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Ventilation Performance Improvement in a Container with an Extraction Free Cooling System

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Abstract. In this study, a far-off local zone telecommunication infrastructure container ventilation system with cabinets is modelled. CFD analysis is performed to obtain the temperature and velocity profile inside the container with given heat loads and volume flow rates provided by fans. In the second part of the study, performance improvement scenarios are simulated. Hot regions are found at the back sides of the cabinets and vortices are formed in the middle plane zone of the volume which reduces the air intake of the fans in corresponding cabinets inside the container. To overcome this issue, a flow director, i.e. vortex breaker is designed to redirect to enhance fan suction, and the orientation of the cabinets have rearranged. According to the results, it is possible to improve the ventilation performance of a container with such an approach. In this study, %2.0735 of improvement is achieved by changing the location of the cabinets and placing a vortex breaker inside the room, where it is a significant change for such far-off local zone telecom applications, considering the extreme environmental conditions.

1 Introduction

This study suggests an alternative approach for reducing the temperature of a telecommunication cabinet inside a container, which is constructed in purpose of using at far-off local zones, such as construction sites, PV-solar electricity generation facilities, and network connection points. This improvement in the temperature distribution inside the cabinet is achieved by rearranging air flow inside the cabinet.

Since the energy consumption is one of the main criteria in designing telecom infrastructures, the cooling facilities energy requirements are also included in the energy consumption of the whole system. PUE, Power Usage Effectiveness, is one of the indicators showing energy consumption of telecom and datacom equipment related to the consumption of the telecom infrastructure and whole facility. PUE is the efficiency of a Datacom and telecommunication infrastructure cooling system. It is the proportion of the total consumption of electricity to the IT equipment electricity consumption and expressed as [1];

$$\text{PUE} = \text{Total facility energy}/\text{IT equipment energy} \quad (1)$$

This expression shows that the decrease of cooling facilities energy consumption will result in a better power usage efficiency. This leads us to some solutions in order to increase the energy efficiency based on natural convection since it is environmental friendly in terms of freedom of refrigerants which have higher global warming potential and consumes less energy whilst no additional cooling equipment in the facility to remove the heat load of telecommunication equipment.

In purpose of convection, this study focuses on fan zones and its effectiveness over air circulation to prevent undesired heat load in the control volume of telecommunication cabinet and cabinet room as the main dynamic in convection is the pressure differences and flow zone and flow characteristics.

The effect of use of telecommunication container as an infrastructure in remote region deals with difficulties such as electricity transportation and maintenance because of the location and the distance between the central regions. Additional equipment that uses electricity for cooling such as chillers will cause losses in these areas during the transportation. Some energy batteries will have lesser operational life as more equipment will be needed to provide sufficient energy for cooling. In addition, maintenance of these cooling equipment is another parameter where should be handled and be taken care of. To prevent these situations free cooling is an option for such telecommunication systems.

Information and communication technology (ICT) solutions, cloud computing and smart services, internet of things (IoT) applications have increased tremendously in the worldwide after the Industry 4.0. As a result of this increased electricity consumption, data services contribute the greenhouse gases in terms of CO_2 or F-gases from refrigerant based cooling solutions. According to the EU targets for 2030, at least 40% cut in

GHGs compared with 1990 levels, at least 27% total energy consumption from renewable energy, and at least 27% increase in energy efficiency were aimed. Therefore, data services have to decrease their share in the total GHGs to achieve aforementioned goals.

Energy footprint of telecommunication networks and energy consumption forecast were performed [2]. Reducing energy consumption is directly related to the energy expenditures for the operators. Many precautions have been applied by the operators to reduce the energy expenditures, such as envelope design, airflow optimization, monitoring and control of inside temperature, integrating renewable energy sources, efficient cooling strategies.

Approximately 30-50% of the total energy is consumed by air conditioning systems to reject generated heat by cabinets or racks [3]. For a whole year operation great energy saving potential can be achieved by different cooling or ventilation methods.

Free cooling technology is generally used in the data centers or base stations to reduce the energy consumption in these highly energy intensive areas [4]. For telecommunication switches, French standard (ETSI EN 300 019) [5] specified thermal conditions as 5-40°C temperature and 5-85% relative humidity and a simplified air conditioning system was offered to reduce the energy consumption to one tenth according to the energy coefficient which is defined as the ratio of air conditioning monthly consumption to telecom total power consumption in kWh [6].

Direct evaporative air coolers for the telecommunication equipment rooms are an alternative method to reduce the energy consumption. The analysis of energy savings with a direct evaporative cooler for different regions in China show that minimum 10% and maximum 82% energy saving potential is available with respect to the outdoor conditions [7].

An air conditioning system assisted with thermosiphon was analyzed for different locations in China for a telecommunication base station. The results showed that higher energy saving potential, approximately 22.7%, can be achieved in colder regions while for warmer regions 6.7% energy saving potential was obtained.

It is developed an energy management tool for a generic telecommunication room with free coolers and air handling units [8]. The model can be used for the lowest energy consumption approach.

CFD analyses are widely used to predict the temperature distribution inside the cabinet for different cooling or ventilation strategies. There are simulations and case comparisons of many types of orientations and displacements for optimizing purposes in free cooling alternative studies [9]. The results showed that a thermal stratification layer was obtained by displacement ventilation which needs lower fan consumption.

This study is an analysis of a telecommunication system where it needs some additional approach to enhance the desired operational conditions.

It is desired to control the temperature difference as lower as possible. The current orientation of cabinets inside the container was in a condition that the temperature difference results undesired situations where it can damage the equipment and use fan power inefficiently.

To achieve the target value of temperature inside the container, a base case was simulated to obtain a temperature distribution. In the second phase, two suggestions, (1) rearranging the cabinets and (2) installing a vortex breaker were simulated. Section 2 gives all details about the CFD modelling such as geometry, mesh structure, boundary conditions etc. Section 3 shows the main results and comparison of the simulations.

2 Modelling of the System

2.1 Original Case

The system considered in this study is a container with telecommunication equipment inside of it. Container has two doors and some additional units included in the telecom facility. Additionally, there are two air channels to direct the air flow as desired. The structure of the container is made of PVC. It has a raised floor where the cables and connections are beneath of it. The components are standing above the raised floor. It is shown in Fig.1 as a model of the original case.

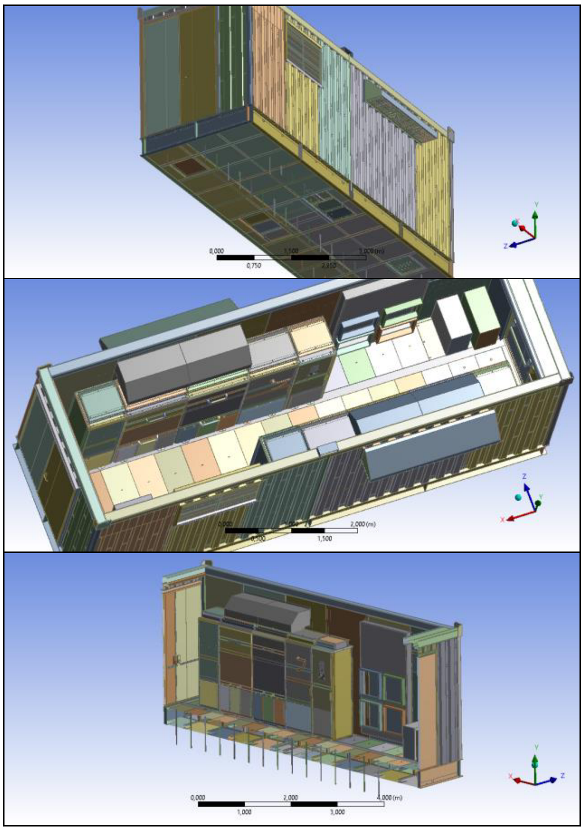

Fig. 1. Solid model and cross section of original case.

The container has four openings to direct the outside air into and outwards the container from each air channels where two of these are considered as inlets of the container and the other two are the outlets where they are creating a connection between top of four cabinets. The inlets have filters to keep the container room safe from the contaminants caused by environmental conditions.

There are ten cabinets inside of the room. Those cabinets are consisting two of each five cabinets. They are called Cabinet 1, 2, 3, 4, and Cabinet 5.

Cabinets have their own fans inside of them to create suction for cooling of the telecommunication equipment. Some of these fans are connected parallel and some of them are connected as series, where the fluid flow is aimed to be enhanced by such kind of orientation. Each of them has their own channels to direct the airflow top of the telecommunication cabinets.

Cabinets of 1^{st}, 3^{rd}, and 4^{th} have opening at the top of them which leads the air through back and front of them. 2^{nd} and 3^{rd} cabinets have an opening at the top of them that directs the waste heat to be discharged by a channel through the container outlet window. All of the cabinets suck air from in front of them and bottom of the front face.

There are four components beside the cabinets. There is one of each Power Scale, Auxiliary Transformer, AC Distribution Board, and Battery Bank inside of the container room where these provide a function as their names indicate so.

2.2 System Modelling

2.2.1 Fluid Volume

The airflow in the container is occurring basically by the entrance through an air channel, and from the air channel through the room. The air that came from the outside inside of the room is being carried by the fans inside the cabinets and transferred to outside and inside both. ISU cabinets are transferring the air to outside. Other cabinets are carrying the air to inside, where the heat load will be dissipated through the room. The raised floor is a cover for the cables connected the cabinets, as there is no air circulation, the only fluid volume is the one expressed above.

There are three cases involved in this study, namely “Case 1”, “Case 2”, and “Case3”. Case 1 is the default room or original case; it has air temperature above the predicted and recommended value, where the telecom cabinets have 100 mm away from the longitudinal wall, and 350 mm away from the sides. The other ones are the solution approaches for the existing real system issues.

These two other cases have the same and new orientation, which the telecom cabinets aligned with the corner of the container room. The outlet of the six cabinets that lead the air from their back and top of them is closed. There is one difference between these two new oriented cases, where one of them consisting an additional part inside the container room, where it is predicted to direct the airflow to enhance the optimization of cooling system, and fan behavior.

The room structure is modelled by using the Solidworks software and the fluid flow is analyzed with ANSYS Fluent code.

2.2.3 Modelling

Several factors are neglected in the modelling of geometry. Thicknesses of cabinets and air channel, the door geometry, vent geometry are neglected. The surface details of cabinets and container are assumed to be a plain plane. The static pressure being created by vent and air channel is considered as a value where it effects the flow but not particularly as a solid geometry. Overall, the geometries inside the fluid volume are simplified as they are not going to affect the reliable analysis results. The simplified geometry of the default case as Case 1 and the two other case geometries are shown in Fig.2. The other cases are simplified with the same approach. From these simplified models, the volume is extracted and used in analysis as fluid control volume.

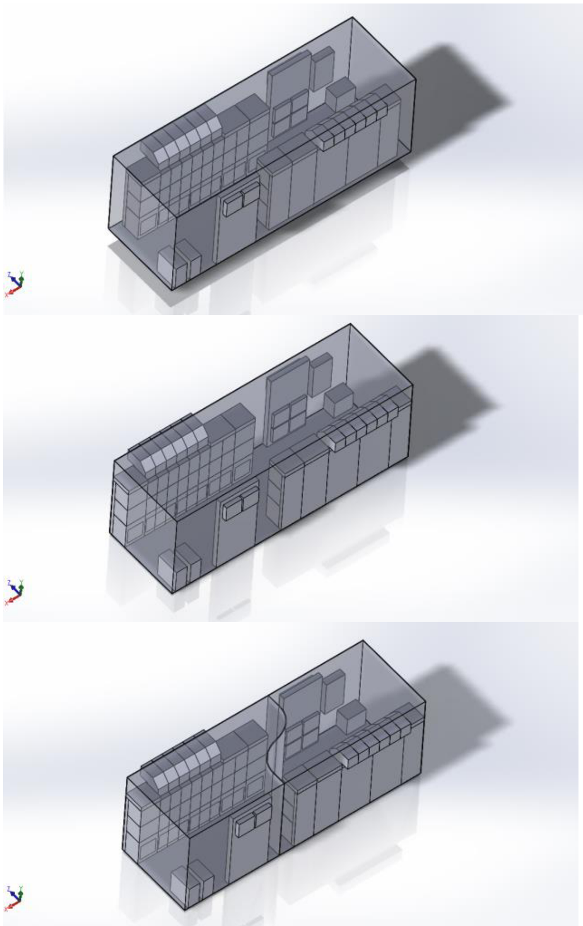

Fig. 2. Simplified model of the Case 1, Case 2 and Case 3

All the bodies inside the room are included owing to the components beside the telecommunication cabinets have effects on the fluid flow.

The entire room boundaries where it is defined as walls are adiabatic; there is no heat transfer occurring

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between environment and no heat transfer occurring by the cabinet material through the room. The effect of sunlight and radiative heat transfer of the components are neglected as well. It is assumed that there is no heat transfer from the ground since there is no connection between ground and fluid volume as the raised floor is preventing the heat transfer.

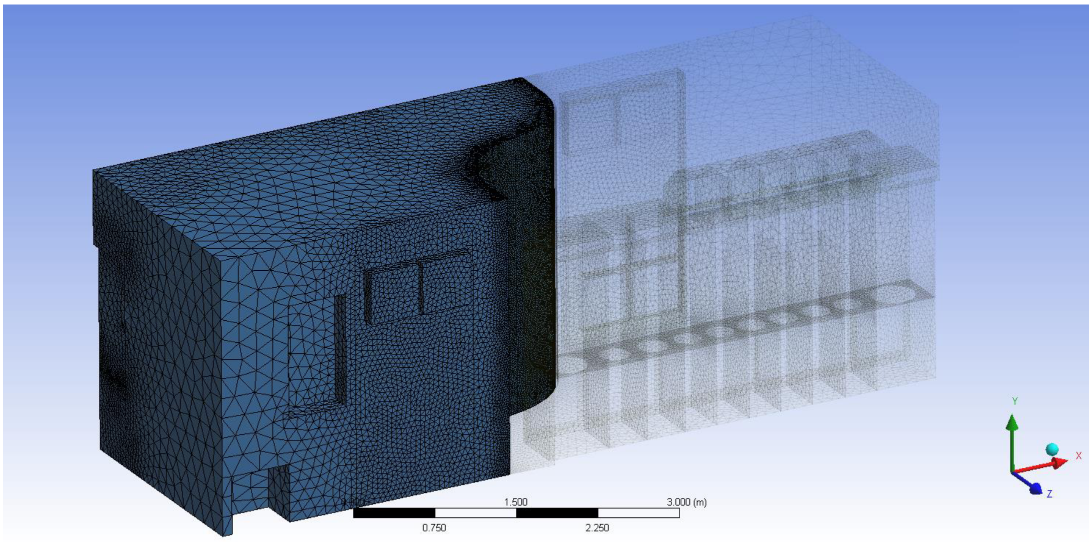


Fig. 3. Mesh structure presentation

The heat generating equipment in the cabinets are assumed as a plane surface where the heat load is dissipated from the telecommunication equipment and transferred through the room, where it will provide the assumed heat load inside the cabinet to be modelled. Additional equipment inside the room has no heat dissipation; hence the heat transfer occurs only between the cabinets and the air inside the room.

The vents and are considered as static pressure sources and not included in the flow volume geometry.

The outlet channel of 2nd and 3rd cabinets has a "U" shape and it is simplified in model where it is just an opening through the environment.

Fans are modelled as circular surfaces creating a pressure jump to enhance the fluid pressure to direct them through heat dissipating components. The details of fan characteristics and the shape of blades etc. are neglected; the fan behaviour is not included in the analysis since they only act as pressure increasing equipment to control the flow. The individual pressure jumps are obtained from the fan curves by each of their own to reach the desired flow rate.

2.2.4 Meshing

Tetrahedron mesh type is chosen for meshing the fluid volume to analyse the flow since there are many fluid zones as container room itself, cabinets, and inlet channels where it is considered as an assembly-meshing situation. The amount of mesh number is increased at critical pressure jump locations such as inlets, outlets, and fan areas. To obtain reliable results, the mesh independence is checked with three additional mesh cases such can be considered coarse, medium, and fine mesh structures. Mesh is structure is shown in Fig.3.

The mesh qualities and quantities of each case are listed on Table 1. Orthogonal qualities of mesh for each case as volume-weighted averages are shown which the orthogonal quality is acceptable mesh quality measure criterion for tri/tetra meshes.

Table 1. Mesh quality and quantities by cases.

Mesh	Case 1	Case 2	Case 3
Quantity (elements)	1607685	2805967	4197562
Orthogonal Quality	0.8443116	0.8502354	0.8524169

2.2.5 Boundary Conditions

The mathematical method of analysis is chosen for calculating cell-face pressures as PRESTO! because of the flow characteristics such as fan involved in the fluid zone creating a swirling flow, and curved flow geometry [10]. Solver is stabilized with enhanced AMG solver in order to decrease the anomalies in iterative method, as choosing the method Biconjugate Gradient Stabilized Method (BCGSTAB) rather than Conjugate Gradient Method (CGM). By this stabilization, the great amount of difference in scalar values of temperature that result as undesired divergence condition in iteration is stabilized in solver action [11, 12].

Interpolation schemes have chosen as Second-Order Upwind for calculating turbulence and such, whilst the nature of mesh structure is tetrahedral mesh and to approach higher order accuracy [13].

There are four groups of boundary conditions in this analysis: heat dissipation areas, fans, inlets, and outlets.

Heat dissipation areas are calculated by each of the heat generation rate of the cabinets. As the heat dissipating equipment lies at the top of the cabinet inside, the heat dissipation is identified as not a heat generation in a volume but as a constant heat flux through the surface. The surface is the surface where the heat is being dissipated. The rate of heat flux is calculated by using the area of the surface and the heat generation of the cabinet and the heating values are given in Table 2.

Table 2. Heat dissipation boundary condition

Cabinets	1st	2nd	3rd	4th	5th
Heat Load (W)	400	25000	25000	2670	500
Heat Flux Surface Area (m²)	0.369	0.6	0.6	0.474	0.375
Heat Flux (W/m²)	8813	41666	41666	5680.85	1333.33

Fan boundary condition is considered as a pressure jump, where the pressure values are obtained from the fan curves of each product. The serial fans are considered as single fan creating the same flow rate as desired. Swirling is also considered as a parameter inside since it is affected by the fluid flow characteristics inside of the room and inside the cabinet as well. Static pressure condition is included in the pressure given to fans while considering the flow rate values, since there are elements belonging to cabinets where they create static pressure.

Inlets and outlets are considered as passive elements, which they provide openings from outside and inside. In this condition where there are filters in front of them, there is a static pressure source element, and this effect is simplified as a static pressure in the case. The pressure outside is considered as the atmospheric pressure at sea level and the temperature of cabinet and environment is considered as having the same value in initial conditions, and it is 300 K.

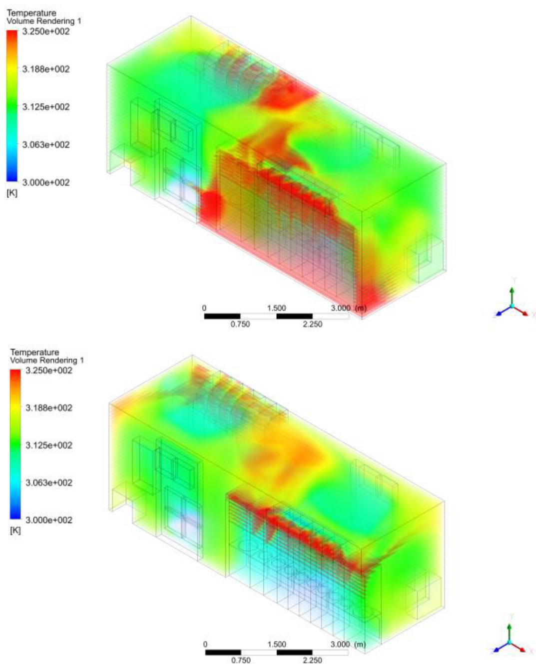
3 Results

The temperature distribution for each case is obtained for the aforementioned boundary conditions. It is clearly seen that the temperature difference between the outside and the inside of the container room is around 15°C, which is not desirable in Case 1, the default orientation of the room equipment. The heat load is piling behind the cabinets between the walls and back of each cabinet and it is flowing through the center from the open sides of the cabinets. This flow is extremely slow and causing extreme amounts of heat load collected behind the cabinets where it is dangerous for telecom infrastructure equipment considering the heat transfer between cabinets and the back of them by convection and conduction. The temperature distribution along the volume is shown in Fig.4.

In other analyzed cases, a considerable amount of uncontrolled heat dissipation is prevented by changing the orientation of the components inside the room. When the cabinets are aligned to the two opposite corners of the room, the air that is escaping back of the cabinets are no longer flowing through there, and the air is directed from the top front of the cabinets. With this rearrangement, the heat carried away to the center of the room, where it can meet the fresh air from the outside.

From the analysis results, the volume-weighted average total temperature of Case 1, Case 2, and Case 3 are 315.00 K, 312.94 K, and 308.47 K respectively. There is a slight change in average total temperature however, this slight change is important for such telecommunication cabinets where it is being used in far-off local zones. Cabinets face extreme weather conditions in far-off local zones and temperature have considerable effect on natural cooling, where it will cool the cabinets in this case.

The main effect of this orientation arrangement is the flow velocity and characteristics of the air inside the facility. Cabinets have fans that are maintaining suction by creating a pressure difference, located at the bottom-front of the cabinets. In the middle of the container room, it can be seen that in Case 1, and Case 2, a vortex is being created, that it behaves as a source of static pressure which is resisting against the fan suction through the cabinets and will lead to much higher suction power to reach the desired volume flow rate.



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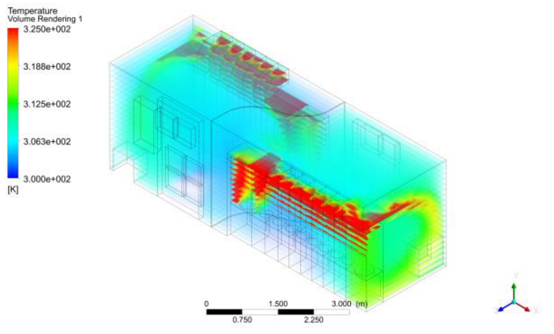
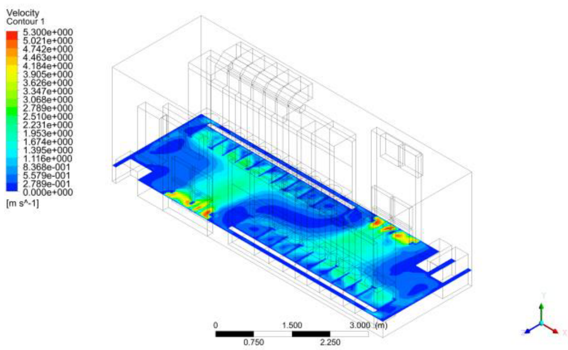
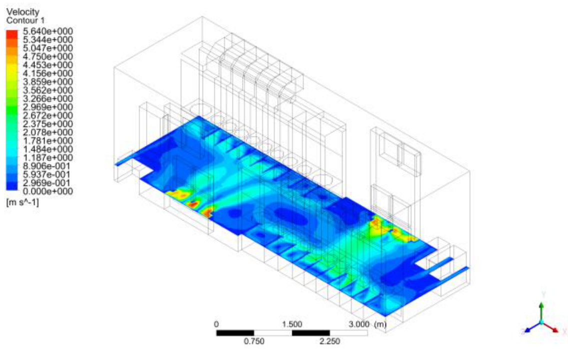


Fig. 4. Volume renders based on temperature of Case 1 (top), Case 2 (middle), and Case 3 (bottom), respectively

Each case have same boundary conditions therefore, the fan suction power and pressure stays the same. However, the change in orientation caused fans to be able to draw more air from outside, where it can be seen in Table 3. Table 3 is showing the volumetric flow rate of air from both inlets for each case.

The vortex velocity profile is perpendicular to the fan suction direction on the top plane of the room. It is causing the air to move around the center and not being diffused around the volume. Fans are incapable of sucking the air as desired by this condition. The velocity profile of the room in Fig.5 is showing the vortex and the flow director's effect on it. From the Table 3, the effect of vortex breaker can be seen by comparison of the volumetric flow rates of Case 1 and Case 2 by Case 3.





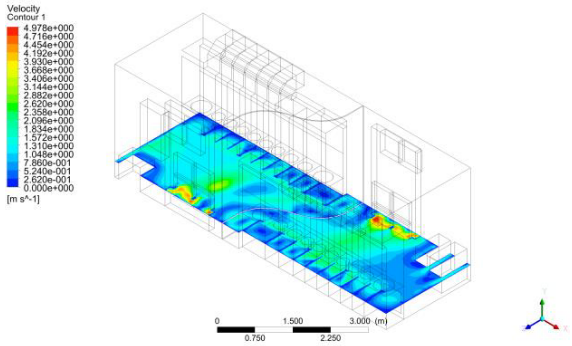


Fig. 5. Velocity profile in the room for each case as Case 1, Case 2, and Case 3, respectively from top to bottom.

Since the suction is decreased, the flow rate inside the cabinet will decrease, and the inlet flow rate will decrease where it will lead the fresh air rate inside the room decreased. Because of these conditions that vortex is creating, at the top of the room, the hot air is circulating but not cooling, where the cool air is not sucked sufficiently by the cabinets. To overcome the vortex problem a flow director, i.e. a vortex breaker, is designed. By this addition in the room, air is directed through the fans. The perpendicular flow is partly broken. The flow change is resulted as a positive effect on fan operation. The Fig. 6 shows temperature distribution of the room as histograms.

Table 3. Volume flow rate of each case created by fans

Cases		Case 1	Case 2	Case 3
Volumetric Flow Rate	(m^3/s)	2.1324761	2.1596061	2.1704595
	(m^3/h)	7676.914	7774.582	7813.654

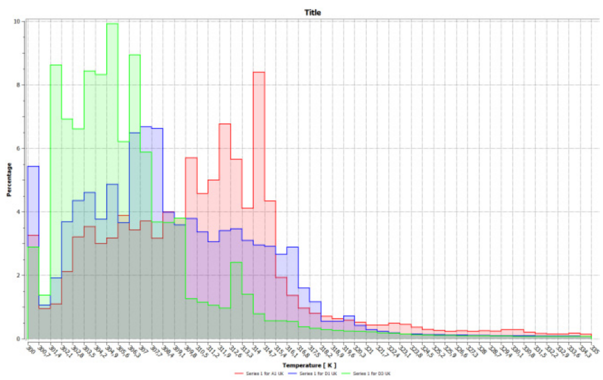


Fig. 6. Temperature histogram by percentage for each case. Case 1 is shown with red, Case 2 is shown with blue, and Case 3 is shown with green graph.

The histogram shows that the average temperature is decreasing by changing the position of cabinets and

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conditioning the air inside by directing it with a flow director that fundamentally acts as a vortex breaker.

4 Conclusions

Even though the cooling equipment such as CRAH, CRAC, chillers etc. is the main cooling drive to cool a telecom and datacom infrastructure, the energy consumption is an essential parameter as well where it should be dragged down for a greener environment and a more sustainable future.

Designing of datacom and telecom facilities, cooling rooms are very important to achieve goals of IT purposes and such as electrical control units where they will be essential in far-off local zones. This design should consist of considerations focused on flow field at first, in order to improve the cooling effect. With or without the cooling equipment, the main functionality of the cooling is totally dependable on the flow characteristics. Flow characteristics are affecting the fan suction, cooling equipment load and heat load dissipated and distributed around the room. These parameters are directly connected to economic concerns since in a facility which is not optimized may cause more fan power to achieve the certain goals of recommended values, and more cooling power to achieve them as well. A coarse flow will result as economical paybacks and undesired errors in time upon the infrastructure.

This can be prevented by changing the design of the room itself and rearranging the components inside the cooling room. This study showed that, flow physics are important in order to make a design applicable.

The temperature difference between each case is around 2°C and 3°C where the difference is considerable for cabinets being used in far-off local zones because of the extreme conditions that cabinets may face during operation. Average total temperature of Case 1, Case 2, and Case 3 are 315.00 K, 312.94 K, and 308.47 K respectively. From Case 1 to Case 3, in this study, %2.1 of improvement is achieved by changing the location of the cabinets and placing a vortex breaker inside the room.

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