A COMPUTATIONAL STUDY ON THE STEADY AND TRANSIENT BEHAVIOR OF DATA CENTERS

By

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And approved by

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ABSTRACT OF THE THESIS

A COMPUTATIONAL STUDY ON THE STEADY AND TRANSIENT BEHAVIOR OF DATA CENTERS

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Thesis Director:

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Data center is a facility that has high energy demands to keep the temperature under control. IT equipment consumes 50% of energy while the cooling system consumes approximately 37% of energy. Hence, it is very important to ensure the cooling of the data center is efficient. In this research, the effect of operating parameters such as inlet velocity, inlet temperature and porosity of the racks on the temperature distribution is studied; furthermore, the effect of different load distribution in the racks and the transient effects during load change are studied.

A raised floor data center is modeled and thermal simulation is done using ANSYS FLUENT.

The research consists of two parts, the first part aims at developing a working steady state model of a data center by modeling the racks as porous media and studying the temperature distribution of the racks and the room with varying load and different operating parameters for steady state condition. The optimal load distribution on the racks for different utilization is identified.

In the second part, a transient state analysis is done in order to understand the change in the system when the load changes. In a data center, the racks do not always operate at 100% and hence most of the temperature issues come when the load increases suddenly. Therefore, it is important to study the transient effects when the load is increased.

ACKNOWLEDGEMENT

I would first like to extend my deepest gratitude to my advisor Dr. Yogesh Jaluria, without whom I would not have been able to do this thesis. I am thankful to him for agreeing to be my advisor and providing me with immeasurable guidance and support. I would like to thank him for being patient with me and help solve the problems that arose during my thesis.

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Last but not least, I would like to express my heartfelt gratitude to my family, for their unparalleled support and encouragement throughout my life.

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NOMENCLATURE

v	Velocity (m/s)
ρ	Density (Kg/m^3)
t	Time (s)
T	Temperature (°C)
P	Pressure
K	Flow Resistance Factor
F	Tile Porosity
k	Turbulence Kinetic Energy
ω	Specific rate of dissipation
Y_k , Y_ω	Dissipation of k and ω
Γ_k, Γ_ω	Effective Diffusivity of k and ω
S_k, S_w	User Defined Source Terms

CHAPTER 1

INTRODUCTION

Data centers are facilities hosting a large number of servers dedicated to data storage and management. In recent years, their power consumption has increased significantly due to the power density of the IT equipment [1].

A typical data center, spanning around 30,000 square feet, houses over 1000 racks, each generating upwards to 10kW of power. A larger data center with over 100,000 square feet will require around 50MW of power to operate [2]. And almost 37% of the energy requirements is for the cooling system. And around 2% of the total US electricity consumption is from data centers [3]. With the usage of data centers becoming larger and larger, the need arises to have efficient cooling of the data centers. This will help save energy and ultimately reduce the operation cost.

1.1 PREVIOUS WORK

Currently, most research in data center revolves around maintaining the room temperature in steady state simulations. H. E. Khalifa and D. W. Demetriou (2010) carried out an analysis to get the tradeoff between low supply air temperature and increased air flow rate. Also, they discussed the importance of using an enclosed aisle configuration which potentially reduces the savings to around 58% and the importance of providing a uniform temperature to the racks [4]. Chandrakant D. Patel, Ratnesh Sharma, Cullen E. Bash and Abdlmonem Beitelmal (2002) presented a case study of the influence of the design and layout of the data center to efficiently utilize the air condition system [2]. While those researches focused on the data center as a whole, Ali Habibi Khalaj and Saman K. Halgamuge (2017), discussed the thermal management of data centers from chips to the cooling system [3]. They also incorporated both air and liquid cooled systems, with direct and indirect liquid cooling. Alessando Beghi, Luca Cecchinato, Giuseppe Dalla Mana, Michele Lionello, Mirco Rampazzo and Enrico Sisti (2017) showed how the efficiency of the CRAC unit can be improved by free cooling technologies such as indirect adiabatic cooling. In this paper, they primarily discussed on reducing the process air temperature economically thereby reducing the room temperature and increased the efficiency of the CRAC units [1].

While most research focuses on steady state conditions, Rajat Ghosh, Vikneshan Sundaralingam, Steven Isaacs and Pramod Kumar (2011) employed a thermocouple network to measure the rack-inlet temperatures for a representative case study characterize rack-level transient heat transfer process [5].

1.2 MOTIVATION

From the literature survey, it can be seen that while steady state work is being done with respect to the operating parameters, it is also important to consider the effect of load distribution on the server racks and the effect of the operating parameters on the optimal load distribution. This is because, in practical applications, the racks do not always operate at 100%, some racks do not need to be in use while others can be used to reduce the temperature and supply velocity.

Also, while the steady state results give the details about the maximum temperature, velocity etc., it doesn’t talk about the problems or temperature spikes that occur when transition between one steady state to another.

In this research, the racks are modeled as a porous media to simplify the setup and reduce computational and design time.

This research focuses on the influence of operating conditions such as the air inlet velocity, inlet temperature on the temperature distribution of the racks and the room in steady state. The optimal rack utilization based on the load is identified and further analysis such as the dependency of porosity on the temperature and the transient case analysis are done on the optimal setup.

Most of the data centers nowadays use the raised floor air cooling system. In this model, the air is supplied by CRAC units through an under-floor plenum, and it is allowed to enter the room through perforated tiles placed near the racks. The aisle through which the cold air is allowed to enter is called the cold aisle and the other aisle is the hot aisle, where there is no inlet. The raised floor is popular due to its flexibility. In the event that the layout of the racks is changed, the tiles can be easily removed and placed near the hot rack.

CHAPTER 2

MODEL AND SETUP

2.1 PHYSICAL MODEL

In this research, a simpler form of the raised floor setup as shown in Figure.1 [6] is modeled. The data center is modeled in ANSYS DesignModeler. The overall dimension of the room is 10m x 7m x 3m and there are 16 server racks each 1m x 1m x 2m tall. Since the model is symmetric, half the model is simulated to reduce computational time.

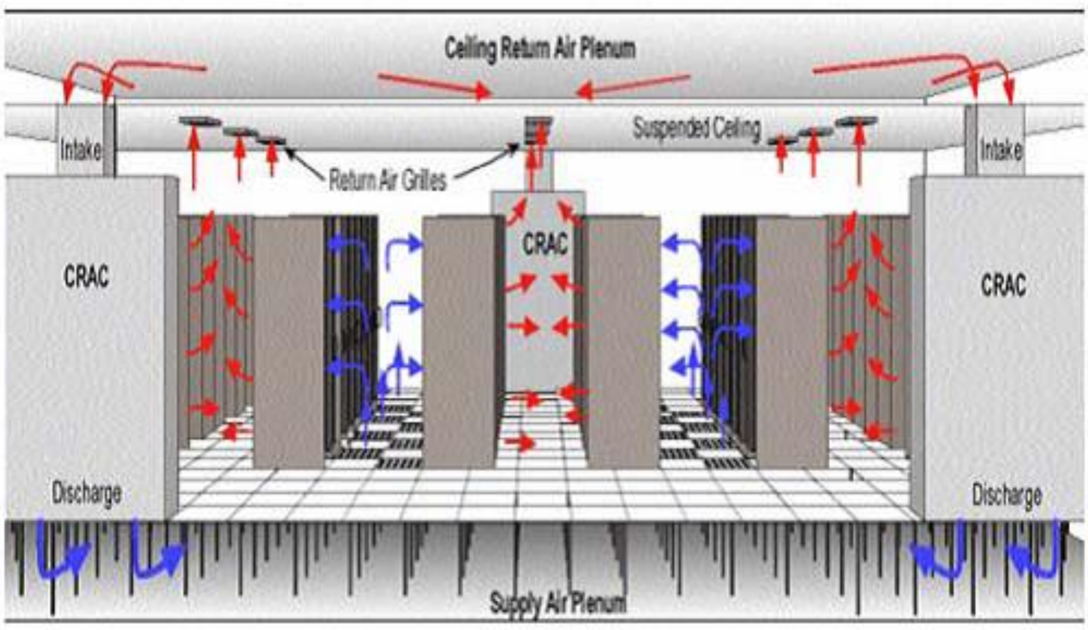


Fig.1.1 A typical raised floor data center model

The racks are modeled as a porous media. The perforated plates are treated as a one-dimensional porous jump boundary condition. The pressure drop across the perforated plates is expressed as [7]:

$$\Delta P = K(0.5\rho v^2) \tag{2.1}$$

v is the inlet velocity, ρ is the density of air and K is the Flow resistance factor which is calculated by [7]:

$$K = \frac{1}{F^2}\left(\left(\frac{1-F}{2}\right)^{\frac{1}{2}} + (1-F)\right)^2 \tag{2.2}$$

Where F is the porosity of the tile.

In practical use, the racks are an enclosure with approximately 24 servers in each rack. Each of these servers contains electronic components which emit heat. While, modeling and simulating this will get exact results, it is very complex and takes a lot of computational time. Therefore, in this research, the entire rack is assumed to be a porous media with a heat source. By setting the rack walls to be of steel and the porous media as copper and air, it can be modeled as close to as a real rack. S.A. Nada, M.A. Said, M.A. Rady (2016) assumes that the rack porosity can be approximated to 35% [8] and Yogesh Fulpagare Yogendra Joshi and Atul Bhargav (2016) assumed it to be 75% [9]. This research will focus on studying the dependency of the porosity on the temperature distribution. Since the porosity is approximated by the number of servers present inside the rack, if the servers are decreased, the porosity increases meaning more air flow. Also, by varying the porosity of the model, we can generate a model which can be closely applied and validated to a real-life model based on the results obtained.

2.2 GOVERNING EQUATIONS:

The K-omega model is used to solve the transport equations for the turbulent kinetic energy and the specific rate of dissipation. The two transport equations are given by:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{d}{dx_j}\left(\Gamma_k \frac{dk}{dx_j}\right) + G_k - Y_k + S_k \tag{2.3}$$

$$\frac{\partial(\rho \omega)}{\partial t} + \frac{\partial(\rho \omega u_i)}{\partial x_i} = \frac{d}{dx_j}\left(\Gamma_\omega \frac{d\omega}{dx_j}\right) + G_\omega - Y_\omega + S_\omega \tag{2.4}$$

Where, G_k represents the generation of turbulence kinetic energy due to mean velocity gradients G_ω represents the generation of ω. Y_k and Y_ω represent the dissipation of k and ω due to turbulence. S_k and S_w are user-defined source terms and Γ_k and Γ_ω are the effective diffusivity of k and ω.

The simulations are done using ANSYS 18.2 (Fluent) and the Standard K-Omega model is used.

2.3 GRID DEPENDCY:

The physical model was meshed with different interval sizes 0.08m, 0.05m and 0.03m. It is found that the temperature distribution doesn't change with interval size less than 0.05m and hence the model with mesh size 0.05m is chosen and this model is applied for all the simulations done in this research.

2.4 SIMULATION SETUP:

The simulation is split into two parts.

1. Effect of operating conditions (inlet velocity, temperature and load distribution) on temperature distribution
2. Effect of porosity on temperature distribution

The simulation cases are setup as shown in Table 2.1 and Table 2.2.

Note: Each rack operates with Heat Output 10kW.

2.4.1 EFFECT OF OPERATING CONDITIONS ON TEMPERATURE DISTRIBUTION:

Table 2.1. Variation of operating conditions

Case Number	Inlet Velocity (m/s)	Inlet Temperature (°C)	Power Output	Racks turned ON	Porosity of Racks
1.	1	20	25%	1,8	0.3
2.	1	20	25%	4,5	0.3
3.	1.5	20	25%	1,8	0.3
4.	1.5	20	25%	4,5	0.3
5.	1	20	50%	1,2,7,8	0.3
6.	1	20	50%	3,4,5,6	0.3
7.	1.5	20	50%	1,2,7,8	0.3
8.	1.5	20	50%	3,4,5,6	0.3
9.	1	12	50%	3,4,5,6	0.3
10.	1.5	12	50%	3,4,5,6	0.3
11.	1	12	75%	1,2,3,6,7,8	0.3
12.	1	12	75%	2,3,4,5,6,7	0.3
13.	1.5	12	75%	1,2,3,6,7,8	0.3
14.	1.5	12	75%	2,3,4,5,6,7	0.3
15.	1	12	100%	All racks	0.3
16.	1.5	12	100%	All racks	0.3

2.4.2 EFFECT OF POROSITY ON TEMPERATURE DISTRIBUTION:

Table 2.2. Variation of porosity

Case Number	Inlet Velocity (m/s)	Inlet Temperature (°C)	Power Output	Racks turned ON	Porosity of Racks
1.	1	20	25%	4,5	0.5
2.	1.5	20	25%	4,5	0.5
3.	1	20	50%	3,4,5,6	0.5
4.	1.5	20	50%	3,4,5,6	0.5
5.	1	12	75%	2,3,4,5,6,7	0.5
6.	1.5	12	75%	2,3,4,5,6,7	0.5

7.	1	12	100%	All racks	0.5
8.	1.5	12	100%	All racks	0.5
9.	1	20	25%	4,5	0.7
10.	1.5	20	25%	4,5	0.7
11.	1	20	50%	3,4,5,6	0.7
12.	1.5	20	50%	3,4,5,6	0.7
13.	1	12	75%	2,3,4,5,6,7	0.7
14.	1.5	12	75%	2,3,4,5,6,7	0.7
15.	1	12	100%	All racks	0.7
16.	1.5	12	100%	All racks	0.7

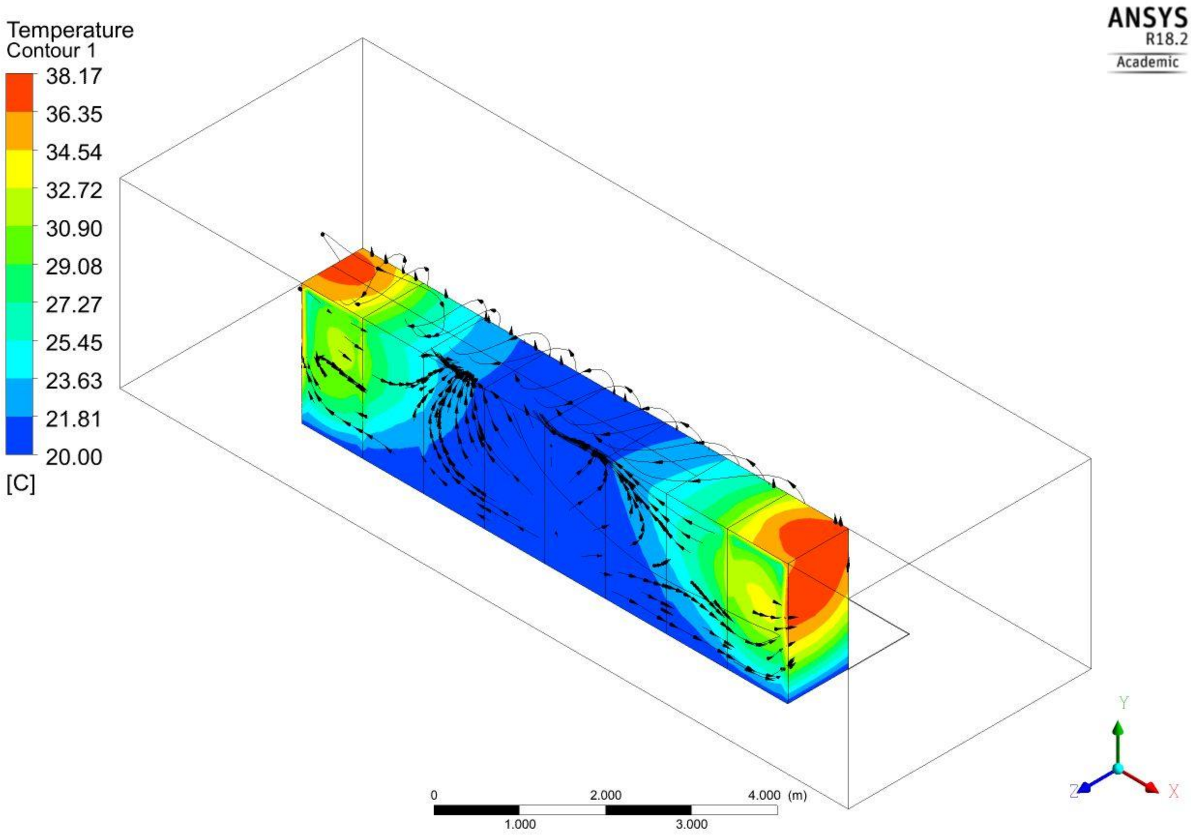
Since half of the room is simulated, 8 racks are present and they are numbered 1 to 8.

CHAPTER 3

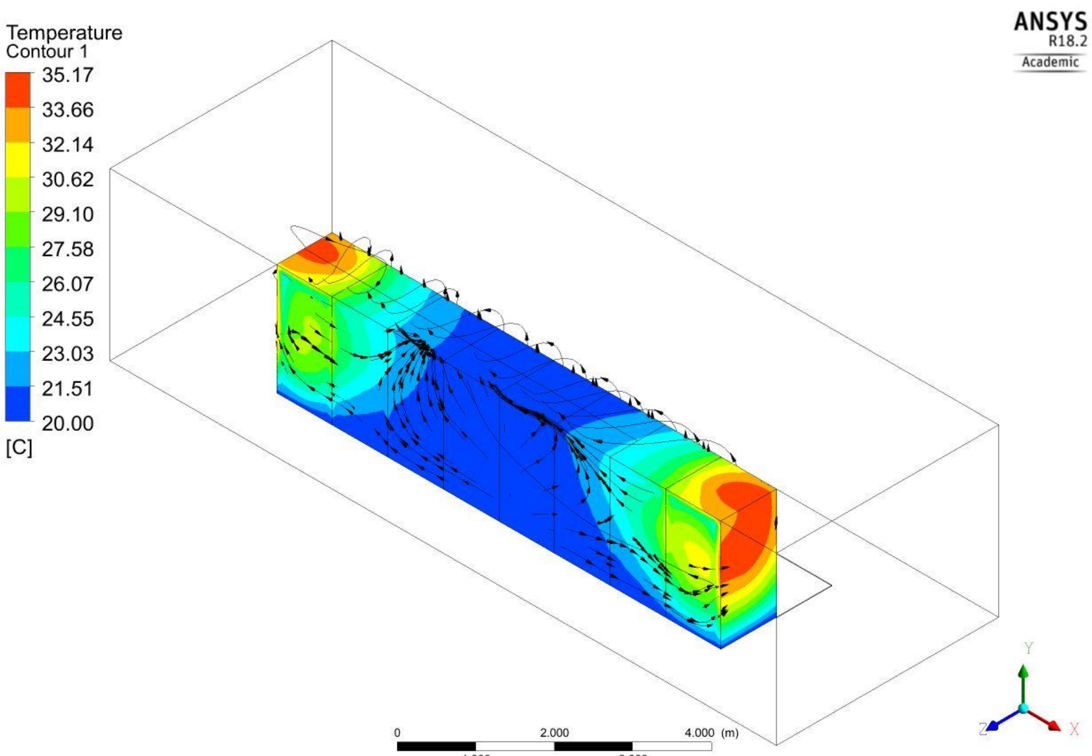
RESULTS AND DISCUSSIONS:

The data center utilization is not always at 100%. It varies based on need and hence cases were taken for 25%, 50%, 75% and 100% utilization. For 25%, 2 racks need to be in operation, for 50% 4 racks and for 75%, 6 racks. Also, for these utilization cases, there can be different racks which are operating. Therefore, the cases presented in the table 2.1 and 2.2 are simulated.

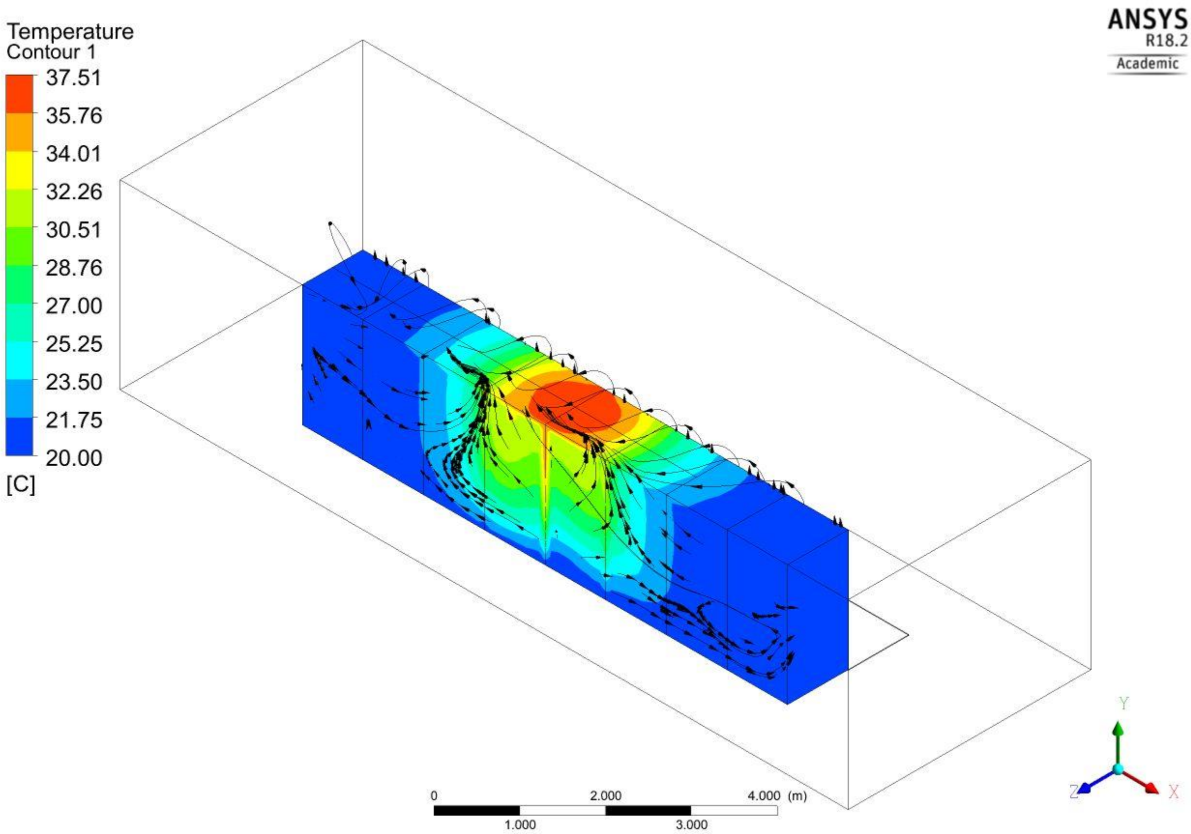
3.1 EFFECT OF INLET VELOCITY, TEMPERATURE AND UTILIZATION OF RACKS ON TEMPERATURE DISTRIBUTION:



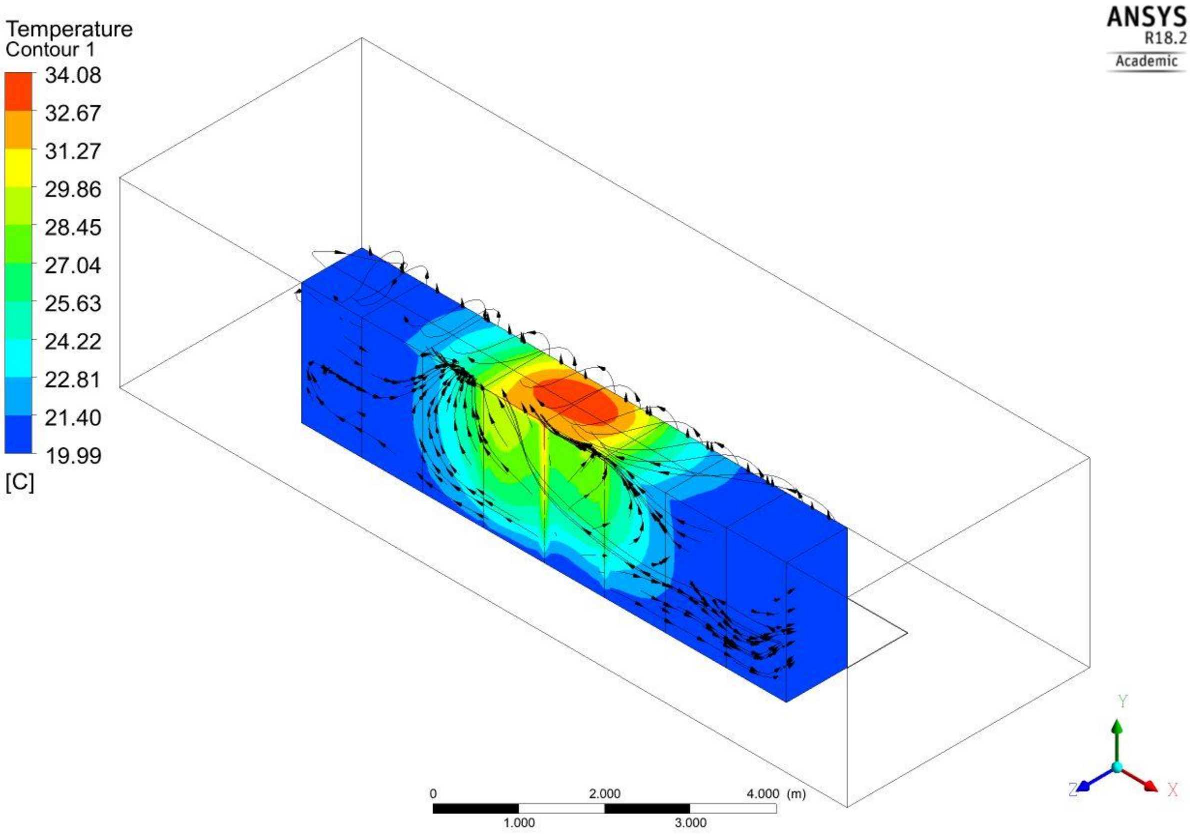
(a)


Temperature
Contour 1
35.17
33.66
32.14
30.62
29.10
27.58
26.07
24.55
23.03
21.51
20.00
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(b)


Temperature
Contour 1
37.51
35.76
34.01
32.26
30.51
28.76
27.00
25.25
23.50
21.75
20.00
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(c)



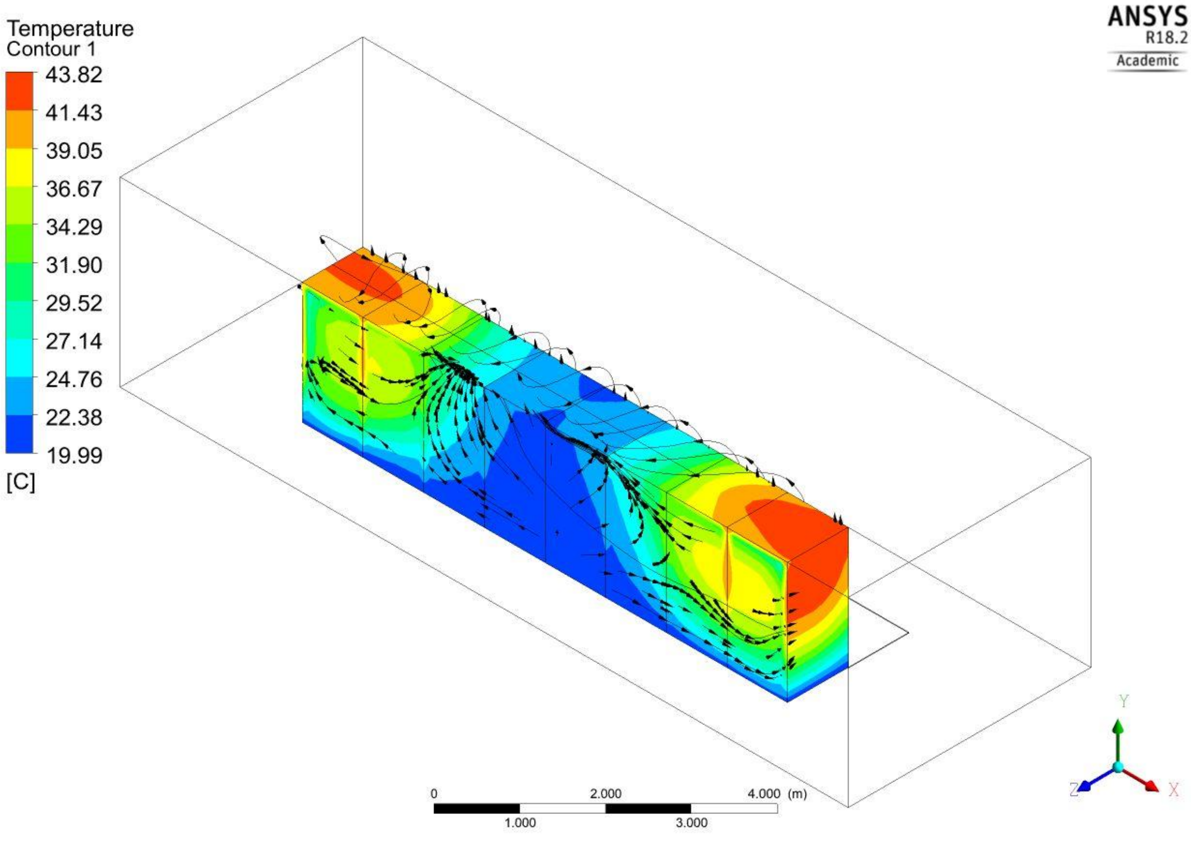
(d)

Fig.3.1 Temperature distribution for 25% utilization with streamlines

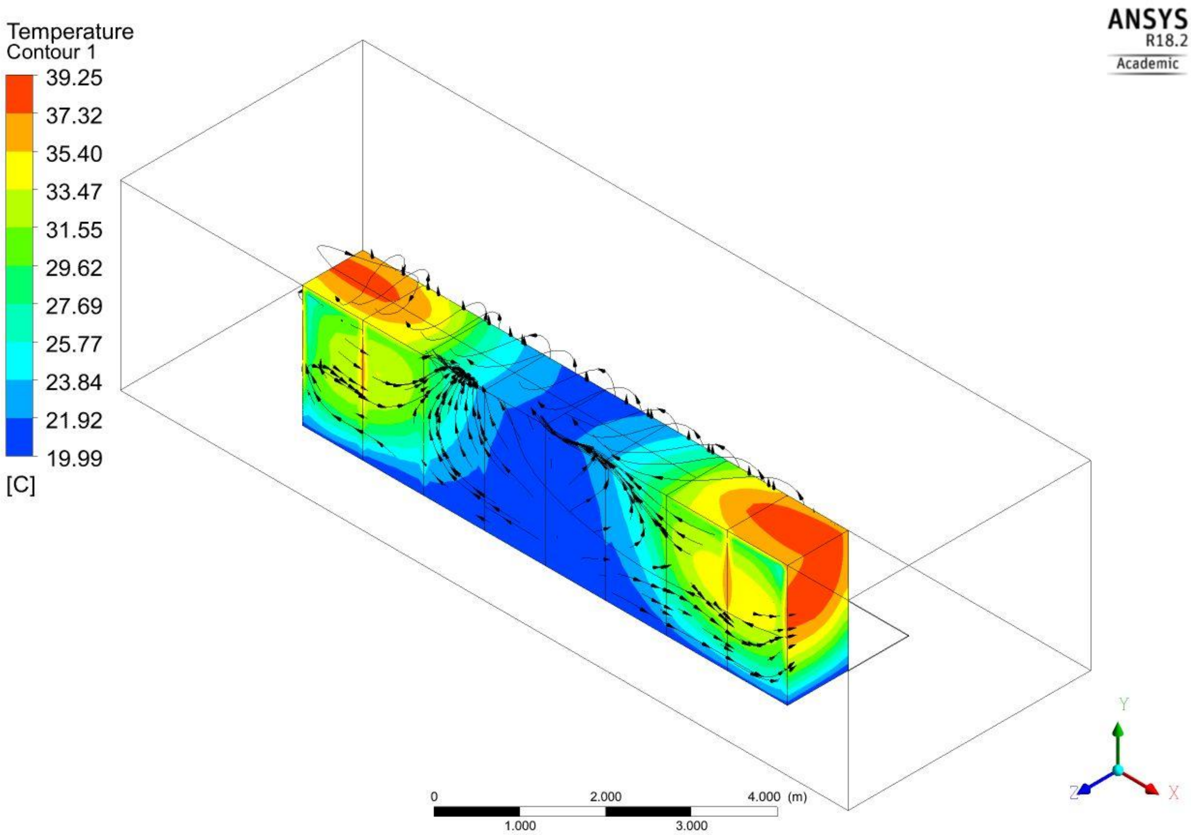
(a) Racks 1 and 8 are operating with 1m/s inlet velocity (b) Racks 1 and 8 are operating with 1.5m/s inlet velocity (c) Racks 4 and 5 are operating with 1m/s inlet velocity (d) Racks 4 and 5 are operating with 1.5m/s inlet velocity

Figure 3.1 shows the temperature distribution in the room for 25% utilization. The inlet temperature is kept constant with 20°C and the velocity is varied from 1 to 1.5m/s. It is seen that for the same velocity, the temperature is lower when the middle racks are operating. This is due to the fact that the hot air from the corner racks has to travel more to reach the outlet than the middle racks. Therefore, if the corner racks are in operation, the hot air will recirculate more within the system, hence increasing the overall temperature of the racks. Therefore, it is more efficient and optimal to turn the middle racks ON first.

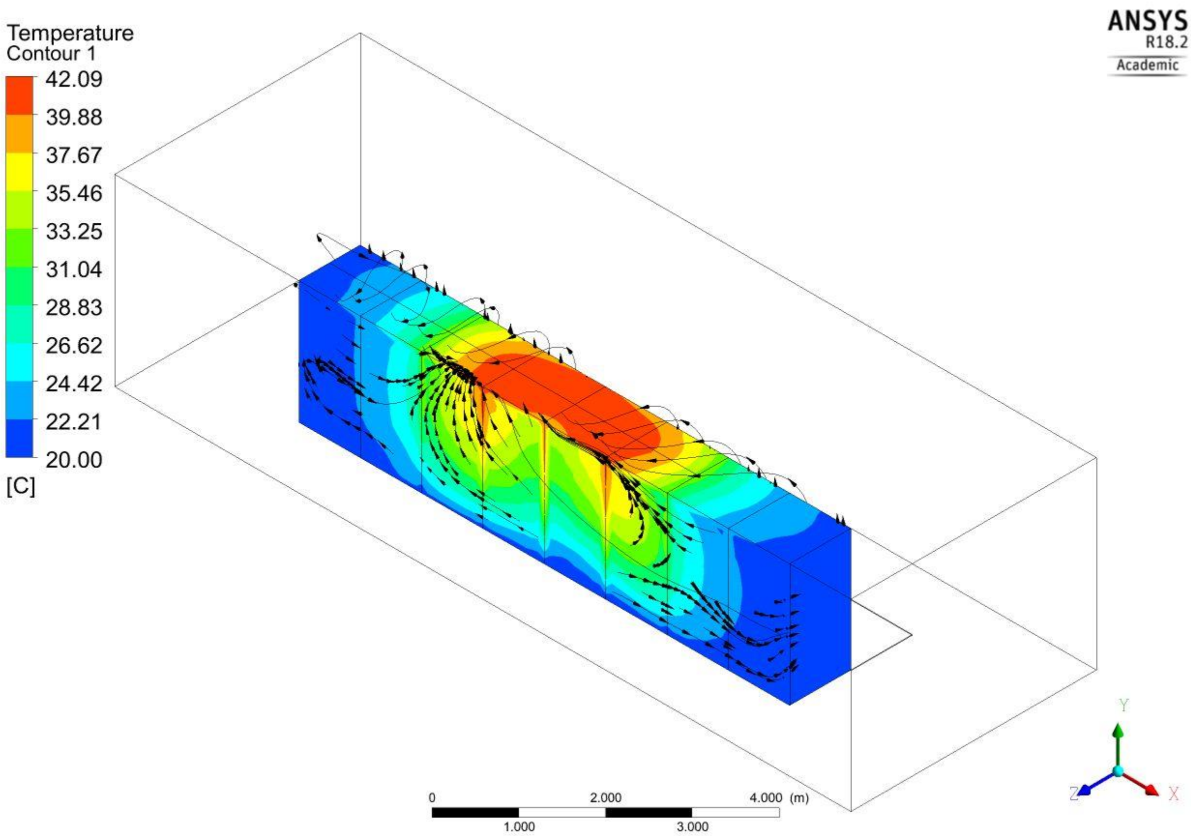
With the increase in velocity, as expected, the temperature decreases. This is known as in the practical case, as velocity increases, the cold air reaches the racks faster and flows through the room faster, facilitating faster cooling. But, it doesn't always mean that the velocity should be kept high as it will increase the energy costs of the CRAC unit. Therefore, based on the utilization and the maximum temperature of the room, a suitable velocity can be selected.



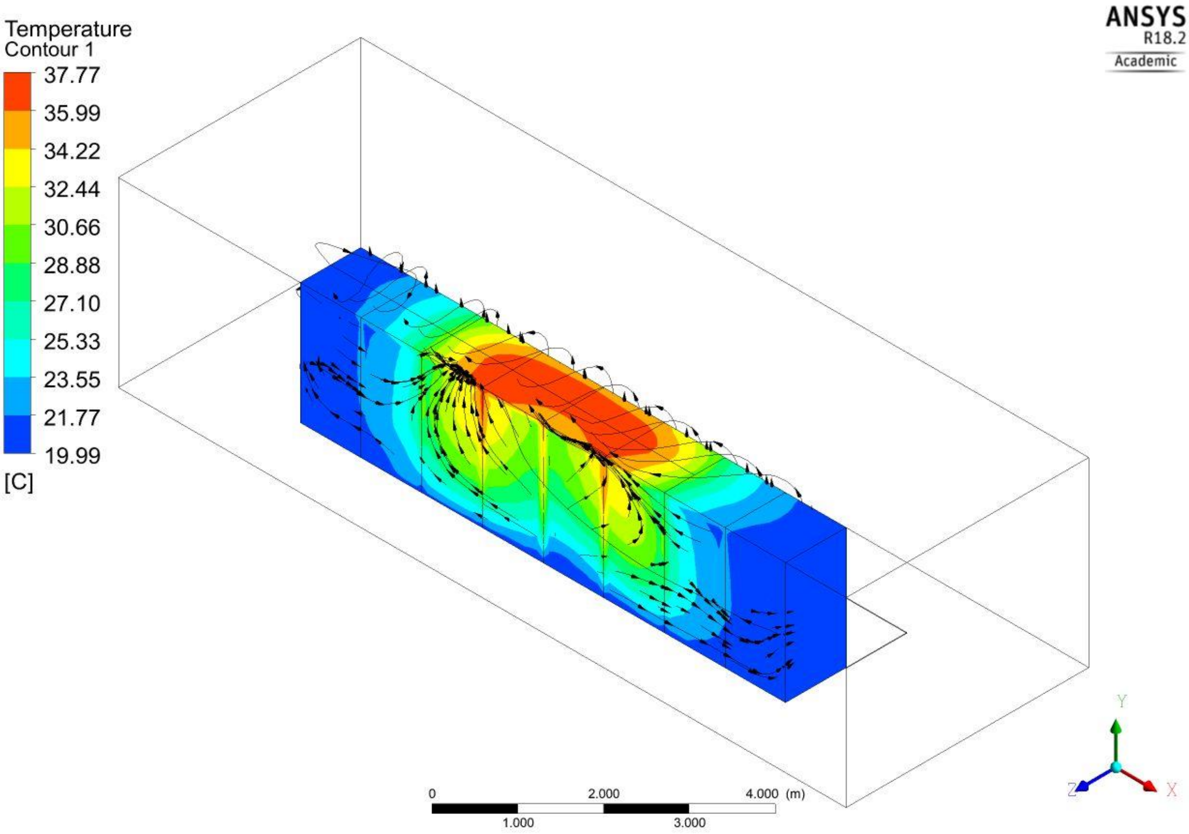
(a)


Temperature
Contour 1
39.25
37.32
35.40
33.47
31.55
29.62
27.69
25.77
23.84
21.92
19.99
[C]
ANSYS
R18.2
Academic
0
1.000
2.000
3.000
4.000 (m)
Y
Z
X

(b)


Temperature
Contour 1
42.09
39.88
37.67
35.46
33.25
31.04
28.83
26.62
24.42
22.21
20.00
[C]
ANSYS
R18.2
Academic
0
1.000
2.000
3.000
4.000 (m)
Y
Z
X

(c)



(d)

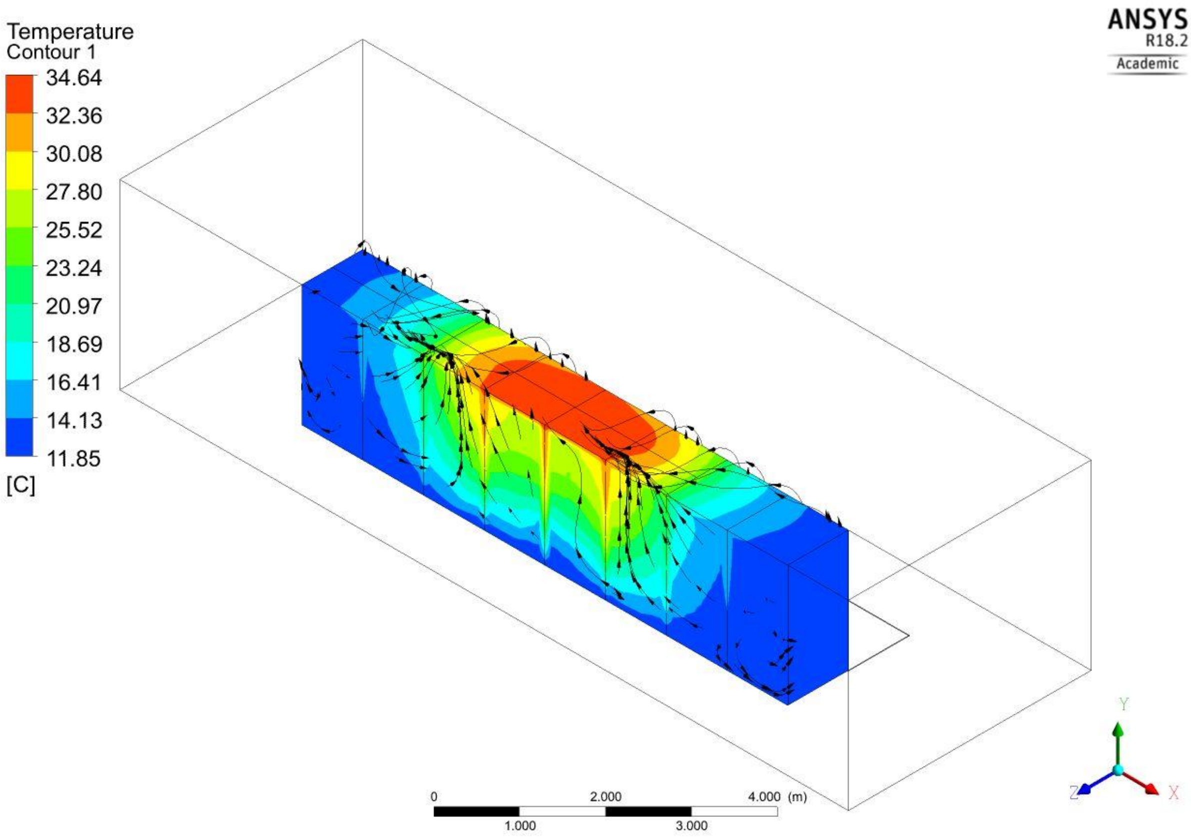
Fig.3.2. Temperature distribution for 50% utilization with streamlines

(a) Racks 1,2,7 and 8 are operating with 1m/s inlet velocity (b) Racks 1,2,7 and 8 are operating with 1.5m/s inlet velocity (c) Racks 3,4,5 and 6 are operating with 1m/s inlet velocity (d) Racks 3,4,5 and 6 are operating with 1.5m/s inlet velocity

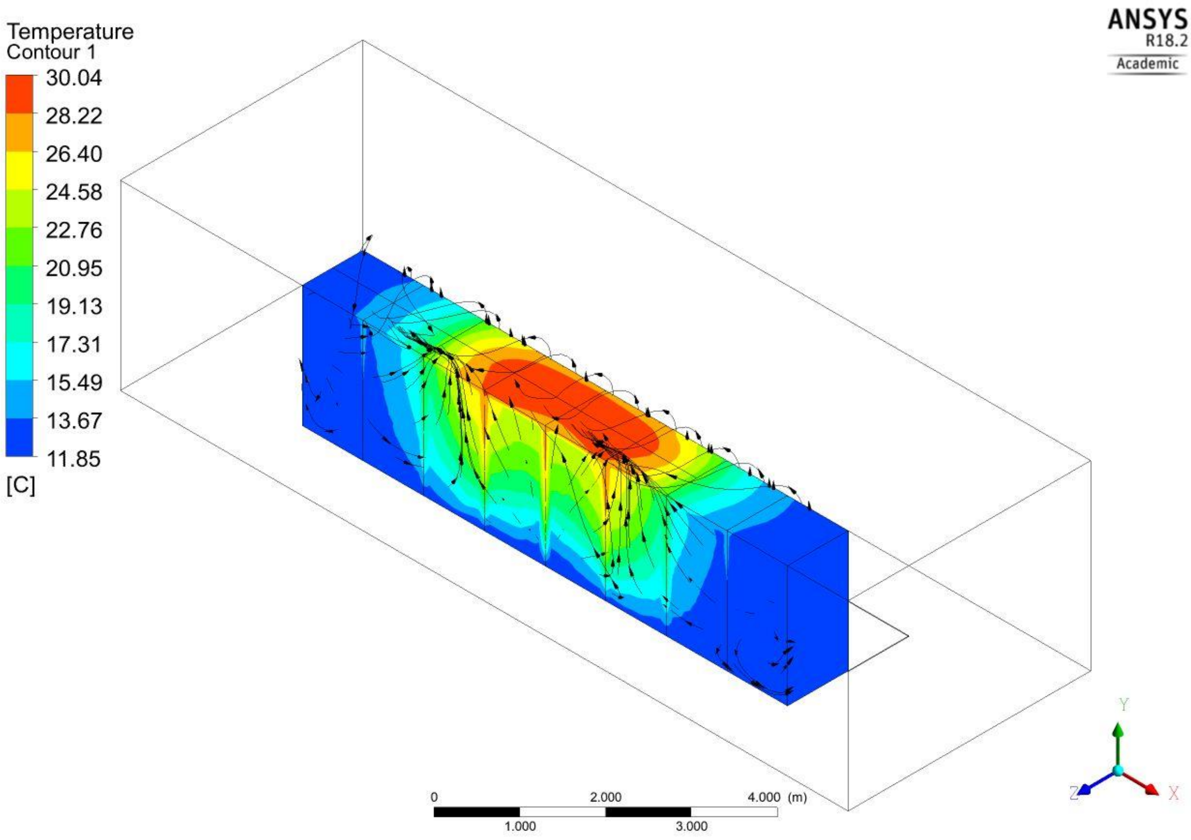
Figure 3.2 shows the temperature distribution when the utilization is 50%, with inlet temperature of 20°C. Similar to the 25% utilization case, it can be seen that the maximum temperature is less when the racks 3, 4,5 and 6 are operating.

Since the temperature is within the limits, this setup can be used in case of 50% utilization. But, any further increase in temperature might damage the electronic components and cause them to malfunction. Therefore, for further utilizations/load change, the chiller will be ON. The chiller temperature was set at 285K (12°C).

Also, to investigate the effect of inlet temperature on the model, the cases where racks 3, 4, 5 and 6 are operating is taken and the inlet temperature is supplied at 12°C.



(a)

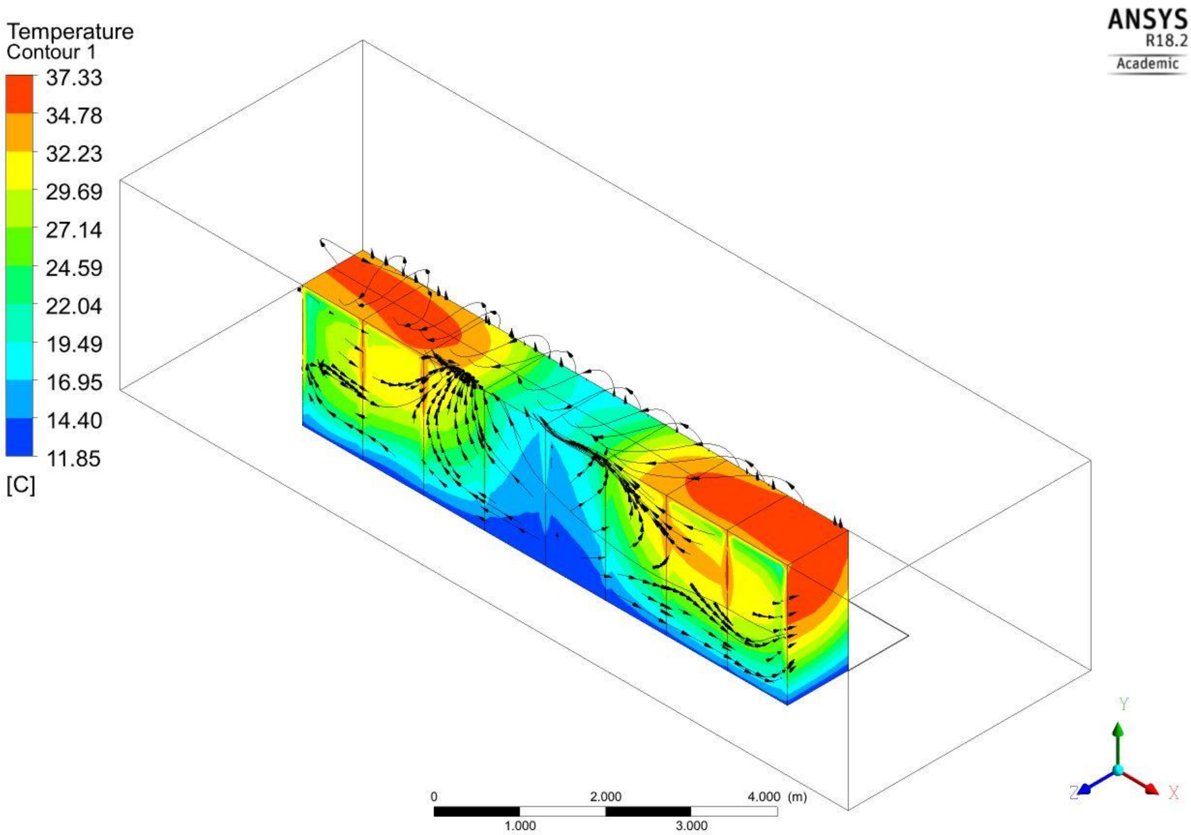


(b)

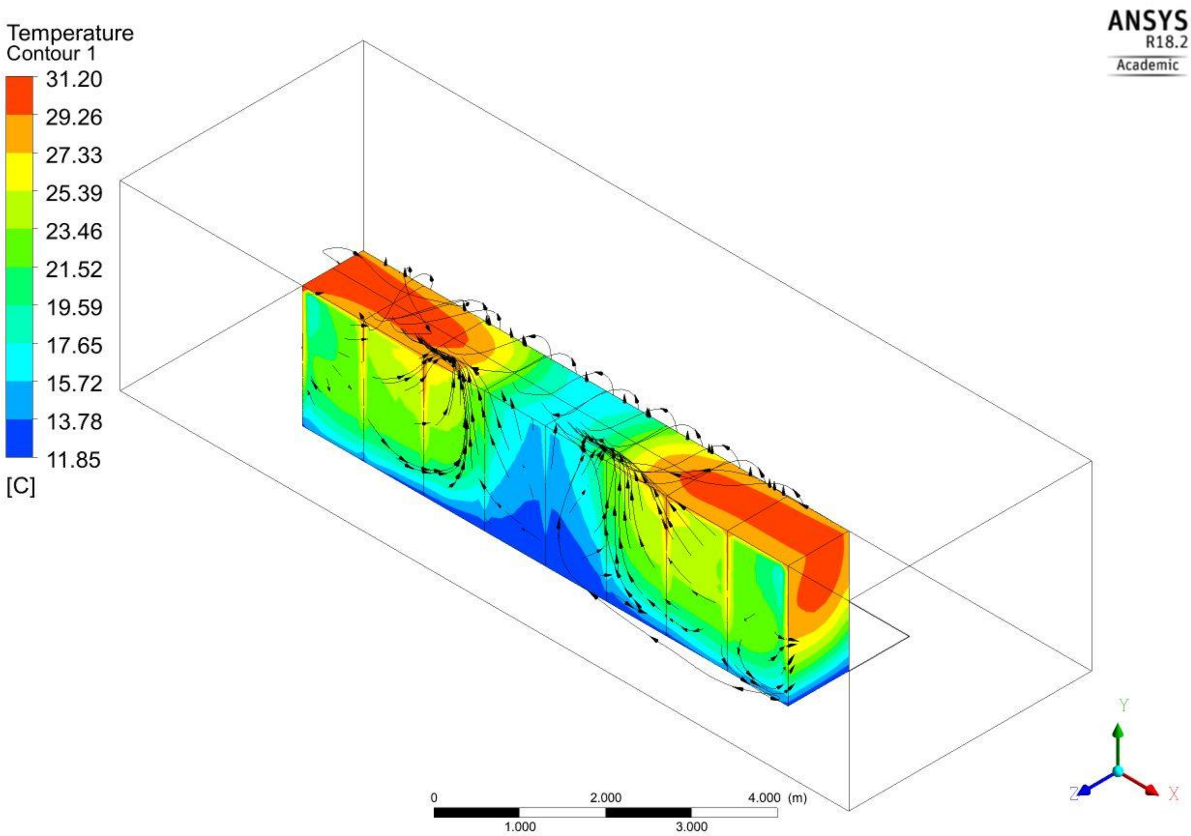
Fig.3.3. Temperature distribution for 50% utilization with streamlines

(a) Racks 3,4,5 and 6 are operating with 1m/s inlet velocity (b) Racks 3,4,5 and 6 are operating with 1.5m/s inlet velocity

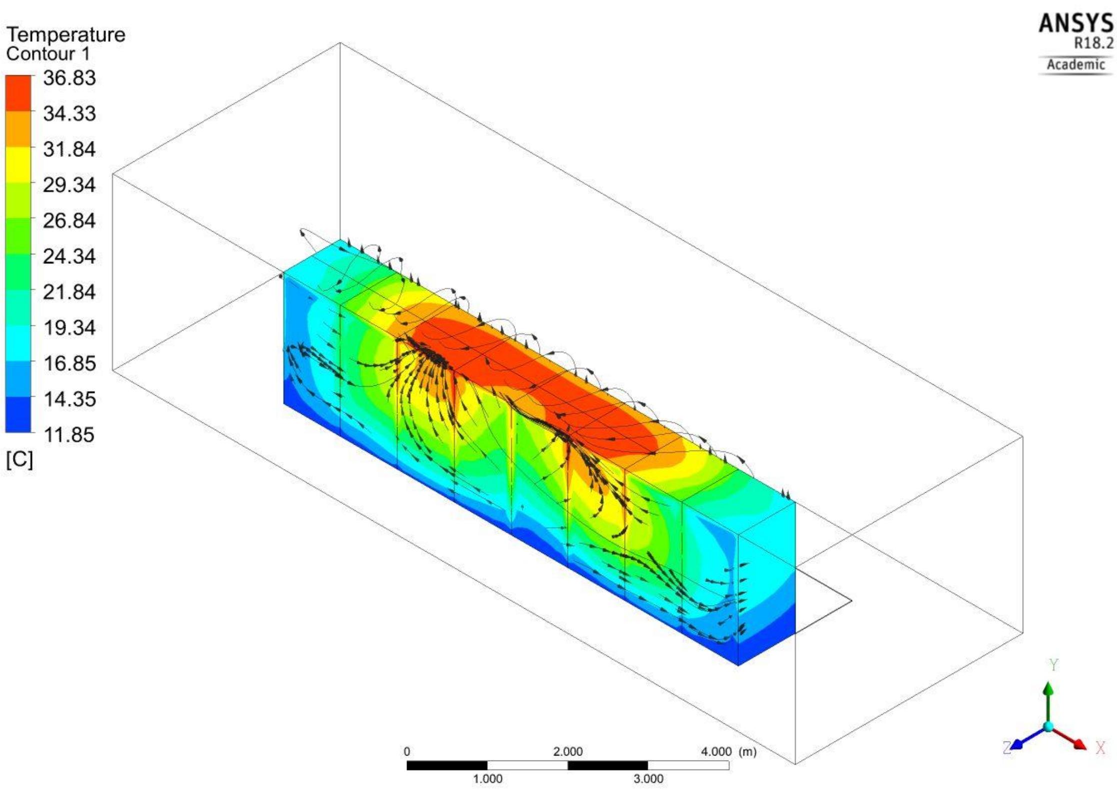
Figure 3.3 shows the temperature distribution when the 50% utilization case has an inlet temperature of 12°C. It can be seen from Figure 3.2 and 3.3 that there is a clear difference in temperature when the inlet temperature is changed from 20°C to 12°C. While the change in inlet temperature cools the room more effectively, it also consumes more energy. Therefore, the inlet temperature and velocity must be chosen carefully to avoid excess energy costs.


Temperature
Contour 1
37.33
34.78
32.23
29.69
27.14
24.59
22.04
19.49
16.95
14.40
11.85
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

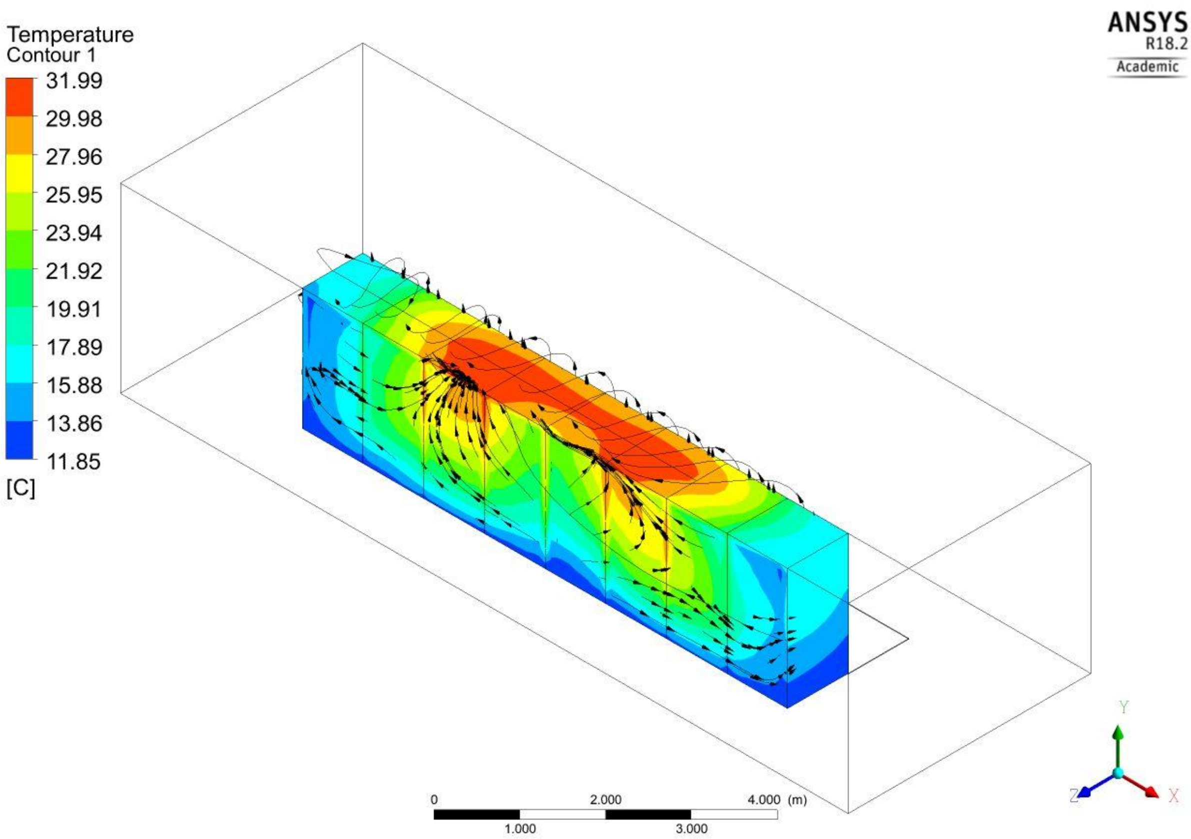
(a)


Temperature
Contour 1
31.20
29.26
27.33
25.39
23.46
21.52
19.59
17.65
15.72
13.78
11.85
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(b)


Temperature
Contour 1
36.83
34.33
31.84
29.34
26.84
24.34
21.84
19.34
16.85
14.35
11.85
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(c)

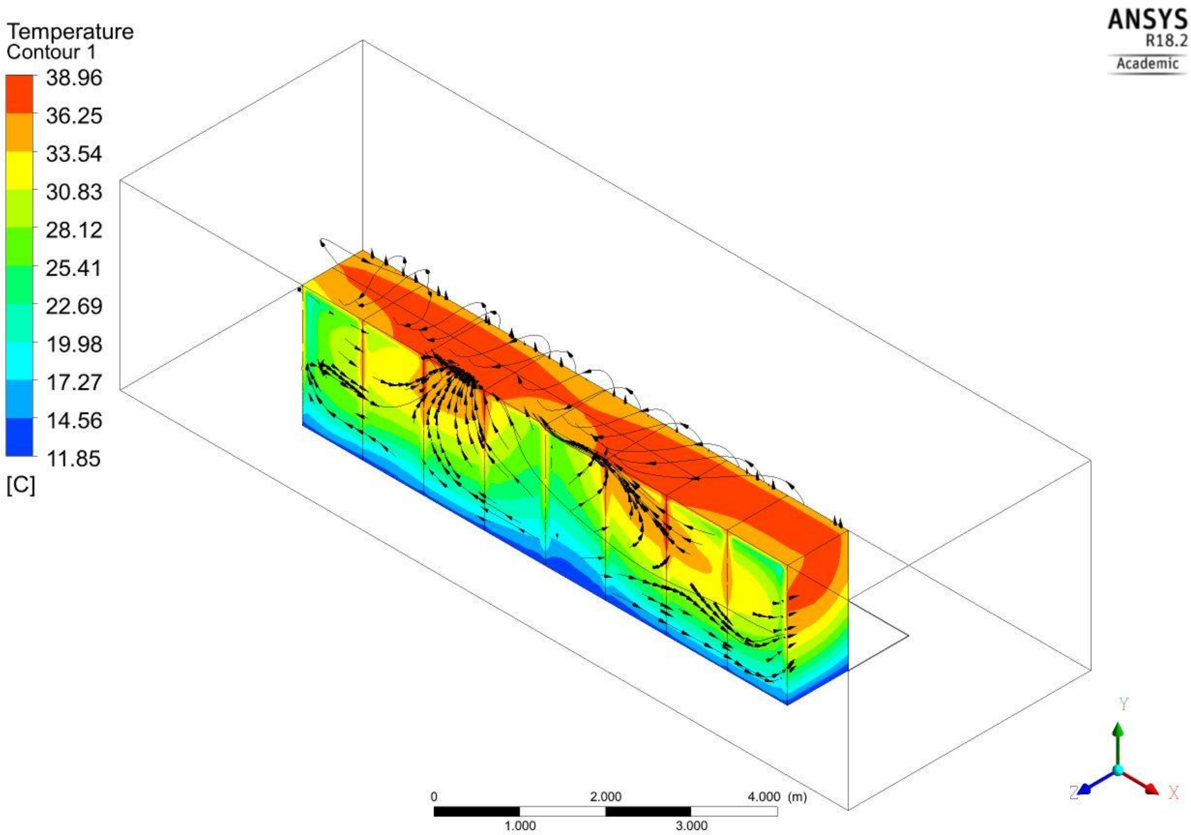

Temperature
Contour 1
31.99
29.98
27.96
25.95
23.94
21.92
19.91
17.89
15.88
13.86
11.85
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(d)

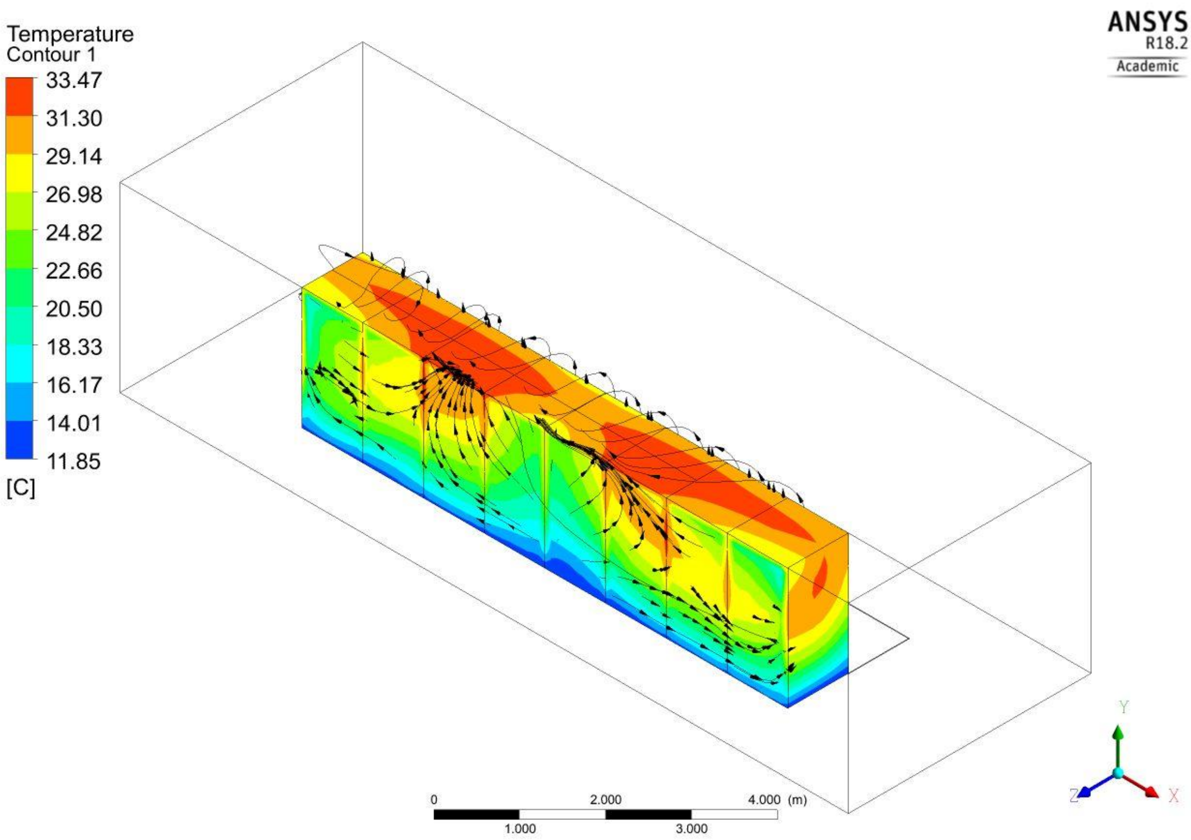
Fig.3.4. Temperature distribution for 75% utilization with streamlines

(a) Racks 1,2,3,6,7 and 8 are operating with 1m/s inlet velocity (b) Racks 1,2,3,6,7 and 8 are operating with 1.5m/s inlet velocity (c) Racks 2,3,4,5,6 and 7 are operating with 1m/s inlet velocity (d) Racks 2,3,4,5,6 and 7are operating with 1.5m/s inlet velocity

Figure 3.4 shows the temperature distribution when the utilization of the racks is 75%. That is, when 6 racks are emitting heat. In this case, the variation of racks which are operating does not change the maximum temperature drastically. This is due to the fact that since almost all the racks are in operation; the hot air which flows from the corner racks does not cause much effect to the system as a whole. Therefore, it is optimal to follow the rack configuration from the previous cases as in a practical scenario; the data center doesn't start working at 75% utilization immediately after being turned ON.


Temperature
Contour 1
38.96
36.25
33.54
30.83
28.12
25.41
22.69
19.98
17.27
14.56
11.85
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(a)


Temperature
Contour 1
33.47
31.30
29.14
26.98
24.82
22.66
20.50
18.33
16.17
14.01
11.85
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(b)

Fig.3.5. Temperature distribution for 100% utilization with streamlines

(a) Racks are operating with 1m/s inlet velocity (b) Racks are operating with 1.5m/s inlet velocity

Figure 3.5 shows the temperature distribution when all of the racks are being utilized. From all of the above results, it can be concluded that most of the hot spots occur on top of the racks. This is due to the fact that the cool air flowing on top of the racks is less when compared to the air that flows through the racks. The air that flows to the top of the racks is already heated and hence the cooling is less. Also, due to the position of the outlet, the amount of air that traverses to the side of the racks is less and hence we see hotspots in the top corners of the racks when utilized. Therefore, this leaves an area of scope to investigate the effect of position of inlet and outlet on the temperature distribution. And also, it can be seen consistently that, with the change in the inlet velocity from 1m/s to 1.5m/s, there is a decrease in the maximum temperature. Therefore, in cold regions, where the data centers are used, the inlet air temperature by itself will be cold and will not require any effect of the chiller. And in these cases, the air velocity can be reduced to save energy and ultimately reducing the overall cost of managing the data center.

While the above results show the temperature contours, it does not give very detail report on the temperature change for the effects. Therefore, a set of 8 points are chosen on the racks in order to check the temperature distribution for the effect of the operating parameters studied above. The points taken are shown in Fig 3.6 and the values are shown in Table 3.1.

Note: The relation is found for the case of 100% utilization and the below mentioned points are used for all the relationships in this research.

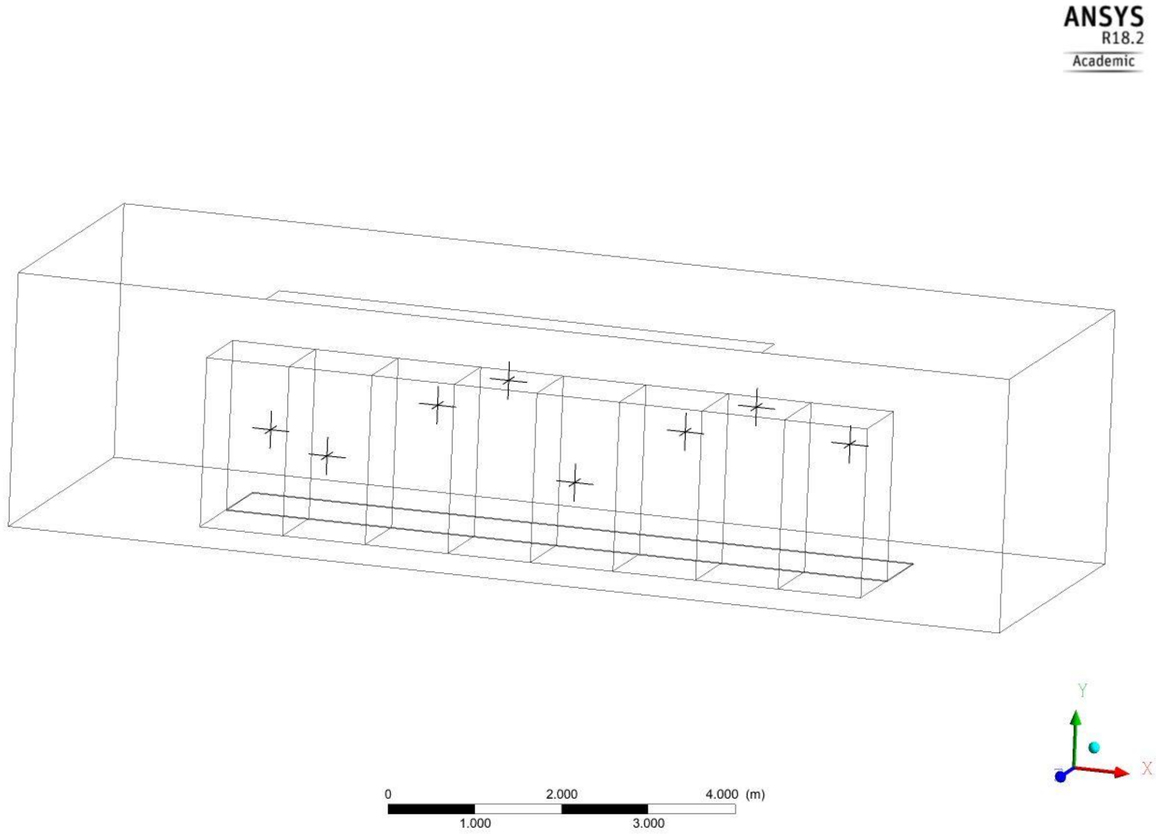


Fig.3.6. Probes for monitoring temperature changes

Table 3.1 Variation of Temperature with Velocity

Position of Probe	Temperature of probe °C (Velocity at 1m/s)	Temperature of probe °C (Velocity at 1.5m/s)
[5.5,2,2.5]	36.95	31.61
[2.5,1,2]	27.20	23.69
[3.5,1,3]	30.67	27.16
[7.5,1.5,2]	30.96	26.37
[8.5,2,2.5]	38.26	32.37

[9.8,1.8,3]	24.74	20.29
[4.5,1.5,2]	31.14	26.51
[6.5,1,3]	23.89	21.28

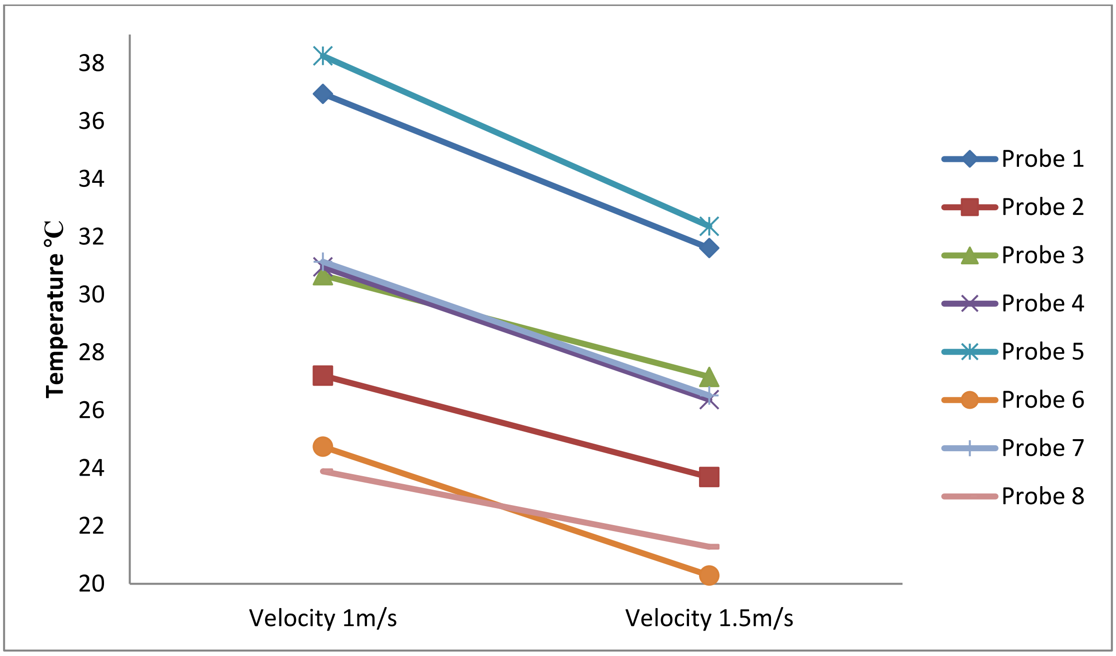
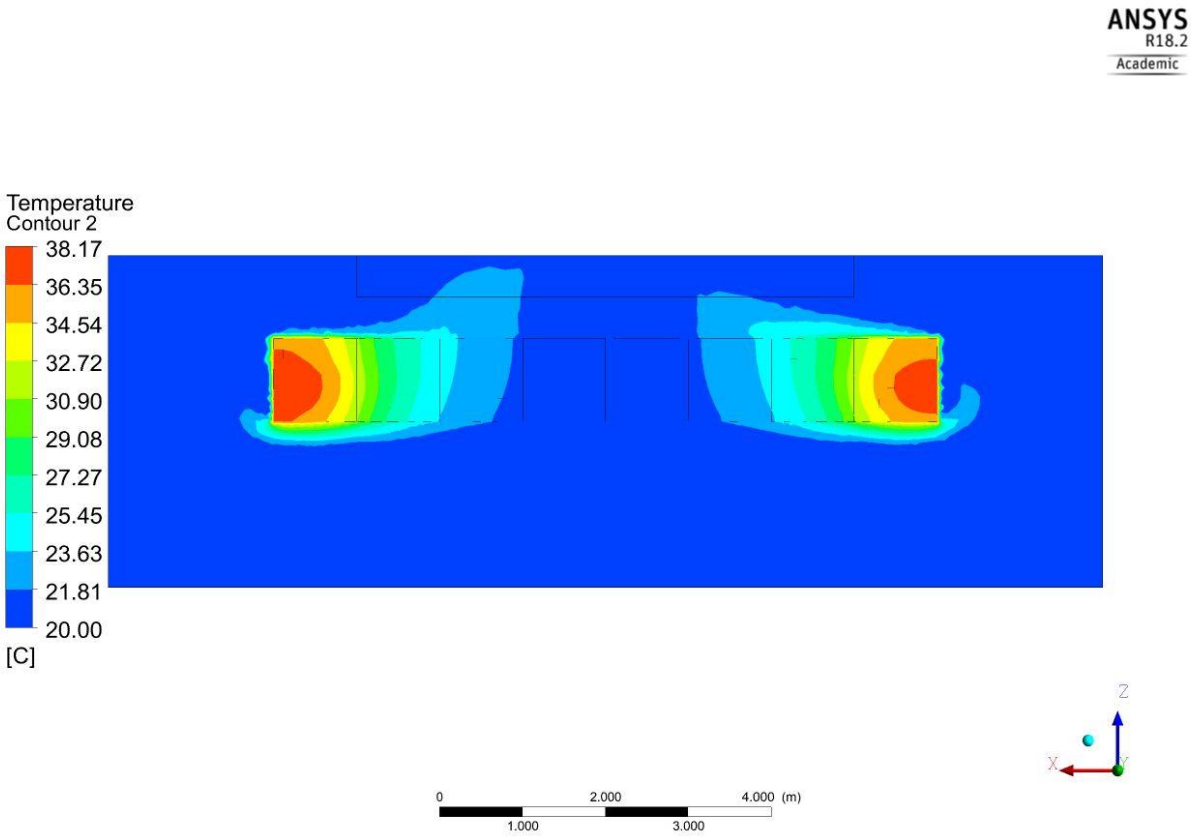


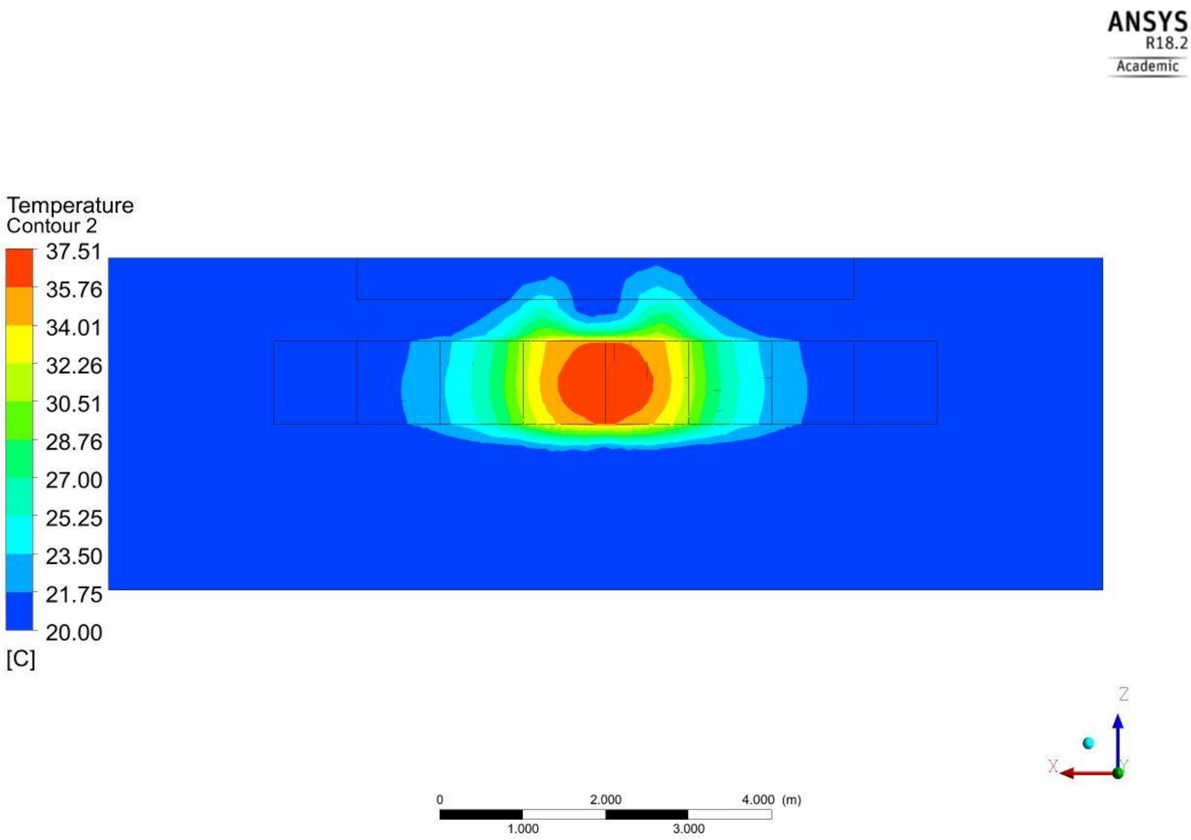
Fig 3.7 Variation of temperature with velocity

The relationship as described before can be seen from the Table 3.1 and Fig 3.8. The temperature difference between all the probes is not uniform as heat from each rack affects the adjacent rack and also the air flow in and around the rack is not uniform.

The above results focused only on the rack temperature distribution. But another important consideration is the room temperature. According to ASHRAE standards, the effective room temperature must not be greater than 35°C.


ANSYS
R18.2
Academic
Temperature
Contour 2
38.17
36.35
34.54
32.72
30.90
29.08
27.27
25.45
23.63
21.81
20.00
[C]
0
2.000
4.000 (m)
1.000
3.000

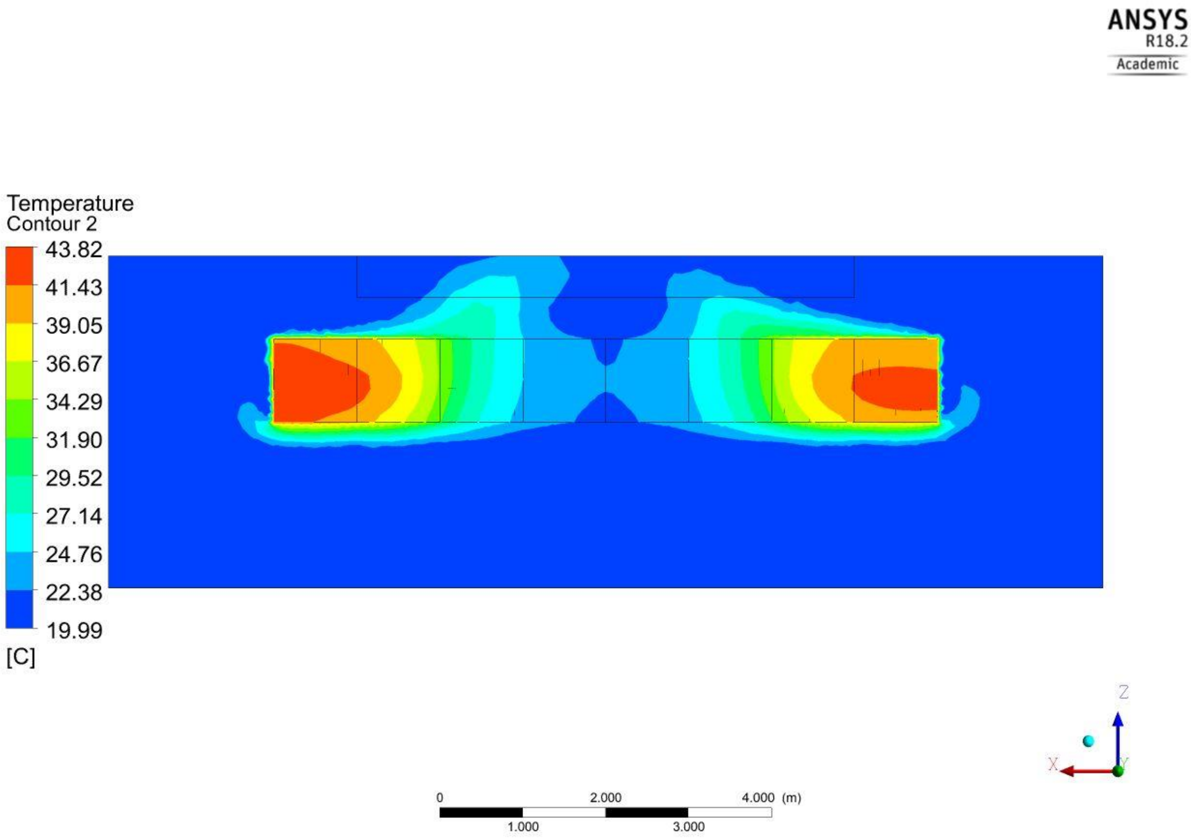
(a)


ANSYS
R18.2
Academic
Temperature
Contour 2
37.51
35.76
34.01
32.26
30.51
28.76
27.00
25.25
23.50
21.75
20.00
[C]
0
2.000
4.000 (m)
1.000
3.000

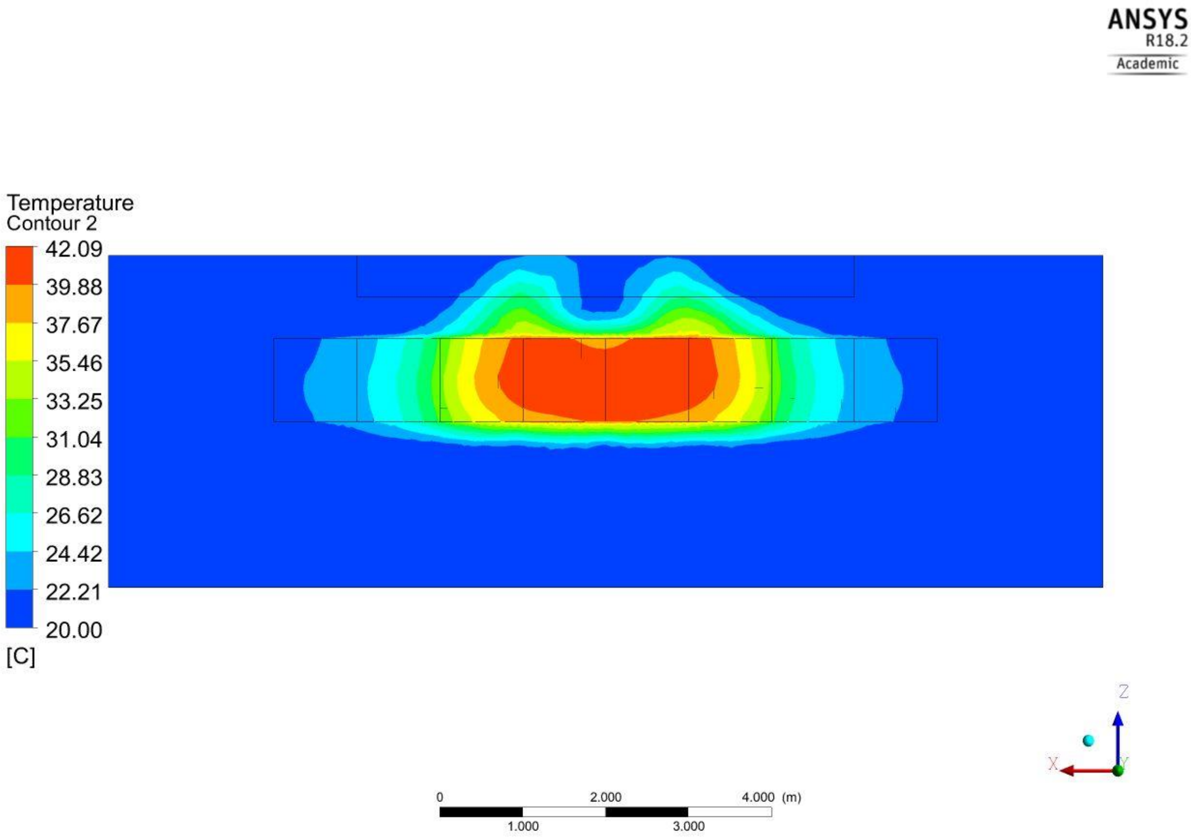
(b)

Fig.3.8. Temperature contours for 25% utilization

(a) Racks 1 and 8 are operating with 1m/s inlet velocity (b) Racks 4 and 5 are operating with 1m/s inlet velocity



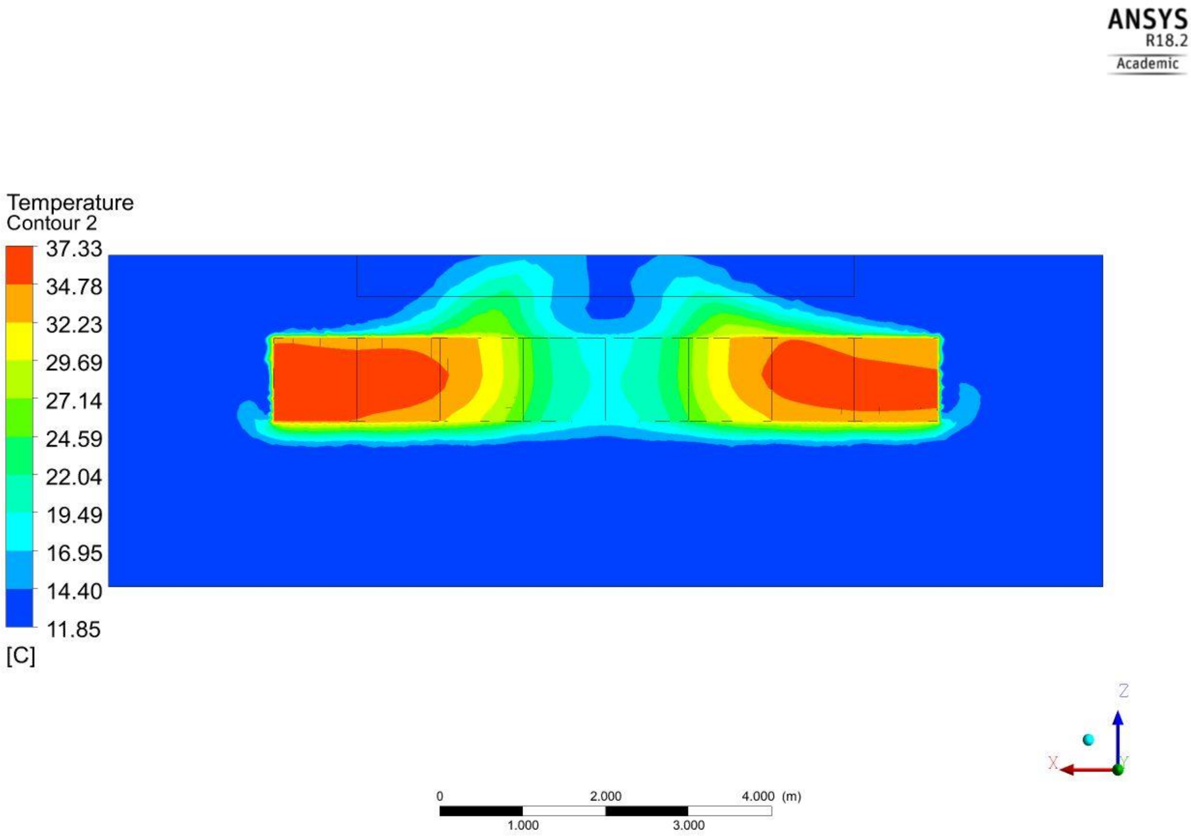
(a)



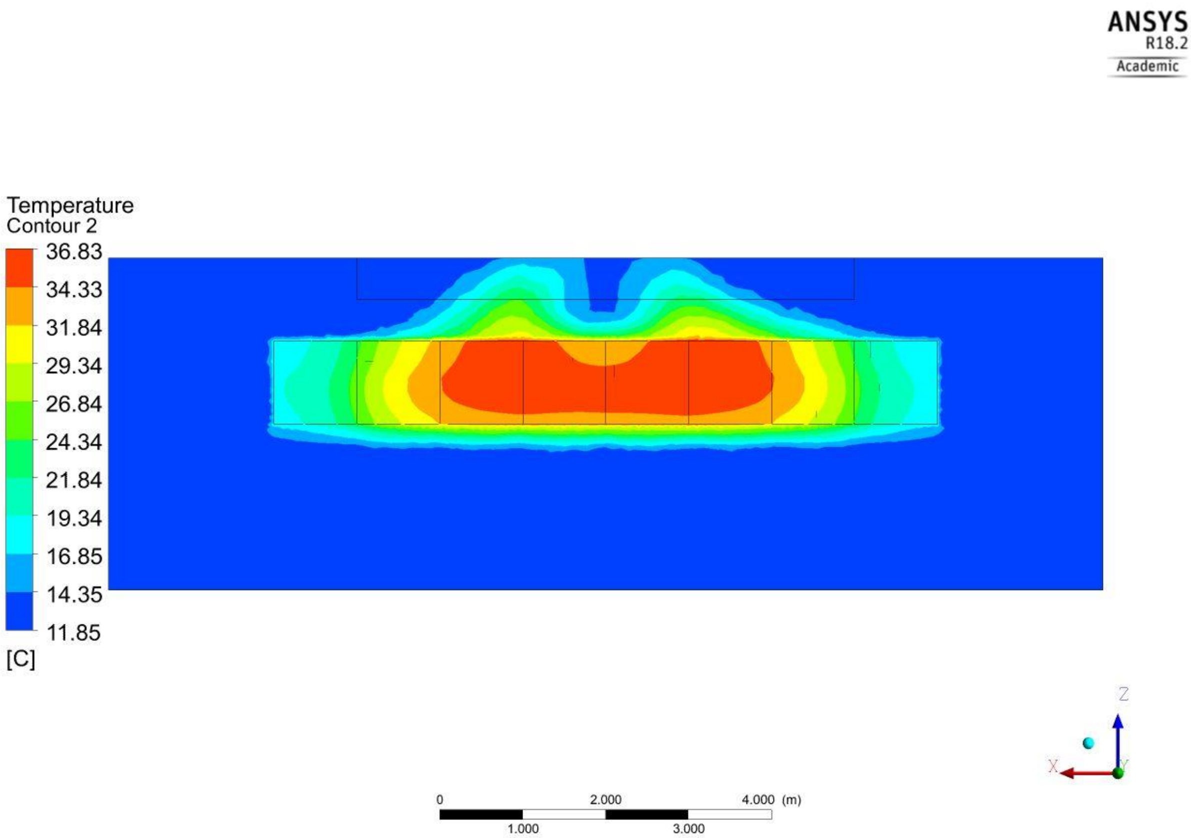
(b)

Fig.3.9. Temperature contours for 50% utilization

(a) Racks 1,2,7 and 8 are operating with 1m/s inlet velocity (b) Racks 3,4,5 and 6 are operating with 1m/s inlet velocity


ANSYS
R18.2
Academic
Temperature
Contour 2
37.33
34.78
32.23
29.69
27.14
24.59
22.04
19.49
16.95
14.40
11.85
[C]
Z
X
0
2.000
4.000 (m)
1.000
3.000

(a)


ANSYS
R18.2
Academic
Temperature
Contour 2
36.83
34.33
31.84
29.34
26.84
24.34
21.84
19.34
16.85
14.35
11.85
[C]
Z
X
0
2.000
4.000 (m)
1.000
3.000

(b)

Fig.3.10. Temperature contour for 75% utilization

(a) Racks 1,2,3,6,7 and 8 are operating with 1m/s inlet velocity (b) Racks 2,3,4,5,6 and 7 are operating with 1m/s inlet velocity

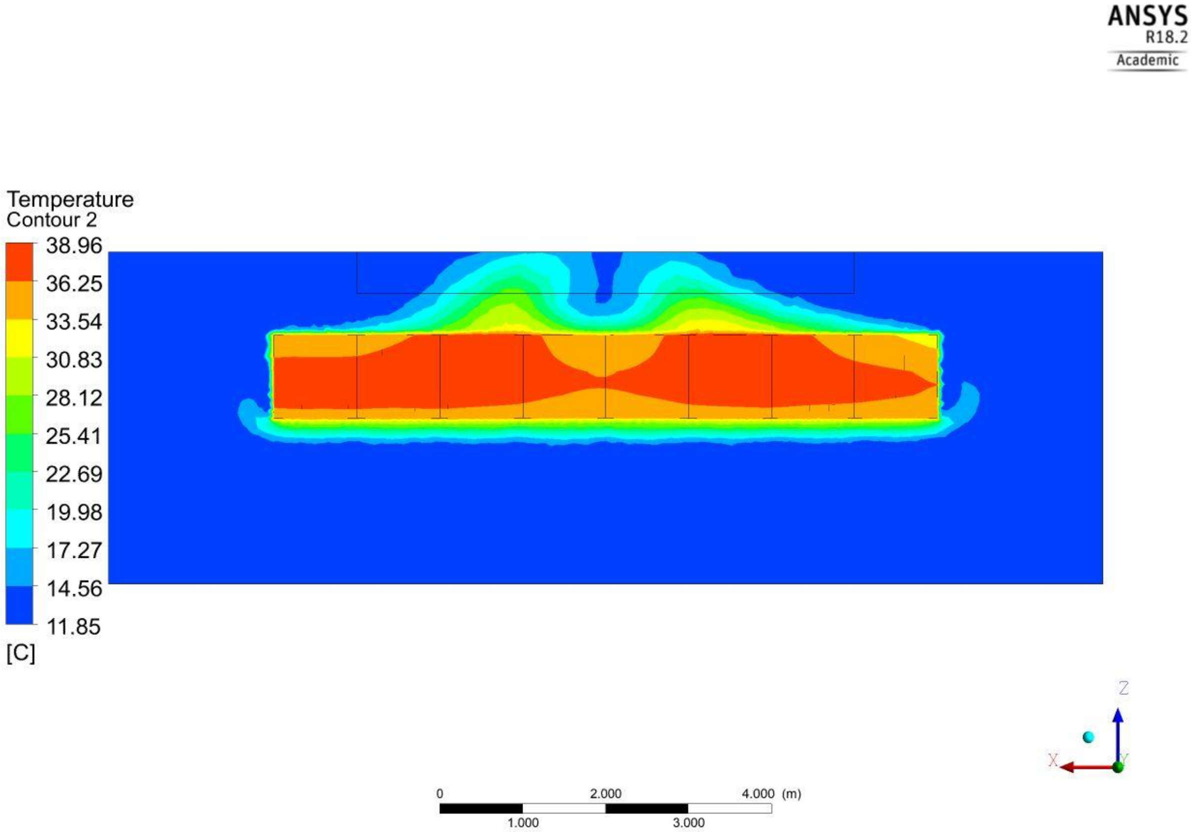


Fig.3.11. Temperature contours for 100% utilization

Racks are operating with 1m/s inlet velocity

From the above results, it can be clearly seen that, for the same operating conditions, the temperature distribution is better when the middle racks are operating. This, as explained before is due to the fact that the hot air travels lesser distance when compared to when the corner racks are in operation. It can also be seen that the hot spots that develop are more concentrated and hence can be easily identified and can be taken care of rather than when the corner racks are in operation, as the hot spots are scattered and encompass a larger area. It can be concluded that the following load distribution is optimal based on the utilization:

Table 3.2 Optimal load distribution

Utilization (%)	Racks which are operating
25% utilization	4,5
50% utilization	3,4,5,6
75% utilization	2,3,4,5,6,7

3.2 EFFECT OF POROSITY ON TEMPERATURE DISTRIBUTION:

As mentioned before, the racks are modeled as a porous media to simplify the actual computer systems present inside the racks. Therefore, the effect of porosity of the racks on the temperature difference is an important factor to be considered.

For the next set of results, the dependency of the temperature distribution on porosity 0.5 and 0.7 is studied.

3.2.1 POROSITY 0.5:

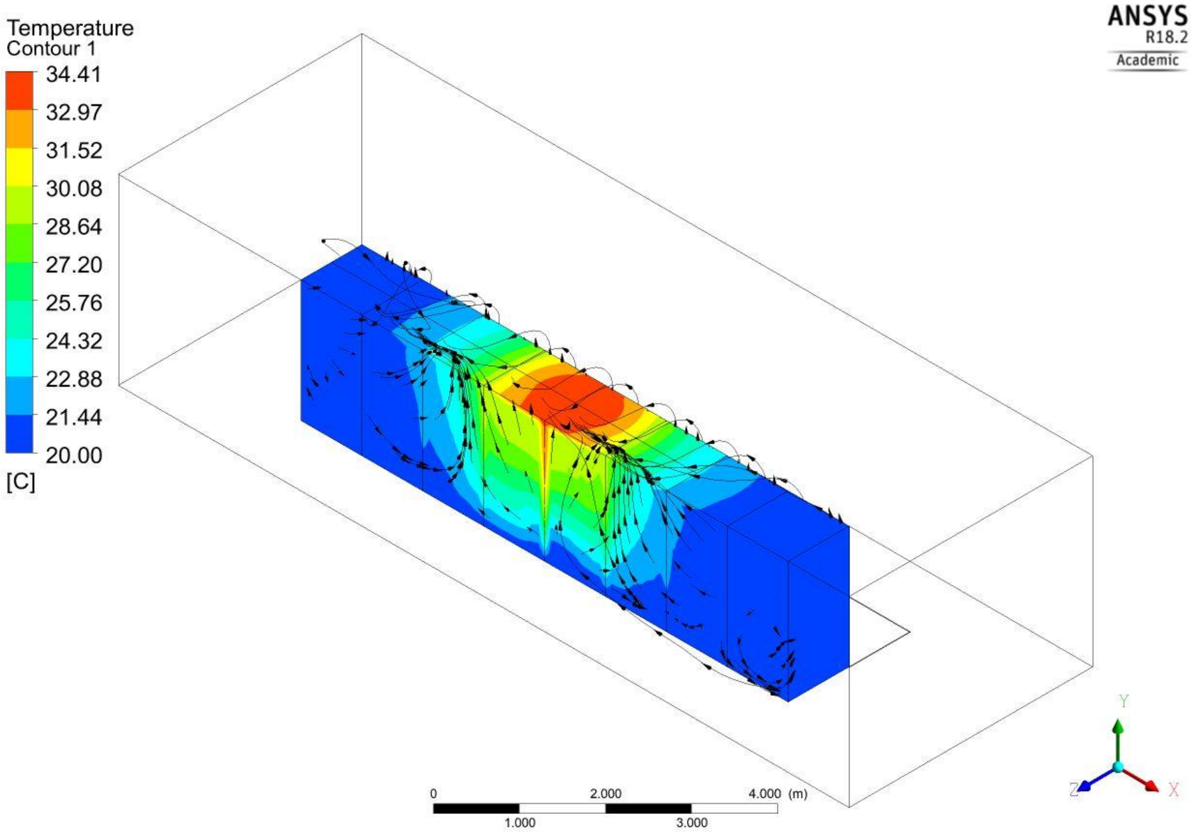


Fig.3.12. Temperature distribution for 25% utilization with streamlines

Racks 4 and 5 are operating with 1m/s inlet velocity

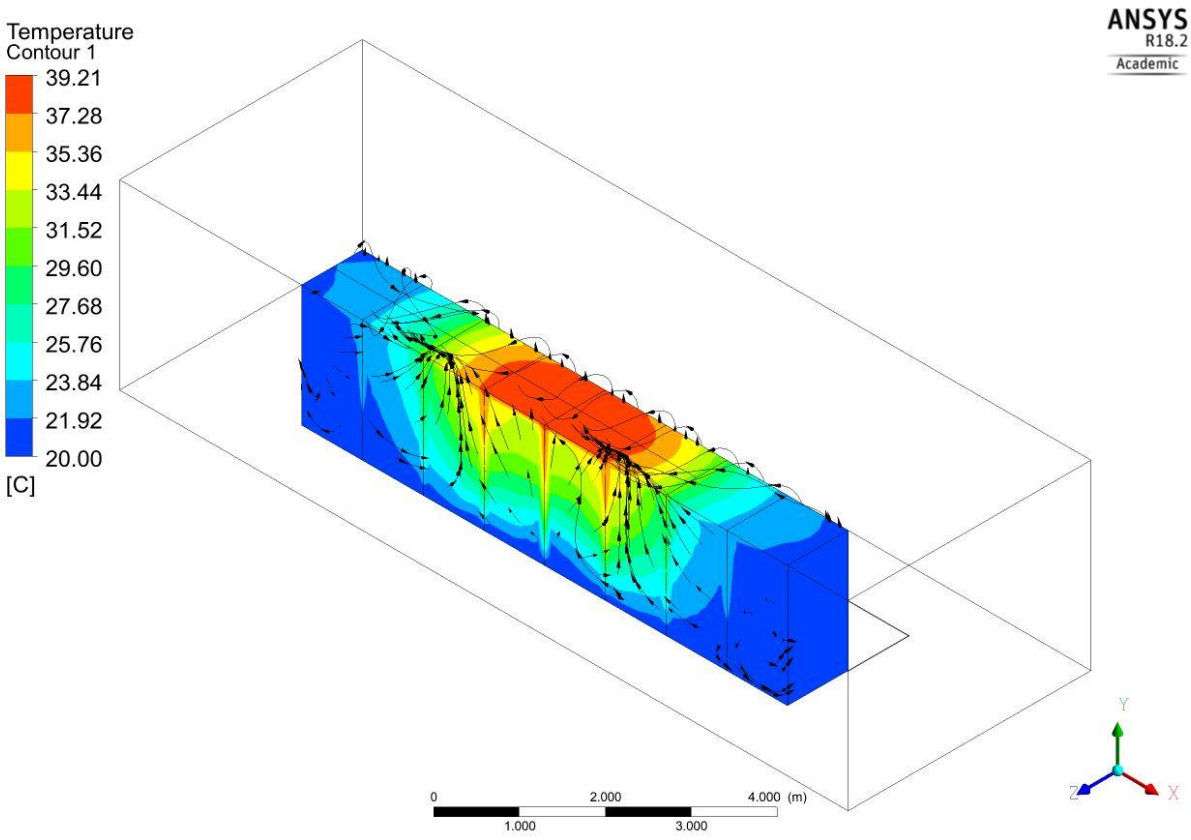


Fig.3.13. Temperature distribution for 50% utilization with streamlines

Racks 3,4,5 and 6 are operating with 1m/s inlet velocity

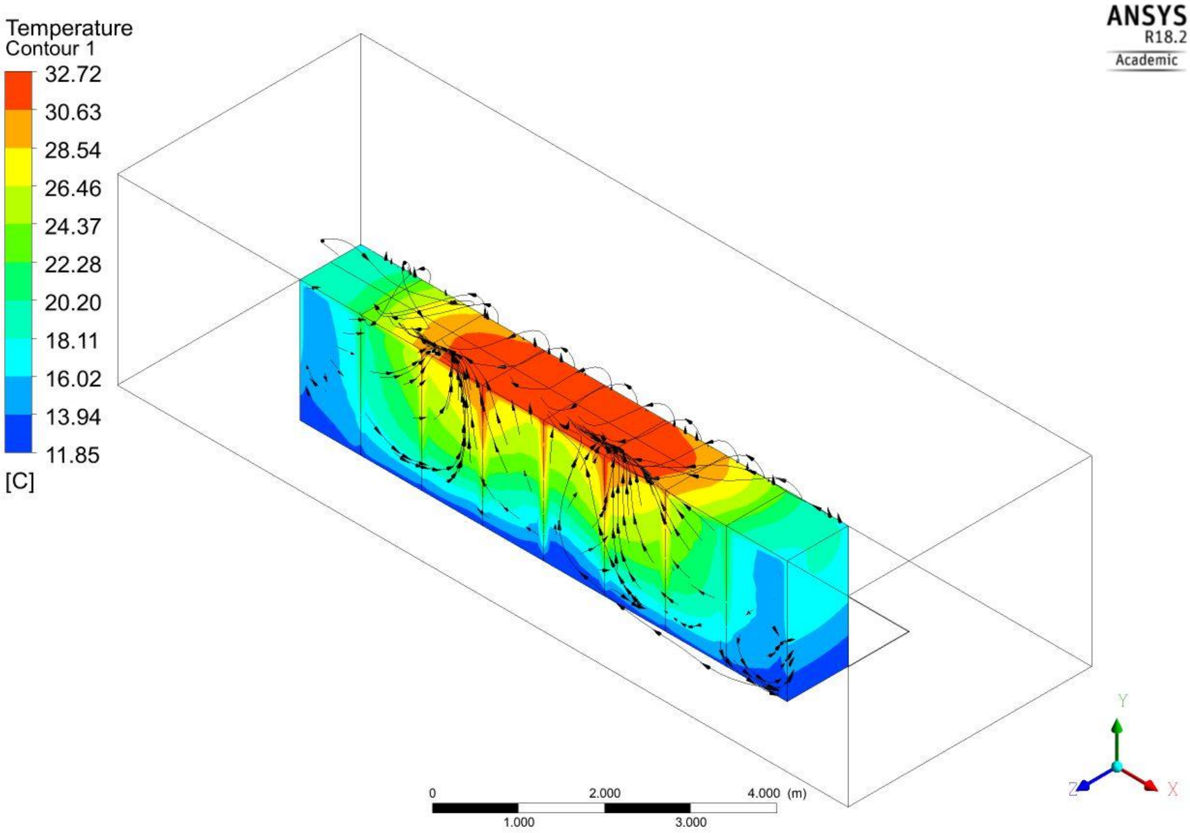


Fig.3.14. Temperature distribution for 75% utilization with streamlines

Racks 2,3,4,5,6 and 7 are operating with 1m/s inlet velocity

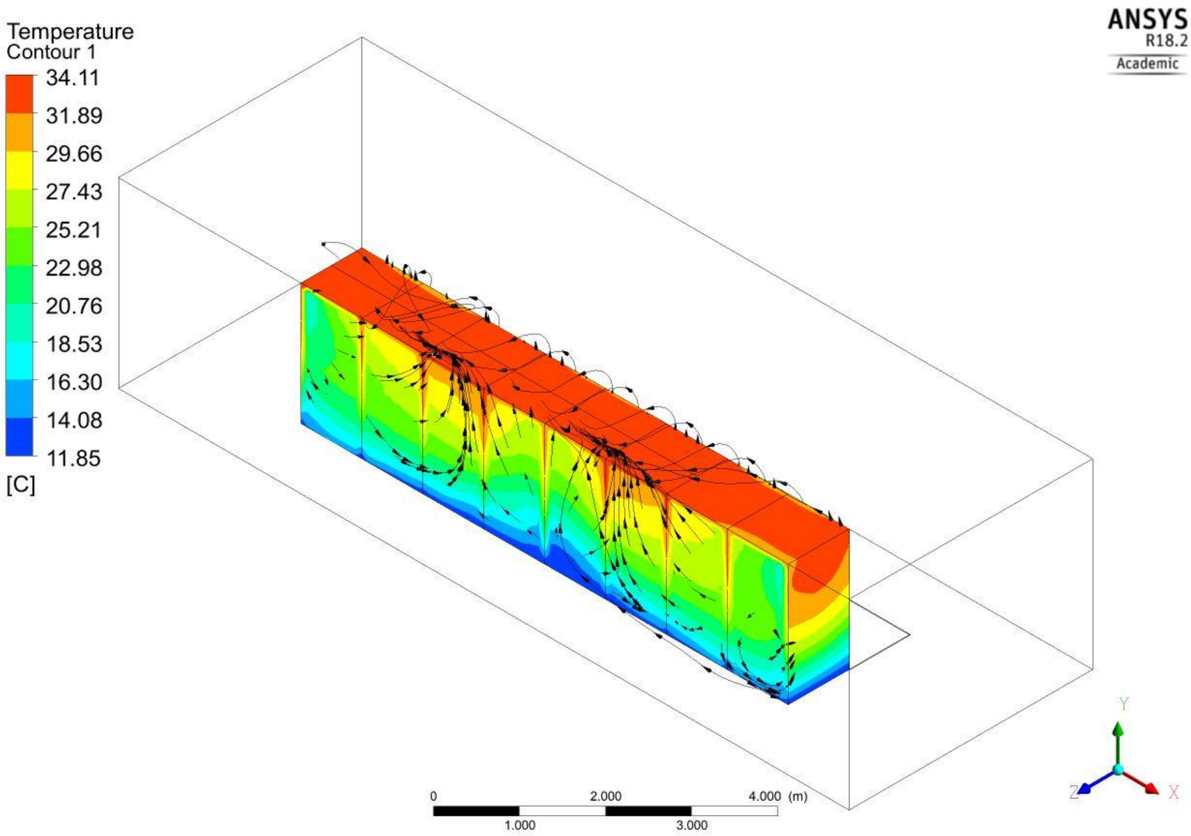


Fig.3.15. Temperature distribution for 100% utilization with streamlines

Racks are operating with 1m/s inlet velocity

3.2.2 POROSITY 0.7:

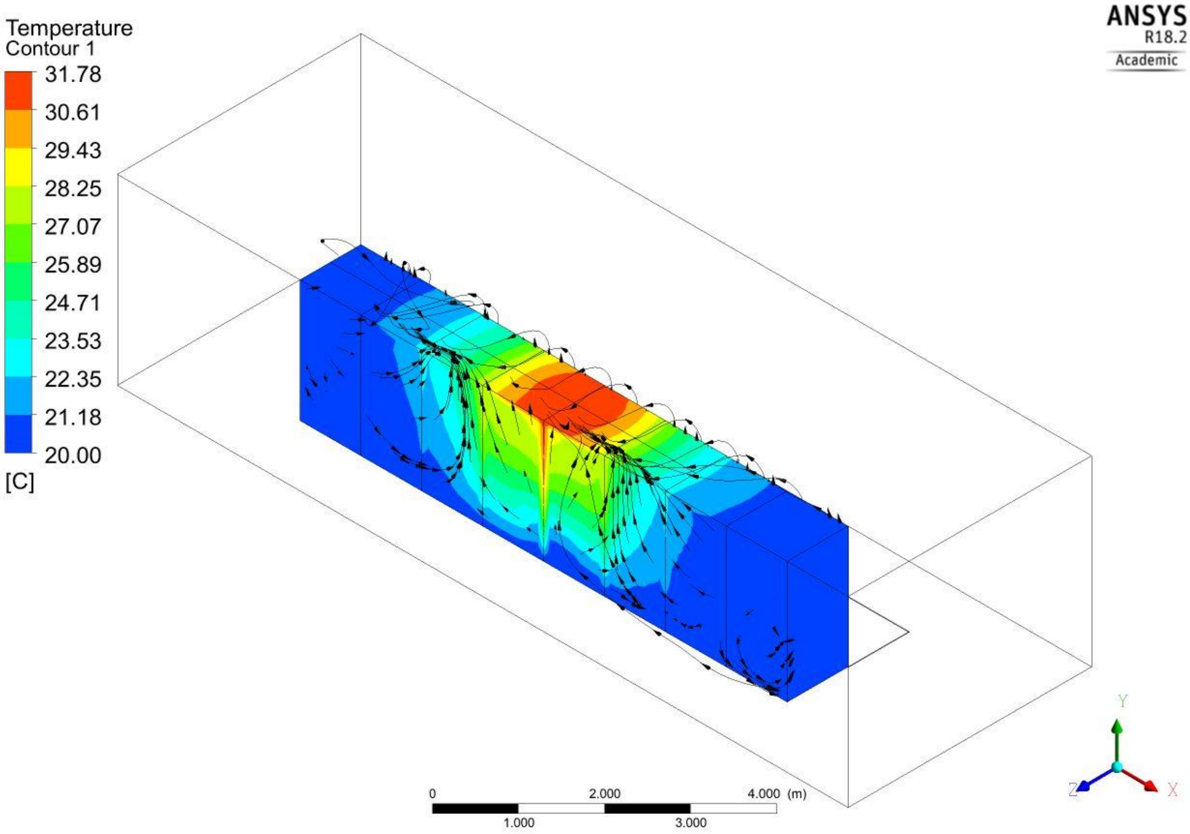
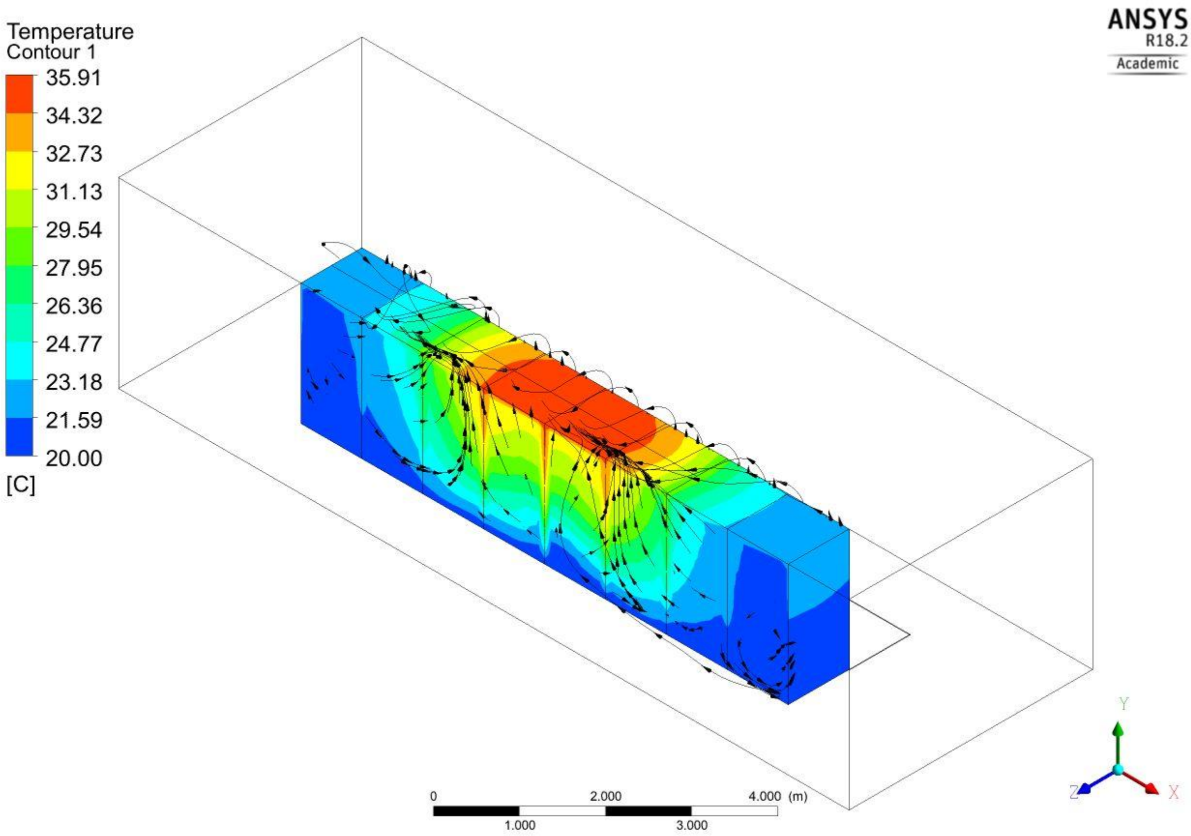


Fig.3.16. Temperature distribution for 25% utilization with streamlines

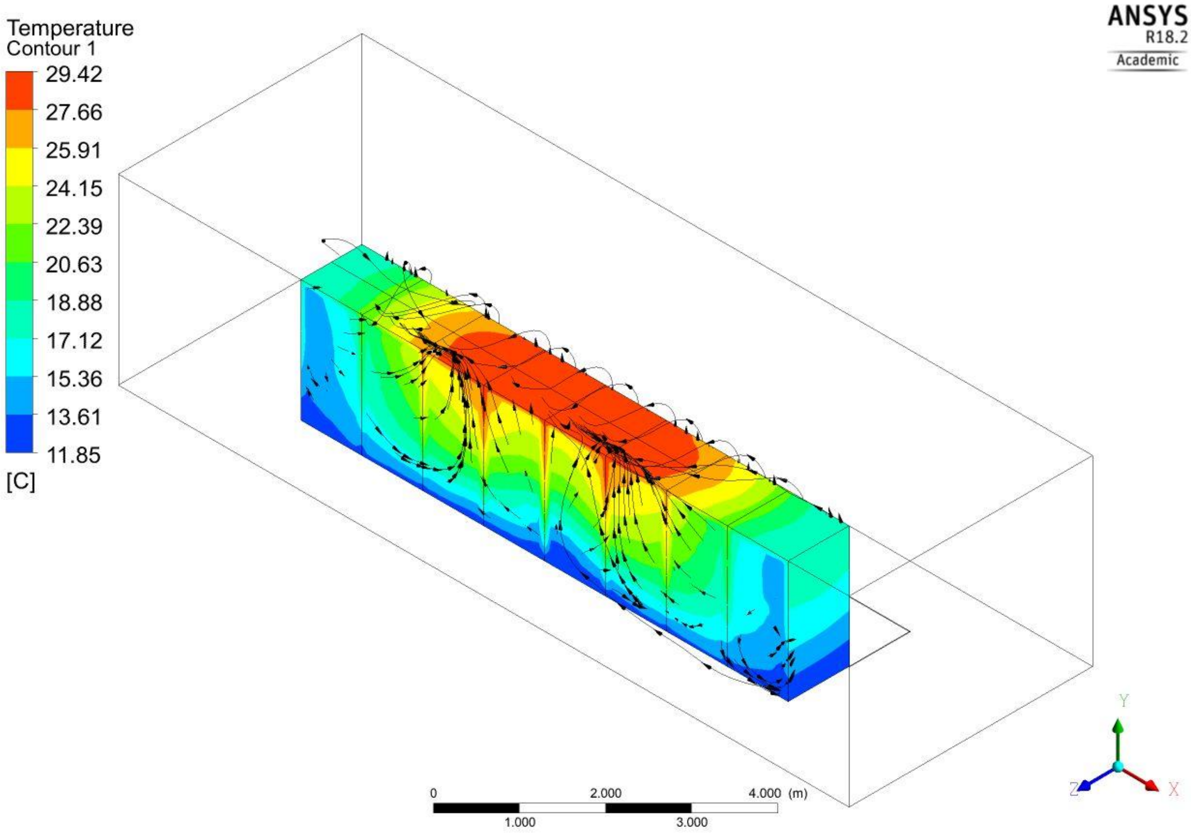
Racks 4 and 5 are operating with 1m/s inlet velocity



(a)

Fig.3.17. Temperature distribution for 50% utilization with streamlines

Racks 3, 4, 5 and 6 are operating with 1m/s inlet



(a)

Fig.3.18. Temperature distribution for 75% utilization with streamlines

Racks 2, 3,4,5,6 and 7 are operating with 1m/s inlet velocity

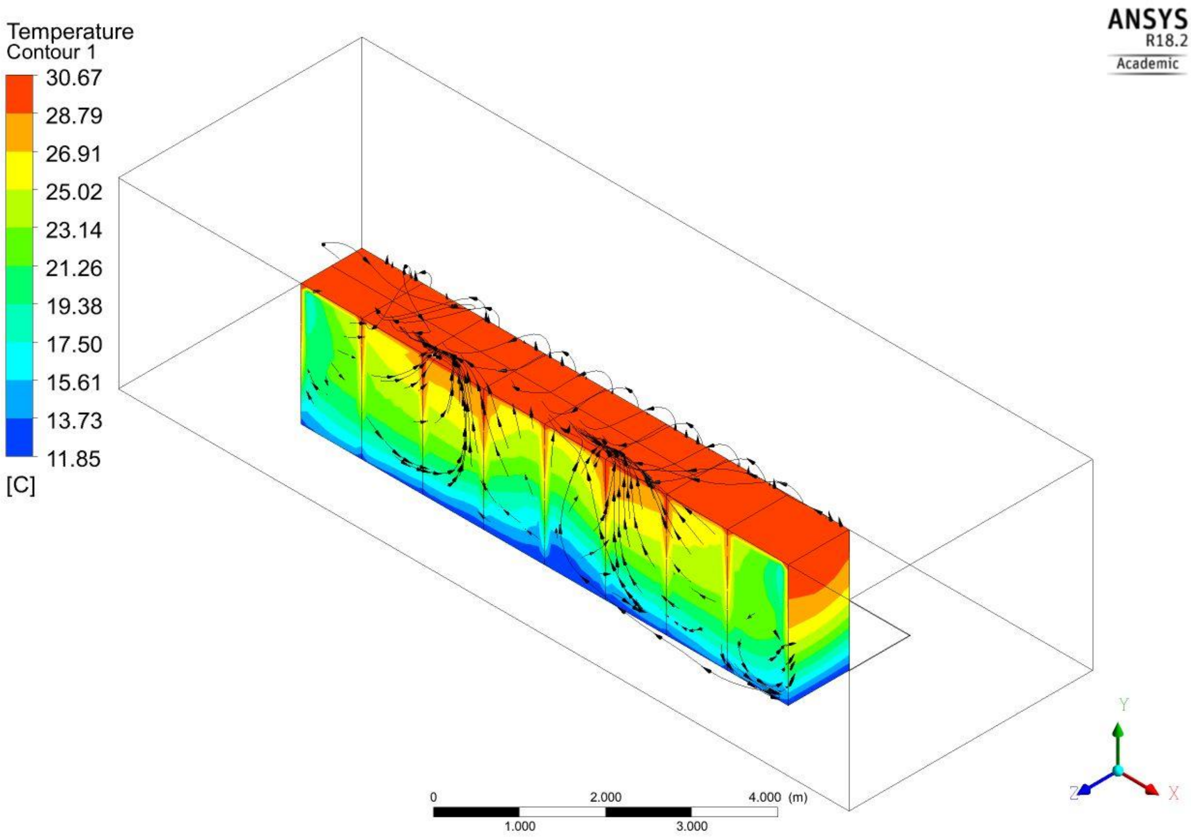


Fig.3.19. Temperature distribution for 100% utilization with streamlines

Racks are operating with 1m/s inlet velocity

Table 3.3 Variation of Temperature with porosity

Position of Probe	Temperature of probe °C (Porosity 0.3)	Temperature of probe °C (Porosity 0.5)	Temperature of probe °C (Porosity 0.7)
[5.5,2,2.5]	36.95	33.66	30.42
[2.5,1,2]	27.20	24.94	23.13
[3.5,1,3]	30.67	24.91	23.01
[7.5,1.5,2]	30.96	28.32	26.14
[8.5,2,2.5]	38.26	33.51	30.33

[9.8,1.8,3]	24.74	20.75	20.67
[4.5,1.5,2]	31.14	28.49	26.30
[6.5,1,3]	23.89	22.55	20.96

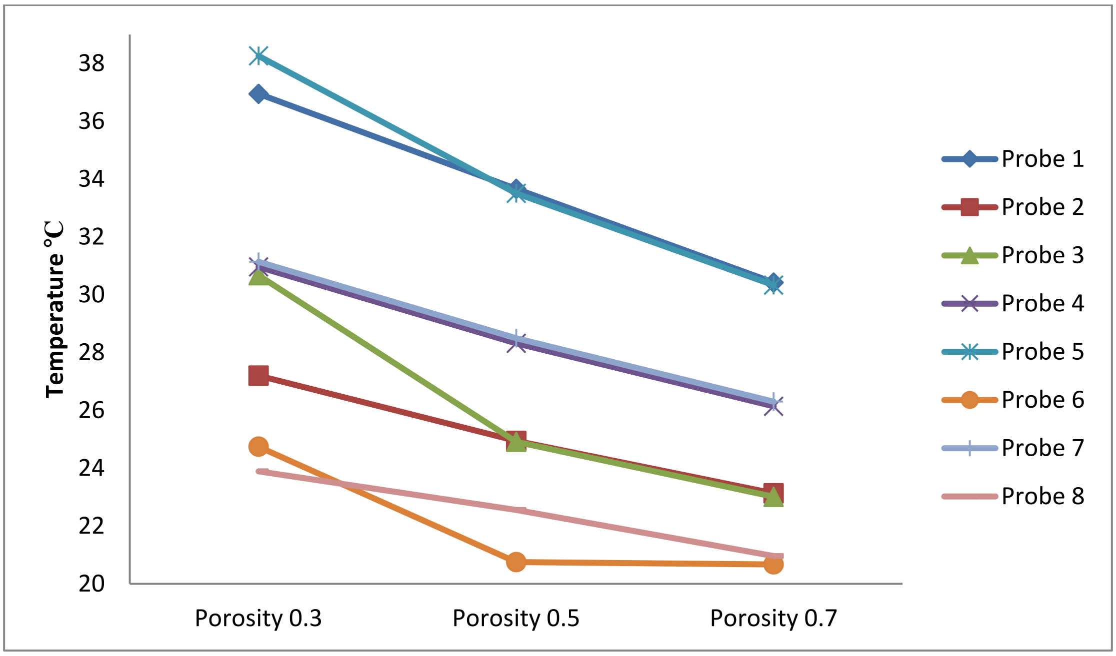


Fig. 3.20 Variation of temperature with porosity

From the above results, it can be seen that the temperature depends inversely on the porosity. This can be validated as in a practical system, if the number of servers is less, even if the power output remains the same, reducing the servers increases the empty space within the rack. This allows more area for the air flow and hence allows more effective cooling. It can also be generalized that, for data centers which do not operate at full load, the racks can be designed to increase the open area by reducing the number of servers and hence increase the efficiency of the air conditioning system.

CHAPTER 4

TRANSIENT EFFECTS:

In data centers, the utilization isn't always at 100%. In most cases, the load increases when there is a sudden surge in usage. While it is important to study the effects of other parameters on the data center, it is also important to study the changes in the data center between the load changes. There might be a sudden rise in temperature which might require the change in parameters as discussed before. These issues cannot be identified by the steady state analysis. Therefore, it makes sense in studying the data center's transient state and the response during this time in depth. To study the transient effect, the following case is simulated and analyzed.

Table 4.1 Transient Setup

Time	t=0	0<t<1800	t>1800
Load	50%	75%	100%
Inlet Temperature	20°C	12°C	12°C
Inlet Velocity	1.5m/s	1.5m/s	1.5m/s

Note: t = 0 is the steady state condition for 50% utilization case.

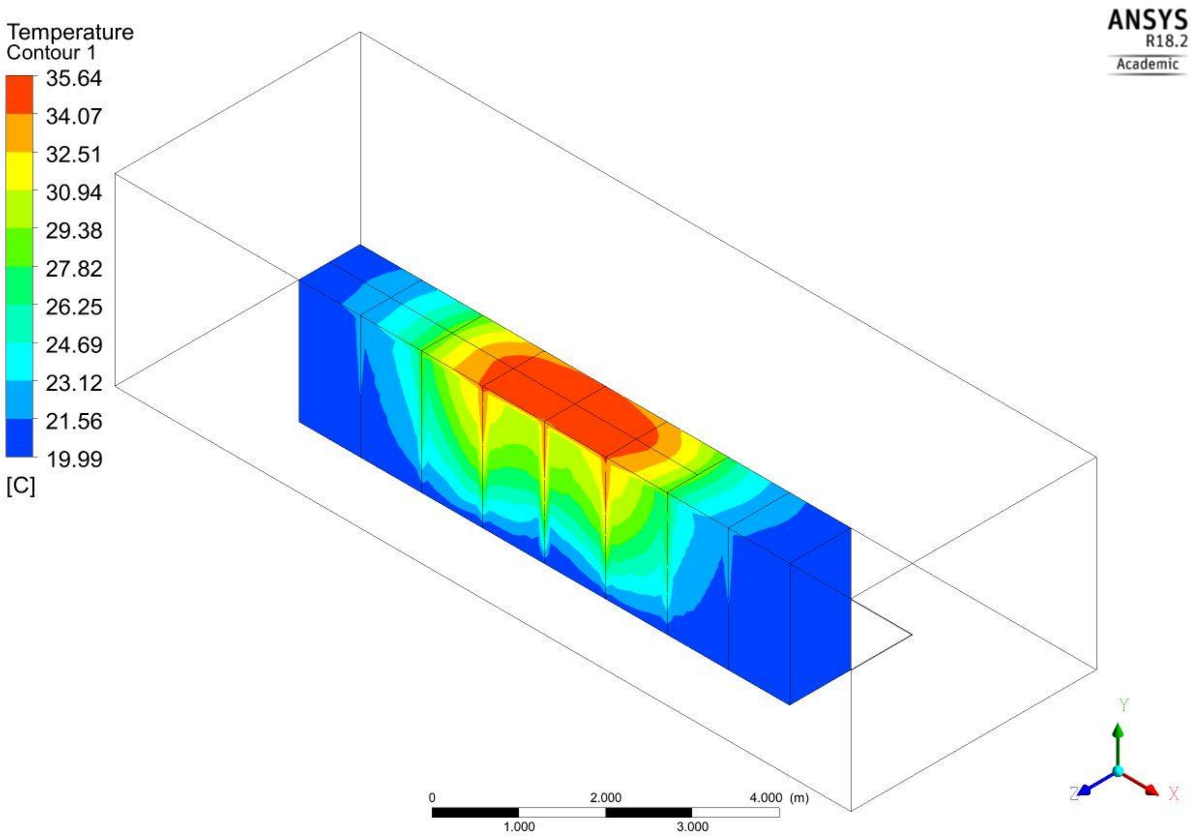
To simulate the above case, a USER DEFINED FUNCTION is written in C and interpreted into FLUENT. The UDF is given by figure 4.1

```
#include "udf.h"
#define Q1 0
#define Q2 5000

DEFINE_SOURCE(energy_source,t)
{
real source;
real time = CURRENT_TIME;

if (time <= 1800)
{

source = Q1;


}
if (time > 1800)
{
source = Q2;

}

return source;
}
```

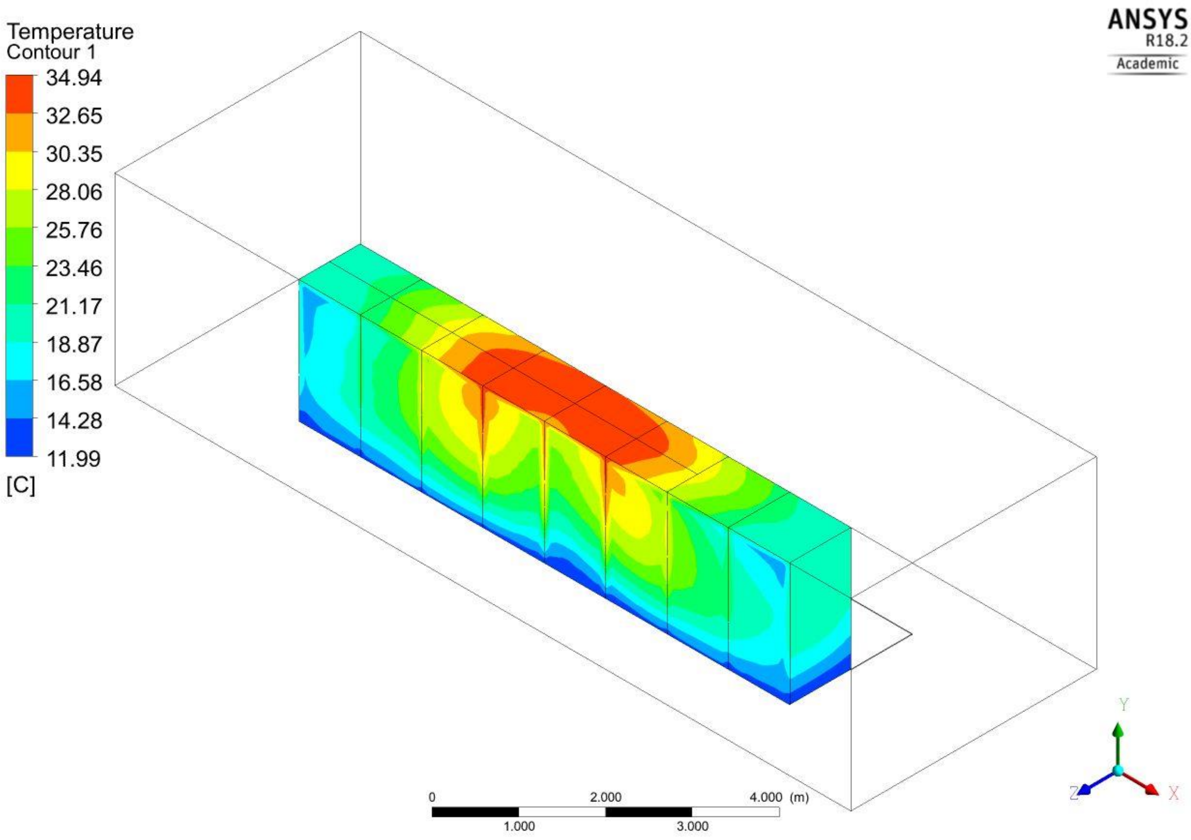
Fig.4.1. User defined function for transient simulation

Q is the heat output of the racks and is given by W/m^3. Time is given in seconds.

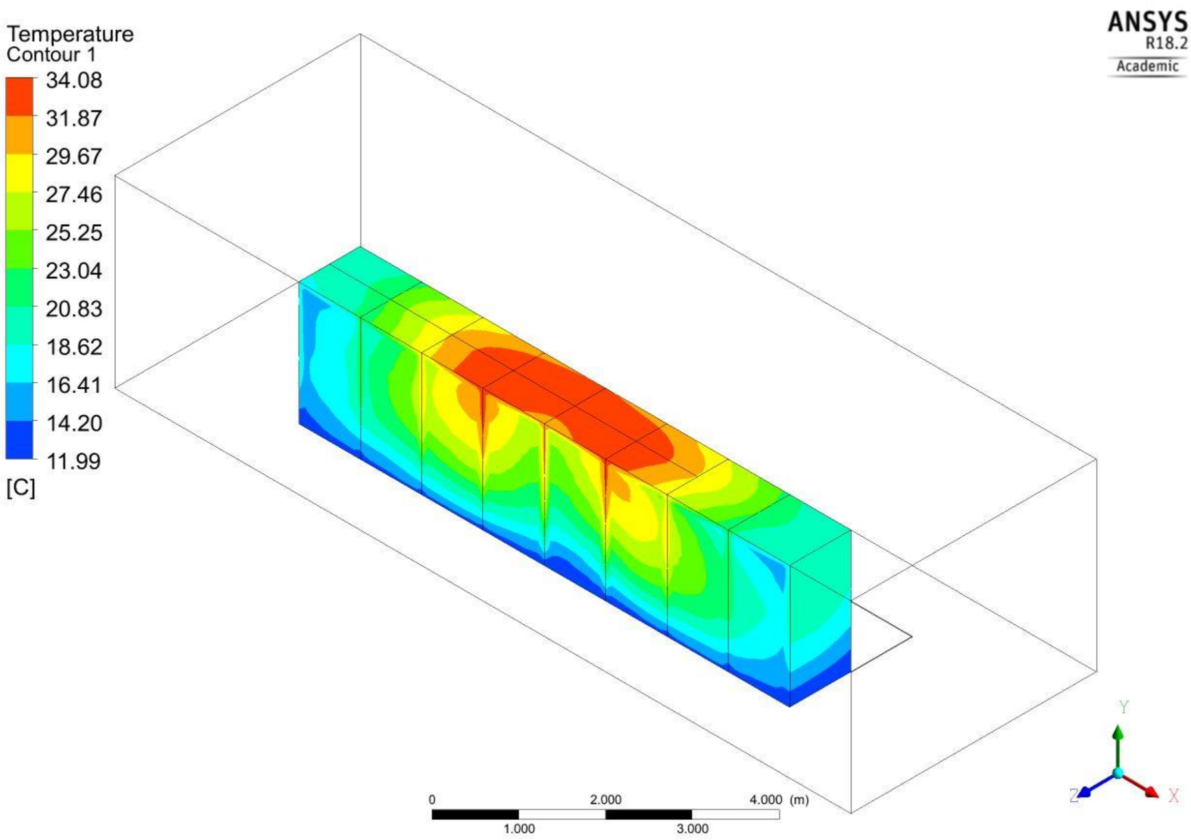
4.1 RESULTS AND DISCUSSIONS:



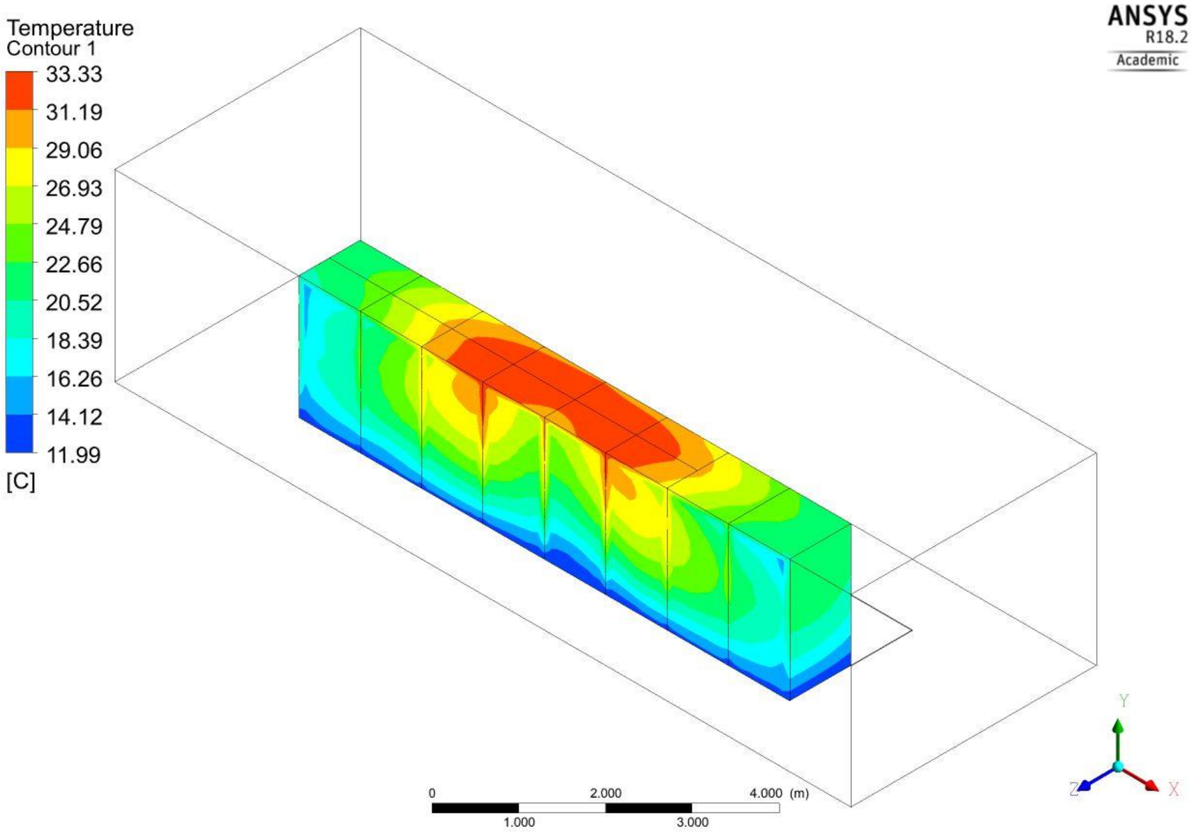
(a)


Temperature
Contour 1
34.94
32.65
30.35
28.06
25.76
23.46
21.17
18.87
16.58
14.28
11.99
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

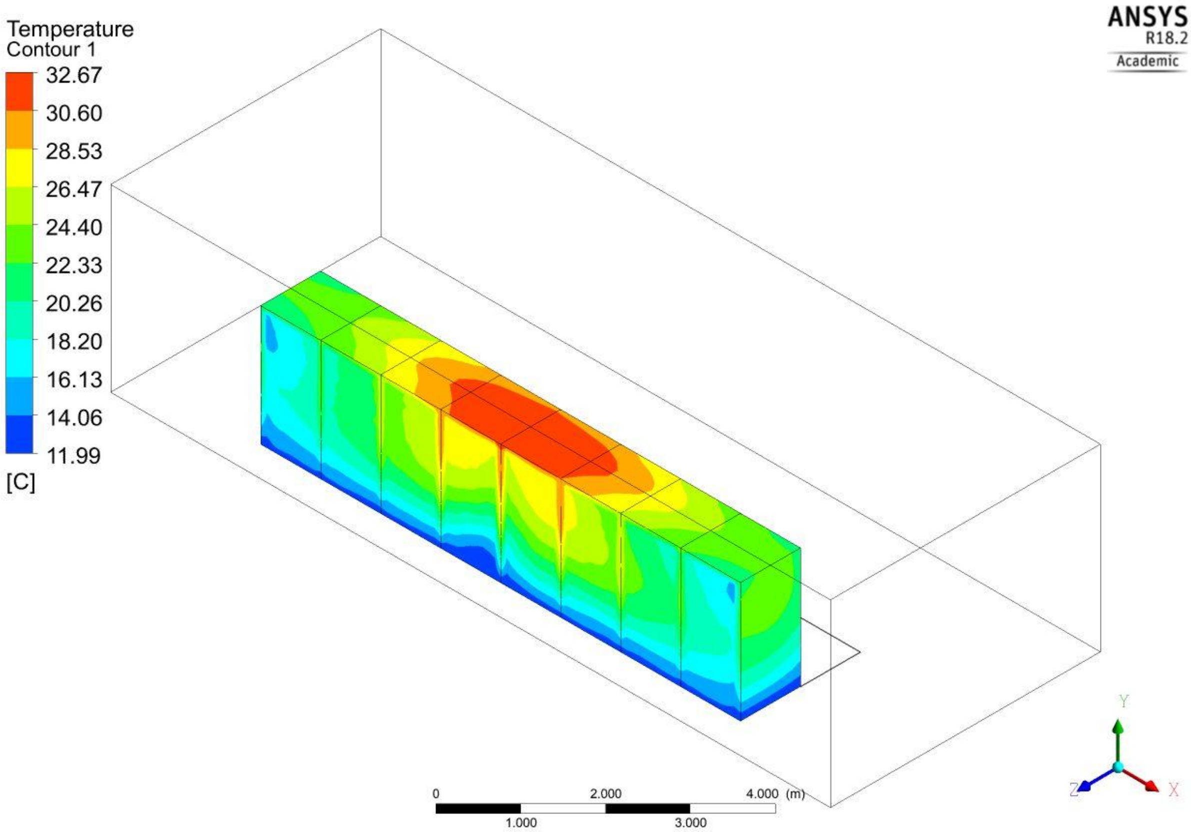
(b)


Temperature
Contour 1
34.08
31.87
29.67
27.46
25.25
23.04
20.83
18.62
16.41
14.20
11.99
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(c)


Temperature
Contour 1
33.33
31.19
29.06
26.93
24.79
22.66
20.52
18.39
16.26
14.12
11.99
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(d)


Temperature
Contour 1
32.67
30.60
28.53
26.47
24.40
22.33
20.26
18.20
16.13
14.06
11.99
[C]
ANSYS
R18.2
Academic
0
2.000
4.000 (m)
1.000
3.000
Y
Z
X

(e)

Fig.4.2 Temperature distribution for transient case

(a) t=0 (b) t=15mins (c) t=30mins (d) t=45mins (e) t=60mins

While the above figures show the temperature variation of the entire system, to get a more concrete understanding, a graph is plotted to see the temperature variation of the probes till steady state.

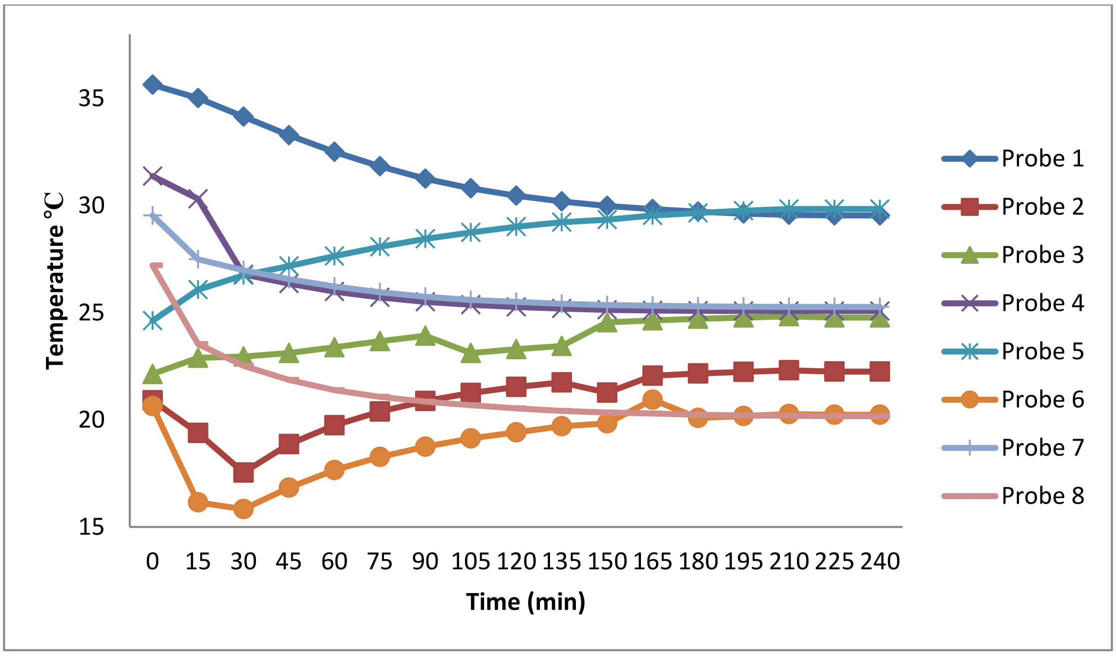
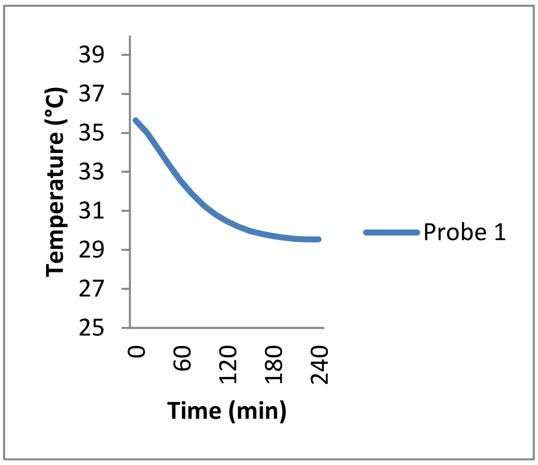
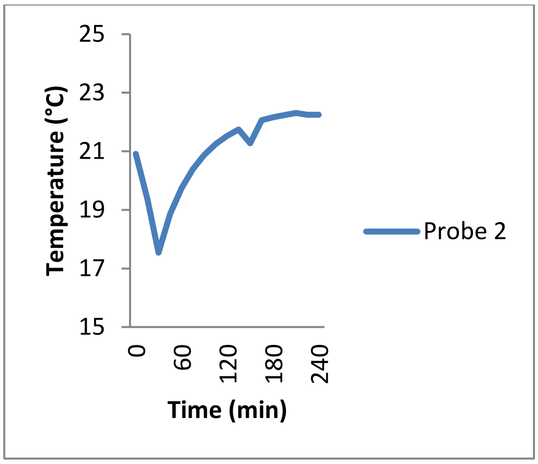
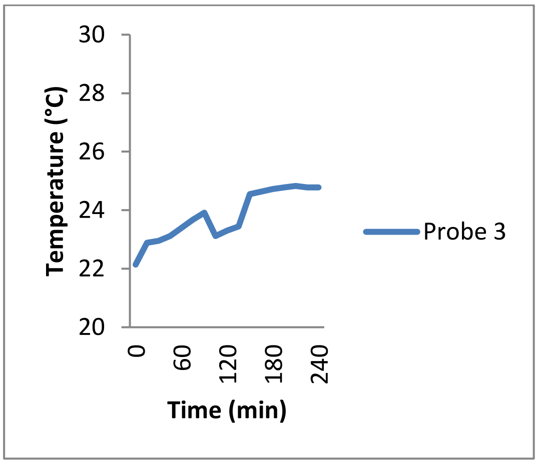


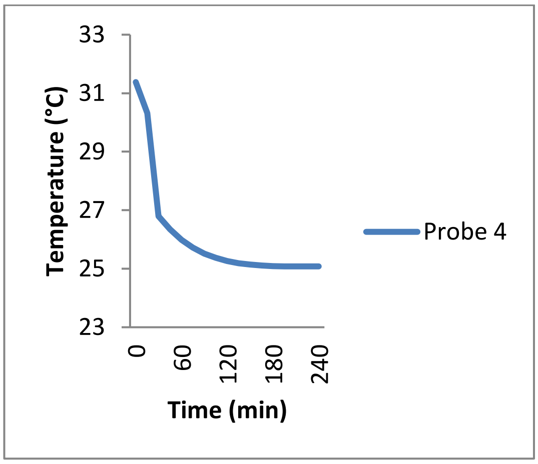
Fig.4.3 Variation of temperature with time

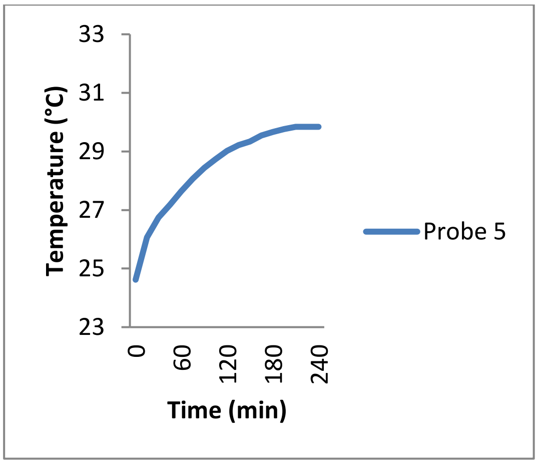
To study the temperature behavior clearly, a set of graphs are plotted for each probe.

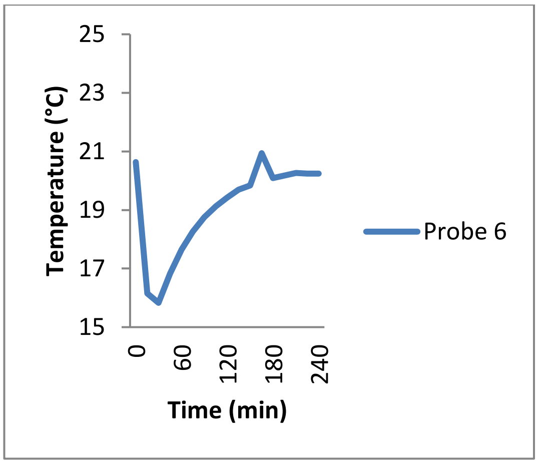

Temperature (°C)
39
37
35
33
31
29
27
25
0
60
120
180
240
Time (min)
Probe 1


Temperature (°C)
25
23
21
19
17
15
0
60
120
180
240
Time (min)
Probe 2


Temperature (°C)
30
28
26
24
22
20
0
60
120
180
240
Time (min)
Probe 3


Temperature (°C)
33
31
29
27
25
23
0
60
120
180
240
Time (min)
Probe 4


Temperature (°C)
33
31
29
27
25
23
0
60
120
180
240
Time (min)
Probe 5


Temperature (°C)
25
23
21
19
17
15
0
60
120
180
240
Time (min)
Probe 6

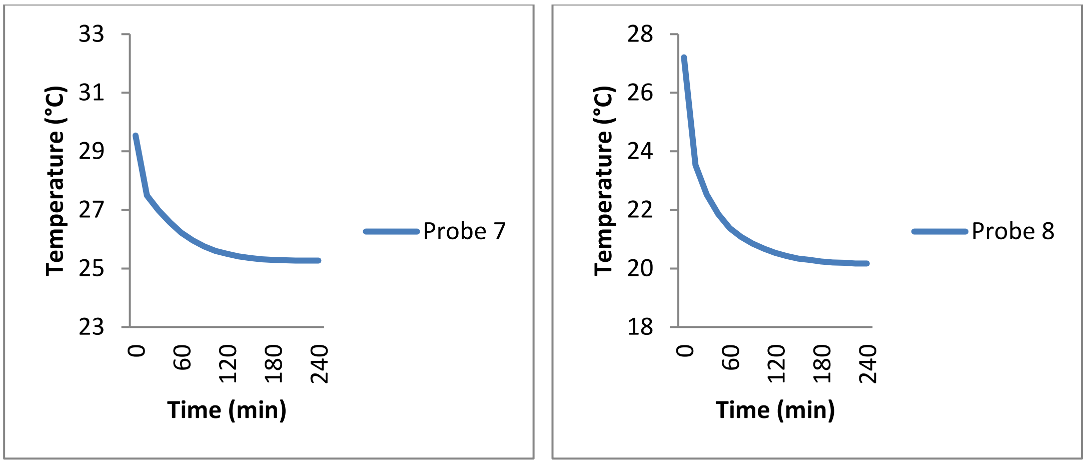


Fig.4.4 Variation of temperature with time for individual probes

From the above figures, it can be seen that the temperature change of the racks from when the chiller turns ON is very slow. While the relationship with temperature and time is not clearly defined, certain points increase in temperature while certain points decrease. This can be attributed to the fact that the place where the airflow is less, the heat output increases the temperature of those areas. These points must be kept in check as these might turn out to be potential hot spot points. Therefore, to summarize, the use of the chiller causes the temperature to drop in certain points while it is ineffective in points where the air flow is scarce. The temperature at these points keep increasing or increase and then decrease again based on where it is located and reaches steady state. In the event that there is a sudden surge in utilization and the heat output is very high, the chiller will not be able to keep up with the load increase and that might cause issues with the system exceeding allowable temperatures. The reduction in the maximum temperature is due to the reduced inlet temperature. Therefore, it can be seen that while it is a good model to analyze the steady state system, the transient response is very low. The entire model reaches steady state in about 4 hours. Therefore, in practical applications, further optimization or more efficient techniques are required to keep the temperature under control and increase the response of the system.

CHAPTER 5

CONCLUSION AND FUTURE WORK:

This research consisted of mainly studying the effects of operating parameters on the temperature distribution on the racks and also the effect of porosity on the same. A transient analysis was also done in order to investigate the response of the model and the transient effects associated with load change.

This chapter reviews and presents the conclusion of this research and is presented below:

I. Effect on Inlet velocity on temperature of the racks:

   The inlet velocity was found to be inversely proportional to the maximum temperature. While the temperature is decreases with increase in velocity, based on the location of the data center, the velocity can be reduced in order to save energy cost. In case the data center is located at a cold region, the inlet temperature would be much lesser than the temperature used in this research.

II. Effect of Utilization on temperature of the racks:

   A data center is not always 100% utilized. Therefore, cases with 25%, 50%, 75% and 100% usage of the data center were analyzed. In these cases, the utilization is varied by turning ON a number of racks. Each rack has a heat output of 10kW when turned ON. It is seen that the temperature is directly proportional to the heat output of the racks. As the number of racks in operation increase, the temperature of the system increases.

III. Effect of Inlet Temperature on Temperature of the racks:

   The ambient temperature used in this research is 293K (20°C). The inlet temperature when the Chiller is ON is 285K (12°C). This change in temperature is incorporated when the utilization is increased from 50% to 75%. The maximum temperature at the 50% case is 42.09°C when the inlet temperature is 20°C. In the case where the temperature was 12°C, the maximum temperature is 34.64°C. Therefore, it can be seen that the change in inlet temperature plays a big role in the maximum temperature of the data center. While, the chiller requires high energy to keep the temperature under control, this can be combatted by building data centers in places which are cold most of the year and the energy cost of the CRAC units will decrease.

IV. Effect of changing racks in operation:

It can be seen that there are different configurations in which the racks can be used. In the cases investigated in this research, it is seen that, for the 25% and 50% utilization, there is a reduction in temperature when the middle racks are operating as opposed to when the corner racks are in operation. This is due to the fact that hot air needs to travel longer distance to the outlet from the corner racks and hence the cooling achieved is less efficient than when the middle racks are operating. We can also see that, after the load increases to 75%, there is negligible change in temperature as even the corner racks are required to be in operation. Based on this, the ideal configurations for the different utilizations are identified.

V. Effect of Porosity:

By modeling the racks as porous media, the model is being simplified. While the porosity can be closely approximated, it is still important to check the dependency of the model on the porosity. As the porosity increases, which means the number of electronic components is less, implies that there is more area for air to flow and in turn cool the racks more efficiently. This is seen as the maximum temperature for the 100% utilization case is 38.96°C for 0.3 porosity, 34.11°C for 0.5 porosity, and 30.67°C for 0.7 porosity for this system. And it can also be generalized that as the number of electronic components decrease, even if the power output is still the same, the maximum temperature decreases. This implies the significance of each electronic component and its influence on the data center. A graph is plotted to study the change in temperature with porosity and to see the general behavior for practical purposes.

VI. Transient effects:

The transient state analysis was done for the load change from 50% utilization to 75% to 100%. It is found that while the model does reach steady state, it takes a long time. Also, it is seen that the response time of the system is very slow. The temperature dependency on time was studied and a graph was plotted. There is no clear relation between the temperature and time, as it depends on the position of the point and the flow of air in the room. This is not ideal as in case of a sudden surge of usage, there might be high heat output and the cooling system will not be able to respond quick enough to overcome any temperature issues that might occur. The points which have low air flow have to be monitored more carefully in order to avoid developments of hotspots.

FUTURE WORK:

This research apart from answering a lot of questions on the effects of operating parameters and transient effects on data centers, also invokes questions. Possible future work includes:

1. Investigating the temperature dependency on the inlet and outlet positions.
2. Pre-cooling of system to combat the slow response time of the system.
3. Experimental investigation to validate the computational model and results.
4. Analyzing different cooling techniques such as cold aisle containment.

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