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Experimental and numerical analysis of the air management in a data centre in Spain

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ABSTRACT

The total energy demand of data centres has experienced an important increase in the last years. This is why data centres industry and researchers are working on implementing energy efficiency measures in data centre portfolio. The cooling system of these unique infrastructures can account for 40% of the total energy consumption. Therefore, air management plays an important role to reduce operating costs and to increase overall cooling system efficiency. In order to improve and optimize the energy consumption and thermal management in data centres, appropriate metrics are imperative to evaluate their efficiency and performance. The present paper examines the air management of a real data centre by the use of the most promising air metrics. Noticeable air recirculation and hot spots were observed in the facility. Dynamic modelling was used to evaluate the benefit of air inefficiency mitigation. The combination of air management improvement with increasing the supply air temperature and reducing the air flow rate would allow important energy reduction in the cooling system.

1. Introduction

Data centres are continuously growing in size, complexity and energy demand due to the increasing demand for storage, networking and computation. These unique infrastructures run 24 h a day, the 365 days of the year and they are up to 100 times more energy intensive than conventional office buildings. The power consumed by the Information Technology (IT) equipment and the electrical losses of the equipment is converted into heat [1] and therefore reliable thermal management is essential to provide an adequate environment for IT devices. Nowadays, up to 40% of the total energy consumption is attributed to cooling and therefore the development of effective and efficient strategies to reduce cooling demand is required. Recently the data centre industry [1,2] has taken consciousness of the need of the implementation of energy efficiency strategies and the use of renewable energy sources (RES) not only to show their environmental commitment, but also to reduce the operational cost. In that sense, Oró et al. [3] presented a literature review on the implementation of energy efficiency strategies and the integration of RES into data centres portfolio.

The evaluation of the air cooling performance in data centres often focuses on air management which has the objective to keep IT equipment intake conditions within the recommended ranges with the minimum energy consumption, i.e. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [4]. This assessment involves the use of air performance metrics which can increase the opportunity for considerable energy reduction. Therefore they can be used as a tool to quantify air performance, diagnose problems, predict the impact of changes, and to continuously monitor improvements. A number of case studies reveal that the fan energy savings in 70–90% range and chiller energy savings in 15–25% range are achievable with effective air management [5]. Lu et al. [6] evaluated the air management and energy performance of the cooling system of a data centre from Finland. They investigated for that specific facility the possibilities of energy savings (mainly the reduction of the fan speed) and heat reuses for space heating and hot water. Similarly, Lajevardi et al. [7] analyzed a small data centre located in the Gresham City Hall (United States) over a period of six weeks proposing different energy efficiency and thermal management issues. Choo et al. [8] evaluated experimentally and numerically the energy efficiency performance of a medium size data centre at the campus of the University of Maryland (United States). They also assessed energy conservation measures such as eliminating unnecessary Computer Room Air Handling (CRAH) units, increasing the return set point temperature, using of cold aisle containment and implementing free cooling.

To evaluate data centre air management, Computational Fluid Dynamics (CFD) modelling of IT equipment and indoor temperature distribution are required in consideration of air distribution system and IT server's operation requirements. Cho et al. [9]

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incorporated an analytical model for air distribution systems with the fluid dynamic code for thermal fluid analysis of a high heat density data centre. Similarly, Cho and Kim [10] used CFD simulation to evaluate the thermal equipment environment using two performance metrics. Later on, Cho et al. [11] presented a CFD simulation to study the thermal environment in a typical data centre module. They used four performance metrics to analyze the air management system and concluded that the major factor that affects airflow efficiency in the IT server room is the supply air temperature. Even though CFD analysis provides valuable inputs for data centre air management system, they are useless for real time data centre cooling management. Therefore, other simulation tools or techniques are needed to overcome these problems, reaching a compromise between time and cost required by the simulation tool and reliable information. The use of dynamic energy model using TraNsient System Simulation program (TRNSYS) [12] can overcome this problem. Kim et al. [13] studied the feasibility of the integration of a hot water cooling system with a desiccant-assisted evaporative cooling system for data centre air conditioning using TRNSYS. Recently, Depoorter et al. [14] developed a dynamic energy model using TRNSYS to assess the potential of direct air free cooling in the data centre portfolio around Europe.

The aim of this paper is to evaluate the air management and explore the opportunities for improving energy efficiency in cooling in data centres. To do so a real data centre of 115 kW IT located in Barcelona (Spain) is characterized. The manuscript presents a variety of metrics from among the most widely used to quantify data centre efficiency and performance. These metrics are first used to characterize the actual air management efficiency and second used to prove the benefit of the implementation of well-known energy efficiency strategies. In order to study the benefit of air management improvement and the effect of negative pressure, bypass and recirculation ratio in the overall system, a novel dynamic energy model using TRNSYS has been developed. This model has been validated with real experimental data from the data centre. Finally this model is used to predict the energy consumption of the facility with an improved whitespace configuration. Although there are variations in the design and operating parameters of the data centre presented, one can expect many similarities and applicability of the general energy efficiency strategies such as those identified in this case study.

2. Methodology

2.1. Operational requirements

The ASHRAE thermal guidelines [4] define recommended and allowable temperature and humidity ranges for four environmental classes, two of which are applicable to data centres. The recommended envelope defines the limits under which IT equipment would most reliably operate while still achieving reasonably energy efficient data centre operation. However, it is acceptable to operate outside the recommended envelope for short periods of time without risk of affecting the overall IT equipment reliability.

2.2. Air management inefficiencies

The aim of air management is to keep IT equipment intake conditions within the recommended ranges with the minimum energy consumption. The basic air management starts with air supply from the CRAHs units to IT servers, heat removal, and ends with hot air return back to the CRAH units. However, in reality, air streams are affected by different phenomena such as bypass, recirculation and pressure air drop, decreasing cooling efficiency and creating a vicious cycle of rise in local temperature. Fig. 1 shows the three main air inefficiencies present in a data centre which are described below [6]:

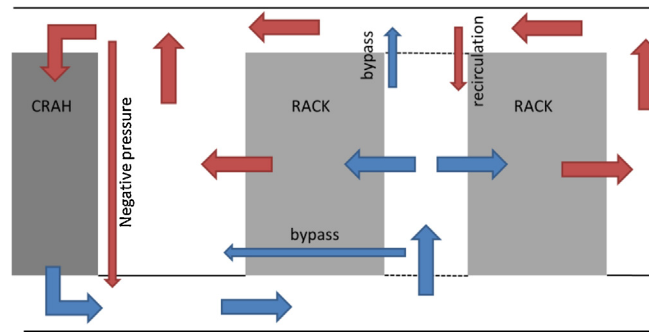

Fig. 1. Air circulation and inefficiencies in an air cooled data centre.

- Bypass air is caused by the air that leaves the CRAH unit and return to it directly without passing through the servers. The causes may be due to an excess of supply air or leakage through cable cut-outs.
- Recirculation air is caused by air that is not sucked by the CRAHs units and mixes again with the cold flow entering the IT equipment. The causes may be due to deficit of supply air. Recirculation air often leads to the rise of the equipment inlet temperature which is considered as one of main reasons for hot spots.
- Negative pressure is caused by the high speed of air and Venturi effect, the static pressure under the tiles becomes negative and some air can be sucked back from the plenum. This phenomenon happens near CRAH units where the air velocities are higher.

2.3. Air and thermal management metrics for data centres

The Smart City Cluster collaboration is formed by eight European projects from the call FP7-SMARTCITIES-2013 and previous FP7 calls: DC4Cities [15], GENiC [16], GreenDataNet [17], GEYSER [18], Dolfin [19], RenewIT [20], CollEmAll and All4Green [21]. It has the objective to define and agree common metrics and methodology to characterize the energy, environmental and economic behaviour of data centres. For this manuscript the outcomes of the Smart City Cluster collaboration have been used, selecting a variety of metrics from among the most widely used have been selected to quantify data centre efficiency and performance [22–24].

2.3.1. Air efficiency metrics

2.3.1.1. Rack cooling index (RCI). The RCI measures the degree to which the IT equipment inside the racks is maintained in the rack intake air temperature range recommended by ASHRAE. Thus, the RCI metric evaluates how effectively an adequate environment is provided for the racks. Over temperatures conditions exist if one or more intake temperatures exceed maximum recommended temperatures. Similarity, under-temperature conditions exist when intake temperatures drop below the minimum recommended. The RCI index thus consists in two metrics, RCI_{HI} (RCI at the high end of the recommended spectrum) and RCI_{LO} (RCI at the low end of the recommended spectrum).

$$RCI_{HI} = \left[1 - \frac{\sum (T_{intake} - T_{max\_rec})T_{intake} > T_{max\_rec}}{(T_{max\_all} - T_{max\_rec})n}\right] \times 100\%$$

$$RCI_{LO} = \left[1 - \frac{\sum (T_{min\_rec} - T_{intake})T_{intake} < T_{min\_rec}}{(T_{min\_rec} - T_{min\_all})n}\right] \times 100\%$$

2.3.1.2. Return temperature index (RTI). RTI assesses the extent to which the air bypasses the IT equipment, as well as the air recirculation in the racks. Therefore, higher deviations from an ideal