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THERMAL PERFORMANCE MODELLING OF DATA CENTRE– A CASE STUDY

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ABSTRACT

This paper presents a computational study of thermal modelling of the data centre located at CQUniversity, Rockhampton Campus, Australia. The data centre was modeled and analyzed using computational fluid dynamics (CFD) model to study the effectiveness of cooling within the racks and aisles of the centre. CoolSim- software was used for designing a graphical user interface (GUI) that allows data centre components to be positioned, sized and characterized in a plan view. Modelling of airflow and temperature distribution in the data centre was performed using the CFD code Fluent.

The CFD model based on thermal mass and energy balance principles was calibrated with the actual measurements of energy consumption, pressure and temperature from a standard rack filled with a set of rack mounted processor and storage units. The simulation results identified the potential high temperature zone within the computer rack in the data centre, and provide a detailed 3D analysis of how cold air is moving through the data centre. The results also provide the performance analysis of computer room air conditionings (CRACs), detailed rack-by-rack inlet and exit temperatures and 3D thermal mapping of the data centre and racks highlighting trouble areas. The model developed was capable of evaluating the airflow rates and thermal loads for optimizing and designing a new or existing data centre.

Key words: Data centre modelling; Computational fluid dynamics (CFD); CoolSim; Thermal mapping

INTRODUCTION

The cooling infrastructure is a significant part of any typical data center. The complicated connection of chillers, compressors and air handlers create the best possible computing environment, ensuring the long life of the servers installed within and the strength of the organization they support [1].

The common scenario for data centre infrastructure is the deployment of high density equipment. But in most cases data centres are not sufficiently capable of handling the additional cooling requirements resulting from these deployments due to the unwanted conditions such as recirculation or mixing of hot and cool air, poorly controlled humidity and costly wasted cooling capacity [1]. Traditional data centres are highly ineffective due to poor airflow management. Because airflow and pressure are not visible, it is not easy to develop a plan for improving airflow management without the use of an airflow management modelling tool. Although most data centres have required more cooling capacity during their operation and they still experience "hot spots" throughout the data centre.

Till now, the main concern for data centre users was the operating reliability. The energy efficiency was not their concern. Hence most of the data centres were designed based on worst case scenario [2]. However, with increase in power densities in the data centre reaching to levels that lead to limitations, energy efficiency is now observed as a way to solve these problems. The benefits of reducing energy inputs at various levels are [2]:

- reduction in cost
- lesser demand on utility grid hence improved reliability
- avoided investment in power plants
- reduced dependence on fossil fuels
- Less greenhouse emissions.

Typical CQUniversity’s main data centre is located at Information Technology Department (ITD) buildings: 19/G-33, Rockhampton that has no windows and minimal fresh air. This is due to fact that data centres are primarily designed for IT equipment and not for the human. It is important that the operating conditions within facility are based on the manufacturer’s limits. Therefore, ASHRAE [3] was followed in this study as a thermal guideline for data processing environments.

A large number of researchers have undertaken study on the dynamic optimization of the data centre thermal environment.

These studies mostly focus on the layout design of the data centre. Bash *et al.* [4] have investigated the need for placing the critical equipment of data centre in closer distance. Nakao *et al.* [5] studied the data centre cooling configurations with different variations. These configurations were - the under floor supply with ceiling exhaust, under floor supply with horizontal exhaust, overhead supply with under floor exhaust and the overhead supply with horizontal exhaust.

Noh *et al.* [6] used three variations for designing the data centre for 5-6 kW rack loads. They used these configurations in telecommunications applications which included under floor supply with ceiling exhaust, overhead supply with under floor exhaust and overhead supply with wall exhaust. Both these studies have suggested that the under floor supply with ceiling return is the best option. Therefore, the under floor supply with ceiling return has chosen for modelling in this study. The cabinet layout scheme, hot aisle/cold aisle is a traditional practice within a data centre for data centre architects, engineers, and end users [1]. This scheme was selected for designing the computer rack configuration. It uses air conditioners, fans, and raised floors as a cooling infrastructure and concentrates on separation of the inlet cold air and the exhaust hot air [1].

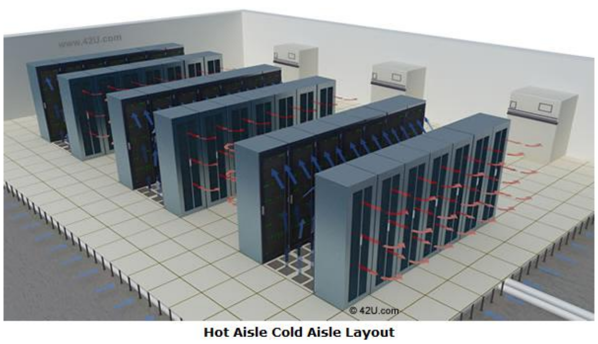

Figure 1 Hot aisle/Cold Aisle Layout [1]

Figure 1 shows the hot aisle/cold aisle configuration. In the hot aisle/cold aisle, the racks are placed into a series of rows, standing on a raised floor. The fronts of the racks face each other and become cold aisles, due to the front-to-back heat dissipation of most IT equipment. Computer Room Air Conditioners (CRACs) situated around the perimeter of the room or at the end of hot-aisles. CRACs deliver cold air under the raised floor. This cold air enters room through perforated raised floor vent tiles and passes through the racks and gets heated up. This hot air then returns to CRAC intake [1, 2].

Energy costs have now become one of the driving factors in data centre design. The increase in computational capabilities of data centres has resulted in corresponding increases in rack and room power densities [7]. Therefore, it is important to know the phenomena to reduce the energy consumption in designing data centres. CFD is the versatile tool for predicting the strategies to optimize the data centre cooling and power savings. The objective of this study is to develop model using CFD code 'Fluent' to study the effectiveness of cooling within the racks and aisles of the data centre of CQUniversity, building 19/G-33 at Rockhampton. This study also identifies the potential high temperature zone within the computer rack in the data centre, and provides a detailed 3D analysis of how cold air is moving through the data centre.

NOMENCLATURE

CFD	[-]	*Computational Fluid Dynamics*
CRAC	[-]	*Computer Room Air Conditioning*
ASHRAE	[-]	*The American Society of Heating, Refrigerating and Air-Conditioning Engineers*
GUI	[-]	*Graphical user interface*
CQUniversity	[-]	*Central Queensland University*
HVAC	[-]	*Heating, Ventilation and Air Conditioning*

DESIGN PROPOSED MODEL

This study was modeled based on conservation principles. For developing this model, the geometry was created using CoolSim 3.2 software [8] and the simulation was undertaken by CFD code "Fluent" [9].

The ITD building (19/G-33) of CQUniversity at Rockhampton has a high-efficiency Heating, Ventilation and Air Conditioning (HVAC) system. Figure 2 shows the 3-D view of the proposed building model

Three (down flow type) Computer Room Air-Conditioning (CRAC) unit were employed in this room. The raised floor was chosen with the room return facility but no supplemental cooling was selected. The CRACs unit is part of the raised floor room layout with cooling air passing through plenum and venting in the room through vent tiles. The racks were arranged in two rows. Each row consists of 5 racks. Air flow direction and air flow rate were defined for all racks from the specifications model of CoolSim 3.2 software [8]. The front face of rack, which generally was air inlet for the equipment, was placed facing vent tiles.

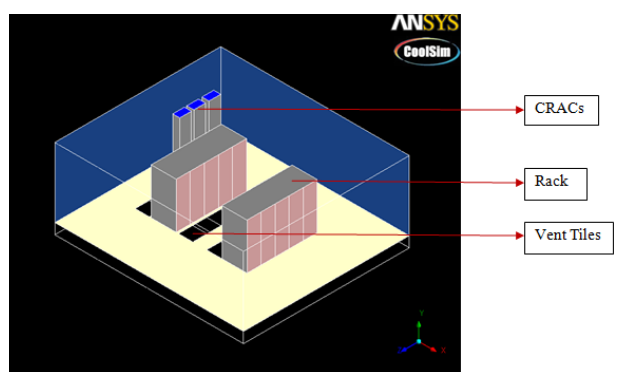

Figure 2 A 3-D view of a data centre of CQU ITD room

The air-moving device inside the racks was assumed to force air straight through the rack, with a constant velocity across the front and back of the racks. The backside of rack from where hot air passes; faces backside of another rack developing a hot aisle. Each rack was assumed to be a high-performance 3.46 kW rack, with a rack airflow rate of 0.23 m^3/s. This model was considered for humid climate as Rockhampton city is in a sub-tropical zone. The description of data centre and data centre components, air flow through racks and vent tiles are summarized in the summery report. It is noted that 56% openings were considered for perforated vent tiles.

Summary Report

Description of data centre:

Model ID: Nur-2ndDataModel
Simulation Date: Feb 14, 2012
Mesh Density: Medium
Mesh Count: 9688
Data Centre Layout: Raised Floor with Room Return

Data centre components:

Room Dimensions 8.05 X 7.08 X 2.96
Room Floor Area 56.99 sq-m
Supply Plenum Height 0.45 m
Number of CRAC Units: 3
Total Flow Through CRAC Units: 17.556 m^3/sec
Supply Air Cooling Capacity: 42265.61 W

Number of Rack Rows: 2
Total Number of Racks: 10
Total Rack Heat Load: 41.12 kW
Total Flow Through Racks: 2.562 m^3/sec

Number Tile Rows: 3
Total Number of Vent Tile: 15
Total Flow Through Tiles: 17.559 m^3/sec
Ave Flow Through Each Tile Vent: 1.171 m^3/sec

Power:

Rack Heat Source 41.12 kW
Wall Heat Transfer 1.11 kW
Total Cooling Load 42.23 kW
Heat Density 740.97 W/sq-m
Supply Air Cooling Capacity: 42265.61 W

Temperature details:

Highest Temperature in Data Centre Room: 29 ^oC
Highest Inlet Temperature in Racks
rackrow_0_1 Rack number 1: 20 ^oC

Relative Humidity:

Between 45% and 50% RH

Flow through tiles:

Maximum Flow Through a Vent Tile
tilerow_0 Tile number 2: 2.245 m^3/sec
Minimum Flow Through a Vent Tile
tilerow_1 Tile number 5: 0.248

RESULTS AND DISCUSSIONS

The CFD simulation was carried out for the model shown in Figure 2. The results of the room and rack thermal maps and static pressure map and the effect on the CRAC return temperatures and CRAC performance are reported in the next section.

Room and Rack Thermal Maps

The results of room and rack thermal profiles at different plane of the data centre are shown in Figure 4 through Figure 11. As discussed earlier, there are 3 CRACs units and the total flow through CRACs is 17.556 m^3/sec. Figure 3 and Figure 4 indicate that the thermal profiles were taken at 3 ft (0.914 m) height and 6 ft (1.83 m) height above the floor respectively. It is seen from these Figures that the temperature rise was observed more in higher height (6 ft) than in the smaller height (3 ft). This is located at the end rack of the data centre. From these Figures, it is evident that the hot exhaust air is being recirculated into the cold aisle and it is mixing with the supplied cold air. This has caused the inlet temperatures of the racks to raise more above the supply temperature.

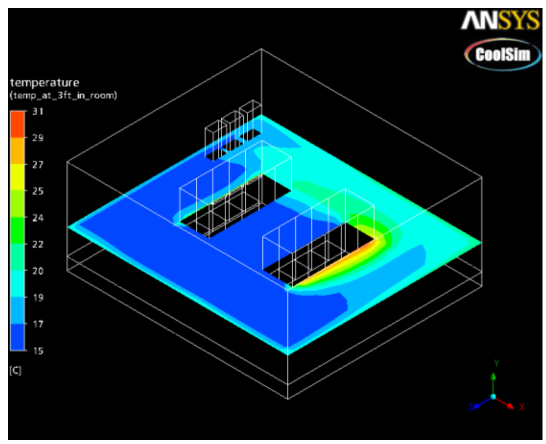

Figure 3 Thermal map at 3 ft (0.914 m) height above the floor of the data centre

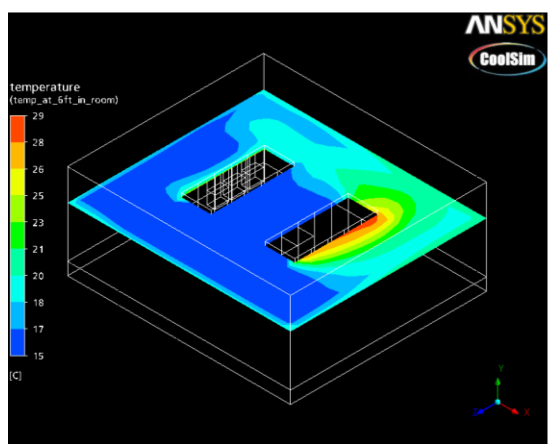

Figure 4 Thermal map at 6 ft (1.83 m) height above the floor of the data centre

Usually, the flow of air is passing from the vent tiles into to the cold aisle, where the cold air is moved into the server inlets and moved out of the back of the servers into the hot aisle. The hot air is then moved to the sides of the room where it is passed into the CRAC's.

Thermal map at mid plane along the width and length at the data centre of CQUniversity are shown in Figure 5 and Figure 6. For both cases, large temperature gradients were found at outside rack. Different recirculation pattern was also observed at outside rack. Because hot air leaving into hot aisle is enforced into cold aisle from the side as well as from top of the racks.

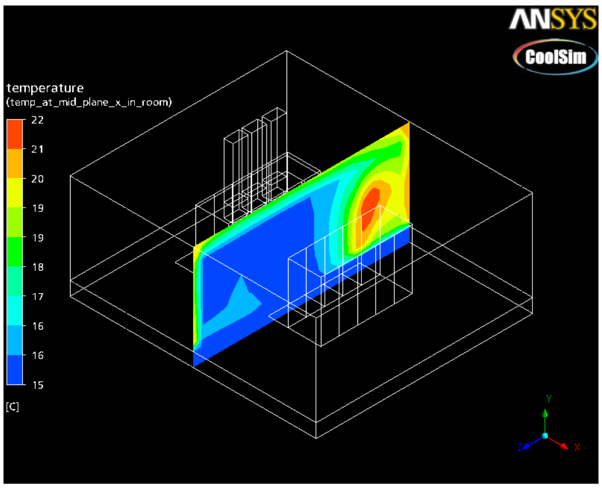

Figure 5 Thermal map at mid plane along the length at the data centre

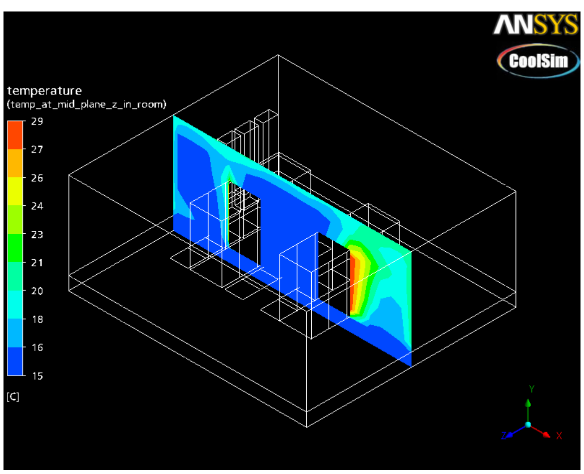

Figure 6 Thermal map at mid plane along the width at the data centre of CQUniversity

Thermal map at quarter plane along the length and width in the data centre are shown in Figure 7 and Figure 8. For both cases, hot and cold air mixing was present, but high temperature zone was found along the width of the data centre.

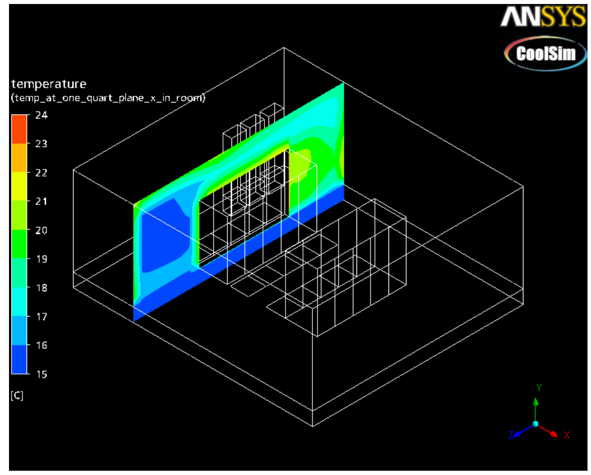

Figure 7 Thermal map at quarter plane along the length at the data centre

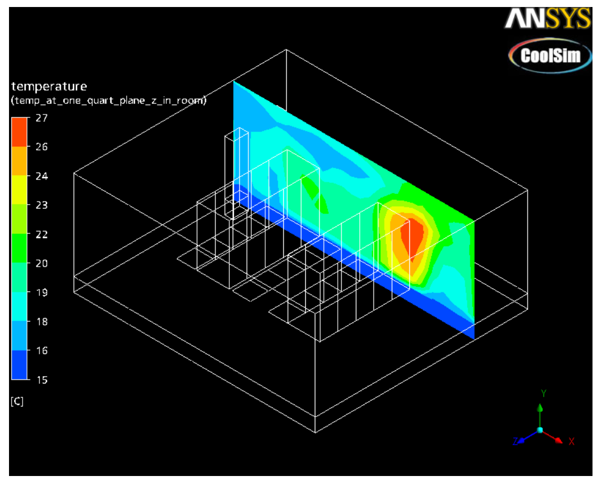

Figure 8 Thermal map at quarter plane along the width at the data centre

Thermal map at three quarter plane along the length and width at the data centre are shown in Figure 9 and Figure 10. Maximum temperature around 29^0C was observed at three quarter plane along length. It is due to the flow re-circulating from the exhaust side of the cabinet.

This high temperature is located at the back of the 2^{nd} rack of the data centre. On the other hand, the low temperature zone was found along the width at three quarter plane. However, high temperature was also seen at both top corners of the rack above floor on this plane. It is due to the server receiving air that is a combination of room air and air leaving from server outlets, instead of the vent tiles in the raised floor.

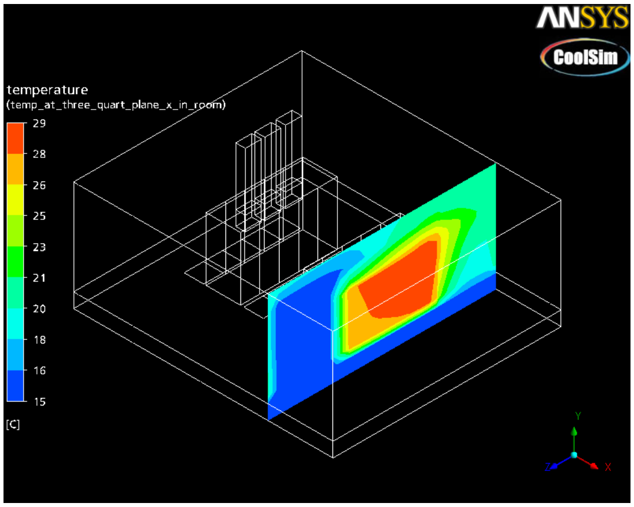

Figure 9 Thermal map at three quarter plane along the length at the room

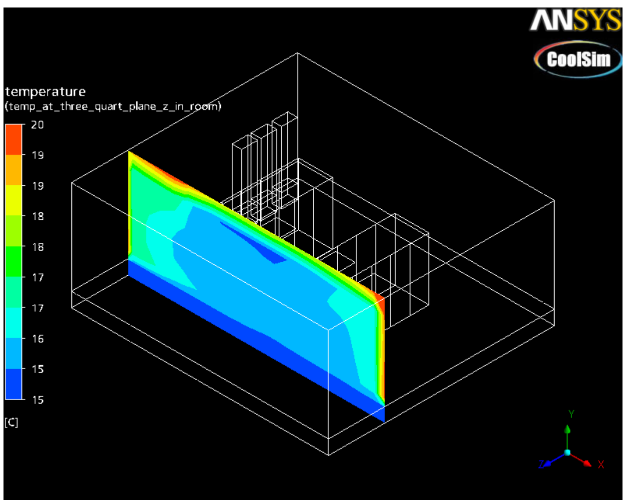

Figure 10 Thermal map at three quarter plane along the width at the room

Rack thermal map is shown in Figure 11. Figure shows the temperature distribution at both racks along length. This temperature distribution is placed between the back side of the 1st rack and the front side of the 2nd rack.

The temperature distributions of both racks were shown nearly 15^{0}C which is similar to the server inlet temperature but there is one exception at the front section of both racks where the temperature was found slightly higher which is nearly 18^{0}C-20^{0}C. This is due to higher dense server causing high recirculation between the inlet and ambient air.

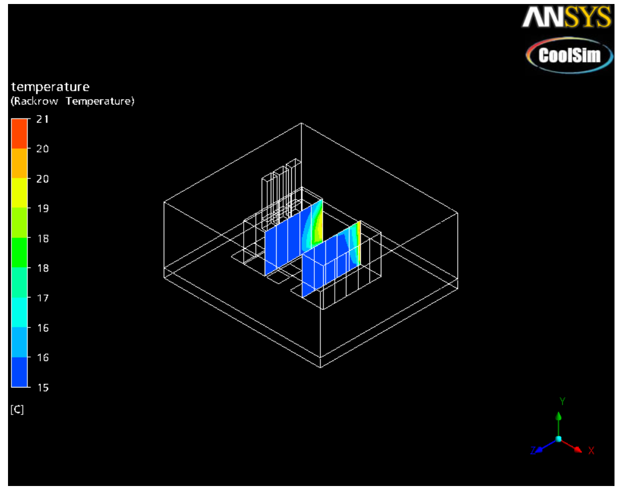

Figure 11 Rack thermal map

Static pressure map in supply plenum is shown in Figure 12 showing the pressure distribution in the data centre room. It is seen that the low pressure areas were observed at the surroundings of the computer racks. On the other hand very low pressure was found in the CRACs unit which is nearly -446.18 Pa to -354.86 Pa. As discussed earlier, the inlet air to the servers is nearly the same temperature as the air at the supply of the CRACs. However, the air in front of the servers at the bottom of the cabinets is moving at a high velocity, causing a low static pressure.

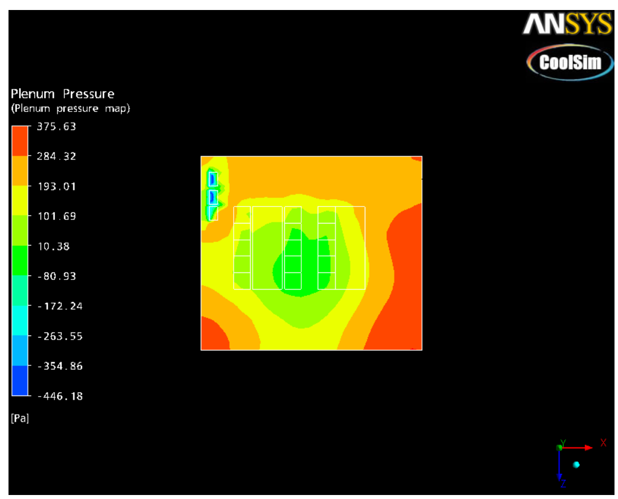

Figure 12 Static pressure map in supply plenum

Kwok Wu [10] has reported his study that cold aisle efficiently creates a thermal and mass flow boundary between the cold aisle and hot aisle. The cold aisle creates a region for mass to be ensnared, which creates a high static pressure region [10]. Since the cooling flow is increased with increase in power density resulting in an increased airflow to the cold aisle. This is due to cold air entering the racks near the cold aisle region and there is an increase of static pressure of cold air as the cooling flow increases.

Lower power density also creates the low static pressure which is due to smaller amount of air-flow from the CRACs ensuing in an insufficient build up of static pressure near the floor of the cold aisle region. This is caused by the higher server inlet temperatures at the servers situated close to the floor.

The Effect on the CRAC Return and Supply Temperatures

The effectiveness of any technology is measured by its ability to maintain data center equipment from overheating despite of the power density of the room [10]. A server is usually assumed overheated if the inlet temperature exceeds 25°C [10]. Another way to evaluate the effectiveness of this solution is temperature of air returning to CRACs units [2].

The CRAC return and supply temperatures profiles are illustrated in Figure 13 and Figure 14. CRAC performance report is summarised in Table 1.

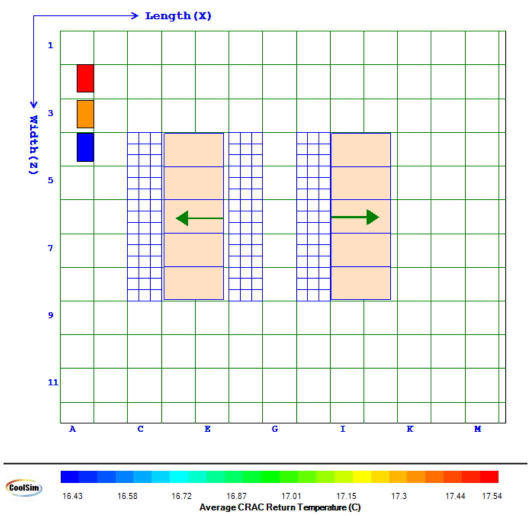

Figure 13 average CRAC return temperature

Figures show that the maximum supply and return temperatures were 15.79^{0}C and 17^{0}C respectively. As discussed earlier in summery report, the maximum inlet temperature to the racks is seen 20^{0}C. Table 1 shows that the average return and supply temperatures of the CRACs unit are 17.33^{0}C and 15.33^{0}C.

These temperatures limits are also meeting the ASHRAE guidelines [3, 11]. This low return temperature in turn reduces the load on CRAC and maintains required supply temperatures.

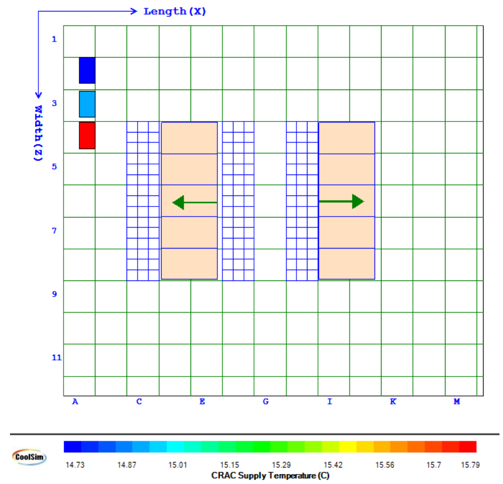

Figure 14 Average CRAC supply temperature

Table 1 CRAC performance report

CRAC Unit Name	Ave. Return Temperature (°C)	Ave. Supply Temperature (°C)	Supply Flow Rate (m3/sec)	Heat Removal (W)
Downflow Units				
crac_0 (A , 1)	18	15	5.852	20237.8
crac_1 (A , 3)	17	15	5.852	17412.15
crac_2 (A , 4)	17	16	5.852	4615.66
Total	--	--	17.56	42265.61
Average	--	--	--	14088.54

CONCLUSION

CoolSim 3.2 (Applied Math Modelling INC) was used to create the graphical user interface (GUI) of CQUniversity's data centre and commercially available CFD code 'FLUENT' under ANSYS 13.0 was used to simulate the data center models. In this study, the raised floor (under floor) configuration was employed in the data centre, and three CRACs units were set to operate based on the temperature of the returning air. The temperature distribution of data centre room and computer racks show the hot spot areas at different plane of the data centre. The effect on the CRAC return and supply temperatures show the capability of determining the cooling strategy to meet the on-going and changing needs of the current facility.

The study identified the potential high temperature zones within the computer rack in the data centre. The high temperature zones were observed at computer racks the along length and width at mid plane of the data centre. Maximum temperature around 29^0C was observed at three quarter plane along the length of the data centre and it was located at the back of the 2^{nd} rack of the data centre. This is due to the flow re-circulating from the exhaust side of the computer rack.

The average return and supply temperatures of the CRACs unit were found to be 17.33^0C and 15.33^0C respectively and the maximum inlet temperature to the rack was observed as 20^0C. These temperatures limits were compared with the ASHRAE guidelines, which are in good agreement. No overheated server was found as the inlet temperature did not exceed 25°C [10].

The low pressure areas were observed at the surroundings of the computer racks. Very low pressure (-446.18 Pa to -354.86 Pa) was also found in the CRACs unit.

This model could be used further to enhance the effectiveness of the data centre airflow by identifying hot zones in any data centre. It could determine the impact on cooling resources such as equipment layout, air flow rate, floor tiles, heat load distribution, and other supplementary cooling strategies. It also could provide temperature estimates for given rack loadings for the future modelling of data centre.

The further study will be to calibrate and validate this model under different operating conditions and thus will predict the energy cost savings using a CoolDoor. CoolDoor is an innovative refrigerated computer rack door that was developed by CoolDoor Pty Ltd, which changes the cooling dynamics of data centres by pre-cooling the ambient air before it enters a rack. The air passes over the heat generating components and re-enters the room near or at the ambient temperature.

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