OPTIMIZATION ANALYSIS OF AIR CONDITIONING SYSTEM IN A DATA CENTRE

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING IN AUTOMOBILE ENGINEERING UNDER THE FACULTY OF ENGINEERING AND TECHNOLOGY

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DECLARATION OF ORIGINALITY AND COMPLIANCE

ACADEMIC ETHICS

I hereby declare that the thesis entitled OPTIMIZATION ANALYSIS OF AIR CONDITIONING SYSTEM IN A DATA CENTRE contains a literature survey and original research work by the undersigned candidate, as a part of his MASTER OF ENGINEERING IN AUTOMOBILE ENGINEERING under the DEPARTMENT OF MECHANICAL ENGINEERING, studies during the academic session 2021-2023.

All information in this document has been obtained and presented in accordance with the academic rules and ethical conduct.

I also declare that, as required by these rules of conduct, I have fully cited and referenced all the material and results that is not original to this work.

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"OPTIMIZATION ANALYSIS OF AIR CONDITIONING SYSTEM IN A DATA CENTRE":** is a bonafide work carried out by SUMIT SEN under our supervision and guidance in fulfilment of the requirements for awarding the degree of Master of Engineering in Automobile Engineering under Department of Mechanical Engineering, Jadavpur University during the academic session, 2021-2023.

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CERTIFICATE OF APPROVAL

The foregoing thesis, entitled "**OPTIMIZATION ANALYSIS OF AIR CONDITIONING SYSTEM IN A DATA CENTRE"** is hereby approved as a creditable study in the area of Automobile Engineering carried out and presented by SUMIT SEN in a satisfactory manner to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned does not necessarily endorse or approve any statement made, opinion expressed, and conclusion drawn therein but approves the thesis only for the purpose for which it has been submitted.

Committee of the final evaluation of the thesis:

Signature of Examiners

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I would like to record here my gratitude to all who supported me and gave constructive suggestions during the completion of this work.

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TABLE AND CONTENTS

CHAPTER-I

ABSTRACT

Today in the era of information and data management, DATA CENTRE becomes the heart of the whole information system. A data center is an integral part of the multiple data storing, transmission, receiving and sending to and from the multiple clients from all over the world for different purposes. A Data Centre houses a suitable number of server racks that are acquainted with internet connection working for 24x7 all the time. Hence the maintenance of data center's server rack becomes vital for swift transmission of information without any delay.

In this thesis work, a study is carried out for the maintenance of server racks at the proper temperature in the racks by means of adequate airflow through the tiles and through the determination of hotspots as well as their mitigation.

In this work the simulation is done by means of ANSYS Software where the data center of Swasthya Bhavan consisting of five Server Racks and two CRAC (Computer Room Air Conditioner) units are being simulated by using FLUENT package of ANSYS Software and then it is compared with the experimental results for its validation.

CHAPTER-II

Introduction :

A data center is a very big computer center that houses a large number of server racks. These racks carry out a very large no. of electronic data transfers at a very high speed. The electrical input to the data center is quite high of the order of 100W to 150W per square foot area of the data center. In order to ensure uninterrupted working of the servers in the numerous racks, efficient control of environment inside the data center is most important that is a proper air-conditioning of its temperature and humidity.

However the air-conditioning system to be used for the data center itself consumes a large amount of electrical power which is roughly estimated as almost 70% of the power required for running the servers of the data centers. Therefore the total estimated power density works to around 250W per square foot area of the data center.

In the event of an inefficient or inaccurate air-conditioning the chips in the server racks become over heated and will ultimately lead to a failure of uninterrupted service or will cause a breakdown of a center

As a result the cost involved will be partly for the maintenance and repair of the defective components of the server racks. Another part of the monetary loss will be due to the breakdown time of the center during which proper replacement of the defective components will have to be procured and installed at site.

From the above it becomes evident that the air-conditioning of the data center is an essential component of its smooth running through 24 hours of the day uninterrupted and throughout the year.

The present work dwells upon the stages of air-conditioning of the data center. These stages include the following:

i) Study of temperature pattern in 3D space of the Data Center based on simulation.

ii) Determination of hot-spots in the entire 3D space of the Data Center.

iii) Mitigation of the hotspot zones by providing adequate supply of cooling air. Also the low temperature regions will also be provided with the required amount of cooling air.

Role of Simulation in the determination of the Thermal Profile in the Data Center space:

CFD (Computational Fluid Dynamics) software ANSYS plays a very important role in visualizing the effect of fluid motion inside the data center in a convenient way. As a result the visualization of the temperature profile becomes easier than the cumbersome process of continuous experimental determination of the parameters involved. Therefore, CFD simulation is used for the sake of convenience in order to visualize every parameter involved with the fluid motion including the thermal parameters as well.

The CFD simulation involves the heat transfer factor which results in determining the temperature contour along with their isotherms. The heat transfer factor used in CFD analysis is achieved by means of activating the Energy Equation in the setup part of Ansys Fluent package.

In this work, CFD simulation is done while the experimental determination of temperature at various locations is actually being done in the data center of Swasthya Bhavan. The standard unknown values which required to be inserted into of Ansys Fluent package are already available from the ASHRAE's handbook.

CHAPTER-III

LITERATURE REVIEW

Jinchen Zhu et al. [1] in their research derived a new index which is known as RHSI (Recirculation and Hot Spot Index) which is valid for different scales that are room scale, row scale and rack scale unlike other indices which are valid in particular scale only. RHSI is used for analyzing the thermal environment of the data center by single index for different scales discussed earlier by overcoming the comprehensive analysis issues of using individual scale metrics. Earlier there are various metrics such as RHI, RTI, SHI, HIOM, IOM and etc for determining the particular thermal environment of a particular scale in a data center and now there is a derived metric RHSI which diminishes that analytical pain of analyzing all the individual metric values for understanding the thermal environment in the data center. Actually RHSI uses the advantages of metrics RTI (Return Temperature Index) and HIOM (Heat Weighted of Mixing). It also provides the vital information of hotspots generation on server racks of data center.

Mohammad I. Tradat et al. [2] in their research paper has studied on the forward and backward CRAH technology. There are two types of CRAH units that are forward CRAH and backward CRAH. In forward CRAH unit that is in forward curved blowers the air enters through the sides and is driven out in the downward direction by the in place rotating blades. In backward CRAH unit that is in backward curved blowers the air enters through the top and is driven outward in all directions by the rotating blades. It was surveyed that backward air blowers provides more airflow than forward air blower with 30% more energy efficiency.

Lin Su et al. [3] in their research paper discussed about improving the thermal environment of the cold aisle data center in this paper the main research point was the bottom ventilation of the server racks of the data centers. Here the intake airflow rate, intake airflow temperature and the outlet airflow temperature are optimized by varying the length of bottom ventilation of server racks. It was also stated in this paper that high porosity bottom ventilation (above 50%) can reduce the inlet and outlet airflow temperatures of the server racks in the data center.

J Kamran Fouladi et al. [4] have done a study on optimizing the thermal efficiency of the data center by means of using the CFD simulation. They studied that by increasing the airflow rates in the data center server racks simultaneously decrease the maximum inlet temperature of the air entering the server racks for different aisle containment configurations that are Full Hot Aisle Containment, Partial Hot Aisle Containment, Full Cold Aisle Containment, Partial Cold Aisle Containment and Without Containment where the minimum temperature is found in Full Hot Aisle Containment. They also studied that by increasing the control supply airflow temperature in the data center server racks simultaneously increase the maximum inlet temperature of the air entering the server racks for different aisle containment configurations that are Full Hot Aisle Containment, Partial Hot Aisle Containment, Full Cold Aisle Containment, Partial Cold Aisle Containment and Without Containment where the minimum temperature is found in Full Hot Aisle Containment.

Sadegh Khalili et al. [5] studied about the effect of different tiles design that are taken as of three different types which are (a) slotted grill type with parallel opening along with understructure scoops (b) directional grill type (c) simple understructure design with along with perpendicular opening on its surface and its effects are analyzed on the airflow inlet temperature of server racks in the data center in open aisle system and cold aisle containment system by considering and not considering the under cabinet leakage.

Qinghe Yao et al. [6] have done a parametric study in the optimizing the air-conditioning in a heat loaded room and in their study they used three turbulence models that are k-epsilon, k-omega and RNG k-epsilon and it was researched that only k-omega gives more accurate results when the simulated values are compared with the experimental values. It was concluded after running CFD simulations that air supply direction has little influence on the cooling rate and energy utilization coefficient.

Long Phan et al. [7] has done a research on improving cooling efficiency by using the mixed tiles to control the airflow uniformity of perforated tiles in a data center model. Here the mixed tile is a type of tile where the porosity of the tiles can be controlled for achieving the uniform airflow rate across the cold aisle. It is concluded that airflow is more uniform in mixed tiles than in the uniformly perforated tiles.

Zhihang Song et al. [8] compared the results of Artificial Neural Network (ANN) model in a data center with the results of that model generated and analyzed in Computational Fluid Dynamics (CFD). It was found that relative error between them is very low which averages about 0.5% hence it was concluded that ANN model can be used for the prediction of distribution of airflow and temperature in a data center.

K. Fouladi et al. [9] studies about available energy destruction in a data center with the help of flow network tool along with proper orthogonal decomposition based airflow modeler. The studies are made to reduce the destruction of available energy in a data center for the increment of optimization of thermal energy in data center.

Dustin W. Demetriou et al. [10] has introduce a methodology which can be alternative of CFD simulation through their research work that is the concept of proper orthogonal decomposition which is a reduced order model for the prediction server racks' inlet temperature distribution within a raised floor air cooled data center.

Sami A. Alkharabsheh et al. [11] studies about important working terminologies in a data center and discuss about the effects on power dissipation and airflow rate through the sever racks in the data center. In this paper the CRAC failure situation is studied and analysis is made on the effect on temperature distribution and airflow pattern in data center due to the CRAC failure situation. The important working terminologies are instant change in CRAC fan speed, tiles perforation ratio and server fan speed.

Michael K. Patterson et al. [12] discusses about thermal management in the data center by controlling CRAH fan speed and discussing their effects on certain parameters that are differential pressure, airflow velocity and differential temperature of airflow so that recirculation of hot air is avoided in the data center.

Zhihang Song et al. [13] have studied about the air flow through the active tiles. They deduced that airflow through the fans of active tiles has swirl velocity hence straightening and non-straightening effects of that swirl velocity has to be considered and this swirl velocity consists of only straightening effect when the CRAC unit is placed far away from the active tiles.

Suhas V. Patankar [14] has done research on how to achieve uniform airflow in a data center by using the CFD software and it was suggested that uniform airflow can be achieved by the following ways that is when height of raised floor in a data center is increased, using the inclined partitions within the raised floor and using the porous wall partitions within the raised floor. It was concluded form his research that cold air distribution across the server racks can be achieved by using the air curtains.

Marcus K. Herrlin et al. [15] have done a research on the 2000 W per sq. ft. and then concluded an index named as Rack Cooling Index (RCI) which is a metric that is developed to tell whether the intake temperature is meeting the guidelines of ASHRAE standard or not. The values of RCI should be between 100% and 90%. It was also discussed that closed aisle containment gives high RCI than open and semi-closed aisle containment.

Amir Radmehr et al. [16] in their paper studies about the airflow distribution across front to rear server racks in a data center and the main research point is about the effect of high velocity jet on the airflow of the data center on bottom of server racks in a data center. The effect of high velocity jet has mild effect on the airflow at the bottom of server racks and in the critical situation the airflow drop in the bottom of the server racks is about 15% but with the use of servers with strong fans the effect of flow reduction completely diminishes.

James W. Vangilder et al. [17] surveyed about the airflow uniformity in a data center through the perforated tiles and found by using the CFD software that there is almost uniform airflow where there is less standard deviation in the simulation results when compared with the experimental results therefore less standard deviation is found in data centers having zero leakage, decreasing the length of cold aisle and having the raised floor of height close to zero.

CHAPTER-IV

ANALYSIS AND SIMULATION

Introduction:

The simulation is done on data center of Swasthya Bhavan where the design is used for performing the simulation and then the temperature contour and isotherm distribution on server racks are analyzed for the determination of hotspots as well as their mitigation. For the mitigation part of the hotspots on the server racks the some cases are observed and cases are formed by changing the boundary conditions and in this way required temperature on the server racks are achieved.

Fundamental Governing Equations:

The fundamental governing equations that are used are mentioned below:

1) Conservation of Mass or Continuity Equation: $\frac{d\rho}{dt} + \rho(\nabla \cdot v) = 0$

2) Navier-Stokes' Equation: $\rho \frac{D\vec{v}}{Dt} = -\nabla p + \nabla \cdot T + \vec{f}$

3) Conservation of Momentum: $\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla \cdot (\rho\vec{v}\vec{v}) = -\nabla p + \rho\vec{g} + \vec{F}$

4) Conservation of Energy: $\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = -\nabla \cdot \left(\sum_j h_j J_j\right) + S_h$

5) k-ε Turbulence Model:

Equation of k: $\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k$

Equation of ε: $\frac{\partial(\rho\epsilon)}{\partial t}+\frac{\partial(\rho\epsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial\epsilon}{\partial x_j}\right]+C_1\frac{\epsilon}{k}(G_k+C_3G_b)-C_2\rho\frac{\varepsilon^2}{k}+S_\varepsilon$

Where, $\varepsilon=\frac{\mu}{\rho}\overline{\left(\frac{\partial u_i'}{\partial x}\right)\left(\frac{\partial u_i'}{\partial x}\right)}$

Where, Turbulent Viscosity is $\mu_t=\rho C_\mu\frac{k^2}{\epsilon}$

6) Energy Equation:

$$\frac{\partial}{\partial t}(\rho E)+\frac{\partial}{\partial x_i}[u_i(\rho E+p)]=\frac{\partial}{\partial x_j}\left(k_{eff}\frac{\partial T}{\partial x_j}+u_i(\tau_{ij})_{eff}\right)+S_h$$

All symbols used are of usual significance.

Simulation Setup for Data Centre:

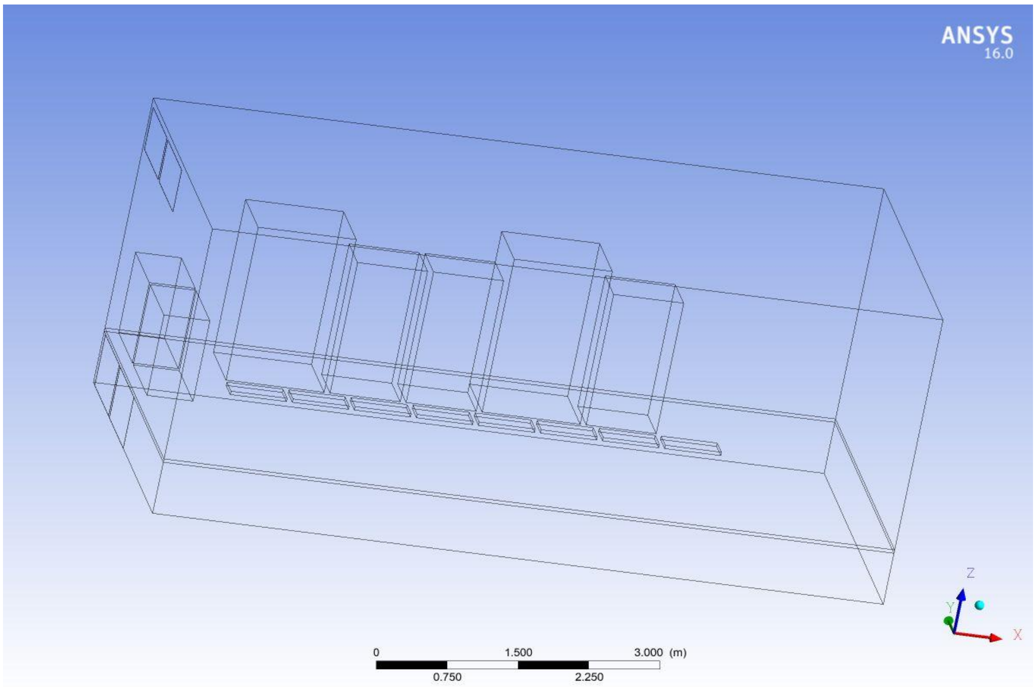
The Data Centre considered for simulation is located in Swasthya Bhawan ,GN-29 Sector-V, Salt Lake, Street Number 2, Kolkata, West Bengal – 700091. Design, airflow rate and heat generation from server racks these data are collected from the Officials of Swasthya Bhavan. A study is made on the following cases mentioned below which are as formed by changing temperature at CRAC outlet and heat generation rate by each of the server racks boundary conditions are as follows:

CONDITIONS	**TEMPERATURE AT THE OUTLET OF CRAC (K)**	**HEAT GENERATION RATE AT EACH SERVER RACK (W/CUBIC MTR.)**
CASE I	284	1500
CASE II	282	1500
CASE III	280	1500
CASE IV	282	1750

ANALYSIS OF DATA CENTER:

1) Design:

The case studies is performed on the design as shown below in figure.



S.no	Name	Size	Units	Quantity
1	Main Room	7950 x 4300 x 2790	mm^3	1
2	Raised Floor	7950 x 4300 x 610	mm^3	1
3	Big Servers	1067 x 915 x 1867	mm^3	2
4	Small Servers	762 x 610 x 1600	mm^3	3
5	CRAC	1000 x 500 x 1000	mm^3	2
6	Vents	610 x 300	mm^2	8
7	Inlets	1000 x 610	mm^2	2
8	Outlets	1000 x 500	mm^2	2

2) Simulation Setup & Solution:

In this work four cases are considered in order to get a clear idea when the feasible temperature on server racks are achieved. The details of the four cases are mentioned in the above table. In this simulation setup pressure based steady state fluid flow is considered where the turbulent flow K – ε model with standard wall function is used. The main room and raised floor are considered as the fluid zones. The five server racks, two CRAC units and false floor are considered as the solid zones. The fluid and solid materials are chosen as air and aluminum respectively. In this setup the Pressure and Velocity coupled SIMPLE method is used. In below table the boundary conditions are mentioned along with the heat generation rate in each of the server racks. The server racks numbered from 1 to 5 starting from extreme left to extreme right.

S.no	Name	Values	Units
1	Inlet air velocity -1	5.5	m/sec
2	Inlet air velocity -2	Idle	m/sec
3	Inlet air Temperature -1	280/282/284	Kelvin
4	Inlet air Temperature -2	Idle	Kelvin
5	Heat generation in Server 1	1500/1750	Watts/m^3
6	Heat generation in Server 2	1500/1750	Watts/m^3
7	Heat generation in Server 3	1500/1750	Watts/m^3
8	Heat generation in Server 4	1500/1750	Watts/m^3
9	Heat generation in Server 5	1500/1750	Watts/m^3
10	Outlet air Pressure &Temperature	Kept as per fluent	Kept as per fluent

3) Simulation Results & Discussion:

a) CASE I (Temperature of air at CRAC outlet is 284 K and heat generation from each server rack is 1500 W/ cum.)

i) Temperature Contour:

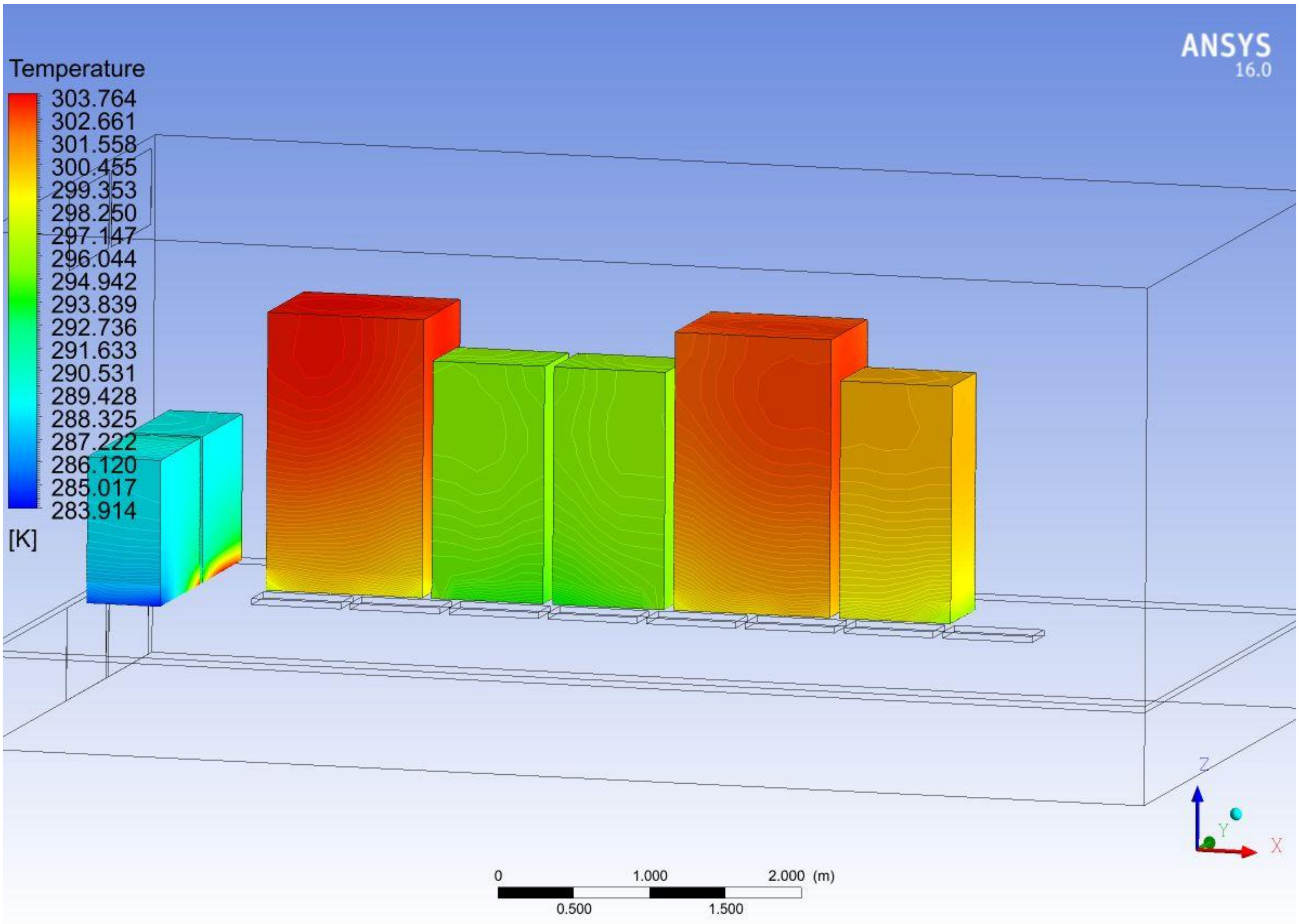


Fig:1

Fig:1 represents the temperature distribution of five server racks and two crac units. The temperature distribution of crac and server racks are clearly visible from the temperature colour coding mentioned above.

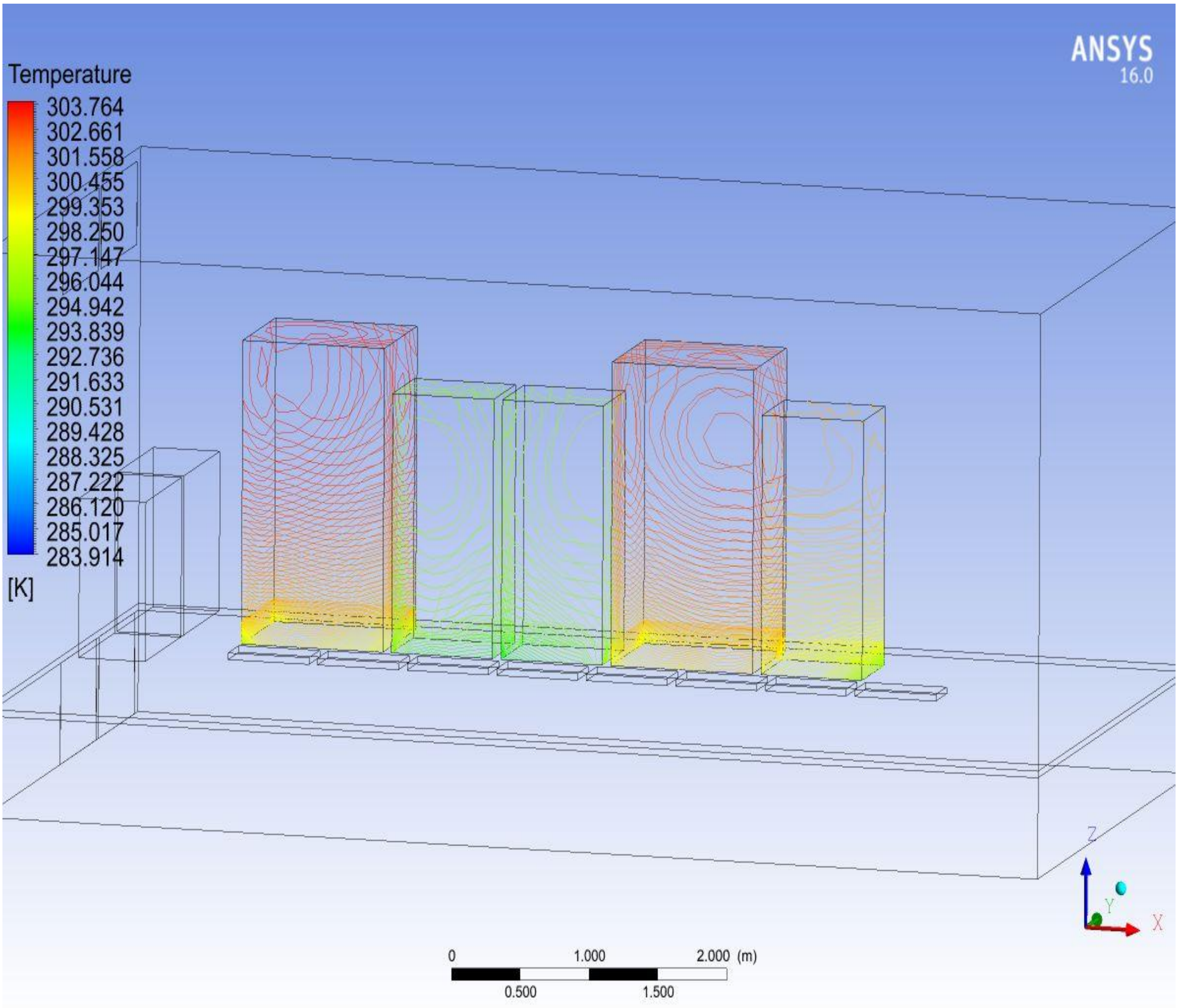


Fig:2

Fig:2 represents the temperature isotherms distribution of five server racks. The temperature isotherms distribution of server racks are clearly visible from the temperature colour coding mentioned above.

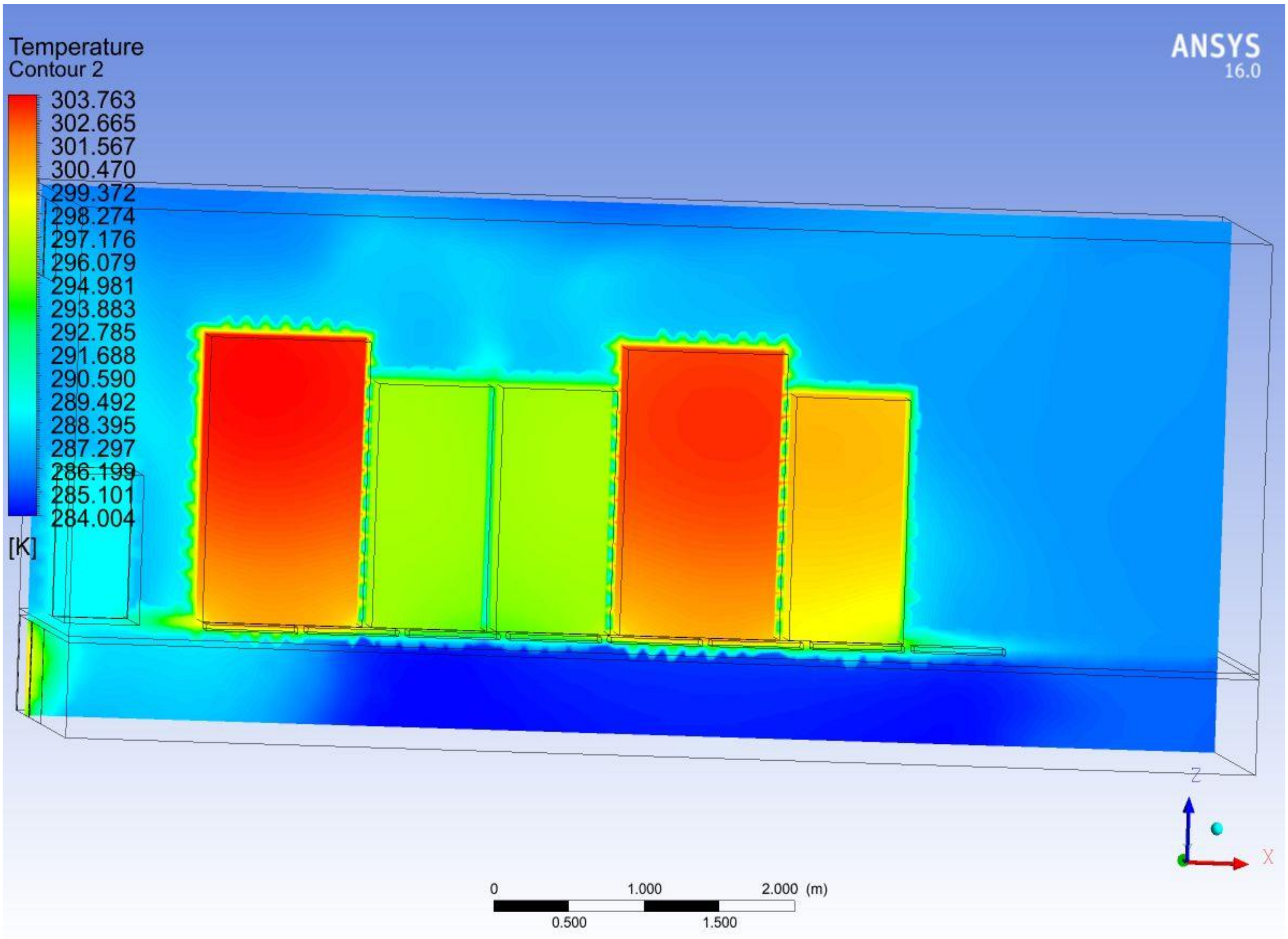


Fig:3

Fig:3 represents the temperature distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

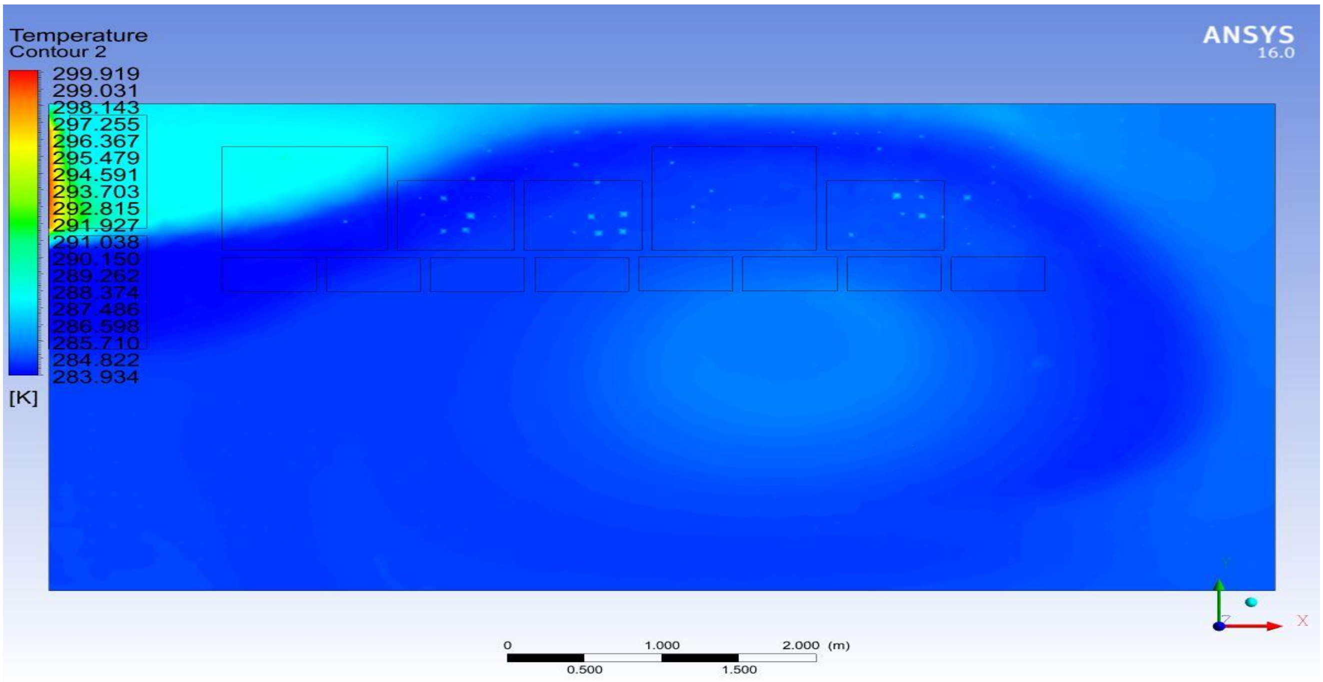


Fig:4

Fig:4 represents the temperature distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

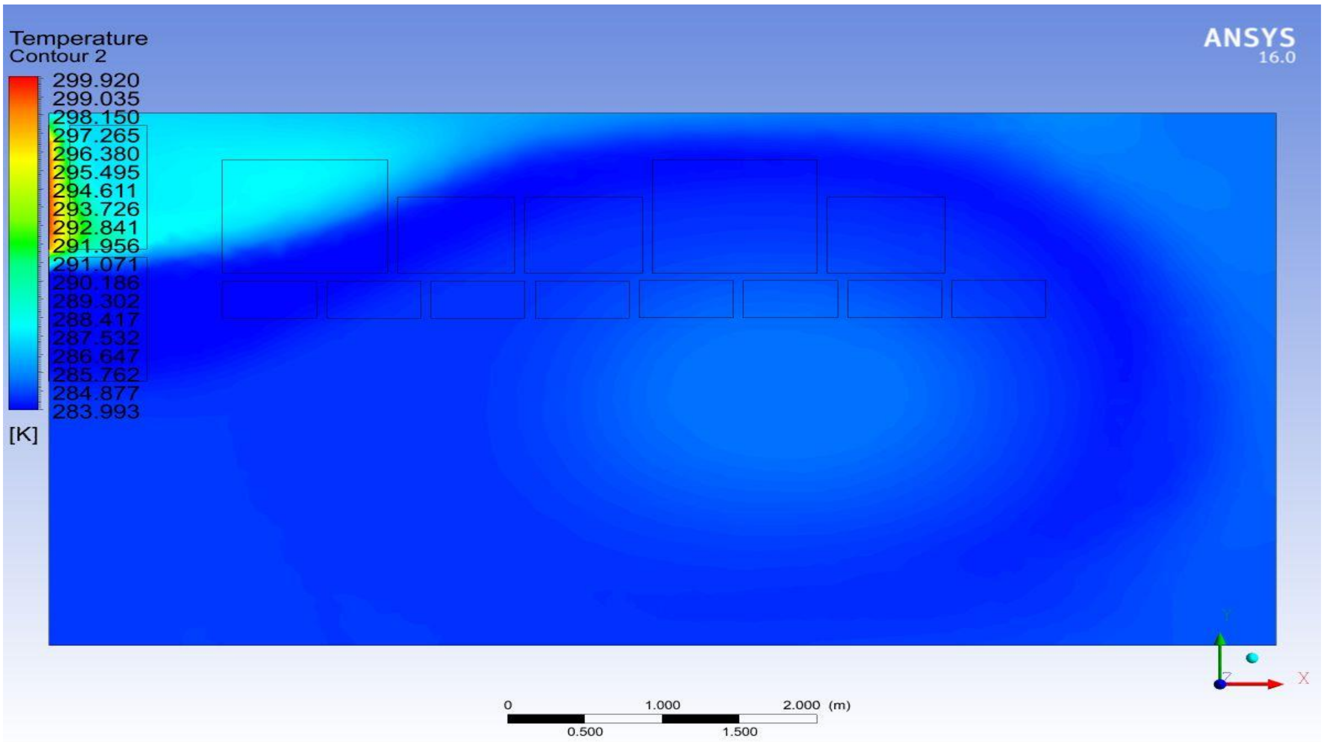


Fig:5

Fig:5 represents the temperature distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

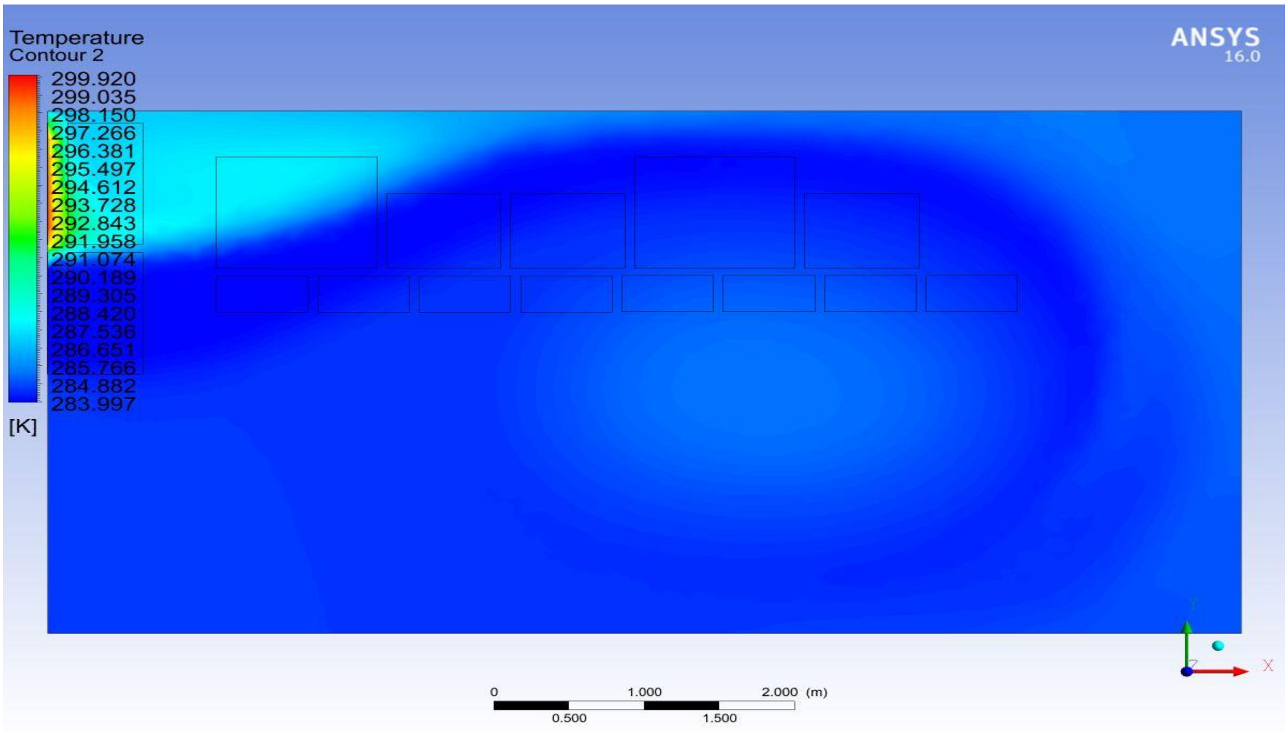


Fig:6

Fig:6 represents the temperature distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

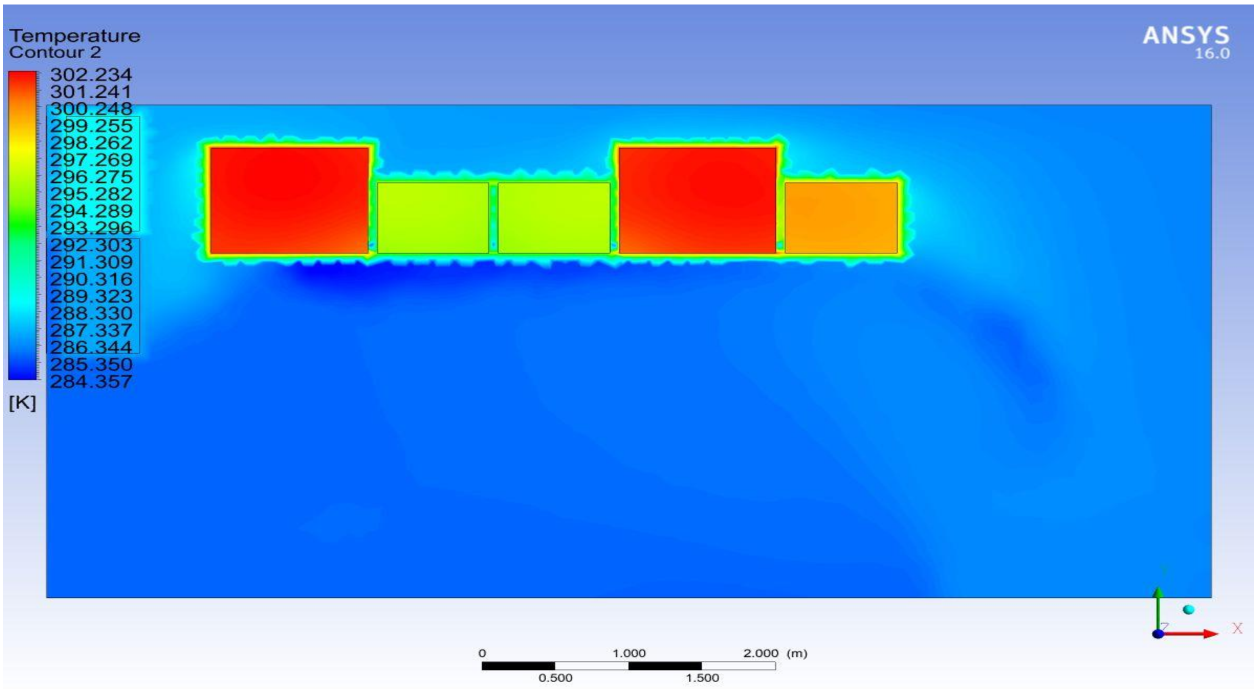


Fig:7

Fig:7 represents the temperature distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

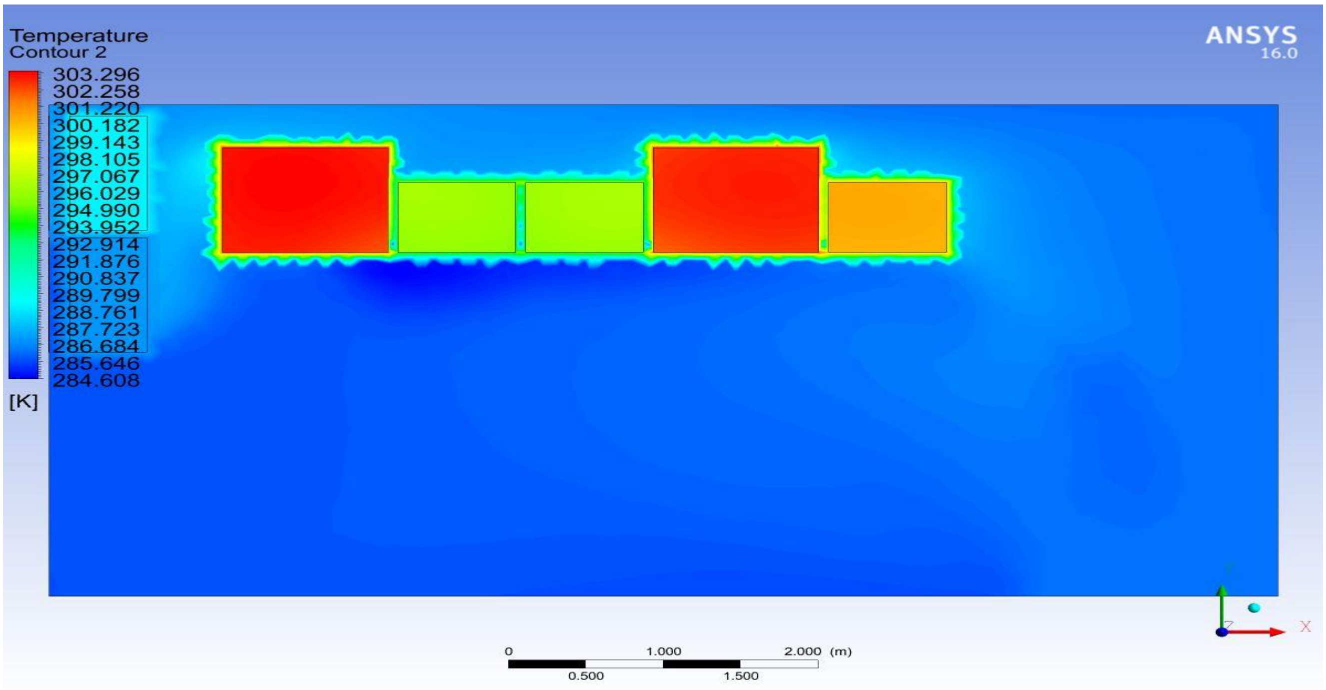


Fig:8

Fig:8 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

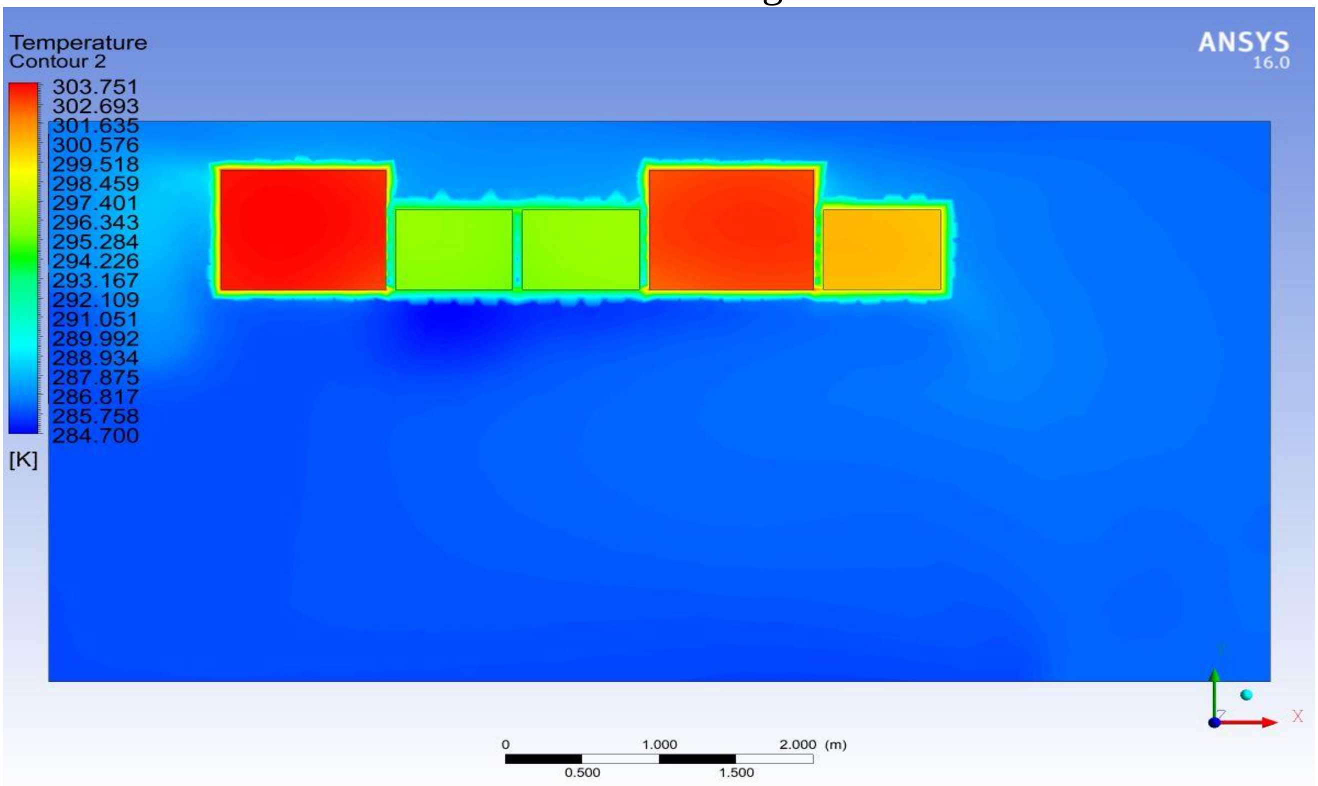


Fig:9

Fig:9 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

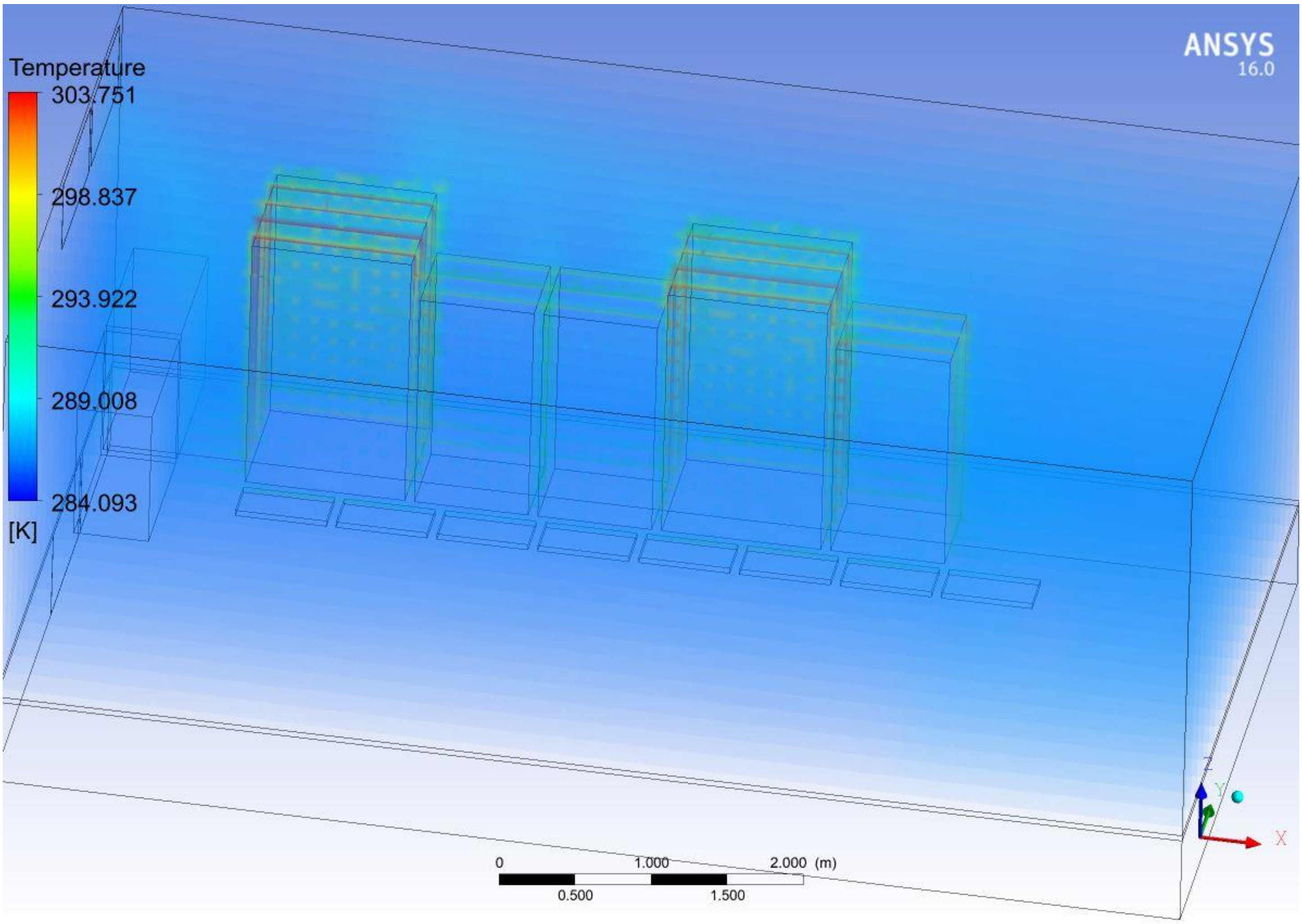


Fig:10

Fig:10 represents the temperature distribution of volume of air present in the server room space located above the raised floor.

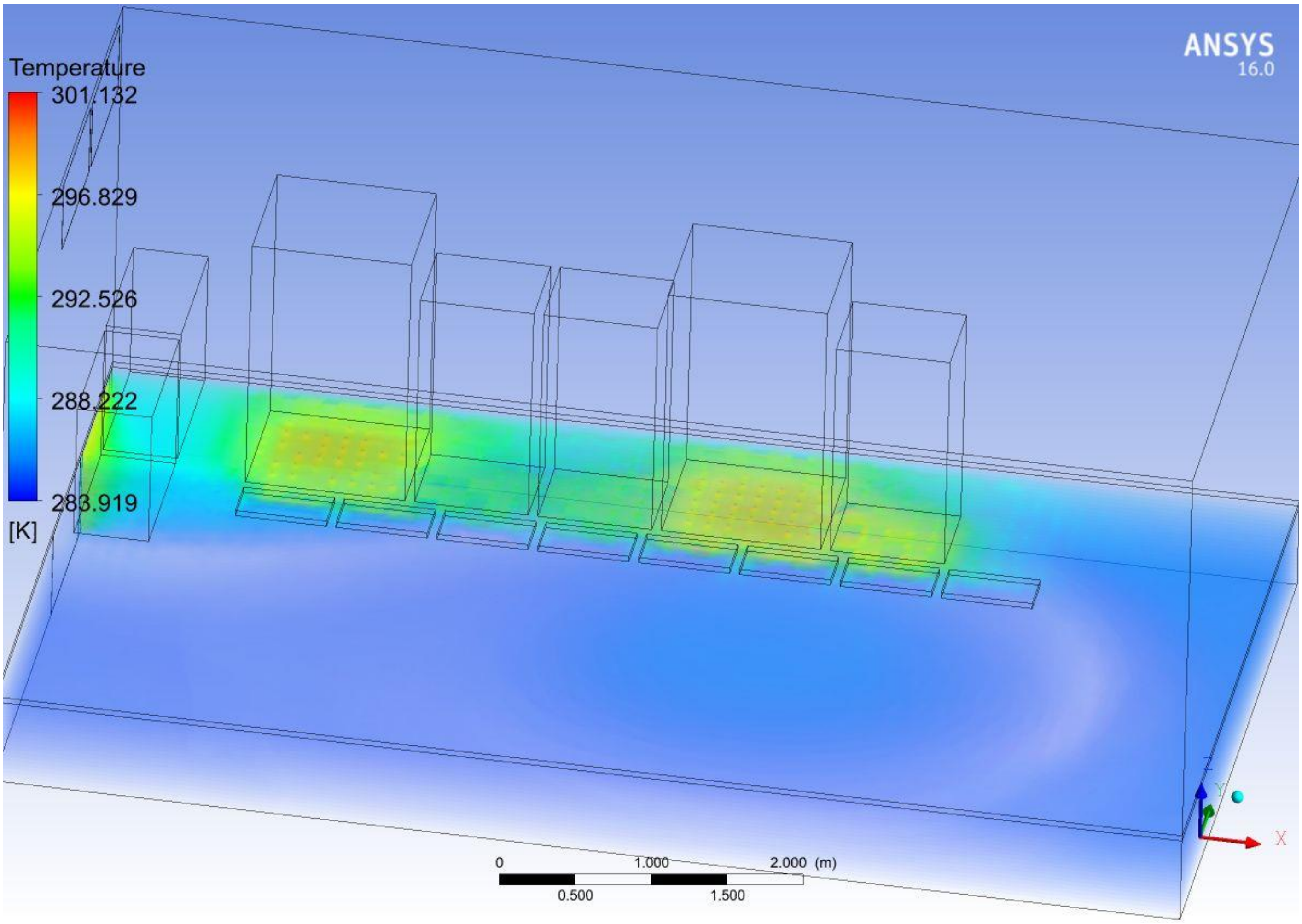


Fig:11

Fig:11 represents the temperature distribution of volume of air present in the space located below the raised floor.

ii) <u>Pressure Contour:</u>

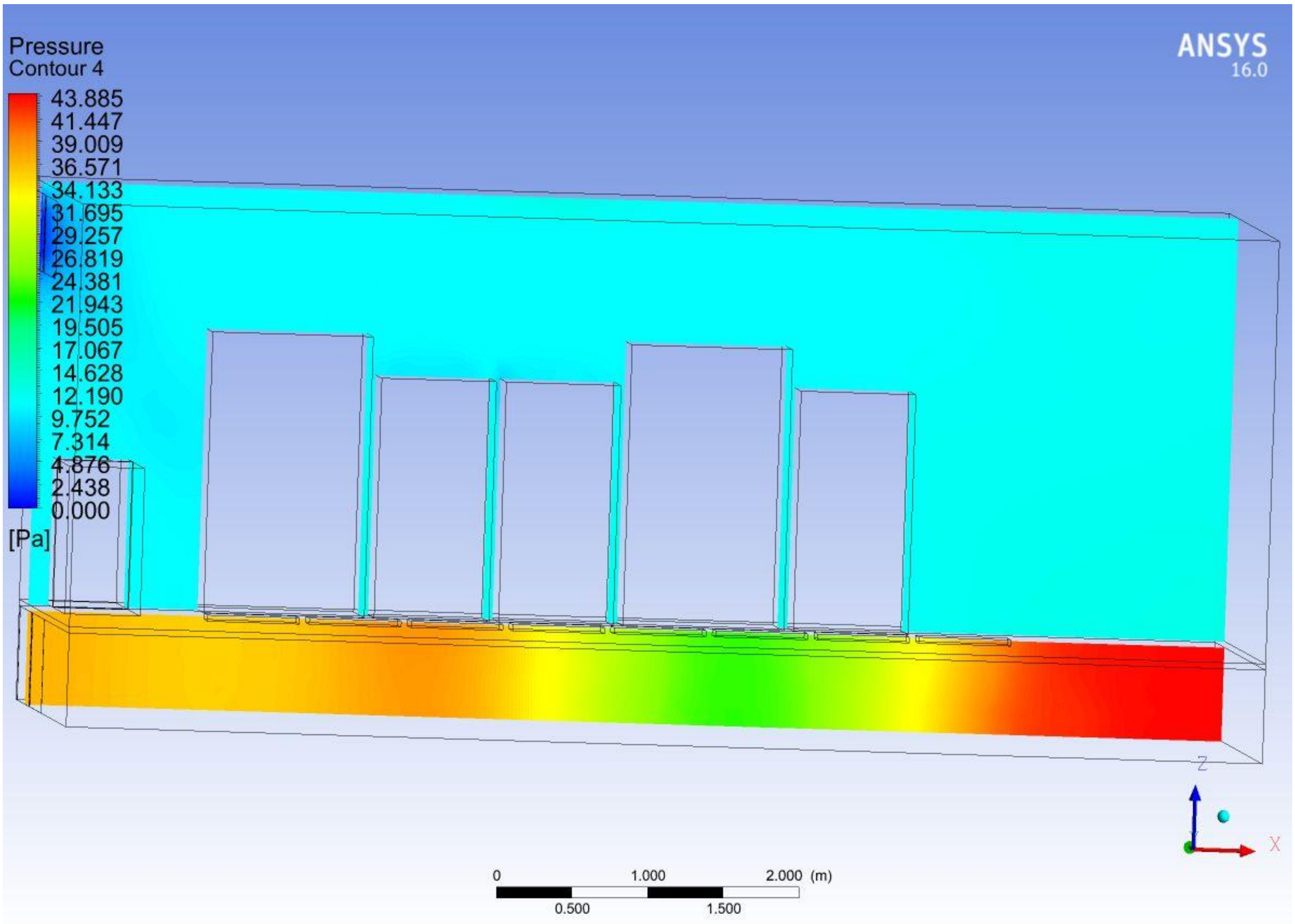


Fig:12

Fig:12 represents the pressure distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

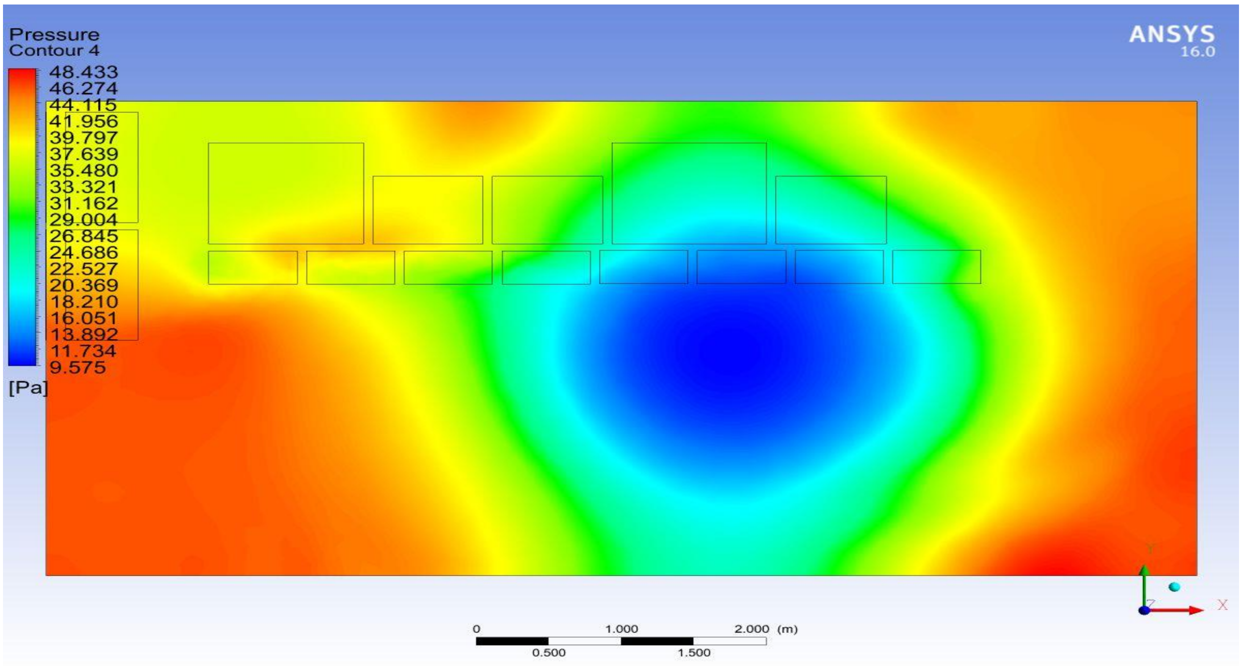


Fig:13

Fig:13 represents the pressure distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

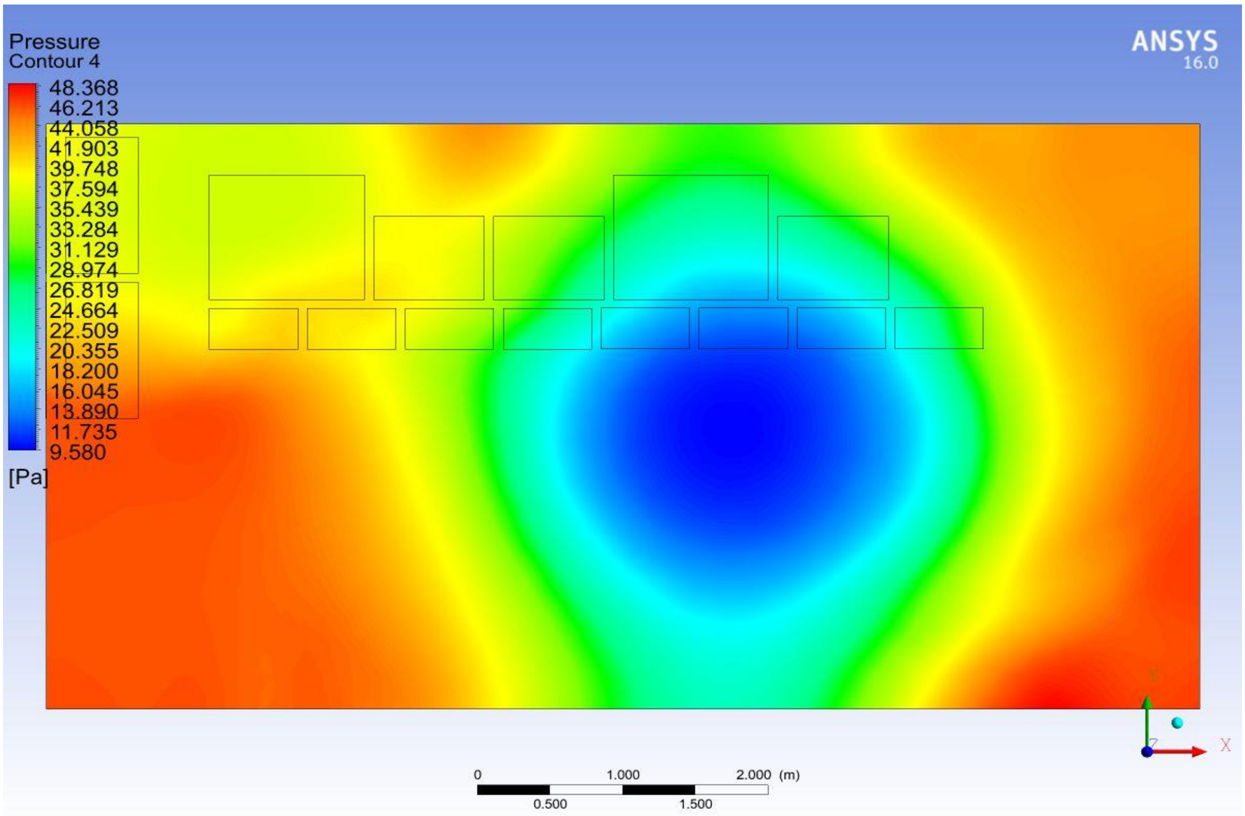


Fig:14

Fig:14 represents the pressure distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

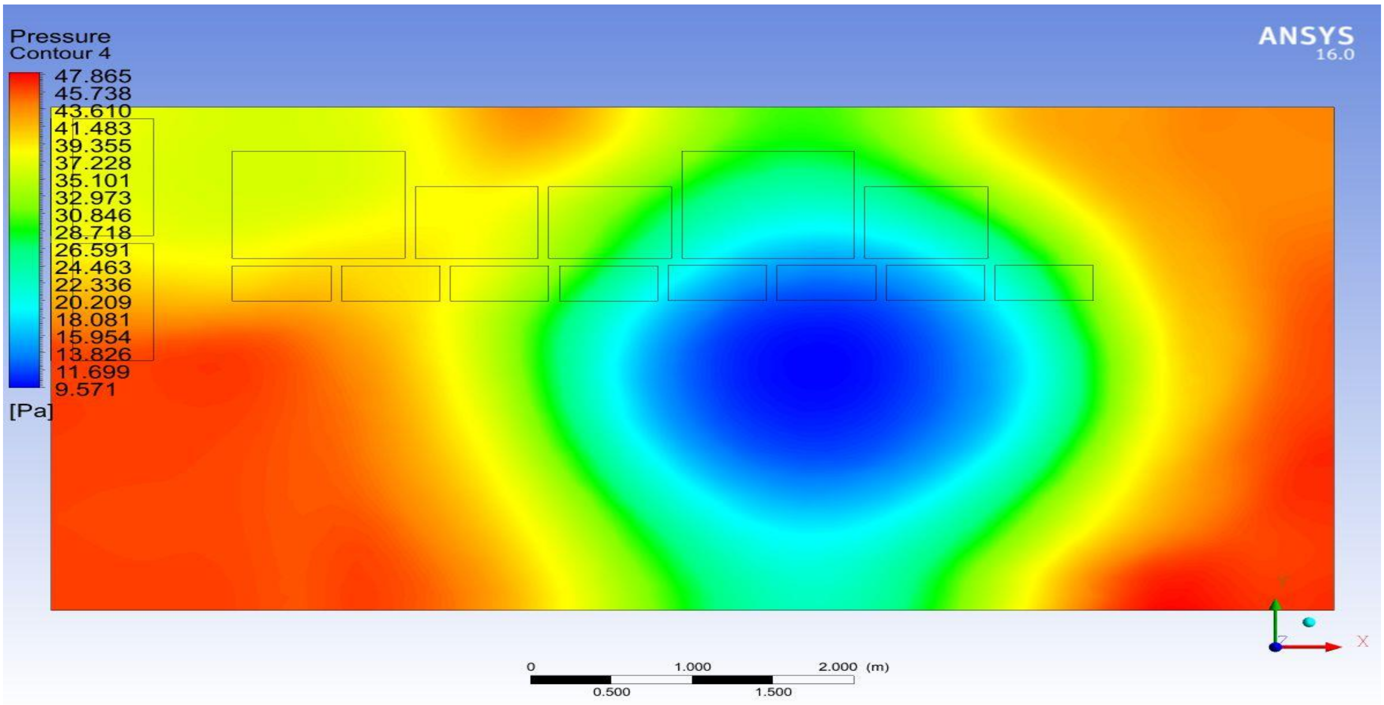


Fig:15

Fig:15 represents the pressure distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

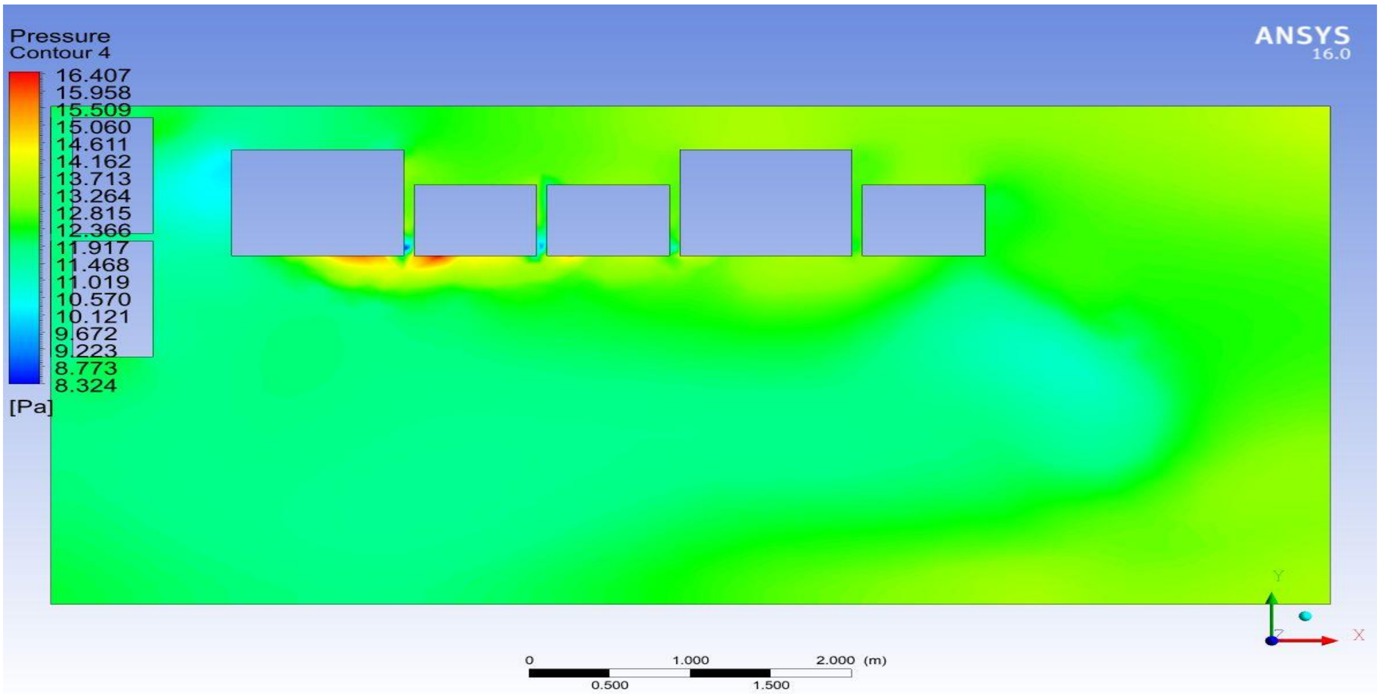


Fig:16

Fig:16 represents the pressure distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

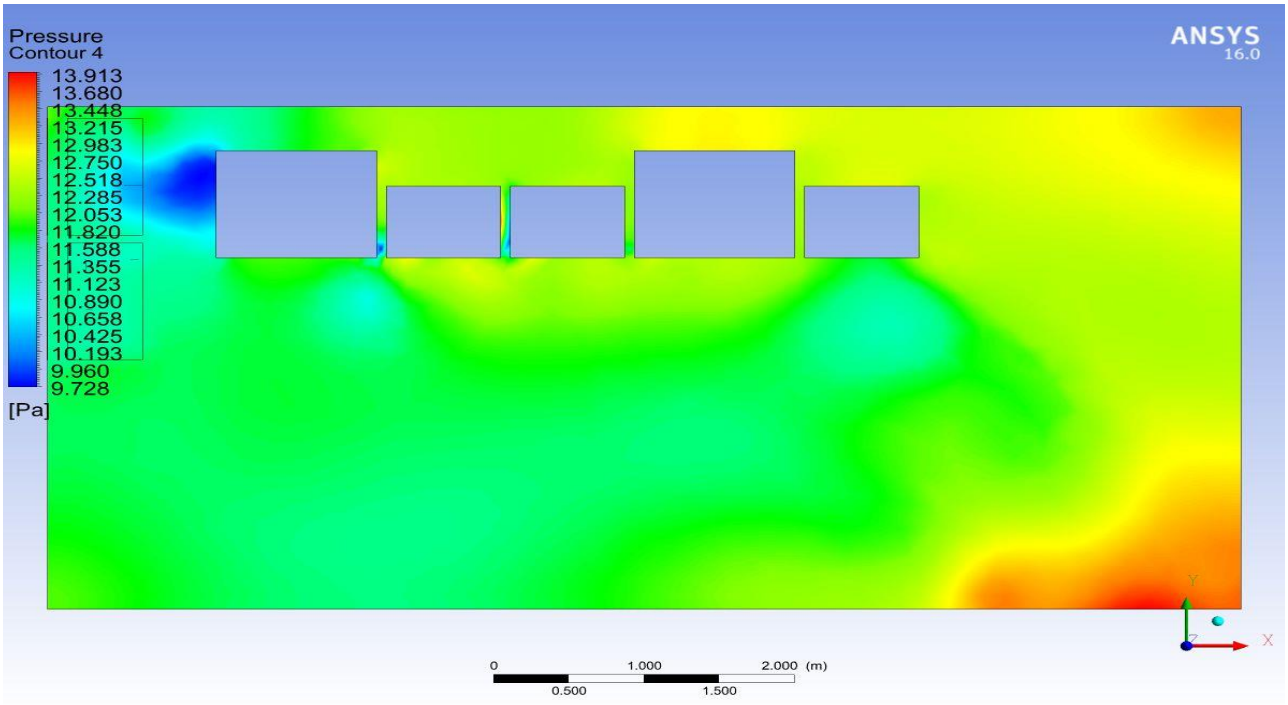


Fig:17

Fig:17 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1000 mm below the raised floor along the Z-axis.

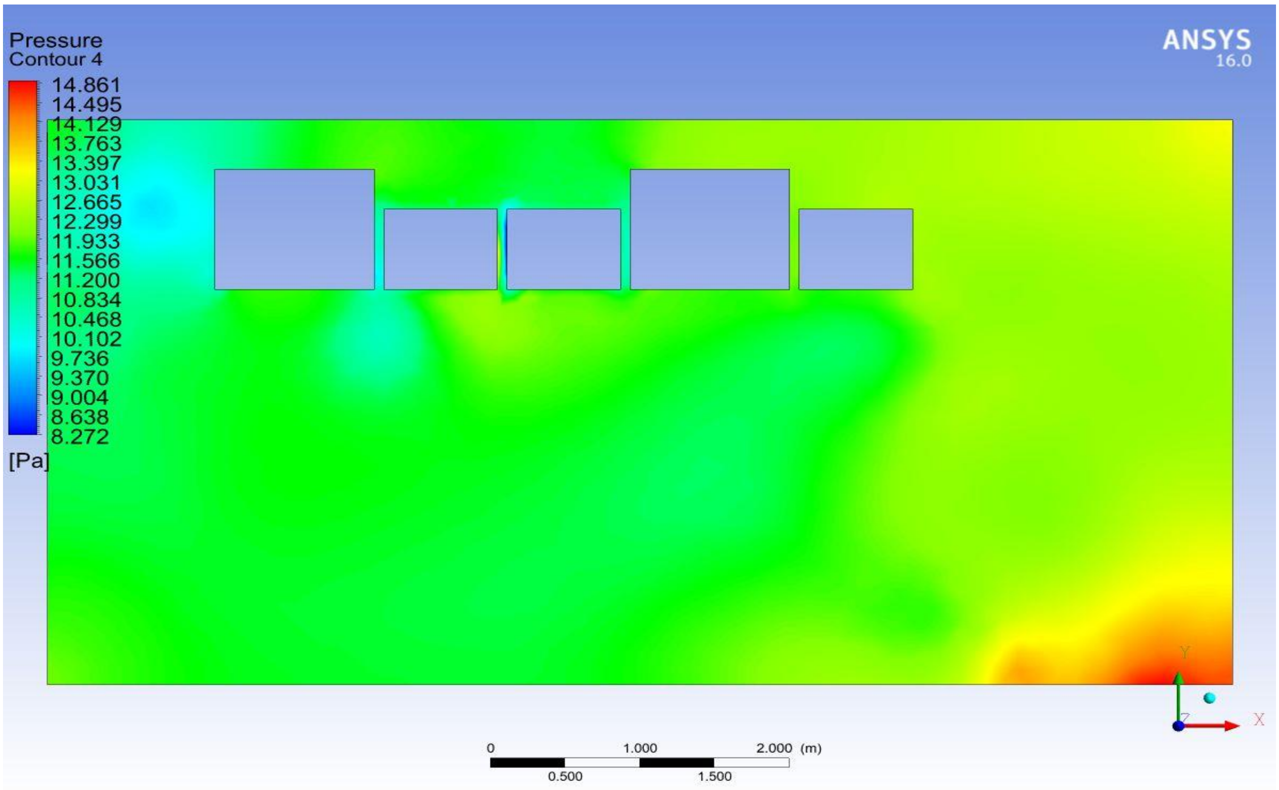


Fig:18

Fig:18 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1500 mm below the raised floor along the Z-axis.

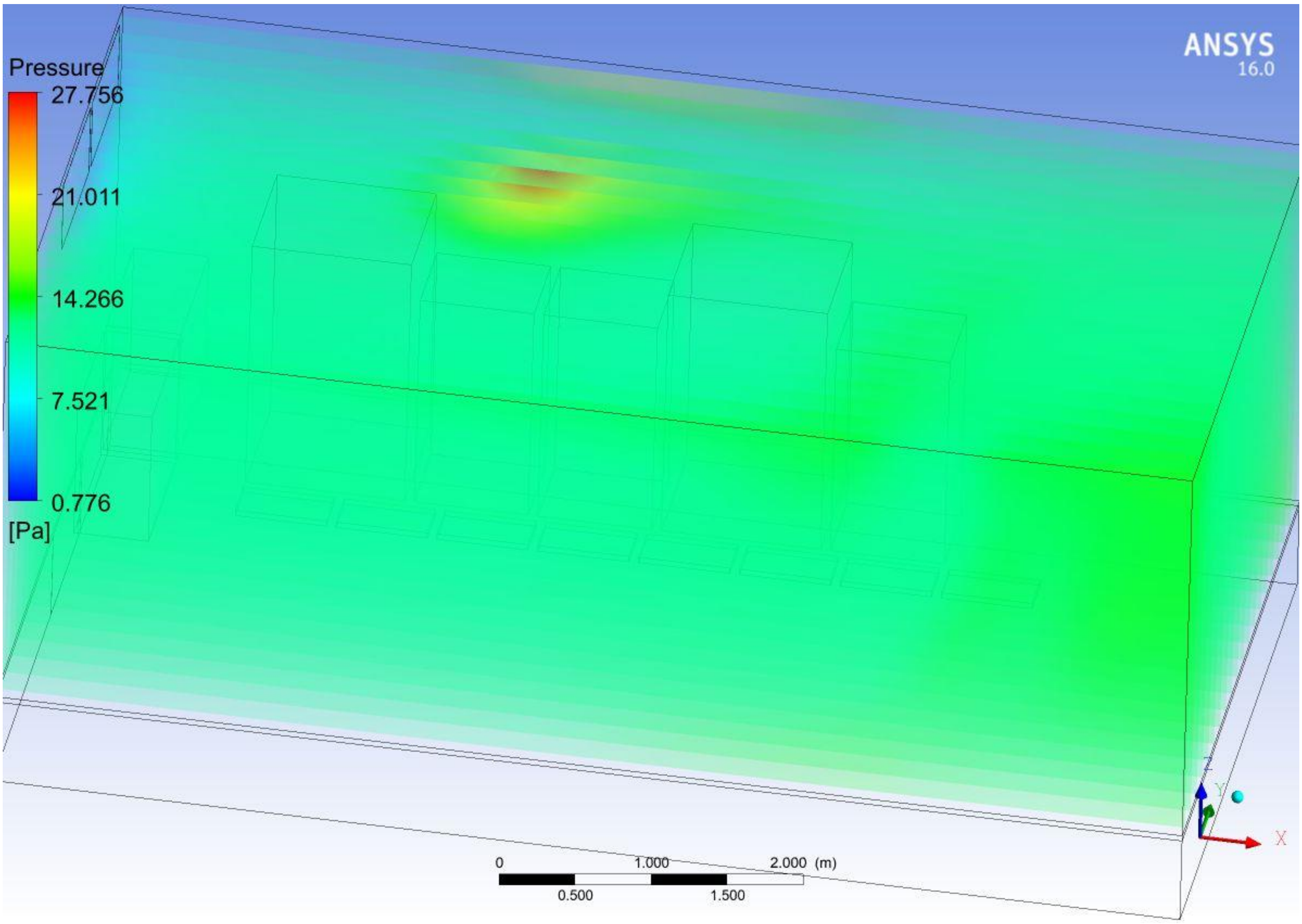


Fig:19

Fig:19 represents the pressure distribution of volume of air present in the server room space located above the raised floor.

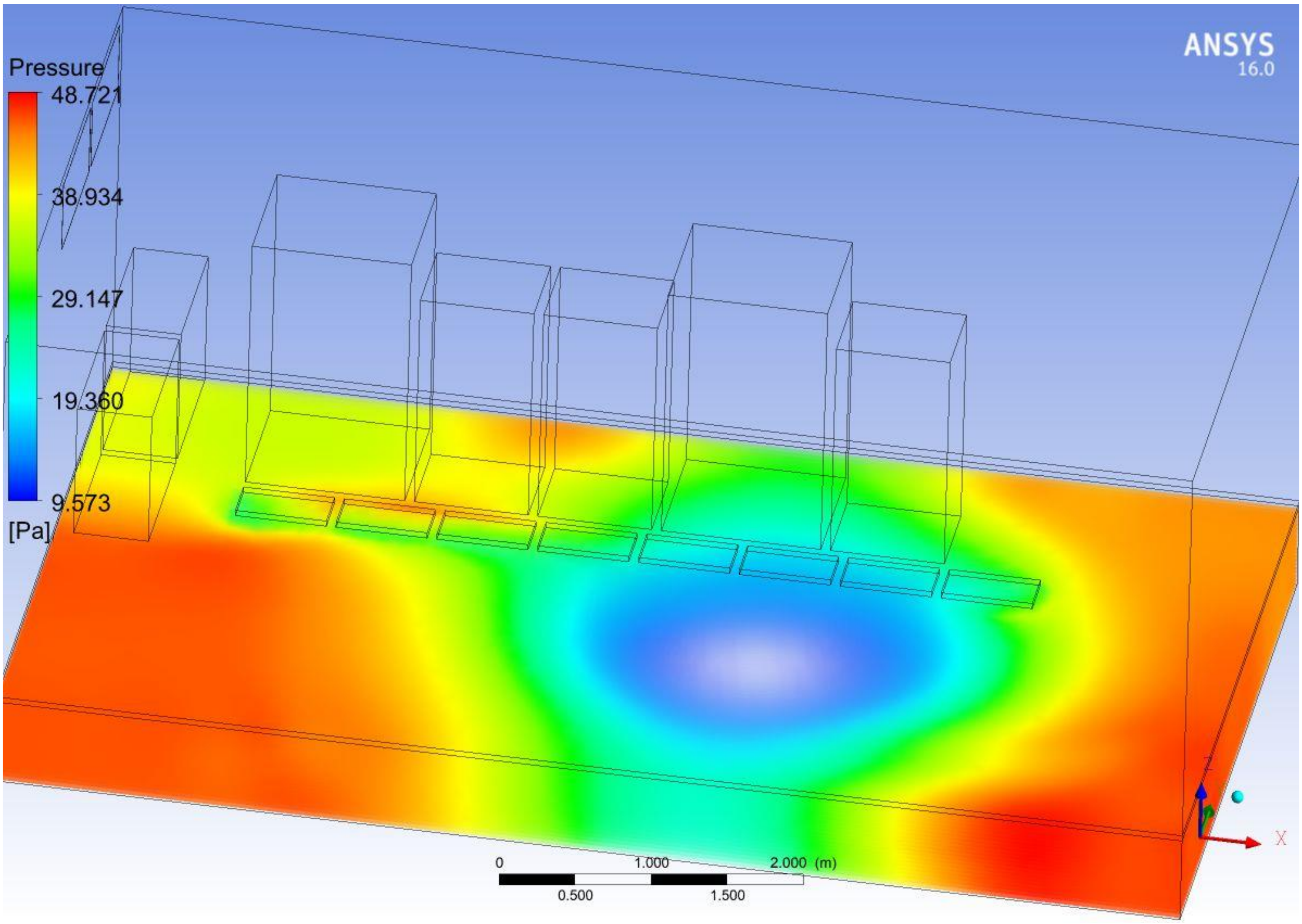


Fig:20

Fig:20 represents the pressure distribution of volume of air present in the server room space located below the raised floor.

iii) Velocity Contour:

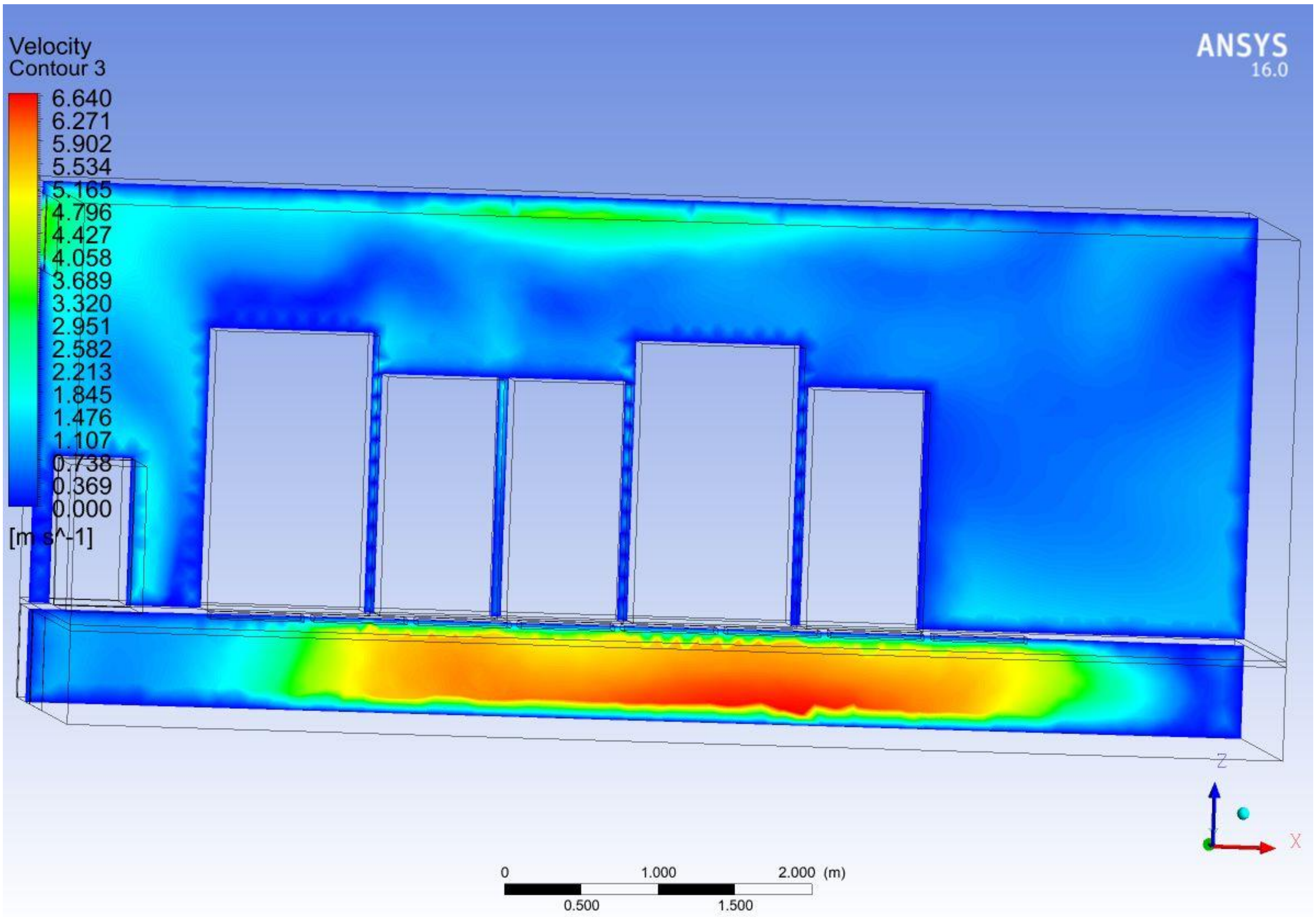


Fig:21

Fig:21 represents the pressure distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

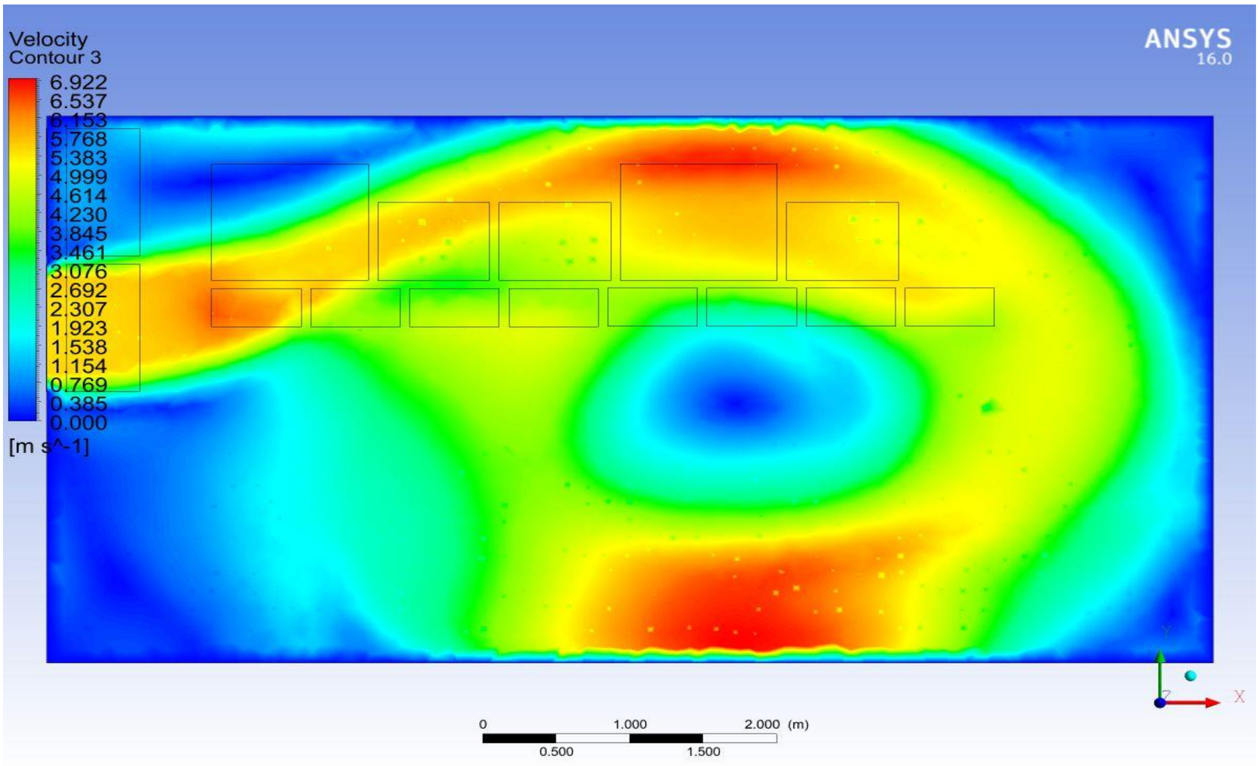


Fig:22

Fig:22 represents the velocity distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

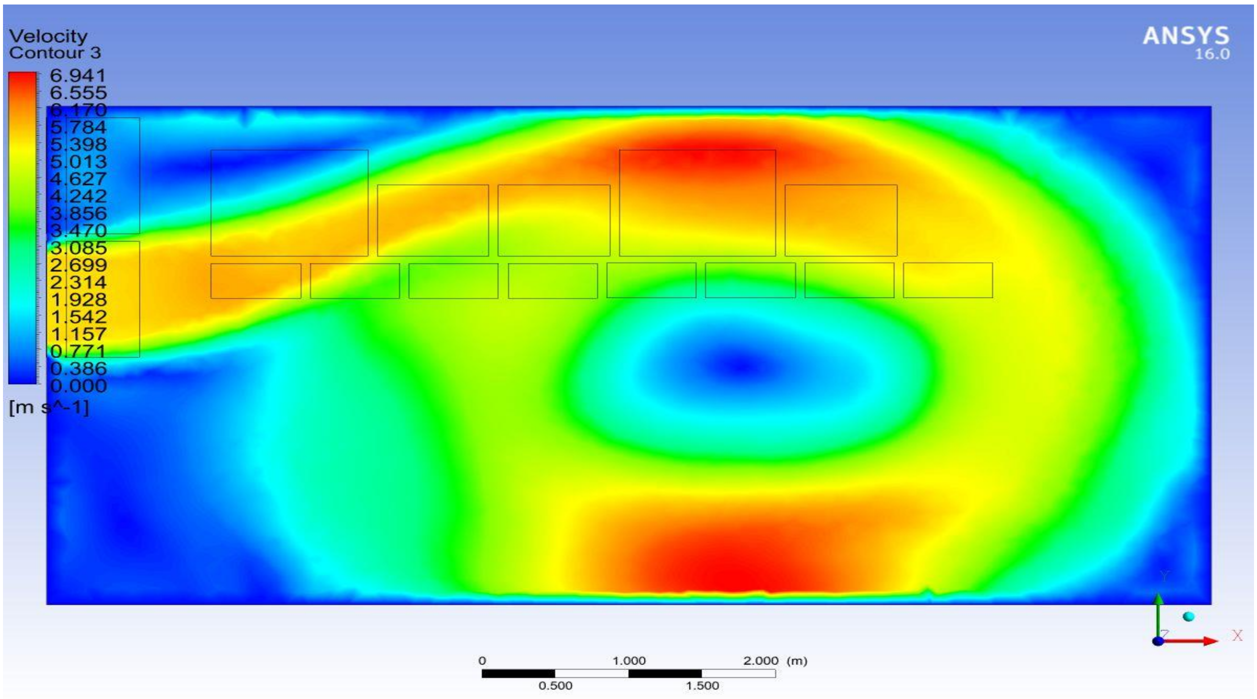


Fig:23

Fig:23 represents the velocity distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

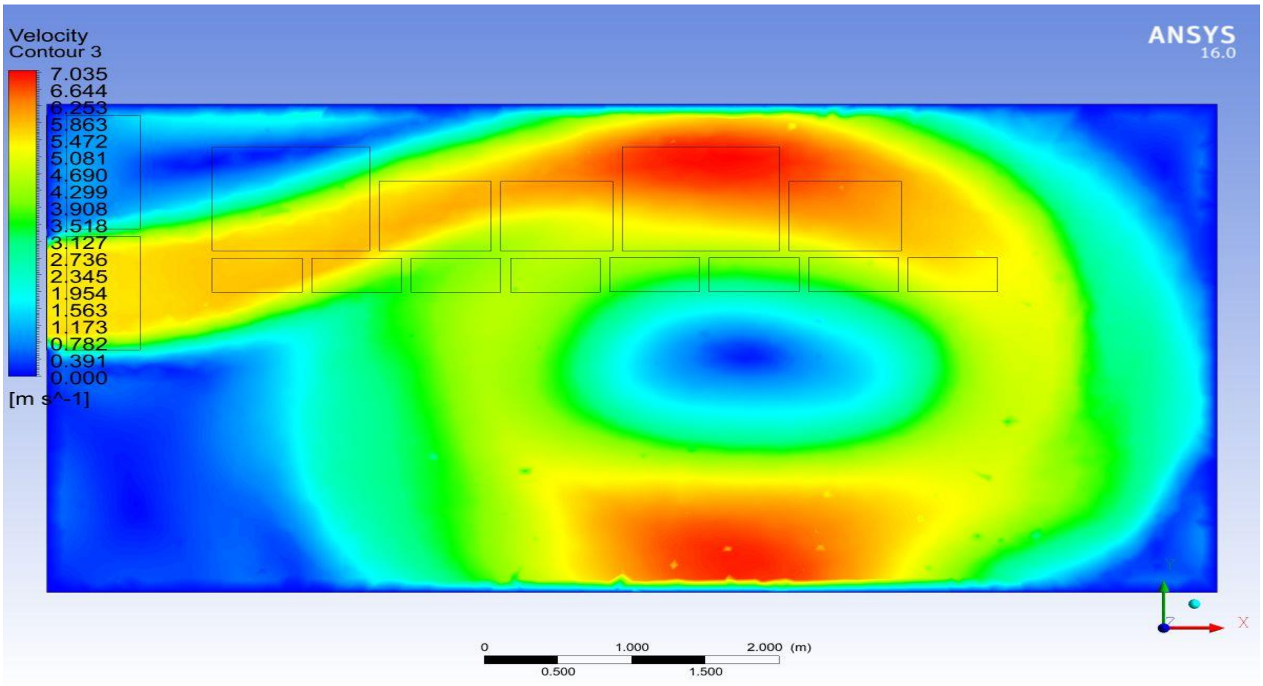


Fig:24

Fig:24 represents the velocity distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

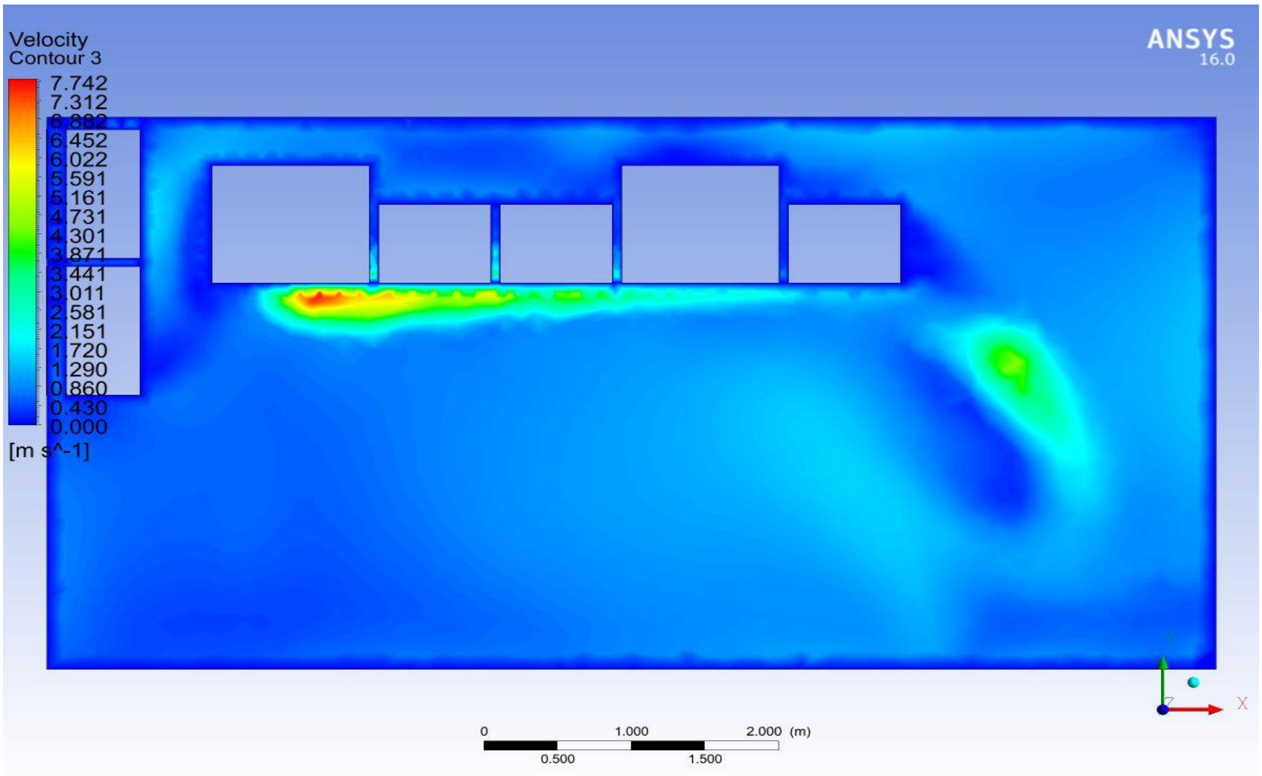


Fig:25

Fig:25 represents the velocity distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

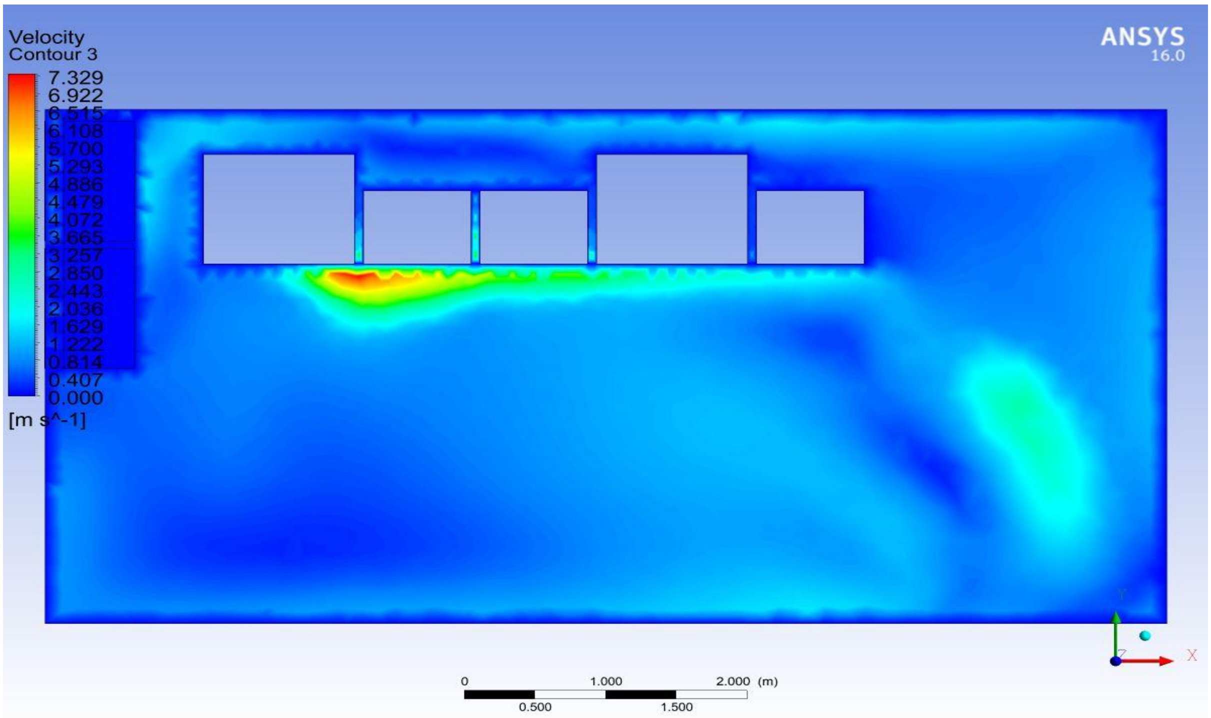


Fig:26

Fig:26 represents the velocity distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

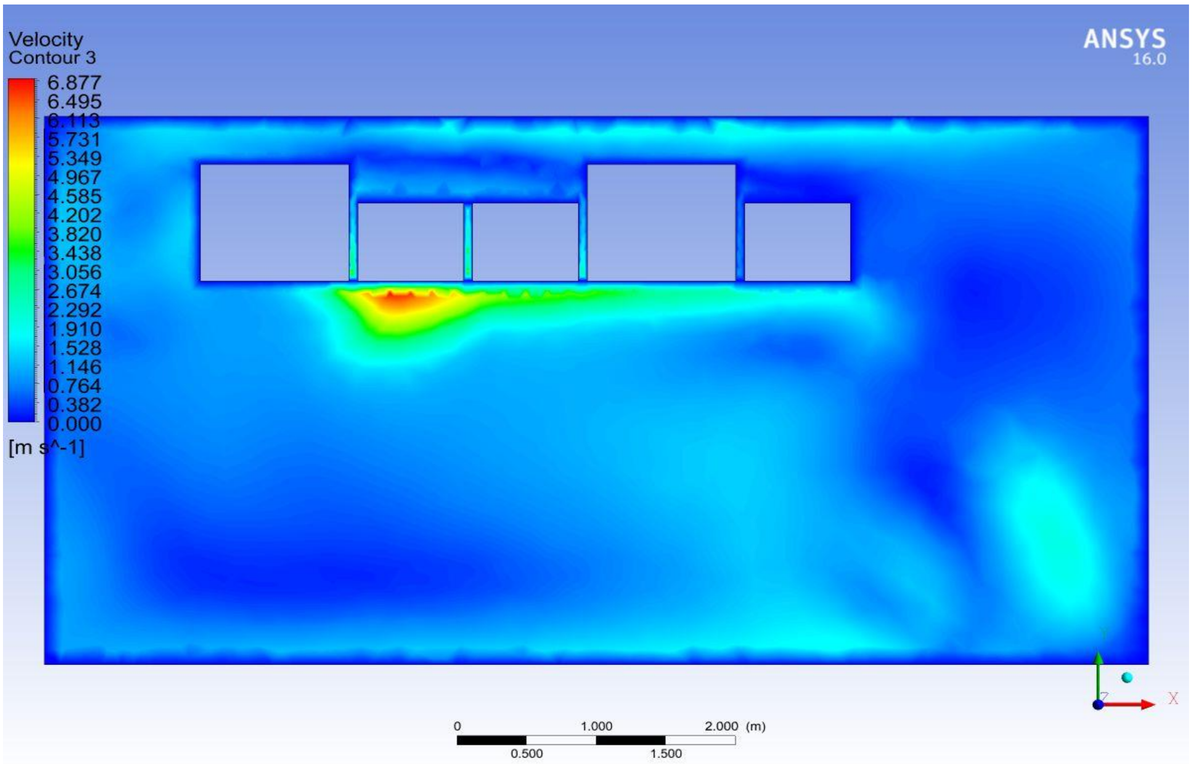


Fig:27

Fig:27 represents the velocity distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

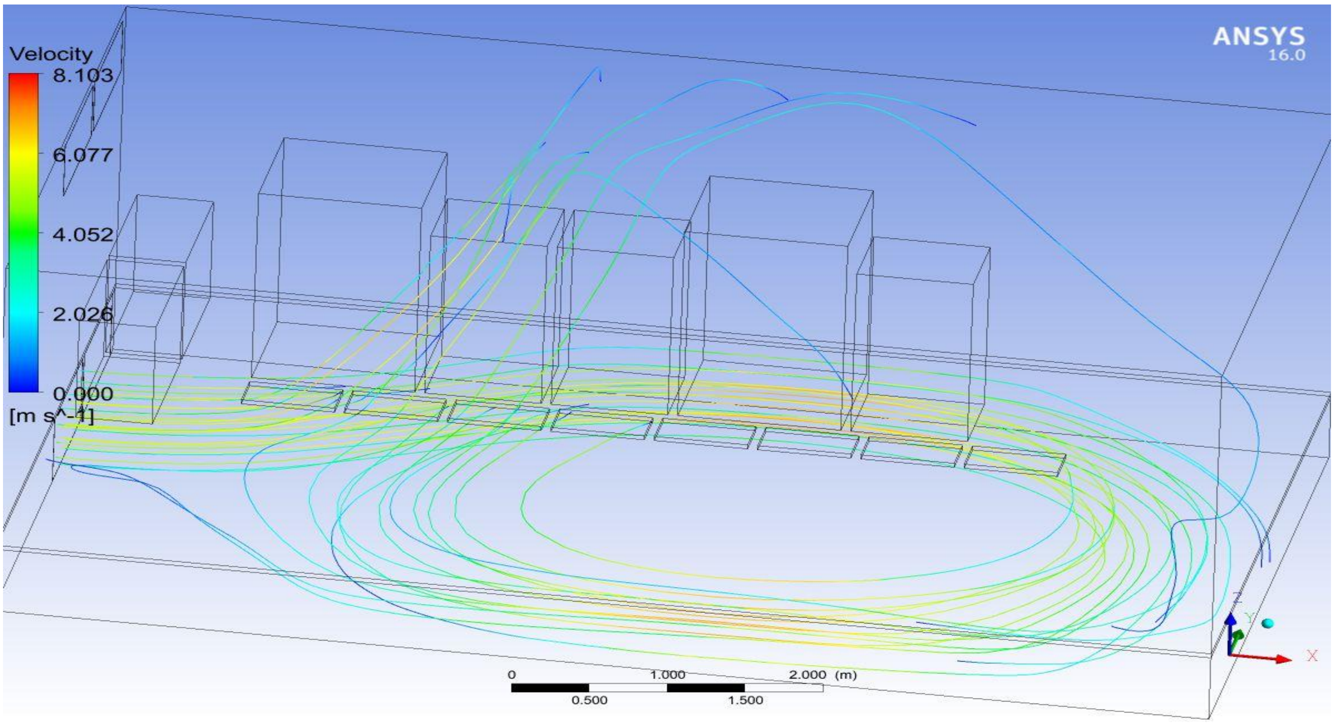


Fig:28

Fig:28 shows velocity streamlines from inlet 1 towards the raised floor space.

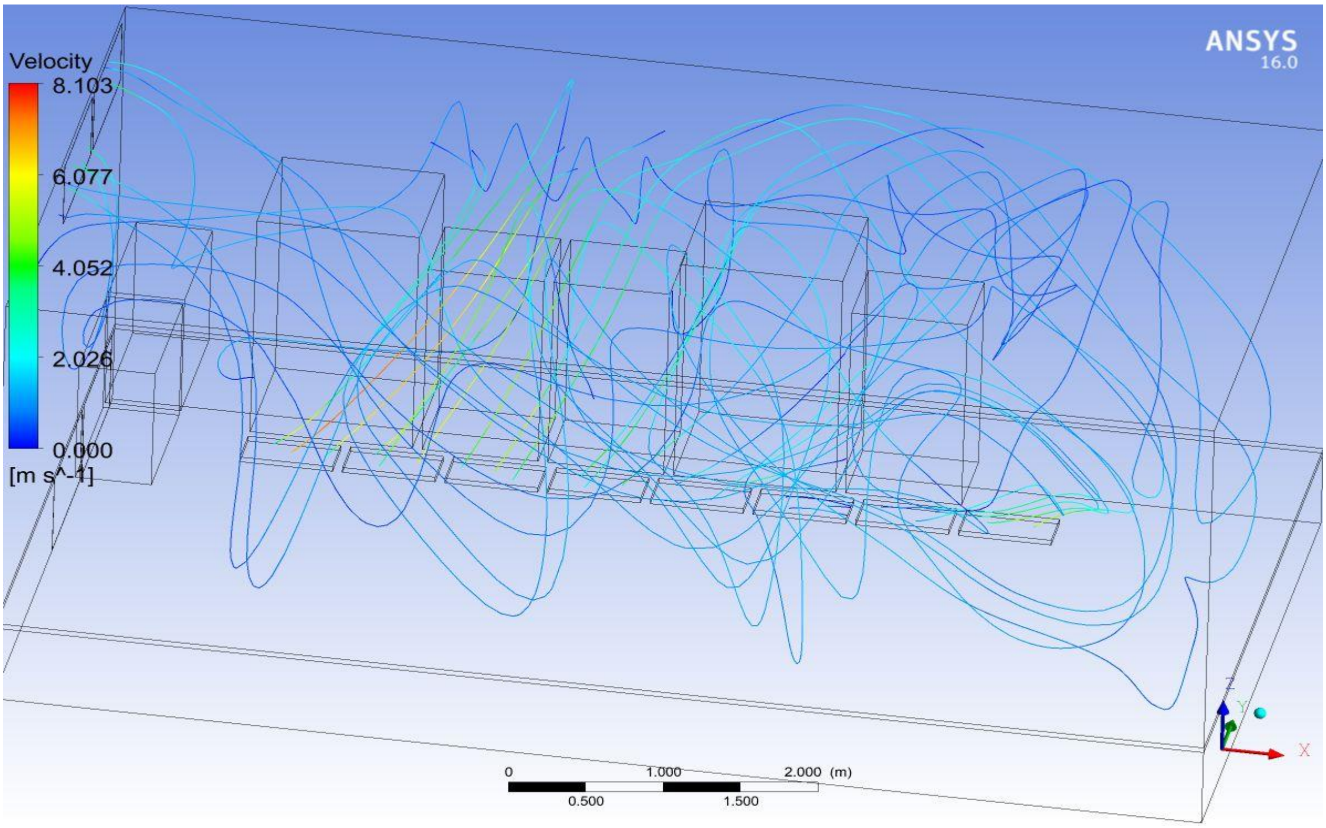


Fig:29

Fig:29 show velocity streamline at the vents of the tiles towards the server room space.

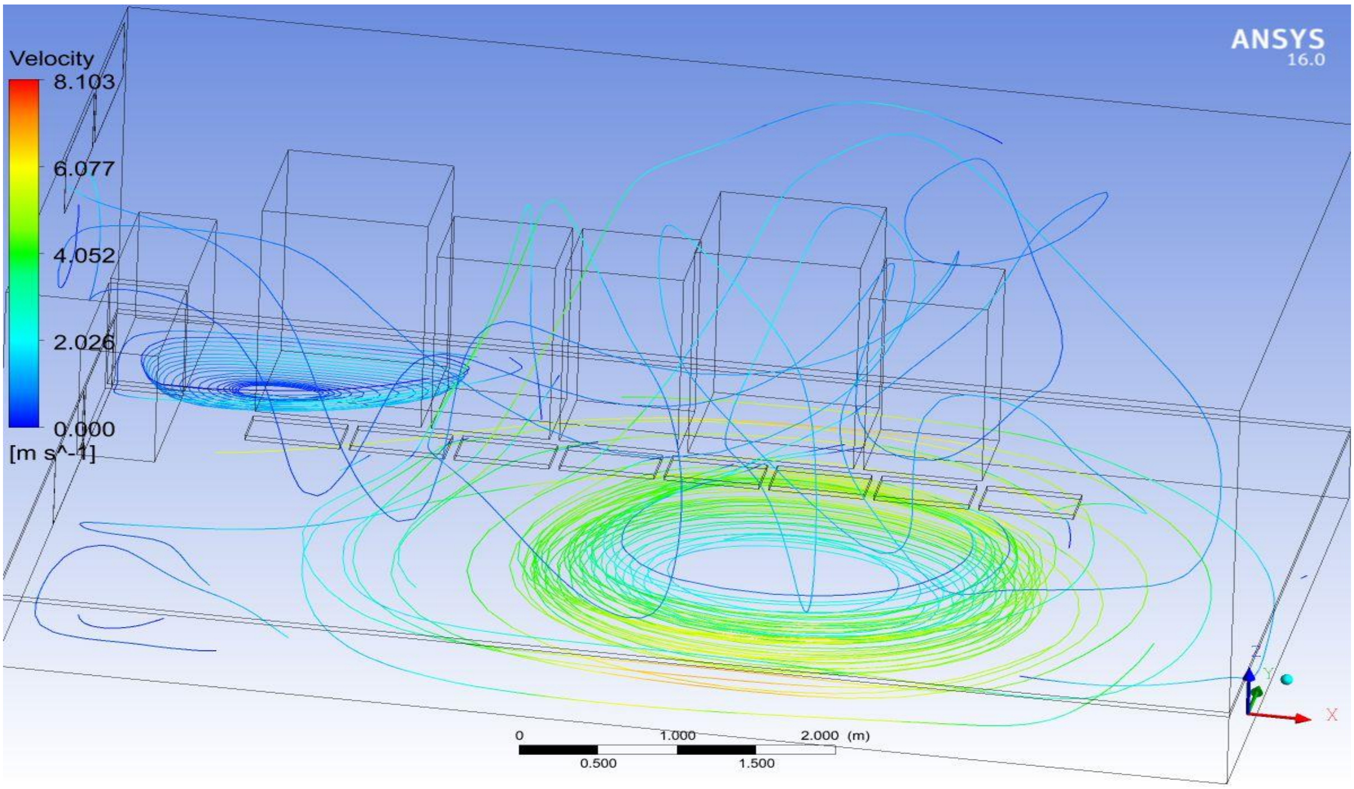


Fig:30

Fig:30 show velocity streamline at the raised floor space.

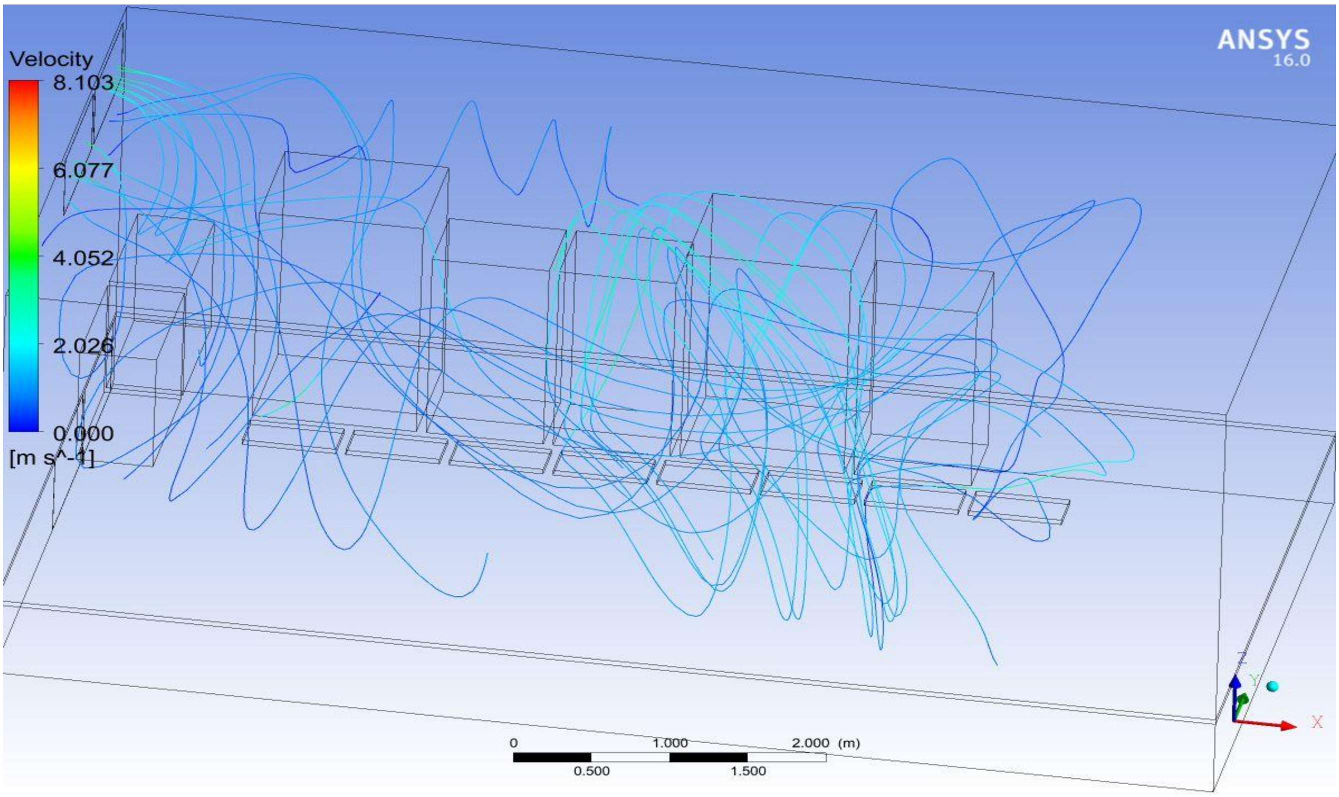


Fig:31

Fig:30 show velocity streamline at the server room space

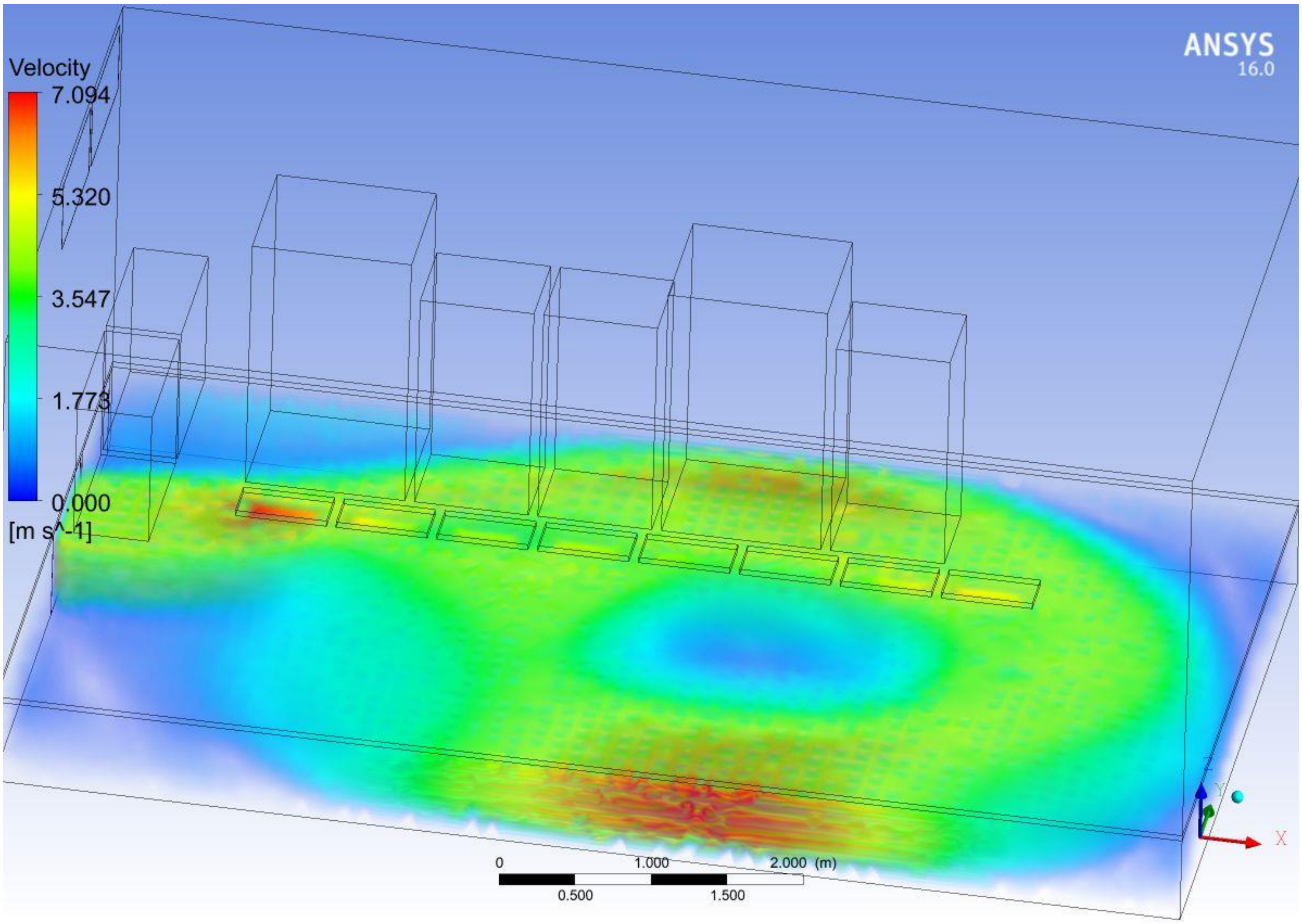


Fig:32

Fig:32 represents the velocity distribution of volume of air present below the raised floor space located below the raised floor.

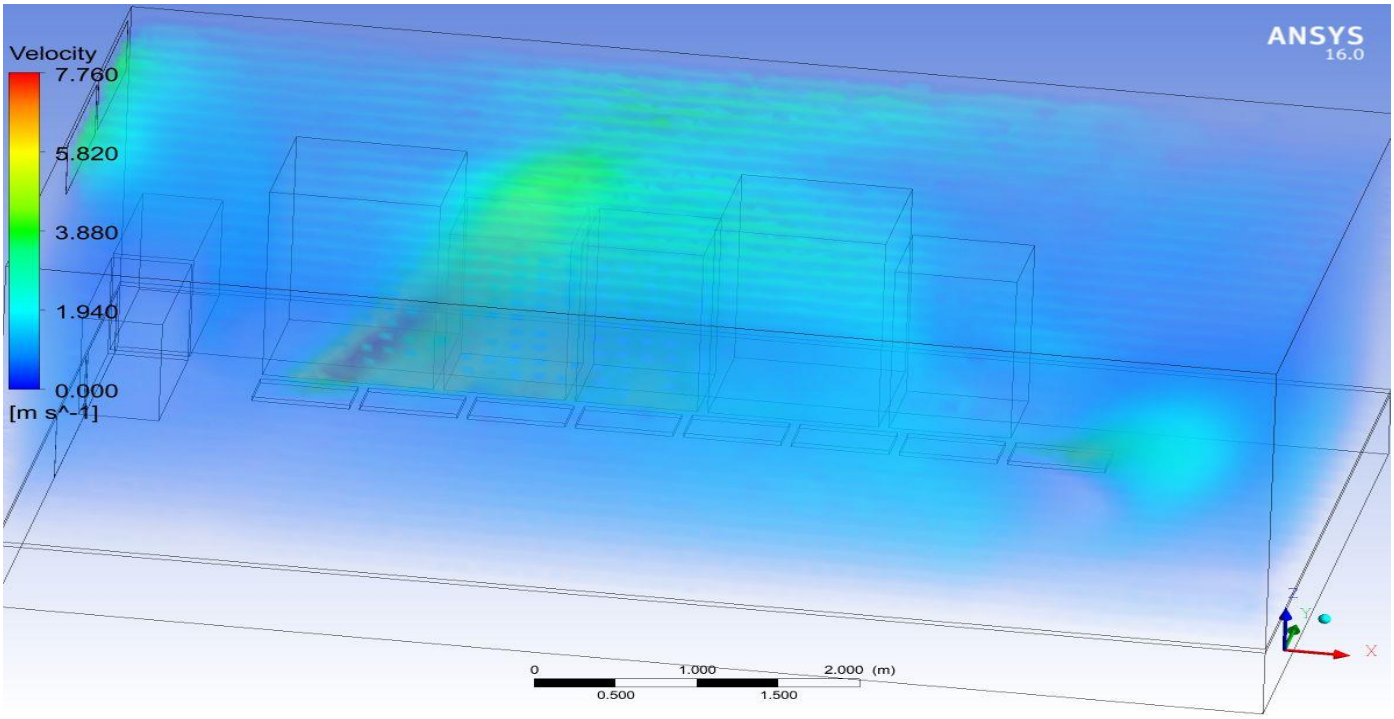


Fig:33

Fig:33 represents the velocity distribution of volume of air present at server room space located above the raised floor.

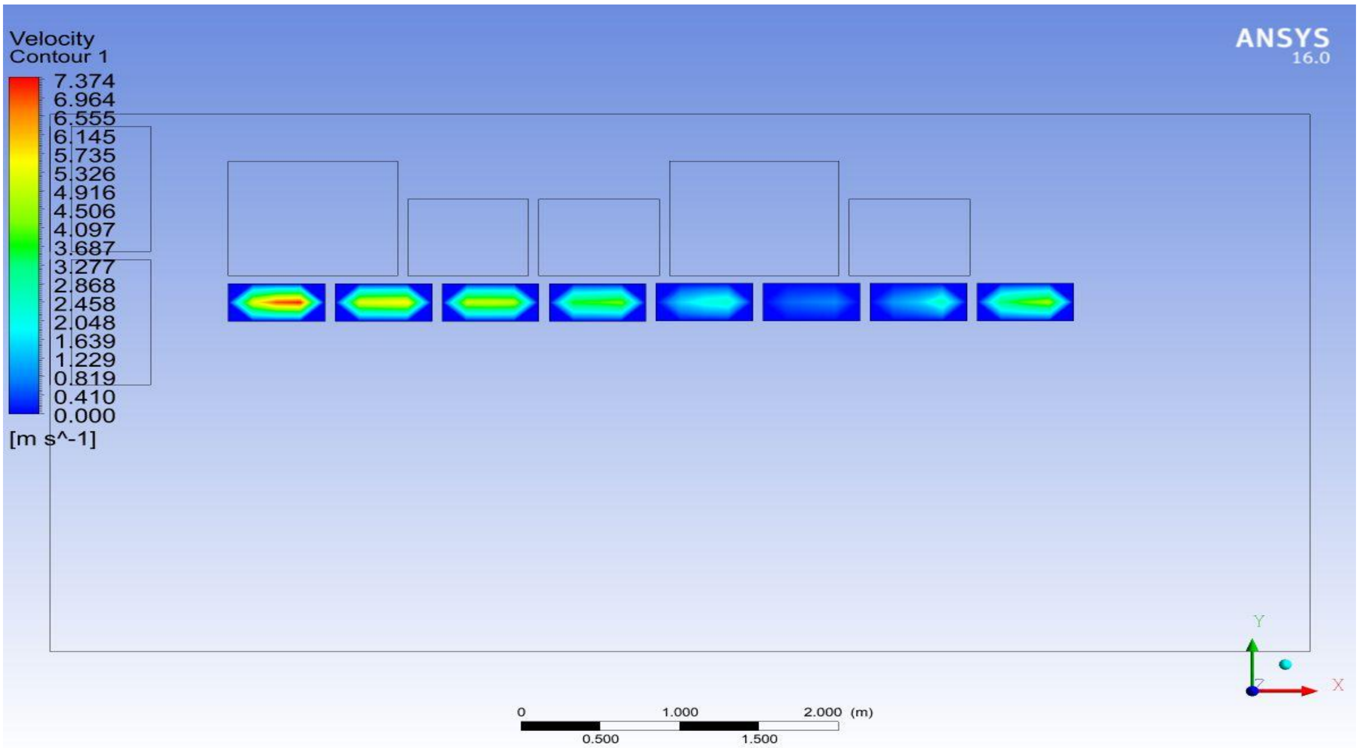


Fig:34

Fig:34 represents the velocity distribution of air at vents of tiles

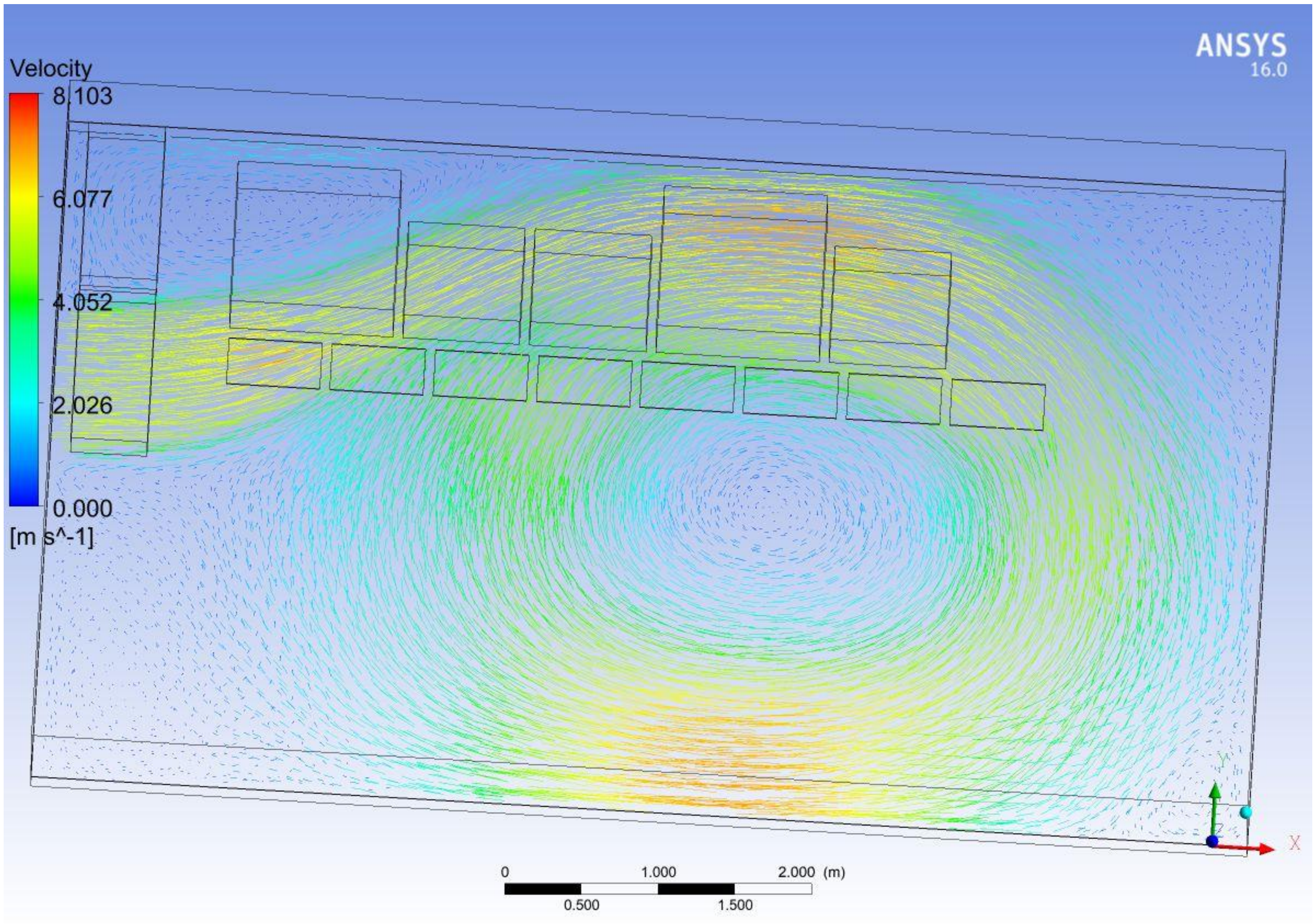


Fig:35

Fig:35 represents the velocity vector distribution of air present at the raised floor space located below the raised floor.

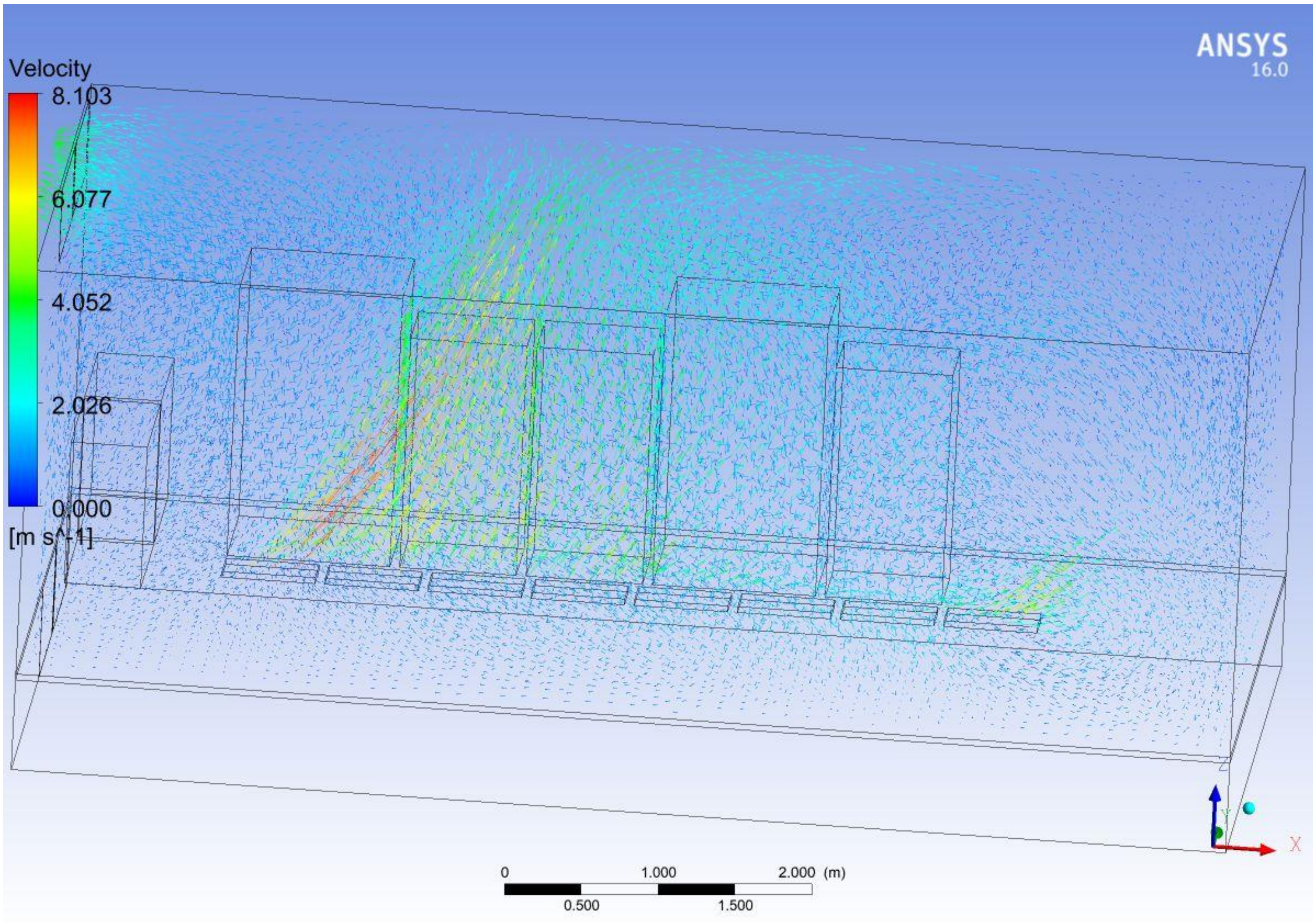


Fig:36

Fig:36 represents the velocity vector distribution of air present at the server room space located above the raised floor.

b) CASE II (Temperature of air at CRAC outlet is 282 K and heat generation from each server rack is 1500 W/ cum.)

i) <u>Temperature Contour:</u>

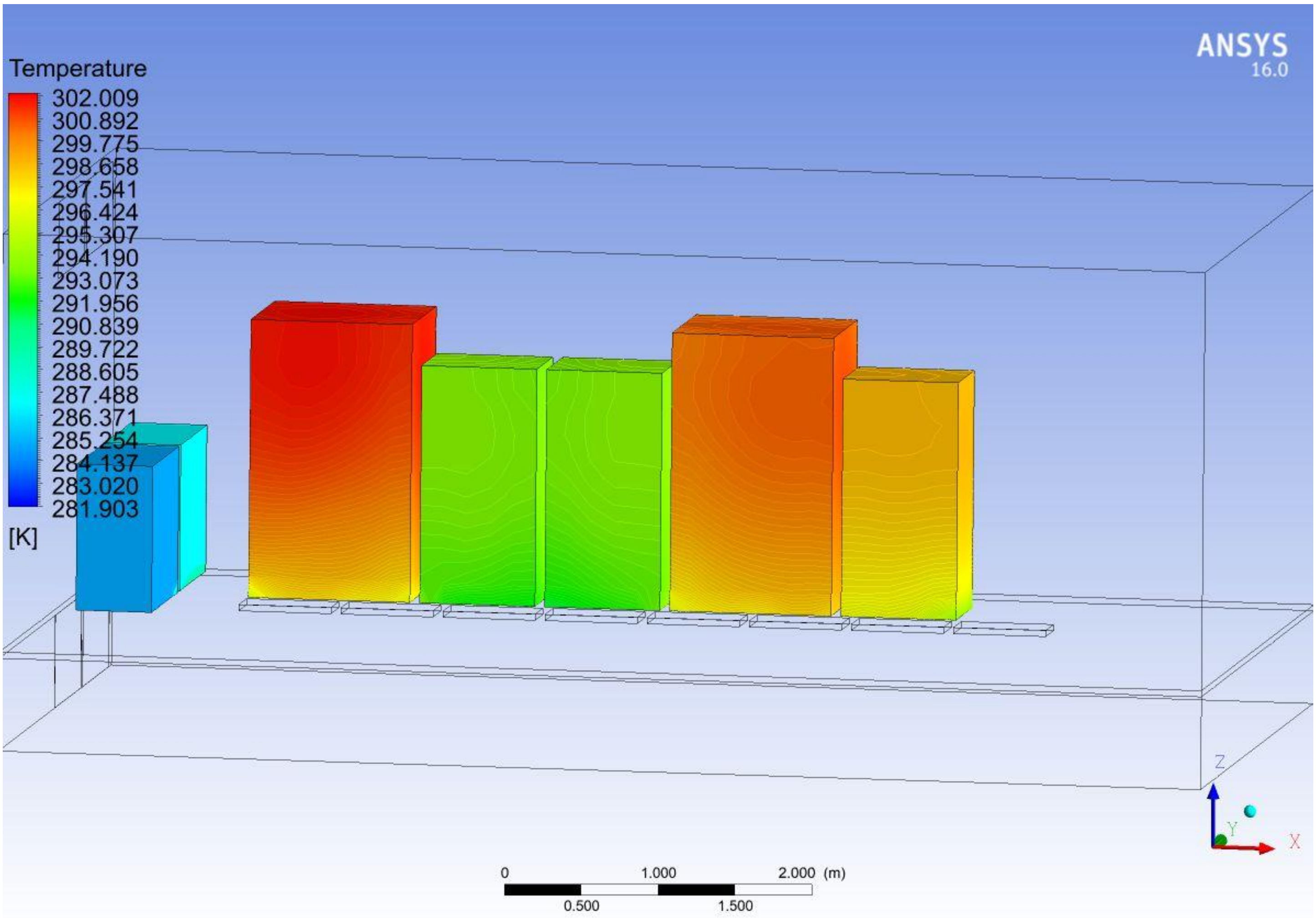


Fig:37

Fig:37 represents the temperature distribution of five server racks and two crac units. The temperature distribution of crac and server racks are clearly visible from the temperature colour coding mentioned above.

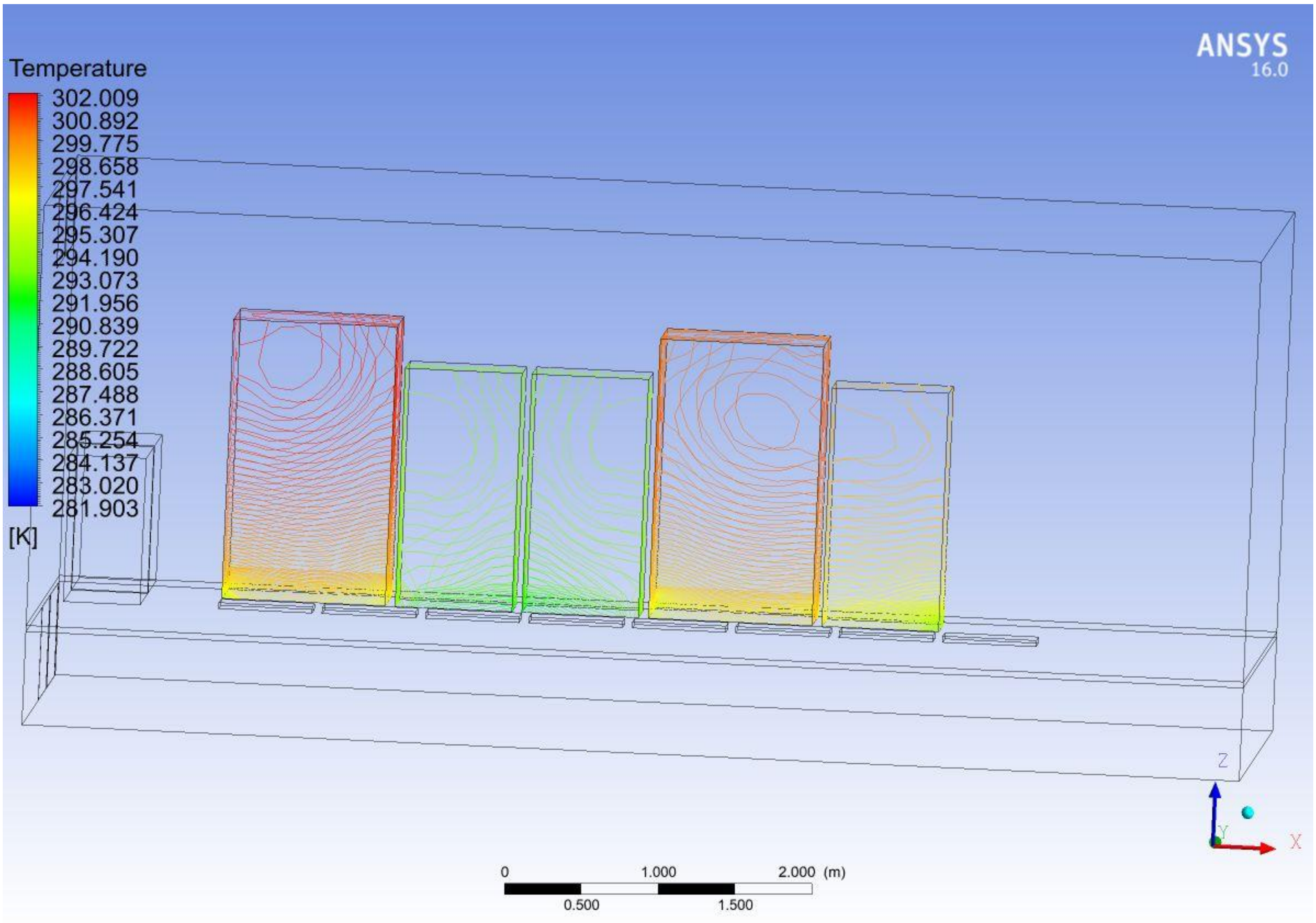


Fig:38

Fig:38 represents the temperature isotherms distribution of five server racks. The temperature isotherms distribution of server racks are clearly visible from the temperature colour coding mentioned above.

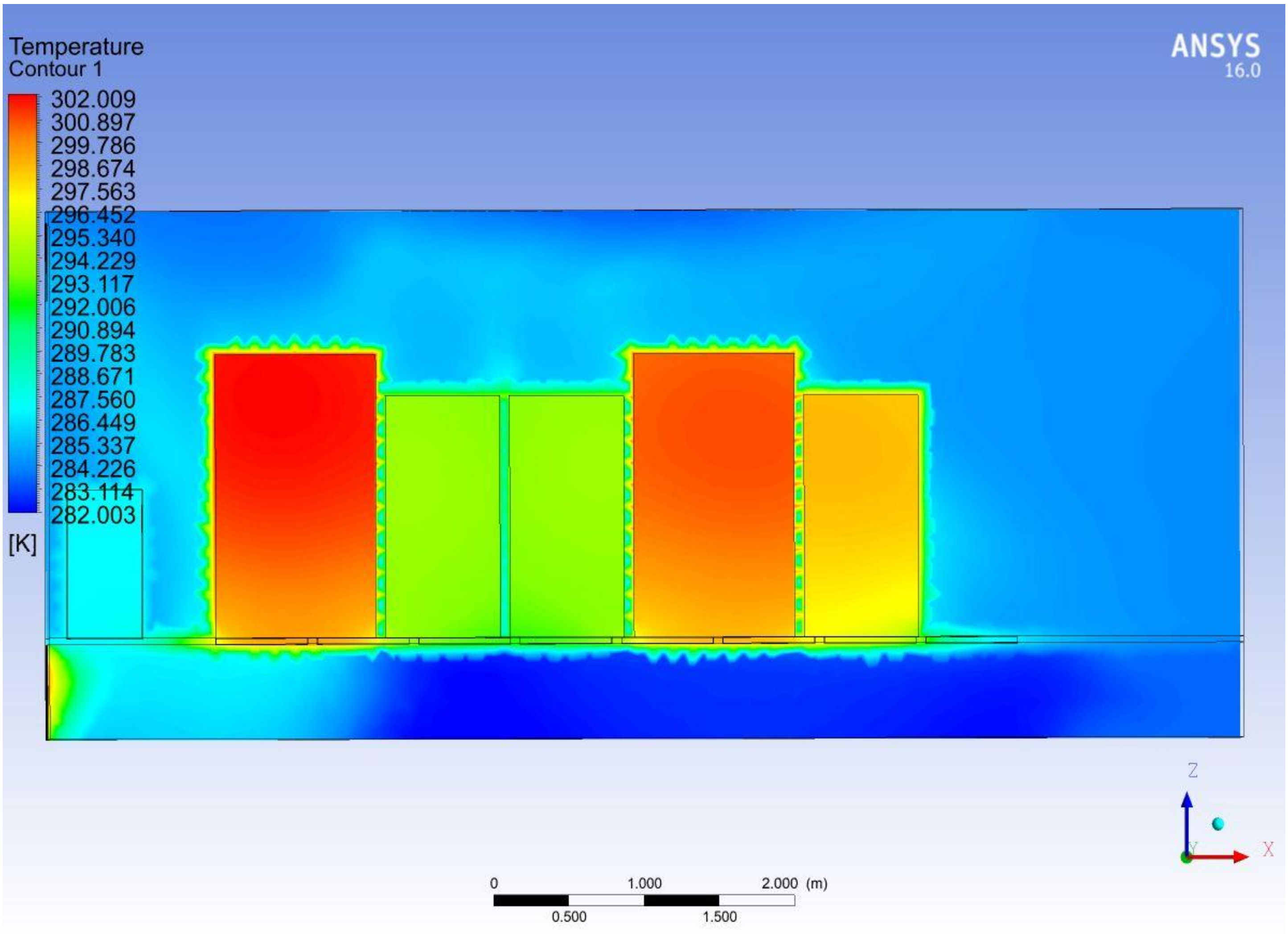


Fig:39

Fig:39 represents the temperature distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

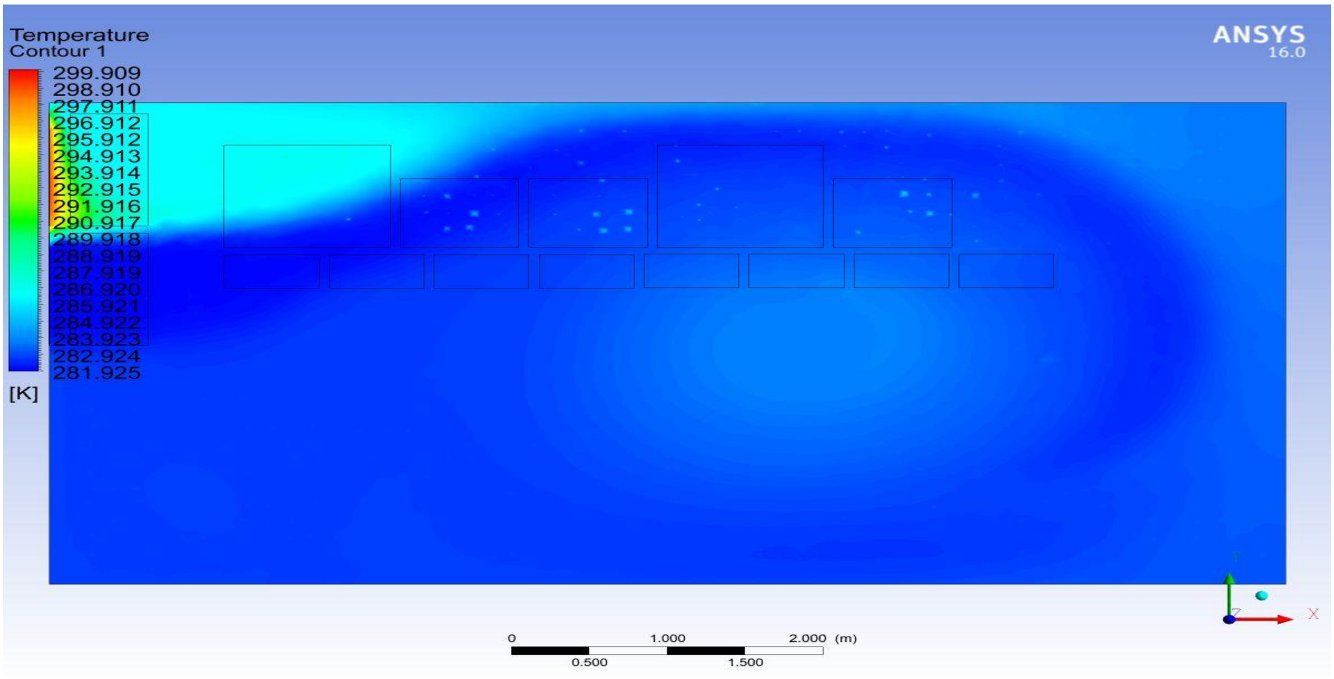


Fig:40

Fig:40 represents the temperature distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

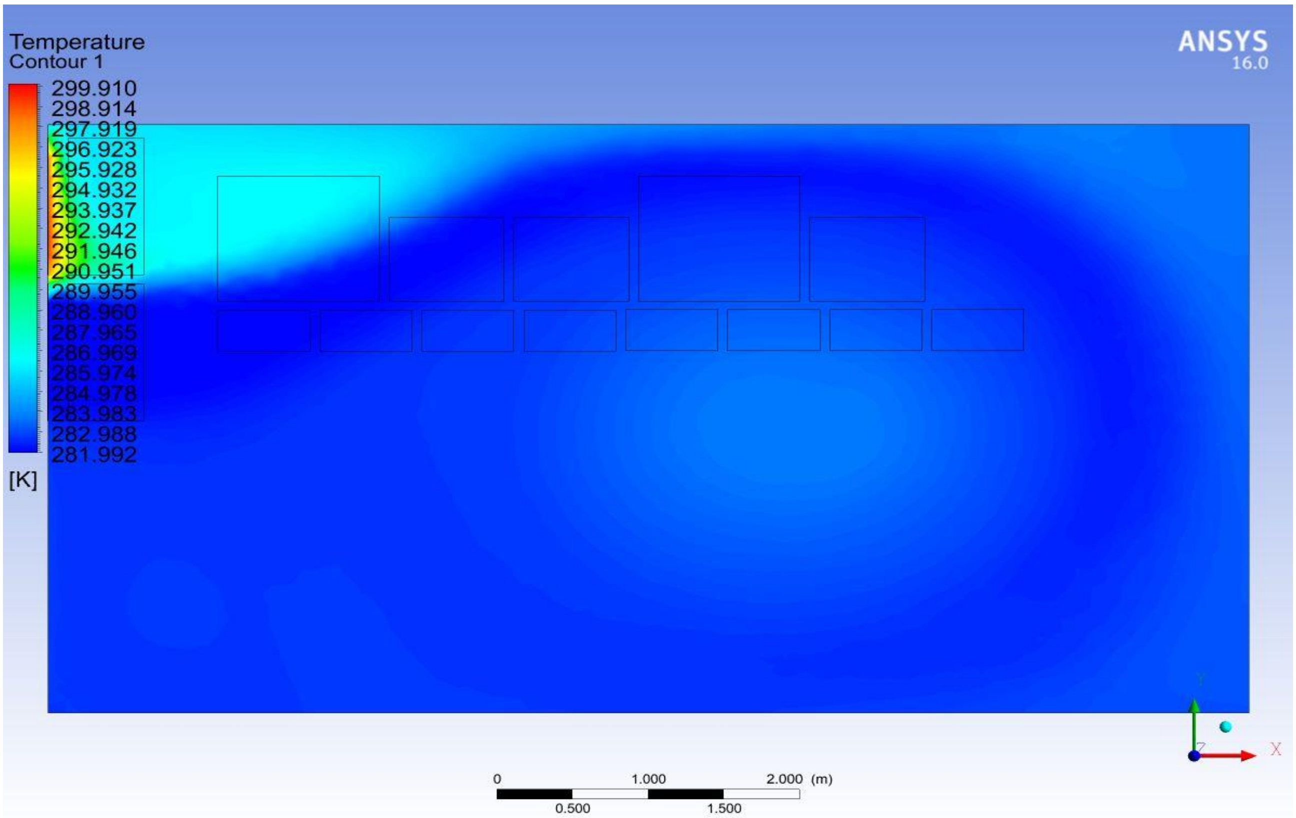


Fig:41

Fig:41 represents the temperature distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

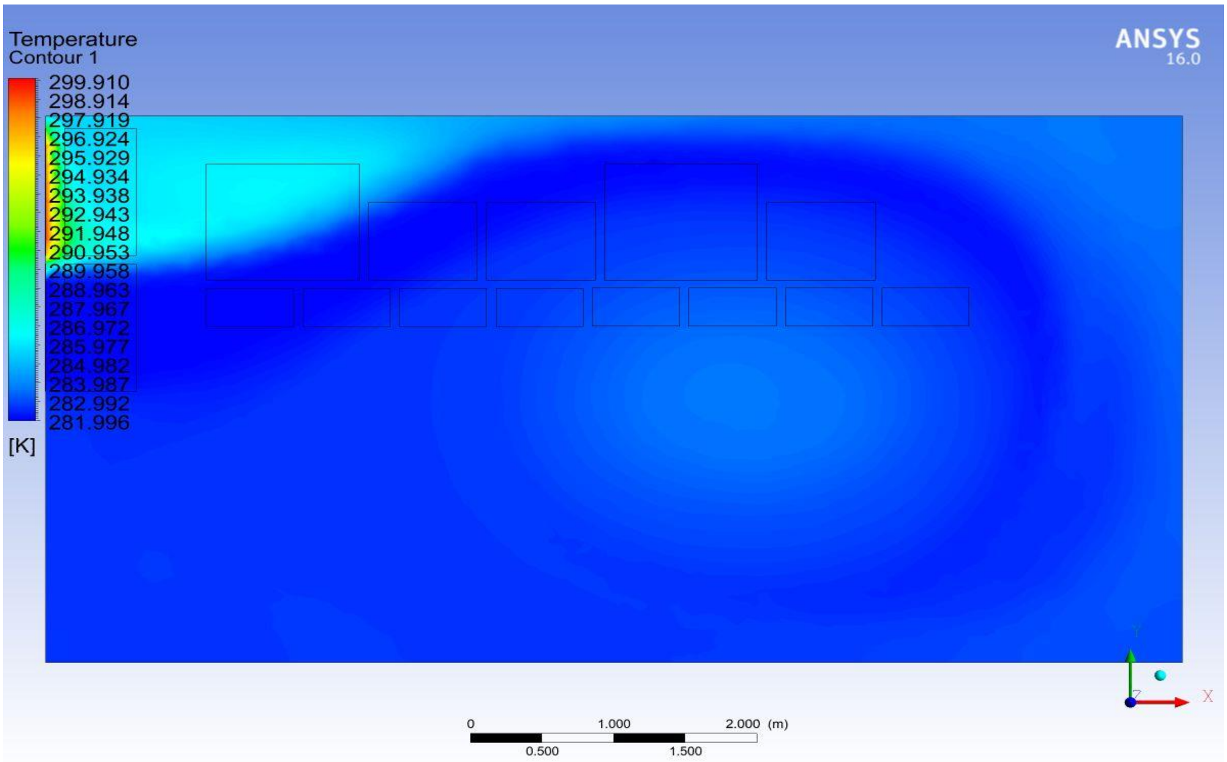


Fig:42

Fig:42 represents the temperature distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

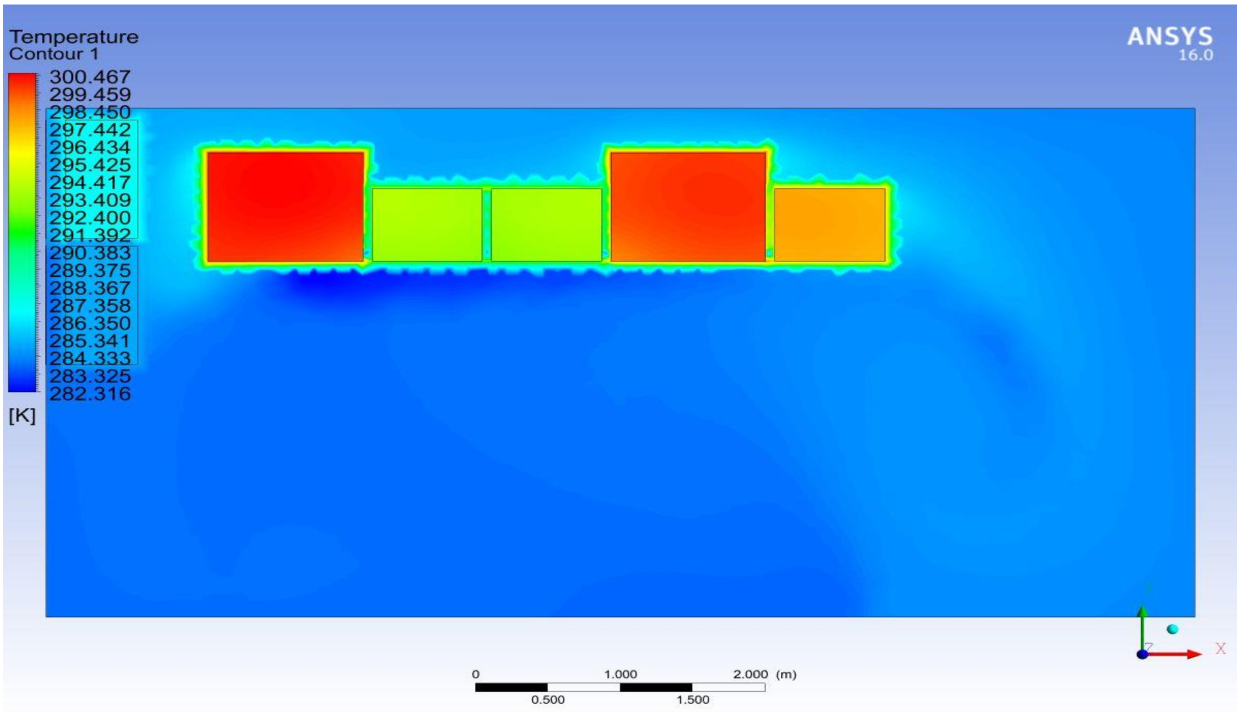


Fig:43

Fig:43 represents the temperature distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

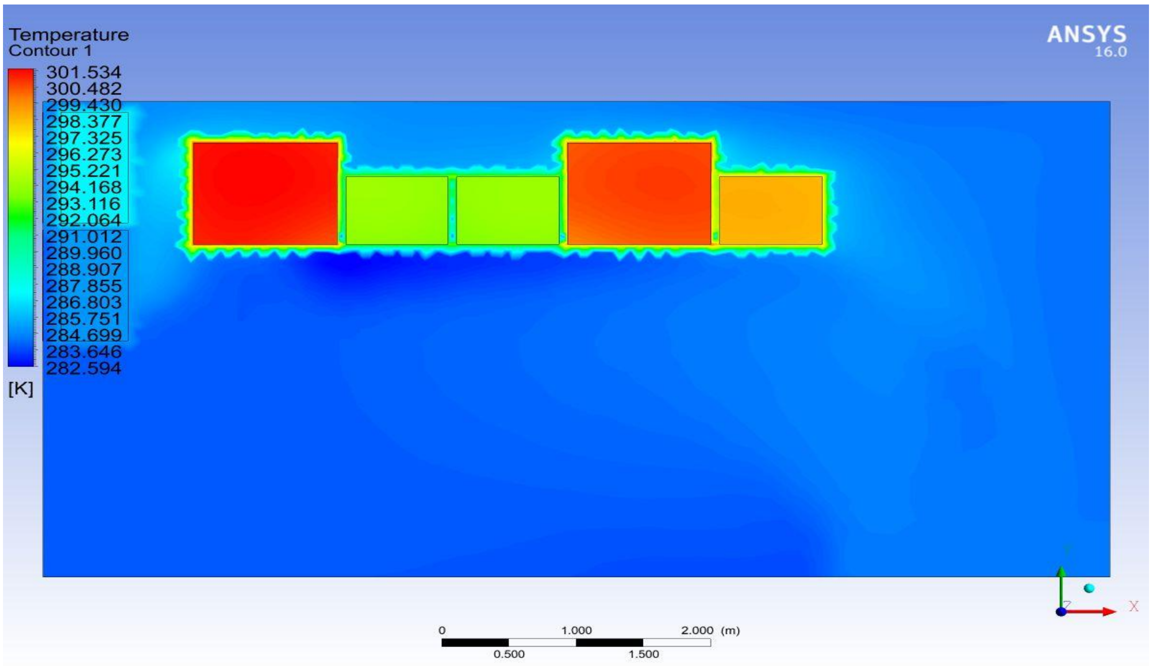


Fig:44

Fig:44 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

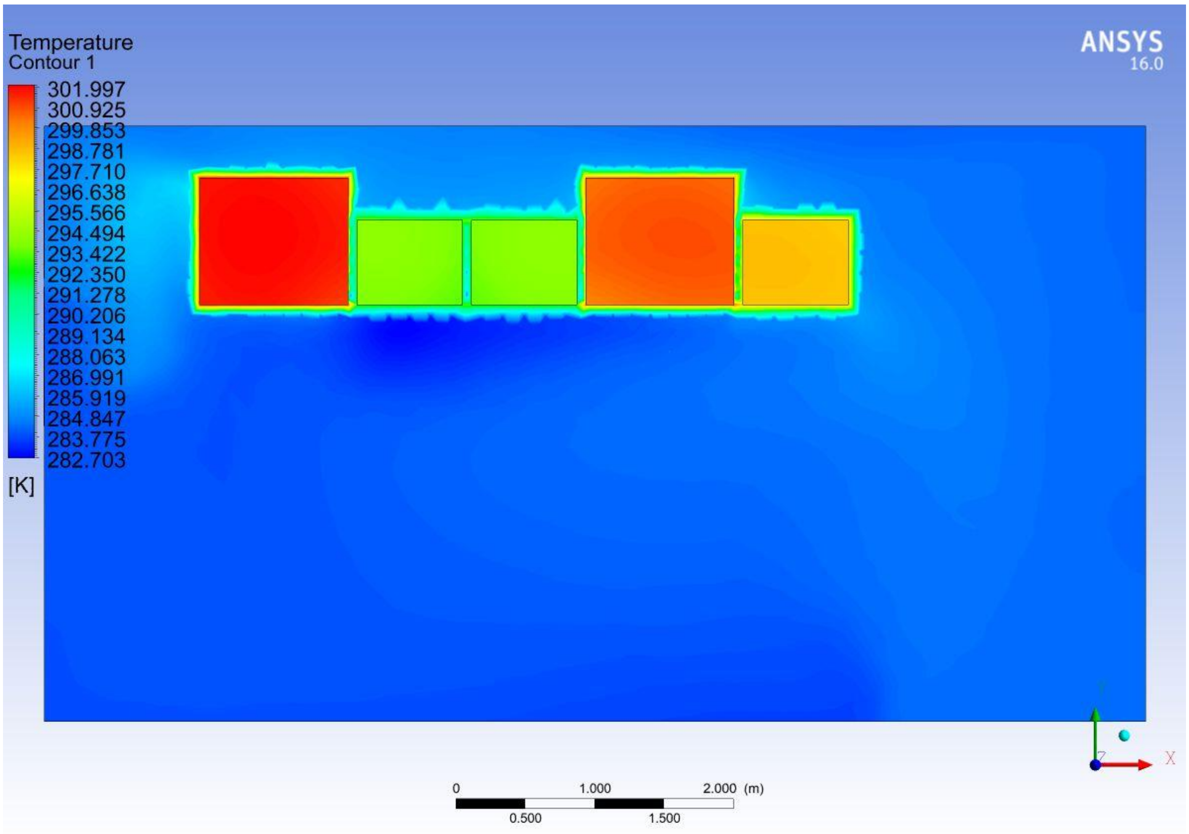


Fig:45

Fig:44 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

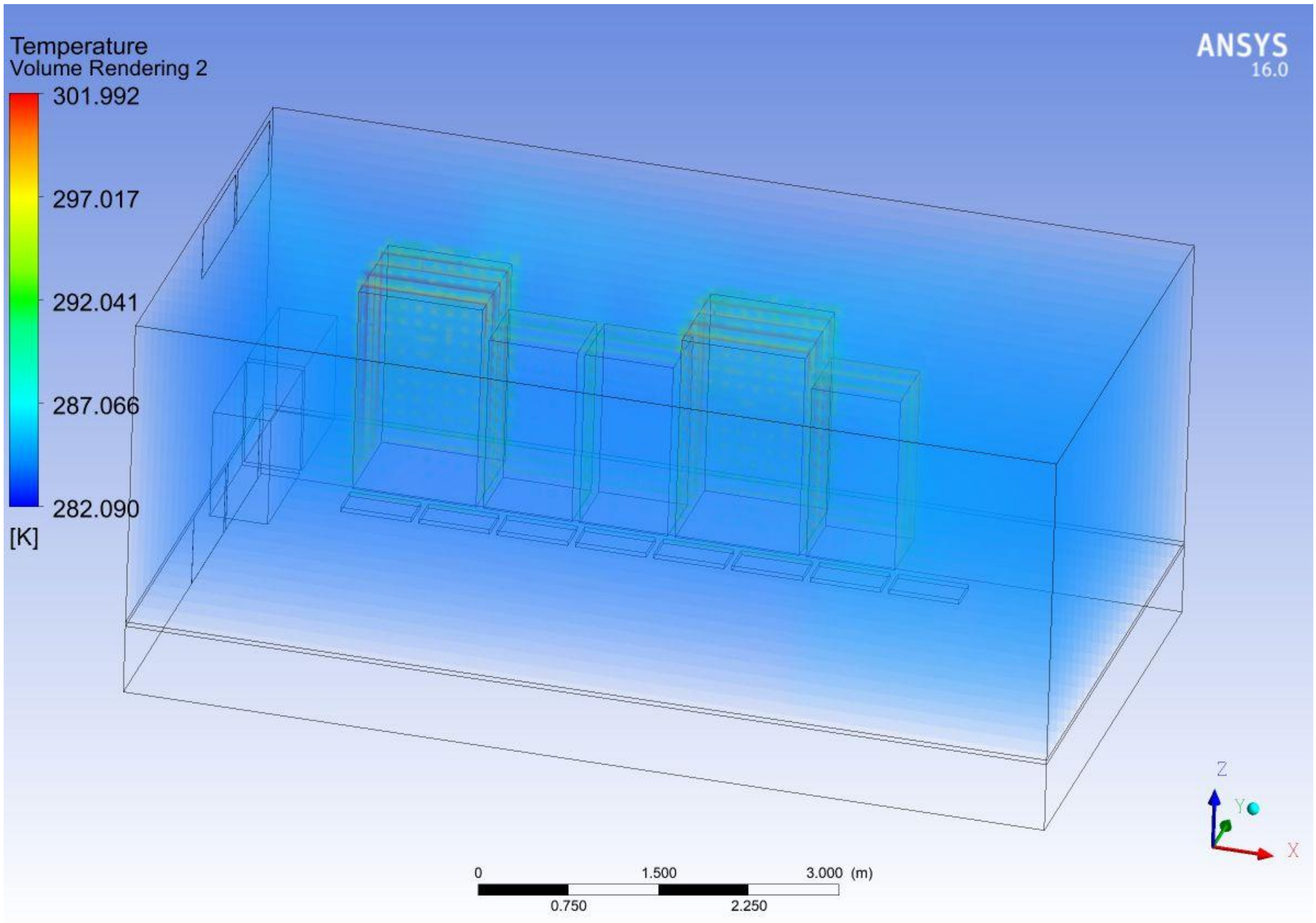


Fig:46

Fig:46 represents the temperature distribution of volume of air present in the server room space located above the raised floor.

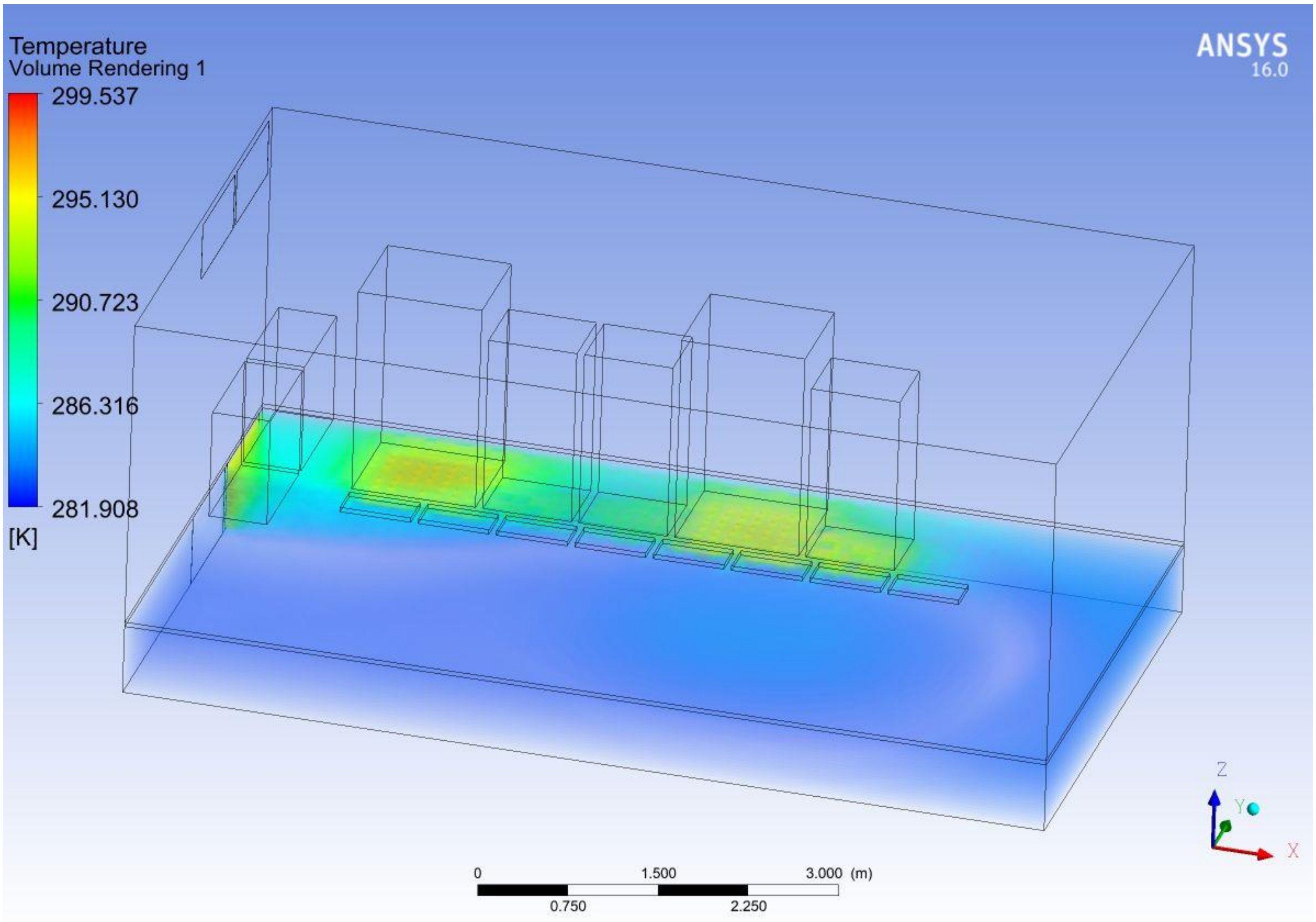


Fig:47

Fig:47 represents the temperature distribution of volume of air present in the server room space located below the raised floor.

ii) Pressure Contour:

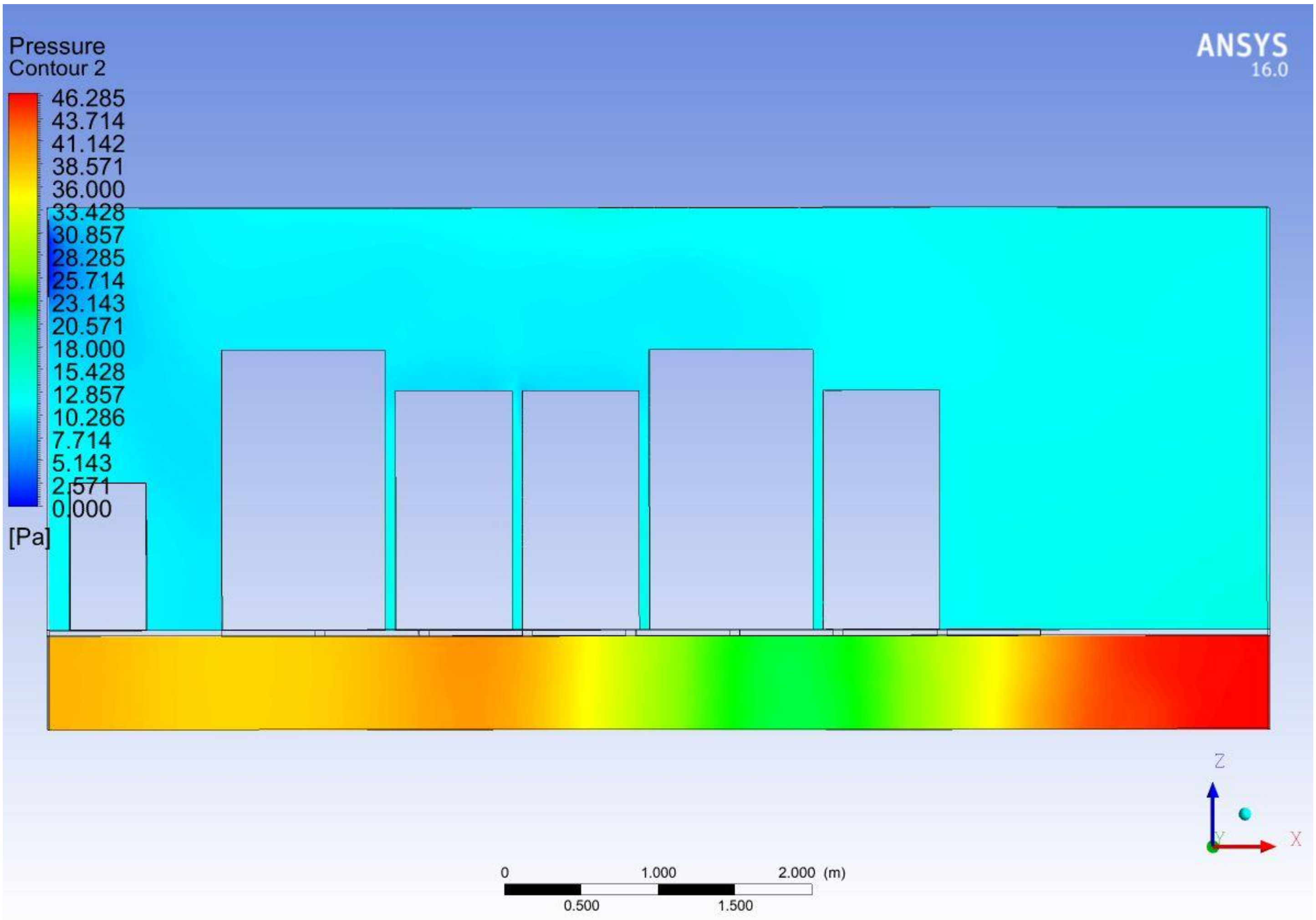


Fig:48

Fig:48 represents the pressure distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

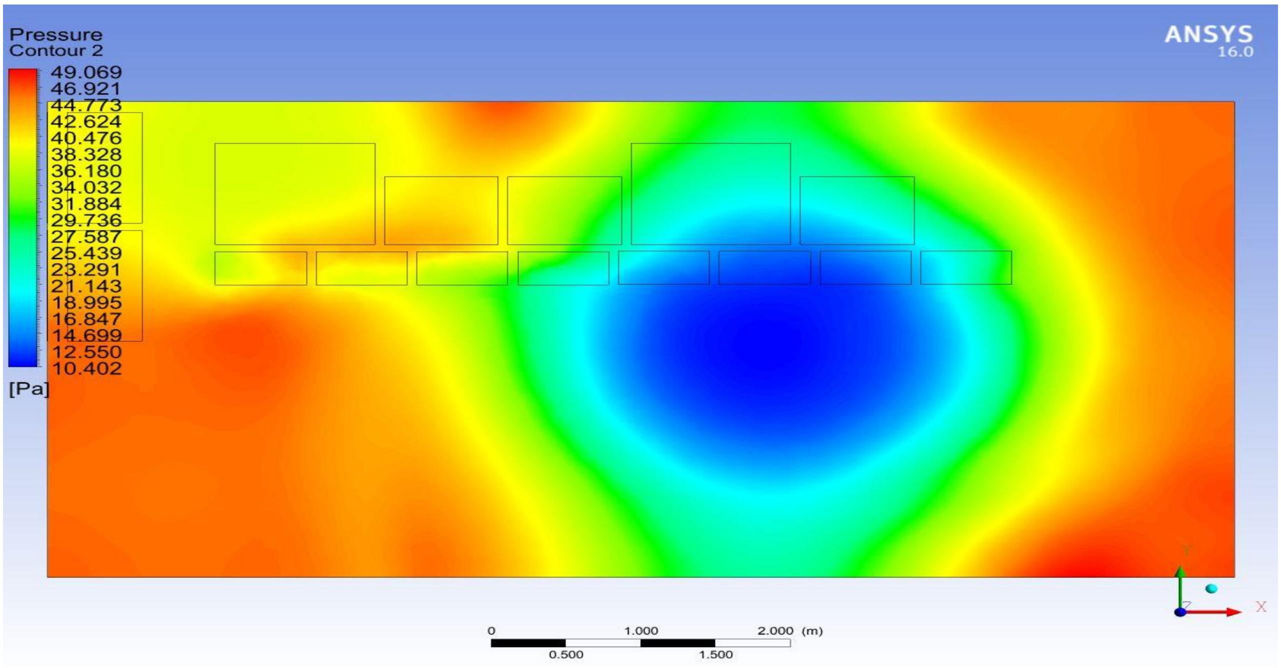


Fig:49

Fig:49 represents the pressure distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

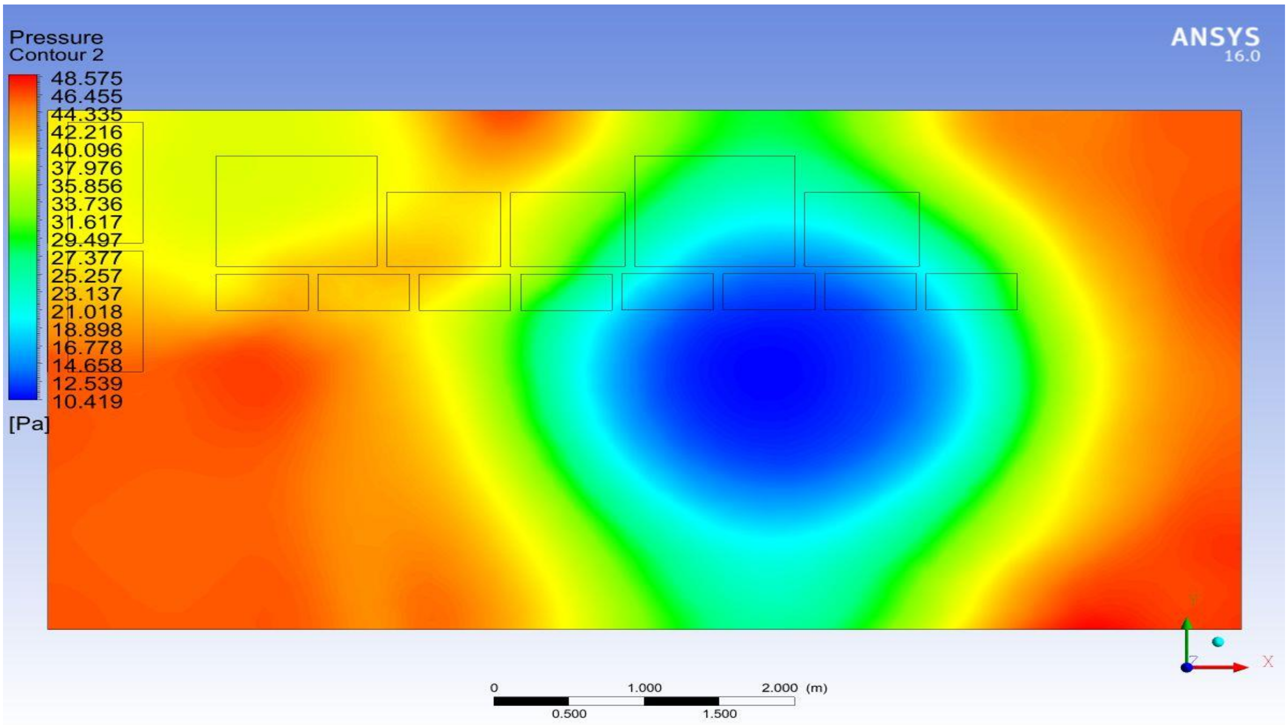


Fig:50

Fig:50 represents the pressure distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

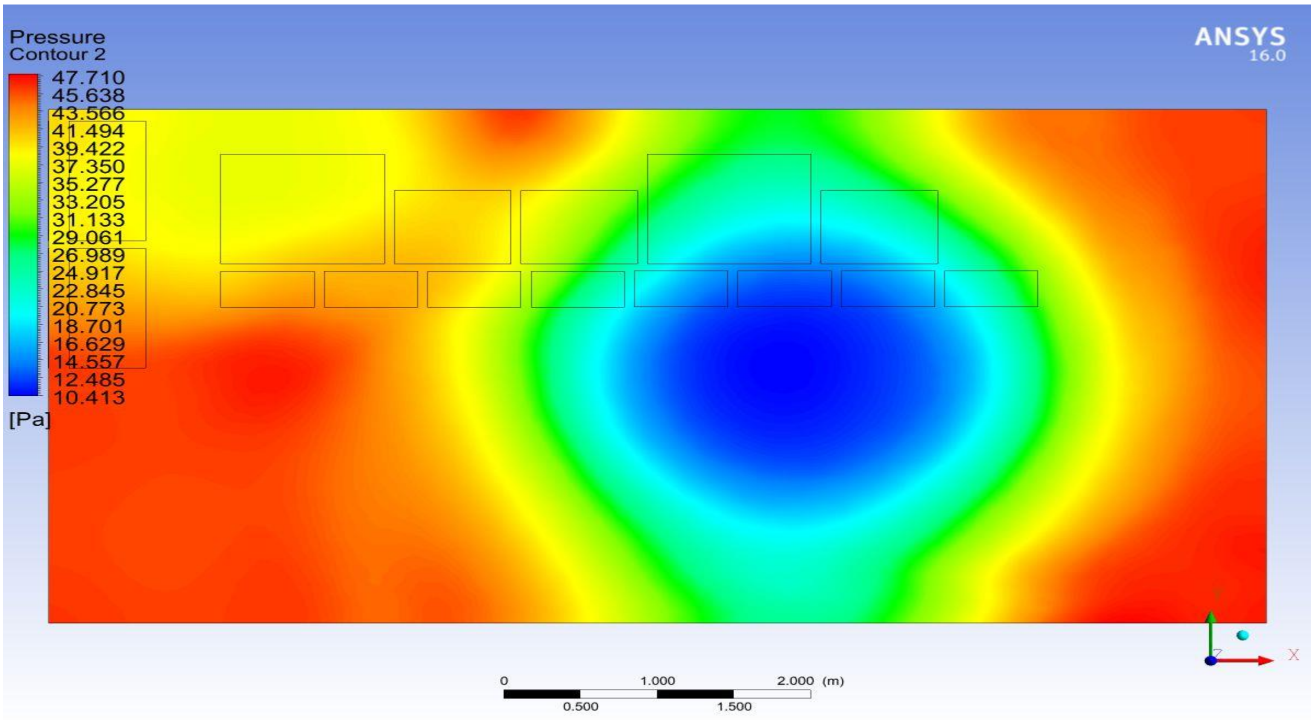


Fig:51

Fig:51 represents the pressure distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

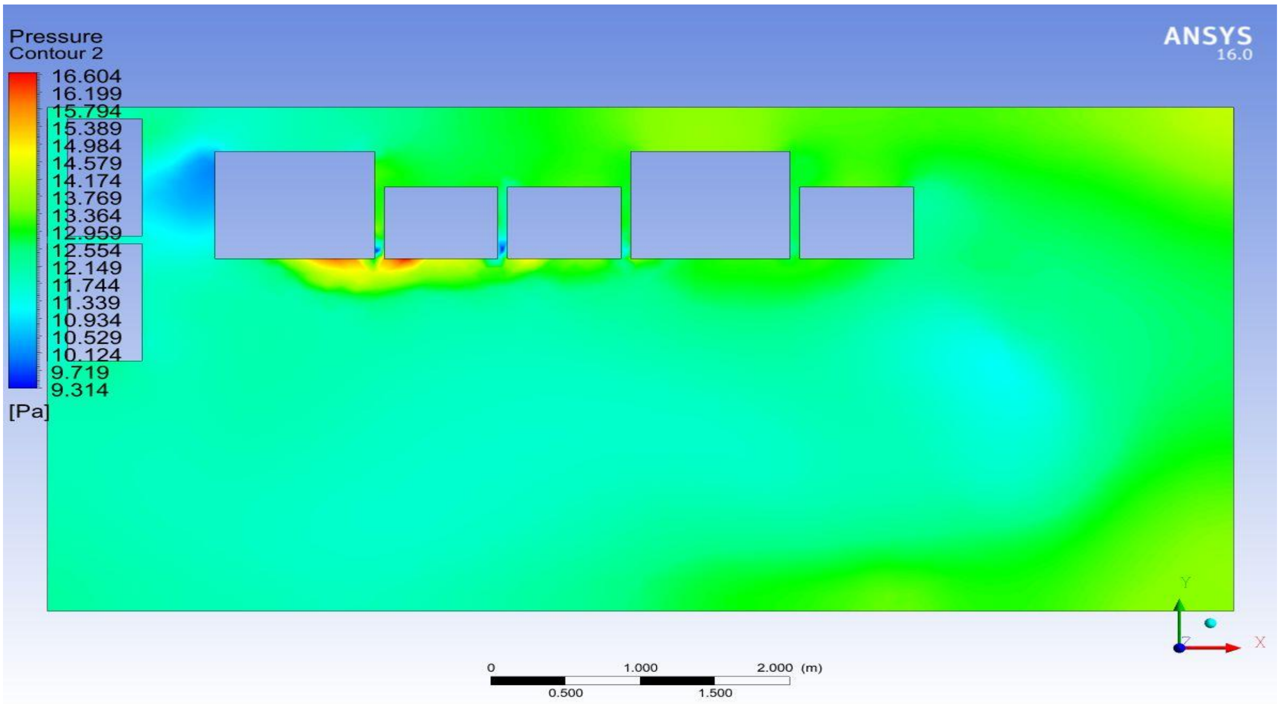


Fig:52

Fig:52 represents the pressure distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

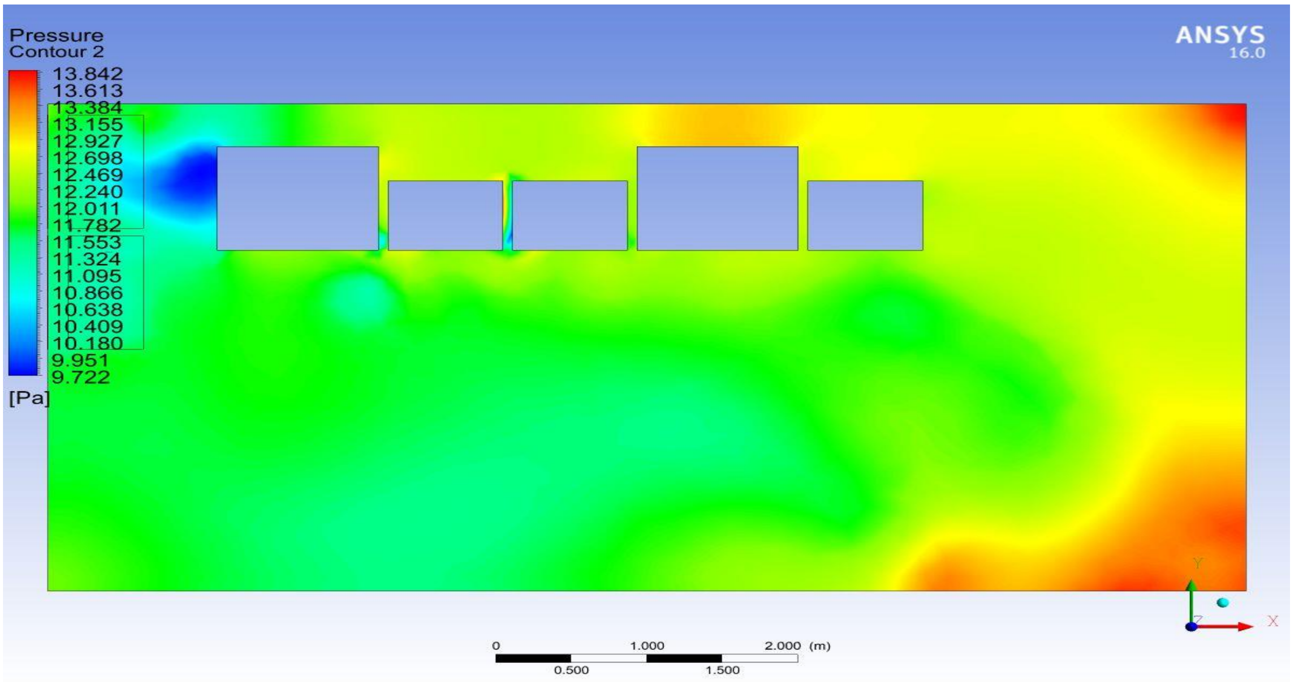


Fig:53

Fig:53 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

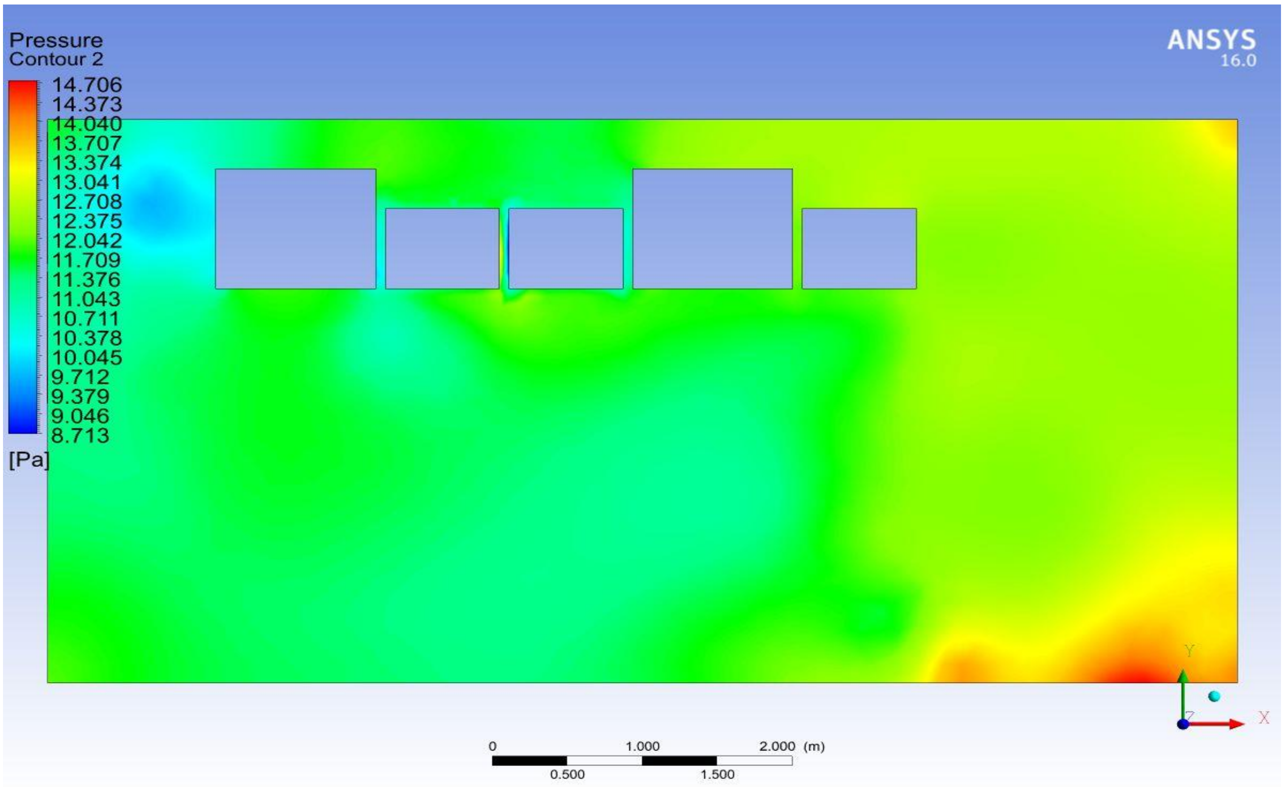


Fig:54

Fig:54 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

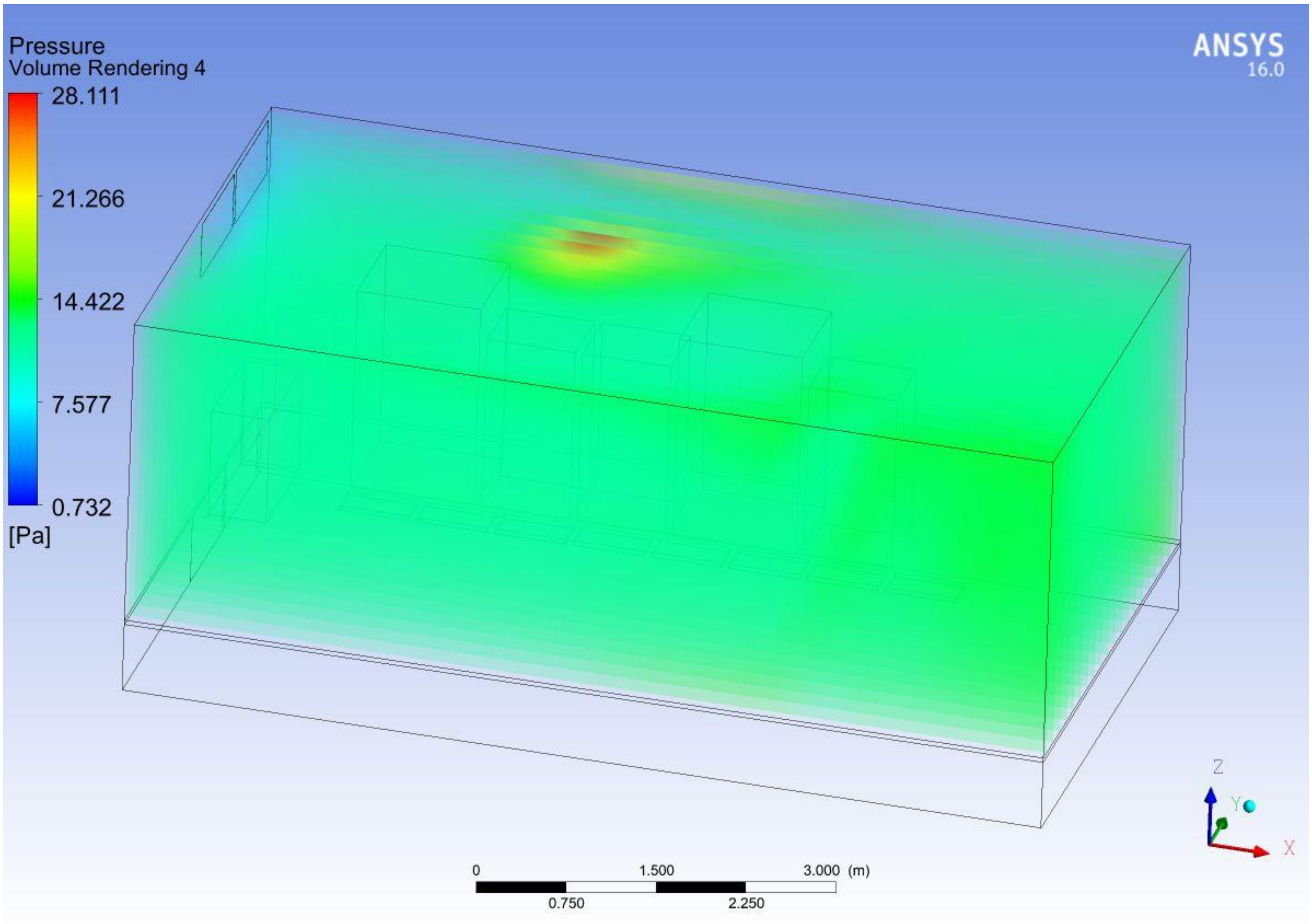


Fig:55

Fig:55 represents the pressure distribution of volume of air present in the server room space located above the raised floor.

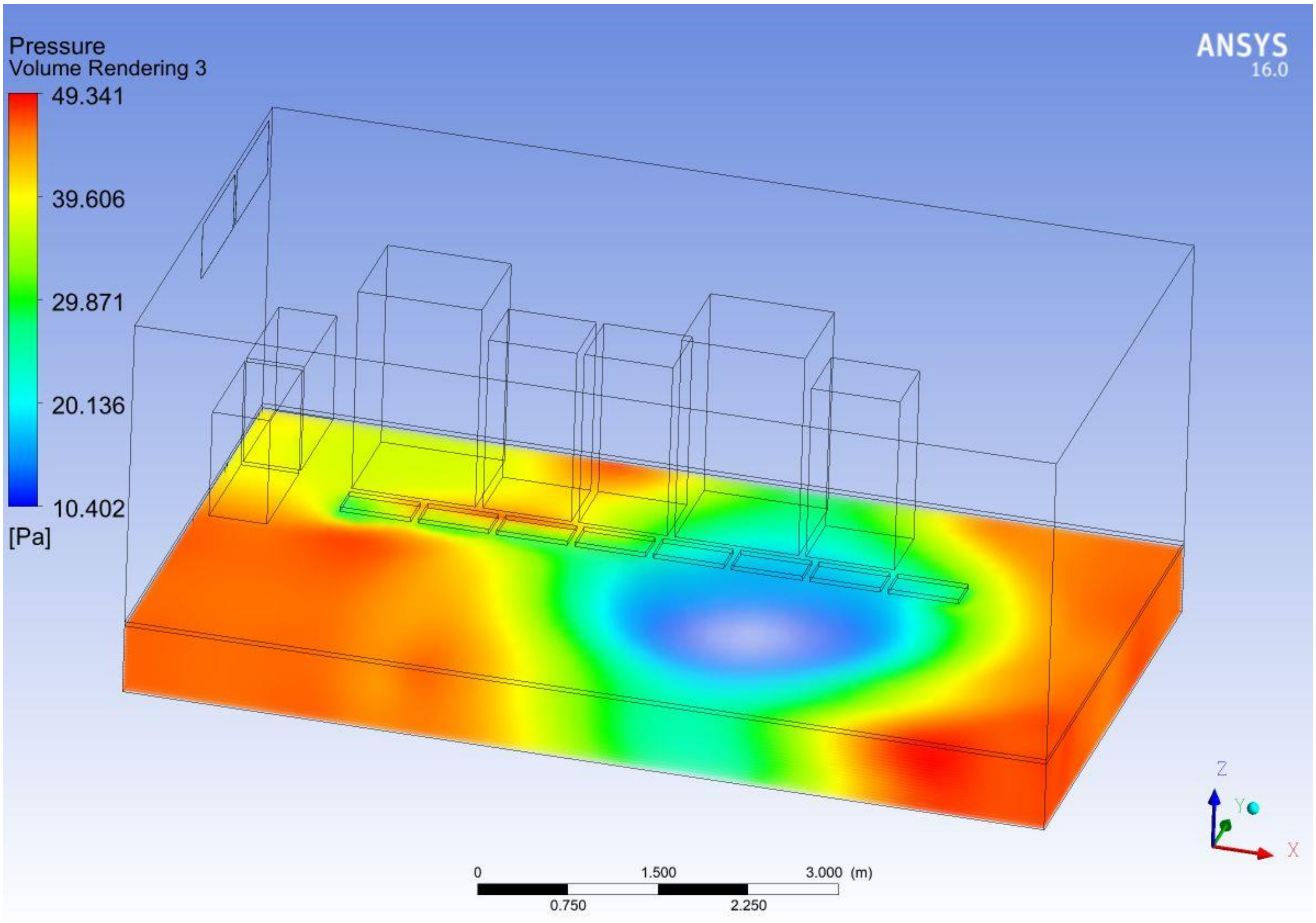


Fig:56

Fig:56 represents the pressure distribution of volume of air present in the server room space located below the raised floor.

iii) Velocity Contour:

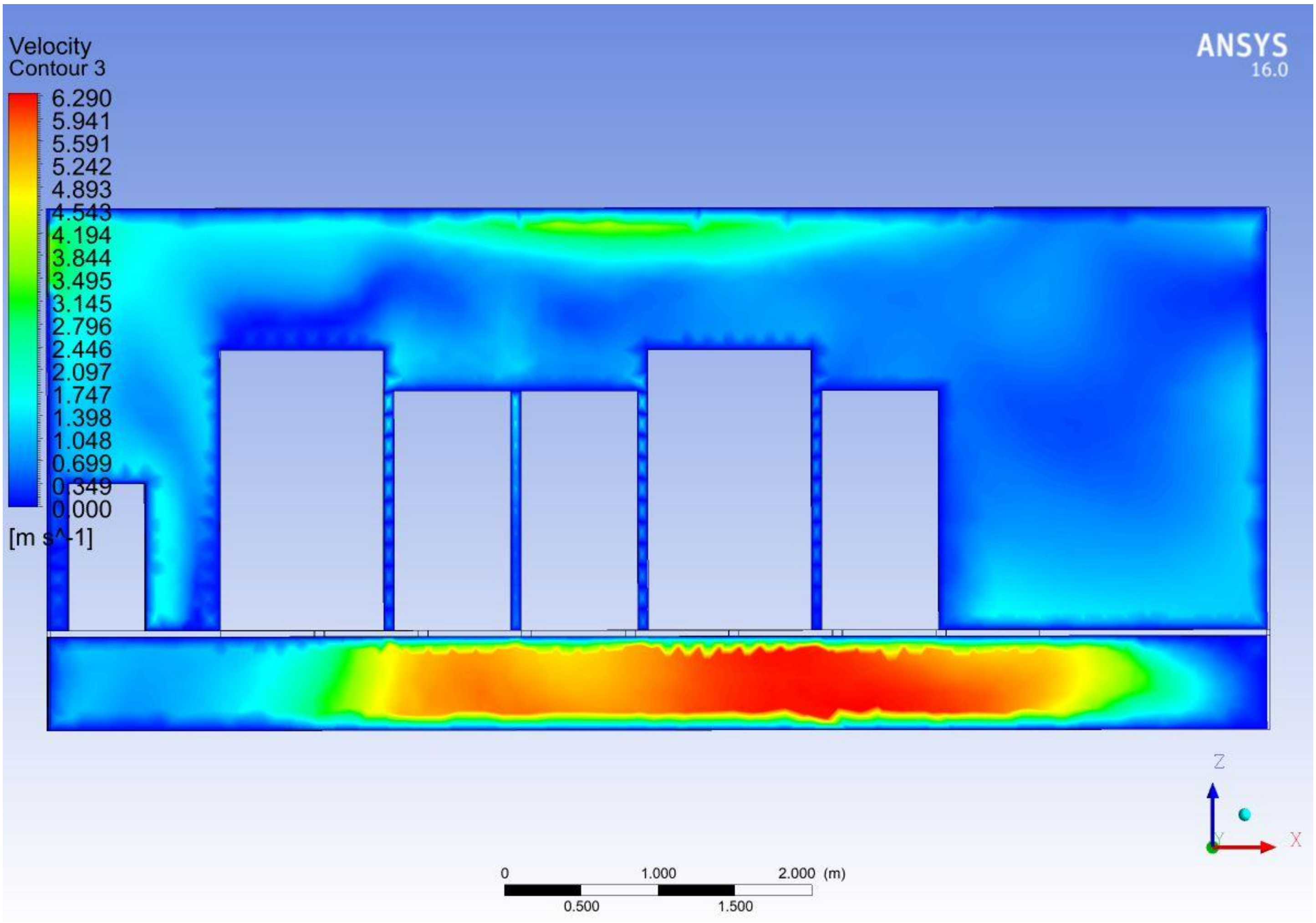


Fig:57

Fig:57 represents the velocity distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

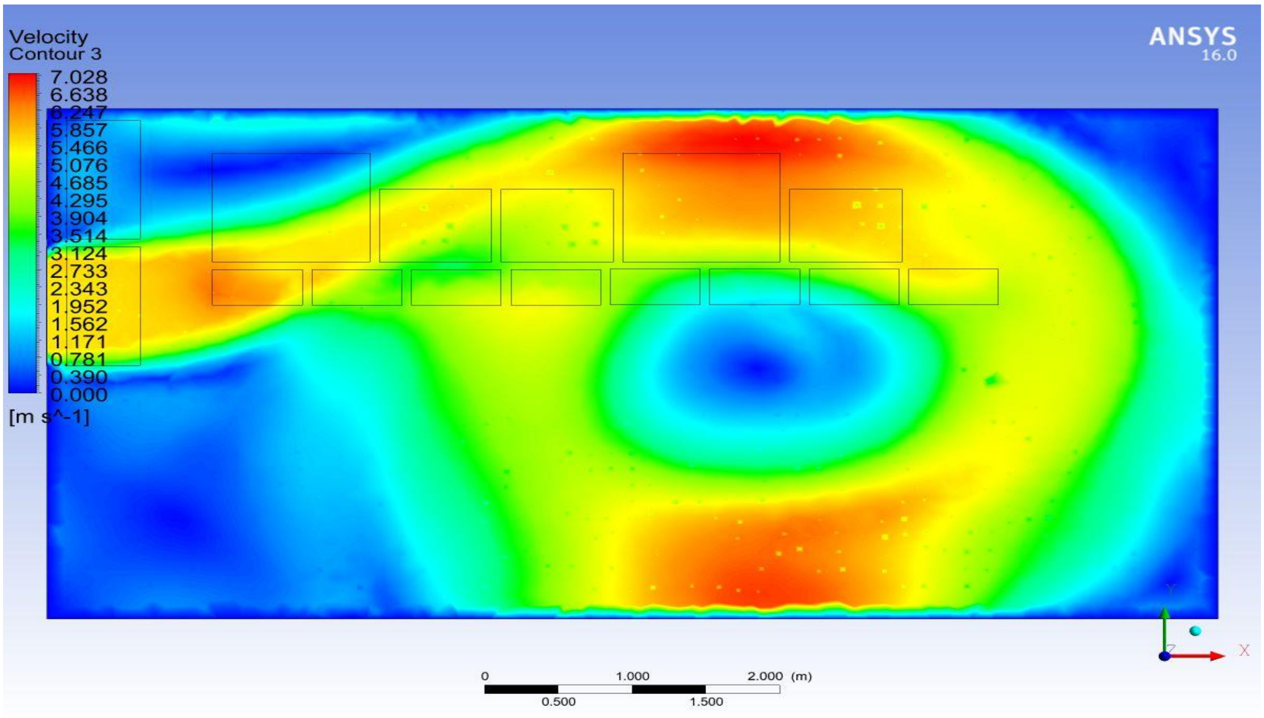


Fig:58

Fig:58 represents the velocity distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

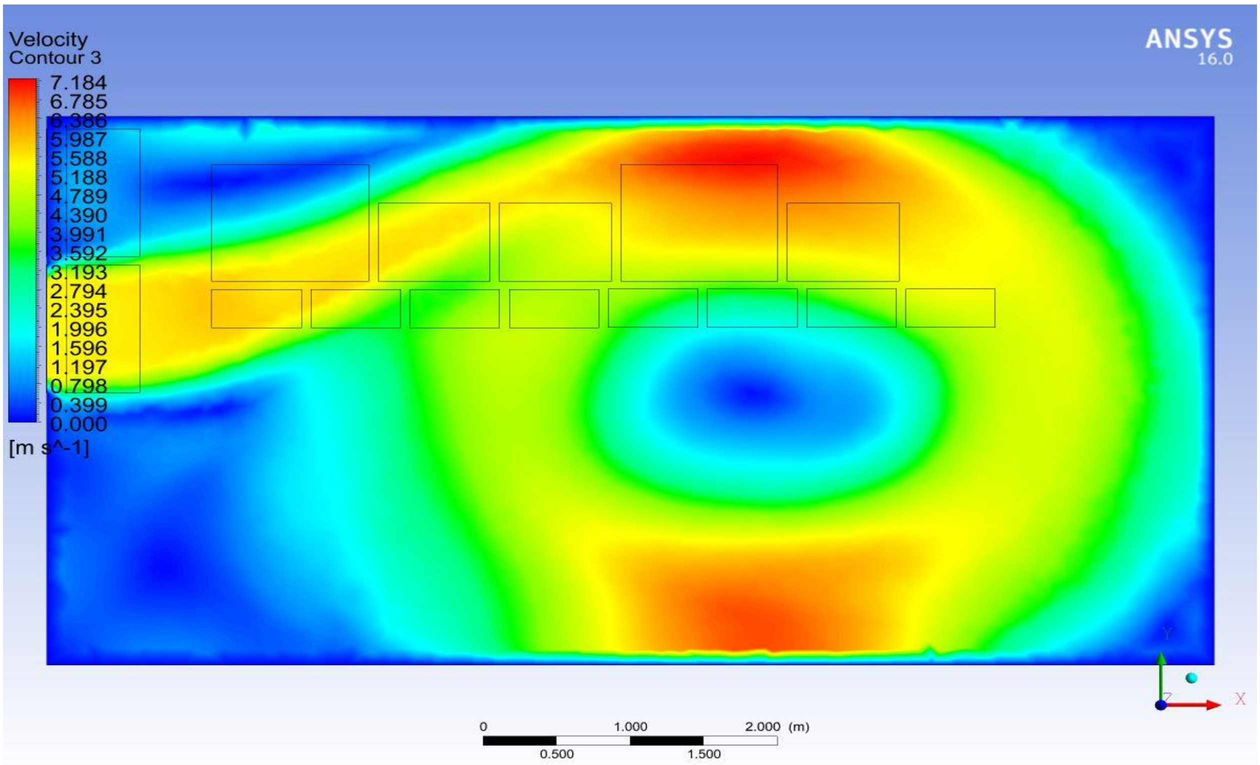


Fig:59

Fig:59 represents the velocity distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

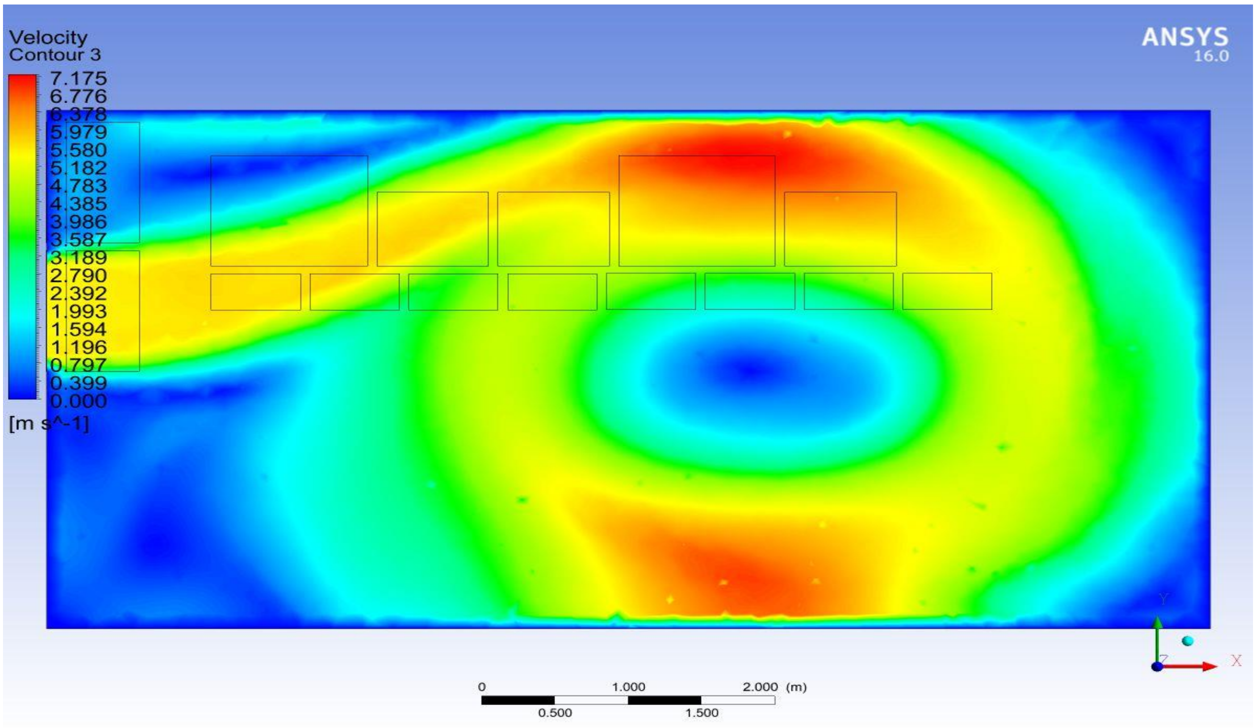


Fig:60

Fig:60 represents the velocity distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

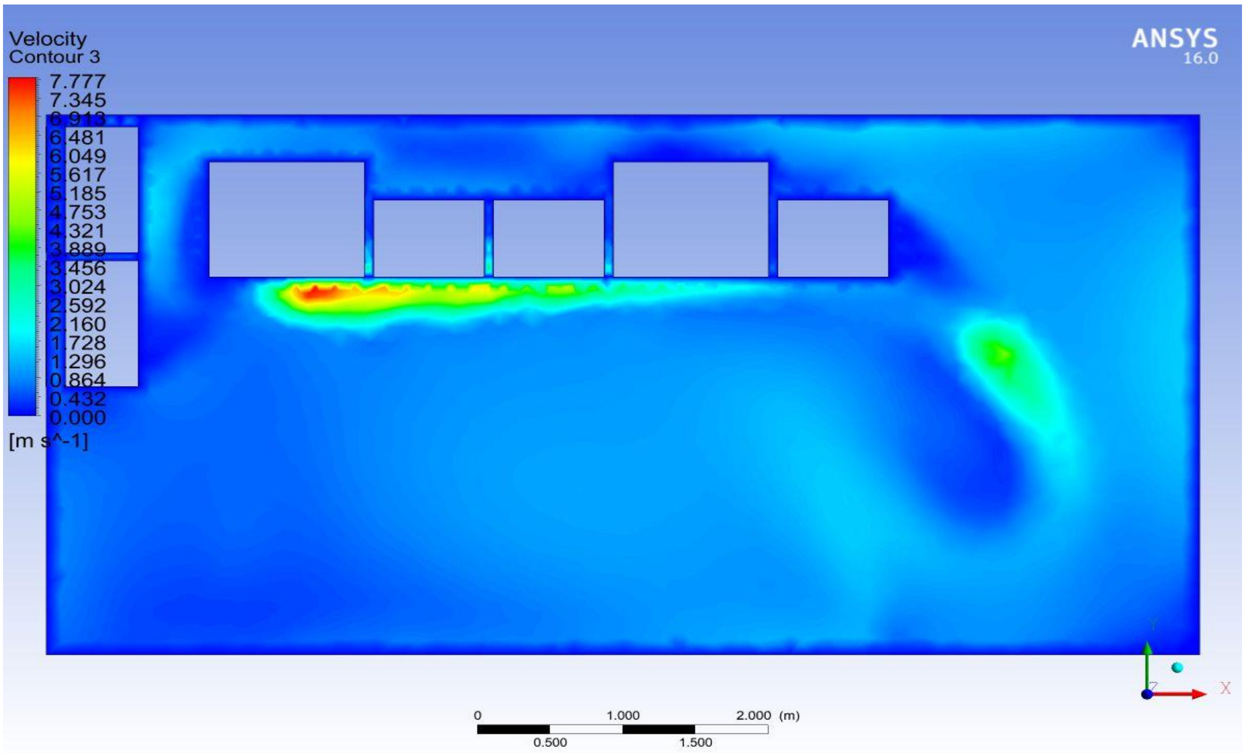


Fig:61

Fig:61 represents the velocity distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

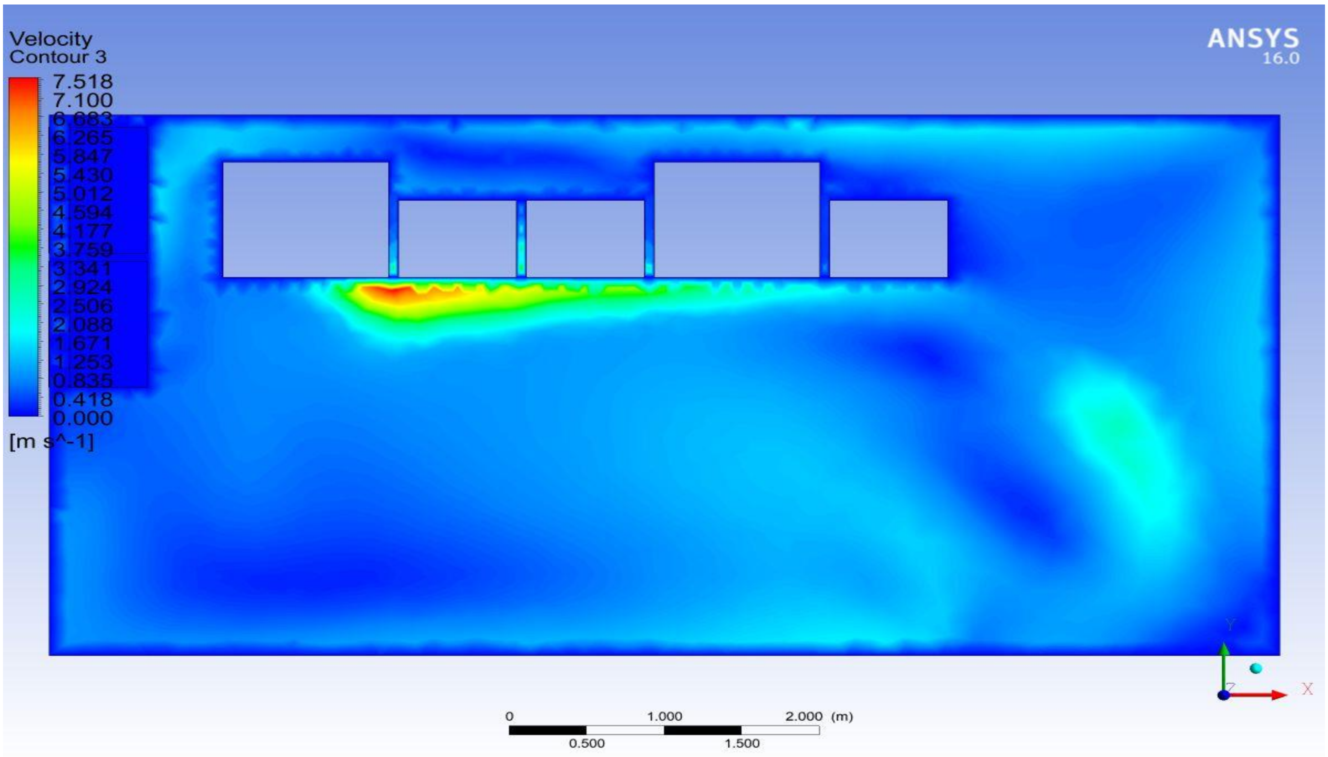


Fig:62

Fig:62 represents the velocity distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

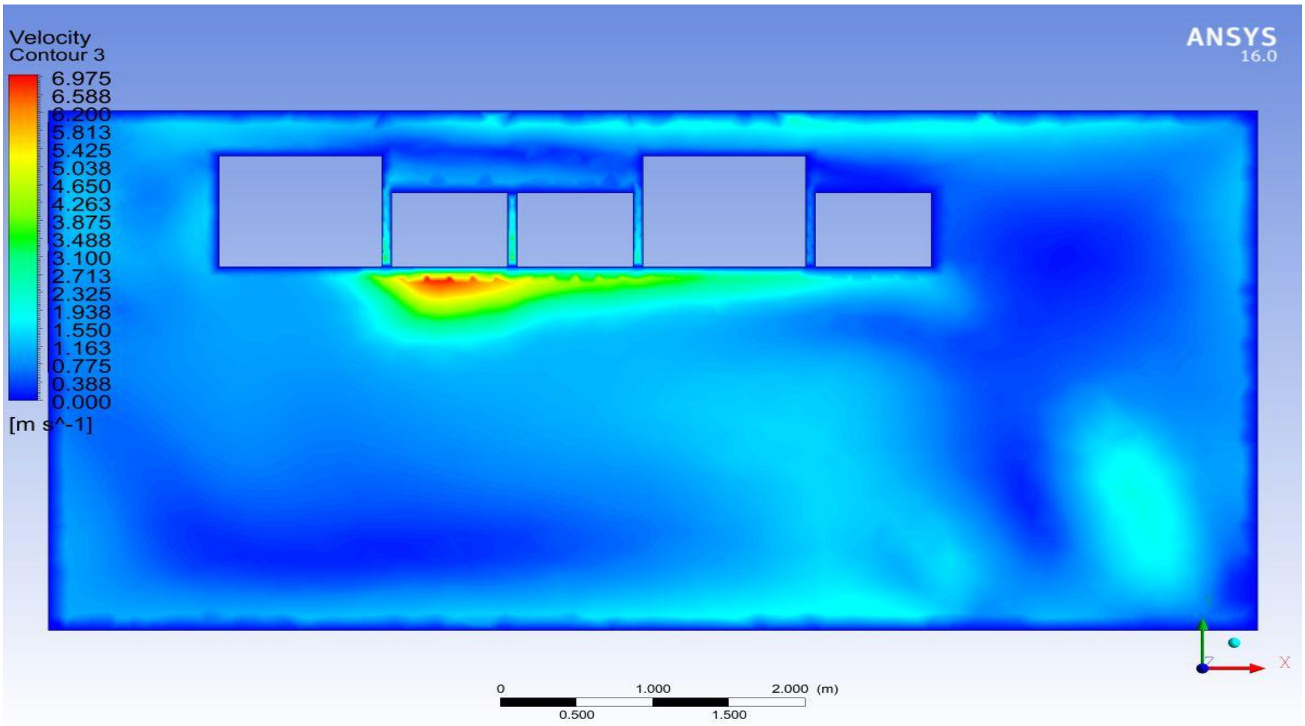


Fig:63

Fig:63 represents the velocity distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

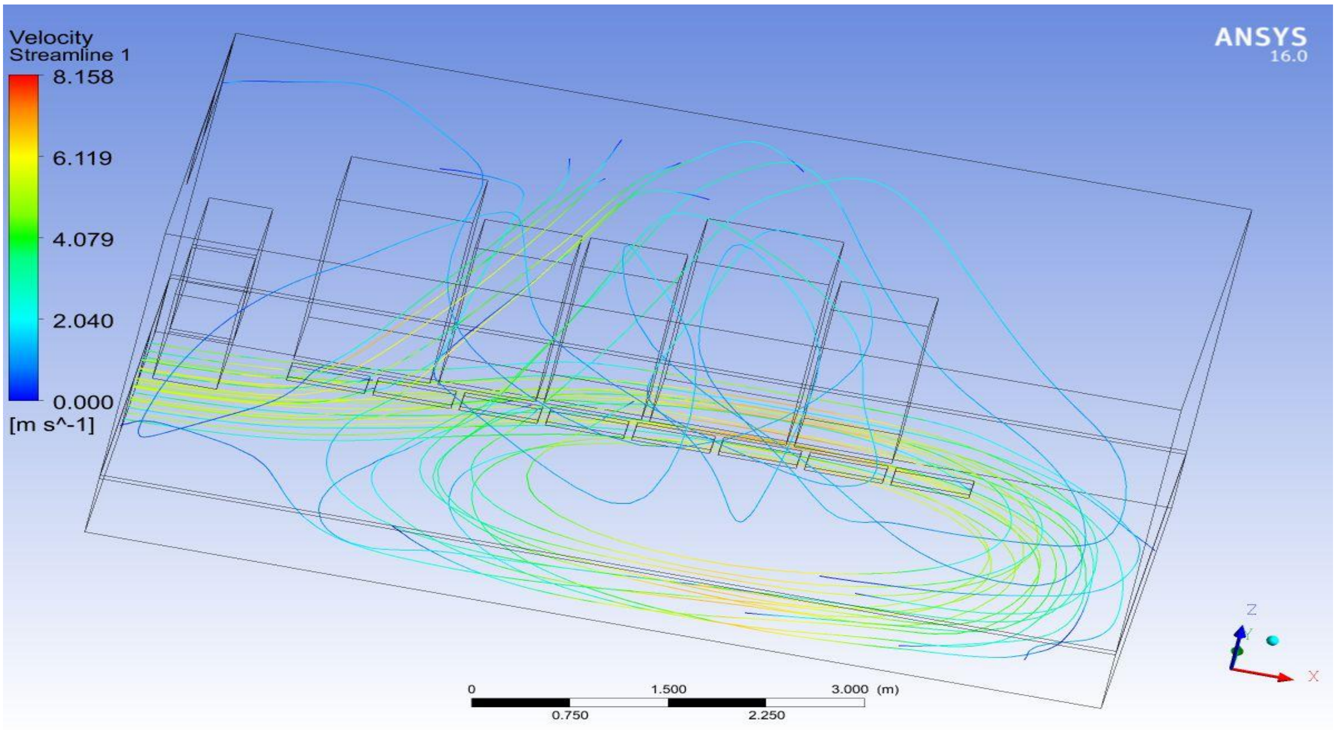


Fig:64

Fig:64 shows velocity streamlines from inlet 1 towards the raised floor space.

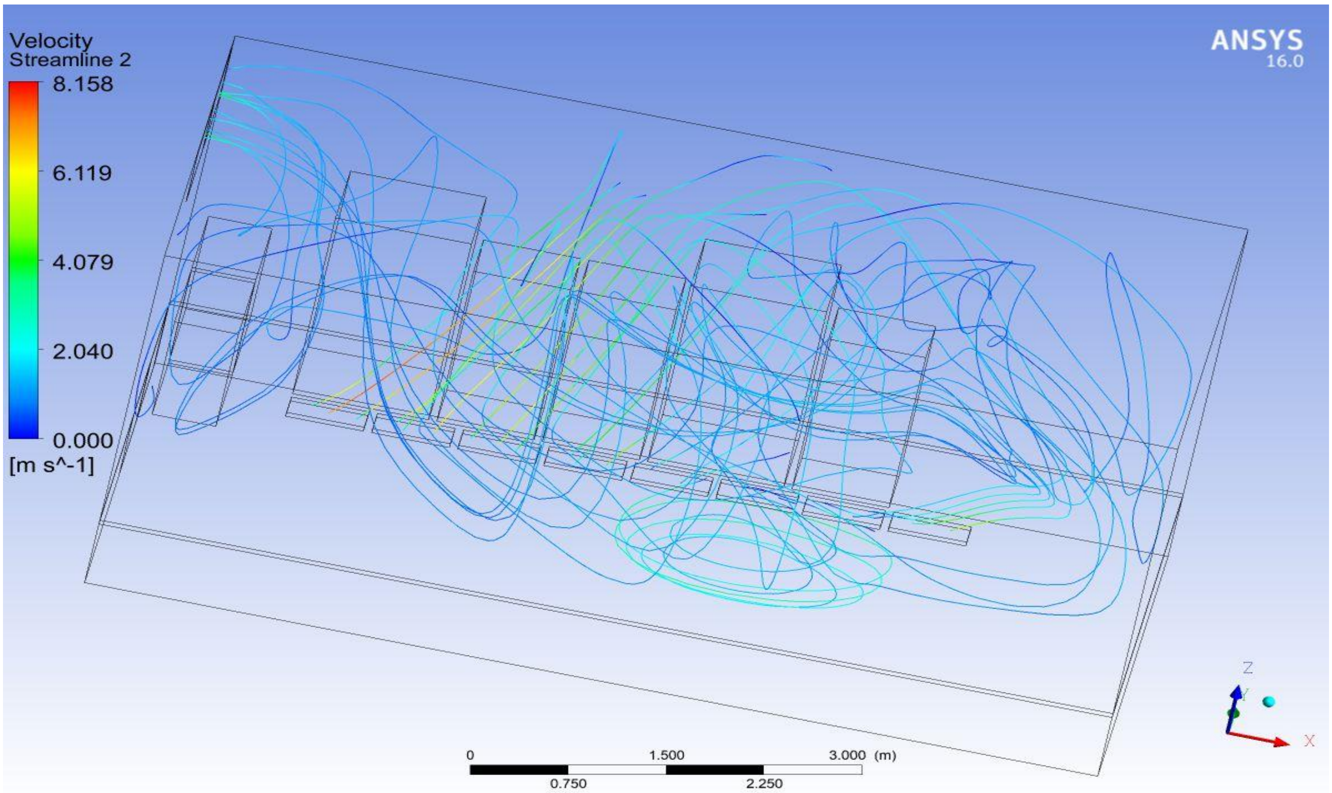


Fig:65

Fig:65 show velocity streamline at the vents of the tiles towards the server room space.

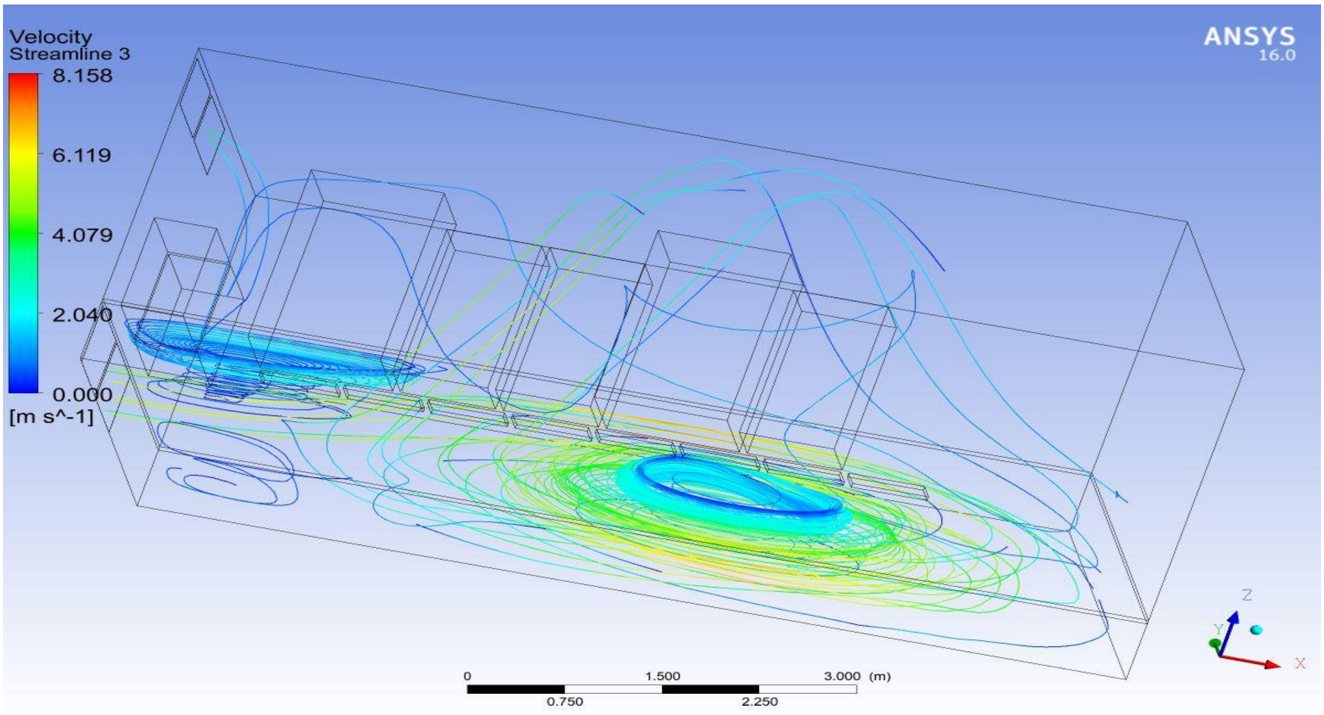


Fig:66

Fig:66 show velocity streamline at the raised floor space.

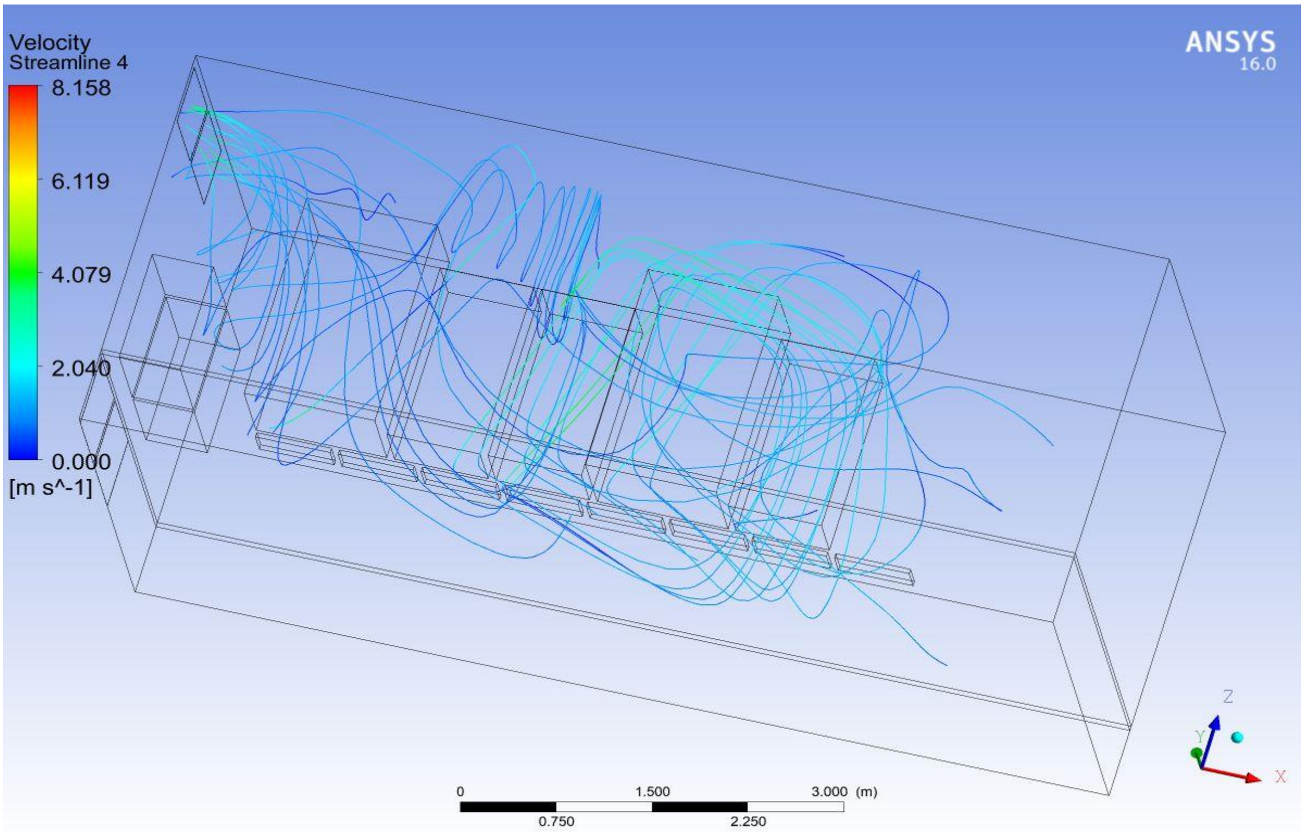


Fig:67

Fig:67 show velocity streamline at the server room floor space

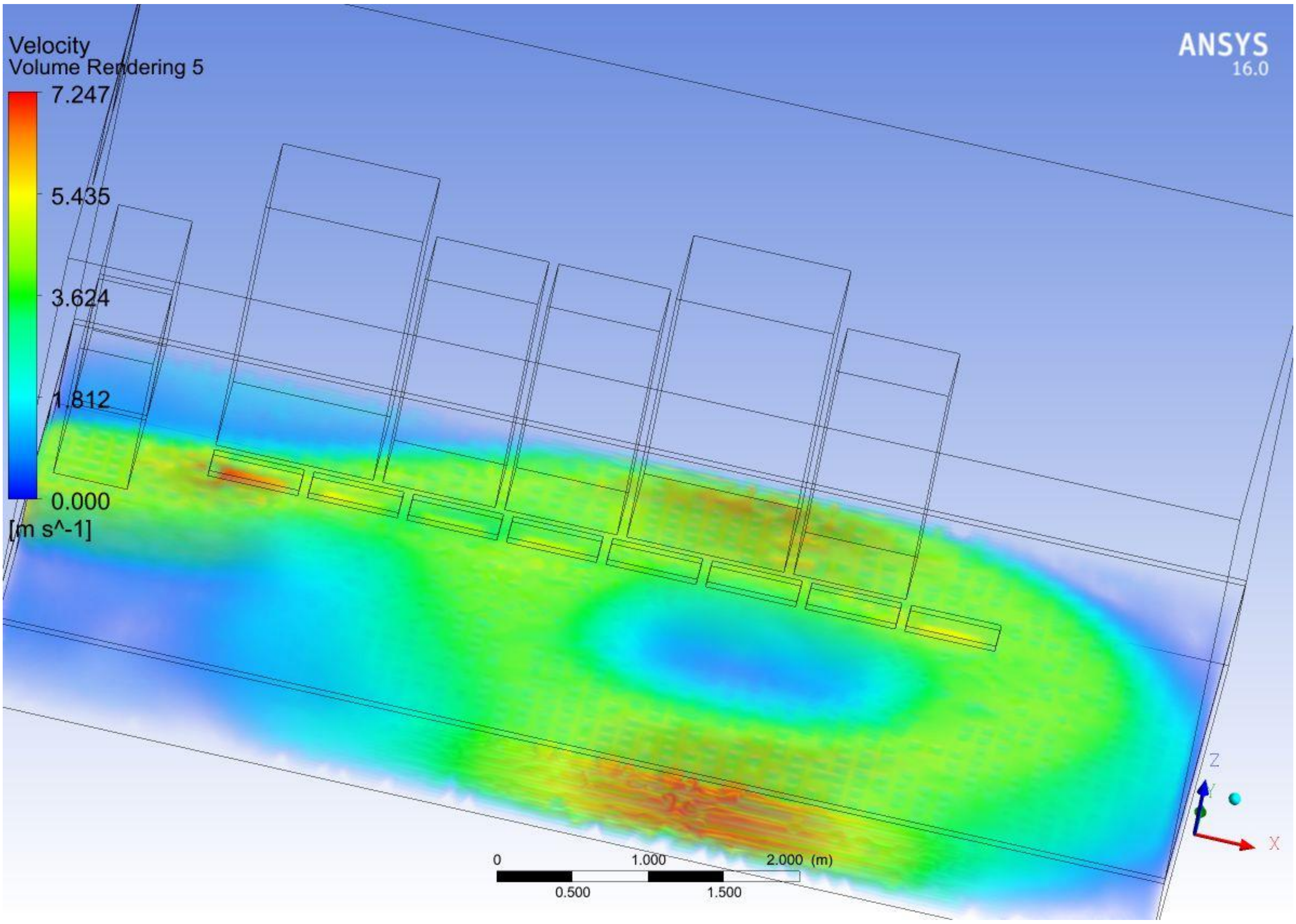


Fig:68

Fig:68 represents the velocity distribution of volume of air present below the raised floor.

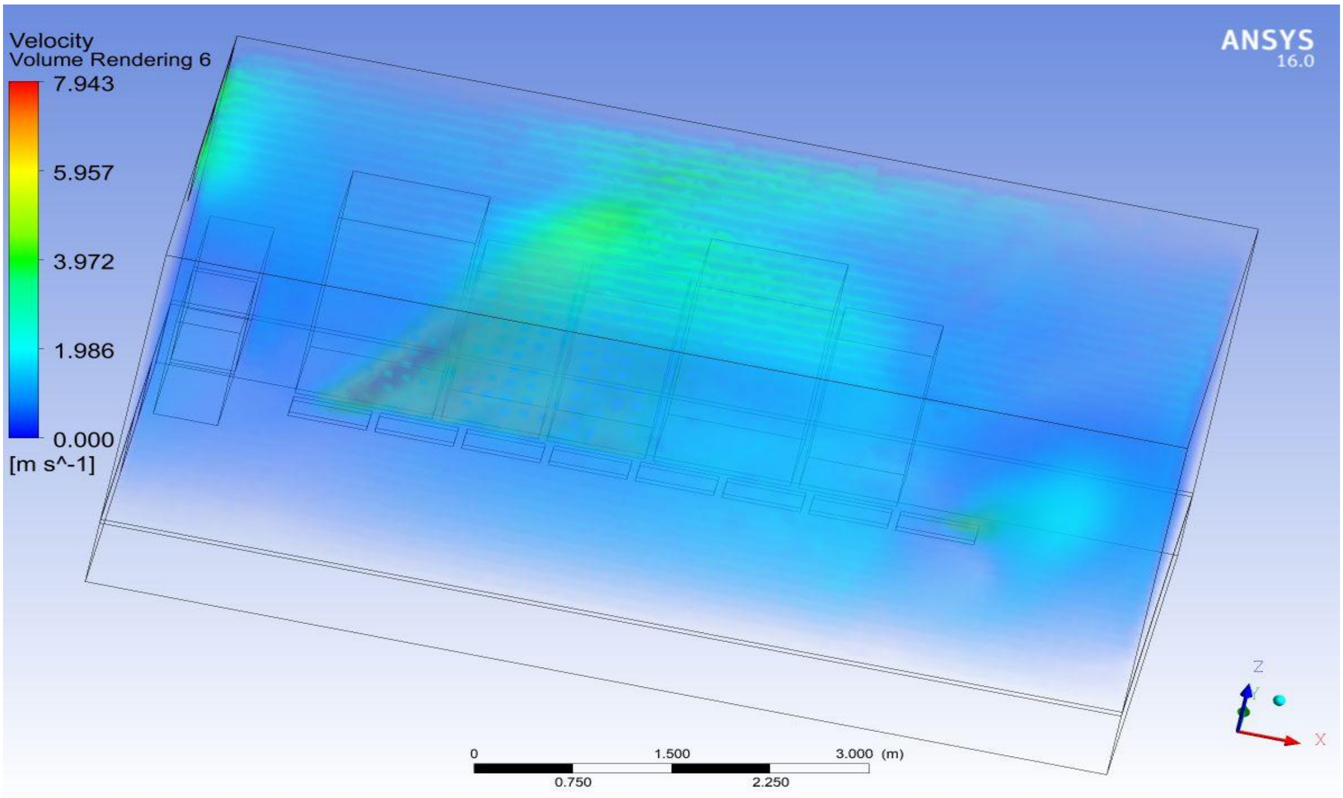


Fig:69

Fig:69 represents the velocity distribution of volume of air present in the server room space located above the raised floor.

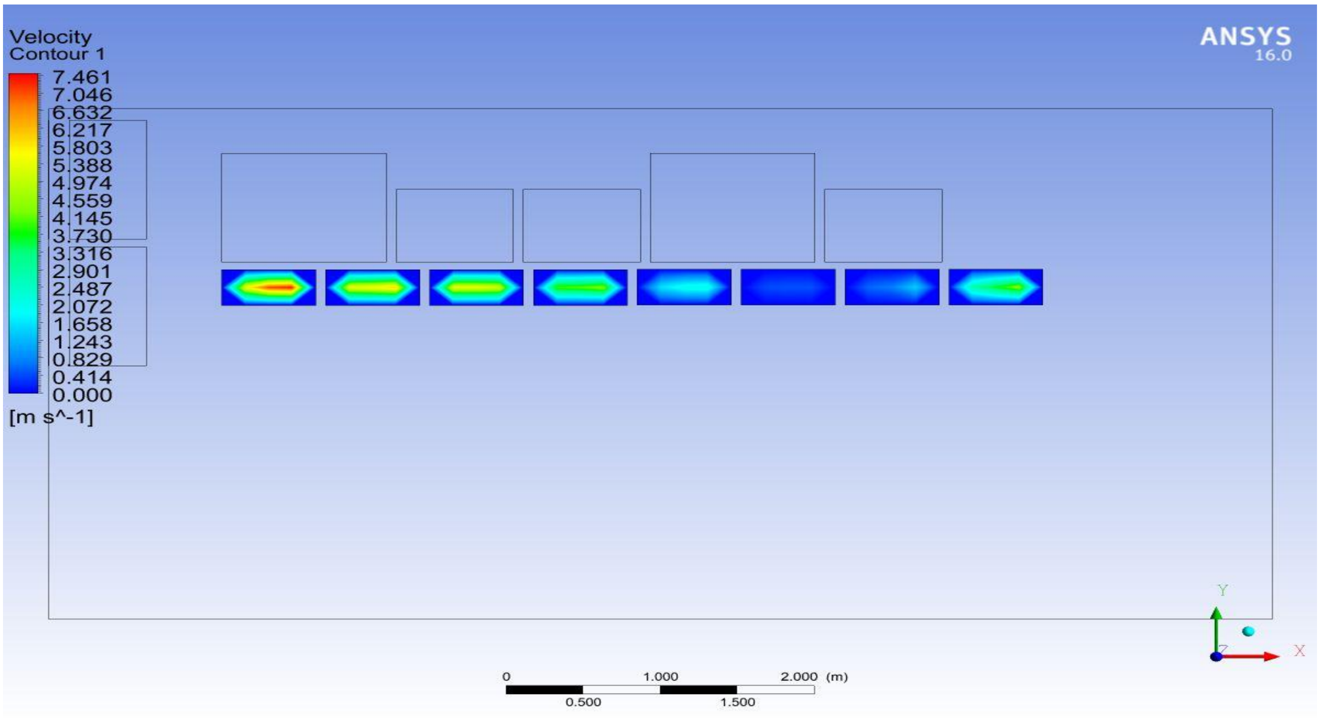


Fig:70

Fig:70 represents the velocity distribution of air at vents of tiles

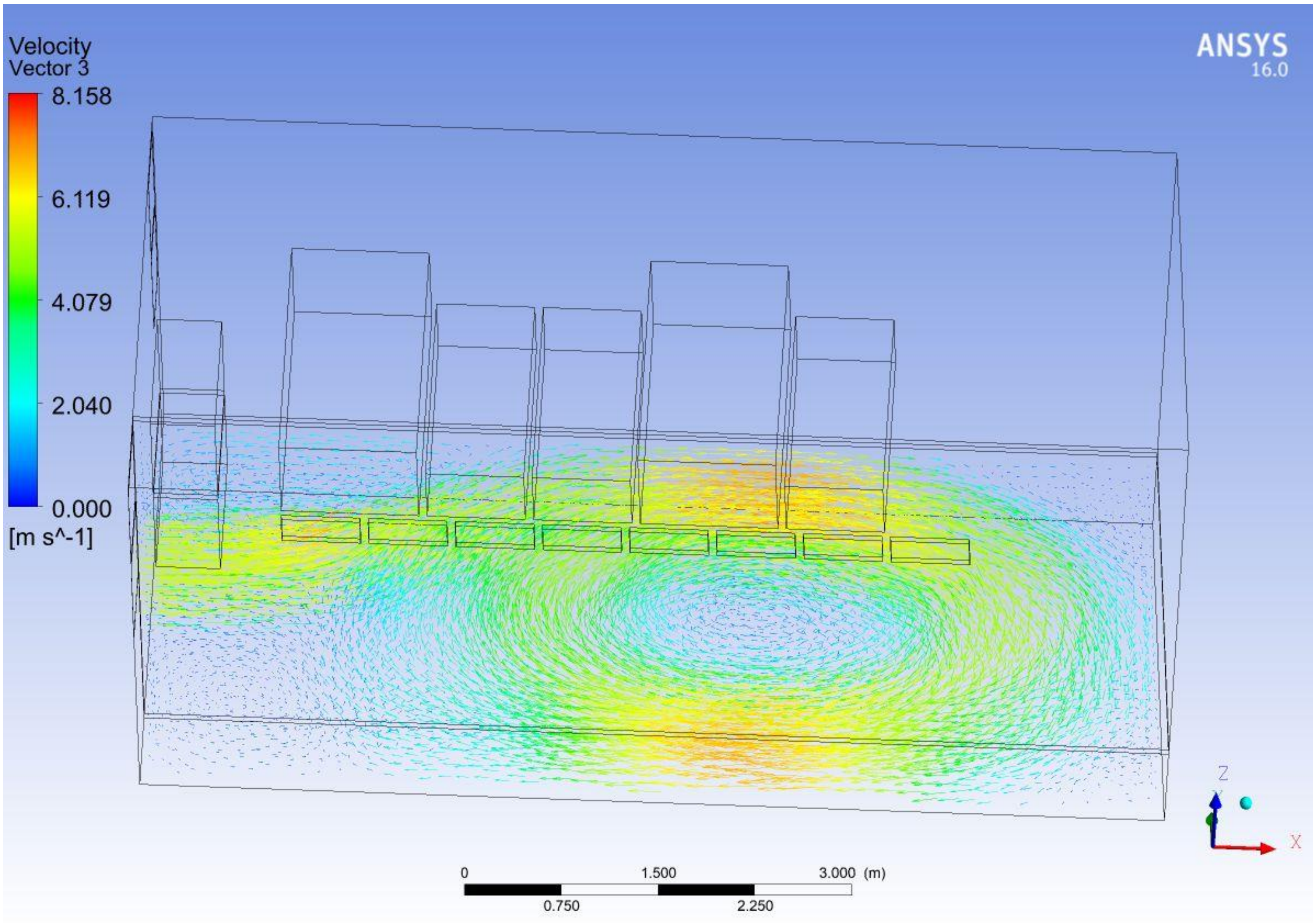


Fig:71

Fig:71 represents the velocity vector distribution of air present below the raised floor.

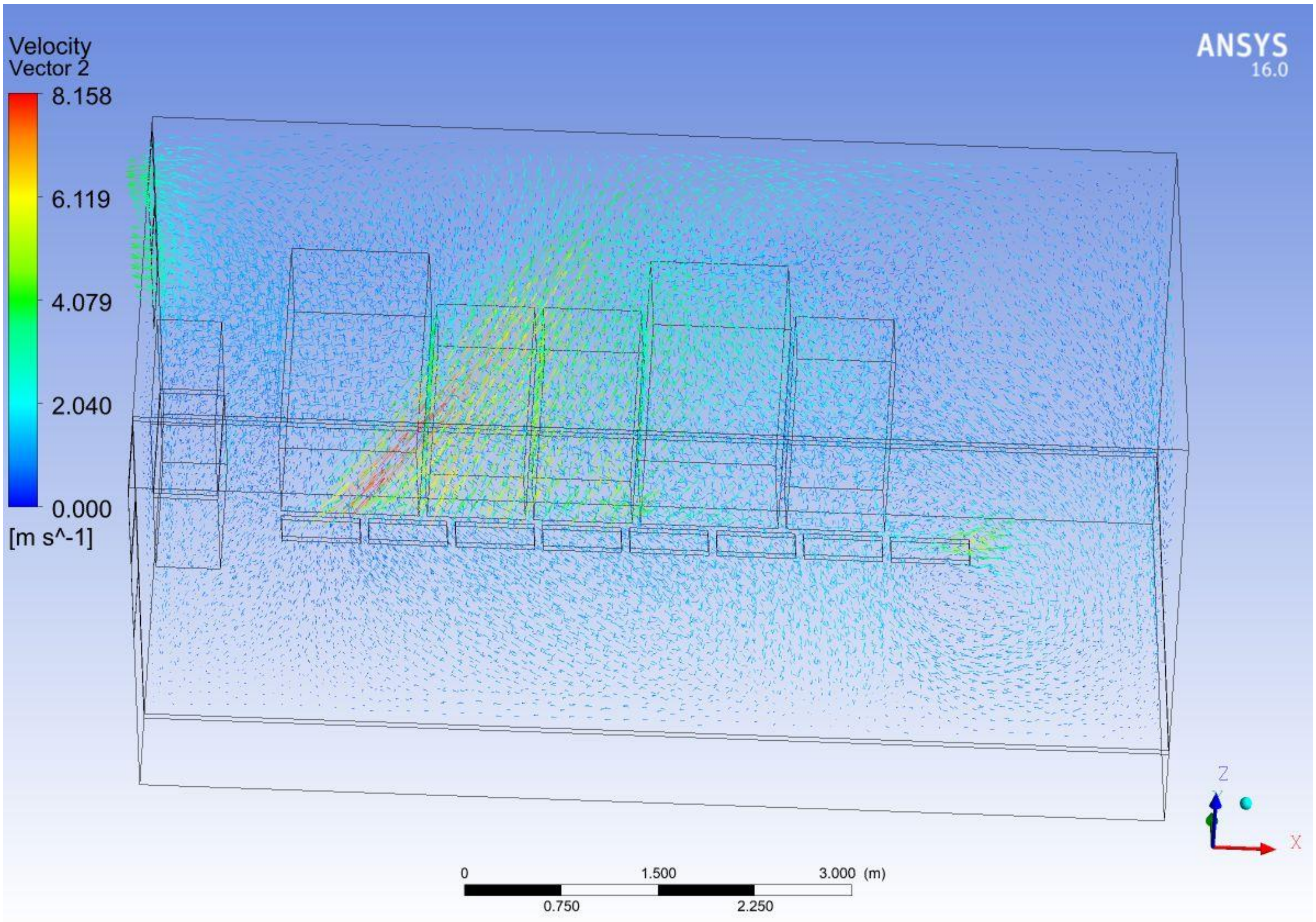


Fig:72

Fig:72 represents the velocity vector distribution of air present above the raised floor.

c) CASE III (Temperature of air at CRAC outlet is 280 K and heat generation from each server rack is 1500 W/ cum.)

i) <u>Temperature Contour:</u>

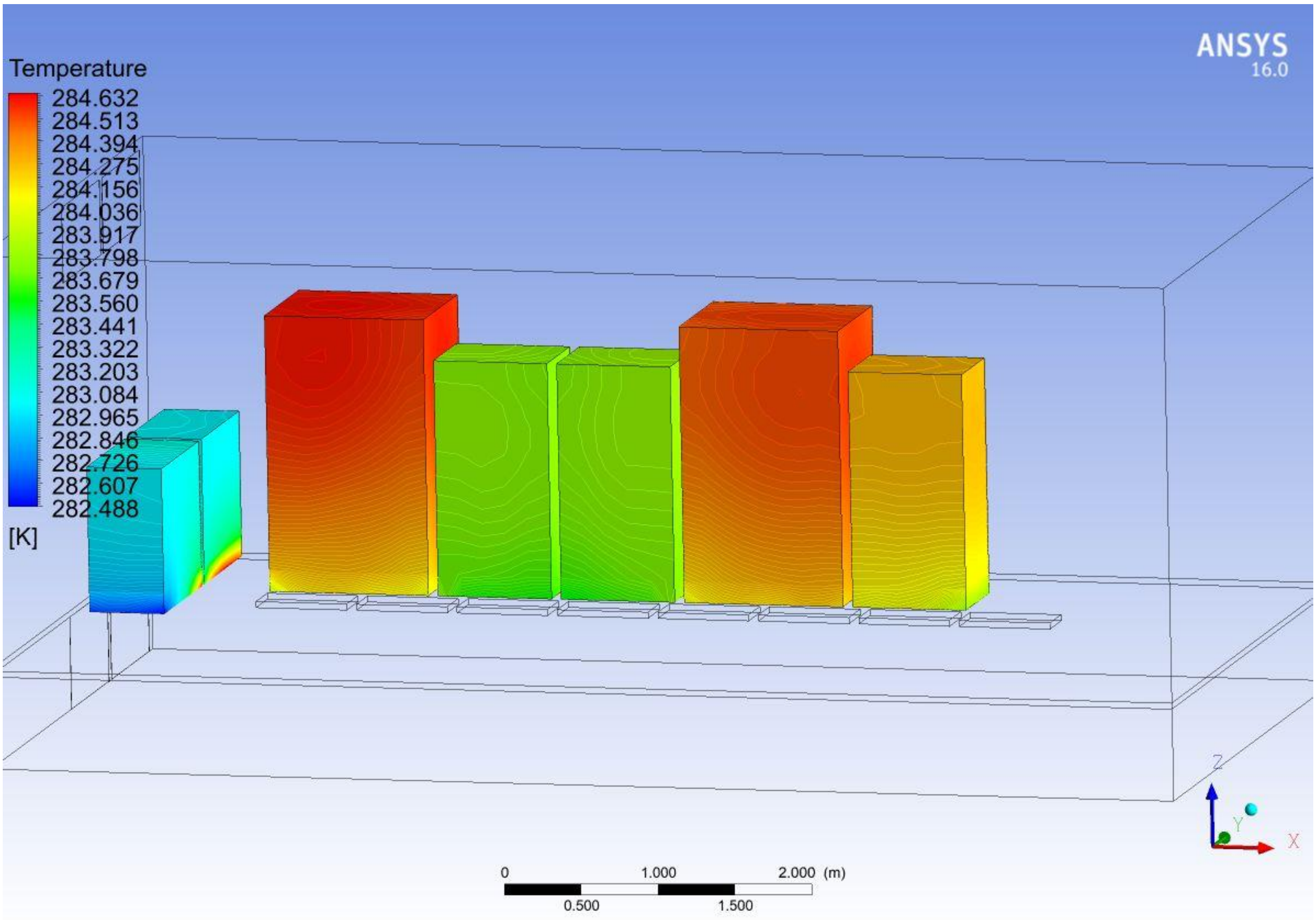


Fig:73

Fig:73 represents the temperature distribution of five server racks and two crac units. The temperature distribution of crac and server racks are clearly visible from the temperature colour coding mentioned above.

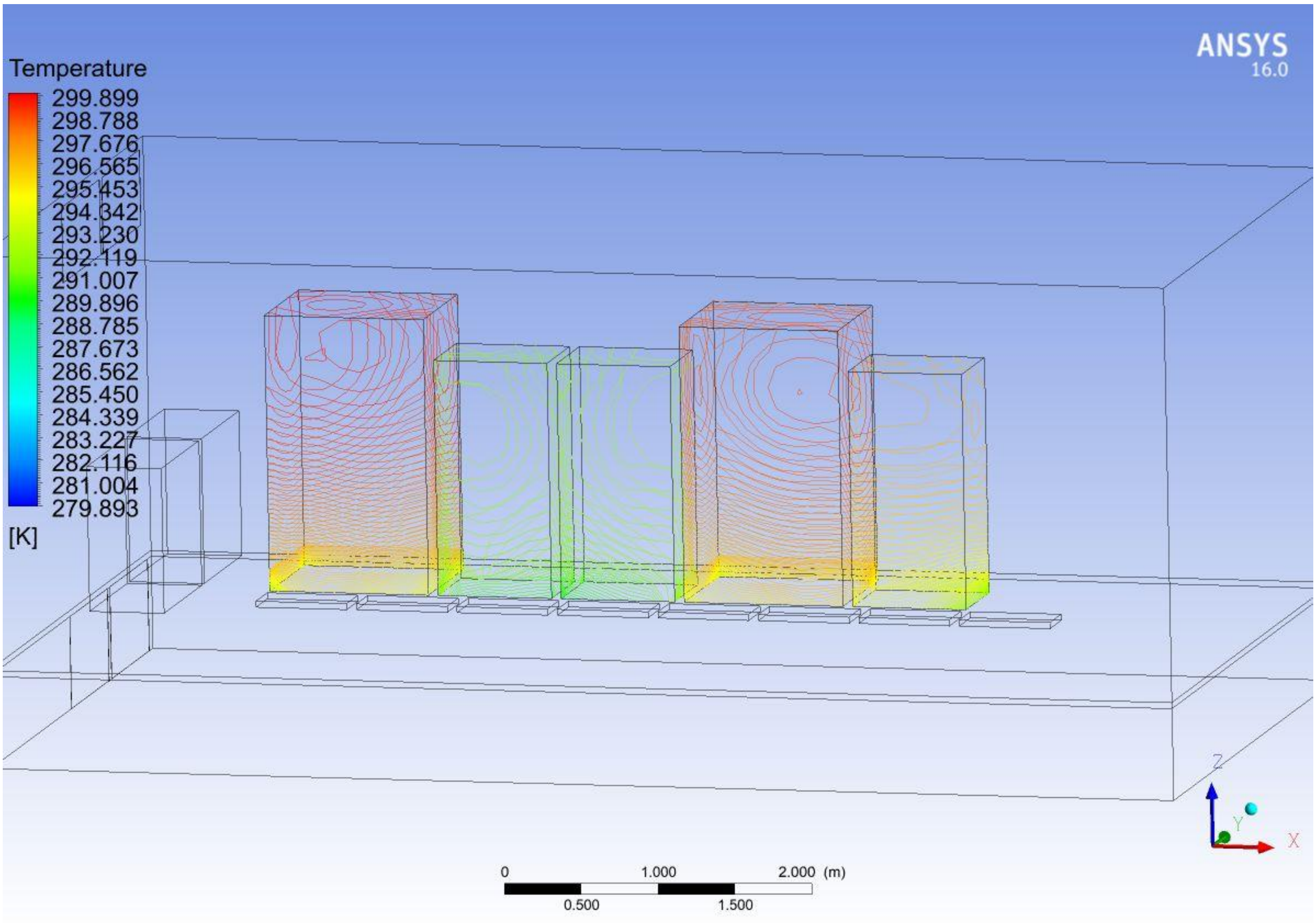


Fig:74

Fig:74 represents the temperature isotherms distribution of five server racks. The temperature isotherms distribution of server racks are clearly visible from the temperature colour coding mentioned above.

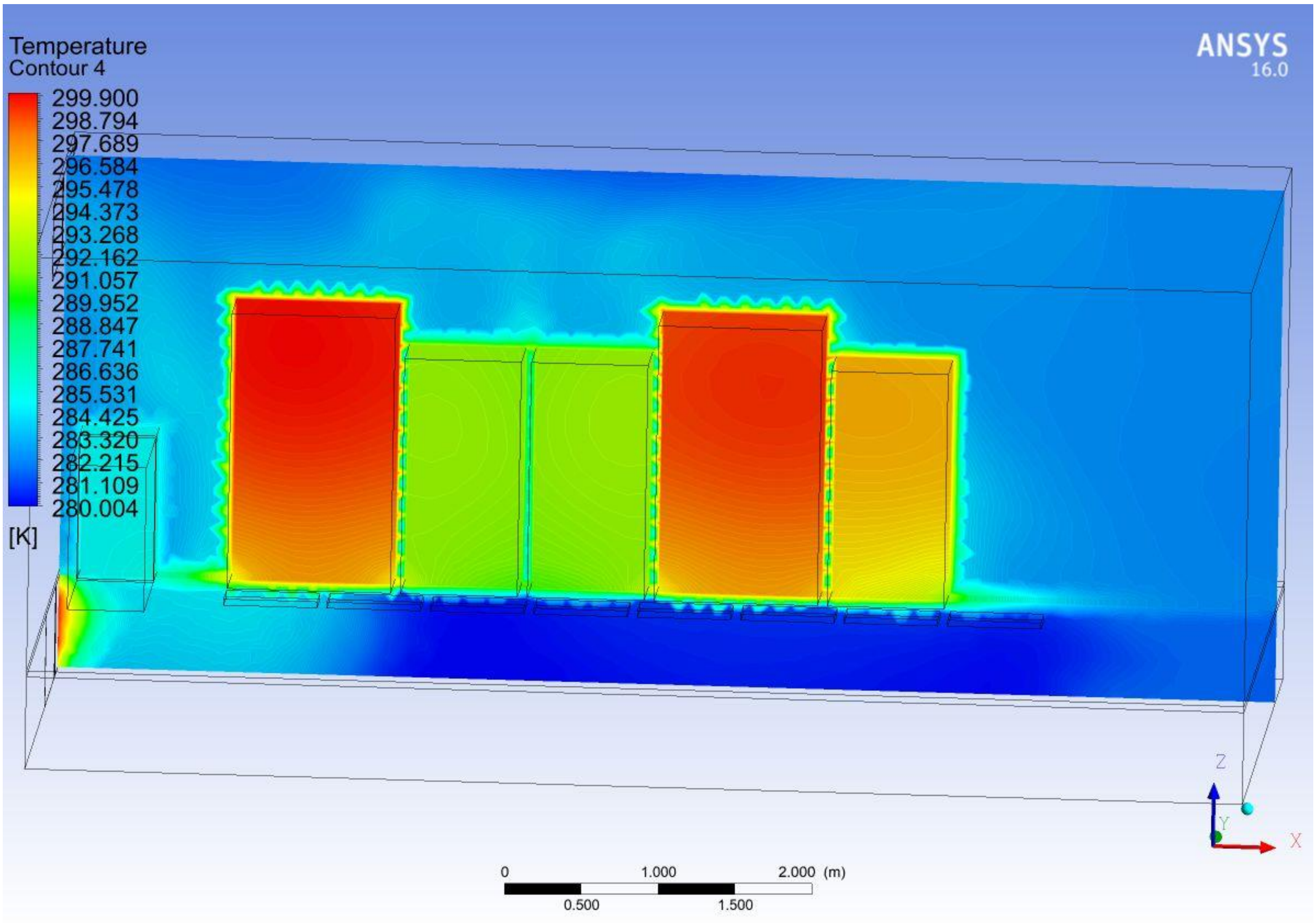


Fig:75

Fig:75 represents the temperature distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

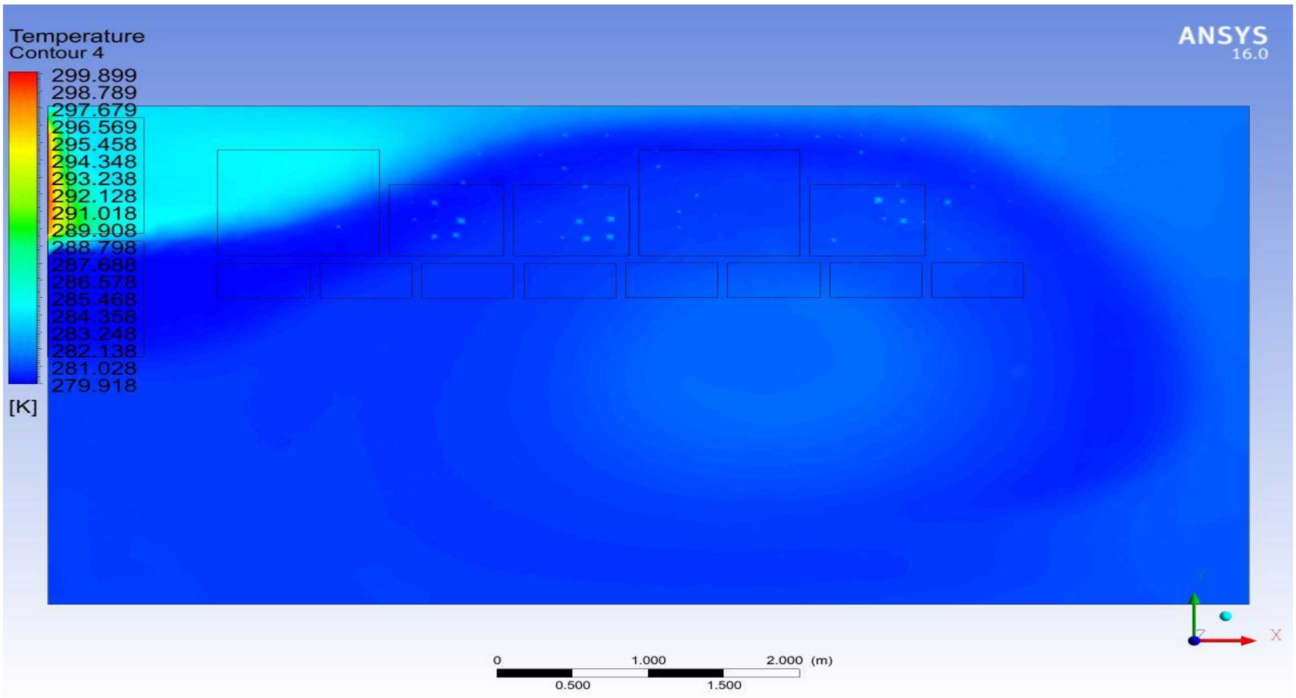


Fig:76

Fig:76 represents the temperature distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

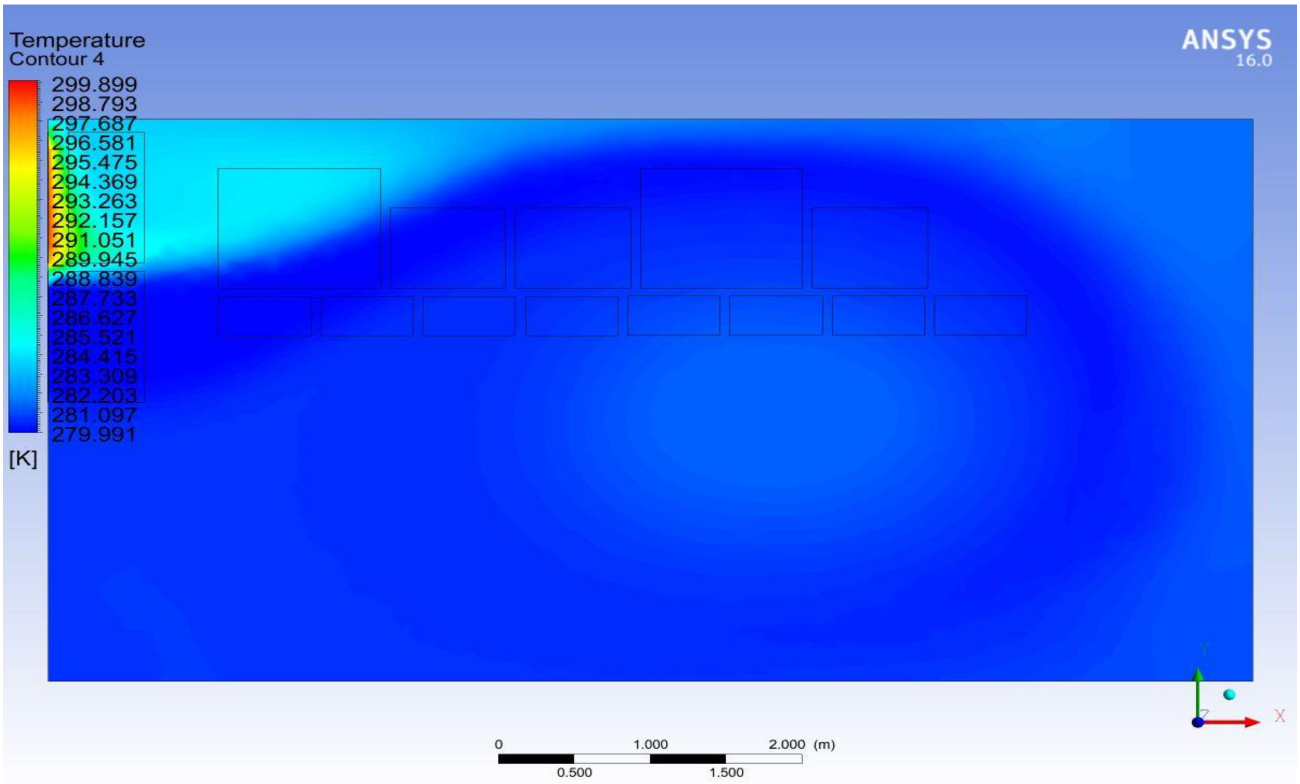


Fig:77

Fig:77 represents the temperature distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

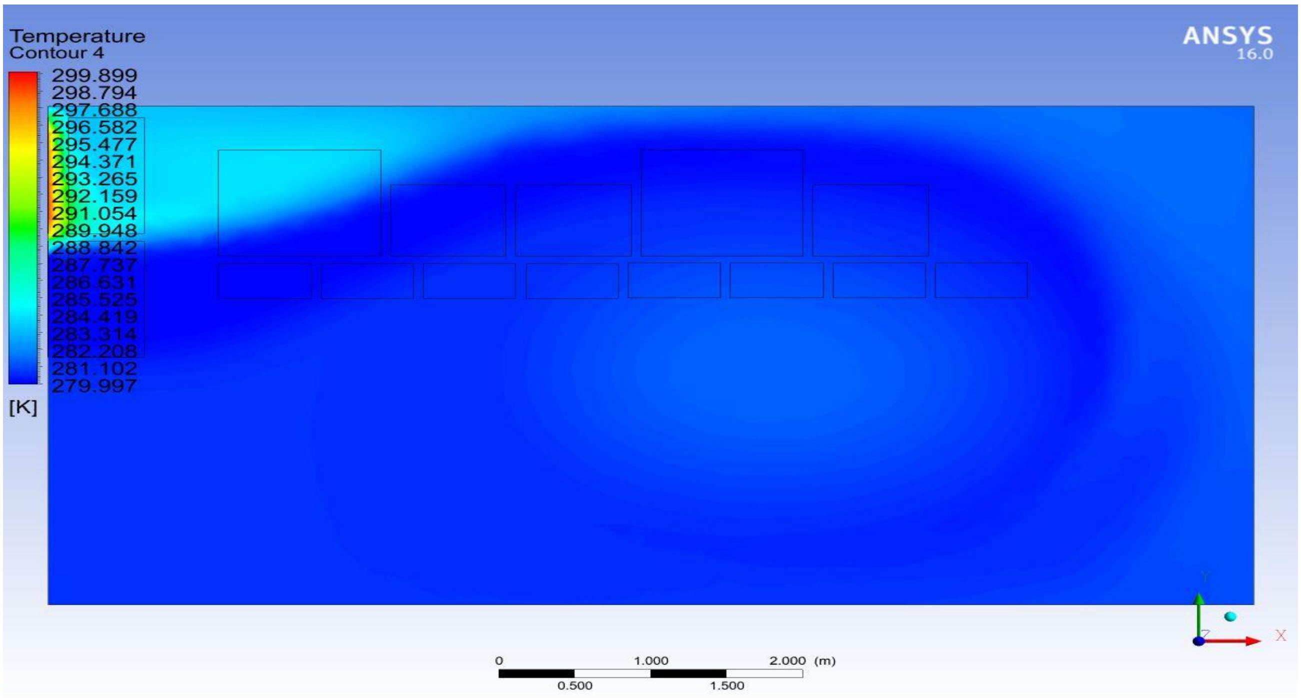


Fig:78

Fig:78 represents the temperature distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

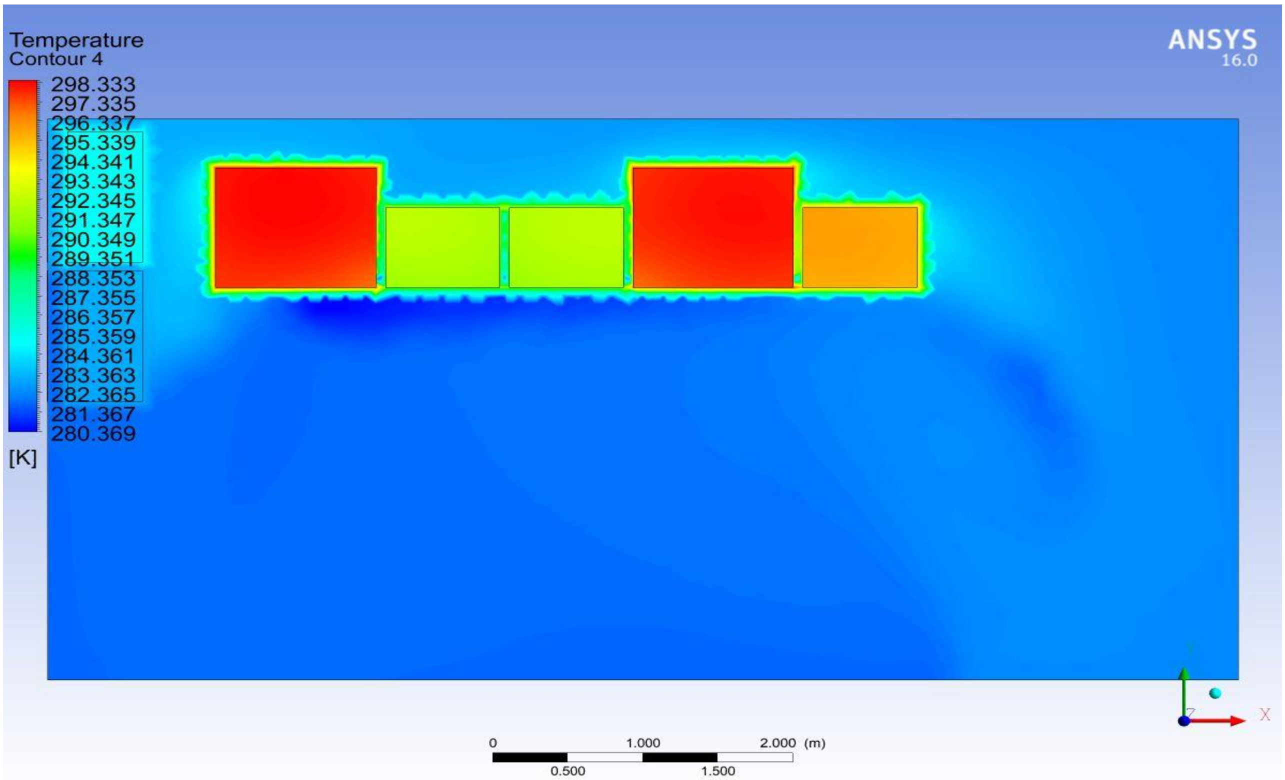


Fig:79

Fig:79 represents the temperature distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

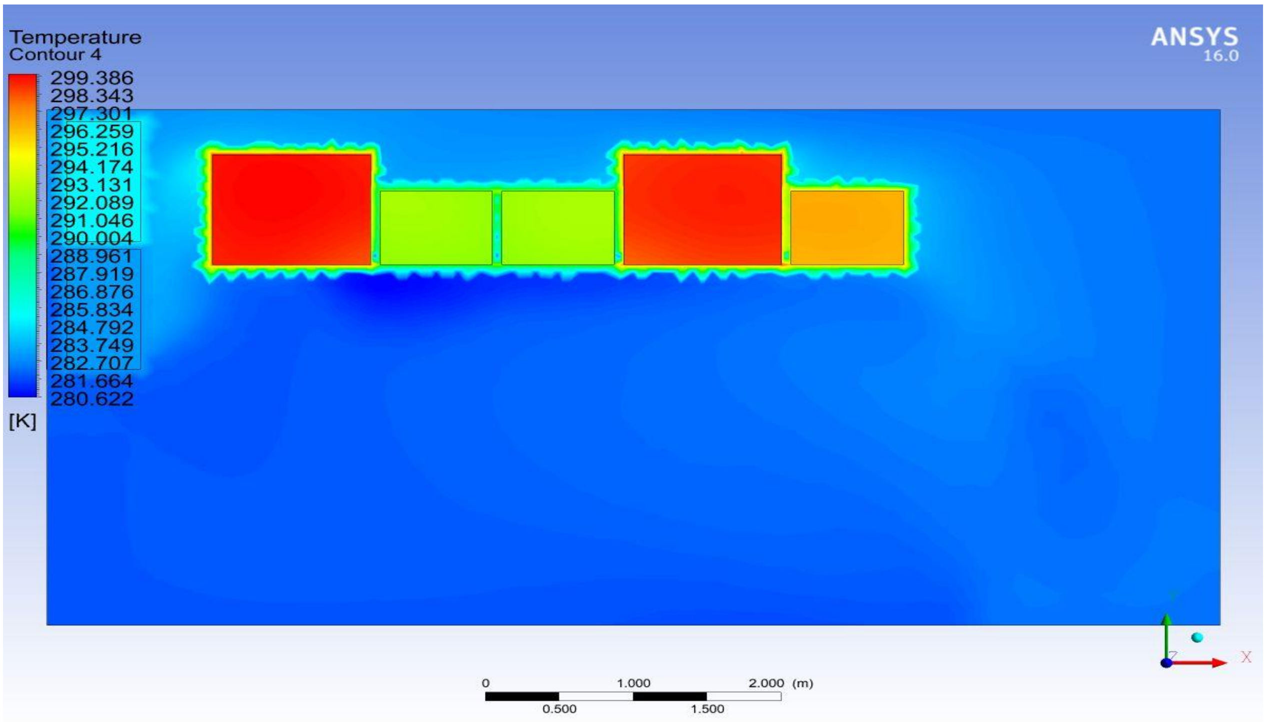


Fig:80

Fig:80 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

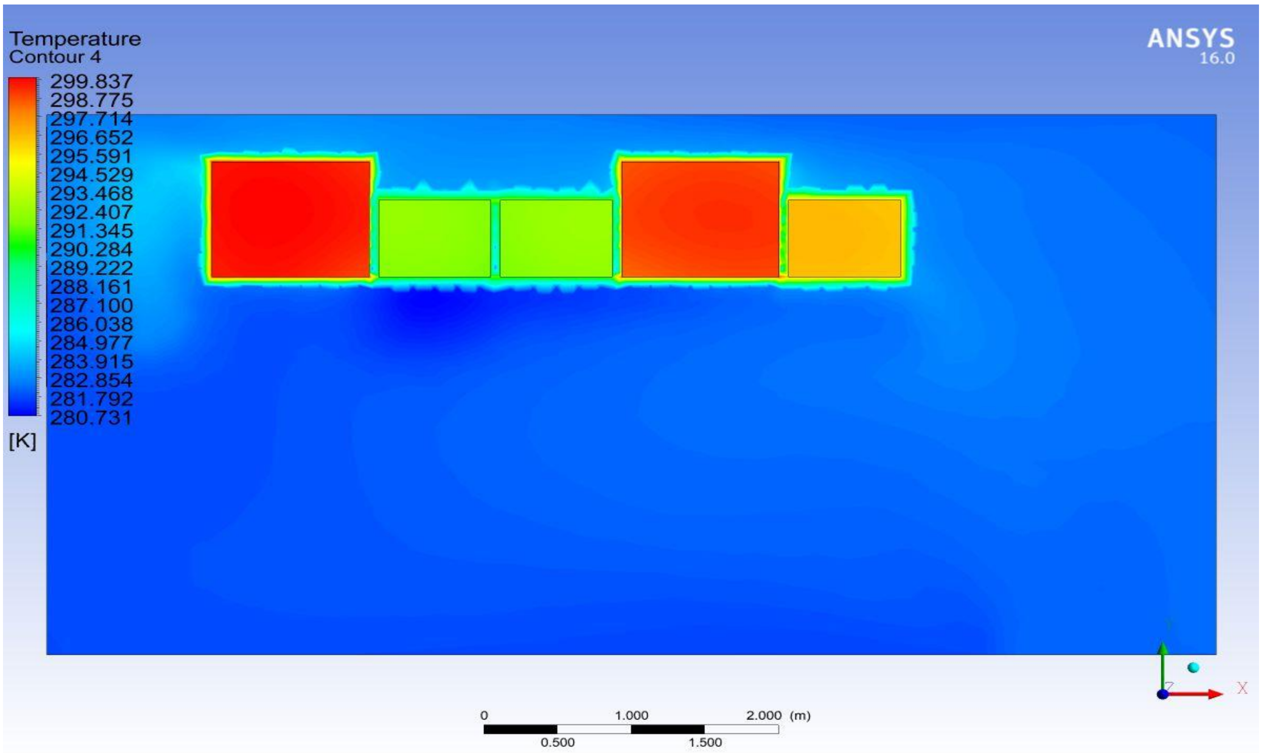


Fig:81

Fig:81 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

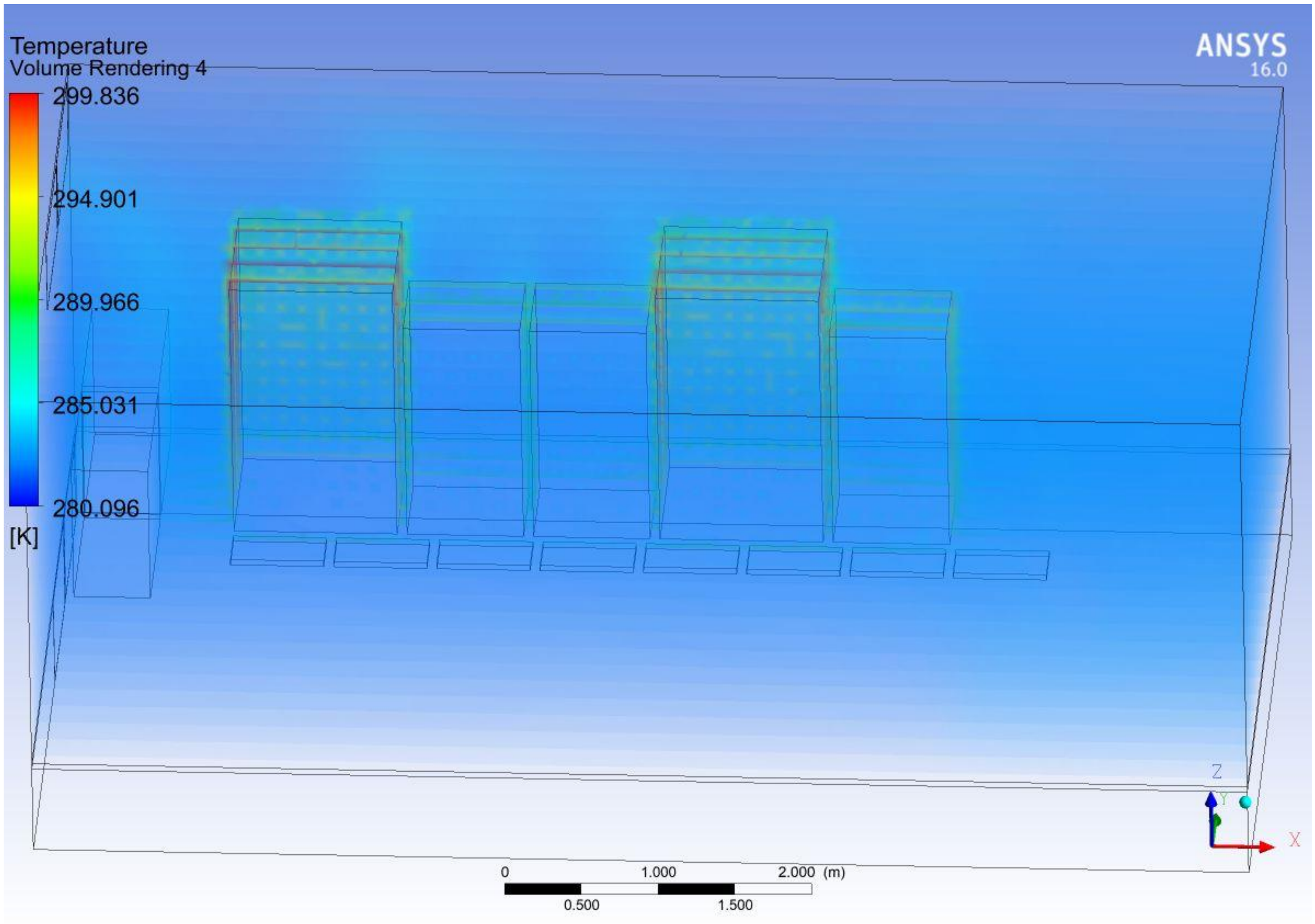


Fig:82

Fig:82 represents the temperature distribution of volume of air present in the server room space located above the raised floor.

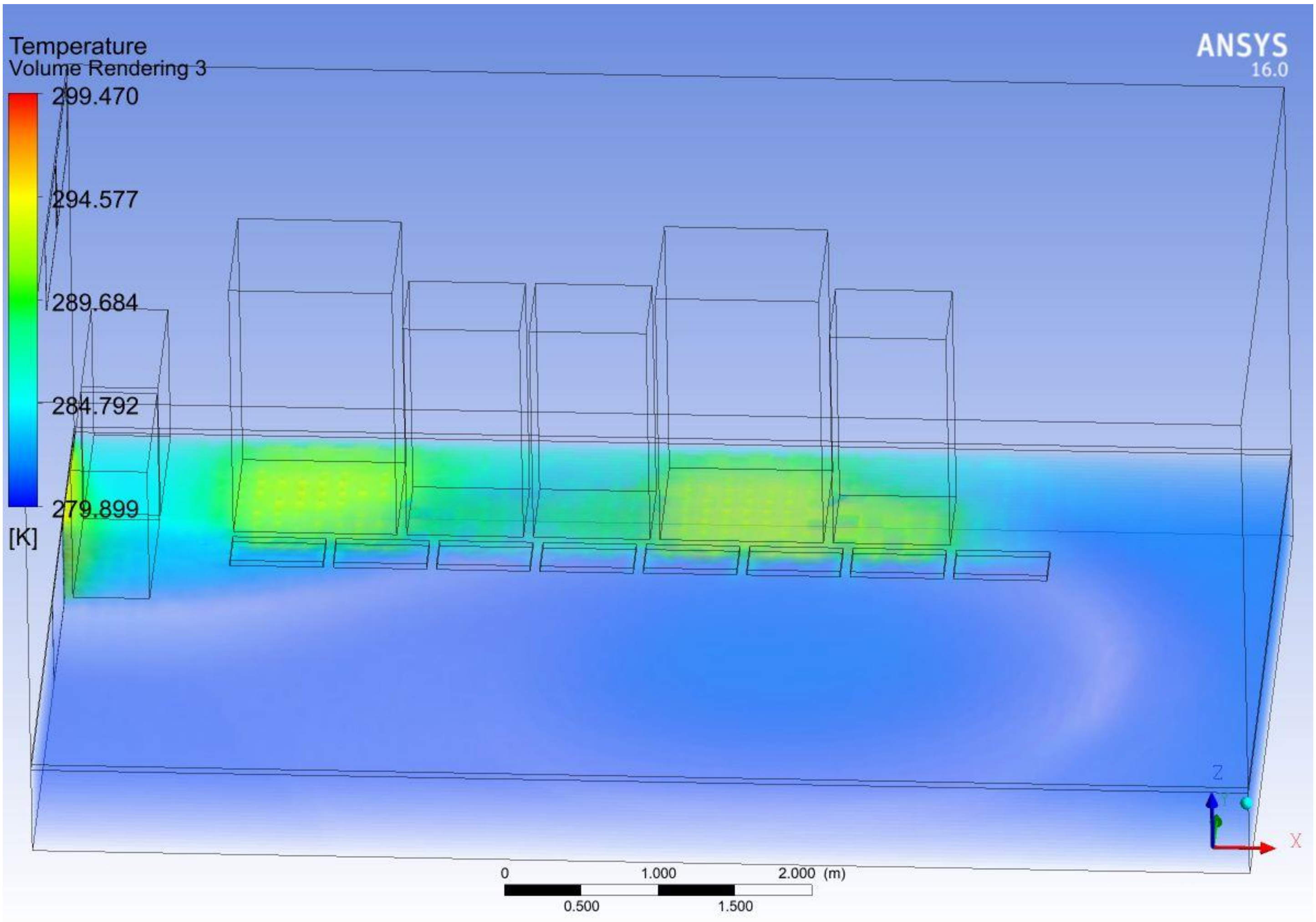


Fig:83

Fig:83 represents the temperature distribution of volume of air present in the server room space located below the raised floor.

ii) Pressure Contour:

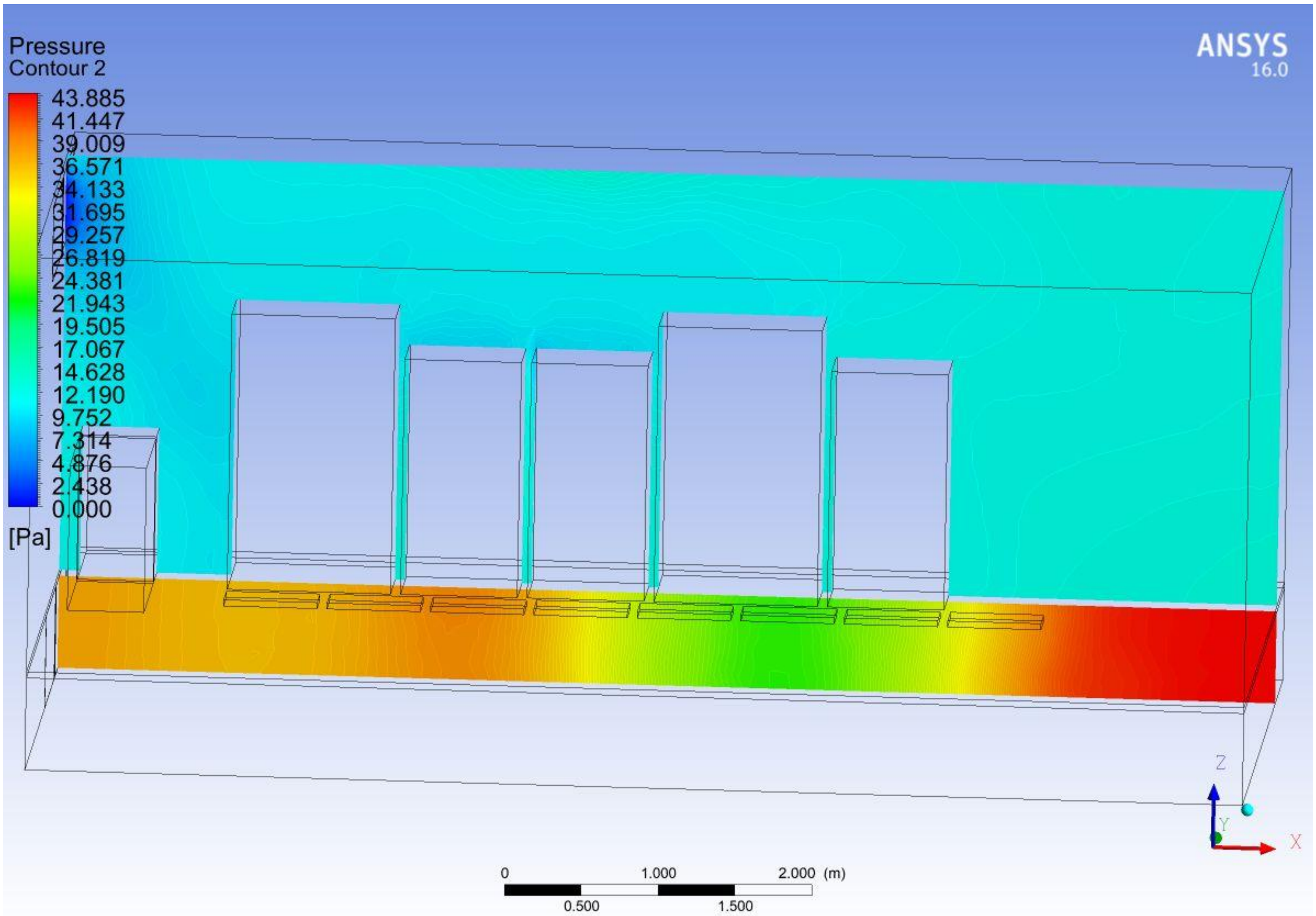


Fig:84

Fig:84 represents the pressure distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

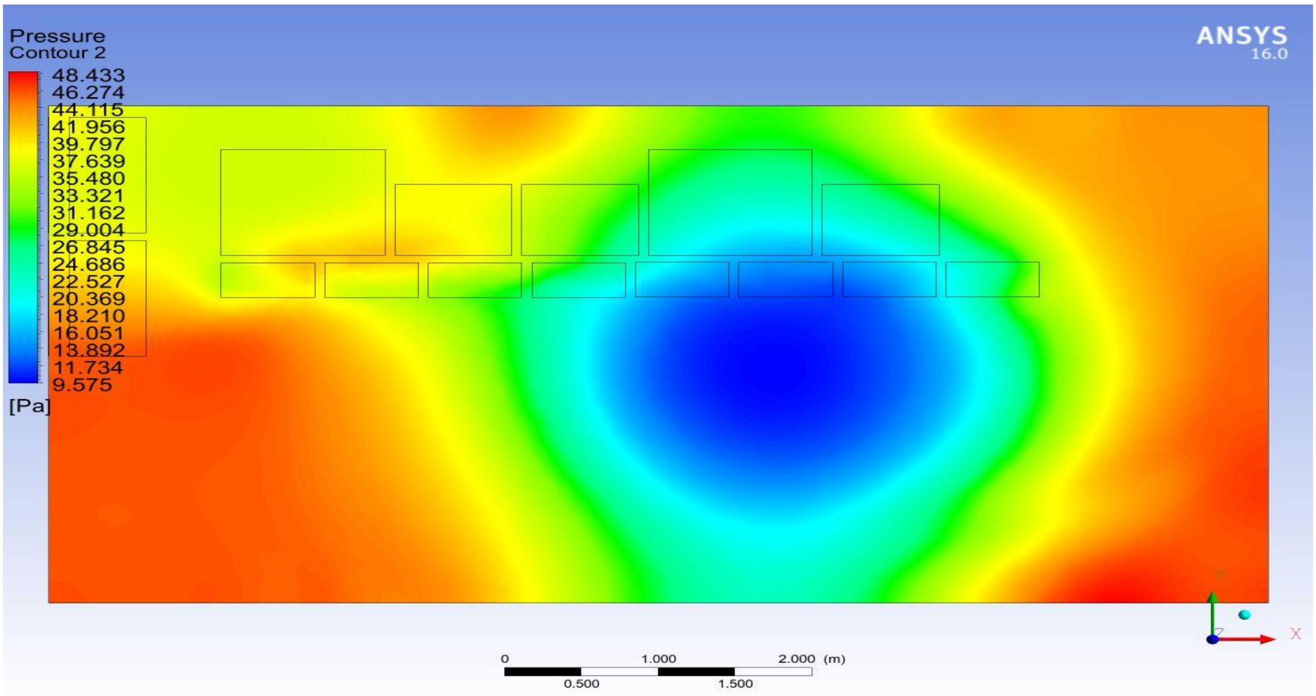


Fig:85

Fig:85 represents the pressure distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

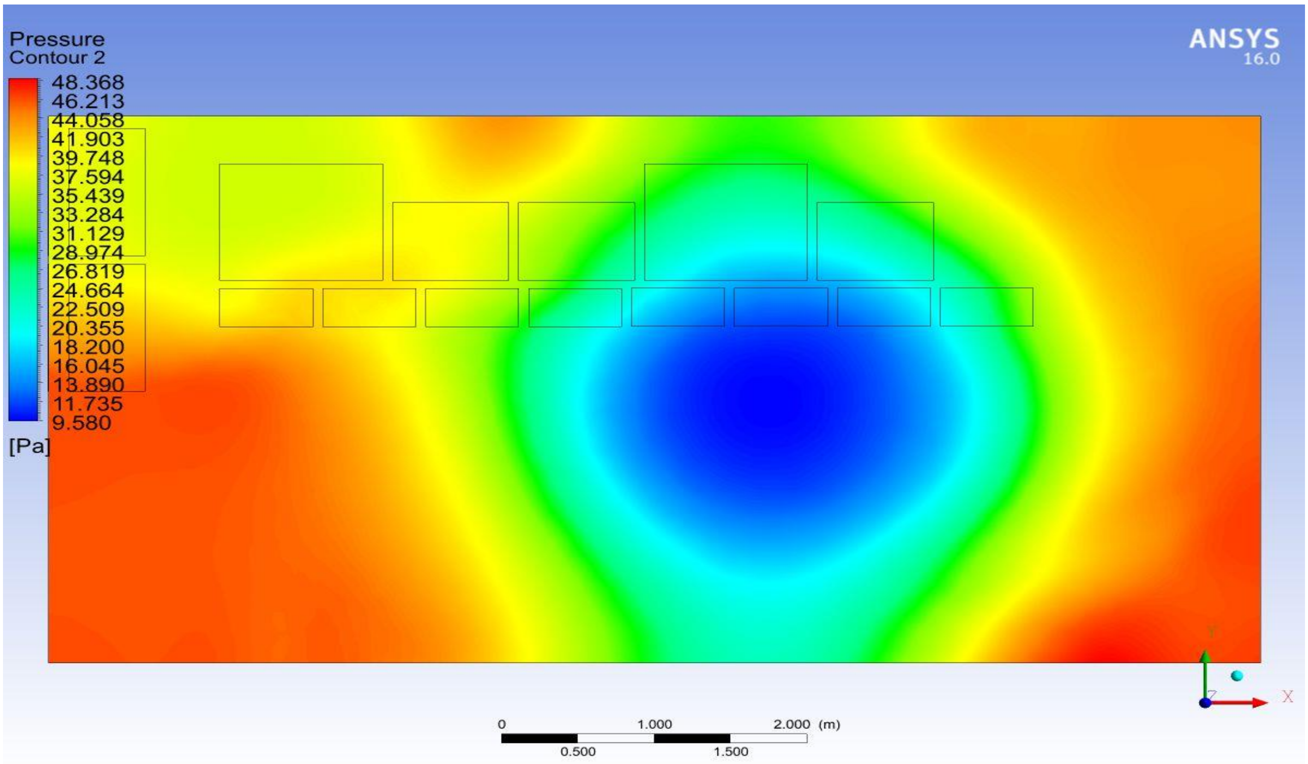


Fig:86

Fig:86 represents the pressure distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

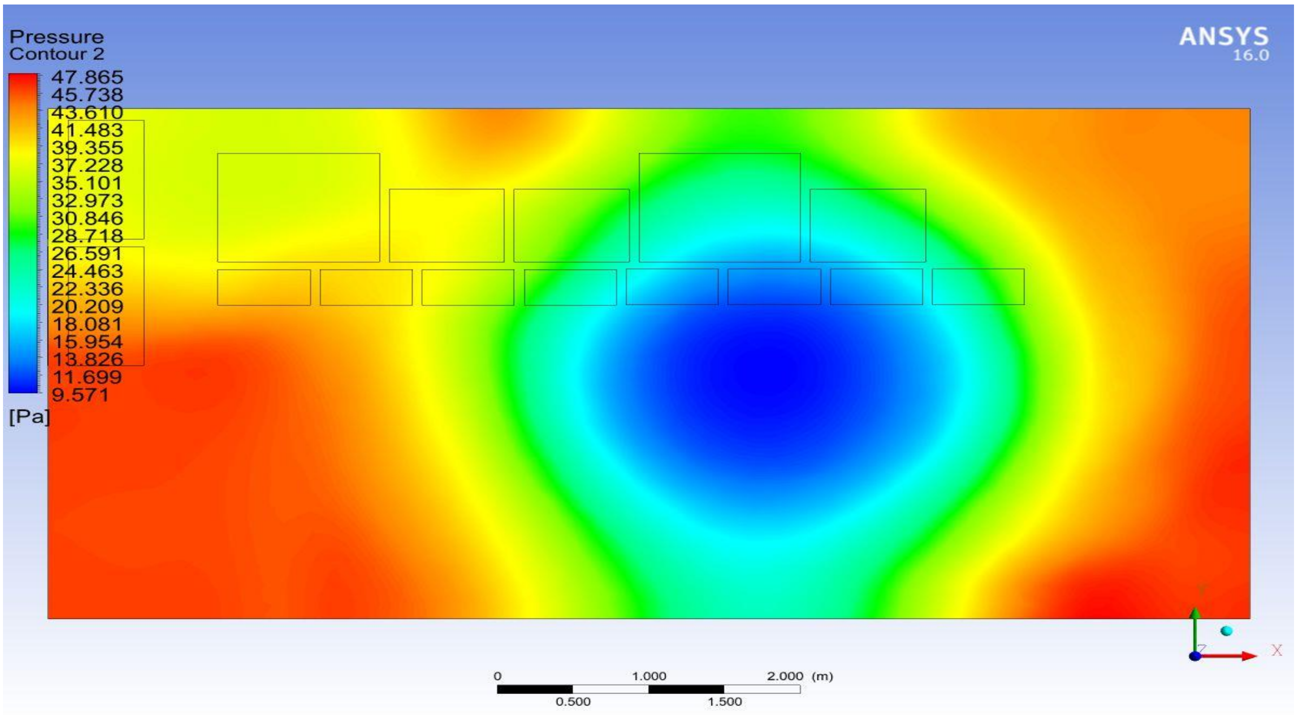


Fig:87

Fig:87 represents the pressure distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

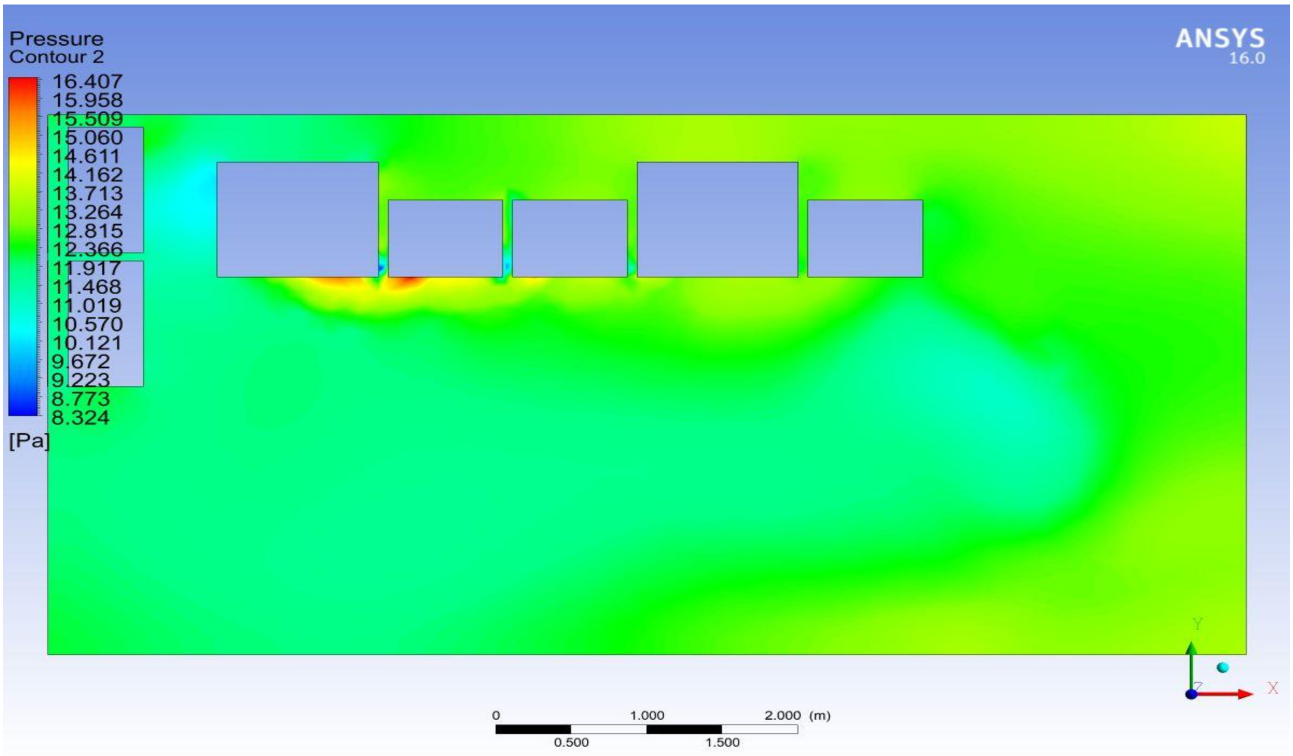


Fig:88

Fig:88 represents the pressure distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis

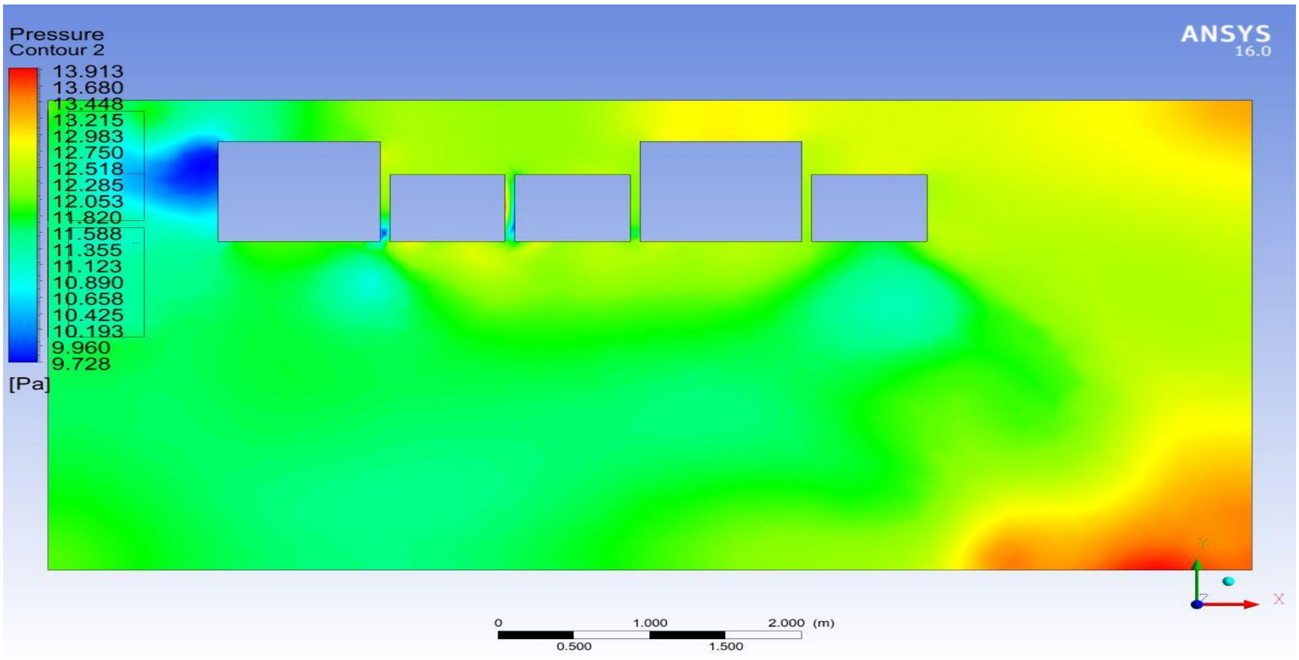


Fig:89

Fig:89 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

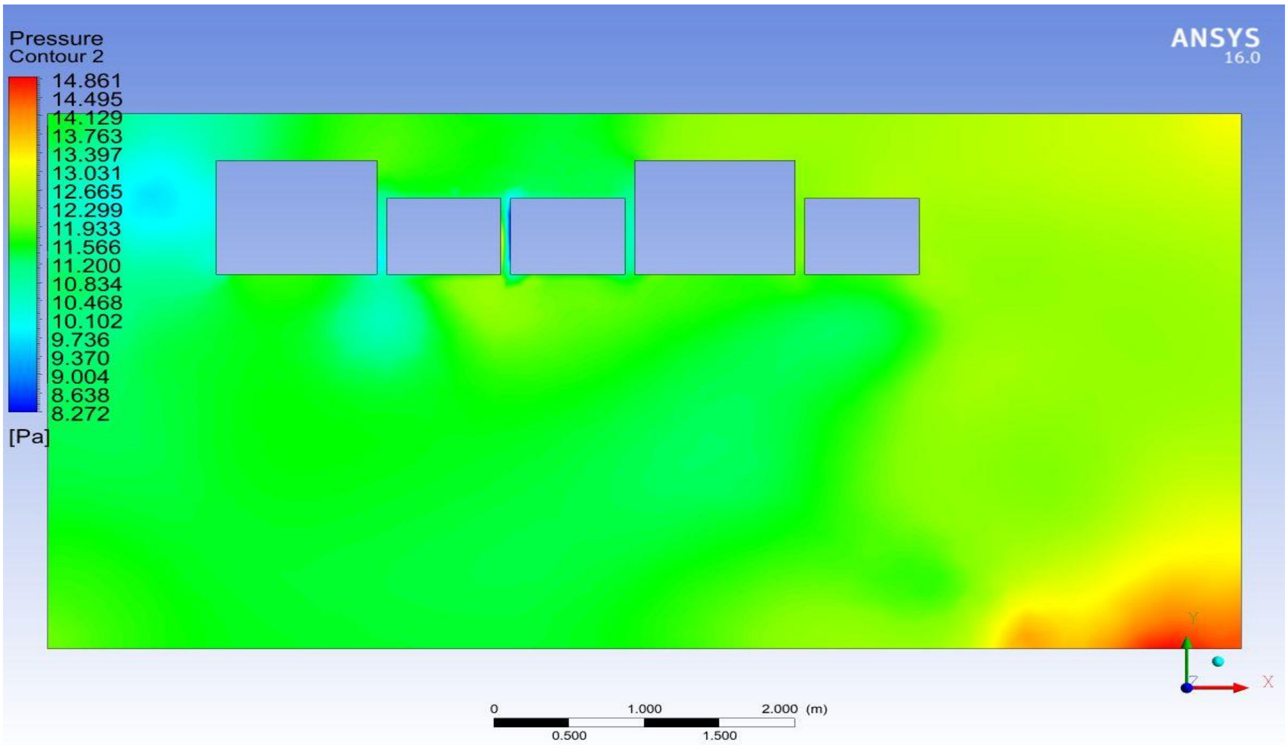


Fig:90

Fig:90 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

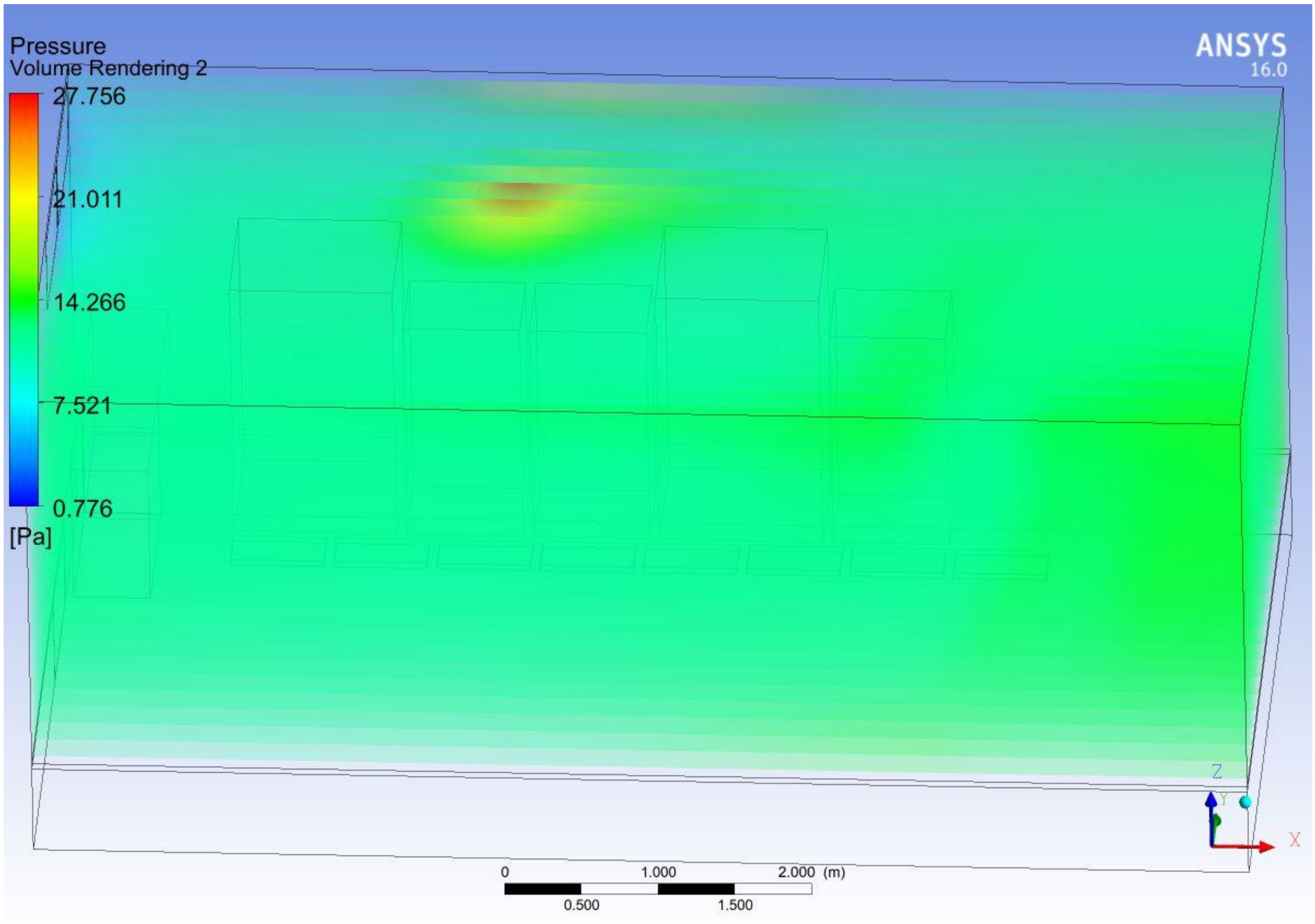


Fig:91

Fig:91 represents the pressure distribution of volume of air present in the server room space located above the raised floor.

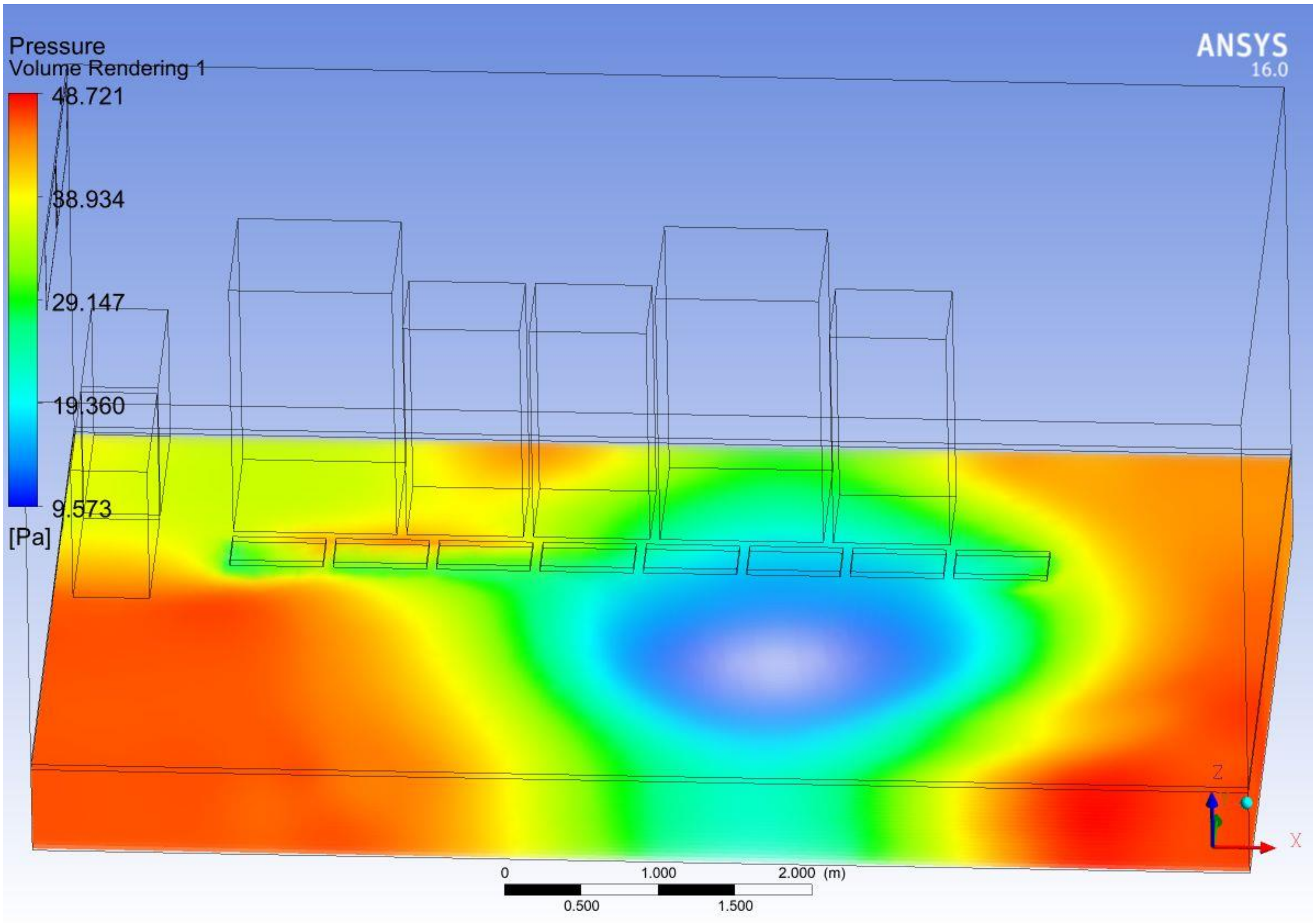


Fig:92

Fig:92 represents the pressure distribution of volume of air present in the server room space located below the raised floor.

iii) Velocity Contour:

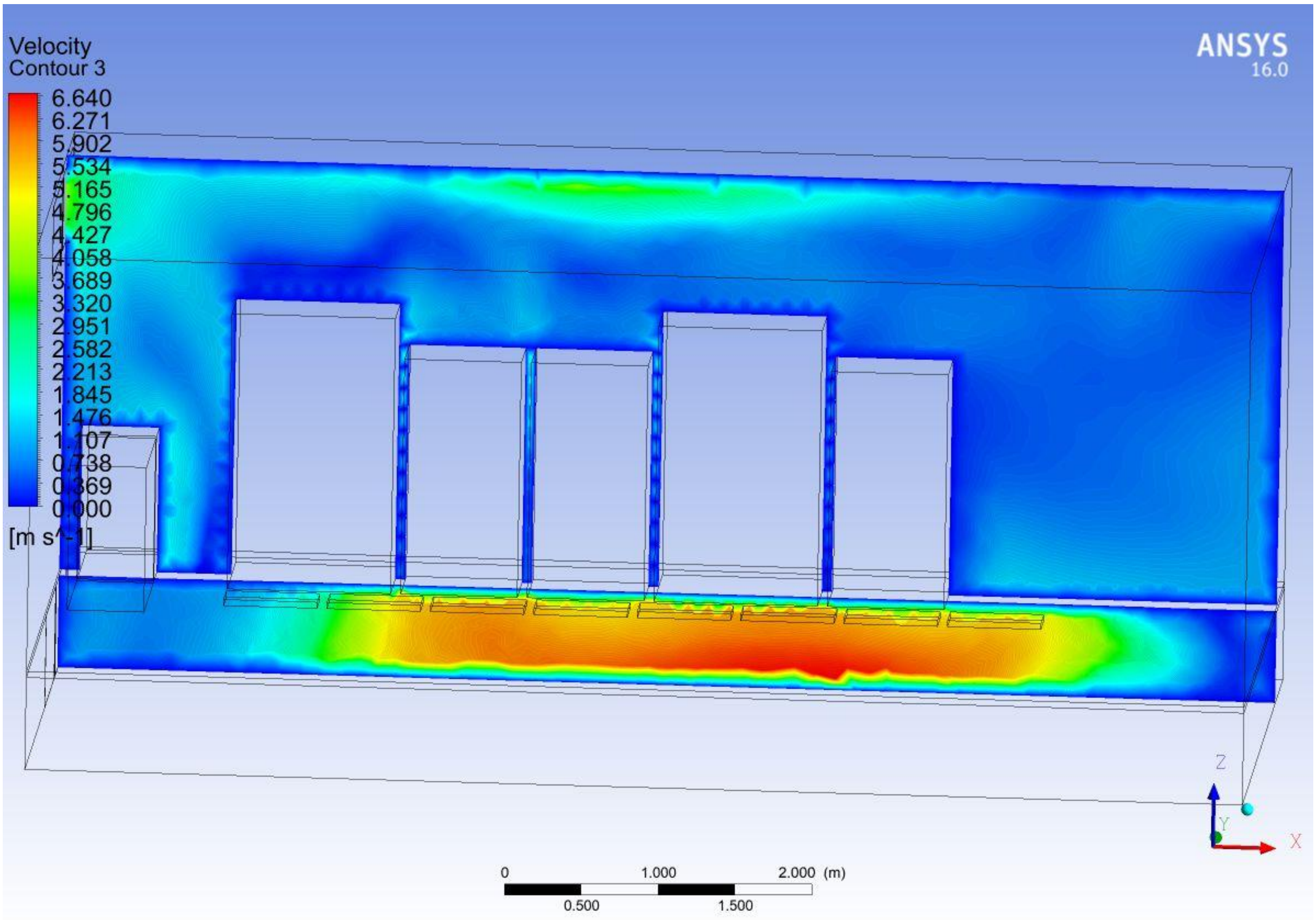


Fig:93

Fig:93 represents the pressure distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

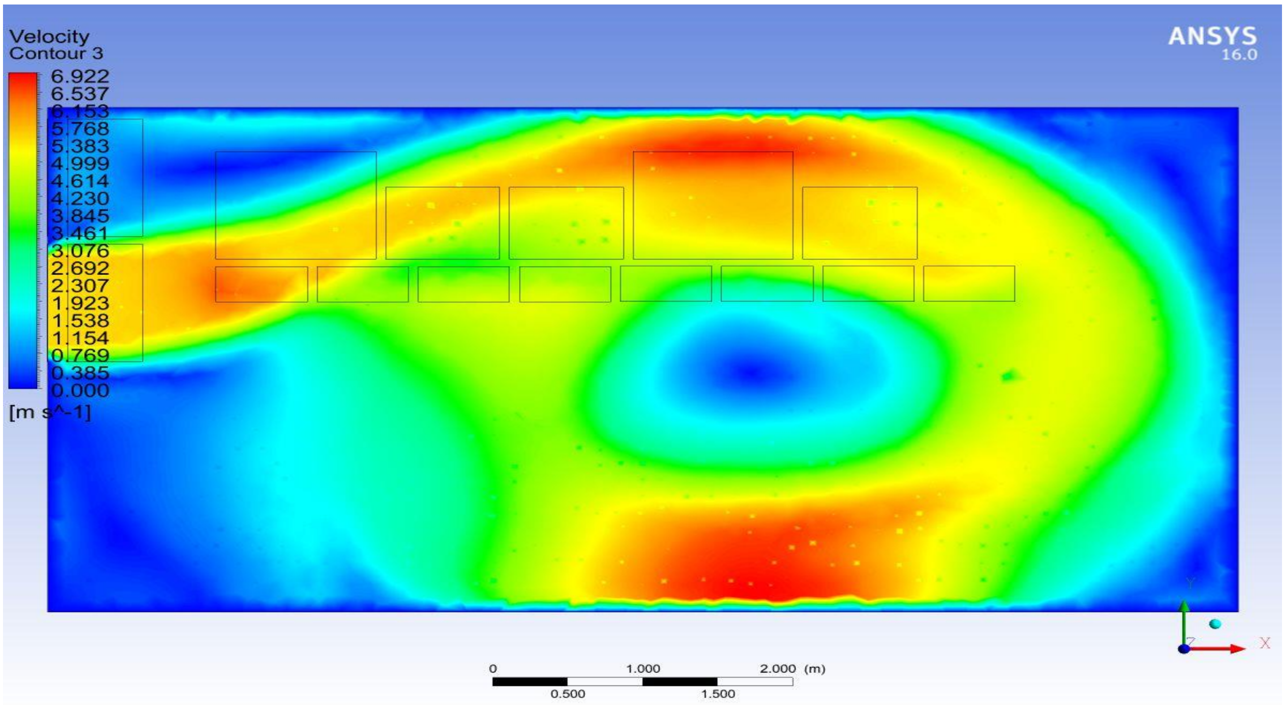


Fig:94

Fig:94 represents the velocity distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

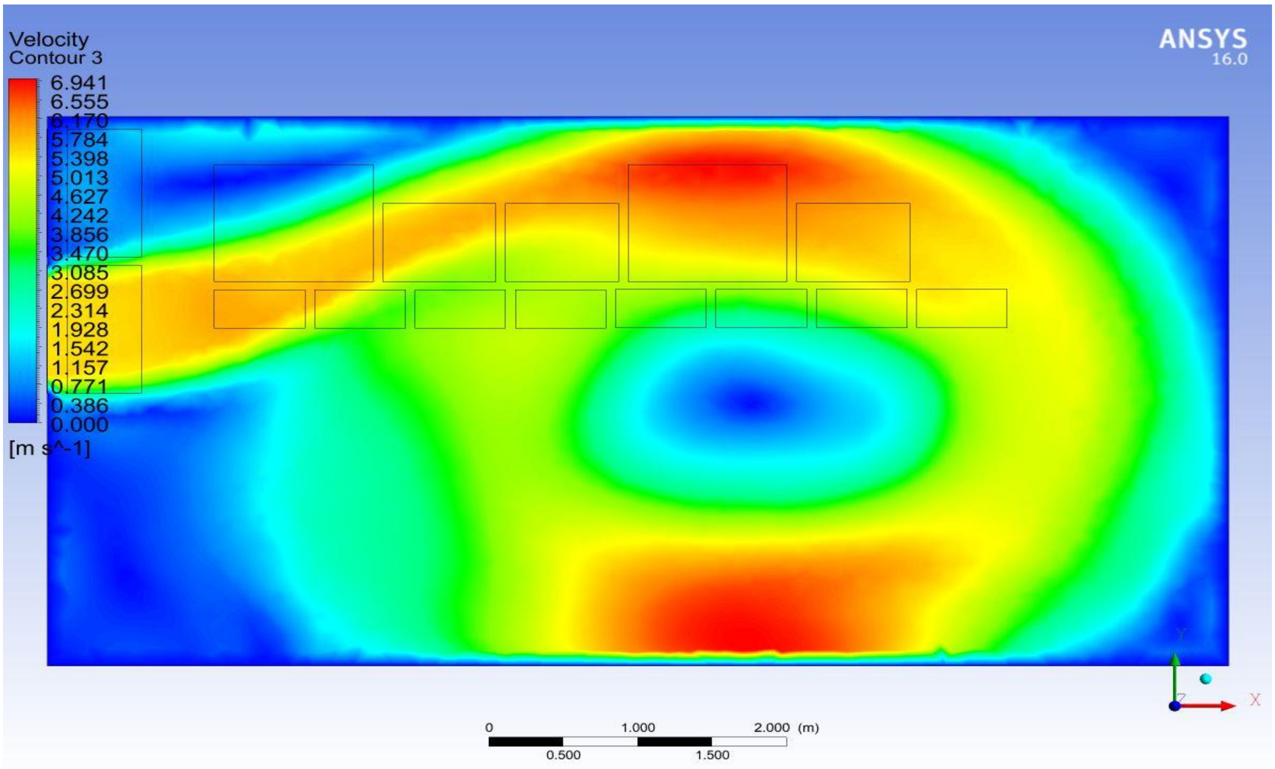


Fig:95

Fig:95 represents the velocity distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

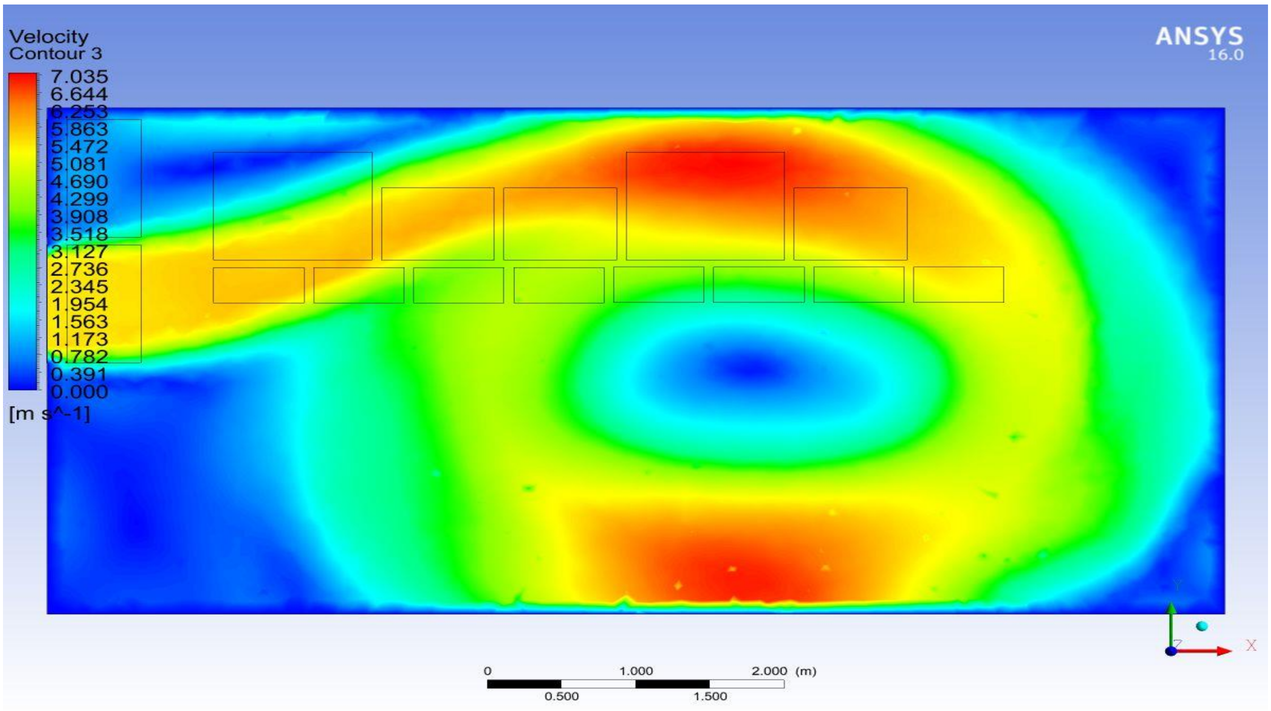


Fig:96

Fig:96 represents the velocity distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

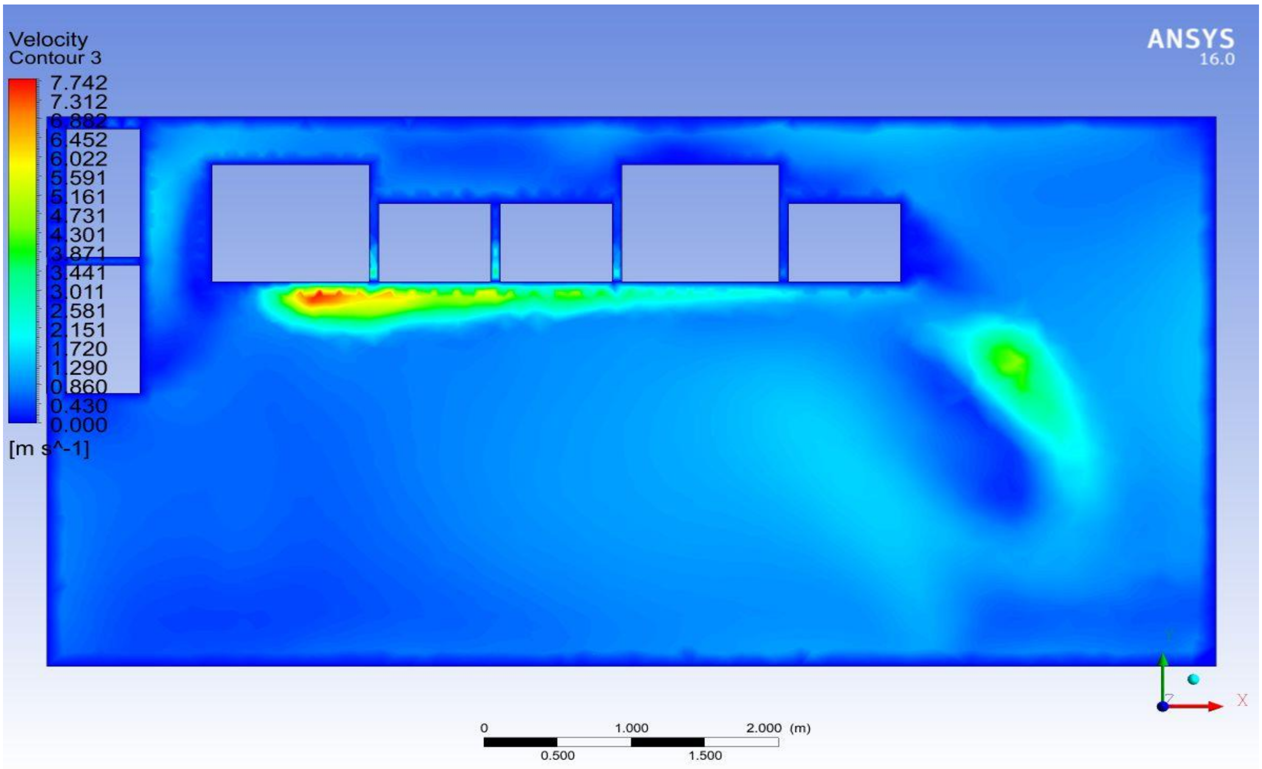


Fig:97

Fig:97 represents the velocity distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

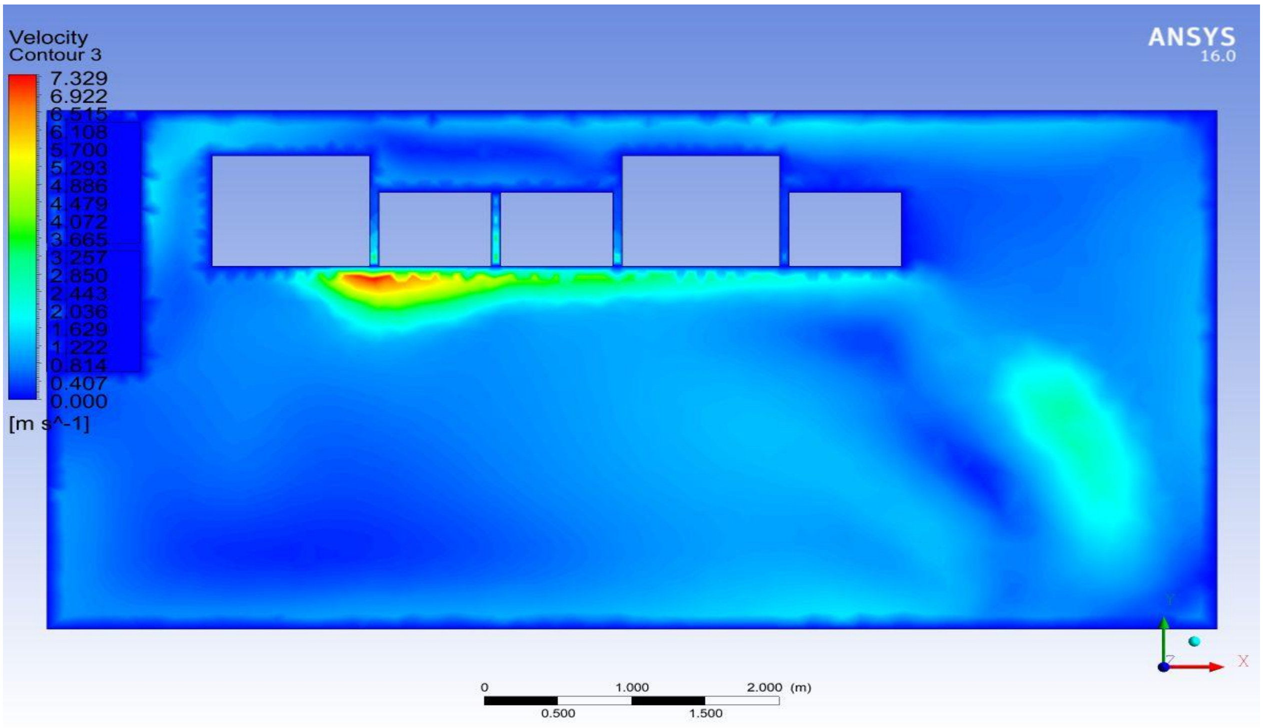


Fig:98

Fig:98 represents the velocity distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

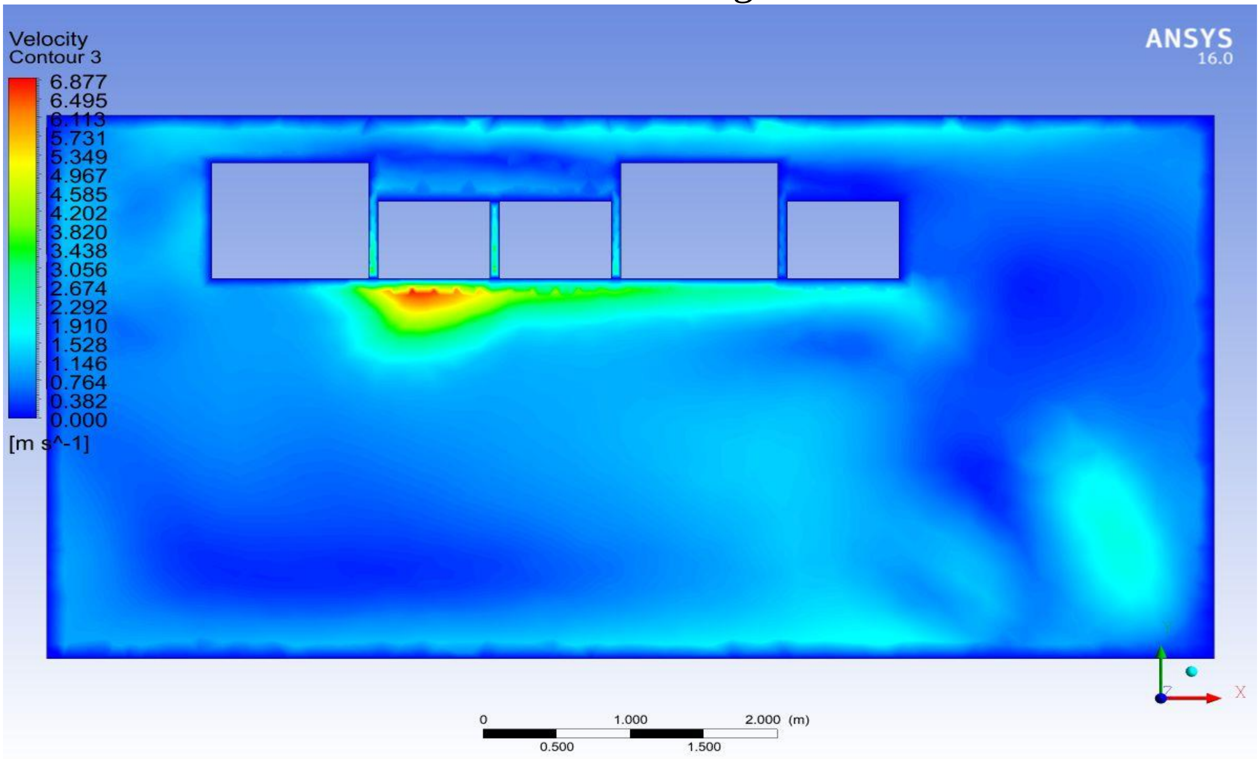


Fig:99

Fig:99 represents the velocity distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

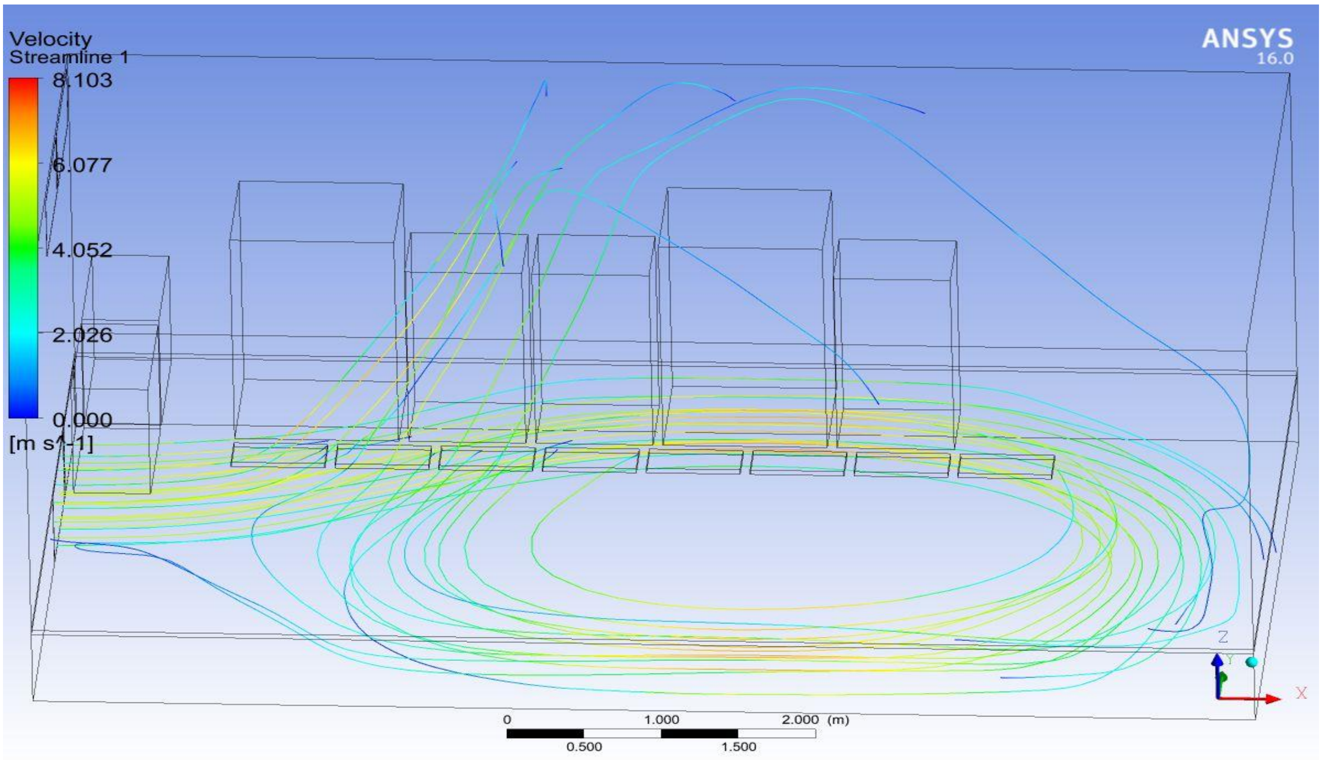


Fig:100

Fig:100 shows velocity streamlines from inlet 1 towards the raised floor space

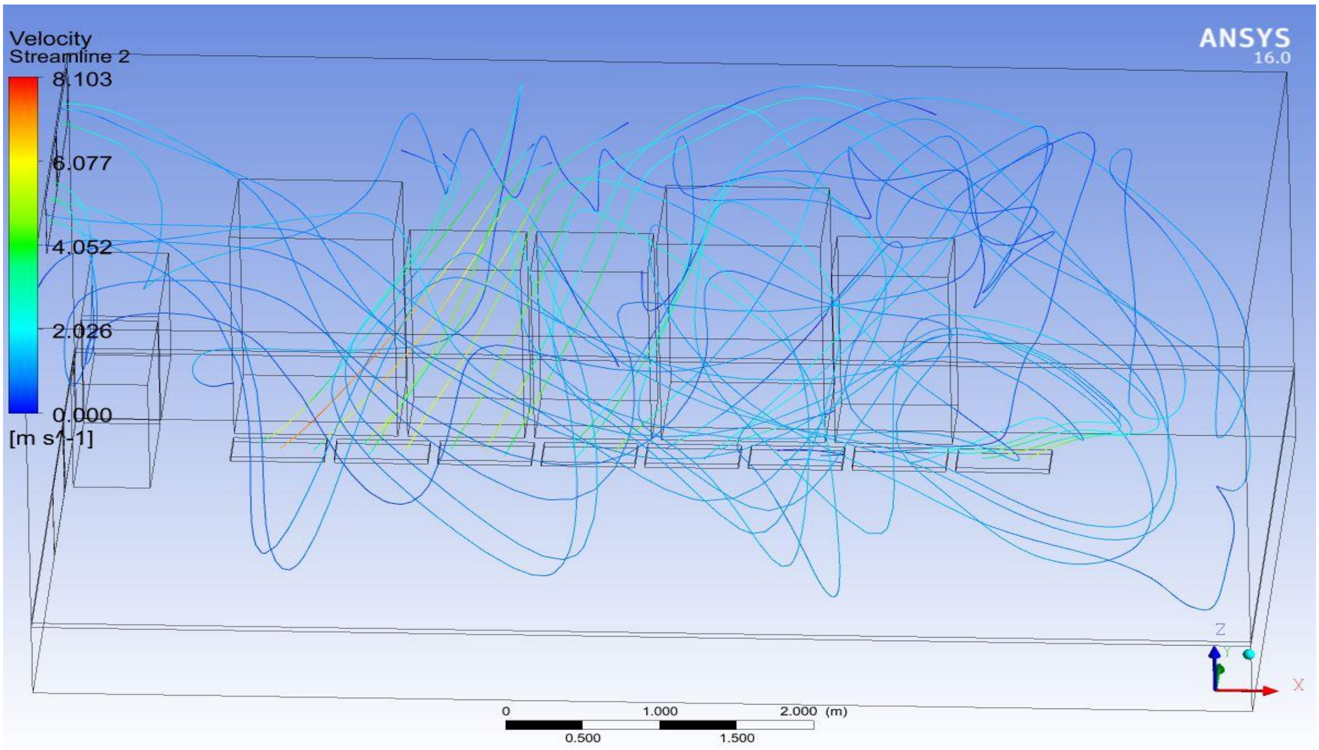


Fig:101

Fig:101 show velocity streamline at the vents of the tiles towards the server room space.

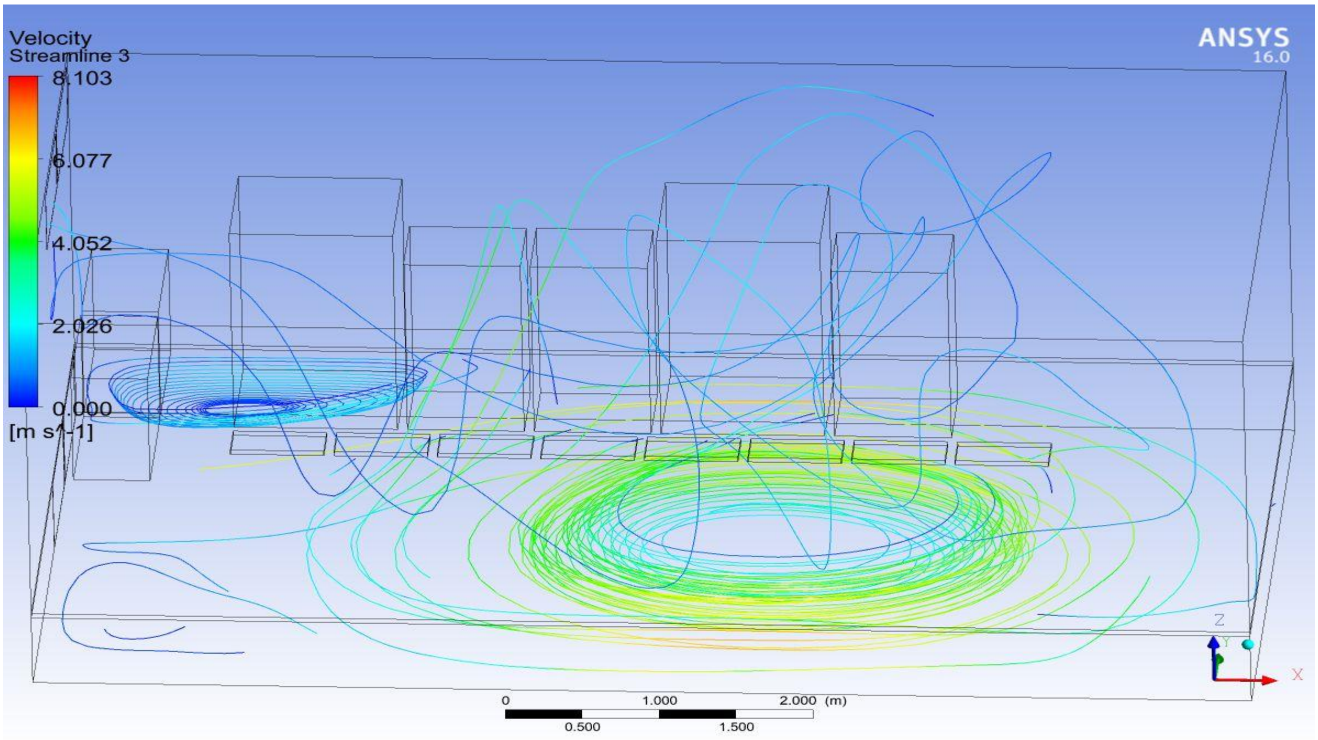


Fig:102

Fig:102 show velocity streamline at the raised floor space.

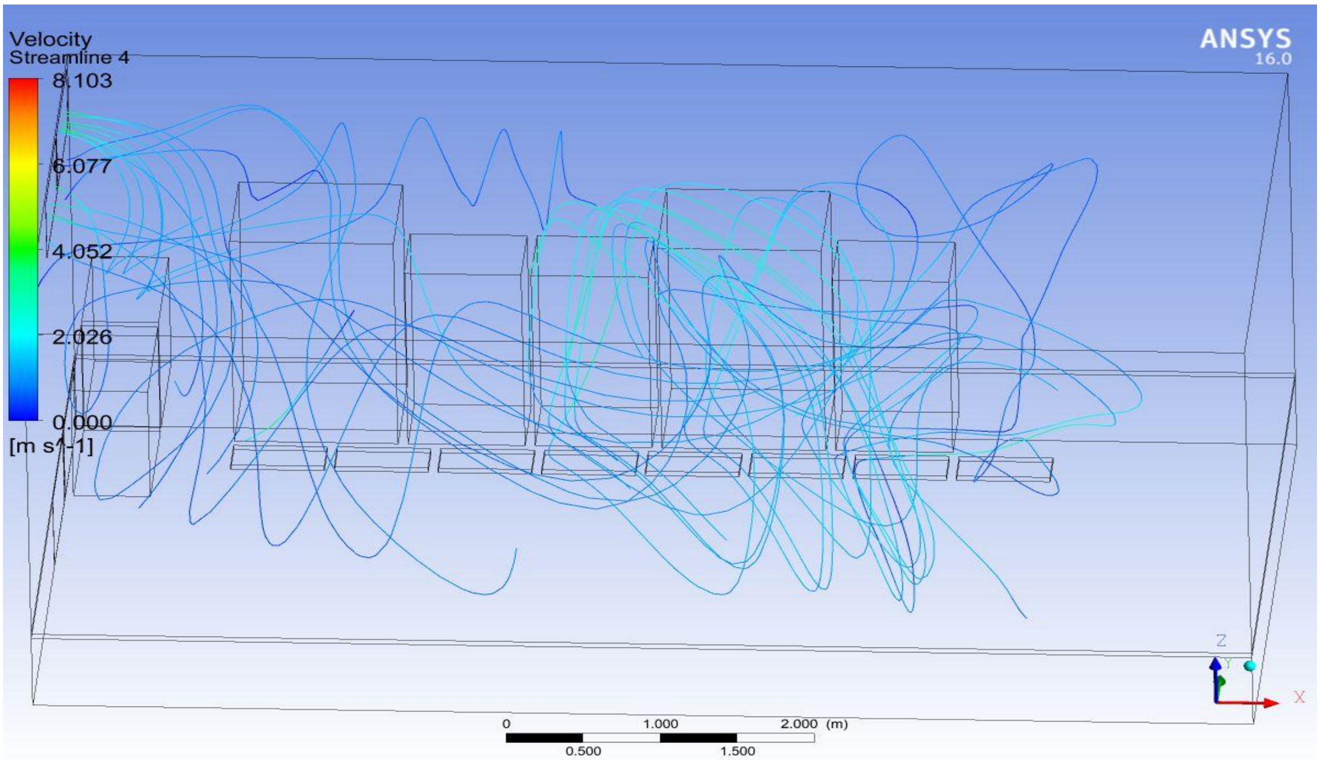


Fig:103

Fig:103 shows velocity streamline at the server room floor space

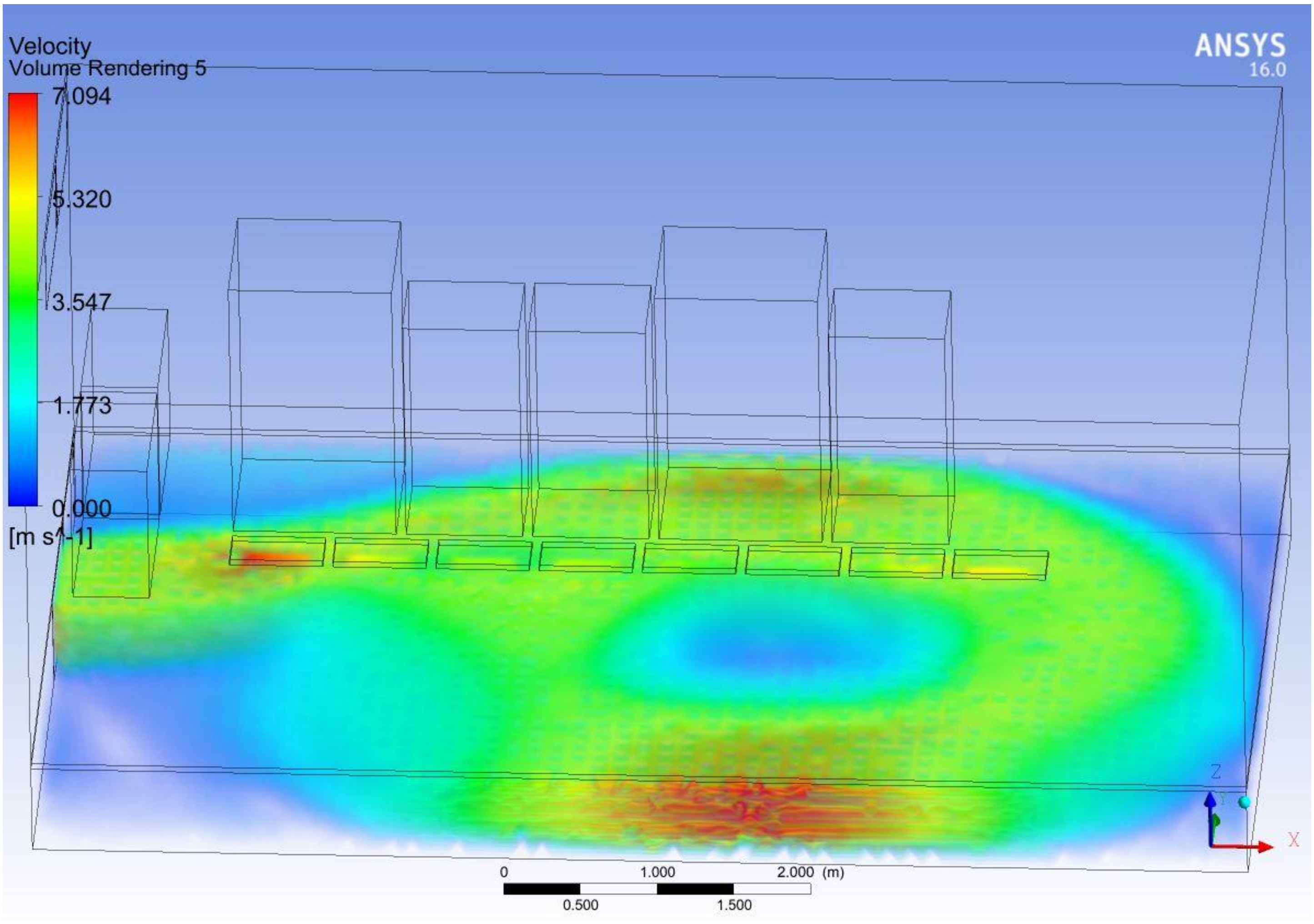


Fig:104

Fig:104 represents the velocity distribution of volume of air present below the raised floor.

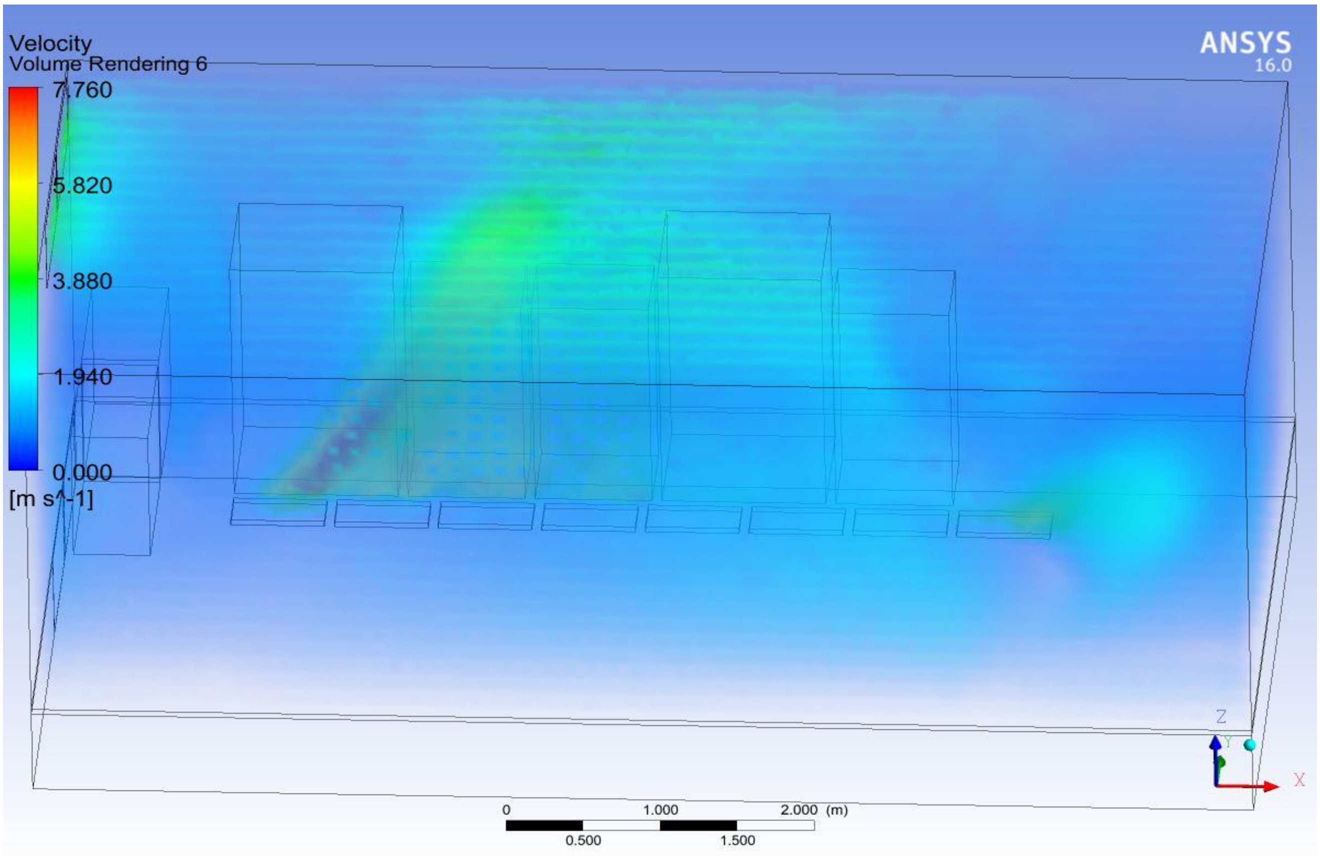


Fig:105

Fig:105 represents the velocity distribution of volume of air present above the raised floor.

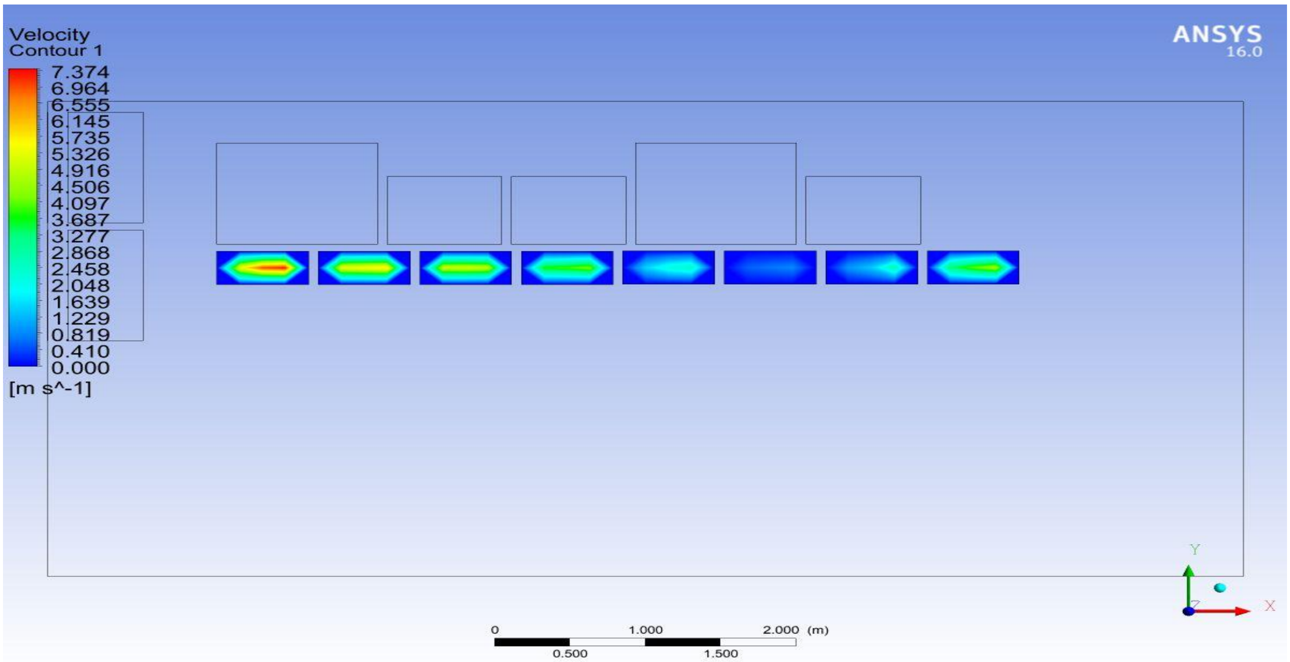


Fig:106

Fig:106 represents the velocity distribution of air at vents of tiles.

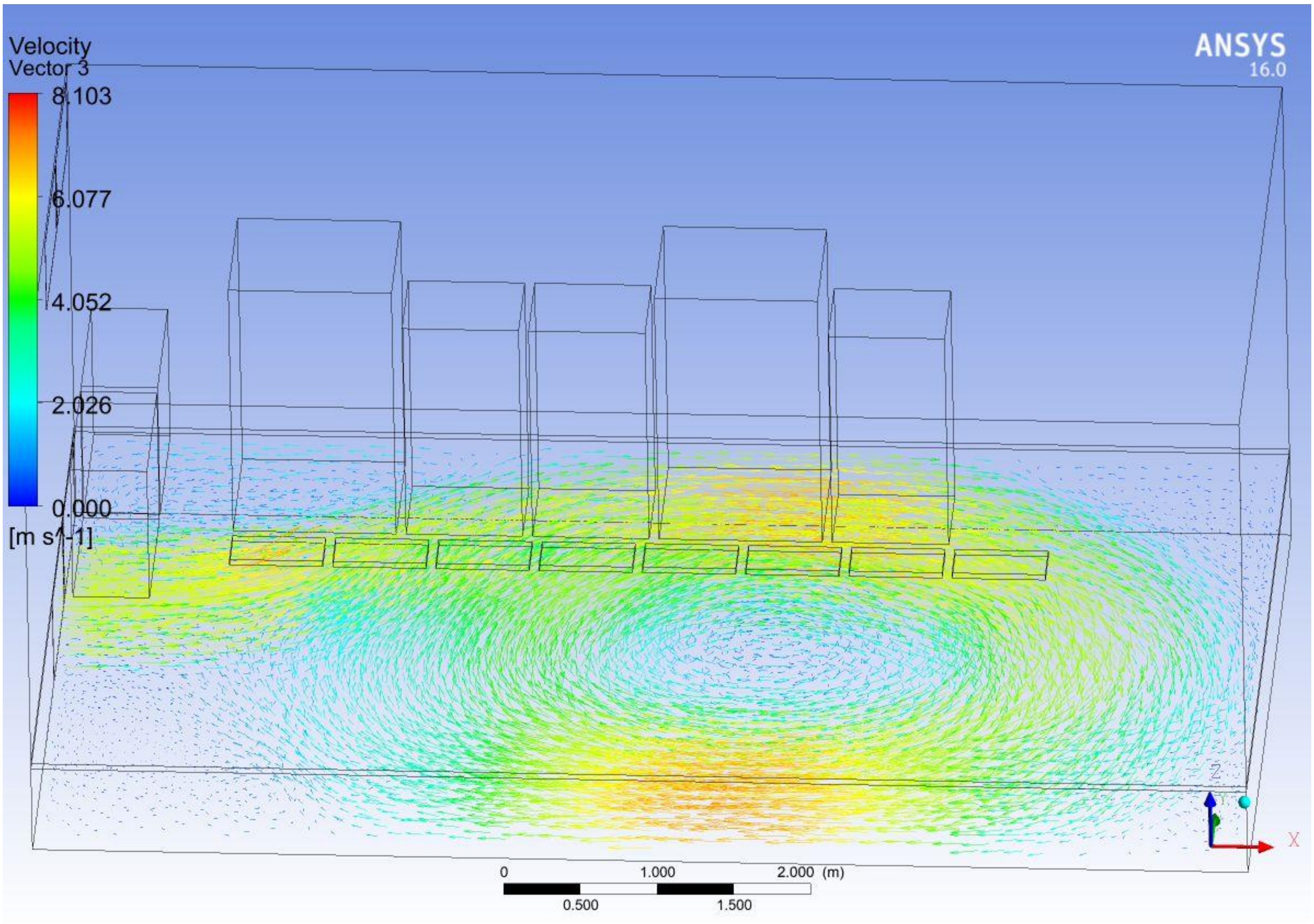


Fig:107

Fig:107 represents the velocity vector distribution of air present below the raised floor.

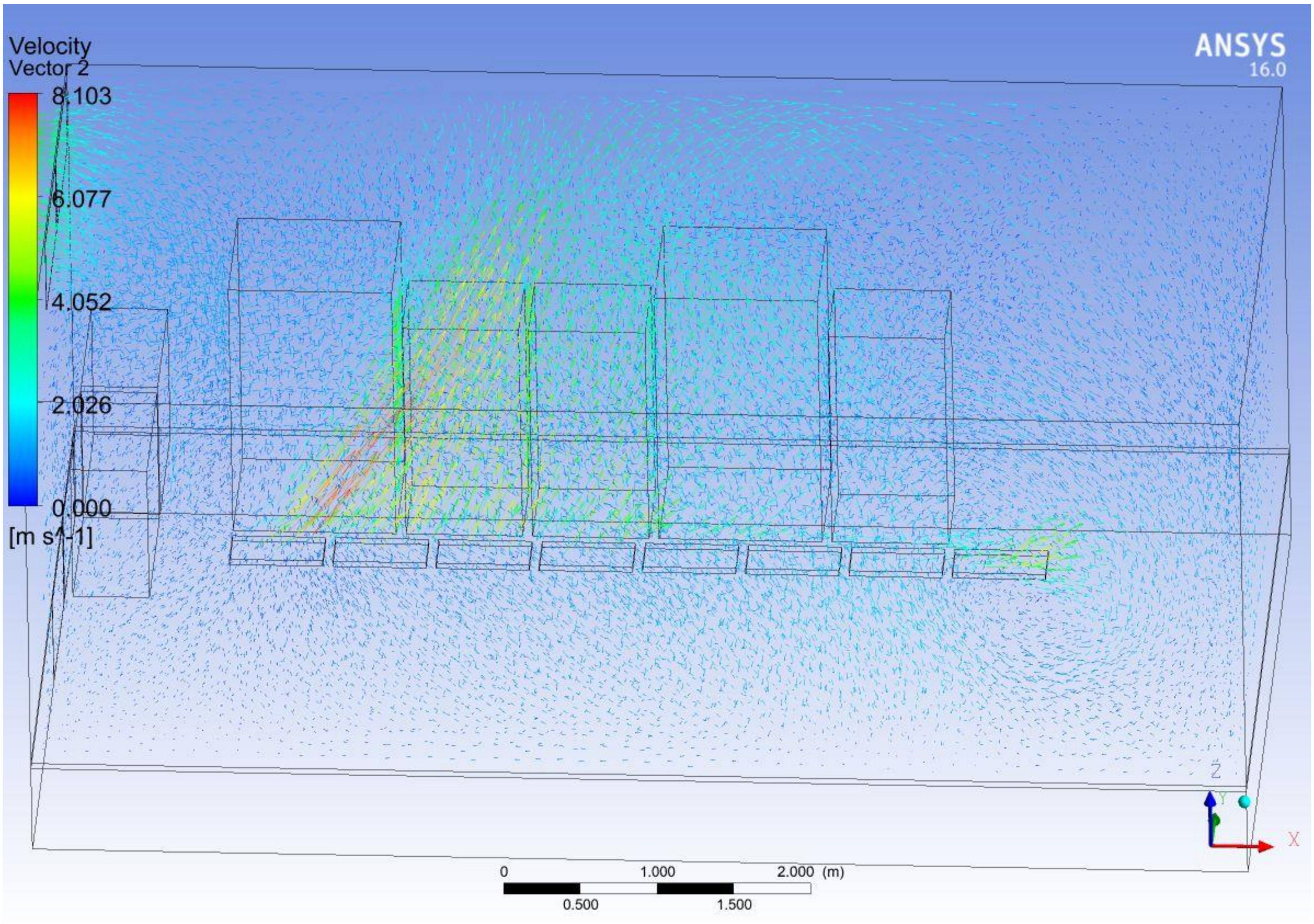


Fig:108

Fig:108 represents the velocity vector distribution of air present above the raised floor.

d) CASE IV (Temperature of air at CRAC outlet is 282 K and heat generation from each server rack is 1750 W/ cum.)

i) Temperature Contour:

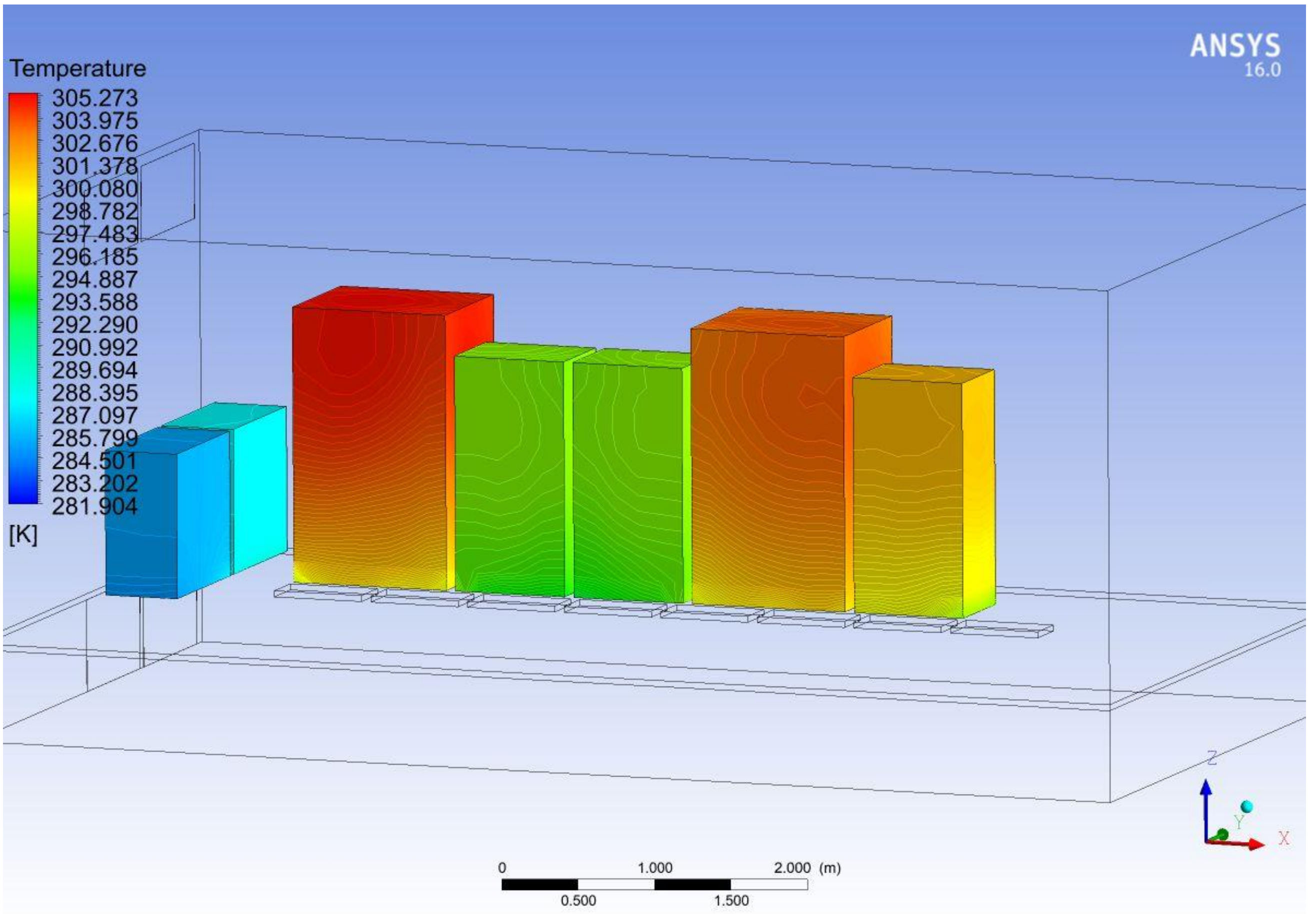


Fig:109

Fig:109 represents the temperature distribution of five server racks. The temperature distribution of crac and server racks are clearly visible from the temperature colour coding mentioned above.

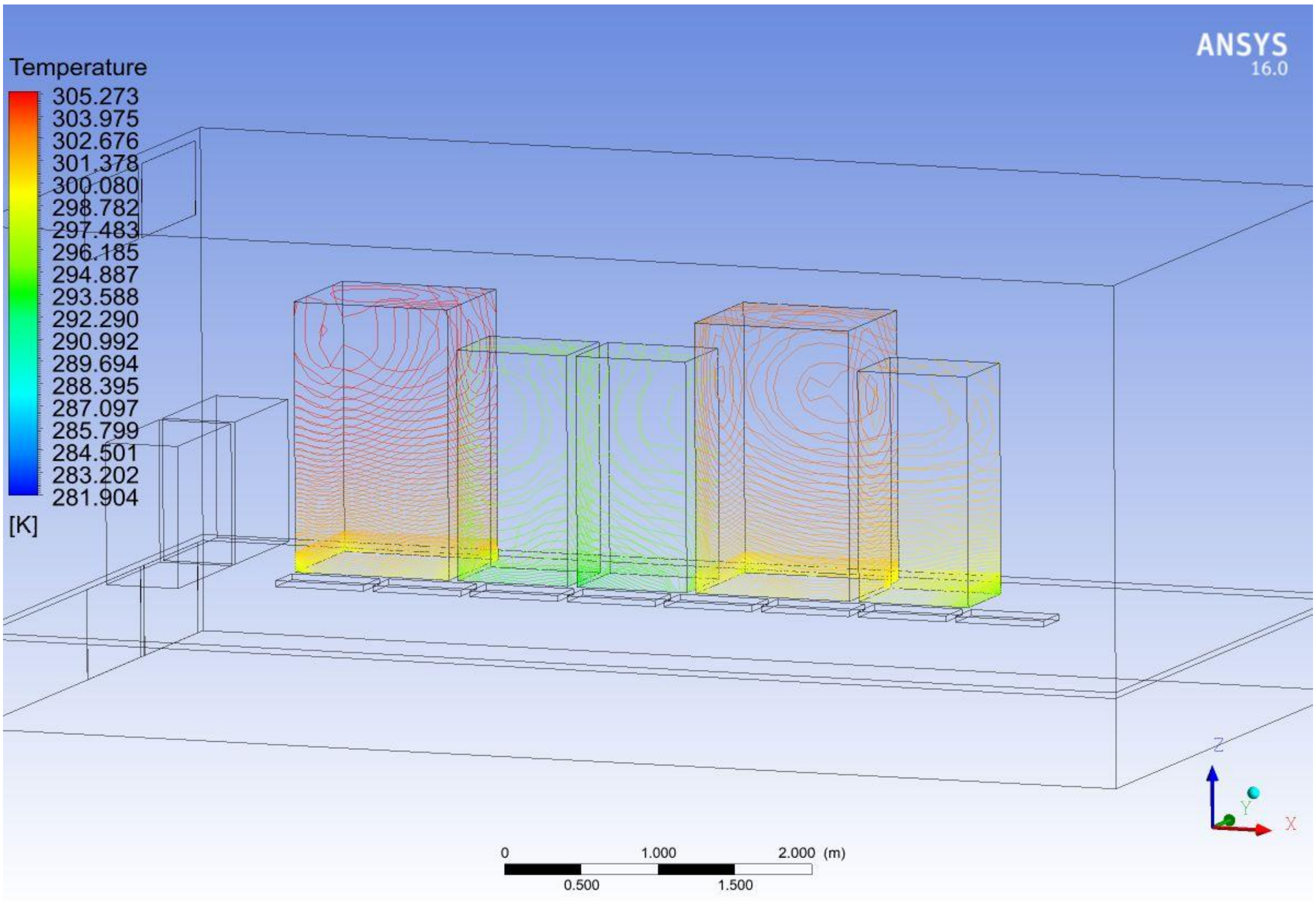


Fig:110

Fig:110 represents the temperature isotherms distribution of five server racks. The temperature isotherms distribution of server racks are clearly visible from the temperature colour coding mentioned above.

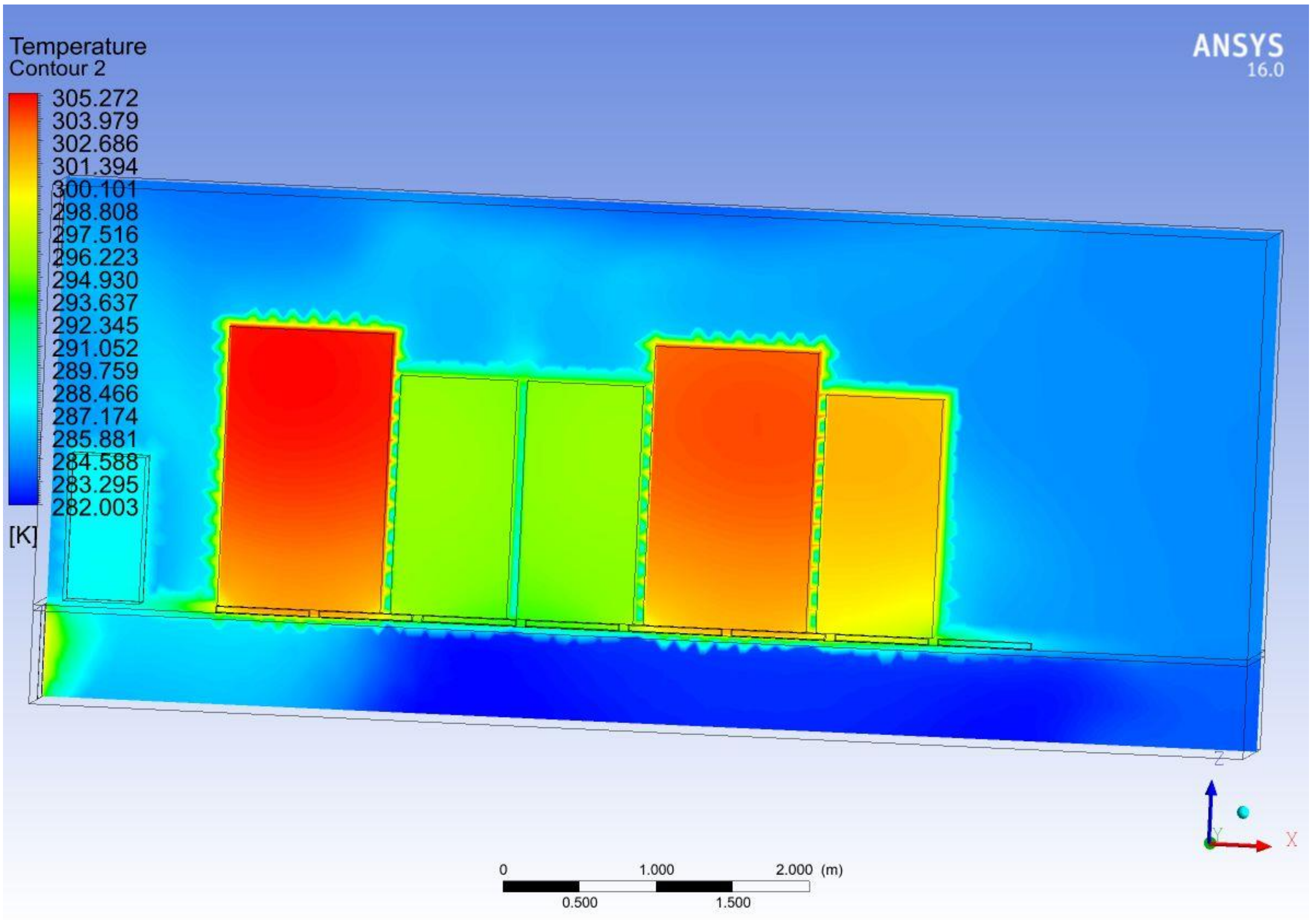


Fig:111

Fig:111 represents the temperature distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

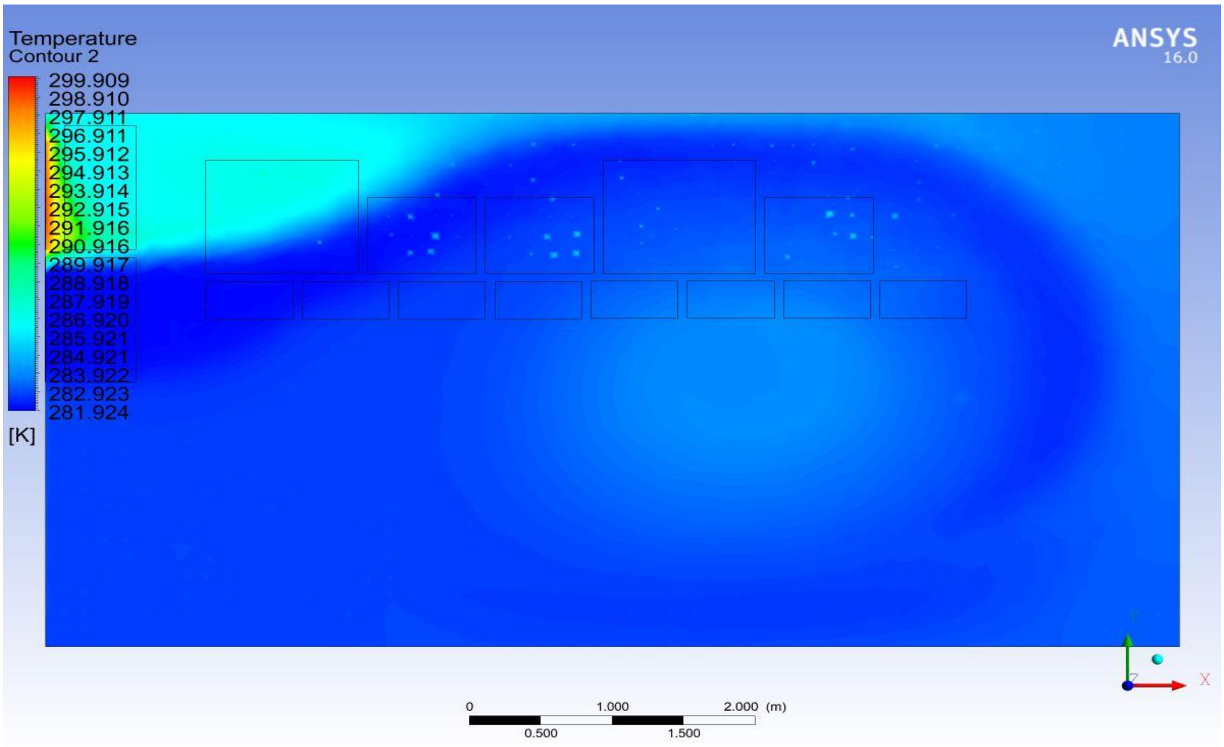


Fig:112

Fig:112 represents the temperature distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

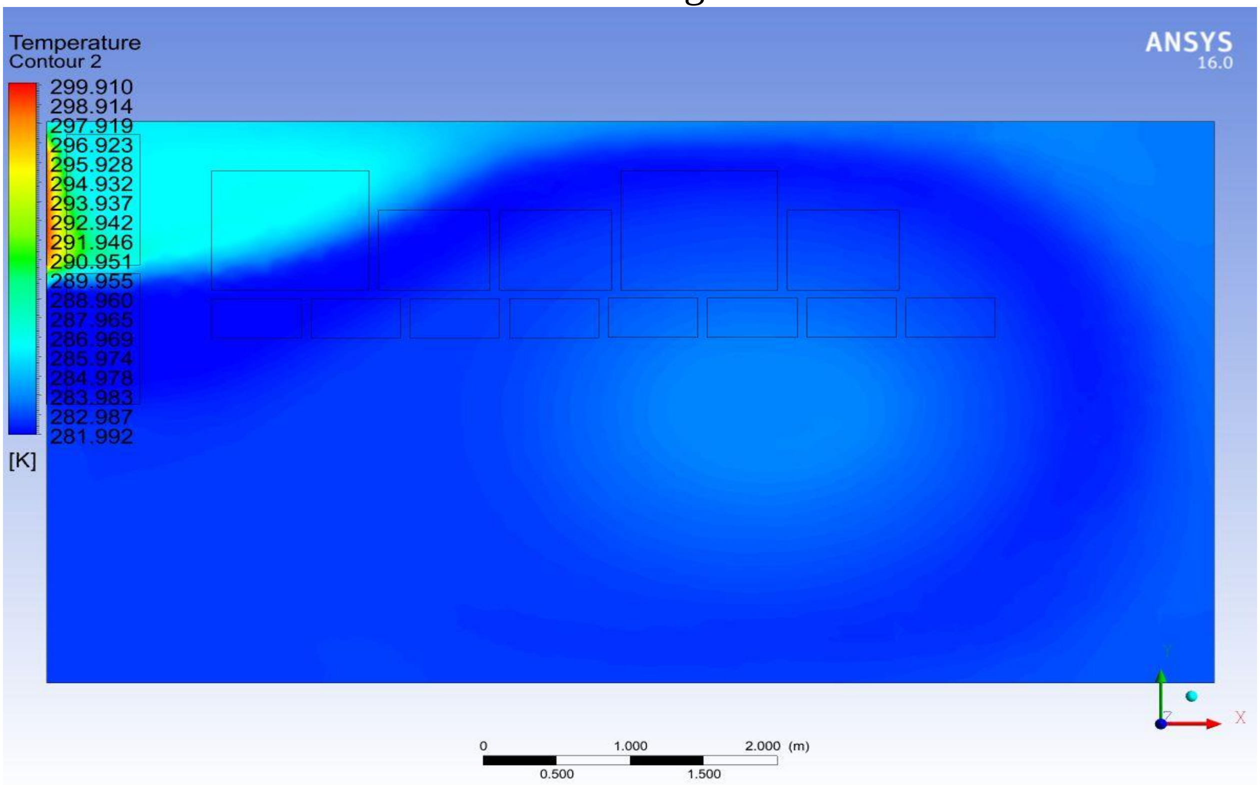


Fig:113

Fig:113 represents the temperature distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

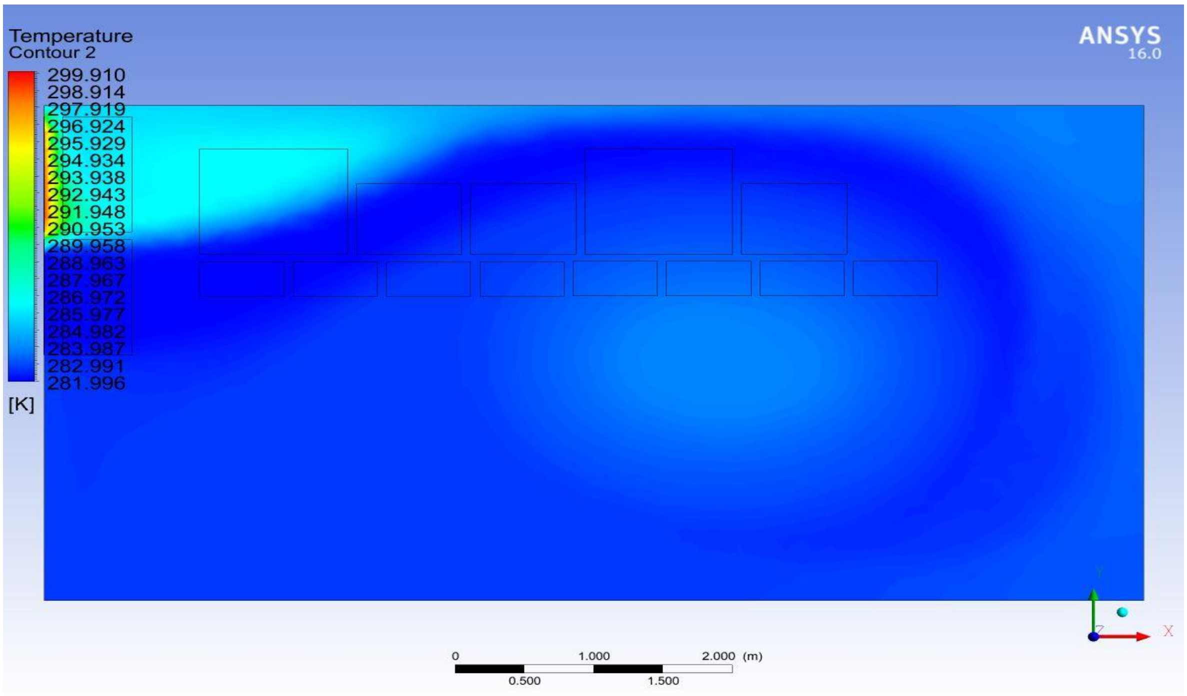


Fig:114

Fig:114 represents the temperature distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

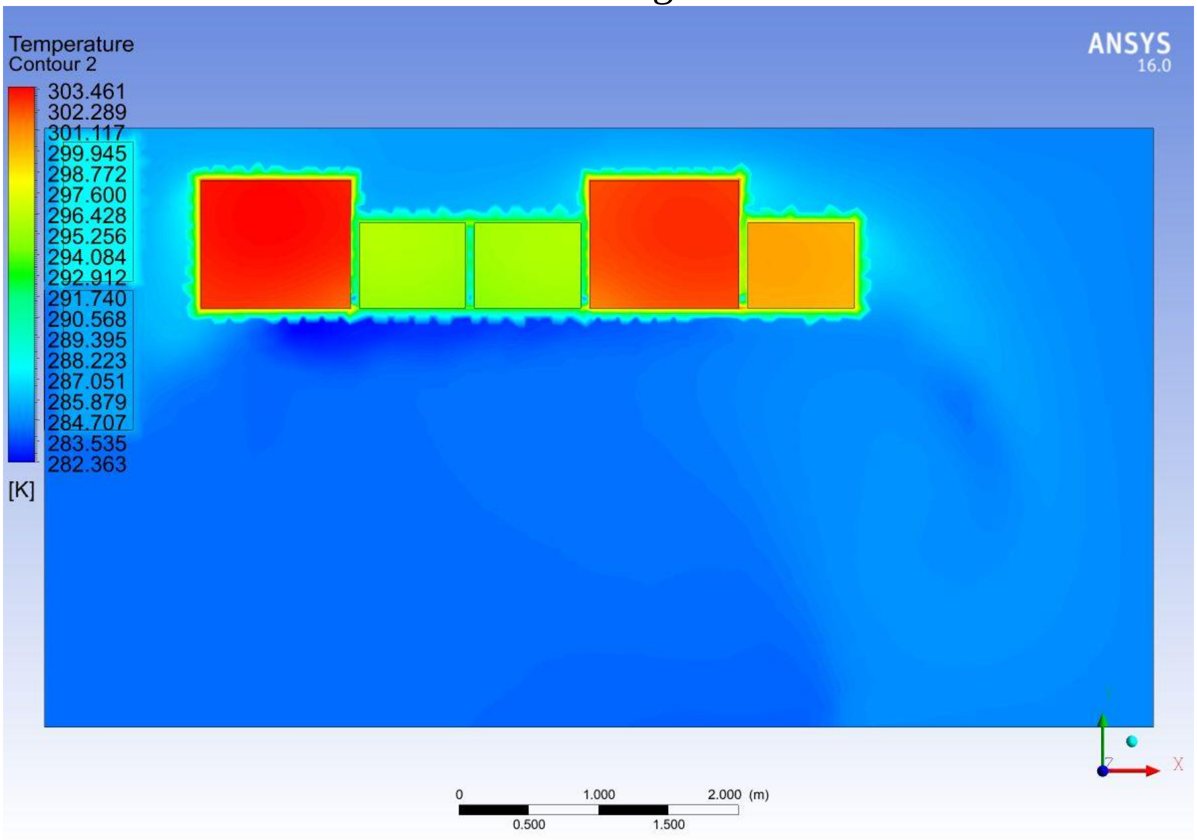


Fig:115

Fig:115 represents the temperature distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

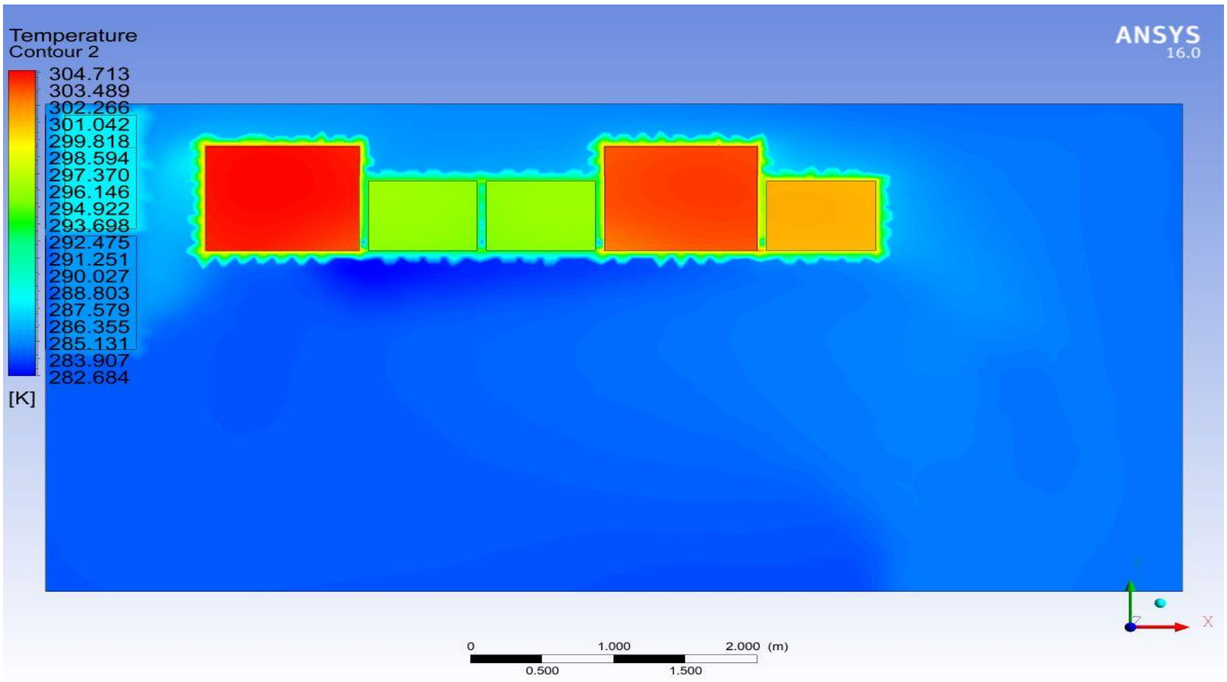


Fig:116

Fig:116 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

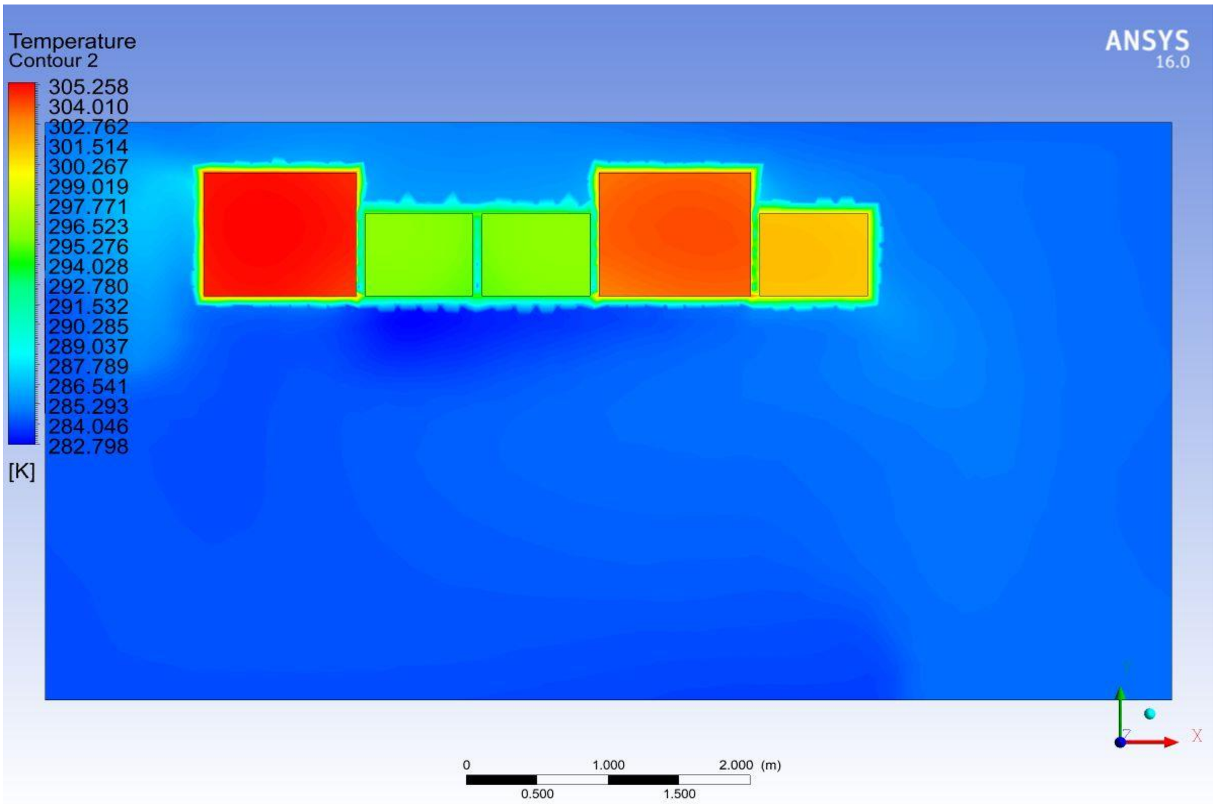


Fig:117

Fig:117 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

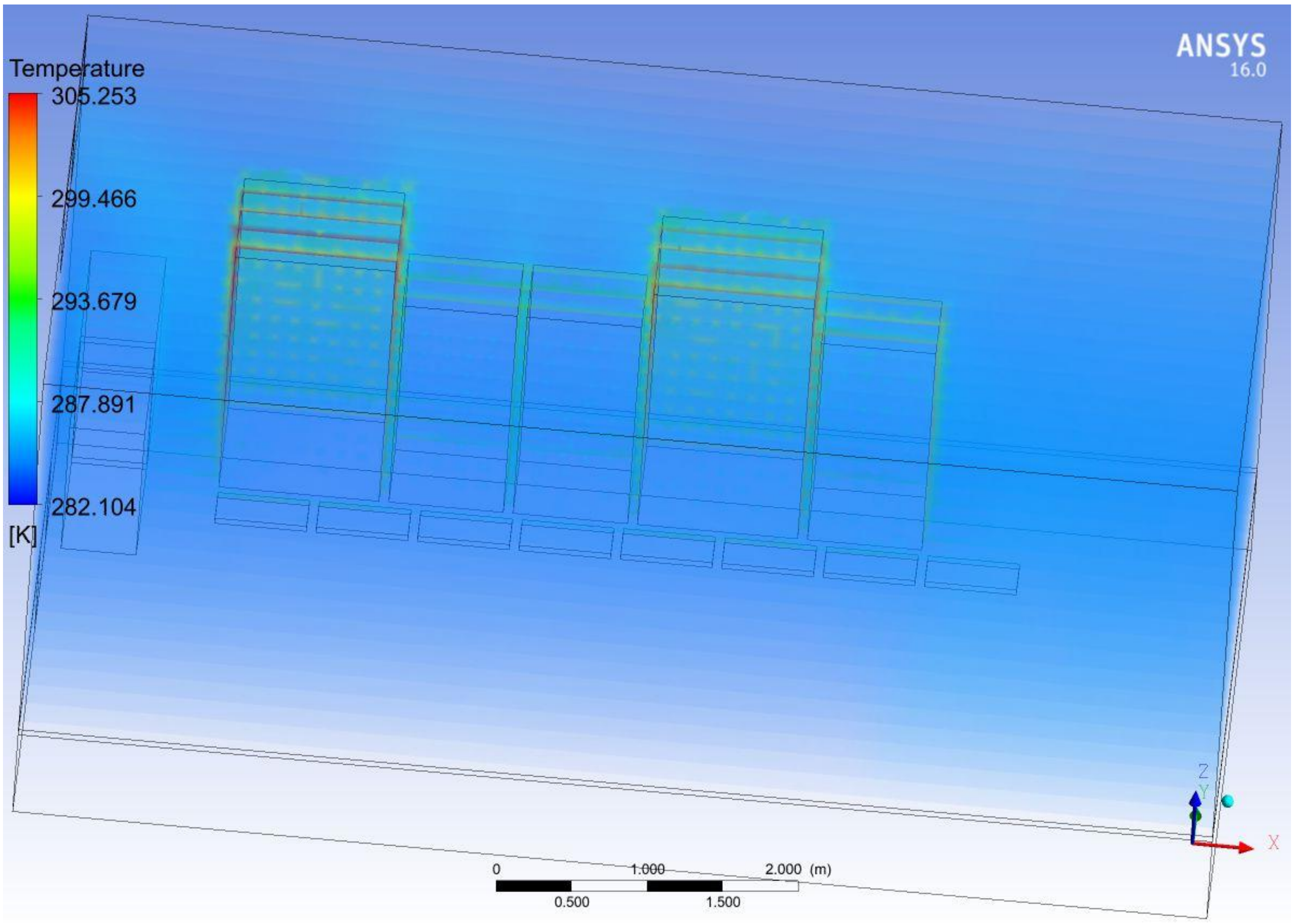


Fig:118

Fig:118 represents the temperature distribution of volume of air present in the server room space located above the raised floor.

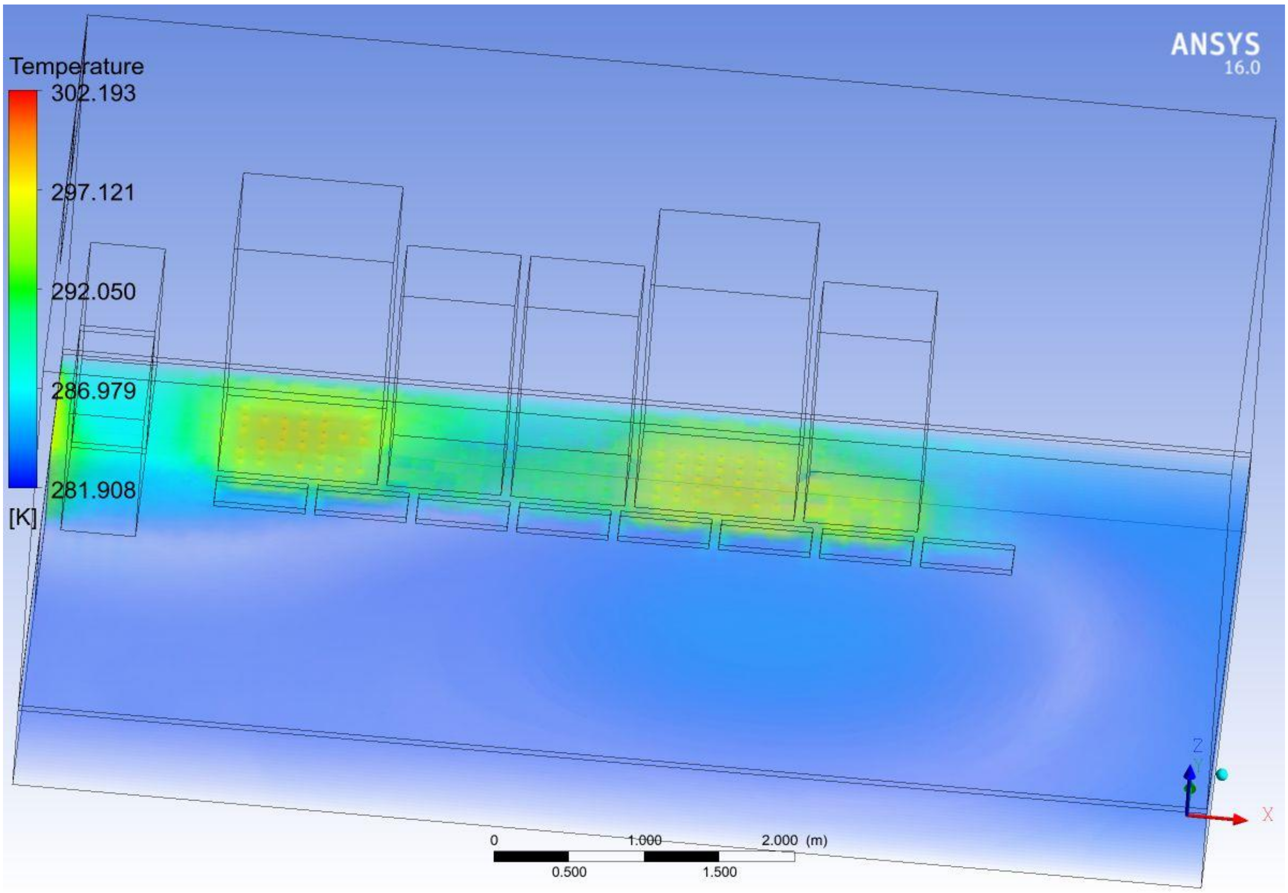


Fig:119

Fig:119 represents the temperature distribution of volume of air present in the server room space located below the raised floor.

ii) Pressure Contour:

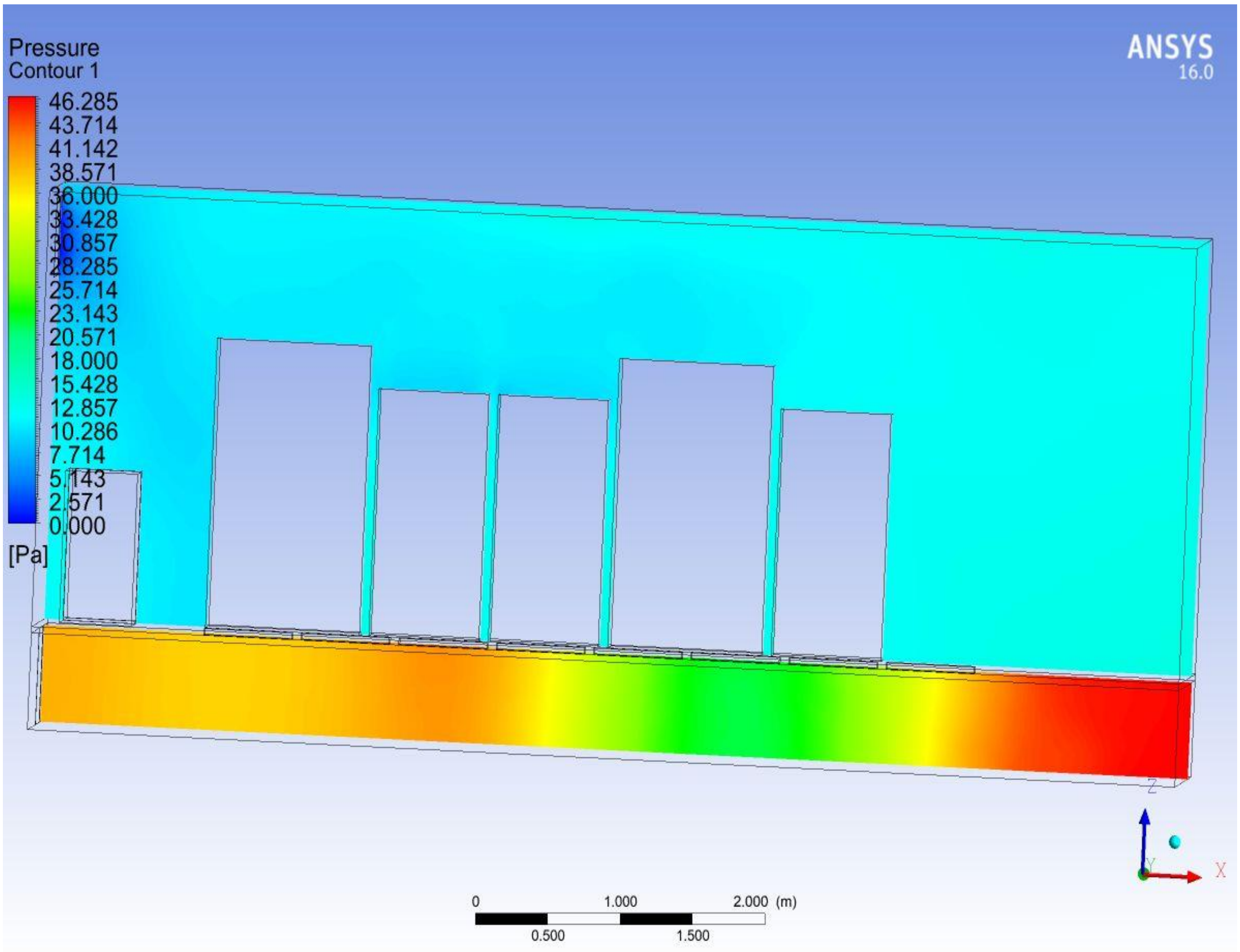


Fig:120

Fig:120 represents the pressure distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

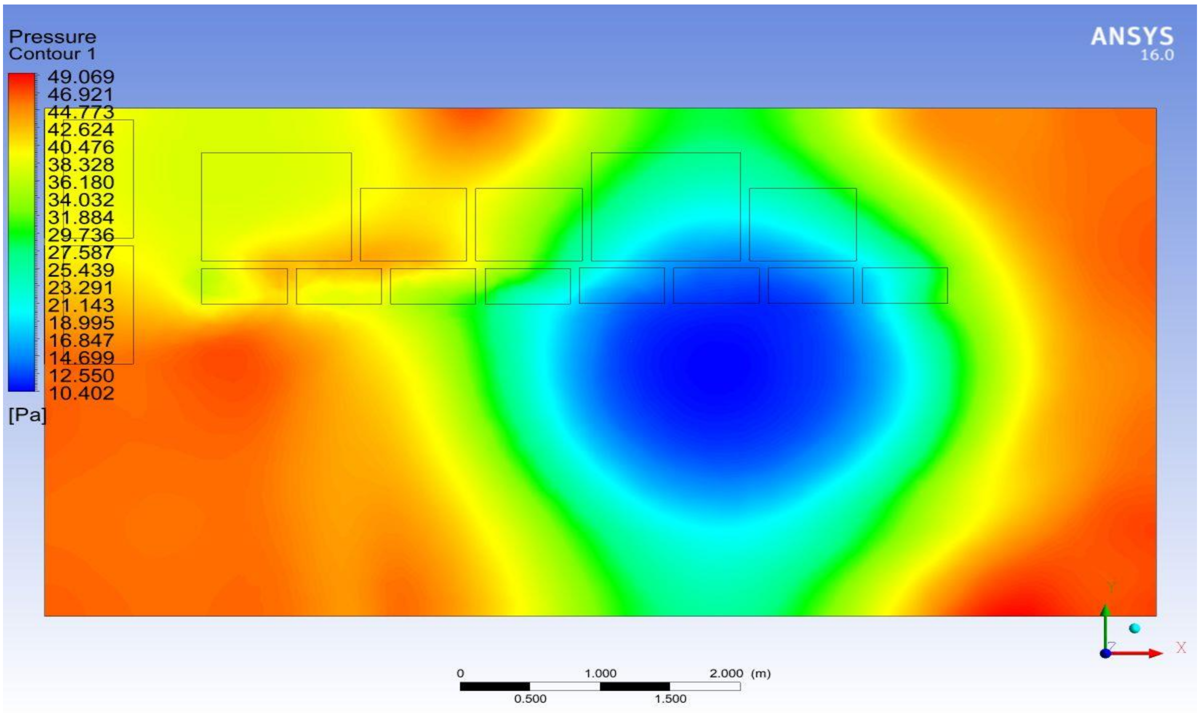


Fig:121

Fig:121 represents the pressure distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

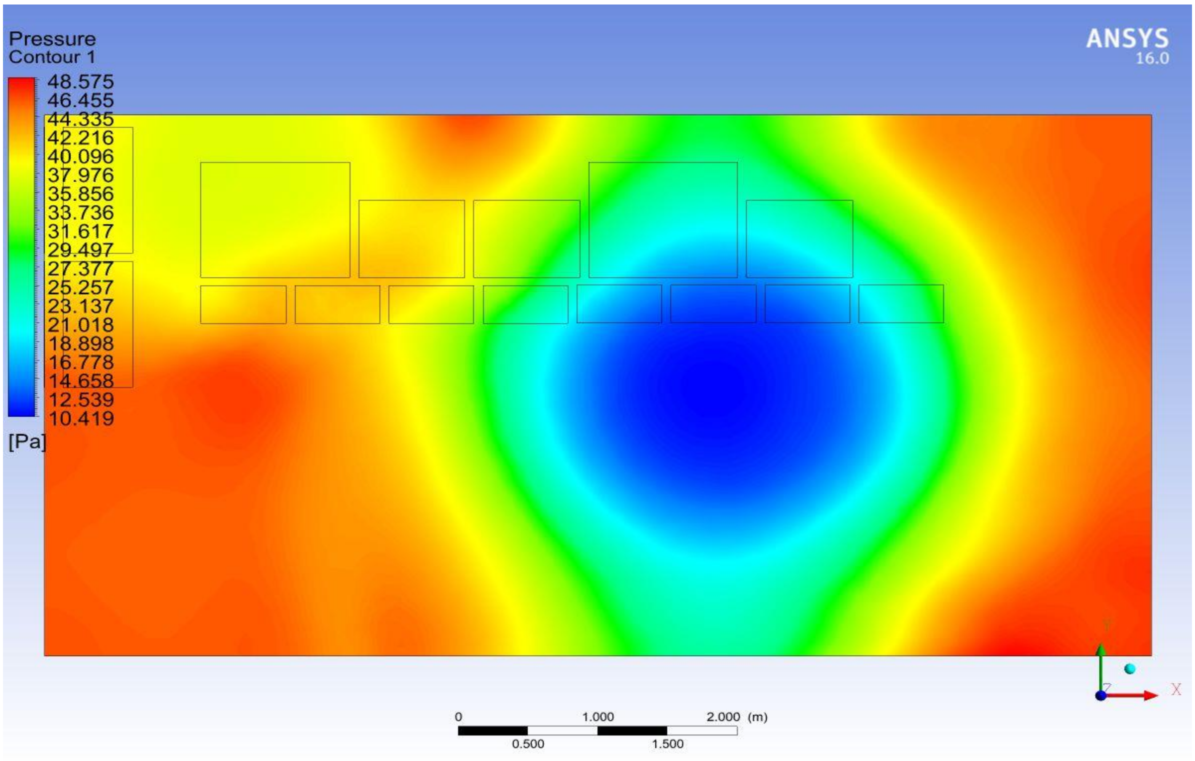


Fig:122

Fig:122 represents the pressure distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

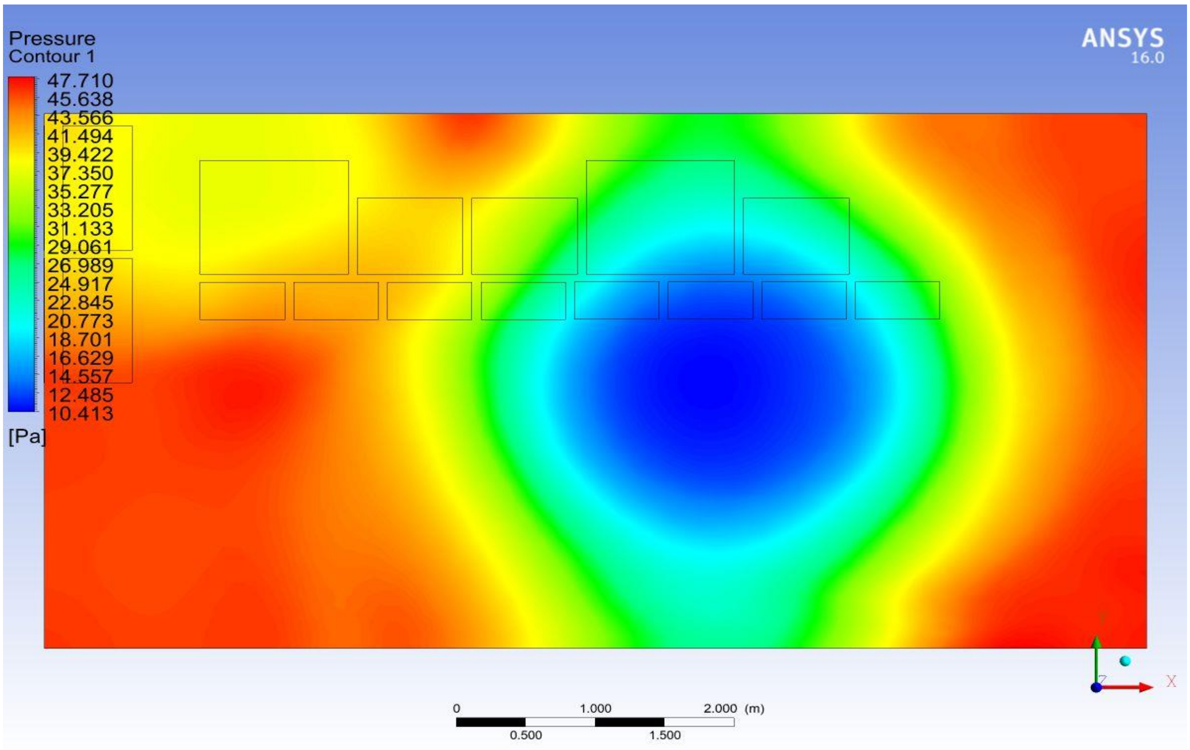


Fig:123

Fig:123 represents the pressure distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

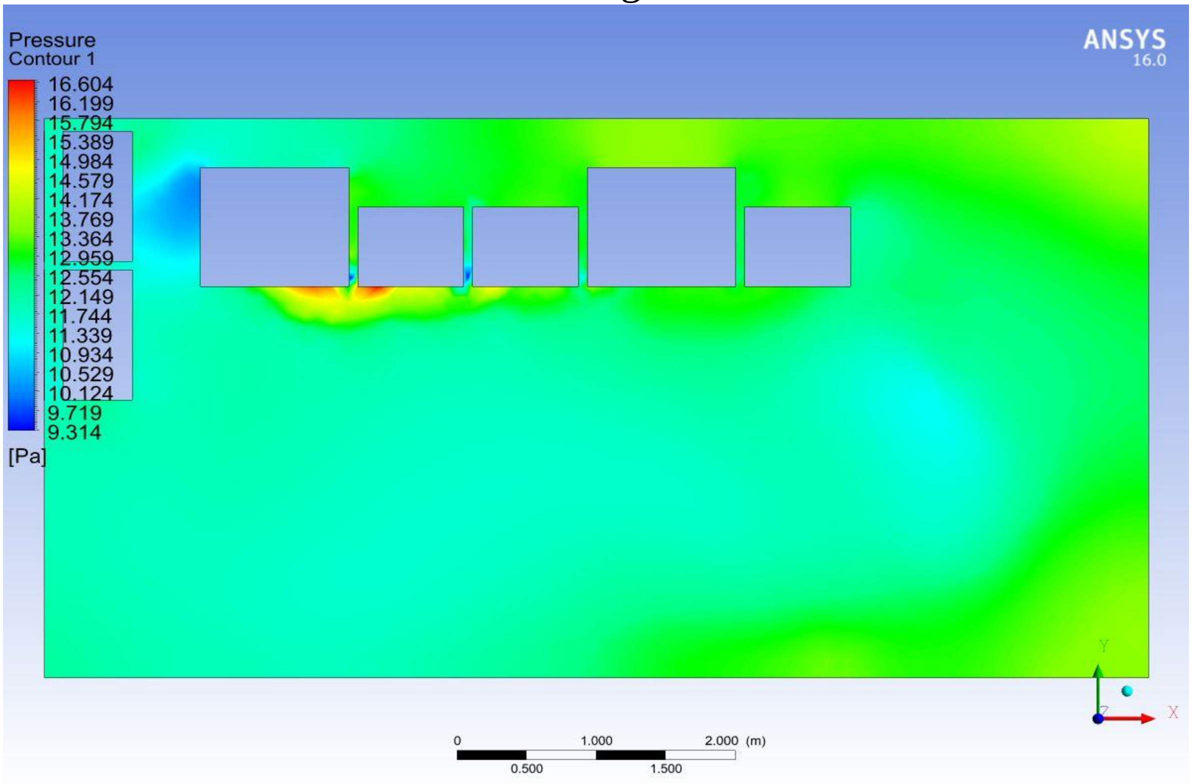


Fig:124

Fig:124 represents the temperature distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

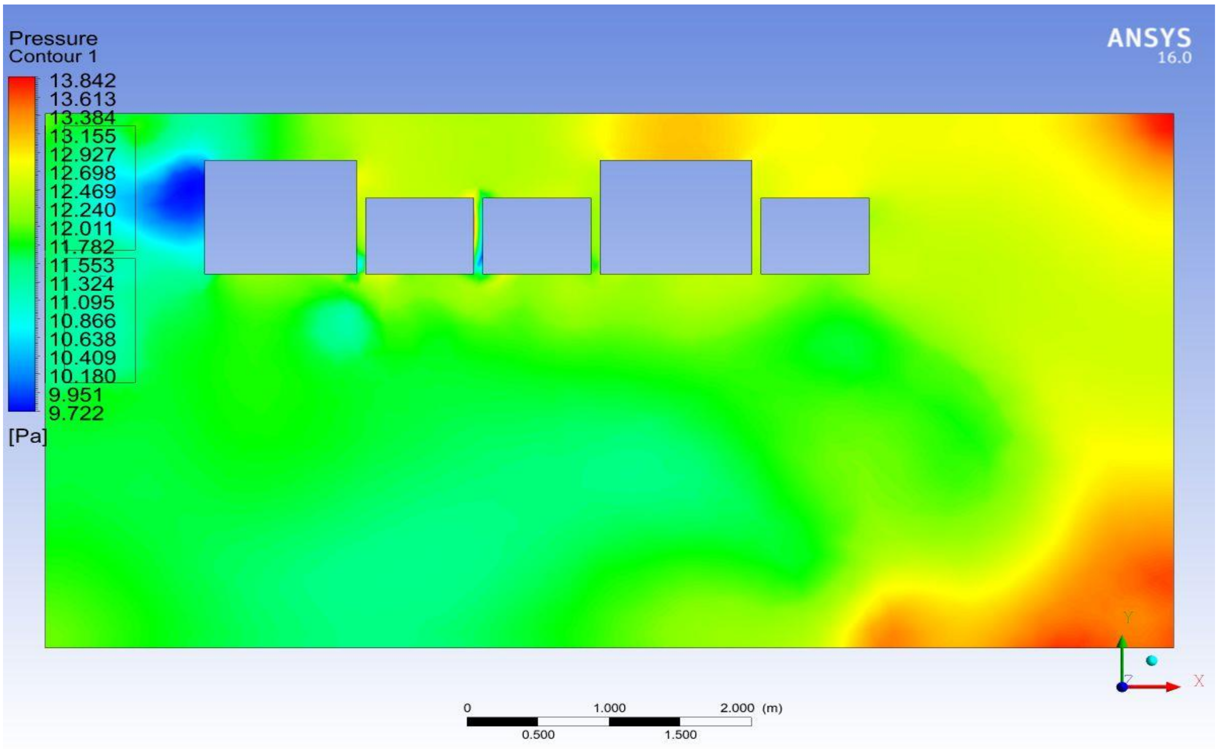


Fig:125

Fig:125 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

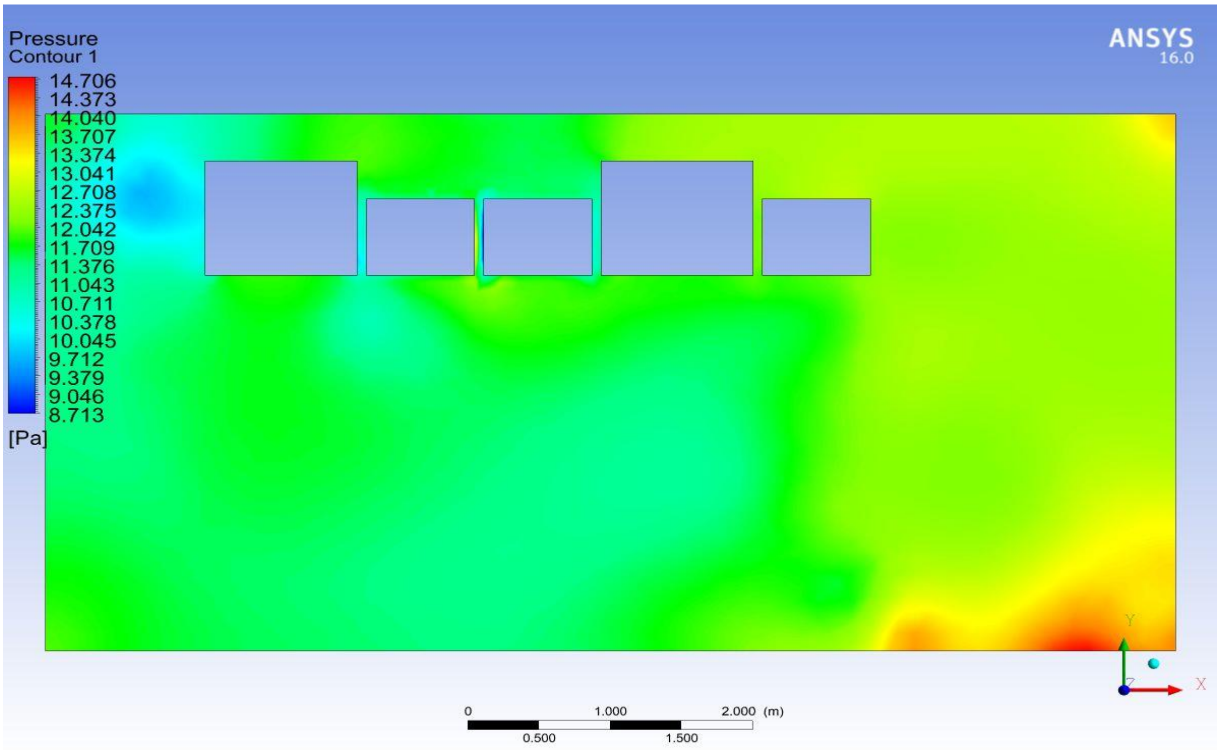


Fig:126

Fig:126 represents the temperature distribution on a plane located at Z-axis. It is at a position of 1500 mm above the raised floor along the Z-axis.

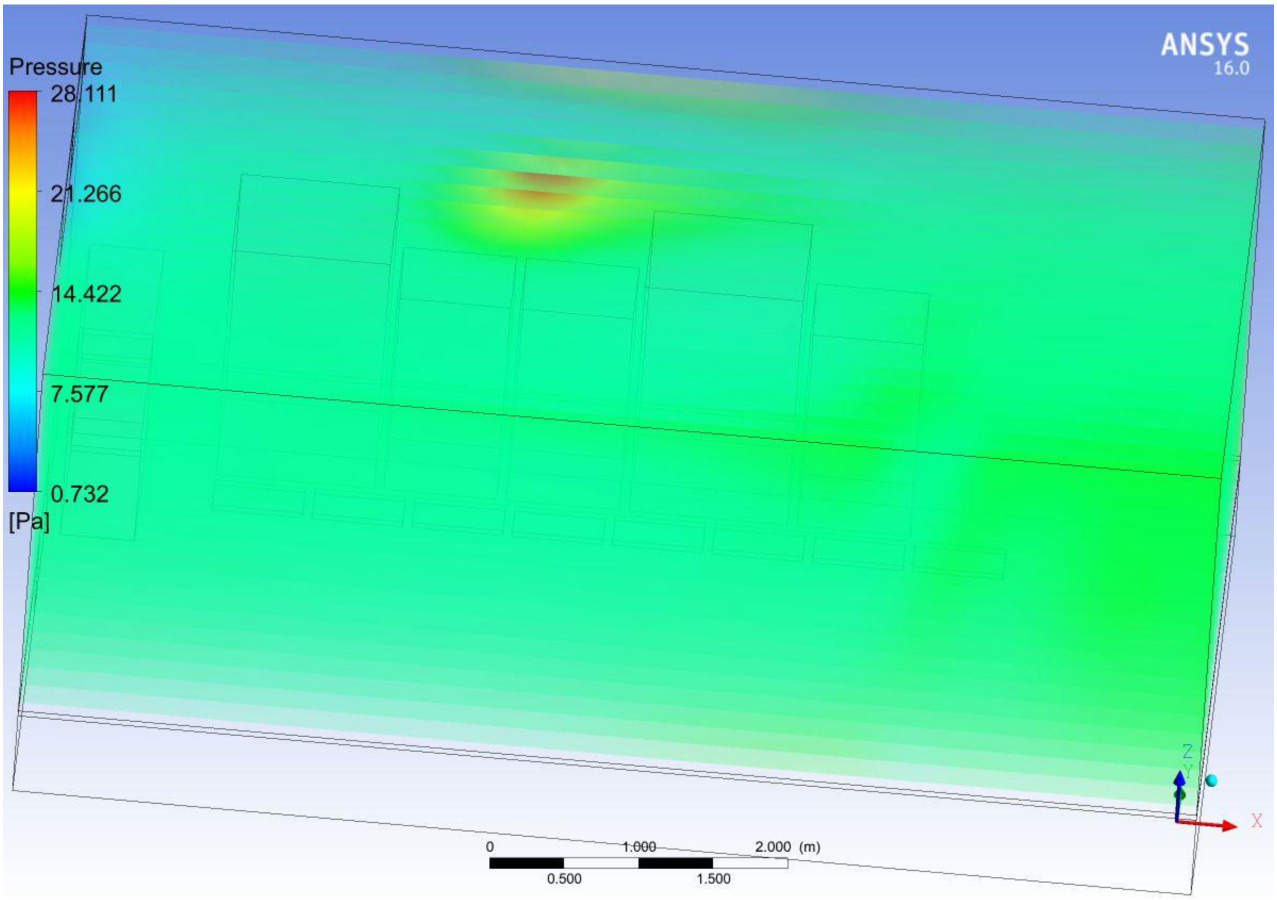


Fig:127

Fig:127 represents the pressure distribution of volume of air present in the server room space located above the raised floor.

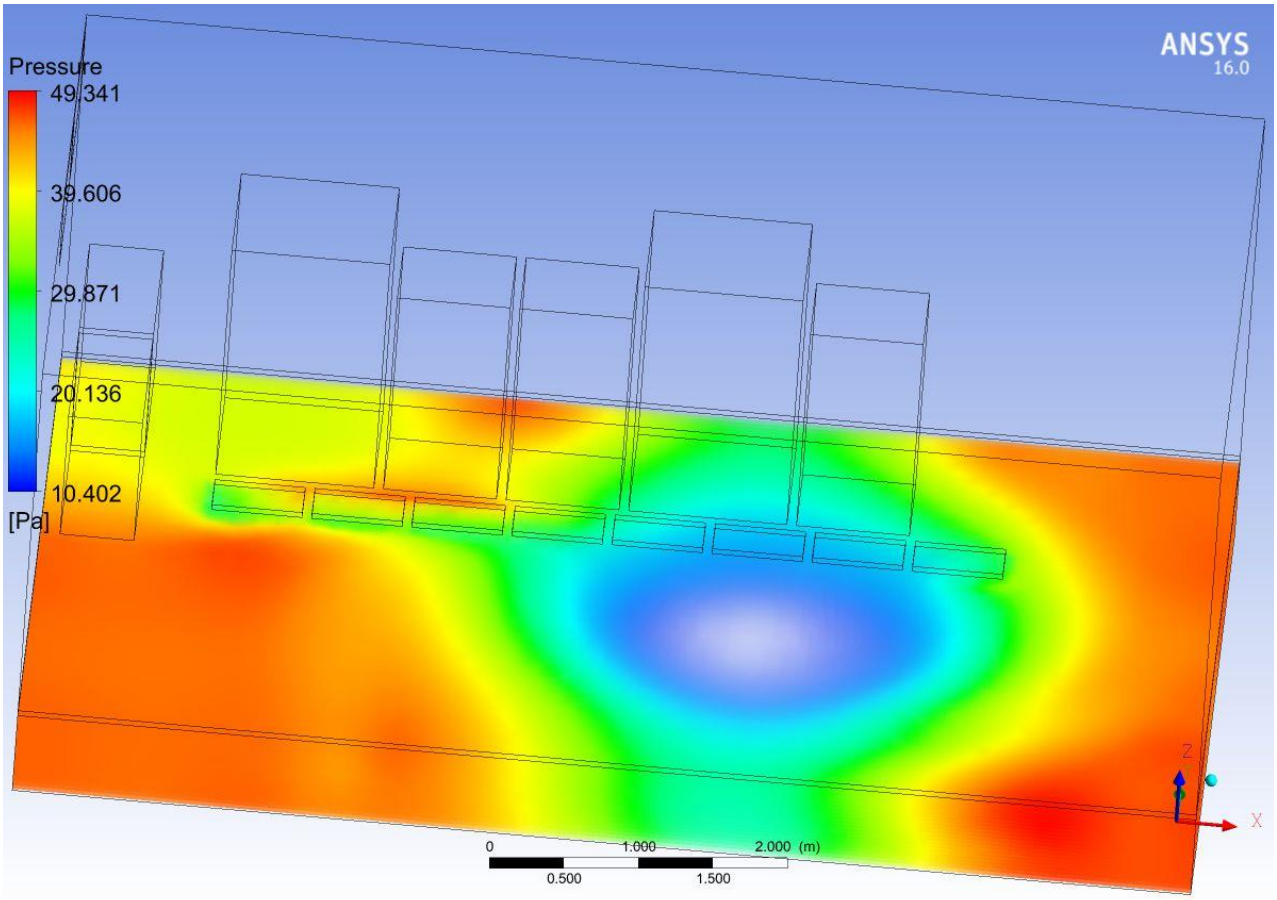


Fig:128

Fig:128 represents the pressure distribution of volume of air present in the server room space located below the raised floor.

iii) <u>Velocity Contour:</u>

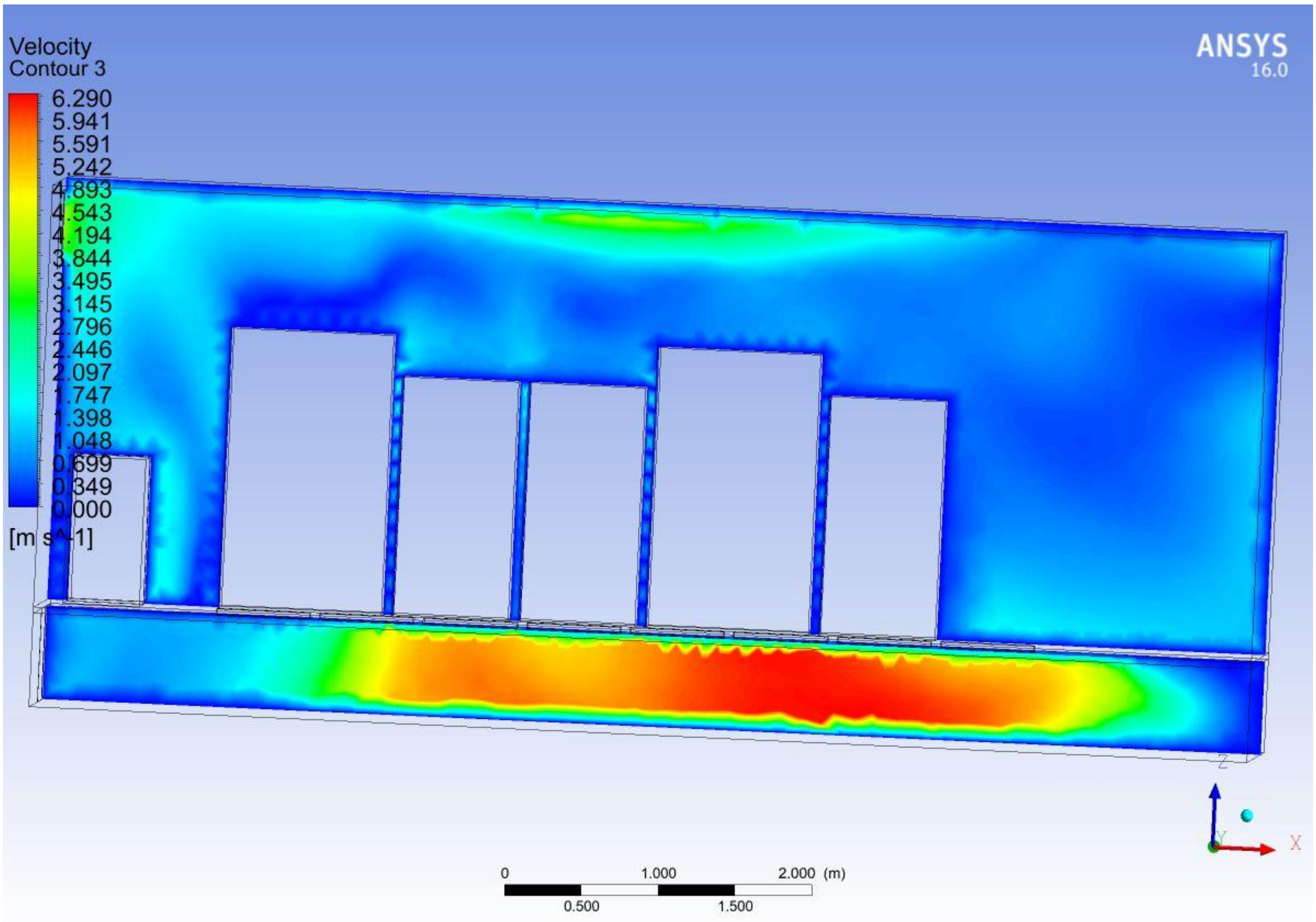


Fig:129

Fig:129 represents the velocity distribution on a plane located at Y-axis. It is at a position of 3500 mm along the Y-axis.

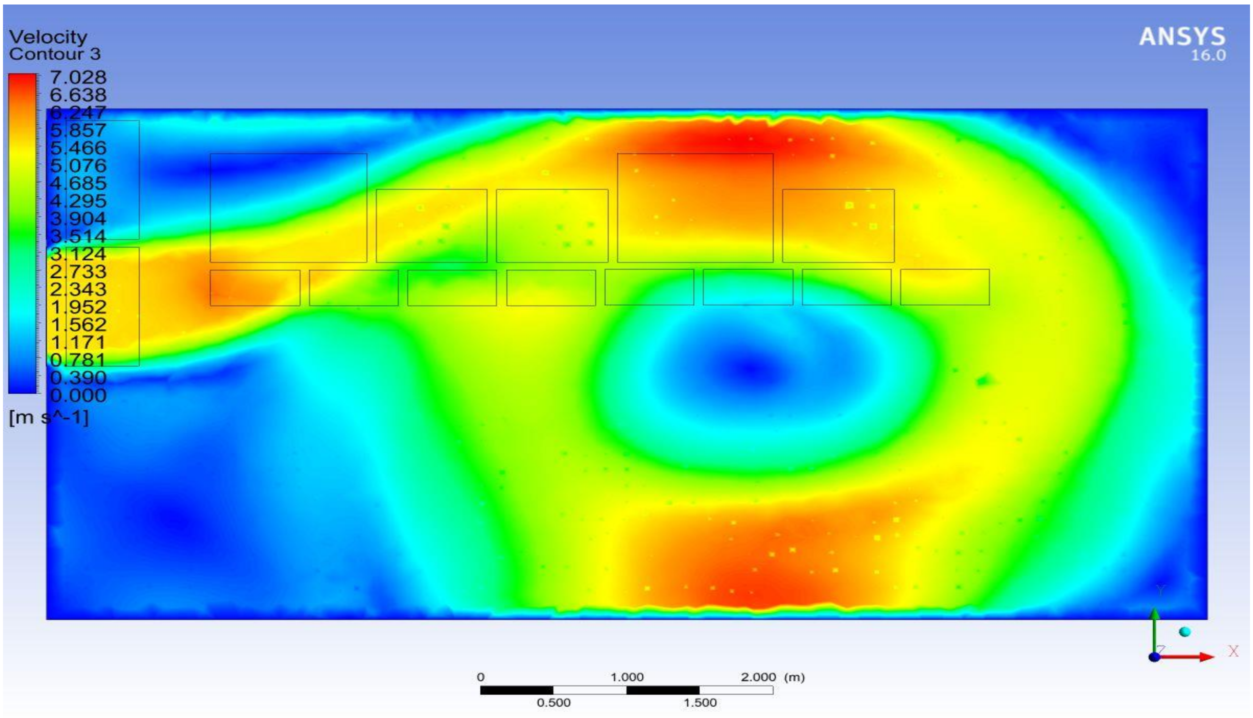


Fig:130

Fig:130 represents the velocity distribution on a plane located at Z-axis. It is at a position of 150 mm below the raised floor along the Z-axis.

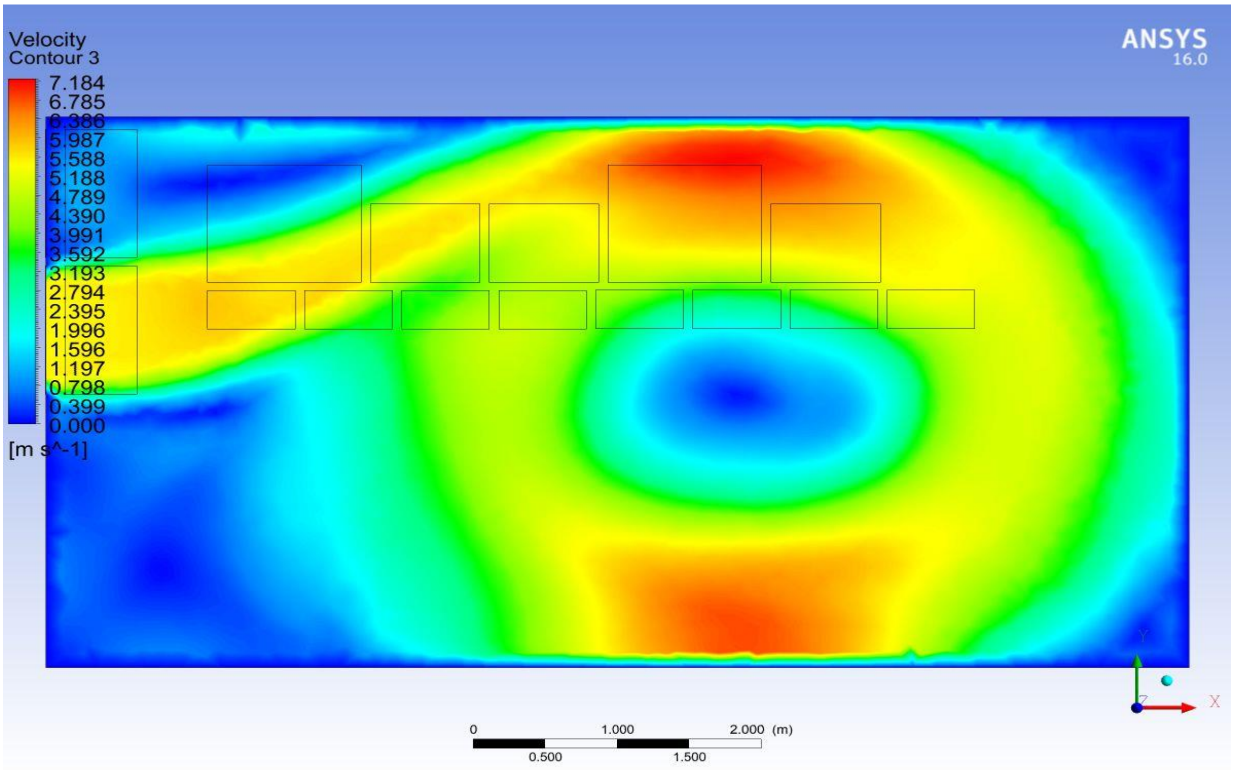


Fig:131

Fig:131 represents the velocity distribution on a plane located at Z-axis. It is at a position of 300 mm below the raised floor along the Z-axis.

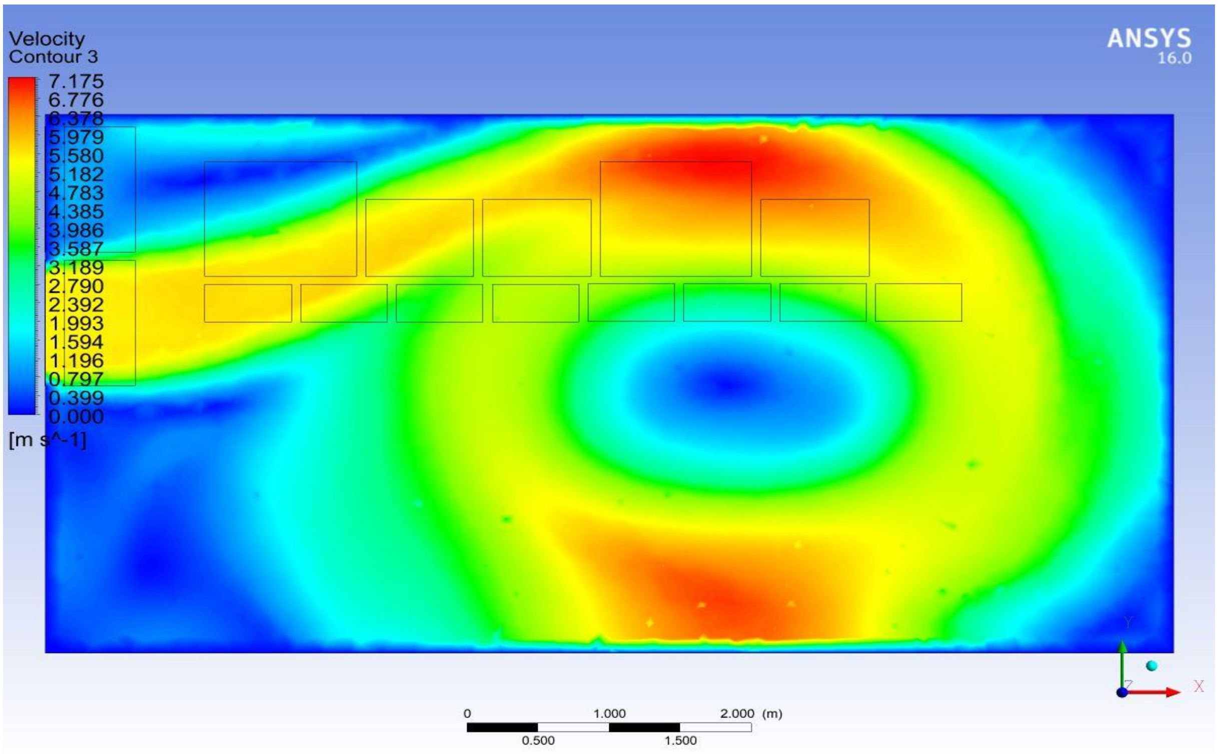


Fig:132

Fig:132 represents the pressure distribution on a plane located at Z-axis. It is at a position of 450 mm below the raised floor along the Z-axis.

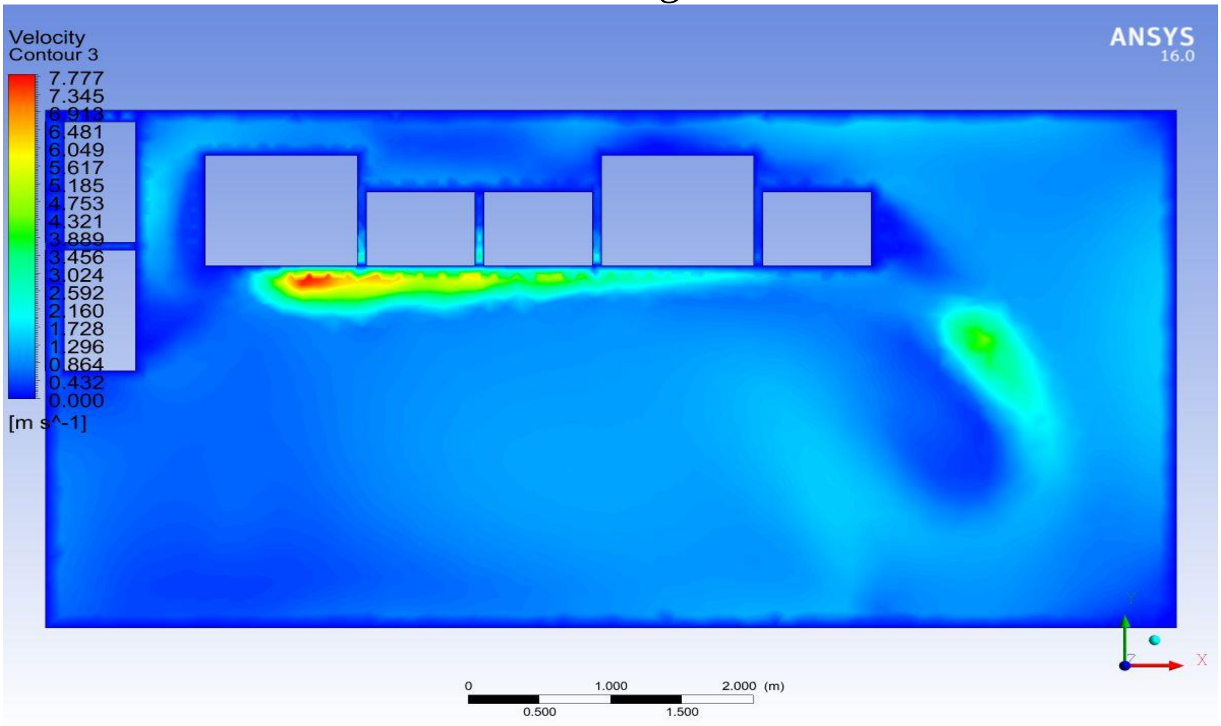


Fig:133

Fig:133 represents the pressure distribution on a plane located at Z-axis. It is at a position of 500 mm above the raised floor along the Z-axis.

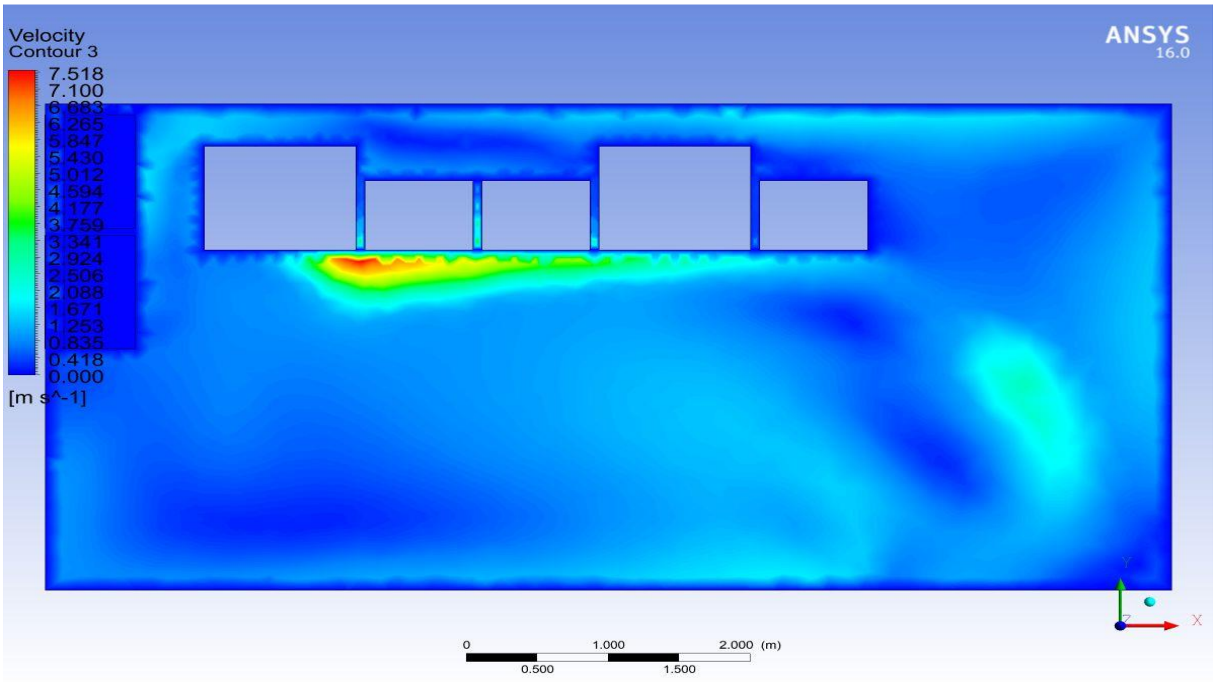


Fig:134

Fig:134 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1000 mm above the raised floor along the Z-axis.

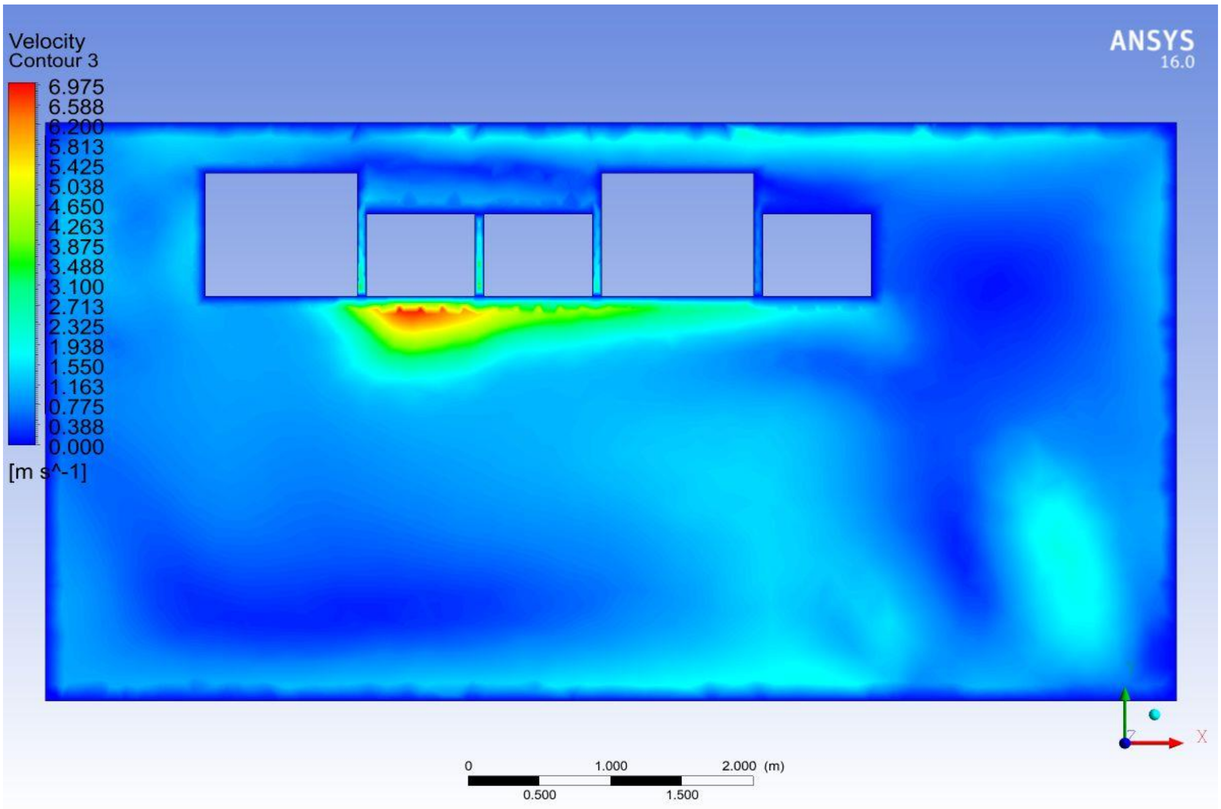


Fig:135

Fig:135 represents the pressure distribution on a plane located at Z-axis. It is at a position of 1500 mm below the raised floor along the Z-axis.

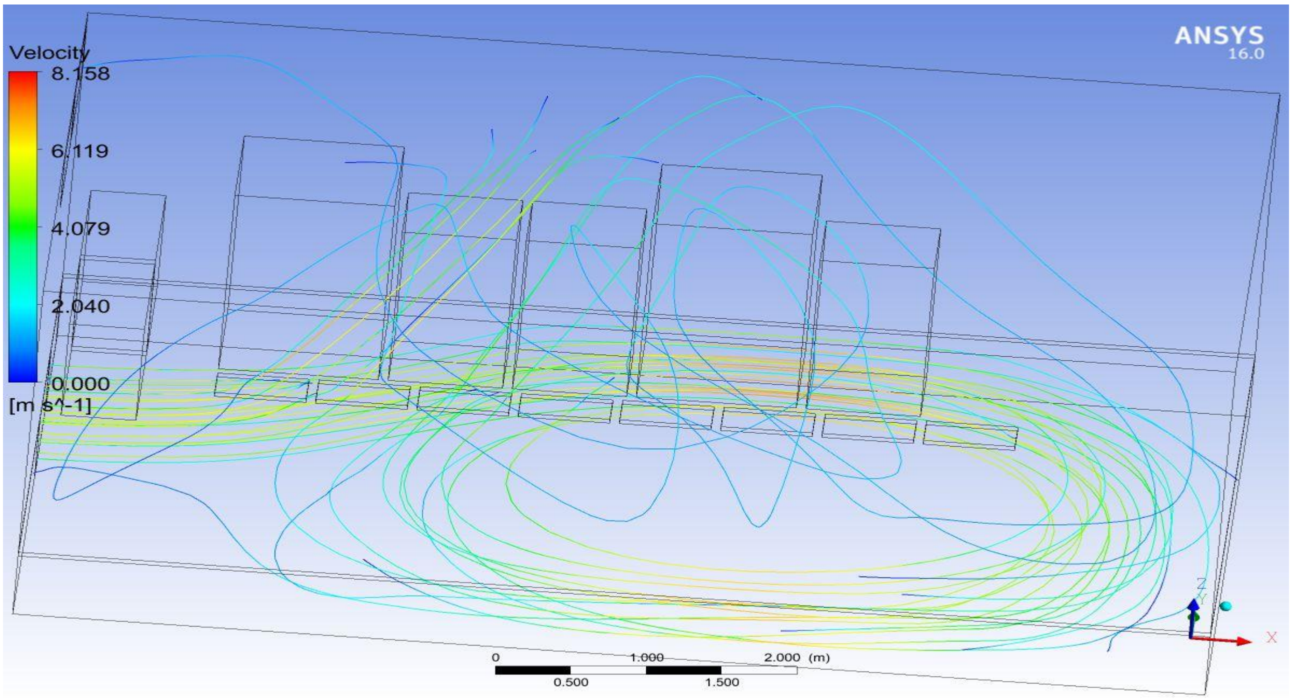


Fig:136

Fig:136 shows velocity streamlines from inlet 1 towards the raised floor space

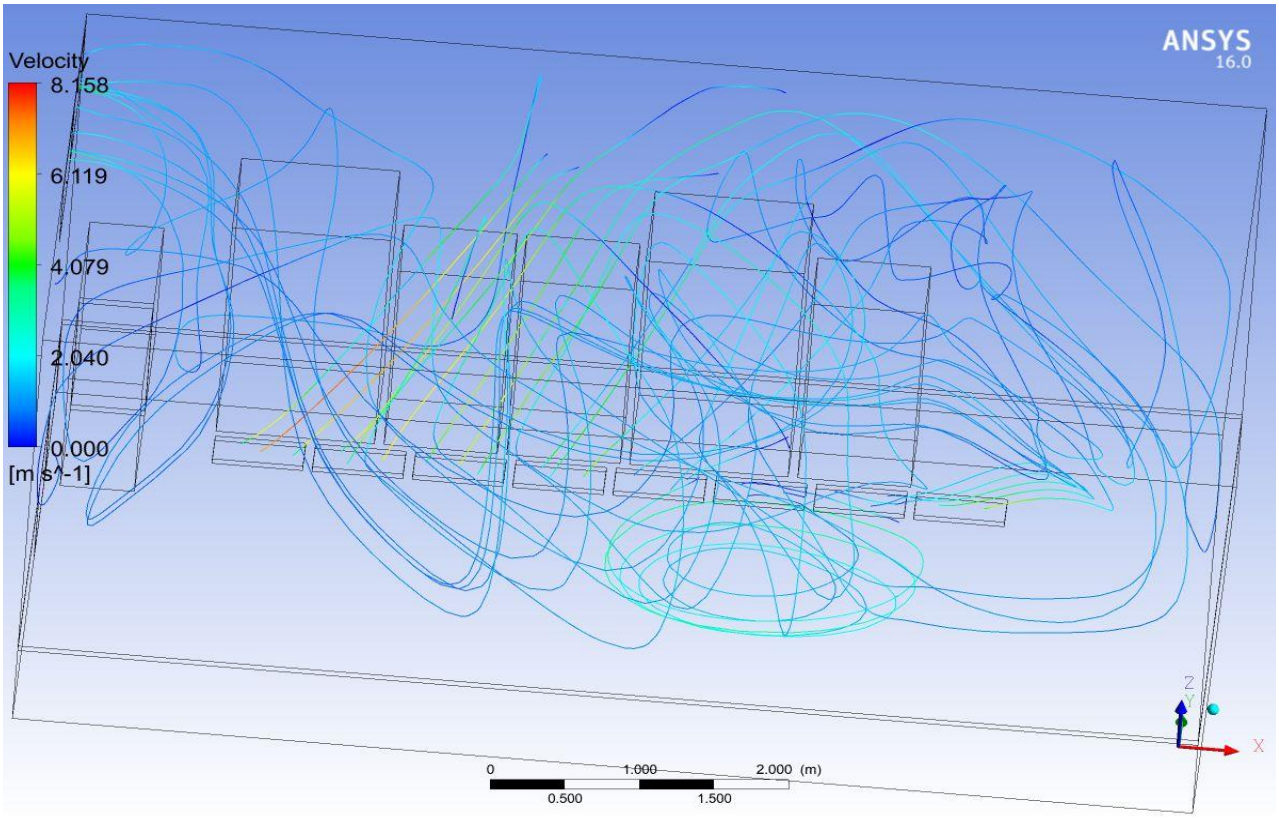


Fig:137

Fig:137 show velocity streamline at the vents of the tiles towards the server room space

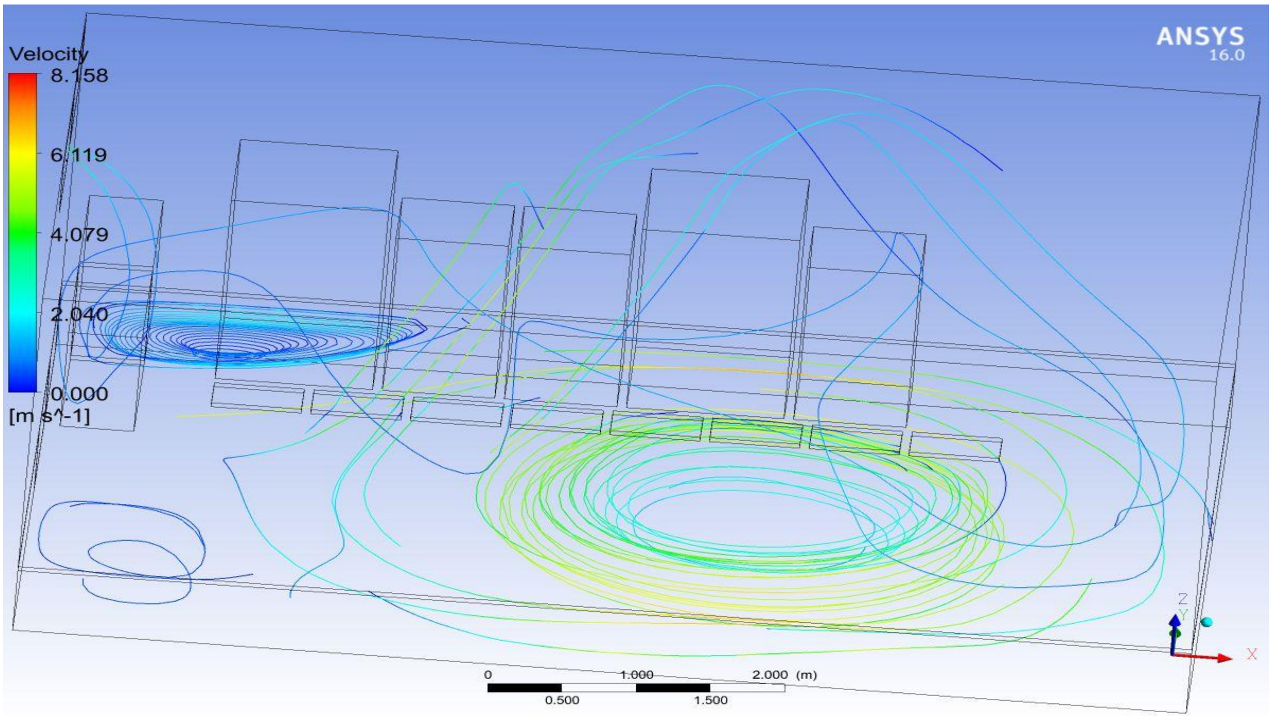


Fig:138

Fig:138 show velocity streamline at the raised floor space.

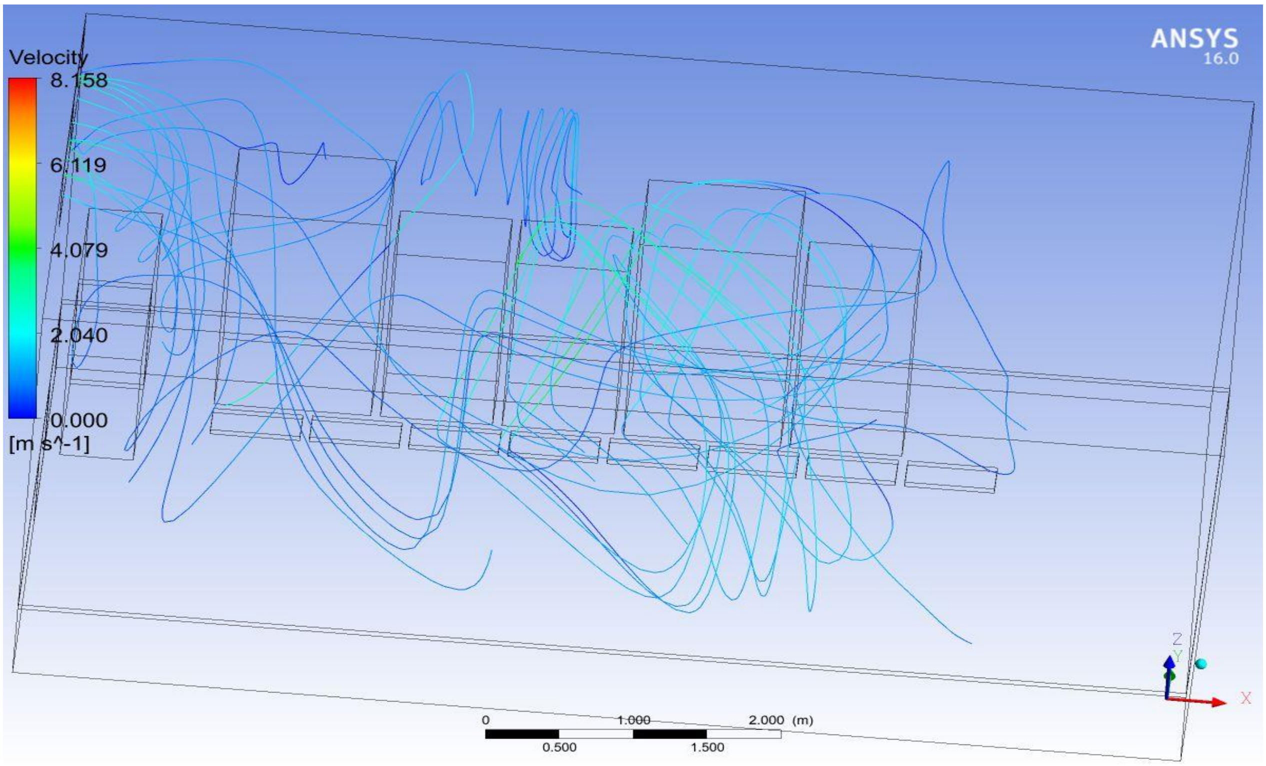


Fig:139

Fig:139 shows velocity streamline at the server room floor space

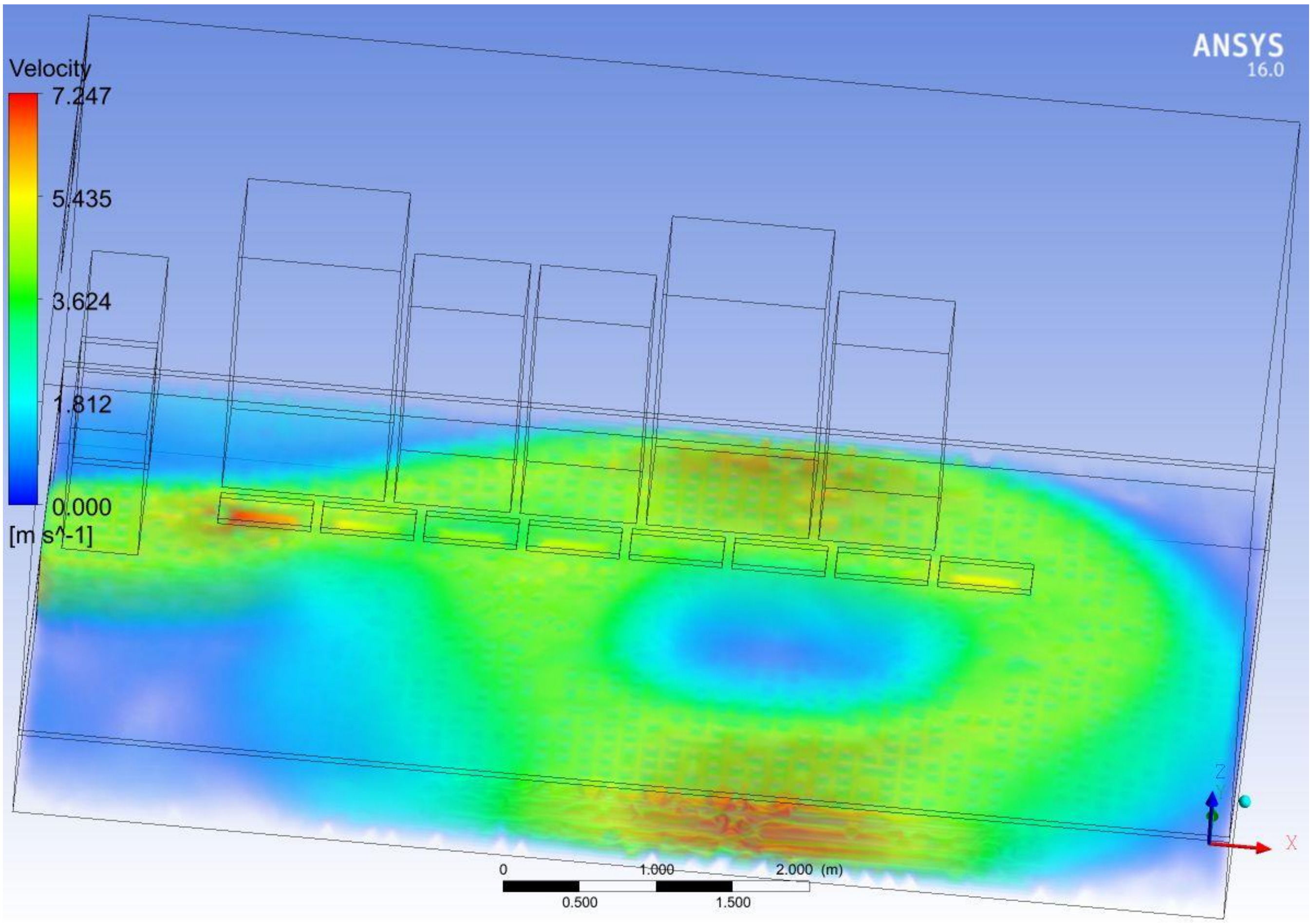


Fig:140

Fig:140 represents the velocity distribution of volume of air present below the raised floor.

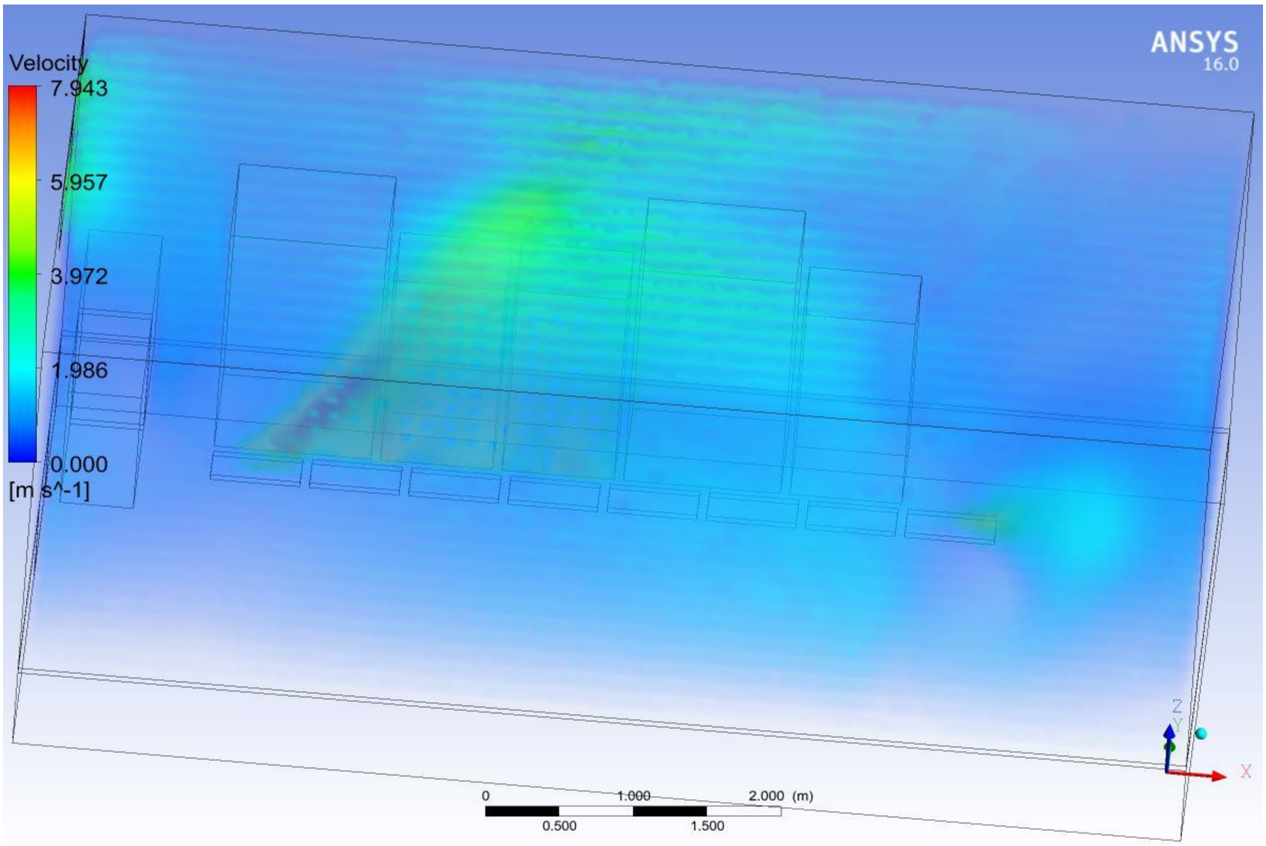


Fig:141

Fig:141 represents the velocity distribution of volume of air present above the raised floor

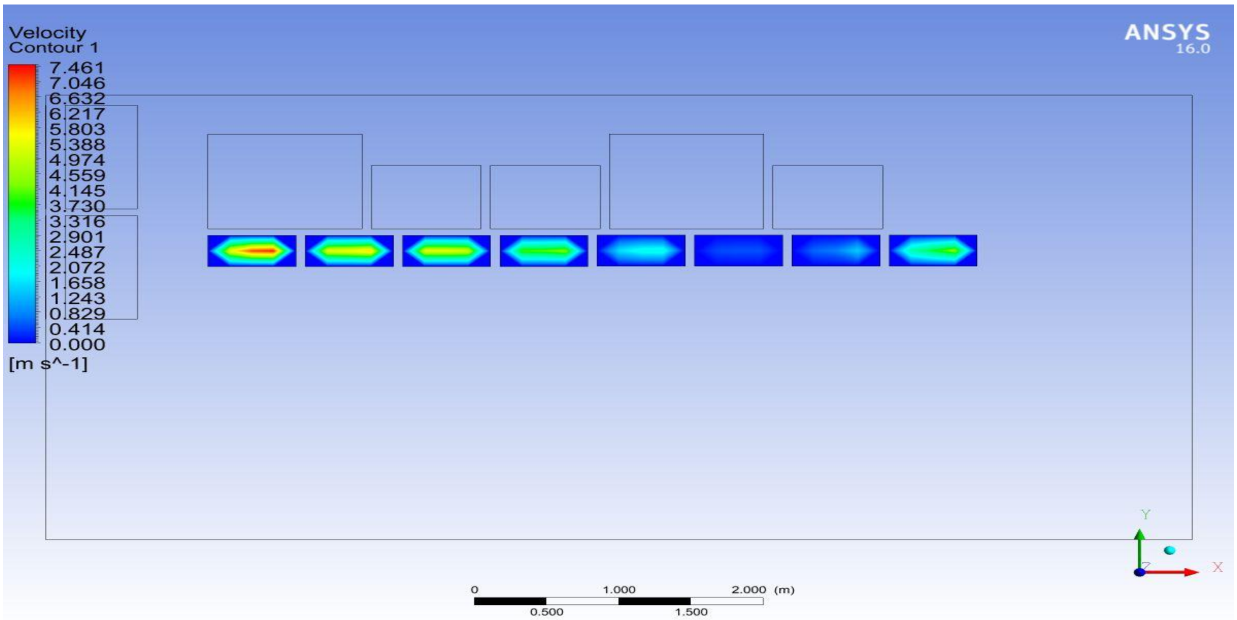


Fig:142

Fig:142 represents the velocity distribution of air at vents of tiles.

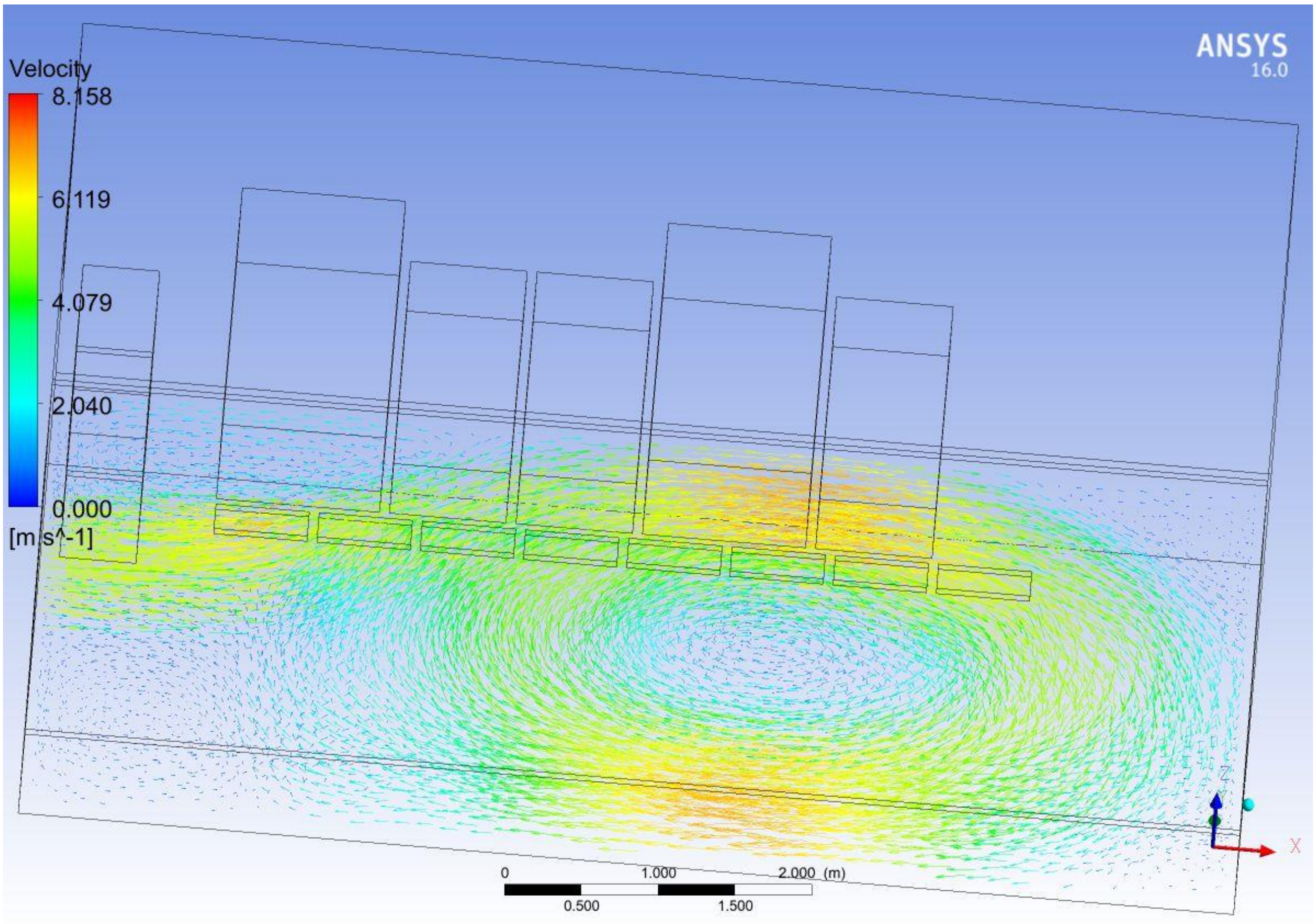


Fig:143

Fig:143 represents the velocity vector distribution of air present below the raised floor.

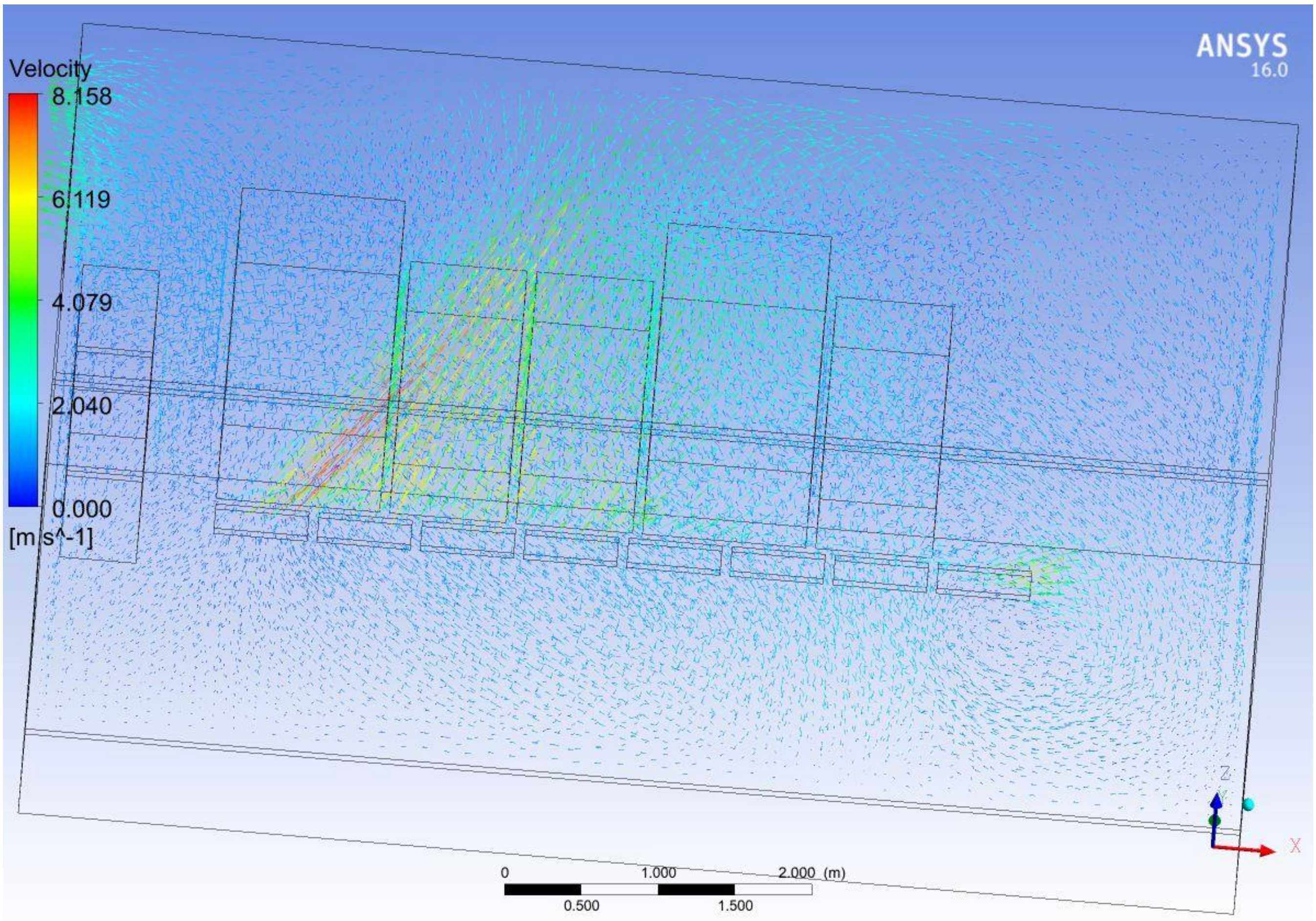


Fig:144

Fig:144 represents the velocity vector distribution of air present above the raised floor.

CHAPTER-V

VALIDATION OF SIMULATED RESULTS ON TEMPERATURE

Temperature on server racks are measured by means of a Laser Gun.

A) CASE I:

I	II	III	IV	V
SERVER	SIMULATED TEMP. (K)	MEASURED TEMP. (K)	TEMP. VARIATION (K)	PERCENTAGE VARIATION IN TEMP. (%)
-	-	-	|III-II|	(IV/III)*100%
1	303.7	285.7	8.0	2.8
2	294.9	285.5	9.4	3.2
3	294.9	285.2	9.7	3.4
4	302.6	288.3	14.3	4.9
5	299.3	290.9	8.4	2.8

B) **CASE II:**

I	II	III	IV	V
SERVER	SIMULATED TEMP. (K)	MEASURED TEMP. (K)	TEMP. VARIATION (K)	PERCENTAGE VARIATION IN TEMP. (%)
-	-	-	|III-II|	(IV/III)*100%
1	302.0	285.7	16.3	5.7
2	292.9	285.5	7.4	2.6
3	292.9	285.2	7.7	2.7
4	299.7	288.3	11.4	3.9
5	297.5	290.9	6.6	2.2

C) **CASE III:**

I	II	III	IV	V
SERVER	SIMULATED TEMP. (K)	MEASURED TEMP. (K)	TEMP. VARIATION (K)	PERCENTAGE VARIATION IN TEMP. (%)
-	-	-	|III-II|	(IV/III)*100%
1	284.6	285.7	1.1	0.3
2	283.6	285.5	1.9	0.6
3	283.6	285.2	1.6	0.5
4	284.5	288.3	3.8	1.3
5	284.3	290.9	6.6	2.2

D) **CASE IV:**

I	II	III	IV	V
SERVER	SIMULATED TEMP. (K)	MEASURED TEMP. (K)	TEMP. VARIATION (K)	PERCENTAGE VARIATION IN TEMP. (%)
-	-	-	|III-II|	(IV/III)*100%
1	305.2	285.7	19.5	6.8
2	293.9	285.5	8.4	2.9
3	293.9	285.2	8.7	3.0
4	302.6	288.3	14.3	4.9
5	300.0	290.9	9.1	3.1

CHAPTER-VI
CURVES ON SIMULATION RESULTS AND DISCUSSION

1) CASE I:

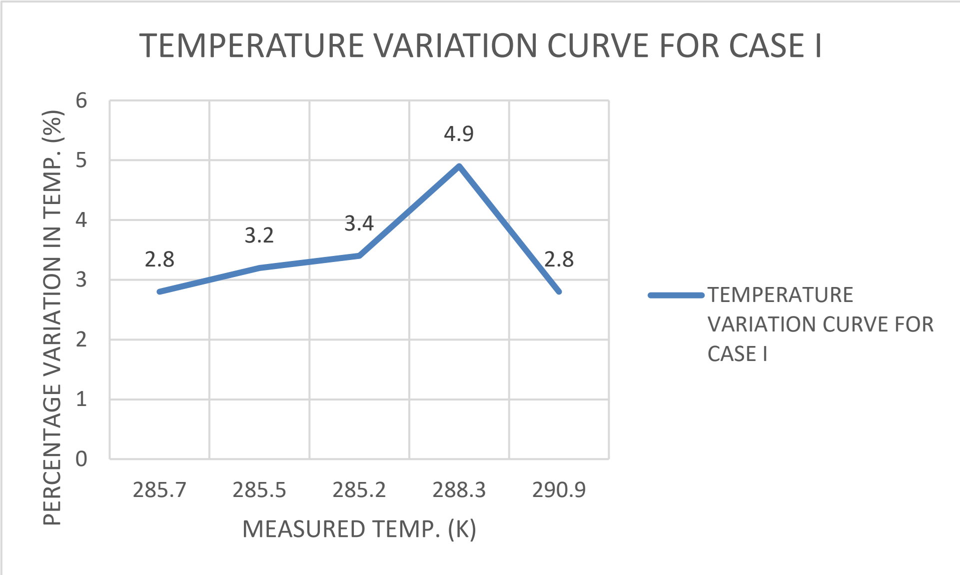


Fig.144

Fig.144 shows that for this case, the simulated results on temperature are within 5% of the measured data which is a moderate variation.

2) CASE II:

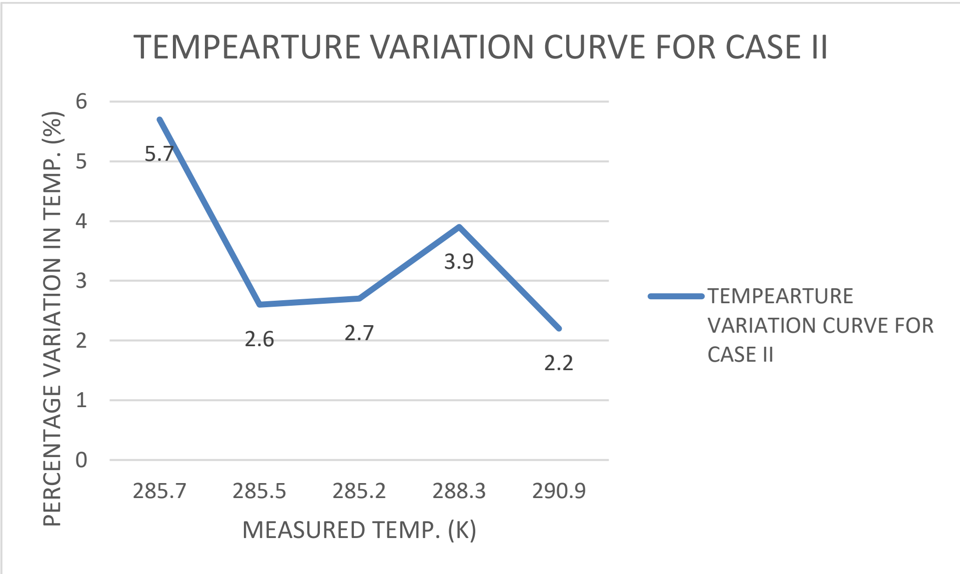


Fig.145

Fig.145 shows that the simulated results on temperature are within 6% of the measured data which also can be considered as a moderate variation.

3) **CASE III:**

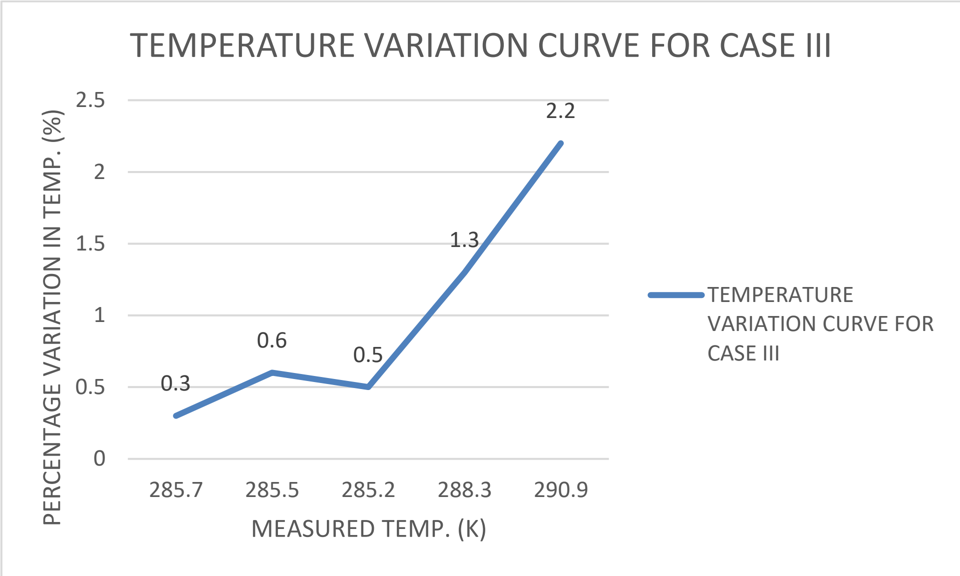


Fig.146

Fig.146 shows that for this case the variation between the simulated and experimental results is quite small and can be considered in agreement with each other.

4) **CASE IV:**

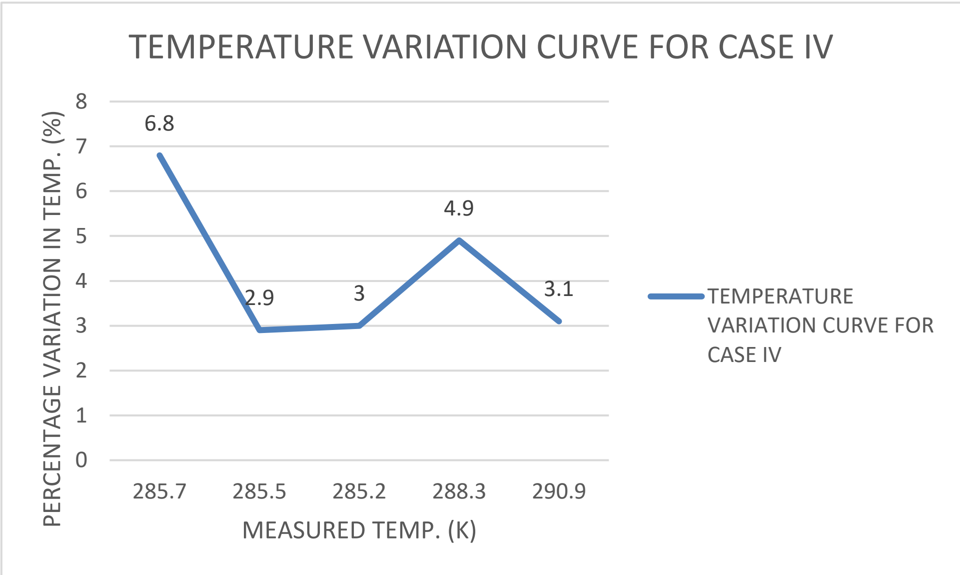


Fig.147

Fig.147 shows that the variation of the simulated results is within a maximum of 6.8% with the measured data.

CHAPTER-VII

CONCLUSION

It has observed from the temperature contour obtained from the simulation that the hotspots on the server racks are almost eliminated when the temperature at the outlet from one CRAC unit that is the inlet 1 temperature which is taken as 280 K and air velocity from that unit is 5.5 m/s along with the heat generation rate of 1500 W/cubic meter from each of server racks which has been mentioned in CASE III.

The simulated temperature of each server racks obtained from the above mentioned condition is then validated with the measured data of temperatures taken from Swasthya Bhavan by means of laser gun and it holds good with the simulated results which has been shown in Temperature Variation Curve in Fig. 148 where the percentage variation in temperature is less than 2.5% whereas in other cases it exceeds 3%.

Hence, it has been concluded that hotspots in each server racks can almost be mitigated by following the conditions mentioned in CASE III.

The following conclusions can also be arrived at:

i) The use of simulation software like ANSYS can be of help in forecasting the zones of hotspots in a Data Centre.

ii) For the hotspot zones the air quantity to be supplied has to be increased. This can be achieved by using mixed tiles where the perforated areas can be varied by using computer control.

CHAPTER-VIII

FUTURE SCOPE OF WORK

a) The work can be done by using customized meshing system that consists of customizing mesh sizing, face meshing, contact sizing and refinement of mesh etc.

b) Density-Based solver, Relative Velocity type Velocity formulation and Transient time based setup can be used as modification for current work.

c) Different turbulent model k-omega can be used instead of current turbulent model that is k-epsilon as modification to this current work.

d) Other solution method that are SIMPLEC, PISO and COUPLED can be used for getting close to real situation.

e) Taking different hybrid materials as materials for server racks must also be taken under consideration instead of only Aluminum Racks.

f) Different types of tiles such mixed tiles or active tiles must be considered into the future work instead of conventional tiles.

g) Use of nozzles should be included into the work so that there is a better air flow into the confined server room space.

h) Further Analysis can be done on the same design by running two CRAC units at the same time instead of keeping one CRAC unit idle.

CHAPTER - IX

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CHAPTER-X

APPENDIX

Steps involved in achieving a Simulation Result for one condition (CASE II):

Step 1 – Creating Geometry of Server Room in Ansys DesignModeler.

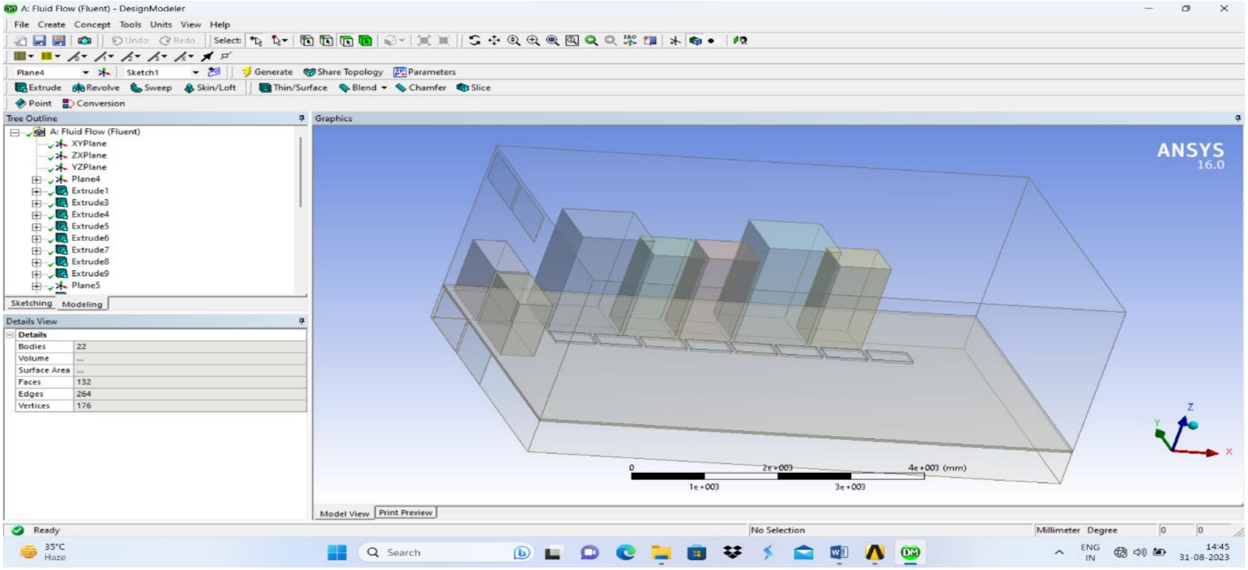

Fig:148

Step 2 – Creating Mesh.

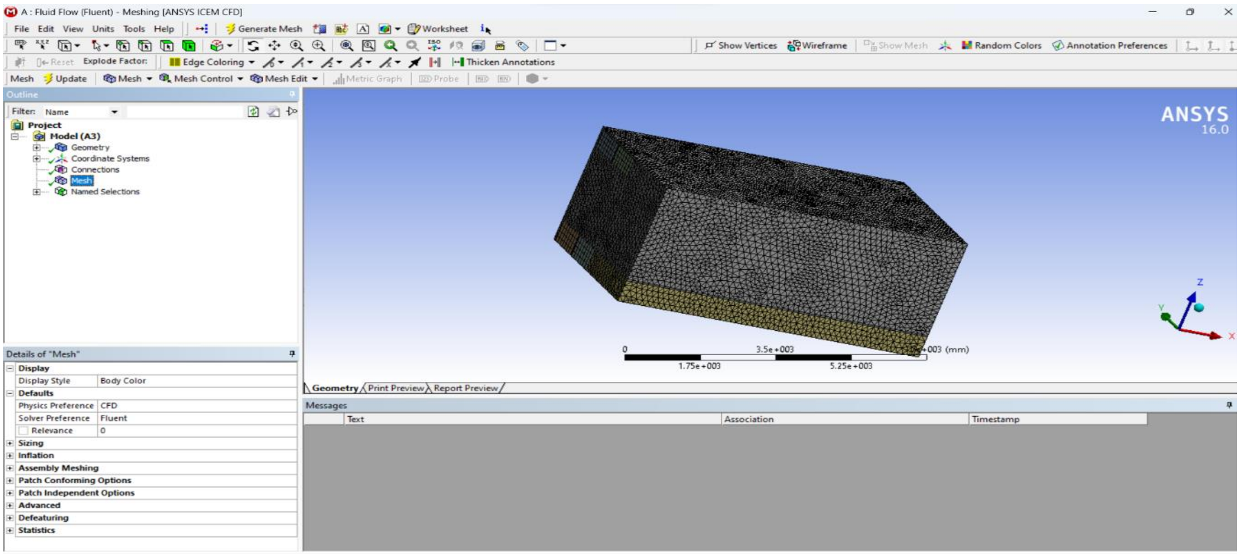

Fig:149

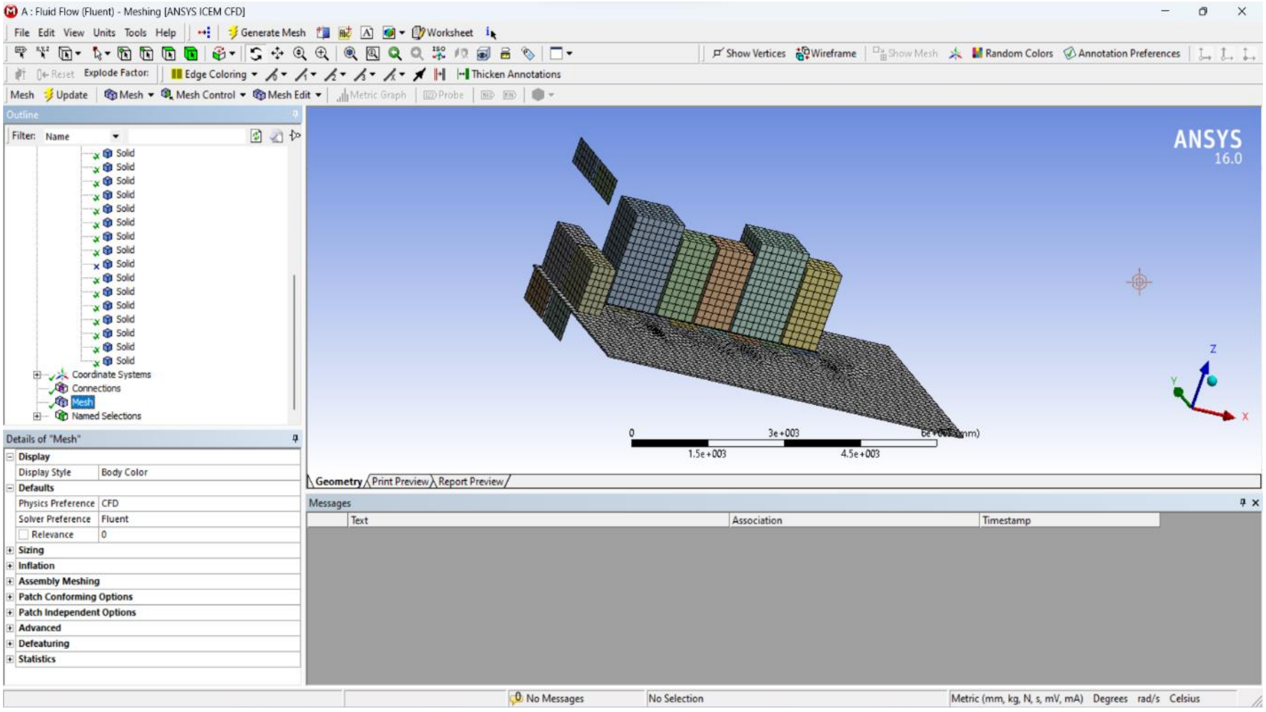

Fig:150

Step 3 – Setting Up of Model

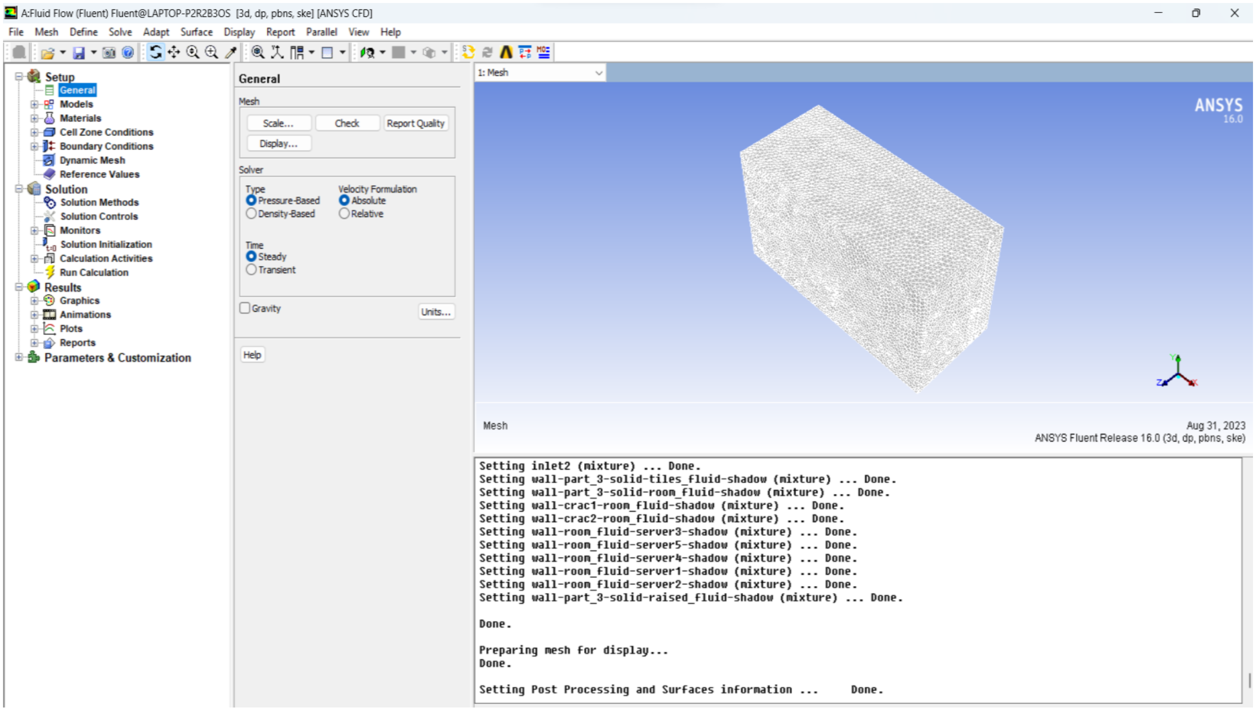

Fig:151

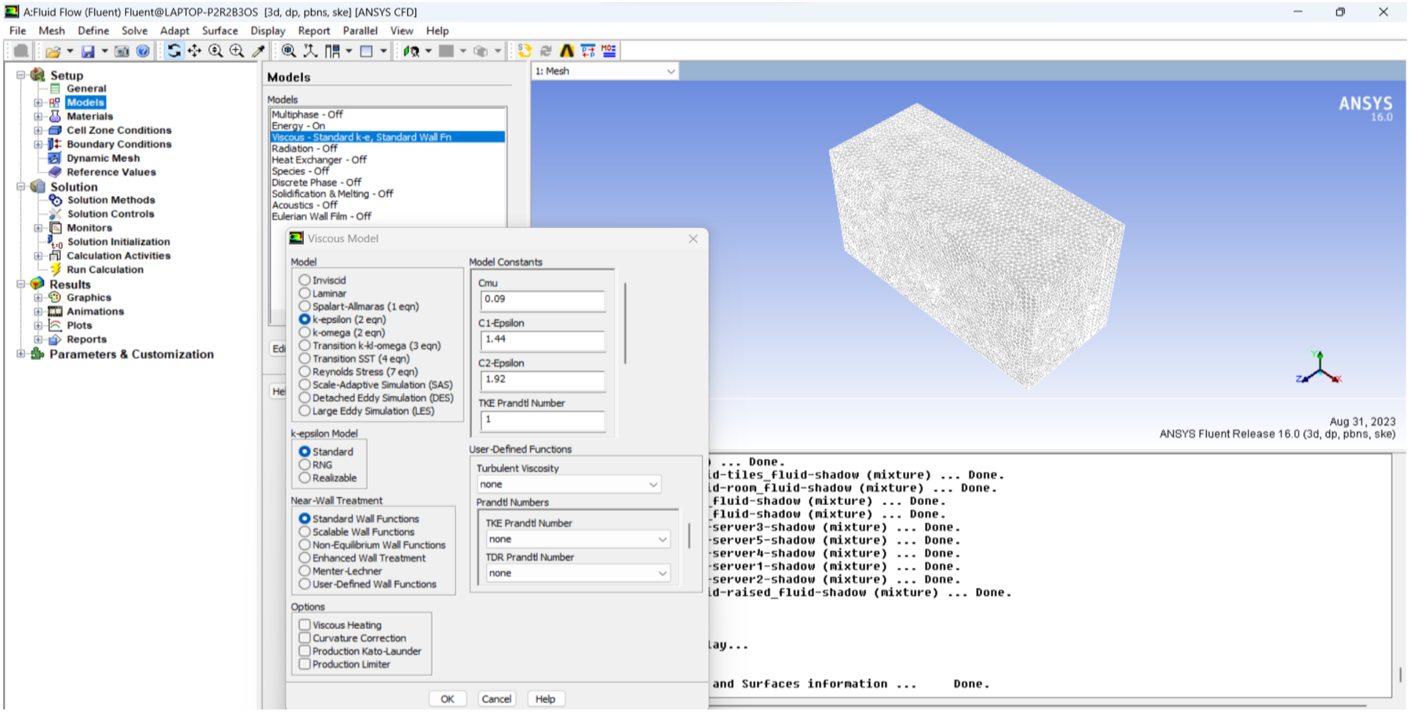

Fig:152

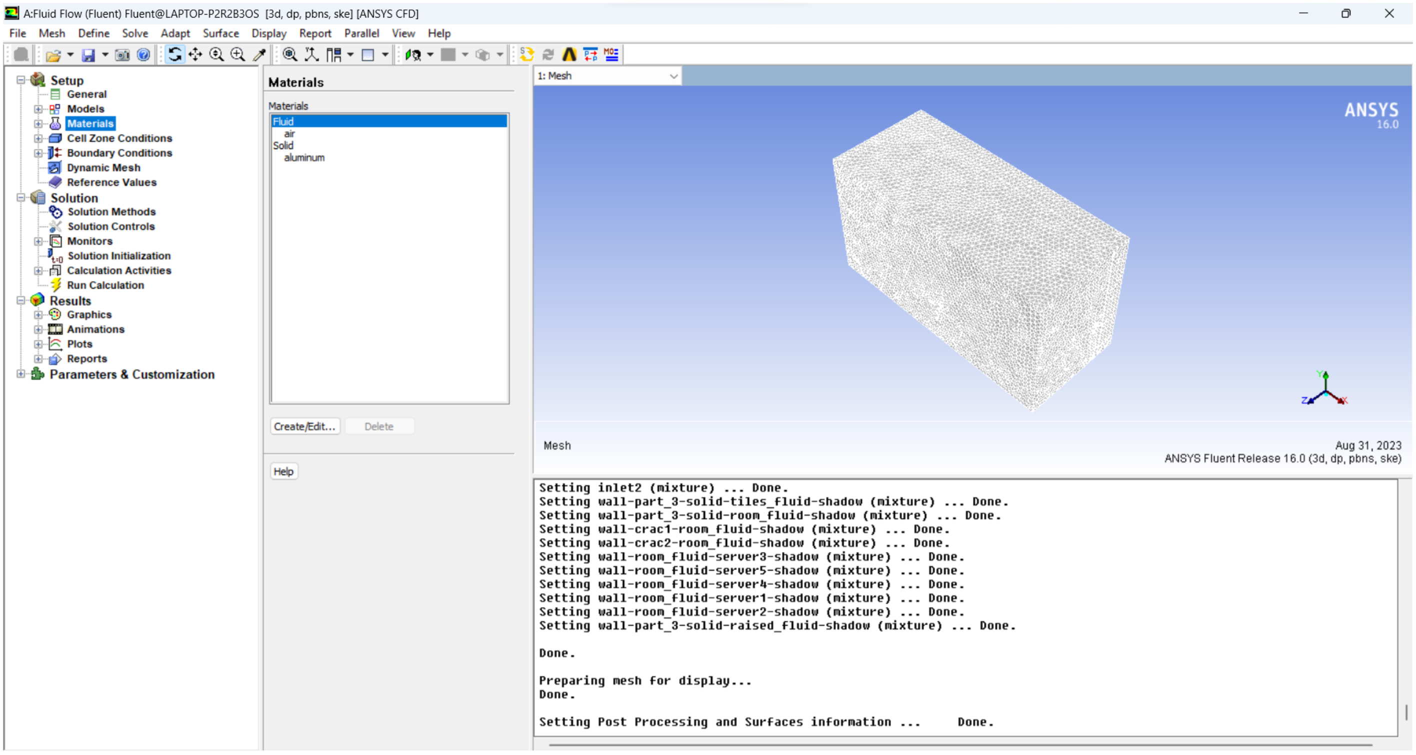

Fig:153

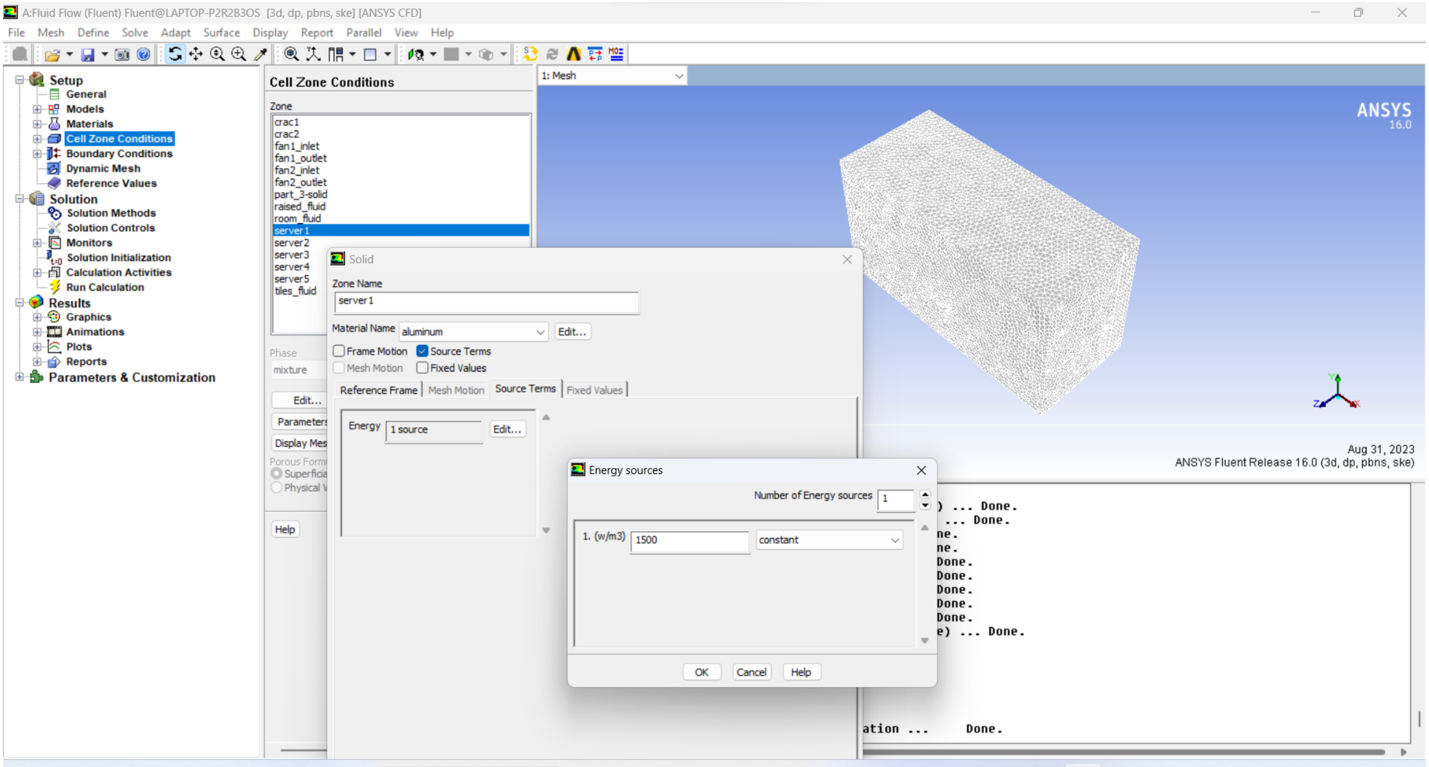

Fig:154

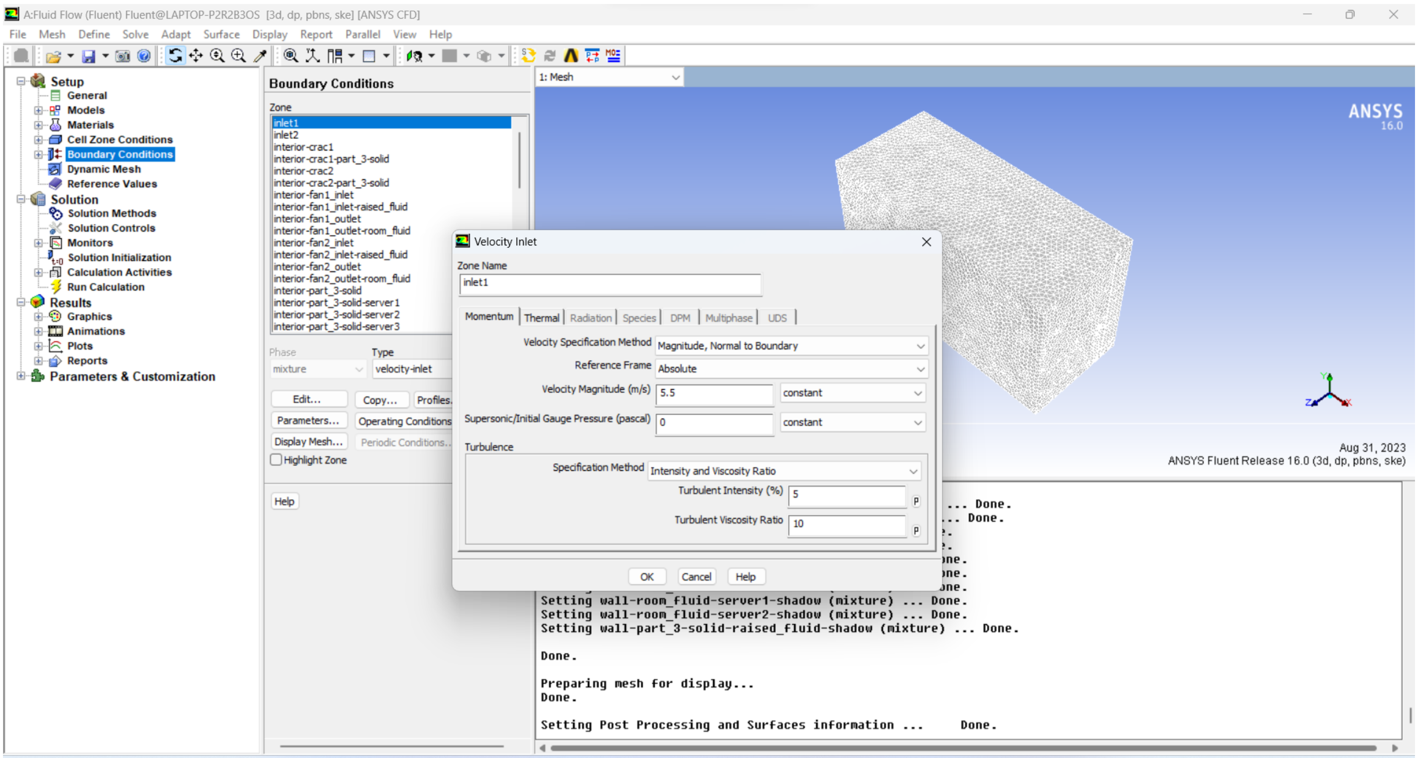

Fig:155

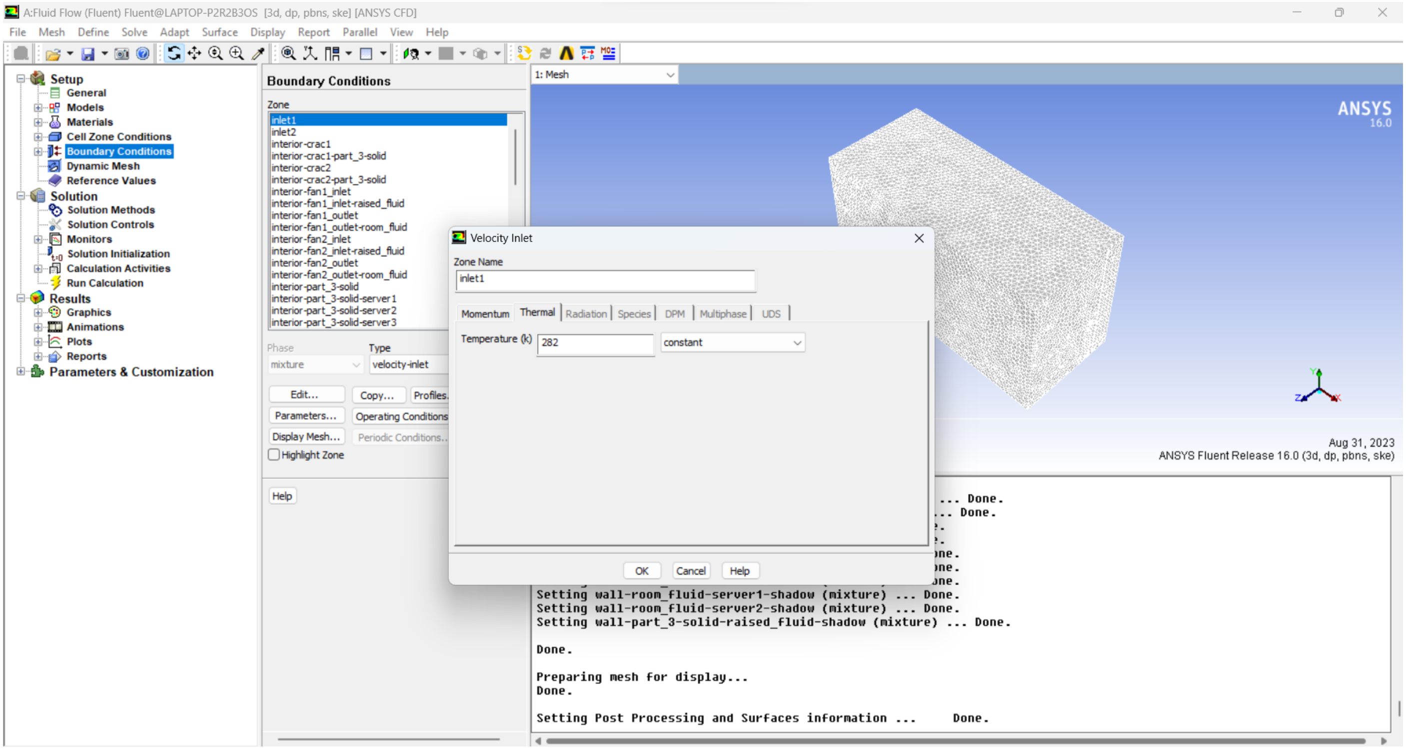

Fig:156

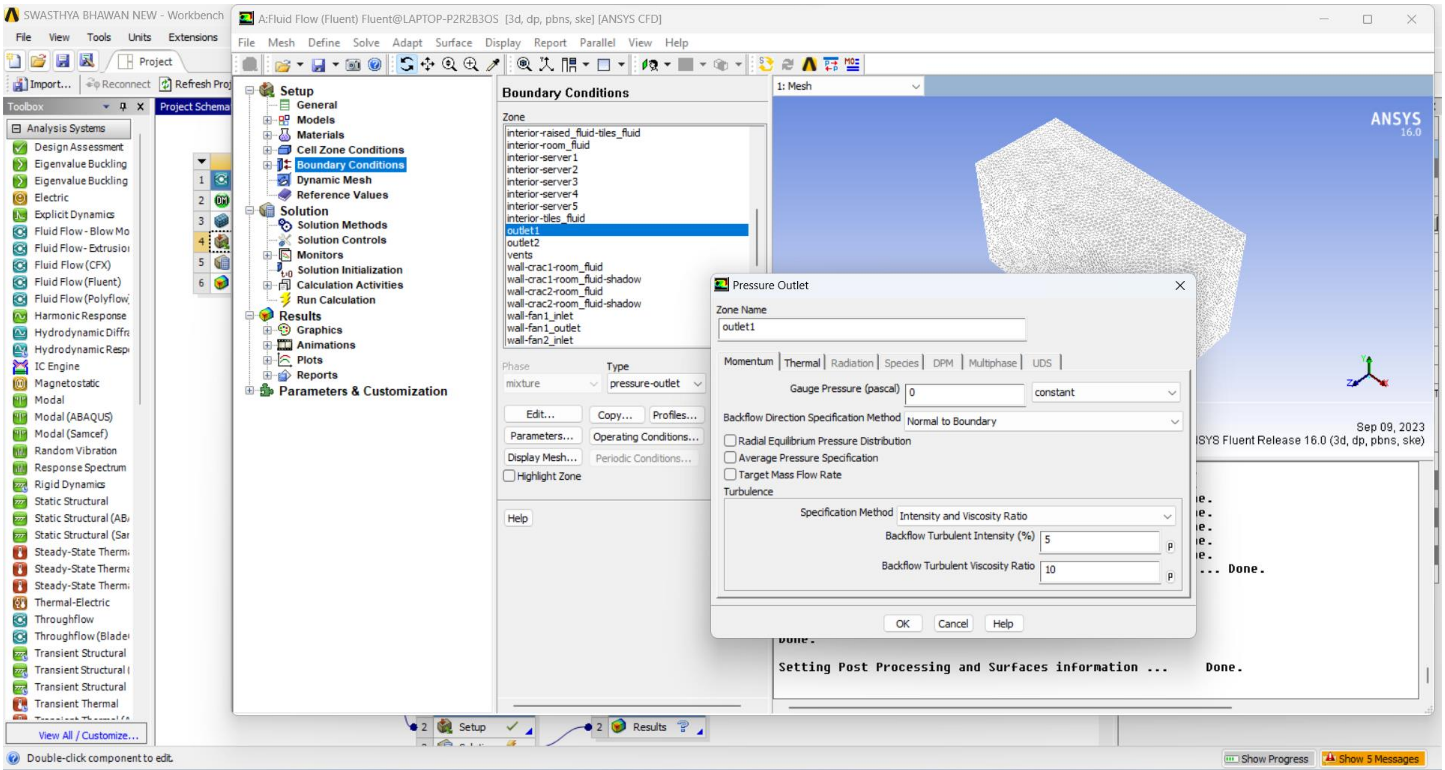

Fig:157

Step 4 – Solution Setup of Model

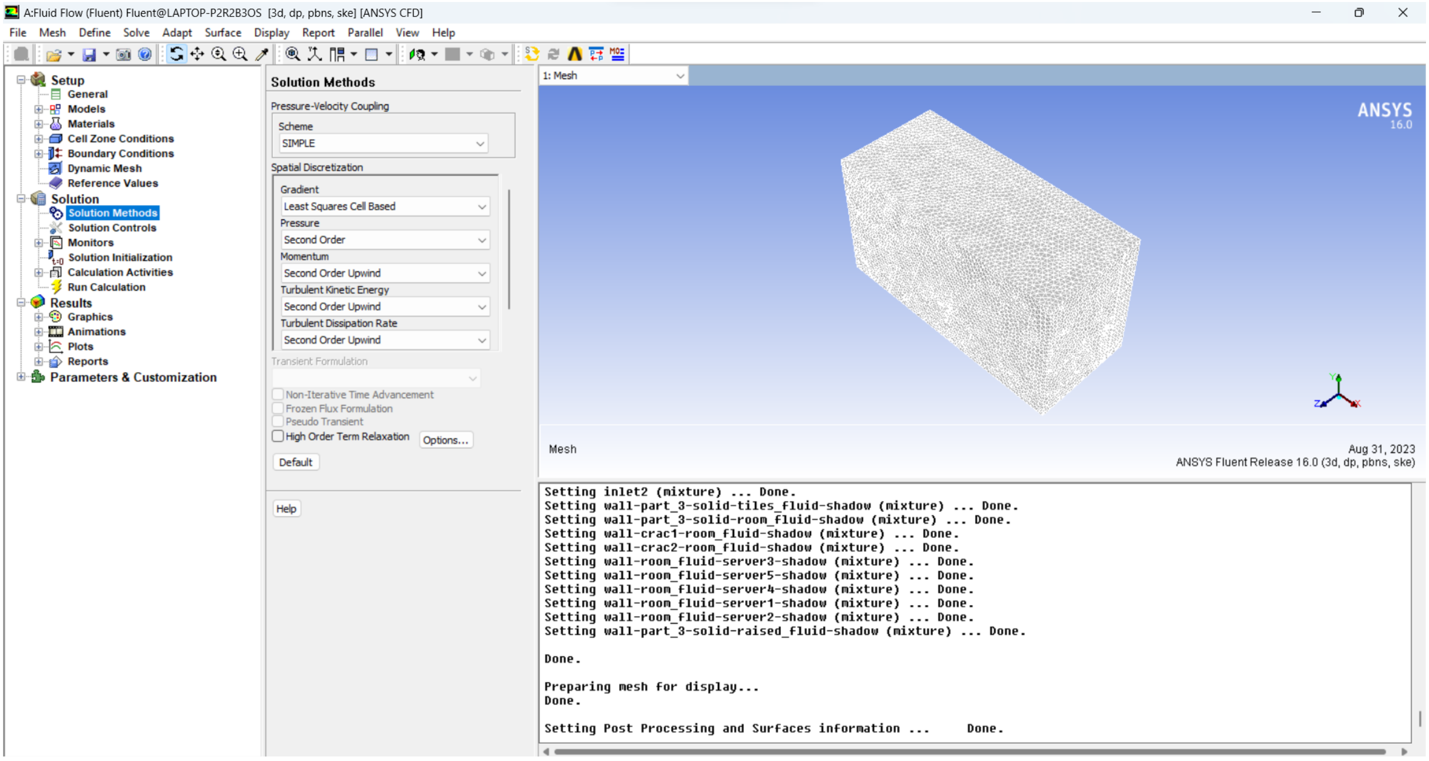

Fig:158

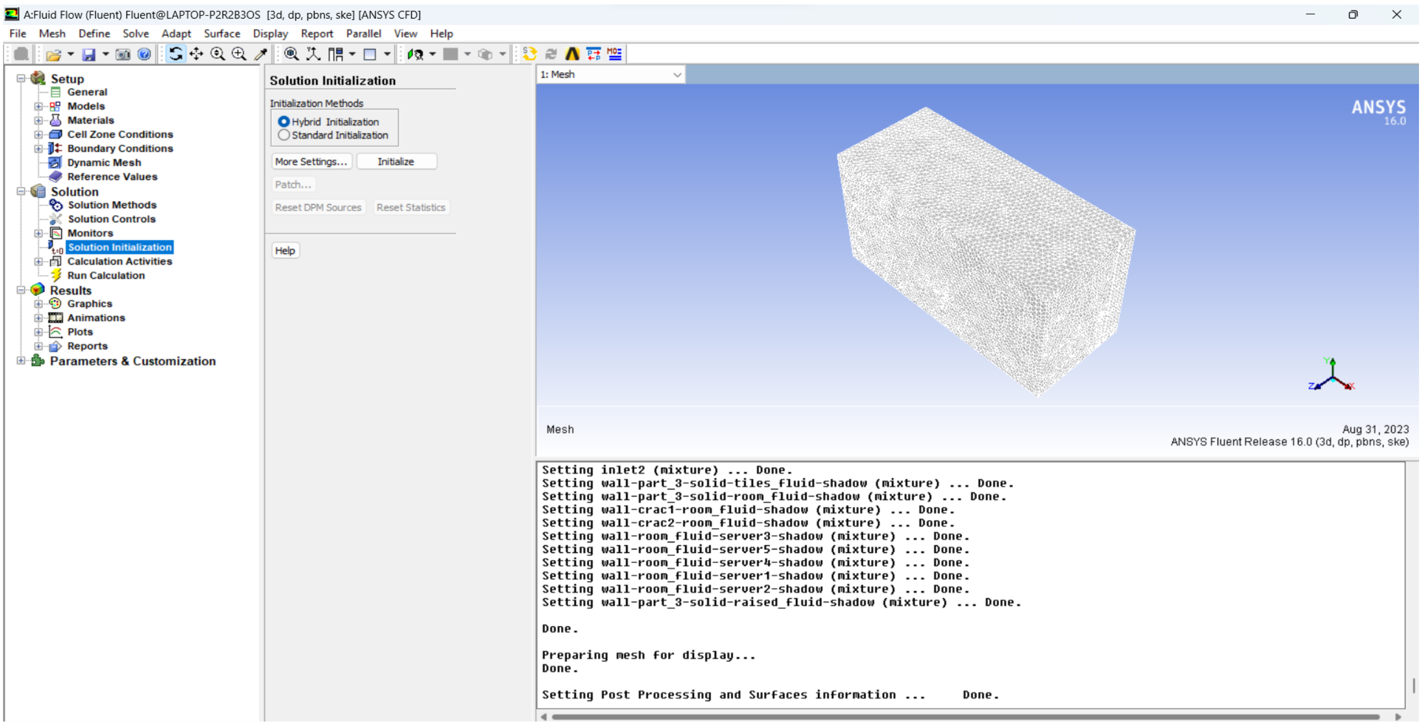

Fig:159

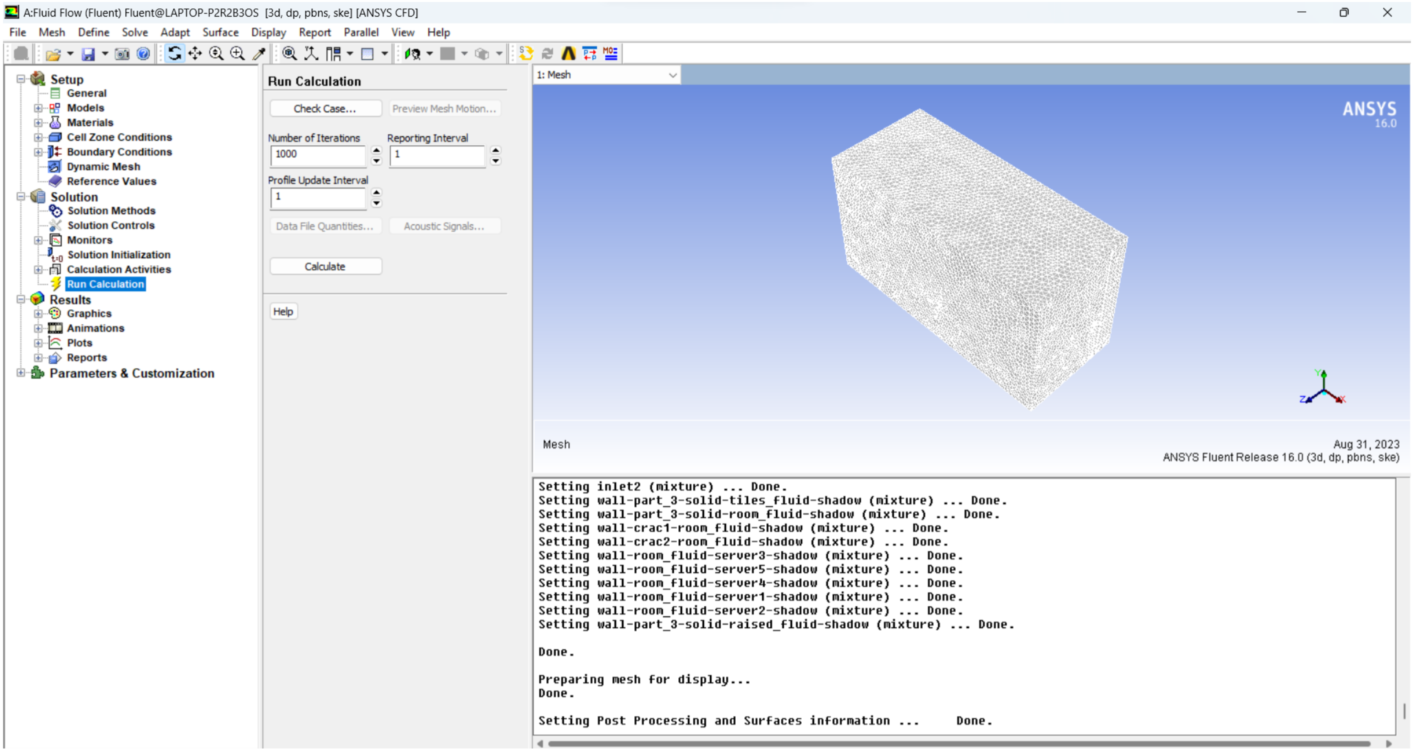

Fig:160

Step 5 – Getting of Results after Iterations

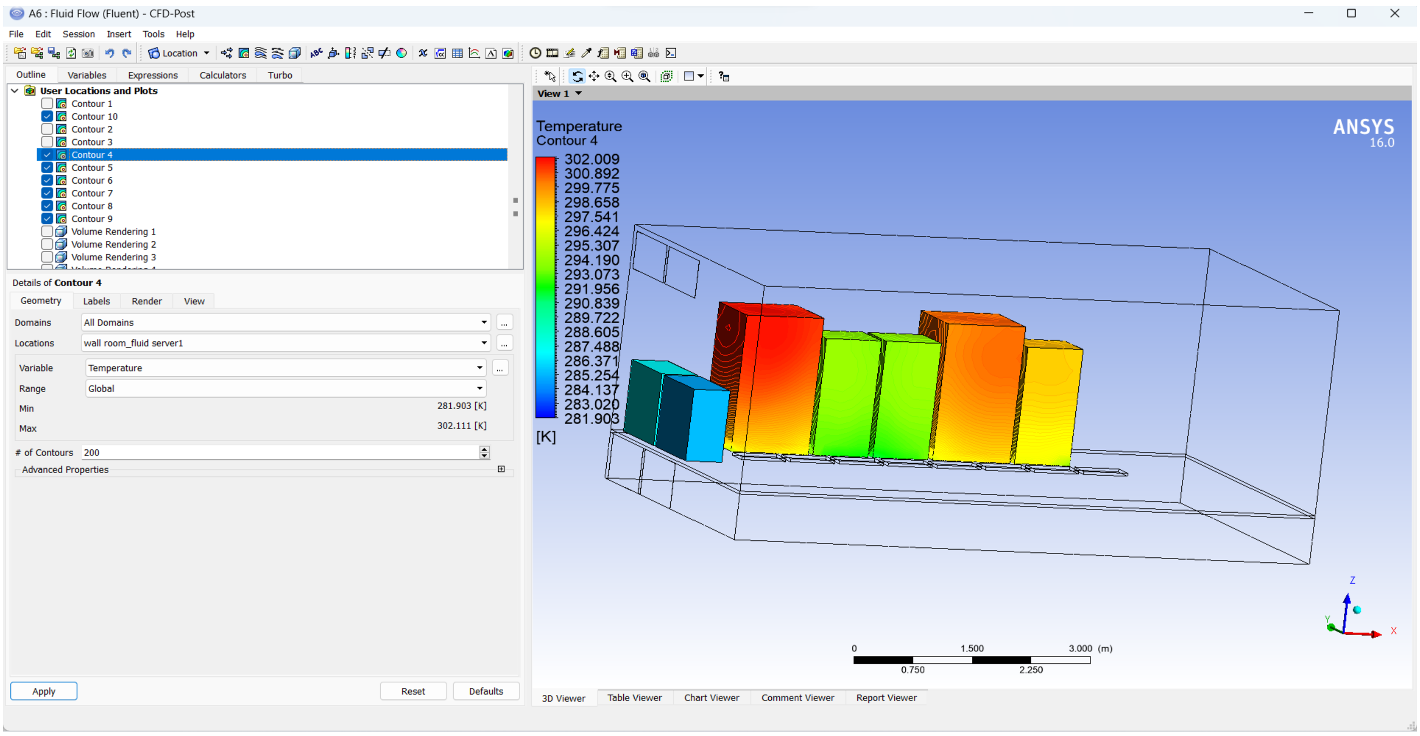

Fig:161