ENHANCEMENT OF THE DESIGN OF AIR-CONDITIONING HEAT EXCHANGERS' CIRCUITS.

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KUALA LUMPUR

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FACULTY OF MECHANICAL ENGINEERING
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ABSTRACT

The important of delivering a higher capability heat exchanger had been identified in the study. The circuit of the heat exchanger is proposed to improve in term of the circuit design. Literatures studied had been performed to acquire various possibilities to improve on the heat exchanger capacity. Several researches had been studied and benchmarked due to the improvement leads by the respective design. A heat exchanger circuitry has been enhanced to deliver higher capacity by using CoilDesigner. Simulation had been performed to estimate the performance of the heat exchanger by changing the design and configuration of the circuitry. The simulated model is being validated by experiment data. Similar researches are being benchmarked to provide reliable justification. Several improvements acquired based on the study on the suggestion of literature review had contributed to improvement of the circuit in this study. Some measures and design proposed had positive impact toward the performance of the heat exchanger. The optimized number of circuitry for this design is being studied and acquired. The fin pattern has also changed from louver pattern to slit fin pattern. The air side capacity of the heat exchanger has increased by 8.46% after adopting some of the design change proposed throughout the study.

ABSTRAK

Kepentingan untuk memberikan penukar haba keupayaan yang lebih tinggi telah dikenalpasti dalam kajian ini. Litar penukar panas dicadangkan untuk meningkatkan dari segi reka bentuk litar. Kajian literatur telah dilakukan untuk memperoleh pelbagai kemungkinan untuk meningkatkan keupayaan penukar haba. Beberapa penyelidikan telah dikaji dan dinilai oleh penanda aras oleh peningkatan reka bentuknya. Litar penukar haba telah diningkatkan untuk menyampaikan kapasiti yang lebih tinggi dengan menggunakan CoilDesigner. Simulasi telah dilakukan untuk menganggarkan prestasi penukar haba dengan menukar reka bentuk dan konfigurasi litar. Model simulasi telah disahkan oleh data eksperimen. Penyelidikan yang sama sedang ditanda aras untuk memberikan justifikasi yang boleh dipercayai. Beberapa penambahbaikan yang diperoleh berdasarkan kajian mengenai cadangan kajian literatur telah membawa peningkatan kepada prestasi penukar haba. Beberapa langkah dan reka bentuk yang dicadangkan mempunyai kesan positif terhadap prestasi penukar haba. Nombor litar yang dioptimumkan untuk reka bentuk ini telah dikaji dan diperolehi. Corak sirip juga telah berubah dari corak louver ke celah corak sirip. Kapasiti sisi udara penukar panas meningkat sebanyak 8.46% selepas menerima pakai beberapa perubahan reka bentuk yang dicadangkan sepanjang kajian.

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LIST OF SYMBOLS AND ABBREVIATIONS

HVAC	:	Heat, Ventilation and Air Conditioning
MCHE	:	Micro-channel Heat Exchanger
Dh	:	Hydraulic Diameter
ISO	:	International Organization for Standardization
ASHRAE	:	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Q	:	Heat Transfer
U	:	Heat Transfer Coefficient
ΔTm	:	Mean Temperature Different
m_a	:	Mass flow of air
m_r	:	Mass flow of refrigerant
h	:	Enthalpy
CFD	:	Computational Fluid Dynamic
CFM	:	Cubic Feet per Meter
T evap in	:	Evaporator Inlet Temperature
P evap in	:	Evaporator Inlet Pressure

CHAPTER 1: INTRODUCTION

1.1 Problem Background

Heat exchanger as one of the very important component in the engineering industry had been utilized in various sector. Heat exchanger serves as an important component in delivering the heat transfer between medium. It is technically maximize the possible heat transfers in practical usage. One of it core application in engineering is in Heating, Ventilation and Air Conditioning (HVAC) industry. The heat exchanger plays a role in delivering the suitable ambient to maximize human comfort despite the reality that weather and outdoor ambient is remained uncontrolled in todays' technology. Energy consumption in HVAC has always been highlighted as a critical concern as it directly involved the cost of the building energy-cost performance (Cho, Kim, Koo, & Park, 2018). In the construction application sector, various modeling techniques is utilized to optimize the building energy efficiency as the HVAC system is the key factor that contribute to the overall energy efficiency (Afroz, Shafiullah, Urmee, & Higgins, 2018). However, optimization can also be performed on the component level of the HVAC system to contribute to the best utilization and optimization of the heat exchanger.

1.2 Problem Statement

Uneven heat transfer distribution for the circuits in heat exchanger has caused the waste in capacity of the coils and sweating issues. Different circuit design has different consequences and patterns of heat transfer mal-distribution. Mal-distribution of refrigerant can cause a significant impact on the loss of capacity up to 25% (ZHANG, WANG, & CHEN, 2014). Different circuit distribution and arrangement can result in different capacity achieved. By improving the capability of the heat exchanger, it provides flexibility to the designer upon the system design process. By enabling a higher capacity heat exchanger with same dimension, it enables the product to hit a higher rating. As such, the product could increase in competitiveness as the capability of the product is increased.

By enhancing the heat exchanger, the overall bottleneck of the system is shifted up as the heat exchanger can now deliver a higher capabilities. The utilization of the heat exchanger by enhancing the design could also possible lead to the increase of energy efficiency. The increase in energy rating which is contributed by the improvement of heat exchanger would increase the overall product performance quality, grab customers satisfaction and distinguish the brand from competitors.

1.3 Research Objectives

i) To validate the reliability of the simulated model by using CoilDesigner.

ii) To study the impact of heat exchanger design arrangement for multiple rows coil.

iii) To optimize the circuit design for air-to-refrigerant heat exchanger in air-conditioning unit.

1.4 Scope of Study

i) The simulation is conducted with the assumption of the air flow distribution is even.

ii) The design point in the study is the circuit arrangement.

iii) The design is bounded to the manufacturing capabilities and efficiency of the heat exchanger manufacturing process.

iv) The experiment reference is in accordance to ISO5151.

v) The optimization is performed on the indoor unit capacity.

CHAPTER 2: LITERATURE REVIEW

Air-conditioning is one the core application of thermodynamic. The air-conditioning unit utilized refrigerant cycle to achieve the capabilities to remove heat from one place to another. Air-conditioning, in order to perform the ability to remove heat of one place to another, it need to perform the refrigeration cycle by integrating few components. The compressor, heat exchanger, expansion device works together to deliver refrigeration cycle and resulted in cooling capacity or heating capacity. However, the design of air-conditioning is not limited to the knowledge of thermodynamic, it also involve heat transfer principle when the heating or cooling is being delivered from one medium to another medium. To capture the heat transfer precisely, we need the help of fluid dynamic to study the flow of air distribution. All these integrated to deliver the best end-user experience and comfort. This is validated by the psychometric testing and reliability testing at the unit level during the design and development stage. The performance, the functionality and the reliability of the unit is often corresponding to the psychometric chart and psychometric sketch to understand the air-conditioning system in various perspective (Legg, 2017). Neglecting any consideration will result in poor performance of the air-conditioning unit. Whereas, when it comes to the unit level, it also comprises of solid mechanic knowledge to the piping of the system, the overall structural performance of the unit. Example, the resonance happened between the compressor frequency and the natural frequency of the piping system, fan motor frequency, etc. In this literature review, some of the important element in the design of air-conditioning will be discussed.

2.1 HVAC Function

In classic view on HVAC system, HVAC is to offer a temperature control over the ambient to a comfortable temperature regardless of the environment. However, the human comfort of the ambient of the room is not limited to temperature control. The indoor comfort quality is generally governed by the temperature control and also the humidity control. These two controls are being delivered by HVAC as a sensible heat load and latent heat load. Overall, the function of the HVAC to deliver human comfort is being summarized in Figure 2.1. According to that, the function of air-conditioning is to perform temperature control, humidity control and some fundamental air cleanliness. The air-conditioning deliver temperature control by it heating and cooling capabilities. Whereas, high end HVAC equipment will control the humidity by the condensation of the moisture as dehumidifying function and vice versa to increase to the moisture of the air. Last but not least, fundamental air quality is assured in air-conditioning unit by the air filter. Some high-end HVAC unit also consist of ionizer to further improve air quality.

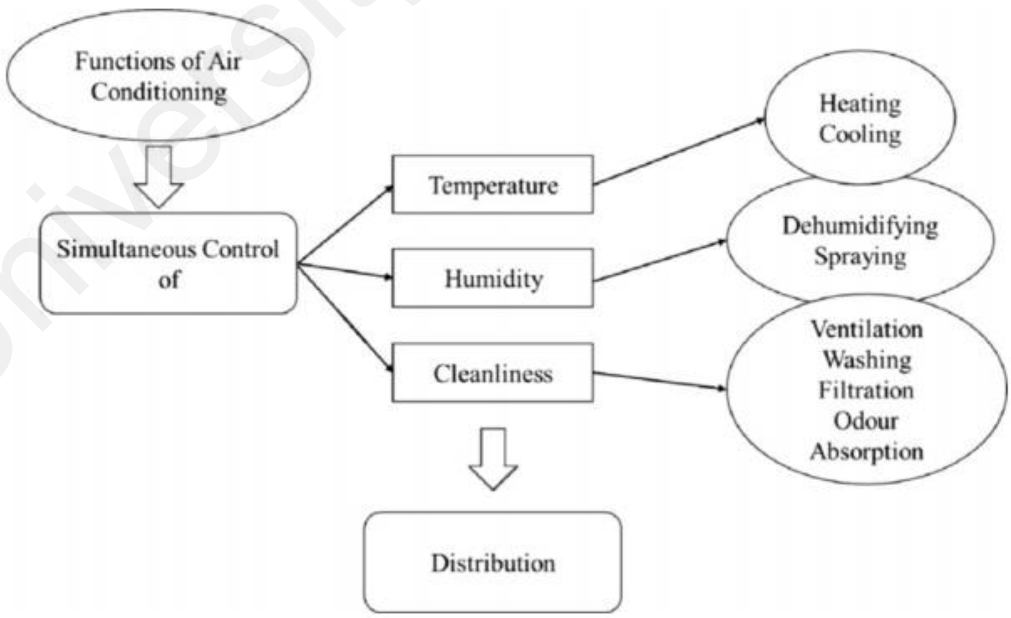

Figure 2.1: The Function of HVAC equipment (Rafique, Rehman, Lashin, & Al Arifi, 2016).

2.2 HVAC Demand

As the technology and civilization of the world is evolving, the population had grown significantly. Number of people in this world had gone up in these years. As the technology and civilization is evolving, the human living standard is also been increasing. People are now demanding a more comfortable living environment (Giampieri, Ma, Smallbone, & Roskilly, 2018). As a result, the heating, ventilation and air conditioning sector have shown a remarkable level in term of demand, as shown in Figure 2.2. The increase in these HVAC equipments have resulted in high fossil fuel consumption which is caused by the loading situation of electric demand (Crofoot, 2012). The urgency of optimizing HVAC equipments has emerged in the field of engineering.

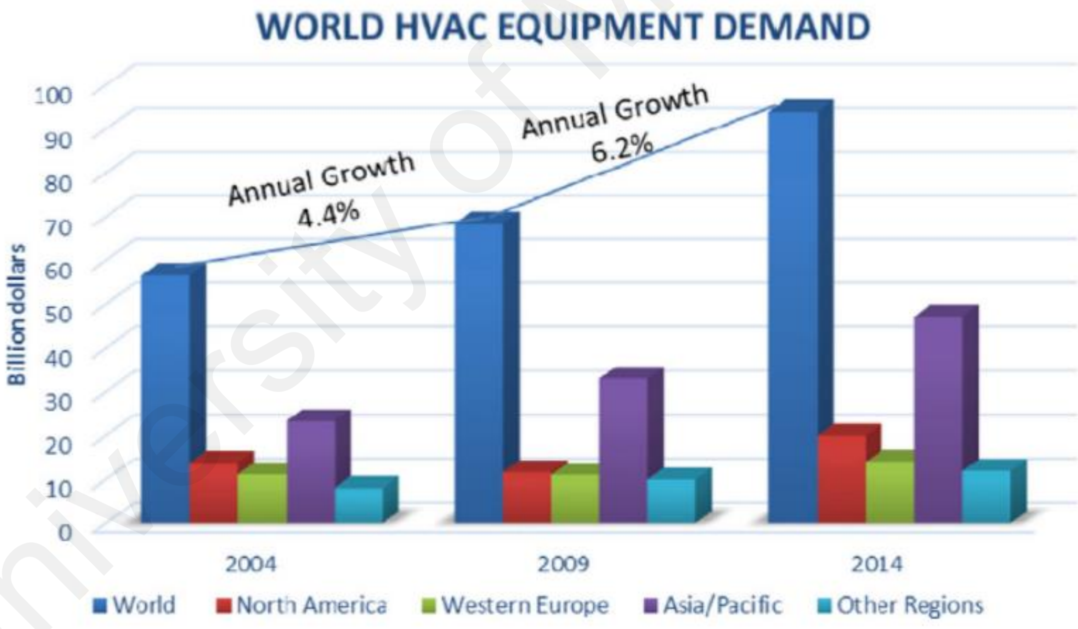

Figure 2.2: The world HVAC Equipment Demand (Mujahid Rafique, Gandhidasan, Rehman, & Al-Hadhrami, 2015).

2.3 HVAC Heat

As discussed in Section 2.2, HVAC unit can deliver various function. However, the primary function of a HVAC unit is to deliver temperature control. Whereas, humidity control is another important consideration in delivering a overall comfort despite of the temperature. Most of the residential and light commercial unit in the market do not cater for the humidity control. However, the temperature and humidity effects delivered by the HVAC equipment can be quantized into 2 measurable parameters. The temperature change capacity is known as sensible heat load and the humidity change capacity is known as latent heat load. These parameters are significant to quantifying the capabilities of the system thermal energy of that environment (Rodrigues, da Silva, Vieira, & Nascimento, 2011) .

2.3.1 Sensible Heat

Sensible heat load is the heat load performed to alter the change in the temperature of the air. The sensible heat load does not effect on the moisture of the air. The sensible cooling performed can be illustrated on the Figure 2.3. The sensible heat load will alter the dry bulb temperature of the air. The shift from point 1 to point 2 indicating the change of dry bulb temperature on x axis. No phase change is occurred in sensible heat.

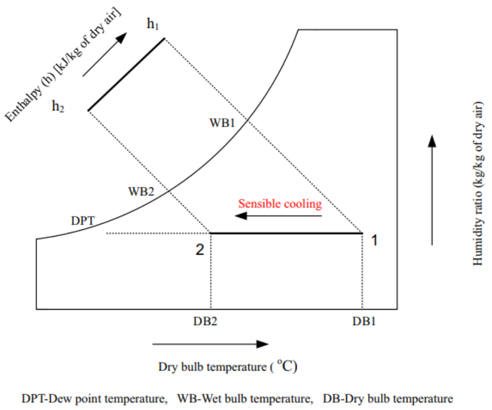

Figure 2.3 : The sensible cooling illustrated on the psychometric chart (Handbook, 1996).

2.3.2 Latent Heat

Latent heat is related to energy in the space when the moisture is remove or added into the system. The latent heat often reflects on the wet bulb temperature. For example, when the HVAC perform latent heat transfer to the air, the moisture of the air is effected by condensation. The energy involved in the condensation of this moisture removal is denoted as latent heat. Generally in a HVAC operating system, the moisture change when:

a. Moisture air from outside the indoor
b. People respiration and activities in the indoor.
c. Vapor condense on cooling apparatus

The latent heat performed by the HVAC unit is very intensive in term of energy. Condensation of water require a lot of energy. Hense, when the moisture is condense on the cooling apparatus, portion of the cooling apparatus capacity is contributed to latent heat.

2.4 Heat Exchanger

Heat Exchanger is a component which is used to perform the heat removal from one place to another place by using the refrigerant fluid. The heat exchanger is a broad study and consist of various specification and specialization as it can be broaden to down to different type of heat exchangers. Various types of heat exchangers can also lead to different design considerations. Generally, heat exchanger can be differentiated into shell and tube heat exchanger, tube-in-tube heat exchanger, fin-tube heat exchanger, micro-channel heat exchanger and etc. In air-conditioning unit industry, fin-tube heat exchanger and micro-channel heat exchanger is commonly used in the residential unit and light commercial unit for both indoor and outdoor application (Jeong, Kim, & Youn, 2006).

2.4.1 Fin-Tube Heat Exchanger

Fin-Tube heat exchanger is the most commonly used heat exchanger in the application of the engineering of air-conditioning unit. The fin-tube heat exchanger is being popular as it is regarded as a compact, low weight and comparatively low fabrication cost with respect to its' performance (C. Joppolo, L. Molinaroli, & A. Pasini, 2015).

The manufacturing process of the fin-tube heat exchanger in the context of air-conditioning unit, it consists of combining the fin and tube. The manufacturing of the fin and tube is being manufactured differently. The fin of the fin-tube heat exchanger is often using the very thin aluminium sheet which can go down to 0.1mm. The thin aluminium sheet is being cut into desired size and the pattern of the fin is being applied on the fin by using stamping or punching processes. Hole is being punched on the fin so that the tube can be inserted into the fin. Whereas for the tube of the fin-tube exchanger in air-conditioning unit, it is often using the copper tube. Raw material of copper tube is being draw and cut into desired length, the copper is then bent to form a hairpin.

After all, the fin and tube are being assemblied by inserting the copper tube into the fin hole. The fin and tube is being stabilized by the expanding the copper tube. The fin will be hold steadily after the tube is being expanded as the tube diameter will be larger than the fin hole after the expansion. The connection between the fin and tube is an important consideration as the connection will affect the transfer efficiency of the fin-tube heat exchanger. However, the effect of this interfaces of non-consistent contact is regarded as thermal contact resistance and the phenomenon have not been studied in detail context as a result of insufficient precise data, difficulty in perform measurement on the fin-tube interface and the complex heat transfer mode across the fin-tube interface (Jeong et al., 2006).

2.4.2 Microchannel Heat Exchanger

Microchanel heat exchanger is made by combing the channels together and channels are with vcarious geometries. Similar to others heat exchanger, the size and shape of the heat exchanger carried significant effect on the performance of the heat exchanger. Some of the research had studied the microchannel heat exchanger performance by studying different cross sectional geometries. These shapes of the channel including round, square, rectangular, triangular and also trapezoidal. After all, one of the research noticed that circular cross sectional shape heat exchanger had given the highest overall capacity in term of thermal and hydraulic efficiency as compared to other channel shapes mentioned (Hasan, Rageb, Yaghoubi, & Homayoni, 2009). In some application, micro-channel used to cool computer application. The capability of the micro channel heat exchanger to convey high density of heat flux. The micro-channel offer the advantages of extremely high surface area to volume ratio. This aspect is critical as comes to the critical thermal issue. However, this offering is coming with the advancement in technology of the manufacturing sector.

2.4.2.1 Manufacturing of Microchannel Heat Exchanger

Microchannel heat exchanger is distinguished by its hydraulic diameter of the diameter can can go to (200 micro m $\geq$ Dh > 10 micro m) (Illán-Gómez, García-Cascales, Hidalgo-Mompeán, & López-Belchí, 2017). The classic way of the microchannel can be created is with micro-machining. The term micro-machining govern the broad range of techniques in the manufacturing of microchannel heat exchanger as any machining processes involve the removal or altering the material with the purpose of producing the channels and to form and channel assemblies (Ashman & Kandlikar, 2006).

2.5 Comfort Zone

Comfort zone, ISO Standard 77300 regard is as a optimal environment with the different combinations criteria in term of thermal factor (such as the temperature of air, the velocity of air, humidity) and individual factors (such as the personal insulation and active level), this comfort zone should provide the satisfaction to 80% of the occupants in the space.(Iso, 2005). Although thermal comfort is a subjective matter. With the researches and quantify the thermal comfort parameters help to understand a person satisfaction toward the environment better. Research had been conducted

2.5.1 Temperature and Humidity

ASHRAE standard had published certain reference toward the comfort zone of temperature and humidity. ASHRAE had published the recommended design temperature and humidity as shown in Figure 2.4.

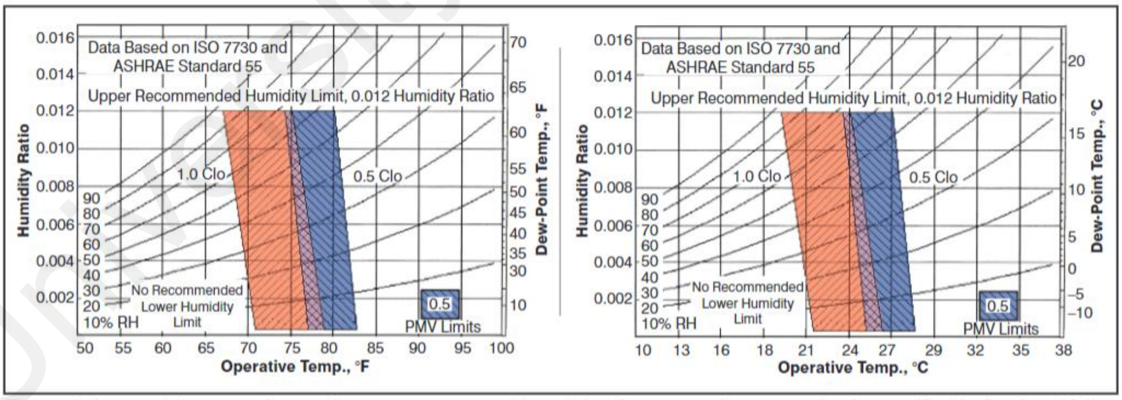

Figure 2.4 : The acceptable range of operative temperature and humidity (Standard, 2004).

2.5.2 Air Speed

One of the graph published in Standard 55-2014 is the graph of air speed versus the rise of temperature above comfort zone. At a particular rise of temperature above the comfort level, the recommended air speed required to offset the temperature rise is given in Fig 2.5. On the other word, when the environment possesses the temperature rise above the comfort zone, what is the air speed required to counter the rise of temperature so that the environment remained as comfort zone.

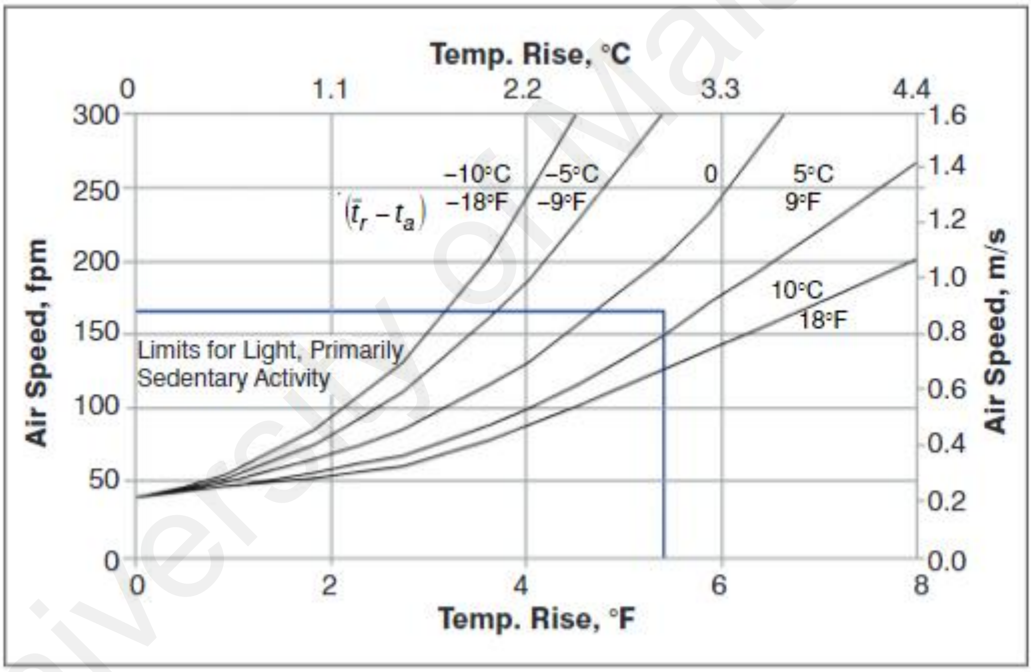

Figure 2.5: The air speed required to offset the temperature rise above comfort level (Standard, 2004).

2.6 Fin

Different types of fin pattern can be stamped on the fin. Different fin surface will create different interface between the heat exchanger and the moving air. Some examples of fin pattern is shown in the Figure 2.6.

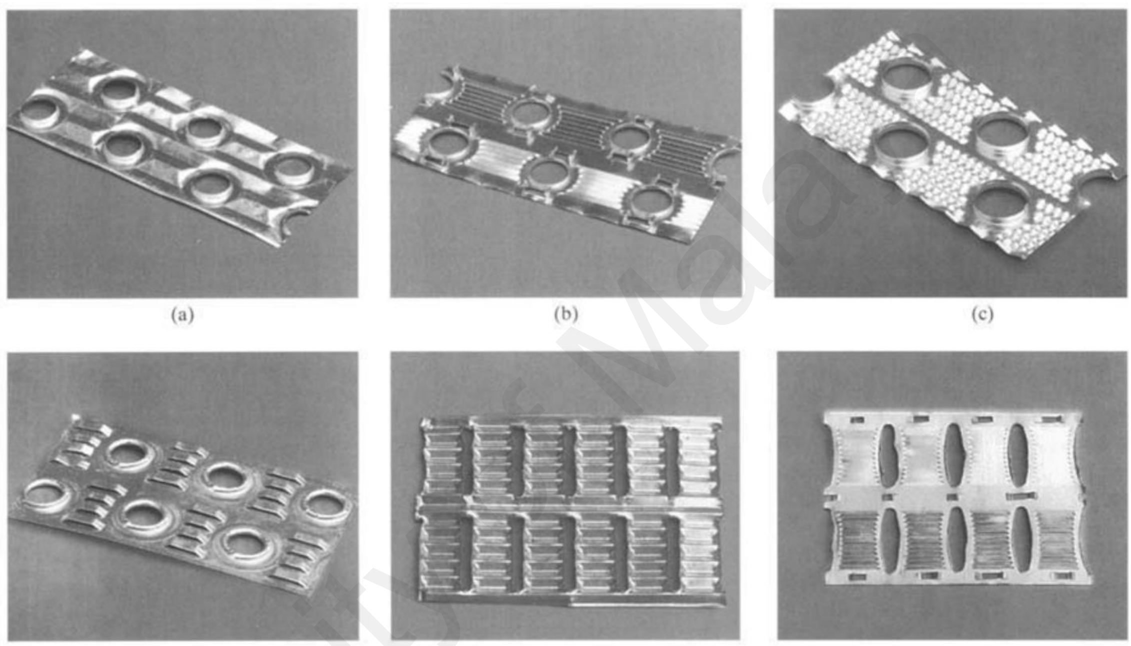

Figure 2.6: Different Fin Pattern Examples is shown(Rohsenow, Hartnett, & Cho, 1998).

Due to the complex geometry of find pattern, the air flow through the fin pattern will experience complex disruption in term of air flow. This complex disruption will contribute to the unpredictable air flow interference between the air and the fin. This is then contribute to the complexity in the study of fin performance. (Wang, Tao, & Chang, 1999).

2.7 Circuit Optimization

Often, changing the refrigeration circuit configuration will result in various changes such as the pressure drop across the coil and the impact will be implied to the whole refrigeration system. had perform by using simulation to suggest on the suitable refrigerant circuitry. With different configuration of the circuitry, the temperature difference to perform the heat transfer is altered. Moreover, the phase change across the coil complicated the whole model, many uncertainty is involved in changing point. There are also research to study the circuitry effect in general perspective. Figure 2.7 shows the example of circuit design.

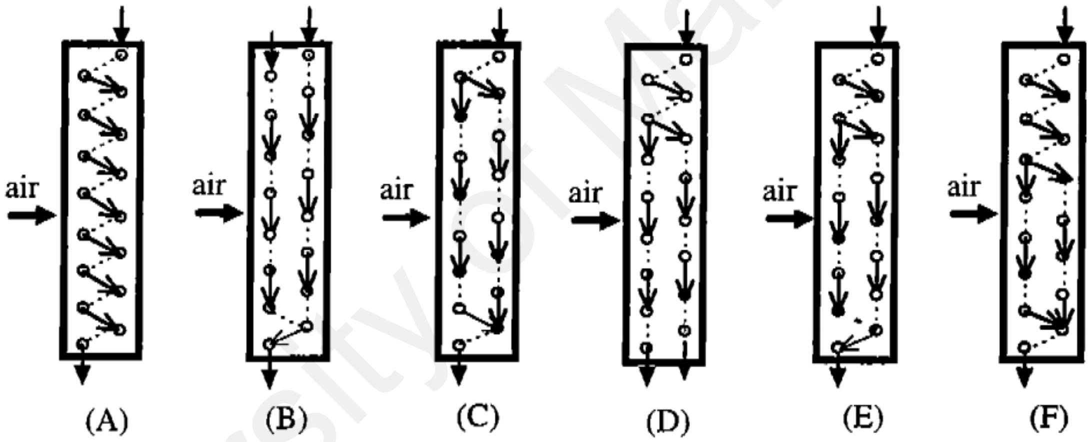

Figure 2.7: Example of circuit design used in simulation (S. Liang, Wong, & Nathan, 1998).

One of the root cause for performance degradation of air-conditioning system which is using the heat exchanging mechanism between air and refrigerant is identified as the air flow mal-distribution (Lee, Li, Ling, & Aute, 2018). The heat exchange distribution is complicated with respect to the complication of the non-uniform air flow profile(Aganda, Coney, & Sheppard, 2000). There are some researches portrayed that the non-uniform profile of air will alter the condenser or evaporator outlet superheat (Choi, Payne, & Domanski, 2003). The configuration is becoming more severe when the circuit design is multiple(Singh, Aute, & Radermacher, 2009). With respect to air-flow mal-distribution, it is found that the degradation performance can spike up to 38%. There are scientist who optimize the refrigerant circuit by counter-acting with different geometry of the heat exchangers(Piotr A Domanski, 1991). The variety of heat exchanger is expected to compromise with the effect of the non-uniform flow of air (Wu, Ding, Wang, & Fukaya, 2008). As the geometry changed, refrigerant flow distribution is also altered.

2.8 Heat Transfer

2.8.1 Heat Transfer Equation

The general equation used in the HVAC application is the fundamental heat transfer equation. Figure 2.8 portray an illustration on the heat transfer equation.

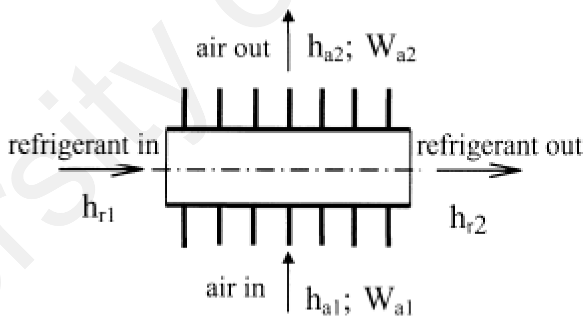

Figure 2.8: HVAC coil heat transfer illustration (S. Y. Liang, Wong, & Nathan, 2000).

For the air side capacity, the enthalpy of the air before and after coil is obtained. From the enthalpy change and the mass flow rate, the cooling capacity and heating capacity could be obtained.

2.9 Maldistribution (Kærn, Brix, Elmegaard, & Larsen, 2011)

According to a numerical study, a maldistributed airflow could reduce the capacity of the coil, the airflow mal distribution will create a recirculation area at the coil and cause the reduce in the cooling capacity as the flow of the air which encounter recirculation has limited heat transfer with the coil .

The refrigerant might exist as two phases in the system. As the liquid phase and vapor phases has different density, the flow orientation might be different. The refrigerant with two phases should be well mixed so that the orientation of the refrigerant is balance. When the circuit consist of branches where a distributor is placed to distribute the refrigerant, the distributor plays a role to control the distribution. The refrigerant distribution could have effect of the capacity of the system.

2.10 Case Studies

2.10.1 Performance of a Finned-tube Evaporator Optimized for Different Refrigerants and its Effect on System Efficiency.

A studied had performed by manually creating circuits to be adopted into simulation to study the impact of the refrigerant. The different circuit is created to adopt with different refrigerant and iterate to acquire equivalent performance evaporator. Figure 2.9 below shows the circuit used for the simulation of the study.

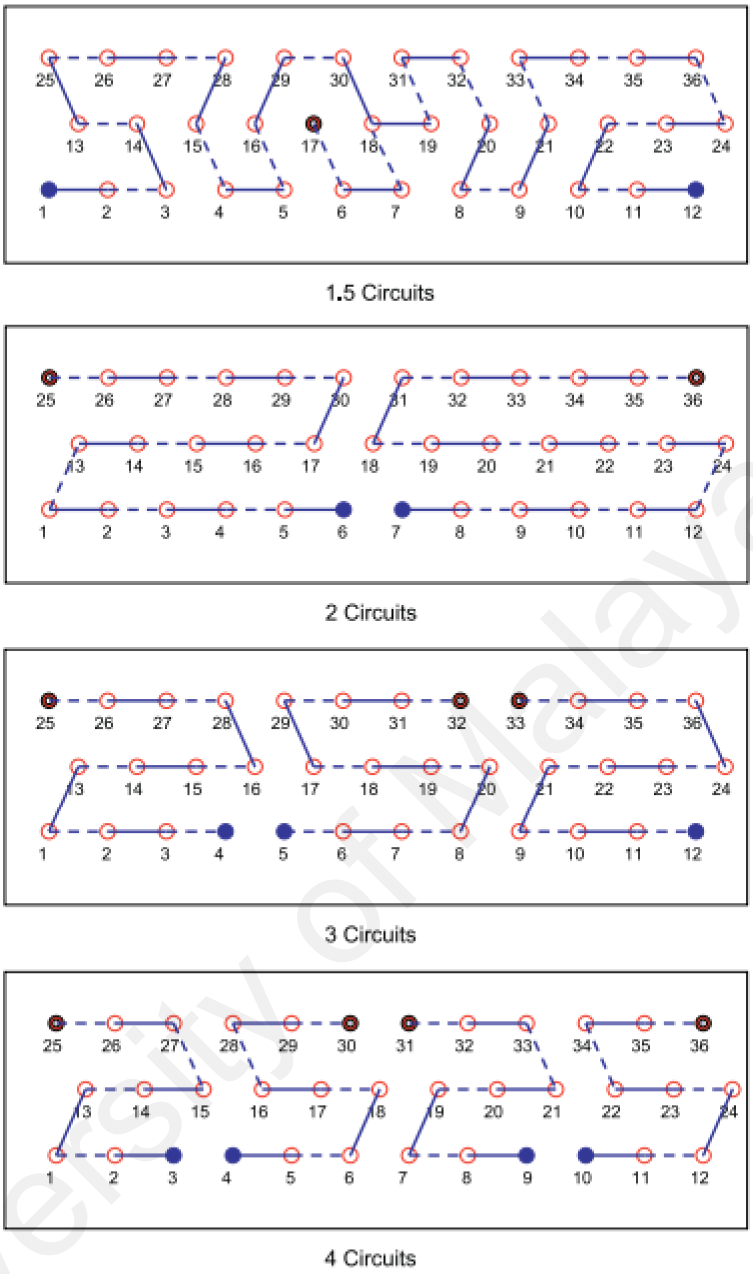

Figure 2.9: Example of circuit design used in the studies (Piotr A. Domanski, Yashar, & Kim, 2005).

2.10.2 Numerical and Experimental Studies of Refrigerant Circuitry (S. Y. Liang, Wong, & Nathan, 2001).

Different circuitry had been used to evaluate on the performance of the coil. A 16 tube height circuit with R134a refrigerant is used in this study. Figure 2.10 shows the circuit design used to the study. Whereas Figure 2.11 shows the respective result of heat flux with respect to the different coil configurations.

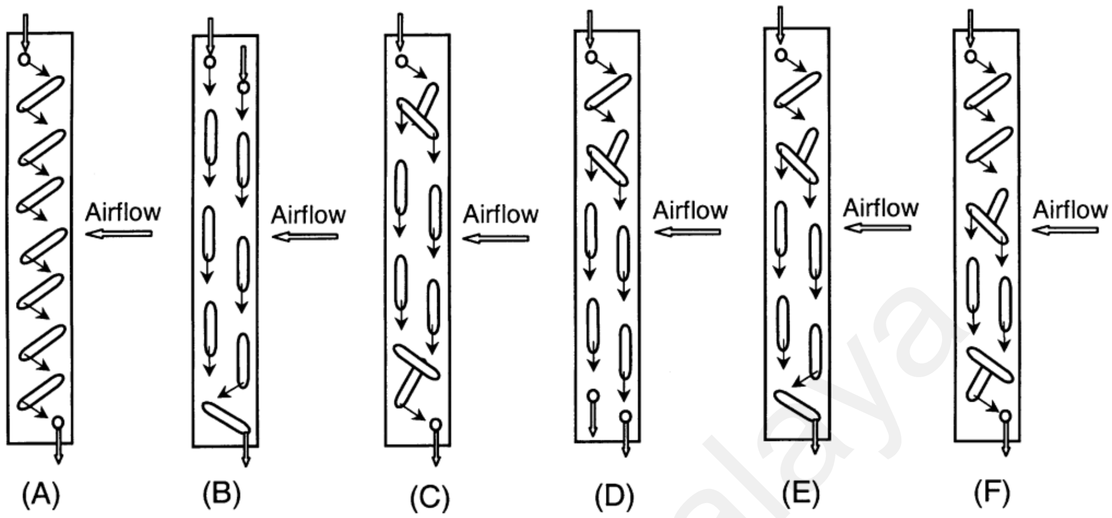

Figure 2.10: Circuit Design used in this study (S. Y. Liang et al., 2001).

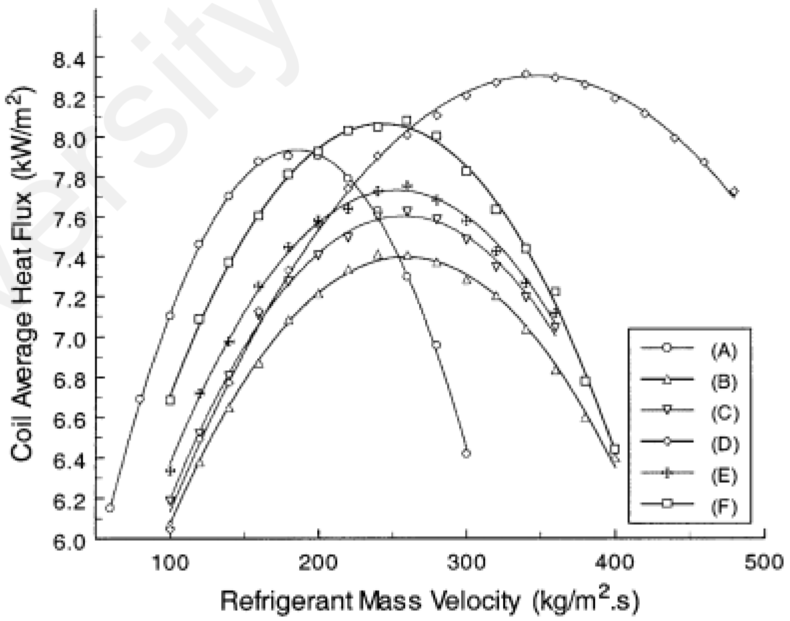

Figure 2.11: The result of heat flux with respect to the velocity flow of different coil configuration (S. Y. Liang et al., 2001).

2.10.3 Simulation and Performance Evaluation of finned-tube CO2 Gas Coolers for Refrigerant System (Ge & Cropper, 2009).

A performance analysis had been performed on different arrangements of circuits. This research is validated by the experiment result which was published. This serves as the reverse simulation methodology. The original circuit is simulated and is validated by the actual experiment. Then, the simulated model is being used to perform estimation on the redesigned heat exchanger. In this particular research, the number of circuit numbers is also being altered. And this research found that when the heat exchanger circuit numbers increase, the capacity of the heat exchanger is also increased. The validation process involved the comparison of the refrigerant outlet temperature between the experimental and simulation. The result is being compared in Table 2.1.

Table 2.1: The Validation by Comparing Actual Refrigerant Outlet Temperature and Simulated Outlet Temperature.

Actual Refrigerant Outlet Temperature (^oC)	Simulated Refrigerant Outlet Temperature (^oC)	% Different
40.4	38	5.94
33.5	33.5	0.00
31.3	31.5	-0.64
41.5	36.9	11.08
32.3	31.2	3.41
31.1	30.3	2.57
40.4	34.3	15.10
31.7	30.4	4.10
30.9	29.9	3.24
43.1	40.06	7.05
39.8	38.8	2.51
38.2	37.9	0.79
45.5	41.9	7.91
38.7	37.9	2.07
37.2	36.6	1.61
46	40.9	11.09
38	36.6	3.68
36.7	35.6	3.00
41.1	41.1	0.00
38.4	38.8	-1.04

37.2	37.8	-1.61
45.8	44.9	1.97
39.1	40.4	-3.32
35.3	37.5	-6.23
49.3	47	4.67
38.4	39.5	-2.86
33.9	35.6	-5.01
43.8	43.3	1.14
40.2	40.9	-1.74
39.4	40	-1.52
48	47.2	1.67
43.4	43.6	-0.46
41.1	42	-2.19
51.5	49.7	3.50
43.6	44.3	-1.61
40.5	41.6	-2.72

The maximum percentage different in this simulation validation process is 15.1 %. This percentage is being benchmark in this project as a reference of validation. This is denoted as the reverse simulation.

Afterall, the result of the study is also studied and portray in Figure 2.12 and Figure 2.13.

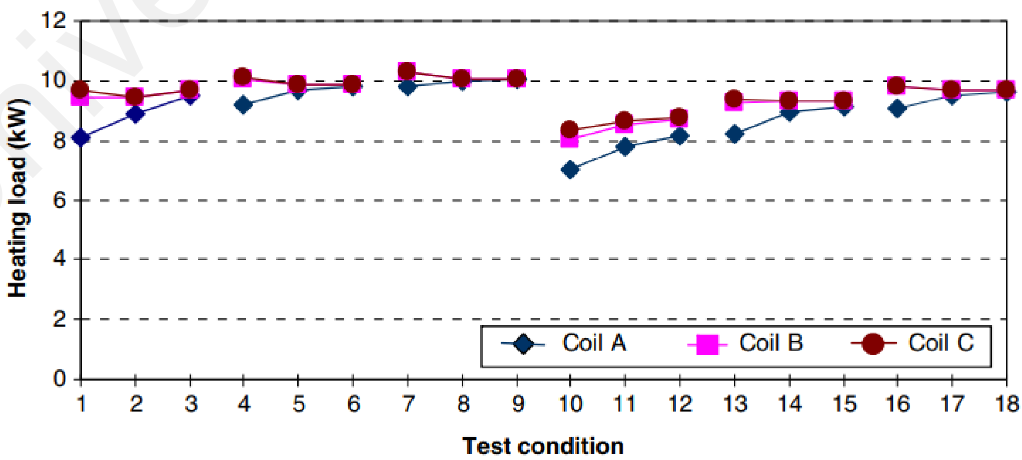

Figure 2.12: The head load for different Coils under different test condition 1-18 (Ge & Cropper, 2009).

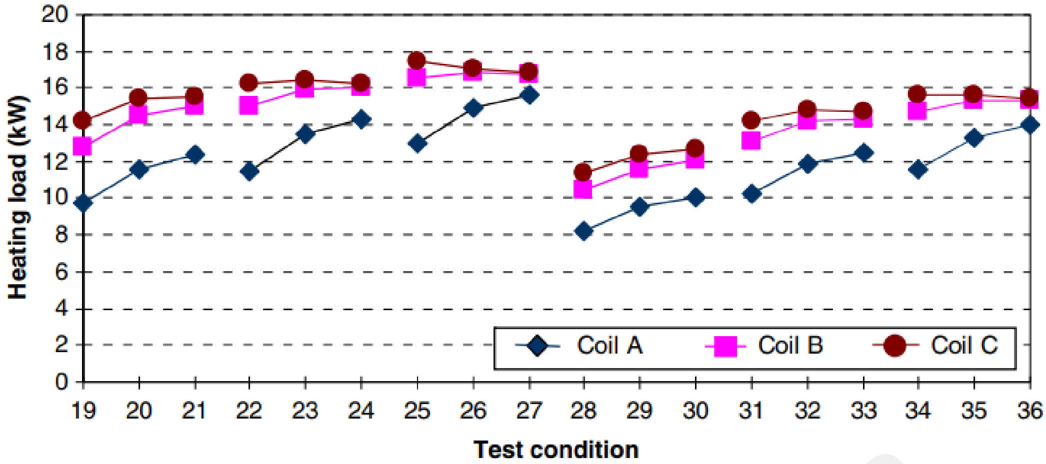

Figure 2.13: The head load for different Coils under different test condition 19-36 (Ge & Cropper, 2009).

By comparing the heat load acquired, it is found that Coil C has the higher capacity compare to Coil B. Whereas Coil B has the higher capacity compared to Coil A. The design of different is also studied and shown in Figure 2.14, Figure 2.15 and Figure 2.16.

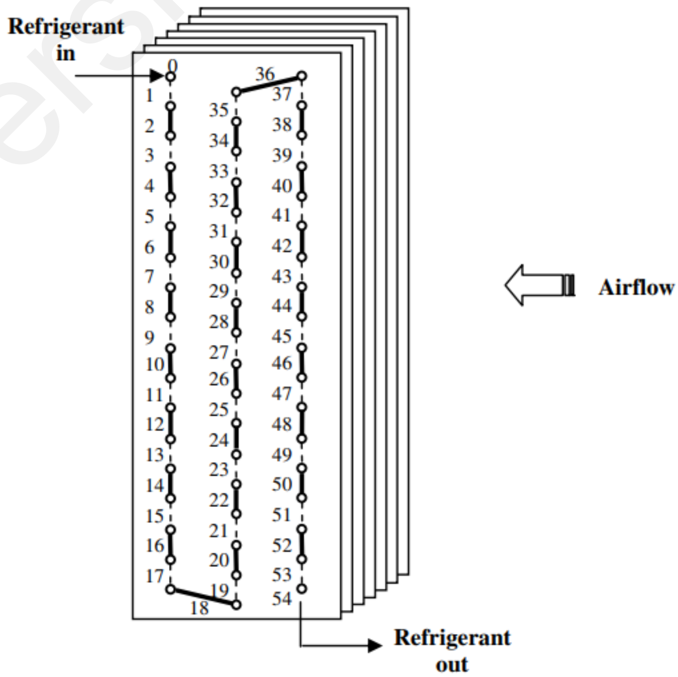

Figure 2.14: Circuit Design for Coil A (Ge & Cropper, 2009).

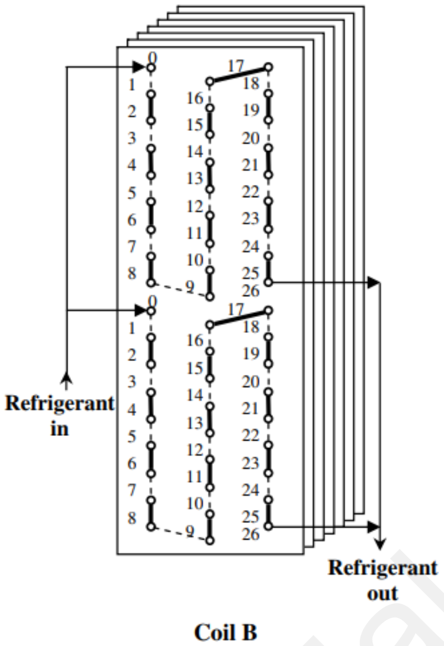

Figure 2.15: Circuit Design for Coil B (Ge & Cropper, 2009).

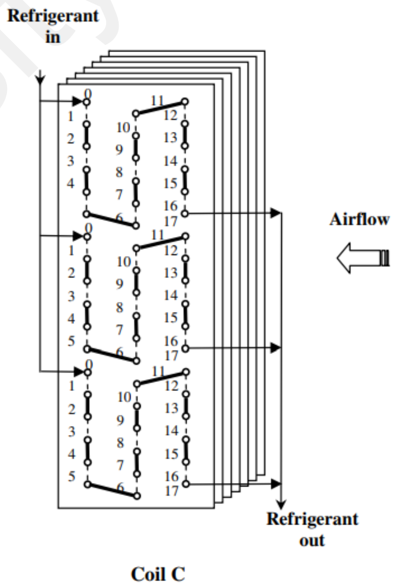

Figure 2.16: Circuit Design for Coil C (Ge & Cropper, 2009).

Overall, this study and its result suggested the increase in circuit number of the heat exchanger carried the possibilities of increase the capacity of the heat exchanger.

The research explained that it is due to the decrease in the approach temperature as shown in Figure 2.17.

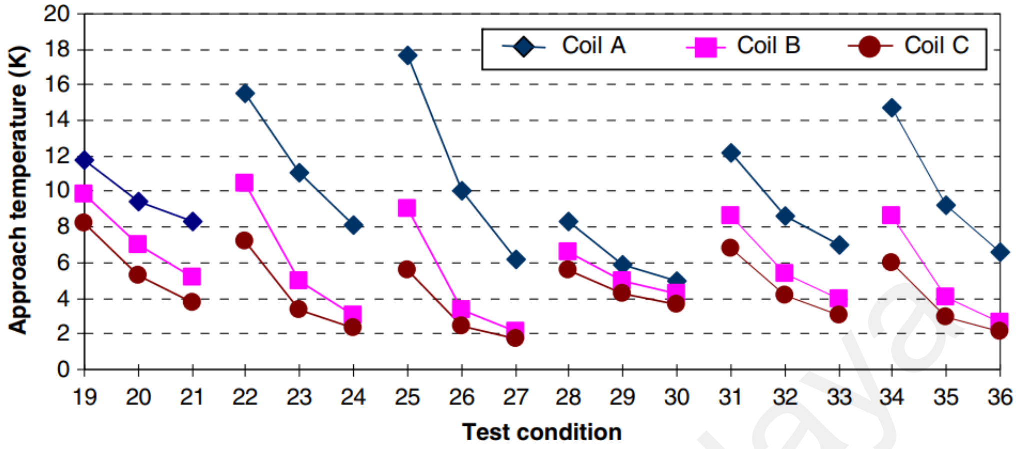

Figure 2.17: The Simulated Approach Temperature.

2.10.4 Analysis of the Influence of Circuit Arrangement on a Fin-Tube Condenser Performance (C. Joppolo et al., 2015).

The study has simulated various coil circuitry arrangement and the performance is predicted. 8 Condenser Circuitries as shown in Figure 2.18 is being analysed.

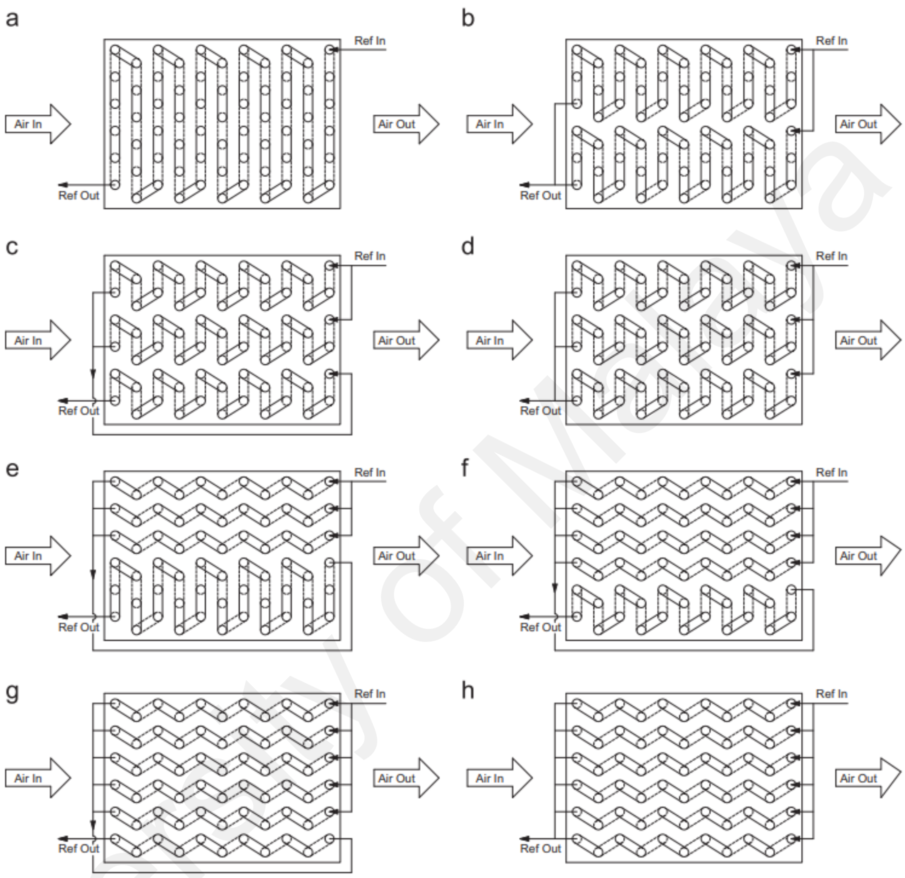

Figure 2.18: The 8 condenser circuitries (C. M. Joppolo, L. Molinaroli, & A. Pasini, 2015).

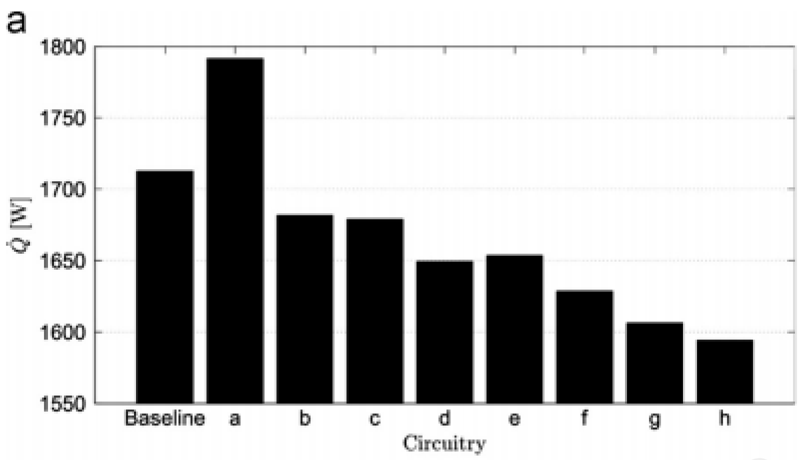

Figure 2.19: The 8 condenser circuitries heat transfer rate (C. M. Joppolo et al., 2015).

According to Figure 2.19, the heat transfer rate of different circuitry is displayed. In this research, it found that the heat transfer tend to reduce when the number of circuitry increase. The research proposed that it is due to the refrigerant is distributed to multiple circuits, the refrigerant flow in each circuit has a reduction in mass flow. Consequently, this reduce the convective heat transfer of it which resulted in the negative in overall heat transfer coefficient.

In this study, the validation process span for heat transfer is within the span of -3.06% to +4.09%. The research is justified to have a have a good capability in term of heat transfer prediction.

Besides, this research also pointed out that the counter flow configuration will be a better choice for heat exchanger.

2.10.5 Study of Three-Dimensional Plate-fin and Tube Heat Exchanger (Jang, Wu, & Chang, 1996)

The CFD study on the staggered circuit arrangement and in-lined circuit arrangement. Staggered (convergence) circuit arrangement and inclined arrangement is being simulated. The staggered and inlined configurations is shown in Figure 2.20.

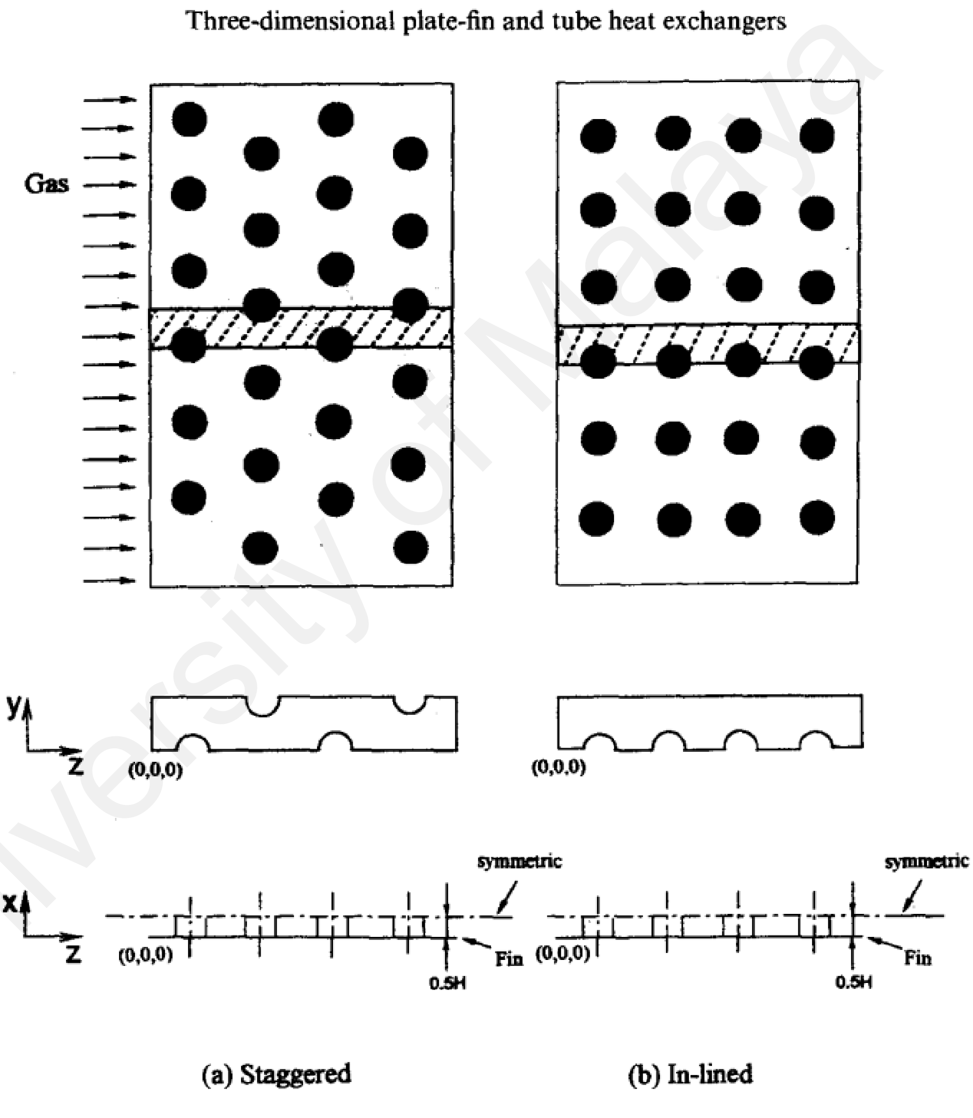

Figure 2.20: The Staggered Arrangement and In-line Arrangement Circuit Diagram (Sarpotdar, Nasuta, & Aute, 2016).

In the study, it is found that the average heat transfer coefficient for the stagger (convergence) arrangement is larger than in-lined arrangement. However, the pressure drop of the convergence arrangement is higher than in-lined configuration.

2.10.6 Investigation of Airside Performance of Slit Fin-Tube Heat Exchanger (Sarpotdar et al., 2016; Wang et al., 1999).

A study had performed to study the performance of slit fin and louver fin. The detail drawing of the fin compared is showed in Figure 2.21.

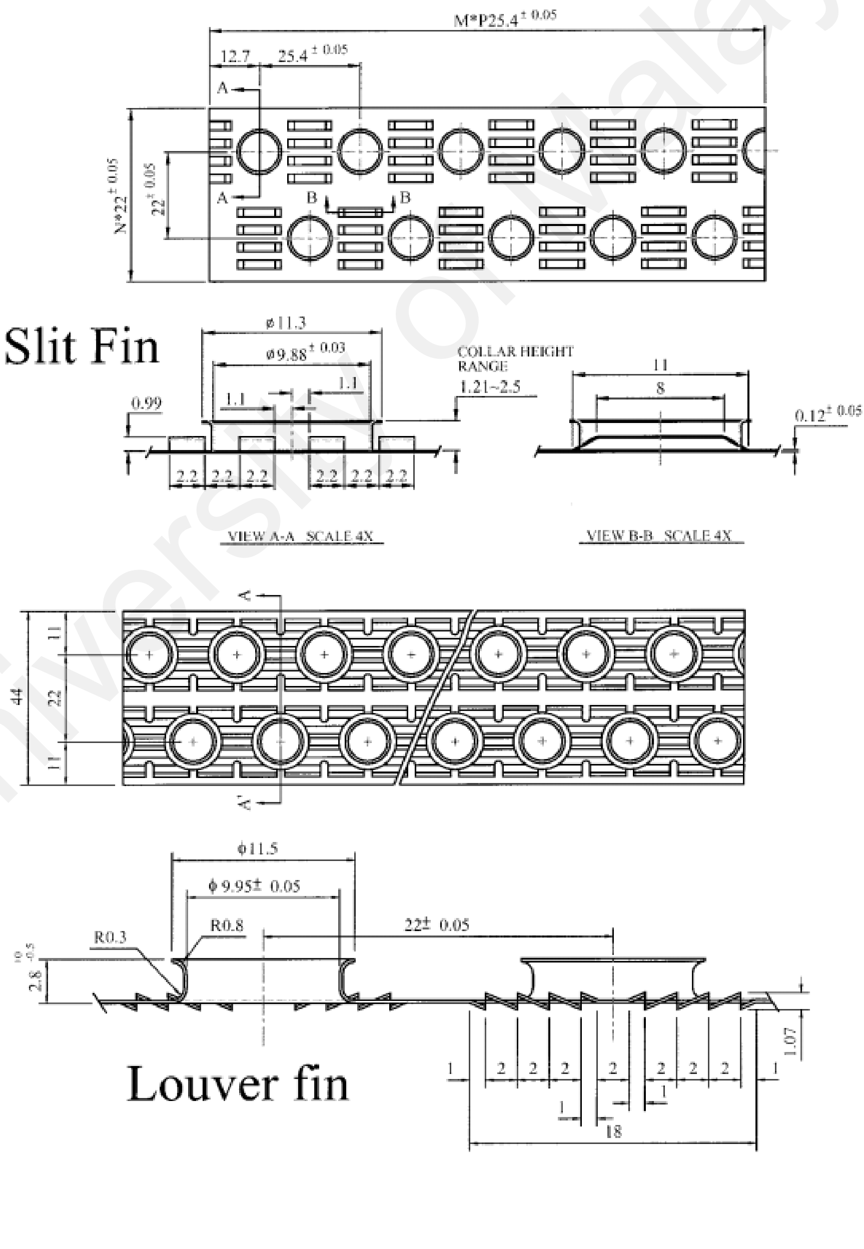

Figure 2.21: The Detail Drawing of Slit Fin and Louver Fin (Wang et al., 1999).

This study had found that fin pitch is an important parameter to slit fin but a less significant parameter to louver fin. It concluded that the louver performance is very independent to the fin pitch. It suggested that interrupted fin surface may induced a vortex circulation on a certain Reynold number. The vortex circulation may enhance the heat transfer. The fin pitch effect on the heat transfer is reversed when the fin pitch is getting small. In other word, the heat transfer will decrease at a certain extend despite the increment when the fin pitch is decreased. This might due to the turbulence stream is disappeared through the interpolate passage when the fin passage is very small.

Also, there is research suggested that the pressure drop induced by slit fins is lower than louver fins.

2.10.7 Conclusion

Overall, the circuit is possible to be enhanced and improved by referring various designs proposed in the research study of fellow researchers. Various design change had been proposed to improve the circuit by studying the respective theories. After all, the design is expected to be improved by increasing the number of circuits.

2.11 Coil Designer

CoilDesigner is an application used for common and basic simulation for the refrigerant-air heat exchanger. It is often used as a design tool for the refrigerant-air system's circuit. The application of computer model to substitude the conventional prototyping design method for the energy optimization where the energy standard and energy efficiency has become an important design criteria in this energy-hungry era. The computer model is said to be greatly improve on the time for the product design and development, reducing the cost due to a more efficient operation and also a better utilization on the energy efficient of the design system.

Most of the refrigerant-air heat exchanger used in the design of heat and ventilation unit is fin-tube heat exchanger and microchannel heat exchanger. The heat exchanger is basically performing the heat transfer between air and refrigerant fluid. With regards to its application, the types of fluid commonly used for the design of air conditioning, heat pump unit and refrigeration system are refrigerant, water, oil and etc.

In the design of such system, there are several considerations in which is then result in the inefficient analysis by using the conventional approaches. Estimating the performance of the systems or coils by using the conventional approaches of correlating the analytical analysis with the graphical design will then be less accurate and comprehensive. The geometry of the heat exchanger can go to the high degree of complexity in the design geometry. Variation of working consideration will then also contribute to the large set of analysis to be considered such as variation in airflow uniformity and also ambient temperature.

Besides, Coil Designer is enhancing its comprehensiveness by allowing the integrating performance with other computer computer software to enhance its' productivity as a HVAC design tools and greatly reduces the design cost of of research and development stage. The application itself also tend to allow the designer to enhance the rating of the heat exchanger (Jiang, Aute, & Radermacher, 2006).

2.12 Summary

In summary, the concept of improving the heat exchanger by changing the flow of circuitry had been studied by various researchers. The following design concept will be adopted in the subject of this research project in Chapter 3. Various information related to the heat exchanger of a air conditioning unit has also been mentioned in Chapter 2.

CHAPTER 3: METHODOLOGY

3.1 Modeling Approach

The modeling approach of this section will be correlate to the modeling methodology of the software. This chapter explained the methodology of adopting the software to perform study on the heat exchanger. The approaches are summarized in Figure 3.1.

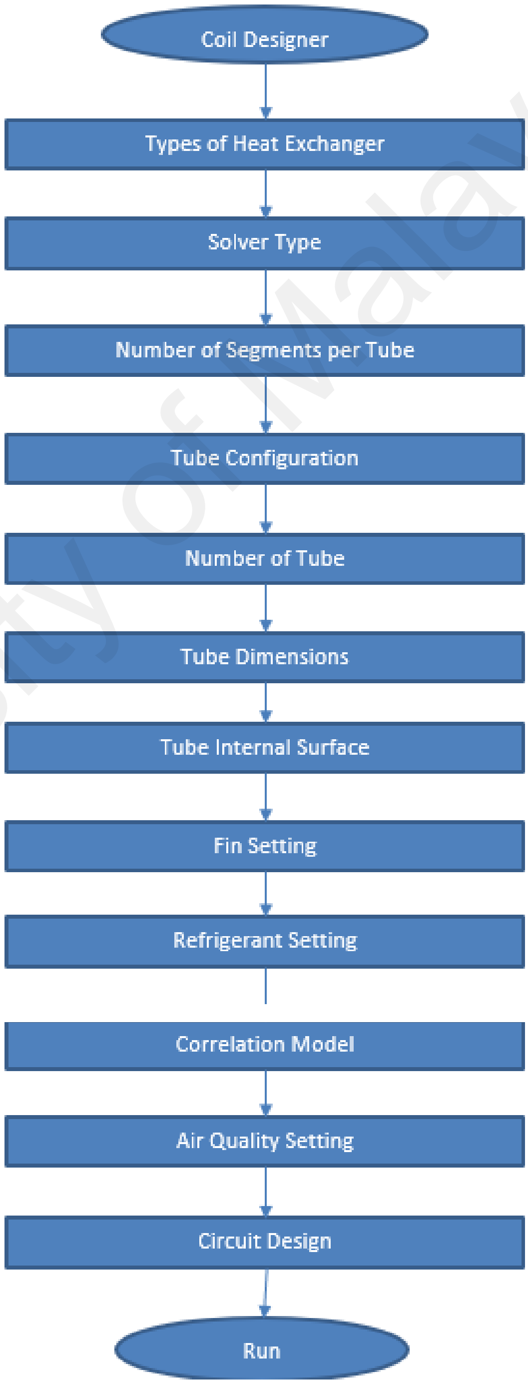

Figure 3.1: The Modelling Sequences for the Simulation.

3.1.1 Heat exchanger Modeling

First, the Fin-Tube Heat Exchanger is to be modelled as shown in Figure 3.2.

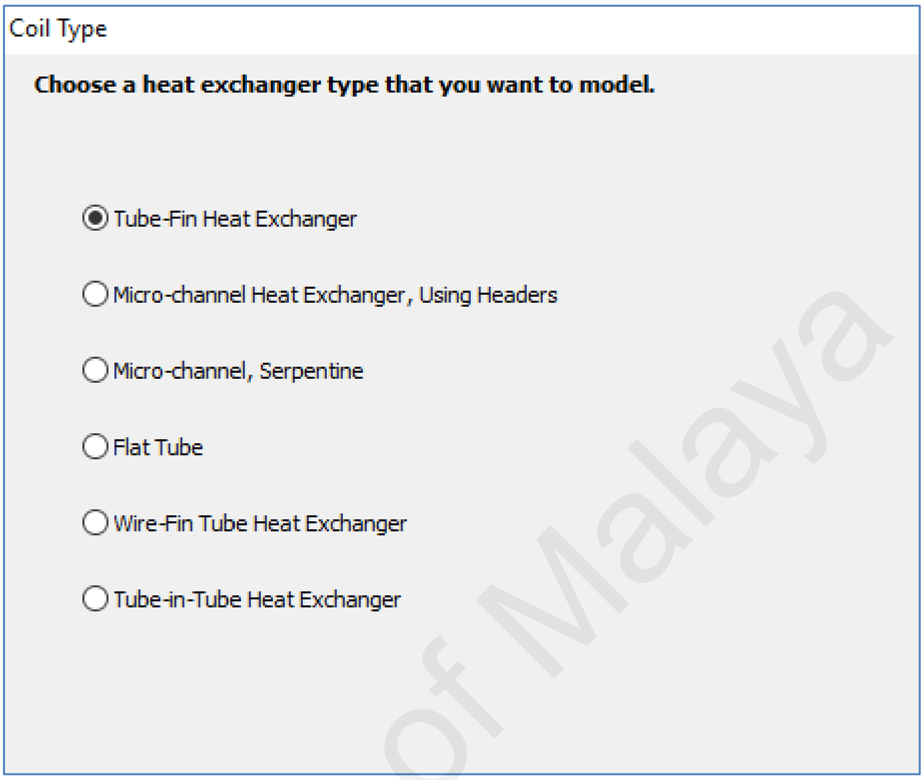

Figure 3.2 The Modeling Interface for Heat Exchanger Selection.

Fin-Tube Heat Exchanger is chosen as the design of the circuit is Fin-Tube Types. The types of Heat Exchanger is further elaborated in Literature Review Section.

3.1.2 Solver Type Modeling

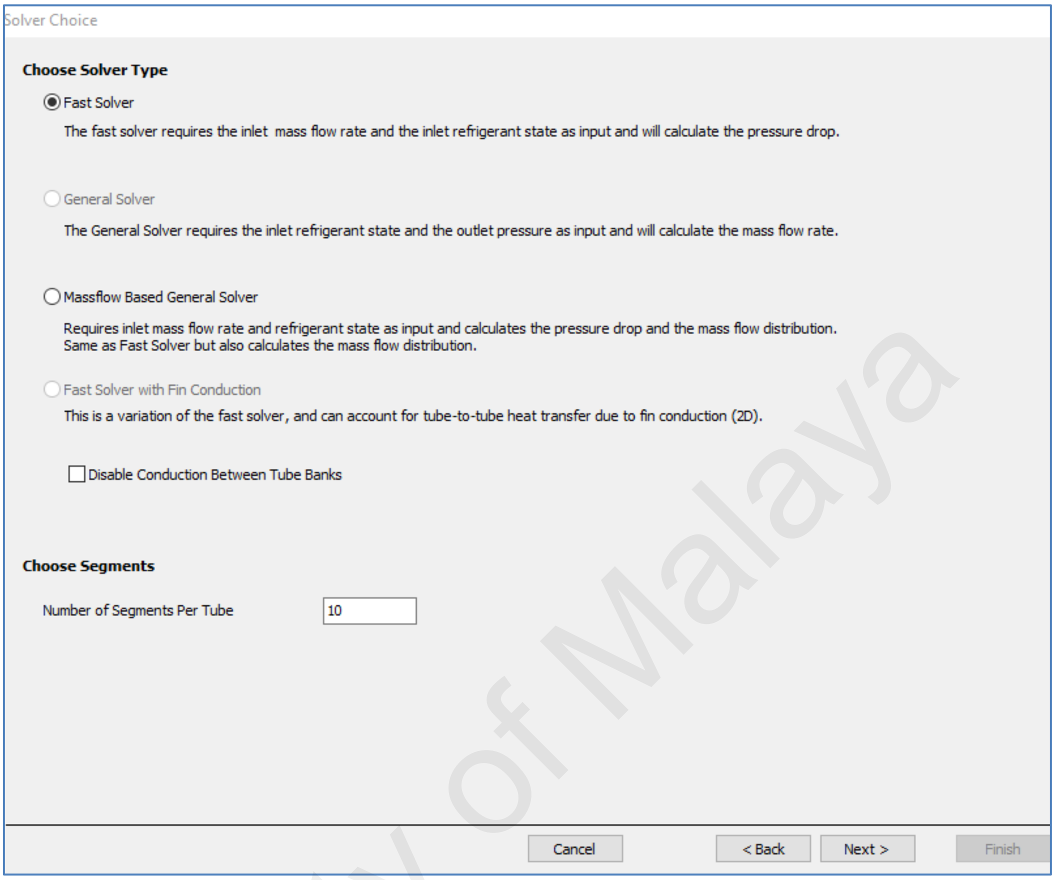

Figure 3.3: The Setting Interface for Solver Type.

Select the fast solver type for the simulation to acquire the preliminiary outcome as shown in Figure 3.3.

The segments is selected to act as the mesh of the simulation. The segment will segregate the air flow inlet to multiple sections for the calculation.

3.1.3 Heat Exchanger Hairpin Configuration Modeling

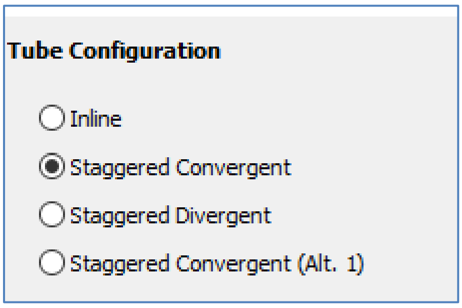

Figure 3.4: The Selection Interface for Tube Configuration.

The Convergent Tube Configuration is selected as the 2 rows coils is arranged in such a way of convergence layout as shown in Figure 3.4.

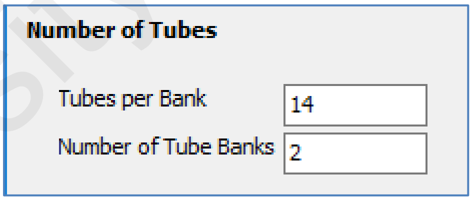

Figure 3.5: The Setting Interface for Number of Tube Height and Row.

The Tubes per Bank refer to the number of tube consisted in each row. In other word, the number tube per bank can also be referred as tube height in technical term. Whereas for the number of tube banks, it refers to the number of rows in the heat exchanger. In this original design, there is total 14 tube heights in each row. The 2 rows coil is used in this design. Figure 3.5 is referred.

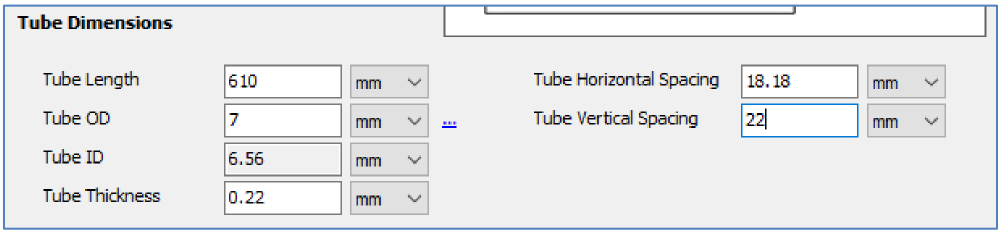

Figure 3.6: The Setting Interface for the Tube Dimension.

Tube dimension is specified in the Figure 3.6. The tube length is regarded as the length of hairpin. However, the absolute length of the hairpin cannot be used. The effective length of heat transfer is assumed to be consider as the tube length. As such, the fin length of the coil which is referring to the length of the fin accumulated on the coil is used. In this design, the fin length is 610mm long. For the tube outer diameter, it is referring to the outer diameter of the fin-tube heat exchanger. As such, the outer diameter will depends on the raw material used to produce the hairpin for the heat exchanger. The tube thickness also solely depends on the raw material of the copper tube used for the hairpin of the heat exchanger. In this design, the copper tube used to produce the heat exchanger has the outer diameter of 7mm and the copper tube wall thickness of 0.22mm. This will result in the hairpin copper tube inner diameter of 6.56mm. The Tube Horizontal Spacing refer to the distance between 2 hairpin is arranged. One hairpin is inserted vertical and another row of hairpin is adopted side-by-side. Hence, the tube horizontal spacing will then refer to the distance between 2 vertical hairpin. The distance will be controlled by the width of the fin as the fin will attach closely next to each other. As one fin width is 18.18mm, the tube horizontal spacing is 18.18mm. The vertical spacing of the tube will then be referring to the dimension of hairpin manufactured. The Vertical spacing of the hairpin is 22mm according to the hairpin design dimension.

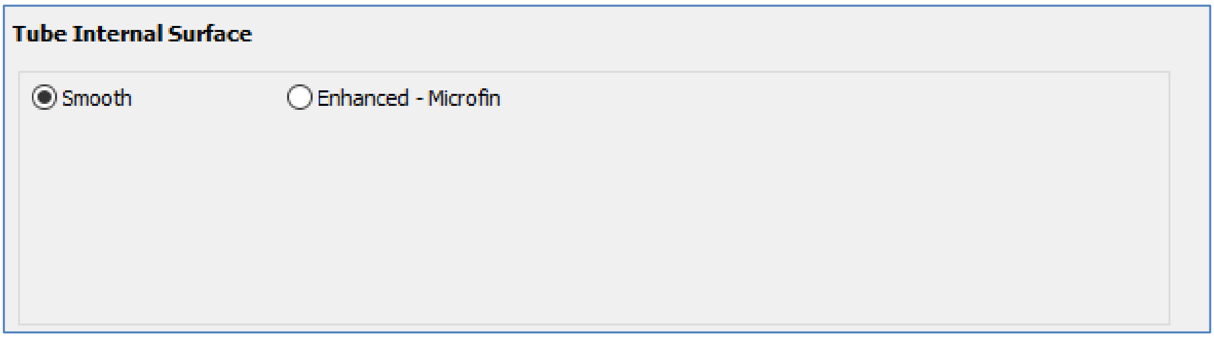

Figure 3.7: The Setting Interface for the Tube Inner Surface

The tube inner surface is inner grove and is selected as shown in Figure 3.7. However, the smooth tube internal surface is assumed in the earlier stage of simulation.

3.1.4 Fin Modeling

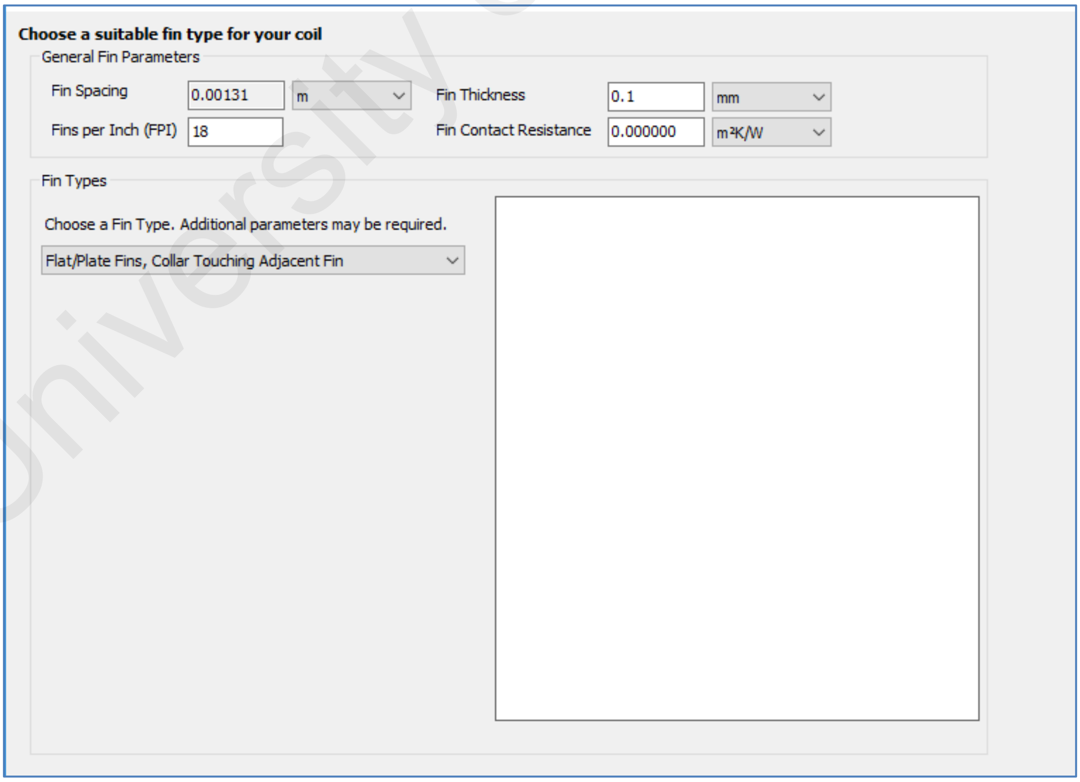

Figure 3.8: The Modeling Interface for the Fin.

The fin per inch of the coil will be regarded by the fin pith. The pin pitch will then be controlled by the collar height during the stamping process of the fin. The fin thickness is relying on the raw material used for the fin. The fin thickness is then be 0.1mm. As the fin will touching each other by the collar, the collar touching adjacent fin will be selected. The selection is shown in Figure 3.8.

3.1.5 Refrigerant Modeling

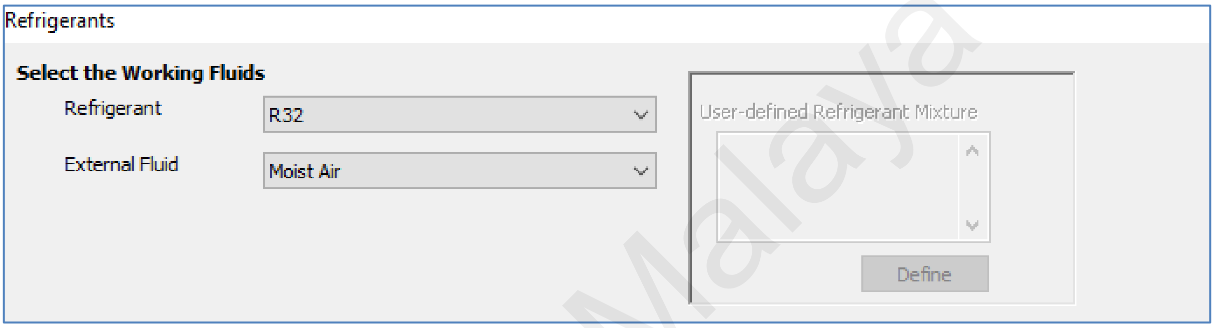

Figure 3.9: The Setting Interface for the Refrigerant Input.

The unit is running with the refrigerant of R32 and the external fluid used is moist air as the surrounding is the air with humidity as shown in Figure 3.9. The properties of R32 refrigerant have been stored in the system.

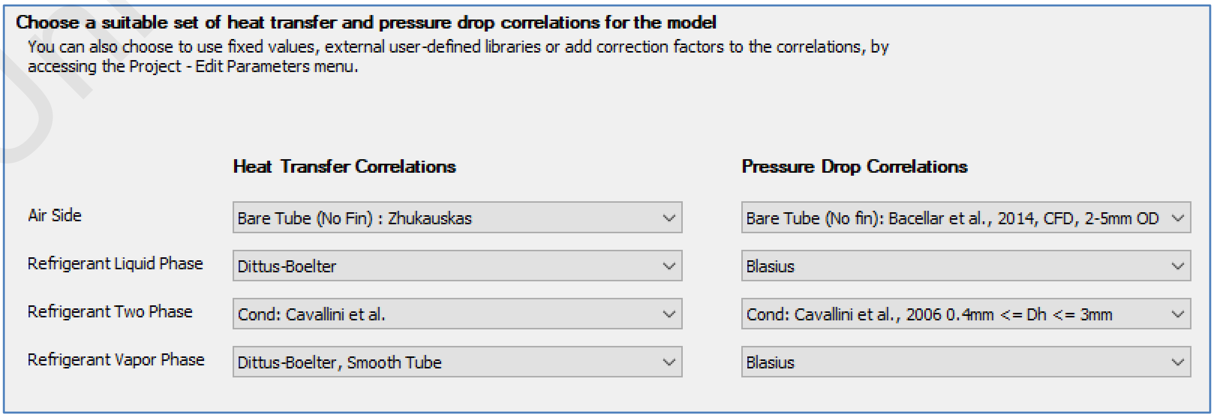

Figure 3.10: The Setting Interface for the Correlation.

Preliminary set of correlation is used for the correlation study as displayed in Figure 3.10.

3.1.6 Circuit Modeling

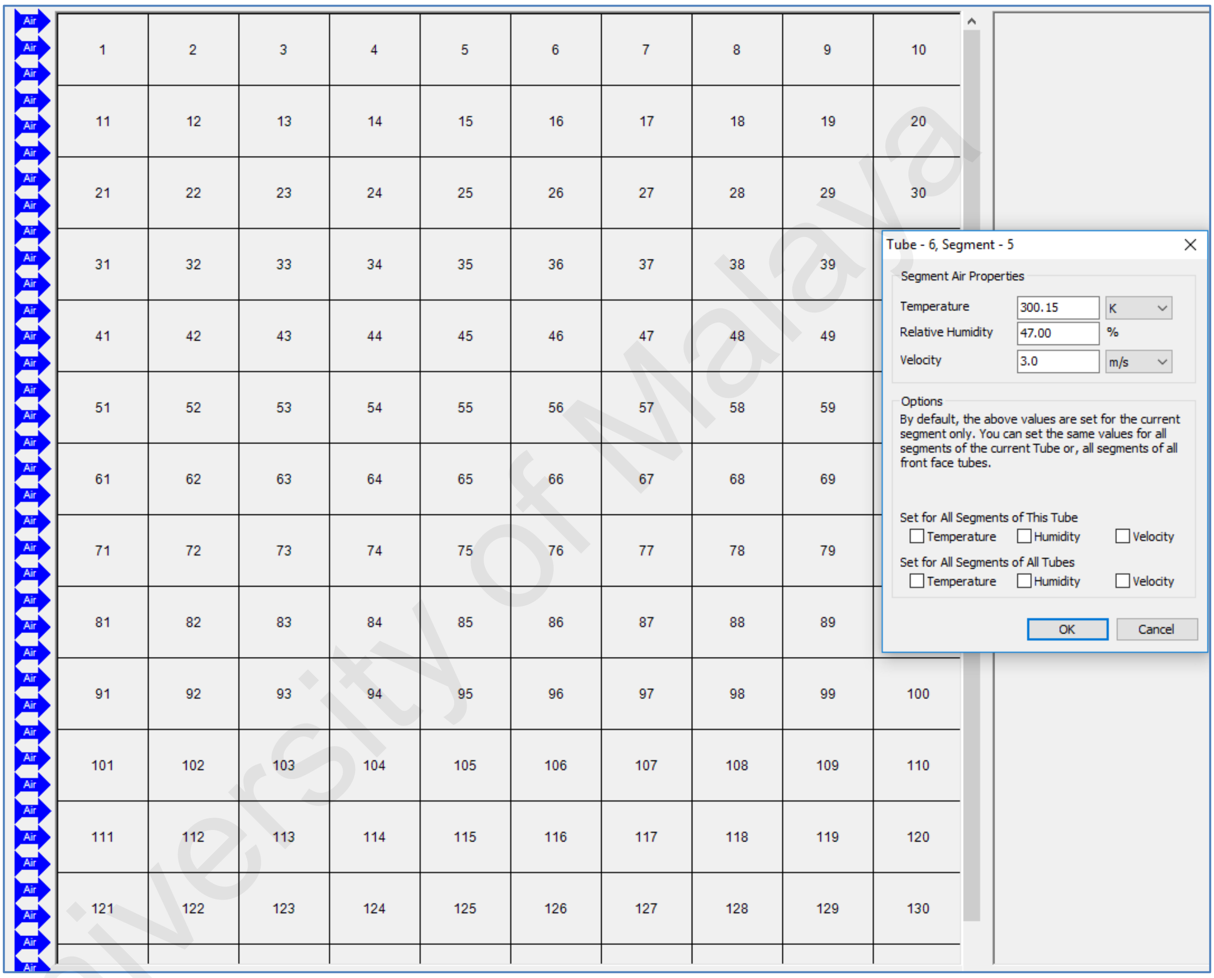

Figure 3.11: The Setting Interface for the Air Inlet Properties.

Input all the air inlet property into the system is inserted as in Figure 3.11. According to ISO5151, the indoor inlet temperature is set to 27 Dry Bulb and 19 Wet Bulb. By using physchometric converter, the relative humidity is 46.9%.

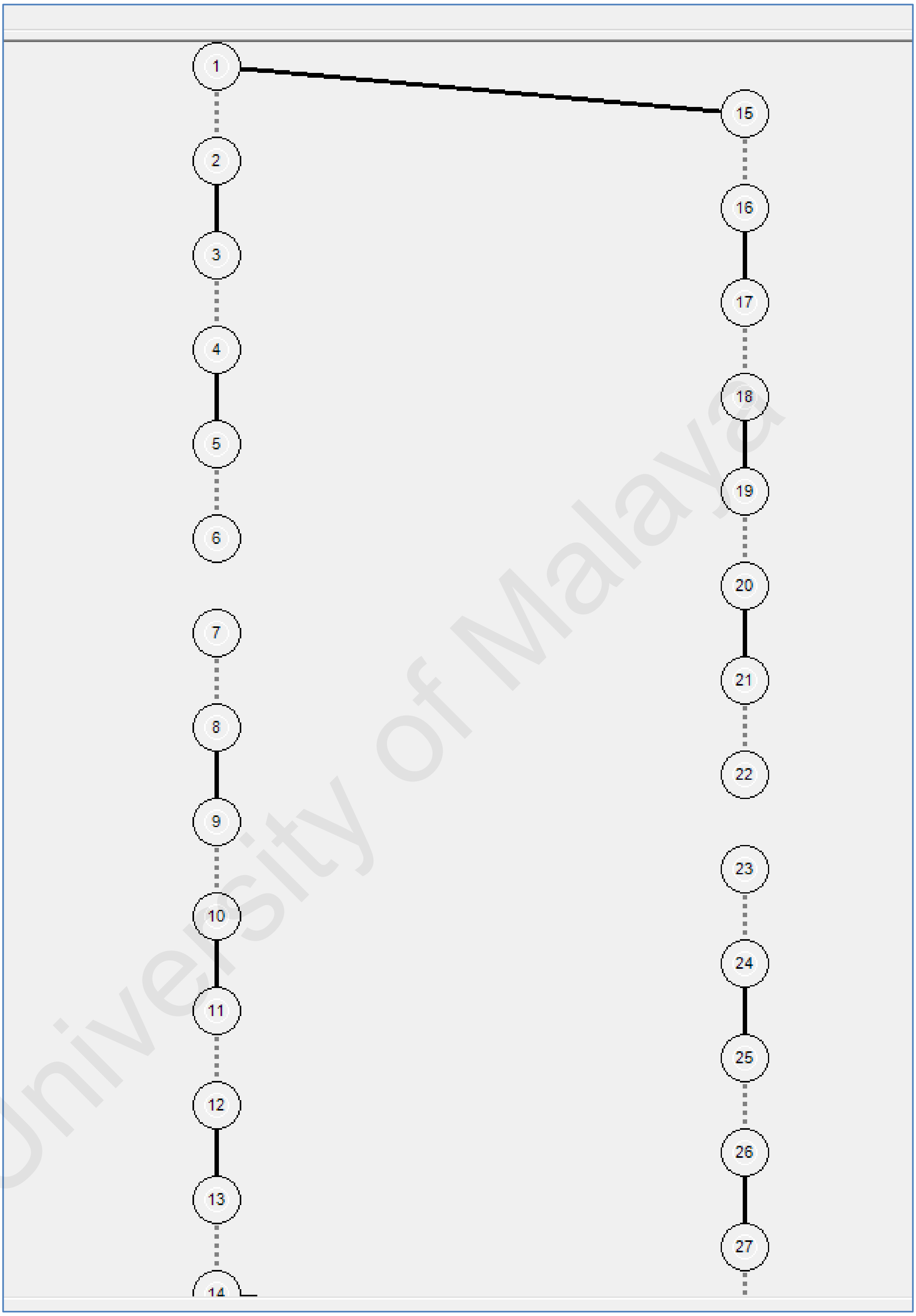

Figure 3.12: The Circuit Modeling for the Heat Exchanger.

The circuit of the heat exchanger is being modelled as shown in Figure 3.12.

3.1.7 Air Flow Modeling

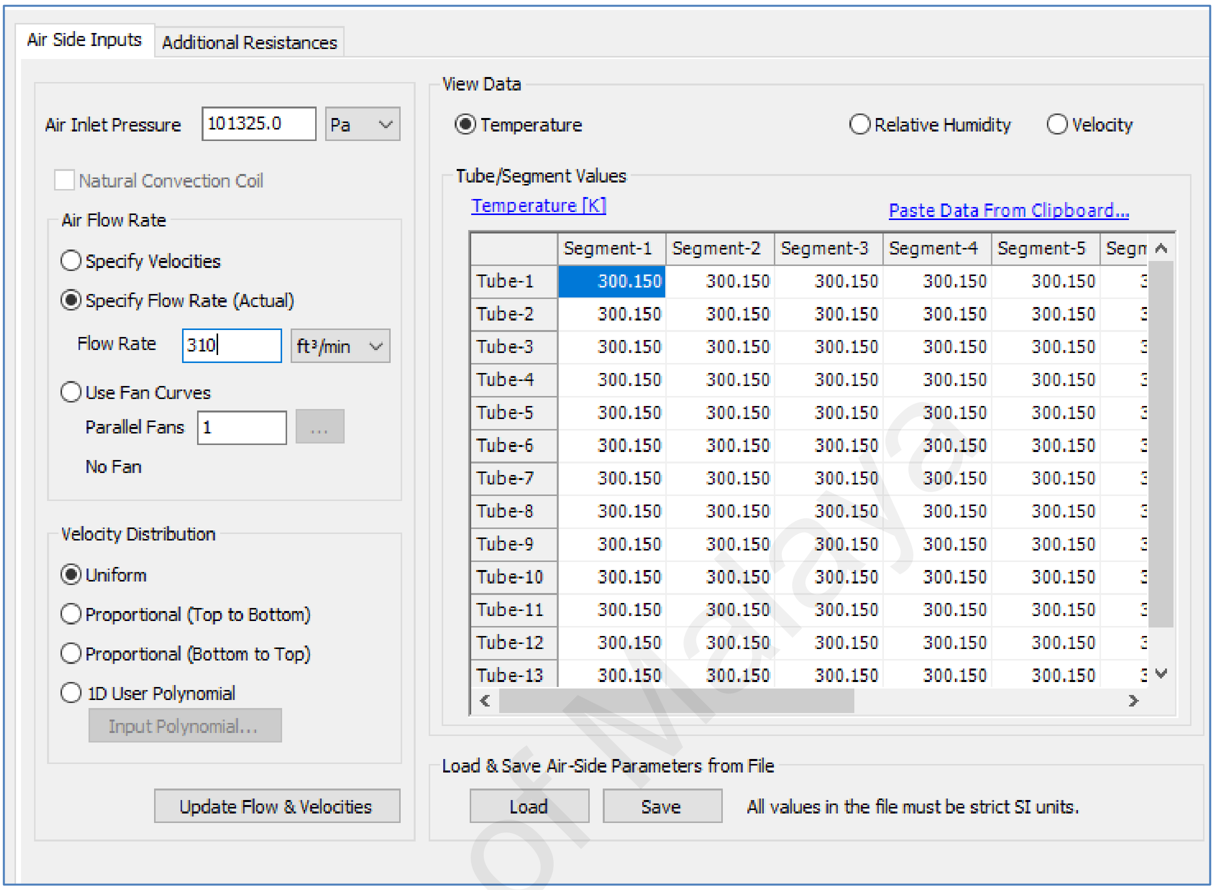

Figure 3.13: The Air Volume Flow Rate Specification.

The inlet air is refined by insert the actual CFM. The distribution is assumed to be normally distributed as displayed in Figure 3.13.

3.1.8 Summary

Overall, the software methodology has been discussed in this chapter. The approaches to apply the software had been discussed. The simulation can be performed by following the modeling approaches.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Reverse Simulation

The reverse simulation is conducted to validate the constructed model. The result is compared with the result obtained from the experiment in accordance to ISO5151. The capacity is compared between the simulation and the actual testing.

4.1.1 Reverse Simulation Set 1

The Setting for Set 1 reverse simulation is as Table 4.1.

Table 4.1: The Input Setting for Reverse Simulation Set 1.

Parameters	Values
T evap in	8.39 °C
P evap in	163.28 psig
Air Volume Flow Rate	313.57 cfm

Table 4.2: The Capacity Acquired from the Simulation.

Heat Loads						
Total Heat Load	2978.7933	W	2978.7933	W	10164.0672	Btu/hr
Sensible Heat Load	2419.4893	W	2419.4893	W	8255.6420	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.2.

4.1.2 Reverse Simulation Set 2

The Setting for Set 2 reverse simulation is as Table 4.3.

Table 4.3: The Input Setting for Reverse Simulation Set 2.

Parameters	Values
T evap in	7.89 °C
P evap in	160.05 psig
Air Volume Flow Rate	328.67 CFM

Table 4.4: The Capacity Acquired from the Simulation.

Heat Loads						
Total Heat Load	3214.4687	W	3214.4687	W	10968.2252	Btu/hr
Sensible Heat Load	2568.6397	W	2568.6397	W	8764.5647	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.4.

4.1.3 Reverse Simulation Set 3

The Setting for Set 1 reverse simulation is as Table 4.5.

Table 4.5: The Input Setting for Reverse Simulation Set 3.

Pameters	Values
T evap in	7.57 ºC
P evap in	157.9 psig
Air Volume Flow Rate	330.4 cfm

Table 4.6: The Capacity Acquired from the Simulation.

Heat Loads						
Total Heat Load	3246.4777	W	3246.4777	W	11077.4445	Btu/hr
Sensible Heat Load	2580.7300	W	2580.7300	W	8805.8185	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.6.

4.1.4 Reverse Simulation Set 4

The Setting for Set 4 reverse simulation is as Table 4.7.

Table 4.7: The Input Setting for Reverse Simulation Set 4.

Pameters	Values
T evap in	7.48 ºC
P evap in	156.6 psig
Air Volume Flow Rate	315.68 cfm

Table 4.11: The Capacity Acquired from the Simulation.

Heat Loads						
Total Heat Load	3247.2548	W	3247.2548	W	11080.0959	Btu/hr
Sensible Heat Load	2536.8627	W	2536.8627	W	8656.1369	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.11.

4.1.5 Reverse Simulation Summary

The reverse simulation had been performed to validate the model constructed to perform the study on this optimization project. One of the similar technique used in one of the research to validate the actual and simulated condition is inserting the condenser inlet pressure, temperature and the compare the outlet air temperature (Datta, Das, & Mukhopadhyay, 2016). The condenser inlet pressure, temperature is input to the simulation and the capacity acquired is being compared from the simulation. The similar method had been used in research to validate the simulation result validity. The compiled result for reverse simulation is shown in Table 4.9.

Table 4.9: Compiled Result for Reverse Simulation.

Reverse	Capacity			Sensible Heat		
	Actual (Btu/hr)	Simualted (Btu/hr)	% Diff	Actual (Btu/hr)	Simualted (Btu/hr)	% Diff
1	10146.7	10688.3	5.34	8177.24	8247.6	0.86
2	10968.23	11062.55	0.85	8316.175	8764.56	5.39
3	11065.42	11344.27	2.52	8445.27	8807.1	4.28
4	11397.97	11080.1	-2.79	8438.938	8656.14	2.57

As compared with the result acquired with experiment, the simulated result processes some deviation. The different is fall into acceptable range with the span of -2.79% to 5.34% in the simulated different. The benchmark of the acceptable range is benchmarks as 15% by reviewing the literature as specified in *Section 2.10.3* (Ge & Cropper, 2009). Also, there is research justify the model with the span of -3.06% to 4.09% as a reliable model as stated in the *Section 2.10.4* (C. M. Joppolo et al., 2015).

Hence, with this validation process and result, the model established can be justified as reliable model.

4.2 Forward Simulation

Forward Simulation is performed on various design based on the proposed design improvement. The capacity after the design change is investigated by using the previous validated reserve simulation model.

4.2.1 Forward Simulation Set 1

The circuit for the heat exchanger is changed to the following configuration in Figure 4.1:

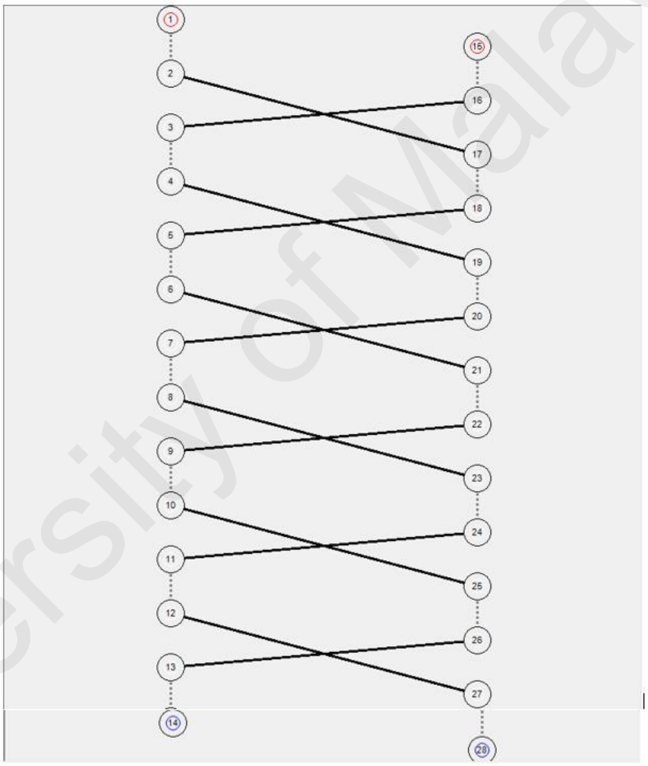

Figure 4.1: The Circuit Design for Forward Simulation Set 1.

Table 4.10: The Capacity Acquired from the Simulation.

Heat Loads								
Total Heat Load	3277.1300	W			3277.1300	W	11182.0345	Btu/hr
Sensible Heat Load	2543.6661	W			2543.6661	W	8679.3510	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.10.

4.2.2 Forward Simulation Set 2

The circuit for the heat exchanger is changed to the following configuration in Figure 4.2:

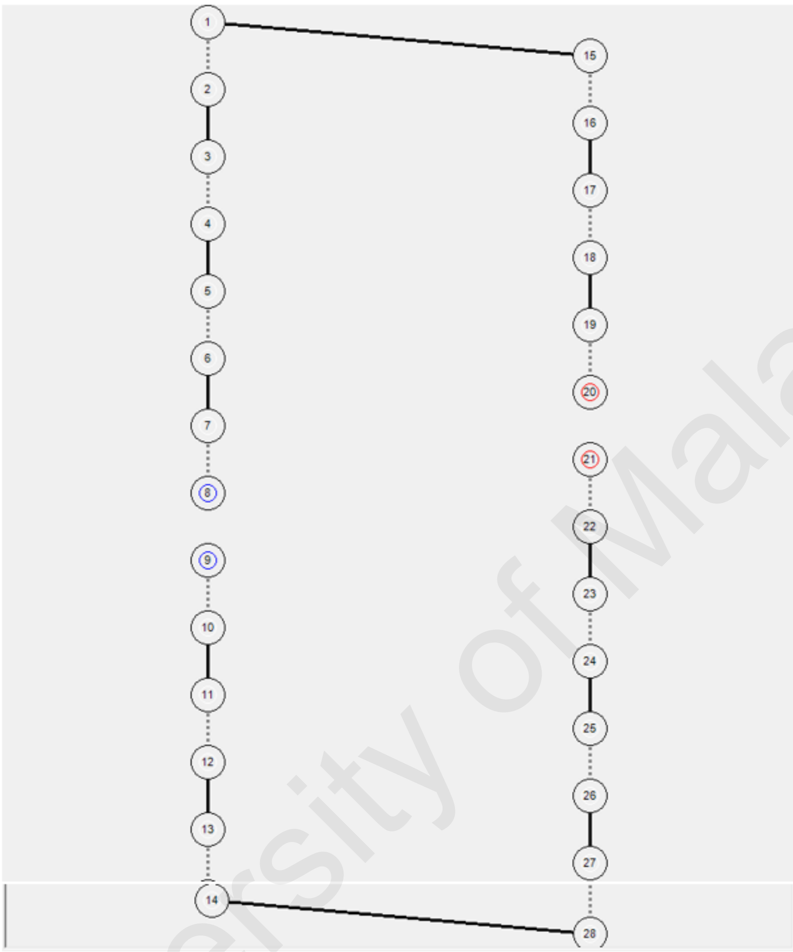

Figure 4.2: The Circuit Design for Forward Simulation Set 2.

Table 4.11: The Capacity Acquired from the Simulation.

Heat Loads								
Total Heat Load	3258.7590	W			3258.7590	W	11119.3500	Btu/hr
Sensible Heat Load	2541.9811	W			2541.9811	W	8673.6017	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.11.

4.2.3 Forward Simulation Set 3

The circuit for the heat exchanger is changed to the following configuration in Figure4.20:

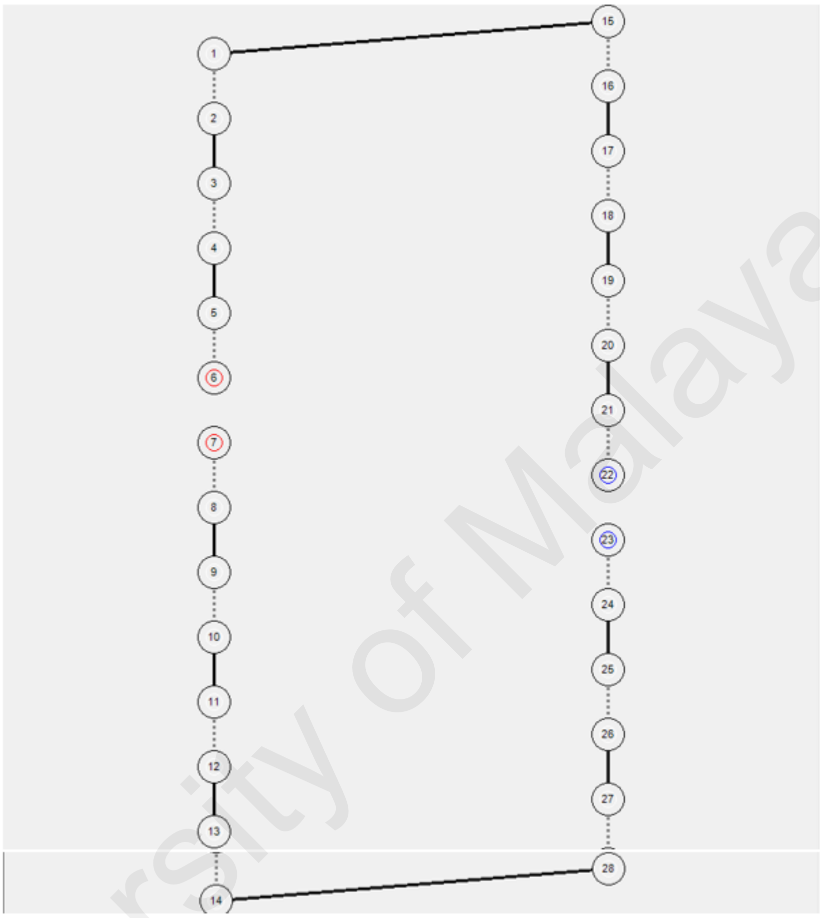

Figure 4.3: The Circuit Design for Forward Simulation Set 3.

Table 4.12: The Capacity Acquired from the Simulation.

Heat Loads								
Total Heat Load	3235.6060	W			3235.6060	W	11040.3484	Btu/hr
Sensible Heat Load	2534.1381	W			2534.1381	W	8646.8401	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.12.

4.2.4 Forward Simulation Set 4

The circuit for the heat exchanger is changed to the following configuration in Figure 4.4.

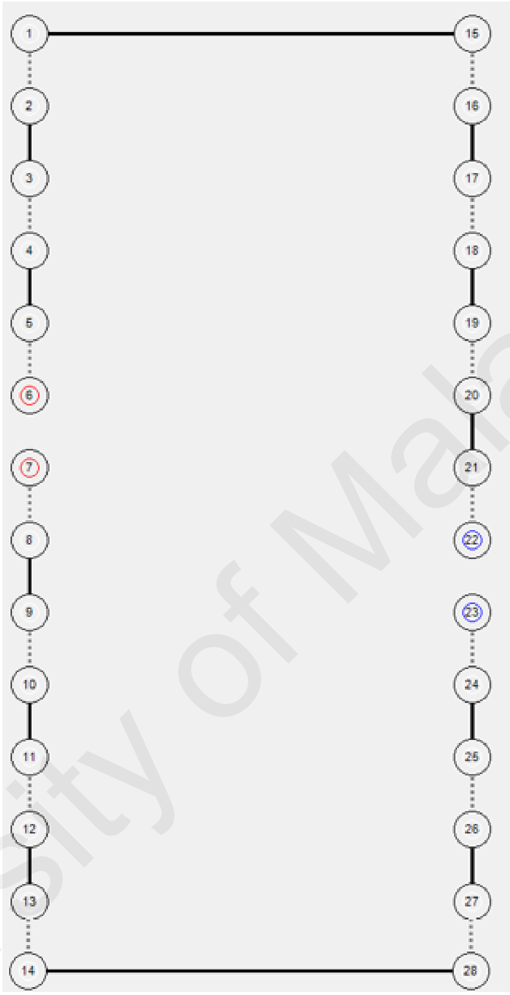

Figure 4.4: The Circuit Design for Forward Simulation Set 4.

Table 4.13: The Capacity Acquired from the Simulation.

Heat Loads								
Total Heat Load	3234.2794	W			3234.2794	W	11035.8219	Btu/hr
Sensible Heat Load	2538.3716	W			2538.3716	W	8661.2855	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.13.

4.2.5 Forward Simulation Set 5

The circuit for the heat exchanger is changed to the following configuration in Figure 4.5.

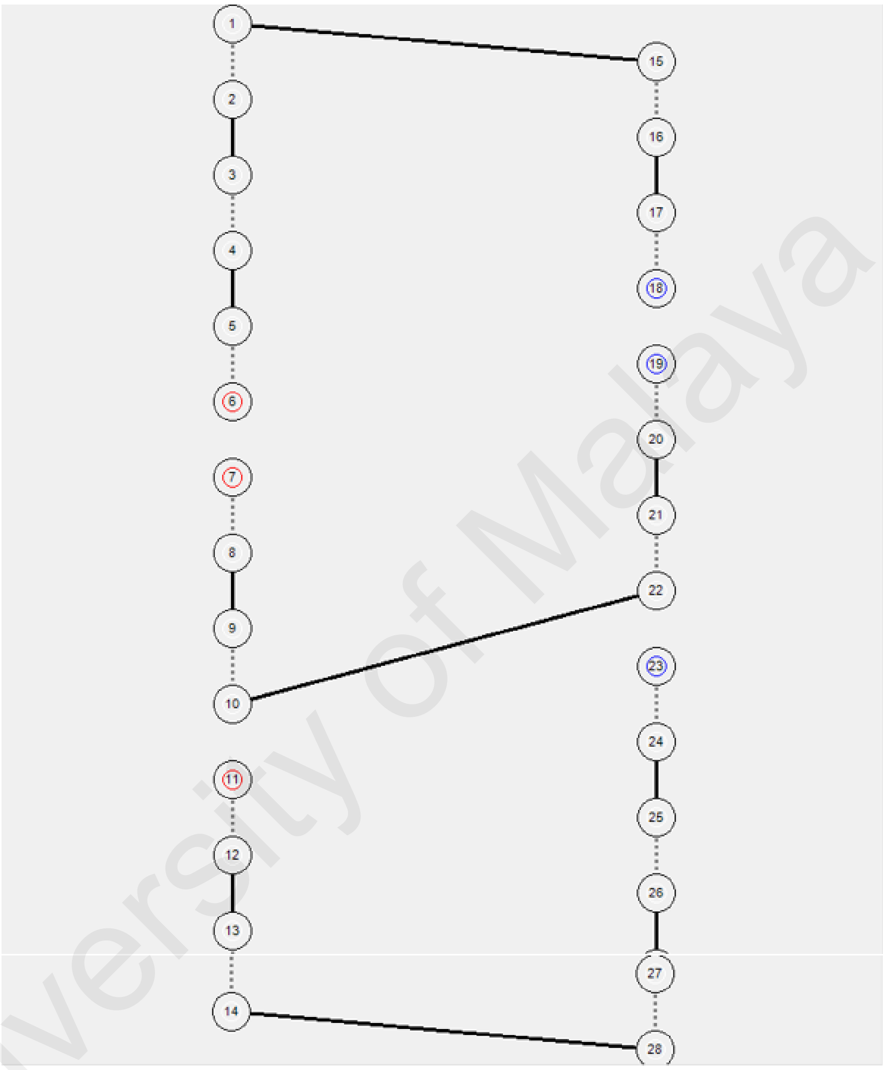

Figure 4.5: The Circuit Design for Forward Simulation Set 5.

Table 4.14: The Capacity Acquired from the Simulation.

Heat Loads								
Total Heat Load	3351.2949	W			3351.2949	W	11435.0955	Btu/hr
Sensible Heat Load	2636.1842	W			2636.1842	W	8995.0359	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.14.

4.2.6 Forward Simulation Set 6

The circuit for the heat exchanger is changed to the following configuration in Figure 4.6.

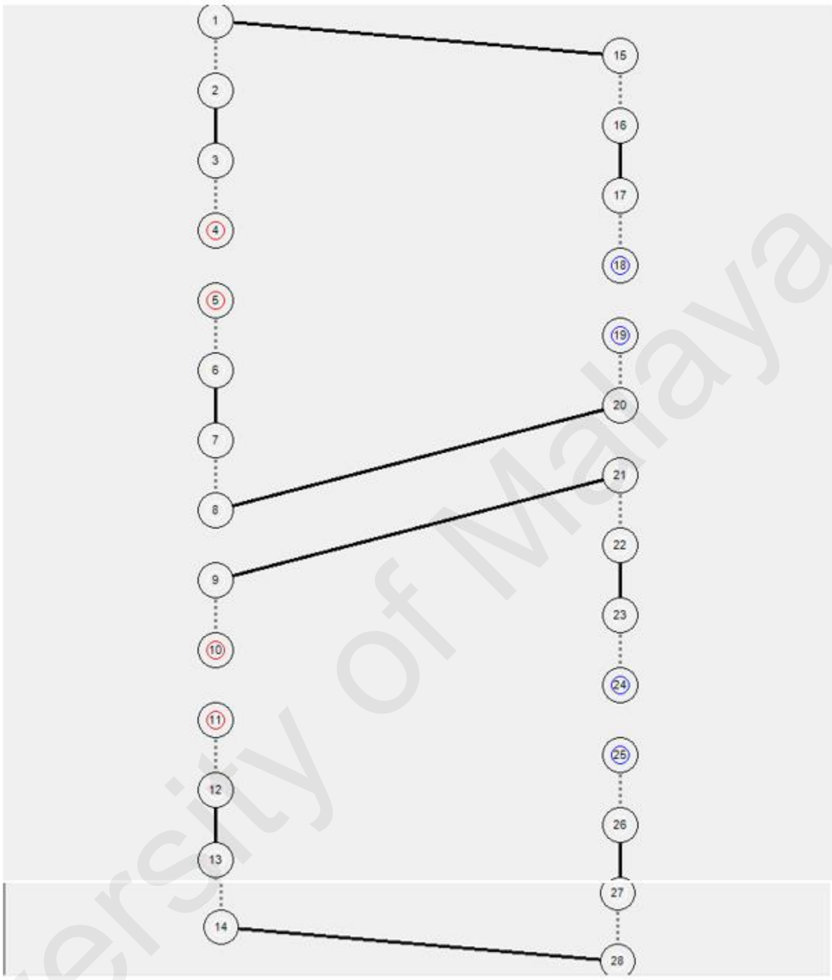

Figure 4.6: The Circuit Design for Forward Simulation Set 6.

Table 4.15: The Capacity Acquired from the Simulation.

Heat Loads						
Total Heat Load	3209.7576	W	3209.7576	W	10952.1501	Btu/hr
Sensible Heat Load	2575.1218	W	2575.1218	W	8786.6825	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.15.

4.2.7 Forward Simulation Set 7

The circuit for the heat exchanger in set 5 is selected to apply slit fin as in Figure 4.7.

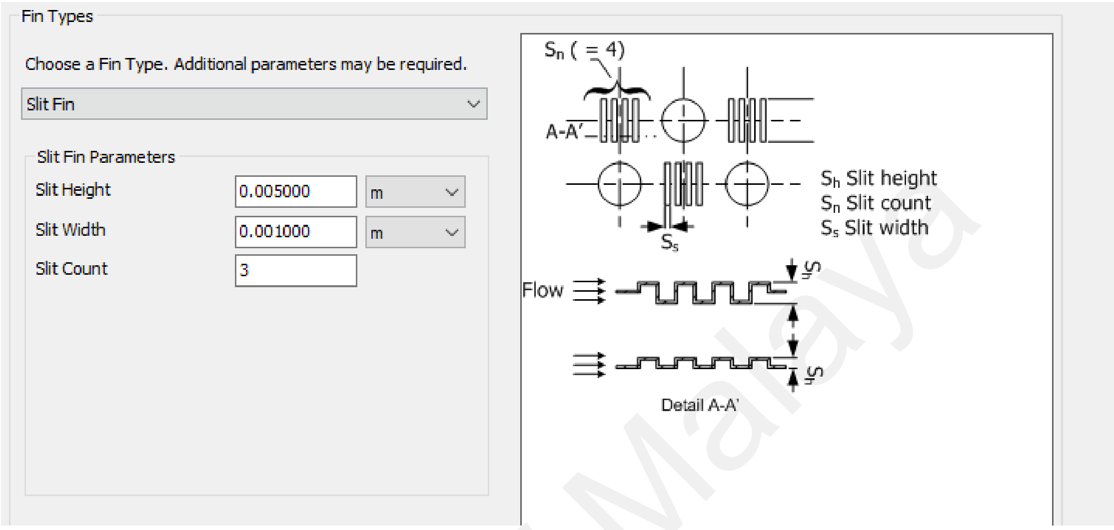

Figure 4.7: The Fin Setting for the Circuit Design Set 7.

Table 4.16: The Capacity Acquired from the Simulation.

Heat Loads						
Total Heat Load	3521.9445	W	3521.9445	W	12017.3763	Btu/hr
Sensible Heat Load	2745.1626	W	2745.1626	W	9366.8860	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.16.

4.2.8 Forward Simulation Set 8

The circuit for the heat exchanger in set 5 is selected to apply wavy louver fin as in Figure 4.8.

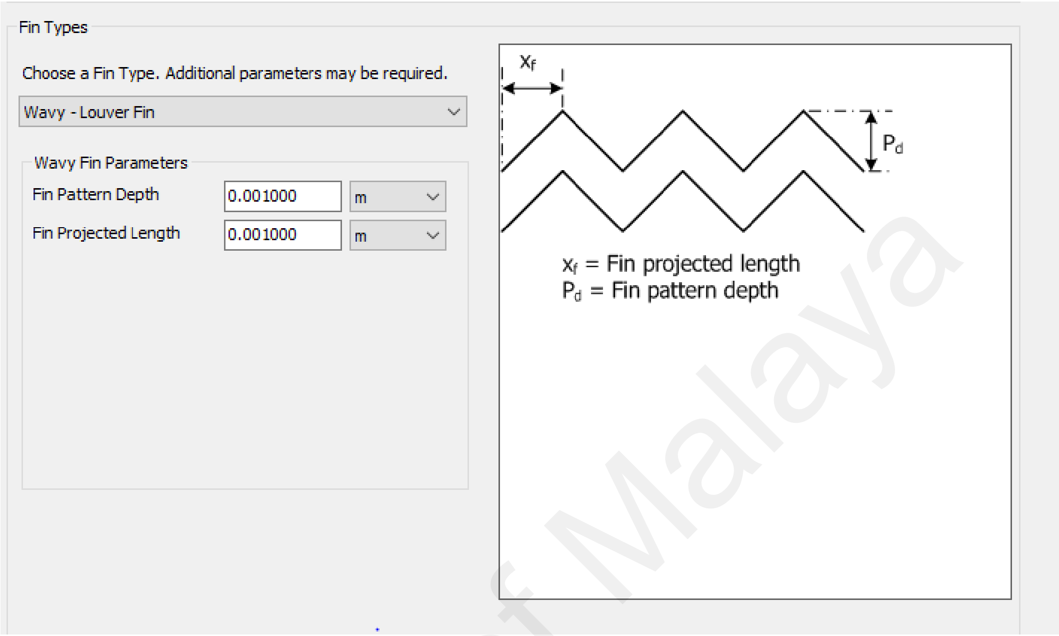

Figure 4.8: The Fin Setting for the Circuit Design Set 8.

Table 4.17: The Capacity Acquired from the Simulation.

Total Heat Load	3424.1649	W			3424.1649	W	11683.7384	Btu/hr
Sensible Heat Load	2685.5617	W			2685.5617	W	9163.5192	Btu/hr
Latent Heat Load	738.6032	W			738.6032	W	2520.2192	Btu/hr

The result of the capacity is acquired and displayed in simulation as in Table 4.17

4.2.9 Forward Simulation Summary

After the validity of the model is being justified, the model is used to predict the performance of different circuitry. Several circuit is being proposed and the performance is being predicted using the simulated model. The compilation of forward simulation is being portrayed in Table 4.18.

Table 4.18: The Compilation Result for the Forward Simulation

circuit	Capacity			Sensible Heat		
	Original Circuit Capacity (Btu/hr)	Proposed Circuit Capacity (Btu/hr)	% Different	Original Circuit Sensible (Btu/hr)	Proposed Circuit Sensible (Btu/hr)	% Differemt
1	11080.1	11182.03	0.92	8656.14	8679.35	0.29
2	11080.1	11119.35	0.35	8656.14	8673.6	0.20
3	11080.1	11040.384	-0.36	8656.14	8646.84	0.11
4	11080.1	11035.8219	-0.4	8656.14	8661.2855	0.06
5	11080.1	11435.09	3.20	8656.14	8995.04	3.92
6	11080.1	10952.15	-1.15	8656.14	8786.68	1.51
7	11080.1	12017.37	8.46	8656.14	9366.88	8.22
8	11080.1	11683.7384	5.45	8656.14	9163.5192	5.86

In forward simulation circuit 1, the circuit is messily crossed and the percentage of increase in term of capacity is very little. After all, in circuit 2, the inlet position is shifted to the back row whereas for the outlet position is shifted to the front row.

This circuit 2 configuration will simulate counter flow heat exchanger configuration. The result obtained showed that there is slight increase of capacity. Despite the research mentioned in *Section 2.10.4* pointed that the counter flow configuration will have a better heat transfer and better efficiency to the heat exchanger, the increment is very minor. This might be caused the very short length of horizontal displacement of the refrigerant with respect to the flow of air. Hence, the interface of the counter flow and parallel flow does not influence greatly on the capacity of the heat exchanger.

For circuit 3 and 4, there are very minor change in term of capacity when the circuit arrangement is change between convergence, divergence and in-lined configuration. The change in the tube arrangement configuration will contribute to the change in boundary layer of the flow. The changes is very minor due to very short horizontal length for flow of air across the tube. However, the resulted obtained which shows the convergence arrangement is comparatively higher can be justified. The boundary layer created in convergence arrange will alter the Nusselt Number of the circuit. Hence, this will contribute to the different in heat transfer coefficient between the convergence arrangement and in-line arrangement. The study specified in *Section 2.10.5* had stated that the heat transfer coefficient for convergence arrangement is higher than the heat transfer coefficient of in-line circuit arrangement.

For Circuit 5 & 6, 3 circuits heat exchanger and 4 circuits exchanger had been proposed. *Section 2.10.1, 2.10.2, 2.10.3, 2.10.4* had suggested that the change in circuit number had an impact on the heat exchanger capacity. Optimum circuit number is intended to be figured out in this simulation. Based on the simulation result, the 3 circuits design is managed to increase the capacity by 3% as compared to the original 2 circuits design, However, the 4 circuits design shows an decrease trend in the capacity. Hence, it suggested that optimum number of circuit for this heat exchanger design is 3.

For Circuit 7 & 8, the circuit design is simulated with different types of fins by using the optimized circuit from circuit 5. The circuit is simulated with slit fin and louver wavy fin. As a result, it is found that both has a positive impact on the capacity. By comparison, Slit fin has a larger impact on the heat exchanger capacity. With the circuit design 5 and with slit fin pattern, the capacity is managed to increase by 8.45%. This might due to the vortex stream created by slit fin enhanced the heat transfer throughout the fin passage as stated in literature *Section 2.10.6*.

Last but not least, the improvement caused by increasing the numbers of circuits is probably caused by the utilization of the heat exchanger area. When the numbers of circuit increased, there are larger area of the coils is in contact with the air heat exchanged with larger difference in temperature. As the flow of refrigerant is split, the initial temperature of the flow which is high is split is different entry. As compared to single circuit design, the flow of refrigerant is in single circuit. As the flow across the heat exchanger, the temperature different between the refrigerant and air is decreasing. Eventually, when the temperature different is decreasing across the coil, the heat exchanging is also decreasing.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

i. The simulation model has been validated by benchmarking the references from several studies. The experimental parameters are input to obtain the simulated capacity. The simulated and experimental results are compared to validate the reliability of the model. The deviation is marked from -2.79% to 5.39%. The model is said to be reliable.

ii. The circuit had been enhanced by several trials. The circuit had been optimized by adopting the optimum number of circuit which is 3. The louver fin pattern is replaced with slit fin. The optimized design is simulated to provide an 8.46% increment in term of capacity. The circuit tube arrangement including parallel flow, counter flow, convergence configuration, divergence configuration, in-line configuration have minor effect on the heat exchanger capacity due to short length of horizontal displacement with respect to the flow of air.

iii. At the end of the study, the design of the circuit has achieved a total capacity of 12017.37 Btu/hr as compared to the original capacity 11080 Btu/hr. It marked a total increment of 8.46%.

5.2 Recommendation

The simulation can be improved by considering the non-uniform flow. By considering the non-uniform inlet flow, the mal-distribution associated with non-uniform flow. can be identified and improved. The non-uniform in practical can be cause the constrain of the unit outer casing and the recirculation flow of the air outlet. Also, the non-uniform flow can be identified by exploring the application of Computational Fluid Dynamic to get the simulated air flow profile.

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