Improving IDC Cooling and Air Conditioning Efficiency

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With the demand for information technology (IT) equipment increasing year by year and data centers with densely packed IT equipment experiencing dramatic jumps in power consumption, energy-saving methods are becoming all the more important. Power consumed by a data center is used for various purposes, but reducing the power supplied to IT equipment followed by that for air conditioning to cool large IT equipment is taking on particular importance. This paper describes the efforts of Fujitsu Advanced Technologies Limited (FATEC) to make air conditioning in data centers more efficient. Surveys focusing on the key parameters of temperature, electrical power, and airflow are crucial to obtaining a clear understanding of actual conditions, and computational fluid dynamics (CFD) simulations constitute an important predictive technology for achieving genuine improvements. The accuracy of temperature predictions for uncovering hot spots is generally within 20%; moreover, this can be brought to within 5% by adjusting the simulations. It has been found that improvements in cooling efficiency achieved by using highly accurate CFD simulations can reduce the power consumed by air conditioning equipment drastically.

1. Introduction

As information technology (IT) continues to advance throughout society, all kinds of IT services, including video delivery, are being provided and the amount of information processed by Japanese society is escalating, with some people predicting a 200-fold increase from 2006 to 2025.[1] This information explosion is not, however, restricted to Japan—it is a worldwide problem. With YouTube delivering more than a hundred million video clips a day and Yahoo! reporting 3 billion page views a day, it is not difficult to agree with such a prognosis. At the same time, the number of pieces of IT equipment needed for this huge volume of information processing is increasing, and power consumed by IT equipment in Japan is expected to increase by about five times from 2006 to 2025 to 240 billion kWh and that throughout the world by about nine times to 4.7 trillion kWh.[2] Energy saving measures for IT equipment and their adoption and application throughout the entire world have become a matter of great urgency. Considering that data centers contain a lot of IT equipment, their power consumption has been attracting much attention. A breakdown of power usage at Fujitsu Group data centers reveals that IT equipment consumes 45% of all consumed power while air conditioning equipment consumes nearly the same at 40% (**Figure 1**). Although the development of energy saving technology for IT equipment itself is certainly important, reducing the power consumed by air conditioning facilities to cool IT equipment is just as important.

The power consumed by the central processing units (CPUs) used in servers and elsewhere is on the increase, while the technology for mounting CPUs in servers is advancing, result-

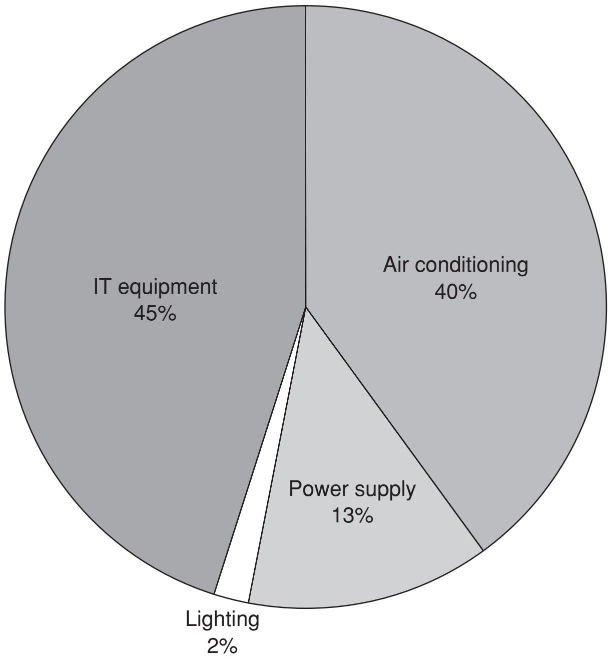

Figure 1
Power-usage breakdown at Fujitsu data centers (fiscal 2006 results).

ing in greater heat generating densities in servers. This means that data centers having high concentrations of servers can exhibit local jumps in the temperature of server intake air, which increases the possibility of heat-related problems. Such heat can impede the stable operation of a system and shorten the life of products, so finding ways to prevent such local temperature increases efficiently has become important.

There is consequently a great need for simultaneously solving these two conflicting issues, namely, preventing heat problems from occurring in data centers and reducing the power consumed by air conditioning equipment. Cooling facilities must be designed in a more intelligent and efficient manner than before and cooling technology to support this aim must be developed.

Fujitsu Advanced Technologies Limited (FATEC) has been developing and providing technology for cooling CPUs and other devices and the interiors of servers and other IT equipment. It has been using, in particular, IT technology with a focus on computational fluid dynamics (CFD) simulations. After taking a close look at the above issues, FATEC decided to expand its active fields to data centers and to seek out solutions by taking the cooling and CFD simulation technologies that it had nurtured in the development of IT equipment and product technologies and using them as environmental support technologies (**Figure 2**).

2. Actual measurements (visualizing current conditions)

Measuring temperature, power, and airflow in data centers is important to prevent heat related problems and reduce air conditioning power consumption, but there have been many cases in the past where such measurements were mostly not performed. To obtain a clear understanding of the data center environment and promote heat-problem solutions and energy-saving measures, various quantities must be measured and visualized and subjected to appropriate analysis. Actual measurements are also extremely important for testing CFD simulation models and the validity of boundary conditions for various levels of planning, such as for replacing and adding IT equipment, improving and maintaining air conditioning equipment, and constructing new data centers based on CFD simulations.

2.1 Temperature measurements

The thermal design of most air cooled IT equipment is based on the temperature of intake air, so the measurement of intake air temperature in IT equipment is crucial. In typical rack mounted equipment, this corresponds to measuring the air temperature at the front of the rack. The temperature of exhaust air, in contrast, differs according to the power consumed and the airflow generated by each piece of IT equipment, and since exhaust air itself does not directly interact with IT equipment, its measurement is not important. (However, in a technique for determining airflow at the rack level using differences in temperature

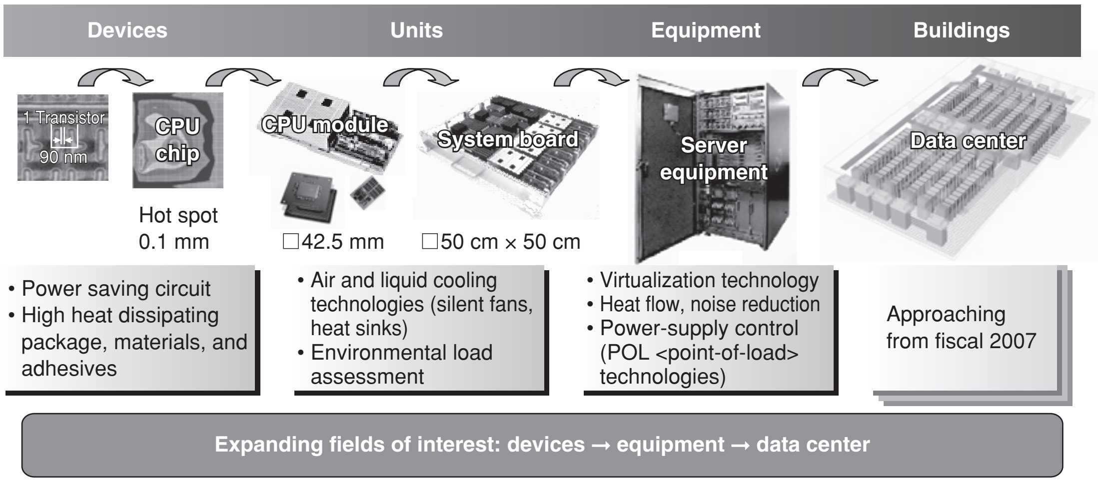

Figure 2
FATEC active fields.

at the rack intake and exhaust sides as well as power consumed by all IT equipment in the rack and the physical properties of air, temperature measurement on the exhaust side is also important.) Of course, the recirculation of exhaust air can be a factor in raising the temperature of air at the intake side, but this can be detected by measuring the airflow temperature at the intake side. Importance is also being attached to temperature measurement inside equipment at the CPU and memory chips, for example, and there is no reason not to do this provided it can be done easily and inexpensively. However, since the reliability of CPU and memory operation in each piece of equipment is guaranteed for a prescribed intake air temperature, such internal temperature measurements are not considered worthwhile for obtaining a valid thermal design for a wide variety of IT equipment. In short, determining the intake air temperature is thought to be quite sufficient at present.

In addition, the temperature of exhaust air from air conditioning equipment is one temperature that does need to be measured to prepare a temperature standard when investigating the temperature distribution of rack intake air throughout a machine room in a data center. If the temperature at the rack inlet side is the same as that of exhaust air from air conditioning equipment, we can conclude that hot exhaust air from IT equipment is not recirculating. On the other hand, a temperature difference between the two can be used to determine the extent to which hot exhaust air is recirculating.

2.2 Power measurements

Two common metrics for expressing the energy efficiency of a data center are the power usage effectiveness (PUE) and data center efficiency (DCE).[3),4)] PUE is the ratio of power consumed by all data center facilities to the power consumed by IT equipment, while DCE is its reciprocal. Total facility power includes power consumed by IT equipment, power consumed by the air conditioning system, distribution loss in the power supply system, and power consumed by data center lighting. Obviously, PUE is greater than 1, and a value close to 1 indicates high energy efficiency. Here, the coefficient of performance (COP), which is generally used as a measure of energy-consumption efficiency in air conditioning equipment, is applied to data centers as a metric for focusing on air conditioning cooling efficiency. It is defined as the ratio of IT equipment power to all air conditioning related power. In this case, the greater the COP value, the higher the air conditioning system's cooling efficiency. It is recommended that either COP or PUE be used depending on the topic under discussion. That is, COP should be used for a discussion of the energy efficiency of air conditioning cooling, which has a big effect on a data center's energy efficiency, and PUE for that of the entire data center. But in either case, various types of power measurements are essential when commenting on energy efficiency. It is important that measurements be made in whatever units are needed.

Although it has become common in recent years to aim for a PUE of, for example, 1.3 as environmental consciousness rises, taking up and discussing only energy efficiency—whether in terms of PUE or COP—is meaningless. While it is easy to improve energy efficiency at the sacrifice of data center availability and reliability, this would mistake the means for the end, considering the original purpose of a data center. Thus, when discussing energy efficiency, it is imperative that information processing performance, availability, reliability, and other data center specifications be discussed at the same time. For this reason, the Green Grid[5)] is proposing data center performance efficiency (DCPE) as a metric that includes net effective work, which is part of the data center specifications.[6)] However, this metric is more difficult to calculate than energy efficiency and it does not yet consider elements like availability and reliability. It appears that more time will be needed to establish a metric that expresses data center specifications comprehensively. Thus, until an objective metric for data center specifications becomes available, we must try to express individual specifications by original techniques.

2.3 Airflow measurements

Air conditioning cooling in a data center is basically accomplished by the airflow from the air conditioning system that reaches the inlet side of IT equipment, passes through the equipment to capture heat, and returns to the air conditioning system from the exhaust side of the IT equipment. Taking this circulation loop into consideration, one must achieve a good balance in airflow to prevent heat problems from occurring and to reduce air conditioning energy requirements. Specifically, this means a balance between the airflow required by IT equipment and the airflow that can be supplied by the air conditioning system. Airflow measurements must be performed in order to visualize this balance and develop optimal controls.

To begin with, two measurement targets are important in airflow measurements: the quantities of airflow used by IT equipment and supplied by the air conditioning system. There are various methods for measuring the quantity of airflow used by IT equipment, such as measuring the flow velocity at the rack intake side or using the temperature at the rack exhaust side and the power consumed by the rack to determine airflow. The methods that can be used to measure the quantity of airflow supplied by the air conditioning system are basically the same as those for measuring the quantity of airflow used by IT equipment. The key point here is to achieve a good balance such that the air conditioning system provides enough airflow for the IT equipment but not too much. Furthermore, when it is necessary to analyze airflow paths within a data center, as in the case of underfloor cooling, it is important to measure the quantity of airflow provided by the perforated tiles to the area above the floor. Whatever the measurement scenario, the use of specialized measuring devices can simplify the task of taking measurements.

3. CFD simulations

CFD simulations can be useful for optimizing cooling efficiency in an air conditioned IT equipment environment. They are already widely used in cooling technology development and thermal design for servers and other types of IT equipment, and at FATEC, they have been used for some time in technology development for various types of IT equipment and products. The

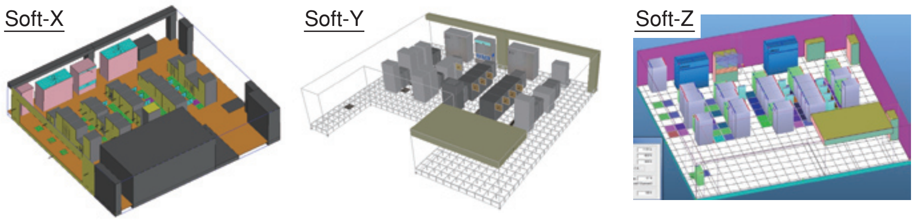

Figure 3
Software benchmarking: examples.

use of CFD simulations can reduce the number of prototypes and hours required for evaluation while also reducing development time and costs. Similarly, the use of CFD simulations can be considered for efforts to raise cooling efficiency in an air conditioned IT equipment environment. If they can be used to predict diverse enhancement measures with good accuracy, it should be possible to maximize the cooling effect for a given air conditioning facility cost. This would make CFD simulation an extremely useful technique for saving energy in data centers.

FATEC performs software benchmarking and improves the accuracy for CFD simulations for data centers, by using the experience gained by its cooling and CFD simulation engineers in the development of IT equipment and products.

3.1 Software benchmarking

CFD simulations come in various types, but with the increasing importance attached to raising air conditioning cooling efficiency in data centers, analysis software designed especially for data centers has been expanding with a more extensive array of functions. Both the strong and weak points of diverse simulation programs—including conventional simulation software dedicated to electronic equipment—must be well understood and optimal simulation software that matches current needs must be selected and mastered. FATEC engineers are performing benchmark evaluations of various types of software based on the company's abundant software-usage technologies and know-how and assessing the features of those software programs. Some examples of benchmarking are shown in **Figure 3** and a comparison with actual measurements to investigate accuracy is shown in **Figure 4**.

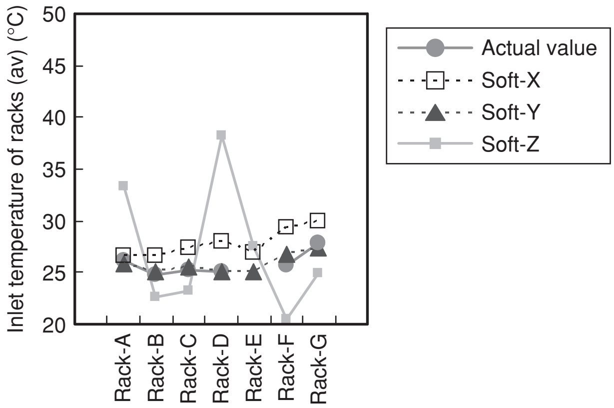

Figure 4
Software benchmarking: results.

3.2 Improvements in accuracy

FATEC is continuously working to improve the accuracy of its software programs. The factors that affect CFD simulation accuracy must be found from within the model and boundary conditions, which must be refined if necessary. Therefore, we need a process that takes actual measurements, compares their results with simulation results, clarifies the differences, and corrects the model and boundary conditions to remove the factors behind those differences.

Fujitsu Group has many data centers, and to perform comparison tests using actual measurements at actual data centers, FATEC performed

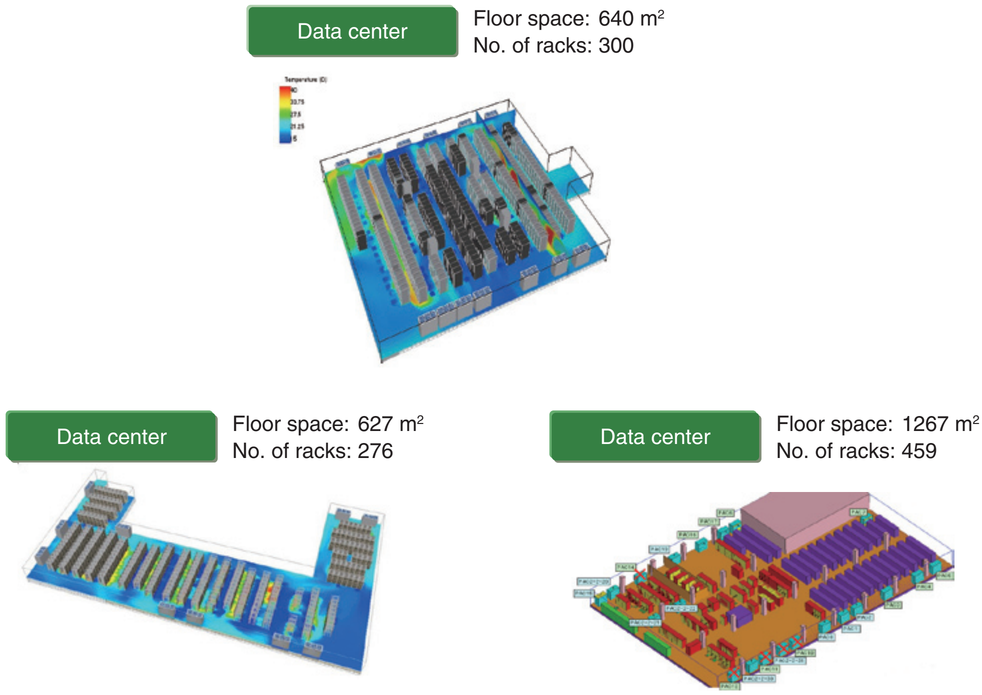

Figure 5
FATEC case studies.

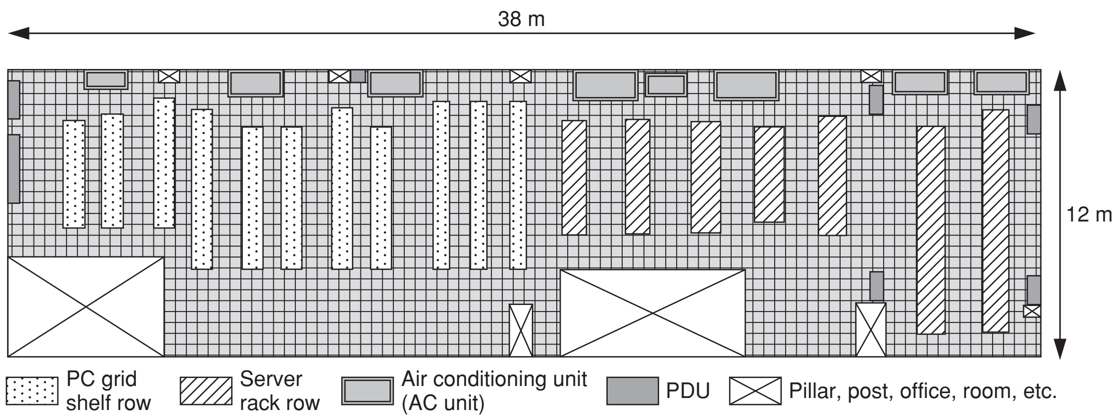

Figure 6
Plan of server room.

CFD simulations at several of different sizes (**Figure 5**). We found that hot spots (where the temperature of intake air rises) could be predicted with an accuracy of ±20% even in the initial CFD simulation trial run. Moreover, for data centers to which more-accurate simulations were applied, a prediction accuracy of ±5% for enhancement measures could be achieved.

4. Examples of measurements and CFD simulations

FATEC has a server room for providing IT services within the Fujitsu Group and has been using it as a laboratory to test various measures for raising air conditioning cooling efficiency. A plan of the server room is shown in **Figure 6**. It is about 400 m² in size with the right half being a

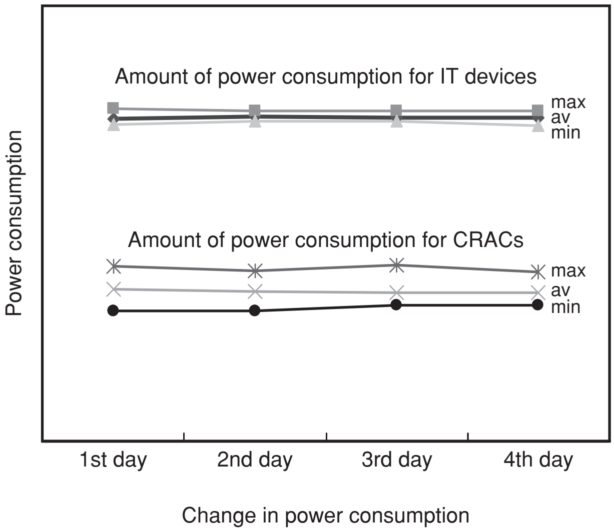

Figure 7
Results of power measurements.

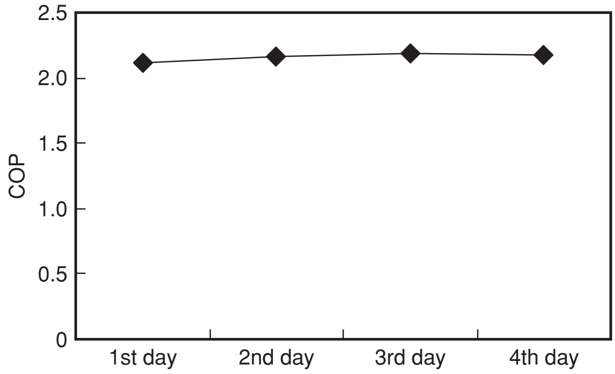

Figure 8
COP calculations.

rack area containing many rack mounted servers and other types of IT devices and the left side being a PC cluster area containing many personal computers (PCs).

Airflow temperature is finely measured at various locations including the rack front, rack back, air conditioning outlets, air conditioning inlets, and perforated tiles. In the PC cluster area, air temperature is measured at one point per aisle. In addition to these measurements, the temperature at walls throughout the room in contact with outside air and the temperature of outside air itself are also measured.

Power is measured at seven power distribution units (PDUs) used for IT equipment and three PDUs used for computer room air conditioning (CRAC) equipment to determine the power consumed by IT and CRAC equipment. The power measurement results are shown in **Figure 7**. These values were used to calculate the COP, which expresses the cooling efficiency for the entire room (**Figure 8**). The COP was about 2.2. The results also show that applying various improvement measures to this room with the older air conditioning equipment having a relatively small unit COP resulted in relatively high efficiency for those units. Power consumption was also measured for each CRAC unit in the server room. A graph depicting the change in power consumed by individual CRAC units is shown in **Figure 9**. Taking individual power consumption measurements in this way enables individual problems to be uncovered and improvements in overall cooling efficiency to be made.

Performing CFD simulations enabled hot spot problems in the rack area to be resolved and improvements in cooling efficiency to be made. The results of performing simulations in the rack area to predict the effect of applying four countermeasures (changing the specifications and conditions of perforated tiles, improving the air flow under the floor, increasing the air flow rate of a CRAC unit, and changing the directions of some racks) are shown in **Figure 10**. As shown in **Figure 11**, these four countermeasures were able to significantly reduce rack inlet temperature.

When we examined the entire room, we found that there was some margin of reserve in the air conditioning units installed in the PC cluster area, where the heat generating density is low. We therefore shut down four of the eight air conditioning units in the room to check cooling efficiency and temperature conditions under such a scenario as a trial (**Figure 12**). This resulted in a COP of 2.8 for the entire room and the air conditioning power could be reduced by 22% compared

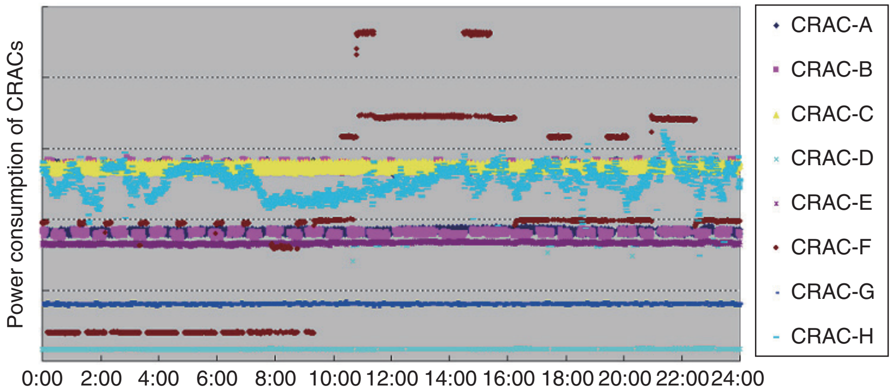

Figure 9
CRAC power consumption over time.

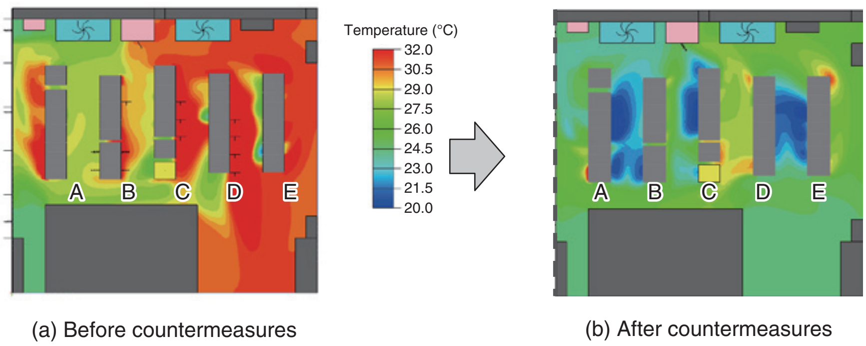

Figure 10
Hot spot improvement in rack area.

with running all eight air conditioning units.

5. Consulting services

FATEC proposes optimal solutions ranging from constructing new data centers to upgrading existing server rooms in accordance with customer applications and needs. These proposals are based on knowledge and experience of cooling technology cultivated over many years of product development by engineers familiar with heat transfer mechanisms and on abundant practical experience and knowledge built up at actual Fujitsu Group data centers.

The typical consulting flow begins with a meeting with the customer to clarify problems and obtain detailed information necessary for performing simulations. The optimal simulation software from among various choices, as de-

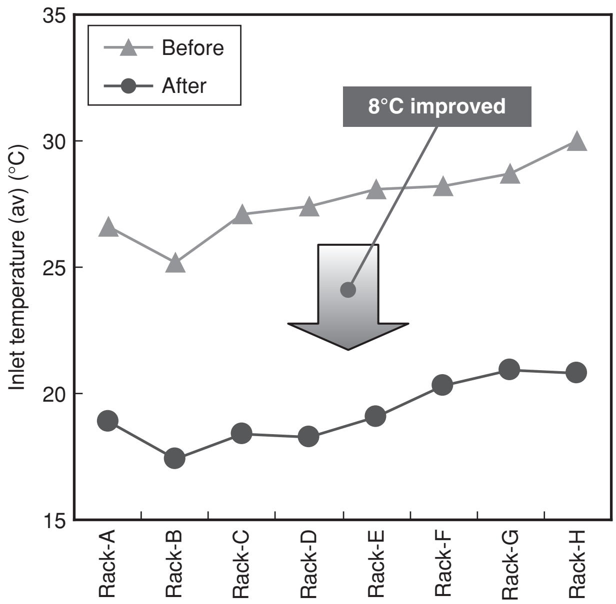

Figure 11
Effect of applying hot-spot countermeasures.

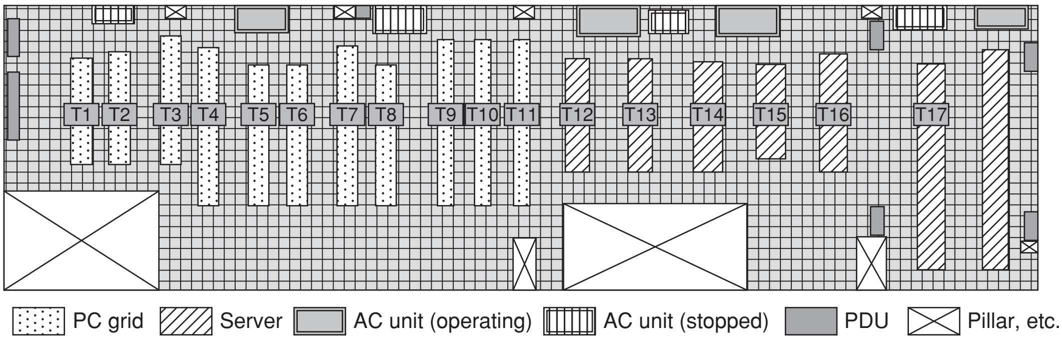

Figure 12
Plan of stopped air conditioning units.

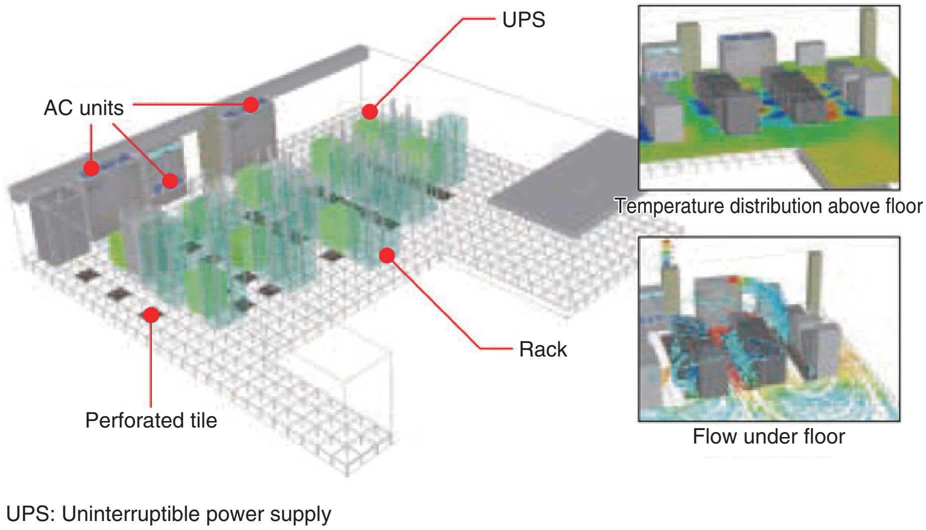

Figure 13
Example of CFD simulation.

scribed above, is then selected and simulations are performed. The temperature distribution and airflow within the data center are visualized and a detailed analysis of air conditioning operations is performed (**Figures 13** and **14**). Finally, problem points and optimal solution methods are presented to the customer in the form of an easy to understand report (**Figure 15**). Simulation results may also be presented by a walk through animation video (**Figure 16**).

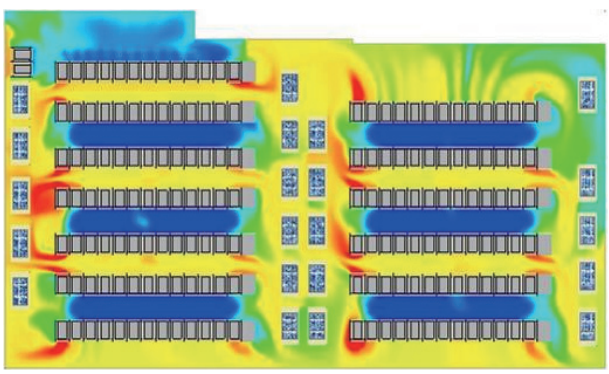

Figure 14
Example of analysis.

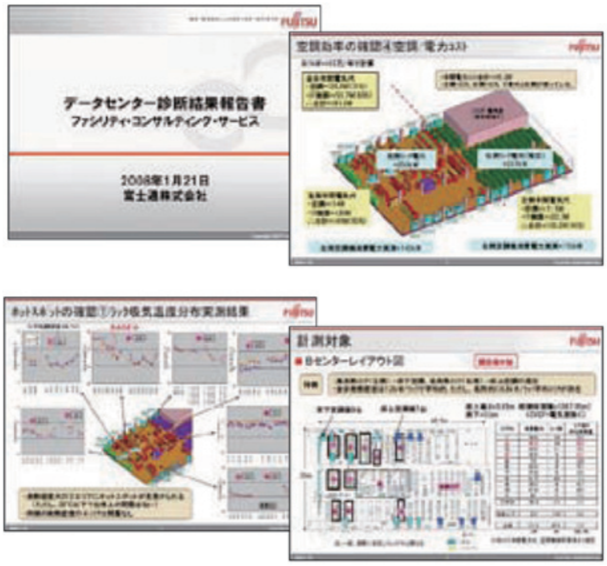

Figure 15
Example of report.

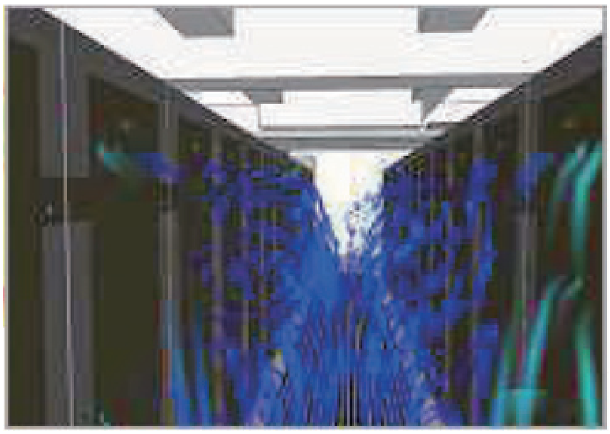

Figure 16
Screenshot of video.

6. Conclusion

Visualizing current conditions through measurements is important for improving cooling efficiency in an air conditioned data center. Important measurement targets are “temperature” for assessing the operational health of IT equipment, “power” for assessing air conditioning efficiency and air conditioning equipment operation, and “airflow” for use as an essential condition in CFD simulations. Predicting measures for improving cooling efficiency based on CFD simulations is also useful, but accuracy must be improved to make CFD simulations even more effective. Accumulating knowledge and experience in modeling and in setting boundary conditions in diverse situations is important for raising accuracy.

Looking to the future, the development of more active cooling efficiency enhancement technology will be needed to prevent heat related problems and reduce the power consumed by air conditioning systems in data centers. In particular, the development of server virtualization technology and super green products is expected to make IT equipment power and airflow fluctuate more dynamically. To accommodate such dynamic operation, we will pursue even greater efficiencies in data center cooling by controlling air conditioning equipment to achieve safe and efficient operation. In this way, we hope to make a genuine contribution to the global environment.

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