AIR-FLOW MODELLING IN DESIGN AND OPERATION OF DATA CENTERS

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ABSTRACT

The main aim of the research was to review common use of air-flow modeling in data center (DC) industry. The paper is based on information found in best-practice publications and gathered from DC practitioners using several different ways of communication. The possible use of air-flow modeling for design and operation of DCs is discussed. Common practice is identified and analyzed in order to assess the importance of the air-flow modeling for design and operation of DCs. The research was motivated by potential use of DC air-flow modeling for the DC integrated management and control platform which is being developed within the scope of the GENiC project.

Keywords: data centers, air-flow modelling, best practice, GENiC control platform

SIMULACE PROUDĚNÍ VZDUCHU PRO DESIGN A PROVOZ DATA CENTER

Hlavním cílem výzkumu bylo získat přehled o využití modelování proudění vzduchu v běžném praxi datových center (DC). Příspěvek je založen na informacích nalezených v odborných publikacích a získaných od DC profesionálů s pomocí několika různých způsobů komunikace. Je diskutováno možné využití modelování proudění vzduchu pro návrh a provoz DC. Běžná praxe je identifikována a analyzována s cílem vyhodnotit nutnost modelování proudění vzduchu pro návrh a provoz DC. Výzkum byl motivován potenciální potřebou modelování proudění vzduchu v DC pro integrovanou řídící platformu, která je vyvíjena v rámci projektu GENiC.

Klíčová slova: data centra, simulace proudění vzduchu, ověřené metody, GENiC řídící platforma

INTRODUCTION

Data centers (DCs) are facilities used to house computational systems and associated components, such as telecommunication devices and data storage systems, HVAC systems, security and safety systems, etc. Large data centers are crucial components of the globalized information technology (IT) infrastructure with high importance, as they shelter many mission critical applications, such as governmental and banking systems, stock transaction systems, mobile communications systems, etc.

DC energy consumption has doubled between 2000 and 2005 and grew by 50 % from 2005 to 2010 consuming 1.5 % of global energy with continued rapid growth [1], [2]. In average DC, computing may consume only 60 % of total energy while cooling consumes 35 % [3]. One of the challenges for DC designers and operators is to maintain a suitable operating environment for IT hardware within the DC, avoiding any downtime, using as little electrical energy as possible for HVAC services. This goal may be met by proper design and operation of DC, providing effective integration between DC control systems and proper air-flow management.

One of the ways how to predict air distribution within the DC and establish the proper air-flow management is computational air-flow modelling. However, it is necessary to review its possible use both for design and operation of DCs and also identify the common practice, in order to assess its importance. This may be done on the basis of information found in the best-practice publications and more importantly, information gathered from DC practitioners.

MOTIVATION

The research was motivated by questions encountered during development of a novel DC management platform GENiC at the Eindhoven University of Technology in the Netherlands.

The goal of the GENiC project is to develop an integrated management and control platform for DC wide optimization of energy consumption by integrating monitoring and control of computation, communication, data storage, cooling, local and renewable power generation, energy storage, and waste heat recovery. The architecture of the control platform will enable the full-fledged automation and interactive decision support for optimizing DC energy efficiency, with particular focus on operational phases of DCs. The goal is to minimize energy use through manipulation of local equipment controller set points and provision of optimized control of computing load and cooling distribution. More information about the GENiC project can be found on the internet [4].

As the development of the GENiC control platform will be supported by a numerical model called Simulators GENiC Component (GC), it was necessary to identify the common practice of DC air-flow modeling and the needs of DC designers and operators, in order to make qualified decisions regarding which method should be used for further work and which issues should be targeted by the Simulators GC. The objective of the Simulators GC is to create a holistic and scalable simulation model of the DC which will provide a virtual response in place of a real system during development of the control platform, as illustrated in Fig. 1. The intention is to test the performance of the GENiC platform before implementation in the real DC and after that provide the virtual system response in order to determine control actions and operational set points during normal GENiC system operation.

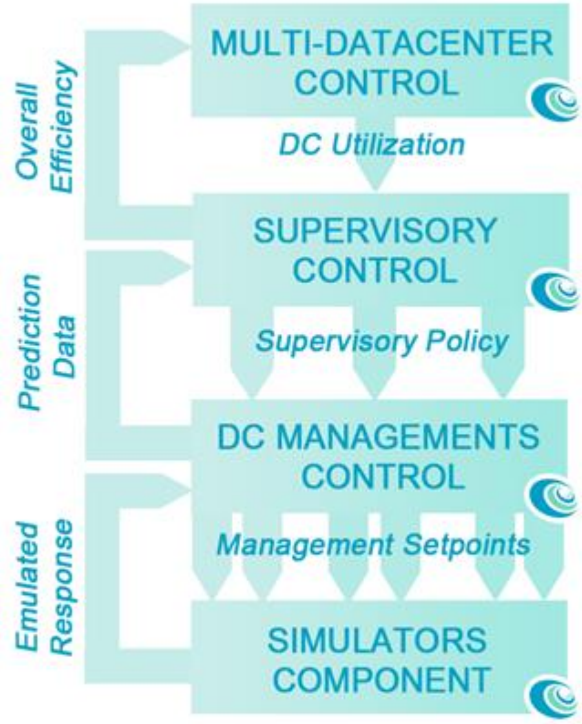

Fig. 1 – GENiC platform work scheme

METHODOLOGY

This study is based on evaluation of information gathered on the basis of:

- **Publications dealing with DC design and operation best-practice.**
- **Discussions with DC design practitioners.** The discussions were targeted generally on the process of DC design, use of any simulation method in general (energy modeling or air-flow modeling at any level of complexity) and on methods of DC operation.
- **Questionnaires filled by DC design practitioners, targeting energy modelling, air-flow modeling and issues related to the GENiC Project.** The questionnaires were targeted on the issues and difficulties encountered during DC design and operation and on use of any simulation method in general (energy modeling or air-flow modeling in any level of complexity). The questionnaire was sent to 65 DC design and operation practitioners.
- **Questionnaires filled by DC design practitioners, targeting air-flow modeling and use of DC Integrated Management systems.** The questions were targeted on the process of DC design and use of any simulation method in general (energy modeling or air-flow modeling in any level of complexity). Design issues targeted by the air-flow modeling were addressed in more detail. Use of DC Integrated Management (DCIM) systems for DC operation was also enquired. The questionnaire was sent to 2 DC design and operation practitioners from the GENiC consortium.
- **Linked-In discussion of DC design practitioners.** The discussion ‚CFD for Data Centers – is it myth or is it real‘ was launched at the LinkedIn network [5].

DC DESIGN AND OPERATION

The goal of the research was to evaluate suitability of common practice air-flow modelling for development and operational support of the GENiC integrated management and control platform, taking into account its specific needs and also uncover the common practice of air-flow modelling use for design an operation of the DCs.

As the best-practice of DC design is well established and documented [6]–[8], it is possible (and not unusual) to approach the design of DCs without the use of any air-flow or energy modelling [9], [10]. However, it has been mentioned by practitioners that simply following the best-practice rules may not be sufficient for optimal design of a DC and achieving low PUE (Power Usage Effectiveness) [11], [12]. Both for the case of the opened and contained design, the distribution of the cold air from the cooling units may not match the IT demand. Incorrect understanding of the air-flow and its poor management can lead to the occurrence of hot spots (undesirable local temperature rise caused by improper cooling of DC equipment) which consequently leads to a greater need of cold air and energy inefficiency or, in extreme cases, to IT equipment failures.

One of the main tasks of the DC designers is to avoid occurrence of the hot spots within the DC, but at the same time keep PUE as low as possible, which ensures energy and financial savings demanded by DC operators. Another driving issue, which is nowadays becoming important, is the effort to promote advanced technology and environmental awareness of the companies designing and operating DCs [12]. Although the over-sizing of HVAC systems is common due to the expectancy of the IT equipment power rise in the future, the systems should be set to deliver only the amount of cold air necessary for the IT equipment which is currently installed. Also the air-flow should be appropriately managed to avoid waste, in order to keep the PUE low.

One of the tools for the air-flow management is Computational Fluid Dynamics (CFD) simulation [6]. It accounts fully for air-flow and its momentum. It may give an insight into cooling performance and identify places where cold air is undersupplied or mixed with hot air by reverse flow, bypass or recirculation (see Fig. 2). Thus the occurrence of the hot spots can be predicted.

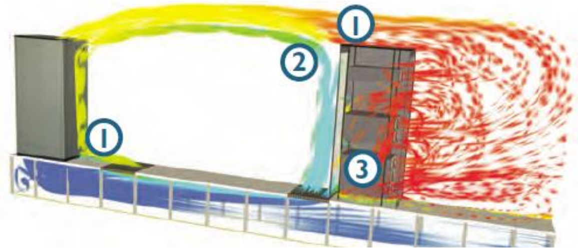

Fig. 2 – Common DC Air-Flow Imperfections [6] *(1 – Reverse flow; 2 – Bypass; 3 – Recirculation)*

CFD SIMULATION FOR DC AIR-FLOW MANAGEMENT

The air-flow modeling simulations can be used by DC practitioners and related professionals (IT hardware manufacturers, HVAC engineers, DC solution architects and consultants etc.) to target the following issues:

Hardware manufacturers

- thermal profile of newly designed equipment

DC designers, DC operators and consultants

- optimal positioning of CRAC (Computer Room Air Conditioning) units
- optimal orientation of racks
- optimal height of raised floor
- impact of structural obstructions and cabling on the air-flow
- testing of failure scenarios
- tracking air-flow changes during operational design management
- trouble-shooting of existing facilities
- graphical support for dealing with customers

When modeling air-flow within a DC facility, there are three different levels of details that can be considered in the CFD model.

These levels will be demonstrated on an example of raised-floor DCs, which are currently the most commonly used for housing high-density IT equipment [7], [13]. The cooling of the DC with the raised floor is achieved by delivery of cold air from CRAC units through the under-floor space (plenum) to the room-level (to the cold aisles). Air consequently circulates through the IT equipment back to the CRAC units. The air is distributed to the room from space under the raised floor by perforated tiles, see Fig. 3.

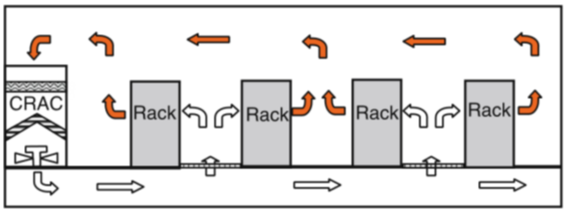

Fig. 3 – Conventional DC arrangement with under-floor plenum [7]

1) Room level – model of DC without plenum.

The model of DC without plenum is a good approximation for evaluating air-flow and thermal performance of facilities with uniform tile flow-raters, or in the cases when the flow rate from the tiles is known (i.e. measured). As the under-floor plenum is not considered, the computational demands are lowered. However, this level of simulation is not appropriate for cases where the tile flow rates are unknown and expected to be highly nonuniform [7].

2) Under-plenum level – model of DC including plenum.

The airflow distribution in the room depends on the flow pattern and pressure distribution in the under-floor plenum. It is a complex function of a large number of variables, including the size of the plenum, the perforation of the tiles, the location of CRAC units and their flow rates, the size and location of the under-floor obstructions like cables, pipes and structural beams, etc. Especially the obstructions impede the cold air streams under the floor, which may result in a poor air distribution through some of the perforated tiles and the occurrence of hot spots above the raised floor. Therefore it may be important to incorporate the under-plenum space into the model of the DC [7].

Although the model of the DC including plenum is more computationally demanding, it may produce results which are more accurate and can help to make better design decisions especially during implementation of the initial design in the real facility [11].

The models of IT equipment and CRAC units are very often simplified in order to save computational time and also time necessary for creating the numerical model of the DC [7], [14].

3) Rack & server level – model of DC including rack and server details.

Models predicting air-flow at rack or even server level may be important for IT equipment designers and engineers, as they can help to set proper thermal management and sufficient cooling of the equipment. However, it has been shown that on the bigger scale, considering the DC as a whole, detailed modeling of air-flow through the IT equipment does not have a significant influence on the results of simulation [15]. For this case, an ASHRAE guideline has been provided explaining how to simplify IT equipment of the DC in a proper way [14] so the detailed modeling of IT equipment is not necessary.

DISCUSSION

The use of air-flow modelling has been confirmed by several practitioners [11], [12], [16], [17]. Although the questions asked were targeted generally to the air-flow modelling at any level of simplification, and also to energy modeling, the responses of the practitioners were aimed mainly to the use of detailed air-flow modeling – CFD.

The use of the simulation was confirmed especially for the preliminary design of DCs and consequently for adapting the preliminary design to the real world situation (such as studying the impact of obstructions on the air-flow in the DC, as they can have a relatively big influence on the actual cold air distribution [11]). The simulations help to achieve better DC design and lead to energy savings. Also the graphical results of the CFD simulations proved to be useful for better communication with customers and other parties cooperating on DC design and operation [12].

The limitation of the CFD simulation use for DC design is the cost of simulation analysis considering the low budget of some projects [11], [12]. Also the complexity of the simulation software and the time necessary for preparing, running and evaluating simulations must be taken into account. Therefore some practitioners approach the DC design solely following best-practice and previous experience [9], [10]. However, the drawbacks of the air-flow modeling (price, complexity, time consumption) are becoming less significant [11]. Some of the available computational programs specialize solely on the DC design and offer drag-and-drop databases of premade models of DC equipment to reduce the work of the users. Also with utilization of DCIM and with better acquisition of measured-data, it is becoming possible to tune up the initial computational models and obtain more reliable results when the model is used for operational DC management and troubleshooting [11].

From the physical point of view, the CFD simulation of the air-flow used for DC design has limitations related to its computational demands. The results from the simulations are usually capturing only one steady-state step in time and do not take in account the changes in thermal conditions within the DC (differences in IT equipment utilization, changes of boundary conditions, unsteady fluctuations of the air-flow in the DC etc.). The simulation is usually used for predicting only a few selected cases or air-flow patterns with a different utilization of IT equipment and/or a different layout of the DC, which are mutually compared to find the best solution [12], [18]. Even after the simplifications, the detailed air-flow simulations are still considered as time-consuming and it is not possible to run them in real time [2]. The continuous simulation of a longer time-period of DC operation has been mentioned by practitioners as a challenge for the future [10], [17].

CONCLUSION

The current use of the CFD simulation has been confirmed solely for the DC design, operational design management (IT equipment changes during the life-time of the DC) and troubleshooting of DCs, i.e. for steady state simulations of one moment in time. None of the addressed DC practitioners mention using (or the need to use) air-flow modelling for the operation of DCs, as a support of the DC control system or for prediction of air-flow future trends within the DC.

The use of detailed air-flow modelling can be advised for primary DC design, secondary DC operational design management and troubleshooting of existing DCs. It can help to establish correct air-flow management within the DC and lead to energy savings. It can also allow for more effective communication with other DC related parties, using its graphical support. However, there is no evidence of the need to simulate the air-flow in the DC in detail for its correct day-by-day operation.

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