BES322764

Autodesk CFD Simulation in Design of Cooling and Backup Power Infrastructure for Business Continuity in a Tier-4 Data Center

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Learning Objectives

- Learn how to characterize Data Center and Backup Power components
- Learn strategies for modeling airflow and heat transfer
- Learn how to set up simulation and visualize results using Autodesk CFD tools
- Learn how to review results and evaluate design for effective cooling and how cooling affects business continuity

Description

This class will cover the use of Autodesk CFD Simulation software in the design of cooling and backup power infrastructure for business continuity in Data Centers. Data-center business is poised for rapid growth around the world. Well-designed cooling and backup power infrastructure is critical to data-center performance. Autodesk CFD is a useful tool for evaluating design strategies to optimize data-center cooling and improve energy efficiency. You'll learn how to characterize data-center and backup power components in Autodesk CFD model. You'll learn how to identify strategies to develop Autodesk CFD model for airflow and temperature simulation. We will highlight assumptions made to reduce overall complexity without losing design intent. You'll learn to capture important results and evaluate the design for effective cooling to ensure business continuity of a Data Center.

Speaker(s)

Dr. M. Munirajulu is the Chief Engineering Manager responsible for CFD analysis in MEP design related to commercial buildings and airports in L&T Construction, Larsen & Toubro Limited, Chennai, India. He has more than 23 years of direct and indirect involvement with CFD technology as a design analysis tool in areas such as HVAC, Automotive, Fluid Handling Equipment, Steam turbines and boilers. He has been using Autodesk CFD Simulation software in AEC applications such as thermal comfort, Data Center cooling, basement car park ventilation, DG room ventilation effectiveness, Rain water free surface flow for roof design, and Smoke simulation in buildings in design stage as well as for trouble shooting. He has published 4 nos. of technical papers in international journals of repute and has been a speaker at technical conferences including AU 2017, AU 2018 Las Vegas and AU India 2019.

Contents

Introduction

Data Center is a facility/building for mission-critical systems such as computing and communications hardware. It is composed of networked computers and storage. It includes processing, storage, networking, management and the distribution of **data** for a business enterprise. In this world of "Big Data" and Internet, Data Center infrastructure is a critical asset for an organization. Data Centers cater to applications, services and data for SaaS, web hosting, data backups, redundancy, email, shared apps, and so many other technologies.

Why is Data Center business continuity important?

Data Centers have to be up and running 24x7x365. Data Center infrastructure and uptime has become a prominent factor with the emergence of cloud-based technologies and internet-based tools. As a result, business continuity factors for Data Centers have become increasingly important, and downtime prevention is more critical than ever.

Factors affecting business continuity

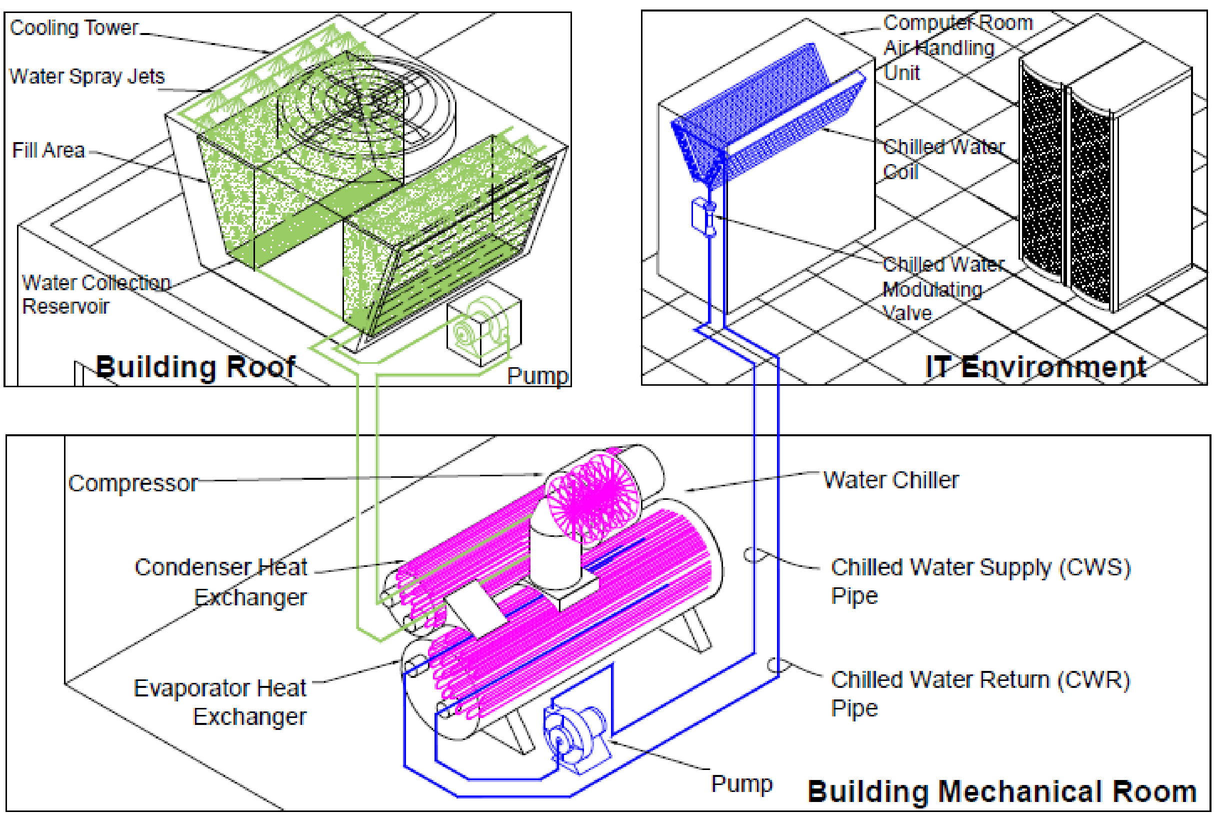
Business continuity plan has to ensure maximum uptime for the Data Center. Data Center cooling infrastructure and emergency backup power are two important factors affecting business continuity.

Data Center cooling infrastructure

Data Center cooling systems are indispensable to the way Data Centers are run. Data Center environment in terms of temperature and humidity play a critical role for maintaining uptime and optimal hardware performance. If temperature or humidity are high, hard drives and other devices may fail prematurely.

Today's Data Centers operate with an average cabinet power density of 5-10kW per cabinet or even higher. Servers in Data Centers generate huge amounts of heat while handling and processing data. Properly designed cooling systems and air flow distribution provide adequate cooling capacity for heat removal from the server hall as well as safe operating temperature for server racks. Energy demand in Data Centers for cooling is about 38%.

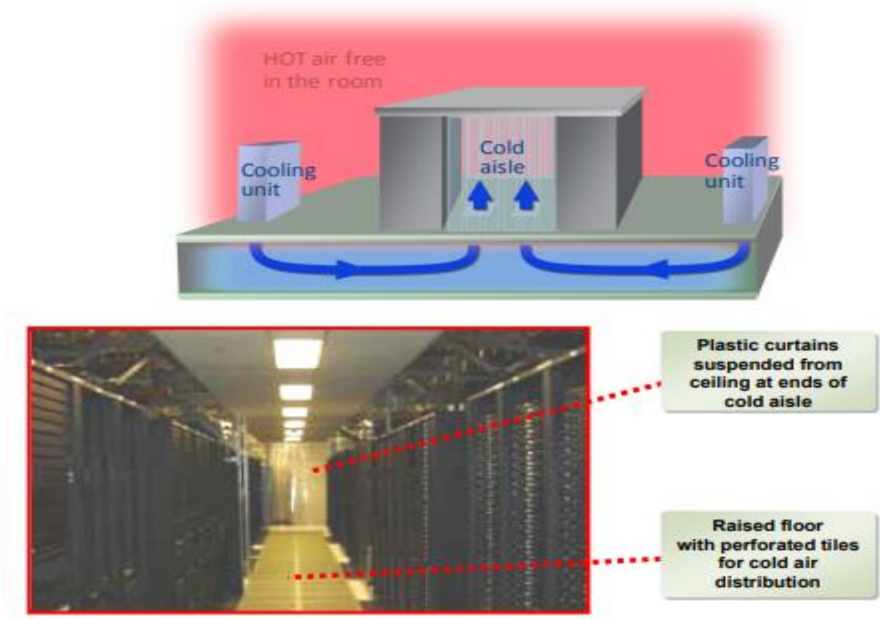
Typical **cooling system** consists of chilled water system with cooling tower, water chiller and CRAH (Computer Room Air Handling) units.



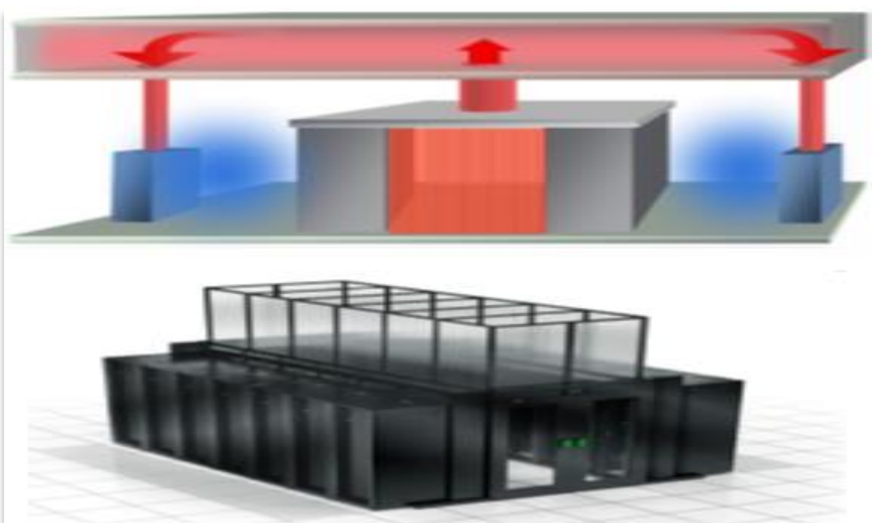
Chilled Water System used in modern Data Centers[1]

Air distribution systems consist air supply and return provisions with a main goal of providing uniform air flow and temperature. Effective air distribution systems are designed to separate IT equipment exhaust air from the IT equipment intake air in order to avoid hot spots and IT equipment from overheating.

Cold air distribution systems consist of raised floor with floor grills/hard floors, Cold Aisle Containment and Hot Aisle Containment.



Cold Aisle Containment (CAC) [2]



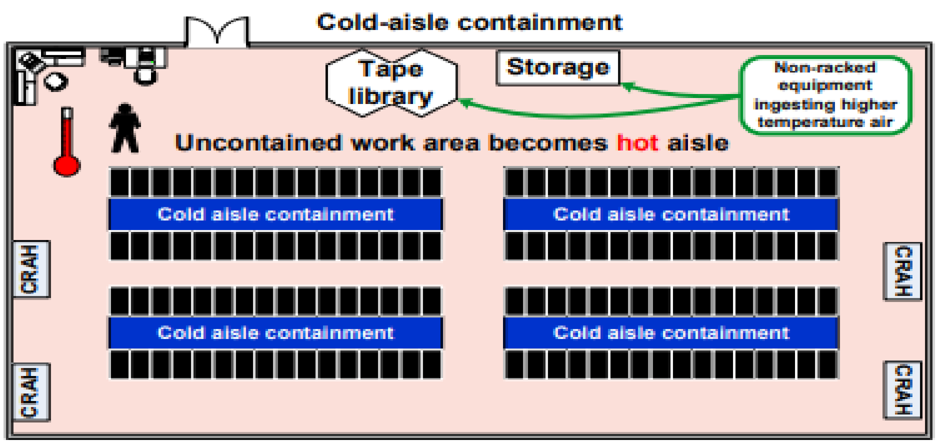
Hot Aisle Containment (HAC)[2]

In general, contained supply or contained return is used for providing cooling to racks which are operating at power levels in the range of 5-15 kW. CAC or HAC results in the separation of hot and cold air and this in turn results in energy efficiency. Also containment allows uniform server rack inlet temperatures and eliminates hot spots otherwise found in traditional uncontained Data Centers.

Research indicates that hot-aisle containment can provide 43% cooling system energy savings over cold-aisle containment due mainly to increased economizer mode hours.

The 2011 version of ASHRAE Standard TC9.9 recommends server inlet temperatures in the range 18-27°C / 64.4-80.6°F. With CACS, the temperature in the uncontained area can get well above 27°C/80°F, and in cases of high-density IT equipment, above 38°C/100°F.

In a raised floor design, cold aisle containment is implemented. For the hard floor design, hot aisle containment is implemented. Cold aisle containment systems operate at lower temperatures to provide acceptable environment for personnel. Hot aisle containment systems work at higher temperatures because personnel are located in cold aisle, hence higher efficiency and efficient cooling plant.   Hence large Data Centers use hot aisle containment and hard floor design.



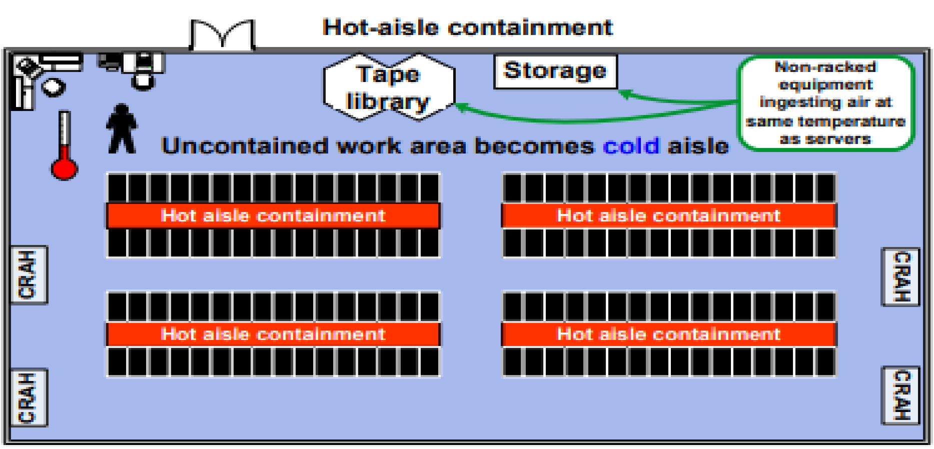
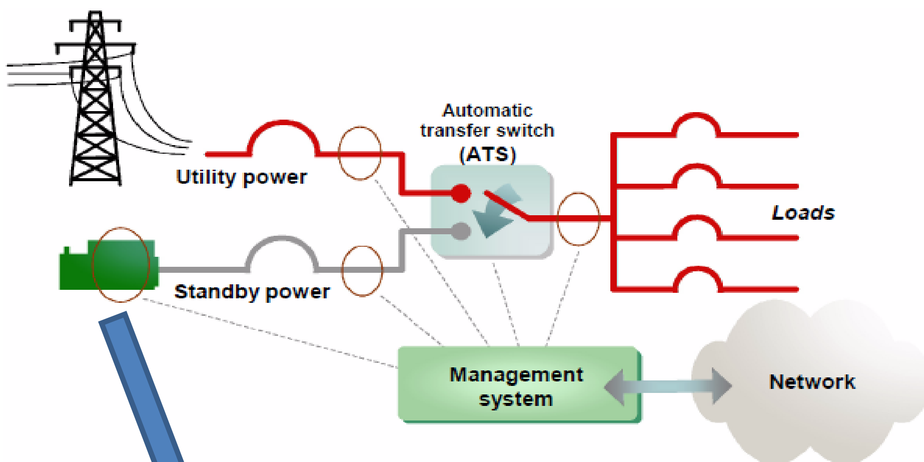


Image Courtesy Ref.#2.

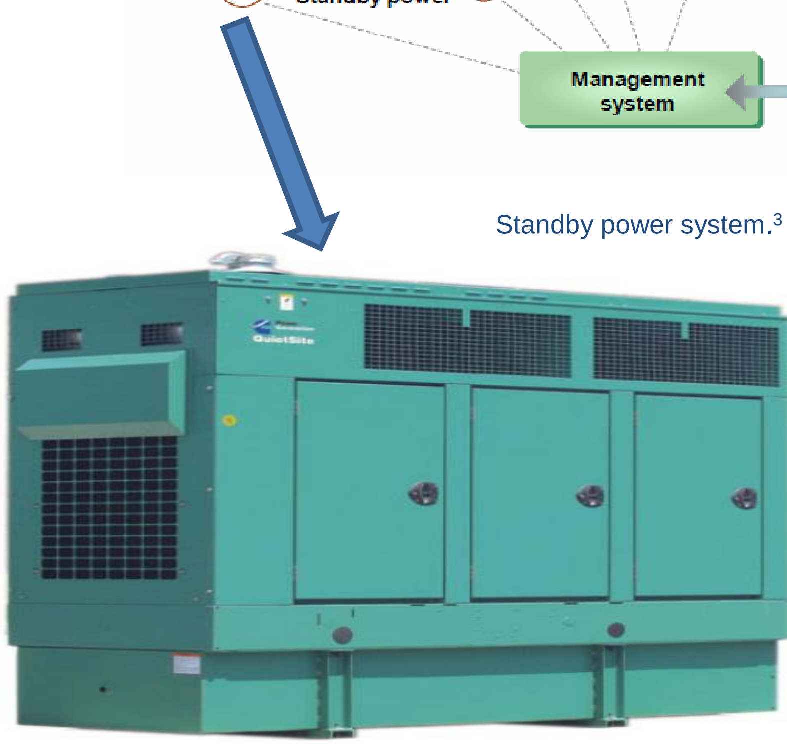
Emergency Backup Power

During normal operation, Data Centers are supplied with utility power. IT systems may operate for a few minutes or even a few hours on battery but local emergency power back up is critical to achieve minimum requirement of power availability. The function of emergency power back up is to provide power when there is interruption of main/utility power. When the utility power is lost/not available, emergency /standby power generator supplies power to critical components such as Data Centers, security centers and UPS so that Data Center operations are not interrupted and continue to operate normally through power loss. Standby generator systems are typically used in conjunction with UPS systems. Hence, standby power generation and availability is a key factor for business continuity of Data Center operation.

Usually diesel engine generator are used for standby power generation. Generator power plants are not used as the continuous power supply for the Data Center but as a reliable redundant power. For large Data Centers, N+1 (or N+2) generator architectures are considered as standard design.



Standby power system.[3]



Diesel Generator

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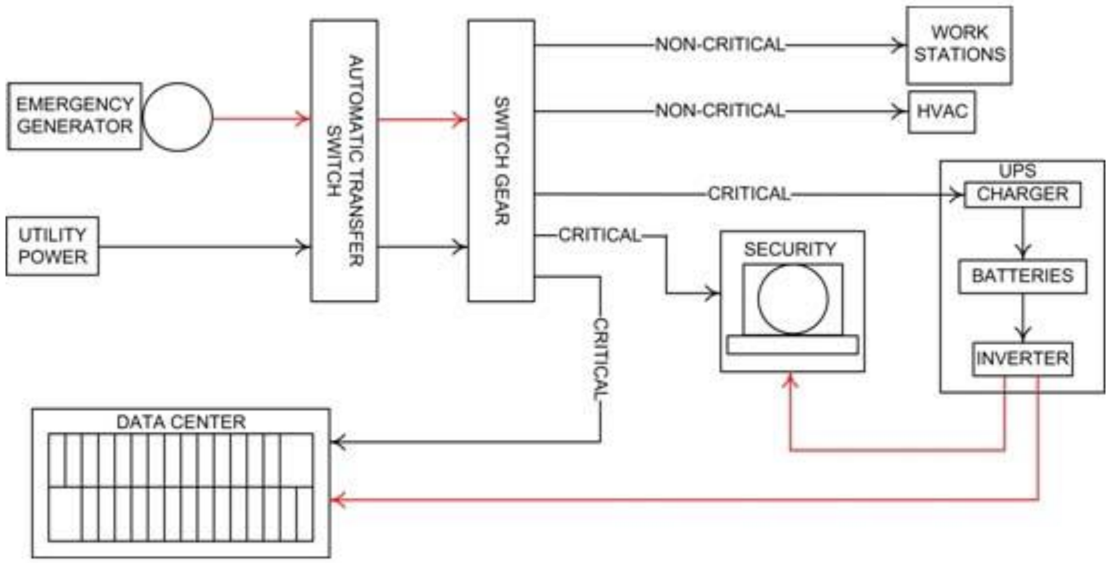


https://www.dieselserviceandsupply.com/Supplying_Backup_Power_to_Data_Centers.aspx

The importance of Data Center backup power cannot be understated. Having uninterrupted power to critical components can be a matter of life and death for a Data Center business.

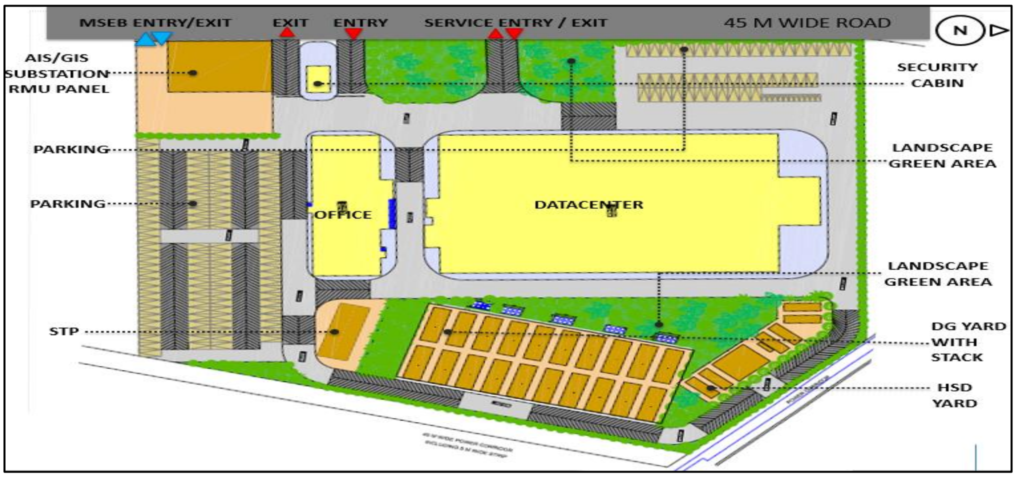
Role of Autodesk CFD in Data Center Design

- Provides detailed 3-D analysis of air flow and heat transfer in Data Center, thereby aiding in design validation (effectiveness of rack and aisle cooling)
- Test design / design changes before implementing it
- Data Center performance issues due to poor air flow management
- Analyse distribution of cooling air (more cold air, any starvation, by pass, recirculation, cold air and hot air mixing)
- Ceiling plenum pressure distribution and hence risk of recirculation can be analysed
- Design scenarios can be analysed, optimised and better design decisions can be made
- Provides predictive results to evaluate what-if scenarios, minimising risk of failure (sever overheating and identifying potential failure)
- Ventilation design effectiveness can be analysed and design changes can be implemented for Backup Power equipment such as Diesel Generator (DG).

Data Center and Backup Power Component Characterisation

Data Center facility is comprised of server racks, Precision Air Handling Units (PAHU), supply air floor grills and return air grills.

Backup power generator facility consists of enclosed DG components- alternator, engine, and radiator, intake and exhaust louvers.



Master Plan of the Data Center Building

Actual Data Center Building

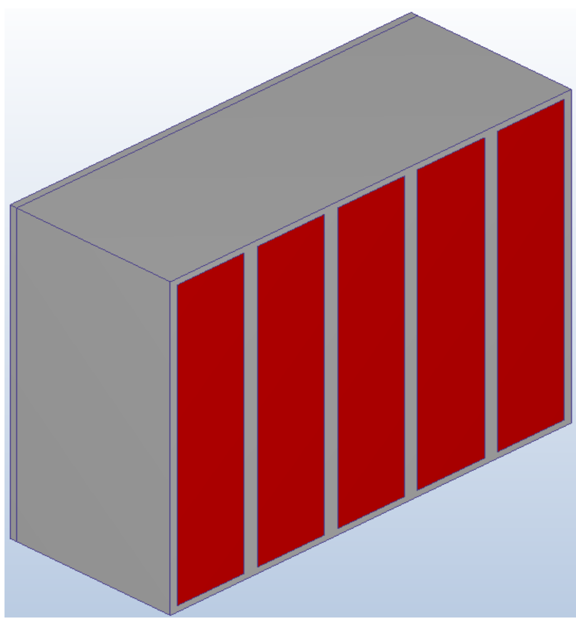
Data Center details

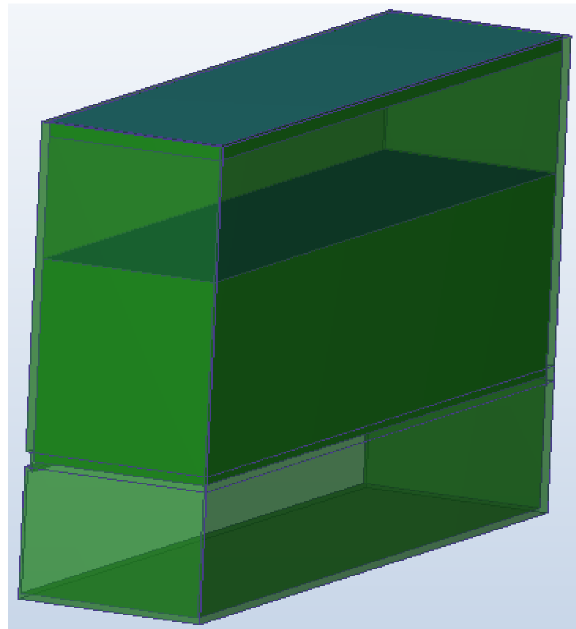
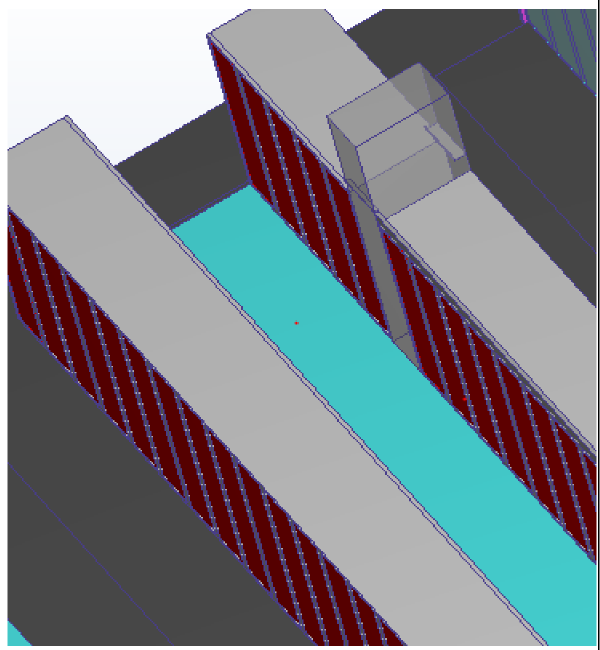
Supply plenum height	= 900 mm
Type of rack	= 52 U
Number of racks	= 154
Heat dissipation/rack	= 10 kW
Air flow through each rack	= 1720.77 CFM
Number of PAHU (26500 CFM each)	= 10(Working) + 2 (Standby)
PAHU supply air temperature	= 21.5 ^{0}C
PAHU filter open area	= 40%
Supply air tile thickness	= 35 mm
Supply air tile open area	= 46%
Return air grill thickness	= 25 mm
Return air grill open area	= 50%

Backup power generator details

DG rating -- 2250 KVA (18 nos.)
Engine heat rejection to coolant – 757 kW
Heat rejection to ambient from engine – 112 kW
Heat rejection to ambient from alternator – 49.7 kW
Combustion air requirement – 4608 CFM
Radiator fan cooling air flow – 110000 CFM
Air entry louver free area ratio -0.5
Air exhaust louver free area ratio – 0.5
Ambient air temperature – 50 ^{o}C

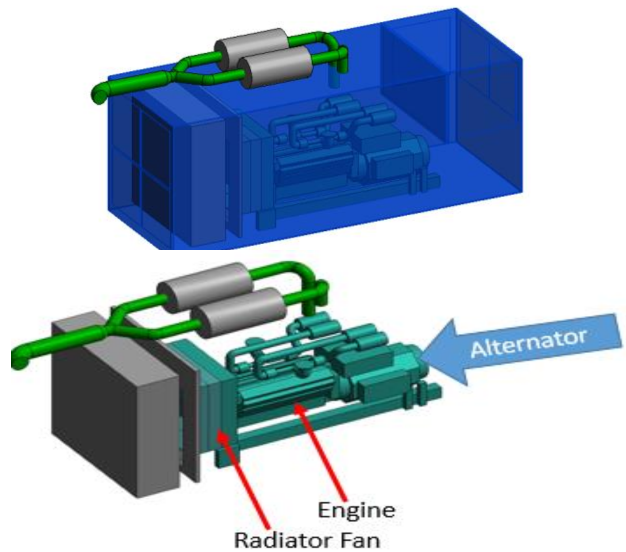
Data Center Component Characterization

	
Server Racks- Physical model	Autodesk CFD model

 PAHU- Physical model	 Autodesk CFD model
 Supply Floor Grill – Physical model	 Autodesk CFD model

Backup Power Component Characterization

DG Set– Physical model



Autodesk CFD model

Strategies for modelling airflow and heat transfer

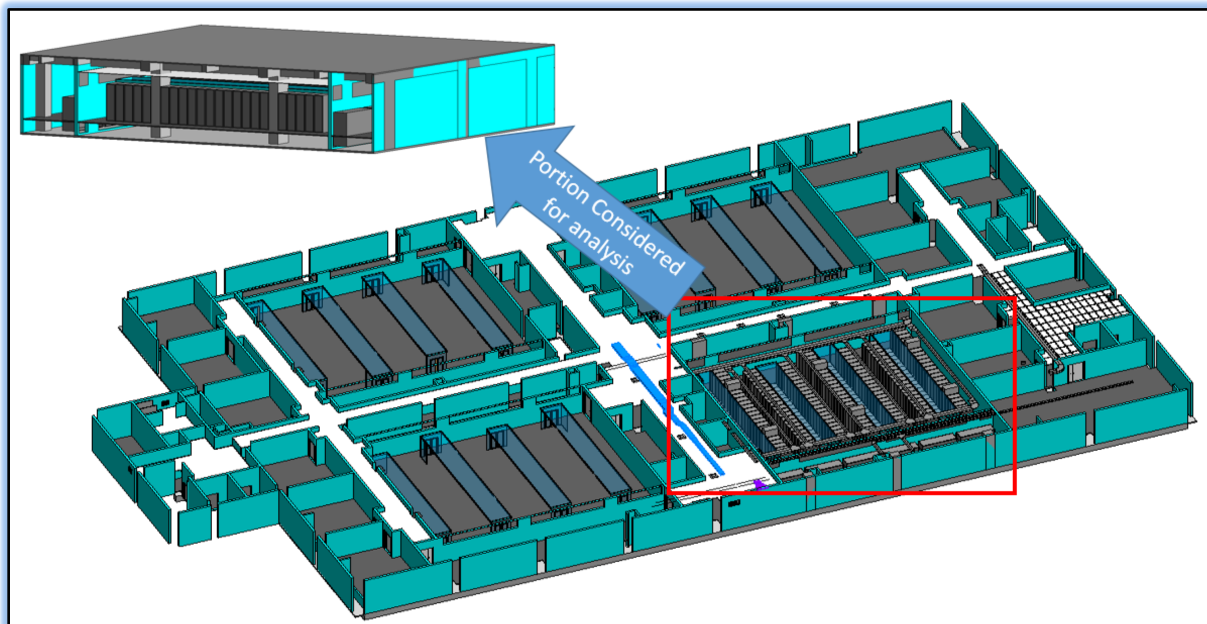
Air flow is modeled with air region and internal obstructions. Supply includes PAHU outlets and floor grills. Exhaust includes return grills and PAHU fans. Columns, containment and racks act as obstructions. Heat transfer is modeled as forced convection taking into account server heat loads and heat removal by PAHU heat exchanger.

Data Center

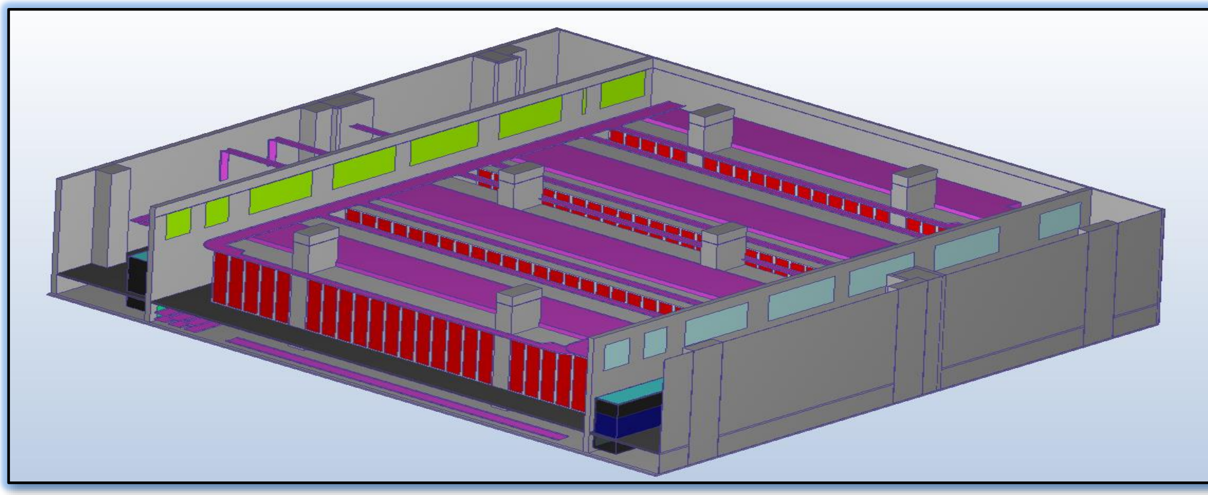
CAD model

Data Center model is prepared from geometry created in Revit and geometrical details that are too small and not affecting air flow and heat transfer are removed or simplified.

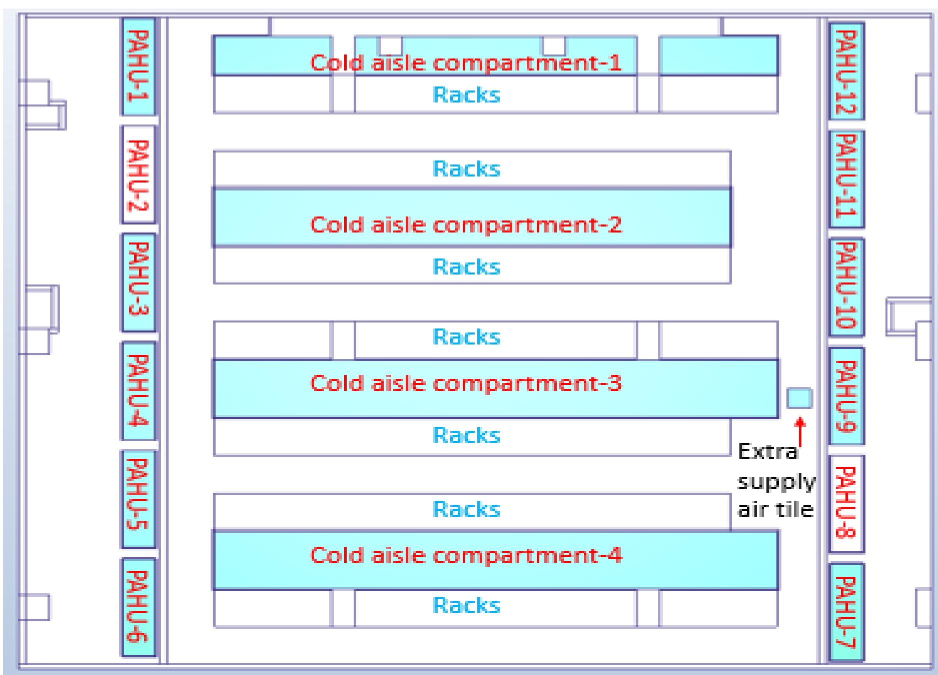
Number of racks = 154
Heat Dissipation/Rack = 10 kW
Air Flow through ach Rack = 1720.77 CFM
No. of PAHUs = 10W+2S (26500 CFM each)
PAHU Supply air temperature = 21.5 ^{0}C
PAHU filter open area = 40%



Data Center Revit model



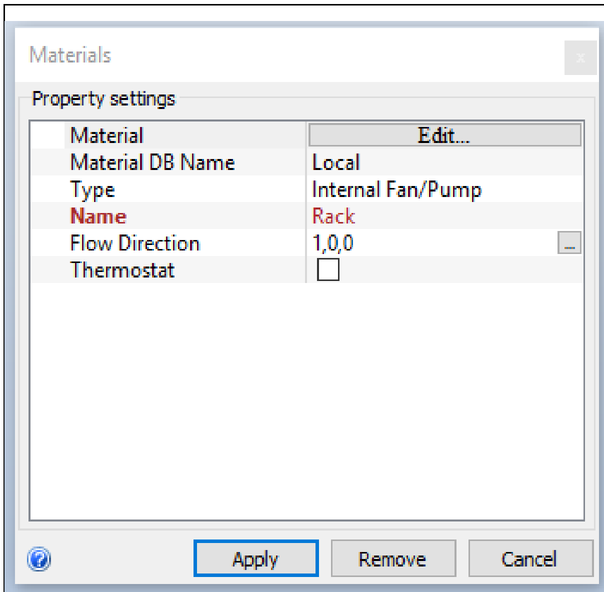
Simplified Data Center with server racks, PAHUs and other significant parts for CFD

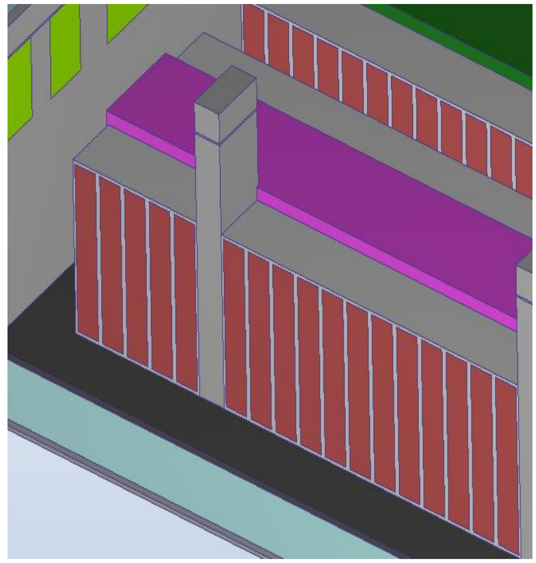


Cold Aisle Containment details

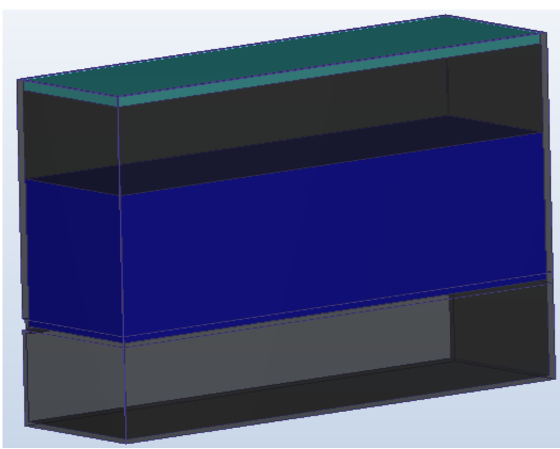
Materials assignment

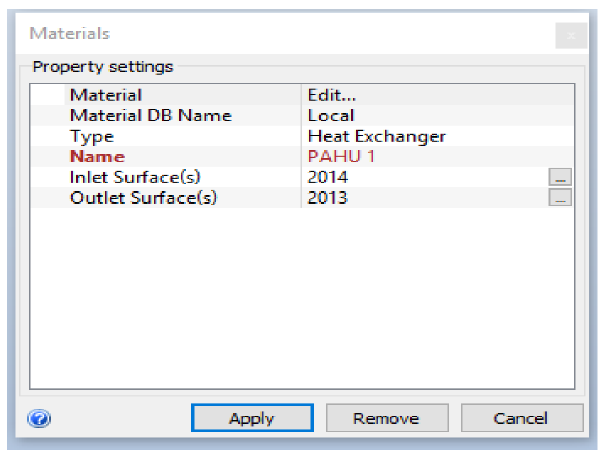
Since heat transfer is by forced convection, air domain is assigned as air with fixed properties (density does not vary with temperature); supply and return grills are assigned resistance material with free area ratio. Server racks are assigned internal/pump material. PAHU is assigned as heat exchanger device.





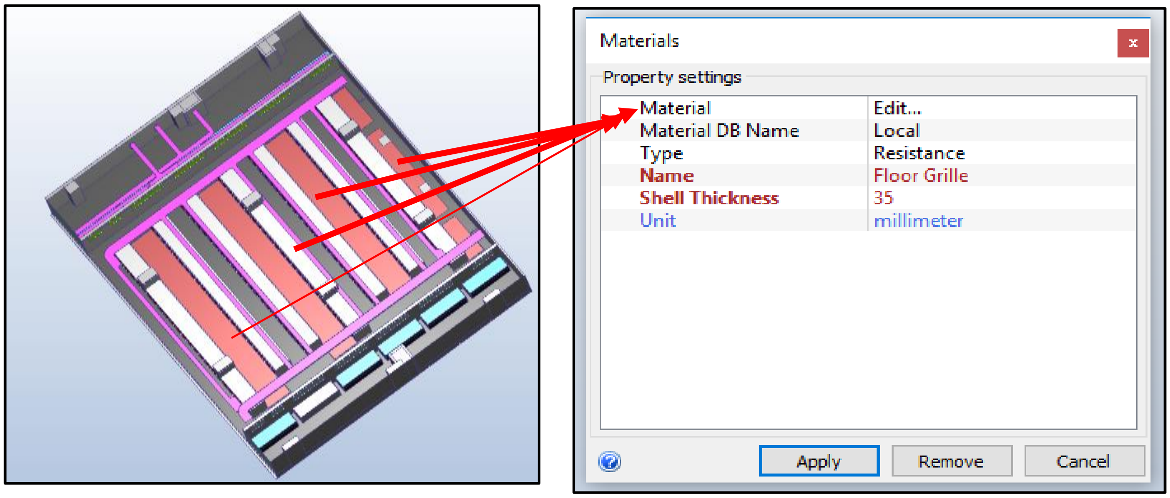
Server Racks assigned as Internal Fan with flow rate (CFM)



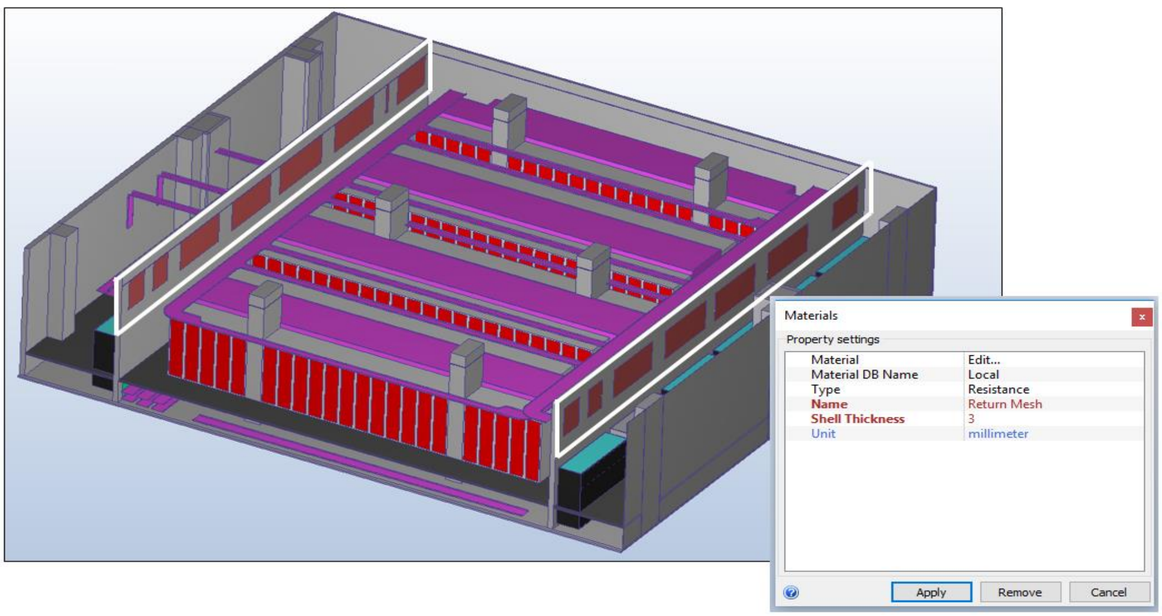


PAHU is assigned “Heat Exchanger” material with constant flow rate with “Set Point Temperature” for supply.

PAHU filter is assigned “Resistance” material with free area ratio of 0.4 in “Through-Flow” direction. In other directions “0” free area ratio is assigned to account for flow only in the specified direction.



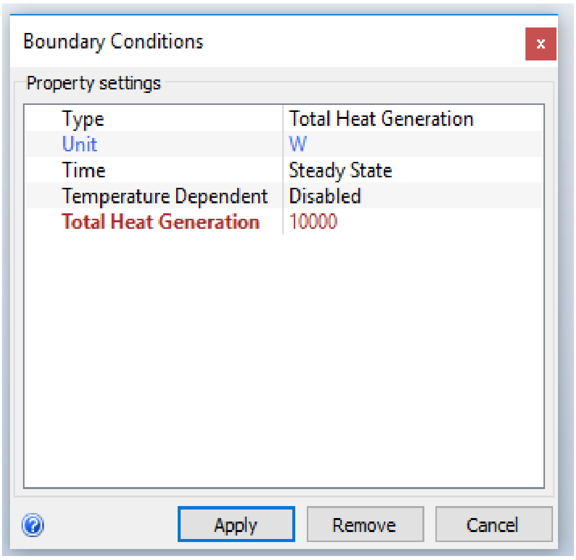
Supply floor grills are assigned as “Resistance” material with free area ration of 0.46

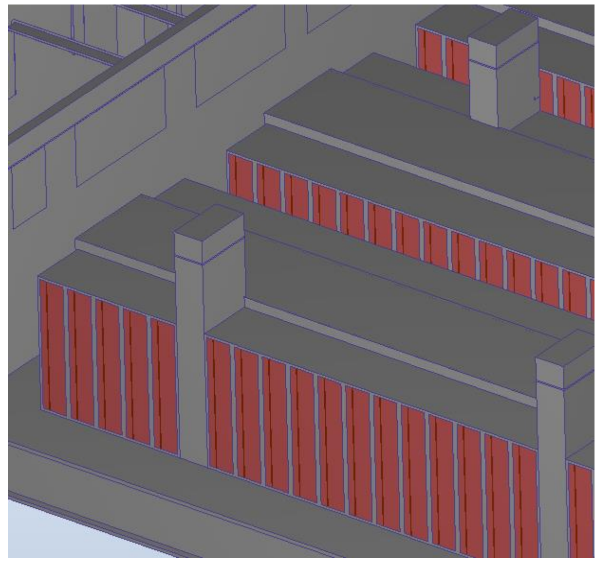


Return grill is assigned “Resistance” material with free area ratio of 0.5 in “Through-Flow” direction. In other directions “0” free area ratio is assigned to account for flow only in the specified direction.

Boundary Conditions (BCs)

BCs for Data Center include Heat Generation for server racks.



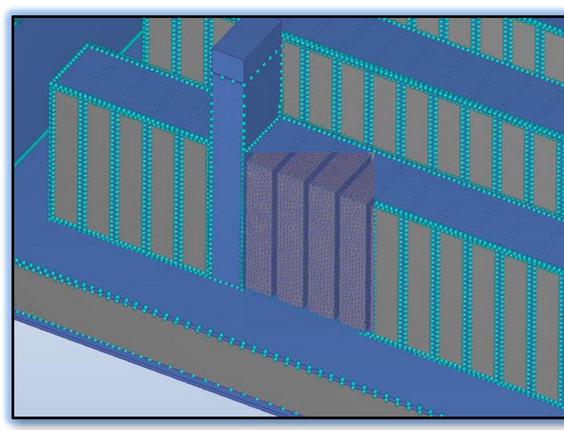


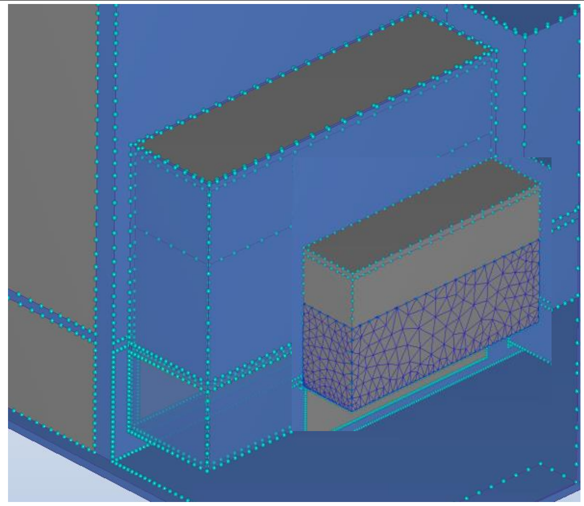
10 kW heat generation BC applied for racks

Meshing

It is important to mesh supply floor grills, server racks and PAHU heat exchanger with uniform 4-5 elements to capture flow properly.

Uniform fine mesh applied on server racks to capture heat transfer and air flow over these parts.



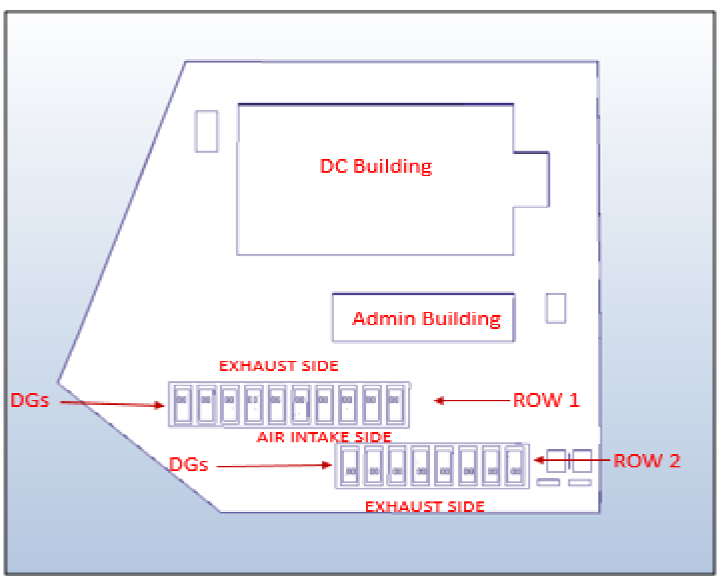
Sufficient uniform mesh to capture effective heat absorption in PAHU(Heat Exchanger)	

Backup Power Generator

CFD modeling and analysis of DG yard workflow starts with CAD model preparation, assigning materials and boundary conditions, setting up solver parameters for air flow and heat transfer and extracting key results.

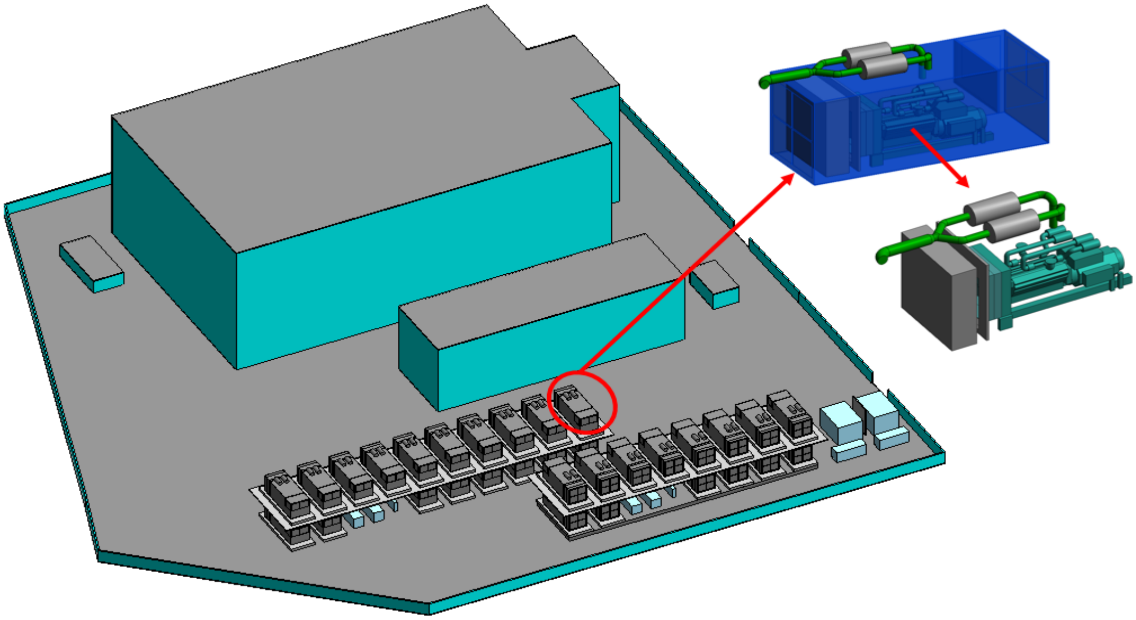
CAD model

DG set geometry is created in Revit and geometrical details that are too small and not affecting air flow and heat transfer are removed or simplified. Especially DG engine set is simplified to make engine and alternator as volume heat generating elements.

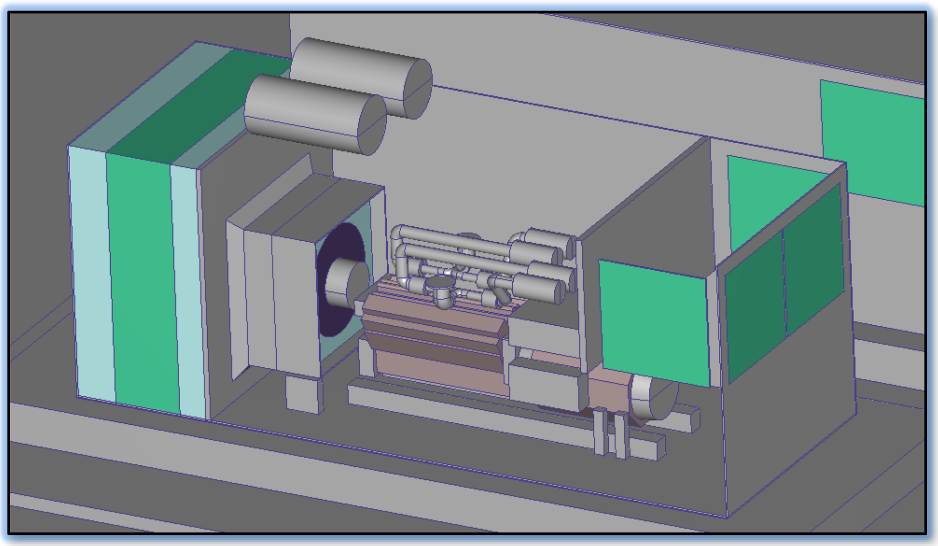


DG rating = 2250 KVA (18 nos.)

DG Yard layout

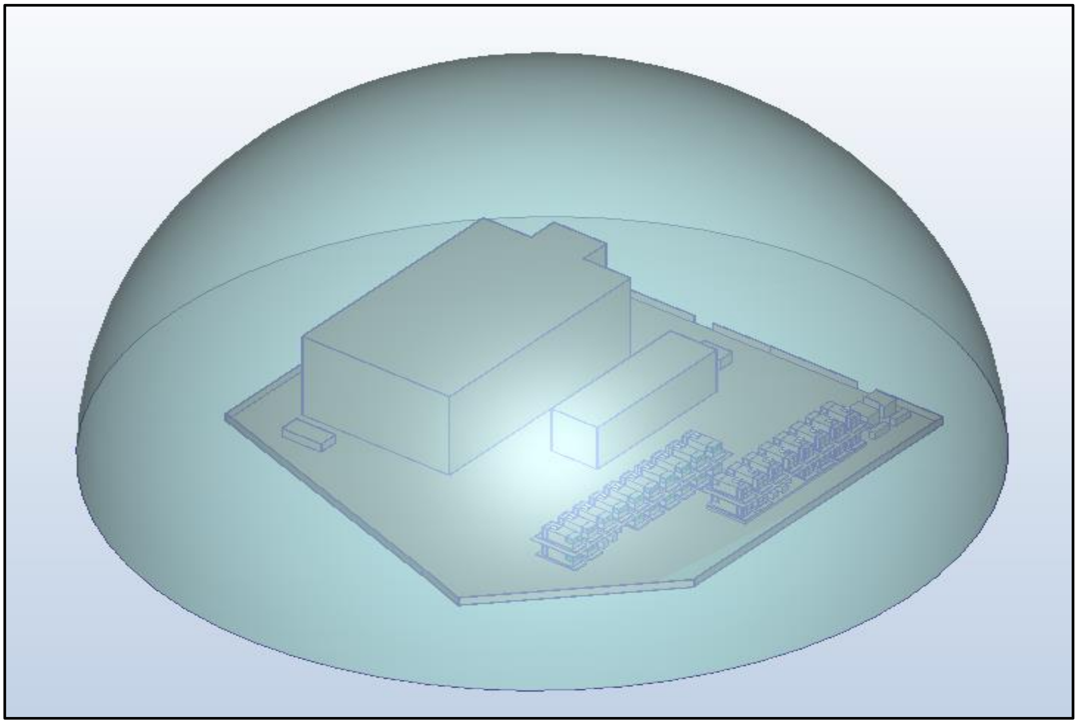


DG Yard Revit model



Simplified DG engine, alternator and other significant parts

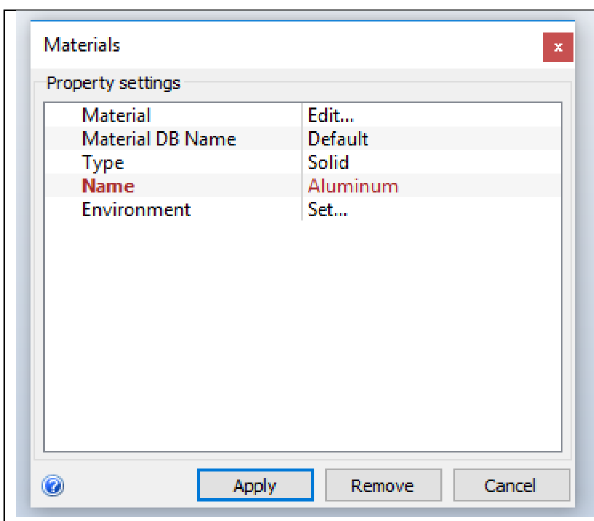
Next step is to external air domain to model air flow realistically in and out of the DG equipment.

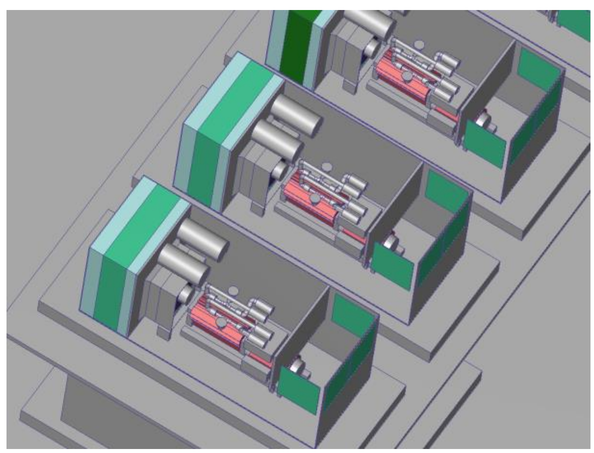


External domain created in CAD model

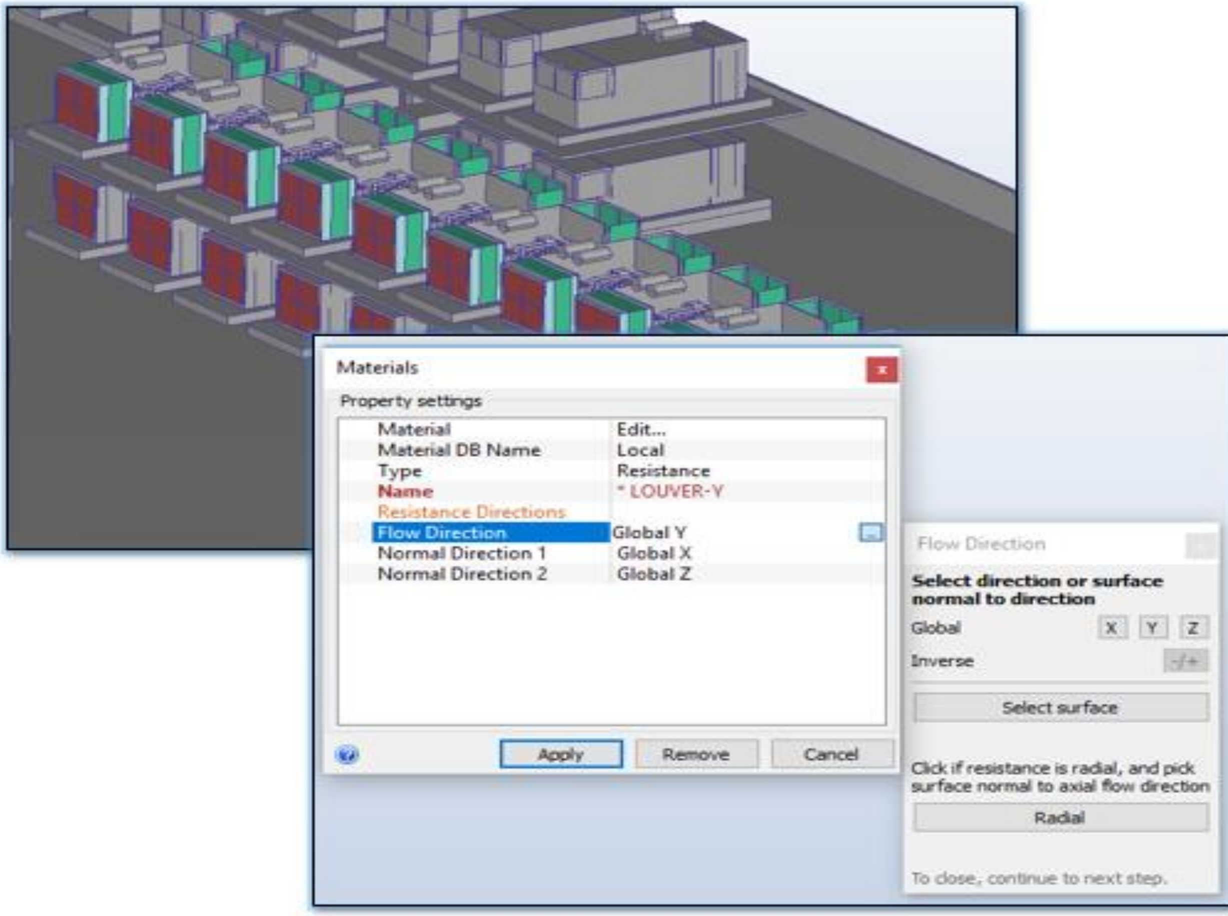
Materials assignment

Since heat transfer is by forced convection, air domain is assigned as air with fixed properties (density does not vary with temperature); inlet ventilation louvers, outlet louvers, radiator coil are assigned resistance material with free area ratio. Radiator fan is assigned with internal fan material. Engine and alternator are assigned with aluminum solid (high conducting material to transfer heat to ambient air). Other construction elements such as walls, panels and pipes are suppressed in the analysis.





Engine and alternator assigned Aluminum material

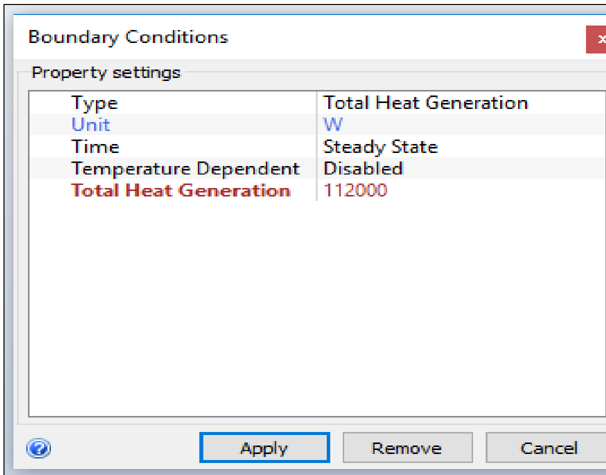


Air inlet and outlet louvers are assigned “Resistance” material with free area ratio of 0.5 in “Through-Flow” direction. In other directions “0” free area ratio is assigned to account for flow only in the specified direction.

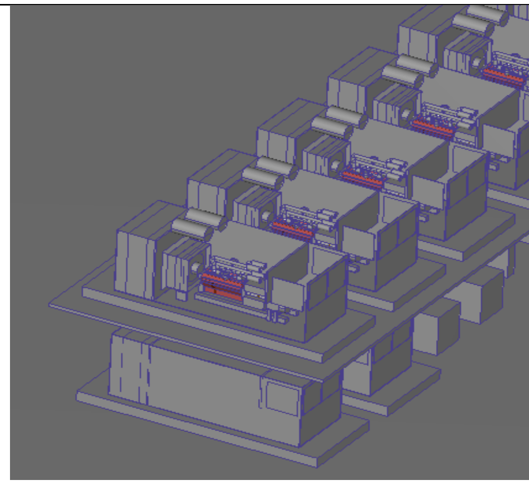
Radiator coil is also assigned “Resistance” material with free area ratio of 0.65 in “Through-Flow” direction.

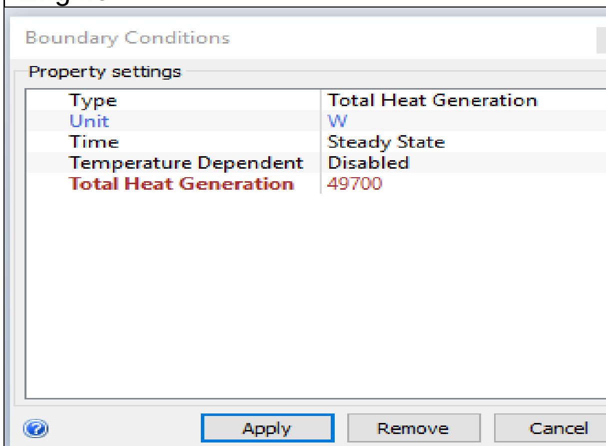
Boundary Conditions (BCs)

BCs for DG yard include inlet flow boundary conditions (pressure and temperature), outlet flow boundary conditions (pressure), and inlet flow rates at combustion air inlets, total heat generation for engine, alternator and radiator coil.

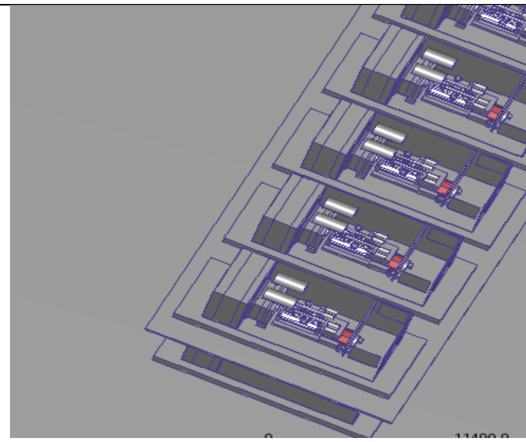


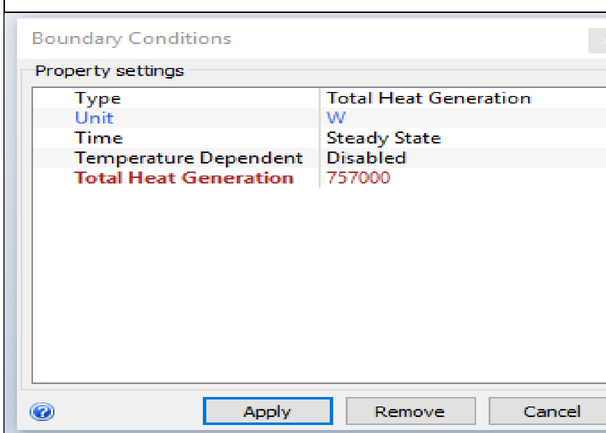
112 kW heat generation BC applied for Engine



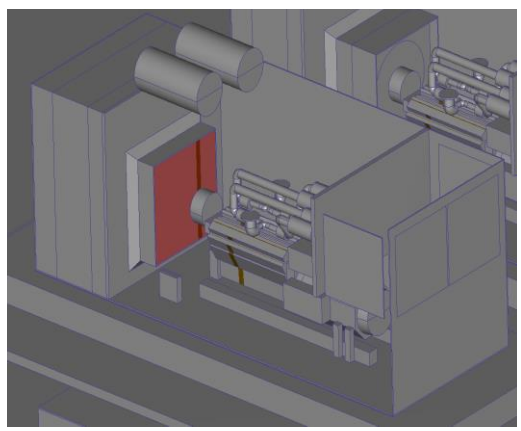


49.7 kW heat generation BC applied for Alternator



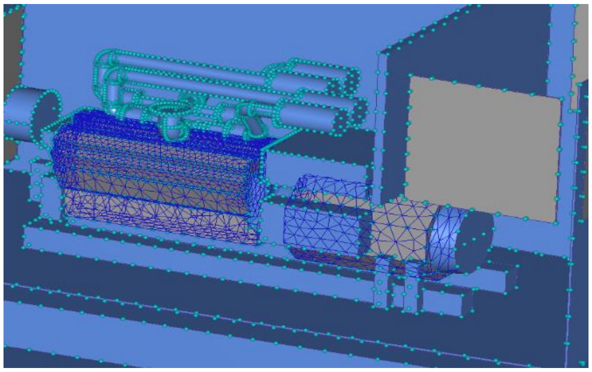
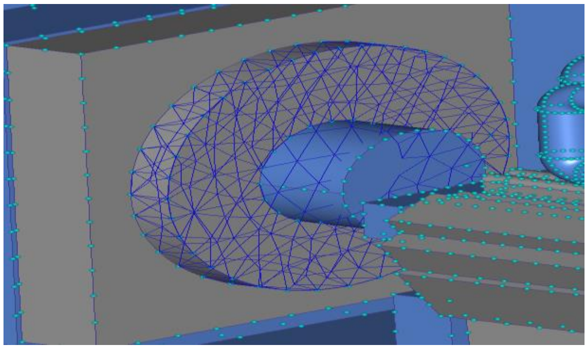
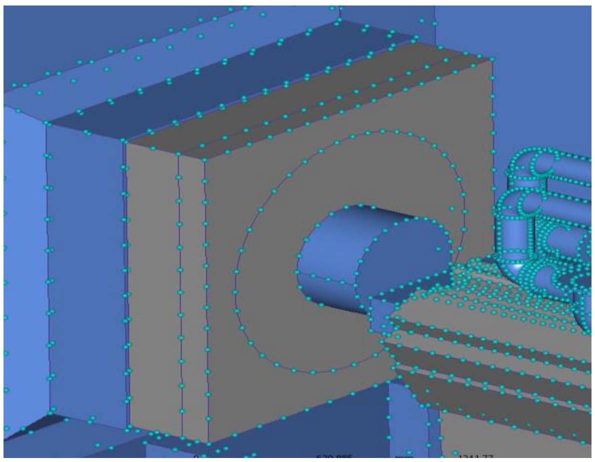


757 kW heat generation BC applied for Radiator



Meshing

It is important to mesh inlet louvers and outlet louvers with uniform mesh of 4-5 elements to capture flow properly. Also radiator fan part to have uniform mesh with 4-5 elements. Fine mesh is applied on engine and alternator volume parts.

Fine mesh applied on engine and alternator parts to capture heat outflow and air flow over these parts.	
Uniform mesh to capture internal fan flow effects on radiator fan	
Uniform mesh to capture flow through radiator coil.	

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Set up Simulation and Visualise Results

Simulation settings include steady state forced convection analysis and results are visualized as "Global" and Plane values for temperature and Plane values for air flow distribution.

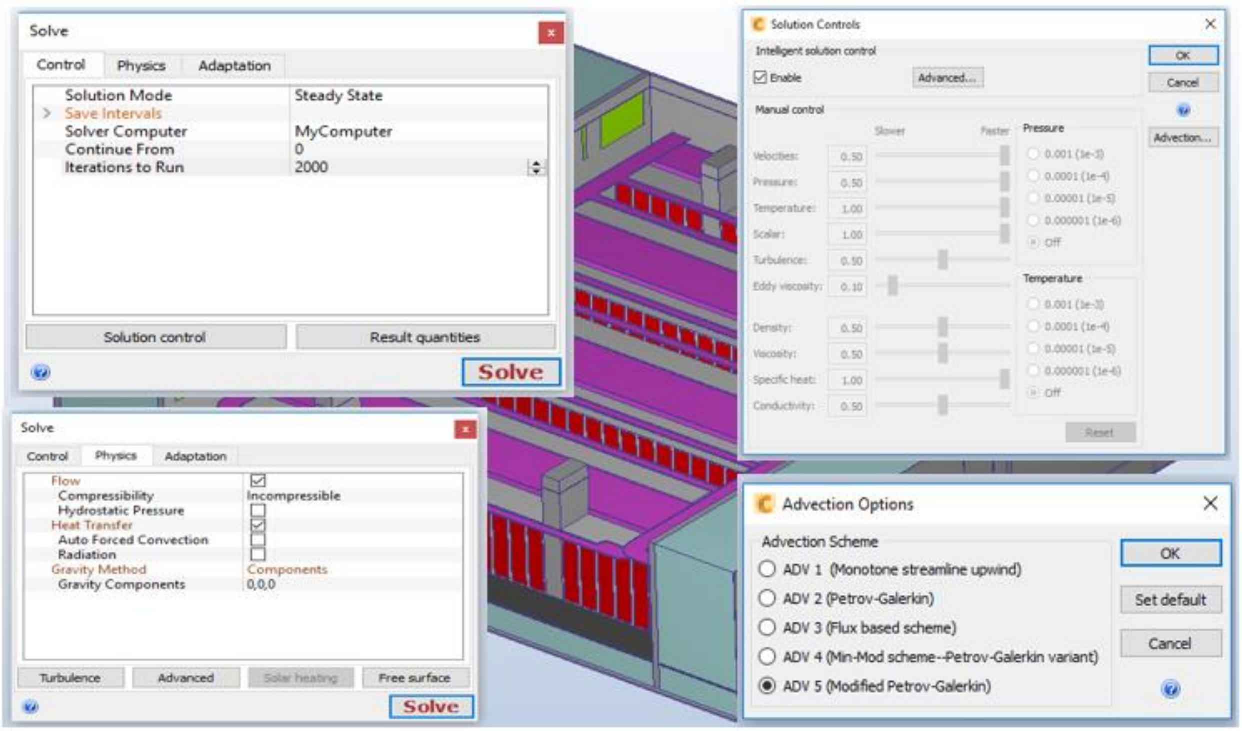
Data Center

Data Center simulation solver settings include steady state flow analysis and forced convection heat transfer analysis.

Solver settings and results visualisation

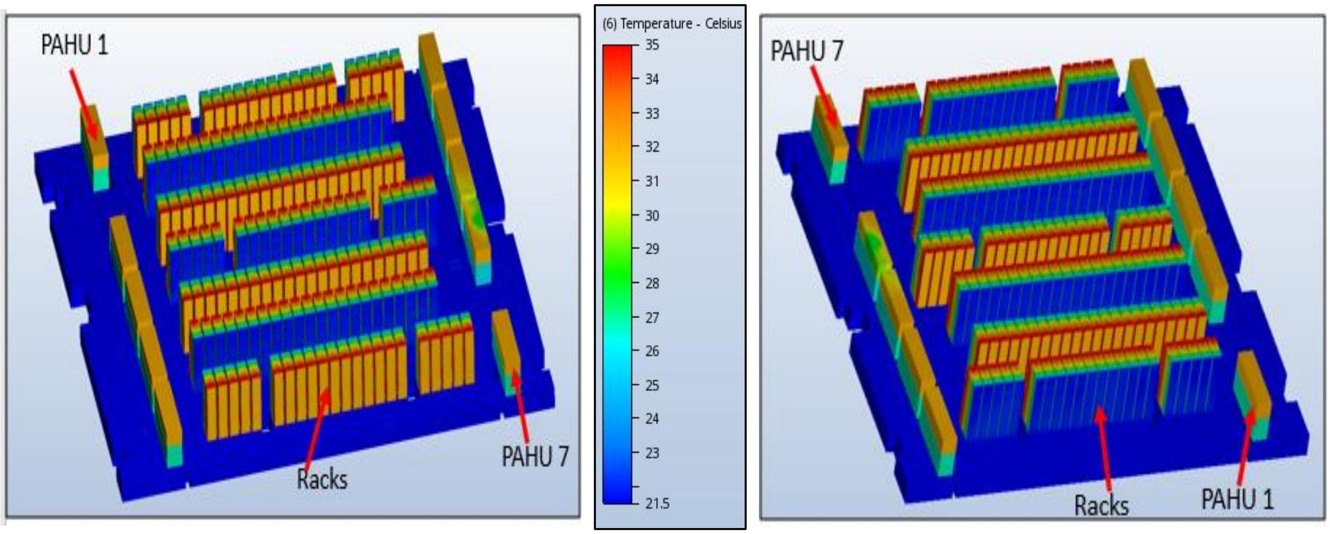
Heat transfer is by forced convection in this case. So flow and heat transfer can be solved together in this case till flow variables and temperature converge.

Solver settings for flow analysis (Intelligent solution control-On, Advection Scheme 5)

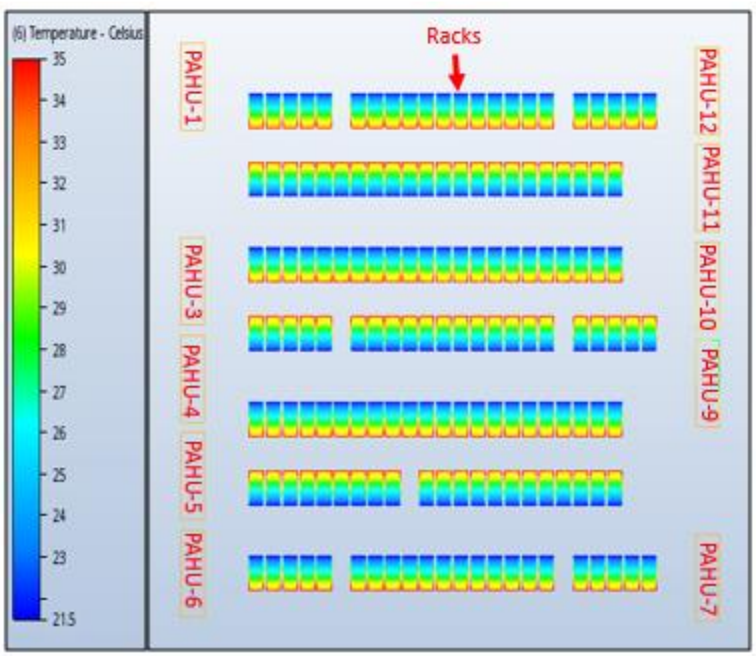


Results - Temperature plot

Server rack "Global" temperature values

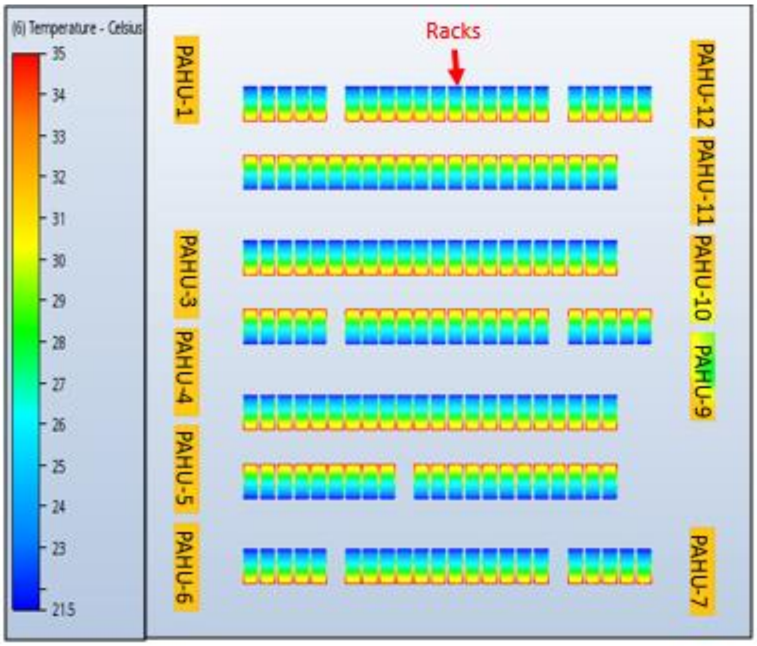


Rack inlet temperature: 21.5 ^{0}C to 22 ^{0}C for all racks, Rack exit Temperature: 31.6 ^{0}C to 32^{0}C for all racks



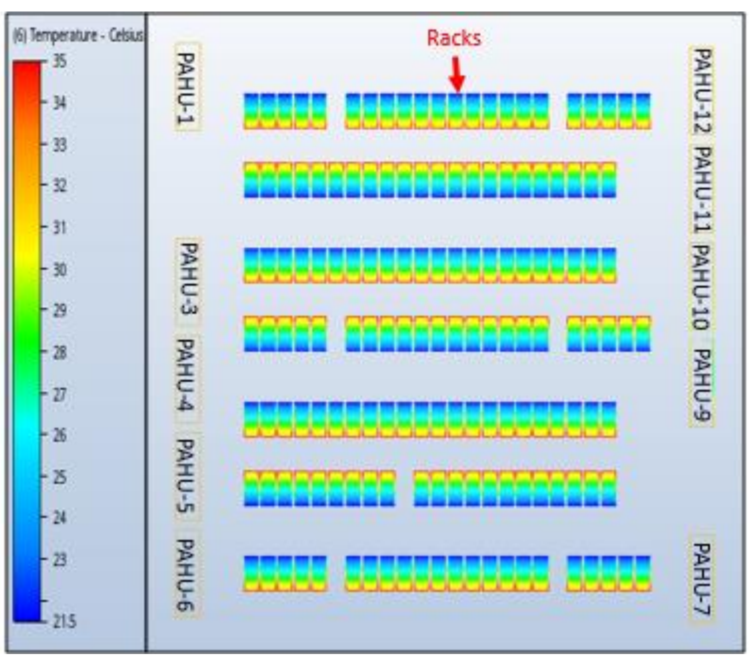
Rack inlet temperature: 21.5 ^{0}C to 22^{0}C for all racks.
Rack exit Temperature: 31.6 ^{0}C to 32^{0}C for all racks.

Temperature contour plot for servers at bottom of server rack



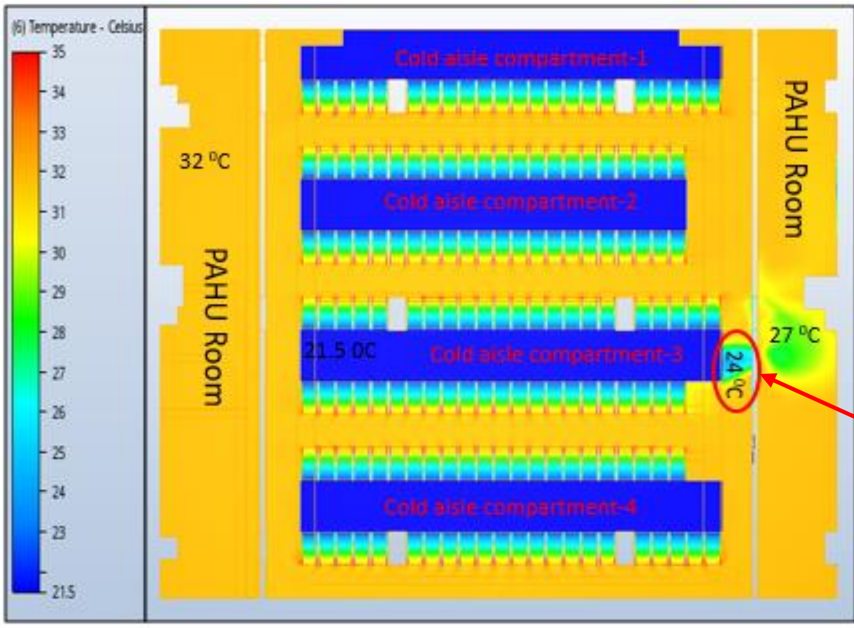
Rack inlet temperature: 21.5 ^{0}C to 22^{0}C for all racks.
Rack exit Temperature: 31.6 ^{0}C to 32^{0}C for all racks.

Temperature contour plot for servers at middle of server rack



Rack inlet temperature: 21.5 ^{0}C 0 to 22^{0}C for all racks.
Rack exit Temperature: 31.6 ^{0}C to 32^{0}C for all racks.

Temperature contour plot for servers at top of server rack



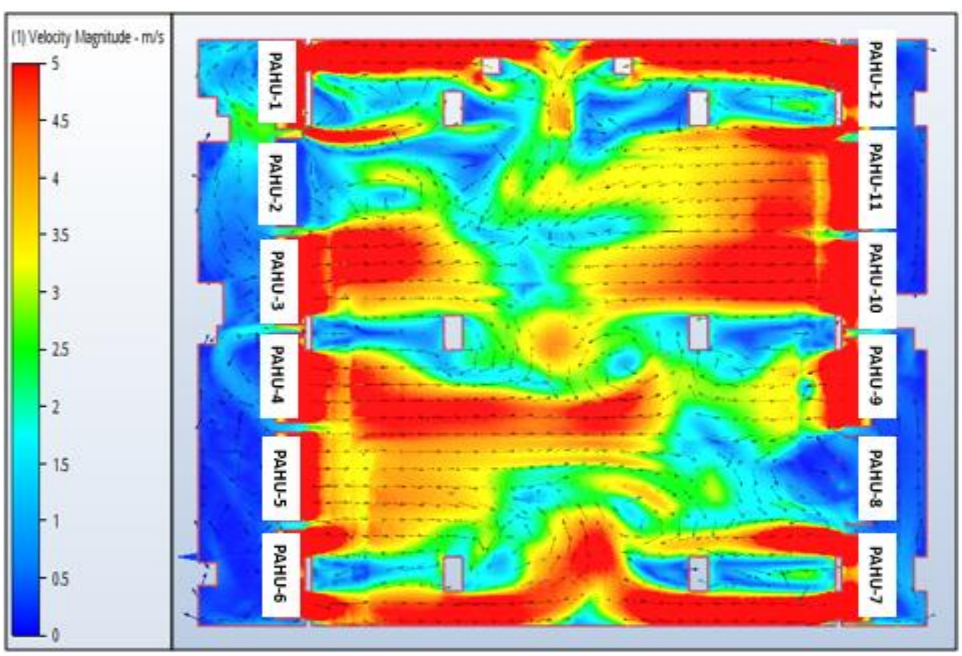
Server hall and return air temperature: 32 ^{0}C

Air supply through extra tile provided outside the cold aisle compartment to take care of any pressure imbalance.

Temperature plot at 1.8m from floor level

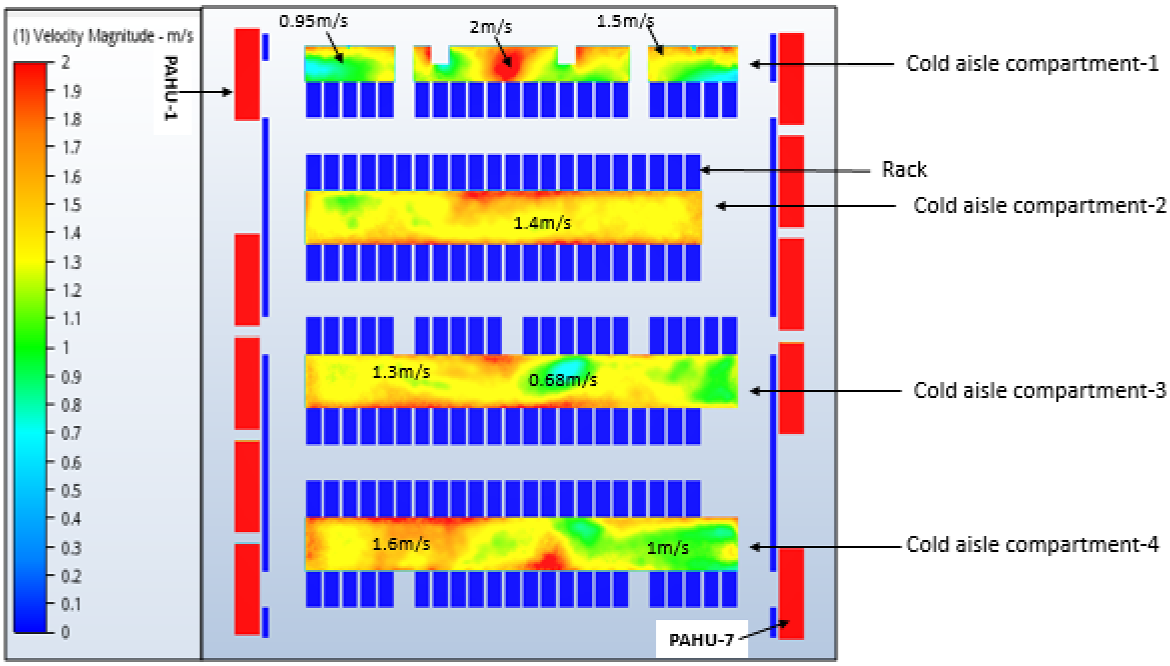
Results – Velocity plots

Velocity plots show air flow throughout Data Center facility.



PAHU-2 and PAHU-8 are considered as standby for the current analysis

Velocity contour plot in the supply plenum



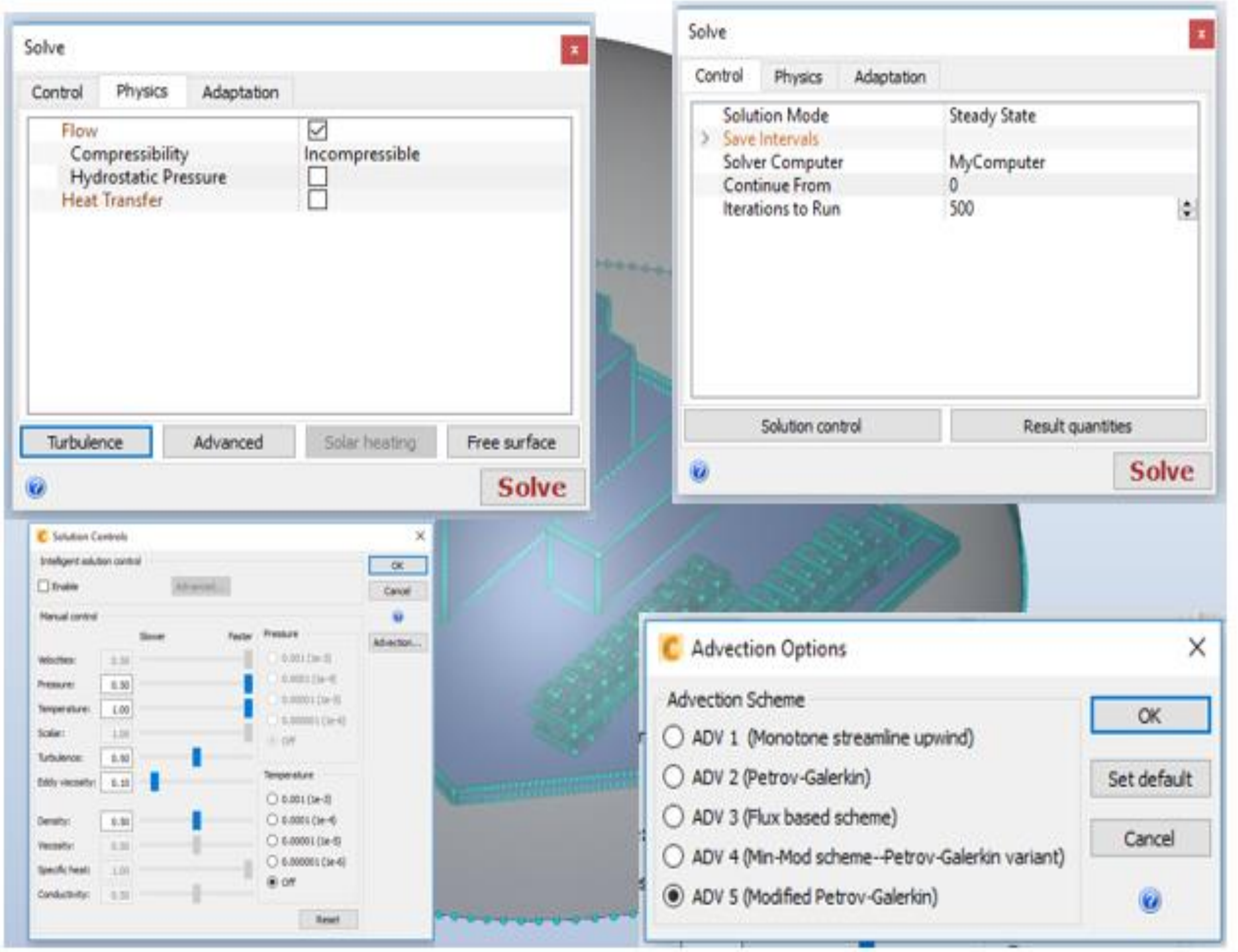
Velocity contour plot- indicating air velocity from supply floor grills

Backup Power Generator

Solver setting for Backup Power Generator include steady state and forced convection analysis.

Solver settings

Heat transfer is by forced convection in this case. So flow and heat transfer can be decoupled during solution, i.e. solve for flow only first till flow convergence and then enable heat transfer till temperature convergence.

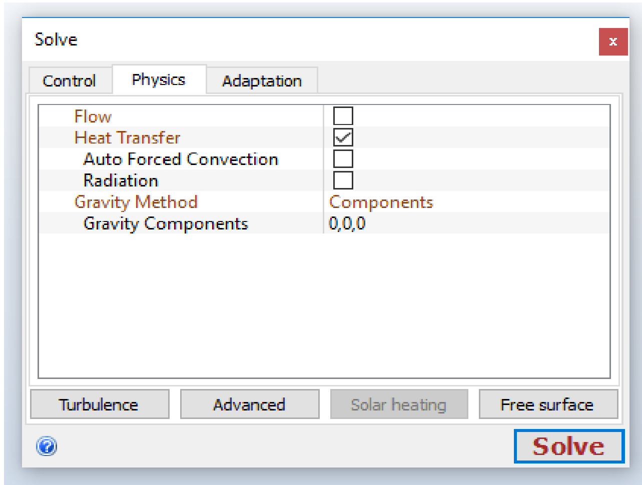


Solver settings for flow analysis (Intelligent solution control-On, Advection Scheme 5)

Switch off Flow
Switch on “Heat Transfer”

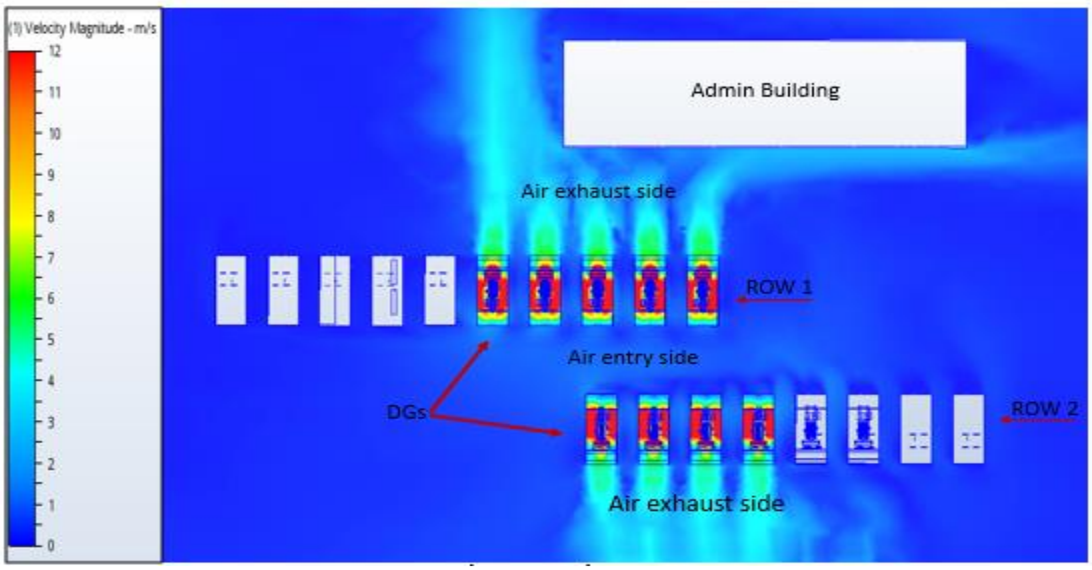
Continue to solve from previous iteration

Solver settings for heat transfer analysis (Intelligent solution control-Off, Advection Scheme 5)

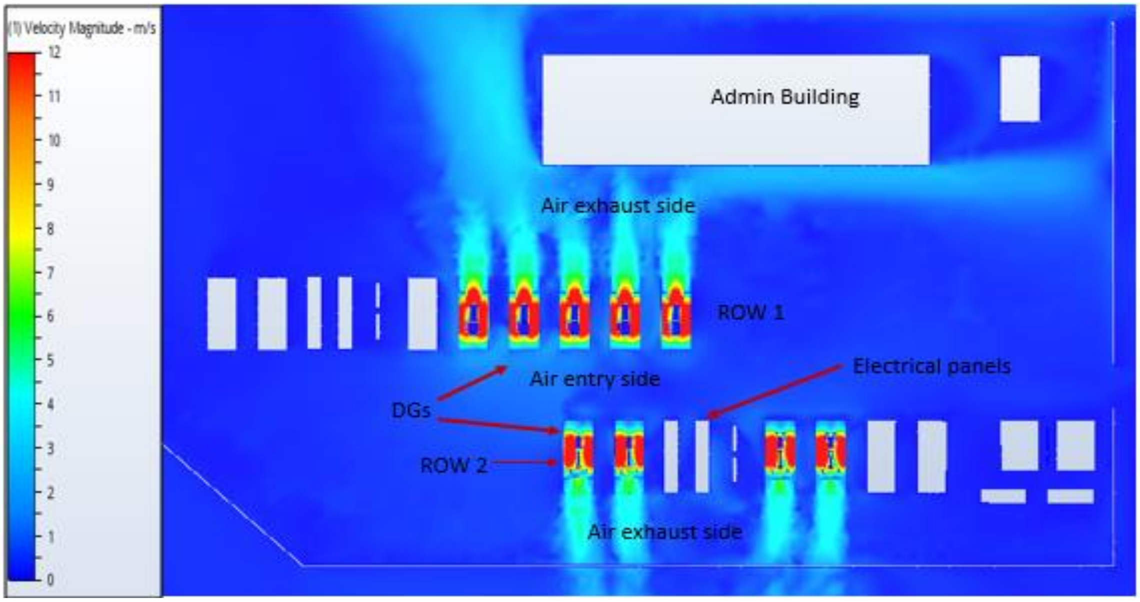


Results - Airflow velocity pattern

Air flow velocity distribution using “Results” on “Plane” option.



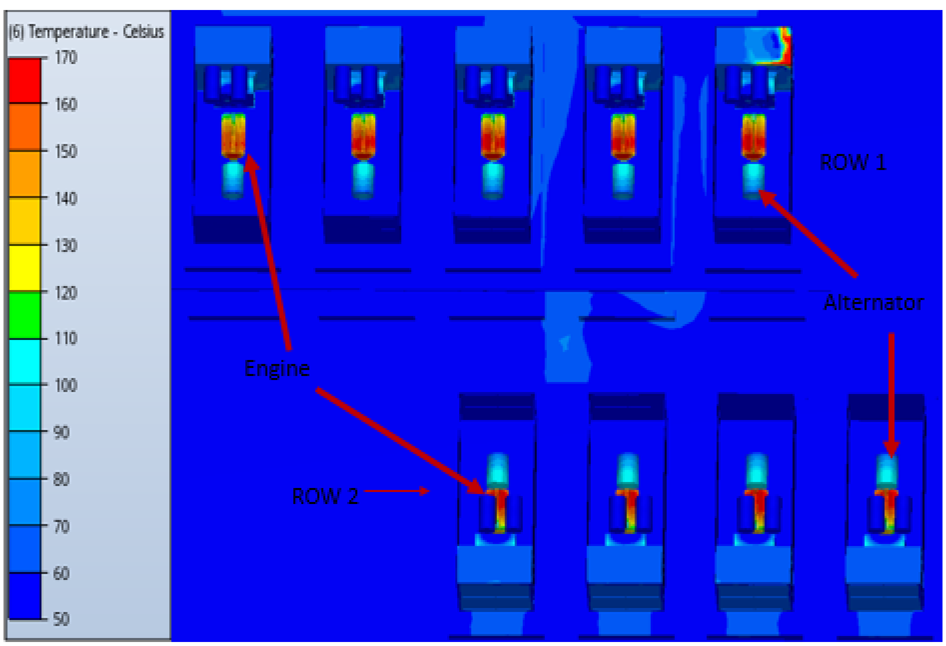
Airflow velocity plot for upper level DGs



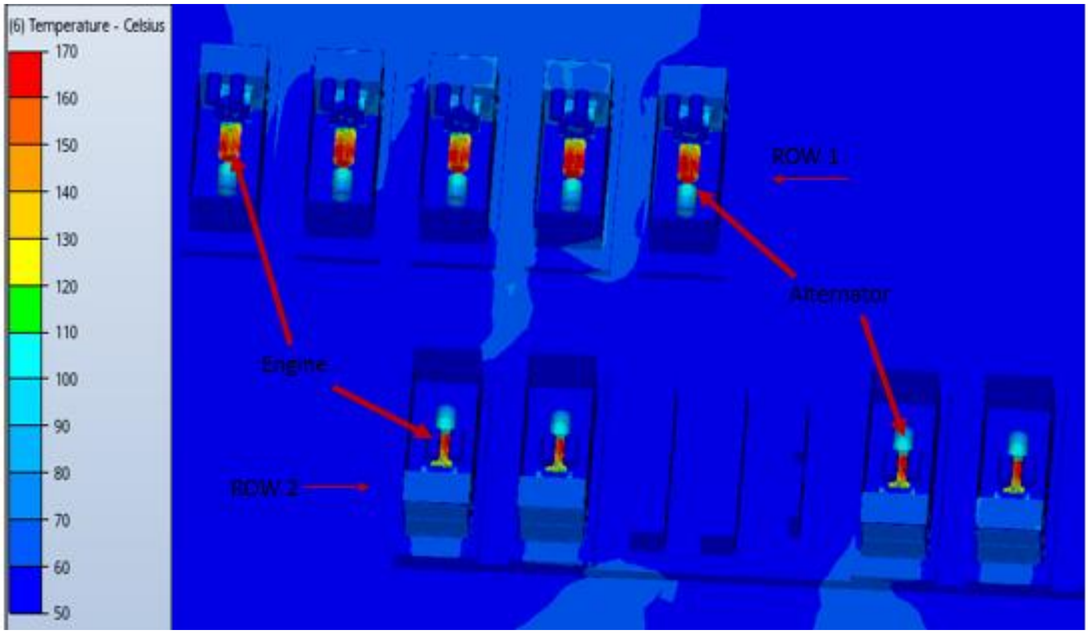
Airflow velocity plot for lower level DGs

Results - Temperature plots

Temperature distribution using "Results" on "Global" option.



Temperature plot for upper level DGs



Temperature plot for lower level DGs

Review results and evaluate design

CFD results of temperature values can be used to evaluate design performance of Data Center and Backup Power Generator.

Data Center

For Data Center cooling design, rack inlet temperatures decide performance of the server and return air temperature decides Data Center personnel thermal comfort.

Rack inlet temperature	21.5 to 22^{0}C
Average return air temperature	32 ^{0}C
Heat Removal	1584kW

Based on CFD predicted server rack inlet temperatures and average return temperature, the server rack temperatures are within recommended limits as per ASHRAE TC 9. 9 (18 ^{0}C to 27^{0}C)

Backup Power Generator

For Backup Power generator, ventilation airflow distribution and resulting temperature field in and around the DG sets determine design performance of ventilation system. Based on CFD results, following can be concluded:

- DGs show engine surface temperature below 170 ^{0}C and alternator temperature below 110 ^{0}C, indicating adequate ventilation
- Alternator and engine temperature of all DGs are in acceptable range.
- Air velocity near the admin and DC building also in the acceptable range
- Ambient temperature around the DG plant is 45 ^{0}C.

References

1. The Different Technologies for Cooling Data Centers Revision 2 by Tony Evans - Schneider Electric

2. Impact of Hot and Cold Aisle Containment on Data Center Temperature and Efficiency

Revision 5 by John Niemann, Kevin Brown, and Victor Avelar- Schneider Electric

3. Fundamental Principles of Generators for Information Technology Revision 1 by Robert Wolfgang - Schneider Electric