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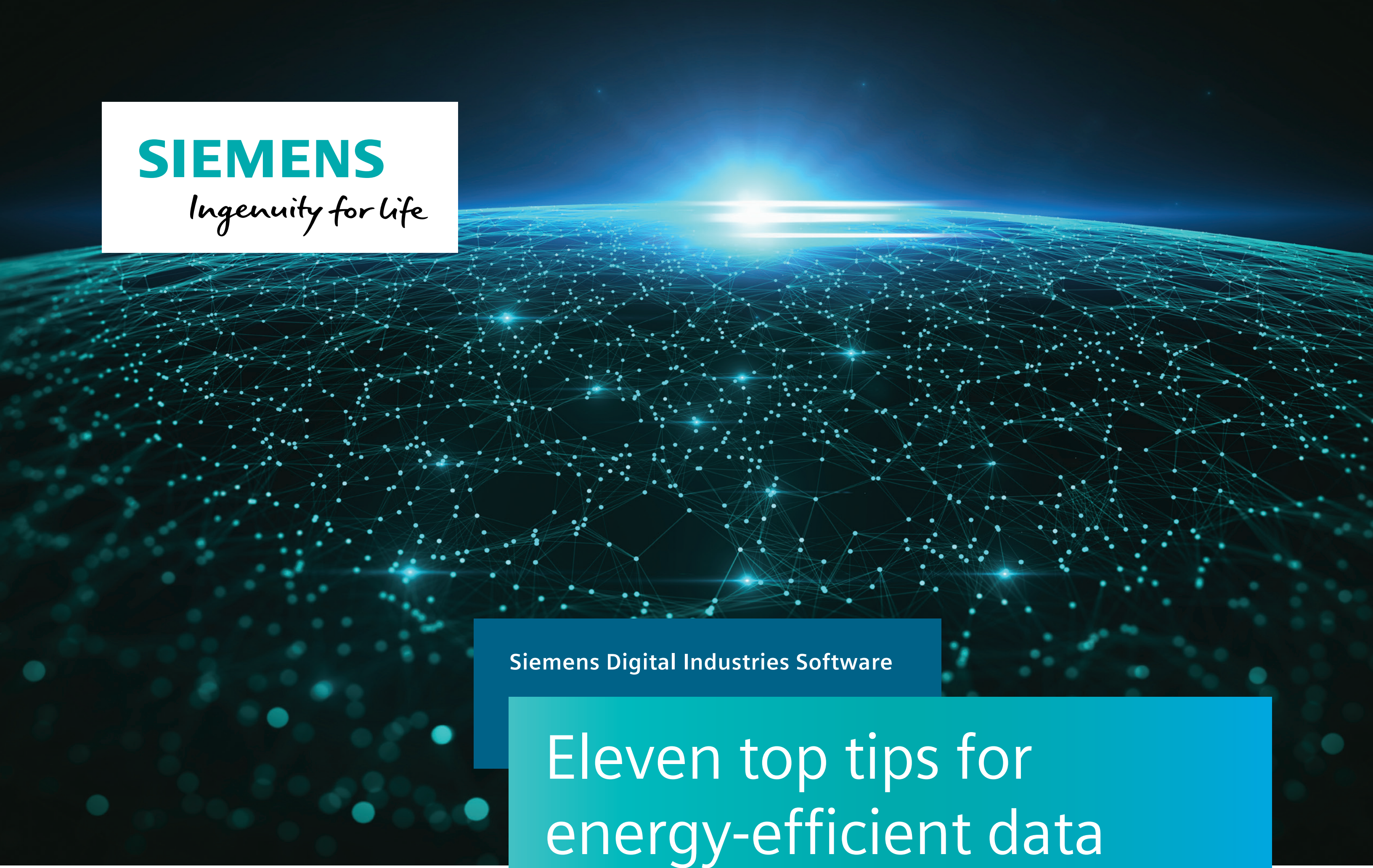

Siemens Digital Industries Software

# Eleven top tips for energy-efficient data center design and operation

## A high-level how-to guide


### Executive summary

The use of data centers globally has skyrocketed in the past three to four years in response to growing demand for information storage and transfer from banks, hospitals, government bodies, telecom operators and hosting facilities. Data center power load (and therefore heat dissipation) foot-prints are continuing to rise, with greenhouse gas emissions from data centers expected to overtake airline industry emissions by 2020.[1] Data centers already consume ~2 percent of total U.S. electricity, growing at ~12 percent compound annual growth (CAGR).[2]

Cooling constitutes a major cost in the operation of a data center. This has led to an increased focus on minimizing energy use in data centers and enters, thereby reducing operating costs. A consistent design goal is to ensure that the power usage effectiveness (PUE) is kept as low as possible, namely, close to unity (for example, 1.0).

# When is data center thermal design essential?

Power densities of server racks continue to increase, from around one to three kilowatts (kW) just a few years ago to 24 to 30 kW per rack currently. Thermal issues are a cause of problems, in that the servers and switches must be kept cool. In particular, the failure rate of electronic products rises sharply with elevated temperatures, while high thermal stresses on solder joints from large temperature variation is another source of failure. With the increasing emphasis on reliability rates available from data centers, this is an obvious concern. This in turn has led to an increased focus on monitoring and reporting in data centers to ensure data equipment does not fail.

Monitoring and reporting are important in an operational data center. For new builds at today's server power levels and in instances when the same space is retrofitted, or old servers are swapped out for new in existing racks, there is increased likelihood of thermal problems due to ever higher power densities. This makes thermal design, proven by computational fluid dynamics (CFD) simulation, essential if the design capacity of the data center is to be reached.

# Data center design

### 1: Start when the data hall is designed

The best time to consider the thermal design of the data center is pre-build (for a greenfield construction). This means that the following can be considered at the outset:

- The overall heating, ventilation and air conditioning (HVAC) system, for example, could be comprised of a raised floor design, in-line cooling approaches, common or individual rack chimneys, dedicated cooling units for racks, ceiling units, etc.
- Once the HVAC system has been determined, the wiring and plumbing arrangements can be determined
- Methodologies for hot swapping of computer room air conditioning (CRAC) and other cooling units, individual servers and/or racks, redundancy, etc.

Note that retrofitting and troubleshooting can and should also be addressed using CFD models, as some changes could be very expensive; for example, switching from raised floor to in-line cooling. The use of CFD can ensure that wise choices are made for legacy data centers and confirmed by simulation prior to physically making a change.

As a result of following this advice, Siemens Digital Industries Software's own regional data centers in Wilsonville, Oregon and Shannon, Ireland now operate with a PUE of around 1.15 to 1.2. There is no real data available on the worldwide spread for PUE values globally, but many data centers have a PUE of 3.0 or greater that a value of 1.6 should be achievable. Measurements completed by Lawrence Berkeley National Labs show that 22 data centers measured had PUE values in the 1.3 to 3.0 range.[3]

### 2: Build a simple model of the data hall

Include key features such as overall structure, raised floor (if present), air handling/cooling units, racks/servers, large floor plenum blockages (if present) and floor tiles (if present). The following is a model of a small data center provided with Simcenter™ Flotherm™ software that can be used for tutorial purposes, or as the starting point to build a model of another data center.

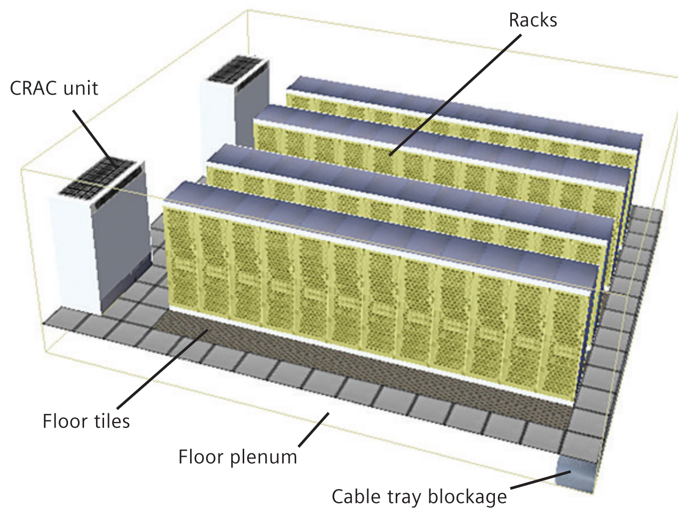


Figure 1: Model of a conventional raised floor data center supplied with Simcenter Flotherm V10.

### 3: Import data from CAD

The design of the data center can be imported from a computer-aided design (CAD) model, DXF files, or from interrogation of appropriate data from data center infrastructure management (DCIM) software or similar, using the Simcenter Flotherm FloXML schema. The latter will be discussed in more detail later. If required, items can be substituted with appropriate Simcenter Flotherm Smartpart or library representations.

### 4: Use intelligent models of data center components

Simcenter Flotherm provides Smartparts for CRAC units, as well as perforated tiles, coolers, racks and servers. Intelligence built into the Smartpart representations provides greater accuracy. For example, a Rack Smartpart correctly accounts for the stratification of air in the rack and servers within it. Appropriate grid can be added by defining suitable grid constraints, etc. to ensure it is always represented with enough mesh for the analysis. The pattern functionality in Simcenter Flotherm is very useful in terms of defining repeating rows of racks and/or floor tiles.

In this first version of the model, the relative performance of the data center can be easily established using a relatively simple representation of each rack. In particular, the rack would be modeled as a single block using the Simcenter Flotherm Rack Smartpart, with an appropriate power dissipation and either flow rate through it or temperature rise of the airflow between inlet and outlet of the rack. Similarly, floor tiles could be modeled using a simple pressure drop versus velocity representation, using the Perforated Plate Smartpart.

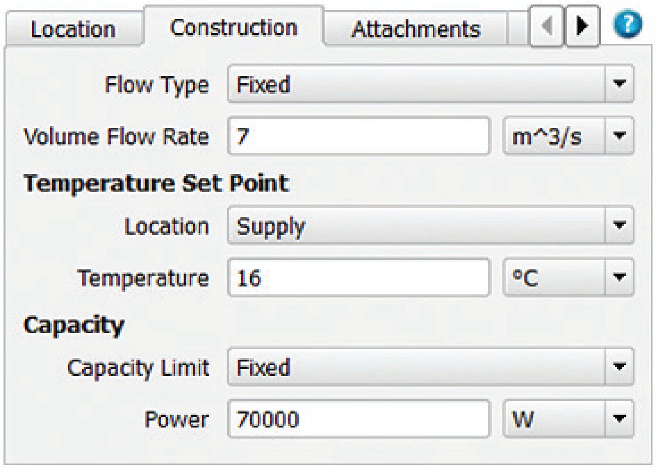


Figure 2: Cooler Smartpart construction dialog in Simcenter Flotherm.

## 5: Consider design alternatives

At this stage the aim is to explore as many design options as possible to select the most suitable design for the data hall. This will depend on many factors, including:

The power density of the racks in the data center and their distribution. While racks tend to be clustered based on function or power density, cooling requirements can vary significantly within the space, potentially needing supplementary cooling.

The space envelope that is available for the design. For example, the use of a chimney on the racks may require upper level real estate that is currently used for wiring, lighting, etc.

Having open aisles of racks is the simplest option, with individual floor tiles or in-line coolers providing cold air to the racks. Typically, this is arranged in hot air and/or cold air designs, when the outlets or inlets of rows of racks face each other. However, hot air from the environment can easily be drawn back into the racks, bypassing the cooling infrastructure. As a result, the cooling will be ineffective, requiring far more cooling than should be necessary to keep the information technology (IT) equipment sufficiently cool, and hence have a relatively high PUE.

There are a number of strategies that can be followed to improve the thermal design of the data hall, for example:

- Cold aisle containment
- Hot aisle containment
- In-line cooling units
- Rear-door heat exchangers
- Dedicated rack cooling units, for example, liquid cooling
- Overhead HVAC system
- Dedicated rack chimneys/ducting to exhaust
- Evaporative free air cooling, supplemented with CRAC units

All of these options can be considered quickly and effectively using CFD.

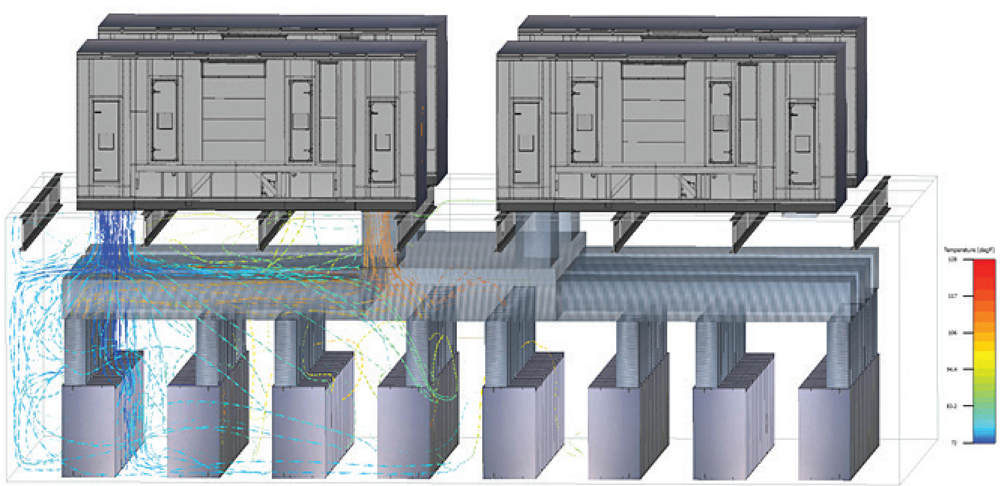

Figure 3: Overhead HVAC system with dedicated rack chimneys.

## 6: Investigate different operational scenarios

CFD can be used to model the change in conditions that occur as the data center is populated. While data centers are generally populated based on functionality or power density, different strategies may be employed in terms of population ramp-up and intended life cycle. For example, data centers may have significant expansion room to be filled over a defined time period.

At low capacity, some cooling strategies result in much higher PUE than others, so a design that gives the lowest total energy consumption over the design life of the data center should be the aim. Using CFD to ensure cooling can be efficiently matched to the data center capacity and identify how best to populate the data center capacity will minimize lifetime operating cost.

By the same token, different operating conditions can be considered as iterations to the baseline model, including, for example, variation in the power loading (and therefore thermal load), flow rates and operation of cooling units, etc., when asset utilization is low. CFD can also be used to investigate the maximum power that can be applied to each rack for a given cooling strategy to help understand how the data center design will cope with future, higher power servers for example. CFD can also be used to determine the impact of equipment failure, for example, the time varying (transient) temperature response at important locations due to a CRAC unit failure.

## 7: Use capture index to judge design worthiness

Consideration of the Capture Index (CI),[4] provides an important tool in the design of the data center. The temperature distributions in a data center are not always the most effective means of determining whether a design is good or not and, therefore, may not guide the designer in trying to make improvements. In particular, the temperature distributions are a symptom of the data center design as opposed to the cause.

Two forms of capture index are available: cold aisle CI and hot aisle CI (see appendix). Both are typically expressed as a percentage. The closer they are to 100 percent, the closer to the cooling system's performance is to the ideal situation. This data is readily tabulated for quick and easy comparison between alternate designs.

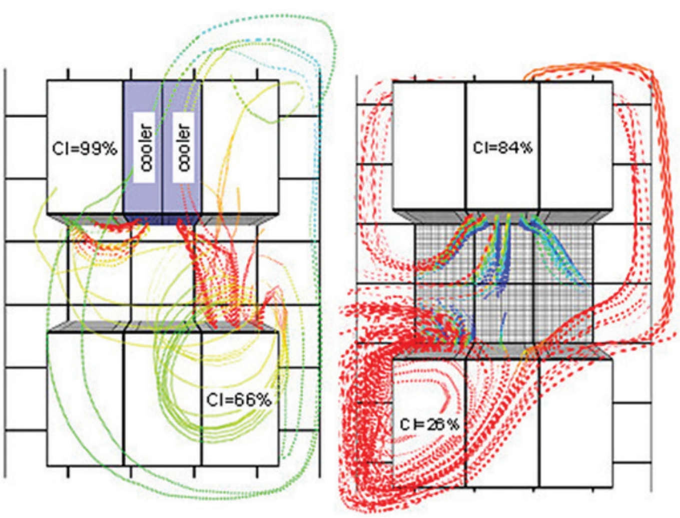


Figure 4: Cooler Smartpart construction dialog in Simcenter Flotherm.

## 8: Minimize the model run time

The unique localized grid technology of Simcenter Flotherm allows the user to obtain rapid simulation turnaround times.

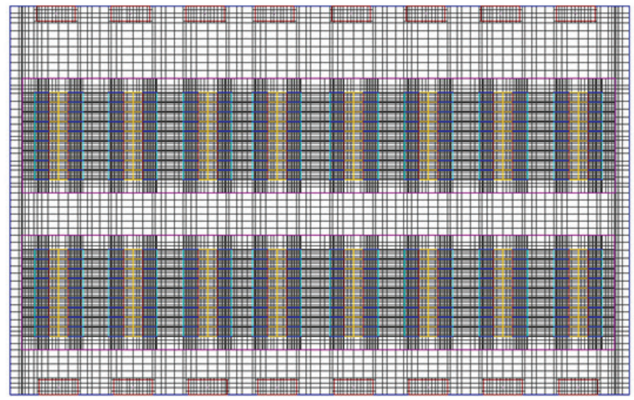

Figure 5: Traditional data center design showing localized mesh through racks.

Localized gridding prevents mesh bleeding; for example, unnecessarily small mesh cells extending beyond the geometry out into the surrounding air. The functionality is therefore appropriate in data centers because it more clearly separates these coarse and fine grid regions. Given these mesh lines bleed in all three directions, and the total mesh is the multiple of the number of cells in all three directions, cell counts can be reduced dramatically by using this technology.

The overall airflow and temperature distributions in a data center are relatively unaffected by typical perturbations to variables such as heat dissipation of racks, CRAC/cooler operating conditions, etc. The data center is therefore a particularly good application in which to use the results from an existing baseline model as the starting point for the next analysis in order to reduce solution time, as this reduces the number of iterations needed to investigate different operational scenarios, and can also help if layout changes are made.

Finally, the speedup in the parallel processor solver in Simcenter Flotherm V10 seems to be particularly well suited to data centers, with speedups in some case above a factor of 10 compared to the previous version.

## 9: Use command center to optimize data center design

The design of experiment and optimization capabilities included in the command center, which forms part of the standard Simcenter Flotherm installation, allows the user to optimize the design of the data center. For example, the user could optimize the flow rate through a CRAC unit to achieve a target inlet temperature to a particular rack or array of racks. Figure 6 shows an example of the command center dialog box accessing the flow rate variable. Note that other variables, such as the CRAC capacity, are also available.

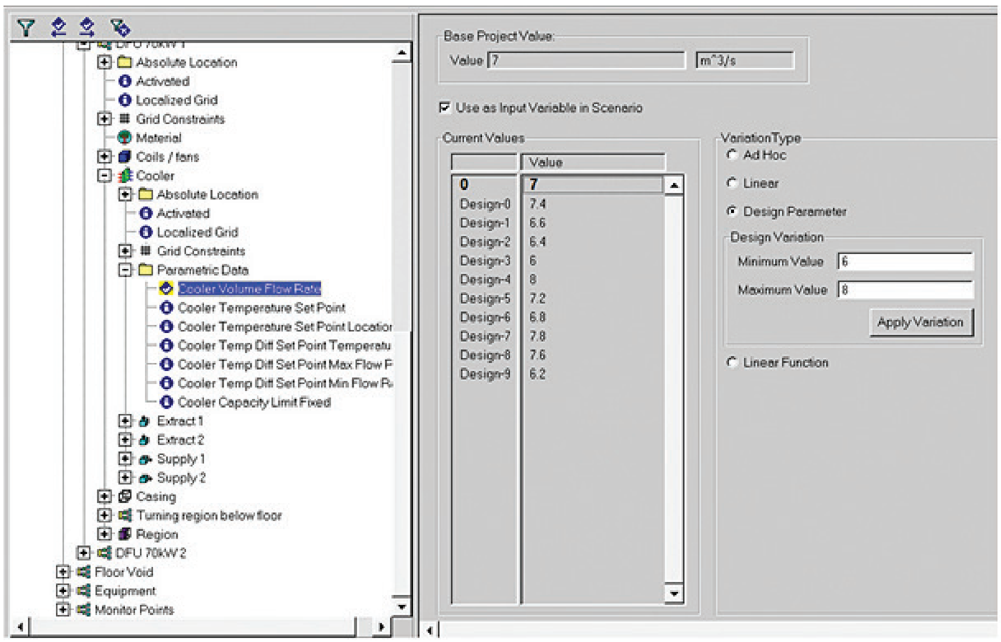


Figure 6: Example dialog box shows access to CRAC unit variables from data center example case.

# Data center commissioning

### 10: Create a spreadsheet-based front-end

The Simcenter FloXML schema included in Simcenter Flotherm software allows the creation/running/postprocessing of a data center model without the need to open up Simcenter Flotherm. It is therefore well suited for nonexpert CFD users, for example, field engineers who may be asked to troubleshoot a data center design.

Data can be entered directly into a spreadsheet, or can be parsed from a third-party source, for example, a DCIM software tool that contains the information needed for the analysis such as rack physical dimensions, power dissipations, etc. This configurable spreadsheet front-end can then create Simcenter FloXML definitions that provide a ready-to-solve (on the command line) Simcenter Flotherm model.

The results can then be viewed using the free-to-download Floviz software, passed back to a postprocessing tool or captured in the spreadsheet. This process is shown as an example in figure 7, with an example of the Simcenter FloXML file itself shown in figure 8. Examples of such spreadsheets and Simcenter FloXML files are installed with the Simcenter Flotherm software in V10 onwards.

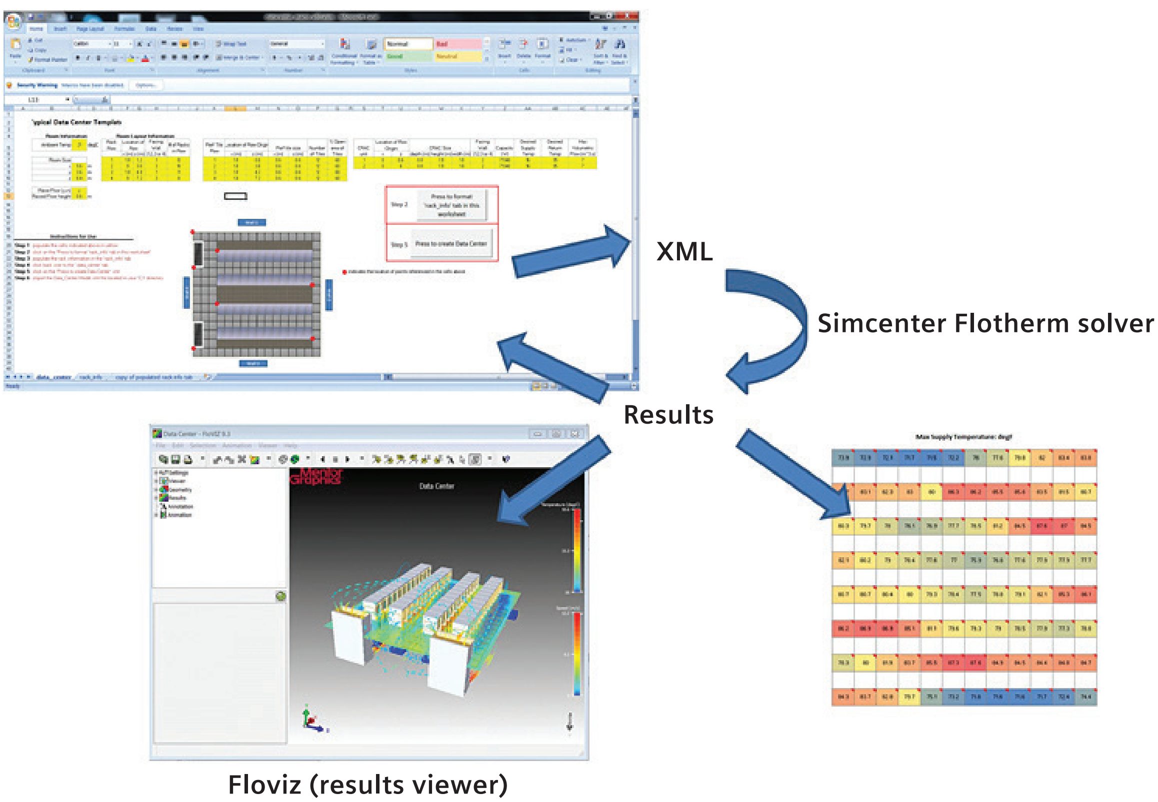


Figure 7: Excel based CFD analysis process and result postprocessing.

# Data center operation

### 11: Simulate the impact of change orders

During operation, whenever a change order is raised to add new IT assets, or move existing assets, the impact of this on the overall operation of the data center can be checked before they are implemented by making the necessary changes in the spreadsheet created above. In the case of conventional designs with perimeter CRAC units, introducing new assets or moving existing assets can have unforeseen consequences on equipment in remote locations due to changes in the overall airflow patterns within the data center. Other cooling strategies, although superior in terms of recirculation, stratification and bypass are not without challenges in terms of equipment cooling.

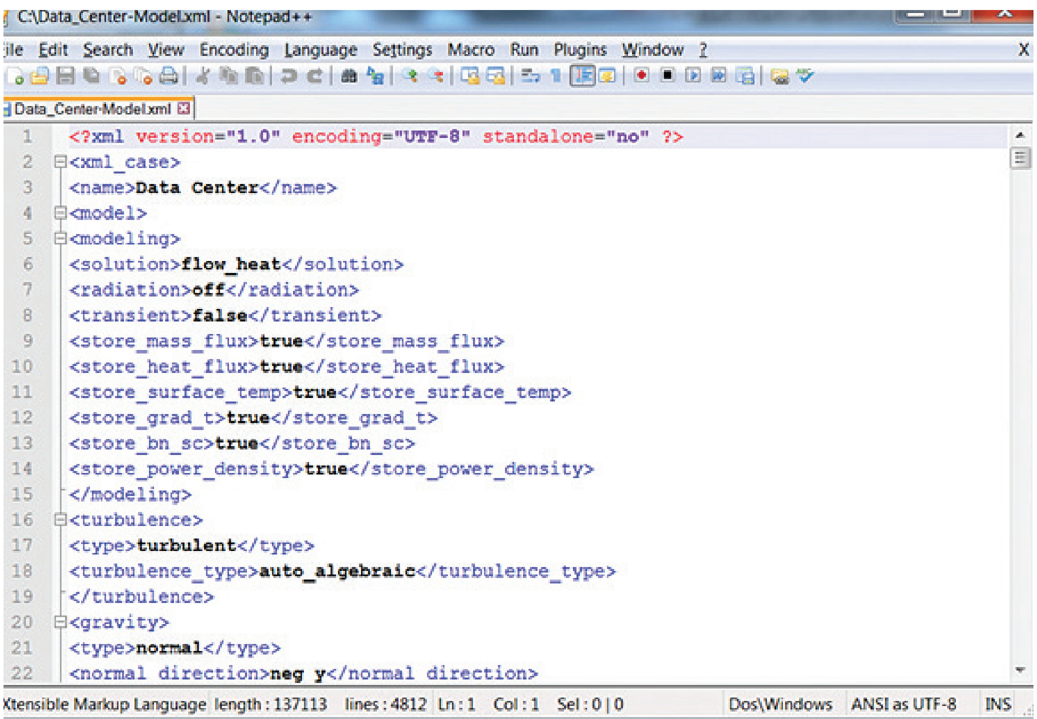


Figure 8: XML schema example for data center case.

# Conclusion

Conventional perimeter CRAC unit layouts focus on room-level design, with the racks and equipment they contain considered as an afterthought. More recent design approaches such as aisle containment, and in particular liquid-cooled racks, focus on the cooling of the individual equipment and bypass the need for full room/cold aisle air cooling. In both cases there is an assumption the airflow environment within the data hall will accommodate the cooling approach from commissioning through to full utilization.

We advocate a holistic approach in which the cooling strategy is proven to achieve this business goal from the outset by CFD simulation during data center design, with CFD used through commissioning and operation to ensure that asset deployment allows for utilization up to the design capacity against a backdrop of changing business needs and increasing equipment power consumption.

## Appendix: definitions

### Definition of power usage effectiveness

Definition of PUE is defined as:

$$PUE = \frac{Total\ Facility\ Energy}{IT\ Equipment\ Energy}$$

Reference 1 indicates there is no real data on the worldwide spread for values globally, but that a PUE value of 1.6 should be achievable (page 13).

### Definition of capture index (CI)

Two forms of capture index are available:

***Cold aisle CI:***

Fraction of air ingested by the rack that originates from local cooling resources (for example, perforated floor tiles or local coolers). This is generally expressed as a percentage.

Cold aisle CI is generally used to assess cooling performance in data centers with raised-floor cooling architectures.

***Hot aisle CI:***

Fraction of air exhausted by a rack that is captured by local extracts (for example, local coolers or return vents). This is generally expressed as a percentage.

Hot aisle CI is generally used to assess the cooling performance in architectures in which row-based coolers or return vents are employed.

## References

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## Acknowledgements

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