8*	*18.4*		
The existing windows/ opening area of the room	Very small	Small	Fair	Big	Very big	3.15	Small
	0.4	*8.0*	*30.5*	*45.8*	*15.3*		
Landscape aspects							
The residential building is sensitively designed for the landscape setting	Strongly disagree	Disagree	Undecided	Agree	Strongly agree	2.79	Disagree
	1.5	*7.3*	*39.7*	*43.1*	*8.4*		
The quality of landscape at residential college areas	Very poor	Poor	Fair	Good	Very good	2.63	Poor
	1.5	*8.0*	*33.7*	*48.7*	*8.0*		
The influence of landscape setting on the quality life	Not at all	Slightly	Moderate	Very	Extremely	3.15	Slightly
	0.8	*7.3*	*30.2*	*47.7*	*14.1*		
The quality of landscape setting at the internal courtyard	Very poor	Poor	Fair	Good	Very good	2.91	Poor
	1.5	*6.1*	*35.9*	*48.9*	*7.6*		
The frequency of spending time at the internal courtyard in a day	Never	Rarely	Sometimes	Frequently	Every time	2.81	Rarely
	11.5	*14.9*	*29.0*	*38.5*	*6.1*		

Table 5.4, continued

The performance indicators	Likert scale / *Residents' responses (%)*					Mean	Overall rating*
	-2	-1	0	+1	+2		
Landscape aspects							
The influence of landscape setting at the internal courtyard on the quality life	Not at all	Slightly	Moderate	Very	Extremely	2.84	Slightly
	3.1	*7.3*	*37.4*	*43.1*	*9.2*		

Note:
* As adapted Hassanain (2007), the percentage of responses for each scale will be multiplied by the corresponding weight which are; 2 with 5 points, 1 with 4 points, 0 with 1 point, -1 with 3 points and -2 with 2 points. The sum of the products of multiplication will be divided by 100 to get the mean value. The following calibration has adapted to be able to quantify the degree of satisfaction for each element of performance:

- if the mean response is less than or equal to 1.49, then the respondents are "neutral, neither/nor, and no changes"
- if the mean response is between 1.50 and 2.49, then the respondents are "strongly dissatisfied, too dark, too hot, still air, very poor, very dirty, very noisy, very uncomfortable, and much decreased"
- if the mean response is between 2.50 and 3.49, then the respondents are "dissatisfied, dark, hot, inconspicuous still air, poor, dirty, noisy, uncomfortable, and decreased"
- if the mean response is between 3.50 and 4.49, then the respondents are "satisfied, bright, cold, breezy, good, clean, quiet, comfortable, and increased"
- if the mean response is between 4.50 and 5.00, then the respondents are "strongly satisfied, too bright, very satisfied, too cold, very breezy, very good, very clean, very quiet, very comfortable, and much increased"

According to the percentage figures, a majority of respondents are experiencing a satisfactory level of comfort in all aspects since more than 40% of the respondents are satisfied with the conditions of their room and building. About 52.1% and 50.2% of respondents claim that the overall quality of the residential building and the general room layout is 'good', respectively. Then, 49.8% 'agreed' that the rooms fulfil their needs, while 49.2% feel 'safe' while in the room and building. Consequently, 49.4% claim that the degree of their work productivity has 'increased' considerably.

In terms of thermal comfort and indoor air quality elements, the majority of respondents feel 'good' with the indoor air temperature (43.6%), as well as the ventilation and air quality in the rooms (46.2%). Unfortunately, a smaller percentage of the respondents were satisfied with two aspects namely; the control of the ventilation in the room (39.8%) and air movement in the room without the aid of mechanical fan (30.9%). Furthermore, the highest percentage of respondents voted 'neither' (39.3%) for the provision of air movement in the room.

Through further survey on the usage pattern of windows and ceiling fan at the 5th RC as presented in Table 5.5, these shows that most of the residents (59%) are highly dependent on the ceiling fan and most of them at the highest speed (49.6%) rather than just relying on natural ventilation through the opening of windows in order to promote air circulation in the room.

Table 5.5: The usage pattern of windows and ceiling fan at 5th RC

	Residents' responses (%)						
The frequency of the windows is kept open in a day	Never	Rarely	Sometimes	Frequently	Every time		
	18.3	*14.8*	*21.0*	*30.4*	*15.6*		
The time of windows has been always open in a day	Never	Morning	Afternoon	Evening	Night		
	25.4	*27.6*	*16.8*	*19.0*	*11.2*		
The reason for not opening the windows	Insect	Safety	Rain	Dust	Privacy	Monkey	Others
	3.4	*16.1*	*6.3*	*9.8*	*20.5*	*38.0*	*5.9*
The frequency of ceiling fan usage in a day	Never	Rarely	Sometimes	Frequently	Every time		
	0.4	*3.4*	*10.7*	*26.4*	*59.0*		
The fan speed is often used	One	Two	Three	Four	Five		
	0.4	*2.7*	*18.1*	*29.2*	*49.6*		

The presence of 'monkeys' (38%) are the main reason for not opening windows which is then followed by 'privacy' (20.5%), 'safety' (16.1%), 'dust' (9.8%), 'rain' (6.3%), 'others' (5.9%) and 'insect' (3.4%). However, some of the residents still keeping their windows 'frequently' open (30.4%) especially in the 'morning' (27.6%).

Regarding visual comfort elements, the majority of respondents (48.5%) are 'satisfied' with the quality of lighting in the room. They claim that the adequacy of both natural daylight (40.9%) and artificial light (46.2%) in the rooms are 'bright' with 'good' control features for both of them (42.4% and 45.7% respectively). The effectiveness of curtains in controlling the level of lighting in the rooms are also 'good' (48.3%), while the existing windows/opening areas of the room are 'big' (45.8%) which indirectly allows for a 'good' view (39.8%) out of the room from the inside. Initially, the acceptance of the residential building layout which has an internal courtyard with open corridors, by the residents were proven through this survey. The majority of respondents recognized the 'good' quality of the building layout (50.2%).

This was also the case for the landscape setting in the internal courtyard (48.9%) which is surveyed to have a 'very influencing' (43.1%) effect on the residents' quality of life, due to them very 'frequently' spending time (38.5%) at the internal courtyard during the day. The same effects were also observed with the residents' interaction with the landscape setting surrounding the 5^{th} RC area. Additionally, 54.3% of the respondents 'agreed' that the residential building of the 5^{th} RC is an environmentally friendly building with efficient use of energy, while 45.7% stated that it was 'really important' for the buildings to be built in an environmentally friendly way.

When ascertaining the degree of satisfaction; where each criterion of performance are based on a graduated scale, the overall rate of respondents' satisfaction and perception are in the range of uncomfortable and dissatisfied level, with a mean response of between 2.50 and 3.49 respectively as presented in the last two columns of Table 5.4. Only in the case of the respondents' perception towards the 'importance of buildings being built in an environmentally friendly way' were the comfortable and satisfied level achieved with a mean response of between 3.50 and 4.49.

For evaluation of thermal comfort elements, a detailed survey was done by adopting thermal sensation votes on ASHRAE 7 point sensation scale, which range from -3 to +3 as presented in Table 5.6. A majority of respondents, 39.8% gave a 'neutral' response.

Table 5.6: Thermal sensation votes

Question	ASHRAE 7 point sensation scale / *Residents' responses (%)*						
	-3	-2	-1	0	+1	+2	+3
Overall, how do you feel about thermal comfort in this room?	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
	0.4	*7.0*	*8.6*	*39.8*	*25.0*	*16.4*	*2.9*

5.2.2 Building performance evaluation

All findings were presented in graphical form while statistics were presented in the form of tables that include the mean, minimum, maximum and standard deviation values. The descriptive analysis was done by putting the opening of windows and fan speeds as independent variables of two parameters. There are also temperature and relative humidity values, which are compared from data collected in the corridor and available microclimate data obtained from the UM weather station managed by the Malaysian Meteorological Department. It appears that the high rainfall during early stages of the analysis, as presented in the graph of each scenario, did not influence the temperature and relative humidity in rooms and in buildings. Most of the low temperature and high relative humidity were recorded on days with no rain. Further analyses were also done to see the daily patterns of indoor temperature, relative humidity and light intensity for each scenario, which are presented in graphical form.

Only the openings of windows were considered as an independent variable where the different speeds of fans do not affect the quality of daylight in the rooms. Due to the maintenance work interrupting the condition of some rooms, the readings which were recorded by data loggers on day 14 starting from 00:00am until 23:00pm, and day 18 starting from 9am until 8am on day 20 were not taken into account in the statistical analysis. In order to assess the level of daylighting in the building, the illuminance data were compared with the international and local illuminance standard. The standards established by the Illuminating Engineering Society (IES) and by the Standards and Industrial Research Institute of Malaysia (SIRIM) specifically MS 1525, were used in as they were the most stringent standards. According to the IES, for circulation areas like the corridor, the minimum illuminance value should be 100 lx. Whilst in general, 150 lx is standard for the living room, 400 lx for casual reading and 100 lx for the bedroom as prescribed by MS 1525.

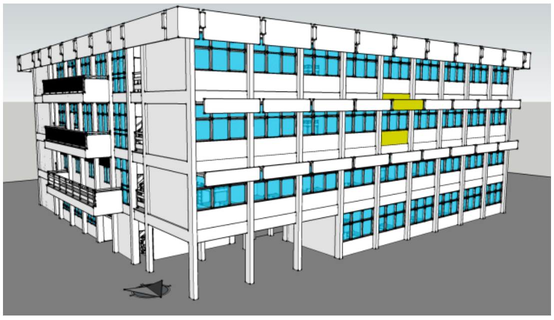
a) Scenario B1 and B4

The detail description of the scenario and the location of selected student room that represent the identified scenarios as well as the position of data loggers are shown in Table 5.7 below. This room was selected to represent two different scenarios.

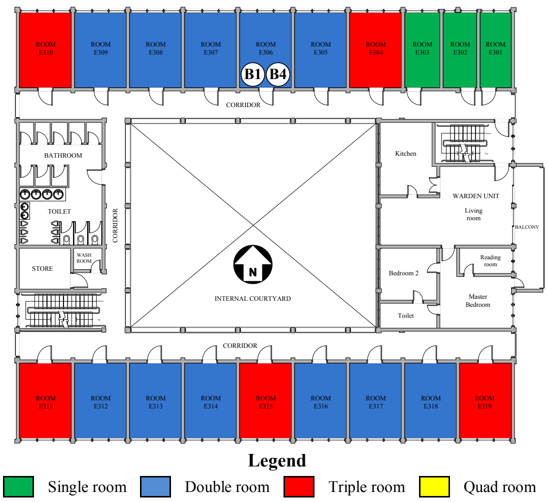
Table 5.7: The detail description of the scenario B1, B4, the location of the selected student room and the position of data loggers

Scenario	Room	Description
B1	E 306	Receiving reflected heat radiation and penetration either from the west or east. Whilst, not influenced with direct heat radiation and penetration by man-made surface either on the top or ground. *(Keyword: North orientation)*
B4	E 306	Not receiving direct heat radiation and penetration from man-made surfaces on the ground, i.e. tarmac, court etc. As well as, direct heat radiation and penetration neither from east nor west. *(Keyword: Avoiding direct contact with man-made surfaces on the ground)*

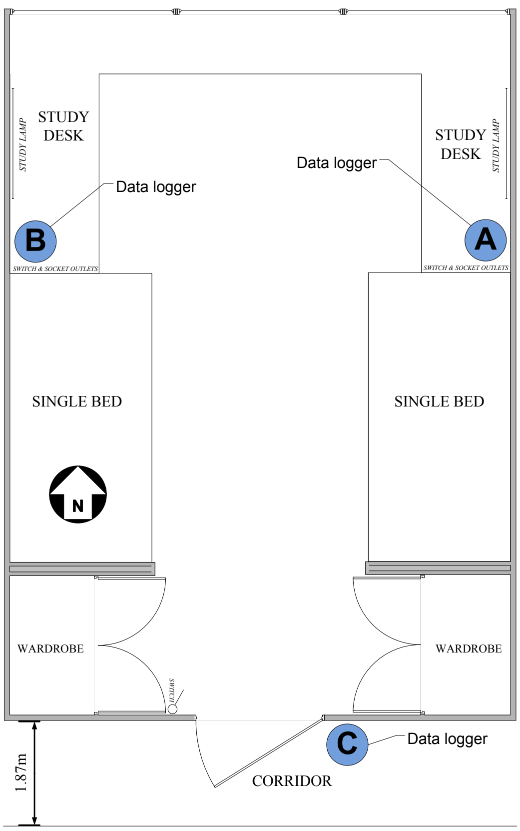
Location of the student room and the position of data loggers



Residential building front isometric elevation

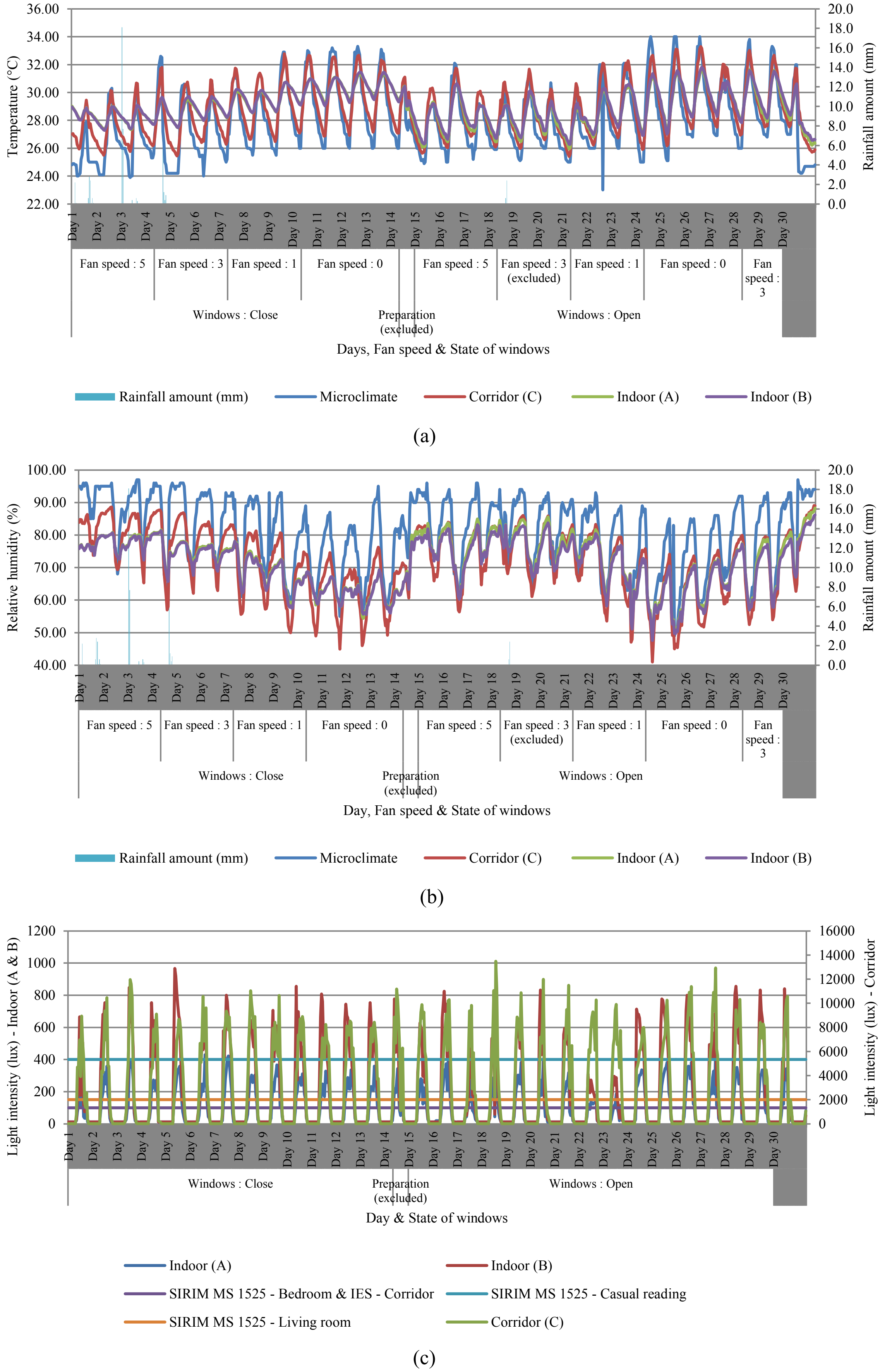


Floor plan of Level 3, Block E



Floor plan of room E 306

The indoor and microclimate profile comprising data on temperature (ºC), relative humidity (%) and illuminance (lux) in room E 306 which represent scenario B1 and B4, are shown in Figure 5.16 and its statistical findings are presented in Table 5.8.



(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.16: The indoor and microclimate profile of scenario B1 and B4

Table 5.8: The statistical analysis of temperature, relative humidity and illuminance values of scenario B1 and B4 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	28.26 (Max-min:27.33-29.04,SD:0.47)	28.24 (Max-min:27.28-29.09,SD:0.49)	27.32 (Max-min:25.50-30.67,SD:1.28)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	28.70 (Max-min:27.48-29.64,SD:0.59)	28.75 (Max-min:27.48-29.72,SD:0.63)	28.04 (Max-min:25.45-31.79,SD:1.66)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	29.55 (Max-min:28.30-30.75,SD:0.63)	29.59 (Max-min:28.32-30.75,SD:0.63)	29.08 (Max-min:26.48-32.77,SD:1.72)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	30.39 (Max-min:29.27-31.33,SD:0.58)	30.38 (Max-min:29.04-31.46,SD:0.65)	29.73 (Max-min:26.87-32.67,SD:1.82)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	29.28 (Max-min:27.33-31.33,SD:1.03)	29.30 (Max-min:27.28-31.46,SD:1.04)	28.60 (Max-min:25.45-32.77,SD:1.89)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.99 (Max-min:26.09-30.62,SD:1.18)	28.15 (Max-min:26.30-30.65,SD:1.09)	28.05 (Max-min:25.65-31.74,SD:1.63)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	29.06 (Max-min:26.21-31.64,SD:1.57)	29.23 (Max-min:26.57-31.59,SD:1.47)	29.12 (Max-min:25.72-33.03,SD:2.06)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	28.54 (Max-min:26.65-30.44,SD:1.09)	28.63 (Max-min:26.82-30.60,SD:1.12)	28.78 (Max-min:25.91-32.28,SD:1.83)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	29.70 (Max-min:27.24-31.61,SD:1.12)	29.73 (Max-min:27.01-31.82,SD:1.21)	29.76 (Max-min:26.18-33.29,SD:1.93)	29.43 (Max-min:25.10-34.00,SD:)
	Overall	28.87 (Max-min:26.09-31.64,SD:1.40)	28.98 (Max-min:26.30-31.82,SD:1.37)	28.96 (Max-min:25.65-33.29,SD:1.97)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	28.12 (Max-min:26.09-30.62,SD:0.91)	28.20 (Max-min:26.30-30.65,SD:0.84)	27.68 (Max-min:25.50-31.74,SD:1.51)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.88 (Max-min:26.21-31.64,SD:1.19)	28.99 (Max-min:26.57-31.59,SD:1.16)	28.58 (Max-min:25.45-33.03,SD:1.94)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	29.05 (Max-min:26.65-30.75,SD:1.02)	29.11 (Max-min:26.82-30.75,SD:1.02)	28.93 (Max-min:25.91-32.77,SD:1.78)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	30.05 (Max-min:27.24-3.61,SD:0.95)	30.06 (Max-min:27.01-31.82,SD:1.02)	29.74 (Max-min:26.18-33.29,SD:1.87)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	29.08 (Max-min:26.09-31.64,SD:1.26)	29.14 (Max-min:26.30-31.82,SD:1.23)	28.78 (Max-min:25.45-33.29,SD:1.94)	28.12 (Max-min:23.00-34.00,SD:2.51)

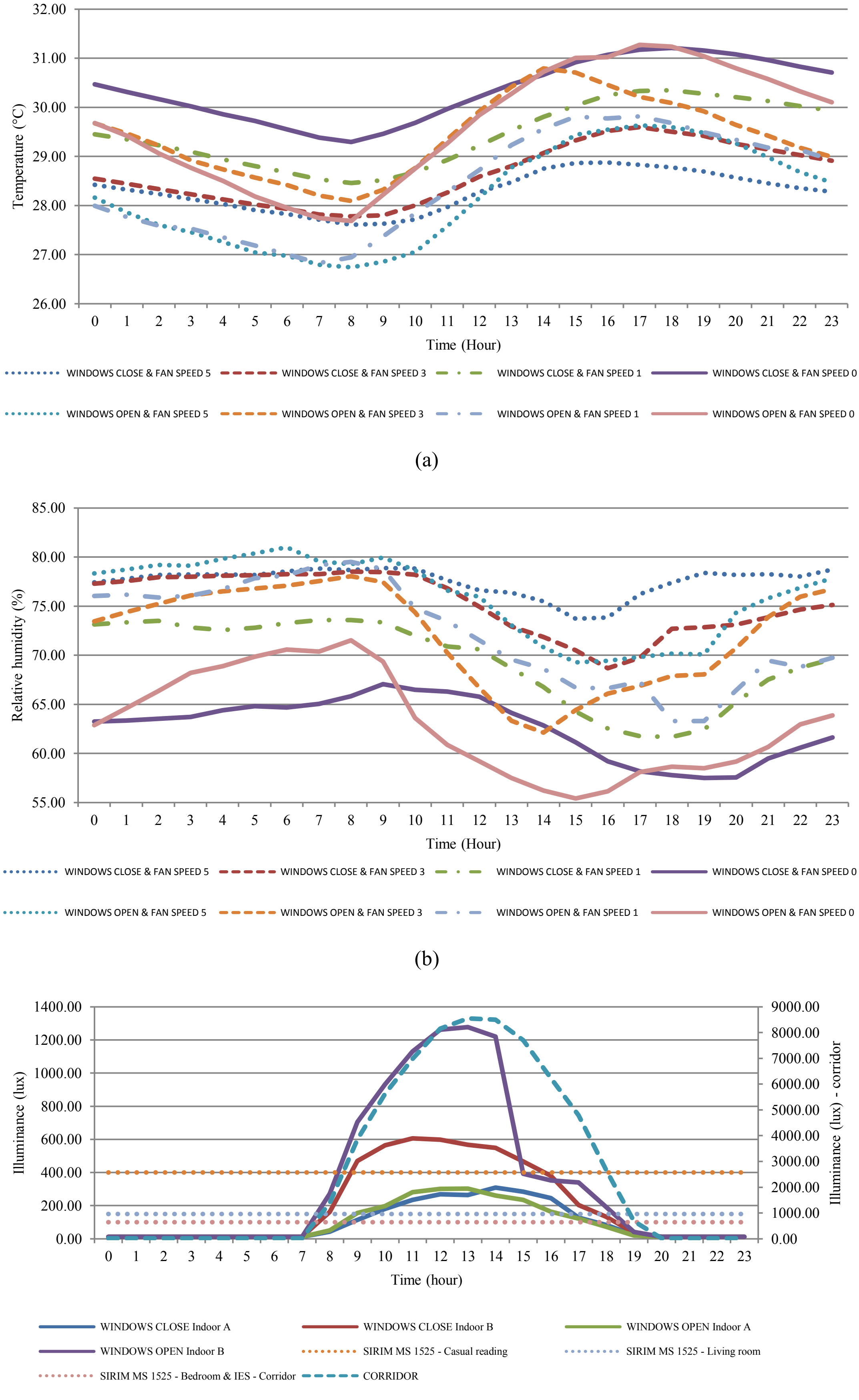
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	77.99 (Max-min:72.82-81.11,SD:2.21)	77.76 (Max-min:72.33-80.91,SD:2.23)	82.26 (Max-min:65.32-88.61,SD:5.52)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	74.89 (Max-min:66.25-81.61,SD:2.80)	74.36 (Max-min:65.76-81.37,SD:2.92)	77.47 (Max-min:56.97-87.05,SD:7.60)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	68.52 (Max-min:58.23-78.10,SD:4.89)	67.89 (Max-min:57.48-78.08,SD:5.00)	69.53 (Max-min:50.00-81.75,SD:9.21)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	62.40 (Max-min:54.51-69.27,SD:3.31)	62.27 (Max-min:55.51-69.32,SD:3.33)	63.17 (Max-min:44.92-76.25,SD:7.88)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	70.51 (Max-min:54.41-81.61,SD:7.11)	70.15 (Max-min:55.51-81.37,SD:7.10)	72.62 (Max-min:44.92-88.61,SD:10.8)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	77.22 (Max-min:60.42-84.98,SD:5.78)	76.03 (Max-min:60.23-83.21,SD:5.31)	75.97 (Max-min:56.40-84.14,SD:7.38)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	74.11 (Max-min:57.04-88.33,SD:8.81)	72.69 (Max-min:56.97-86.20,SD:8.15)	73.09 (Max-min:52.48-89.08,SD:10.3)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	71.66 (Max-min:52.68-81.69,SD:6.63)	70.79 (Max-min:51.09-80.43,SD:6.79)	70.11 (Max-min:47.10-83.28,SD:8.88)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	63.84 (Max-min:49.17-77.38,SD:6.99)	63.30 (Max-min:47.59-77.24,SD:7.19)	62.97 (Max-min:40.94-79.95,SD:9.54)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	71.28 (Max-min:49.17-88.33,SD:8.79)	70.30 (Max-min:47.59-86.20,SD:8.47)	70.12 (Max-min:40.94-89.08,SD:10.4)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	77.60 (Max-min:60.42-84.98,SD:4.38)	76.90 (Max-min:60.23-83.21,SD:4.15)	79.12 (Max-min:56.40-88.61,SD:7.22)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	74.50 (Max-min:57.04-88.33,SD:6.52)	73.52 (Max-min:56.97-86.20,SD:6.16)	75.28 (Max-min:52.48-89.08,SD:9.29)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	70.09 (Max-min:52.68-81.69,SD:6.02)	69.34 (Max-min:51.09-80.43,SD:6.12)	69.82 (Max-min:47.10-83.28,SD:9.02)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	63.12 (Max-min:49.17-77.38,SD:5.50)	62.79 (Max-min:47.59-77.24,SD:5.62)	63.07 (Max-min:40.94-79.95,SD:8.73)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	70.89 (Max-min:49.17-88.33,SD:8.00)	70.22 (Max-min:47.59-86.20,SD:7.81)	71.37 (Max-min:40.94-89.08,SD:10.6)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	94.38 (Max-min:11.80-429.70,SD:116.82)	197.88 (Max-min:3.90-965.80,SD:258.93)	2,583.03 (Max-min:11.80-11,971.50,SD:3,373.63)
Open	87.58 (Max-min:11.80-453.30,SD:453.30)	176.02 (Max-min:3.90-855.40,SD:243.49)	2,710.42 (Max-min:11.80-12,933.30,SD:3,553.16)
Overall	90.98 (Max-min:11.80-453.30,SD:114.31)	186.95 (Max-min:3.90-965.80,SD:251.37)	2,646.72 (Max-min:11.80-12,933.30,SD:3,462.44)

Statistically, there were no differences in the mean temperature and relative humidity at the two different sides of walls in the room known as Indoor A and B. The mean temperature was 29°C and the recorded temperatures were between 26°C and 32°C. The average relative humidity was 70%, with a minimum value of 48% and a maximum value of 88%. Along the corridor, the same value of mean temperature and relative humidity were recorded with readings of between 25°C and 33°C for temperature and between 41% to 89% of relative humidity.

According to Table 5.8, there were no significant differences or changes seen in the mean temperature and relative humidity values when opening or closing all of the windows in the room. In contrast, the reduction of fan speed would consistently and drastically increase the room temperature from 1°C to 3°C, and reduce the relative humidity from 13% to 16%. In comparison to the room and corridor, the UM microclimate had a lower mean temperature of 28°C and a higher mean relative humidity percentage of 79% with maximum value of 97%.

Further analysis of the daily patterns show that indoor temperatures would gradually decrease until it reaches the minimum value at 0800 hours and progressively increase to the maximum at 1700 hours, exceeding 31°C as presented in Figure 5.17. There was more than a 1°C difference between the minimum and the maximum values. After 1800 hour, the indoor temperature began and continued to decline by less than 1°C. According to Figure 5.17(a), the indoor temperature decreased with the increasing speed of the fan, especially when all the windows were closed. At similar fan speeds, the temperature was further reduced by the opening of windows. In comparison, the indoor temperatures were not reduced when the fan speed was increased while the windows were already open. There were also instances of higher temperatures recorded at higher fan speeds.



(a)

(b)

(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.17: The indoor daily pattern of scenario B1 and B4

The same pattern was also observed in the indoor relative humidity but with an inverse relationship, as the increase of temperature reduces the relative humidity [Figure 5.17(b)]. These daily patterns show that the fan speed and state of windows have influence on the values of indoor temperature and relative humidity.

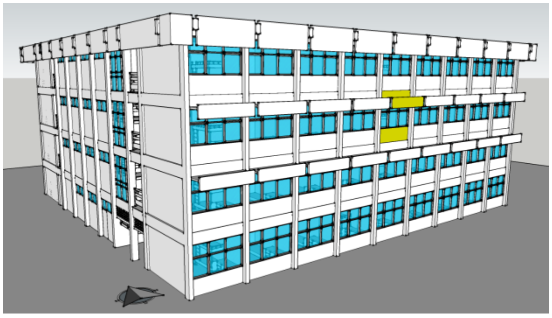
In terms of illuminance, there were significant differences of values between readings at Indoor A and B. The mean illuminance value at Indoor B was 187 lux with a maximum value of 966 lux. This was 2 times higher than readings at Indoor A which was 91 lux with a maximum value of 453 lux (Table 5.8). The adequacy of daylight in the room met the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms, with values recorded exceeding 400 lux particularly from 8 a.m. to 4 p.m., as presented in Figure 5.17(c). The openings of windows were found to considerably influence the illuminance values in the room. When the windows were open, the variances in the mean illuminance values were much lower with the range of 6 lux for Indoor A and 22 lux for Indoor B. Finally, the adequacy of daylight in the corridor met the IES minimum requirement particularly from 8 a.m. to 7 p.m. where its maximum illuminance value was 12,933 lux with a 2,647 lux mean value.

b) Scenario B2

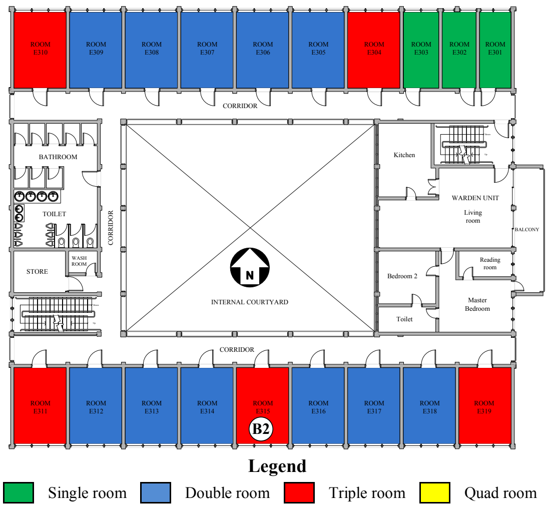
The detail description of the scenario, the location of the selected student room that represent the identified scenario and the position of data loggers are shown in Table 5.9 below.

Table 5.9: The detail description of the scenario B2, the location of the selected student room and the position of data loggers

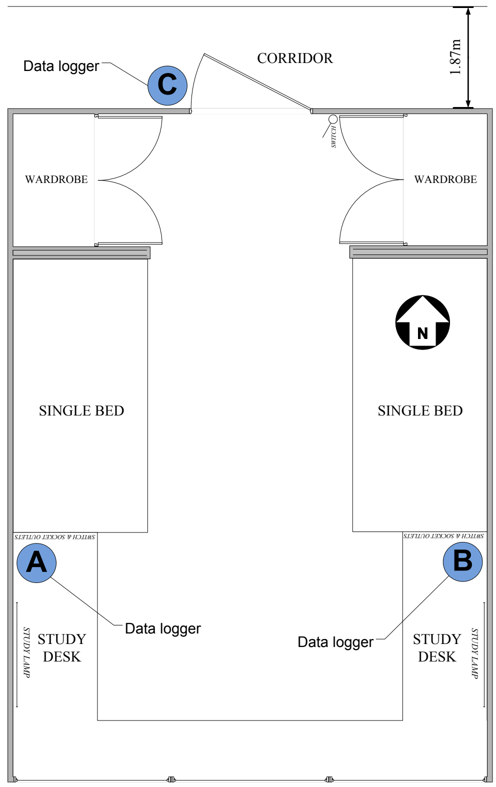
Scenario	Room	Description
B2	E 315	Receiving reflected heat radiation and penetration either from the west or east. Whilst, not influenced with direct heat radiation and penetration by man-made surface either on the top or ground. *(Keyword: South orientation)*
Location of the student room and the position of data loggers		



Residential building rear isometric elevation

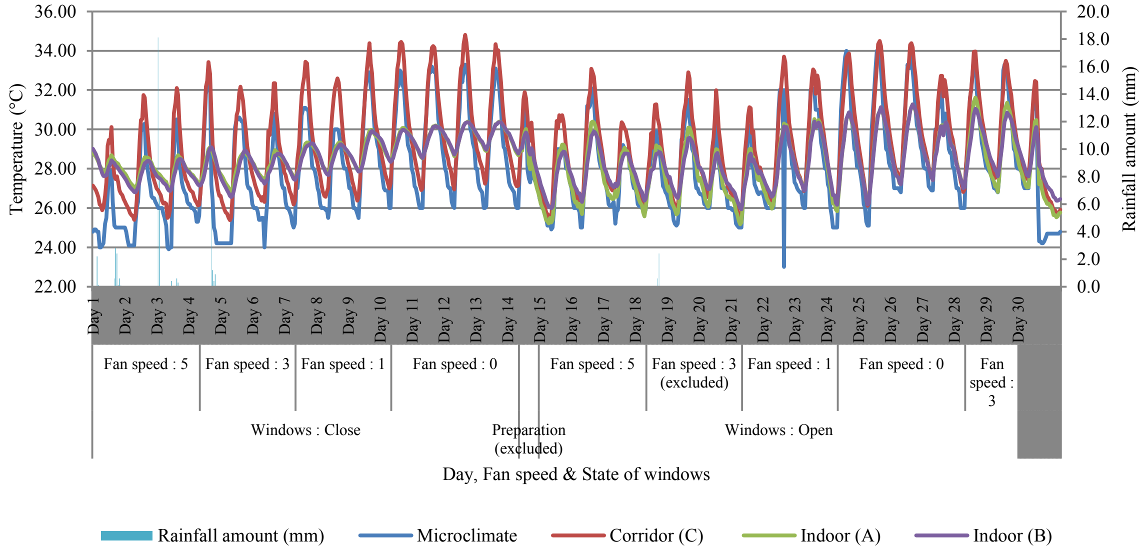


Floor plan of Level 3, Block E

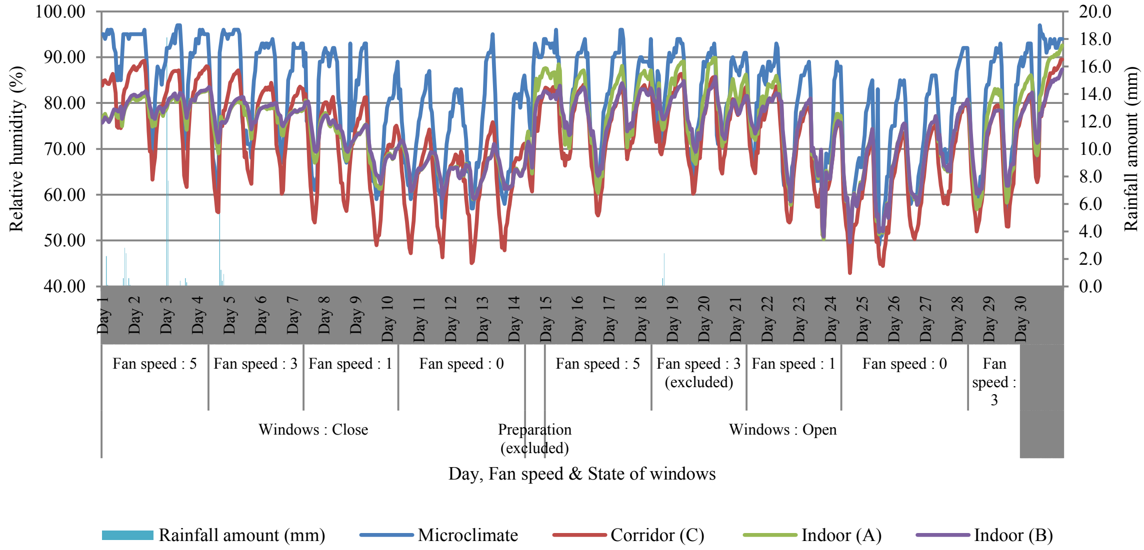


Floor plan of room E 315

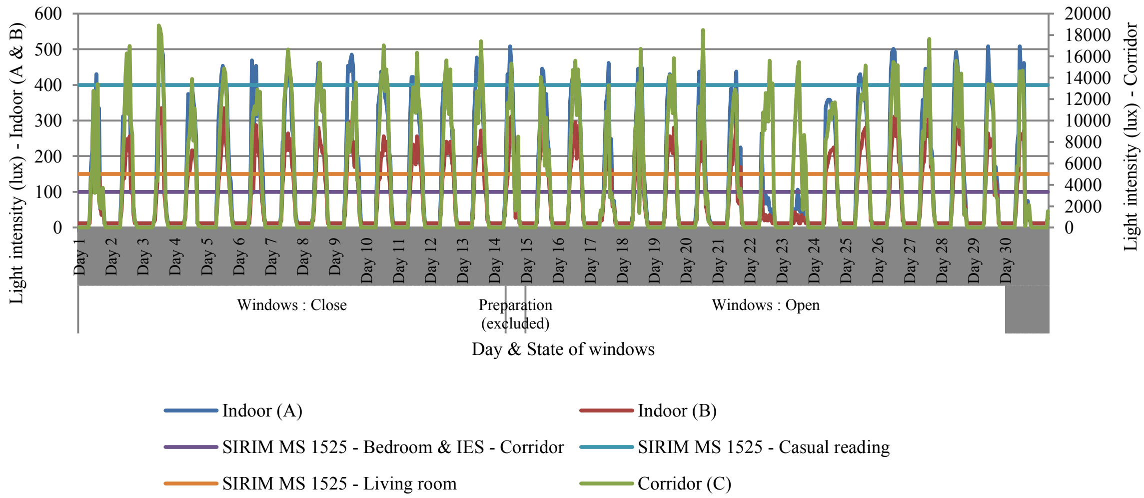
The indoor and microclimate profile which cover the temperature (ºC), relative humidity (%) and illuminance (lux) in room E 315 representing scenario B2 is shown in Figure 5.18 and its statistical data presented in Table 5.10.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.18: The indoor and microclimate profile of scenario B2

Table 5.10: The statistical analysis of temperature, relative humidity and illuminance values of scenario B2 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	27.92 (Max-min:26.99-28.84,SD:0.50)	27.76 (Max-min:26.79-29.02,SD:0.54)	27.58 (Max-min:25.40-32.10,SD:1.74)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	28.09 (Max-min:26.84-29.09,SD:0.58)	27.97 (Max-min:26.55-29.09,SD:0.67)	28.50 (Max-min:25.38,SD:33.42)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	28.82 (Max-min:27.63-29.97,SD:0.60)	28.77 (Max-min:27.55-29.92,SD:0.62)	29.54 (Max-min:26.38-34.39,SD:2.21)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	29.59 (Max-min:28.52-30.39,SD:0.53)	29.59 (Max-min:28.42-30.37,SD:0.52)	30.47 (Max-min:26.92-34.81,SD:2.42)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	28.66 (Max-min:26.84-30.39,SD:0.88)	28.58 (Max-min:26.55-30.37,SD:0.95)	29.09 (Max-min:25.38-34.81,SD:2.43)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.41 (Max-min:25.21-30.39,SD:1.41)	27.72 (Max-min:25.99-29.89,SD:1.41)	28.26 (Max-min:25.57-33.08,SD:1.94)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	28.40 (Max-min:25.53-31.61,SD:1.78)	28.74 (Max-min:26.38-31.05,SD:1.35)	29.37 (Max-min:25.67-33.97,SD:2.35)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	28.12 (Max-min:25.84-30.52,SD:1.37)	28.19 (Max-min:26.16-30.39,SD:1.19)	29.13 (Max-min:25.99-33.70,SD:2.16)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	29.03 (Max-min:26.23-31.28,SD:1.33)	29.01 (Max-min:26.18-31.28,SD:1.34)	30.20 (Max-min:26.11-34.49,SD:2.31)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	28.28 (Max-min:25.21-31.61,SD:1.58)	28.44 (Max-min:25.99-31.28,SD:1.33)	29.28 (Max-min:25.57-34.49,SD:2.30)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	27.67 (Max-min:25.21-30.39,SD:1.09)	27.74 (Max-min:25.99-29.89,SD:0.81)	27.92 (Max-min:25.40-33.08,SD:1.87)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.25 (Max-min:25.53-31.61,SD:1.33)	28.36 (Max-min:26.38-31.05,SD:1.13)	28.94 (Max-min:25.38-33.97,SD:2.30)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	28.47 (Max-min:25.84-30.52,SD:1.11)	28.48 (Max-min:26.16-30.39,SD:0.99)	29.34 (Max-min:25.99-34.39,SD:2.19)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	29.31 (Max-min:26.23-31.28,SD:1.05)	29.30 (Max-min:26.18-31.28,SD:1.05)	30.34 (Max-min:26.11-34.81,SD:2.36)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	28.47 (Max-min:25.21-31.61,SD:1.29)	28.51 (Max-min:25.99-31.28,SD:1.16)	29.19 (Max-min:25.38-34.81,SD:2.37)	28.12 (Max-min:23.00-34.00,SD:2.51)

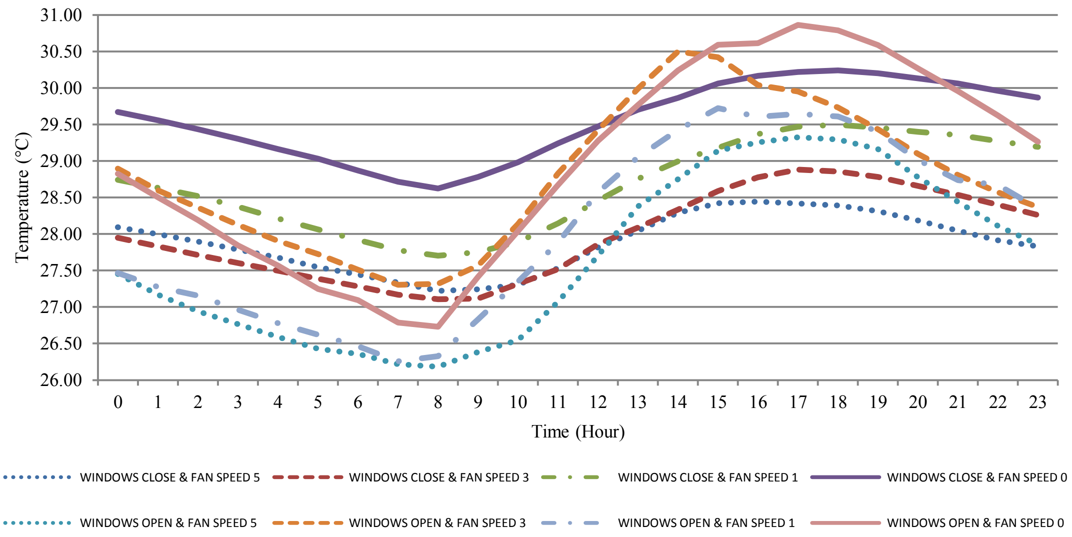
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	79.29 (Max-min:74.19-82.82,SD:2.22)	79.93 (Max-min:75.68-83.14,SD:2.11)	81.58 (Max-min:61.64-89.21,SD:7.02)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	77.38 (Max-min:69.02-83.23,SD:2.54)	78.09 (Max-min:71.39-83.52,SD:2.33)	76.34 (Max-min:56.14-87.15,SD:8.40)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	71.34 (Max-min:61.28-80.59,SD:)	72.04 (Max-min:62.37-80.38,SD:4.31)	69.10 (Max-min:49.00-82.00,SD:9.43)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	65.13 (Max-min:59.01-70.92,SD:2.96)	65.23 (Max-min:59.01-71.84,SD:3.10)	61.90 (Max-min:45.08-75.85,SD:8.24)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	72.84 (Max-min:59.01-83.23,SD:6.62)	73.35 (Max-min:59.01-83.52,SD:6.74)	71.72 (Max-min:45.08-89.21,SD:11.3)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	79.87 (Max-min:60.43-88.43,SD:7.39)	78.24 (Max-min:64.12-84.36,SD:5.05)	75.89 (Max-min:55.48-84.68,SD:7.81)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	77.27 (Max-min:56.80-92.55,SD:10.5)	75.16 (Max-min:60.23-87.37,SD:7.58)	73.00 (Max-min:51.94-89.50,SD:10.8)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	73.58 (Max-min:50.30-85.94,SD:8.34)	73.12 (Max-min:50.87-82.19,SD:7.45)	69.96 (Max-min:50.64-83.64,SD:8.88)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	66.46 (Max-min:50.07-80.52,SD:8.04)	66.51 (Max-min:49.61-80.80,SD:8.03)	62.44 (Max-min:42.89-80.23,SD:9.86)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	73.87 (Max-min:50.07-92.55,SD:10.0)	72.89 (Max-min:49.61-87.37,SD:8.44)	69.89 (Max-min:42.89-89.50,SD:10.7)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	79.58 (Max-min:60.43-88.43,SD:5.44)	79.08 (Max-min:64.12-84.36,SD:3.95)	78.74 (Max-min:55.48-89.21,SD:7.93)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	77.33 (Max-min:56.80-92.55,SD:7.60)	76.63 (Max-min:60.23-87.37,SD:5.78)	74.67 (Max-min:51.94-89.50,SD:9.78)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	72.46 (Max-min:50.30-85.94,SD:6.87)	72.58 (Max-min:50.87-82.19,SD:6.09)	69.53 (Max-min:49.00-83.64,SD:9.14)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	65.80 (Max-min:50.07-80.52,SD:6.08)	65.87 (Max-min:49.61-80.80,SD:6.10)	62.17 (Max-min:42.89-80.23,SD:9.07)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	73.36 (Max-min:50.07-92.55,SD:8.52)	73.12 (Max-min:49.61-87.37,SD:7.64)	70.80 (Max-min:42.89-89.50,SD:11.1)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	136.60 (Max-min:11.80-508.50,SD:164.82)	78.88 (Max-min:11.80-335.10,SD:91.47)	3,957.35 (Max-min:3.90-18,893.40,SD:5,420.38)
Open	116.80 (Max-min:11.80-508.50,SD:155.13)	73.31 (Max-min:11.80-358.70,SD:93.92)	3,738.62 (Max-min:11.80-17,624.10,SD:5,142.24)
Overall	126.70 (Max-min:11.80-508.50,SD:160.23)	76.10 (Max-min:11.80-358.70,SD:92.67)	3,847.99 (Max-min:3.90-18,893.40,SD:5,280.16)

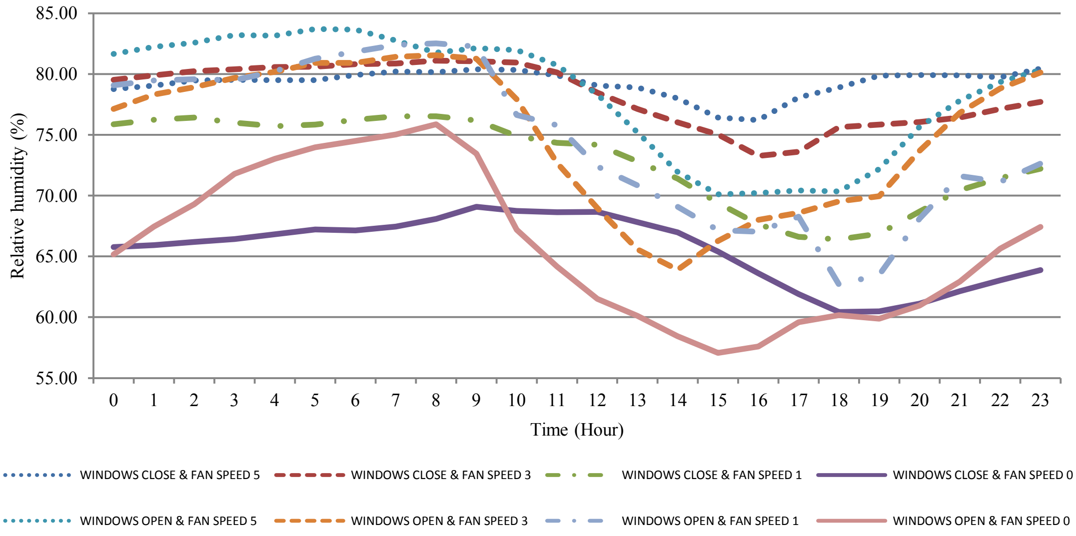
Statistically, there were differences in the mean temperatures at the two different sides of the walls in the room; Indoor A and B. The mean temperature at Indoor A was 28°C with recorded temperatures of between 25°C and 32°C while at Indoor B, the mean temperature is 1°C higher compared to Indoor A with recorded temperatures of between 26°C and 31°C. The relative humidity of the both sides reached 73%, with a minimum value of 50% and a maximum value of 93%. In the corridor, the mean temperature value was only marginally higher at 29°C with measured values of between 25°C to 35°C. A lower relative humidity percentage was recorded in the corridor which was 71% with minimum and maximum percentages of 43% and 90%, respectively.

A shown by Table 5.10, there was a 1°C mean temperature reduction and increments of 1% in mean relative humidity with the opening of windows. The reduction of fan speed drastically increased the room temperature in the range of 1°C to 2°C, and consistently reduced the relative humidity by a margin of 11% to 15%. In comparison to the room and corridor, the UM microclimate has a lower mean temperature of 28°C and a higher mean relative humidity percentage of up to 79%. The maximum recorded relative humidity value of the UM microclimate was 97%.

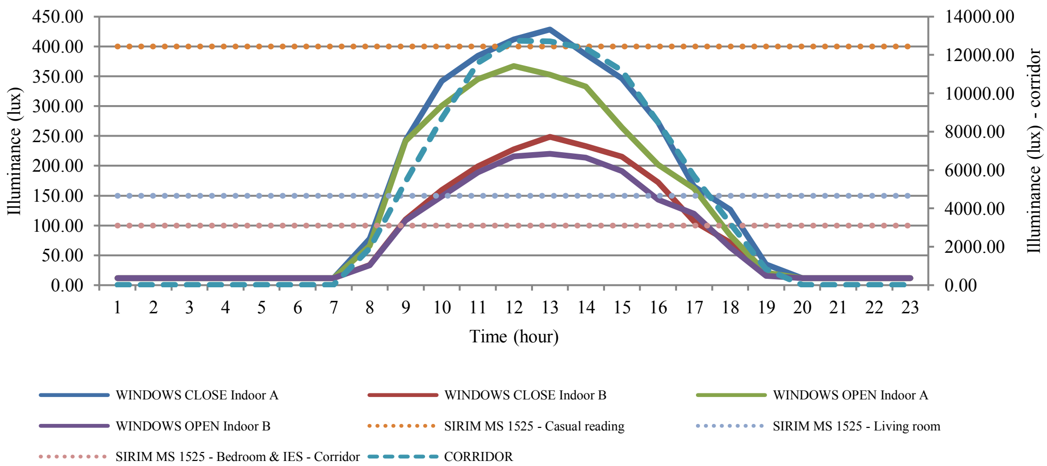
A further analysis of the daily pattern show that the indoor temperature gradually decreased to the minimum value at 0800 hours and progressively increased to the maximum at 1700 hours, exceeding 30°C as presented in Figure 5.19. There was more than a 1°C margin of difference between the minimum and the maximum indoor temperature values. After 1800 hours, the indoor temperature began to continuously decline until reaching a value, lower by less than 1°C. Referring to Figure 5.19(a), the indoor temperature decreased when the fan speed was increased especially when all the windows were closed. At similar fan speeds, the temperature was further reduced by the opening of the windows.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.19: The indoor daily pattern of scenario B2

However the indoor temperatures were not reduced with the increase of fan speed for when the windows were open. Instead there were instances where higher temperatures were recorded with higher fan speeds. The same pattern was also observed in the indoor relative humidity percentages but with an inverse relationship, as the increase of temperature would tend to reduce the relative humidity values [Figure 5.19(b)]. These daily patterns therefore show that the fan speed and state of windows have influence on the values of indoor temperatures and relative humidity.

With regard to illuminance, there were significant differences in the recorded values of Indoor A and B. The mean illuminance value of Indoor A was 127 lux with a maximum value of 509 lux, which was higher than that of Indoor B with 76 lux and a maximum value of 359 lux as presented in Table 5.10. The adequacy of daylight in the room partially met the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms, particularly at Indoor A from 10 a.m. to 2 p.m. [Figure 5.19(c)]. The opening of the windows considerably influenced the illuminance values in the room. The mean illuminance value was much lower however with a variance of between 20 lux for Indoor A and 6 lux for Indoor B when the windows were open. Finally, the adequacy of daylight in the corridor met the IES minimum requirement from 8 a.m. to 7 p.m. with a maximum value of 18,893 lux and a mean value of 3,848 lux.

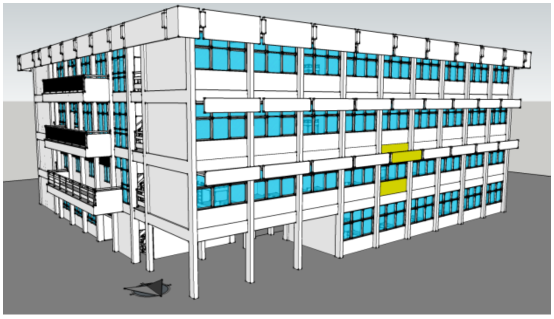
c) Scenario B3 and W5

The detail description of these scenarios, the location of the selected student room that represent the identified scenarios and the position of data loggers are shown in Table 5.11 below. This selected room was evaluated to represent two different scenarios.

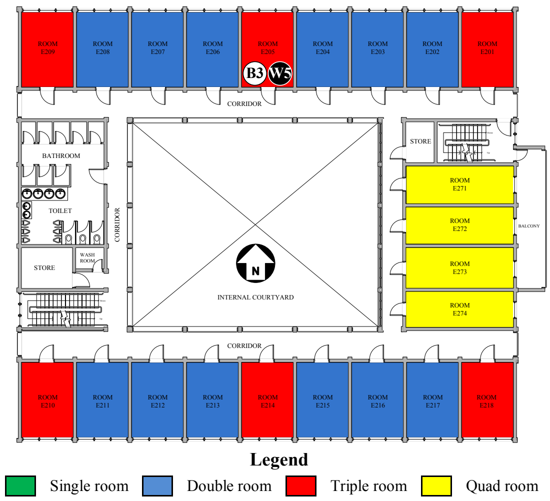
Table 5.11: The detail description of the scenario B3, W5, the location of the selected student room and the position of data loggers

Scenario	Room	Description
B3	E 205	Not receiving direct heat radiation and penetration from man-made surfaces on the top, i.e. roof, wall etc. and with north-south building orientation. *(Keyword: Avoiding direct contact with man-made surfaces on the top)*
W5	E205	Exposed to open spaces and with a north-south building orientation. Whilst, not affected by directing heat radiation and penetration man-made surface either from the top or ground. *(Keyword: Exposed)*

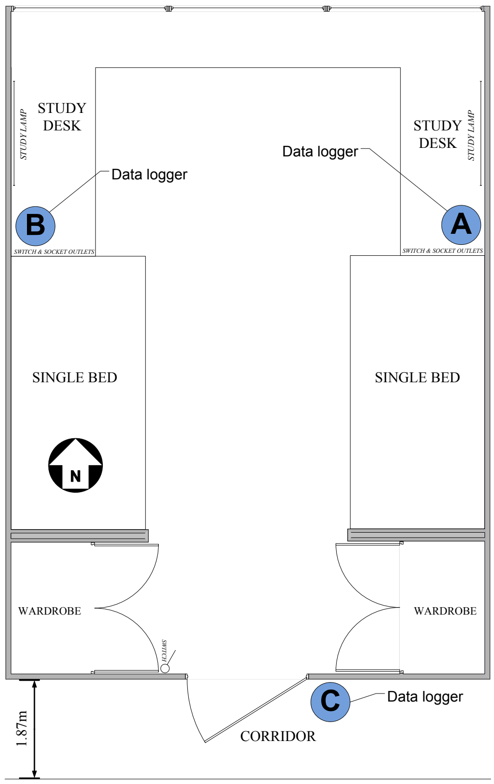
Location of the student room and the position of data loggers



Residential building front isometric elevation

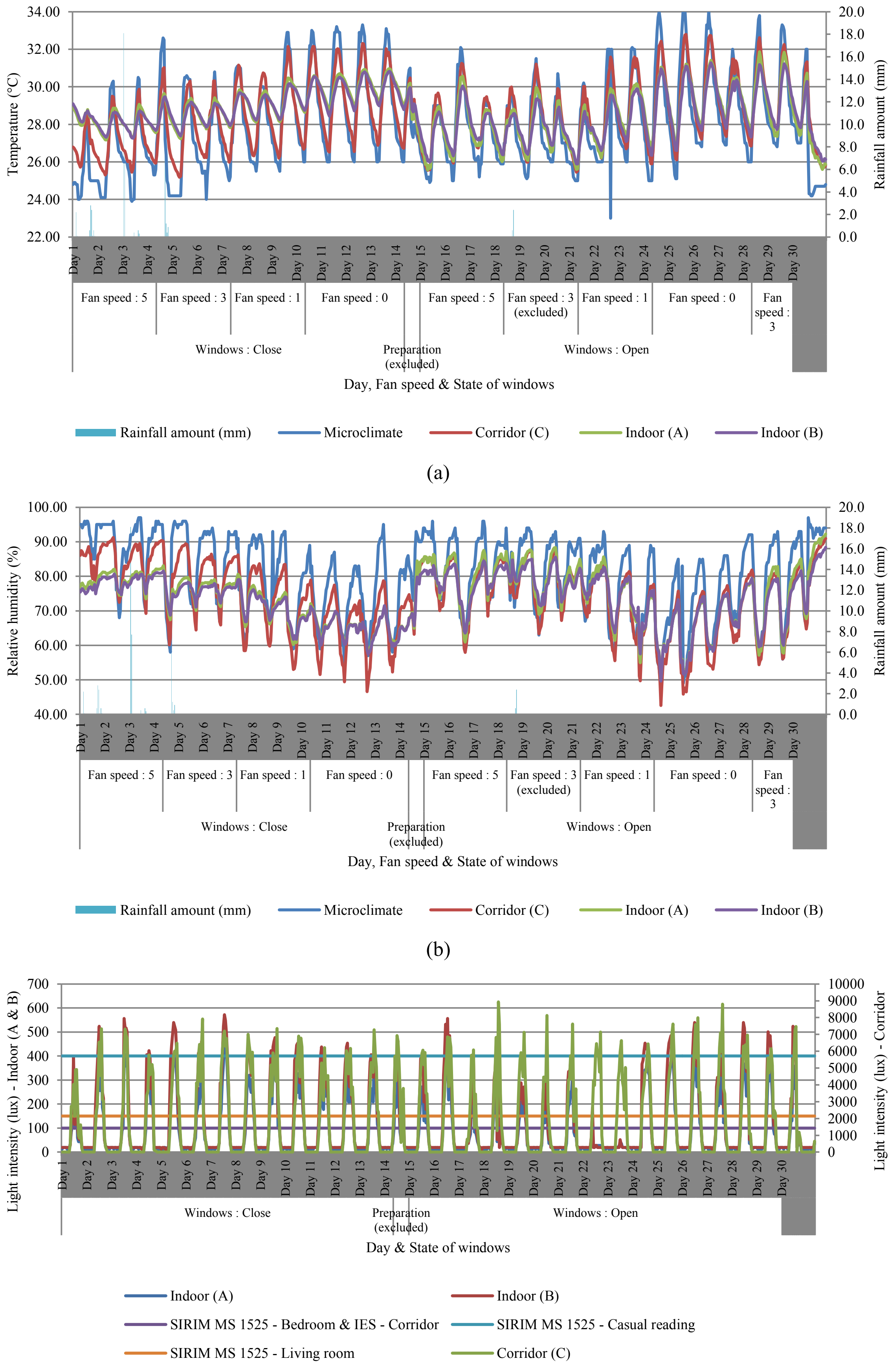


Floor plan of Level 2, Block E



Floor plan of room E 205

The indoor and microclimate data, which consist of temperature (ºC), relative humidity (%) and illuminance (lux) in room E 205 which were used represent scenario B3 and W5, are shown in Figure 5.20 and its statistical analysis presented in Table 5.12.



(a)

(b)

(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.20: The indoor and microclimate profile of scenario B3 and W5

Table 5.12 : The statistical analysis of temperature, relative humidity and illuminance values of scenario B3 and W5 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	28.13 (Max-min:27.16-29.07,SD:0.50)	28.14 (Max-min:27.26-29.09,SD:0.45)	26.94 (Max-min:25.31-29.87,SD:1.14)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	28.49 (Max-min:27.24-29.64,SD:0.62)	28.49 (Max-min:27.38-29.46,SD:0.53)	27.70 (Max-min:25.19-31.03,SD:1.57)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	29.19 (Max-min:27.97-30.47,SD:0.66)	29.15 (Max-min:28.02-30.17,SD:0.57)	28.65 (Max-min:26.21-32.15,SD:1.63)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	29.98 (Max-min:28.77-30.95,SD:0.62)	29.82 (Max-min:28.44-30.82,SD:0.64)	29.36 (Max-min:26.52-32.30,SD:1.77)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	29.00 (Max-min:27.16-30.95,SD:0.95)	28.95 (Max-min:27.26-30.82,SD:0.87)	28.22 (Max-min:25.19-32.30,SD:1.82)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.62 (Max-min:25.57-30.57,SD:1.27)	27.72 (Max-min:25.99-30.04,SD:1.01)	27.79 (Max-min:25.55-31.26,SD:1.49)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	28.67 (Max-min:25.60-31.87,SD:1.82)	28.78 (Max-min:26.04-31.23,SD:1.49)	28.91 (Max-min:25.70-32.61,SD:1.95)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	28.27 (Max-min:26.23-30.17,SD:1.12)	28.10 (Max-min:26.35-29.89,SD:1.01)	28.51 (Max-min:25.89-31.59,SD:1.66)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	29.41 (Max-min:26.87-31.41,SD:1.17)	29.24 (Max-min:26.60-31.28,SD:1.22)	29.57 (Max-min:26.11-32.79,SD:1.85)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	28.54 (Max-min:25.57-31.87,SD:1.51)	28.50 (Max-min:25.99-31.28,SD:1.34)	28.73 (Max-min:25.55-32.79,SD:1.87)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	27.88 (Max-min:25.57-30.57,SD:1.00)	27.93 (Max-min:25.99-30.04,SD:0.80)	27.36 (Max-min:25.31-31.26,SD:1.39)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.58 (Max-min:25.60-31.87,SD:1.36)	28.64 (Max-min:26.04-31.23,SD:1.12)	28.30 (Max-min:25.19-32.61,SD:1.87)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	28.73 (Max-min:26.23-30.47,SD:1.03)	28.62 (Max-min:26.35-30.17,SD:0.97)	28.58 (Max-min:25.89-32.15,SD:1.64)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	29.70 (Max-min:26.87-31.41,SD:1.00)	29.53 (Max-min:26.60-31.28,SD:1.01)	29.46 (Max-min:26.11-32.79,SD:1.81)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	28.77 (Max-min:25.57-31.87,SD:1.28)	28.72 (Max-min:25.99-31.28,SD:1.15)	28.47 (Max-min:25.19-32.79,SD:1.86)	28.12 (Max-min:23.00-34.00,SD:2.51)

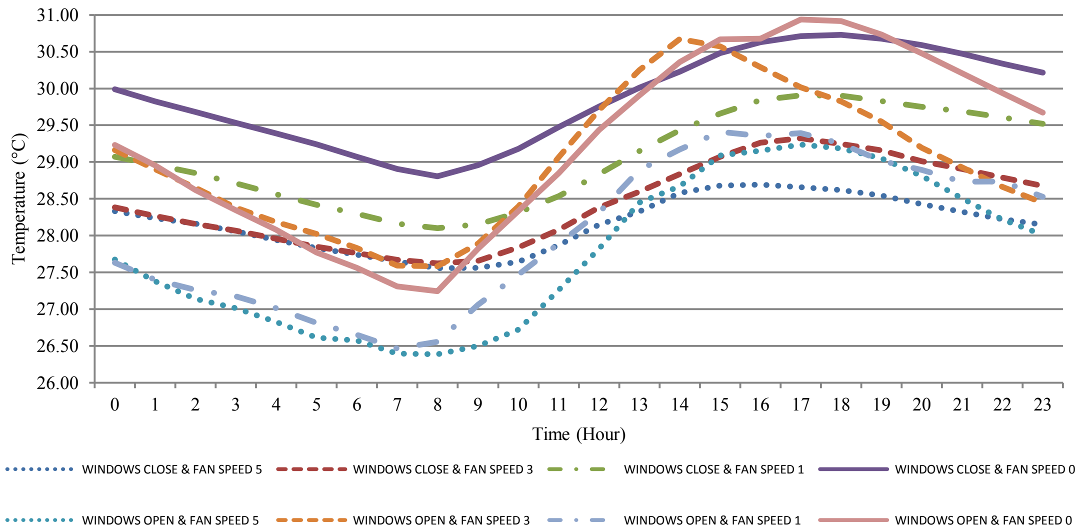
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	79.25 (Max-min:73.43-82.43,SD:2.23)	78.39 (Max-min:74.60-81.09,SD:1.92)	85.12 (Max-min:69.22-91.26,SD:5.09)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	76.48 (Max-min:67.44-83.08,SD:2.88)	75.90 (Max-min:68.72-81.55,SD:2.21)	80.18 (Max-min:60.14-90.16,SD:7.29)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	70.82 (Max-min:60.19-80.57,SD:4.92)	70.57 (Max-min:61.75-79.06,SD:4.22)	72.41 (Max-min:53.00-86.22,SD:9.17)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	65.07 (Max-min:57.89-72.05,SD:3.02)	64.76 (Max-min:57.46-71.51,SD:3.26)	65.84 (Max-min:46.60-78.89,SD:7.95)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	72.50 (Max-min:57.89-83.08,SD:6.59)	72.00 (Max-min:57.46-81.55,SD:6.25)	75.40 (Max-min:46.60-91.26,SD:10.7)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	80.05 (Max-min:60.92-87.55,SD:6.48)	78.52 (Max-min:63.59-84.46,SD:4.87)	78.56 (Max-min:57.91-86.07,SD:7.16)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	76.90 (Max-min:57.16-92.25,SD:10.3)	75.06 (Max-min:59.58-88.41,SD:8.06)	74.96 (Max-min:64.35-90.95,SD:10.3)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	73.94 (Max-min:54.95-85.61,SD:6.95)	74.05 (Max-min:57.48-82.59,SD:5.98)	72.24 (Max-min:49.75-84.64,SD:8.64)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	66.00 (Max-min:50.04-79.43,SD:7.26)	65.90 (Max-min:49.61-79.47,SD:7.48)	64.58 (Max-min:42.59-81.82,SD:9.82)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	73.77 (Max-min:50.04-92.25,SD:9.53)	72.97 (Max-min:49.61-88.41,SD:8.30)	72.15 (Max-min:42.59-90.95,SD:10.5)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	79.65 (Max-min:60.92-87.55,SD:4.85)	78.46 (Max-min:63.59-84.46,SD:3.69)	81.84 (Max-min:57.91-91.26,SD:7.01)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	76.69 (Max-min:57.16-92.25,SD:7.55)	75.48 (Max-min:59.58-88.41,SD:5.90)	77.57 (Max-min:54.35-90.95,SD:9.26)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	72.38 (Max-min:54.95-85.61,SD:6.20)	72.31 (Max-min:57.48-82.59,SD:5.44)	72.32 (Max-min:49.75-86.22,SD:8.88)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	65.53 (Max-min:50.04-79.43,SD:5.57)	65.33 (Max-min:49.61-79.47,SD:5.78)	65.21 (Max-min:42.59-81.82,SD:8.93)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	73.13 (Max-min:50.04-92.25,SD:8.21)	72.49 (Max-min:49.61-88.41,SD:7.36)	73.78 (Max-min:42.59-91.26,SD:10.7)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	100.92 (Max-min:11.80-461.20,SD:121.56)	138.08 (Max-min:11.80-571.60,SD:166.49)	1,730.01 (Max-min:11.80-7,911.40,SD:2,331.68)
Open	85.57 (Max-min:11.80-445.40,SD:114.03)	118.85 (Max-min:11.80-579.50,SD:160.20)	1,770.43 (Max-min:11.80-8,794.30,SD:2,380.91)
Overall	93.24 (Max-min:11.80-461.20,SD:118.01)	128.47 (Max-min:11.80579.50,SD:163.53)	1,750.22 (Max-min:11.80-8,794.30,SD:2,354.671)

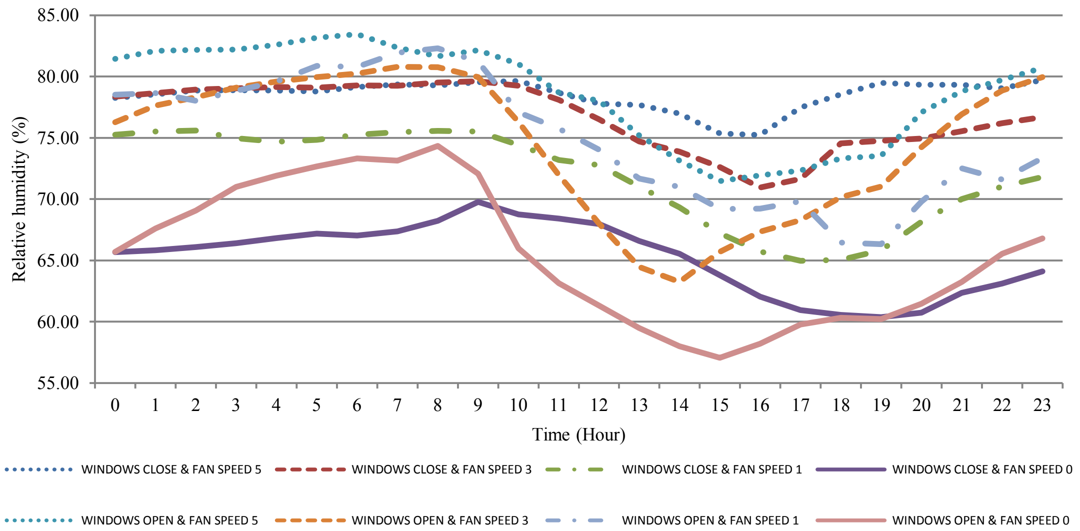
Statistically, there were no differences in the mean temperature and relative humidity at the two different sides of the walls in the room; Indoor A and B. The mean temperature was 29°C and recorded temperatures were between 26°C and 32°C. The relative humidity reached 73%, with a minimum value of 50% and a maximum value of 92%. In the corridor, a lower mean temperature value of 28°C was recorded and a higher mean relative humidity percentage of 74%. The measured values were between 25°C and 33°C; 43% and 91%, respectively.

Referring to the Table 5.12, there were no significant differences in the mean temperature when comparing all the states of all the windows in the room. However there was a 1% increment in relative humidity with the opening of all the windows. In contrast, the reduction of fan speed drastically increased the room temperature and reduced the relative humidity consistently, from 1°C to 2°C, and 13% to 14%. Compared to this, the UM microclimate had a lower mean temperature of 28°C; which was similar to the corridor mean temperature and the mean relative humidity percentages were significantly higher at 79% with a 97% maximum value.

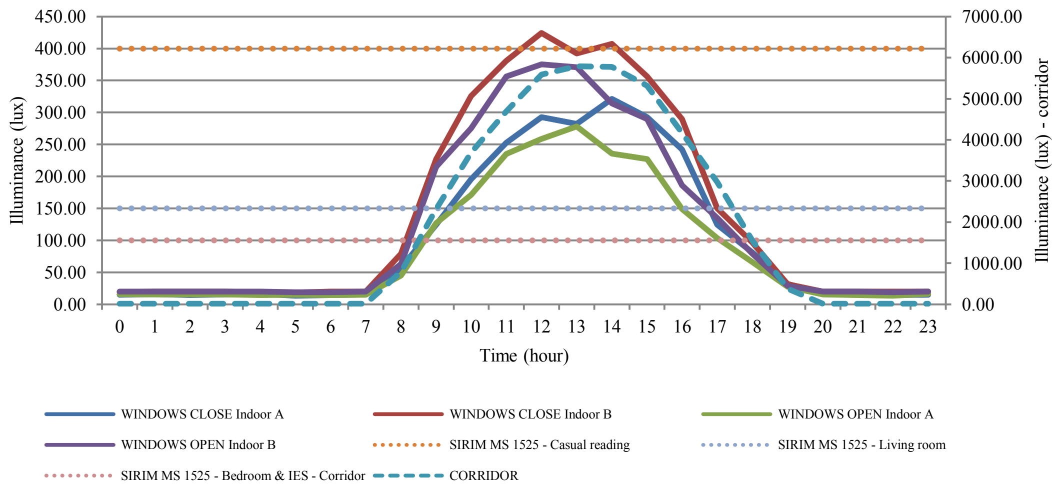
Further analysis of the daily pattern show that the indoor temperature would gradually decrease to the minimum value at 0800 hours and then proceeded to progressively increase to the maximum at 17 hours, at times exceeding 30°C as presented in Figure 5.21. There was more than a 1°C difference between the minimum and the maximum temperature values. After 1800 hours, the indoor temperature began to continuously decline to a value lower by less than 1°C. Referring to Figure 5.21(a), the indoor temperature decreased with the increasing of fan speed especially when all the windows were closed. At similar fan speeds, the temperature would further be reduced by the opening of the windows. In comparison, the indoor temperatures were not reduced with the increasing of fan speed while the windows were open. There were also instances of higher temperature recorded at higher fan speeds.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.21: The indoor daily pattern of scenario B3 and W5

The same pattern was also observed in the indoor relative humidity but on the inverse relationship, as the increase of temperature reduces the relative humidity values [Figure 5.21(b)]. These daily patterns show that the fan speed and state of windows have influence on the values of indoor temperatures and relative humidity.

There were significant differences between the illuminance value at Indoor A and B. The mean value of illuminance at Indoor B was 128 lux with a maximum value of 580 lux which was higher than that of Indoor A which was 93 lux with a maximum value of 461 lux, as presented in Table 5.12. The adequacy of daylight in the room met the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms particularly from 10 a.m. to 4 p.m. as presented in Figure 5.21(c). The opening of windows considerably influenced the illuminance values in the room. When open, the mean illuminance values were much lower with a variance of 15 lux for Indoor A and 29 lux for Indoor B. Finally, the daylight in the corridor were found to adequately meet the IES minimum requirement from 8 a.m. to 7 p.m. with a maximum value of 8,794 lux and a mean value of 1,750 lux.

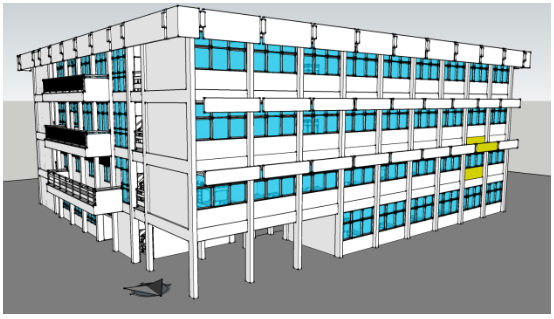
d) Scenario B5

The detail description of this scenario, the location of the selected student room that represent the identified scenario and the position of data loggers are shown in Table 5.13 below.

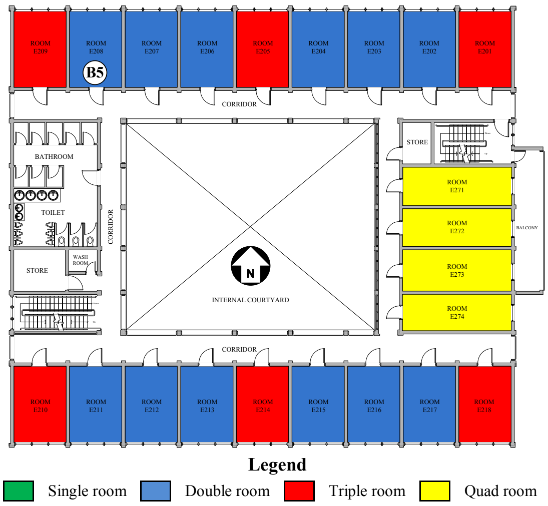
Table 5.13: The detail description of the scenario B5, the location of the selected student room and the position of data loggers

Scenario	Room	Description
B5	E 208	Shaded by landscape or trees or adjacent buildings and with a north-south building orientation. Whilst, not affected by directing heat radiation and penetration of man-made surface either from the top or ground. *(Keyword: Shaded)*

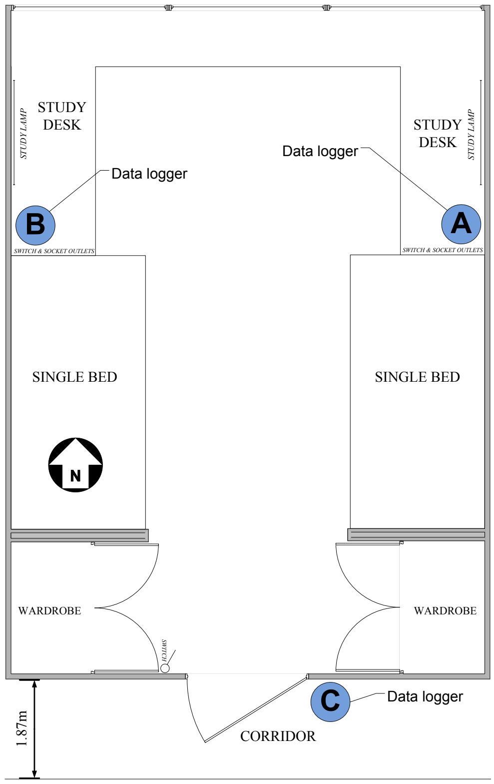
Location of the student room and the position of data loggers



Residential building front isometric elevation

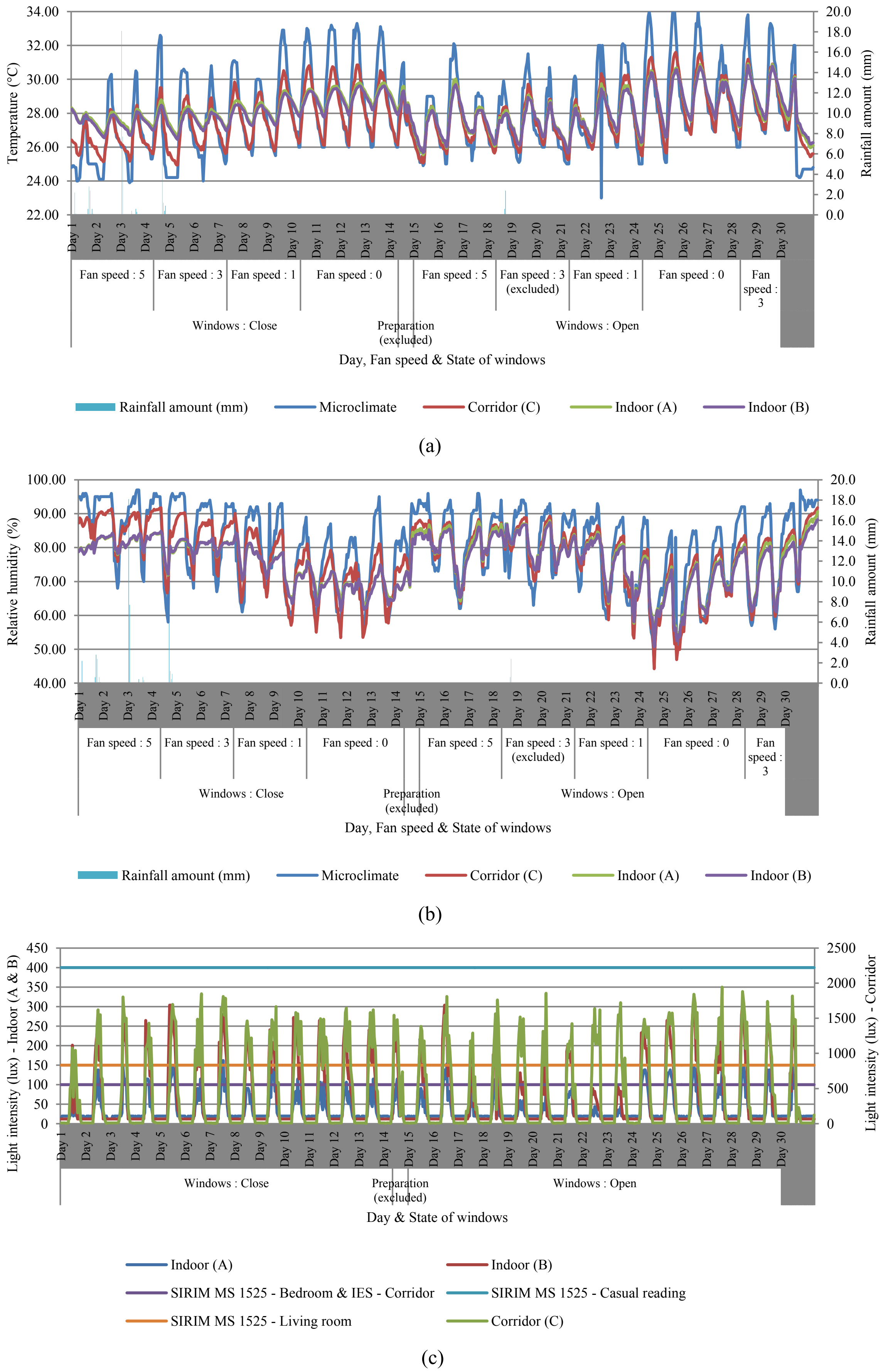


Floor plan of Level 2, Block



Floor plan of room E 208

The indoor climate and microclimate data that include the temperature (ºC), relative humidity (%) and illuminance (lux) in room E 208 and represent scenario B5, are shown in Figure 5.22 and statistically presented in Table 5.14.



(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.22: The indoor and microclimate profile of scenario B5

Table 5.14: The statistical analysis of temperature, relative humidity and illuminance values of scenario B5 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	27.57 (Max-min:26.72-28.32,SD:0.40)	27.42 (Max-min:26.55-28.25,SD:0.42)	26.37 (Max-min:25.14-28.47,SD:0.82)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	27.71 (Max-min:26.65-28.79,SD:0.51)	27.53 (Max-min26.45-28.47:,SD:0.49)	26.96 (Max-min:24.94-29.52,SD:1.24)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	28.26 (Max-min:27.21-29.34,SD:0.54)	28.11 (Max-min:27.09-29.19,SD:0.54)	27.80 (Max-min:25.77-30.52,SD:1.30)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	29.03 (Max-min:27.97-29.79,SD:0.50)	28.86 (Max-min27.75-29.62:,SD:0.51)	28.51 (Max-min:26.09-30.85,SD:1.46)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	28.19 (Max-min:26.65-29.79,SD:0.78)	28.03 (Max-min:26.45-29.62,SD:0.77)	27.46 (Max-min:24.94-30.85,SD:1.49)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.41 (Max-min:25.55-30.02,SD:1.09)	27.38 (Max-min:25.67-29.69,SD:0.97)	27.10 (Max-min:25.07-29.94,SD:1.24)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	28.54 (Max-min:25.96-30.93,SD:1.42)	28.61 (Max-min:26.18-30.82,SD:1.31)	28.24 (Max-min:25.43-31.18,SD:1.65)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	27.90 (Max-min:26.11-29.74,SD:1.03)	27.82 (Max-min:26.28-29.44,SD:0.95)	27.82 (Max-min:25.48-30.34,SD:1.39)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	28.98 (Max-min:26.57-30.87,SD:1.10)	28.93 (Max-min:26.60-30.75,SD:1.06)	28.87 (Max-min:25.65-31.59,SD:1.62)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	28.24 (Max-min:25.55-30.93,SD:1.32)	28.22 (Max-min:25.67-30.82,SD:1.25)	28.04 (Max-min:25.07-31.59,SD:1.63)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	27.49 (Max-min:25.55-30.02,SD:0.83)	27.40 (Max-min:25.67-29.69,SD:0.74)	26.74 (Max-min:25.07-29.94,SD:1.11)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.12 (Max-min:25.96-30.93,SD:1.14)	28.07 (Max-min:26.18-30.82,SD:1.13)	27.60 (Max-min:24.94-31.18,SD:1.59)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	28.08 (Max-min:26.11-29.74,SD:0.84)	27.97 (Max-min:26.28-29.44,SD:0.78)	27.81 (Max-min:25.48-30.52,SD:1.34)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	29.01 (Max-min:26.57-30.87,SD:0.86)	28.90 (Max-min:26.60-30.75,SD:0.83)	28.69 (Max-min:25.65-31.59,SD:1.55)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	28.22 (Max-min:25.55-30.93,SD:1.08)	28.12 (Max-min:25.67-30.82,SD:1.04)	27.75 (Max-min:24.94-31.59,SD:1.59)	28.12 (Max-min:23.00-34.00,SD:2.51)

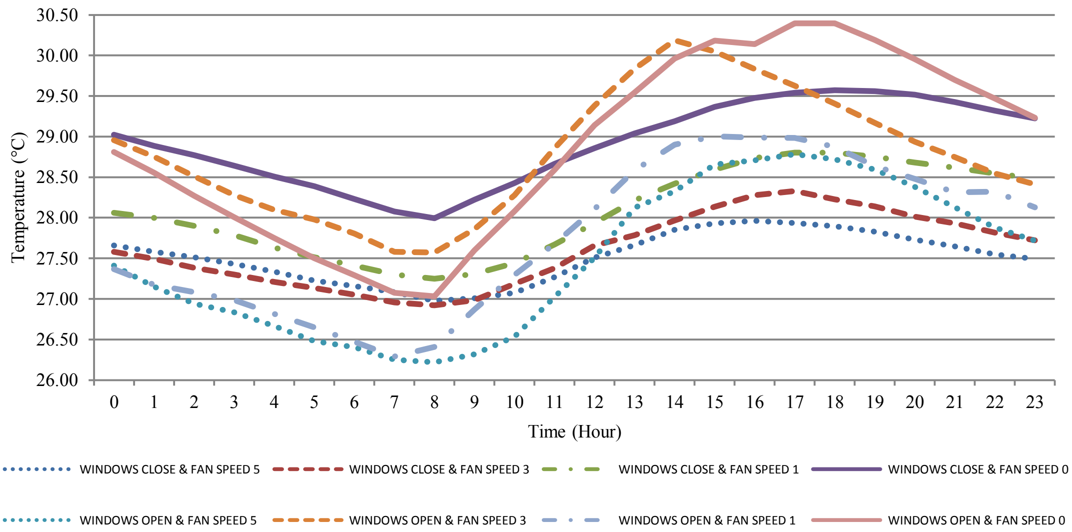
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	81.72 (Max-min:77.94-84.28,SD:1.80)	81.79 (Max-min:77.96-84.36,SD:1.90)	87.37 (Max-min:75.85-91.69,SD:3.78)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	80.12 (Max-min:71.89-84.59,SD:2.37)	80.29 (Max-min:72.13-84.83,SD:2.31)	83.20 (Max-min:66.63-91.74,SD:6.01)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	74.88 (Max-min:64.01-84.16,SD:4.73)	74.77 (Max-min:63.46-84.25,SD:4.90)	75.91 (Max-min:57.08-90.08,SD:8.26)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	68.69 (Max-min:63.22-76.25,SD:3.00)	68.31 (Max-min:61.34-76.04,SD:3.39)	69.01 (Max-min:53.45-81.13,SD:6.98)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	75.93 (Max-min:63.22-84.59,SD:6.17)	75.85 (Max-min:61.34-84.83,SD:6.44)	78.37 (Max-min:53.45-91.74,SD:9.72)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	80.99 (Max-min:64.21-87.70,SD:5.52)	80.35 (Max-min:65.31-86.08,SD:4.98)	81.54 (Max-min:63.46-88.31,SD:6.16)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	77.12 (Max-min:61.71-90.57,SD:8.10)	75.88 (Max-min:61.07-88.25,SD:7.60)	77.74 (Max-min:58.69-91.74,SD:9.27)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	75.53 (Max-min:57.67-84.61,SD:6.27)	75.18 (Max-min:58.11-83.91,SD:6.07)	75.11 (Max-min:53.31-86.48,SD:8.02)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	67.67 (Max-min:51.28-80.98,SD:7.27)	67.05 (Max-min:50.71-80.12,SD:7.25)	67.10 (Max-min:44.26-83.59,SD:9.66)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	74.91 (Max-min:51.28-90.57,SD:8.53)	74.21 (Max-min:50.71-88.25,SD:8.28)	74.92 (Max-min:44.26-91.74,SD:10.1)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	81.35 (Max-min:64.21-87.70,SD:4.11)	81.07 (Max-min:65.31-86.08,SD:3.83)	84.45 (Max-min:63.46-91.69,SD:5.88)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	78.62 (Max-min:61.71-90.57,SD:6.13)	78.09 (Max-min:61.07-88.25,SD:6.02)	80.47 (Max-min:58.69-91.74,SD:8.25)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	75.20 (Max-min:57.67-84.61,SD:5.54)	74.98 (Max-min:58.11-84.25,SD:5.50)	75.51 (Max-min:53.31-90.08,SD:8.12)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	68.18 (Max-min:51.28-80.98,SD:5.56)	67.68 (Max-min:50.71-80.12,SD:5.68)	68.05 (Max-min:44.26-83.59,SD:8.46)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	75.42 (Max-min:51.28-90.57,SD:7.46)	75.03 (Max-min:50.71-88.25,SD:7.46)	76.65 (Max-min:44.26-91.74,SD:10.1)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	37.38 (Max-min:11.80-161.60,SD:33.95)	67.59 (Max-min:11.80-303.50,SD:84.10)	421.45 (Max-min:3.90-1,848.70,SD:565.99)
Open	37.21 (Max-min:11.80-153.70,SD:36.02)	61.50 (Max-min:11.80-303.50,SD:81.30)	423.24 (Max-min:3.90-1,943.30,SD:569.73)
Overall	37.30 (Max-min:11.80-161.60,SD:35.00)	64.54 (Max-min:11.80-303.50,SD:82.70)	422.34 (Max-min:3.90-1,943.30,SD:567.42)

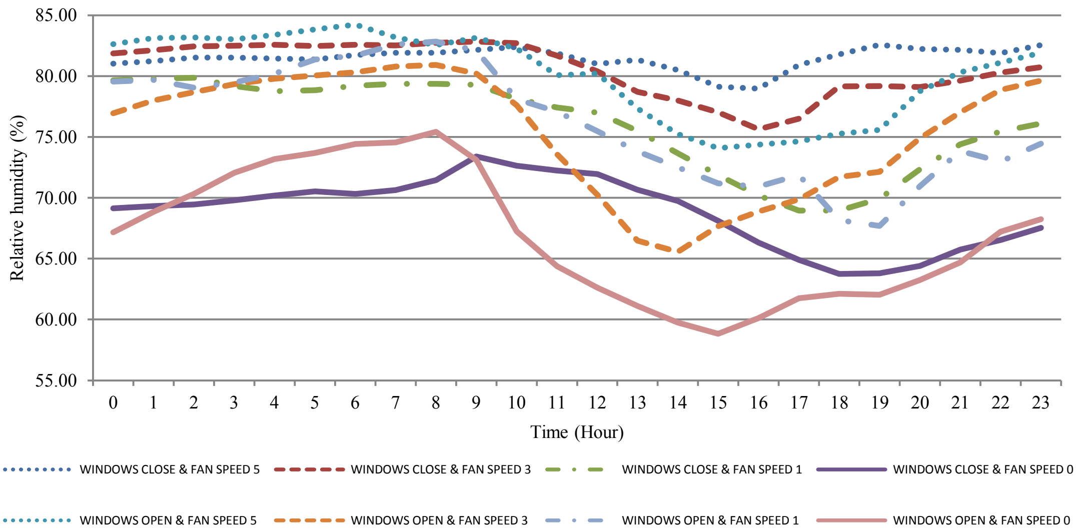
Statistically, there were no differences between the mean temperatures and relative humidity of the two different sides of the walls in the room; Indoor A and B. The mean temperature was 28°C and the recorded temperatures were between 26°C and 31°C.The relative humidity reached 75%, with a minimum value of 51% and a maximum value of 91%. The mean temperature in the corridor was similar to that of the room, 28°C with measured temperatures of between 25°C to 32°C. A higher relative humidity percentage was recorded which exceeded 77% with a minimum of 44% and a maximum percentage of 92%.

As presented in Table 5.14, there were no significant differences in the mean temperature when comparing the opened or closed state of all windows in the room. However, there was a 1% to 2% reduction in relative humidity with the opening of all windows. In contrast, the reduction of fan speed drastically increased the room temperature by a margin of 1°C to 2°C and reduces the relative humidity by a margin of 13% to 14% consistently. The room and corridor had the same mean temperatures as the UM microclimate which was 28°C. The relative humidity of the microclimate was slightly higher, exceeding 79% with a maximum of 97%.

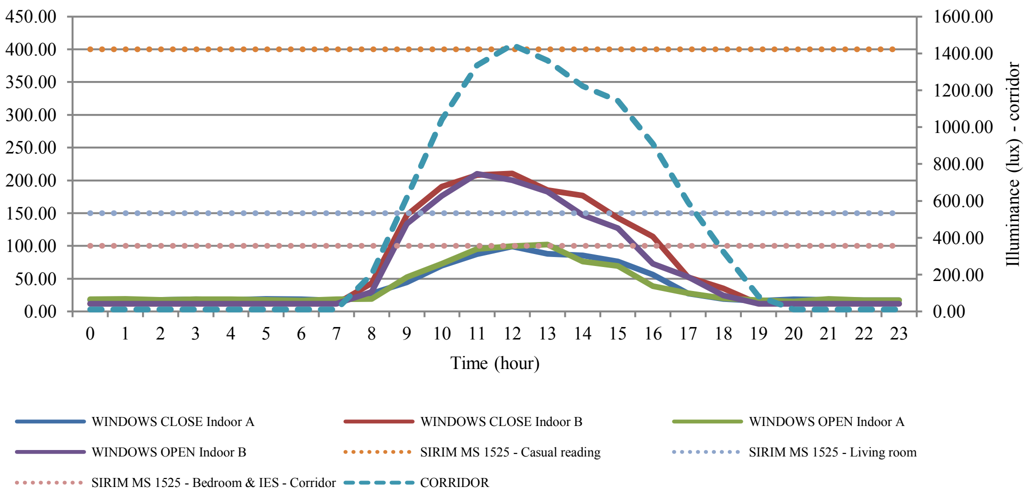
Further analysis of the daily pattern show that the indoor temperature would gradually decrease until reaching the minimum value at 0800 hours and then continue to progressively increase until reaching the maximum at 1700 hours, exceeding 30°C as presented in Figure 5.23. There was more than a 1°C margin of difference between the minimum and the maximum temperature values. After 1800 hours, the indoor temperature would continuously decline by less than 1°C. Referring to Figure 5.23(a), the indoor temperature decreased with the increase of fan speed especially when all the windows were closed. At similar fan speeds, the temperature was further reduced by the opening of windows.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.23: The indoor daily pattern of scenario B5

In comparison, the indoor temperatures were not reduced with the increase of fan speed when the windows are already open. There were also instances when higher temperatures were recorded at higher fan speeds. The same pattern was also observed in the indoor relative humidity but with an inverse relationship, as the increase of temperature reduces the relative humidity values [Figure 5.23(b)]. These daily patterns therefore show that the fan speed and state of windows have influence on the values of indoor temperatures and relative humidity.

There were significant differences between the illuminance values of Indoor A and B. The mean illuminance value at Indoor B was 65 lux with a maximum value of 304 lux which was higher than that of Indoor A with 37 lux and a maximum value of 162 lux (Table 5.13). The adequacy of daylight in the room met the MS 1525 minimum requirement for lighting in living rooms and bedrooms [Figure 5.23(c)] but not for book reading as the maximum value recorded was less than 400 lux. The opening of the windows considerably influenced the illuminance values in the room specifically at Indoor B. The illuminance mean value variance was much lower with a maximum of 6 lux while the windows were open. There was no recorded change with the illuminance at Indoor A. Finally, the adequacy of daylight in the corridor met the IES minimum requirement from 8 a.m. to 7 p.m. with a maximum value of 1,943 lux and a mean value of 422 lux.

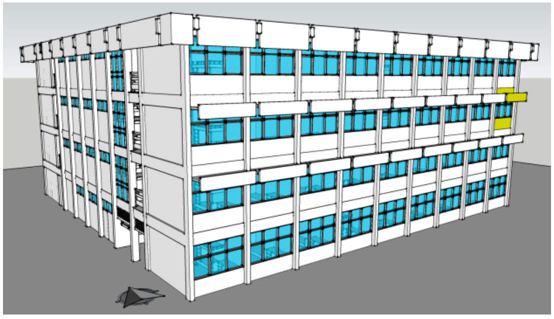
e) Scenario W1

The detail description of this scenario, the location of the selected student room that represent the identified scenario and the position of data loggers are shown in Table 5.15 below.

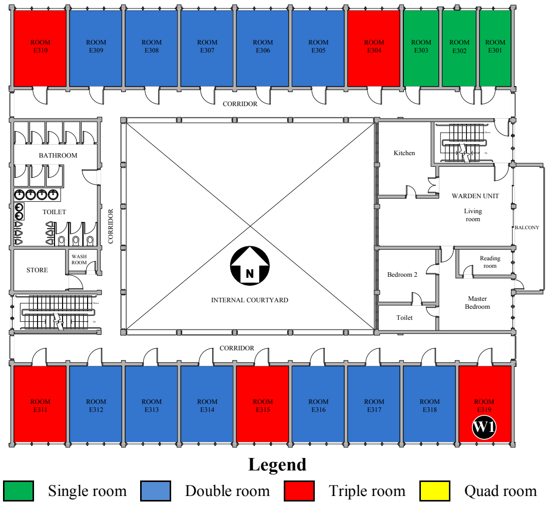
Table 5.15: The detail description of the scenario W1, the location of the selected student room and the position of data loggers

Scenario	Room	Description
W1	E 319	Receiving direct heat radiation and penetration from east. Whilst, not affected by direct heat radiation and penetration of man-made surface either on the top or ground. *(Keyword: East orientation)*

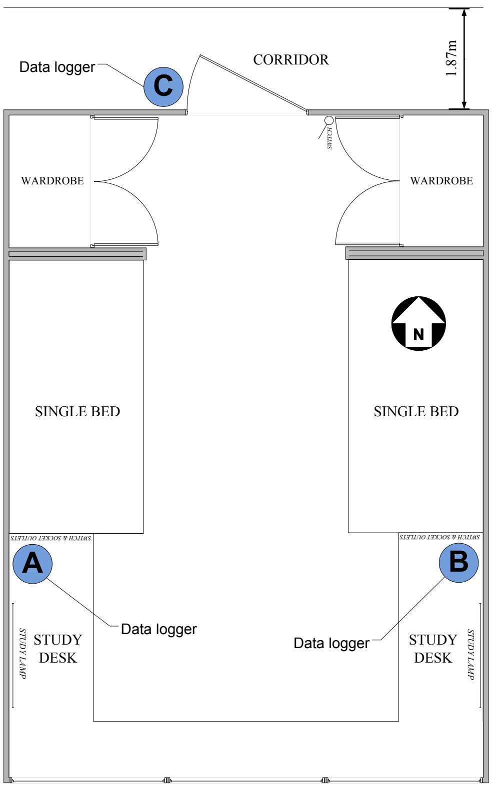
Location of the student room and the position of data loggers



Residential building rear isometric elevation

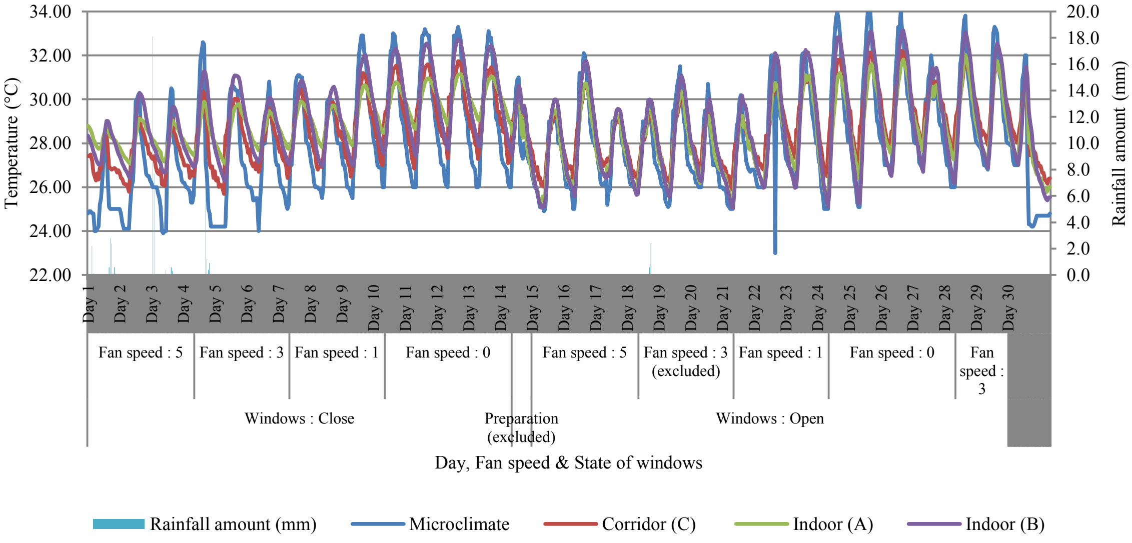


Floor plan of Level 3, Block

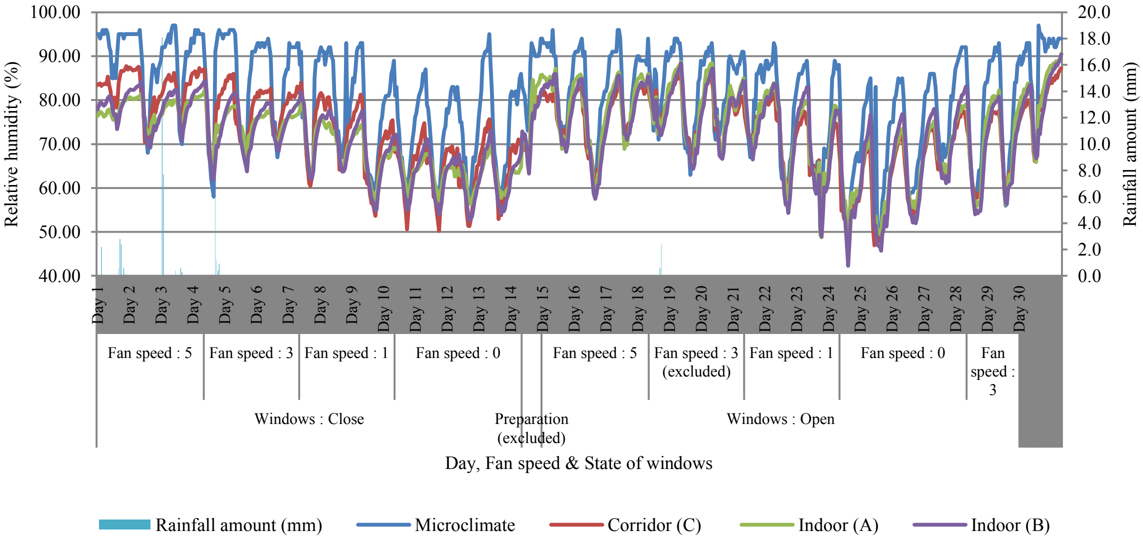


Floor plan of room E 319

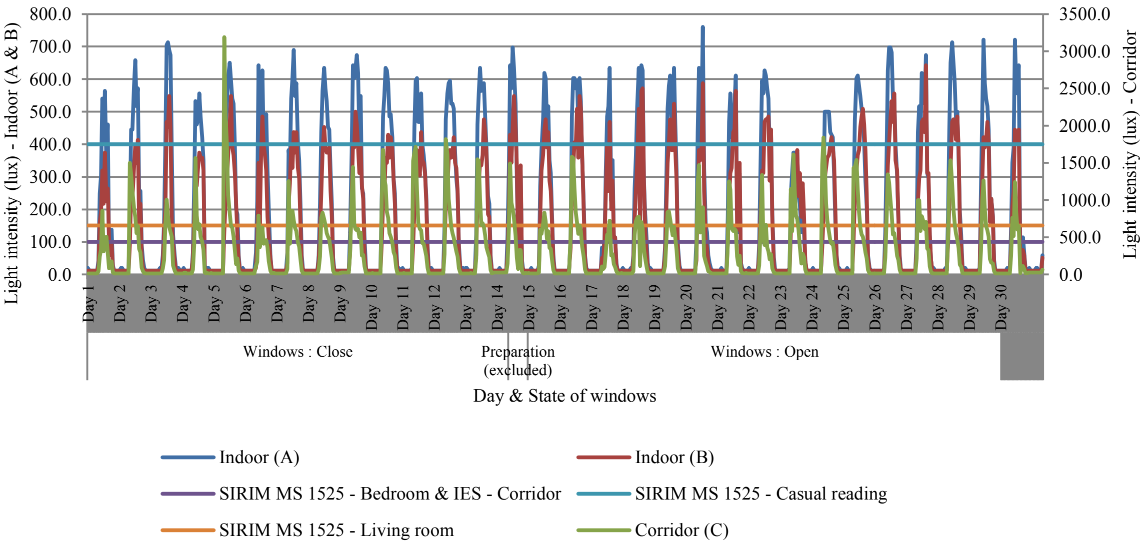
The indoor and microclimate data on the temperature (ºC), relative humidity (%) and illuminance (lux) in room E 319 which represents scenario W1 is shown in Figure 5.24 and its statistical analysis are presented in Table 5.16.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.24: The indoor and microclimate profile of scenario W1

Table 5.16: The statistical analysis of temperature, relative humidity and illuminance values of scenario W1 compared to that of the corridor and the UM microclimate

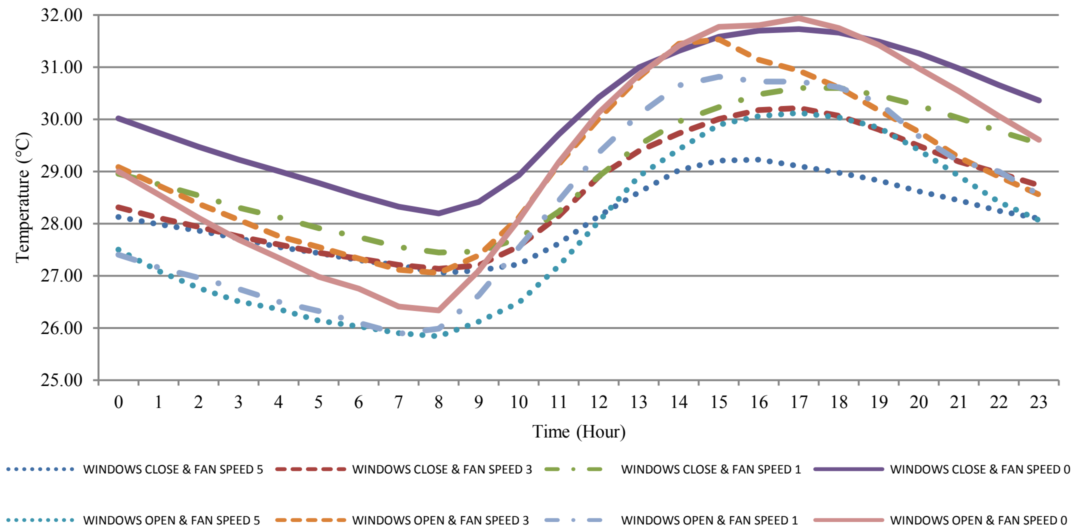
Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	28.11 (Max-min:27.06-29.12,SD:0.55)	28.00 (Max-min:26.40-30.27,SD:1.02)	27.29 (Max-min:25.79-29.17,SD:0.86)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	28.55 (Max-min:27.06-29.89,SD:0.76)	28.75 (Max-min:26.28-31.31,SD:1.45)	28.03 (Max-min:25.70-30.37,SD:1.24)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	29.12 (Max-min:27.83-30.65,SD:0.77)	29.17 (Max-min:26.97-32.00,SD:1.46)	28.72 (Max-min:26.48-31.20,SD:1.26)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	30.02 (Max-min:28.64-31.15,SD:0.71)	30.25 (Max-min:27.43-32.74,SD:1.67)	29.70 (Max-min:26.84-31.74,SD:1.36)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	29.01 (Max-min:27.06-31.15,SD:1.02)	29.10 (Max-min:26.28-32.74,SD:1.66)	28.50 (Max-min:25.70-31.74,SD:1.51)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.61 (Max-min:25.33-30.72,SD:1.48)	27.82 (Max-min:25.07-31.74,SD:1.84)	27.98 (Max-min:26.01-30.62,SD:1.21)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	28.75 (Max-min:25.77-32.02,SD:1.80)	29.05 (Max-min:25.40-33.05,SD:2.21)	29.16 (Max-min:26.16-31.74,SD:1.59)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	28.32 (Max-min:25.40-31.10,SD:1.58)	28.63 (Max-min:25.11-32.25,SD:2.11)	28.76 (Max-min:26.50-31.05,SD:1.30)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	29.33 (Max-min:26.38-31.82,SD:1.42)	29.51 (Max-min:25.26-33.13,SD:2.29)	29.87 (Max-min:26.45-32.20,SD:1.38)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	28.54 (Max-min:25.33-32.02,SD:1.69)	28.78 (Max-min:25.07-33.13,SD:2.21)	28.99 (Max-min:26.01-32.20,SD:1.54)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	27.86 (Max-min:25.33-30.72,SD:1.14)	27.91 (Max-min:25.07-31.74,SD:1.48)	27.64 (Max-min:25.79-30.62,SD:1.10)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.65 (Max-min:25.77-32.02,SD:1.38)	28.90 (Max-min:25.40-33.05,SD:1.87)	28.59 (Max-min:25.70-31.74,SD:1.53)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	28.72 (Max-min:25.40-31.10,SD:1.30)	28.90 (Max-min:25.11-32.25,SD:1.83)	28.74 (Max-min:26.48-31.20,SD:1.27)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	29.68 (Max-min:26.38-31.82,SD:1.17)	29.88 (Max-min:25.26-33.13,SD:2.04)	29.78 (Max-min:26.45-32.20,SD:1.88)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	28.77 (Max-min:25.33-32.02,SD:1.42)	28.94 (Max-min:25.07-33.13,SD:1.96)	28.74 (Max-min:25.70-32.20,SD:1.55)	28.12 (Max-min:23.00-34.00,SD:2.51)

Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	78.00 (Max-min:71.84-81.42,SD:2.48)	78.73 (Max-min:69.13-84.17,SD:3.83)	82.64 (Max-min:70.38-87.73,SD:4.31)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	74.65 (Max-min:64.31-82.17,SD:3.41)	74.41 (Max-min:61.95-84.38,SD:5.33)	77.71 (Max-min:62.30-87.10,SD:5.87)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	69.22 (Max-min:56.62-79.88,SD:5.41)	69.74 (Max-min:54.71-81.89,SD:6.63)	71.44 (Max-min:53.65-84.06,SD:7.84)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	63.25 (Max-min:56.40-70.02,SD:3.31)	62.70 (Max-min:52.72-73.03,SD:5.37)	64.11 (Max-min:50.23-75.62,SD:6.32)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	70.87 (Max-min:56.40-82.17,SD:6.93)	70.95 (Max-min:52.72-84.38,SD:8.19)	73.48 (Max-min:50.23-87.73,SD:9.51)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	78.07 (Max-min:58.18-87.17,SD:7.58)	77.01 (Max-min:57.50-85.97,SD:7.49)	76.63 (Max-min:60.30-83.60,SD:5.99)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	74.98 (Max-min:54.02-90.58,SD:10.4)	73.39 (Max-min:54.02-90.40,SD:10.3)	73.08 (Max-min:56.55-87.33,SD:8.69)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	71.87 (Max-min:48.78-83.90,SD:8.59)	71.02 (Max-min:48.94-84.15,SD:9.39)	70.42 (Max-min:51.01-81.46,SD:7.36)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	64.60 (Max-min:47.06-79.03,SD:8.18)	64.21 (Max-min:42.30-83.05,SD:10.4)	62.81 (Max-min:43.48-78.35,SD:8.55)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	71.96 (Max-min:47.06-90.58,SD:10.1)	71.02 (Max-min:42.30-90.40,SD:10.7)	70.31 (Max-min:43.48-87.33,SD:9.39)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	78.04 (Max-min:58.18-87.17,SD:5.62)	77.87 (Max-min:57.50-85.97,SD:6.00)	79.64 (Max-min:60.30-87.73,SD:6.02)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	74.82 (Max-min:54.02-90.58,SD:7.73)	73.90 (Max-min:54.02-90.40,SD:8.18)	75.40 (Max-min:56.55-87.33,SD:7.75)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	70.55 (Max-min:48.78-83.90,SD:7.27)	70.38 (Max-min:48.94-84.15,SD:8.12)	70.93 (Max-min:51.01-84.06,SD:7.59)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	63.92 (Max-min:47.06-79.03,SD:6.26)	63.45 (Max-min:42.30-83.05,SD:8.30)	63.46 (Max-min:43.48-78.35,SD:7.53)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	71.41 (Max-min:47.06-90.58,SD:8.68)	70.99 (Max-min:42.30-90.40,SD:9.50)	71.89 (Max-min:43.48-87.83,SD:9.57)	79.75 (Max-min:46.00-97.00,SD:12.1)

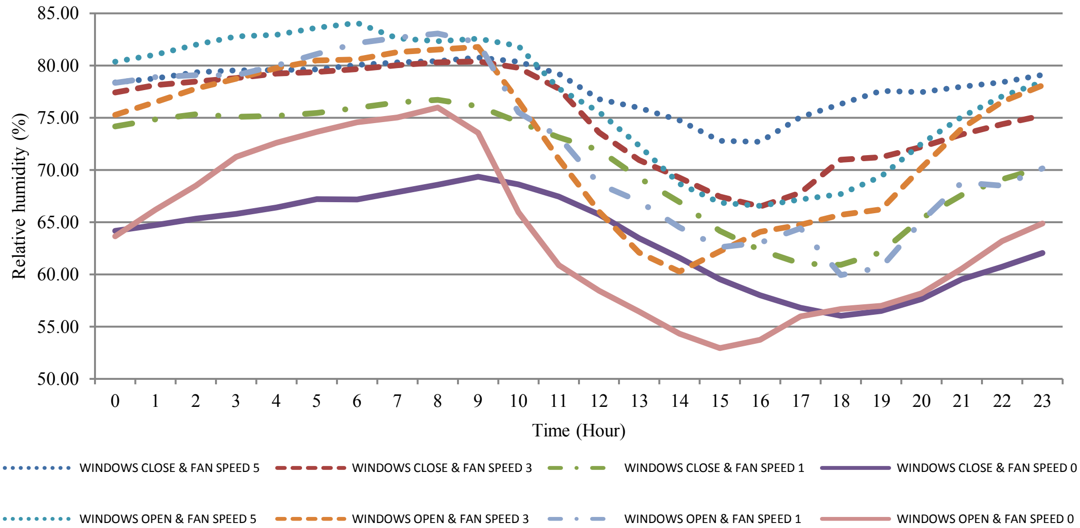
Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	188.89 (Max-min:11.80-713.50,SD:230.16)	130.53 (Max-min:11.80-547.90,SD:157.13)	288.75 (Max-min:11.80-3,189.00,SD:445.77)
Open	182.04 (Max-min:11.80-721.40,SD:226.55)	142.10 (Max-min:11.80-642.50,SD:173.69	274.85 (Max-min:11.80-1,840.90,SD:402.81)
Overall	185.46 (Max-min:11.80-721.40,SD:228.21)	136.32 (Max-min:11.80-642.50,SD:165.59)	281.80 (Max-min:11.80-3,189.00,SD:424.56)

There were no differences in the mean temperature and relative humidity at the two different sides of the walls in the room represented by Indoor A and B. The mean temperature was 29°C and the recorded temperatures ranged between 25°C and 33°C. The relative humidity reached 71%, with a minimum value of 42% and a maximum value of 91%. The mean temperature value in the corridor was the same as in the room, at 29°C with the recorded temperatures ranging between 26°C to 32°C while the minimum relative humidity was 1% higher at 43% and the maximum relative humidity at 88%.

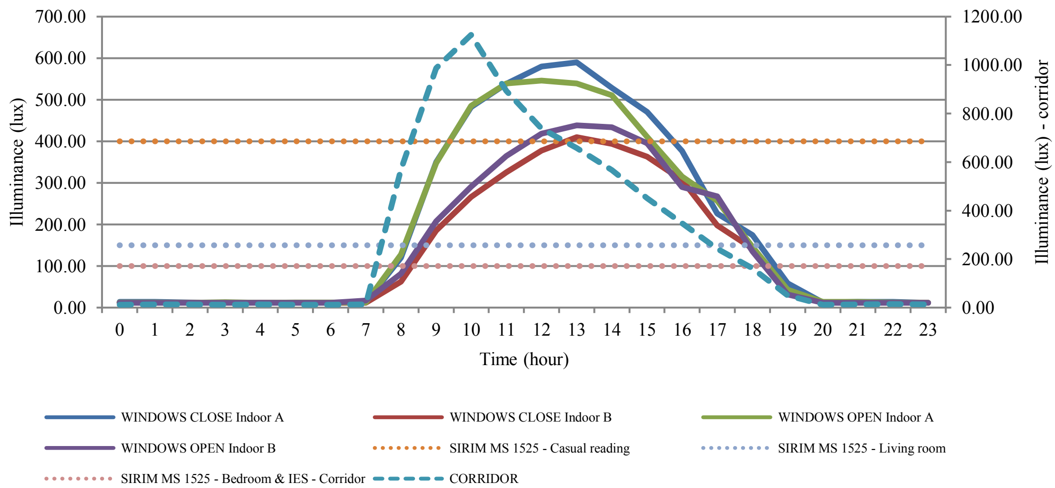
There were no significant differences in the mean temperature and relative humidity resulting from the opening or closing of all windows in the room as shown in Table 5.16. However, the reduction of fan speed consistently and drastically increased the room temperature by a range of 1°C to 2°C and reduced the relative humidity by 13% to 16%. In comparison, the UM microclimate has a lower mean temperature of 28°C and significantly higher mean relative humidity percentage of up to 79%. Further analysis of the daily pattern show that the indoor temperature gradually decreases until reaching the minimum value at 0800 hours and then after progressively increases until reaching the maximum at 1700 hours, exceeding 31°C as presented in Figure 5.25. There was more than a 1°C margin of difference between the minimum and the maximum temperature values. After 1800 hours, the indoor temperature would continuously decline by less than 1°C. Referring to Figure 5.25(a), the indoor temperature decreased when fan speed is increased especially when all the windows were closed. At similar fan speeds, the temperature would further be reduced by the opening of the windows. In comparison, the indoor temperatures were not reduced when the fan speed is increased while the windows were already open. There were also instances where higher temperatures were recorded at higher fan speeds.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.25: The indoor daily pattern of scenario W1

The same pattern was also being observed with the indoor relative humidity but with an inverse relationship, as the increase in temperature reduces the relative humidity values [Figure 5.25(b)]. These daily patterns therefore show that the fan speed and state of windows do have an influence the values of indoor temperatures and relative humidity.

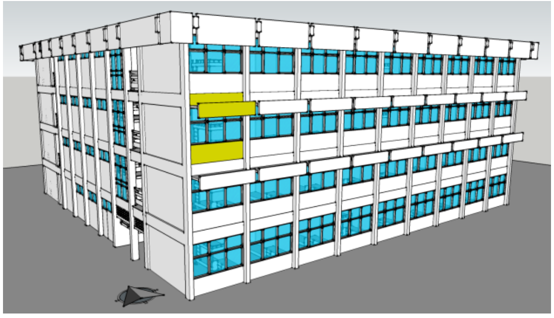
There were differences in the illuminance values between Indoor A and B. The mean illuminance value at Indoor A was 185 lux with a maximum value of 721 lux which was higher than that of Indoor B with 136 lux and a maximum value of 643 lux as presented in Table 5.16. The adequacy of daylight in the room meets the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms from 9 a.m. to 5 p.m. [Figure 5.25(c)]. The opening of the windows considerably influenced the illuminance values in the room. The variance in the mean illuminance value was lower while the windows were open with a range of 7 lux for Indoor A and 12 lux for Indoor B. The adequacy of daylight in the corridor met the IES minimum requirement from 8 a.m. to 7 p.m. with a maximum value of 3,189 lux and a mean value of 282 lux.

f) Scenario W2

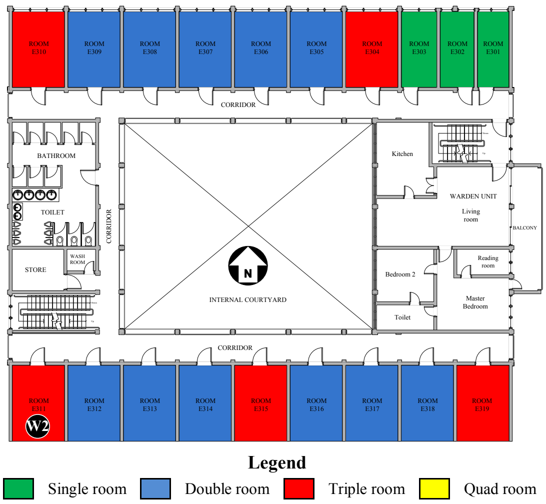
The detail description of this scenario, location of the selected student room that represents the identified scenario and the position of data loggers are shown in Table 5.17 below.

Table 5.17: The detail description of the scenario W2, the location of the selected student room and the position of data loggers

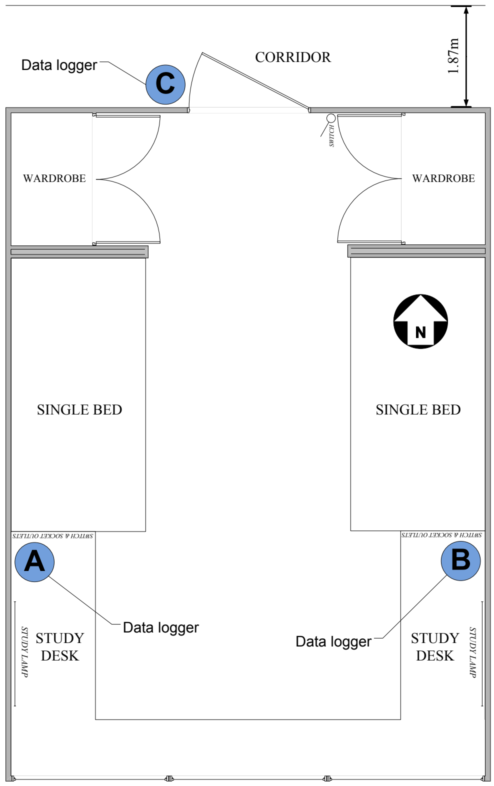
Scenario	Room	Description
W2	E 311	Receiving direct heat radiation and penetration from the west. Whilst, not affected by directing heat radiation and penetration of man-made surface either on the top or ground. *(Keyword: West orientation)*
Location of the student room and the position of data loggers		



Residential building rear isometric elevation

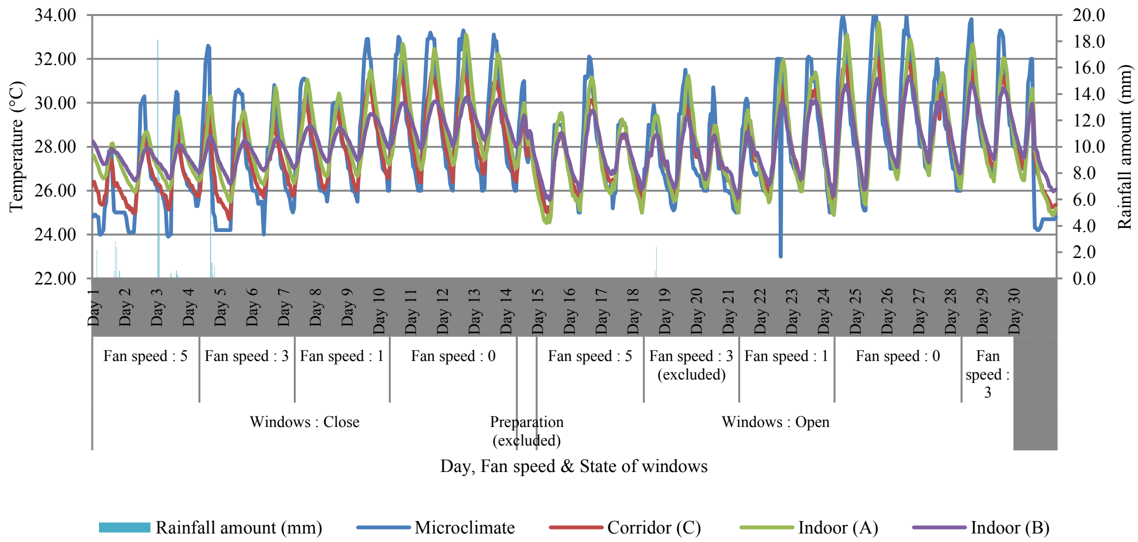


Floor plan of Level 3, Block

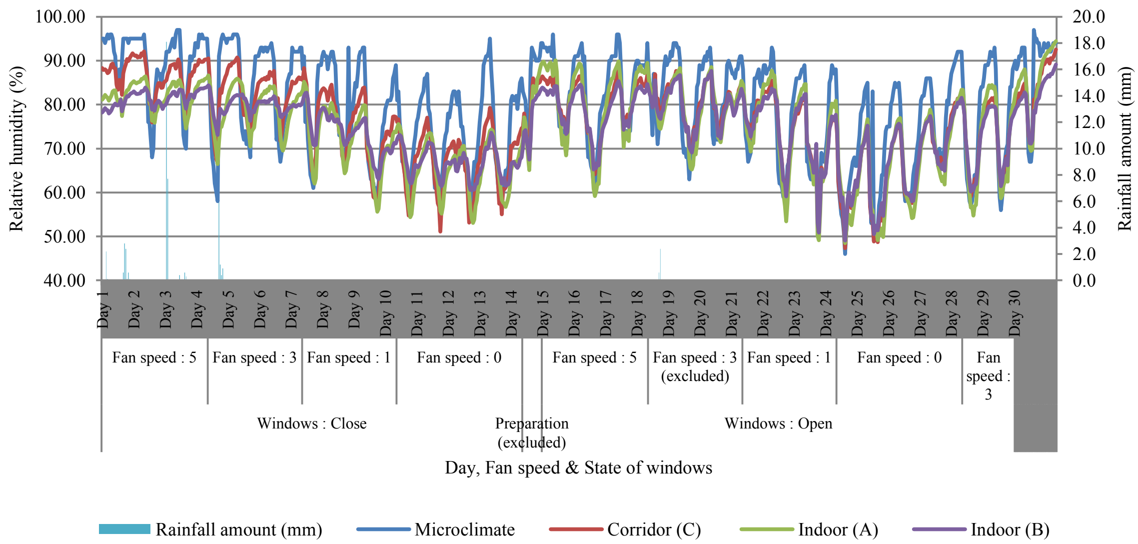


Floor plan of room E 311

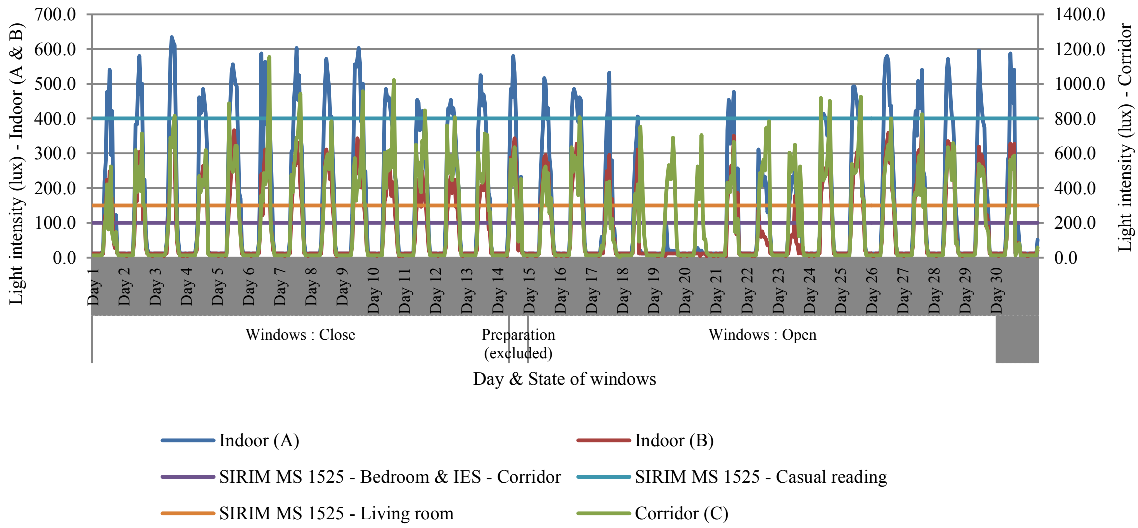
The indoor and microclimate profile which comprise data on the temperature (ºC), relative humidity (%) and illuminance (lux) in room E 311 which is used to represent scenario W2 is shown in Figure 5.26 and the statistical analysis is presented in Table 5.18.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.26: The indoor and microclimate profile of scenario W2

Table 5.18: The statistical analysis of temperature, relative humidity and illuminance values of scenario W2 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	27.24 (Max-min:25.94-29.39,SD:0.83)	27.37 (Max-min:26.45-28.25,SD:0.46)	26.38 (Max-min:24.97-28.84,SD:0.93)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	27.71 (Max-min:25.50-30.70,SD:1.36)	27.55 (Max-min:26.30-28.47,SD:0.58)	27.11 (Max-min:24.70-29.97,SD:1.35)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	28.61 (Max-min:26.52-31.48,SD:1.39)	28.33 (Max-min:27.09-29.49,SD:0.63)	28.10 (Max-min:25.96-31.03,SD:1.38)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	29.54 (Max-min:26.97-33.11,SD:1.74)	29.17 (Max-min:27.90-30.27,SD:0.68)	28.97 (Max-min:26.38-31.54,SD:1.52)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	28.34 (Max-min:25.50-33.11,SD:1.66)	28.17 (Max-min:26.30-30.27,SD:0.95)	27.71 (Max-min:24.70-31.54,SD:1.66)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.16 (Max-min:24.53-31.15,SD:1.77)	27.42 (Max-min:25.57-29.64,SD:1.06)	27.22 (Max-min:24.82-30.12,SD:1.33)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	28.32 (Max-min:24.90-32.67,SD:2.18)	28.53 (Max-min:25.96-30.93,SD:1.39)	28.32 (Max-min:25.23-31.46,SD:1.77)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	28.10 (Max-min:24.90-31.94,SD:1.94)	27.96 (Max-min:25.77-30.12,SD:1.23)	28.06 (Max-min:25.67-30.82,SD:1.47)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	29.25 (Max-min:25.36-33.65,SD:2.21)	28.90 (Max-min:26.04-31.20,SD:1.38)	29.11 (Max-min:25.77-32.05,SD:1.69)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	28.26 (Max-min:24.53-33.65,SD:2.17)	28.23 (Max-min:25.57-31.20,SD:1.40)	28.22 (Max-min:24.82-32.05,SD:1.72)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	27.20 (Max-min:24.53-31.15,SD:1.38)	27.40 (Max-min:25.57-29.64,SD:0.82)	26.80 (Max-min:24.82-30.12,SD:1.22)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.01 (Max-min:24.90-32.67,SD:1.83)	28.04 (Max-min:25.96-30.93,SD:1.17)	28.04 (Max-min:25.96-30.93,SD:1.69)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	28.35 (Max-min:24.90-31.94,SD:1.70)	28.15 (Max-min:25.77-30.12,SD:0.99)	28.08 (Max-min:25.67-31.03,SD:1.42)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	29.39 (Max-min:25.36-33.65,SD:1.98)	29.04 (Max-min:26.04-31.20,SD:1.09)	29.04 (Max-min:25.77-32.05,SD:1.60)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	28.30 (Max-min:24.53-33.65,SD:1.93)	28.20 (Max-min:25.57-31.20,SD:1.20)	27.96 (Max-min:24.70-32.05,SD:1.71)	28.12 (Max-min:23.00-34.00,SD:2.51)

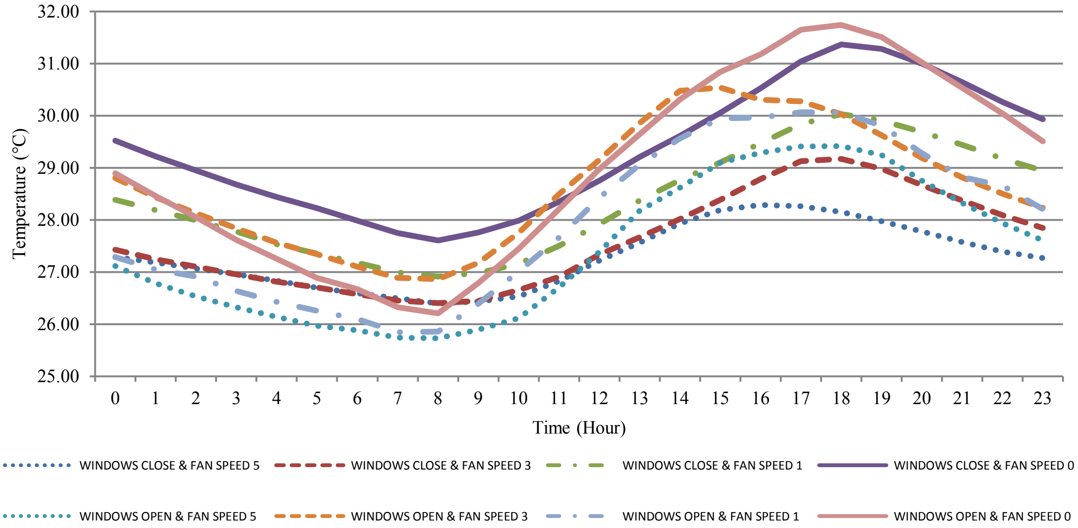
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	82.39 (Max-min:74.55-86.43,SD:2.85)	81.37 (Max-min:77.97-84.04,SD:1.72)	87.02 (Max-min:75.73-92.10,SD:3.79)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	79.34 (Max-min:66.50-86.62,SD:4.93)	79.77 (Max-min:73.10-84.41,SD:1.99)	82.54 (Max-min:66.74-90.76,SD:5.69)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	72.29 (Max-min:55.60-85.17,SD:7.01)	73.52 (Max-min:63.02-82.74,SD:4.61)	74.76 (Max-min:56.89-88.36,SD:7.85)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	65.44 (Max-min:53.07-75.58,SD:5.89)	66.57 (Max-min:60.57-73.62,SD:3.36)	67.10 (Max-min:51.08-79.27,SD:6.64)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	74.37 (Max-min:53.07-86.62,SD:8.68)	74.82 (Max-min:60.57-84.41,SD:6.85)	77.31 (Max-min:51.08-92.10,SD:10.0)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	80.80 (Max-min:59.16-90.07,SD:8.49)	79.13 (Max-min:65.23-85.34,SD:5.19)	80.80 (Max-min:64.12-87.73,SD:5.93)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	77.61 (Max-min:54.71-94.47,SD:11.3)	75.97 (Max-min:60.18-89.12,SD:5.19)	77.14 (Max-min:59.12-92.56,SD:9.27)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	73.76 (Max-min:49.12-87.83,SD:9.74)	73.83 (Max-min:50.91-83.69,SD:7.71)	74.11 (Max-min:53.65-85.50,SD:7.70)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	65.56 (Max-min:48.48-83.34,SD:9.51)	66.46 (Max-min:49.08-81.58,SD:8.34)	66.02 (Max-min:47.33-82.59,SD:9.06)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	73.95 (Max-min:48.48-94.47,SD:11.4)	73.44 (Max-min:49.08-89.12,SD:8.89)	73.96 (Max-min:47.33-92.56,SD:9.85)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	81.59 (Max-min:59.16-90.07,SD:6.36)	80.25 (Max-min:65.23-85.34,SD:4.01)	83.71 (Max-min:64.12-92.10,SD:5.97)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	78.47 (Max-min:54.71-94.47,SD:8.73)	77.87 (Max-min:60.18-89.12,SD:6.10)	79.84 (Max-min:59.12-92.56,SD:8.13)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	73.03 (Max-min:49.12-87.83,SD:8.49)	73.67 (Max-min:50.91-83.69,SD:6.33)	74.43 (Max-min:53.68-88.36,SD:7.75)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	65.50 (Max-min:48.48-83.34,SD:7.89)	66.52 (Max-min:49.08-81.58,SD:6.34)	66.56 (Max-min:47.33-82.59,SD:7.94)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	74.16 (Max-min:48.48-94.47,SD:10.1)	74.13 (Max-min:49.08-89.12,SD:8.00)	75.63 (Max-min:47.33-92.56,SD:10.1)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	161.65 (Max-min:11.80-634.60,SD:197.43)	82.52 (Max-min:3.90-366.60,SD:100.95)	199.99 (Max-min:11.80-1,155.00,SD:262.32)
Open	139.79 (Max-min:11.80-595.20,SD:178.22)	81.71 (Max-min:3.90-398.10,SD:106.76)	183.17 (Max-min:3.90-926.30,SD:238.85)
Overall	150.72 (Max-min:11.80-634.60,SD:188.24)	82.11 (Max-min:3.90-398.10,SD:103.82)	191.58 (Max-min:3.90-1,155.00,SD:250.81)

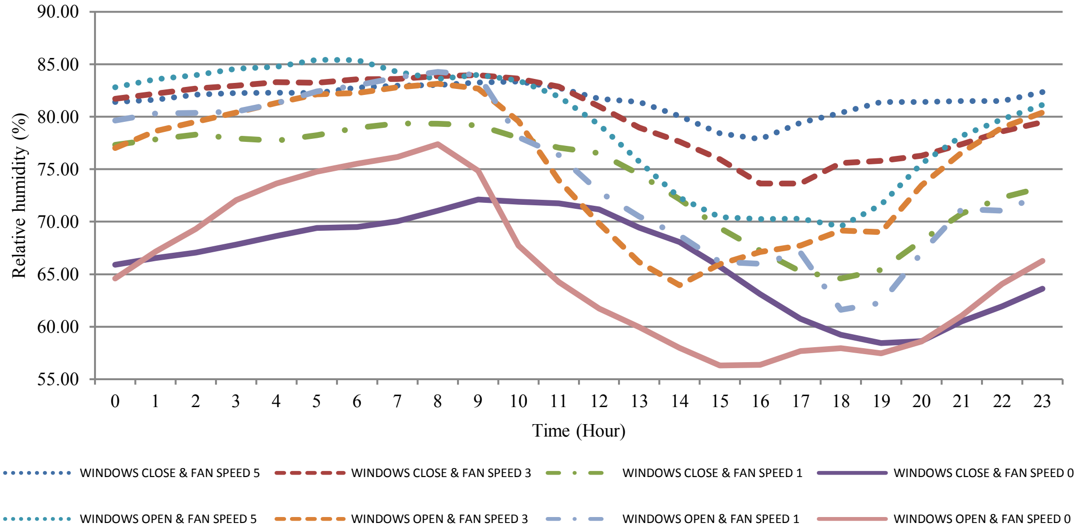
Statistically, there were no differences in the mean temperature and relative humidity at the two different sides of the walls in the room; Indoor A and B. The mean temperature was 28°C and the recorded temperatures ranged between 25°C and 34°C. The relative humidity reached 74%, with a minimum value of 48% and a maximum value of 94%. The mean value of the temperature in the corridor was same as in the room, which was 28°C with temperatures ranging between 25°C to 32°C. However, the corridor had a higher relative humidity percentage which was 76% with minimum and maximum percentages of 47% and 93%, respectively.

According to Table 5.18, there were no significant differences in the mean temperature for when the windows are opened or closed. However, there was a reduction of 2% in the maximum relative humidity with the opening of all windows. As in other rooms, the reduction of fan speed drastically increased the room temperature by 1°C to 2°C and consistently reduced the relative humidity by a margin of 13% to 17% of margin. The room and the the corridor had the same mean temperature as the UM microclimate which was 28°C. The UM microclimate had a slightly higher relative humidity exceeding 79% with a maximum value of 97%.

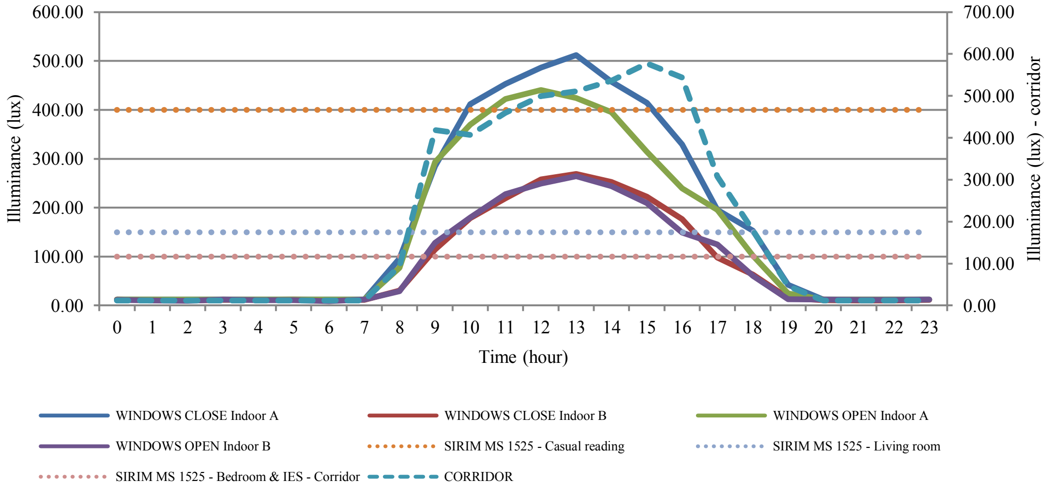
Further analysis of the daily pattern show that the indoor temperature gradually decreased until reaching the minimum value at 0800 hours and then on progressively increased until reaching a maximum at 1700 hours, exceeding 31°C as presented in Figure 5.27. There was more than a 1°C difference between the minimum and the maximum temperature values in the room. After 1800 hours, the indoor temperature began to continuously decline to a value lower by less than 1°C. As shown by Figure 5.27(a), the indoor temperature decreased when the fan speed is increased especially when all the windows were closed. At similar fan speeds, the temperature would further be reduced by the opening of the windows. In comparison the indoor temperatures were not reduced with the increasing of fan speed when the windows were already open.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.27: The indoor daily pattern of scenario W2

There were also higher temperatures recorded at higher fan speeds. The same pattern was also observed in the indoor relative humidity but with an inverse relationship, as the increase of temperature reduces the relative humidity values [Figure 5.27(b)]. These daily patterns therefore show that the fan speed and state of windows have influence on the values of indoor temperatures and relative humidity.

There were differences found when comparing the illuminance values of Indoor A and B. The mean illuminance value for Indoor A was 151 lux with a maximum value of 635 lux which was higher than that of Indoor B with illuminance of 82 lux and a maximum value of 398 lux, as shown in Table 5.18. The adequacy of daylight in the room partially met the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms from 9 a.m. to 4 p.m. particularly at Indoor A [Figure 5.27(c)]. The opening of the windows considerably influenced the illuminance values of the room. The variance from the mean illuminance value was much lower with a maximum variance of 1 lux for Indoor B and 22 lux for Indoor A. On the other hand the adequacy of daylight in the corridor met the IES minimum requirement from 8 a.m. to 6 p.m. with a maximum recorded value of 1,133 lux and a mean value of 192 lux.

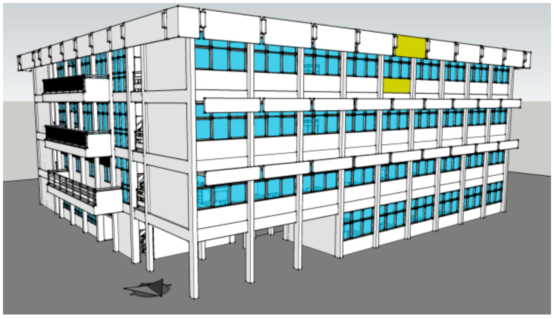
g) Scenario W3

The detail description of the scenario, location of the selected student room that represent identified scenario and the position of data loggers are shown in Table 5.19 below.

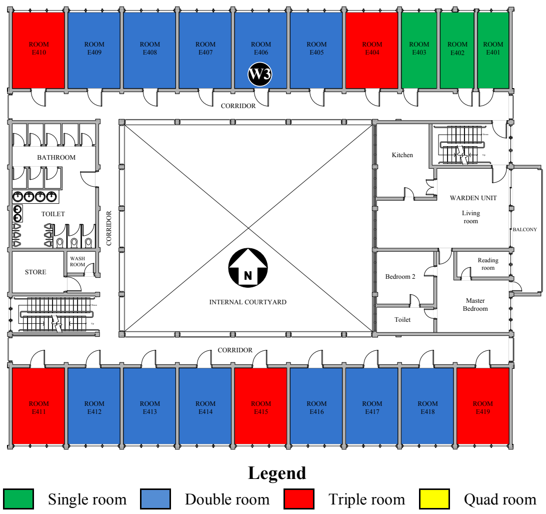
Table 5.19: The detail description of the scenario W3, the location of the selected student room and the position of data loggers

Scenario	Room	Description
W3	E 406	Receiving direct heat radiation and penetration from man-made surfaces on the top solely, i.e. roof, wall etc. and with north-south building orientation. *(Keyword: Direct contact with man-made surfaces on the top only)*

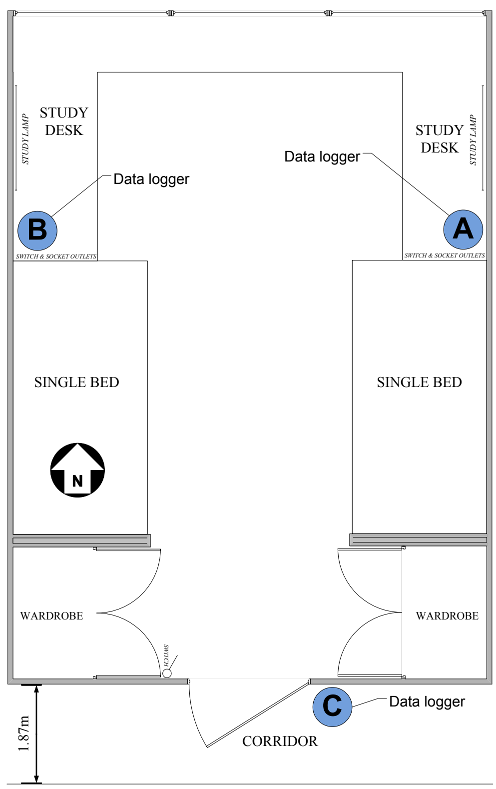
Location of the student room and the position of data loggers



Residential building front isometric elevation

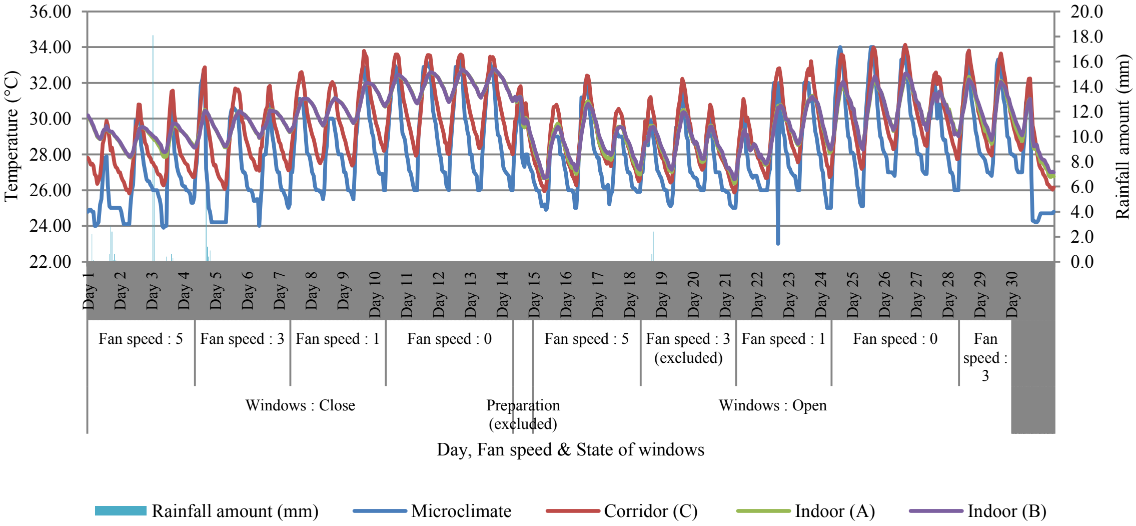


Floor plan of Level 4, Block

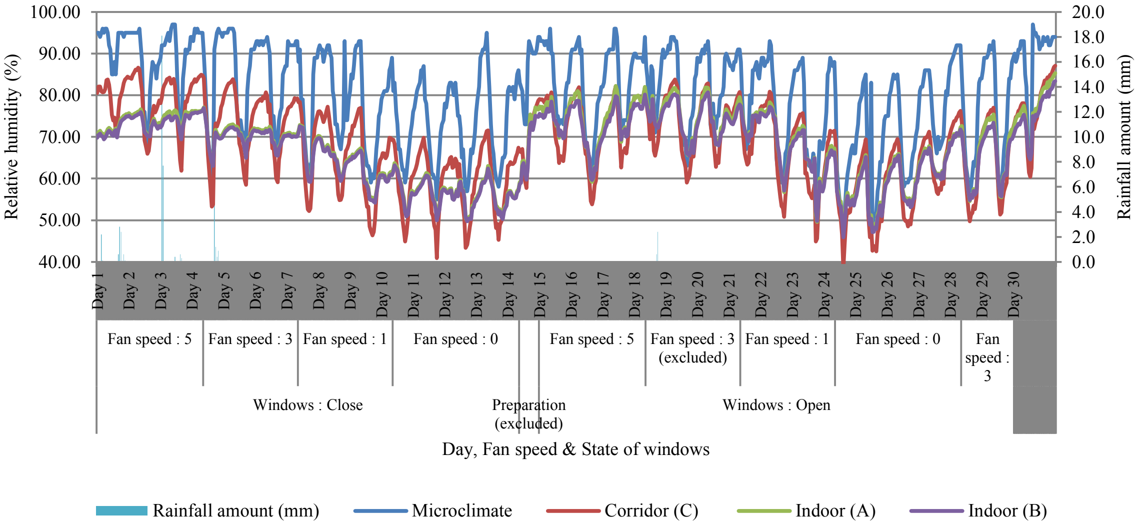


Floor plan of room E 406

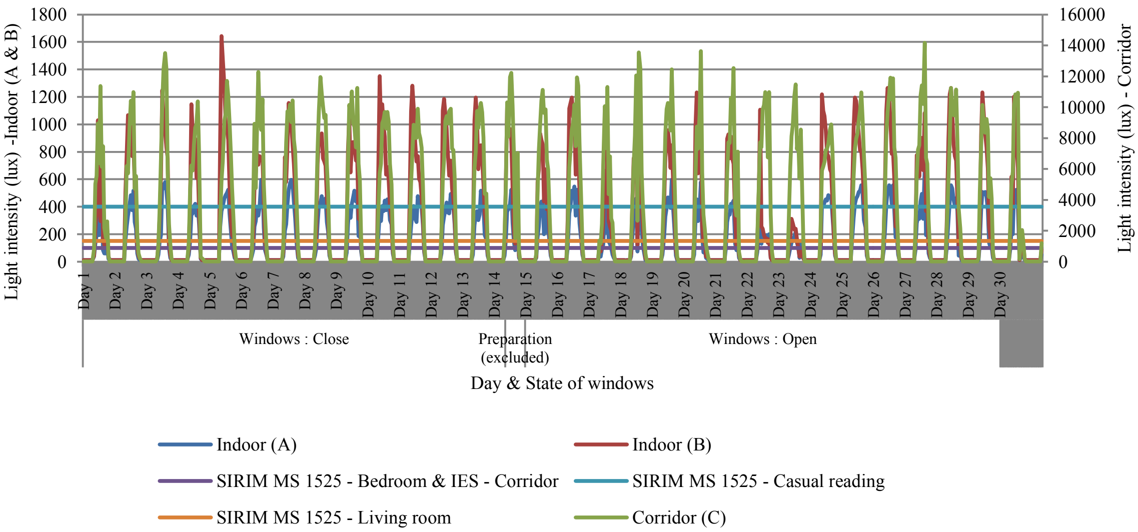
The indoor and microclimate profile which included data on the temperature (ºC), relative humidity (%) and illuminance (lux) in room E 406 which represents scenario W3, are shown in Figure 5.28 and its statistical analysis presented in Table 5.20.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.28: The indoor and microclimate profile of scenario W3

Table 5.20: The statistical analysis of temperature, relative humidity and illuminance values of scenario W3 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	28.94 (Max-min:27.83-30.14,SD:0.56)	29.00 (Max-min:27.88-30.19,SD:0.54)	27.90 (Max-min:25.82-31.56,SD:1.36)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	29.66 (Max-min:28.39-30.52,SD:0.61)	29.66 (Max-min:28.42-30.47,SD:0.60)	28.94 (Max-min:26.06-32.87,SD:1.74)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	30.74 (Max-min:29.32-32.02,SD:0.69)	30.74 (Max-min:29.34-32.02,SD:0.69)	30.03 (Max-min:27.38-33.78,SD:1.74)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	31.91 (Max-min:30.80-32.74,SD:0.55)	31.92 (Max-min:30.85-32.77,SD:0.55)	30.82 (Max-min:27.92-33.60,SD:1.78)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	30.39 (Max-min:27.83-32.74,SD:1.32)	30.41 (Max-min:27.88-32.77,SD:1.30)	29.49 (Max-min:25.82-33.78,SD:2.01)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	28.47 (Max-min:26.67-30.98,SD:1.14)	28.57 (Max-min:26.67-30.82,SD:1.05)	28.61 (Max-min:25.94-32.41,SD:1.65)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	29.73 (Max-min:26.74-32.33,SD:1.60)	29.89 (Max-min:26.99-32.20,SD:1.50)	29.84 (Max-min:26.04-33.81,SD:2.16)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	29.24 (Max-min:27.06-31.28,SD:1.14)	29.26 (Max-min:27.16-31.23,SD:1.11)	29.49 (Max-min:26.67-33.21,SD:1.87)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	30.64 (Max-min:28.35-32.43,SD:1.01)	30.67 (Max-min:28.27-32.54,SD:1.07)	30.60 (Max-min:27.19-34.12,SD:1.86)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	29.58 (Max-min:26.67-32.43,SD:1.47)	29.65 (Max-min:26.67-32.54,SD:1.43)	29.68 (Max-min:25.94-34.12,SD:2.02)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	28.70 (Max-min:26.67-30.98,SD:0.93)	28.78 (Max-min:26.67-30.82,SD:0.86)	28.26 (Max-min:25.82-32.41,SD:1.55)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	29.69 (Max-min:26.74-32.33,SD:1.21)	29.77 (Max-min:26.99-32.20,SD:1.14)	29.39 (Max-min:26.04-33.81,SD:2.01)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	29.99 (Max-min:27.06-32.02,SD:1.20)	30.00 (Max-min:27.16-32.02,SD:1.18)	29.76 (Max-min:26.67-33.78,SD:1.82)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	31.28 (Max-min:28.35-32.74,SD:1.03)	31.30 (Max-min:28.27-32.77,SD:1.05)	30.71 (Max-min:27.19-34.12,SD:1.82)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	29.98 (Max-min:26.67-32.74,SD:1.45)	30.03 (Max-min:26.67-32.77,SD:1.42)	29.58 (Max-min:25.82-34.12,SD:2.02)	28.12 (Max-min:23.00-34.00,SD:2.51)

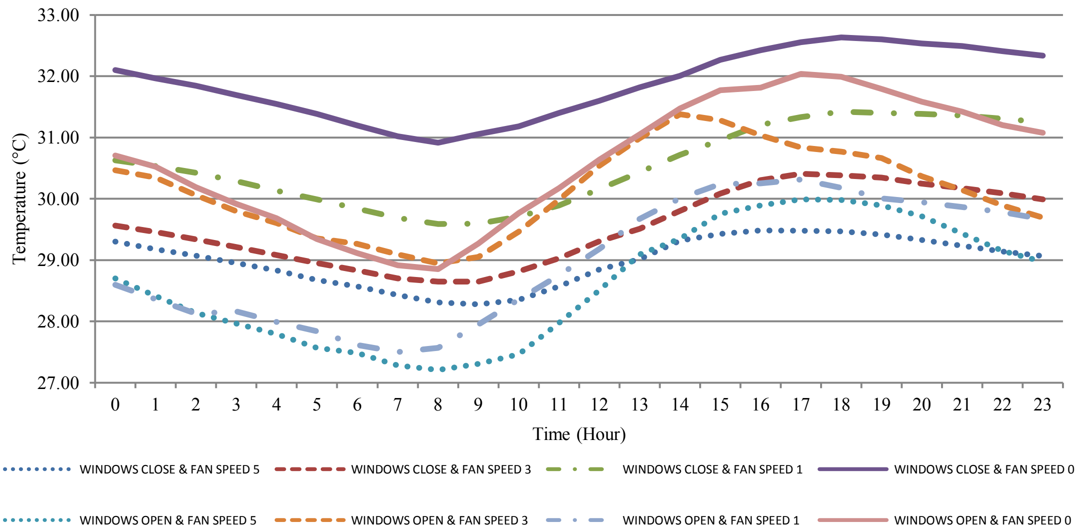
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	73.97 (Max-min:70.12-76.65,SD:2.11)	73.28 (Max-min:69.41-76.29,SD:2.06)	79.41 (Max-min:61.89-86.58,SD:5.72)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	70.50 (Max-min:63.31-77.08,SD:2.37)	70.04 (Max-min:63.05-76.95,SD:2.28)	73.38 (Max-min:53.27-84.16,SD:7.69)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	63.85 (Max-min:54.74-72.85,SD:4.53)	63.33 (Max-min:54.16-72.55,SD:4.56)	65.49 (Max-min:46.40-78.36,SD:9.05)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	56.55 (Max-min:49.79-63.75,SD:3.26)	56.10 (Max-min:49.75-63.17,SD:3.23)	58.92 (Max-min:40.93-71.52,SD:7.58)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	65.71 (Max-min:49.79-77.08,SD:7.65)	65.18 (Max-min:49.75-76.95,SD:7.57)	68.81 (Max-min:40.93-86.58,SD:11.0)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	74.39 (Max-min:59.22-82.26,SD:5.46)	73.25 (Max-min:59.66-80.18,SD:4.78)	73.06 (Max-min:53.80-82.15,SD:7.30)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	70.77 (Max-min:54.56-85.28,SD:8.55)	69.41 (Max-min:54.83-83.42,SD:7.84)	69.85 (Max-min:49.72-87.11,SD:10.4)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	68.37 (Max-min:49.63-78.30,SD:6.84)	67.82 (Max-min:49.79-77.37,SD:6.63)	66.92 (Max-min:44.90-80.86,SD:8.86)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	60.02 (Max-min:46.77-72.35,SD:6.23)	59.37 (Max-min:45.91-71.81,SD:6.35)	59.61 (Max-min:38.28-76.26,SD:9.11)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	67.93 (Max-min:46.77-85.28,SD:8.76)	67.02 (Max-min:45.91-83.42,SD:8.36)	66.94 (Max-min:38.28-87.11,SD:10.3)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	74.18 (Max-min:59.22-82.26,SD:4.13)	73.27 (Max-min:59.66-80.18,SD:3.67)	76.23 (Max-min:53.80-86.58,SD:7.27)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	70.63 (Max-min:54.56-85.28,SD:6.26)	69.73 (Max-min:54.83-83.42,SD:5.76)	71.62 (Max-min:49.72-87.11,SD:9.30)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	66.11 (Max-min:49.63-78.30,SD:6.21)	65.58 (Max-min:49.79-77.37,SD:6.10)	66.20 (Max-min:44.90-80.86,SD:8.95)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	58.28 (Max-min:46.77-72.35,SD:5.26)	57.74 (Max-min:45.91-71.81,SD:5.29)	59.26 (Max-min:38.28-76.26,SD:8.37)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	66.82 (Max-min:46.77-85.28,SD:8.29)	66.10 (Max-min:45.91-83.42,SD:8.02)	67.87 (Max-min:38.28-87.11,SD:10.7)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	145.34 (Max-min:11.80-595.20,SD:180.23)	298.40 (Max-min:11.80-1,643.80,SD:395.68)	3,107.43 (Max-min:3.90-13,500.90,SD:3,996.30)
Open	133.26 (Max-min:11.80-681.90,SD:176.20)	258.57 (Max-min:3.90-1,265.30,SD:371.19)	3,132.99 (Max-min:3.90-14,178.90,SD:4,048.20)
Overall	139.30 (Max-min:11.80-681.90,SD:178.19)	278.48 (Max-min:3.90-1,643.80,SD:383.85)	3,120.21 (Max-min:3.90-14,178.90,SD:4,019.22)

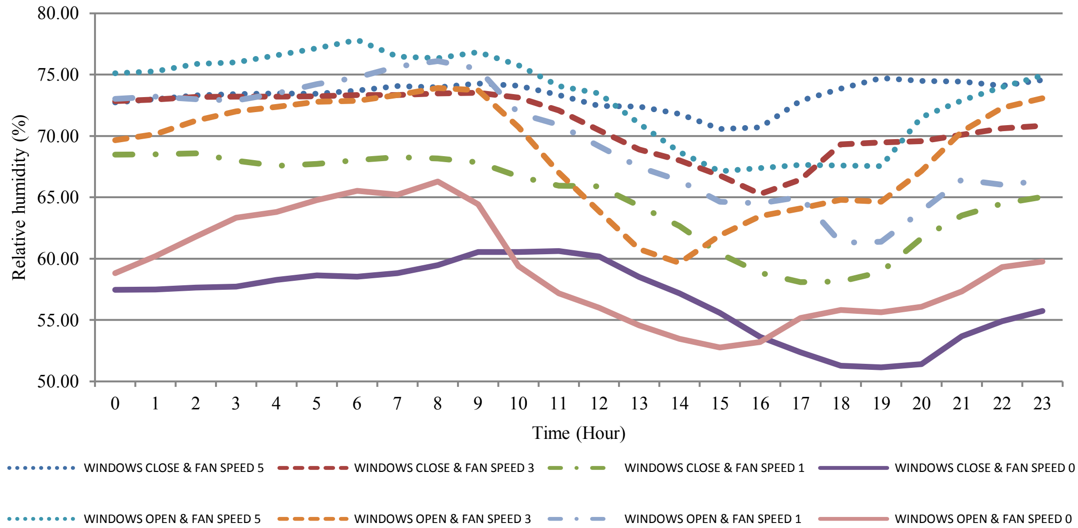
Statistically, there were no differences in the mean temperature of the two different sides of the walls in the room represented by Indoor A and B. The mean temperature is 30°C and recorded temperatures were between 27°C and 33°C. The relative humidity only reached 66%-67% with a minimum value of 46% and a maximum value of 85%. The mean value of the temperature in the corridor is same as in the room, which is 30°C with temperatures ranging between 26°C to 34°C. Higher relative humidity percentages were recorder with a mean value of 68% and a minimum and maximum percentages of 38% and 87%, respectively.

Referring to the Table 5.20, there were no significant changes detected in the mean temperature of the room in relation to the opening or closing of all windows in the room. Still, there was only a 2% reduction of relative humidity with the opening of all windows. The reduction of fan speed drastically increased the room temperature by 1°C to 3°C and reduced the relative humidity consistently a margin of 14% to 17%. In comparison the UM microclimate has a lower mean temperature of 28°C and a significantly the higher mean relative humidity percentage of up to 79% with a maximum value of 97%.

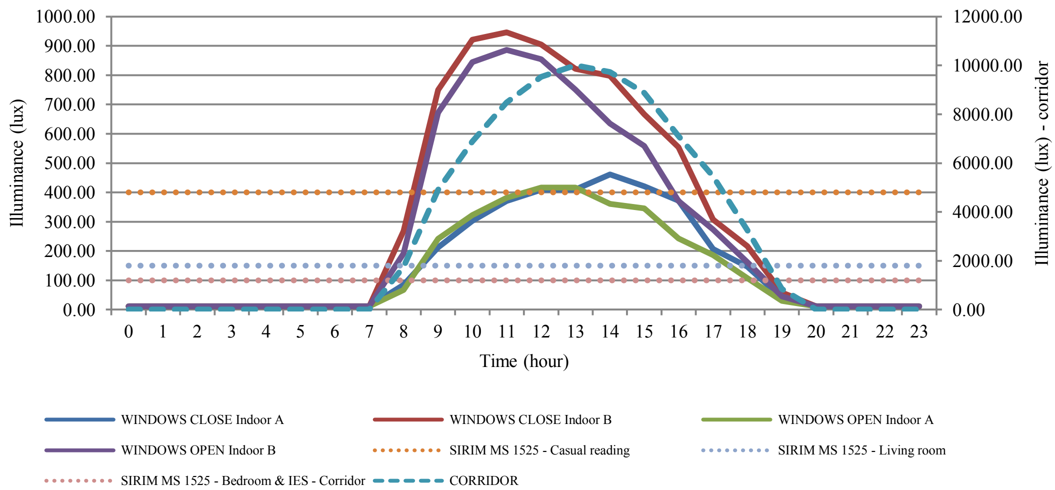
Further analysis on the daily pattern show that the indoor temperature gradually decreases to the minimum value at 0800 hours and progressively increases to the maximum at 1700 hours, at times exceeding 32°C as presented in Figure 5.29. There was more than a 1°C margin between the minimum and the maximum temperature values. After 1800 hours, the indoor temperature gradually declined by no more than 1°C. According to Figure 5.29(a), the indoor temperature decreased with the increase of fan speeds especially when all the windows were closed. At the same fan speed, the temperature was further reduced by the opening of all the windows. In comparison the indoor temperatures were not reduced with the increase of fan speed when the windows were already open.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.29: The indoor daily pattern of scenario W3

There were also higher temperatures recorded with higher fan speeds. The same pattern was also observed with the indoor relative humidity but with an inverse relationship, as temperature increases, the relative humidity values decrease [Figure 5.29(b)]. Through this daily pattern it is shown that the fan speed and state of windows play a role in influencing the values of indoor temperatures and relative humidity.

There were significant differences between the recorded illuminance values of Indoor A and B. The mean illuminance value of Indoor B (278 lux with a maximum value of 1,644 lux) was 2 times higher than that of Indoor A (139 lux with the maximum value was 682 lux), as shown in Table 5.20. The adequacy of daylight in the room meets the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms from 8 a.m. to 5 p.m., more so at the position of Indoor B [Figure 5.29(c)]. The opening of the operable windows considerably influenced the illuminance values in the room. In the open state, the variations from mean illuminance values were much lower with the maximum range of between 12 lux for Indoor A and 39 lux for Indoor B. The adequacy of daylight in the corridor met the IES minimum requirement from 8 a.m. to 7 p.m. while the maximum value was 14,179 lux with a mean value of 3,120 lux.

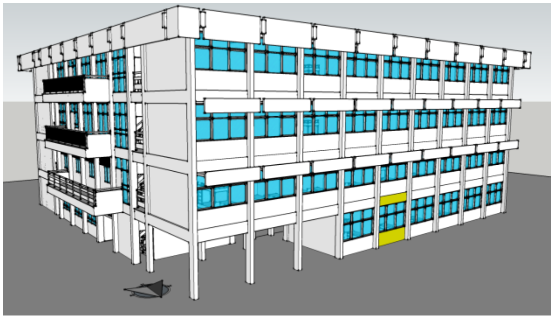
h) Scenario W4

The detail description of the scenario, the location of the selected student room in representing the scenario, and the position of data loggers are shown in Table 5.21 below.

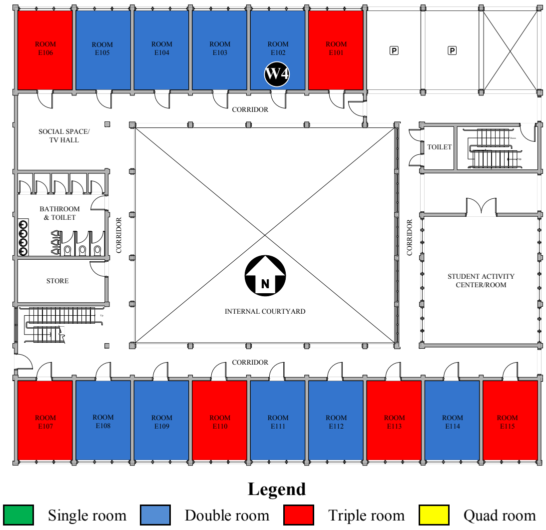
Table 5.21: The detail description of the scenario W4, the location of the selected student room and the position of data loggers

Scenario	Room	Description
W4	E 102	Receiving direct heat radiation and penetration from man-made surfaces on the ground solely, i.e. tarmac, court etc. Whilst, not affected by directing heat radiation and penetration either from east or west. *(Keyword: Direct contact with man-made surfaces on the ground only)*

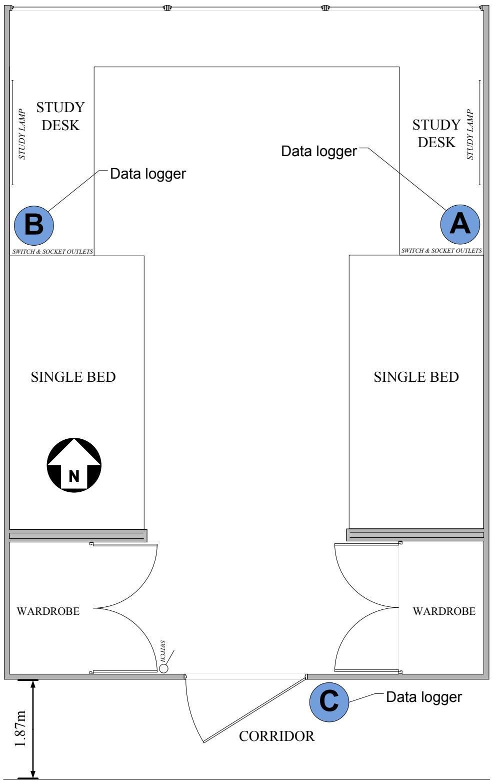
Location of the student room and the position of data loggers



Residential building front isometric elevation

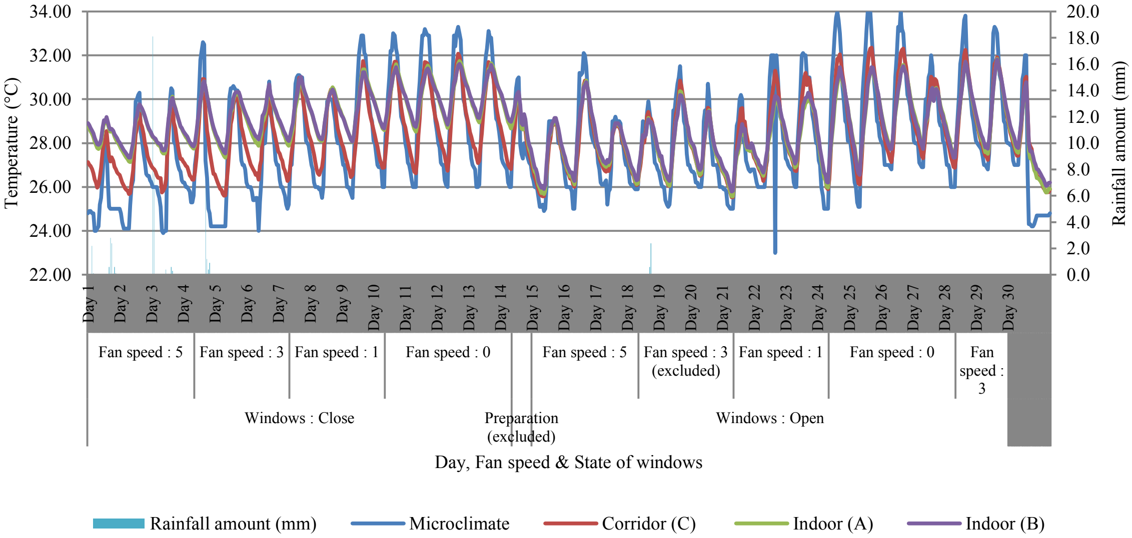


Floor plan of Level 1, Block

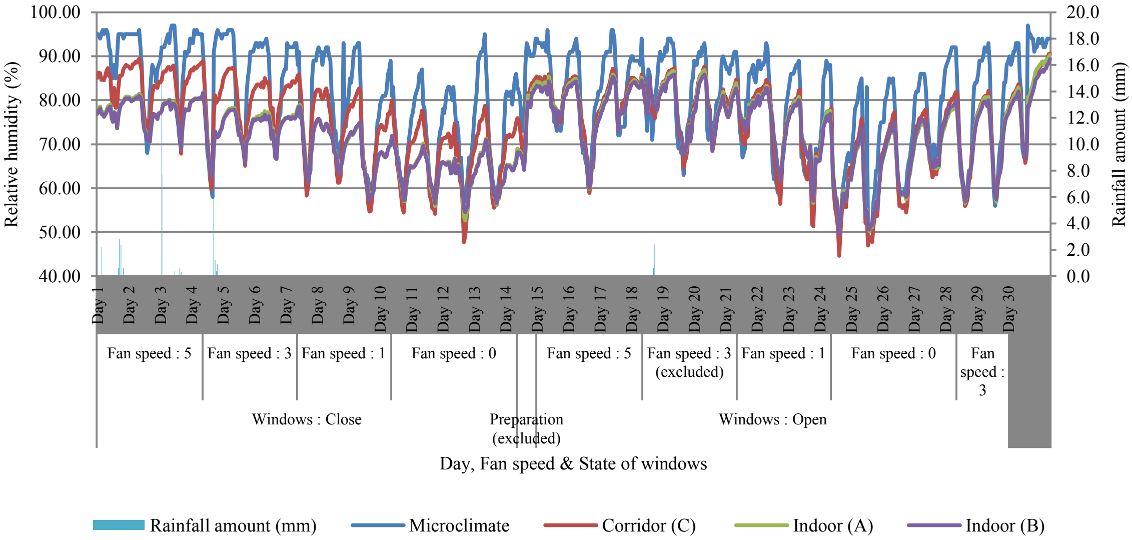


Floor plan of room E 102

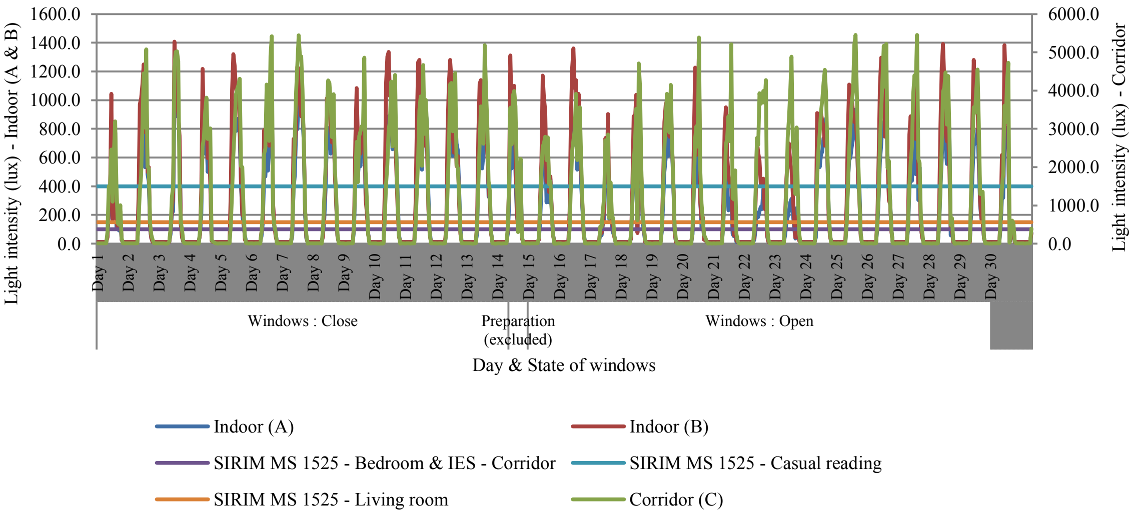
The indoor and microclimate profile which comprised the temperature (ºC), relative humidity (%) and illuminance (lux) in room E 102, that represent scenario W4, are shown in Figure 5.30 and with its statistic data presented in Table 5.22.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.30: The indoor and microclimate profile of scenario W4

Table 5.22: The statistical analysis of temperature, relative humidity and illuminance values of scenario W4 compared to that of the corridor and the UM microclimate

Windows	Fan speed	Temperature (ºC)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	28.41 (Max-min:27.14-30.12,SD:0.71)	28.51 (Max-min:27.33-30.07,SD:0.66)	27.17 (Max-min:25.67-29.82,SD:1.02)	26.14 (Max-min:23.90-30.50,SD:1.75)
	3	29.01 (Max-min:27.33-30.82,SD:0.91)	29.14 (Max-min:27.53-30.82,SD:0.85)	27.86 (Max-min:25.60-30.93,SD:1.41)	27.12 (Max-min:24.00-32.60,SD:2.41)
	1	29.53 (Max-min:28.05-31.36,SD:0.90)	29.55 (Max-min:28.07-31.23,SD:0.86)	28.60 (Max-min:26.45-31.74,SD:1.43)	28.42 (Max-min:26.00-33.30,SD:2.41)
	0	30.19 (Max-min:28.52-31.74,SD:0.91)	30.24 (Max-min:28.74-31.61,SD:0.80)	29.23 (Max-min:26.62-32.07,SD:1.58)	29.42 (Max-min:26.00-33.30,SD:2.41)
	Overall	29.33 (Max-min:27.14-31.74,SD:1.10)	29.40 (Max-min:27.33-31.61,SD:1.03)	28.26 (Max-min:25.60-32.07,SD:1.59)	27.85 (Max-min:23.90-33.30,SD:2.53)
Open	5	27.77 (Max-min:25.67-30.85,SD:1.29)	27.87 (Max-min:25.91-30.77,SD:1.22)	27.60 (Max-min:25.57-30.85,SD:1.31)	27.44 (Max-min:24.90-32.10,SD:1.81)
	3	28.75 (Max-min:25.74-31.84,SD:1.75)	28.92 (Max-min:26.06-31.82,SD:1.64)	28.78 (Max-min:25.74-32.25,SD:1.84)	28.34 (Max-min:24.20-33.80,SD:2.84)
	1	28.09 (Max-min:25.96-30.12,SD:1.14)	28.27 (Max-min:26.21-30.29,SD:1.14)	28.36 (Max-min:25.89-31.31,SD:1.51)	28.09 (Max-min:23.00-32.10,SD:2.20)
	0	29.35 (Max-min:26.60-31.56,SD:1.28)	29.34 (Max-min:26.55-31.51,SD:1.32)	29.35 (Max-min:26.11-32.36,SD:1.72)	29.43 (Max-min:25.10-34.00,SD:2.47)
	Overall	28.54 (Max-min:25.67-31.84,SD:1.51)	28.64 (Max-min:25.91-31.82,SD:1.46)	28.56 (Max-min:25.57-32.36,SD:1.73)	28.38 (Max-min:23.00-34.00,SD:2.46)
Overall	5	28.09 (Max-min:25.67-30.85,SD:1.08)	28.19 (Max-min:25.91-30.77,SD:1.03)	27.39 (Max-min:25.57-30.85,SD:1.19)	26.79 (Max-min:23.90-32.10,SD:1.89)
	3	28.88 (Max-min:25.74-31.84,SD:1.39)	29.03 (Max-min:26.06-31.82,SD:1.31)	28.32 (Max-min:25.60-32.25,SD:1.70)	27.73 (Max-min:24.00-33.80,SD:2.69)
	1	28.81 (Max-min:25.96-31.36,SD:1.25)	28.91 (Max-min:26.21-31.23,SD:1.19)	28.48 (Max-min:25.89-31.74,SD:1.47)	28.25 (Max-min:23.00-32.90,SD:2.12)
	0	29.77 (Max-min:26.60-31.74,SD:1.18)	29.79 (Max-min:26.55-31.74,SD:1.18)	29.29 (Max-min:26.11-32.36,SD:1.65)	29.43 (Max-min:25.10-34.00,SD:2.44)
	Overall	28.93 (Max-min:25.67-31.84,SD:1.37)	29.02 (Max-min:25.91-31.82,SD:1.32)	28.41 (Max-min:25.57-32.36,SD:1.67)	28.12 (Max-min:23.00-34.00,SD:2.51)

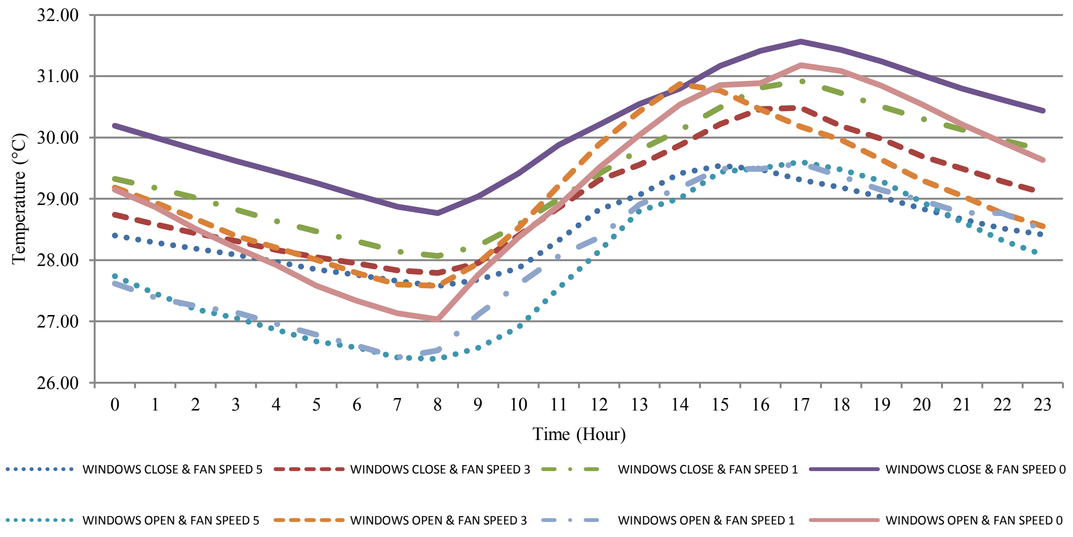
Windows	Fan speed	Relative humidity (%)			
		Indoor (A)	Indoor (B)	Corridor (C)	UM microclimate
Close	5	77.86 (Max-min:68.84-81.51,SD:2.85)	77.63 (Max-min:68.92-80.97,SD:2.74)	84.21 (Max-min:67.87-89.40,SD:4.49)	90.82 (Max-min:68.00-97.00,SD:7.24)
	3	74.03 (Max-min:62.77-81.87,SD:3.83)	73.67 (Max-min:62.74-81.66,SD:3.73)	79.71 (Max-min:59.73-88.95,SD:6.57)	85.11 (Max-min:58.00-96.00,SD:10.8)
	1	69.38 (Max-min:57.93-78.90,SD:5.10)	69.24 (Max-min:57.15-78.55,SD:5.22)	73.16 (Max-min:54.64-85.85,SD:8.29)	78.63 (Max-min:59.00-93.00,SD:10.9)
	0	63.62 (Max-min:52.65-71.84,SD:4.16)	63.64 (Max-min:54.53-71.89,SD:3.76)	67.20 (Max-min:47.69-79.99,SD:7.29)	73.34 (Max-min:55.00-95.00,SD:9.94)
	Overall	70.84 (Max-min:52.65-81.87,SD:6.86)	70.68 (Max-min:54.53-81.66,SD:6.69)	75.64 (Max-min:47.69-89.40,SD:9.52)	81.44 (Max-min:55.00-97.00,SD:11.8)
Open	5	79.07 (Max-min:59.82-85.83,SD:6.21)	78.62 (Max-min:60.09-85.33,SD:5.97)	79.90 (Max-min:58.93-87.15,SD:6.32)	83.44 (Max-min:62.00-96.00,SD:9.30)
	3	75.49 (Max-min:56.64-90.28,SD:9.59)	74.75 (Max-min:56.92-89.38,SD:8.99)	75.65 (Max-min:55.93-90.60,SD:9.66)	81.51 (Max-min:56.00-97.00,SD:12.9)
	1	74.37 (Max-min:56.63-83.29,SD:6.18)	73.82 (Max-min:57.16-82.80,SD:6.15)	73.32 (Max-min:51.35-84.60,SD:8.19)	76.68 (Max-min:56.00-93.00,SD:10.9)
	0	65.59 (Max-min:49.50-79.22,SD:7.70)	65.85 (Max-min:49.27-79.90,SD:7.99)	65.82 (Max-min:44.61-81.82,SD:9.57)	71.98 (Max-min:46.00-92.00,SD:12.0)
	Overall	73.18 (Max-min:49.50-90.28,SD:9.15)	72.86 (Max-min:49.27-89.38,SD:8.85)	73.26 (Max-min:44.61-90.60,SD:10.1)	78.07 (Max-min:46.00-97.00,SD:12.2)
Overall	5	78.46 (Max-min:59.82-85.83,SD:4.85)	78.13 (Max-min:60.09-85.33,SD:4.66)	82.06 (Max-min:58.93-89.40,SD:5.88)	86.86 (Max-min:62.00-97.00,SD:8.99)
	3	74.76 (Max-min:56.64-90.28,SD:7.31)	74.21 (Max-min:56.92-89.38,SD:6.88)	77.68 (Max-min:55.93-90.60,SD:8.48)	83.31 (Max-min:56.00-97.00,SD:11.9)
	1	71.87 (Max-min:56.63-83.29,SD:6.18)	71.53 (Max-min:57.15-82.80,SD:6.13)	73.24 (Max-min:51.35-85.85,SD:8.21)	77.65 (Max-min:56.00-93.00,SD:10.9)
	0	64.60 (Max-min:49.50-79.22,SD:6.25)	64.75 (Max-min:49.27-79.90,SD:6.33)	66.51 (Max-min:44.61-81.82,SD:8.52)	72.66 (Max-min:46.00-95.00,SD:11.0)
	Overall	72.01 (Max-min:49.50-90.28,SD:8.16)	71.77 (Max-min:49.27-89.38,SD:7.92)	74.45 (Max-min:44.61-90.60,SD:9.88)	79.75 (Max-min:46.00-97.00,SD:12.1)

Windows	Illuminance (lux)		
	Indoor (A)	Indoor (B)	Corridor (C)
Close	248.57 (Max-min:3.90-1,052.50,SD:328.68)	304.94 (Max-min:11.80-1,407.30,SD:412.30)	1,111.14 (Max-min:3.90-5,443.70,SD:1,556.51)
Open	192.99 (Max-min:3.90-1,131.30,SD:272.22)	267.36 (Max-min:11.80-1,391.50,SD:379.43)	1,082.87 (Max-min:3.90-5,451.60,SD:1,514.97)
Overall	220.78 (Max-min:3.90-1,131.30,SD:302.82)	286.15 (Max-min:11.80-1,407.30,SD:396.34)	1,097.01 (Max-min:3.90-5,451.60,SD:1,534.75)

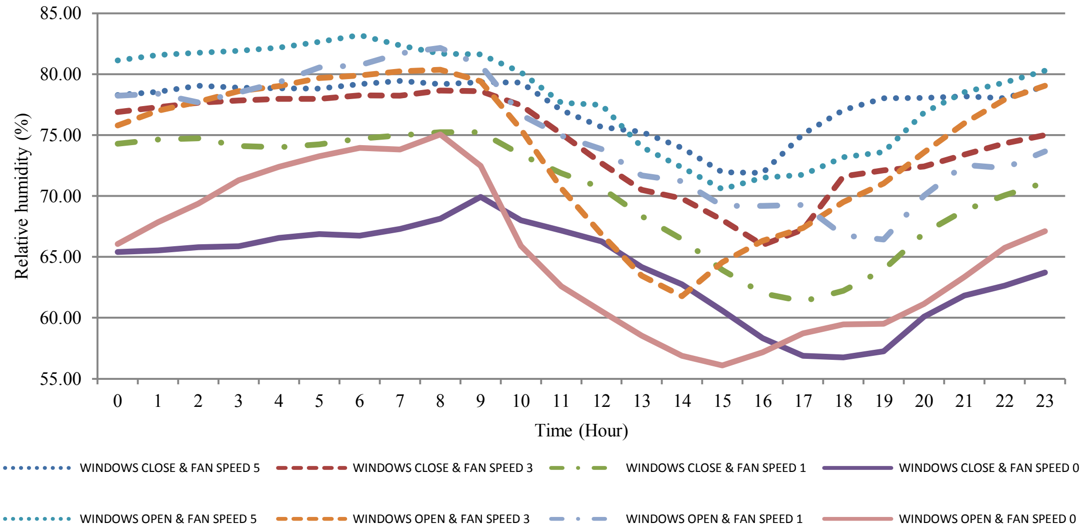
Statistically, there were no differences between the two different sides of the walls in the room; Indoor A and B in terms of mean temperature and relative humidity. The mean temperatures were 29°C with the recorded temperatures ranging between 26°C and 32°C. The relative humidity reached 72%, with a minimum value of 49% and a maximum value of 90%. Compared with the indoor condition, the mean temperature values at the corridor were 1°C lower which was 28°C, with temperatures ranging between 26°C to 32°C, while their percentage relative humidity was higher at 74% with minimum and maximum percentages of 45% and 91%, respectively.

Referring to Table 5.22, there were no significant differences seen in the mean temperature caused by the opening or closing of all windows in the room. However, there was a 2% increment of relative humidity with the opening of all operable windows. The reduction of fan speed drastically increased the room temperature by 1°C to 2°C and consistently reduced the relative humidity by a margin of 13% to 14%. The corridors had the same mean temperature with the UM microclimate which was 28°C. However, the UM microclimate's relative humidity was slightly higher exceeding 79% with a maximum value of 97%.

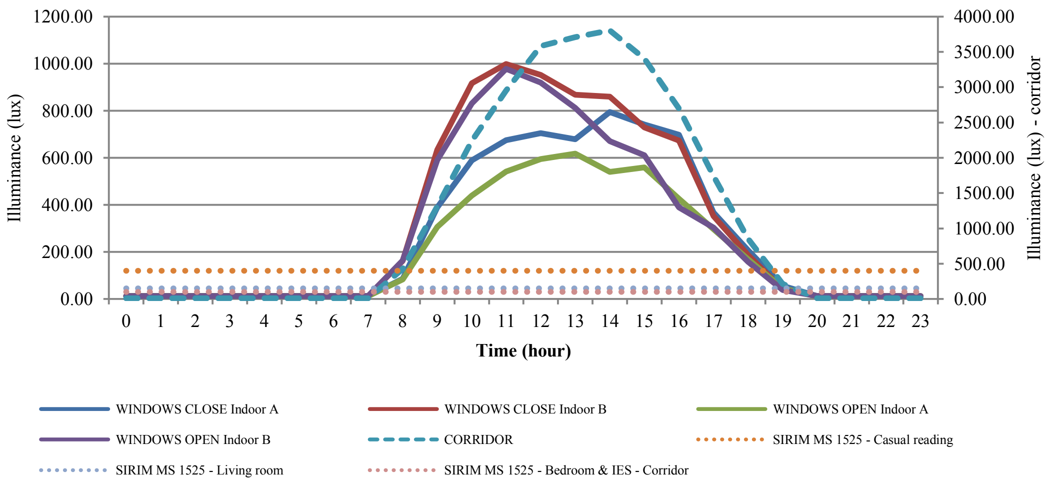
Further analysis of the daily pattern showed that the indoor temperature gradually decreases until achieving the minimum value at 0800 hours and progressively increases until achieving the maximum value at 1700 hours, exceeding 31°C as presented in Figure 5.31. There was a margin of more than 1°C between the minimum and the maximum values. After 1800 hours, the indoor temperature gradually declined by less than 1°C. According to Figure 5.31(a), the indoor temperature decreased with the increase of fan speed especially when all the windows were closed. At the same fan speed, the temperature was further reduced by the opening of the windows. In comparison the indoor temperatures were not reduced with the increase of fan speed when the windows were already open.



(a)



(b)



(c)

(a). Temperature (°C), (b). Relative humidity (%), (c). Illuminance (lux)

Figure 5.31: The indoor daily pattern of scenario W4

There were also times when higher temperatures were recorded with higher fan speeds. The same pattern was also observed with the indoor relative humidity but with an inverse relationship, as the increase of temperature reduces the relative humidity values [Figure 5.31(b)]. Through this daily pattern it is shown that the fan speed and state of windows play a role in influencing the values of indoor temperature and relative humidity.

There are slight differences between the illuminance values of position Indoor A and B . The mean illuminance value of Indoor A which is 221 lux with a maximum value of 1,131 lux, was lower than that of Indoor B which is 286 lux with a maximum value of 1,407 lux, as shown in Table 5.22. The adequacy of daylight in the room met the MS 1525 minimum requirement for book reading, lighting in living room and bedrooms from 9 a.m. to 5 p.m. [Figure 5.31(c)]. The opening of the windows considerably influenced the illuminance values in the rooms. In the open state, the mean illuminance value had a much lower maximum difference range of between 38 lux (Indoor B) and 56 lux (Indoor A). The adequacy of daylight in the corridor met the IES minimum requirement from the period between 8 a.m. to 7 p.m. The maximum recorded illuminance value was 5,452 lux with the mean value of 1,097 lux.

5.2.3 Living behaviour assessment

The living behaviour assessment was done in a general manner due to the reluctance and lack of cooperation from residents in giving their response to determine their satisfaction and perception levels toward their rooms. Data collected from eight rooms representing ten different scenarios, were analysed with regards to three different time periods; 6 a.m.- 12 p.m. (morning), 12 p.m. - 6 p.m. (afternoon) and 6 p.m. - 12 a.m. (evening). Data from periods between 12 a.m. to 6 a.m. were excluded as all residents were considered to be asleep.

All climate data are presented in *Appendix U - Climate profile of living behaviour assessment*. Some microclimate data for certain periods are not shown due to technical errors at the UM weather station.

The mean values of the climate conditions, including that of the indoor climate, the climate of the corridors and the area microclimate, during three different time periods are presented in Table 5.23.

Table 5.23: The mean values of climate condition according to three different time periods

Climate	Parameter	Time		
		6 a.m. – 12 p.m. (Morning)	*12 p.m. – 6 p.m. (Afternoon)*	*6 p.m. – 12 a.m. (Evening)*
Indoor climate	Temperature	29°C (25-31°C)[1]	30°C (26-34°C)[1]	30°C (26-33°C)[1]
	Relative humidity	77% (61-90%)[1]	72% (54-88%)[1]	74% (57-90%)[1]
	Illuminance	72 lux (4-737 lux)[1]	94 lux (4-919 lux)[1]	20 lux (4-264 lux)[1]
Corridor climate	Temperature	28°C (24-32°C)[1]	30°C (25-35°C)[1]	29°C (25-34°C)[1]
	Relative humidity	81% (61-94%)[1]	69% (48-93%)[1]	77% (50-94%)[1]
	Illuminance	2,240 lux (4-12,263 lux)[1]	4,644 lux (12-17,806 lux)[1]	154 lux (4-6,232 lux)[1]
Microclimate	Temperature	27°C (25-30°C)[1]	30°C (26-33°C)[1]	28°C (24-31°C)[1]
	Relative humidity	84% (62-95%)[1]	67% (56-90%)[1]	81% (59-95%)[1]
	Total rain duration	0 min	105 min	200 min
	Total rain amount	0 mm	6.1 mm	45.4 mm

Note: [1] Minimum and maximum value

The microclimate condition was better compared to the climate in the corridors which in turn were better than the indoor climate in terms of lowest temperature and highest relative humidity. This was clearly the case during the morning period of 6 a.m. - 12 p.m. and the evening period of 6 p.m. - 12 a.m. when there were temperature differences of up to 1°C from the mean temperature with 7% of relative humidity. The temperatures drastically increased in the afternoon and decreased slightly in the evening.

It was apparent that the evening temperatures in student rooms remained mostly the same as it was in the afternoon with only small increments of relative humidity percentage of up to 2%. In the corridors and in the area's microclimate, the percentages of relative humidity were considerably increased by 8 to 14 %, with the reductions in temperature values. The same pattern was also discovered with light intensity, the values increase in the afternoon and drastically decrease in the evening.

The largest recorded total rainfall was 45.4mm and the longest rainfall duration recorded was 200 minutes, they both occurred in the evening. These high levels of rainfall contribute to the percentage relative humidity of the microclimate. Only 6.1 mm of total rainfall and 105 minutes of total rainfall duration were recorded in the afternoon. As shown in Table 5.23, there was no rain recorded in the morning from 6 a.m. to 12 p.m. during the whole time the assessment was conducted.

Residents were able to adapt well with the significant temperature increase in the afternoon, which would rise up by 3°C. To reduce metabolic heat production, the majority of residents only did light activities or are otherwise seated or relaxing, while most of the time wearing garments with small clothing insulation, as shown in Table 5.24.

Table 5.24: The pattern of activities, garment worn, use of room openings and electronic devices according to different time periods of the day

The performance indicator		Time / *Percentages of usage*			*Overall*
		6 am - 12 pm	12 pm - 6 pm	6 pm - 12 am	*Percentage*
Activity	Reclining (0.8 Met)	*17.2*	*4.1*	*3.7*	*8.3*
	Seating relaxing (1.0 Met)	*59.3*	*70.7*	*65.9*	*65.0*
	Sedentary activity (1.2 Met)	*20.7*	*21.1*	*27.4*	*23.4*
	Standing relaxed (1.2 Met)	*0.0*	*0.0*	*0.6*	*0.3*
	Domestic work (1.7 Met)	*2.1*	*2.4*	*1.8*	*2.1*
	Walking on 5 km (3.4 Met)	*0.7*	*1.7*	*0.6*	*0.9*
Garment worn	Mean value (clo)	*0.18*	*0.20*	*0.19*	*0.19*
	Min-Max value (clo)	*0.06-1.03*	*0.06-1.03*	*0.06-0.83*	*0.06-1.03*
Windows	Open	*18.0*	*26.5*	*42.0*	*29.6*
	Close	*82.0*	*73.5*	*58.0*	*70.4*
Curtain	Open	*50.6*	*49.3*	*64.4*	*55.4*
	Close	*49.4*	*50.7*	*35.6*	*44.6*
Fan	On	*98.8*	*96.7*	*99.5*	*96.7*
	Off	*1.2*	*9.3*	*0.5*	*3.3*
Fan speed	0	*1.2*	*8.6*	*0.6*	*3.1*
	1	*0.0*	*0.6*	*0.0*	*0.3*
	2	*3.5*	*2.0*	*2.6*	*2.7*
	3	*30.2*	*6.0*	*8.9*	*11.8*
	4	*15.0*	*12.6*	*18.8*	*15.7*
	5	*60.1*	*70.2*	*69.1*	*66.4*
Ceiling lamp	On	*20.8*	*21.9*	*90.1*	*46.8*
	Off	*79.2*	*78.1*	*9.9*	*53.2*
Study lamp	On	*15.7*	*16.6*	*71.7*	*36.8*
	Off	*84.3*	*83.4*	*28.3*	*63.2*
Computer	On	*42.4*	*43.7*	*71.7*	*53.7*
	Off	*57.6*	*56.3*	*28.3*	*46.3*
Mobile phone charger	On	*18.0*	*22.5*	*46.8*	*30.0*
	Off	*82.0*	*77.5*	*53.2*	*70.0*

The fan was used at full speed at all times to maintain air circulation in the room when the operable windows were closed. The curtains were used in the afternoon by half of the respondents to reduce glare. Common electrical appliances in student rooms such as ceiling lamps, study lamps and computers were all fully utilised in the evenings when all rooms were fully occupied. Hence, there were internal thermal loads produced by the residents as well as the electrical appliances. This explains the higher temperatures retained in the rooms compared temperatures in the corridors and that of the microclimate which drastically dropped after 6 p.m. In addition to this, the majority of residents are assumed to charge their mobile phones from 12 a.m. to 6 a.m.

The changes in microclimate were found to indirectly influence room conditions. However, with good adaptation through changes in living behaviour; which include residents' choice of activities in the room, choice of garment or attire and the use of electrical appliances, the comfort level of the rooms were successfully maintained. This is proven through the satisfaction and perception shown towards room conditions at different time periods of the day as in Table 5.25.

The majority of the residents feel that there were no changes on the quality of lighting, indoor ventilation, and thermal comfort with regards to the different time periods of the day. Most of them voted 'neither/nor' for the quality of lighting and indoor ventilation, whereas they were neutral on thermal comfort. Thus, the overall comfort level is 'neutral' and there were 'no changes' on their work productivity.

However, there were some changes in perception particularly on natural daylighting, artificial lighting and air movement with regards to different time periods of the day. Most residents claim that the quality of natural daylighting is 'dark' in late afternoon as the sun sets, compared to the morning which was 'neither/nor'. Besides that, the quality of artificial lighting is 'bright' in the evening when all artificial lights were switched on.

Table 5.25: The satisfaction and perception of the selected rooms according to different time periods of the day

The performance indicator		Time / *Percentages of residents' responses*			*Overall*
		6 am - 12 pm	12 pm - 6 pm	6 pm - 12 am	*Percentage*
Natural daylighting	Too dark	*2.3*	*2.0*	*14.0*	*6.6*
	Dark	*22.0*	*33.1*	*38.5*	*31.4*
	Neither/Nor	*31.8*	*30.4*	*30.7*	*31.0*
	Bright	*41.6*	*32.5*	*15.6*	*29.3*
	Too Bright	*2.3*	*2.0*	*1.2*	*1.7*
Artificial lighting	Too dark	*0.0*	*0.0*	*0.0*	*0.0*
	Dark	*13.3*	*17.9*	*24.0*	*18.6*
	Neither/Nor	*64.7*	*57.0*	*28.0*	*48.8*
	Bright	*21.4*	*24.5*	*47.4*	*32.0*
	Too Bright	*0.6*	*0.6*	*0.6*	*0.6*
Quality of lighting	Too dark	*2.3*	*0.0*	*0.0*	*0.8*
	Dark	*12.1*	*17.2*	*24.5*	*18.2*
	Neither/Nor	*43.4*	*53.0*	*39.6*	*44.8*
	Bright	*41.6*	*29.1*	*35.9*	*35.9*
	Too Bright	*0.6*	*0.7*	*0.0*	*0.3*
Air movement	Still air	*14.5*	*14.7*	*10.9*	*13.2*
	Inconspicuous still air	*14.0*	*14.0*	*8.3*	*11.9*
	Neither/Nor	*39.5*	*45.3*	*38.0*	*40.7*
	Breezy	*32.0*	*26.0*	*40.1*	*33.3*
	Very breezy	*0.0*	*0.0*	*2.7*	*0.9*
Quality of indoor ventilation	Very poor	*0.5*	*1.3*	*0.0*	*0.6*
	Poor	*11.0*	*10.6*	*8.3*	*9.9*
	Neither/Nor	*43.4*	*51.0*	*44.8*	*46.1*
	Good	*43.4*	*36.4*	*43.2*	*41.3*
	Very good	*1.7*	*0.7*	*3.7*	*2.1*
Thermal comfort	Too hot	*0.0*	*1.3*	*0.0*	*0.4*
	Hot	*10.4*	*25.8*	*9.9*	*14.7*
	Neutral	*52.6*	*42.4*	*50.5*	*48.8*
	Cool	*37.0*	*29.8*	*37.0*	*34.9*
	Cold	*0.0*	*0.7*	*2.6*	*1.2*
Overall comfort level	Very comfortable	*0.0*	*0.7*	*0.5*	*0.5*
	Comfortable	*6.4*	*15.2*	*6.8*	*9.1*
	Neutral	*50.9*	*49.7*	*47.4*	*49.2*
	Comfortable	*41.6*	*33.1*	*41.7*	*39.1*
	Very comfortable	*1.1*	*1.3*	*3.6*	*2.1*
Work productivity	Much decreased	*1.2*	*0.7*	*0.5*	*0.9*
	Decreased	*10.4*	*16.5*	*14.1*	*13.6*
	No Changes	*72.3*	*69.5*	*64.9*	*68.7*
	Increased	*14.5*	*12.6*	*17.8*	*15.1*
	Much increased	*1.6*	*0.7*	*2.7*	*1.7*

With the reduction of mean temperature and the increase of relative humidity during this period of the day, most residents described the air movement in their rooms as 'breezy'.

CHAPTER 6
Case study – Analysis

A survey on residents' satisfaction and perception towards existing implementation of bioclimatic design concepts particularly on those addressing natural ventilation and daylighting, were used as a subjective measurement of their effectiveness. The perception towards architectural and landscaping elements were also included as part of the performance indicator. A majority of occupants at the 5^{th} RC, who represented 53.6% of respondents, were 'comfortable' with the condition of their rooms, while 52.1% voted 'good' on the overall quality of their residential buildings. Indirectly, these findings indicate the occupants' acceptance of existing bioclimatic design concept implementations. Further statistical analyses were done by comparing the percentage of respondents with regards to their gender, race and ethnicity, as well as location of the rooms according to the floor level. All the results are presented in *Appendix V - Statistical analysis of satisfaction and perception survey*.

There were no differences of response between the genders for all performance indicators, except for the landscape elements. The majority of female respondents who represented 47.8% of respondents, rated the internal courtyard as highly influential ('very') to their quality of life, whilst 43.3% of male respondents voted for 'moderate' influence.

However, many differences were seen when comparing the responses between respondents from different cultural and ethnic backgrounds due to dissimilarities in beliefs, way of life and traditions which include their diet and clothing. These differences were seen to affect all elements especially on visual comfort and the landscape aspects. Compared to overall responses, the majority of Chinese and 'Others' respondents rated some of the elements one rate lower than respondents of other races.

The majority of Indian respondents rated one rate higher than respondents of other races for general room layout, safety, and thermal comfort which was based on a seven point sensation scale. Hence, most of the Indian respondents felt ‘slightly warm’ while respondents of other races felt ‘neutral’. ‘Safety’ was the main reason for Indians not opening windows, whilst respondents of other races voted for the disturbance caused by monkeys.

Differences of response were also observed for different locations of rooms. High levels of dissatisfactions were mainly expressed by those living on the ground floor, particularly in terms of thermal comfort, indoor air quality and visual comfort elements. They rated one rate lower than the overall responses compared to respondents who live on other floors. These could be due to the presence of various barrier structures either natural or man-made that prevent them from getting good daylighting and limit natural ventilation such as nearby covered parking area for motorcycles and trees with big crowns. ‘Privacy’ is the main reason for those who live on the ground floor to not open their windows while ‘monkeys’ are a major problem for those living on the higher levels. This happen because all operable windows of rooms on the ground floors are fixed with a grill which is not available for rooms on the upper levels. This prevents the intrusion of wild monkeys into the rooms but does not stop pedestrians who pass through the room from looking in through the windows. Thus, most of them who live on the ground floor rated ‘fair’ for ventilation and air quality, whilst they rate ‘inconspicuous still air’ for air movement.

This differs from those who live on the higher levels, the majority of them rated ventilation and air quality as ‘good’ and rated ‘breezy’ for air movement. With regards to thermal comfort, the majority of respondents who live on the top floor felt ‘warm’ while other respondents from other floors felt ‘neutral’.

Perhaps this is related to the degree of work productivity which is 'rated increased' in comparison with 'no changes' for those occupying the ground floor.

Further statistical analyses were also done by using the Pearson correlation to correlate between each performance indicators and the overall comfort, as well as the degree of work productivity with regards to residents' satisfaction and perception.

The correlations were done based on four elements of performance criteria namely; functional elements, thermal comfort and indoor air quality, visual comfort and finally landscape elements which are presented in Table 6.1 to 6.4.

Table 6.1: Correlation of residents' satisfaction and perception between overall comfort, work productivity and performance criteria of functional element

		Building layout	Overall quality of building	General room layout	Fulfil needs	Provision of privacy	Safety
Overall comfort	Pearson correlation	.284**	.354**	.491**	.526**	.385**	.455**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
Work productivity	Pearson correlation	.192**	.246**	.318**	.391**	.394**	.225**
	Sig. (2-tailed)	.003	.000	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 6.2: Correlation of residents' satisfaction and perception between overall comfort, work productivity and performance criteria of thermal comfort and indoor air quality

		Thermal comfort	Ventilation & air quality	Control of ventilation	Air movement	Provision of air movement
Overall comfort	Pearson correlation	.409**	.432**	.396**	.250**	.262**
	Sig. (2-tailed)	.000	.000	.000	.000	.000
Work productivity	Pearson correlation	.336**	311**	.376**	.239**	.286**
	Sig. (2-tailed)	.003	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 6.3: Correlation of residents' satisfaction and perception between overall comfort, work productivity and performance criteria of visual comfort elements

		Natural daylight	Control of natural daylight	Artificial light	Control of artificial light	Effective ness of curtains	Satisfaction with light quality	View out of room	Existing window area
Overall comfort	Pearson correlation	.328**	.318**	.242**	.301**	.115	.308**	.301**	.295**
	Sig. (2-tailed)	.000	.000	.000	.000	.076	.000	.000	.000
Work productivity	Pearson correlation	.135*	.201**	.268**	.302**	.267**	.268**	.292**	.298**
	Sig. (2-tailed)	.039	.002	.000	.000	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 6.4: Correlation of residents' satisfaction and perception between overall comfort, work productivity and performance criteria of landscape aspects

		Building sensitively designed for landscape setting	Landscape quality	Influence of landscape on quality of life	Internal courtyard quality	Frequency at internal courtyard	Influence of internal courtyard on quality of life
Overall comfort	Pearson correlation	.324**	.337**	.312**	.288**	.275**	.271**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
Work productivity	Pearson correlation	.205**	.236**	.327**	.125	.0.96	.336**
	Sig. (2-tailed)	.003	.000	.000	.052	.139	.000

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

The correlation coefficient takes on values ranging between +1and -1 where r = +1.0 describes a perfect positive correlation and r = -1.0 describes a perfect negative correlation. The guidelines for strength of the relationship between the variables are shown in Table 6.5 below,

Table 6.5: The guidelines for the relationship strength between the variables

Value of r	Strength of relationship
-1.0 to -0.5 or 1.0 to 0.5	Strong
-0.5 to -0.3 or 0.5 to 0.3	Moderate
-0.3 to -0.1 or 0.3 to 0.1	Weak or fair
-0.1 to 0.1	None or very weak

Overall, there were significant positive relationships between, the overall comfort as well as degree of work productivity and all of the performance criteria. Only the ability of the rooms to fulfill the need of residents showed a strong relationship with the overall comfort. There were moderate or weak/fair relationship shown between other performance criterias and both overall comfort level and degree of work productivity. According to Table 6.4, there were higher correlation coefficients that the landscaping of the surroundings of 5th RC were influencing the level of overall comfort and the degree of work productivity of residents, compared to the landscaping of the internal courtyard.

In order to obtain a thorough validation of comfort levels that was achieved at the 5th RC, further objective measurements were conducted to identify the performance of the building and the living behaviour of residents at the selected rooms.

Indirectly, the results were expected to shed some light on a number of issues that arose from the previous subjective measurement. The mean values of the building performance evaluation are presented in Table 6.6. Generally, the mean temperature and relative humidity in all of the selected unoccupied rooms at the 5th RC were in the range of 28°C to 30°C, and 66% to 75%, respectively. Whereas, the UM microclimate mean temperature was 28°C and its relative humidity was79%. There was a drop in temperature and a rise in relative humidity during rainy periods especially in the corridor spaces. This phenomenon was also seen in the outdoor surroundings of the 5th RC, which indicate that the microclimate is affected by precipitation. Additionally, there is distinguishable difference between minimum and maximum daily temperatures due to day and night factor.

One of the coolest recorded room was E208 with a low mean temperature of 28°C and a high mean relative humidity of 75%. This room represents scenario B5 which is shaded by surrounding landscape and trees with a north-south orientation. It is also not affected by direct heat radiation and penetration from man-made surfaces either from the top or from the ground.

Compared to room E205 which is exposed to open spaces, has a north-south building orientation and represents scenario W5, room E208 is a room shaded by the surrounding green landscape which provides a better room condition. The mean temperature of room E205 was 1°C higher than that of room E208 and has a relative humidity of 72% to 73%.

Similar to conditions of room E208 was also discovered in room E311 differing only in its 1% lower relative humidity. According to common established theories, this corner room which represents scenario W2, should have had a higher mean temperature reading as it receives direct heat radiation and penetration from the west on one side of its wall.

Table 6.6: The comparison of mean values of building performance evaluation

Floor	Scenario	Scenario
4th Floor	**Scenario W3 - ROOM E 406** *(Direct contact with man-made surfaces on the top)* Location A: Temp: 30°C (27-33°C)[1]; RH: 67% (47-85%)[1]; LI: 139 lux (682 lux)[2] Location B: Temp: 30°C (27-33°C)[1]; RH: 66% (46-83%)[1]; LI: 278 lux (1,644 lux)[2] *Time (duration) : 8 am - 5 pm (9 hours) Reduction of fan speed : +1 to 3°C of temp. & -14 to 17% of RH Opening of operable windows : +2% of RH CORRIDOR Temp: 30°C (26-34°C)[1], RH: 68% (38-87%)[1] LI: 3,120 lux (14,179 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)	
3rd Floor	**Scenario B1/B4 - ROOM E 306** *(North orientation/Avoid direct contact man-made surfaces on the ground)* Location A: Temp: 29°C (26-32°C)[1]; RH: 71% (49-88%)[1]; LI: 91 lux (453 lux)[2] Location B: Temp: 29°C (26-32°C)[1]; RH: 70% (48-86%)[1]; LI: 187 lx (966 lux)[2] *Time (duration) : 8 am - 4 pm (8 hours) Reduction of fan speed : +1 to 2°C of temp. & -13 to 16% of RH Opening of operable windows : Nil CORRIDOR Temp: 29°C (25-33°C)[1], RH: 71% (41-89%)[1] LI: 2,647 lux (12,933 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)	
2nd Floor	**Scenario B3/W5 - ROOM E 205** *(Avoiding direct contact with man-made surfaces on the top/Exposed)* Location A: Temp: 29°C (26-32°C)[1]; RH: 73% (50-92%)[1]; LI: 93 lux (461 lux)[2] Location B: Temp: 29°C (26-31°C)[1]; RH: 72% (50-88%)[1]; LI: 128 lux (580 lux)[2] *Time (duration) : 10am - 4 pm (6 hours) Reduction of fan speed : +1 to 2°C of temp. & -13 to 14% of RH Opening of operable windows : +1% of RH CORRIDOR Temp: 28°C (25-33°C)[1], RH: 74% (43-91%)[1] LI: 1,750 lux (8,794 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)	**Scenario B5 - ROOM E 208** *(Shaded)* Location A: Temp: 28°C (26-31°C)[1]; RH: 75% (51-91%)[1]; LI: 37 lux (162 lux)[2] Location B: Temp: 28°C (26-31°C)[1]; RH: 75% (51-88%)[1]; LI: 65 lux (304 lux)[2] *Time (duration) : Nil Reduction of fan speed : +1 to 2°C of temp. & -13 to 14% of RH Opening of operable windows : -1 to 2% of RH CORRIDOR Temp: 28°C (25-32°C)[1], RH: 77% (44-92%)[1], LI: 422 lux (1,943 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)
1st /Ground Floor	**Scenario W4 - ROOM E 102** *(Direct contact with man-made surfaces on the ground)* Location A: Temp: 29°C (26-32°C)[1]; RH: 72% (50-90%)[1]; LI: 221 lux (1,131 lux)[2] Location B: Temp: 29°C (26-32°C)[1]; RH: 72% (49-89%)[1]; LI: 286 lux (1,407 lux)[2] *Time (duration) : 9 am - 5 pm (8 hours) Reduction of fan speed : +1 to 2°C of temp. & -13 to 14% of RH Opening of operable windows : +2% of RH CORRIDOR Temp: 28°C (26-32°C)[1], RH: 74% (45-91%)[1] LI: 1,097 lux (5,452 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)	

3rd Floor

Scenario W2 - ROOM E 311	Scenario B2 - ROOM E 315	Scenario W1 - ROOM E 319
(West orientation)	*(South orientation)*	*(East orientation)*
Location B: Temp: 28°C (26-31°C)[1]; RH: 74% (49-89%)[1]; LI: 82 lux (398 lux)[2]	Location B: Temp: 29°C (26-31°C)[1]; RH: 73% (50-87%)[1]; LI: 76 lux (359 lux)[2]	Location B: Temp: 29°C (25-33°C)[1]; RH: 71% (42-90%)[1]; LI: 136 lux (643 lux)[2]
Location A: Temp: 28°C (25-34°C)[1]; RH: 74% (48-94%)[1]; LI: 151 lux (635 lux)[2]	Location A: Temp: 28°C (25-32°C)[1]; RH: 73% (50-93%)[1]; LI: 127 lux (509 lux)[2]	Location A: Temp: 29°C (25-32°C)[1]; RH: 71% (47-91%)[1]; LI: 185 lux (721 lux)[2]
*Time (duration) : 9 am - 4 pm (7 hours)	*Time (duration) : 10 am - 2 pm (4 hours)	*Time (duration) : 9 am - 5 pm (8 hours)
Reduction of fan speed : +1 to 2°C of temp. & -13 to 17% of RH	Reduction of fan speed : +1 to 2°C of temp. & -11 to 15% of RH	Reduction of fan speed : +1 to 2°C of temp. & -13 to 16% of RH
Opening of operable windows : -2% of RH	Opening of operable windows : -1°C of temperature & +1% of RH	Opening of operable windows : Nil
CORRIDOR	CORRIDOR	CORRIDOR
Temp: 28°C (25-32°C)[1], RH: 76% (47-93%)[1] LI: 192 lux (1,133 lux)[2] **Time (duration) : 8 am - 6 pm (10 hours)	Temp: 29°C (25-35°C)[1], RH: 71% (43-90%)[1] LI: 3,848 lux (18,893 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)	Temp: 29°C (26-32°C)[1], RH: 72% (43-88%)[1] LI: 282 lux (3,189 lux)[2] **Time (duration) : 8 am - 7 pm (11 hours)

UM Microclimate
Temp: 28°C (23-34°C)[1] RH: 79% (46-97%)[1]

Note: Temp : Temperature, RH : Relative humidity, LI : Illuminance
[1] Minimum - Maximum values
[2] Maximum value
* The time when daylight is competence with SIRIM MS 1525 for casual reading, 400 lux (Department of Standards Malaysia, 2007).
** The time when daylight is competence with IES for circulation areas - corridor, 100 lux (IES, 2011).

This shows the highest recorded temperature for this room which was 34°C. However, having a higher density landscape being adjacent to the ‘Rimba Ilmu’ area, the mean temperature was reduced drastically. This room also recorded the lowest temperature and the highest percentage of relative humidity for the overall study at 25°C and 94% respectively. E208 and E311 proves the effectiveness of landscaping in improving thermal comfort of rooms.

Nevertheless, there were insignificant differences discovered between room E311 and room E315 which represents B2, the opposite scenario as it is an intermediate room, orientated to the south and receives reflected heat radiation and penetration either from the west or east.

Room E406 which represents scenario W3 is an intermediate room that receives direct heat radiation and penetration from man-made surfaces such as the the top of the roof. It was the hottest recorded room with the mean temperature of 30°C, and the lowest relative humidity percentage in the range of 66% to 67%. Therefore, it was not surprising that the majority of respondents who are living on the top floor felt ‘warm’ whilst residents located on other floors felt ‘neutral’, with regard to the seven point scale of thermal environment in the survey. Compared to room E406, room E205 which represents scenario B3, is also an intermediate room but does not receive direct heat radiation and penetration from man-made surfaces on the top. Given that its room condition was cooler than room E406 with a mean temperature 1°C lower than that of room E406 with a higher relative humidity percentage that reached up to 73%.

Initially, room E102 and E319 were predicted to have relatively high temperatures compared to other rooms based on certain theories. Room E102 represents scenario W4, is an intermediate room that receives direct heat radiation and penetration from man-made surfaces on the ground.

While room E319 which represent scenario W1,is a corner room which receives direct heat radiation and penetration from the east on one side of the wall. Results indicate little difference between these two rooms and room E306 which represent the contrary scenario. The mean temperature was 29°C with a relative humidity range of between 70% to 73%. Room E306 was used to represent two different scenarios B1 and B4. This intermediate room receives reflected heat radiation and penetration from either the west or east but does not receive direct heat radiation and penetration from man-made surfaces on the ground.

Conditions at the corridor were similar to the rooms with a similar mean temperature value or less by 1°C and a higher percentage of relative. The 'good' quality of building layout with an internal courtyard and green landscape gave rise to the better conditions in this circulation area compared to other residential colleges.

The 'good' quality of landscape setting surrounding the residential college area is a great influence on the 5th RC giving a positive impact on the building conditions. Generally, the UM microclimate recorded lower temperatures and higher percentage of relative humidity as compared to the corridor and certain rooms. Presences of tress with large canopies have made the condition of rooms E208 and E311 slightly similar to the microclimate. The mean temperature was 28°C, while the relative humidity was almost 79%. Theoretically, a higher mean temperature with lower relative humidity was expected to be recorded at room E311 due to direct heat radiation and penetration from the west due to its orientation which was acknowledged to be the worst. However, this was not true for room E311 due to what was explained in the previous paragraphs, the effectiveness of landscape in providing better conditions for buildings.

This finding is supported by the subjective measurement which were done earlier, where the majority of the building's residents claim that the quality of landscape setting in both the internal courtyards and the surrounding residential college area were 'good' and 'very' influential in improving their quality of life.

The usage pattern of windows and ceiling fans which was studied as part of the survey, reveal the full reliance of occupants on ceiling fans at full speed for maintaining the comfort level of the rooms rather than the opening of operable windows. Faster fan speeds encourage more air circulation and movement in the room which indirectly influences the reduction of mean temperatures in the range of 1°C to 3°C. It was also found to influence relative humidity in all the rooms which are increased by approximately 11% to 17%.

Vice versa, there were no changes in the mean temperatures of the rooms with the opening of all operable windows. The percentages of relative humidity would slightly increase by about 1% to 2%. These were seen in rooms E406, E205, and E102. The same conditions were recorded in room E315, but with a 1°C reduction in mean temperature. In rooms E311 and E208 however, the percentages of relative humidity are slightly decreased by a range of 1% to 2%. Stagnant conditions with no changes in mean temperature and relative humidity were seen at rooms E306 and E319.

There were no natural ventilation in the rooms as most of the residents chose to keep the windows closed due to disruptions of wild monkeys and the need for privacy especially for those who lives on the ground floor. Only a few of them opened their room windows early in the morning. As a consequence the majority of respondents rated 'neither' for the provision for air movement in the room and less than 40% of respondents voted 'good' for the control of ventilation inside the room.

Despite this, the majority of respondents who reside on the 2nd, 3rd, and 4th floor rated 'good' on ventilation and air quality inside the room with 'breezy' air movement without the use of a mechanical fan.

To improve the natural ventilation and comfort level of the rooms some modifications are needed to be done on the windows. This would reduce the reliance of occupants on the ceiling fans at full speed hence reducing the electricity consumption of the building. The use of adjustable grill or net on the windows seems to be a good solution to avoid wild monkey intrusion. At the same time, it increases the safety level of the room. On the issue of 'privacy'; which was the second reason for not opening the windows, it is seen as a minor problem as the majority of respondents stated that they felt 'good' with the provisions of privacy in the rooms. Moreover, a majority of respondents who raised the issue of 'privacy' were lives on the ground floor.

In comparing the rooms of different floor levels it was found that rooms at the top level of the building had higher recorded temperatures due to heat penetration from the roof compared to rooms on the ground floor which were affected by heat penetration from the ground/tarmac, especially when there were no tree with a large canopy around. The orientation of the rooms had no significant impact on the mean temperatures of the rooms even when the exposed walls of rooms E311 and E319 had a west-east orientation.

Further analysis of the daily pattern show that the indoor temperature begin to gradually decrease reaching the minimum value at 0800 hours and progressively increase to the maximum of between of 30°C and 32°C at 1700 hours. There was more than a 1°C margin of difference between the minimum and the maximum values. After 1800 hours, the indoor temperature continuously declined until reaching a value that is lower by less than 1°C. The indoor temperature decreased with the increase of fan speed especially when all the windows were closed.

At similar fan speeds, the temperature would further be reduced by the opening of the windows. Comparatively, the indoor temperatures were not reduced with the increase of fan speed when the windows were already open. Higher temperatures were also recorded with the higher fan speeds. The same pattern was also observed with the indoor relative humidity but in the inverse relationship, as the increase of temperature reduces the relative humidity values. These daily patterns show that the fan speed and state of windows have a level of influence one the indoor temperature values and relative humidity.

Additional statistical analysis of temperature and relative humidity were done to investigate the effectiveness of the different ventilation conditions for when the fan in the rooms were switched off in the rooms of a multi-residential college building. Conditions of daytime ventilation, night-time ventilation, full day ventilation and no ventilation were studied. The mean values of temperature and relative humidity of the rooms with different ventilation conditions are presented in Table 6.7.

Overall, the room set for studying conditions of night ventilation which had its operable windows open from 8 p.m. to 7 a.m., gave the lowest mean temperature value and the highest percentage of relative humidity. The room set for full day ventilation which had its operable windows kept open all day, had a mostly similar mean temperature values or at times 1°C higher and relative humidity percentage that were slightly lower by within 3% to 6% as compared with night ventilation conditions. There were no prominent differences between the mean temperatures in the rooms with no ventilation compared to the one with daytime ventilation where the operable windows were kept open from 8 a.m. to 7 p.m.

Table 6.7: The mean values of temperature and relative humidity with different ventilation conditions

Scenario	Location	Ventilation conditions			
		Daytime ventilation	Night ventilation	Full-day ventilation	No ventilation
B1/B4 ROOM E306	Indoor (A)	30°C / 61% (27-32°C / 48-77%)[1]	29°C / 67% (27-30°C / 54-76%)[1]	30°C / 64% (27-32°C / 49-77%)[1]	30°C / 62% (29-31°C / 54-69%)[1]
	Indoor (B)	30°C / 60% (27-32°C / 48-77%)[1]	29°C / 66% (27-30°C / 53-76%)[1]	30°C / 63% (27-32°C / 48-77%)[1]	30°C / 62% (29-31°C / 56-69%)[1]
	Corridor	31°C / 58% (26-33°C / 41-80%)[1]	29°C / 68% (26-30°C / 52-80%)[1]	30°C / 63% (26-33°C / 41-80%)[1]	30°C / 63% (27-33°C / 45-76%)[1]
B2 ROOM E315	Indoor (A)	30°C / 63% (26-31°C / 48-81%)[1]	29°C / 70% (26-30°C / 55-80%)[1]	29°C / 66% (26-31°C / 50-81%)[1]	30°C / 65% (29-30°C / 59-71%)[1]
	Indoor (B)	29°C / 63% (26-31°C / 48-81%)[1]	29°C / 70% (26-30°C / 55-80%)[1]	29°C / 67% (26-31°C / 50-81%)[1]	30°C / 65% (28-30°C / 59-72%)[1]
	Corridor	31°C / 57% (26-34°C / 43-80%)[1]	29°C / 68% (26-31°C / 52-80%)[1]	30°C / 62% (26-34°C / 43-80%)[1]	30°C / 62% (27-35°C / 45-76%)[1]
B3/W5 ROOM E205	Indoor (A)	30°C / 63% (27-31°C / 48-79%)[1]	29°C / 69% (27-30°C / 56-79%)[1]	29°C / 66% (27-31°C / 50-79%)[1]	30°C / 65% (29-31°C / 58-72%)[1]
	Indoor (B)	30°C / 62% (27-31°C / 48-79%)[1]	29°C / 69% (27-30°C / 56-79%)[1]	29°C / 66% (27-31°C / 49-79%)[1]	30°C / 65% (28-31°C / 57-72%)[1]
	Corridor	30°C / 60% (26-33°C / 43-82%)[1]	29°C / 69% (26-30°C / 53-81%)[1]	30°C / 65% (26-33°C / 43-82%)[1]	29°C / 66% (27-32°C / 47-79%)[1]
B5 ROOM E208	Indoor (A)	29°C / 64% (27-31°C / 48-81%)[1]	29°C / 71% (27-30°C / 60-80%)[1]	29°C / 68% (27-31°C / 51-81%)[1]	29°C / 69% (28-30°C / 63-76%)[1]
	Indoor (B)	29°C / 64% (27-31°C / 48-80%)[1]	29°C / 70% (27-30°C / 57-79%)[1]	29°C / 67% (27-31°C / 51-80%)[1]	29°C / 68% (28-30°C / 61-76%)[1]
	Corridor	30°C / 62% (26-32°C / 44-84%)[1]	28°C / 72% (26-29°C / 55-83%)[1]	29°C / 67% (26-32°C / 44-84%)[1]	29°C / 69% (26-31°C / 53-81%)[1]
W1 ROOM E319	Indoor (A)	30°C / 61% (26-32°C / 47-79%)[1]	29°C / 68% (26-30°C / 54-79%)[1]	29°C / 65% (26-32°C / 47-79%)[1]	30°C / 63% (29-31°C / 56-70%)[1]
	Indoor (B)	30°C / 60% (25-33°C / 42-83%)[1]	29°C / 69% (25-31°C / 51-82%)[1]	30°C / 64% (25-33°C / 42-83%)[1]	30°C / 63% (27-33°C / 53-73%)[1]
	Corridor	31°C / 58% (28-32°C / 43-76%)[1]	29°C / 67% (26-30°C / 53-78%)[1]	30°C / 63% (26-32°C / 43-78%)[1]	30°C / 64% (27-32°C / 50-76%)[1]
W2 ROOM E311	Indoor (A)	30°C / 62% (25-34°C / 48-83%)[1]	29°C / 69% (25-31°C / 50-82%)[1]	29°C / 66% (25-34°C / 48-83%)[1]	30°C / 65% (27-33°C / 53-76%)[1]
	Indoor (B)	29°C / 63% (26-31°C / 48-82%)[1]	28°C / 70% (26-30°C / 55-81%)[1]	29°C / 66% (26-31°C / 49-82%)[1]	29°C / 67% (28-30°C / 61-74%)[1]
	Corridor	30°C / 62% (26-32°C / 47-83%)[1]	28°C / 70% (26-30°C / 53-82%)[1]	29°C / 66% (26-32°C / 47-83%)[1]	29°C / 67% (26-32°C / 51-79%)[1]
W3 ROOM E406	Indoor (A)	31°C / 57% (28-32°C / 47-72%)[1]	30°C / 63% (28-31°C / 52-71%)[1]	31°C / 60% (28-32°C / 47-72%)[1]	32°C / 57% (31-33°C / 50-64%)[1]
	Indoor (B)	31°C / 57% (28-33°C / 46-72%)[1]	30°C / 62% (28-31°C / 51-71%)[1]	31°C / 59% (28-33°C / 46-72%)[1]	32°C / 56% (31-33°C / 50-63%)[1]
	Corridor	31°C / 55% (27-34°C / 38-76%)[1]	30°C / 64% (27-31°C / 50-76%)[1]	31°C / 60% (27-34°C / 38-76%)[1]	31°C / 59% (28-34°C / 41-72%)[1]
W4 ROOM E102	Indoor (A)	30°C / 62% (27-32°C / 48-79%)[1]	29°C / 69% (27-30°C / 55-78%)[1]	29°C / 66% (27-32°C / 50-79%)[1]	30°C / 64% (29-32°C / 53-72%)[1]
	Indoor (B)	30°C / 62% (27-32°C / 48-80%)[1]	29°C / 70% (27-30°C / 55-79%)[1]	29°C / 66% (27-32°C / 49-80%)[1]	30°C / 64% (29-32°C / 55-72%)[1]
	Corridor	30°C / 61% (26-32°C / 45-82%)[1]	29°C / 71% (26-30°C / 54-81%)[1]	29°C / 66% (26-32°C / 45-82%)[1]	29°C / 67% (27-32°C / 48-80%)[1]
Microclimate		31°C / 65% (25-34°C / 46-92%)[1]	28°C / 79% (25-29°C / 64-92%)[1]	29°C / 72% (25-34°C / 46-92%)[1]	29°C / 73% (26-33°C / 55-95%)[1]
Note :	[1] Minimum – Maximum values				

However, in the room which was set for no ventilation where all operable windows were kept completely closed throughout the day and night, a higher mean relative humidity percentage was recorded while its mean temperature reached a higher value of 32°C as recorded in room E406 which represents scenario W3.

The ranking of ventilation conditions as was observed to be in the following order according to ascending mean temperatures and descending relative humidity percentages, night ventilation > full day ventilation > daytime ventilation ≥ no ventilation. This show that night ventilation provides better thermal comfort for residents in residential college buildings located in the tropical climate region.

Regarding visual comfort, the majority of residents were 'satisfied' with the quality of lighting in the room. The 'big' existing windows/opening area of the rooms gave a 'good' view from inside of the room. Moreover, the adequacy of natural daylight was considered to be 'bright' with a 'good' measure of control on it. Similar results were obtained of residents' reamsrks on the levels of artificial light and the effectiveness of curtains in controlling levels of daylighting in the rooms. Unfortunately, through objective measurements, different levels of daylight were recorded in the selected rooms and corridor.

Higher values of illuminance were recorded in the corridor as compared to the rooms. The adequate daylight with according to the minimum requirement of IES for a corridor is 100 lux from 8 a.m. to 7 p.m. However, the availability of daylight at the corridor of room E 311 was limited to only from 8 a.m. to 6 p.m.

Different amounts of daylight were recorded even within the same room. The sides of the rooms that faced outwards east received more daylight due to the sun path. There were times and periods of when the available daylight met the minimum requirement of MS 1525 for casual reading which is 400 lux in the rooms. Prolonged periods of this were recorded in the room that was recognised as the hottest room, E406. The duration of available daylight reached 9 hours, starting from 8 a.m. to 5 p.m. daily. The duration was drastically reduced at the lower floor levels and on average significantly increased on the ground floor.

As for intermediate rooms, the adequacy of daylight in room E315 fulfilled the minimum requirement of MS 1525 for casual reading, but only for four hours, between 10 a.m. to 2 p.m. Rooms E311 and E319 which are both corner rooms received higher amounts of daylight and for longer durations of up to eight hours (9 a.m. to 5 p.m.). Identified as the coolest room, the amount of daylight in room E208 was less than the minimum MS 1525 requirement for casual reading of 400 lux with a maximum daylight illuminance value of only 304 lux.

There was a constant minimum illuminance value both in the rooms and the corridors due to the corridor and street lamps which are closely located to the selected rooms. The corridor and street lamps are switched on from 7 p.m. to 7 a.m. daily. It appeared that the illuminance values were slightly lower when the operable windows were open.

The living behaviour assessment revealed that the residents were well adapted to maintaining their comfort levels in the room. These can be seen through the satisfaction and perception of the selected rooms according at different time periods of 6 a.m.- 12 p.m. (morning), 12 p.m. - 6 p.m. (afternoon) and 6 p.m. - 12 a.m. (evening). The majority of residents felt that there were no changes in the quality of lighting, indoor ventilation and thermal comfort with regards to the different time periods even with significant temperature increments in the afternoon, which went up by 3°C. Even worse, the evening temperature in occupied student rooms remained as high as in the afternoon with small increments of relative humidity, due to the internal thermal load produced by people and equipment. At the same time, the corridor climate and the microclimate recorded some reductions in temperature with a higher increment of relative humidity. However, there were only a few who were recorded to have changed their perceptions on the natural daylighting, artificial lighting and air movement influenced by the sun path and the microclimate for different periods of time.

Only light activities such as sitting or relaxing (1.0 Met), sedentary activities (1.2 Met) and domestic work (1.7 Met), were conducted in the rooms to reduce metabolic heat production. The result was found to be the same with that of the general satisfaction and perception survey which were done previously, where the fan were fully turned on at the maximum speed of five to maintain air circulation and movement in the room due to the operable windows being closed most of the time. Only light clothes were worn with insulation values in the range of 0.06 to 1.03 clo; with the mean value of up to 0.20 clo, most of the time especially on sunny days. In order to fulfil the need for privacy, the curtains were overly overused which required the use of artificial light. Generally, there were no major differences between conditions of occupied rooms compared to conditions of unoccupied rooms which were initially observed in the building performance evaluation. There were some decrease in temperature and increase of relative humidity on periods of high rainfall, especially in the corridor and the microclimte. The mean temperature in all selected occupied rooms remained in the same range of 28°C to 30°C, as presented in Table 6.8.

The presence of residents in the rooms have apparently increased the mean relative humidity percentage in all of the studied rooms while in some such as E 208, E 311 and E 319 the mean temperature also rose by 1°C. Then, there were also some fluctuations on the minimum and maximum values of both temperature and relative humidity values. Regarding light intensity in the rooms, all the mean and maximum values were drastically reduced. Whereas the light intensity in the corridor, showed values which were much higher compared to the results from the building performance evaluation.

Table 6.8: The comparison of mean values of living behaviour assessment

4th Floor

Scenario W3 - ROOM E 406 *(Direct contact with man-made surfaces on the top)*	
Location A	Location B
Temp: 30°C (27-32°C)[1] RH: 70% (54-81%)[1] LI: 59 lux (422 lux)[2]	Temp: 30°C (27-32°C)[1] RH: 70% (55-81%)[1] LI: 93 lux (982 lux)[2]
CORRIDOR	
Temp: 30°C (25-35°C)[1], RH: 71% (48-89%)[1] LI: 3,737 lux (17,806 lux)[2]	

3rd Floor

Scenario B1/B4 - ROOM E 306 *(North orientation/Avoid direct contact man-made surfaces on the ground)*	
Location A	Location B
Temp: 29°C (27-31°C)[1] RH: 75% (62-84%)[1] LI: 17 lux (106 lux)[2]	Temp: 29°C (27-31°C)[1] RH: 74% (62-85%)[1] LI: 15 lx (83 lux)[2]
CORRIDOR	
Temp: 29°C (25-33°C)[1], RH: 75% (53-91%)[1] LI: 3,262 lux (17,159 lux)[2]	

2nd Floor

Scenario B3/W5 - ROOM E 205 *(Avoiding direct contact with man-made surfaces on the top/Exposed)*		Scenario B5 - ROOM E 208 *(Shaded)*	
Location A	Location B	Location A	Location B
Temp: 29°C (27-31°C)[1] RH: 75% (59-85%)[1] LI: 23 lux (138 lux)[2]	Temp: 29°C (27-31°C)[1] RH: 75% (57-84%)[1] LI: 41 lux (375 lux)[2]	Temp: 29°C (26-31°C)[1] RH: 77% (64-87%)[1] LI: 20 lux (43 lux)[2]	Temp: 29°C (26-30°C)[1] RH: 78% (64-88%)[1] LI: 12 lux (20 lux)[2]
CORRIDOR		CORRIDOR	
Temp: 28°C (25-33°C)[1], RH: 77% (55-92%)[1] LI: 1,909 lux (12,161 lux)[2]		Temp: 28°C (24-31°C)[1], RH: 81% (61-94%)[1], LI: 491 lux (2,921 lux)[2]	

1st /Ground Floor

Scenario W4 - ROOM E 102 *(Direct contact with man-made surfaces on the ground)*	
Location A	Location B
Temp: 29°C (27-31°C)[1] RH: 75% (64-84%)[1] LI: 25 lux (99 lux)[2]	Temp: 29°C (27-31°C)[1] RH: 75% (63-84%)[1] LI: 25 lux (193 lux)[2]
CORRIDOR	
Temp: 29°C (25-33°C)[1], RH: 78% (55-91%)[1] LI: 1,219 lux (9,914 lux)[2]	

3rd Floor

Scenario W2 - ROOM E 311 *(West orientation)*		Scenario B2 - ROOM E 315 *(South orientation)*		Scenario W1 - ROOM E 319 *(East orientation)*	
Location B	Location A	Location B	Location A	Location B	Location A
Temp: 29°C (26-31°C)[1] RH: 76% (65-87%)[1] LI: 20 lux (154 lux)[2]	Temp: 29°C (25-33°C)[1] RH: 77% (59-90%)[1] LI: 57 lux (430 lux)[2]	Temp: 29°C (26-31°C)[1] RH: 76% (63-88%)[1] LI: 54 lux (351 lux)[2]	Temp: 29°C (26-31°C)[1] RH: 76% (62-90%)[1] LI: 90 lux (619 lux)[2]	Temp: 30°C (26-34°C)[1] RH: 73% (55-87%)[1] LI: 115 lux (572 lux)[2]	Temp: 29°C (27-32°C)[1] RH: 74% (59-85%)[1] LI: 141 lux (729 lux)[2]
CORRIDOR		CORRIDOR		CORRIDOR	
Temp: 28°C (24-31°C)[1], RH: 80% (59-94%)[1] LI: 176 lux (1,360 lux)[2]		Temp: 29°C (24-33°C)[1], RH: 76% (53-93%)[1] LI: 3,009 lux (14,416 lux)[2]		Temp: 29°C (25-31°C)[1], RH: 76% (57-90%)[1] LI: 307 lux (2,732 lux)[2]	

UM Microclimate
Temp: 28°C (24-33°C)[1] RH: 80% (56-95%)[1]

N

Note: Blue coloured : Increment as compared to building performance analysis.
Red coloured : Decrement as compared to building performance analysis.
Temp : Temperature, RH : Relative humidity, LI : Illuminance
[1] Minimum - Maximum values
[2] Maximum value
* The time when daylight is competence with SIRIM MS 1525 for casual reading, 400 lux (Department of Standards Malaysia, 2007).
** The time when daylight is competence with IES for circulation areas - corridor, 100 lux (IES, 2011).

CHAPTER 7
Discussion and conclusion

This chapter discusses the research objectives and the conclusion, which is based upon the preliminary studies, as well as field investigation and evaluations. This chapter ends with the final conclusions which addresses the research questions and provide recommendations to improve the research methodology for further studies.

7.1 Discussion of research objectives

Five objectives were decided in determining the aim and purpose of this research. The aim of this research is to analyse the impact of the implementation of two aspects of bioclimatic design strategies which are daylighting and natural ventilation, on the comfort level of selected student rooms in the UM campus with the purpose of justifying the effectiveness of applying bioclimatic design strategies for residential colleges in the UM campus. The findings related to the five research objectives are discussed in the following and are also simplified in Table 7.1 at the end of this subtopic.

7.1.1 The residential college building in UM campus with the best practice of bioclimatic design strategies and the performance of energy usage

The natural ventilation and daylighting have been implemented in all residential college buildings in the UM campus in order to provide optimum ventilation and lighting system at minimum cost. As mention by Cândido et al. (2010), natural ventilation combined with sun shading devices are the most effective building design strategies to achieve thermal comfort without resorting to mechanical cooling. Only the administrative block is fixed with air conditioning which is operated only during office hours, from 8.30 a.m. until 5.30 p.m.

The residential college buildings are all made of the same material like concrete and bricks using similar construction methods applying post and beam with pitched roof (with slight varying angle). They were only partially built with a flat roof.

Most of the residential college buildings built in 1990's and earlier are low-rise buildings with a maximum height of four floors. Every floor is accessible via corridors and connected by staircases. The building layout is linear in concept to accommodate a high number of occupants. This limits the implementation of bioclimatic design strategies, especially those applying natural ventilation and daylighting. Natural ventilation inside the rooms depend solely on window openings that face outwards, while there are no transoms above the entrance door. Hence an acceptable level of comfortibility in the rooms is quite difficult to achieve without the presence of mechanical and electrical appliances. The distribution of daylight and circulation of air in the corridor area relies on the open staircase located at the end of the corridor. In some of the studied buildings, the staircase is located at the middle of the corridor. The open staircase creates wind pressure effects in the corridor area. Unfortunately, this special feature of the staircase is unable to encourage air circulation and day light penetration due to the doors between the staircase area and corridor always being closed for security purposes. The small fixed opening devices in the staircase area at the middle of corridor was not capable of providing adequate air circulation and daylight along the corridor area even where there is no door between the staircase area and the corridor. As consequences, ventilation fans and artificial lights are required to be switched on during daytime.

Only two residential colleges the 5^{th} RC and the 11^{th} RC were designed with an internal courtyard in a square shape which encourages various implementations of bioclimatic design strategies.

The internal courtyard at the 5th RC allows for the transom on top of entrance doors and walls to fully function in providing air circulation and daylight in the rooms. Indirectly they form cross-flow/two sided ventilation with the open staircase area and the corridor that face the internal courtyard while the lamps do not need to be switched on during daytime. At the 11th RC, four student rooms facing to each other create a cubicle. Each cubicle is connected by an open corridor that faces the internal courtyard. Therefore there is no direct connection between the internal courtyard and rooms. Additionally, there is no transom on top of the entrance doors and walls. However, there is balcony in each room that encourage daylighting and air circulation inside the room. According to Tantasavasdi et al. (2001), a rectangular shape form of a building should be avoided as it is not good for natural ventilation compared to a square shape.

Bioclimatic design strategies particularly addressing natural ventilation and daylighting issues, which were well implemented in residential buildings of the UM campus are listed below, in descending order starting with the most applied strategies.

i. Window opening with horizontal and vertical adjustable/closing devices.
ii. Horizontal and vertical overhangs along the wall with windows.
iii. Large window area with tinted window glass.
iv. Transom/fixed opening over the doorway of rooms.
v. High and low level fixed/adjustable exhaust opening.
vi. Different types of window designs such as centre pivot and awning. These types of windows offer occupants the ability of channelling the outside air/wind into the room.
vii. Balconies/verandas.
viii. Courtyards/ sky courts.
ix. Wall openings that create wind pressure inside of rooms.

Most of these design strategies have been adopted in building designs of old residential college buildings; which were established in the 1980s or earlier, where the typical room floor areas are in the range of $13m^2$ to $20m^2$ with two or three occupants in each room.

Nevertheless, with the numerous renovations carried out on them to accommodate a higher number of residents, the function and effectiveness of these strategies have gradually declined. This is further complicated by the top priority given to requirements for the provision of privacy and safety. Transoms/fixed openings over doorways of rooms and low level exhaust openings have been replaced with tinted glass or fully covered with the concrete. Glass windows have been covered with wallpaper by residents even though curtains are hung in all rooms. At staircase areas, where there are walls with small adjustable or fixed openings and doors, the adjustable openings and doors are frequently closed for security purposes. As consequences of all these unanticipated changes, air circulation is prevented and daylight penetration reduced inside the corridor areas and rooms.

Due to limitations in land area, the 12^{th} RC is the newest and only one with high rise residential college buildings in the UM campus. Each floor is accessible via a corridor and between them connected by staircase and elevator. The capacity of this residential college is equivalent to four older residential college buildings. The balcony was introduced to encourage natural ventilation and daylighting into the room. However, the advantages afforded by the balconies were limited in the view of the thousands of residents accommodated in the high rise residential buildings and dependent on their different needs and habits especially in their preferences on privacy. With the buildings' linear arrangement, the distribution of daylight and air circulation at the corridor areas rely on open staircases located at the end of the corridors, and open social areas at the middle of corridor.

As mentioned before, these special features are unable to encourage air circulation and daylight penetration when in the presence of doors between the staircases and corridor areas as well as at the open social area which are always closed for security purposes.

The average electricity usage at residential colleges in the UM campus are in the range of 24 to 125 kWh/m^2/year. Fluorescent lights and fans are identified as the two major electrical appliances used at the residential colleges. Building designs influence the amount of electricity consumption in buildings. The residential college building arranged with an internal courtyard or designed with balconies in each room, consume lower amounts of electricity within the range of 24 to 33 kWh/m^2/year.

This is different from other residential college buildings with linear arrangements; which are limit in their adaptability of bioclimatic design strategies, and where the average of electricity usage is within the range of 40 to 125 kWh/m^2/year. Through the energy audit done in the preliminary studies, about 40 to 90% of the yearly average electricity use is estimated to be conservable by improving the indoor environment. This is deemed achievable through the adoption of appropriate bioclimatic design strategies in the building design involving a combination of natural ventilation and daylighting (Jamaludin et al., 2013). Basically, daylighting is among the most suitable solution to achieve a more efficient building in terms of energy use (Mazloomi, 2010).

The ability of designing for natural ventilation and daylight to reach the corridor areas will have a significant impact on the overall electricity consumption, since corridor fluorescent lighting were identified as the biggest contributor to electricity wastage, particularly at residential colleges with a linear arrangement.

Thus, the element of courtyards and balconies should be considered seriously as part of a multi-storey residential building design due to its enormous potential for lowering energy consumption per unit floor area as they allow for the full utilisation of daylight and natural ventilation.

Furthermore, the balconies and landscaping were able to act as buffers to protect the rooms from harsh solar radiation. The shading effect of the balconies offer substantial energy savings in air-conditioning systems of the multi-residential building of various orientations, N, E, S, W, NE, SE, SW and NW (Chan & Chow, 2010). Open corridors in the middle part of a building with a linear arrangement layout would be more practical for optimising day lighting and natural ventilation in order to lower energy consumption in residential college buildings compared to the layout with open ended corridors which are covered throughout except at both ends. However, both strategies would not work as well as if there were a courtyard and balconies (Jamaludin et al., 2012).

The long daylight hours which are available at a consistent intensity all year round in the tropical regions should be capitalized on as part of the bioclimatic design principle in a way to optimise and guarantee a balance of energy efficiency and occupant comfort levels. Despite this, the population density should also be critically considered. An unplanned for high population density is expected to obstruct the effectiveness of energy conservation approaches and indirectly reduces the residents' comfort levels.

The comparisons between the twelve residential colleges in the UM campus done in the preliminary studies, revealed that the 5th RC is the residential college that best demonstrate bioclimatic design concepts particularly addressing natural ventilation and day lighting.

Besides that, it possessed the advantage of having posed the least number of uncontrollable variables due to the homogeneity of building design. Therefore, this residential college was selected as the most suitable candidate for the case study. As mentioned earlier, the building designs are what influences the amount of electricity consumed and it appears that the 5th RC is not the residential college with the most efficient use of electricity with an electricity consumption rate of 33 kWh/m^2/year for a duration of five years from 2005-2009. Instead it was the 11th RC that was the most efficient in electricity usage with only 24 kWh/m^2/year that having been designed with the combination of concepts like the internal courtyard and balconies for each room. Therefore, the adaptation of balconies as part of the building design is crucial and should be highly recommended for future refurbishments. This would perhaps improve the efficiency of electricity usage at the 5th RC in the long run, especially when the further studies and energy audits had done in the field investigation and evaluations at the 5th RC show some increment of electricity usage from year 2009 to 2011. Indirectly, it gives more control on daylighting to the residents as the current operable window design of the 5th RC was found to be ineffective even in theory with a WWR value of 0.66. On the current update, the ASHRAE 90.1 Standards Committee voted to continue the current 0.24<WWR<0.40 for low-rise buildings (US Glass News Network, 2012).

7.1.2 The comfort level of student rooms according to the survey

The internal courtyard arrangement and various implementations of bioclimatic design strategies which address daylighting and natural ventilation of a residential college building were found to significantly influence the satisfaction and the perception levels of residents in a positive manner. The majority of respondents were satisfied with the comfort levels in terms of all the performance indicators of architectural elements such as thermal comfort and indoor air quality, visual comfort and landscape aspects (*refer to Chapter 5.2.1*). However, there are still room for improvement as shown otherwise by the degree of mediocre satisfaction measured based on a graduated scale (Hassanain, 2008). The race and different cultural backgrounds or ethnicity of the occupants and location of rooms were found to considerably influence the satisfaction and perception level of the respondents, more so than the gender aspect. Therefore, these aspects should be highly considered when implementing any measures for improving the comfort levels of the student rooms.

It is quite difficult to compare the result of this survey with other studies in Malaysia when there has been no systematic collection of data for various types of buildings in Malaysia (Zakaria, 2007). The approach taken here is still new in Malaysia and there are a lack of standard or agreed-upon protocols, measures and procedures, which make comparisons difficult, while it remains to be true that the acceptance, consistency and formalization of POE through surveys are inevitable (Mier et al., 2009). Therefore, in order to get a comprehensive perspective of the comfort levels achieved at the 5th RC, the results from the survey should be compared to other objective measurements conducted to identify building performance and living behaviour of the residents, and they should be considered holistically.

7.1.3 The building performance with current implementations of bioclimatic design strategies

While they were not being occupied, the mean temperature and relative humidity in all selected rooms of the residential college building with its internal courtyard arrangement and various implementations of bioclimatic design strategies, particularly daylighting and natural ventilation with minimal integration of active system; ceiling fan, were in the range of between 28°C to 30°C and 66% to 75% respectively. With regards to the floor level, higher temperatures were recorded on the top level of the building compared to the ground floor due to direct heat penetration and radiation from the roof. The same results were also reported by Davis et al. (2006) who did a study on the thermal comfort of honeycomb housing. According to Chan (2009b), more than 40% of the solar gain in a typical five storey block of flat is through its roof and that radiation on a flat roof is greater than on a vertical wall (Al-Temeemi, 1995). Thus, a rooftop garden would the best strategy for improving a top floor room's thermal condition in a residential building with a flat rooftop. The room temperature would be reduced while the percentage of relative humidity increased drastically (Wong et al., 2003). Indirectly it would improve the quality of the surrounding environment. On the ground floor, there is a slightly higher temperature recorded compared to the second and third floors due to heat penetration of the ground/tarmac, especially when there are no trees with large canopies around (Davis et al., 2006).

Theoretically, the east and west facing surfaces are acknowledged to be the worst orientations as they receive the most sun in mid-morning and mid-afternoon respectively (Ali et al., 2006). Unfortunately, there were no significant differences observed in the mean temperatures of the rooms based on the orientation of the room due to the presence of shady landscaping. All of the four selected rooms which represented north, south, east and west orientations were recorded to have the same mean temperature value of 29°C.

The presence of a landscape with green trees provides better an environment than an open sky (Monteiro & Alucci, 2009). Consequently, this improves the room and overall building condition even despite receiving direct heat radiation and penetration from the west. A tree with a big canopy is capable of reducing the temperature and increasing the percentage of relative humidity. The tree canopy has a significant filtration capability which contributes to the reduction of terrestrial radiation, cooling the ground surfaces by capturing more latent heat, reducing air temperature by promoting more evapotranspiration, and effectively improves the outdoor thermal comfort, especially in open spaces of the tropical climate region (Shahidan et al., 2010; Chan, 2009a; Hyde, 2000). Indirectly, they affect the indoor temperature and the cooling load of an adjacent building through shading and insulation effects (Yeang, 2008). Thus, reducing cooling energy and improving the air quality especially in urban areas (Akbari et al., 2001). The selection of tropical forest trees as a part of the landscape setting is key to successfully improving urban green infrastructure (Thaiutsa et al., 2008); which were already well adopted at the 5th RC, besides fruit plants to generate a village like scene and comfortable living environment (Jamaludin et al., 2014). According to the results of building performance evaluation, the Jackfruit plant (*Artocarpus cempeden*) which has a conical form is able to give a significant shading effect on rooms providing them better indoor environment.

With the current implemented bioclimatic design concepts, night ventilation, where all the operable windows are kept open from 7 p.m. until 8 a.m., has a large cooling effect on a room.

There is a 3°C margin in mean temperature decrease and up to 6% increase in relative humidity respectively, as compared to other ventilation strategies namely; daytime ventilation when all operable windows were kept open from 8 a.m. until 7 p.m., full-day ventilation when all operable windows were kept open 24 hours daily and no ventilation for when all operable windows were kept closed 24 hours daily. Therefore, night ventilation would provide better thermal comfort for residents in residential college buildings located in the tropical climate region in accordance with efforts to move towards the objective of low energy buildings. These findings are in the line with Kubota et al. (2009) who found that night ventilation cooling of a terrace house, lowered peak indoor air temperature by 2.5°C and reduced nocturnal air temperatures by 2.0°C on average, making its' effects therefore larger than those of other ventilation strategies.

The study of the daily pattern of lighting showed higher recorded illuminance values in the corridor than in the rooms. Daylighting in the corridor was adequate with regards to the 100 lux minimum requirement of IES from 8 a.m. to 7 p.m. This helps to reduce the electricity usage for artificial lighting in the corridor area more than residential buildings with linear arrangements. However, the availability of daylight at the corridor of certain rooms on the 3rd floor was limited even though these rooms are orientated to the west, showing that the shading effects of large tree canopies, the building being adjacent to the 'Rimba Ilmu' area, is a disadvantage to the illuminance of the corridor.

Different amounts of daylight were recorded even in similar rooms which were designed with the same windows/opening area. The WWR of the typical room is 0.66 which is not effective according to the latest decision of the ASHRAE 90.1 Standards Committee which states that the ideal WWR should be between 0.24 and 0.4 $0.24<WWR<0.4$ (ASHRAE, 2010; US Glass News Network, 2012).

The side of the room or wall that faces east received more daylight due to the sun path. At different times and periods of the day there were adequate amounts of daylight, with regards to the minimum requirement of MS 1525 for casual reading which is 400 lux, in the rooms. Prolonged periods were recorded in rooms on the top floor with drastically reduced time periods when going to the lower floor levels specifically on the 3rd and 2nd floor. However, the duration was significantly increased on average on the ground floor due to absence of overhangs over windows and the reflection of solar radiation on the concrete paving (Lechner, 2009).

The wide overhangs over the windows particularly along the walls of the 1st, 2nd, and 3rd floors, was limiting the adequacy of daylight in the intermediate rooms from fulfilling the minimum required 400 lux according to MS 1525 for casual reading. The adequacy of daylight in these rooms were only limited to four hours, from 10 a.m. to 2 p.m. Therefore, artificial lighting was required to deal with the shadows inside caused by the overly efficient solar protection and shades (David et al., 2011).

It is a different case altogether with corner rooms which received higher amounts of daylight for longer durations, of up to eight hours a day. The presence of larger openings on the wall that encourages wind pressure inside the room has reduced the need for the transom over the doorway to provide daylight from the internal courtyard into the room. As a comparison, higher illuminance value were recorded in the corridor of intermediate rooms which exceeded 18,000 lux, but only 1,000 lux to 3,000 lux were recorded in the corridor of the corner rooms. Therefore, the appropriate choice of sun shading devices for windows are necessary to prevent the undesirable amount of solar radiation into the rooms but instead only enough and desirable amounts of solar radiation to penetrate the aperture for daylighting purposes (Chung et al., 2010).

The efficiency of solar shades must be considered from both the thermal and visual point of view, plus a good solar shade typically excludes all direct sun and much of the indirect light from the sky as well (David et al., 2011).

The amount of daylight in the rooms that are shaded by the dense canopies of green trees was less than the minimum requirement of MS 1525 for casual reading. The maximum illuminance value was only 304 lux. Thus it is vital to consider that in optimising the utilisation of landscape and trees to improve conditions of the rooms through shading effects, visual comfort should not be sacrificed.

There were constant minimum illuminance values recorded in the rooms and corridors due to the corridor and street lamps which are closely located to the selected rooms. The corridor and street lamps are switched on from 7 p.m. to 7 a.m. daily.

It was found that with the opening of windows, the illuminance values were slightly reduced. Usage of plastic nettings with a 1.5 cm of mesh size for security during the measurement has influenced the adequacy of daylight in the room. However, there were no differences recorded for rooms on the ground floor. The plastic nettings were not used in this room as window grills were already in place prior to this measurement with an iron mesh of 4cm wide. Therefore, the use of window grills or the iron mesh for security purposes should be well planned to avoid the reduction of illuminance level, as well as to avoid disruption to the natural ventilation of the room (Aynsley, 2007).

In this case room conditions are influenced more by the presence of a fan rather than the opening of operable windows. Better conditions were achieved when the fan is set at the highest speed as the ceiling fan is beneficial in moderating the vertical temperature difference (Wakamatsu et al., 2010). It also proves that there is a significant correlation between pleasantness of air movement and thermal comfort (Momoi et al., 2011).

The presence and disruption of wild monkeys and privacy are the main concern which discourages residents from opening their operable room windows. Therefore, most of the residents of naturally ventilated residential college buildings rely on their room fans set at the highest speed for maintaining air circulation in their rooms since the ceiling fan is able to increase the air velocity in a room (Tantasavasdi et al., 2001).

Therefore to optimise natural ventilation in the room through the opening of operable windows, an adjustable/operable window grill or netting could be fixed over the existing operable window. This will be able to eliminate risk of disruption by wild monkeys while ensuring the function of the windows as emergency exit during a fire. However, the use of window grill or nettings should be well planned with particular considerations on the mesh size to avoid the reduction of daylighting levels, as well as natural ventilation in the rooms. The use of window grills or nettings with an optimum 4cm mesh size is recommended for it to be functional while maintaining the quantity of daylight penetration into a room.

The use of overhangs over windows and wall openings inside of rooms as a part of a building design, must be evaluated critically by considering the location of each room. So does the planting of trees with large canopies in the landscape both in the internal courtyard and in the surroundings of the residential college area. These three strategies would be effective in improving room conditions by reducing temperature levels and encourage more air circulation in the room. Unfortunately, the adequacy of daylight in the rooms and corridor areas will become a big problem as the illuminance level would also be reduced drastically. Here, the effectiveness of the internal courtyard and transoms above the doorways count in promoting daylighting in the rooms were denied significantly by the earlier strategies. In achieving low energy building, artificial light should always be avoided especially with the abundance of available constant daylight outside the building.

7.1.4 Residents' living behaviour in achieving a state of comfort

The living behaviour assessment revealed that the residents have adapted well to maintain the comfort level of their rooms even with a significant temperature increment in the afternoon, which was as high as 3°C. The utilisation of electrical appliances during occupancy especially in the evening influences the indoor climate as there are internal thermal loads produced by the occupants and equipment. The evening temperature in the student rooms maintained as it in the afternoon with small increments in relative humidity. However temperature reductions and relative humidity increments were recorded in the microclimate and the climate in the corridors in the evening. According to Ghisi and Massignani (2007), occupied rooms would probably give different recorded results due to the internal thermal load produced by the occupants and equipment, and also due to the opening and closing of windows which affect ventilation and sunshine control.

This study showed that the majority of residents felt that there were no changes in the quality of lighting, indoor ventilation and thermal comfort during the different time periods of 6 a.m.- 12 p.m. (morning), 12 p.m. - 6 p.m. (afternoon) and 6 p.m. - 12 a.m. (evening). There were only some changes of perception towards natural daylight, artificial lighting and air movement that were influenced by the sun path and the microclimate. This showed clearly that the residents were able to adapt well to the changes of the room condition.

Only light activity was carried out in the rooms; such as sitting and relaxing (1.0 Met), sedentary activities (1.2 Met) and domestic work (1.7 Met) to reduce metabolic heat production. The fans were turned on fully at the maximum speed of five for maintaining air circulation and movement in the room when the windows are closed as how it was most of the time.

Light clothes with the cloth insulation value of between 0.06 to 1.03 clo; with a mean value of 0.20 clo, were worn most of the time especially on sunny days. This value is much lower than the common cloth insulation value of tropical clothing which is 0.55 clo as reported by Nughoro et al. (2007). The curtains were fully utilised in controlling the amount of daylight allowed into the room to reduce glare and heat caused by daylight penetration (Omer, 2008). Unfortunately to fulfil the need for privacy the curtains were often overused especially for those who are living on the ground floor or fronting the adjacent residential block occupied by different residents of a different gender. Through observation, most of the residents who have classes in the daytime would leave their rooms with its operable windows and curtains completely closed due to the same reasons of privacy and security. This carries on when they return and denies the residents daylighting in the room and forces them to switch on the light in their rooms, even though there were an abundance of natural daylight outside the room. Therefore, the mean values of light intensity in the selected rooms were drastically reduced compared to the mean values recorded during the building performance evaluation which was done earlier.

The fixed external venetian blinds which are placed on all bedroom windows should be highly considered for their effectiveness, as these devices are very effective in providing privacy and allowing users to control the amount of sunshine entering their bedrooms (Ghisi & Massignani, 2007). To improve the thermal comfort of the room, night ventilation could be used especially in rooms with high mean temperatures and low relative humidity as a result of receiving direct heat radiation and penetration. The cooling effect of night ventilation is larger than other ventilation strategies mentioned in the previous paragraph.

Findings in the satisfaction and perception survey, the building performance evaluation and living behaviour assessment indirectly show the range of comfort levels for residents of the 5^{th} RC. There were no significant differences in the condition of either an occupied or unoccupied room. The range of indoor climate and conditions faced by residents of the 5^{th} RC falls in the mean temperature range of between 28-30°C and relative humidity of 70-78%. These values are much higher compared to the ASHRAE and SIRIM MS 1525 standards. ASHRAE has set the comfortable temperature and relative humidity in the range of 23-25°C and 20-60% respectively, which is quite low compared with SIRIM MS 1525; 22-26°C and 30-70% (Zain-Ahmed et al., 2005). However, the values are quite similar to the various studies on comfort ranges for Malaysians which were done previously by Abdulmalik (1993) who gave the temperature range and relative humidity range of 25.5-29.5°C and 45-90%; AbdulRahman (1997) with 23.4-28°C and 54-76%; and Zain-Ahmed et al. (2004) with 24.5-28°C and ~73%.

The general point of view is that the global warming phenomenon has directly increased the requirements of achieving comfortability for Malaysians which indirectly increases the electricity consumption for cooling. This is exacerbated by the inefficiency of existing bioclimatic design strategies which may have been previously well functioning in providing comfortable rooms for residents, having lost their effectiveness gradually as they were changes were made through various renovations to accommodate ever higher number of residents.

7.1.5 The bioclimatic design strategies for residential college building

Bioclimatic design strategies that promote natural ventilation and daylighting to reduce energy consumption while sustaining the thermal and visual comfort of residents, for low-rise naturally ventilated residential buildings located in tropical regions, are given below;

i. A building layout which incorporates an internal courtyard that creates an open corridor and staircase area. Thus, allowing the transom on top of the entrance doors and walls to fully function in providing air circulation and daylight in the rooms. In addition to that the square shape of the building's floor plan is a good design for natural ventilation rather than a rectangular shape (Tantasavasdi et al., 2001).

ii. All openings of rooms/windows that are in the north-south orientation help reduce the cooling load of the rooms and the building. Furthermore, it would be better to orientate larger wall areas to the north-south direction (Ahmad, 2008; Chan, 2009a).

iii. Only service areas, such as toilets, bathrooms, stores, staircases and balconies should be in the west-east orientation. With a high penetration of sunlight into the toilets and bathrooms, the humidity level in those particular building area would be controlled, in a way it eliminates any risk of mould growth, which can be a major contributor to unhealthy buildings conditions and poor indoor air quality. To reduce solar gain through the roof, place as many service areas on the rooftop as possible (Chan, 2009a).

iv. A bigger floor area of more than $17m^2$ and volume of more than $47m^3$ with a low maximum occupant density of 2 people should be considered for each room to promote air circulation.

A higher population density should be avoided as it would deny the effectiveness of the bioclimatic design strategies as tools for energy conservation for indirectly reducing residents' comfort levels (Jamaludin et al., 2013).

v. A large window area with a WWR of 0.69 with tinted glass gives the residents full control of daylight penetration into the room. As referred to ASHRAE (2010), the current implemented WWR is not effective. Unfortunately, there is no guideline for the maximum size of an opening for when practically, other requirements such as sun control, security and privacy are considered (Aynsley, 2007). According to Tantasavasdi et al. (2001), the total area of the inlet and outlet apertures should be about 40%. Then, a larger inlet than outlet apertures should be used to increase the ventilation rate.

vi. Two types of window; centre pivot and awning offer occupants the possibility of channelling the outside air/wind into the room even if the position of the windows or the orientation of the building not in accordance with the wind flow direction. Moreover they act as low-level inlets and high-level exhaust openings that allow fresh air to be drawn in and foul air to be expelled (Yeang, 2006).

vii. Transoms or fixed openings over the doorway of rooms could provide air circulation and daylight penetration into the room. Indirectly creating a cross-flow or two sided ventilation with the opening of the operable windows (Omer, 2008).

viii. Horizontal and vertical overhangs along the wall with windows could reduce daylight penetration into the building thereby functioning as the simplest and most effective form of heat gain control through the windows (Edmonds & Greenup, 2002). It could be made compulsory for the east and west facades due to the low sun angles in early mornings and late afternoons compared to the north and south facades (Al-Temeemi, 1995; Soebarto et al., 2008).

ix. Wall openings could create wind pressure inside the rooms. However, this approach should be well planned considering the wind speed in the internal courtyard area (Yeang, 2008). If the wind speed is not sufficient meaning if it is less than 0.4m/s then the indoor space must be designed to be as open as possible by reducing the number of walls inside the room for the air to freely circulate (Tantasavasdi et al., 2001).

x. A well designed landscape in both the internal courtyard and the surrounding area of the residential college building. The appropriate types of trees must be selected to avoid over efficient solar protection and shade (David et al., 2011), which would deny the use of daylighting in the rooms. The use of vertical landscapes on the walls should be highly considered as studies have shown that vertical plant cover on exposed wall surfaces improves the energy efficiency of the wall by up to 8% (Yeang, 2008).

Proven in promoting natural ventilation and daylighting, all these strategies should be considered in any modification or retrofitting approaches for residential college buildings heading towards the goal of low energy buildings. In a broader perspective they should also be considered in the development of new residential college buildings. However, they should be well planned to ensure that the comfort of occupants are not compromised in order to optimise the utilisation of bioclimatic design concepts towards achieving the target of low energy buildings.

Table 7.1: The findings related to the five research objectives with regards to the methods employed for the research

Objectives	Phase	Methods		Finding
The residential college building in UM campus with the best practice of bioclimatic design strategies and the performance of energy usage	1	Preliminary studies		➢ The 5th RC is the best & the ranking was found to be in the following order, 5th RC > 11th RC > 10th RC > 12th RC > 4th RC > 7th RC > 9th RC = 1st RC = 2nd RC = 3rd RC > 6th RC > 8th RC. ➢ Various implementations: 24 to 33 kWh/m^2/year. ➢ Less application: 40 to125 kWh/m^2/year.
The comfort level of student room through the survey	2	Post Occupancy Evaluation (POE)	Satisfaction & perception survey	The satisfaction & perception level of the residents were in a positive manner which influenced by the racial, ethnic & location of the room. There is still room for improvement where the degree of satisfaction which was based on a graduated scale has shown otherwise.
The building performance on current implementation of bioclimatic design			Building performance evaluation	➢ The mean temperature and relative humidity in all selected unoccupied rooms were in the range of 28°C to 30°C and 66% to 75% respectively; which provide a comfortable living space for the residents. Higher temperatures were recorded at the top level of the building, while there were no substantial differences that can be recognized in the corner room which orientated to the west-east axis. The condition of the room is more influenced by the ceiling fan at the full speed of five rather than the opening of operable windows. The trees with a large canopy can be used to improve the condition of the rooms. ➢ Different amounts of daylight were recorded even within the same room. The internal courtyard provides the adequacy of daylight at the corridor up to ten hours daily, and offers a comfortable room as a living space and a bedroom.
Resident living behaviour in achieving a state of comfort			Living behaviour assessment	The comfort level was successfully maintained with the good adaptation of living behaviour including the activity in the room (seated relaxed), garment dressed (cloth insulation value in the range of 0.06 to 1.03 clo), usage of room opening (curtain to control amount of daylight) & electronic devices (ceiling fan at max speed of five).
The bioclimatic design strategies for residential college building	3	Data analysis		➢ Internal courtyard of building layout. ➢ All openings of the rooms/windows located on the north-south orientation. ➢ Only service areas, such as the toilet, bathroom, store, staircase and balcony locate at west-east orientation. ➢ Big room's floor area & volume (more than 17m^2 and 47m^3) with lower density (max. 2 occupants in each room). ➢ Large window area with tinted glass. ➢ Two types of window; centre pivot and awning. ➢ Transom/fixed opening over the doorway of the room. ➢ Horizontal & vertical overhangs along the wall with windows. ➢ Wall opening to create wind pressure inside the room. ➢ Well-designed of landscape setting at internal courtyard & the surrounding of residential college building.

7.2 Final conclusion

Residential college buildings that have appropriate implementations of bioclimatic design strategies particularly those that address natural ventilation and daylighting were found to achieve a desired comfort level with cost effective and efficient use of electricity. With the various implementations of bioclimatic design strategies, the amount of electricity consumed are in the range of 24 to 33 kWh/m^2/year. In comparison about 40 to125 kWh/m^2/year of annual electricity consumption were recorded by residential colleges with less application of bioclimatic design strategies.

The current implementations of bioclimatic design strategies were found to reduce the amount of electricity used for lighting. The internal courtyard creates an open corridor and staircase area which encourage air circulation and daylight penetration into the rooms through transoms located on top of entrance doors and walls. Compared to buildings with a linear layout where the corridor and staircase areas are the largest consumer of electricity for lighting due to the fluorescent lamp being switched on all day. Glare protection and adjustable natural ventilation options for enclosures and façade designs give residents more control on ventilation and daylighting of their rooms.

The survey which was done as part of the POE showed that, the residents' satisfaction and acceptance levels towards currently implemented natural ventilation and daylighting approaches, were positive. The majority of respondents perceived that comfortable levels were achieved according to the performance indicators of all related architectural elements like thermal comfort and indoor air quality, visual comfort and landscape elements. The level of satisfaction and perception of residents were influenced by cultural and ethnic background of the residents as well as the location of rooms. The majority of respondents with Chinese and 'other' cultural backgrounds rated one rate lower than the overall rate on some of the elements.

Whilst, the majority of Indian respondents gave one rating higher than the overall results for general room layout, safety, and thermal comfort based on a seven point sensation scale. These differences surfaced due to dissimilarity of beliefs, way of life and traditions which include diet and clothing. Dissatisfactions were mainly expressed by those who live on the ground floor, especially regarding thermal comfort, indoor air quality and visual comfort elements. This is different from those who live on the higher levels, where the majority of them are in a comfort level that is indirectly 'increased' according to the degree of their work productivity. There were no obvious differences in responses between the different genders of residents.

Field measurements show that a residential college building with appropriate bioclimatic design strategy implementations and integrate minimal active system namely; ceiling fan, is able to provide a comfortable living space with indoors temperatures ranging from 28°C to 30°C with 70% to 78% relative humidity. Different locations influence the conditions of rooms differently. Higher temperatures were recorded at the top level of the building compared to lower floors due to direct heat radiation and penetration through the roof. Whilst, rooms on the ground floor recorded higher temperatures than rooms on the second and third floors due direct heat radiation and penetration from man-made surfaces on the ground, there were no significant differences recognised based on the orientation of the rooms due to effects of the green landscape. Trees with large crowns; specifically Jackfruit trees (*Atrocarpus cempeden*) that have a conical form, are able to provide shading which improves the condition in the rooms even at the higher levels. With regards to illuminance, higher values were measured in the corridor compared to the rooms and different illuminance values were recorded even within the same room. The use of some lighting strategies must be critically evaluated.

The effectiveness of overhangs as sun shading devices, wall openings and green landscapes in providing a better environment in the rooms cannot be denied with reductions in temperature levels and increased air circulation in the rooms. However, should they be too efficient, these strategies would prevent adequate levels of daylighting.

Residents have adapted well to maintain the comfort level of their rooms. Only light activities like relaxed seating (1.0 Met) were done in the room at times of high temperature to reduce metabolic heat production. The ceiling fans were fully utilised at the maximum speed of five for maintaining air circulation in rooms when operable windows were closed mostly due to safety issues. Light clothes with a cloth insulation value of between 0.06 and 1.03 clo and a mean value of up to 0.20 clo, were worn at most times of the day especially on sunny days. In fulfilling the need for privacy, curtains were overused to the point of requiring residents' to use artificial light even when daylighting would have been sufficient.

Some of the bioclimatic design strategies were well demonstrated in the residential college building to achieve an optimal electricity usage. The presence of an internal courtyard in the building layout encourages more implementation of strategies especially involving enclosure and façade design. There were two types of windows used in the building, the centre pivot and awning windows with large window area and horizontal as well as vertical overhangs along the wall with windows. All openings of the rooms/windows were located on the north-south orientation and only service areas were located at the west-east orientation. Also noted were the performance of transoms or fixed openings over doorways of the rooms which allowed air circulation in the rooms as well as the typical room floor area of $17m^2$ and volume of $47m^3$.

The number of residents however, should be strictly limited to two per room, because a higher population density is predicted to obstruct the effectiveness of bioclimatic design strategies due to diverse living behaviours and increased discomfort of the residents'. Finally and most importantly is the strategy involving the design of the landscape in both the internal courtyard and the surroundings of the residential college buildings.

The energy audit shows that the combination of an internal courtyard and balcony increased the efficiency of electricity use. Unfortunately, the limitation faced by this research restrained further investigations on the satisfaction and perception levels of residents with these bioclimatic design approaches. This is also true for the precise performance measurements of the building to accommodate a comfortable room for the residents.

As the details in this case study show, the appropriate implementation of bioclimatic design strategies contribute to the reduction of wasteful energy use especially for cooling and lighting purposes, in residential college buildings. They indirectly help to reduce GHG generation from the energy and building sector. In the larger perspective they help ease effects of climate change. All these findings and information offer a new knowledge framework on how to achieve energy efficiency in residential college buildings through the optimisation of bioclimatic design strategies and their applications, particularly involving daylighting and natural ventilation in current and future building designs for the tropics. Furthermore, they contribute to the establishment of design guidelines and best practices for modification or retrofitting approaches on existing residential college buildings or multi-storey residential buildings in line with the move towards low energy buildings.

The compilation of results from critical appraisals and examination of information on the current implemented bioclimatic design strategies and energy performances of residential college buildings in Kuala Lumpur; which was done in the preliminary studies for this research, contribute to the body of knowledge which reference the established Energy Efficiency Index (EEI) specifically for residential college buildings in the tropical region.

7.3 Recommendations

To evaluate buildings in a systematic and rigorous manner, the POE should integrate more than one of data collection techniques. There are an objective and subjective assessments including walk-through survey, focus group, documentary analysis, monitored data and questionnaire surveys. The combination of several techniques which form a methodological triangulation will be able to enhance the credibility and persuasiveness of a research by giving a more detailed picture of the situation and facilitates the validation of data through cross verification from more than two sources in the study. A better quality is reached by instrumental data rather than questionnaire data; as questionnaire tends to accentuate discomfort conditions in thermal comfort perspective (Buratti & Ricciardi, 2009).

The POE in the tropical climate region, particularly as an objective assessment can be done on any month in a year as there is little seasonal variation with constant annual average temperature and humidity (Ahmad, 2008). Thus, it will not significantly influence the collected data. However, it should be covered at least 24 hours duration when there is relevant distinguish between minimum and maximum of daily temperature due to day and night factor.

For getting the accurate result of satisfaction and perception survey, the number of respondents must exceed the minimum number of feedbacks which relying on 95% of confident level and ±5% margin of error from the overall population. Therefore, the number and scope of questions must properly design with regards to the research objectives. The language and phrases used must be easily understood to get positive number of feedbacks. Long questions with many words and terms that are not easily understood, make the respondents not interested to answer the questionnaire.

The findings from the building performance analysis and living behaviour assessment did not represent the whole condition of the room and the building as each selected rooms are only represented one specific scenario that is based on the grounded theory. Thus, it only gives a general view of room condition based on the identified scenario. The worse or better conditions were expected at the room with the combination of two and more scenarios. For example, higher mean temperature with lower percentage of relative humidity in the corner room located on the top floor, receives direct heat radiation and penetration from man-made surfaces on the top and from the west on one side of the room's wall. On the other hand, lower mean temperature with a higher percentage of relative humidity in the intermediate room on the second or third floor and shaded by a big canopy of trees.

Thus, more rooms and measured parameter such as air velocity should be included in the building performance analysis and living behaviour assessment to obtain more accurate condition of the rooms and the buildings. In other words, not only limited to ten best and worst scenarios. Referring to this study; which was a multi-level residential building with an internal courtyard of building layout, all the intermediate and corner rooms on each floor should be included in this evaluation. So does, the service area such as a bathroom, toilet, store and staircase area.

With the air velocity as a measured parameter, the effectiveness of transom and the wall opening to create wind pressure in the room can be identified holistically. Also the two types of window as low-level inlets and high-level exhaust openings that allow fresh air to be drawn in and foul air to be expelled. Furthermore, the combination of windows and transom in creating cross-flow/two sided ventilation in the room.

For the comparison, other residential college should be included especially with the different application of bioclimatic design strategies. The energy audit which has been done in the preliminary studies revealed that different building design influences the efficiency of electricity usage. Unfortunately, it is too brief when the satisfaction and perception of residents not absolutely revealed, as well as the exact performance of the building through field investigation and experiments.

The access to selected rooms and residential blocks should not be limited to a certain area and period due to the safety issues. The full support from the admin and all residents should be highly inspired through the comprehensive briefing session as the findings of the research will contribute to the improvement of residential colleges later on. By giving some compensation, perhaps the cooperation of residents in recording the important information for living behaviour assessment is much better. Also, the satisfaction and perception of the residents itself during the survey for the POE.

Additionally, an adequate micro weather station for the outdoor measurement should be placed at the middle of the internal courtyard and outside of the building to obtain microclimate condition. Therefore, the effectiveness of bioclimatic design strategies in encouraging natural ventilation and daylighting in the rooms can be determined precisely. Moreover, the condition of the building can be identified holistically.

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APPENDICES

Appendix A - World energy consumption and demand

World Energy Consumption (Mtoe)**

	1971	1977	2010	2020	1997-2020*
Total Final Consumption	3,627	5,808	7,525	9,117	2.0
Coal	620	635	693	757	0.8
Oil	1,888	2,823	3,708	4,493	2.0
Gas	608	1,044	1,338	1,606	1.9
Electricity	377	987	1,423	1,846	2.8
Heat	68	232	244	273	0.7
Renewable	66	87	118	142	2.2

Note :
* Average annual growth rate, in percent
** Million tonnes of oil equivalent

Source : International Energy Agency (2000a)

World Primary Energy Demand in the Reference Scenario* (Mtoe)

	1980	2000	2005	2015	2030	2005-2030**
Coal	1,786	2,292	2,892	3,988	4,994	2.2%
Oil	3,106	3,647	4,000	4,720	5,585	1.3%
Gas	1,237	2,089	2,354	3,044	3,948	2.1%
Nuclear	186	675	721	804	854	0.7%
Hydro	147	226	251	327	416	2.0%
Biomass & waste	753	1,041	1,149	1,334	1,615	1.4%
Other renewable	12	53	61	145	308	6.7%
Total	7,228	10,023	11,429	14,361	17,721	1.8%

Note:
* World total primary energy demand, which is equivalent to total primary energy supply, includes international marine bunkers, which are excluded from the regional totals. Primary energy refers to energy in its initial form, after production or importation. Some energy is transformed, mainly in refineries power stations and heat plants. Final consumption refers to consumption in end-use sectors, net of loses in transformation and distribution. In all regions, total primary and final demand includes traditional biomass and waste, such as fuel wood, charcoal, dung and crop residues, some of which are not traded commercially.
** Average annual growth

Source : International Energy Agency (2000a)

Appendix B - Climate data of UM weather station for the period 1981 to 2009

Station : Universiti Malaya, Kuala Lumpur
Latitude : 3° 07' N
Longitude : 101° 39' E
Height above Mean Sea Level : 104.0 m

Records of 24 Hour Mean Temperature
Unit:°C

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	26.0	26.9	27.9	27.1	26.9	27.9	27.2	27.7	26.3	26.8	26.5	26.7	27.0
1982	26.7	27.0	27.0	26.9	27.0	27.5	26.7	26.6	26.8	26.1	26.3	26.7	26.8
1983	27.3	28.2	28.3	28.4	27.4	27.5	26.9	26.6	26.1	26.9	26.7	26.1	27.2
1984	25.9	25.8	26.8	26.7	27.0	27.1	26.2	26.7	26.2	26.0	25.9	25.7	26.3
1985	26.5	26.7	26.1	26.8	26.7	27.4	26.5	26.7	26.1	26.0	25.7	25.9	26.4
1986	25.7	26.5	26.4	26.5	27.1	26.9	26.7	27.2	26.3	26.1	25.7	26.5	26.5
1987	26.1	27.1	27.7	26.9	27.1	27.7	27.1	26.6	26.4	26.4	26.8	26.1	26.8
1988	26.9	27.0	27.1	27.0	27.6	26.7	26.7	26.1	26.2	27.0	26.2	26.0	26.7
1989	26.5	26.5	26.2	26.7	27.4	27.1	27.1	26.9	25.9	26.5	26.6	26.7	26.7
1990	26.8	27.9	28.1	27.7	27.5	27.6	26.9	27.3	26.6	26.6	26.5	26.7	27.2
1991	26.9	27.3	27.4	26.4	26.9	27.7	27.0	26.8	26.4	26.1	25.7	25.6	26.7
1992	26.9	26.9	27.7	27.5	27.0	27.2	26.3	26.9	26.5	26.7	25.9	26.0	26.8
1993	26.4	26.4	26.8	27.1	26.8	27.3	26.8	26.6	26.2	26.4	25.9	26.0	26.6
1994	26.7	26.8	26.3	27.1	27.0	26.7	27.1	26.4	26.5	25.9	26.1	26.8	26.6
1995	26.6	26.6	27.0	26.8	27.6	27.1	27.0	26.0	26.8	26.8	26.5	26.0	26.7
1996	26.2	26.8	26.9	27.0	27.5	27.1	26.9	26.4	27.1	26.2	26.3	25.6	26.7
1997	26.6	26.8	27.2	27.0	27.7	27.0	26.8	27.3	26.9	26.1	26.3	26.9	26.9
1998	27.6	28.5	28.6	28.6	N.A.	27.8	27.3	26.5	27.1	27.7	27.4	26.3	27.6
1999	26.3	27.0	26.6	27.9	26.7	26.8	26.7	26.6	26.1	26.0	26.1	26.4	26.6
2000	26.4	26.5	26.6	26.7	27.4	26.8	27.1	26.6	26.2	26.7	26.1	26.8	26.7
2001	26.2	26.7	28.0	27.3	28.1	27.2	27.0	27.5	26.5	26.6	27.1	26.9	27.1
2002	27.3	28.2	28.4	27.2	27.8	27.5	27.6	27.2	26.7	27.0	26.4	26.9	27.4
2003	26.7	27.0	27.7	27.0	28.2	26.8	26.7	26.7	26.3	26.4	25.9	26.1	26.8
2004	26.9	26.7	27.3	26.8	27.8	27.9	26.2	27.5	26.5	26.4	26.1	26.3	26.9
2005	27.0	28.0	27.7	27.3	27.2	28.3	27.1	27.6	27.5	26.5	26.5	26.5	27.3
2006	27.1	28.0	28.9	28.3	27.3	27.5	28.3	27.5	27.1	26.9	26.5	27.2	27.6
2007	26.8	27.0	27.7	27.2	27.6	27.1	26.9	26.5	27.6	26.7	26.5	27.2	27.1
2008	27.2	26.5	27.0	26.8	27.5	27.0	27.5	27.8	27.5	27.7	27.3	26.7	27.2
2009	28.0	27.5	27.7	28.8	29.0	28.6	28.1	28.1	28.3	27.5	N.A.	N.A.	N.A.

Note : N.A. - Data Not Available

Records of Mean Maximum Temperature
Unit: °C

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	31.7	33.8	34.9	33.8	33.7	33.9	33.5	34.8	32.7	32.7	32.2	32.6	33.4
1982	32.8	33.9	33.4	33.1	33.1	32.9	32.3	32.3	32.8	32.6	32.8	32.3	32.9
1983	33.5	35.1	35.2	34.7	33.5	33.2	32.4	32.5	32.3	32.9	32.7	31.4	33.3
1984	32.1	31.8	33.0	33.3	33.0	32.8	32.4	32.7	32.8	32.0	32.6	31.6	32.5
1985	33.0	34.0	32.8	32.9	32.9	33.8	32.9	32.8	32.4	31.7	31.4	31.8	32.7
1986	31.4	32.8	32.7	33.2	32.6	32.7	32.7	33.1	32.2	32.1	31.3	32.7	32.5
1987	31.8	33.5	34.3	33.8	33.0	32.9	32.9	32.4	32.4	33.2	32.1	31.5	32.8
1988	33.0	33.4	33.2	33.3	33.1	33.0	32.1	32.0	32.0	32.3	31.3	31.7	32.5
1989	32.5	33.3	32.5	32.7	33.1	32.9	32.9	32.5	32.2	31.8	32.4	32.2	32.6
1990	32.7	34.4	34.9	34.1	33.5	33.1	32.9	33.1	32.5	32.3	31.5	32.0	33.1
1991	33.0	33.6	34.1	32.9	32.6	32.9	32.1	31.9	31.6	31.9	31.4	30.3	32.4
1992	32.8	33.4	34.3	33.9	33.1	32.5	32.2	32.7	33.2	32.3	31.5	31.5	32.8

Appendix B, continued

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1993	32.1	32.9	33.0	33.3	32.7	32.7	32.1	32.3	32.3	32.4	32.1	31.5	32.5
1994	32.8	33.1	32.5	33.8	32.7	32.1	32.3	32.4	31.9	32.6	32.2	32.6	32.6
1995	32.3	32.9	34.1	33.5	33.6	33.3	32.5	31.7	32.3	32.9	31.9	31.2	32.7
1996	32.2	32.7	33.7	33.2	33.0	32.5	31.9	32.2	32.7	31.7	31.8	31.1	32.4
1997	32.3	33.0	33.5	33.2	33.5	32.8	32.0	32.2	32.0	32.5	33.0	32.7	32.7
1998	33.5	35.1	35.2	35.2	N.A.	33.4	33.2	31.7	32.3	32.9	32.5	31.2	33.3
1999	31.5	33.0	32.8	33.2	32.4	32.6	31.6	32.1	32.1	31.6	31.7	31.3	32.2
2000	32.1	32.7	33.2	32.9	33.6	32.2	32.4	31.5	31.9	32.1	31.9	32.4	32.4
2001	31.9	32.2	33.7	33.1	33.1	32.6	32.1	31.9	32.2	31.7	31.9	31.9	32.4
2002	32.8	34.7	34.1	33.4	33.1	32.4	32.4	32.5	31.9	32.7	32.1	32.7	32.9
2003	31.9	32.9	34.1	33.5	33.2	32.6	31.7	32.2	31.7	31.9	32.5	31.7	32.5
2004	33.1	33.2	33.4	34.0	33.8	33.0	32.0	32.5	32.7	32.4	32.7	32.0	32.9
2005	33.0	34.7	34.3	34.2	33.0	33.8	32.7	32.8	33.4	31.6	32.1	31.7	33.1
2006	32.4	33.8	35.2	34.7	33.0	32.9	33.0	32.5	32.5	32.7	32.7	32.5	33.2
2007	32.0	33.1	33.2	33.6	33.2	33.2	32.3	32.1	32.6	32.0	31.7	31.9	32.6
2008	33.0	32.7	32.7	33.1	33.2	32.3	31.9	32.6	32.2	32.3	32.1	31.9	32.5
2009	32.1	32.9	32.6	33.3	33.7	33.2	32.4	32.6	32.1	32.3	31.1	N.A	32.6

Note : N.A. - Data Not Available

Records of Mean Minimum Temperature
Unit: °C

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	22.1	22.7	23.1	23.3	23.4	23.6	23.0	22.9	22.9	22.9	22.7	22.6	22.9
1982	22.1	22.8	23.0	23.1	23.5	23.4	22.4	22.8	22.8	22.5	22.7	23.0	22.8
1983	22.8	23.4	23.9	24.5	23.8	23.7	23.1	23.1	22.8	22.9	22.9	22.6	23.3
1984	22.4	22.4	23.0	23.4	23.5	23.2	22.5	22.9	22.7	22.7	22.7	22.5	22.8
1985	22.5	23.4	23.0	23.5	23.6	23.1	22.7	23.0	22.7	22.9	22.8	22.6	23.0
1986	22.7	22.6	23.1	23.3	23.7	23.4	23.1	23.3	22.9	23.1	22.6	22.8	23.1
1987	22.7	22.8	23.9	23.7	23.9	24.0	23.5	23.3	23.3	23.3	23.6	23.1	23.4
1988	23.4	23.3	23.8	23.9	24.2	23.6	23.1	23.1	22.9	23.4	23.1	22.5	23.4
1989	23.0	22.5	23.0	23.5	23.9	23.2	23.3	23.0	22.5	22.8	23.1	22.8	23.1
1990	22.7	23.7	23.6	24.0	23.9	23.8	23.3	23.5	23.3	23.3	23.3	23.1	23.5
1991	23.3	23.4	23.7	23.4	24.0	24.2	23.7	23.3	23.1	23.0	22.7	23.0	23.4
1992	22.9	23.1	23.5	23.6	23.9	23.9	23.0	23.4	23.1	23.1	22.9	22.7	23.3
1993	22.9	22.6	23.0	23.9	23.7	23.7	23.3	23.1	22.8	23.2	23.1	23.2	23.2
1994	23.0	23.1	23.3	23.7	23.9	23.1	23.1	23.2	23.1	22.9	23.3	23.2	23.2
1995	23.3	23.3	23.3	23.7	24.2	23.8	23.5	23.1	23.4	23.6	23.5	23.0	23.5
1996	22.8	23.4	23.5	23.9	24.1	23.7	23.4	23.0	23.6	22.8	23.3	22.8	23.4
1997	22.9	23.4	23.7	23.7	24.1	23.7	23.6	24.0	24.0	23.2	23.3	23.7	23.6
1998	24.0	24.5	24.9	25.0	N.A.	24.4	23.8	23.5	23.7	24.1	23.8	23.4	24.1
1999	23.3	23.3	23.5	24.2	23.7	23.5	23.1	23.3	22.8	23.1	23.2	23.3	23.4
2000	23.2	23.3	23.4	23.7	24.0	23.6	23.7	23.1	23.3	23.4	23.6	23.6	23.5
2001	23.2	23.3	24.1	23.8	24.5	23.8	23.8	24.0	23.2	23.5	23.6	23.6	23.7
2002	23.7	24.0	24.3	24.0	24.6	24.2	24.1	24.0	23.4	23.6	23.5	23.8	23.9
2003	23.8	23.8	24.3	24.1	24.8	24.0	23.5	23.8	23.4	23.3	23.2	23.4	23.8
2004	23.7	23.7	24.3	23.8	24.4	24.4	22.8	23.9	23.3	23.5	23.1	23.3	23.7
2005	23.6	24.1	24.2	23.6	23.9	24.6	23.7	24.0	24.2	23.6	23.5	23.5	23.9
2006	23.9	24.1	25.2	25.1	23.9	24.0	24.5	23.8	23.5	23.6	23.2	24.1	24.1
2007	24.0	23.6	23.9	23.7	24.3	23.9	23.9	23.5	24.0	23.5	23.6	23.5	23.8
2008	23.5	22.6	23.3	23.4	24.3	23.7	23.6	23.9	23.1	23.4	23.7	23.3	23.5
2009	23.1	23.2	23.4	24.2	24.2	24.2	23.6	23.8	23.6	23.1	22.9	N.A.	23.6

Note : N.A. - Data Not Available

Appendix B, continued

Records of 24 hour Mean Relative Humidity
Unit : %

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	84.3	82.8	79.9	85.4	86.9	80.7	81.4	76.3	85.6	85.3	84.6	80.5	82.8
1982	79.7	81.8	84.9	85.3	86.4	84.3	82.9	84.3	84.0	87.0	88.2	85.1	84.5
1983	80.4	80.4	82.0	82.5	86.3	83.0	84.6	85.3	86.9	84.5	87.1	84.5	84.0
1984	85.1	87.3	85.5	85.6	85.2	82.5	85.8	80.6	83.3	85.3	87.7	86.0	85.0
1985	78.7	84.4	86.1	85.5	85.6	74.8	81.0	79.7	82.7	85.5	87.8	85.7	83.1
1986	82.8	80.8	83.2	87.5	84.2	83.0	81.3	79.2	84.7	86.6	88.2	83.8	83.8
1987	83.9	80.0	80.0	86.5	83.4	83.9	83.6	86.3	88.1	89.0	87.7	89.3	85.1
1988	85.0	86.0	87.5	89.0	85.8	87.2	84.5	87.8	88.1	83.0	88.0	81.9	86.2
1989	83.0	81.9	85.5	87.2	86.2	84.1	83.1	84.5	88.3	88.0	88.0	83.3	85.3
1990	82.7	78.7	79.4	85.7	86.2	84.5	85.5	80.0	86.0	88.1	88.7	84.7	84.2
1991	85.0	83.7	85.7	89.9	89.3	85.7	84.7	84.6	87.1	88.2	89.8	89.7	87.0
1992	81.1	85.4	82.6	85.7	88.3	84.2	86.6	82.6	83.9	83.6	87.0	85.9	84.7
1993	82.8	82.8	83.8	85.7	87.8	83.9	84.7	84.5	85.3	85.6	89.6	89.1	85.5
1994	82.3	84.6	86.3	86.0	87.6	86.3	81.4	84.7	86.2	88.6	87.3	80.9	85.2
1995	82.9	81.4	83.1	86.1	83.4	84.2	80.7	85.7	82.6	82.5	85.5	85.5	83.6
1996	80.4	76.6	80.6	85.3	83.4	85.4	82.8	84.9	80.9	86.7	86.5	89.1	83.6
1997	81.2	84.5	83.0	86.4	82.7	85.1	84.0	81.6	84.9	87.9	87.3	85.9	84.5
1998	83.6	81.5	80.5	83.0	N.A.	83.1	83.5	87.0	84.7	81.7	83.9	87.6	83.6
1999	87.2	81.2	85.6	81.2	84.2	81.3	80.6	84.0	86.7	87.9	86.8	84.1	84.2
2000	81.0	83.4	86.7	88.0	83.8	86.1	83.9	86.3	85.9	83.9	87.4	86.0	85.2
2001	85.5	82.7	78.2	85.4	80.2	77.7	79.0	78.9	80.5	81.2	80.0	79.6	80.7
2002	74.0	70.5	76.7	80.1	78.2	77.8	77.2	77.4	80.8	82.0	83.4	82.2	78.4
2003	78.6	77.7	76.3	80.3	73.5	76.5	76.5	74.0	75.1	72.9	78.7	70.9	75.9
2004	65.5	69.3	71.2	75.0	70.8	67.0	76.7	75.4	80.0	80.2	80.8	80.2	74.3
2005	74.3	76.3	78.3	81.5	80.5	78.0	80.8	80.0	80.2	85.0	84.2	83.4	80.2
2006	79.5	78.0	80.7	85.3	83.7	82.3	82.0	82.4	83.1	83.9	85.9	80.2	82.3
2007	79.5	78.1	81.0	81.6	79.6	79.7	79.3	78.7	77.5	81.7	81.3	79.2	79.8
2008	79.1	71.6	78.4	79.7	75.3	79.0	76.9	78.1	76.8	78.8	78.8	75.7	77.4
2009	72.8	73.8	73.0	71.1	68.7	69.5	67.4	71.1	71.3	69.4	N.A.	N.A.	N.A.

Note : N.A. - Data Not Available

Records of Monthly Rainfall Amount
Unit: millimetre

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	177.3	262.0	144.8	473.1	510.3	46.9	104.6	117.2	226.7	327.6	225.3	112.2	2728.0
1982	52.5	292.0	442.6	458.7	174.1	183.5	106.7	154.7	200.1	367.3	462.0	210.3	3104.5
1983	146.2	146.5	161.4	219.8	271.1	101.9	161.2	162.2	316.2	360.0	240.0	179.9	2466.4
1984	175.0	438.8	109.2	256.2	175.2	173.6	118.6	116.0	228.6	127.4	443.6	261.8	2624.0
1985	75.6	251.8	315.2	188.9	453.0	4.0	127.8	93.3	236.9	188.4	215.3	341.1	2491.3
1986	170.0	151.9	156.8	442.5	274.5	140.0	280.7	48.8	125.7	231.1	208.0	158.9	2388.9
1987	254.6	127.5	159.7	332.5	195.1	167.7	70.3	194.7	172.7	648.2	264.2	263.3	2850.5
1988	266.8	348.4	255.0	397.8	287.3	118.8	93.8	357.9	496.8	121.9	316.4	122.9	3183.8
1989	123.8	140.5	333.7	217.1	80.9	160.8	95.5	183.0	264.0	272.6	262.8	363.5	2498.2
1990	130.9	146.7	284.3	215.9	230.1	154.5	65.0	115.4	195.6	314.6	210.5	93.2	2156.7
1991	145.4	138.3	357.9	565.7	284.2	65.6	105.6	N.A.	226.4	300.9	478.1	344.0	N.A.
1992	124.1	242.3	313.4	352.6	406.1	90.0	280.9	54.3	207.2	60.8	288.2	294.3	2714.2
1993	244.6	245.7	158.2	262.9	409.0	237.7	178.5	102.4	223.2	185.5	531.1	372.8	3151.6
1994	260.4	300.3	295.3	189.2	268.8	226.3	48.2	153.0	207.7	316.5	472.8	159.1	2897.6
1995	169.7	124.1	305.5	461.1	182.3	252.5	87.1	324.6	193.3	203.2	205.7	503.5	3012.6
1996	314.6	87.7	479.9	439.2	133.4	279.0	130.2	217.0	65.0	475.6	300.2	344.5	3266.3
1997	192.1	300.7	310.8	424.6	263.7	92.0	244.5	71.2	305.8	357.2	619.9	178.2	3360.7
1998	292.5	234.4	285.5	N.A.	N.A.	155.1	188.1	N.A.	120.7	N.A.	218.4	216.6	N.A.
1999	191.4	223.7	414.2	88.4	489.5	68.1	163.0	267.9	340.5	331.0	317.3	201.8	3096.8
2000	367.1	162.0	315.3	304.8	132.7	159.5	231.8	165.1	238.9	361.3	514.0	483.1	3435.6
2001	502.8	192.3	101.2	349.1	129.6	163.3	115.6	62.7	317.7	303.9	244.5	169.3	2652.0
2002	51.0	149.4	242.8	N.A.	133.0	N.A.	20.5	156.6	203.1	351.3	588.9	290.3	N.A.
2003	76.9	226.7	197.8	353.0	138.7	221.1	244.1	174.8	140.3	194.7	386.8	300.7	2655.6
2004	271.6	179.9	274.3	413.6	261.6	27.3	296.7	55.4	379.9	178.0	575.1	158.8	3072.2
2005	118.7	266.7	N.A.	499.9	142.5	23.2	110.4	189.0	187.3	255.6	185.4	333.8	N.A.

Appendix B, continued

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
2006	300.7	334.4	348.4	499.2	320.3	337.7	188.8	212.1	297.5	364.7	473.4	N.A.	N.A.
2007	340.9	113.6	271.3	412.9	204.9	382.0	241.1	124.6	159.8	401.9	326.8	245.2	3225.0
2008	442.6	117.9	N.A.	547.4	78.4	354.4	80.2	463.5	N.A.	468.7	416.9	N.A.	N.A.
2009	171.5	391.9	N.A.	269.0	175.4	63.9	179.5	170.9	358.5	N.A.	N.A.	N.A.	N.A.

Note: N.A. - Not Available

Records of Mean Daily Evaporation

Unit : mm.

Month Year	Jan.	Feb	Mar	Apr	May	Jun.	Jul.	Aug.	Sep	Oct.	Nov	Dec	Annual
1981	N.A.	N.A.	4.5	4.4	3.7	4.0	3.7	4.3	3.8	3.6	3.5	3.5	N.A.
1982	3.5	3.8	3.9	3.6	3.4	3.7	3.5	3.4	3.7	3.7	3.8	3.2	3.6
1983	4.0	N.A.	4.5	N.A.	3.8	N.A.	N.A.	N.A.	3.4	3.9	N.A.	2.9	N.A.
1984	N.A.	3.1	4.0	4.2	N.A.	3.7	N.A.	N.A.	N.A.	N.A.	3.4	3.1	N.A.
1985	4.2	3.9	3.7	4.0	4.2	N.A.	N.A.	N.A.	N.A.	N.A.	3.4	3.9	N.A.
1986	3.4	4.4	4.0	4.3	4.0	4.2	4.2	4.5	3.9	3.9	3.3	3.9	4.0
1987	3.7	4.6	4.8	4.1	3.9	3.8	4.0	4.0	3.6	3.9	3.4	2.7	3.9
1988	4.1	4.3	3.9	3.9	3.8	3.6	3.4	3.2	3.5	4.1	3.1	3.8	3.7
1989	3.4	3.9	3.7	3.8	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
1990	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	3.8	4.1	4.2	3.6	4.1	N.A.
1991	4.0	4.6	4.8	4.8	3.8	3.9	3.7	3.8	3.3	3.3	2.9	2.1	3.8
1992	3.9	3.8	4.8	4.1	4.2	3.5	3.1	3.6	4.2	N.A.	3.4	3.5	N.A.
1993	4.0	4.0	4.3	4.2	3.8	3.7	3.5	3.3	3.4	3.3	3.3	2.4	3.6
1994	3.7	4.0	3.6	4.2	3.7	3.5	3.9	3.5	3.2	3.3	3.8	3.6	3.7
1995	3.5	3.7	4.5	4.2	3.6	3.7	3.4	3.2	3.4	4.3	3.2	3.0	3.6
1996	3.8	4.2	4.6	4.1	3.9	3.6	3.4	3.6	4.1	4.0	3.6	3.3	3.9
1997	4.0	4.1	4.5	4.0	4.5	3.3	3.7	3.3	3.1	3.4	4.0	3.2	3.8
1998	4.1	4.6	5.0	4.5	N.A.	3.4	3.6	3.4	3.4	3.6	3.6	2.4	N.A.
1999	2.6	3.5	3.0	3.0	2.4	3.1	2.7	2.8	2.6	2.8	3.2	2.4	2.8
2000	3.1	2.9	3.2	3.2	3.7	2.6	3.5	2.7	3.4	3.6	2.5	3.2	3.1
2001	3.0	2.8	4.1	3.2	3.4	3.3	3.4	3.0	3.2	3.1	2.5	2.6	3.1
2002	3.3	4.3	3.8	3.2	3.2	3.2	2.8	3.0	2.6	3.1	2.1	2.4	3.1
2003	2.5	3.3	3.9	3.1	3.2	3.3	3.1	3.2	2.9	3.0	2.7	2.6	3.1
2004	3.8	3.8	4.3	3.6	4.1	3.8	3.8	4.3	3.8	3.5	3.4	3.2	3.8
2005	4.5	4.1	4.0	4.6	3.4	3.5	3.7	4.0	5.1	3.1	3.2	3.0	3.9
2006	4.1	4.4	4.0	4.0	3.8	3.5	3.9	3.9	3.7	3.4	3.0	3.3	3.8
2007	3.5	3.4	4.1	3.9	4.0	3.8	3.1	3.3	3.7	3.1	3.3	2.9	3.5
2008	3.5	3.8	3.8	3.5	3.5	3.5	3.4	3.9	3.7	3.6	3.2	3.6	3.6
2009	3.3	4.1	3.6	3.9	3.9	3.6	4.3	3.4	3.8	3.1	N.A.	N.A.	N.A.

Note : N.A. - Data Not Available

Appendix B, continued

Records of Monthly Maximum Surface Wind
Unit : direction in degree / speed in metre per second

Year													
1981	220/12.0	080/12.5	080/15.2	230/16.4	010/28.4	250/12.8	270/16.8	260/12.0	310/18.4	010/29.1	280/15.8	050/13.5	010/29.1
1982	040/13.3	120/17.2	270/18.8	330/18.8	230/16.0	280/21.3	270/17.6	260/20.0	270/16.3	120/16.8	240/16.2	080/11.3	280/21.3
1983	120/22.6	270/17.0	240/14.3	250/23.5	300/17.0	030/13.9	280/18.1	150/18.7	100/17.7	270/17.2	280/15.9	250/12.6	250/23.5
1984	020/16.2	120/14.4	330/15.0	290/26.0	320/15.2	290/15.1	340/14.0	340/15.3	N.A.	200/16.3	190/13.4	260/13.1	N.A.
1985	110/12.6	020/14.5	340/15.7	340/13.0	350/17.4	350/14.7	350/15.7	210/14.9	300/17.9	320/16.1	350/17.3	300/16.0	300/17.9
1986	100/14.0	330/15.5	100/15.8	030/22.4	290/21.2	280/16.9	050/15.8	020/14.3	010/13.5	340/14.8	050/20.2	290/15.1	030/22.4
1987	040/14.4	240/16.1	290/17.5	100/25.0	210/12.2	280/18.2	210/18.0	200/14.5	220/11.8	050/24.5	240/12.5	300/15.1	100/25
1988	N.A.	N.A.	N.A.	070/16.5	260/16.0	330/15.5	260/13.4	110/13.4	220/11.8	240/14.5	Sev./10.0	N.A.	N.A.
1989	290/10.0	270/11.4	210/17.7	020/14.0	230/13.0	250/14.2	210/13.9	270/15.6	290/34.6	260/17.1	210/13.7	010/12.0	290/34.6
1990	290/10.0	N.A.	030/13.0	N.A.	N.A.	210/16.0	200/13.7	N.A.	220/13.1	210/13.6	290/17.0	010/14.3	N.A.
1991	040/12.5	280/13.1	040/14.6	310/13.3	090/22.9	250/14.6	230/12.4	N.A.	290/15.1	210/15.5	270/15.0	060/16.0	N.A.
1992	300/15.3	270/13.6	150/20.2	360/23.2	350/18.1	030/14.7	280/14.6	130/16.1	210/13.3	310/15.3	040/14.0	N.A.	N.A.
1993	040/13.5	230/14.7	230/15.3	240/15.5	200/19.0	N.A.	290/16.7	240/14.5	240/13.5	120/14.5	190/14.2	030/13.1	N.A.
1994	330/14.6	040/13.3	020/18.2	230/12.5	160/14.6	220/15.9	280/15.5	010/20.4	300/16.8	030/15.0	020/15.4	040/12.4	010/20.4
1995	100/14.5	050/12.5	100/25.7	050/16.0	040/19.3	230/14.4	310/15.8	300/13.5	280/26.8	110/14.5	320/13.6	350/14.1	280/26.8
1996	070/10.0	060/12.3	110/15.1	140/15.8	320/16.6	250/14.8	250/15.3	N.A.	N.A.	290/21.0	020/13.1	300/12.3	N.A.
1997	260/16.8	050/19.1	N.A.	120/14.5	280/14.9	290/14.1	110/17.5	240/11.6	260/13.6	120/14.5	070/16.0	010/17.6	N.A.
1998	350/13.1	280/16.1	250/12.1 330/12.1	N.A.	N.A.	N.A.	090/15.5	N.A.	250/15.1	N.A.	N.A.	230/16.6	N.A.
1999	N.A.	N.A.	N.A.	270/14.5	200/11.4	N.A.	330/13.5	N.A.	290/13.5	N.A.	060/11.1	080/11.3	N.A.
2000	050/13.9	060/15.5	N.A.	N.A.	090/15.7	270/13.1 310/13.1	N.A./22.0	N.A.	360/13.5	030/16.3	150/13.9	060/11.6	N.A.
2001	040/13.5	020/12.6	140/13.0	360/16.2	030/13.1	090/23.1	030/12.5	060/18.3	040/14.5	080/13.5	050/12.0	260/15.1	090/23.1
2002	210/14.0	240/14.0	210/15.5	260/19.2	040/11.2	N.A.	050/12.0	120/16.9	010/12.8	350/12.0 360/12.0	240/11.5	240/12.2	N.A.
2003	230/10.1	250/13.3	N.A.	140/16.5	270/9.5	200/12.1	230/12.9 270/12.9	190/13.5	220/10.2	290/14.9	080/14.6	180/10.2	N.A.
2004	160/9.3	180/13.0	120/16.0	070/13.0	050/12.5	070/15.7	090/15.0	040/13.7	230/18.0	200/14.0	030/11.0	N.A.	N.A.
2005	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	090/14.0	N.A.	N.A.	280/12.9	N.A.	N.A.	N.A.
2006	N.A.	N.A.	240/15.4	270/18.0	040/14.4	N.A.	180/15.5	100/20.3	280/13.0	070/21.7	060/11.5 250/11.5	220/12.4	N.A.
2007	250/12.0	280/12.8	090/12.9	240/14.6	130/13.6	170/12.9	080/10.0	100/11.4	140/14.1	120/11.6	090/11.5	210/15.0	210/15.0
2008	110/16.7	070/8.6	300/13.0	100/14.2	280/11.0	120/12.1	N.A.	270/13.0	250/11.9	310/11.8	060/14.5	080/10.2	N.A.
2009	100/9.1	230/11.4	070/10.6	350/15.1	360/12.1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Note : N.A. - Not Available
Sev. - Several Occasions

Appendix C - Minimum requirements/standards on thermal comfort, natural ventilation & day lighting of various evaluation instruments for residential buildings

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
GBI Residential New Construction (Malaysia)	Indoor Environmental Quality (IEQ)	EQ1	Minimum IAQ Performance	▪ Meet the minimum requirement of ventilation rate in the local code ▪ Provide cross ventilation for all public and circulation spaces	GREENBUILDING INDEX (2009a)
		EQ2	Day lighting	Encourage and recognise designs that provide good levels of day lighting for building occupants. Demonstrate that a nominated percentage of the Habitable Rooms as defined under UBBL has a daylight factor in the range 1.0-3.5% as measured at floor level; ▪ if > 50% of Habitable spaces OR ▪ if > 75% of Habitable spaces	
Green Mark Residential Building (Singapore)	Mandatory Requirements	M3	Air-Conditioning System	a) Where the cooling capacity of any air-conditioning system exceeds 3030kW, the equipment shall comply with the relevant provisions of SS 530-Code of Practice for Energy Efficiency Standard for Building Services and Equipment b) Air-conditioning shall be equipped with manual switches, timers or automatic controllers for shutting off part of the air-conditioning system to reduce energy use whenever conditions permit.	Building and Construction Authority [BCA] (2008)
		M4	Air Tightness and Leakage	All windows on the building envelope shall not exceed the air leakage rates specified in SS 212-Specification for Aluminium Alloy Windows	
		M6	Ventilation	Ventilation shall be adequately provided in a building for its intended occupancy. a) Where natural ventilation is applicable, it shall be provided by means of openable windows or other openings with an aggregate area of not less than; i. 5% of the floor area of the room or space required to be ventilated ii. 15% of the floor area of the aboveground car parking area required to be ventilated. b) Where mechanical ventilation or air-conditioning systems are used, the ventilation rates of these systems shall comply with SS CP 13-Code of Practice for Mechanical Ventilation and Air-Conditioning in Buildings.	

Appendix C, continued

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
Green Mark Residential Building (Singapore)	Elective Requirements	1-2	Dwelling Unit Indoor Comfort	Enhance dwelling unit indoor comfort either through the provision of better efficient air-conditioners or good natural ventilation design. a) (i). Use of energy efficient air conditioners that are certified under the Singapore Energy Labelling Scheme. *(Extent of coverage: At least 90% of the air-conditioners used in all dwelling units).* OR (ii). Design for natural ventilation (applicable to development where air-conditioners are not provided). ▪ Building layout design : Proper design of building layout that utilizes prevailing wind conditions to achieve adequate cross ventilation *(0.6 points for every 10% of units with window openings facing north & south directions).* ▪ Dwelling unit design : Good ventilation in indoor units through sufficient openings *(0.6 points for every 10% of living rooms & bedrooms designed with true cross ventilation).* b) Use of ventilation simulation software to identify the most effective building design and layout to achieve good natural ventilation.	BCA (2008)
		1-3	Natural Ventilation in Common Areas	Design for natural ventilation in following common areas; a). Lift lobbies and corridors b). Staircases *Extent of Coverage: All applicable areas* *(1 point is awarded for each common areas)*	
		1-4	Lighting	Encourage the use of better efficient lighting or day lighting in common areas to minimise energy consumption from lighting usage while maintaining a proper lighting level. c) Artificial lighting in common areas. Baseline = Maximum lighting power budget stated in SS 530. d) Day lighting in the following areas; i. Lift lobbies and corridors ii. Staircase iii. Car parks	

Appendix C, continued

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
Green Star Multi Unit Residential (Australia)	Indoor Environment Quality	IEQ-4	Day lighting	▪ A Daylight Factor (DF) of no less than 2% for the kitchen and 15% for other living areas measured at the floor level under a uniform design sky OR ▪ A Daylight Illuminance (DI) of no less than 200 lux for kitchen and 150 lux for other living areas measured at the floor level under a uniform design sky. *The point is awarded as follows;* ▪ *1 point is awarded where 95% of the apartments meet the daylight criteria for kitchen and 60% of the living area in these apartments meets the daylight criteria above; and* ▪ *2 points are awarded where 95% of the apartments meet the daylight criteria for kitchens and 90% of the living area of these apartments meets the daylight criteria above.*	Green Building Council Australia [GBCA] (2010) GBCA (2008)
		IEQ-5	Thermal comfort	▪ Ceiling fans are provided for at least 95%of all apartments and average heating and cooling loads of less than 30MJ/m2 ▪ All heating and cooling loads must be calculated using NatHERS (2nd generation) approved software. *Documentation that required to demonstrate the compliance;* ▪ *Short report which includes assumptions made and calculations demonstrating the average loads achieved.* ▪ *Architectural plans, elevations and sections.* ▪ *Specifications/drawings confirming materials used in the assessment.* ▪ *Evidence that the software used complies with the 'Protocol for Housing Energy Rating Software (Version 2006.1)*	
		IEQ-22	Natural ventilation	Dual aspect design is provided in dwellings so that effective natural ventilation can be achieved in all living areas. *The point are awarded as follows;* ▪ *1 point is awarded where 70% of dwelling are provided with effective natural ventilation;* ▪ *2 points are awarded where 90% of dwellings are provided with effective natural ventilation.* At least 95% of the net floor area of the common lobbies is provided with natural ventilation. The operable size of windows must be 5% or more of the net floor area on a floor-by-floor basis.	

Appendix C, continued

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
LEED Building Design & Construction (USA)	Indoor Environmental Quality (IEQ)	EQp1	Minimum IAQ Performance	ANSI/ASHRAE Standard 62. 1-2007: Ventilation for Acceptable Indoor Air Quality	Department of General Services (2010)
		EQc1	Outdoor Air Delivery Monitoring	▪ ANSI/ASHRAE Standard 62. 1-2007: Ventilation for Acceptable Indoor Air Quality	
		EQc2	Increased Ventilation	▪ ANSI/ASHRAE Standard 62. 1-2007: Ventilation for Acceptable Indoor Air Quality ▪ Chartered Institute of Building Services (CIBSE) Applications Manual 10-2005, Natural Ventilation in Non-Domestic Buildings	
		EQc 6.2	Controllability of Systems: Thermal Comfort	▪ ANSI/ASHRAE Standard 62. 1-2007: Ventilation for Acceptable Indoor Air Quality ▪ ASHRAE Standard 55-2004: Thermal Comfort Conditions for Human Occupancy	
		EQc7.1	Thermal Comfort: Design	▪ ASHRAE Standard 55-2004: Thermal Comfort Conditions for Human Occupancy ▪ Chartered Institute of Building Services (CIBSE) Applications Manual 10-2005, Natural Ventilation in Non-Domestic Buildings	
		EQc7.2	Thermal Comfort: Verification	ASHRAE Standard 55-2004: Thermal Comfort Conditions for Human Occupancy	
		EQc8.1	Daylight and Views: Daylight	ASTM D1003-07e1, Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics	
BREEAM Multi-Residential (UK)	Health and Well being	Hea 1	Day lighting	Evidence provided demonstrates that at least 80% of floor area in each occupied space is adequately day lit.	Building Research Establishment Environment Assessment Method [BREEAM] (2009a)
		Hea 7	Potential for natural ventilation	Evidence should be provided demonstrates that fresh air is capable of being delivered to the occupied spaces of the building via a natural ventilation strategy, and there is sufficient user-control of the supply of fresh air. *(Trickle vents are provided on majority of windows, window operable area is equivalent to 5% gross internal area of building, and plan depth is no more than 15m otherwise, extra ventilation required).*	

Appendix C, continued

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
BREEAM Multi-Residential (UK)	Health and Well being	Hea 10	Thermal comfort	Evidence should be provided demonstrates that thermal comfort levels in occupied spaces of the building are assessed at the design stage to evaluate appropriate servicing options, ensuring appropriate thermal comfort levels are achieved.	Building Research Establishment Environment Assessment Method [BREEAM] (2009a)
		Hea 11	Thermal zoning	Evidence should be provided demonstrates that local occupant control is available for temperature adjustment in each occupied space to reflect differing user demands	
CASBEE (JAPAN)	Q - Environmental quality & performance of the building	Q-1. Indoor environment	2.Thermal comfort 3.Lighting and illumination 4.Air Quality		Sinou & Kyvelou (2006)

Appendix D - Minimum requirements/standards on thermal comfort, natural ventilation & day lighting of Green Building Index (GBI) for non-residential new construction

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
GBI (Malaysia)	Indoor Environmental Quality (IEQ)	EQ1	Minimum IAQ Performance	Meet the minimum requirement of ventilation rate in ASHRAE 62. 1-2007or the local building codes whichever is the more stringent.	GREENBUILDING INDEX (2009b)
		EQ6	Thermal Comfort: Design & Controllability of Systems	▪ Design to ASHRAE 55 in conjunction with the relevant localized parameters as listed in MS1525:2007 ▪ Provide individual comfort controls for ≥ 50% of the building occupants to enable adjustments to suit individual task needs and preferences AND Provide comfort system controls for all shared multi-occupant spaces to enable adjustments to suit group needs and preferences *Conditions for thermal comfort include the primary factors of air temperature, radiant temperature, air speed and humidity. Comfort system control for this purpose is defined as the provision of control over at least one of these primary factors in the occupants' local environment.*	
		EQ7	Air Change Effectiveness	▪ Provide effective delivery of clean air through reduced mixing with indoor pollutants in order to promote a healthy indoor environment. Demonstrate that the Air Change Effectiveness (ACE) meets the following criteria for at least 90% of the Net Lettable Area (NLA); The ventilation systems are designed to achieve an ACE of ≥ 0.95 when measured in accordance with ASHRAE 129-1997: Measuring air change effectiveness where ACE is to be measured in the breathing zone (nominally 1.0m from finished floor level)	
		EQ8	Day lighting	Provide good levels of day lighting for building occupants ▪ Demonstrate that ≥ 30% of the NLA has a daylight factor in the range 1.0-3.5% as measured at the working plane, 800mm from floor level OR ▪ Demonstrate that ≥ 50% of the NLA has a daylight factor in the range 1.0-3.5% as measured at the working plane, 800mm from floor level OR	

Appendix D, continued

EVALUATION INSTRUMENTS	PART/ITEM	CRITERIA	AREA OF ASSESSMENT	REQUIREMENT/STANDARDS	SOURCE
		EQ9	Daylight Glare Control	Reduce discomfort of glare from natural light. Where blinds or screens are fitted on all glazing and atrium as a base building, incorporate provisions to meet the following criteria; 1. Eliminate glare from all direct sun penetration and keep horizontal workspace lux level below 2,000; 2. Eliminate glare from diffuse sky radiation for occupant workspace at viewing angles of 15° to 60° from the horizontal at eye level (typically 1.2m from floor level) 3. Control with an automatic monitoring system (for atrium and windows with incident direct sunlight only-not applicable for fixed blinds/screens); AND 4. Equip with a manual override function accessible by occupants (not applicable for fixed blinds/screens)	GREENBUILDING INDEX (2009b)
		EQ12	External Views	Reduce eyestrain for building occupants by allowing long distance views and provision of visual connection to the outdoor. ▪ Demonstrate that > 60% of the NLA has a direct line of sight through vision glazing at a height of 1.2m from floor level. Demonstrate that >75% of the NLA has a direct line of sight through vision glazing at a height of 1.2m from floor level	

Appendix E - Clo values regarding to the garment dressed

Garment description		I_{clu} Clo	I_{clu} m^2°C/W
Underwear, pants	Pantyhose	0.02	0.003
	Panties	0.03	0.005
	Briefs	0.04	0.006
	Pants ½ long legs, wool	0.06	0.009
	Pants long legs	0.1	0.016
Underwear, shirts	Bra	0.01	0.002
	Shirt sleeveless	0.06	0.009
	T-shirt	0.09	0.014
	Shirt with long sleeves	0.12	0.019
	Half-slip, nylon	0.14	0.022
Shirts	Tube top	0.06	0.009
	Short sleeve	0.09	0.029
	Light weight blouse, long sleeves	0.15	0.023
	Light weight, long sleeves	0.20	0.031
	Normal, long sleeves	0.25	0.039
	Flannel shirt, long sleeves	0.3	0.047
	Long sleeves, turtleneck blouse	0.34	0.053
Trousers	Shorts	0.06	0.009
	Walking shorts	0.11	0.017
	Light-weight trousers	0.20	0.031
	Normal trousers	0.25	0.039
	Flannel trousers	0.28	0.043
	Overalls	0.28	0.043
Coveralls	Daily wear, belted	0.49	0.076
	Work	0.50	0.078
Highly-insulating coveralls	Multi-component, filling	1.03	0.160
	Fibre-pelt	1.13	0.175
Sweaters	Sleeveless vest	0.12	0.019
	Thin sweater	0.2	0.031
	Long sleeves, turtleneck (thin)	0.26	0.040
	Sweater	0.28	0.043
	Thick sweater	0.35	0.054
	Long sleeves, turtleneck (thick)	0.37	0.057
Jacket	Vest	0.13	0.020
	Light summer jacket	0.25	0.039
	Jacket	0.35	0.054
	Smock	0.3	0.047
Coats & over jackets & over trousers	Coat	0.6	0.020
	Down jacket	0.55	0.039
	Parka	0.7	0.054
	Overalls multi-component	0.52	0.047
Sundries	Socks	0.02	0.003
	Thick, ankle socks	0.05	0.008
	Thick, long socks	0.1	0.016
	Slippers, quilted fleece	0.03	0.005
	Shoes (thin soled)	0.02	0.003
	Shoes (thick soled)	0.04	0.006
	Boots	0.1	0.016
	Gloves	0.05	0.008
Skirts, dresses	Light skirt, 15cm, above knee	0.10	0.016
	Light skirt, 15cm, below knee	0.18	0.028
	Heavy skirt, knee-length	0.25	0.039
	Light dress, sleeveless	0.25	0.039
	Winter dress, long sleeves	0.4	0.062
Sleepwear	Long sleeve, long gown	0.3	0.047
	Thin strap, short gown	0.15	0.023
	Hospital gown	0.31	0.048
	Long sleeve, long pyjamas	0.50	0.078
	Body sleep with feet	0.72	0.112
	Undershorts	0.1	0.016
Robes	Long sleeve, wrap, long	0.53	0.082
	Long sleeve, wrap, short	0.41	0.064
Chairs	Wooden or metal	0.00	0.000
	Fabric-covered, cushioned, swivel	0.10	0.016
	Armchair	0.20	0.032

Source : ASHRAE (2004)

Appendix F - Met values regarding to the activities

Activity	Metabolic rate	
Reclining	46 W/m^2	0.8 Met
Seated relaxed	58 W/m^2	1.0 Met
Clock and watch repairer	65 W/m^2	1.1 Met
Standing relaxed	70 W/m^2	1.2 Met
Sedentary activity (office, dwelling, school, laboratory)	70 W/m^2	1.2 Met
Car driving	80 W/m^2	1.4 Met
Graphic profession – Book binder	85 W/m^2	1.5 Met
Standing, light activity (shopping, laboratory, light industry)	93 W/m^2	1.6 Met
Teacher	95 W/m^2	1.6 Met
Domestic work – shaving, washing and dressing	100 W/m^2	1.7 Met
Walking on the level, 2km/h	110 W/m^2	1.9 Met
Standing, medium activity (shop assistant, domestic work)	116 W/m^2	2.0 Met
Building industry – Brick laying (Block of 15.3kg)	125 W/m^2	2.2 Met
Washing dishes standing	145 W/m^2	2.5 Met
Domestic work – raking leaves on the lawn	170 W/m^2	2.9 Met
Domestic work – washing by hand and ironing (120-220W/m^2)	170 W/m^2	2.9 Met
Iron and steel – ramming the mould with pneumatic hammer	175 W/m^2	3.0 Met
Building industry – forming the mould	180 W/m^2	3.1 Met
Walking on the level, 5km/h	200 W/m^2	3.4 Met
Forestry – cutting across the grain with a one-man saw	205 W/m^2	3.5 Met
Agriculture – Ploughing with a team of horses	235 W/m^2	4.0 Met
Building industry – loading a wheelbarrow with stones and mortar	275 W/m^2	4.7 Met
Sports – Ice skating, 18km/h	360 W/m^2	6.2 Met
Agriculture – digging with a spade (24 lifts/min)	380 W/m^2	6.5 Met
Sports – Skiing on level, good snow, 9km/h	405 W/m^2	7.0 Met
Forestry – Working with an axe (weight 2kg. 33 blows/min)	500 W/m^2	8.6 Met
Sports – Running, 15km.h	550 W/m^2	9.5 Met

Source : ASHRAE (2004)

Appendix G - Wind speeds : Beaufort scale

Beaufort number	Wind speed (m/s)	Description	Land condition	Comfort
0	0-0.5	Calm	Smoke rises vertically	No noticeable wind
1	0.5-1.5	Light air	Smoke drifts	
2	1.6-3.3	Light breeze	Leaves rustle	Wind felt on face
3	3.4-5.4	Gentle breeze	Wind extends flags	Hair disturbed, clothing flaps
4	5.5-7.9	Moderate breeze	Small branches in motion, raises dust and loose paper	Hair disarranged
5	8.0-10.7	Fresh breeze	Small trees in leaf begin to swat	Force of wind felt on body
6	10.8-13.8	Strong breeze	Whistling in telegraph wires, large branches in motion	Umbrellas used with difficulty. Difficult to walk steadily. Noise in ears.
7	13.9-17.1	Near gale	Whole trees in motion	Inconvenience in walking
8	17.2-20.7	Gale	Twigs broken from trees	Progress impeded. Balance difficult in gusts
9	20.8-24.4	Strong gale	Slight structural damage (chimneypots and slates)	People blown over in gusts
10	24.4-28.5	Storm	Seldom experienced inland. Trees uprooted, considerable structural damage	

Source : Yeang (2008)

Appendix H - Indicators of outdoor and indoor performance requirements

Outdoor performance requirements

Spatial configuration

01. Ease to identify the sub-zone where your housing unit is located.
02. Quality of road pavement and side-walks.
03. Quality of the outdoor image (exterior finish) of the housing unit.

Parking

04. Capacity of on-site car parking.
05. Design of on-site car parking space is efficient (roof, space arrangement).
06. Adequacy of artificial lighting levels in the car parking space.

Landscape

07. Quality and presentation of landscape around the housing units.
08. Availability of adequate sidewalks between the housing units.
09. Quality of open space design (green parks and walkways).
10. Adequacy of artificial lighting design in the outdoor spaces.

Children playground

11. Adequacy of children playground areas.
12. Design quality of children playground areas.
13. Adequacy of artificial lighting design in the children playground areas.

Support service/Utilities

14. Quality of sewage and drainage systems outdoor.
15. Cleanliness of the streets.
16. Efficiency of insect spray services.
17. Efficiency of garbage collection and cleanliness of their collection points.
18. Capacity of utility systems (sewage, electrical, water supply and gas).
19. Speed and efficiency of maintenance services for outdoor facilities.
20. Quality of landscape services for outdoor public areas (between units).
21. Quality of landscape services for private gardens (surrounding each unit).

Safety and security

22. Level of safety measures in children playground areas.
23. Level of safety measures in outdoor areas.
24. Level of safety measures in streets and walkways.
25. Availability of emergency preparedness measures in outdoor planning.
26. Enforcement of maximum speed limit rules.
27. Quality of provided speed pumps.
28. Quality of landscape design in facilitating safe driving.

Indoor performance requirements

Housing unit layout

29. Appropriateness of the number of rooms to your standards of living.
30. Amount of quest reception/family-living space.
31. Amount of bedroom space.
32. Amount of bathroom space.
33. Amount of kitchen space.
34. Amount of storage space.
35. Amount of corridor space.
36. Suitability of the location of bathrooms relative to guest reception area.
37. Number of bathrooms per housing unit.
38. Adequacy of opening design (windows and doors).

Visual comfort

39. Adequacy of natural lighting reaching bedrooms.
40. Adequacy of natural lighting reaching kitchen.
41. Adequacy of natural lighting reaching corridors.
42. Adequacy of natural lighting reaching guest reception/family-living space.
43. Adequacy of natural lighting reaching in all indoor space.

Thermal comfort and indoor air quality

44. Level of control of temperature in all rooms within the unit.
45. Capability of cooling systems to provide comfortable temperature in summers.
46. Capability of heating systems to provide comfortable temperature in winters.
47. Quality of air inside the guest reception/family-living space.
48. Quality of air inside the bedroom space.
49. Quality of air inside the bathroom space.
50. Quality of air inside the kitchen space.
51. Quality of air inside the corridor.
52. Quality of conditioned air (HVAC) throughout the housing unit.

Finish systems and furniture

53. Quality and presentation of the exterior wall finishing.
54. Quality and presentation of the interior finishes of the rooms.
55. Quality and presentation of the interior finishes of the kitchen.
56. Quality and presentation of the interior finishes of the bathroom.
57. Quality of the indoor image of the housing unit.
58. Quality of carpentry work for the doors and windows.
59. Quality of carpentry work for the kitchen cabinets.
60. Quality of carpentry work for the bathroom cabinets.
61. Quality of carpentry work for closets (wardrobe).
62. Quality of provided furniture.

Support services/Utilities

63. Availability and quality of drinking water.
64. Adequacy of number and suitability of locations of 110V power sockets.
65. Adequacy of number and suitability of locations of 220V power sockets.
66. Quality and capacity of provided refrigerator.
67. Quality and capacity of stove, oven and kitchen exhaust vent.
68. Quality and capacity of washing machine.
69. Speed and efficiency of maintenance services for indoor facilities.
70. Speed and efficiency of housing services for indoor facilities.

Source: Hassanain et al. (2010)

Appendix I - A self-administered questionnaire format based on Likert-Scale

	No	QUESTIONS	LIKERT-SCALE				
			1	2	3	4	5
Cleanliness	1	What is your perception with the level of cleanliness in this building?	Very Dirty	Dirty	Medium Clean	Clean	Very Clean
Visual Comfort	2	How satisfied are you with the natural day lightings in this building?	Too Dark	Dark	Medium	Bright	Too Bright
	3	How satisfied are you with the quality of artificial lightings in this building?	Too Dark	Dark	Medium	Bright	Too Bright
Thermal Comfort	4	How do you feel with the cooling system (air-conditioning) in this building?	Too Hot	Hot	Medium	Cold	Too Cold
Air Movement	5	How satisfied are you with the provision of air movement in this building (e.g. opening)	Very Unsatisfied	Unsatisfied	Medium	Satisfied	Very Satisfied
	6	What is your rate for the overall quality of indoor ventilation in this building?	Very Poor	Poor	Medium	Good	Very Good
Noise pollution	7	How do you feel with the noise control or vibration? (e.g. From traffic, mechanical systems)	Very Quiet	Quiet	Medium	Good	Very Good
	8	What is your rate for the overall quality of noise control in this building?	Very Poor	Poor	Medium	Good	Very Good
Overall comfort	9	What is your overall comfort level in your building area?	Very Un-comfortable	Un-comfortable	Medium	Comfortable	Very Comfortable
	10	To what extent do you think your productive work is affected by the poor indoor environmental conditions of the building?	Much Decreased	Decreased	Medium	Increased	Much Increased

Source: Khalil and Husin (2009)

Appendix J - Technical and functional performance requirement

Technical elements of performance

1. Thermal comfort

1. Room temperature during summer
2. Room temperature during winter
3. Overal perception of the thermal environment in the building

2. Acoustic comfort

4. Conversation privacy at the room relative to other rooms
5. Level of noise generated from the air conditioning system
6. Level of noise generated from the lighting fixtures in the room
7. Level of noise generated outside the room
8. Overal perception of the acoustical environment in the room

3. Visual comfort

9. Adequancy of natural lighting reaching the room
10. Adequancy of artificial lighting above study-living areas
11. Control of artificial lighting levels in the room
12. Adequency of lighting levels in the corridors of the building
13. Overal perception of the quality of the lighting in the building

4. Indoor air quality

14. Quality of air inside the room
15. Quality of air throughtout the corridors
16. Control of mechanical ventilation levels in the room
17. Control of natural ventilation by means of opening windows
18. Overal perception of the quality of indoor air in the building

5.Fire safety

19. Ease to identify emergency exits to occupants and visitors
20. Ease to exiting the building in cases of fire emergencies
21. Ease to identify and reach fire safety systems
22. Quality and perception of fire safety systems in the building

Functional elements of performance

6. Interior and exterior finish systems

23. Quality and presentation of the interior finishes of the room
24. Quality and ease of use of doors and windows in the room
25. Quality and presentation of finishes in common spaces
26. Quality and presentation of building finishes

7. Room layout and furniture quality

27. Amount of living-study space in the room
28. Type of chair where you sit
29. Type and size of desk where you study
30. Type of bed where you sleep
31. Capacity of wardrobe
32. Furniture arrrangement in the room
33. Adequacy of personal storage space in the room
34. Colour of furniture and surface finishes in the room
35. Overall perception of the quality of furniture in the room

8. Supprot services

36. Adequacy of washroom facilities for occupants and visitors
37. Cleanliness and trash removal on your floor or building
38. Stability of power supply to the building
39. Adequacy of power sockets required for equipment
40. Flexibility of IT connection points
41. Adequacy of circulation routes around the building

9. Efficiency of circulation

42. Arrangement of rooms in each level in the building
43. Width of corridor for circulation inside the building
44. Locantion and number of stairs in the building
45. Ease by which visitors can locate rooms in the building

10.Proximity to other facilities on campus

46. Position of the building relative to campus restaurant
47. Position of the building relative to academic facilities
48. Position of the building relative to sports facilities

Appendix K - Questionnaire for satisfaction and perception survey

Post Occupancy Evaluation of Residential College Building
University of Malaya, Kuala Lumpur
Penilaian Selepas Pendudukan Bangunan Kolej Kediaman, Universiti Malaya, Kuala Lumpur

Block: ………. *Blok* | **Room No.** ………. *No. bilik* | **Age:** …………. *Umur* | **Gender: Male / Female** *Jantina: Lelaki / Perempuan* | **Race: Malay / Chinese / Indian / __________** *Kaum : Melayu / Cina / India / __________*

Please circle/mark a box/answer of each question that represents how you feel about your residential block generally and room specifically. This questionnaire uses Likert Scale format where each number response to a specific scale. For example;

Scale				
-2	**-1**	**0**	**+1**	**+2**
Very poor	**Poor**	**Fair**	**Good**	**Very good**
Not at all	**Slightly**	**Moderate**	**Very**	**Extremely**
Very dissatisfied	**Dissatisfied**	**Neither**	**Satisfied**	**Very satisfied**
Strongly disagree	**Disagree**	**Undecided**	**Agree**	**Strongly agree**
Never	**Rarely/Occasionally** *(in about 25% of chances when I could have)*	**Sometimes** *(in about 50% of chances when I could have)*	**Frequently/Usually** *(in about 75% of chances when I could have)*	**Every time**

However, question 1, 20, 21, 23, and 24 are not used Likert Scale format where it is represented by specific scale that clearly described in the question itself.

Sila bulatkan/tandakan satu ruangan/kotak/jawapan bagi setiap soalan yang menunjukkan perasaan/persepsi anda terhadap blok penginapan secara umumnya dan bilik anda secara khususnya. Borang soal selidik ini menggunakan format skala "Likert" di mana setiap nombor secara amnya mewakili skala tertentu. Sebagai contoh;

Skala				
-2	*-1*	*0*	*+1*	*+2*
Sangat teruk	*Teruk*	*Berpatutan*	*Baik*	*Sangat baik*
Tidak secara keseluruhannya	*Sebahagian*	*Sederhana*	*Sangat*	*Amat*
Sangat tidak berpuas hati	*Tidak berpuas hati*	*Kedua-duanya tidak*	*Berpuas hati*	*Sangat berpuas hati*
Sangat tidak bersetuju	*Tidak bersetuju*	*Tiada keputusan*	*Bersetuju*	*Amat bersetuju*
Tidak pernah	*Jarang (kira-kira 25% daripada peluang yang saya perolehi)*	*Kadang-kadang (kira-kira 50% daripada peluang yang saya perolehi)*	*Kerap/selalu(kira-kira 75% daripada peluang yang saya perolehi)*	*Setiap masa*

Walaubagaimanapun,soalan bernombor 1, 20, 21 23, dan 24, tidak menggunakan format skala "Likert" di mana diwakili oleh skala tertentu seperti mana yang diperjelaskan di dalam soalan terbabit.

No. *No.*	**QUESTIONS** *Soalan*					
General						
1	How long have you lived in this residential college? *Berapa lamakah anda telah tinggal di kolej kediaman ini?*	*< 6 month*	*1 year*	2 years	*3 years*	*> 3 years*
2	How long do you spend in the room during a day? *Berapa lamakah anda menghabiskan masa di dalam bilik sepanjang hari?*	-2	-1	0	+1	+2
3	How long do you spend studying/working at a desk? *Berapa lamakah anda menghabiskan masa untuk belajar/membuat kerja di meja?*	-2	-1	0	+1	+2
Architectural elements						
4	How would you rate the residential building layout which is internal courtyard with open corridor? *Bagaimanakah anda menilaikan susun atur bangunan penginapan yang berhalaman dalaman dan koridor terbuka?*	-2	-1	0	+1	+2
5	The residential building is an environmentally friendly with efficient energy usage? *Bangunan penginapan adalah mesra alam sekitar dengan penggunaan tenaga yang cekap?*	-2	-1	0	+1	+2
6	How important is it to you that buildings are built in an environmentally friendly way? *Bagaimana pentingkah kepada anda bangunan yang dibina adalah secara mesra alam sekitar?*	-2	-1	0	+1	+2
7	How would you rate the overall quality of the building residential? *Bagaimanakah anda menilai kualiti keseluruhan bangunan penginapan?*	-2	-1	0	+1	+2
8	How would you rate the general room layout? *Bagaimanakah anda menilai susun atur umum bilik?*	-2	-1	0	+1	+2
9	Does the room meet your needs? *Adakah bilik memenuhi keperluan anda?*	-2	-1	0	+1	+2
10	Is there provision within the room for privacy when need? *Adakah terdapat peruntukan/ruangan di dalam bilik bagi tujuan privasi apabila diperlukan?*	-2	-1	0	+1	+2
11	How safe do you feel in the room and building? *Sejauhmanakah selamatnya anda rasakan semasa berada di dalam bilik and bangunan?*	-2	-1	0	+1	+2
12	What is your overall comfort level in your room? *Apakah tahap keselesaan di dalam bilik anda secara keseluruhannya?*	-2	-1	0	+1	+2
13	Do the overall room conditions affect the degree of your work productivity? *Adakah keadaan keseluruhan persekitaran dalaman bilik mempengaruhi darjah produktiviti kerja anda?*	-2	-1	0	+1	+2

...continued on next page / ...bersambung di halaman berikutnya

Thermal comfort and indoor air quality								
14	How would you describe the thermal comfort/indoor air temperature in your room? *Bagaimana anda menggambarkan keselesaan terma/suhu udara dalaman di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
15	How would you describe the ventilation and air quality of your room? *Bagaimana anda menggambarkan pengudaraan dan kualiti udara di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
16	How much control do you have over the ventilation of the room? *Berapa banyak kawalan yang anda perolehi dalam mengawal pengudaraan di dalam bilik?*			*-2*	*-1*	*0*	*+1*	*+2*
17	Without the aid of mechanical fans; just by opening the windows or/and doors, please rate the air movement of your room? *Tanpa bantuan kipas mekanial iaitu dengan hanya melalui bukaan tingkap atau/dan pintu, sila nilaikan tahap peredaran udara di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
18	How satisfied are you with the provision of air movement in this room (e.g. opening)? *Bagaimanakah kepuasan anda terhadap proses/peruntukan peredaran udara di dalam bilik ini? (Cth: bukaan)*			*-2*	*-1*	*0*	*+1*	*+2*
19	How long do you keep the windows open in a day? *Berapa lamakah anda membuka tingkap dalam sehari?*			*-2*	*-1*	*0*	*+1*	*+2*
20	What time do you always open the window in a day? *Pada masa bilakah anda kerap membuka tingkap dalam sehari?*			*Never*	*Mor ning*	After - noon	*Even ing*	*Nig ht*
21	What is the reason for you don't open the windows? *Apakah sebab anda untuk tidak membuka tingkap?*	*Inse cts*	*Safe ty*	Rain	*Dust*	*Priv acy*	*Mon key*	*Oth ers*
22	How long do you use the ceiling fan in your room in a day? *Berapa lamakah anda menggunakan kipas siling di dalam bilik anda dalam sehari?*			*-2*	*-1*	*0*	*+1*	*+2*
23	What is the speed of the fan is often used? *Berapakah tahap kelajuan kipas yang sering digunakan?*			*1*	2	3	*4*	*5*
Predicted Mean Vote Index / Indek Jangkaan Mean Undian								
24	Overall, how do you feel about thermal comfort/indoor air temperature in your room? *Secara keseluruhannya, bagaimanakah anda rasakan keselesaan terma/suhu udara dalaman di dalam bilik anda?*	*Cold Sejuk*	*Cool Dingin*	*Slightly cool Sedikit dingin*	*Neutral Neutral*	*Slightly warm Sedikit hangat*	*Warm Hangat*	*Hot Panas*
Visual comfort								
25	In your own perception, please rate the adequacy of natural daylighting in your room? *Melalui persepsi anda sendiri, sila nilaikan tahap kecapaian pencahayaan semulajadi di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
26	How much control do you have over the daylighting in your room? *Berapa banyak kawalan yang anda perolehi dalam mengawal pencahayaan semulajadi di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
27	In your own perception, please rate the adequacy of artificial daylighting in your room. *Melalui persepsi anda sendiri, sila nilaikan tahap kecapaian pencahayaan buatan di dalam bilik anda.*			*-2*	*-1*	*0*	*+1*	*+2*
28	How much control do you have over the artificial light in the building? *Berapa banyak kawalan yang anda perolehi dalam mengawal pencahayaan buatan di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
29	How effective is the shading (curtains) which is provided for controlling the lighting level in your room? *Sejauh manakah keberkesanan teduhan (langsir) yang disediakan dalam mengawal pencahayaan di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
30	Overall, how satisfied are you with the quality of lightings in your room? *Secara keseluruhannya, bagaimanakah kepuasan anda terhadap kualiti pencahayaan di dalam bilik ini?*			*-2*	*-1*	*0*	*+1*	*+2*
31	How would you rate the views from inside the room to outside the building? *Bagaimana anda nilaikan pandangan dari dalam bilik ke luar bangunan?*			*-2*	*-1*	*0*	*+1*	*+2*
32	What do you think of the existing area of windows/openings in your room? *Apa yang anda fikirkan dengan keluasan tingkap/bukaan di dalam bilik anda?*			*-2*	*-1*	*0*	*+1*	*+2*
Landscape								
33	Do you feel that the residential building is sensitively designed for the landscape setting? *Adakah anda rasa bangunan penginapan ini direka bentuk berpandukan kepada susun atur landskap?*			*-2*	*-1*	*0*	*+1*	*+2*
34	How would you rate the quality of landscape around the residential buildings? *Bagaimana anda nilaikan kualiti landskap di sekeliling bangunan penginapan?*			*-2*	*-1*	*0*	*+1*	*+2*
35	How does the landscape setting around the residential building affect the quality of your life? *Bagaimanakah landskap di sekeliling bangunan penginapan mempengaruhi kualiti hidup anda?*			*-2*	*-1*	*0*	*+1*	*+2*
36	What is your rate for the quality of the internal courtyard in your residential building? *Apakah nilai anda terhadap kualiti halaman dalaman bangunan penginapan anda?*			*-2*	*-1*	*0*	*+1*	*+2*
37	How long do you spend at the internal courtyard in one day? *Berapa lamakah anda menghabiskan masa di halaman dalaman dalam sehari?*			*-2*	*-1*	*0*	*+1*	*+2*
38	How does the internal courtyard in the residential building affect the quality of your life? *Bagaimanakah halaman dalaman di dalam bangunan penginapan mempengaruhi kualiti hidup anda?*			*-2*	*-1*	*0*	*+1*	*+2*

Thank you / Terima kasih

Appendix L - Pilot study of satisfaction and perception survey

A total of 414 respondents was retrieved fully filled by the respondents who represent 38.8% of male and 61.2% of female residents. The number of respondents is exceeding the minimum number of feedbacks; 271, which relying on 95% of confident level and ±5% margin of error from the overall population. About 27.4% of respondents are live on the ground floor, 30.4% on the first floor, 22.6% on the second floor while 19.6% was coming from the third floor.

The results of satisfaction and perception survey from the occupants are presented in Table 1. Referring to the percentage, the majority of the respondents are in comfort level in all aspects especially air movement (breezy: 23.8%, good quality of indoor ventilation: 27.1%, satisfied with the provision of air movement: 30.6%), and overall comfort (comfortable: 33.6%). Moreover, most of the respondents indicated that their work productivity is increased (32.7%) due to comfortable of room conditions.

Table 1: Result of satisfaction and perception survey

		Questions	Likert scale / *Occupants' responses (%)*					Mean	Overall Rate
			- 2	-1	0	+1	+2		
Visual Comfort	1	In your own perception, please rate the natural daylighting in this room.	Too Dark	Dark	Neither	Bright	Too Bright	2.904	Dark
			16.7	*20.5*	*22.9*	*26.9*	*13.0*		
	2	In your own perception, please rate the artificial daylighting in this room.	Too Dark	Dark	Neither	Bright	Too Bright	2.935	Dark
			8.9	*18.8*	*28.3*	*29.0*	*15.0*		
	3	Overall, how satisfied are you with the quality of lightings in this room?	Strongly dissatisfied	Dissatisfied	Neither	Satisfied	Strongly Satisfied	2.882	Dissatisfied
			8.7	*17.0*	*31.3*	*26.5*	*16.5*		
Thermal Comfort	4	How do you feel about thermal comfort in this room?	Too Hot	Hot	Neither	Cold	Too Cold	2.95	Hot
			12.8	*17.0*	*26.6*	*26.2*	*17.4*		
Air Movement	5	Without the aid of mechanical fans; just by opening the windows or/and doors, please rate the air movement of your room.	Still air	Inconspicuous still air	Neither	Breezy	Very breezy	2.926	In-conspicuous still air
			18.4	*20.4*	*21.9*	*23.8*	*15.5*		
	6	What is your rate for the overall quality of indoor ventilation in this room?	Very poor	Poor	Neither	Good	Very good	2.901	Poor
			14.8	*16.4*	*26.4*	*27.1*	*15.3*		
	7	How satisfied are you with the provision of air movement in this room (e.g. opening)	Strongly dissatisfied	Dissatisfied	Neither	Satisfied	Strongly Satisfied	3.003	Dissatisfied
			13.3	*16.5*	*24.0*	*30.6*	*15.5*		
Overall comfort	8	What is your overall comfort level in your room?	Very un-comfortable	Uncomfortable	Neither	Comfortable	Very comfortable	3.149	Un-comfortable
			14.5	*11.6*	*21.2*	*33.6*	*19.1*		
	9	Do the overall room conditions affect the degree of your work productivity?	Much decreased	Decreased	No changes	Increased	Much increased	3.185	Decreased
			14.8	*11.6*	*20.3*	*32.7*	*20.6*		

Note: As adapted Hassanain (2007), the percentage of responses for each scale will be multiplied by the corresponding weight which are; 2 with 5 points, 1 with 4 points, 0 with 1 point, -1 with 3 points and -2 with 2 points. The sum of the products of multiplication will be divided by 100 to get the mean value. The following calibration has adopted to be able to quantify the degree of satisfaction for each element of performance:

- if the mean response is less than or equal to 1.49, then the respondents are "neutral, neither/nor, and no changes"
- if the mean response is between 1.50 and 2.49, then the respondents are "strongly dissatisfied, too dark, too hot, still air, very poor, very dirty, very noise, very uncomfortable, and much decreased"
- if the mean response is between 2.50 and 3.49, then the respondents are "dissatisfied, dark, hot, inconspicuous still air, poor, dirty, noise, uncomfortable, and decreased"
- if the mean response is between 3.50 and 4.49, then the respondents are "satisfied, bright, cold, breezy, good, clean, quiet, comfortable, and increased"
- if the mean response is between 4.50 and 5.00, then the respondents are "strongly satisfied, too bright, very satisfied, too cold, very breezy, very good, very clean, very quiet, very comfortable, and much increased"

Regarding on visual comfort, the overall perception of respondents towards quality of lightings in the room is neutral (31.3%) even though the majority of the respondents is satisfied with both natural day lighting (bright: 26.9%) and artificial lighting (bright: 29%). The same result also stated on the subject of thermal comfort when most of the respondents are feeling neutral (26.6%) with the level of thermal comfort.

By adopting the degree of satisfaction, where each criterion of performance is based on graduate scale, the overall rate of respondents' satisfaction and perception in uncomfortable level when the mean response is between 2.50 and 3.49 as presented in the last two columns in **Table 1** and **Figure 1**.

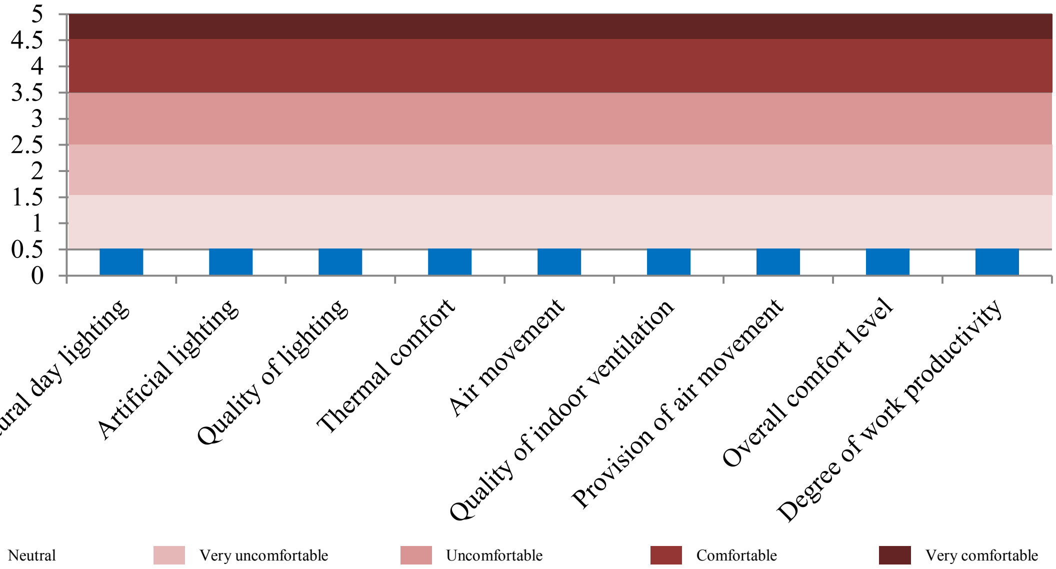


Figure 1: Overall rate of respondents' satisfaction and perception in each aspect based on graduate scale

Regarding on thermal comfort, detailed survey has been done by adopting predicted Mean Vote (PMV) Index where the scale ranging from -3 to +3 as presented in Table 2. The majority of the respondents (48.1%) is feeling neutral. By implementing Predicted Percentage of Dissatisfied (PPD), where people who vote -3, -2, +2 and +3 on PMV Index are regarded as thermally dissatisfied, only 16.5% of respondents are included as presented in Figure 2.

Table 2: Predicted Mean Vote Index (PMV)

Question	Predicted Mean Vote Index / *Residents' responses (%)*						
	-3	-2	-1	0	+1	+2	+3
Overall, how do you feel about thermal comfort in this room?	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
	0.8	*2.5*	*10.7*	*48.1*	*25.5*	*9.9*	*2.5*

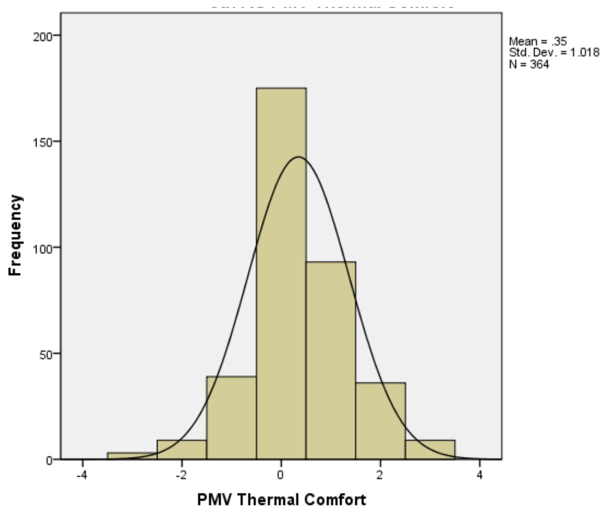


Figure 2: Predicted Mean Vote Index (PMV) of 5th RC

Further statistical analysis was done to find out the correlation among indoor environment conditions which also include visual comfort, thermal comfort, air movement and overall comfort in the rooms at 5th RC. The inter-correlations between the indoor environments conditions are presented in Table 3.

Appendix L, continued

Table 3: The inter-correlation between the indoor environment conditions

		Natural Daylighting	Artificial Lighting	Quality of Lighting	Thermal Comfort	Air Movement	Quality of Indoor Ventilation	Provision of Air Movement	Overall Comfort	Affected Degree of Work Productivity
Natural Daylighting	Correlation Coefficient	1.000	.629**	.420**	.179**	.153**	.210**	.259**	.234**	.182**
	Sig. (2-tailed)	.	.000	.000	.000	.002	.000	.000	.000	.000
	N	414	414	412	413	412	413	412	414	413
Artificial Lighting	Correlation Coefficient	.629**	1.000	.717**	.387**	.152**	.106*	.125*	.223**	.197**
	Sig. (2-tailed)	.000	.	.000	.000	.002	.031	.011	.000	.000
	N	414	414	412	413	412	413	412	414	413
Quality of Lighting	Correlation Coefficient	.420**	.717**	1.000	.638**	.388**	.184**	.174**	.218**	.195**
	Sig. (2-tailed)	.000	.000	.	.000	.000	.000	.000	.000	.000
	N	412	412	412	411	410	411	410	412	411
Thermal Comfort	Correlation Coefficient	.179**	.387**	.638**	1.000	.696**	.450**	.353**	.195**	.183**
	Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000	.000	.000
	N	413	413	411	413	411	412	411	413	412
Air Movement	Correlation Coefficient	.153**	.152**	.388**	.696**	1.000	.628**	.511**	.142**	.138**
	Sig. (2-tailed)	.002	.002	.000	.000	.	.000	.000	.004	.005
	N	412	412	410	411	412	411	410	412	411
Quality of Indoor Ventilation	Correlation Coefficient	.210**	.106*	.184**	.450**	.628**	1.000	.836**	.303**	.263**
	Sig. (2-tailed)	.000	.031	.000	.000	.000	.	.000	.000	.000
	N	413	413	411	412	411	413	411	413	412
Provision of Air Movement	Correlation Coefficient	.259**	.125*	.174**	.353**	.511**	.836**	1.000	.380**	.334**
	Sig. (2-tailed)	.000	.011	.000	.000	.000	.000	.	.000	.000
	N	412	412	410	411	410	411	412	412	411
Overall Comfort	Correlation Coefficient	.234**	.223**	.218**	.195**	.142**	.303**	.380**	1.000	.914**
	Sig. (2-tailed)	.000	.000	.000	.000	.004	.000	.000	.	.000
	N	414	414	412	413	412	413	412	414	413
Affected Degree of Work Productivity	Correlation Coefficient	.182**	.197**	.195**	.183**	.138**	.263**	.334**	.914**	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.005	.000	.000	.000	.
	N	413	413	411	412	411	412	411	413	413

Note: **. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

The correlation coefficient takes on values ranging between +1and -1 where r = +1.0 is described a perfect positive correlation and r = -1.0 is described a perfect negative correlation.

Value of r	Strength of relationship
-1.0 to -0.5 or 1.0 to 0.5	Strong
-0.5 to -0.3 or 0.5 to 0.3	Moderate
-0.3 to -0.1 or 0.3 to 0.1	Weak or fair
-0.1 to 0.1	None or very weak

The satisfaction with the quality of lighting in the room (*n*=412) is significantly related with artificial lighting (*M*=0.22, *SD*=1.178) and natural daylighting (*M*=-0.01, *SD*=1.291). However, there was a strong, positive correlation between artificial lighting and lighting quality, *r*=0.717, *p*=0.000. Whilst, the natural dayligthing only has moderate and positive correlation, *r*=0.420, *p*=0.000.

Referring to the Table 3, the quality of lighting (*r*=0.638, *p*=0.000) and air movement (*r*=0.696, *p*=0.000) are strongly correlated with the thermal comfort in the room. Better perception of the thermal comfort level of the residents was associated with better quality of lighting and air movement in the room. Then, the data in the Table 3 also revealed that the air movement (*r*=0.628, *p*=0.000) and the provision of air movement (*r*=0.836, *p*=0.000) in the room were strongly related with the quality of the indoor ventilation. Unfortunately, none of the indoor environment conditions have a strong correlation with the overall comfort even though there are significantly related (p<0.05). With strong and positive correlation, the degree of work productivity is more affected by overall comfort (*r*=0.914, *p*=0.000). Other indoor environmental conditions were only having moderate and weak correlation even though there are significant (p<0.05) and positive correlation. Thus, higher degree of work productivity was associated with a higher level of overall comfort.

Appendix M - Pilot study of building performance evaluation

A pilot study of building performance evalution was done at two unoccupied student rooms which were critically identified due to limitation of accessibility by residential colleges' management. Thus, the most excellent of student rooms in representing worst and best scenario were selected as shown in Figure 1. These two scenarios are based on the levels of radiation and the penetration of sunlight into the rooms, as explained extensively below.

i. Worst scenario: A student room on the top floor, which is affected by heat penetration from the roof, since more than 40% of the solar gain of a typical five storey block of flats is through its roof (Chan, 2009b). Higher temperatures have also been recorded by Davis et al. (2006) at the top level of flats and apartments compared to the ground floor, which in turn are affected by heat penetration from the ground/tarmac, especially when there are no trees with a large canopy around. Additionally, the selected student rooms are also freely exposed to direct sunlight penetration/radiation in the afternoon, when higher temperatures were recorded after 12.00pm (Davis et al., 2006). In other words, these were student rooms with a west-east orientation and not shadowed by any large tree canopy or other buildings nearby.

ii. Best scenario: A student room on the first or second floor, which is not affected by the heat penetration from the roof or the heat radiation from the ground/tarmac. Moreover, it is either shadowed by a large tree canopy or near to a green area. Furthermore, a student room that is not freely exposed to direct morning or afternoon sunlight penetration/radiation due to a north-south building orientation.

Room D410 at Block D was selected in representing worst scenario and labelled as RW, while room B303 at Block B for best scenario and labelled as RB. The location of ONSET HOBO U12-012 data logger for indoor climate and location of manual measurement of daylight distribution is shown in Figure 2. There is constantly 1m in length from one point to another point, which only includes point X, A, B, C and D.

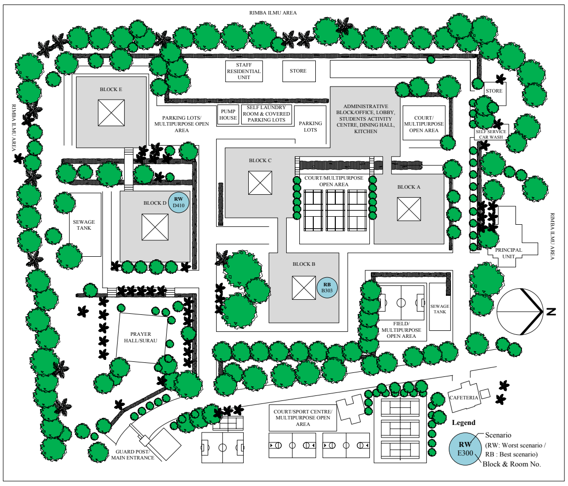


Figure 1: Location of pilot study for building performance evaluation

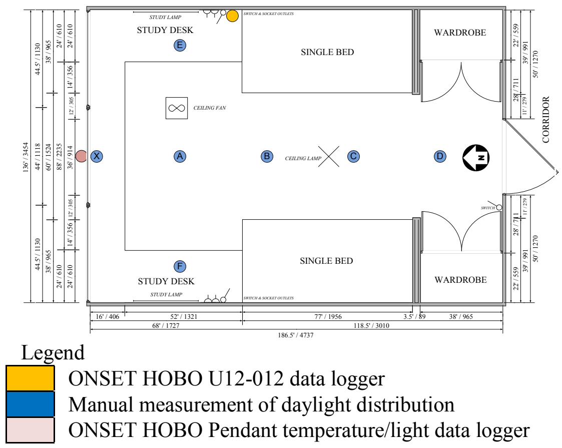


Figure 2: Location of data logger for internal microclimate and manual measurement of daylight distribution

Additionally, two ONSET HOBO Pendant temperature/light data logger were also fixed for microclimate. One was fixed at the rooftop of the administration building for representing worst scenario and labelled as MW, while another one was on the outside of RB for representing best scenario, labelled as MB. The rooftop of administrative building was selected rather than residential building itself due to accessibility and safety issues.

Generally, both selected rooms, representing the different scenarios, displayed the same mean and minimum temperature values, of 28°C and 24°C, as shown in Figure 3 and Table 1.

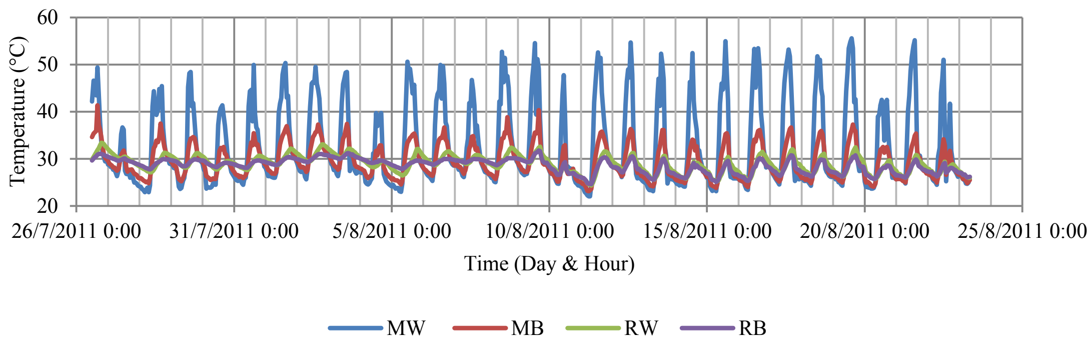


Figure 3: Temperature profile of pilot study

However, a higher maximum temperature was recorded at room RW, exceeding 33°C with 1.8118 of a standard deviation, compared to the maximum temperature at room RB, which was 2°C lower. For the microclimate, the mean temperature value for the worst scenario was 32.48°C with 8.6329 of a standard deviation, while the minimum and maximum temperature values were 22.05°C and 55.58°C, respectively. Comparatively, lower temperature values were recorded at the best scenario area, in the range of 23.10°C to 41.34°C, with the mean temperature value being 29.32°C and 3.5282 of standard deviation values. There were no significant differences in the mean temperature values for the indoor climate between the two conditions, RB and RW, in connection with different fan speeds. The room temperatures could not be reduced with the higher fan speed when higher mean temperatures were also recorded either with lower or higher fan speed. In contrast, the opening of the operable windows drastically reduced the room temperatures consistent, with a 1°C to 3°C margin.

Table 1: Statistical analysis of pilot study of temperature values

Location	Scenario	Operable window	Fan speed	Statistical analysis of temperature (°C)				
				Mean	Min	Max	Std. dev.	Range
Indoor	Worst (RW)	Close	5	29.92	27.14	33.40	1.5942	6.30
			3	29.20	27.58	31.23	0.9917	3.65
			1	30.77	28.30	33.05	1.1855	4.76
			0	29.56	26.48	32.33	1.3882	5.86
		Open	5	28.39	24.34	32.54	2.0850	8.20
			3	27.70	25.14	31.23	1.5937	6.09
			1	28.28	25.45	32.05	1.7295	6.59
			0	28.02	25.67	32.41	1.5612	6.74
		Overall		28.96	24.34	33.39	1.8118	9.05
	Best (RB)	Close	5	29.46	27.75	31.08	0.8458	3.33
			3	28.98	28.05	29.89	0.5031	1.84
			1	30.14	28.89	31.20	0.5794	2.31
			0	29.34	27.83	30.14	0.5379	2.32
		Open	5	27.98	24.61	31.74	1.7806	7.14
			3	27.35	25.09	30.50	1.3761	5.41
			1	27.64	25.31	30.72	1.3904	5.42
			0	27.58	25.70	30.75	1.1803	7.14
		Overall		28.54	24.61	31.74	1.4559	7.135
Outdoor	Worst(MW)	-	-	32.48	22.05	55.58	8.6329	33.53
	Best (MB)	-	-	29.32	23.10	41.34	3.5282	18.24

The same results were also recorded for relative humidity, where the opening of the operable windows considerably influenced the percentage values of both selected rooms, compared to the fan speed, as shown in Figure 4 and Table 2. Nevertheless, lower relative humidity values were recorded at the highest fan speed, while the humidity values increased when the fan was switched off in both conditions and states of operable windows. The mean values of relative humidity were measured in the range of 73 to 78% with the opening of operable windows. These values were higher than those measured in the closed state, which were between 64 and 72%. Additionally, higher maximum values were also recorded, exceeding 87.63%, in the case of opening the operable windows, whereas the situation without opening the windows resulted in values below 78.50 %.

Referring to local climate data, there were more rainy days with a higher total of rainfall recorded during the second half of the pilot study, where all operable windows were opened. As a consequence, the humidity levels inside the rooms increased significantly. Unfortunately, these changes only happened during a short period, when higher temperatures were also recorded on the same day. Additionally, the total rainfall was measured daily only at 08:00, which was not exactly representative of the daily temperature and relative humidity data.

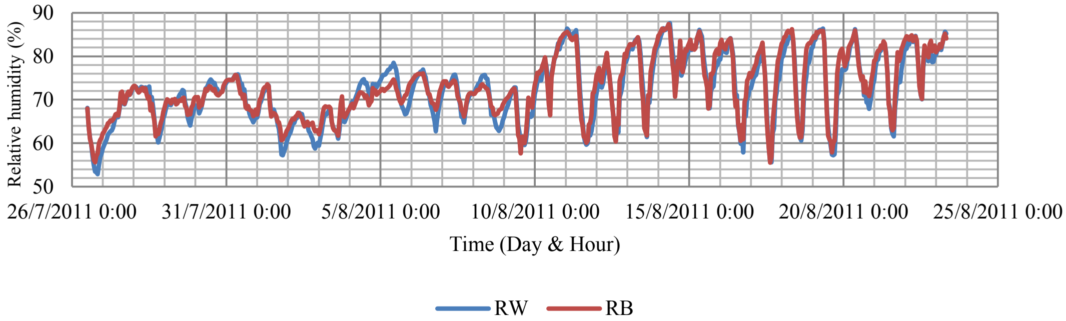


Figure 4: Relative humidity profile of pilot study

Table 2: Statistical analysis of pilot study of relative humidity values

Location	Scenario	Operable window	Fan speed	Statistical analysis of relative humidity (%)				
				Mean	Min	Max	Std. dev.	Range
Indoor	Worst (RW)	Close	5	66.24	52.90	73.12	5.7234	20.22
			3	70.85	64.08	75.85	3.2760	11.77
			1	64.85	57.21	74.00	3.7900	16.79
			0	71.60	62.74	78.50	3.9118	15.76
		Open	5	73.12	59.13	86.40	8.4072	27.27
			3	77.97	60.71	87.63	6.9444	26.91
			1	74.79	55.57	85.45	7.7852	29.88
			0	76.46	57.19	86.39	7.5191	29.20
		Overall		72.27	52.90	87.63	7.4455	34.73
	Best (RB)	Close	5	67.05	55.60	73.16	4.6455	17.56
			3	70.90	66.19	75.70	2.5692	9.506
			1	65.79	60.66	71.74	2.6403	11.08
			0	71.57	66.14	76.06	2.3719	9.92
		Open	5	73.91	57.67	85.64	8.1524	27.97
			3	78.45	60.38	87.38	7.0519	27.00
			1	76.27	55.56	86.20	7.9066	30.63
			0	77.85	57.85	85.94	7.4036	28.10
		Overall		73.00	55.56	87.38	7.2288	31.81

Overall, the differences between the mean percentage values of the two scenarios including the arrangement of the operable windows were small. The room representing the best scenario, RB, measured 73.00% with 7.2288 of a standard deviation, which was 0.73% higher than in the worst scenario, where a value of 72.27% with 7.4455 of standard deviation was noted. The minimum values for both scenarios, the worst and the best, were 52.90% and 55.56%, respectively while the maximum values were 87.63% and 87.38%, respectively.

By taking both aspects, temperature and relative humidity into consideration, lower percentages of relative humidity were recorded with the increase of temperature values as shown in Figure 5.

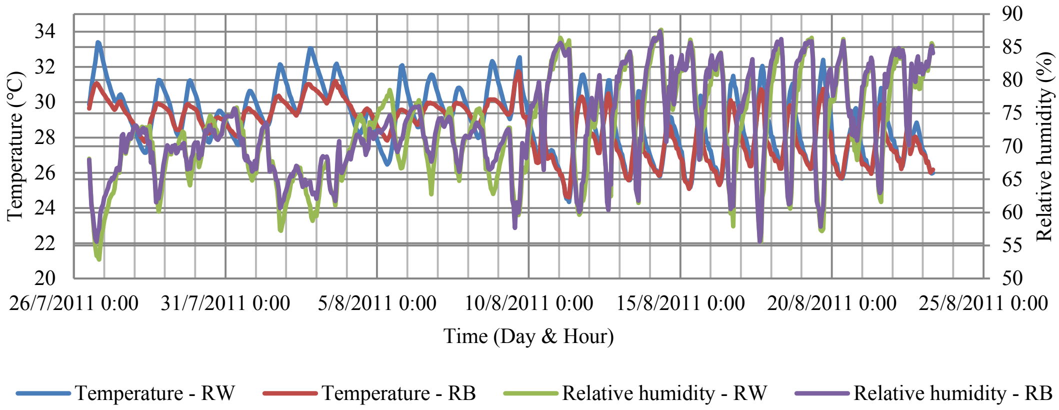


Figure 5: The temperature and relative humidity profile at RW and RB

The statistical analysis of illuminnance for both scenarios found only small differences between the mean values. The values were 145.75 lx with 184.8887 of standard deviation and 150.57 lx with 181.4552 of the standard deviation as revealed in Figure 6 & 7 and Table 3. The access of daylight was still permitted, although room RB was shadowed by a dense tree canopy unlike room RW. The maximum values stated by both scenarios were 618.9 lx and 642.5 lx for RB and RW, respectively, with constant minimum values of 11.8 lx and 19.7 lx. For the microclimate, an eight times higher mean illuminance value was recorded, exceeding 35016.34 lx with 57691.3278 of standard deviation for the worst scenario. In comparison, the best scenario only logged a value of 4422.31 lx with 10121.3806 of standard deviation. The maximum illuminance value for the worst scenario was 220445.9 lx, about two times higher than that of the best scenario, which measured only 121245.2 lx.

There are constant minimum values for both scenarios due to the corridor and street lamps located close to both the selected residential units. The efficiency of tinted window glass in controlling daylight penetration into the rooms is clearly described, with lower intensity values achieved by the closing of operable windows. Additionally, the mean light intensity values recorded by the rooms with either closed or open operable windows are within the range of illumination standards set up by the Illuminating Engineering Society (IES) and the Public Works Department of Malaysia, which recommend 150 lux for casual reading and general requirements for bedroom areas. This is inconsistent with the Malaysia Standard-MS 1525, where the minimum requirements are in the range of 300 to 400 lux, which is only achievable from 09:00 to 15:00, especially on bright days with clear sky.

Appendix M, continued

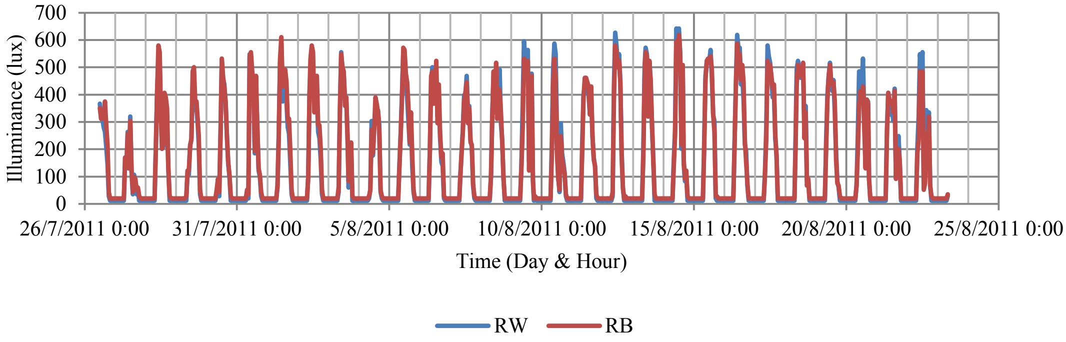


Figure 6: Illuminance profile of pilot study of indoor climate

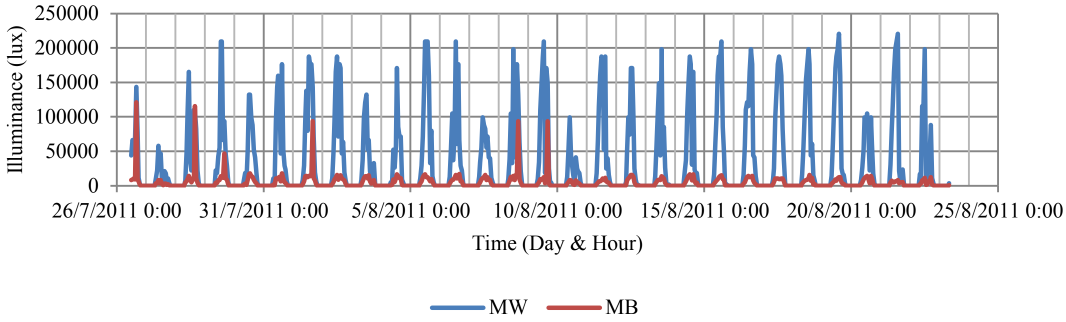


Figure 7: Illuminance profile of pilot study of microclimate

Table 3: Statistical analysis of pilot study of illuminance values

Location	Scenario	Operable window	Statistical analysis of illuminance (lux)				
			Mean	Min	Max	Std. dev.	Range
Indoor	Worst (RW)	Close	134.98	11.8	587.3	167.8167	575.5
		Open	156.50	11.8	642.5	200.1440	630.7
		-	145.75	11.8	642.5	184.8887	630.7
	Best (RB)	Close	146.20	19.7	611.0	173.0622	591.3
		Open	154.93	19.7	618.9	189.6128	599.2
		-	150.57	19.7	618.9	181.4552	599.2
Outdoor	Worst (MW)	-	35016.34	0.0	220445.9	57691.3278	220445.9
	Best (MB)	-	4422.31	0.0	121245.2	10121.3806	121245.2

The daylight distribution at both selected student rooms were measured for five times with the opening and closing of operable windows. The average reductions of daylight distribution were calculated as presented in Table 4. The daylight distributions in both selected student rooms gradually decrease with the increasing of distance from windows. Comparatively, RB stated higher percentages of reduction and the same results were also stated by both student rooms with the closing of operable windows.

Table 4: Statistical analysis (mean) for the reduction of daylight distribution

Scenario	Operable window	Mean reduction of daylight distribution (%) at selected location					
		A	B	C	D	E	F
Worst (RW)	Close	60.63	75.90	85.30	90.77	59.46	74.39
	Open	56.38	70.57	80.13	87.89	37.37	57.10
Best (RB)	Close	69.43	84.77	89.50	92.36	74.27	77.04
	Open	66.81	81.96	88.35	91.59	66.29	68.20

Indirectly, it shows the efficiency of tinted window glass in controlling daylight penetration into the student room.

Regarding on the measurements taken at the study desk area, E and F, the daylight distribution is generally lower than location which marked with A, even the distance toward windows is same, 1 m. It is hypothesized that the limitation of daylight distribution was contributed by the wall, which was built in conjunction with a fixed transom / opening over a doorway in creating wind pressure effect inside the student rooms.

Consequently, the internal climate, temperature (°C) and relative humidity (%) of student room is more influences by the opening of operable windows compared to the fan speed. The fan will give a significant influence towards relative humidity just only in full speed when it was drastically reduced compared to the situation where the fan was switched off. Then, the illuminance (lx) and daylight distribution in the student room are drastically influenced by the location and landscape elements, which directly giving a shadow effect to the building. Regarding on temperature, it is also influenced by the location, where with west-east orientation at the top level of the building will resulted hotter temperature due to higher heat radiation from the roof and direct sunlight penetration in the afternoon.

Appendix N - HOBO U12 Temperature/Relative Humidity/Light/External Data Logger - U12-012

Measures:
4-20mA, AC Current, AC Voltage, Air Velocity, Carbon Dioxide, Compressed Air Flow, DC Current, DC Voltage, Gauge Pressure, Kilowatts (kW), Light Intensity, Relative Humidity, Temperature, Volatile Organic Compound

Features:

- 12-bit resolution provides high accuracy
- Large memory for long-term deployments or fast sampling
- Programmable and push button start
- Direct USB interface for fast data offload
- Compatible with Onset's HOBO U-Shuttle for convenient data transport

Description:

The HOBO U12-012 accepts a wide range of energy and environmental sensors. It provides 12-bit resolution measurements for detecting greater variability in recorded data, and stores 43,000 measurements.

Detailed Specifications:

Measurement range:
Temperature: -20° to 70°C (-4° to 158°F)
RH: 5% to 95% RH
Light intensity: 1 to 3000 footcandles (lumens/ft2) typical; maximum value varies from 1500 to 4500 footcandles (lumens/ft2)
Analog channels:
0 to 2.5 Vdc (w/CABLE-2.5-STEREO); 0 to 5 Vdc (w/CABLE-ADAP5); 0 to 10 Vdc (w/ CABLE-ADAP10); 4-20 mA (w/CABLE-4-20MA)

Accuracy:
Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F), see Plot A
RH: ±2.5% from 10% to 90% RH (typical), to a maximum of ±3.5%, see Plot B
Light intensity: Designed for indoor measurement of relative light levels, see Plot D for light wavelength response
External input channel (see sensor manual): ± 2 mV ± 2.5% of absolute reading

Resolution:
Temperature: 0.03°C at 25°C (0.05°F at 77°F), see Plot A
RH: 0.03% RH

Sample Rate:
1 second to 18 hours, user selectable

Drift:
Temperature: 0.1°C/year (0.2°F/year)
RH: <1% per year typical; RH hysteresis 1%
Response time in airflow of 1 m/s (2.2 mph):
Temperature: 6 minutes, typical to 90%
RH: 1 minute, typical to 90%
Time accuracy: ± 1 minute per month at 25°C (77°F), see Plot C

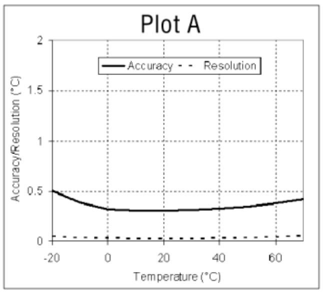
Operating temperature:
Logging: -20° to 70°C (-4° to 158°F)
Launch/readout: 0° to 50°C (32° to 122°F), per USB specification

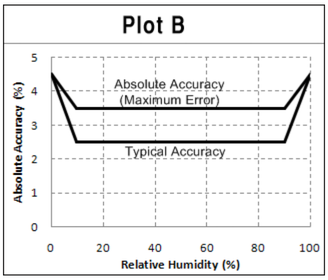
Battery life: 1 year typical use

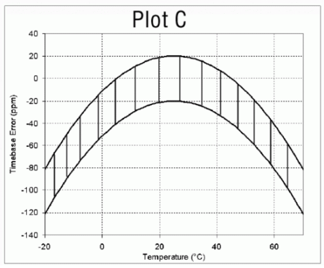
Memory: 64K bytes (43,000 12-bit measurements)

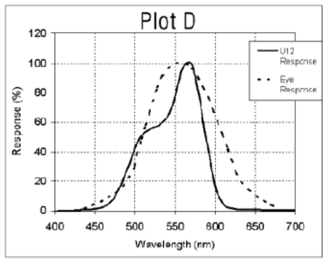
Weight: 46 g (1.6 oz)

Dimensions: 58 x 74 x 22 mm (2.3 x 2.9 x 0.9 inches)
The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).









Serial No.: 10099726, 10099727, 10099728, 10099729, 10099730, 10099731, 10099732, 10099733, 10099734, 10099735, 10099736, 10099737, 10099738, 10099739, 10099740, 10099741, 10099742, 10099743, 10099744, 10099745, 10099746, 10099747, 10099748, 10099749.

Appendix O - Luxmeter LX100

LX100 hand-held luxmeter, self-contained and automatic is specially designed to illuminance measurement.

Sensing element in silicon photodiode, with spectral responsivity in accordance with photonic curve (CIE).

Illuminance measurement in lux or in foot-candelas for illuminance levels below 10 lux, with 0,1 lux calculation accuracy and with 1% accuracy beyond until 150000 lux.

Instantaneous measurement, display illuminance for local measurements.

With timed measurement:
- Illuminance min/max values display
- Illuminance averaged value calculation

With relative illuminance function :
- *allows a relative measurement to a reference point for the quantification of a luminous contribution or an illuminance decrease.*

With hold function :
- Allows to avoid illuminance noise or to save on screen local measurement.

Measurement saving when unexpected power cut occurs

Technical features:

Measuring range: from 0,1 to 150 000 Lux from 0.01 to 13940 fc
Spectral response: as per standard photopic curve V(λ) NF C 42 -710 class C.
Error limit V(λ) (f1): < 10%
True cosine evaluation (f2): < 6%
Linearity (f3): < 3%
Measurement capability: 3 days – 03D00H00M
Display: Backlit LCD graphic 128x64.
Working temperature: from 0°C to +50°C
Storage temperature: from 0°C to +50°C
Housing dimensions (without sensor): 120x58x34 mm
Weight (housing+sensor+battery): 185 gr
Digital electronic: low drift
Mini-USB plug: for USB power supply adaptor
Power supply: 3 batteries 1.5V type LR3-AAA
Battery life: 72 hours min, continuous operation.
Electromagnetic compatibility: according to 89/336/CEE
Conformity: as per RoHS

Illuminance measuring range:

- from 0.1 to 150 000 Lux

Display	Unit	Resolution	Accuracy
0.1 to 10.0	lx	0.1	0.1 lux
10.0 to 99.9	lx	0.1	1%
100.0 to 999.9	lx	0.1	1%
1000.0 to 9999.9	lx	1	1%
10.00 to 99.99	klx	10	1%
100.0 to 150.0	klx	100	1%

- from 0 t o 13940 fc

Display	Unit	Resolution	Accuracy
0.00 to 1.00	fc	0.01	0.1 fc
1.00 to 99.99	fc	0.01	1%
100.0 to 999.9	fc	0.1	1%
1000 to 9999	fc	1	1%
10.00 to 13.94	kfc	10	1%

Appendix P - HOBO Pendant Temperature/Light Data Logger 64K-UA-002-64

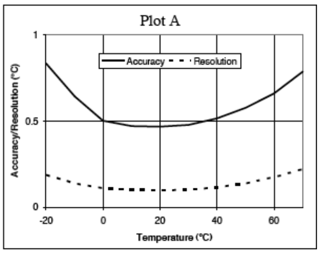
Measures:
Light Intensity, Temperature

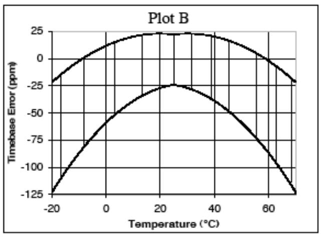
Description:

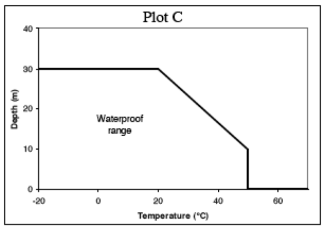
A miniature two-channel temperature and relative light level data logger, this 64K model is waterproof and value-priced for deployment in indoor, outdoor, and underwater applications measuring relative light levels and ambient temperatures. This 64K model stores approximately 52K of 10-bit readings.

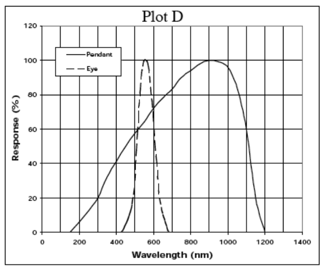
- Low-cost temperature with alarm indication or light intensity
- Waterproof housing for wet or underwater use
- Data readout in less than 30 seconds via fast Optic USB interface

Detailed Specifications:









Measurement range:
Temperature: -20° to 70°C (-4° to 158°F)
Light: 0 to 320,000 lux (0 to 30,000 lumens/ft2)

Accuracy:
Temperature: +/- 0.54°C from 0° to 50°C (0.97°F from 32° to 122°F)
Light intensity: Designed for measurement of relative light levels

Resolution:
Temperature: 0.10°C at 25°C (0.18°F at 77°F), see Plot A

Drift: Less than 0.1°C/year (0.2°F/year)

Response time: Airflow of 2 m/s (4.4 mph): 10 minutes, typical to 90%
Water: 5 minutes, typical to 90%

Time accuracy: ± 1 minute per month at 25°C (77°F), see Plot B

Operating range:
In water/ice: -20° to 50°C (-4° to 122°F)
In air: -20° to 70°C (-4° to 158°F)

Water depth rating: 30 m from -20° to 20°C (100 ft from -4° to 68°F), see Plot C

NIST traceable certification: Available for temperature only at additional charge; temperature range -20° to 70°C (-4° to 158°F)

Battery life: 1 year typical use

Memory:
UA-002-08: 8K bytes (approximately 3.5K combined temperature and light readings or events)
UA-002-64: 64K bytes (approximately 28K combined temperature and light readings or events)

Materials: Polypropylene case; stainless steel screws; Buna-N o-ring

Weight: 18 g (0.6 oz)

Dimensions: 58 x 33 x 23 mm (2.3 x 1.3 x 0.9 inches)
The CE Marking identifies this product as complying with the relevant directives in the European Union (EU).

Serial No.: 9894083, 9894084, 9906100, 9906103.

Appendix Q - Living behaviour assessment form

Date & Day			1 October 2012 & Monday					
Time			6am-12pm		12pm-6pm		6pm-12am	
Garment dressed (Please specify)								
Activity (Please specify)								
Weather		Sunny						
		Raining						
		Cloudy						
Opening		Window	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
		Curtain	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
Electrical appliances		Fan	ON	OFF	ON	OFF	ON	OFF
			Speed		Speed		Speed	
		Ceiling Lamp	ON	OFF	ON	OFF	ON	OFF
		Study lamp	ON	OFF	ON	OFF	ON	OFF
		Computer	ON	OFF	ON	OFF	ON	OFF
		Charger mobile phone	ON	OFF	ON	OFF	ON	OFF
	Others (Please specify : ……………………..)		ON	OFF	ON	OFF	ON	OFF
Visual comfort	Natural daylighting	*Too dark*						
		Dark						
		Neither/Nor						
		Bright						
		Too bright						
	Artificial light	*Too dark*						
		Dark						
		Neither/Nor						
		Bright						
		Too bright						
	Quality of lighting	*Too dark*						
		Dark						
		Neither/Nor						
		Bright						
		Too bright						
Ventilation	Air movement	*Still air*						
		Inconspicuous still air						
		Neither/Nor						
		Breezy						
		Very breezy						
	Quality of indoor ventilation	*Very poor*						
		Poor						
		Neither/Nor						
		Good						
		Very good						
Thermal comfort	Thermal	*Too hot*						
		Hot						
		Neither/Nor						
		Cold						
		Too Cold						
Comfort level	Overall comfort level	*Very uncomfortable*						
		Uncomfortable						
		Neutral						
		Comfortable						
		Very comfortable						
	Do the overall room conditions affect the degree of your work productivity?	*Much decreased*						
		Decreased						
		No changes						
		Increased						
		Much increased						

Appendix R - EEI of UM residential college for 2005-2009

Year	Name of residential colleges, Year established, Total Floor Area – TFA, Capacity/No. Of tenants, Annual Energy Consumption – AEC (kWh/year) and Energy Efficiency Index – EEI (kWh/m^2/year).							
	1st RC *Year established: 1959* *Capacity: 816* *TFA: 12,727.44 m^2*		2nd RC *Year established: 1958* *Capacity: 611* *TFA: 11,224.71 m^2*		3rd RC *Year established: 1962* *Capacity: 765* *TFA: 7,159.92 m^2*		4th RC *Year established: 1963* *Capacity: 705* *TFA: 11,427.67 m^2*	
	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)
2005	1,168,612	91.82	774,834	69.03	828,630	115.73	1,061,666	92.90
2006	995,028	78.18	600,589	53.51	923,357	128.96	894,062	78.24
2007	594,892	46.74	670,486	59.73	899,048	125.57	617,160	54.01
2008	540,286	42.45	743,160	66.21	855,319	119.46	557,538	48.79
2009	547,331	43.00	679,086	60.50	966,445	134.98	547,970	47.95
Statistical analysis								
Mean	769,230	60.44	693,631	61.80	894,560	124.94	735,679	64.38
Median	594,892	46.74	679,086	60.50	899,048	125.57	617,160	54.01
Std. Dev.	292,634.15	22.99	67,917.43	6.051	54,551.54	7.619	230,417.20	20.163
Variance	8653E+10	528.650	4.613E+09	36.611	2.976E+09	58.049	5.309E+10	406.550
Min	540,286	42.45	600,589	53.51	828,630	115.73	547,970	47.95
Max	1,168,612	91.82	774,834	69.03	966,445	134.98	1,061,666	92.90

Year	Name of residential colleges, Year established, Total Floor Area – TFA, Capacity/No. Of tenants, Annual Energy Consumption – AEC (kWh/year) and Energy Efficiency Index – EEI (kWh/m^2/year).							
	5th RC *Year established: 1966* *Capacity: 885* *TFA: 18,212.51 m^2*		6th RC *Year established: 1967* *Capacity: 630* *TFA: 21,148.03 m^2*		7th RC *Year established: 1975* *Capacity: 798* *TFA: 12,989.87 m^2*		8th RC *Year established: 1985* *Capacity: 694* *TFA: 11,274.23 m^2*	
	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)
2005	958,107	52.61	837,140	39.58	626,860	48.26	907,906	80.53
2006	834,917	45.84	859,488	40.64	735,941	56.65	995,365	88.29
2007	435,443	23.91	899,174	42.52	747,862	57.57	979,982	86.92
2008	378,933	20.81	963,799	45.57	722,421	55.61	951,899	84.43
2009	389,968	21.41	917,096	43.37	651,007	50.12	897,900	79.64
Statistical analysis								
Mean	599,474	32.92	895,339	42.34	696,818	53.64	946,610	83.96
Median	435,443	23.91	899,174	42.52	722,421	55.61	951,899	84.43
Std. Dev.	275,448.86	15.124	49,616.69	2.346	54,277.95	4.178	42,980.74	3.812
Variance	7.587E+10	228.740	2.462E+09	5.504	2.946E+09	17.460	1.847E+09	14.534
Min	378,933	20.81	837,140	39.59	626,860	48.26	897,900	79.64
Max	958,107	52.61	963,799	45.57	747,862	57.57	995,365	88.29

Year	Name of residential colleges, Year established, Total Floor Area – TFA, Capacity/No. Of tenants, Annual Energy Consumption – AEC (kWh/year) and Energy Efficiency Index – EEI (kWh/m^2/year).							
	9th RC *Year established: 1995* *Capacity: 1,001* *TFA: 22,288.14 m^2*		10th RC *Year established: 1997* *Capacity: 747* *TFA: 15,217.02 m^2*		11th RC *Year established: 1997* *Capacity: 897* *TFA: 34,305.32 m^2*		12th RC *Year established: 2002* *Capacity: 2,990* *TFA: 89,545.91 m^2*	
	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)	AEC (kWh/yr)	EEI (kWh/m^2/yr)
2005	877,791	39.38	687,419	45.17	734,522	21.41	2,109,232	23.55
2006	976,652	43.82	816,117	53.63	691,948	20.17	2,298,031	25.66
2007	1,052,896	47.24	839,622	55.18	867,012	25.27	2,628,368	29.35
2008	956,252	42.90	682,868	44.88	955,667	27.86	2,575,618	28.76
2009	894,622	40.14	617,365	40.57	907,742	26.46	2,613,043	29.18
Statistical analysis								
Mean	951,643	42.70	728,678	47.89	831,378	24.24	2,444,858	27.30
Median	956,252	42.90	687,419	45.17	867,012	25.27	2,575,618	28.76
Std. Dev.	70,007.81	3.141	95,059.97	6.247	113,325.65	3.303	230,902.18	2.579
Variance	4.901E+09	9.866	9.036E+09	39.024	1.284E+10	10.913	5.332E+10	6.649
Min	877,791	39.38	617,365	40.57	691,948	20.17	2,109,232	23.56
Max	1,052,896	47.24	839,622	55.18	955,667	27.86	2,628,368	29.35

Appendix S - Comparison of twelve residential buildings particularly in the characteristic of a typical student room, building design and adaptation of bioclimatic design concepts

INTERNAL SYSTEMS	CHARACTERISTIC	University of Malaya Residential College (RC) / *Year established*			
		1st RC *1959*	2nd RC *1958*	3rd RC *1962*	4th RC *1963*
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING, & FEATURES	FORM OF BUILDING	Low-rise	Low-rise	Low-rise	Low-rise
	BUILDING LAYOUT	Linear	Linear	Linear	Linear
	ORIENTATION TO SUN PATH	N - S	N - S	NE - SW & NW - SE	N - S, NW - SE & NE - SW
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle	Rectangle	Rectangle	Rectangle
	WIND DIRECTION OF THE LOCALITY	SW	SW	SW	SW
	BUILDING LOCATION ON THE GROUND	Different altitude	Different altitude	Different altitude	Different altitude
	FLOOR LEVEL (excluding GF)	3	3	3	3
	TOTAL AREA (m^2)	26,152.49	41,014.10	18,740.60	22,199.00
	TOTAL BUILT UP AREA (m^2)	12,530.88	7,499.98	4,196.08	10,599.03
	TOTAL FLOOR AREA (m^2)	12,727.44	11,224.71	7,159.92	11,427.67
	CAPACITY	816	611	765	705
	DENSITY (capacity/total floor area)	0.064	0.054	0.107	0.062
	RATIO OF AIR CONDITIONED AND NON AIR CONDITIONED AREA	3 : 97	2 : 98	5 : 95	2 : 98
TYPICAL STUDENT ROOM - FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	5.0 x 3.3 x 2.6	5.0 x 3.5 x 2.9	4.63 x 3.8 x 2.86	4.98 x 3.3 x 2.5
	TYPICAL ROOM'S FLOOR AREA (m^2)	16.50	17.50	17.59	16.43
	TYPICAL ROOM VOLUME (m^3)	42.90	50.75	50.32	41.09
	TYPICAL OF CORRIDOR WIDTH (m)	1.52	1.52	1.83	1.50
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection, adjustable & fix natural ventilation option	Glare protection, adjustable & fix natural ventilation option
	WINDOW AREA (m^2)	2.60	4.31	5.76	2.60
	WINDOW TO WALL RATIO	0.30	0.42	0.53	0.32
	OPERABLE WINDOW AREA (m^2)	2.60	2.39	5.76	2.60
	OPERABLE WINDOW TO WALL RATIO	0.30	0.24	0.53	0.32
	WINDOW DESIGN	Louver window/Jalousie & Casement window	Louver window/Jalousie	Louver window/Jalousie & Casement window	Louver window/Jalousie
	LOCATION	N - S	N - S	NE - SW & NW - SE	N - S, NW - SE & NE - SW
SOLAR CONTROL DEVICES	HORIZONTAL OVERHANGS ALONG THE WALL WITH WINDOWS	•	•	•	•
	VERTICAL OVERHANGS ALONG THE WALL WITH WINDOWS				•
	TINTED WINDOW GLASS				
	BALCONIES/VERANDA				
	DEEP RECESSES				
	SKY COURTS/INTERNAL COURTYARD				
PASSIVE DAYLIGHT CONCEPTS	ARTICULATED LIGHT SHELVES	•	•	•	•
	LIGHT PIPES				
	SKY COURTS/INTERNAL COURTYARD				
	BALCONIES/VERANDA				
WIND AND NATURAL VENTILATION	WINDOW OPENING WITH HORIZONTAL ADJUSTABLE/CLOSING DEVICES	•	•	•	•
	WINDOW OPENING WITH VERTICAL ADJUSTABLE/CLOSING DEVICES				
	HIGH LEVEL FIXED/ADJUSTABLE EXHAUST OPENING	•	•	•	•
	LOW LEVEL FIXED/ADJUSTABLE INLETS OPENING				•
	TRANSOM/FIXED OPENING OVER THE DOORWAY OF RESIDENTIAL UNIT	•	•	•	•
	WALL OPENING (create wind pressure inside the room)				
	BALCONIES/VERANDA				
	INTERNAL COURTYARD				
	LOCATION OF OPENING WITH RESPECT TO WIND DIRECTION				•
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	52 : 48	82 : 18	78 : 22	52 : 48
OTHERS	CORRIDOR	Closed corridor with adjustable & fixed opening devices	Closed corridor with adjustable & fixed opening devices	Closed corridor with fixed opening devices	Closed corridor with adjustable & fixed opening devices
	STAIRCASE AREA	Closed staircase area with fixed opening devices	Closed staircase area with fixed opening devices	Closed staircase area with fixed opening devices	Closed staircase area with fixed opening devices
ARCHITECT		Chawangan Bangunan, Malaysia Barat	No information	No information	No information
PHASE OF CONSTRUCTION		Various phase	Various phase	Various phase	Various phase
POTENTIAL AS CASE STUDY (MAIN REASON)		No (non-homogeinity of building design)	No (non-homogeinity of building design)	No (non-homogeinity of building design)	No (non-homogeinity of building design)

Appendix S, continued

INTERNAL SYSTEMS	CHARACTERISTIC	University of Malaya Residential College (RC) / *Year established*			
		5th RC *1966*	6th RC *1967*	7th RC *1975*	8th RC *1985*
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING, & FEATURES	FORM OF BUILDING	Low-rise	Low-rise	Low-rise	Low-rise
	BUILDING LAYOUT	Courtyard arrangement	Linear arrangement	Linear arrangement	Linear arrangement
	ORIENTATION TO SUN PATH	N - S	N - S & W - E	NW - SE & NE - SW	N - S, NW - SE & NE - SW
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle	Rectangle	Rectangle	Rectangle
	WIND DIRECTION OF THE LOCALITY	SW	SW	SW	SW
	BUILDING LOCATION ON THE GROUND	Different altitude	Different altitude	Different altitude	Different altitude
	FLOOR LEVEL (excluding GF)	3	3	3	3
	TOTAL AREA (m^2)	43,185.06	29,121.64	19,263.41	32,806.00
	TOTAL BUILT UP AREA (m^2)	16,971.02	12,822.28	11,786.98	9,213.63
	TOTAL FLOOR AREA (m^2)	18,212.51	21,148.03	12,989.87	11,274.23
	CAPACITY	847	630	798	694
	DENSITY (capacity/total floor area)	0.047	0.030	0.061	0.062
	RATIO OF AIR CONDITIONED AND NON AIR CONDITIONED AREA	1 : 99	1 : 99	2 : 98	2 : 98
TYPICAL STUDENT ROOM - FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	4.74 x 3.45 x 2.80	4.23 x 4.0 x 3.0	3.23 x 4.8 x 3.0	(1.52 x 1.52 x 3.20) + (4.27 x 2.92 x 3.20)
	TYPICAL ROOM'S FLOOR AREA (m^2)	16.35	16.92	15.50	14.78
	TYPICAL ROOM VOLUME (m^3)	45.78	50.76	46.50	47.30
	TYPICAL OF CORRIDOR WIDTH (m)	1.87	1.83	1.37	1.7
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option
	WINDOW AREA (m^2)	6.41	2.27	4.68	3.34
	WINDOW TO WALL RATIO	0.66	0.19	0.33	0.38
	OPERABLE WINDOW AREA (m^2)	4.20	2.27	4.18	3.34
	OPERABLE WINDOW TO WALL RATIO	0.43	0.19	0.29	0.38
	WINDOW DESIGN	Centre pivot & awning	Louver window/Jalousie	Casement & Awning window	Louver window/Jalousie
	LOCATION	N - S	N - S & W - E	NE - SW & NW - SE	N - S, NW - SE & NE - SW
SOLAR CONTROL DEVICES	HORIZONTAL OVERHANGS ALONG THE WALL WITH WINDOWS	•	•		•
	VERTICAL OVERHANGS ALONG THE WALL WITH WINDOWS				
	TINTED WINDOW GLASS	•		•	
	BALCONIES/VERANDA				
	DEEP RECESSES	•			
	SKY COURTS/INTERNAL COURTYARD	•			
PASSIVE DAYLIGHT CONCEPTS	ARTICULATED LIGHT SHELVES	•		•	
	LIGHT PIPES				
	SKY COURTS/INTERNAL COURTYARD	•			
	BALCONIES/VERANDA				
WIND AND NATURAL VENTILATION	WINDOW OPENING WITH HORIZONTAL ADJUSTABLE/CLOSING DEVICES	•	•	•	•
	WINDOW OPENING WITH VERTICAL ADJUSTABLE/CLOSING DEVICES	•	•	•	
	HIGH LEVEL FIXED/ADJUSTABLE EXHAUST OPENING	•	•	•	
	LOW LEVEL FIXED/ADJUSTABLE INLETS OPENING				
	TRANSOM/FIXED OPENING OVER THE DOORWAY OF RESIDENTIAL UNIT	•			
	WALL OPENING (create wind pressure inside the room)	•			
	BALCONIES/VERANDA				
	INTERNAL COURTYARD	•			
	LOCATION OF OPENING WITH RESPECT TO WIND DIRECTION			•	•
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	61 : 39	56 : 44	39 : 61	72 : 28
OTHERS	CORRIDOR	Open corridor (facing to internal courtyard)	Closed corridor with fixed opening devices	Closed corridor with adjustable & fixed opening devices	Closed corridor with adjustable opening devices
	STAIRCASE AREA	Open staircase area	Closed staircase area	Closed staircase area with fixed opening devices	Open staircase area
ARCHITECT		No information	Arkitek Kitas Sdn. Bhd	No information	No information
PHASE OF CONSTRUCTION		One phase	Various phase	One phase	One phase
POTENTIAL AS CASE STUDY (MAIN REASON)		Yes (homogeinity of building design & high adaptation of green building strategies)	No (non-homogeinity of building design)	No (non-homogeinity of building orientation & less adaptation of green building strategies)	No (non-homogeinity of building orientation & less adaptation of green building strategies)

Appendix S, continued

INTERNAL SYSTEMS	CHARACTERISTIC	University of Malaya Residential College (RC) / *Year established*			
		9th RC *1995*	10th RC *1997*	11th RC *1997*	12th RC *2002*
BUILT-FORM CONFIGURATION, ORIENTATION, SITE LAYOUT PLANNING, & FEATURES	FORM OF BUILDING	Low-rise	Low-rise	Low-rise	High-rise
	BUILDING LAYOUT	Linear arrangement	Linear arrangement	Courtyard arrangement	Linear arrangement
	ORIENTATION TO SUN PATH	N - S	N - S & NW - SE	N - S & W - E	N - S
	SHAPE OF THE BUILDING'S FLOOR PLATE	Rectangle	Rectangle	L-shape	Rectangle
	WIND DIRECTION OF THE LOCALITY	SW	SW	SW	SW
	BUILDING LOCATION ON THE GROUND	Different altitude	Different altitude	Same altitude	Same altitude
	FLOOR LEVEL (excluding GF)	3	3	3	9
	TOTAL AREA (m^2)	36,858.00	24,751.08	26,766.14	46,415.84
	TOTAL BUILT UP AREA (m^2)	17,451.85	7,224.38	11,250.44	30,724.87
	TOTAL FLOOR AREA (m^2)	22,288.14	15,217.02	34,305.32	89,545.91
	CAPACITY	1,001	747	897	2,990
	DENSITY (capacity/total floor area)	0.045	0.049	0.026	0.033
	RATIO OF AIR CONDITIONED AND NON AIR CONDITIONED AREA	1 : 99	3 : 97	1 : 99	0.3 : 99.7
TYPICAL STUDENT ROOM - FORM CONFIGURATION & LAYOUT PLANNING	TYPICAL ROOM DIMENSION (l) x (w) x (h)	4.15 x 3.88 x 2.91	4.15 x 3.17 x 3.0	5.0 x 4.0 x 2.87	5.0 x 3.0 x 3.0
	TYPICAL ROOM'S FLOOR AREA (m^2)	16.10	13.16	20.00	15.00
	TYPICAL ROOM VOLUME (m^3)	46.86	39.47	57.40	45.00
	TYPICAL OF CORRIDOR WIDTH (m)	1.65	1.65	1.6	1.85
ENCLOSURAL AND FAÇADE DESIGN	DESIGN	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option	Glare protection & adjustable natural ventilation option
	WINDOW AREA (m^2)	0.82	2.52	Type A : 1.65 / Type B : 4.12	2.9
	WINDOW TO WALL RATIO	0.07	0.26	Type A : 0.14 / Type B : 0.36	0.32
	OPERABLE WINDOW AREA (m^2)	0.82	2.52	Type A : 1.10 / Type B : 2.75	0.95
	OPERABLE WINDOW TO WALL RATIO	0.07	0.26	Type A : 0.1 / Type B : 0.24	0.11
	WINDOW DESIGN	Louver window/Jalousie	Louver window/Jalousie	Casement & Turn window	Louver window/Jalousie
	LOCATION	N - S	N - S & NW - SE	N - S & W - E	N - S
SOLAR CONTROL DEVICES	HORIZONTAL OVERHANGS ALONG THE WALL WITH WINDOWS	•			
	VERTICAL OVERHANGS ALONG THE WALL WITH WINDOWS				
	TINTED WINDOW GLASS			•	
	BALCONIES/VERANDA		•	•	•
	DEEP RECESSES	•	•	•	•
	SKY COURTS/INTERNAL COURTYARD			•	
PASSIVE DAYLIGHT CONCEPTS	ARTICULATED LIGHT SHELVES	•	•		•
	LIGHT PIPES				
	SKY COURTS/INTERNAL COURTYARD			•	
	BALCONIES/VERANDA		•	•	•
WIND AND NATURAL VENTILATION	WINDOW OPENING WITH HORIZONTAL ADJUSTABLE/CLOSING DEVICES	•	•		•
	WINDOW OPENING WITH VERTICAL ADJUSTABLE/CLOSING DEVICES			•	
	HIGH LEVEL FIXED/ADJUSTABLE EXHAUST OPENING	•	•		•
	LOW LEVEL FIXED/ADJUSTABLE INLETS OPENING		•		
	TRANSOM/FIXED OPENING OVER THE DOORWAY OF RESIDENTIAL UNIT				
	WALL OPENING (create wind pressure inside the room)				
	BALCONIES/VERANDA		•	•	•
	INTERNAL COURTYARD			•	
	LOCATION OF OPENING WITH RESPECT TO WIND DIRECTION				
LANDSCAPE	RATIO OF SOFT & HARD SURFACE AREA	53 : 47	71 : 29	58 : 42	34 : 66
OTHERS	CORRIDOR	Closed corridor with fixed opening devices	Closed corridor with adjustable & fixed opening devices	Open corridor (facing to internal courtyard)	Closed corridor with adjustable opening devices
	STAIRCASE AREA	Closed staircase area with adjustable & fixed opening devices	Open staircase area	Open staircase area	Open staircase area
ARCHITECT		Hijjas Kasturi Associates Sdn. Bhd.	Hijjas Kasturi Associates Sdn. Bhd.	AbRAZ Arkitek	Zull.G.Architect
PHASE OF CONSTRUCTION		One phase	One phase	One phase	One phase
POTENTIAL AS CASE STUDY (MAIN REASON)		Yes (homogeinity of building design & adaptation of green building strategies)	No (non-homogeinity of building design)	Yes (homogeinity of building design & adaptation of green building strategies)	No (different form of building)

Appendix T - The performance of electricity consumption at 5th RC for seven years duration (2005-2011)

		Electricity consumption		Efficiency of usage		Carbon footprint		Electricity usage			Special occasion		
Year	Month	Monthly (kWh/month)	Annually (kWh/year)	BEI (kWh/m²)	EEI (kWh/m²/year)	CO2 emission (kg)	Annual CO_2 emission (kg)	Tariff (RM/kWh)	Monthly total cost (RM)	Annual total cost (RM)	Sem. Break (Day)	Exam Prep. (Days)	Orientation (Days)
2005	Jan	85,490		4.69		58,133.20			24,621.12		4	-	-
	Feb	88,685		4.87		60,305.80			25,541.28		-	-	-
	March	107,161		5.88		72,869.48			30,862.37		17	-	-
	Apr	60,742		3.34		41,304.56			17,493.70		30	-	-
	May	65,696		3.61		44,673.28			18,920.45		31	-	-
	June	59,840		3.29		40,691.20			17,233.92		14	-	6
	July	98,741		5.42		67,143.88			28,437.41		-	-	-
	Aug	95,119		5.22		64,680.92			27,394.27		7	-	-
	Sept	76,440		4.20		51,979.20			22,014.72		-	-	-
	Oct	79,290		4.35		53,917.20			22,835.52		7	6	-
	Nov	69,971		3.84		47,580.28			20,151.65		14	-	-
	Dec	70,932	958,107	3.89	52.61	48,233.76	651,512.76		20,428.42	275,934.82	-	-	-
2006	Jan	57,398		3.15		39,030.64			16,530.62		9	-	-
	Feb	69,532		3.82		47,281.76		0.0288	20,025.22		-	1	-
	March	74,881		4.11		50,919.08			21,565.73		11	4	-
	Apr	94,946		5.21		64,563.28			27,344.45		30	-	-
	May	65,641[b]		3.60		44,635.71			21,201.96		31	-	-
	June	65,641[b]		3.60		44,635.71			21,201.96		30	-	-
	July	65,641[b]		3.60		44,635.71			21,201.96		2	-	7
	Aug	65,641[b]		3.60		44,635.71			21,201.96		4	-	-
	Sept	82,518		4.53		56,112.24			26,653.31		4	-	-
	Oct	86,600		4.75		58,888.00			27,971.80		-	9	-
	Nov	52,766		2.90		35,880.88			17,043.42		3	6	-
	Dec	53,712	834,916	2.95	45.84	36,524.16	567,742.88		17,348.98	259,291.37	25	-	-
2007	Jan	53,014		2.91		36,049.52			17,123.52		-	-	-
	Feb	37,427		2.06		25,450.36			12,088.92		11	-	-
	March	41,281		2.27		28,071.08			13,333.76		-	-	-
	Apr	41,313		2.27		28,092.84			13,344.10		-	9	-
	May	35,087		1.93		23,859.16			11,333.10		26	-	-
	June	17,720		0.97		12,049.60			5,723.56		30	-	-
	July	34,836		1.91		23,688.48			11,252.03		1	-	7
	Aug	35,616		1.96		24,218.88			11,503.97		-	-	-
	Sept	47,663		2.62		32,410.84			15,395.15		9	-	-
	Oct	34,108		1.87		23,193.44			11,016.88		-	11	-
	Nov	36,534		2.01		24,843.12			11,800.48		4	5	-
	Dec	20,844	435,443	1.14	23.91	14,173.92	296,101.24		6,732.61	140,648.09	25	-	-
2008	Jan	38,243		2.10		26,005.24			12,352.49		-	-	-
	Feb	32,143		1.76		21,857.24			10,382.19		11	-	-
	March	34,608		1.90		23,533.44			11,178.38		-	-	-
	Apr	42,677		2.34		29,020.36			13,784.67		-	7	-
	May	29,495		1.62		20,056.60			9,526.89		25	-	-
	June	19,519		1.07		13,272.92			6,304.64		30	-	-
	July	33,357		1.83		22,682.76			10,774.31		8	-	7
	Aug	28,653		1.57		19,484.04		0.323	9,254.92		-	-	-
	Sept	35,776		1.96		24,327.68			11,555.65		-	-	-
	Oct	32,046		1.76		21,791.28			12,273.62		-	18	-
	Nov	27,223		1.49		18,511.64		0.383	10,426.41		6	-	-
	Dec	25,193	378,933	1.38	20.81	17,131.24	257,674.44		9,648.92	127,463.08	30	-	-

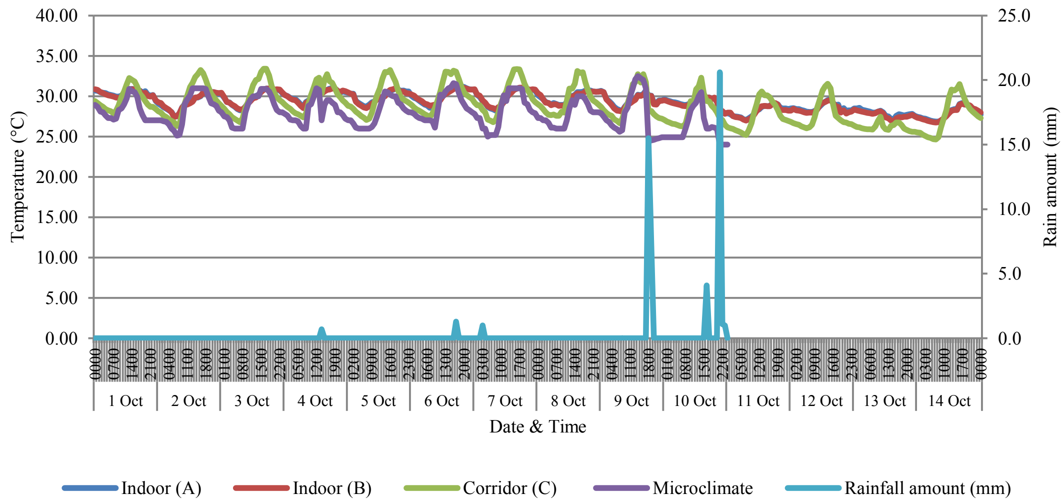
Note: [a] : 1kWh of electricity used emits 0.68 kg of CO_2 (KeTTHA, 2011)
[b] : Monthly electricity usage was based on the average calculation due to technical problems with the meter.
BEI : Building Energy Index
EEI : Energy Efficiency Index

Appendix T, continued

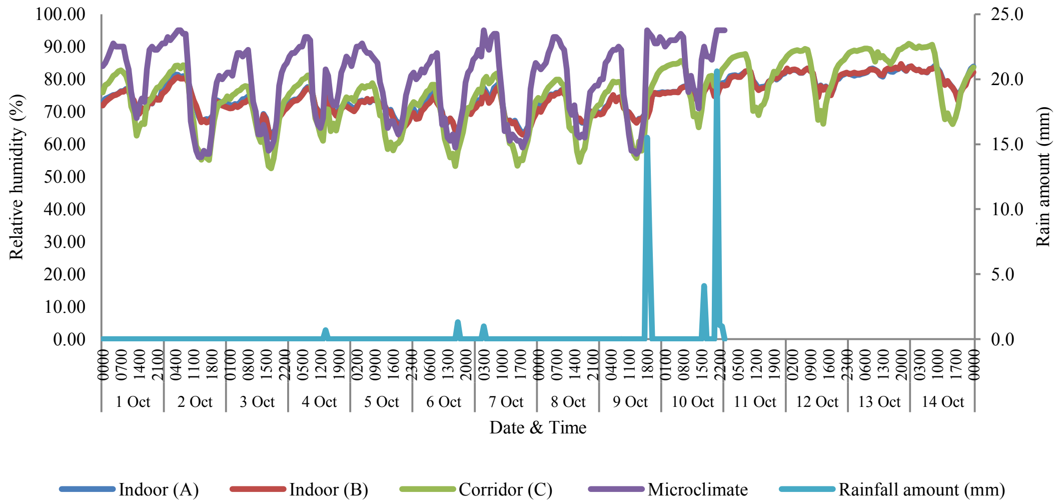
Year	Month	Electricity consumption: Monthly (kWh/month)	Electricity consumption: Annually (kWh/year)	Efficiency of usage: BEI (kWh/m²)	Efficiency of usage: EEI (kWh/m²/year)	Carbon footprint: CO2 emission (kg)	Carbon footprint: Annual CO_2 emission (kg)	Electricity usage: Tariff (RM/kWh)	Electricity usage: Monthly total cost (RM)	Electricity usage: Annual total cost (RM)	Special occasion: Sem. Break (Day)	Special occasion: Exam Prep. (Days)	Special occasion: Orientation (Days)
2009	Jan	27,366		1.50		18,608.88		0.383	10,481.18		-	-	-
	Feb	24,577		1.35		16,712.36			9,412.99		8	-	-
	March	33,848		1.86		23,016.64		0.370	12,523.76		-	-	-
	Apr	43,145		2.37		29,338.60			15,963.65		-	8	-
	May	25,920		1.42		17,625.60			9,590.40		21	-	-
	June	17,419		0.96		11,844.92		0.397	6,915.34		28	-	2
	July	40,505		2.22		27,543.40			16,080.49		6	-	6
	Aug	32,661		1.79		22,209.48			12,966.42		7	-	-
	Sept	28,188		1.55		19,167.84			11,190.64		4	-	-
	Oct	36,369		2.00		24,730.92			14,438.49		5	5	-
	Nov	36,369		2.00		24,730.92			14,438.49		6	2	-
	Dec	43,601	389,968	2.39	21.41	29,648.68	265,178.24		17,309.60	151,311.44	29	-	-
2010	Jan	51,203		2.81		34,818.04			20,327.59		6	-	-
	Feb	38,684		2.12		26,305.12			15,357.55		1	-	-
	March	38,871		2.13		26,432.28			15,431.79		-	-	-
	Apr	62,084		3.41		42,217.12			24,647.35		-	7	-
	May	50,442		2.77		34,300.56			20,025.47		21	-	-
	June	28,409		1.56		19,318.12			11,278.37		30	-	3
	July	48,498		2.66		32,978.64			19,253.71		5	-	5
	Aug	49,772		2.73		33,844.96			19,759.48		7	-	-
	Sept	49,800		2.73		33,864.00			19,770.60		9	-	-
	Oct	46,136		2.53		31,372.48			18,315.99		-	6	-
	Nov	53,571		2.94		36,428.28			21,267.69		8	1	-
	Dec	51,122	568,592	2.81	31.22	34,762.96	386,642.56		20,295.43	225,731.02	27	-	-
2011	Jan	75,180		4.13		51,122.40			29,846.46		-	-	-
	Feb	53,158		2.92		36,147.44			21,103.73		9	-	-
	March	62,313		3.42		42,372.84			24,738.26		-	-	-
	Apr	79,494		4.36		54,055.92			31,559.12		-	7	-
	May	53,461		2.94		36,353.48			21,224.02		22	-	-
	June	49,603		2.72		33,730.04		0.430	21,329.29		30	-	-
	July	38,578		2.12		26,233.04			16,588.54		31	-	-
	Aug	31,588		1.73		21,479.84			13,582.84		31	-	-
	Sept	52,485		2.88		35,689.80			22,568.55		3	-	6
	Oct	56,390		3.10		38,345.20			24,247.70		-	-	-
	Nov	52,411		2.88		35,639.48			22,536.73		9	-	-
	Dec	67,918	672,579	3.73	36.93	46,184.24	457,353.72		29,204.74	278,259.97	-	8	-

Note: [a] : 1kWh of electricity used emits 0.68 kg of CO_2 (KeTTHA, 2011)
BEI : Building Energy Index
EEI : Energy Efficiency Index

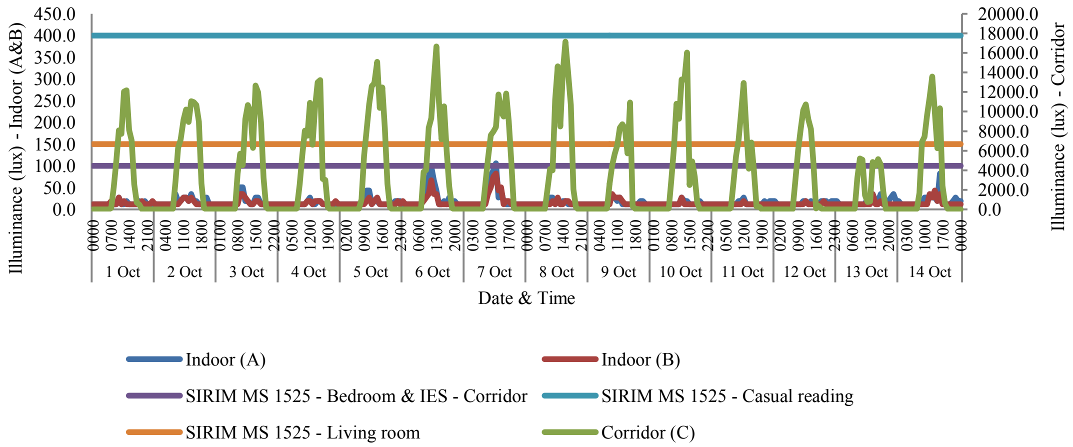
Appendix U - Climate profile of living behaviour assessment



(a)

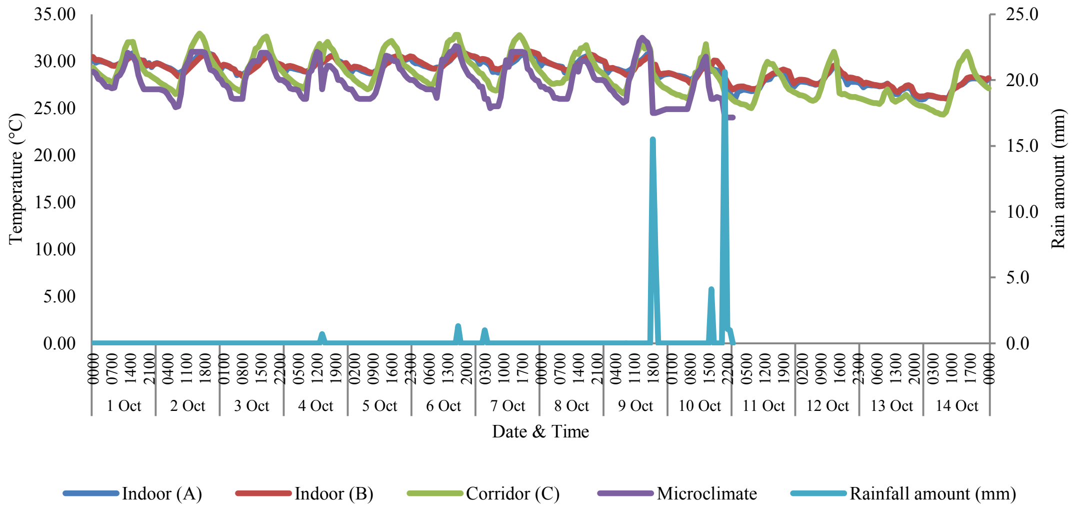


(b)

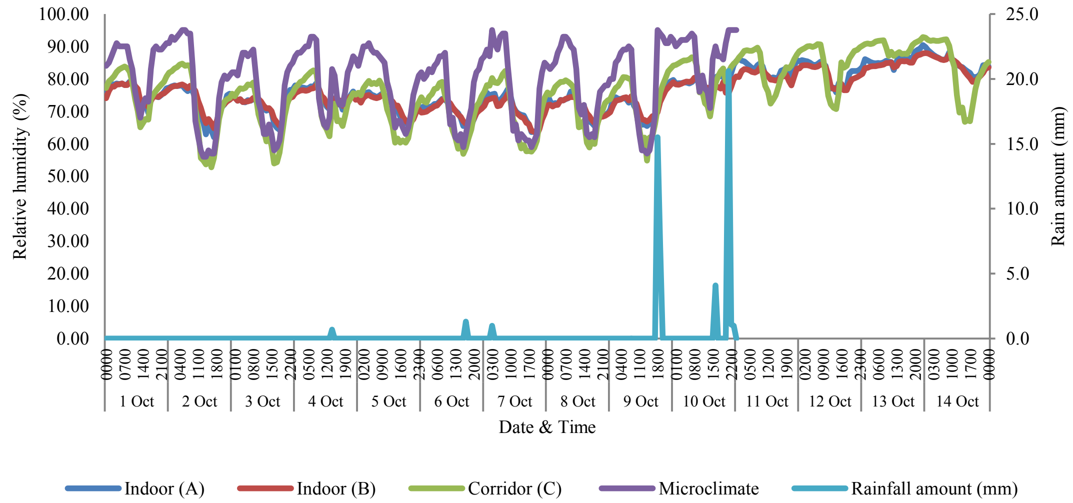


(c)

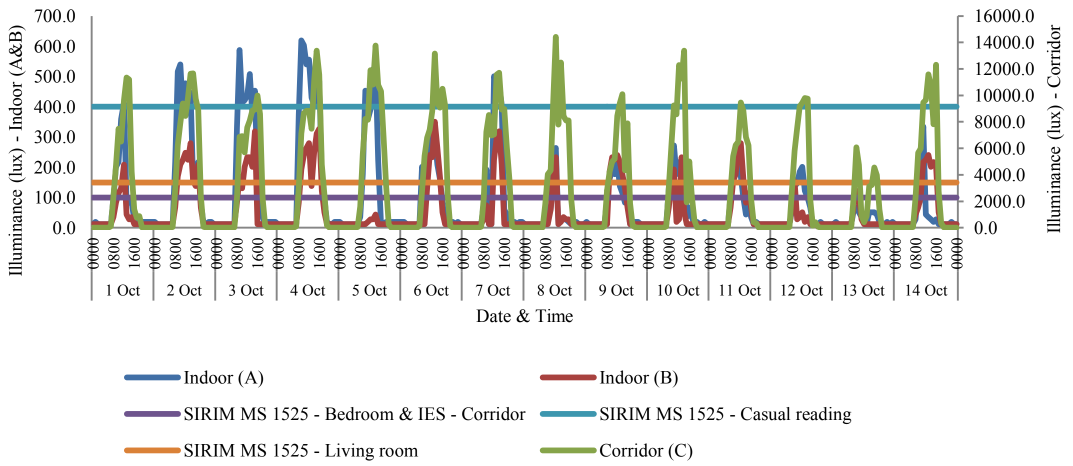
(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario B1 and B4



(a)

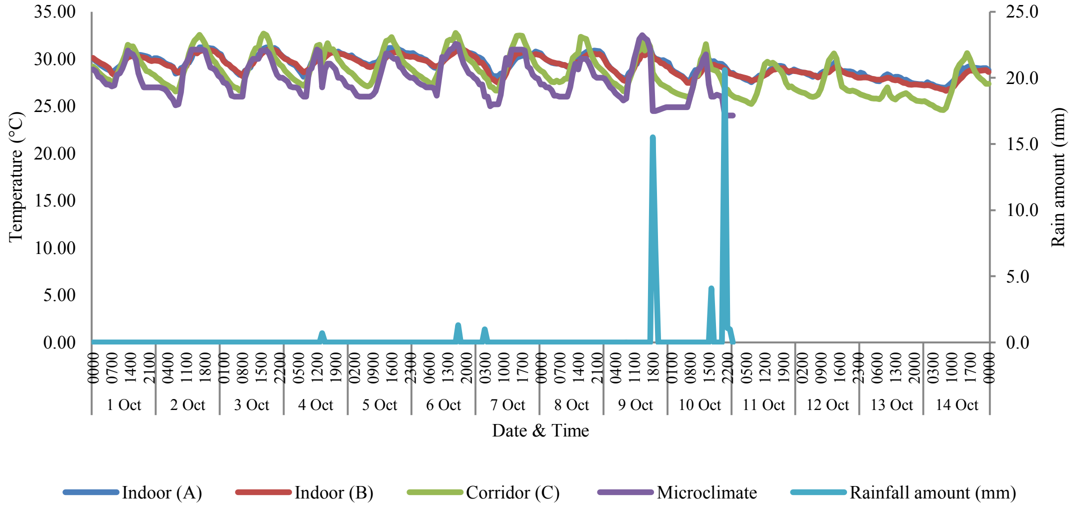


(b)

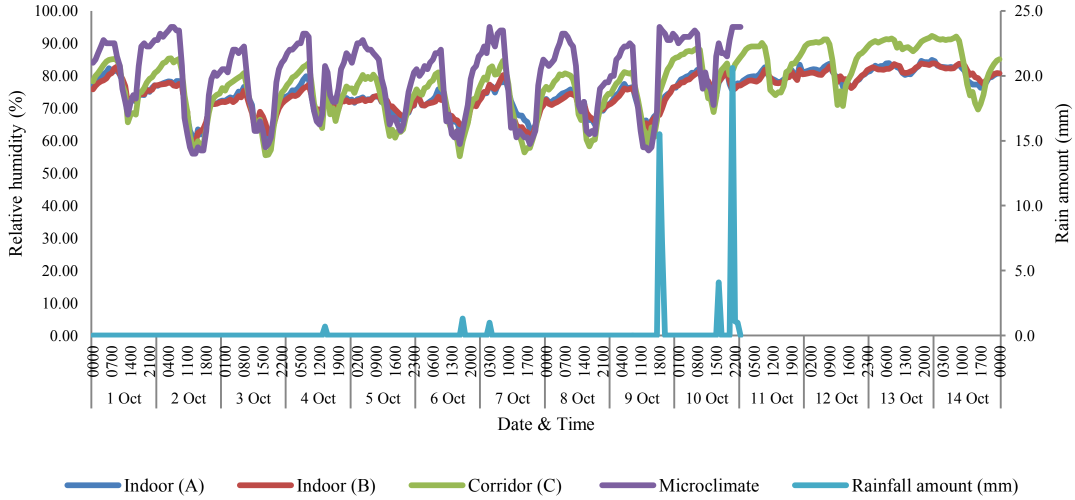


(c)

(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario B2



(a)

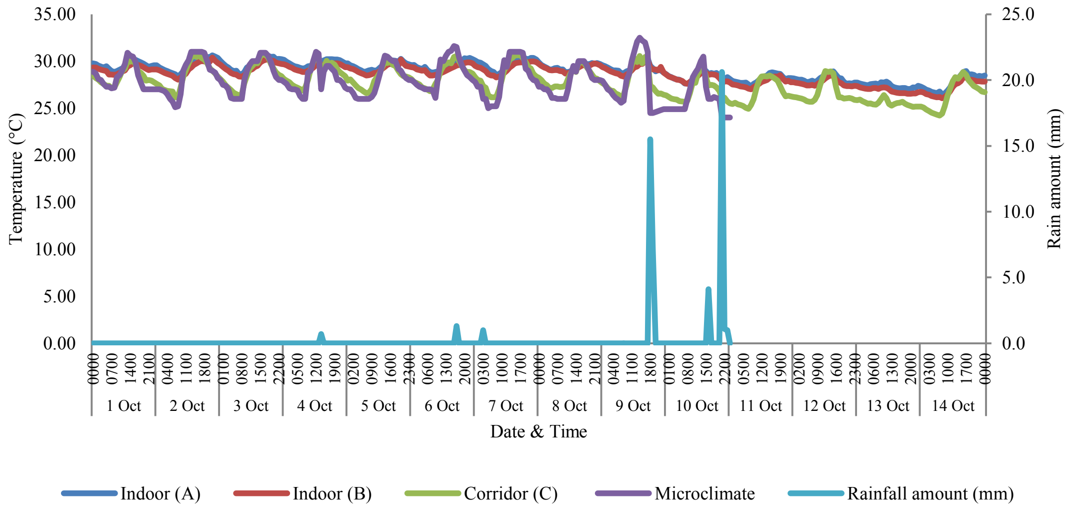


(b)

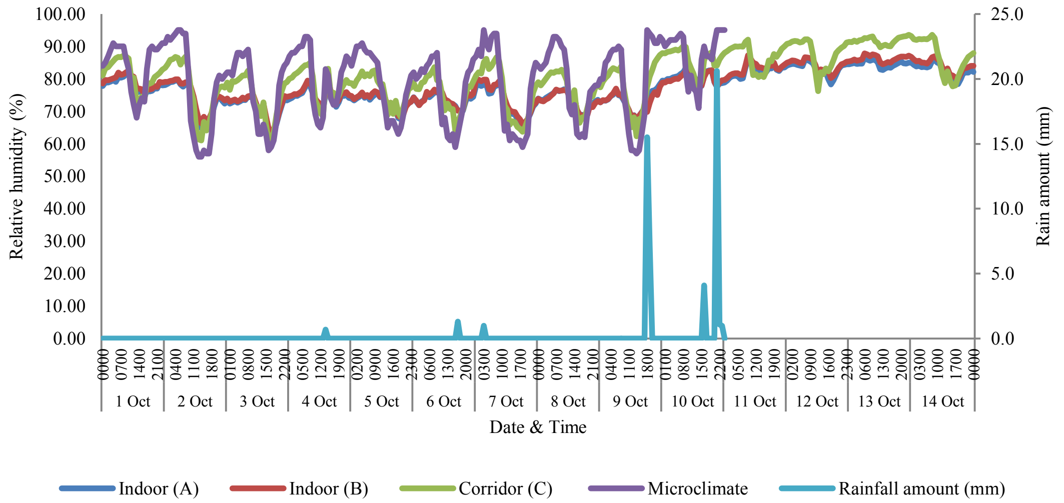
(c)

(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario B3 and W5

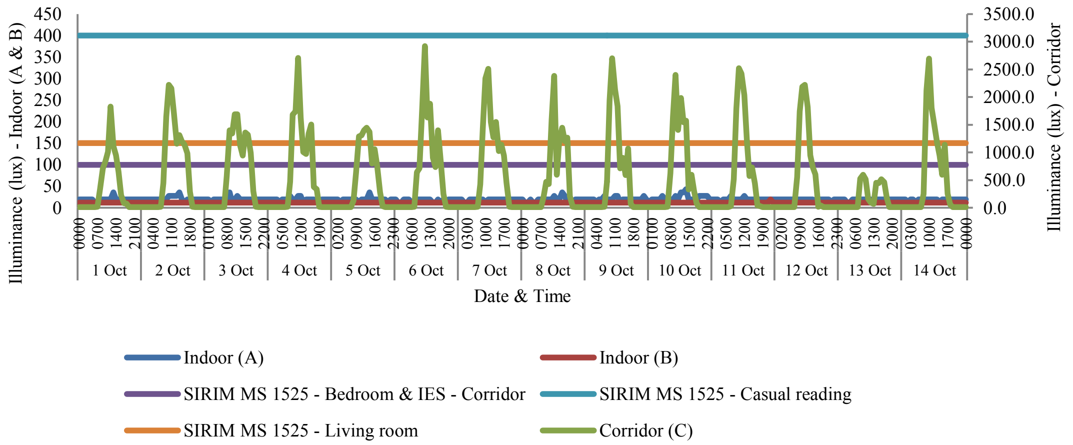
Appendix U, continued



(a)



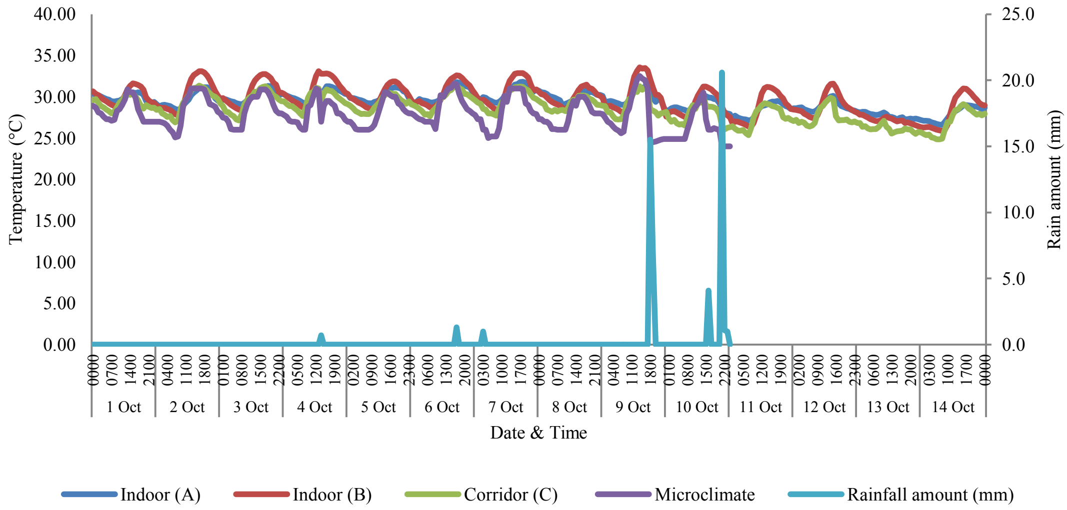
(b)



(c)

(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario B5

Appendix U, continued



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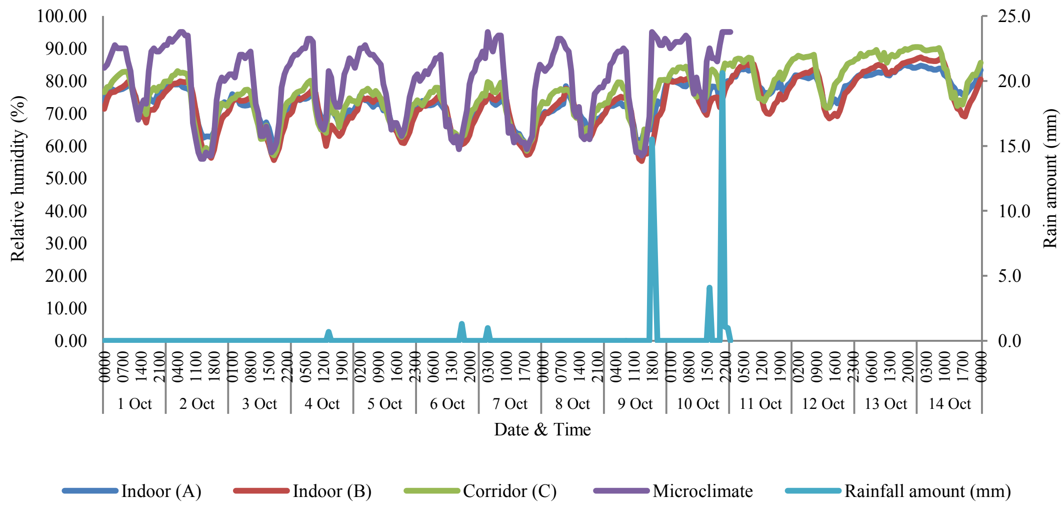

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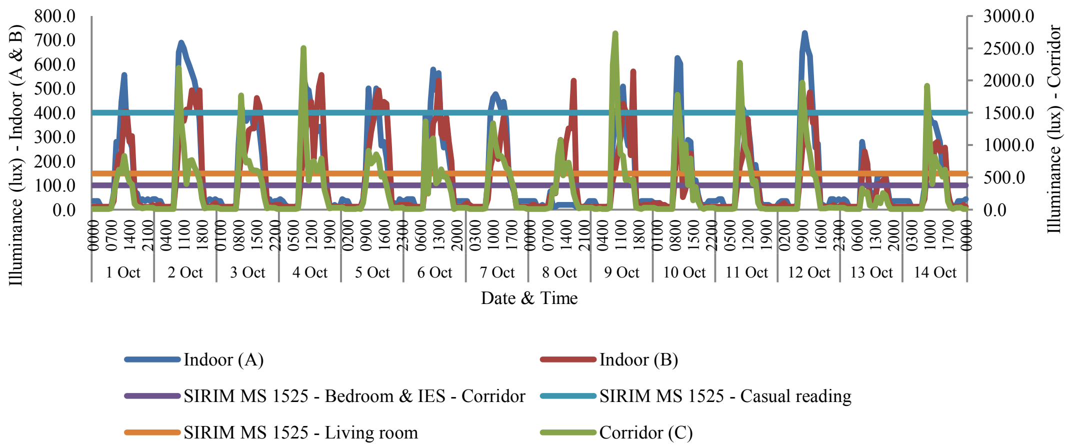
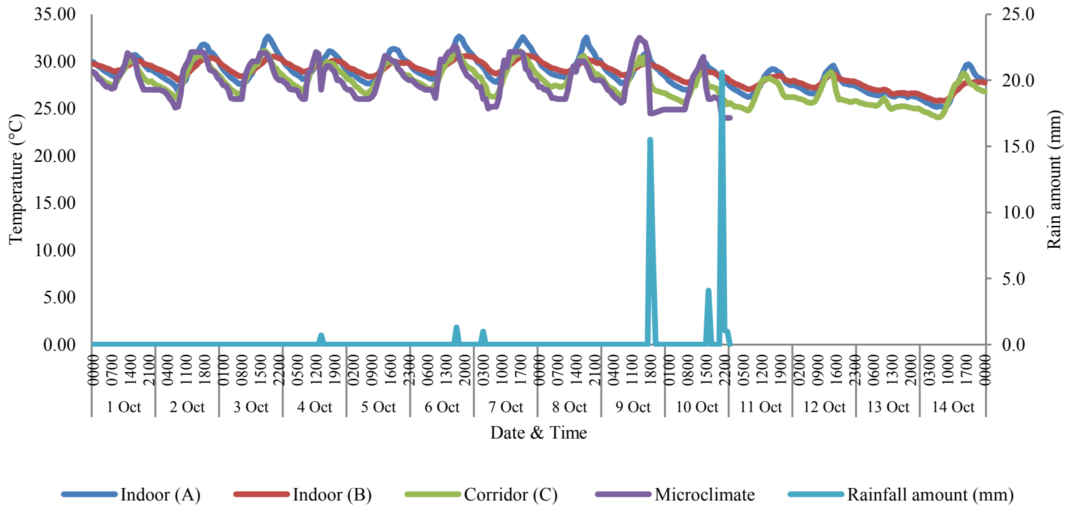


(c)

(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario W1

Appendix U, continued



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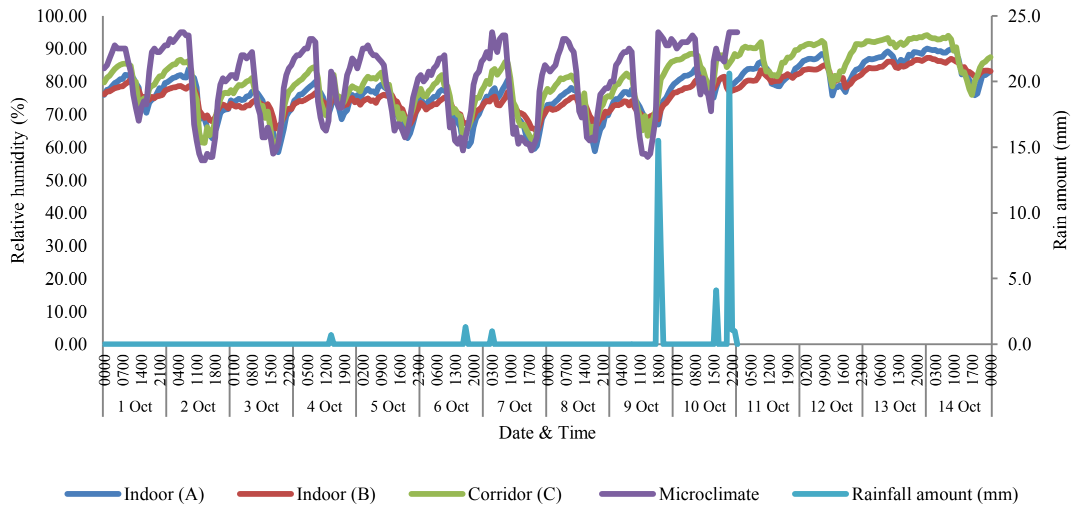

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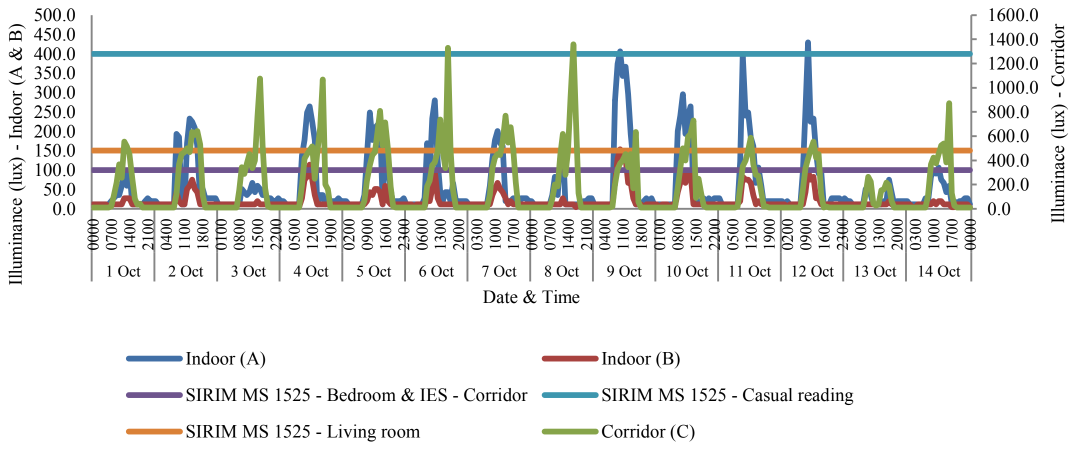
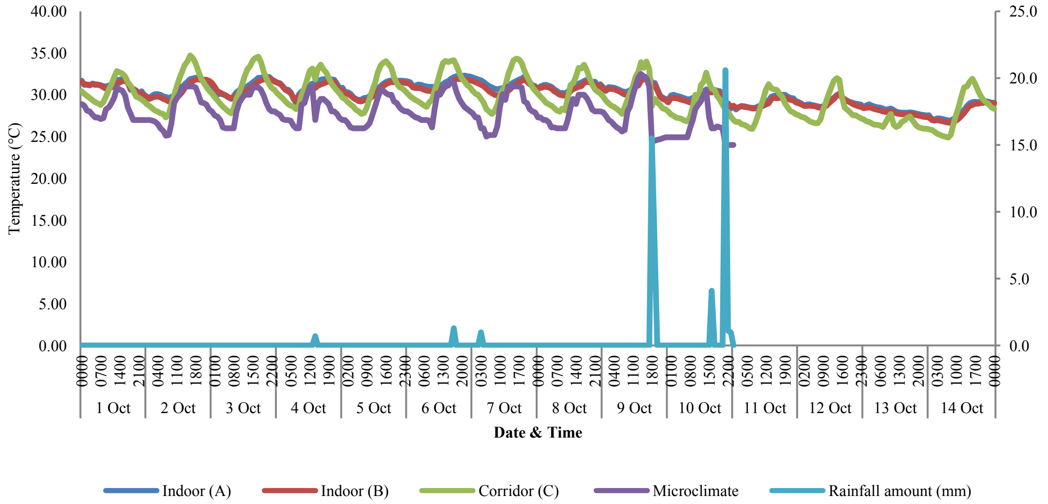
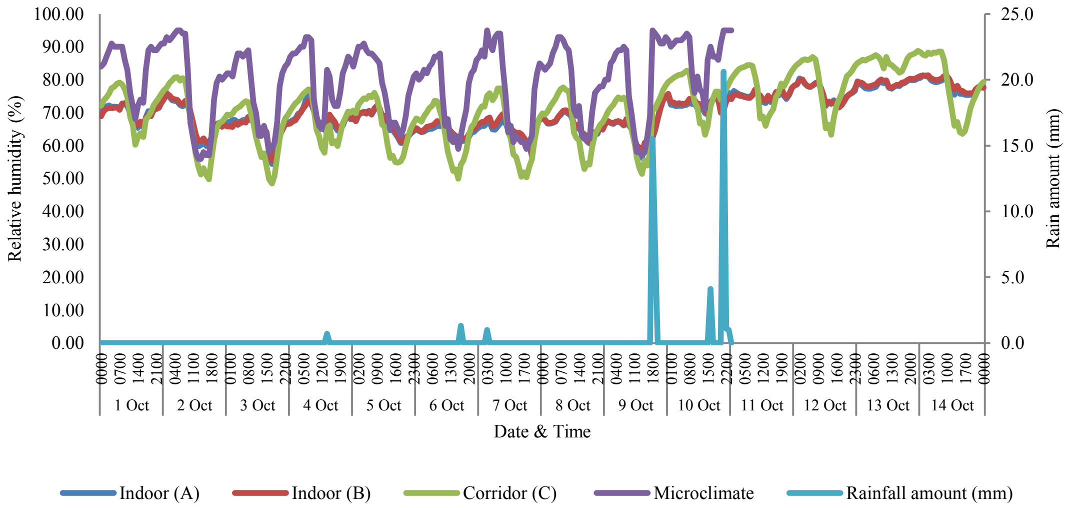


(c)

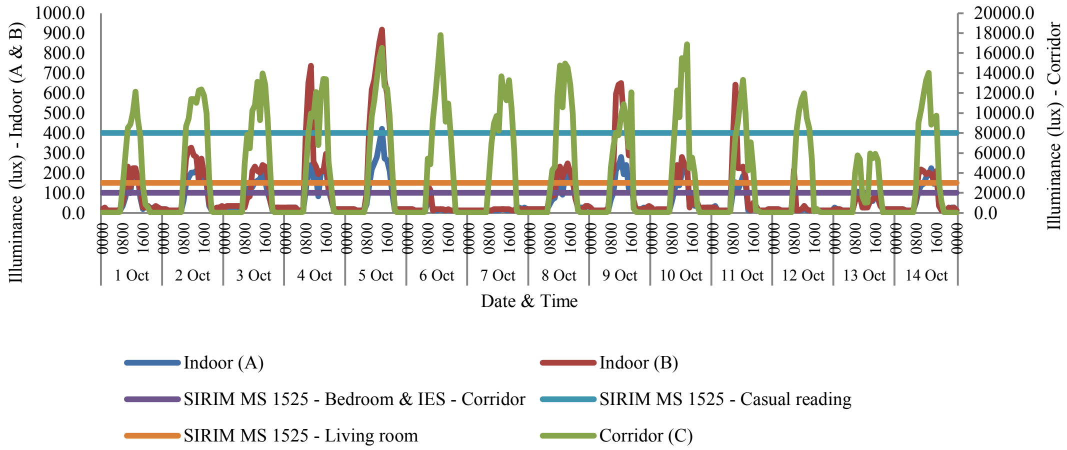
(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario W2



(a)



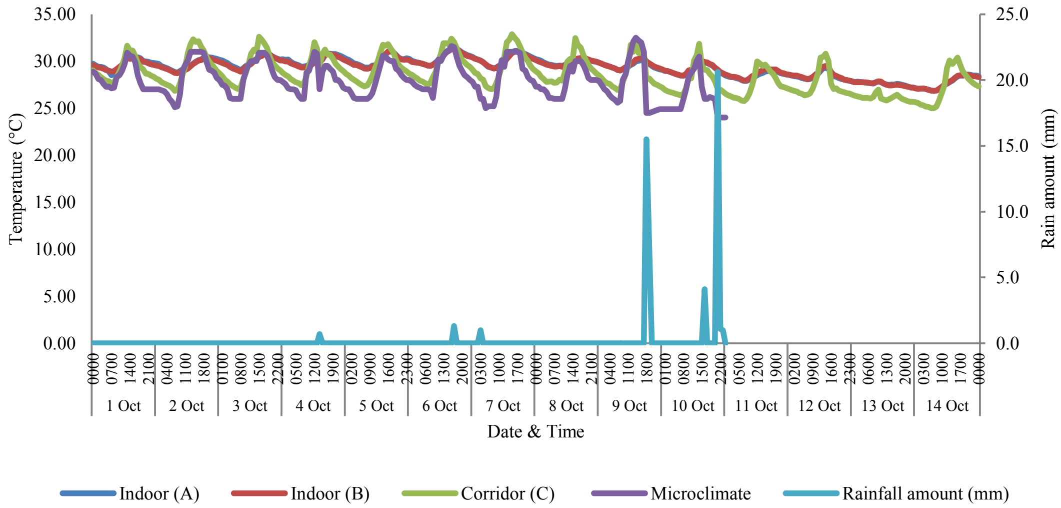
(b)



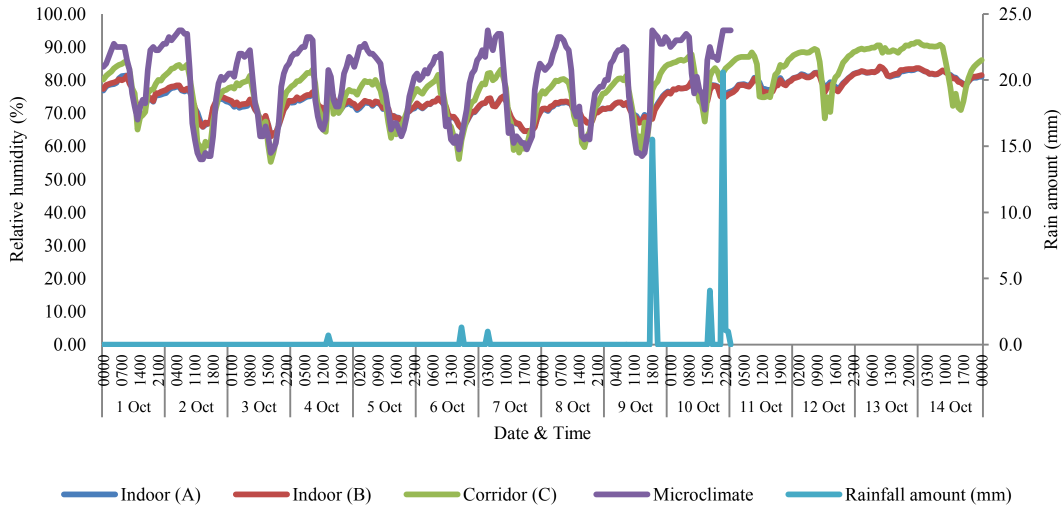
(c)

(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario W3

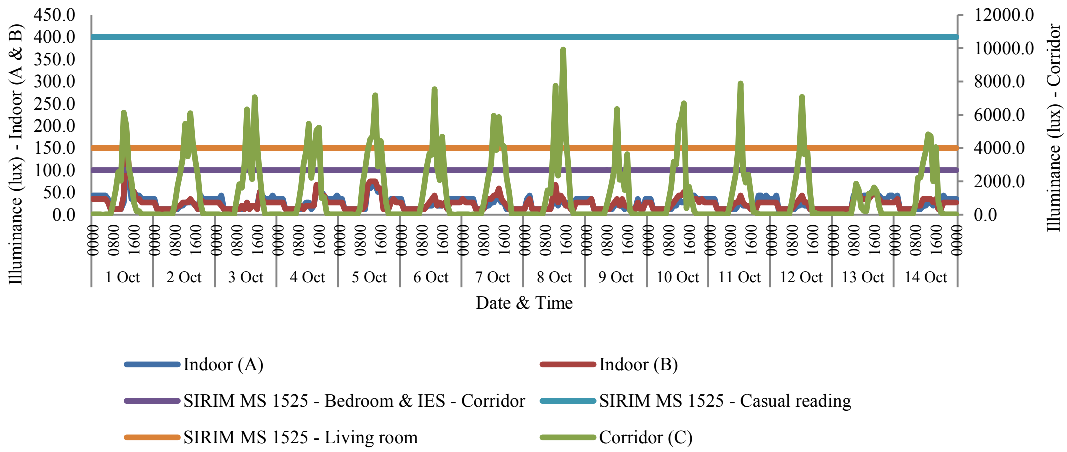
Appendix U, continued



(a)



(b)



(c)

(a). The temperature, (b). The relative humidity, (c). The illuminance, and microclimate profile of scenario W4

Appendix V - Statistical analysis of satisfaction and perception survey

The performance indicators	Likert scale / *Residents' responses (%)*									
	-2		-1		0		+1		+2	
Architectural elements										
The residential building layout (internal courtyard with open corridor)	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.0	1.0	7.5	10.5	28.3	29.5	50.9	48.6	13.2	10.5
Total % within gender	*0.4*		*8.7*		*28.8*		*50.0*		*12.1*	
The residential building is an environmental friendly with efficient energy usage	Strongly disagree		Disagree		Undecided		Agree		Strongly agree	
	F	M	F	M	F	M	F	M	F	M
	0.6	0.0	8.2	5.7	20.1	29.5	55.3	52.4	15.7	12.4
Total % within gender	*0.4*		*7.2*		*23.9*		*54.2*		*14.4*	
The importance of the buildings is built in an environmentally friendly way	Not at all		Slightly important		Moderate		Very important		Extremely important	
	F	M	F	M	F	M	F	M	F	M
	0.0	0.0	2.5	3.8	14.5	13.3	42.1	50.5	40.9	32.4
Total % within gender	*0.0*		*3.0*		*14.0*		*45.5*		*37.5*	
The overall quality of the residential building	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	1.9	0.0	5.7	6.7	23.9	36.2	53.5	50.5	15.1	6.7
Total % within gender	*1.1*		*6.1*		*28.8*		*52.3*		*11.7*	
The general room layout	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.6	2.9	8.1	6.7	21.9	35.6	53.1	45.2	16.3	9.6
Total % within gender	*1.5*		*7.6*		*27.3*		*50.0*		*13.6*	
The room is fulfil the needs	Strongly disagree		Disagree		Undecided		Agree		Strongly agree	
	F	M	F	M	F	M	F	M	F	M
	0.6	1.9	10.1	13.6	23.9	28.2	50.9	47.6	14.5	8.7
Total % within gender	*1.1*		*11.5*		*25.6*		*49.6*		*12.2*	
The provision of privacy in the room	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	1.3	5.7	17.0	17.1	26.4	25.7	41.5	40.0	13.8	11.4
Total % within gender	*3.0*		*17.0*		*26.1*		*40.9*		*12.9*	
The feeling of safety in the room and building	Very unsafe		Unsafe		Neither		Safe		Very safe	
	F	M	F	M	F	M	F	M	F	M
	0.6	1.0	6.9	4.9	24.4	29.1	48.1	50.5	20.0	14.6
Total % within gender	*0.8*		*6.1*		*26.2*		*49.0*		*17.9*	
The overall comfort level of the room	Very uncomfortable		Uncomfortable		Neither		Comfortable		Very comfortable	
	F	M	F	M	F	M	F	M	F	M
	0.6	1.0	3.8	5.8	26.3	33.7	56.9	48.1	12.5	11.5
Total % within gender	*0.8*		*4.5*		*29.2*		*53.4*		*12.1*	
The influence of overall room conditions on the degree of work productivity	Much decreased		Decreased		No changes		Increased		Much increased	
	F	M	F	M	F	M	F	M	M	F
	0.0	1.9	2.5	7.6	22.6	32.4	53.5	43.8	21.4	14.3
Total % within gender	*0.8*		*4.5*		*26.5*		*49.6*		*18.6*	
Thermal comfort and indoor air quality										
The thermal comfort/indoor air temperature at the room	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	3.1	3.8	11.9	11.4	28.1	32.4	43.8	42.9	13.1	9.5
Total % within gender	*3.4*		*11.7*		*29.8*		*43.4*		*11.7*	
The ventilation and air quality of the room	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	2.5	1.0	15.3	10.6	28.0	32.7	43.9	49.0	10.2	6.7
Total % within gender	*1.9*		*13.4*		*29.9*		*46.0*		*8.8*	
The control of the ventilation of the room	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.6	1.9	17.3	9.6	36.5	39.4	36.5	44.2	9.0	4.8
Total % within gender	*1.2*		*14.2*		*37.7*		*39.6*		*7.3*	
The air movement in the room (without the aid of mechanical fan)	Still air		Inconspicuous still air		Neither		Breezy		Very breezy	
	F	M	F	M	F	M	F	M	F	M
	13.4	14.4	23.6	20.2	26.1	27.9	29.9	31.7	7.0	5.8
Total % within gender	*13.8*		*22.2*		*26.8*		*30.7*		*6.5*	
The provision of air movement in the room	Very dissatisfied		Dissatisfied		Neither		Satisfied		Very satisfied	
	F	M	F	M	F	M	F	M	F	M
	4.5	1.0	20.4	13.5	37.6	42.3	28.0	37.5	9.6	5.8
Total % within gender	*3.1*		*17.6*		*39.5*		*31.8*		*8.0*	
Visual comfort										
The adequacy of natural daylight in the room	Too dark		Dark		Neither		Bright		Too bright	
	F	M	F	M	F	M	F	M	F	M
	4.5	3.8	14.9	7.7	33.1	35.6	39.6	43.3	7.8	9.6
Total % within gender	*4.3*		*12.0*		*34.1*		*41.1*		*8.5*	
The control of the daylight in the room	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	1.9	1.0	9.6	9.6	37.6	37.5	40.8	44.2	10.2	7.7
Total % within gender	*1.5*		*9.6*		*37.5*		*42.1*		*9.2*	

Note : F - Female; M - Male

Appendix V, continued

The performance indicators	*Likert scale / Residents' responses (%)*									
	-2		-1		0		+1		+2	
The adequacy of artificial light in the room	Too dark		Dark		Neither		Bright		Too bright	
	F	M	F	M	F	M	F	M	F	M
	1.3	1.0	8.9	8.7	35.7	33.7	42.7	51.9	11.5	4.8
Total % within gender	*1.1*		*8.8*		*34.9*		*46.4*		*8.8*	
The control of the artificial light in the room	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.0	1.0	9.0	8.8	32.9	39.2	47.7	42.2	10.3	8.8
Total % within gender	*0.4*		*8.9*		*35.4*		*45.5*		*9.7*	
The effectiveness of curtains in controlling the level of lighting	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.0	1.0	5.7	7.8	24.2	23.3	47.1	49.5	22.9	18.4
Total % within gender	*0.4*		*6.5*		*23.8*		*48.1*		*21.2*	
The satisfaction with the quality of the lights in the room	Very dissatisfied		Dissatisfied		Neither		Satisfied		Very satisfied	
	F	M	F	M	F	M	F	M	F	M
	1.3	1.9	9.0	5.8	31.0	26.0	43.2	55.8	15.5	10.6
Total % within gender	*1.5*		*7.7*		*29.0*		*48.3*		*13.5*	
The view out of the room from the inside	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.6	0.0	9.0	14.4	28.8	31.7	42.9	35.6	18.6	18.3
Total % within gender	*0.4*		*11.2*		*30.0*		*40.0*		*18.5*	
The existing windows/ opening area of the room	Very small		Small		Fair		Big		Very big	
	F	M	F	M	F	M	F	M	F	M
	0.0	1.0	7.6	8.7	29.3	32.7	47.1	43.3	15.9	14.1
Total % within gender	*0.4*		*8.0*		*30.7*		*45.6*		*15.3*	
Landscape										
The residential building is sensitively designed for the landscape setting	Strongly disagree		Disagree		Undecided		Agree		Strongly agree	
	F	M	F	M	F	M	F	M	F	M
	1.9	1.0	5.7	9.6	38.2	41.3	44.6	41.3	9.6	6.7
Total % within gender	*1.5*		*7.3*		*39.5*		*43.3*		*8.4*	
The quality of landscape at residential college areas	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	F	M
	0.6	2.9	5.8	11.5	34.6	32.7	50.6	45.2	8.3	7.7
Total % within gender	*1.5*		*8.1*		*33.8*		*48.5*		*8.1*	
The influence of landscape setting on the quality life	Not at all		Slightly		Moderate		Very		Extremely	
	F	M	F	M	F	M	F	M	F	M
	0.6	2.9	5.8	11.5	34.6	32.7	47.8	48.1	16.6	10.6
Total % within gender	*0.8*		*7.3*		*29.9*		*47.9*		*14.2*	
The quality of landscape setting at the internal courtyard	Very poor		Poor		Fair		Good		Very good	
	F	M	F	M	F	M	F	M	M	F
	0.6	2.9	5.7	6.7	36.3	35.6	47.8	50.0	9.6	4.8
Total % within gender	*1.5*		*6.1*		*36.0*		*48.7*		*7.7*	
The frequency of spending time at the internal courtyard in a day	Never		Rarely		Sometimes		Frequently		Every time	
	F	M	F	M	F	M	F	M	F	M
	10.8	12.5	12.1	19.2	31.2	26.0	37.6	39.4	8.3	2.9
Total % within gender	*11.5*		*14.9*		*29.1*		*38.3*		*6.1*	
The influence of landscape setting in the internal courtyard on the quality life	Not at all		Slightly		Moderate		Very		Extremely	
	F	M	F	M	F	M	F	M	F	M
	1.9	4.8	7.0	7.7	33.1	43.3	47.8	36.5	10.2	7.7
Total % within gender	*3.1*		*7.3*		*37.2*		*43.3*		*9.2*	
The usage pattern of windows and ceiling fan										
The frequency of the windows is kept open in a day	Never		Rarely		Sometimes		Frequently		Every time	
	F	M	F	M	F	M	F	M	F	M
	21.6	13.6	15.7	13.6	23.5	16.5	25.5	37.9	13.7	18.4
Total % within gender	*18.4*		*14.8*		*20.7*		*30.5*		*15.6*	
The time of windows has been always open in a day	Never		Morning		Afternoon		Evening		Night	
	F	M	F	M	F	M	F	M	F	M
	27.6	22.1	28.3	26.7	14.5	19.8	21.4	15.1	8.3	16.3
Total % within gender	*25.5*		*27.7*		*16.5*		*19.0*		*11.3*	
The frequency of ceiling fan usage in a day	Never		Rarely		Sometimes		Frequently		Every time	
	F	M	F	M	F	M	F	M	F	M
	0.6	0.0	0.6	6.7	9.6	12.5	25.0	28.8	64.1	51.9
Total % within gender	*0.4*		*3.1*		*10.8*		*26.5*		*59.2*	
The fan speed is often used	One		Two		Three		Four		Five	
	F	M	F	M	F	M	F	M	F	M
	0.0	1.0	2.6	2.9	16.7	19.4	26.9	33.0	53.8	43.7
Total % within gender	*0.4*		*2.7*		*17.8*		*29.3*		*49.8*	

The reason for not opening the windows

Insect		Safety		Rain		Dust		Privacy		Monkey		Others	
F	M	F	M	F	M	F	M	F	M	F	M	F	M
1.6	6.1	20.3	9.8	5.7	7.3	10.6	8.5	26.0	12.2	30.1	50.0	5.7	6.1
*3.4**		*16.1**		*6.3**		*9.8**		*20.5**		*38.0**		*5.9**	

Thermal comfort based on ASHRAE 7 sensation scale

Cold		Cool		Slightly cool		Neutral		Slightly warm		Warm		Hot	
F	M	F	M	F	M	F	M	F	M	F	M	F	M
0.0	1.1	6.1	8.4	7.4	10.5	37.8	42.1	25.7	24.2	18.2	13.7	4.7	0.0
*0.4**		*7.0**		*8.6**		*39.5**		*25.1**		*16.5**		*2.9**	

Note : F - Female; M - Male; * - Total % within gender.

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
Architectural elements																				
	Very poor				Poor				Fair				Good				Very good			
The residential building layout (internal courtyard with open corridor)	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	8.9	7.8	8.3	14.3	26.3	31.3	33.3	71.4	51.4	50.0	41.7	14.3	12.8	10.9	16.7	0.0
Total % within race	*0.4*				*8.8*				*29.0*				*49.6*				*12.2*			
	Strongly disagree				Disagree				Undecided				Agree				Strongly agree			
The residential building is an environmental friendly with efficient energy usage	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	6.1	7.8	16.7	16.7	20.6	32.8	25.0	16.7	57.8	48.4	25.0	66.7	15.0	10.9	33.3	0.0
Total % within race	*0.4*				*7.3*				*23.7*				*54.2*				*14.5*			
	Not at all				Slightly important				Moderate				Very important				Extremely important			
The importance of the buildings is built in an environmentally friendly way	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.0	0.0	0.0	0.0	2.8	3.1	8.3	0.0	12.8	15.6	16.7	28.6	48.0	40.6	8.3	71.4	36.3	40.6	66.7	0.0
Total % within race	*0.0*				*3.1*				*14.1*				*45.0*				*37.8*			
	Very poor				Poor				Fair				Good				Very good			
The overall quality of the residential building	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.7	0.0	0.0	0.0	7.3	3.1	8.3	0.0	24.0	43.8	25.0	28.6	54.7	45.3	33.3	71.4	12.3	7.8	33.3	0.0
Total % within race	*1.1*				*6.1*				*29.0*				*51.9*				*11.8*			
	Very poor				Poor				Fair				Good				Very good			
The general room layout	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	2.2	0.0	0.0	0.0	7.3	9.4	8.3	0.0	25.1	34.4	25.0	28.6	52.0	45.3	25.0	71.4	13.4	10.9	41.7	0.0
Total % within race	*1.5*				*7.6*				*27.5*				*49.6*				*13.7*			
	Strongly disagree				Disagree				Undecided				Agree				Strongly agree			
The room is fulfil the needs	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.7	0.0	0.0	0.0	13.0	7.8	16.7	0.0	25.4	31.3	8.3	14.3	48.0	50.0	50.0	71.4	11.9	10.9	25.0	14.3
Total % within race	*1.2*				*11.5*				*25.8*				*49.2*				*12.3*			
	Very poor				Poor				Fair				Good				Very good			
The provision of privacy in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	3.3	3.1	0.0	0.0	18.3	15.6	16.7	0.0	26.1	25.0	16.7	50.0	37.8	48.4	50.0	33.3	14.4	7.8	16.7	16.7
Total % within race	*3.1*				*17.2*				*26.0*				*40.8*				*13.0*			
	Very unsafe				Unsafe				Neither				Safe				Very safe			
The feeling of safety in the room and building	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.1	0.0	0.0	0.0	6.2	7.8	0.0	0.0	21.3	35.9	25.0	57.1	54.5	37.5	33.3	42.9	16.9	18.8	41.7	0.0
Total % within race	*0.8*				*6.1*				*26.1*				*49.0*				*18.0*			
	Very uncomfortable				Uncomfortable				Neither				Comfortable				Very comfortable			
The overall comfort level of the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	1.6	0.0	0.0	6.1	1.6	0.0	0.0	27.9	32.8	25.0	28.6	53.1	53.1	50.0	71.4	12.3	10.9	25.0	0.0
Total % within race	*0.8*				*4.6*				*29.0*				*53.4*				*12.2*			
	Much decreased				Decreased				No changes				Increased				Much increased			
The influence of overall room conditions on the degree of work productivity	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.1	0.0	0.0	0.0	3.9	7.8	0.0	0.0	26.7	26.6	27.3	28.6	49.4	45.3	54.5	71.4	18.9	20.3	18.2	0.0
Total % within race	*0.8*				*4.6*				*26.7*				*49.2*				*18.7*			

Note : M - Malay; C - Chinese; I - Indian; O - Others

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
Thermal comfort and indoor air quality																				
	Very poor				Poor				Fair				Good				Very good			
The thermal comfort/indoor air temperature at the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.7	9.4	0.0	0.0	12.8	10.9	8.3	0.0	29.4	31.3	33.3	28.6	43.3	40.6	33.3	71.4	12.8	7.8	25.0	0.0
Total % within race	*3.4*				*11.8*				*30.0*				*43.0*				*11.8*			
	Very poor				Poor				Fair				Good				Very good			
The ventilation and air quality of the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.1	4.8	0.0	0.0	15.2	11.3	8.3	0.0	25.8	40.3	41.7	28.6	47.2	40.3	33.3	71.4	10.7	3.2	16.7	0.0
Total % within race	*1.9*				*13.5*				*30.1*				*45.6*				*8.9*			
	Very poor				Poor				Fair				Good				Very good			
The control of the ventilation of the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.1	1.6	0.0	0.0	13.0	19.4	8.3	14.3	40.1	32.3	41.7	28.6	37.9	41.9	33.3	57.1	7.9	4.8	16.7	0.0
Total % within race	*1.2*				*14.3*				*38.0*				*39.1*				*7.4*			
	Still air				Inconspicuous still air				Neither				Breezy				Very breezy			
The air movement in the room (without the aid of mechanical fan)	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	12.9	14.5	33.3	0.0	23.6	19.4	8.3	42.9	24.2	38.7	16.7	14.3	30.3	25.8	41.7	42.9	9.0	1.6	0.0	0.0
Total % within race	*13.9*				*22.4*				*27.0*				*30.1*				*6.6*			
	Very dissatisfied				Dissatisfied				Neither				Satisfied				Very satisfied			
The provision of air movement in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	3.9	1.6	0.0	0.0	18.0	14.5	25.0	28.6	36.0	50.0	50.0	28.6	31.5	32.3	16.7	42.9	10.7	1.6	8.3	0.0
Total % within race	*3.1*				*17.8*				*39.8*				*31.3*				*8.1*			
Visual comfort																				
	Too dark				Dark				Neither				Bright				Too bright			
The adequacy of natural daylight in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	5.1	3.3	0.0	0.0	12.4	11.5	9.1	16.7	30.3	41.0	36.4	83.3	43.8	34.4	45.5	0.0	8.4	9.8	9.1	0.0
Total % within race	*4.3*				*12.1*				*34.4*				*40.6*				*8.6*			
	Very poor				Poor				Fair				Good				Very good			
The control of the daylight in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.7	1.6	0.0	0.0	11.2	6.5	0.0	14.3	35.4	41.9	33.3	71.4	43.3	37.1	58.3	14.3	8.4	12.9	8.3	0.0
Total % within race	*1.5*				*9.7*				*37.8*				*41.7*				*9.3*			
	Too dark				Dark				Neither				Bright				Too bright			
The adequacy of artificial light in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.7	0.0	0.0	0.0	8.4	11.3	0.0	14.3	31.5	43.5	33.3	57.1	50.0	37.1	41.7	28.6	8.4	8.1	25.0	0.0
Total % within race	*1.2*				*8.9*				*35.1*				*45.9*				*8.9*			
	Very poor				Poor				Fair				Good				Very good			
The control of the artificial light in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	9.1	9.7	0.0	16.7	33.7	41.9	33.3	33.3	48.0	35.5	58.3	33.3	8.6	12.9	8.3	16.7
Total % within race	*0.4*				*9.0*				*35.7*				*45.1*				*9.8*			
	Very poor				Poor				Fair				Good				Very good			
The effectiveness of curtains in controlling the level of lighting	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	7.3	4.8	0.0	14.3	18.1	35.5	25.0	57.1	53.1	38.7	33.3	28.6	20.9	21.0	41.7	0.0
Total % within race	*0.4*				*6.6*				*23.6*				*48.1*				*21.3*			

Note : M – Malay; C – Chinese; I – Indian; O - Others

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
	Very dissatisfied				Dissatisfied				Neither				Satisfied				Very satisfied			
The satisfaction with the quality of the lights in the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.1	3.2	0.0	0.0	9.0	4.8	0.0	14.3	27.7	32.3	16.7	57.1	46.9	51.6	58.3	28.6	15.3	8.1	25.0	0.0
Total % within race	*1.6*				*7.8*				*29.1*				*48.1*				*13.6*			
	Very poor				Poor				Fair				Good				Very good			
The view out of the room from the inside	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	11.3	12.9	0.0	14.3	26.0	38.7	41.7	42.9	42.9	32.3	25.0	42.9	19.2	16.1	33.3	0.0
Total % within race	*0.4*				*11.2*				*30.2*				*39.5*				*18.6*			
	Very small				Small				Fair				Big				Very big			
The existing windows/ opening area of the room	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.0	1.6	0.0	0.0	7.9	8.1	0.0	14.3	29.2	32.3	41.7	42.9	45.5	45.2	50.0	42.9	17.4	12.9	8.3	0.0
Total % within race	*0.4*				*7.7*				*30.9*				*45.6*				*15.4*			
Landscape																				
	Strongly disagree				Disagree				Undecided				Agree				Strongly agree			
The residential building is sensitively designed for the landscape setting	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	1.7	1.6	0.0	0.0	8.4	4.8	8.3	0.0	37.1	48.4	33.3	42.9	43.3	40.3	41.7	57.1	9.6	4.8	16.7	0.0
Total % within race	*1.5*				*7.3*				*39.8*				*42.9*				*8.5*			
	Very poor				Poor				Fair				Good				Very good			
The quality of landscape at residential college areas	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	2.3	0.0	0.0	0.0	9.0	6.5	8.3	0.0	32.8	40.3	16.7	42.9	48.0	45.2	66.7	42.9	7.9	8.1	8.3	14.3
Total % within race	*1.6*				*8.1*				*34.1*				*48.1*				*8.1*			
	Not at all				Slightly				Moderate				Very				Extremely			
The influence of landscape setting on the quality life	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	1.6	0.0	0.0	7.3	8.1	8.3	0.0	26.4	41.9	25.0	28.6	48.3	41.9	50.0	71.4	17.4	6.5	16.7	0.0
Total % within race	*0.8*				*7.3*				*30.1*				*47.5*				*14.3*			
	Very poor				Poor				Fair				Good				Very good			
The quality of landscape setting at the internal courtyard	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	2.4	0.0	0.0	0.0	6.7	6.5	0.0	0.0	32.6	45.2	33.3	57.1	49.4	45.2	50.0	42.9	9.0	3.2	16.7	0.0
Total % within race	*1.5*				*6.2*				*36.3*				*48.3*				*7.7*			
	Never				Rarely				Sometimes				Frequently				Every time			
The frequency of spending time at the internal courtyard in a day	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	12.9	11.3	0.0	0.0	12.9	22.6	8.3	14.3	26.4	35.5	25.0	57.1	41.0	29.0	41.7	28.6	6.7	1.6	25.0	0.0
Total % within race	*11.6*				*15.1*				*29.3*				*37.8*				*6.2*			
	Not at all				Slightly				Moderate				Very				Extremely			
The influence of landscape setting in the internal courtyard on the quality life	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	3.9	1.6	0.0	0.0	7.9	8.1	0.0	0.0	32.0	46.8	41.7	85.7	46.6	37.1	33.3	14.3	9.6	6.5	25.0	0.0
Total % within race	*3.1*				*7.3*				*37.5*				*42.9*				*9.3*			

Note : M – Malay; C – Chinese; I – Indian; O - Others

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
	Never				Rarely				Sometimes				Frequently				Every time			
The frequency of the windows is kept open in a day	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	16.3	24.6	30.0	0.0	14.6	16.4	20.0	0.0	18.5	26.2	20.0	40.0	32.6	19.7	30.0	60.0	18.0	13.1	0.0	0.0
Total % within race	*18.5*				*15.0*				*20.9*				*29.9*				*15.7*			
	Never				Morning				Afternoon				Evening				Night			
The time of windows has been always open in a day	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	23.9	28.8	33.3	25.0	32.9	11.9	25.0	50.0	17.4	16.9	8.3	0.0	19.4	15.3	33.3	25.0	6.5	27.1	0.0	0.0
Total % within race	*25.7*				*27.4*				*16.5*				*19.1*				*11.3*			
	Never				Rarely				Sometimes				Frequently				Every time			
The frequency of ceiling fan usage in a day	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	3.9	1.6	0.0	0.0	9.6	14.5	9.1	14.3	27.0	21.0	36.4	28.6	59.0	62.9	54.5	57.1
Total % within race	*0.4*				*3.1*				*10.9*				*26.0*				*59.7*			
	One				Two				Three				Four				Five			
The fan speed is often used	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
	0.6	0.0	0.0	0.0	2.8	1.6	0.0	14.3	16.5	19.4	8.3	28.6	30.7	30.6	16.7	14.3	49.4	48.4	75.0	42.9
Total % within race	*0.4*				*2.7*				*17.1*				*29.6*				*50.2*			

The reason for not opening the windows

Insect				Safety				Rain				Dust				Privacy				Monkey				Others			
M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
3.4	4.4	0.0	0.0	17.2	4.4	55.6	20.0	8.3	0.0	0.0	20.0	11.7	4.4	0.0	20.0	24.8	11.1	0.0	20.0	30.3	66.7	22.2	20.0	4.1	8.9	22.2	0.0
*3.4**				*16.2**				*6.4**				*9.8**				*20.6**				*37.7**				*5.9**			

Thermal comfort based on ASHRAE 7 sensation scale

Cold				Cool				Slightly cool				Neutral				Slightly warm				Warm				Hot			
M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O	M	C	I	O
0.6	0.0	0.0	0.0	8.5	3.3	9.1	0.0	4.9	16.7	18.2	14.3	41.5	31.7	27.3	71.4	23.8	30.0	36.4	0.0	17.1	16.7	9.1	14.3	3.7	1.7	0.0	0.0
*0.4**				*7.0**				*8.7**				*39.3**				*25.2**				*16.5**				*2.9**			

Note : M - Malay; C - Chinese; I - Indian; O - Others; * - Total % within race

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
Architectural elements																				
	Very poor				Poor				Fair				Good				Very good			
The residential building layout (internal courtyard with open corridor)	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	1.3	0.0	2.5	7.4	12.5	10.5	35.0	25.9	32.5	24.6	52.5	64.2	37.5	47.4	10.0	2.5	16.3	17.5
Total % within floor	*0.4*				*8.9*				*29.1*				*50.4*				*11.2*			
	Strongly disagree				Disagree				Undecided				Agree				Strongly agree			
The residential building is an environmental friendly with efficient energy usage	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	1.2	0.0	0.0	0.0	6.1	10.1	10.5	22.5	29.3	22.8	17.5	62.5	57.3	48.1	56.1	15.0	6.1	19.0	15.8
Total % within floor	*0.4*				*7.4*				*23.6*				*55.0*				*13.6*			
	Not at all				Slightly important				Moderate				Very important				Extremely important			
The importance of the buildings is built in an environmentally friendly way	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	0.0	0.0	2.5	1.2	7.5	0.0	12.5	14.6	15.0	12.5	47.5	52.4	42.5	37.5	37.5	31.7	35.0	50.0
Total % within floor	*0.0*				*3.1*				*14.0*				*45.3*				*37.6*			
	Very poor				Poor				Fair				Good				Very good			
The overall quality of the residential building	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	0.0	3.5	2.6	4.9	8.8	7.0	35.9	34.1	26.3	21.1	43.6	54.9	55.0	50.9	17.9	6.1	10.0	17.5
Total % within floor	*0.8*				*6.2*				*29.1*				*52.3*				*11.6*			
	Very poor				Poor				Fair				Good				Very good			
The general room layout	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	1.2	1.3	0.0	5.0	11.0	8.8	3.6	30.0	26.8	32.5	21.4	47.5	54.9	45.0	51.8	15.0	6.1	12.5	23.2
Total % within floor	*1.2*				*7.8*				*27.9*				*50.0*				*13.2*			
	Strongly disagree				Disagree				Undecided				Agree				Strongly agree			
The room is fulfil the needs	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	5.0	0.0	1.3	0.0	5.0	17.5	11.3	7.1	35.0	23.8	20.0	30.4	37.5	50.0	53.8	50.0	17.5	8.8	13.8	12.5
Total % within floor	*1.2*				*11.3*				*25.8*				*49.2*				*12.5*			
	Very poor				Poor				Fair				Good				Very good			
The provision of privacy in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	7.7	4.9	1.3	0.0	17.9	18.3	13.8	21.1	25.6	23.2	31.3	24.6	38.5	41.5	40.0	43.9	10.3	12.2	13.8	10.5
Total % within floor	*3.1*				*17.4*				*26.4*				*41.1*				*12.0*			
	Very unsafe				Unsafe				Neither				Safe				Very safe			
The feeling of safety in the room and building	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	1.3	1.8	5.0	11.1	3.8	3.5	32.5	21.0	31.6	22.8	42.5	50.6	50.6	52.6	20.0	17.3	12.7	19.3
Total % within floor	*0.8*				*6.2*				*26.5*				*49.8*				*16.7*			
	Very uncomfortable				Uncomfortable				Neither				Comfortable				Very comfortable			
The overall comfort level of the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	0.0	0.0	1.8	0.0	6.1	5.1	3.5	37.5	31.7	29.1	21.1	50.0	52.4	51.9	61.4	10.0	9.8	13.9	12.3
Total % within floor	*0.8*				*4.3*				*29.5*				*53.9*				*11.6*			
	Much decreased				Decreased				No changes				Increased				Much increased			
The influence of overall room conditions on the degree of work productivity	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	1.2	0.0	1.8	0.0	3.7	5.1	8.8	42.5	29.3	22.8	19.3	37.5	43.9	58.2	52.6	20.0	22.0	13.9	17.5
Total % within floor	*0.8*				*4.7*				*27.1*				*49.2*				*18.2*			

Note : G – Ground floor/1st floor; S – 2nd floor; T – 3rd floor; F – 4th floor

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
Thermal comfort and indoor air quality																				
	Very poor				Poor				Fair				Good				Very good			
The thermal comfort/indoor air temperature at the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	4.9	1.3	7.0	12.5	11.0	7.5	19.3	35.0	26.8	35.0	26.3	45.0	41.5	47.5	35.1	7.5	15.9	8.8	12.3
Total % within floor	*3.5*				*12.0*				*30.5*				*42.5*				*11.6*			
	Very poor				Poor				Fair				Good				Very good			
The ventilation and air quality of the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	0.0	1.3	5.4	12.5	15.0	8.9	19.6	42.5	27.5	35.4	19.6	32.5	51.3	46.8	44.6	10.0	6.3	7.6	10.7
Total % within floor	*2.0*				*13.7*				*30.6*				*45.5*				*8.2*			
	Very poor				Poor				Fair				Good				Very good			
The control of the ventilation of the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	2.5	0.0	0.0	12.5	17.5	9.0	19.6	45.0	37.5	37.2	35.7	30.0	40.0	46.2	33.9	10.0	2.5	7.7	10.7
Total % within floor	*1.2*				*14.6*				*38.2*				*39.0*				*7.1*			
	Still air				Inconspicuous still air				Neither				Breezy				Very breezy			
The air movement in the room (without the aid of mechanical fan)	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	17.5	15.0	12.7	12.5	37.5	23.8	19.0	16.1	25.0	23.8	29.1	32.1	15.0	32.5	32.9	28.6	5.0	5.0	6.3	10.7
Total % within floor	*14.1*				*22.7*				*27.5*				*29.0*				*6.7*			
	Very dissatisfied				Dissatisfied				Neither				Satisfied				Very satisfied			
The provision of air movement in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	3.8	1.3	5.4	22.5	20.0	16.5	14.3	50.0	43.8	34.2	35.7	15.0	28.8	39.2	35.7	10.0	3.8	8.9	8.9
Total % within floor	*3.1*				*18.0*				*40.0*				*31.4*				*7.5*			
Visual comfort																				
	Too dark				Dark				Neither				Bright				Too bright			
The adequacy of natural daylight in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	5.0	5.2	5.4	12.8	8.8	13.0	14.3	56.4	40.0	28.6	21.4	25.6	41.3	42.9	46.4	5.1	5.0	10.4	12.5
Total % within floor	*4.4*				*11.9*				*34.9*				*40.5*				*8.3*			
	Very poor				Poor				Fair				Good				Very good			
The control of the daylight in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	1.3	1.3	1.8	7.5	8.8	12.7	7.1	52.5	41.3	35.4	28.6	37.5	45.0	43.0	39.3	2.5	3.8	7.6	23.2
Total % within floor	*1.2*				*9.4*				*38.4*				*42.0*				*9.0*			
	Too dark				Dark				Neither				Bright				Too bright			
The adequacy of artificial light in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	2.5	1.8	2.5	10.0	11.4	8.9	52.5	31.3	39.2	25.0	37.5	55.0	41.8	46.4	7.5	3.8	5.1	17.9
Total % within floor	*1.2*				*9.0*				*35.7*				*46.3*				*7.8*			
	Very poor				Poor				Fair				Good				Very good			
The control of the artificial light in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	1.3	0.0	7.5	6.5	14.1	7.1	45.0	33.8	37.2	32.1	42.5	50.6	42.3	42.9	5.0	9.1	5.1	17.9
Total % within floor	*0.4*				*9.2*				*36.3*				*45.0*				*9.2*			
	Very poor				Poor				Fair				Good				Very good			
The effectiveness of curtains in controlling the level of lighting	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	1.3	0.0	0.0	0.0	8.8	8.9	5.4	15.4	31.3	26.6	14.3	61.5	43.8	46.8	48.2	23.1	15.0	17.7	32.1
Total % within floor	*0.4*				*6.7*				*23.6*				*48.4*				*20.9*			

Note : G – Ground floor/1st floor; S – 2nd floor; T – 3rd floor; F – 4th floor

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	`-2				-1				0				+1				+2			
	Very dissatisfied				Dissatisfied				Neither				Satisfied				Very satisfied			
The satisfaction with the quality of the lights in the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	1.3	5.4	7.5	6.3	14.1	1.8	42.5	27.8	29.5	21.4	40.0	53.2	48.7	44.6	10.0	12.7	6.4	26.8
Total % within floor	*1.6*				*7.9*				*29.2*				*47.8*				*13.4*			
	Very poor				Poor				Fair				Good				Very good			
The view out of the room from the inside	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	0.0	0.0	0.0	17.5	12.5	11.5	5.4	42.5	32.5	24.4	26.8	30.0	40.0	44.9	39.3	7.5	15.0	19.2	28.6
Total % within floor	*0.4*				*11.4*				*30.3*				*39.8*				*18.1*			
	Very small				Small				Fair				Big				Very big			
The existing windows/ opening area of the room	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	1.3	0.0	0.0	12.5	8.8	10.1	1.8	50.0	33.8	29.1	16.1	32.5	45.0	41.8	60.7	5.0	11.3	19.0	21.4
Total % within floor	*0.4*				*8.2*				*31.0*				*45.5*				*14.9*			
Landscape																				
	Strongly disagree				Disagree				Undecided				Agree				Strongly agree			
The residential building is sensitively designed for the landscape setting	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	2.5	1.3	1.8	10.0	6.3	6.3	8.9	42.5	42.5	41.8	32.1	42.5	43.8	40.5	46.4	5.0	5.0	10.1	10.7
Total % within floor	*1.6*				*7.5*				*40.0*				*43.1*				*7.8*			
	Very poor				Poor				Fair				Good				Very good			
The quality of landscape at residential college areas	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	2.5	1.3	1.8	10.0	12.5	5.1	5.4	32.5	31.3	39.7	32.1	50.0	46.3	46.2	51.8	7.5	7.5	7.7	8.9
Total % within floor	*1.6*				*8.3*				*34.3*				*48.0*				*7.9*			
	Not at all				Slightly				Moderate				Very				Extremely			
The influence of landscape setting on the quality life	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	0.0	3.6	2.5	11.3	7.6	5.4	32.5	30.0	31.6	28.6	52.5	48.8	46.8	41.1	12.5	10.0	13.9	21.4
Total % within floor	*0.8*				*7.5*				*30.6*				*47.1*				*14.1*			
	Very poor				Poor				Fair				Good				Very good			
The quality of landscape setting at the internal courtyard	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	2.5	0.0	1.3	3.6	2.5	6.3	7.6	7.1	35.0	43.8	36.7	28.6	55.0	46.3	49.4	46.4	5.0	3.8	5.1	14.3
Total % within floor	*1.6*				*6.3*				*36.9*				*48.6*				*6.7*			
	Never				Rarely				Sometimes				Frequently				Every time			
The frequency of spending time at the internal courtyard in a day	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	10.0	12.5	11.4	10.7	10.0	17.5	13.9	17.9	32.5	28.8	32.9	23.2	45.0	37.5	39.2	33.9	2.5	3.8	2.5	14.3
Total % within floor	*11.4*				*15.3*				*29.4*				*38.4*				*5.5*			
	Not at all				Slightly				Moderate				Very				Extremely			
The influence of landscape setting in the internal courtyard on the quality life	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	2.5	3.8	5.4	12.5	3.8	5.1	12.5	35.0	51.3	38.0	21.4	37.5	35.0	51.9	44.6	15.0	7.5	1.3	16.1
Total % within floor	*3.1*				*7.5*				*38.0*				*42.7*				*8.6*			

Note : G – Ground floor/1st floor; S – 2nd floor; T – 3rd floor; F – 4th floor

Appendix V, continued

The performance indicators	Likert scale / *Residents' responses (%)*																			
	-2				-1				0				+1				+2			
	Never				Rarely				Sometimes				Frequently				Every time			
The frequency of the windows is kept open in a day	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	25.6	20.3	13.2	19.6	25.6	10.1	18.4	10.7	30.8	24.1	15.8	16.1	7.7	30.4	42.1	28.6	10.3	15.2	10.5	25.0
Total % within floor	*18.8*				*15.2*				*20.8*				*30.0*				*15.2*			
	Never				Morning				Afternoon				Evening				Night			
The time of windows has been always open in a day	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	52.8	24.7	17.6	15.4	30.6	31.5	29.4	19.2	8.3	20.5	10.3	25.0	8.3	13.7	23.5	28.8	0.0	9.6	19.1	11.5
Total % within floor	*24.9*				*27.9*				*16.6*				*19.2*				*11.4*			
	Never				Rarely				Sometimes				Frequently				Every time			
The frequency of ceiling fan usage in a day	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	1.3	0.0	0.0	2.5	5.1	3.6	15.0	8.8	11.5	8.9	22.5	31.3	28.2	19.6	62.5	57.5	53.8	67.9
Total % within floor	*0.4*				*3.1*				*10.6*				*26.4*				*59.4*			
	One				Two				Three				Four				Five			
The fan speed is often used	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
	0.0	0.0	1.3	0.0	2.6	1.3	3.8	1.8	25.6	17.5	19.2	8.9	25.6	22.5	35.9	30.4	46.2	58.8	39.7	58.9
Total % within floor	*0.4*				*2.4*				*17.4*				*28.9*				*51.0*			

The reason for not opening the windows

Insect				Safety				Rain				Dust				Privacy				Monkey				Others			
G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F	G	S	T	F
3.6	2.9	3.4	4.3	14.3	21.4	16.9	8.5	0.0	5.7	6.8	10.6	7.1	14.3	6.8	8.5	28.6	15.7	25.4	17.0	25.0	35.7	37.3	48.9	21.4	4.3	3.4	2.1
3.4				*16.2*				*6.4*				*9..8*				*20.6*				*37.7*				*5.9*			

Thermal comfort based on ASHRAE 7 sensation scale

Cold				Cool				Slightly cool				**Neutral**				Slightly warm				Warm				Hot			
G	S	T	F	G	S	T	F	G	S	T	F	**G**	**S**	**T**	F	G	S	T	F	G	S	T	**F**	G	S	T	F
0.0	0.0	1.4	0.0	2.6	8.0	8.3	5.5	0.0	18.7	6.9	3.6	**55.3**	**38.7**	**40.3**	27.3	26.3	20.0	30.6	25.5	13.2	12.0	12.5	**30.9**	2.6	2.7	0.0	7.3
0.4				*6.7*				*8.8*				***39.2***				*25.4*				*16.7*				*2.9*			

Note : G – Ground floor/1st floor; S – 2nd floor; T – 3rd floor; F – 4th floor; * - Total % within floor