# Chapter 26
# Energy Demand Reduction in Data Centres Using Computational Fluid Dynamics


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**Abstract** A data centre is a facility where it hosts the server systems, computer systems, and its associated components such as cooling units, redundancy power supplies and power storage systems. Data centres are a very energy-demanding sector. Data Centre Dynamics magazine forecasts that by 2025, Data Centres will consume more than 2% of the global electricity supply. Due to this forecast, it is become vital to reduce the energy consumption in the data centre industry. On average, data centres use 30–50% of their total energy supply on mechanical cooling to cool their IT equipment. However, many of them still have difficulties with high-temperature regions such as hot spots in the server data hall which contributes to server downtime. Along with this, the power densities of the data centres are on the rise as the telecommunication industry at exponential growth over the years. This inefficiency in the temperature distribution can be resolved through advanced computational fluid dynamics software. It also becomes essential to expand the use of CFD (computational fluid dynamics) into key sections of Data Centre design, to reduce thermal inefficiencies. It is necessary to identify the potential issues at the initial stages to deliver efficient solutions which will work at a low Power Usage Effectiveness (PUE), to future-proof data centre facilities. This paper outlines the importance of a computational fluid dynamics (CFD) analysis in the data centre design. The mock-up data centre internal and external models are analysed in 6Sigma Software. The various parameters were investigated to optimise the energy performance of the infrastructure. The results also provided the analysis of the data hall with detailed rack inlet and 3D modelling of the data hall, external simulations with chillers and generators inlet temperatures highlighting trouble areas. Additional to this, Water cooled, and Air-cooled chiller performance comparison also studied and concluded that Water cooled chiller performance well than Air cooled chiller. Having the data hall air

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supply temperature 27 °C than 24 °C, has improved the energy efficiency in the data centre. The model developed in this study can be used as a benchmark study for the present and future thermal optimization of data centres.

**Keywords** Computational fluid dynamics · Data centre cooling · 6Sigma · k-epsilon RANS model · Internal modelling · External modelling

## 26.1 Introduction

The rapid increase in the number of internet users in recent years has demanded very high heat density servers. Data centres are a very energy-intensive sector with rapid developments in the 5G and AI (Artificial Intelligence). The number of internet users will increase from 3.6 million to 5 billion between 2018 to 2025 respectively [1]. In 2018, data centres' electricity consumption has reached 1% of global electricity demand [2]. During pandemic conditions, the data centres industry has seen rapid growth in its IT loads due to digitalization. Energy consumption in data centres is expected to rise by 15–20% each year [3]. Cooling of the IT equipment demands substantial power as 40% of the total power consumption in the data centres is from the cooing equipment. Also, the high demand for cloud-based data centres and High-Power Computers (HPSs) is leading to an increase in the cooling demand.

Traditionally all data centres are air cooled where they use the hot/cold containment systems to decrease the air circulation, reducing hot–cold air mixing and removing thermal inefficiencies. However, these energy-efficient design solutions are not alone enough to make the data centre very efficient. An in-depth analysis of thermal distribution is needed to avoid any downtime and to make the design flawless. CFD analysis method could be used to identify any flaws in the design in the early development stage. Therefore, this study will investigate reducing the cooling energy demand in the data centre by using external and internal CFD Simulations.

Simulation of internal and external thermal conditions in a data centre by using the CFD has become a very thriving research area in recent years. Swift development in the computational power and accuracy in the numerical models in the last decade made CFD a more viable and reliable option to understand the flow behaviour in the data centre. 6Sigma CFD models are important in the data centre industry because of their flexibility due to their specific features that are specifically designed for data centre sectors [4]. Commercial CFD solver software is proven to be accurate in data centre thermal modelling. Cho et al. [5] studied a series of simulations for various design options using commercial software to investigate thermal performance in data centres. Similarly, Nada and Said [6] analysed the importance of the CRAC (Computer Room Airconditioned Unit) layout for the high heat density data centre and found that placing the CRACs perpendicular to the data hall containment improved the thermal performance of the data hall.

So, the aim of this study is to develop a design of an external and internal layout of the data centre with a focus on enhancing their thermal performance that changes the dynamics of data centre cooling to energy savings. Therefore, the main objective is to accurately model the data centre and enhance the thermal distribution. Finally, evaluate the energy performance in the data centre.

## 26.2  Models

Internal computational fluid dynamics (CFD) studies have been conducted for the server data hall room. These studies are intended to determine the flow direction of air and assess the intake air temperature at the electrical equipment and the average temperature of the IT cabinet data hall room. The capability of the cooling system to deliver the required cooling capacity within the temperature tolerance under both normal operation and failure scenarios has also been assessed. The CFD simulations have been conducted using 6SigmaRoom R15 software to build the 3D geometry of the IT data hall room. All structural obstructions such as columns and beams have been included in the 3D CFD model. Figure 26.1 illustrates the 3D model of the data hall.

Along with this, A computational fluid dynamics (CFD) external study was conducted for the data centre, to investigate the potential uplift in supply air temperature for the chillers on the roof. The principal concern is the risk of cooling unit's derating due to warm air entering from the neighbouring cooling units (normal operation) exhaust vents and generator exhaust flues (emergency operation). Figure 26.2 illustrates the 3D model layout for the roof of the data centre which includes the generators and chillers. The local microclimate was evaluated based on historical meteorological data from the NOAA (National Oceanic and Atmospheric Administration) weather website [7]. The meteorological data, which was associated with
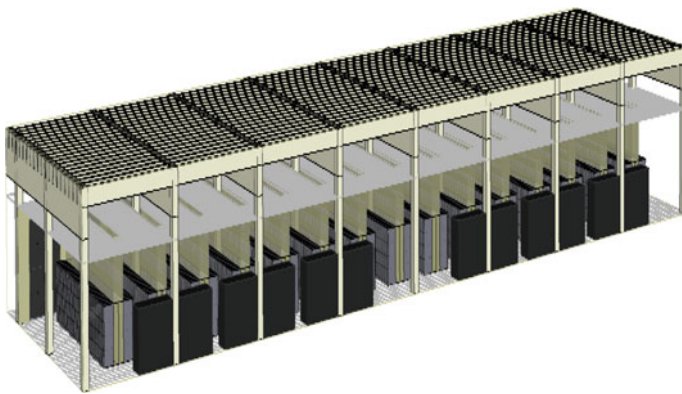


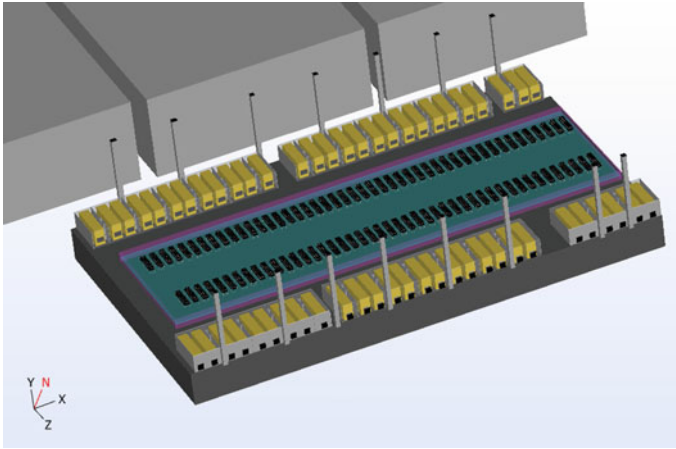**Fig. 26.1**  Internal design of data hall

**Fig. 26.2** External design of data centre roof with chillers and generators

the hourly wind speeds recorded over a 20-year period between 2001 and 2020, were analysed., the maximum recorded dry-bulb temperature in the area is 39.1 °C in a 20-year period. Following the wind analysis, a temperature analysis was conducted for the 20-year period (2001–2020). As per the analysis, the dominant wind of 7 m/s from the SW direction was chosen for this study. Additional to this, the key properties that need to be considered in the energy-efficient data centre design are the cooling load and total facility load. For this application, the total IT load (Each rack 8.33 kW heat load) and cooling load are assumed as 96 MW IT data centre and chiller load 112.32 MW for this study.

## 26.3 Theory

The airflow, temperature and pressure differences were governed by the following continuity, momentum and energy conservation equations including buoyancy effects. The solver breaks down the Navier stokes equation as Reynolds averaged Navier stoked equations to solve simulations within the realistic time scale and with less computational power [8]. A comprehensive description of the RANS model equations is expressed in Eqs. (26.1–26.4). 6Sigma uses the K-epsilon RANS Turbulence model to simulate the flow characteristics.

Continuity equations:

$$div\underline{U} = 0 \tag{26.1}$$

Momentum equation for the RANS model:

$$\frac{\partial}{\partial t}(\underline{U}) + div(\underline{U}\,\underline{U}) = \frac{1}{\rho}div(\underline{\sigma} - \rho\underline{u'u'}) + \frac{1}{\rho}\underline{S} \tag{26.2}$$

where

$$\underline{\sigma} = -PI + \mu\big(grad(\underline{U}) + grad(\underline{U}^T)\big) \tag{26.3}$$

$\underline{U}$—Average velocity vector, $\underline{\sigma}$—Average stress tensor, $\underline{u'}$—Velocity fluctional vector, S—additional momentum source and energy term for the RANS can be expressed as below:

$$\frac{\partial T}{\partial t} + div(\underline{U}T) = div\left(\left(\frac{v}{Pr} + \frac{v_r}{Pr_r}\right)gradT\right) + \frac{1}{\rho C_p}S_Q \tag{26.4}$$

T—Temperature, V—Dynamic Viscosity, Pr—Prandtl Number, $S_Q$—energy source.
    Table 26.1 illustrates the boundary conditions and assumptions made in the 6Sigma Solver.
    The simulations are not conducted on transient simulation and along with this simulation has not considered the solar gain on the roof of the building.

**Table 26.1**  Boundary conditions and assumptions

| Boundary conditions | Value/units | Boundary conditions | Value/units |
|---|---|---|---|
| External wind conditions | 7 NE/37.5 °C | RANS model | K-epsilon |
| Data hall air supply | Ranges between 24 and 27 °C | Mesh count internal | 6 million |
| CRAC redundancy | N + 2 | Mesh count external | 24 million |
| Max chiller cooling load | 2745 kW | Algorithm | SIMPLE |
| Building orientation | N 33° | Computational time/internal simulations | 7 h/HPC Solver |
| GE heat rejection loads | 2442 kW/through exhaust 3034 kW | Computational time/internal simulations | 16 h/HPC solver |
| CRAC cooling max capacity | 450 kW | Cabinet heat capacity | 8.33 kW |

## 26.4   Energy Metric

The most popular method to calculate energy effectiveness is PUE (power usage effectiveness). This method was initially proposed and promoted by Green Grid (a non-profit IT organization) [9]. PUE is described as the ratio between the total facility power divided by the power required by the IT to operate. Along with PUE, the green grid also developed and promoted the DCiE (Data Centre Infrastructure Efficiency) which is inverse of the PUE. Equation 26.5 states the description of the PUE.

$$\text{PUE} = \frac{Total\ Data\ Centre\ Facility\ Energy\ Consumption}{IT\ Equipment\ Energy\ Consumption} \tag{26.5}$$

## 26.5   Results and Discussion

In this section of the article, several results of the internal and external simulations are presented along with two various options for the chiller. The proposed sample data centre internal and external simulation illustrated vital role of the CFD to enhance the thermal performance of the data centre and increase its efficiency.

Figure 26.3a illustrate results as follows, data hall normal operation at 24.0 °C room temperature results showed that average room temperature distribution at 1.0 m from the floor level at 25.0 °C, highest data hall cold aisle temperature is—26.0 °C, highest averaged IT cabinet inlet temperature is 25.3 °C, maximum IT cabinet inlet temperature—26.2 °C, highest return temperature is 35.3 °C and average air velocity within cold aisle—1.2 m/s.

To push the data centres further to their thermal limits, the inlet temperature has been set to increase, to achieve the most efficient solutions possible. Figure 26.4a illustrate results as, data hall normal operation at 27.0 °C showed that average room temperature distribution at 1.0 m from floor level at 27.5 °C, highest cold aisle temperature is—31.0 °C, highest averaged IT cabinet inlet temperature is—28.9 °C, maximum IT cabinet inlet temperature—29.4 °C, highest return temperature is 38.2 °C, Average air velocity within cold aisle—0.9 m/s with the highest velocity as 3 m/s. Figure 26.4b illustrates ASHRAE standards for the rack inlet temperature in a failure scenario, failure scenario simulation results have illustrated that the rack inlet temperature has slightly in comparison with CRAC 24.0 °C increased but not exceeded the ASHRAE standards. The uplift (27.0 °C) in the inlet rack temperature made the data centre more efficient in comparison with the rack inlet temperature of 24.0 °C.
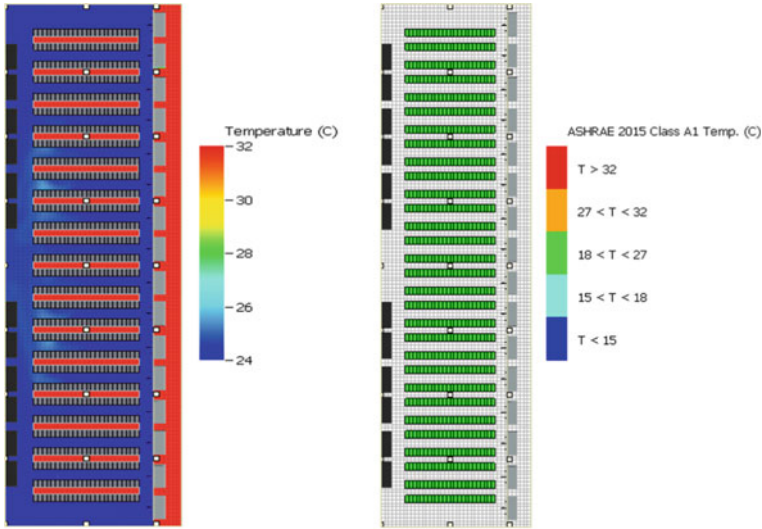
**Fig. 26.3  a** Temperature contour of data hall at 24.0 °C, **b** ASHRAE temperature limit for data hall cabinets at 24.0 °C
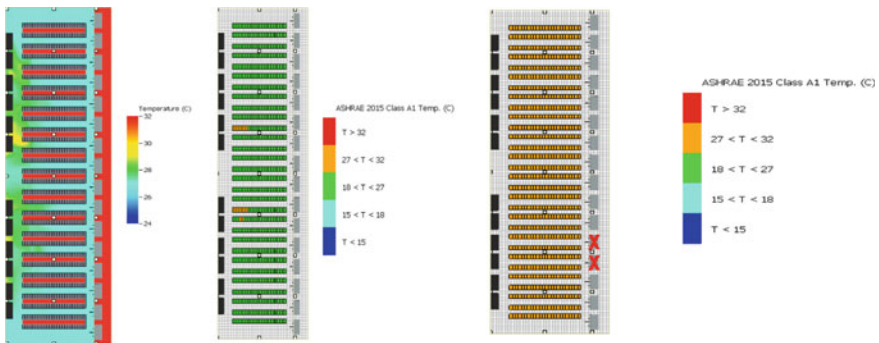


**Fig. 26.4  a** Temperature contour of data hall at 27.0 °C, **b** ASHRAE temperature limit for data hall cabinets at 27.0 °C, **c** ASHRAE temperature limit for data hall cabinets at 27.0 °C (failure scenario–where are 2-cooling units failed)

Figure 26.5 illustrates the external CFD simulation temperature contour at roof level. Following boundary conditions are simplified to analyse the thermal performance of the roof design. Velocity: 7 m/s; Wind Direction: NE; Power failure so Generator's Engine so all generators ON; All chillers status: On; the results showed that given roof layout design could work under the peak thermal and dominant wind conditions along with power failure mode where generator will be running. This has given very high confidence on the design work which will work flawlessly under any given worst-case conditions. Chart 26.1 presents the analytical calculation of cost

saving on various inlet conditions along with the Water-Cooled Chiller (WCC) versus Air Water Cooled Chiller (ACC) option. Inlet water Temperature under options at 20.0 °C and 24.0 °C respectively. These results indicated that WCC chillers could potentially save money by around €100,000 per annum than ACC chillers. Along with this, Table 26.2 illustrates that better PUE also can be also achieved by using the WCC chiller as increasing the supply water temperature to the data halls.
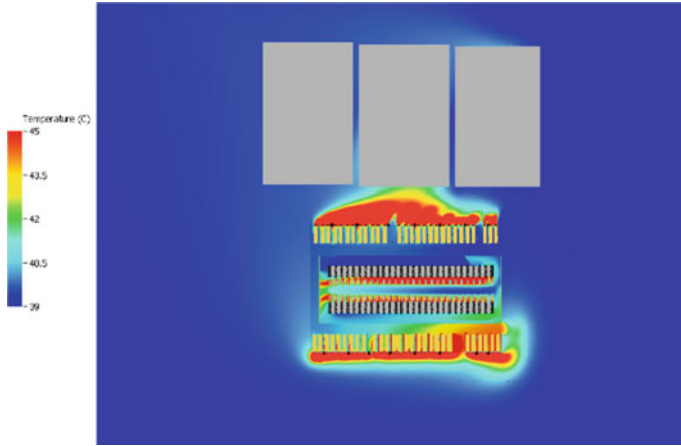


**Fig. 26.5** External temperature contour on the roof of the data centre building
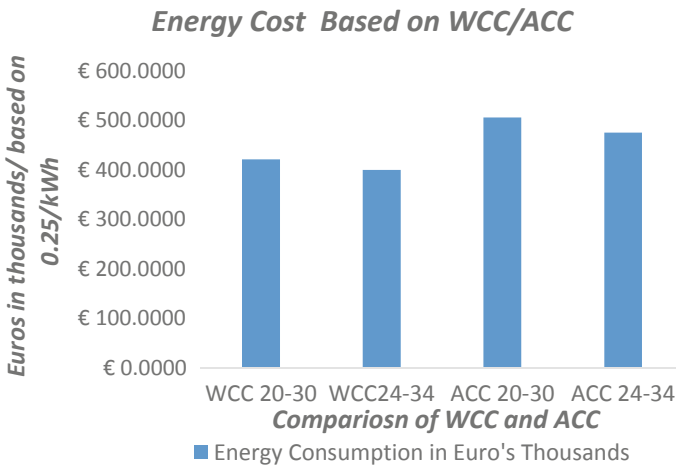


**Chart 26.1** Energy cost in comparison of WCC and ACC

**Table 26.2** PUE comparison

| Chiller types | Water supply temperature ( C) | Annual PUE |
|---|---|---|
| Water cooled chiller | 20 | 1.32 |
| | 24 | 1.28 |
| Air cooled chiller | 20 | 1.42 |
| | 24 | 1.38 |

## 26.6  Conclusion

The following conclusions are drawn from this article and future work is to improvise the CFD analysis strategies to further improve the energy efficiency of the data centre.

- High inlet temperature to data hall within the ASHRAE limit potentially improves the efficiency.
- External simulation of the CFD concluded that the design of the data centre roof will work flawlessly under peak thermal and wind conditions.
- 6sigma CFD solver proven to be extremely useful and reliable in simulating the data centre CFD scenarios both internally and externally.
- Finally, this study also found that a water-cooled chiller solution is more efficient than air-cooled chillers.
- As the solver only capable of using K-epsilon model to solve the simulations, more RANS model cannot be investigated. Addition to this, solver also not accounted the solar gain on the roof. This could be investigated further to model the roof behaviour very accurate.
- As future work of this study, more realistic experimental data will be recorded in comparison with the CFD results to evaluate the accuracy of the solver in detail.

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