NUMERICAL SIMULATION OF TELEKOM MALAYSIA(TM) SERVER FARM THERMAL TRANSPORT PHENOMENA USING ANSYS FLUENT

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FACULTY OF ENGINEERING
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RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING
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2019

UNIVERSITY OF MALAYA

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Name of Candidate: Mohd Aswad bin Othman

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Name of Degree: Master of Mechanical Engineering

Title of Research Report: Numerical simulation of Telekom Malaysia(TM) server farm thermal transport phenomena using Ansys Fluent

Field of Study: Computational fluid dynamics (CFD)

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NUMERICAL SIMULATION OF TELEKOM MALAYSIA(TM) SERVER FARM THERMAL TRANSPORT PHENOMENA USING ANSYS FLUENT

ABSTRACT

A server farm or server cluster is a computer server collection maintained by an organization to provide server functionality far beyond a single machine's capability. Since the servers are stored in close proximity to one another, an efficient cooling is a must. Thus this research aims to simulate the thermal transport phenomena of a server farm managed by Telekom Malaysia(TM) under the TM city project. To simulate the thermal transport phenomena, Ansys-Fluent was used. Using Ansys Fluent, temperature distribution across the server farm had been determined. It is found that using original setup, cooling air distributed at the front of the server racks can reach a maximum of 27°C and almost exceeds the maximum recommended temperatures as per guidelines released by ASHRAE. This is mainly due to hot air recirculation from the back of the server racks back into the cold aisles. To eliminate this problem, cold aisle containment system is suggested to be installed. Simulation on the server farm equipped with cold aisle containment system shows that the maximum temperature in front of the server racks drops to 25°C and becomes more evenly distributed. The cold aisle containment system also managed to eliminate hot air recirculation from the back of the server racks.

Keywords: Computational fluid dynamics (CFD), server farm, thermal management, cold aisle containment, Ansys Fluent

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	:	2-Dimensional
3D	:	3-Dimensional
ASHRAE	:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFD	:	Computational Fluid Dynamics
C_p	:	Specific heat capacity
CRAC	:	Computer Room Air -Conditioning
DNS	:	Direct Numerical Solution
h	:	Enthalpy
P_{abs}	:	Absolute pressure
Re	:	Reynold’s Number
R_o	:	Universal gas constant
RPP	:	Remote Power Panel
S	:	Source term
t	:	Time
T	:	Temperature
TM	:	Telekom Malaysia
u	:	Velocity vector
u, v, w	:	Velocity components
w	:	Molecular weight
Γ	:	Diffusion Coefficient
ε	:	The specific rate of dissipation of turbulent kinetic energy
Φ	:	Additional variable
ω	:	The specific rate of dissipation of turbulent kinetic energy

CHAPTER 1: INTRODUCTION

1.1 Background of study

A server farm or server cluster is a computer server collection maintained by an organization to provide server functionality far exceeding a single machine's capability. Server farms are often made up of thousands of computers thus require a great deal of power to run and keep cool. Like any server farm, TM city server farm requires efficient cooling in order to function properly and thus reducing server downtime. Especially since the server farm is located in a hot and humid climate country such as in Malaysia. Failure to sufficiently cool the servers can result in decrease in system performance, loss of stored information and worst of all total failure of the components. However, over supply of cool air on the other hand can result in a waste of energy and thus increase in operation costs. Therefore, a balance in between is a must.

TM city server farm employs air cooled system to cool their server racks. This system features raised-floor system and perforated tiles to supply cold air from underneath the floor directly to the front of the server racks. This configuration is more efficient than older overhead cooling system from the facts that as air heats up, it becomes less dense and will go up. This setup thus ensures proper cooling from the bottom to the top of the server racks.

The server racks arrangement also plays an important role in determining the efficiency of the cooling system. The server racks in TM city data center are arranged in a cluster of hot and cold aisles. This is to reduce the hot air recirculation from the back of the server racks into the cold aisles. However, current setup had shown an increase in temperature around the upper portion of the server racks. This can happen due to several reason such as not enough volume of cold air supplied to the racks or excessive hot air recirculation into the cold aisle. To investigate the cause of temperature increase and also assess the overall efficiency of the air cooled system, a computational fluid dynamics (CFD) simulation can be done using computational software such as Ansys Fluent. Therefore, this study intends to investigate the root cause of this problem and try to suggest a plan to improve the overall cooling efficiency of the system.

1.2 Problem statement

All data center strives to ensure zero downtime and optimum efficiency of all their servers. This can be achieved through proper optimization and maintenance of the components involved in the operation of the data centers. Downtime or failure of a server can be caused by various reasons and one of it is overheating. Overheating happens when the temperature of a server exceeds the maximum operating temperature and this results in reduced in performance, loss of data or even total failure of the server. As per American Society of Heating, Refrigerating and Air-Conditioning Engineers(ASHRAE) guidelines, the recommended temperature range of a server farm are between 18 to 27°C while the maximum allowable temperatures are between 15 to 32°C (ASHRAE, 2016).

However, recent data on TM server farm 1 found that several server racks are indeed operating on the borderline of the maximum recommended temperature. This is especially true for servers that are located on the upper portion of the racks where less cold air able to reach. They also suffer from hot air recirculation over the top of the server racks resulting in relatively higher average supply air temperature.

By using Ansys Fluent, the server farm environment can be recreated and analyzed to produce a temperature distribution plot of the server farm. The result can then be used to determine if there are any localized hotspots and excessive hot air recirculation. A proper plan of action can also be suggested in order to improve the overall cooling efficiency of the server farm.

1.3 Aim and objectives

This research project aims to analyze the current air-cooled system used in TM City server farm 1. In order to achieve the aim, the research project is broken down into four (4) smaller objectives as below:

1. To produce three-dimensional(3D) environments from the two-dimensional(2D) blueprint of the server farm.
2. To simulate the airflow and thermal transport phenomena of the server farm.
3. To determine the average temperature, localized hot spot and hot air recirculation problem in server farm.
4. To suggest a method to increase the cooling efficiency of the server racks.

1.4 Outline of research report

This research report begins with an introduction in chapter 1. This chapter contains the background of study, problem statements and aim and objectives. Chapter 2 is the literature review which summarizes previous work related to the scope of study such as data centers configuration, ASHRAE guidelines, mesh, Reynold's number, turbulence models and the governing equations. Chapter 3 is the methodology section, which discussed the methods used in this research project. Then chapter 4 will contain the results and discussion for this research. Lastly chapter 5 will conclude the overall founding of this research project.

CHAPTER 2: LITERATURE REVIEWS

2.1 Data center configuration

Generally, a data center or server room will normally adapt either the hard floor or raised floor design. The TM city utilizes raised floor configuration for their server rooms. It is a general notion, that raised floor configuration is more efficient compared to hard floor configuration for several reasons such as better cable management, easier to upgrade and higher cooling efficiency as warm air rises thus cooling the racks from below makes more sense than using a traditional overhead cooler (Dataspan Inc., 2019). However, a drawback of using raised floor configuration is the higher initial installation cost compared to the hard floor configuration.

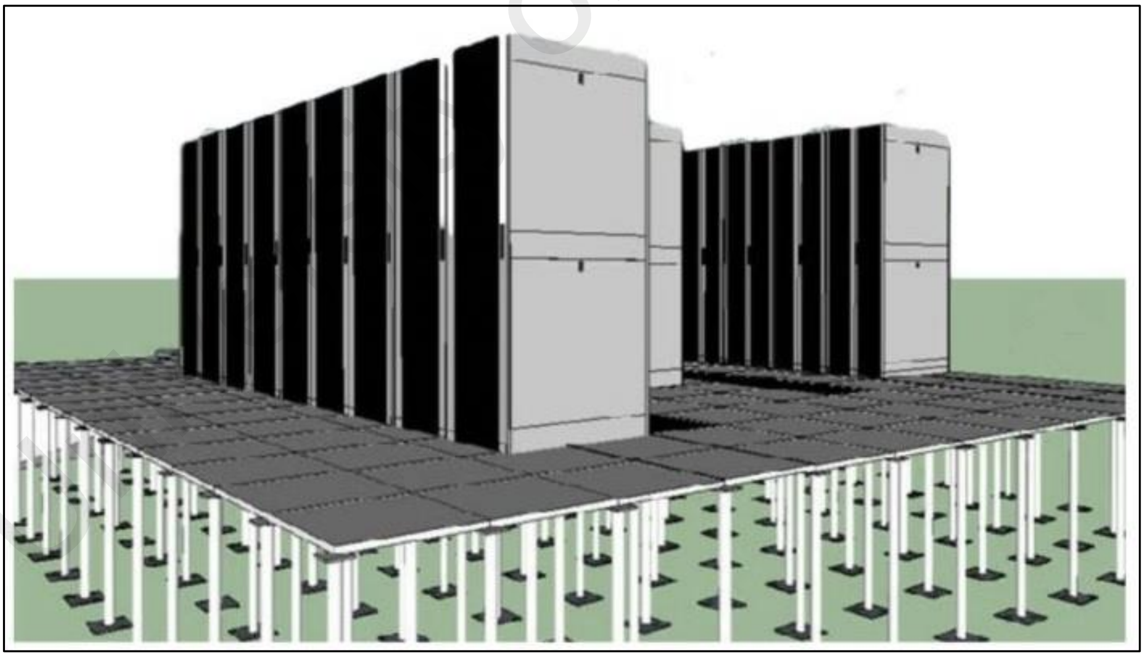
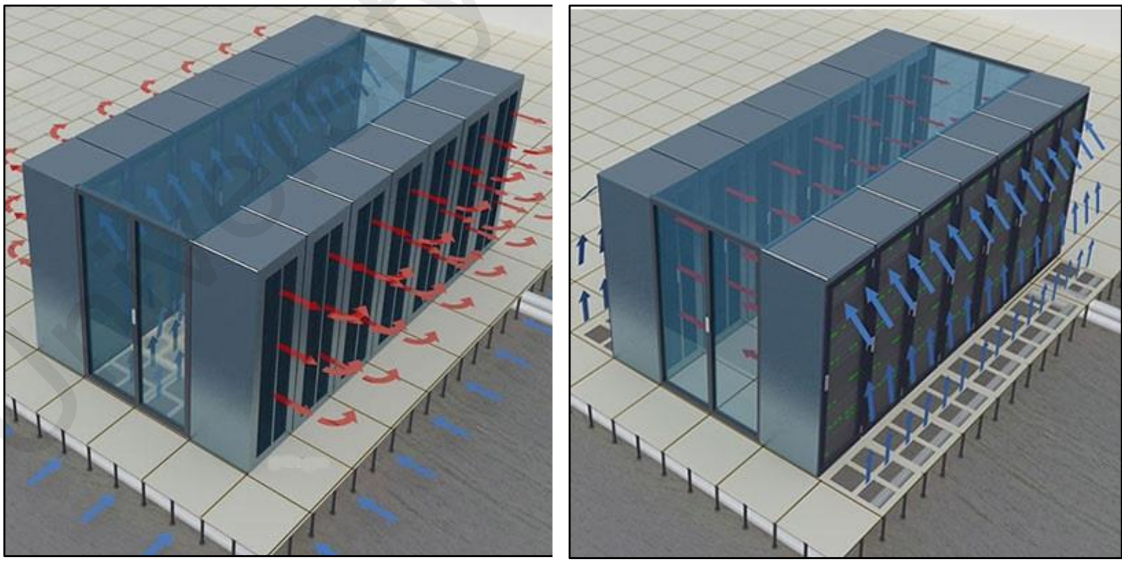


Figure 2. 1: Raised flooring in data centers (CtrlTech, 2018)

Other than that, the arrangement of server racks plays important role in determining the cooling efficiency. In short, good arrangement of server racks will provide optimum cooling and reduce the mixing of hot and cold air and thus maintain the racks temperature within the recommended temperature or at the very least within the maximum allowable temperature. As mentioned in the ASHRAE's thermal guidelines, the recommended temperature at the front of the of the server racks are 18 - 27℃ while the maximum allowable temperature is 15 - 32℃ (ASHRAE, 2016).

Generally, servers are clustered together with the aim of separating the hot aisle from the cold aisle. This is done to reduce the mixture of hot air and cold air which will result in higher feeding temperature at the front of the server rack. This is not an ideal condition since higher feeding temperature means lower cooling efficiency and thus higher operating temperature of the servers. Therefore, general configurations of the server racks include single aisle rack and double aisle rack with or without hot/cold air containment system. As illustrated in figure 2.2, cold air containment system contains cold air from getting mixed with hot air while hot air containment system contains hot air to prevents it from mixing with the surrounding cold air.



(a) Cold aisle containment system **(b) Hot aisle containment system**

Figure 2. 2: Hot and cold aisle in data (42U Data Centre Solutions, 2017)

However as illustrated in figure 2.3, the TM City server farm 1 server racks are comprises of single and double aisle configuration without any containment system.

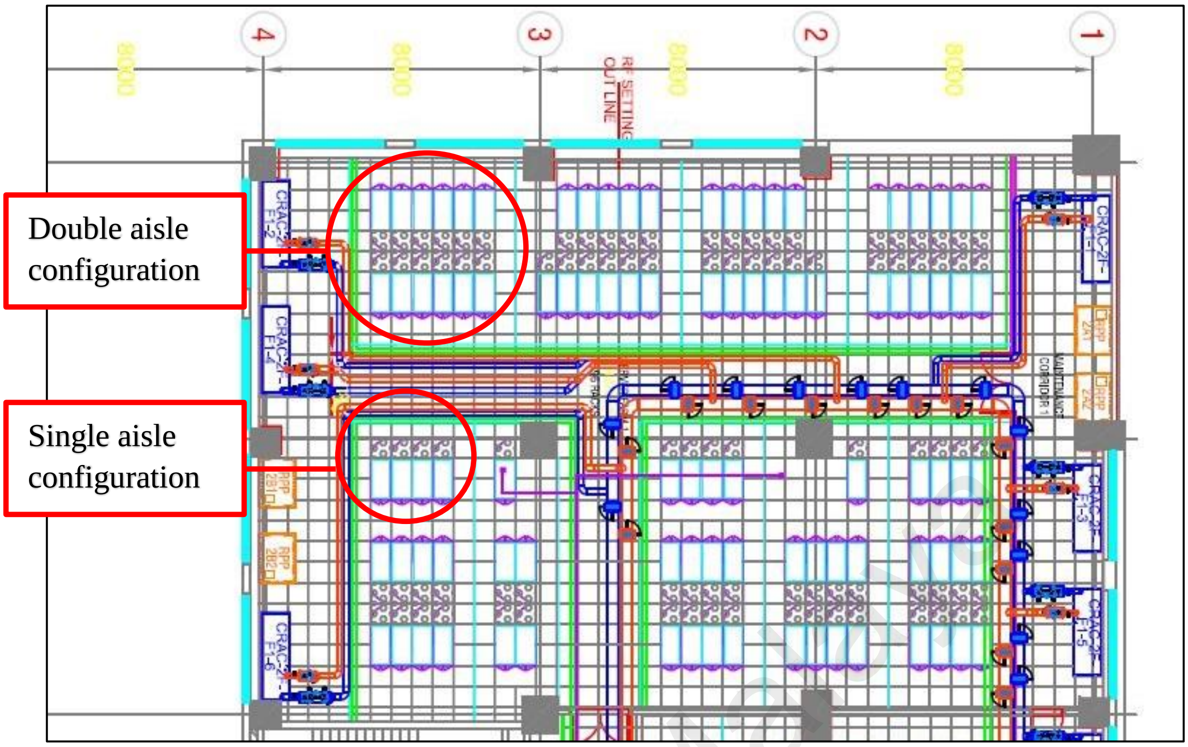
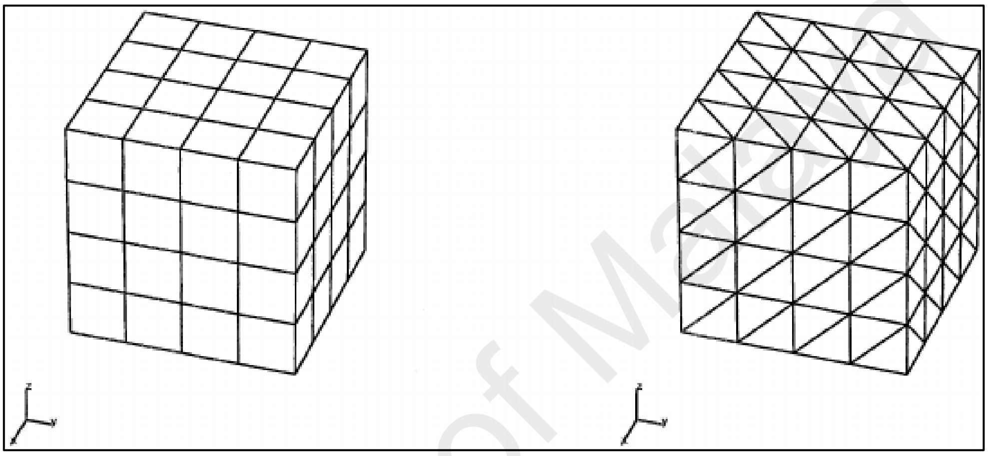


Figure 2. 3: TM City server farm 1 single and double aisle configuration

Without containment system it can be estimated that without adequate cooling airflow, the top most racks will receive less cold air due to mixing of hot air from the back of the rack with cold air at the front of the rack. This is the reason why it is important to use either hot or cold containment system. For the purpose of this study, simulation of the server room equipped with cold air containment system was also performed to serve as a benchmark of how simple improvements such as installing the cold air containment panel can improve the overall heat distribution of the server room.

2.2 Mesh limitations

In general, mesh characteristic plays an important role in any type of engineering simulation particularly computational fluid dynamics(CFD). In order to get a good simulation result, suitable mesh characteristics such as mesh type and average mesh size need to be considered. Other mesh variation such as resolution, aspect ratio, clustering, skew, taper, and wiggle should also be considered. However, highly detail meshing consumes a lot of computing power thus will result in longer computing time. Therefore, a balance between good mesh quality and acceptable computing time is a must. Generally, tetrahedral mesh is used for complex geometry and hexahedral mesh for simpler geometry (E. Wang, 2004). Since the geometry of the components in the server room is relatively simple, it is best to use hexahedral mesh. This is also to reduce the computing time of the cfd simulation since tetrahedral mesh requires more computing power than hexahedral mesh (E. Wang, 2004).



(a) Hexahedral mesh **(b) Tetrahedral mesh**

Figure 2. 4: Hexahedral and tetrahedral mesh (F.V.D. Vosse, 2003)

Complex geometries were also simplified to further reduce computation time. One such case is at the perforated tiles. The perforated tiles used on a raised floor configuration have a lot of small holes. To mesh this detail will require very fine mesh and a lot of computing power. Therefore, for this purpose it is generally acceptable to treat the perforated tiles as fully open tiles (Wibron, 2015). The reason behind this simplification is since the opening of the perforated tiles are very small, it is assumed that the small jets will quickly merge into a single large jet such as one produced by fully open tiles (Wibron, 2015).

Figure 2. 5: Perforated tiles used in data centers (Stulz, n.d.)

Other factors affecting the mesh quality such as the average cell size were also investigated using the mesh independence test. The detail of this test is further explained in chapter 3 – research methodology.

2.3 Mesh quality test

Mesh quality test is an important test to measure the quality of the mesh generated for a specific problem. There are a lot of test that can be used to assess the quality of a mesh such as element quality, aspect ratio, jacobian ratio, warping factor and etc. However, for the purpose of this study skewness and orthogonal quality was chosen to as the parameter to test for mesh quality.

As shown in tables 2.1 & 2.2 for orthogonal quality the mesh is considered bad for the value of 0.14 and below while higher than 0.14 is acceptable and value of 1 is considered perfect. On the other hand, for skewness 0 to 0.94 is acceptable while 0.95 to 1 is considered bad. These mesh metrics can be checked easily in the mesh module inside Ansys Fluent.

Table 2. 1: Skewness mesh metrics spectrum (Smith, 2017)

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Table 2. 2: Orthogonal quality mesh metrics spectrum (Smith, 2017)

Unacceptable	Bad	Acceptable	Good	Very good	Excellent
0-0.001	0.001-0.14	0.15-0.20	0.20-0.69	0.70-0.95	0.95-1.00

2.4 Reynold's Number

Reynold's number is a dimensionless number to measure a fluid inertial forces relative to the viscous forces around the fluid. This is a very important factor to determine the fluid flow pattern, whether it will be laminar or turbulent flow. Reynold's number is calculated by (Bill Rehm, 2009),

$$N_{\mathrm{Re}} = \frac{\rho \upsilon d}{\mu} \tag{2.1}$$

Where, ρ=density, v=velocity, d=diameter and μ=viscosity

Generally, for Reynold's number less than 2100 the flow is considered laminar while for Reynold's number more than 2100 the flow is turbulent (Bill Rehm, 2009). Turbulent flow is characterized by random fluctuation and chaotic motion of the fluid and it is found that the appropriate model to be use for cases such as the data center flow simulation is turbulent modeling and the most commonly used turbulent model is the k−ε. (Zhang X, 2008) & (Wibron, 2015).

2.5 Turbulence model

Most engineering application for computational fluid dynamics are turbulent in nature and thus requires turbulence model to produce an accurate simulation (Steven, 2015).

However, there are various turbulence models available such as Direct Numerical Simulation(DNS), Spalart-Allmaras, k−ε , k-ω and many more. From the various turbulence model available, k−ε is the most well-established turbulence model used for server room cfd simulation (Zhang X, 2008) & (Wibron, 2015). However, the adequacy of using this turbulent model for this research has not been further investigated.

2.6 The governing equations

The governing equations of fluid mechanics are the conservation of laws for mass, momentum and energy. These equations can be stated either in integral or differential form. The differential form of the equation will be defined here.

Since the mass of a fluid is conserved, the continuity equation for a compressible fluid turn into

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \tag{2.2}$$

The first term denotes the rate of change of mass and the second term denotes the net rate of mass moves out of the volume. Both surface and body forces are acting on the fluid. Since the degree of change of momentum is equivalent to the sum of the forces gives the momentum equations

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u \mathbf{u}) = \frac{\partial (-p + \tau_{xx})}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{Mx} \tag{2.3}$$

$$\frac{\partial (\rho v)}{\partial t} + \nabla \cdot (\rho v \mathbf{u}) = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial (-p + \tau_{yy})}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + S_{My} \tag{2.4}$$

$$\frac{\partial (\rho w)}{\partial t} + \nabla \cdot (\rho w \mathbf{u}) = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial (-p + \tau_{zz})}{\partial z} + S_{Mz} \tag{2.5}$$

The left-hand side terms denote the rate of change of momentum and the net rate of movement of momentum out of the volume correspondingly. On the other hand, the right-hand side terms denote surface stresses and the rate of change of momentum due to sources.

Since the rate of change of energy is equivalent to the sum of the rate of heat totaling to and the work performs on the fluid gives the energy equation

$$\begin{aligned}\frac{\partial(\rho E)}{\partial t}+\nabla\cdot(\rho E\mathbf{u})=&-\nabla\cdot(p\mathbf{u})+\left[\frac{\partial(u\tau_{xx})}{\partial x}+\frac{\partial(u\tau_{yx})}{\partial y}+\frac{\partial(u\tau_{zx})}{\partial z}+\frac{\partial(v\tau_{xy})}{\partial x}\right.\\&\left.+\frac{\partial(v\tau_{yy})}{\partial y}+\frac{\partial(v\tau_{yz})}{\partial z}+\frac{\partial(w\tau_{xz})}{\partial x}+\frac{\partial(w\tau_{yz})}{\partial y}+\frac{\partial(w\tau_{zz})}{\partial z}\right]\\&+\nabla\cdot(\lambda\nabla T)+S_E\end{aligned} \tag{2.6}$$

The left-hand side terms denote the rate of change of energy and the net rate of flow of energy out of the volume, correspondingly. The terms on the first two rows on the right-hand side denote the total rate of work due to surface stresses. The last two terms denote the rate of heat accumulation due to heat conduction across the boundaries of the volume and the rate of change of energy due to sources (Versteeg HK, 2007).

The total five governing equations comprise of 7 unknown variables. To close the system of equations, fundamental equations of state for density and enthalpy are required. The general arrangement of these equations is

$$\rho=\rho(p,T)\quad dh=\left.\frac{\partial h}{\partial T}\right|_p dT+\left.\frac{\partial h}{\partial p}\right|_T dp=c_p dT+\left.\frac{\partial h}{\partial p}\right|_T dp\quad c_p=c_p(p,T) \tag{2.7}$$

For an ideal gas, the ideal gas law is used to compute density and the specific heat capacity can be utmost a function of temperature. The fundamental equations for an ideal gas will become

$$\rho = \frac{w p_{abs}}{R_0 T} \quad dh = c_p dT \quad c_p = c_p(T) \tag{2.8}$$

This is one of a range of numerous cases of the constitutive equations for particular material classes that can be selected in Ansys Fluent.

Transport equations for other variables can also be defined. Other variables are scalar components that are transported through the flow. An additional variable is stereotypically taken as a concentration in Ansys Fluent. A volumetric extra variable is defined as

$$\phi = \frac{\text{conserved quantity}}{\text{volume of fluid}} \tag{2.9}$$

And if the conserved quantity has unit of mass, the extra variable will have similar unit as concentration. The transport equation for an extra variable is as per below

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla \cdot (\rho\phi\mathbf{u}) = \nabla \cdot (\Gamma\nabla\phi) + S_\phi \tag{2.10}$$

The left-hand side terms denote the rate of change of the supplementary variable and the net rate of flow of the supplementary variable out of the volume. The right-hand terms denote the rate of change of the supplementary variable due to diffusion and the rate of change of the supplementary variable due to sources. For most applications, the transport of supplementary variables is a both convective and diffusive process which necessitates that a rate of the diffusion coefficient is specified. But there are applications where the transport of the supplementary variable is a virtuously convective process and diffusion effects can then be ignored.

CHAPTER 3: METHODOLOGY

3.1 The geometry and mesh

The TM city server farm 1 is consists of 96 server racks, 6 computer room air conditioning(CRAC) and 4 remote power panels(RPP). The server racks are arranged in single and double aisles while cooling air is provided from underneath the raised floor by the CRAC. The dimensions of the room are 24m x 16m x 4m. The environment of the server farm are modeled using Autodesk Inventor and figure 3.1 shows the wireframe model of the server farm.

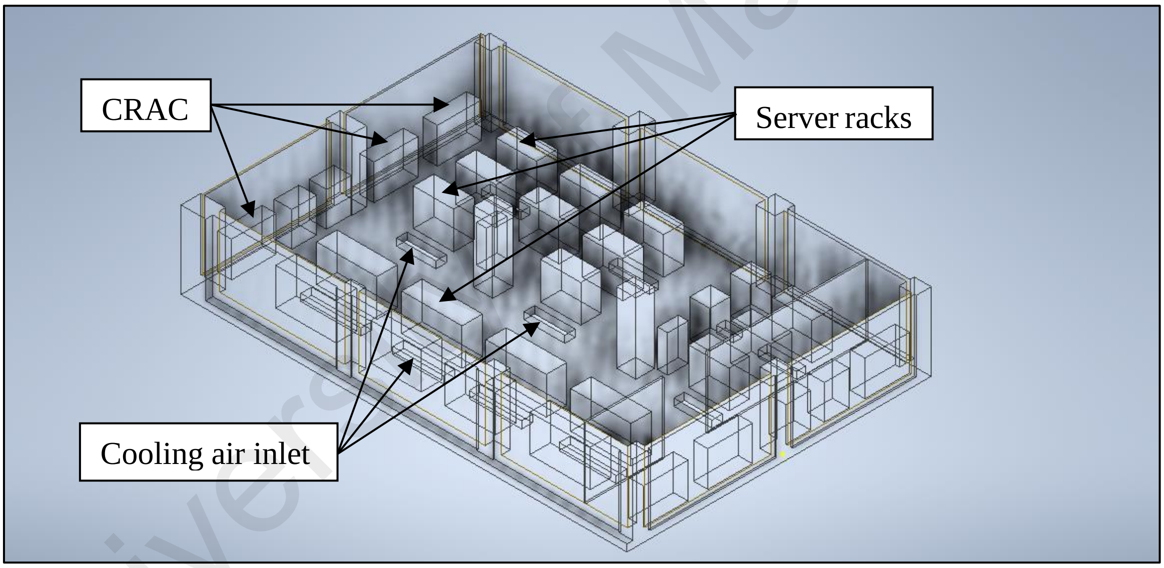


Figure 3. 1: TM City server farm 1 modeled using Autodesk Inventor in wireframe view

To simplify the simulation, all components in the server farm are treated as black boxes. This means that the airflow inside the server racks, crac and underneath the raised floor are not modeled. Only the the airflow inside the room and over the components are resolved. All of the components are also assumed as rectangular boxes and other components such as cables and lights are neglected. The boundary conditions are applied to the inlet and outlet of the server racks and CRACs and related walls with heat fluxes.

The 3D model was then imported to Ansys design modeler and using the boolean function, the fluid domain was recreated as shown in figure 3.2.

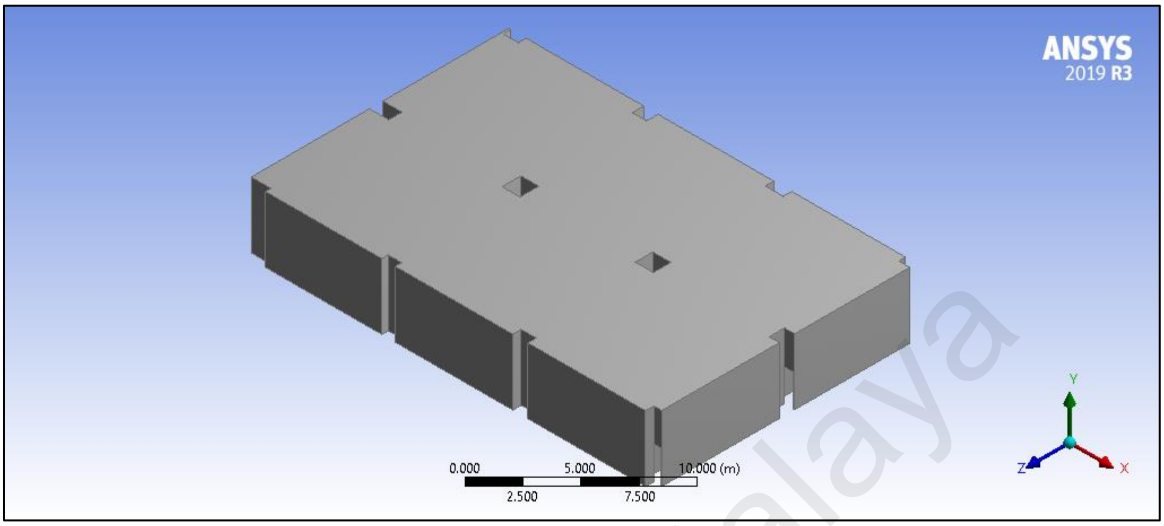


Figure 3. 2: The fluid domain recreated in Ansys design modeler using boolean function

The fluid domain was then discretized into smaller mesh as shown in figure 3.3. The hexahedral mesh was used due to the relatively simple geometry of the server farm components. By meshing the flow field, essentially the large area is divided into smaller rectangular boxes which are connected together by edges and vertices. The edges and vertices then conform to the surfaces of the components. The number of mesh is controlled using the average mesh size setting in Ansys Fluent. Due to the large area of the server farm, initially larger mesh size(30cm) were used. Then to improve the result, smaller average mesh size(15cm) were used which comprised of a total of 473660 nodes and 475063 elements. The mesh was illustrated in figure 3.3. Generally, the aspect ratio of the mesh is kept as close as possible to 1 however there are deviations at some location due to the dimensions of the geometry in the server farm. This deviation requires mesh improvement and is reflected in the plotted scaled residuals data which shows difficulty in converging. This data is further discussed in Chapter 4, the results and discussion section.

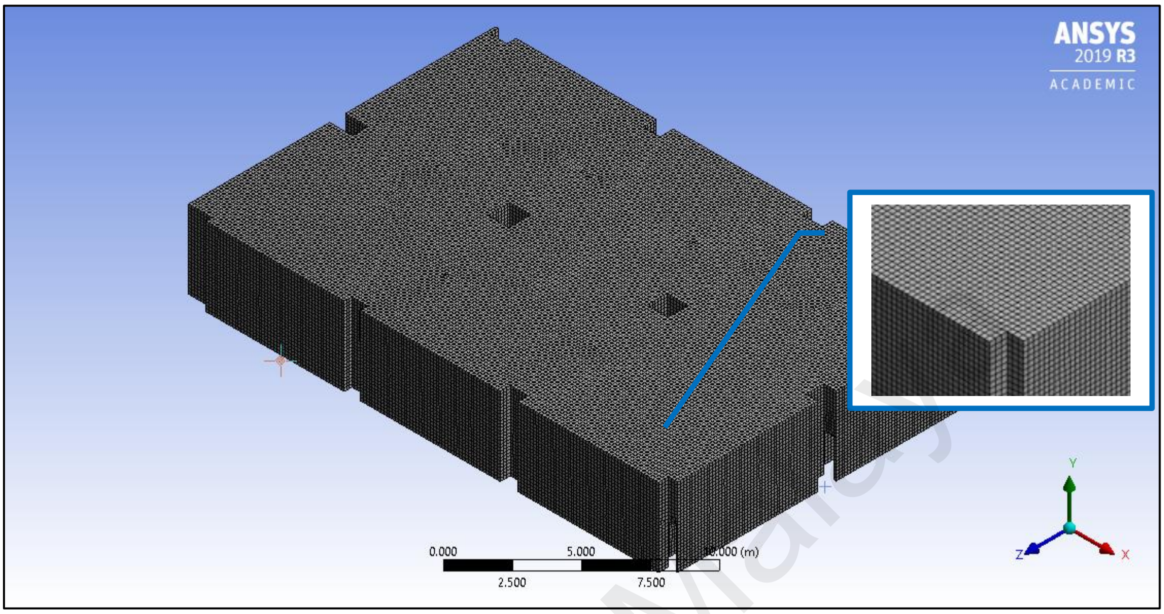


Figure 3. 3: The average mesh size of 0.015m, hex dominant mesh with average orthogonal quality of 0.92046(very good) and average skewness of 0.12689(very good). Nodes: 473660 Elements: 475063

Next, the mesh quality was investigated using mesh metrics option in the Ansys fluent. Two mesh metrics that were used for this evaluation were orthogonal quality and skewness. By referring to tables 3.1 & 3.2, the average orthogonal quality of the mesh is 0.92046 which is falls under the category of very good orthogonal quality mesh. On the other hand, the average skewness of the mesh is 0.12689 which also falls under the category of very good mesh skewness. However, this does not prove that the mesh is out of problem, since even a small amount of localized mesh problem can result in difficulty to achieve convergence.

Table 3. 1: Investigated mesh metrics – orthogonal quality

Mesh Metric	Orthogonal Quality
Min	2.335e-006
Max	1.
Average	0.92046
Standard Deviation	0.20039

Table 3. 2: Investigated mesh metrics – skewness

Mesh Metric	Skewness
Min	1.2325e-008
Max	1.
Average	0.12689
Standard Deviation	0.20451

3.2 Boundary conditions

For the purpose of this study, the walls, floor and ceiling of the server farm are assumed to be adiabatic. It means that heat energy does not enter nor escaped from the server farm. It is also assumed that there is no leakage of air through the server farms and components involved. Thermal energy is used to model the heat transfer occurs within the server farm. Figure 3.4 shows the boundary conditions setup for the server racks and CRACs.

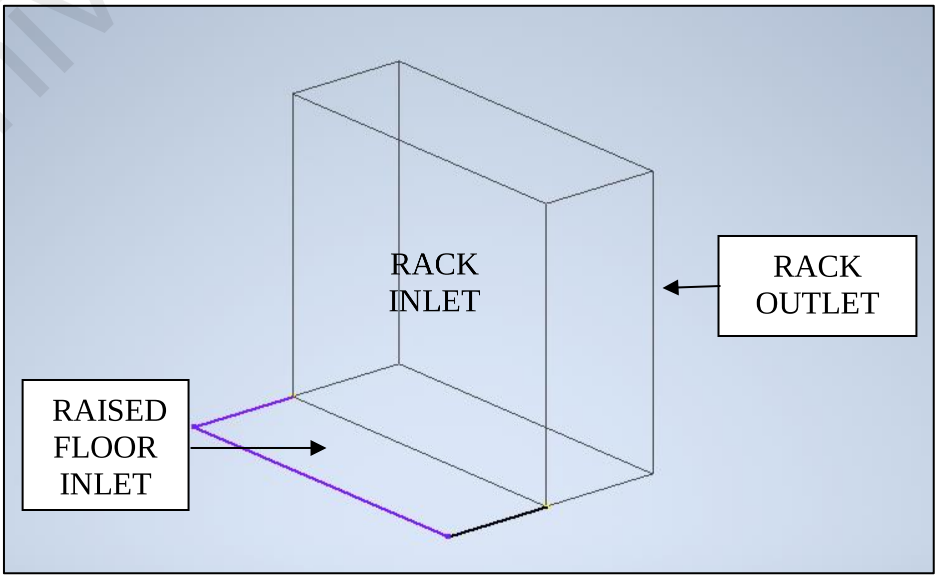


Figure 3. 4: Server racks boundary conditions setup in Ansys Fluent

Since there is no information available, it is assumed that the server rack internal fan generates an airflow of 0.56m/s and each rack generate full heat load of 3kW. The heat load results in temperature difference between the front and back of the server rack and it can be as high as 7°C difference (Wibron, 2015).

The problem with TM City server farm 1 original setup is when no containment system is installed, the hot air exhausted at the rear of the server rack can recirculate and enter the cold aisles of nearby server racks. This results in higher inlet air temperature in front of the server racks. Therefore, to evaluate the effectiveness of cold aisles containment system similar analysis were also done to TM's server farm 1 model equipped with cold aisle containment system.

3.3 Cold aisle containment system

As illustrated in figure 3.5, the cold aisle containment system works by containing the cold aisles essentially separating it from the warm exhaust air. This is simply done by installing several panels on top of the cold aisles.

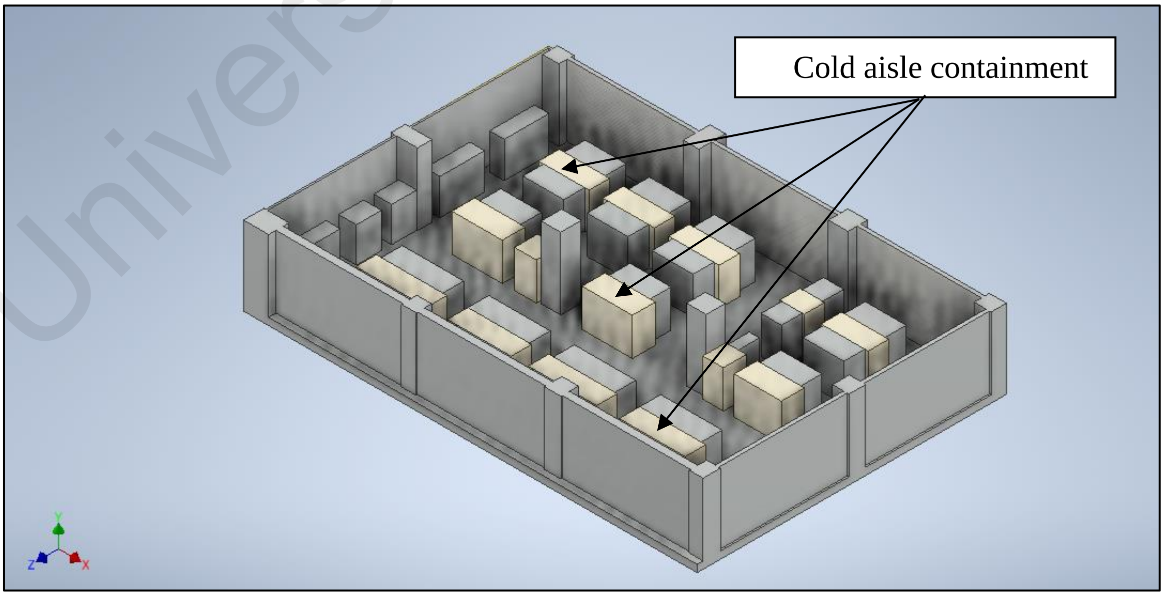


Figure 3. 5: The cold aisles containment system modeled in Autodesk Inventor

The model was then imported to Ansys Fluent where the fluid domain is generated using Boolean function in the design modeler. Then the flow field was meshed using hexahedral dominant elements of 0.015m average size. The cold aisle system was treated similarly to the original design to ensure similar conditions and variables are applied. Figure 3.6 illustrate the mesh used to discretize the cold aisle containment model and table 3.3 & 3.4 shows the orthogonal quality and skewness mesh metric results. The mesh average orthogonal quality is 0.67251(good) while the average skewness is 0.38708(very good).

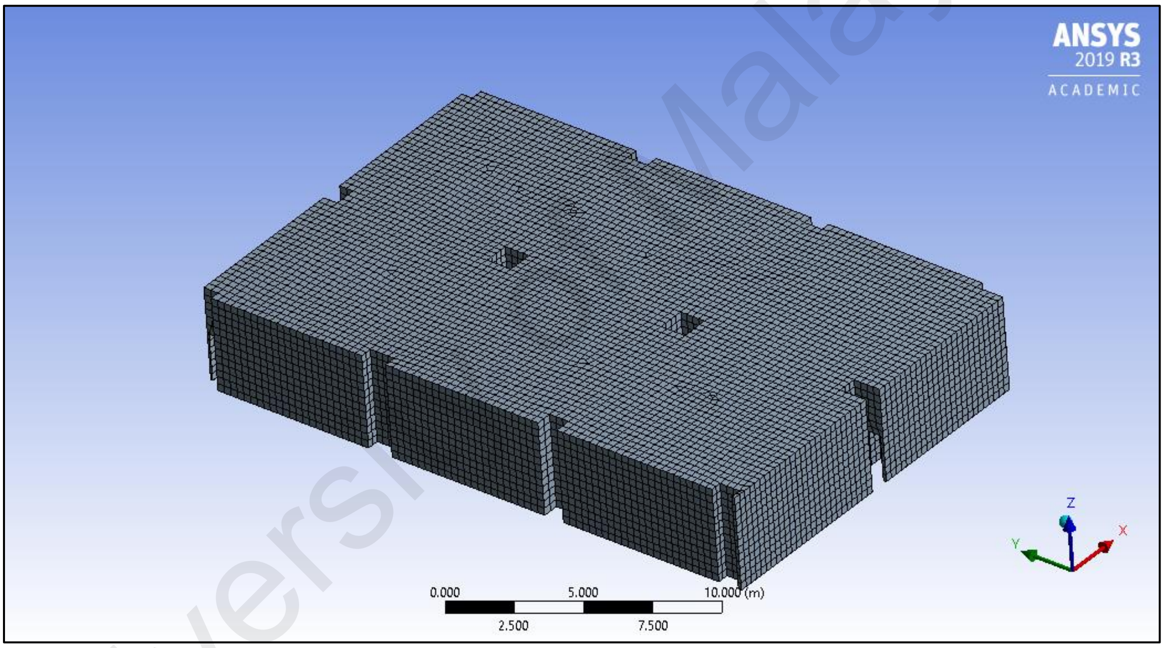


Figure 3. 6: The mesh for server farm installed with cold aisle containment system.

Table 3. 3: Investigated mesh metrics – orthogonal quality

Mesh Metric	Orthogonal Quality
Min	2.5188e-009
Max	1.
Average	0.67251
Standard Deviation	0.35525

Table 3. 4: Investigated mesh metrics – Skewness

Mesh Metric	Skewness
Min	1.337e-006
Max	1.
Average	0.38708
Standard Deviation	0.32334

3.4 Setup

The setup function in the Ansys Fluent is where you set the conditions for the calculations. There are wide range of variables to be choose and therefore require extensive reading and familiarity with the system to ensure the results resemble how the actual physical system should behave. Table 3.5 shows the setup configuration used for the simulation.

Table 3. 5: Settings used under the setup function in Ansys Fluent

No.	Setup		
1.	General	Solver	Pressure based
		Velocity formulation	Absolute
		Time	Steady
		Gravity	-9.81 in the y direction
2.	Models	Energy	On
		Viscous	Realizable k−ε, standard wall function
		Other settings	Off
3.	Materials	Fluid	Air
		Solid	Aluminum
4.	Cell zone conditions	Fluid	Inverted model
5.	Boundary conditions	Raised floor inlet	Velocity : 1.12 m/s, Temp: 20°C
		Server rack inlet	Pressure 0 Pa, Temp: 25°C
		Server rack outlet	Velocity: 0.58 m/s, Temp: 30°C
		CRAC inlet	Pressure 0 Pa, Temp: 30°C
		Server walls	Stationary wall, Convection (3kW)
		CRAC walls	Stationary wall, Convection (3kW)
6.	Reference values	Compute from	Raised floor inlet
		Reference zone	Inverted model
7.	Methods	Pressure-Velocity coupling	Coupled
		Gradient	Least squares cell based

		Pressure	Second order
		Momentum	Second order upwind
		Energy	Second order upwind
8.	Initialization	Methods	Hybrid initialization
9.	Run calculation	Number of iterations	300, 500, 1000, 3000

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Original setup (Without cold aisle containment)

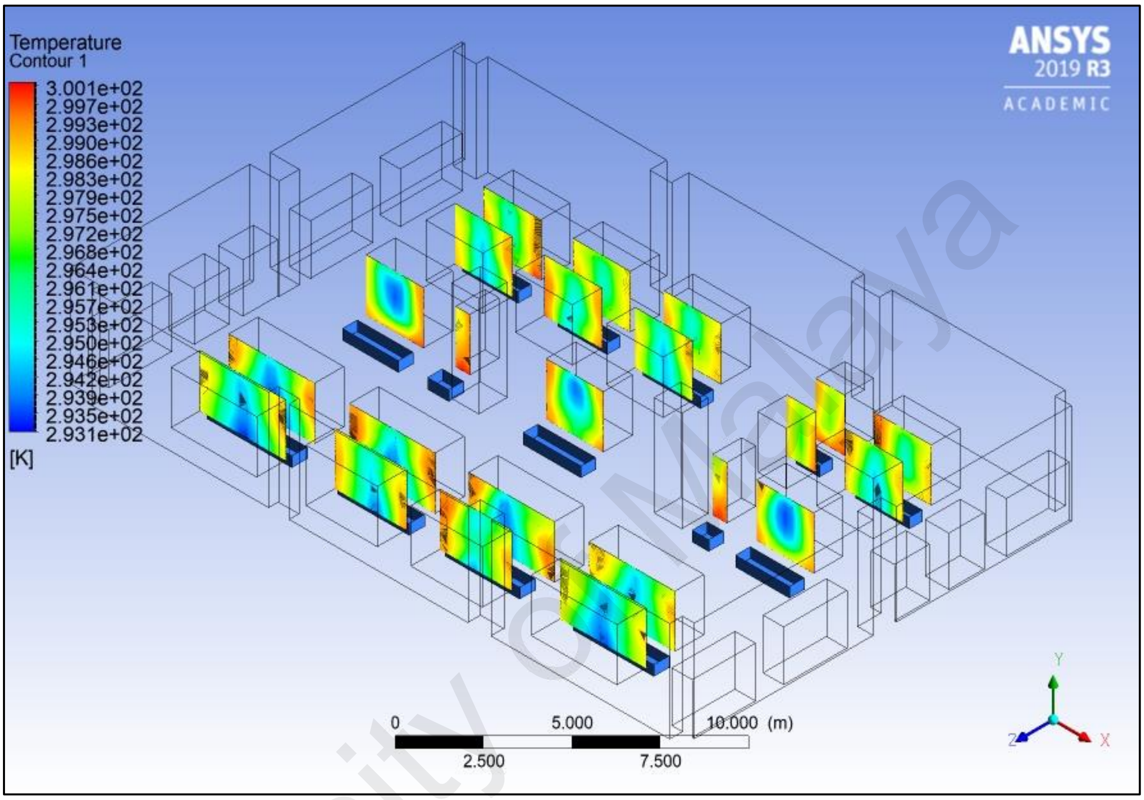


Figure 4. 1: Temperature distribution in front of the server racks of original setup

As shown in figure 4.1, in the original setup the temperature in front of the rack varies from 20°C to 26.8°C. It can be seen that on most of the racks, the temperature distribution is lowest on lower portion of the rack and the highest on the upper portion and the side of the racks. This is due to the cold air supplied from underneath the floor from the raised floor inlet and as the cold air come into contact with the server wall, the air gets warmer and flows up. The temperature rise on the side of the racks are also mainly due to the reverse flow of hot air from the back of the server racks into the sides of the aisle. This mixture of hot and cold air results in warmer air at the side of the server racks. This can be confirmed by looking at the streamline of exhaust air as shown in figure 4.2.

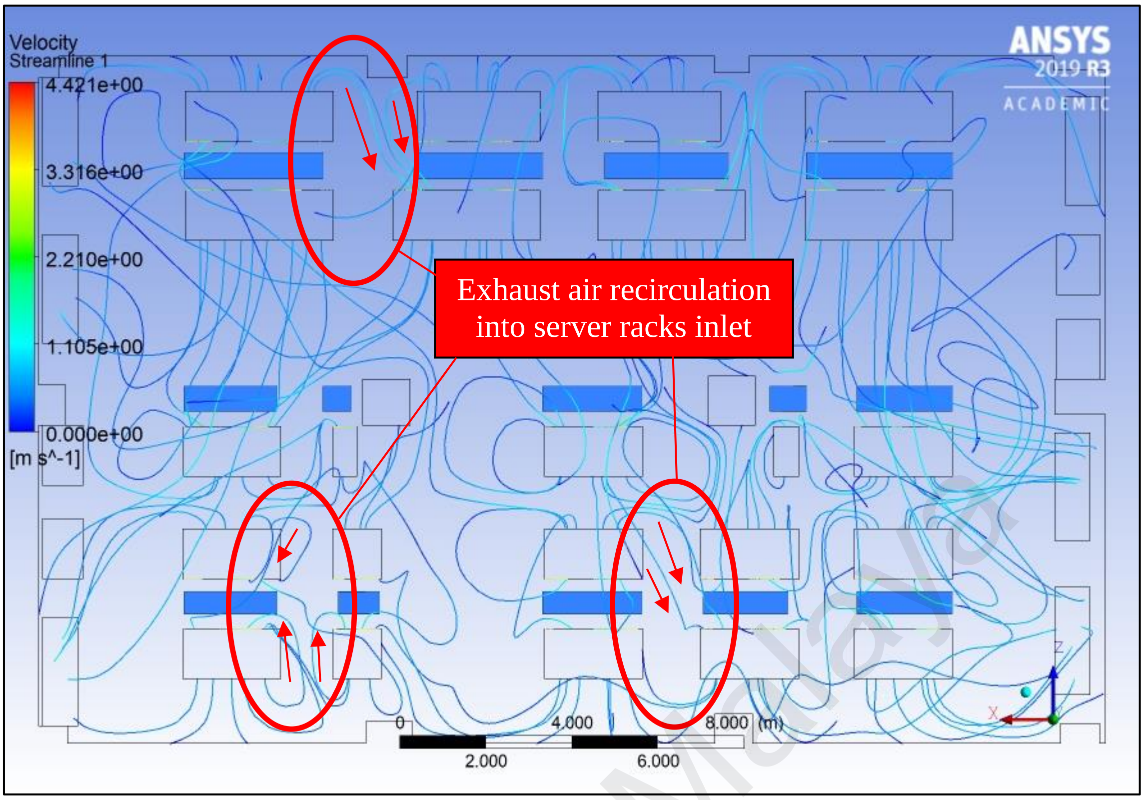


Figure 4. 2: Streamline flow of exhaust air from the back of server racks

As shown in figure 4.2, the reverse flow exists on most sides of the server racks. This is also due to suction force created by the internal fan of the server racks. It is noticeable by looking at the increased velocity of the streamline as it approaches the front area of the server racks.

The maximum temperature of 27°C on the server racks are on the borderline of the maximum recommended temperature as suggested by ASHRAE in the white paper TC9.9. Therefore, other means to increase cooling efficiency of the server racks is necessary.

Other than that, further insight into the heat distribution of the room can be investigated by observing the thermal contour of the floor on different elevation. As shown in figure

4.3, the elevations are at 0.1m (floor level), 1.05m (mid rack height) and 2.02m (top of the rack).

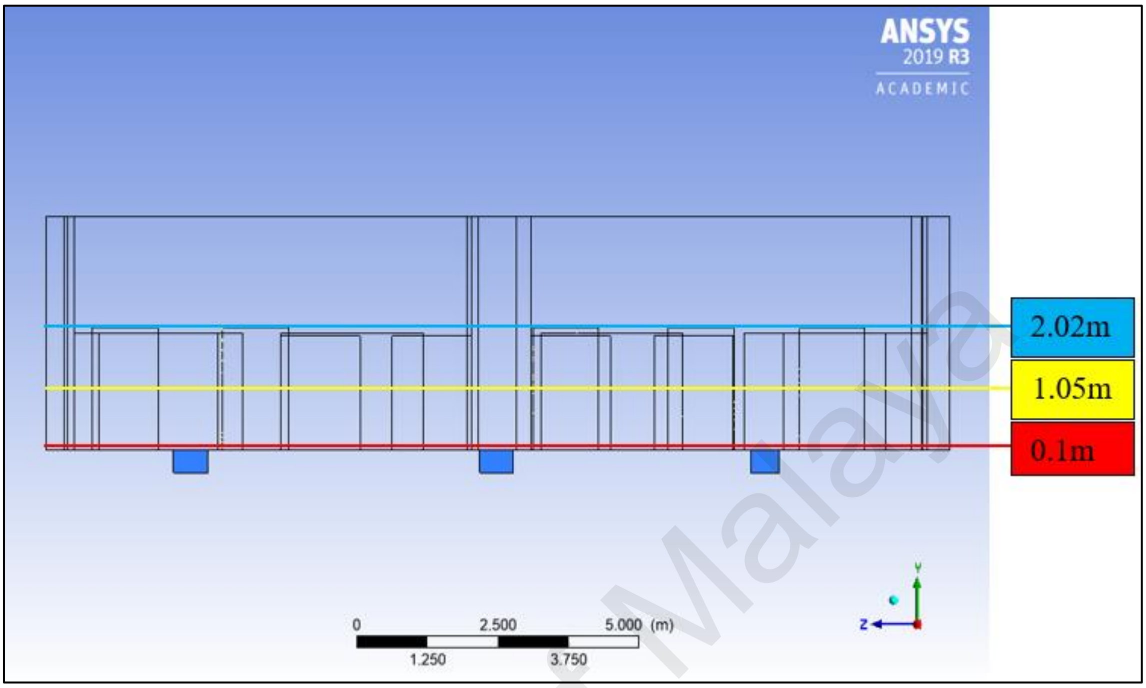
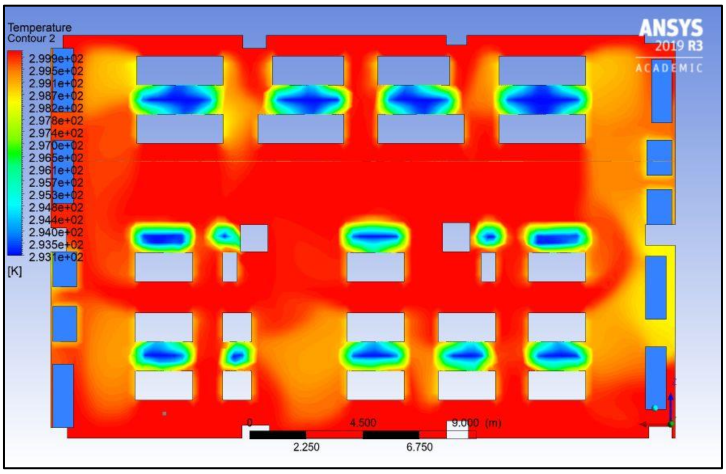
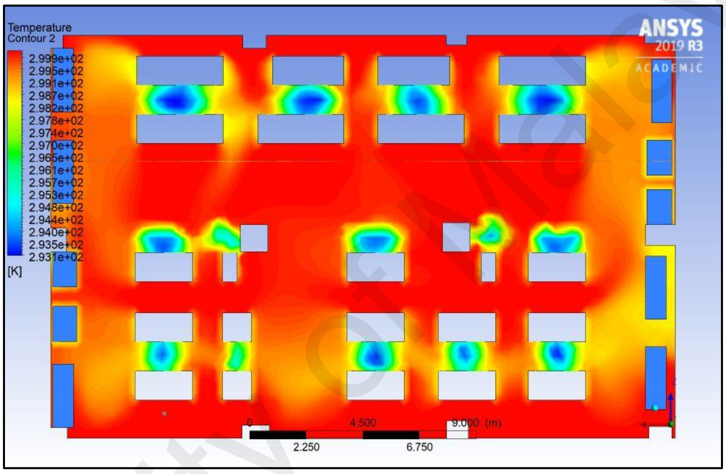


Figure 4. 3: Different horizontal planes used for thermal contour plot

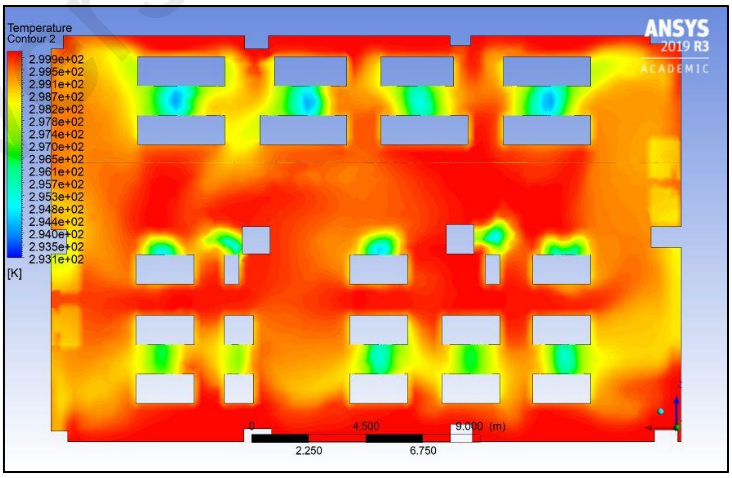
As shown in figure 4.4, the temperature of the room varies from 20°C to 26°C. It can be seen that on the floor level (0.1m), large portion in the front of the server racks are relatively cooler at approximately 20°C while only small portion on the side of the rack are higher in temperatures. However, on higher planes (1.05m and 2.02m), the cold air portion in front of the server racks started to shrink and the warm air portion on the sides becomes larger. At the 2.02m elevation, it can be seen that only small portion of cold air(20°C) are able to reach that height. Most of the air at the top of the racks are consists of relatively warmer air of 23 to 25°C.



(a) Heat distribution at floor level (0.1m



(b) Heat distribution at mid rack height(1.05m)



(c) Heat distribution at top of the rack (2.02m)

Figure 4.4: Heat distribution on different elevation planes of server farm 1

The heat distribution across the room can also be evaluated by using several vertical planes across the room. As in figure 4.5, the room is divided into three vertical planes at 4m, 12m and 20m on the x-axis.

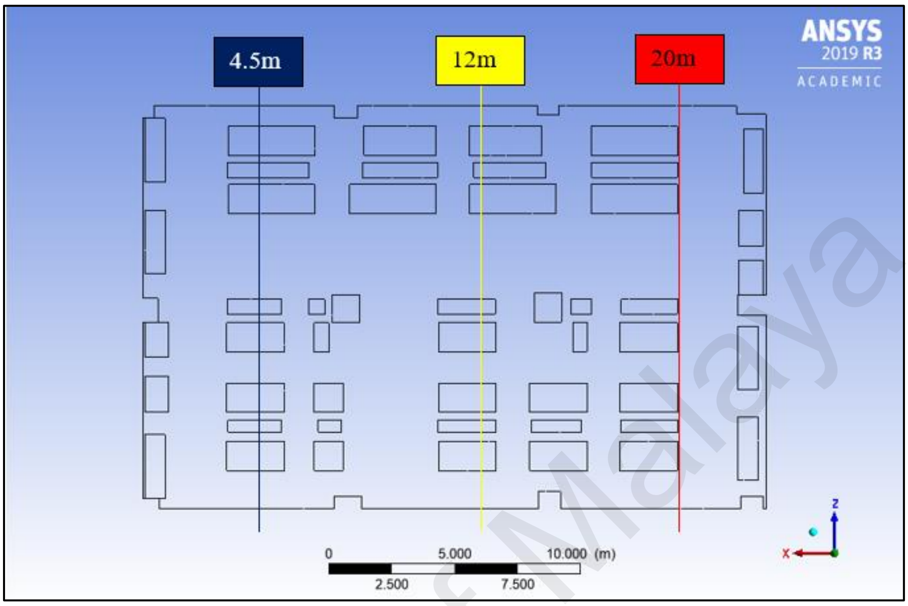
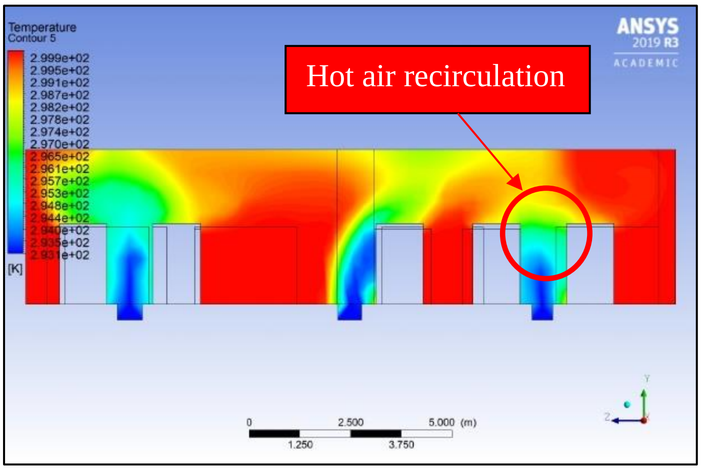
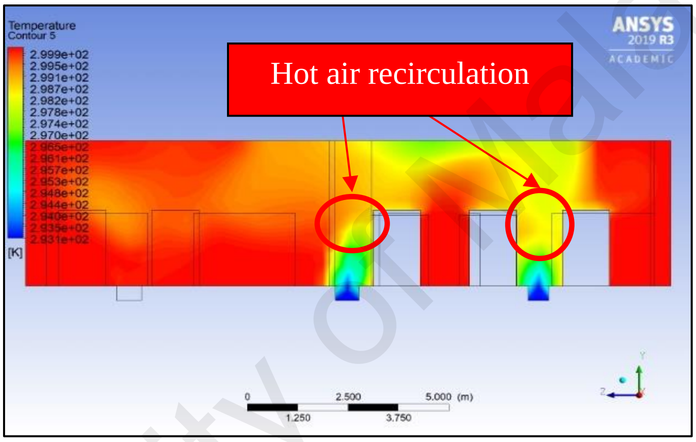


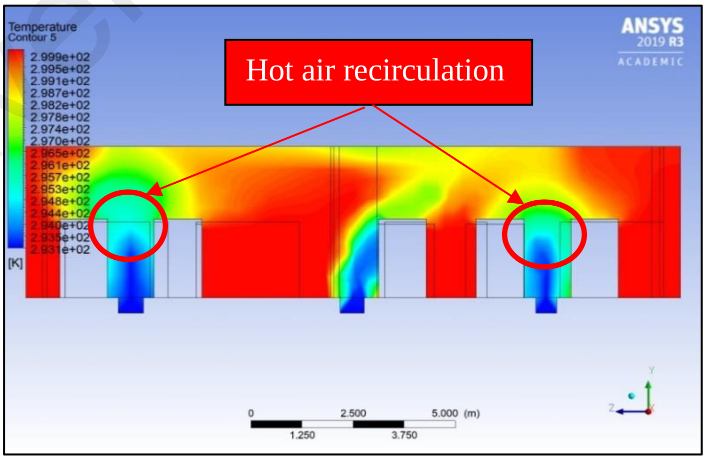
Figure 4. 5: Vertical planes across the room at 4.5m, 12m and 20m on the x-axis



(a) Heat distribution at 4.5m vertical plane



(b) Heat distribution at 12m vertical plane



(c) Heat distribution at 20m vertical plane

Figure 4. 6: Heat distribution on different vertical planes of server farm 1

As shown in figure 4.6, it can be seen that for most server racks the flow of cold air from the raised floor inlet is sufficient to provide cooling from the lower to the upper racks. However, it can be seen that on 4.5m, 12m and 20m vertical plane there are some hot air recirculation over the top of the server racks. The recirculation of hot air at the side and top of the server racks will gradually increase the cooling air temperature. Therefore, to prevent hot air recirculation simple method such as installing cold aisle containment system is suggested.

4.2 Simulation of server farm 1 with cold aisle containment system

To improve the cooling efficiency, an alternative method of installing cold aisle containment system in the server farm is investigated. Cold aisle containment system is a relatively easy and cheap modification that can be used to improve cooling efficiency. As shown in figure 4.7, by installing the cold aisle containment system the cold air from the raised floor inlet is contained on the front portion of the server racks. The containment system also prevents warm exhaust air from the rear of the server racks from entering the front of the server racks thus improving the cooling efficiency of the server racks.

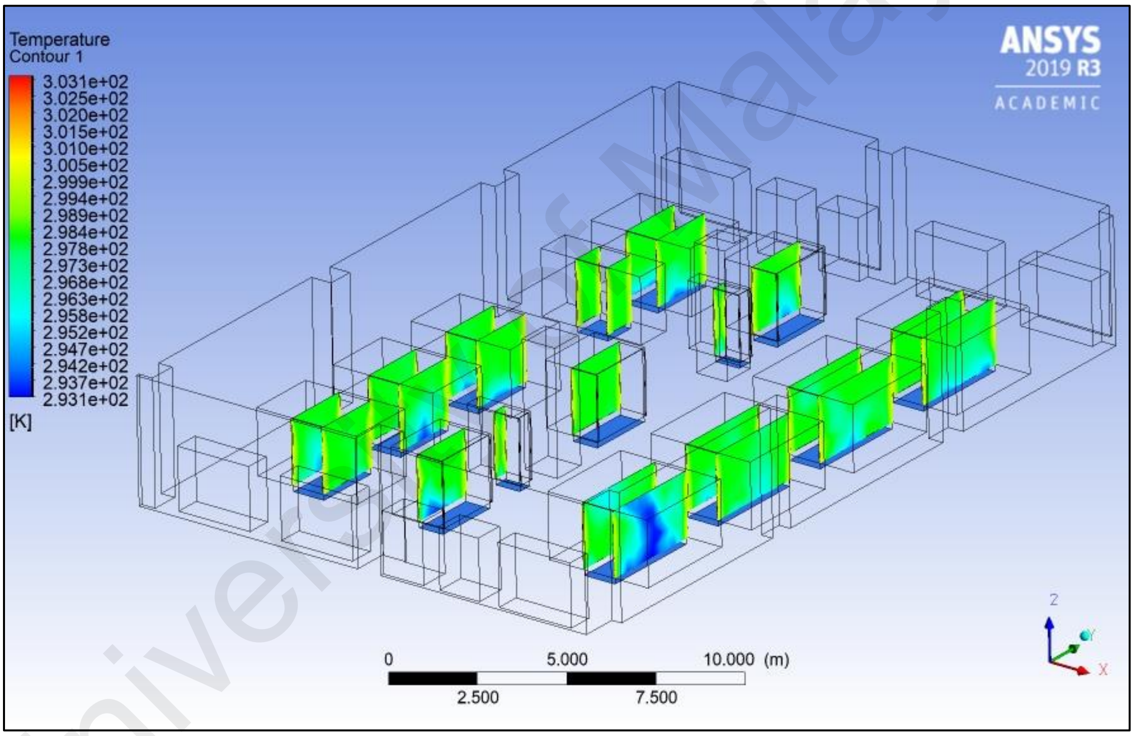


Figure 4. 7: Heat distribution in front of the server racks (Cold aisle containment system)

As shown in figure 4.7, the heat distribution in front of the server racks are more evenly distributed compared to the original setup without the cold aisle containment system. The temperature in front of the server racks varies from 20 to 25°C. The temperature is more evenly distributed since there is no backflow of air from the back of the server rack into the cold aisle. This can be confirmed by observing the streamline flow of the exhaust air as shown in figure 4.8 below.

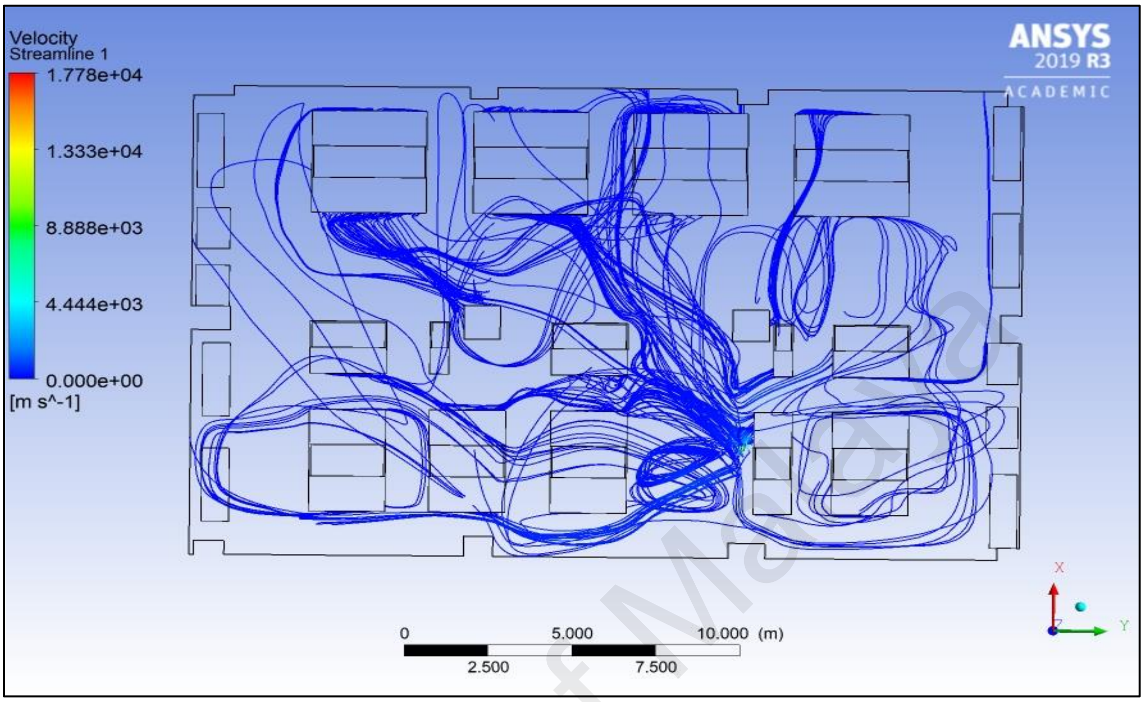
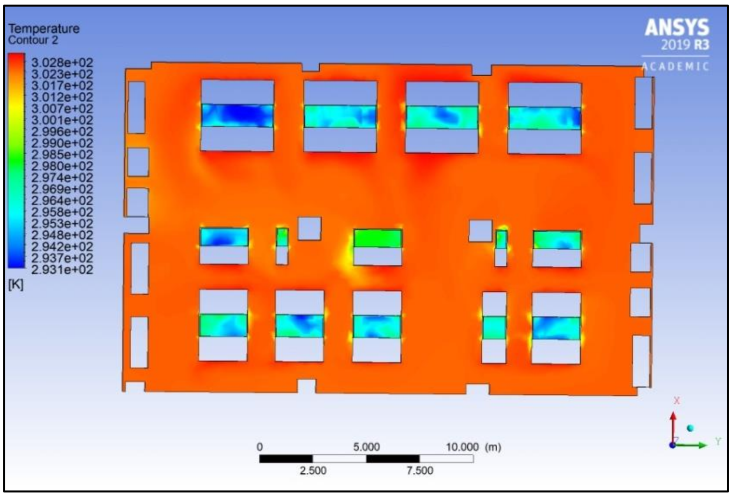


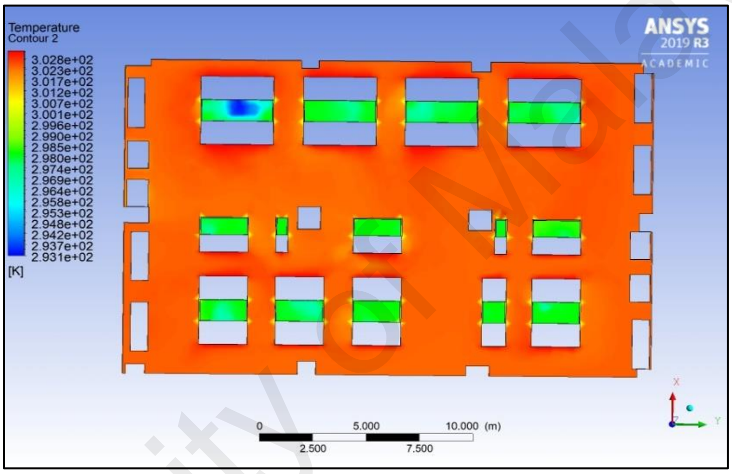
Figure 4.8: Streamline flow of exhaust air from the back of server racks

From figure 4.8, it can be seen that the exhaust air flows everywhere other than into the cold aisles. By eliminating the hot air recirculation problem, the cooling efficiency of the server racks are increased thus achieving a more even temperature distribution in front of the server racks.

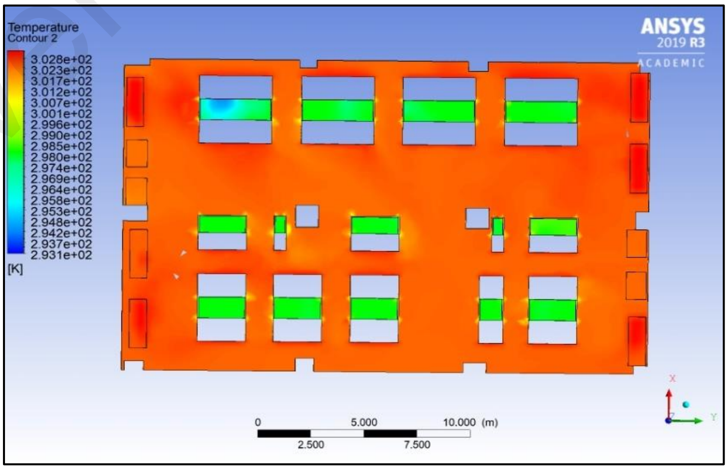
However, the cold aisle containment system is not without flaw, by observing the heat distribution on different horizontal planes as in figure 4.9. It can be seen that the main drawback of using cold aisle containment system is that the temperature across the room becomes warmer compared to when no cold aisle containment system is installed. As shown in figure 4.9, the heat distribution across the room varies from 27 to 30°C compared to the maximum of 26°C temperature without using the cold aisle containment. This can also be seen from the vertical contour across the room as shown in figure 4.10.



(a) Heat distribution at 0.1m plane

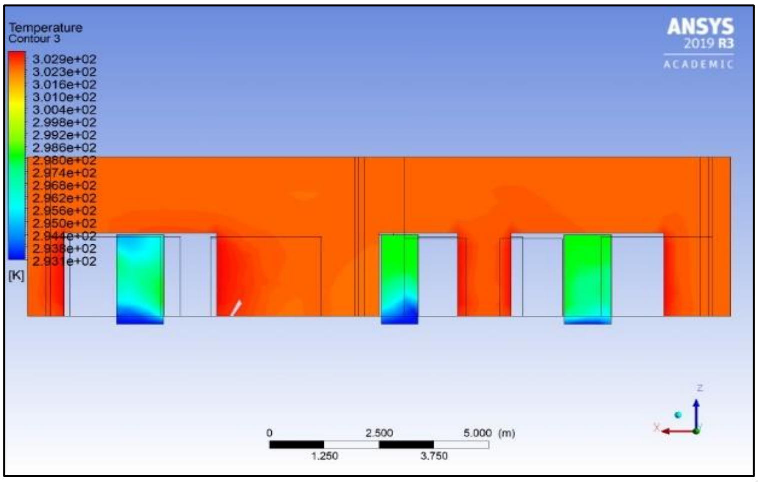


(b) Heat distribution at 1.05m plane

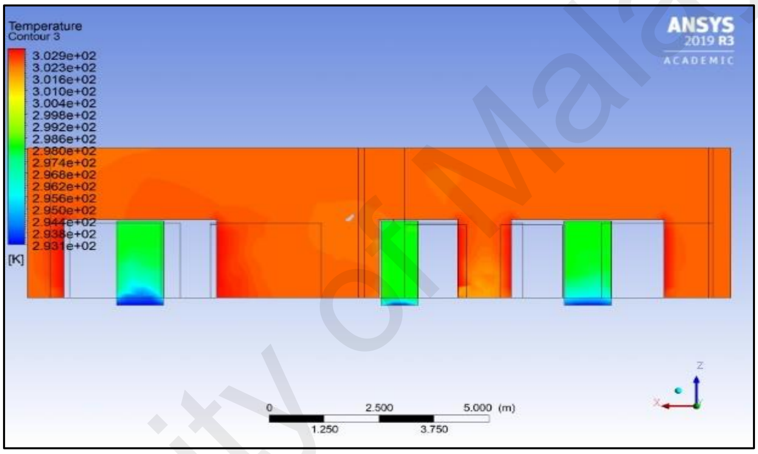


(c) Heat distribution at 2.02m plane

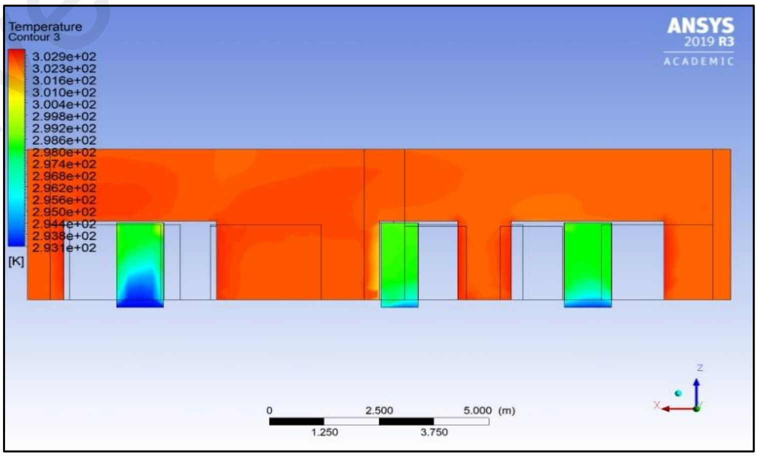
Figure 4.9: Heat distribution at different horizontal planes with cold aisle containment system installed



(a) Temperature distribution at 4.5m vertical plane across the room



(b) Temperature distribution at 12m vertical plane across the room



(c) Temperature distribution at 20m vertical plane across the room

Figure 4.10: Temperature distribution across server farm 1 at three different vertical planes

From figure 4.10, it can be clearly seen that the cold air from raised floor inlet is completely contained in the cold aisle container and have managed to completely eliminates hot air recirculation. This results in lower average temperature at the front of the server racks. However, it can also be seen that the temperature across the room outside of the cold air containment has also increase uniformly across the room. This large increase in temperature across the room is due to the fact that the cold aisle containment system contains the cold air only in the cold aisle container. Thus, only hot exhaust air from the server racks flows into the room. This increase in temperature across the room can create problem for other components that is installed in the room if it is not designed to operate under such temperature. This is surely one of the most important factors that should be address upon installing the cold aisle containment system.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The three-dimensional(3D) environment of the server farm had been successfully modeled from the 2D blueprint. The model is a simplified version of the actual server farm since all components are assumed to be rectangular in shape and also modeled as black boxes. This simplification is primarily done to reduce computing power and calculation time. However, the simplification process can result in reduced accuracy. The result should be further validated by comparing the calculated results with the actual measurement taken from the server farm.

Using Ansys Fluent, thermal transport phenomena of the server farm were successfully simulated. The airflow within the server farm was also successfully visualized using the velocity streamline plot.

From this visualization, the average temperature and localized hot spot in front of the server farms had been determined. From the temperature plot, it can be seen that the increase in temperature occurs mostly at the side and top region of server racks. The temperature at the side and top of the server racks can reach to as high as 27°C. The increase in temperature is mainly due to hot air recirculation which can clearly be seen from the velocity streamline plot.

To overcome this problem the server farm was recommended to be fitted with cold aisle containment system. Similar analysis were performed with the server farm model fitted with the cold aisle containment system. The result shown that the cold aisle containment system is able to completely eliminate the hot air recirculation problem and thus maintaining a lower cooling air temperature that is more evenly distributed over the server racks inlet.

5.1 Recommendations

This research project can be further improved by investigating other options to be used for the simulation since as highlighted in chapter 4, the scaled residuals shows difficulty to achieve convergence. This instability can result in a less reliable results produced from the calculation. Other options can include changing the mesh features, using other turbulent models such as k-ω or using different setting for under-relaxation factor.

Although the results in chapter 4 confirms that usage of containment system can indeed improve server racks cooling efficiency. However, it is by no means that the containment system (hot or cold aisle) is without drawbacks. To install such system requires initial capital that is higher than the average air-cooling system without it. However, further research can also be done to investigate if the long-term benefits of such configuration outweighs the high initial cost of the setup.

Other than that, various other modern data center cooling system can also be considered. These modern data centers cooling system are not only efficient but even environmentally friendly. One such example is the google data center in Hamina, Finland which uses cold sea water and rain water to cool their data center. Since about 17% of carbon footprint caused by technology is due to data centers (Isberto, 2018), this environmentally friendly new generation data center cooling system can help to reduce a significant amount greenhouse gases(GHGs) towards building a greener future for our world.

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