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ANALYSIS OF THE AIR CONDITIONING SYSTEM OF A DATA CENTER USING THERMOGRAPHY AND CFD

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Abstract. A data processing center is an ambient designed to allocate servers for data processing and storage, in addition to network asset systems, such as switches and routers. In order to house lots of equipments to process large amounts of data, they are usually organized in racks. These metal structures have a cooling system to keep equipment temperature within a safe operating standard. In this paper, an analysis of the temperatures in the racks and an analysis of the airflow behavior in the room of a data center were performed in order to determine the thermal load of this environment for the correct design of the air conditioning system. The technique of thermography was applied to analyze the temperatures in the racks and the application of the CFD (Computational Fluid Dynamics) tool made possible the evaluation of the airflow in the room and determination of the thermal load dissipated by the equipment. Different values of this variable were inferred and input in the CFD model, to calculate the temperatures in the racks. The behavior of the temperatures was verified so that they were equal to the thermograms obtained by the thermal camera. The process was performed countless times until the convergence and determination of the thermal load of the room.

Keywords: Thermography, CFD, data center.

1. INTRODUCTION

Data centers are rooms designed to house servers and other components such as storage systems and network assets (switches, routers, among others). The primary purpose of a data center is to ensure the availability of equipment that operates with systems critical to an organization's business.

Air conditioning is a critical system in a data center because it is the second system that consumes the biggest energy amount (behind only the data center equipment) and, at the same time, the one responsible for maintaining the ambient temperature favorable to the correct operation of the equipment.

The air conditioning system dedicated to a data center has three main functions, which are described below. The first function is the temperature control. Equipments in a data center become very hot during operation, with the risk of self-shutdown or burning, which can cause an unplanned shutdown and disruption of the services they provide. Such heat dissipation may lead to ambient temperatures of up to 50°C in a data center, while the ideal operating temperature is 25°C. Thus, to keep the temperature lower and stable, it is necessary to use specific air conditioning machines.

The second function is air quality control. To ensure the purity of the air inside the data center, it is necessary to eliminate solid particles and contaminants present in it. The presence of dust, in the long term, can impair the system operation and cause equipment stops. Therefore, cleaning the air inside the room is necessary, what makes plausible to install filtering systems in the air conditioning units.

The third and last function is the air humidity control. Electronic equipment is very sensitive to air humidity. When it lowers, it can originate electrostatic charges along the electronic components that, eventually, can cause short circuit and, consequently, burn the components. Since the high humidity of the air can cause condensation of water in the components and by the same electrical principle, a short circuit can occur. In addition, bacteria proliferate at both extremes of air humidity conditions, so relative humidity needs to be maintained around 50%.

Because air conditioning equipment consumes a significant portion of the energy required in a data center, special care must be taken during the design of the refrigeration system for global energetic optimization. There are several cooling techniques that should be adopted during the design of any data center to promote energetic efficiency. Among them, the positioning of the air conditioning outputs closest to the most heat-generating equipment (servers) to avoid the accumulation of thermal energy with the air movement, the use of free cooling, which uses external air to cool internally, optimizing the consumption of electric energy, the use of chilled water systems (chillers) and hot or cold confinement of the corridors.

The climate control system of a data center is little noticed when it works correctly. However, when it becomes inefficient numerous problems can appear, among them the most tragic, that is the interruption of service. With a careful and well-done design that takes into account these and the other technical variables, it is possible to guarantee an internal atmosphere conducive to the operation of all the equipment and, consequently, the continuous operation of the data center.

It is not an easy task to determine the dissipated power of each equipment or the behavior of the airflow in the room that houses a data center so that the good cooling and consequent operation of the equipment can be guaranteed. With all of the above, this article proposes the measurement of the equipment temperatures in a data center room using the thermographic technique and the analysis of the air flow behavior and determination of the thermal load required in the room using a CFD model.

2. TERMOGRAPHY AND MATHEMATICAL MODEL OF THERMAL CAMERA

Thermography is a non-contact measurement technique of the temperature field of a surface, through an image generated by the infrared thermal radiation emitted by the surface of the objects. It allows the observation of stopped or moving objects (Chrzanowski, 2010). It is currently used to define the non-destructive thermal test. In this regard, thermography stands out as one of the most important techniques in the diagnosis of anomalies in electrical devices. With thermography, it is possible to measure the surface temperature of components without physical contact with the installation (safety), check equipment in full operation (without interference in production) and inspect large surfaces in a short time (high efficiency), identifying successfully points of failure in electricity distribution systems (Teixeira, 2012).

The infrared radiation emitted by an object travels a given distance until it is captured by the array of thermal sensors of the thermal imager. In addition to emitting radiation, the object of interest may also reflect part of the radiation coming from other nearby sources, or even the Sun. Figure 1 illustrates this scenario for non-contact temperature measurement of an object of emissivity ε and temperature T_{ob}, positioned at distance d from a thermal imager.
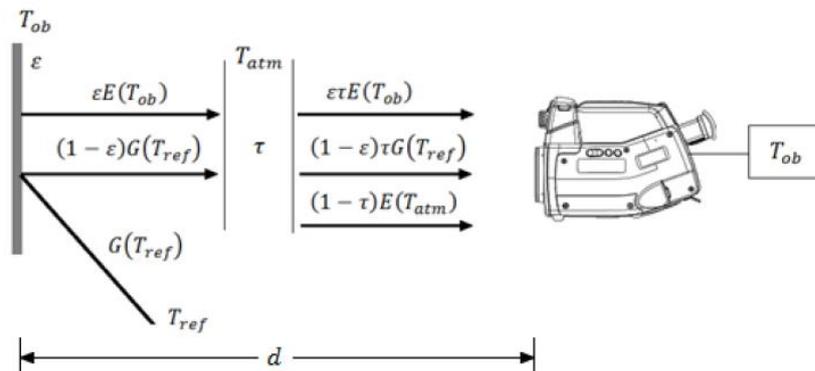

Figure 1. Mathematical model of measurement. Source: Teixeira (2012).

Where, $\varepsilon\tau E(T_{ob})$ is the radiation flux emitted by the object of emissivity ε, at the temperature T_{ob} and attenuated by the atmospheric transmissivity τ. The portion $(1-\varepsilon)\tau G(T_{ref})$ refers to the reflected irradiance on the object of reflectivity $(1-\varepsilon)$, originating from a heat source at T_{ref} temperature and attenuated by atmospheric transmissivity τ. Finally, the plot $(1-\tau)E(T_{atm})$ is the atmospheric emission of emissivity $(1-\tau)$ and temperature T_{atm}. Thus, the total radiation flux G received by the thermal imager is given by Eq. (1).

$$G = \varepsilon\tau E(T_{ob}) + (1\text{-}\varepsilon)\tau G(T_{ref}) + (1\text{-}\tau)E(T_{atm}) \tag{1}$$

When operating a thermal imager, one needs to be aware of certain important adjustment parameters. The focus of the image and the point of interest, the considerations regarding the radiation reflected from other sources and the radiation absorbed by the atmosphere. The method chosen (active or passive) for analysis is also relevant. In addition, it is important to select the thermal imager that will best meet the measurement objectives, considering the temperatures range to be measured and the resolution required (Chrzanowski, 2001).

There are some limitations in the use of thermography to evaluate temperature of objects (Araújo et al., 2008). The thermography operator or inspector is decisive in interpreting the results. This can vary with training, motivation and even with the visual ability of the inspector. The thermography inspector must know the operation of the equipment under inspection as well as the operation and the characteristics of the thermal camera used. Apart from that, knowing the basic theory that involves infrared radiation and the principles of heat transfer is of extreme importance (Host, 2000). For consistent results, the inspector must be qualified for inspection, have adequate training and knowledge so that he can be able to discern between a real defect and a false anomaly which, if avoided, can save thousands of dollars in unnecessary downtime and maintenance.

The selection of equipment is a crucial factor for achieving good results. For that, the following characteristics should be observed in your choice:

- Temperatures range: It should be suitable for the application. In the case of electrical systems, there is hardly a need to exceed 500°C;
- Spectral response: The wavelength ranges most used for the manufacture of thermal cameras are from 2 to 5.6 μm and from 8 to 14 μm;
- Spatial resolution: Defines the smallest image detail that can be perceived. It is a function of detector size and system optics (Snell and Renowden, 2000);
- Measure Resolution: Defines the smallest object that can have its temperature measured accurately at a given distance. This parameter can have great influence in the analysis of the severity of a defect;
- Equipment weight: Very heavy equipment influences the handling and consequently the inspection quality, as well as increasing the inspector's fatigue and limiting the duration of the inspection.

The radiation received by the thermal imager produces an electrical signal proportional to it, and the signals S_{ob}, S_{ref} e S_{atm} are proportional to the radiation emitted by the object, by the environment and by the atmosphere, respectively. Thus, the signal S is given by Eq. (2).

$$S = \varepsilon\tau S_{ob} + (1\text{-}\varepsilon)\tau S_{ref} + (1\text{-}\tau)S_{atm} \tag{2}$$

Then, the signal proportional to the object emission is given by Eq. (3).

$$S_{ob} = \frac{S}{\varepsilon\tau} - \left[\frac{(1\text{-}\varepsilon)}{\varepsilon} S_{ref} + \frac{(1\text{-}\tau)}{\varepsilon\tau} S_{atm} \right] \tag{3}$$

3. COMPUTATIONAL FLUID DYNAMICS (CFD)

The flows of gases or liquids are governed by partial differential equations that represent laws of mass conservation, movement and energy of a fluid (Versteeg; Malalasekera, 2007). Computational Fluid Dynamics (CFD) is a computational tool that uses a series of algebraic equations that can be solved by software, making a numerical simulation of the fluid dynamics, taking into account all data that involves the project, such as temperature , pressure, type of fluid, geometry and physical limits of the environment, contact surfaces, etc. With the results obtained through the CFD, it is possible to validate experimental results and give more certainty to measurements. When variables calculated by CFD analysis cannot be measured, CFD can also have the main role in an optimization, sizing or components selection process.

The work of Wang et al. (2015), which presents the application of CDF in the simulation of the ventilation system of a refrigerator, can be used as an example. In this work, the impacts of the cold air passage holes, cooling chamber and, consequently, their respective characteristics, such as temperature, direction and speed are evaluated. With the CDF, it is possible to obtain the cooling times of the system in each phase, that is, from room temperature to working temperature, and during on-off phase to maintain temperature stability. With the thermal simulation in software, the practical experiments were reduced, reducing the costs and time of the air conditioning system design.

Currently, CFD analysis is used in various situations, as to calculate the aerodynamics of airplanes and cars, to foresee the operation of hydraulic turbines, in weather forecasting, in civil construction, in wind power plants, in open or closed cooling systems, etc.

4. METHODOLOGY

Having as main objective the determination of the thermal load of the room, it is necessary to obtain the dissipated power of each rack. For this, the thermograms were obtained from the front and back of each rack. Due to the short corridor space and consequent low field of view of the thermal imager, obtaining the thermograms was accomplished by dividing the racks into three regions, bottom, center and top.

Air temperatures and velocities were collected in all room environments, especially the air flowing through each rack, to verify how much power the current air conditioning system removes from each one.

For each corridor the information of ambient temperature, air humidity and reflected temperature were recorded. The thermographic inspection was done with the racks open, at the front and back.

The thermo-hygro-anemometer was used to measure the ambient temperature, relative humidity and air speed. To evaluate the reflected temperature, it was used a plate coated with aluminum foil, with dimensions of 10 cm x 15 cm, and the thermal camera, considering the emissivity equal to 1.

To perform the inspection, the following equipment was used: FLIR i60 thermal imager, with uncertainty of $\pm$ 2%; thermo-hygro-anemometer EXTECH 45170; aluminum foil assembly; digital camera.

A laser thermometer was used for comparison with the values obtained and for calibration of the camera. Temperature measurements were performed and the emissivity value adjusted to an approximate value as observed in the thermometer.

Thus, the entire environment was simulated in stationary state in the CFD software. Inputs were the air temperature and speed, airflow rate from the air conditioner and geometry of the racks and room. A hybrid mesh (hexahedral and tetrahedral) was adopted in CFD analysis, with 25,778 nodes and 115,210 elements.

The power dissipated by the equipments was estimated. At each value of power inferred, the temperatures in the racks resultant of the simulation were compared to the obtained thermograms. The process was performed countless times until convergence.

After the temperature equaled, it was found that the dissipated power inferred was correct. Besides the temperature, the CFD also had the direction of the air flow as a function of the flows of each corridor.

4.1 Determination of emissivities

The Racks are made of metal coated with black paint. To evaluate the emissivity of this surface, a strip of tape was nailed to the rack and the comparative method was used. After thermal equilibrium was achieved between the tape and the rack, the temperature of the surface covered with tape was measured, whose emissivity is considered 0.95. Then, the rack surface next to the tape was measured and, with the help of the thermal imager, the emissivity of the rack surface was evaluated. It was then considered that the tape and the rack surface had similar values of emissivity.

Considering that the tape region and the neighboring region are in thermal equilibrium, it is possible to say that the signals received by the camera in these two regions are the same. Matching the signal equation for the two regions, the emissivity of the rack can be calculated by Eq. (4).

$$\varepsilon_{rack} = \varepsilon_{tape} \frac{T_{rack}^4 - T_{amb}^4}{T_{tape}^4 - T_{amb}^4} \tag{4}$$

Using FLIR Tools, one can extract the average region temperature of the tape and the rack. Since the emissivity of the tape is known, the emissivity of the equipment can be determined.

Some racks have equipment with casings containing uncoated metal material and other plastic materials. In these cases, an emissivity between $\varepsilon = 0.70$ and $\varepsilon = 0.85$ was used, according to the proportion of metallic material. Figure 2 illustrates the types of racks.

Figure 2. Rack types.

In a data center, the air conditioning system is a down-flow type, that is, the discharge of cold air is performed under the floor, near the bases of the racks and the return of the air is given above. Figure 3 illustrates the system and Fig. 4 shows the perforated plates where cold air is distributed in the hallways of the room.
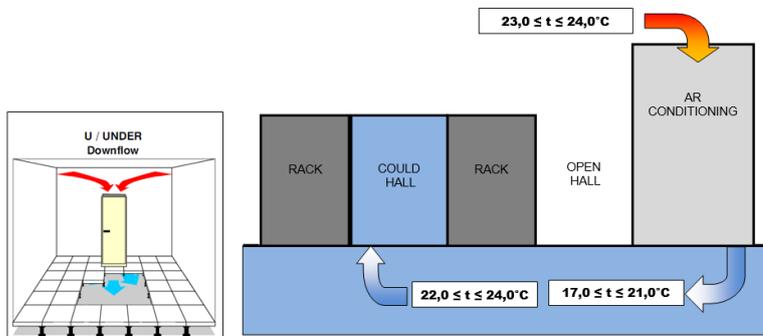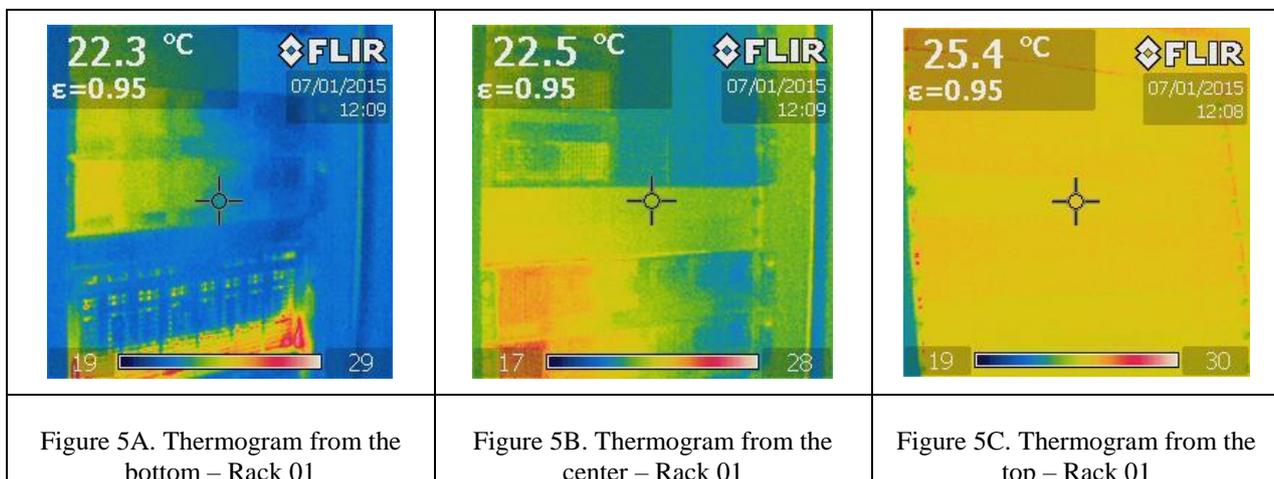

Figure 3. Air conditioning system.   Figure 4. Perforated floor.

5. RESULTS

According to the thermograms obtained by the thermal imager shown in Fig. 5, the CFD simulation shown in Fig. 6 and the values of Tab. 1, it can be noted the temperatures in the racks 01 and 09 obtained by the thermocouple are identical to the temperatures obtained by CFD. It is observed that the temperature recorded in CFD simulations was an output data, obtained through the dissipation of power. Satisfactory and consistent results are then shown.

Temperatures at the bottom of the rack are lower than in other regions because cold air discharge is being carried out by the floor in the perforated plates. The images obtained by the CFD demonstrate that the racks are influenced by the temperatures of the neighboring racks. This is also observed in the thermograms.
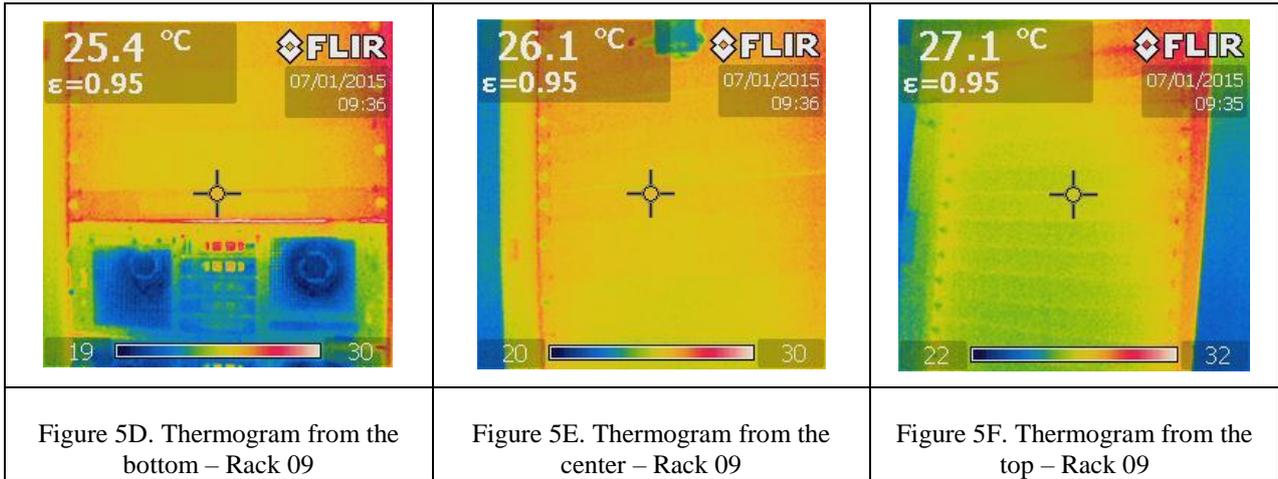

Figure 5A. Thermogram from the bottom – Rack 01	Figure 5B. Thermogram from the center – Rack 01	Figure 5C. Thermogram from the top – Rack 01

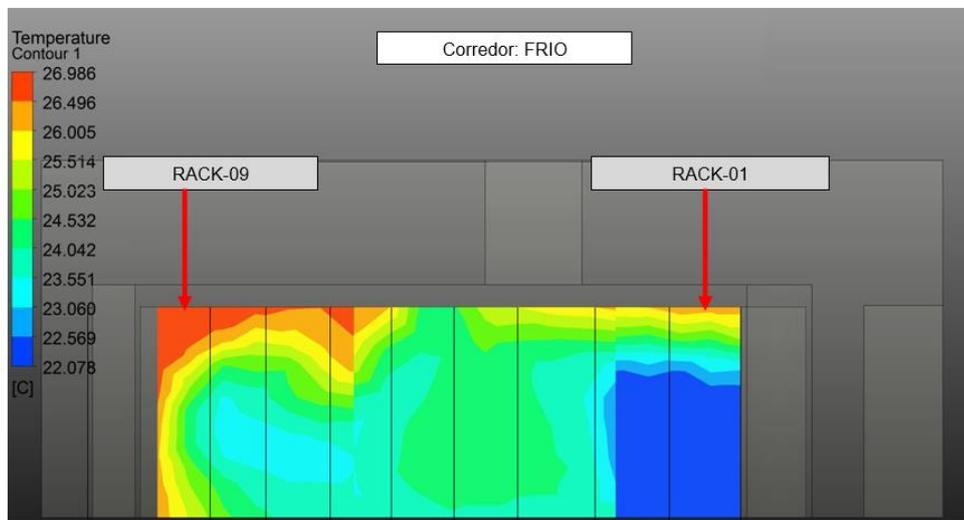|		
Figure 5D. Thermogram from the bottom – Rack 09	Figure 5E. Thermogram from the center – Rack 09	Figure 5F. Thermogram from the top – Rack 09

Figure 6. Boundary temperatures obtained by CFD.

Table 1. Boundary temperatures of Rack 01.

Analysis	Rack	Average temperature (ºC)		
		Bottom	Center	Top
Thermogram	1	22.9	22.5	25.4
CFD	1	22	22.5	25.4
Thermogram	9	25.4	26.1	27.1
CFD	9	24.5	25.5	26.5

Figure 7 presents the analysis of air flow through the room via CFD, demonstrating the air velocity in the suction of the air conditioner and the distribution of the room.

The air velocity in the suction of the air conditioning (upper part) is higher than in other regions. This is because the load loss is low relative to other areas. As air circulates around the room, the loss increases due to obstructions resulting in lower air velocity.
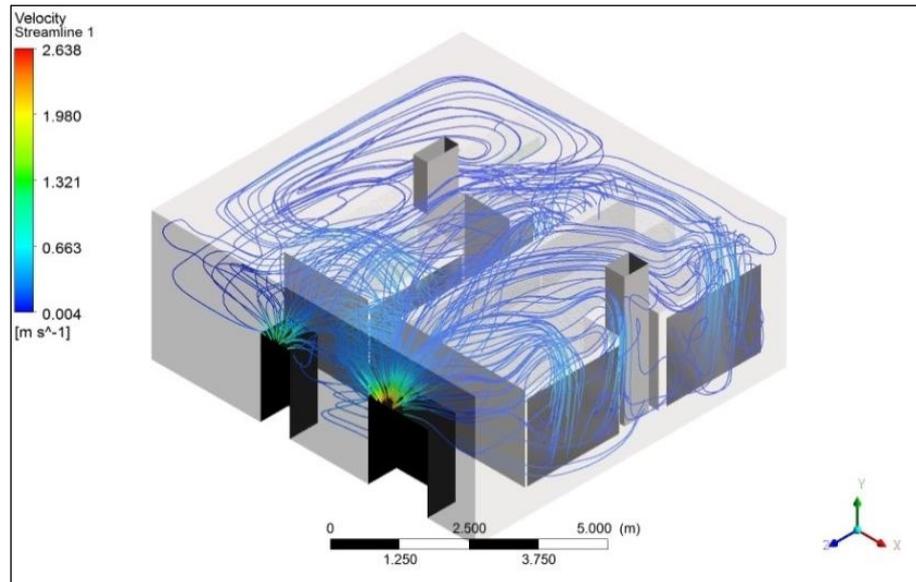
Figure 7. CFD – Air flow lines.

6. CONCLUSION

It is not an easy task to determine the dissipated power of equipment, especially when there are electrical and electronic components dissipating energy. In this article, the use of the thermography technique (non-contact measurement) proved to be quite efficient, what can be proved by the temperature values obtained by CFD analysis.

Generally, dissipated power values are estimated, based on tables and other methods of established references, but in this study, the dissipated power data were calculated based in real temperature data. From the direct application of these data in the air conditioning sizing and selection, it is possible to affirm and conclude that non-contact measurement technique using thermography should be widely used in order to reduce working time and ensure reliability to the design of such systems.

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