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Energy performance analysis between two air conditioning systems used in an educational Building in warm-climate

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Energy performance analysis between two air conditioning systems used in an educational Building in warm-climate

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Abstract. Energy saving measures, in the design air conditioning systems, are crucial in the development of energy schemes with rational energy consumption. Traditionally, integrated buildings systems have been assessed individually to optimize the energy performance, however they have different parameters that affect energy performance that demands the use of detailed analysis using dynamic simulation. This paper is focused on compare an air conditioning system to be implemented in educational buildings in warm-climate, considering energy schemes provide for a constant air volume (CAV) flow system with a water chiller, while the other integrates a variable refrigerant flow (VRF) system. Adding in each case dedicated outdoor air System (DOAS) units. Energy consumption achieved by each AC system is obtained considering the configuration achieving energy savings of 40% of the annual electricity demand for cooling. Finally, the use of DOAS represents an increase of 20% of total electricity consumption.

Keywords: constant air volume; variable refrigerant flow; outdoor air System; energy efficiency.

1. Introduction

According to the Energy Information Administration (EIA), estimations, energy consumption will increase approximately in 56% in all regions during the following three decades, however this percentage is led by residential and commercial sector with 51 %, industry with 47%, and transportation with a 2 % [1]. It is expected that in dynamic regions energy consumption will falls in relation to final energy consumption related with emerging economies, due to population growth, lives standard improvement such as countries located in South-East Asia and Latin America region. Otherwise, Colombia posts an annual and sustained growth of 3.7% of electric consumption, being the commercial and public services, the fastest-growing sector (5.6%) [2], which is characterized for the high energy consumption of heating, ventilation and air conditioning (HVAC) systems, which is approximately between 40% to 60% of the total electricity consumption of buildings [3,4].

The HVAC systems have been identified as one of the largest energy consumers in developed countries, it is necessary to know the energy efficiency requirements of these equipment, which can be classified into: minimum efficiency of equipment, fluid distribution systems, HVAC control, ventilation, heat recovery and free cooling [5]. As a result of this behavior, mature economies have developed programs that have allowed the establishment of good practices in the construction sector, without compromising the comfort conditions. These good practices require verification through a detailed analysis of factors that affect the final consumption of energy in a building [6–9].

The method used for this analysis corresponds to the application of the heat transfer function, developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), that allows to calculate with precision the profiles of energy consumption of all the components which integrate the building such as: climate, location, loads, occupation profiles, construction characteristics, end-use technologies and variations in the configurations of the integrated systems [10,11].

These models require the use of computational tools due to their level of complexity since it considers the interaction of all the components of the building with the dynamic flows derived from the climate and levels of occupation. Therefore, this type of analysis contemplates a holistic approach based on dynamic simulation, which is precise and efficient because it allows to quantify the impact of important factors in the energy consumption that can have the components of the buildings [12]. For an accurate simulation, four factors that play a vital role in the energy consumption of a building are taken into account: (a) physical properties such as location, orientation and materials, (b) equipment installed to search internal comfort conditions, C) external environmental conditions, such as temperature, humidity, solar radiation, among others, and (d) the behavior of its occupants such as their schedules, activities and ways of using energy [13].

The literature reports the evaluation of savings measures focussed on improve the quality of the enclosure by limiting the thermal transmittance of the envelope in a dynamic regime [14]. Results showed that the surround with superior quality can reduce the energy consumption by approximately 35% [15]. Likewise, the incidence of ten constructive parameters in final energy consumption in commercial buildings in fourteen cities in Brazil was evaluated in [16]. In 2009 a comparative analysis was developed between variable air volume (VAV) and variable refrigerant volume (VRF) technologies in an existing office building [17]. These highlights the energy advantages that the VRF system can achieve, compared to the VAV system, which variates from 32.3% to 37% for the primary system and from 81.4% to 83.4% for the secondary system. In 2010, various energy saving measures combining construction alternatives, internal loads, and low-and high-efficiency air conditioning systems applied to a medium-sized non-residential building were studied in [7].

In 2013, it was characterized the energy performance of different systems and configurations of air conditioning systems in an existing educational building through using computational tools [18]. The results show a reduction in the energy consumption of auxiliary equipment from 15 to 35% and from 5 to 15% of the total energy consumption of the building when a VAV system is used versus a VRF. Likewise, it was demonstrated that the use of heat to recover and economize in the proposed air conditioning schemes, reducing the final energy consumption based on the refrigeration concept between 33 and 65% respectively.

Also, in 2017 an energy consumption comparison between air conditioning system Mini-Split and VRF in an educational building was realized in Barranquilla city (Colombia), obtaining a 30% of energy savings after the replacement of the air conditioning system technology. A 26% of savings were obtained as energy consume reduction [19].

Likewise, the comparative advantages of the three typical configurations for water chillers are described in [20]. Similarly, the strategies in the configuration in the design of chillers have demonstrated potential savings of approximately 10% in subtropical climates [21,22]. Where, the cooling load profiles of the buildings have been simulated using detailed analysis tools, allowing in this way to establish strategies in the design of these technologies. Also, the use of DOAS mixed with cooling has been studied its energy behavior for different climatic conditions. The results showed increases in energy efficiency between 10 and 40% depending on the climate [23-26].

2. Materials and methods.

This study is focused on the analysis of variable refrigerant volume (VRF) and chiller technologies, in the configurations of each of the systems contemplating the energy efficiency. The methodology used makes it possible to verify in detail the influence of the installation of a dedicated aerial unit (DOAS), construction parameters, internal loads, among others, in the energetic demand that reaches by the air conditioning system for a typical year of operation. The computational tool for the detailed analysis considered dynamic simulation using Energy Plus V.8.4 (E +), which provides excellent reference points in the modelling of energy demand in buildings and mechanical equipment that admit the detailed configuration of the system of generation, transportation and final distribution; The modelling of the educational building of the University was carried out to simulate the energy performance of the technological variants as viable alternatives to cover the energy needs that the building can demand to achieve thermal comfort.

2.1 Building Characteristics

The simulated building has a total area of 2.695 m^2 spread over eight floors. Between the second and the seventh floor the building's characteristics do not change, a zone multiplier factor was used, so that in the graphic representation of the building only 4 of the 8 floors are shown. The height of the ground floor is 5 m, plus a plenum of 1.2 m in height. The long wide ratio is approximately 1.4 m, with glazing proportions regarding the envelope of 6.7%, the building is intended for classrooms, offices and two auditoriums as is shown in **¡Error! No se encuentra el origen de la referencia..**

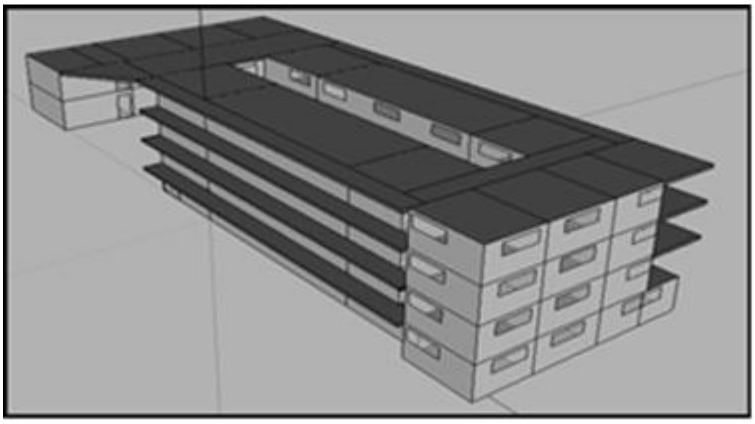

Figure 1. Educational building 3D view.

During the different simulations, the specific characteristics of the building envelope and of internal loads were kept constant. In Table 1, the characteristics of the the building are listed.

Table 1 Characteristics of base building envelope model.

Item	**Material**	**Value**	**Unit**	**Property**
Walls	Brick	150	mm	Case 1
Glazing	Standard clear glass	8	mm	Case 2
Heat Transfer	---	3.56	W/m^2K	Case 3

The typical work schedules of the building were considered, usually in the full operation from 7:00 am to 10:00 pm with slight variations between 12:30 pm to 2:00 pm. for a load level of 80% [5]. The operating levels for lighting and electrical equipment correspond to 100% during the working day, and for the rest of the time, it remains with a load of 20%. The internal charge levels for electrical equipment and illumination correspond to 10 and 12 W/m^2 respectively.

2.2 Air conditioning system specifications

The installed air conditioning system is a Chiller with a Screw compressor (COP 3) condensed by water. The configuration is based on VRF. Figure 2 describes HVAC operation scheme. Also, it can be observed a pump control flow and a bypass valve [19].

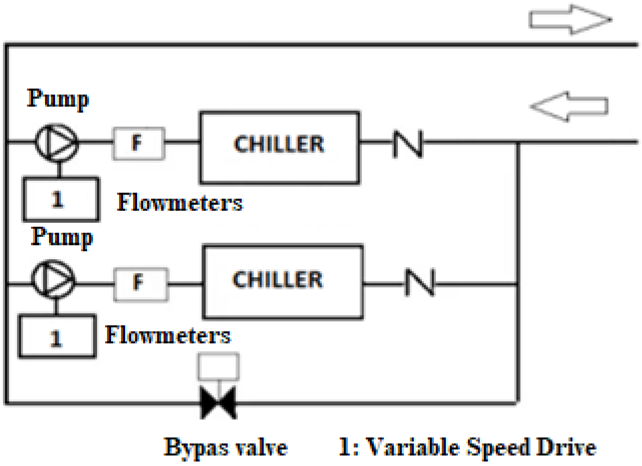

Figure 2. Configuration of the air conditioning system of the educational building.

2.3 Simulation model

The first simulated air-conditioning scheme corresponds to a constant air system (CAV), considering in some cases air units (DOAS) and forty-one Fan Coil type terminal units for the same number of air-conditioned zones. The cold production system corresponds to a water condensing chiller and an average performance coefficient (COP) of 3.0 and a screw type compressor. The temperature of the water was set at 7 ° C and return 12 ° C. The thermostat control is independent in each zone at 25 °C.

Also, the second technological variant analyzed for the building under study corresponds to a variable refrigerant volume system (VRF), capable of providing air to multiple zones. This was configured to operate at a drive temperature of approximately 14 ° C, equally, this type of system was simulated considering the use of dedicated air units (DOAS) in many scenarios. The average yield coefficient (COP) is 3.3. The system has a master control for the 41 climate zones. The technological characteristics of simulated air conditioning systems are shown in table 2.

Table 2. Air conditioning system specifications and configurations.

Features/Components	Description
Air Conditioning System	Constant air volume (CAV), with and without dedicated air units (DOAS) with 41 Fan Coil for an equal number of air-conditioned zones. Chiller with an average performance coefficient (COP) of 3.0 and compressor type Screw. Variable coolant volume (VRF), with and without dedicated air units (DOAS) with 41 direct expansion terminal units and 5 air condensing units, with an average efficiency coefficient (COP) of 3.3.
Thermostat	25°C
Ventilation Airflow	10 / person

3. Results.

Figure 3 shows the percentage distribution of the electrical demands for end-use equipment of the electric energy integrated into the educational building. This shows the significant impact of air conditioning systems on final energy consumption with a 49% for VRF and 64% for CAV, with an increase in energy consumption with the addition of DOAS of 5% and 7% respectively. The impact of these systems is not only due to the climatic severity but also as a product of the great internal load generated in the interior.

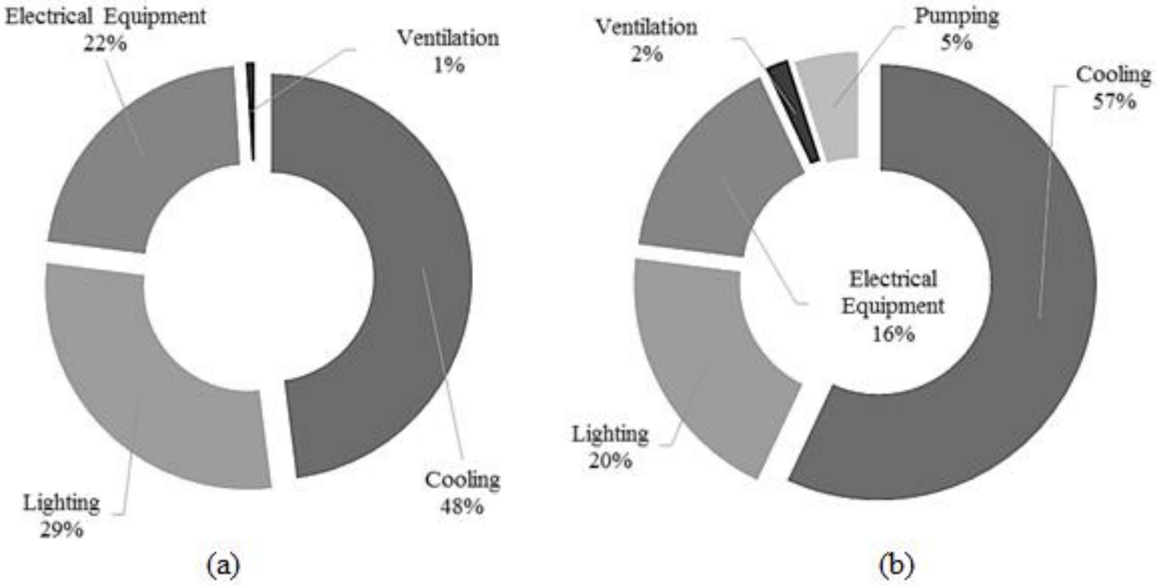

Figure 3. Distribution of energy final consumption in the education building. a) VRF b) CAV

For its part, Table 3 shows the energy impact derived from the scenarios of the four technological variants of the air-conditioning system. It stands out for its high performance the behaviour of the air conditioning system configured with the VRF technology, it shows a reduction of 40% in the electric consumption by refrigeration.

Table 3. Consumption of electrical energy per system or subsystem in the educational building.

System and Subsystem	VRF	VRF-DOAS	CAV	CAV-DOAS
Refrigeration	335016.88	422066.39	560990.25	675212.74
Lighting	197762.74	197762.74	197762.74	197762.74
Electrical Equipment	152557.57	152557.57	152557.57	152557.57
ventilation	9682.46	41454.58	16905.75	37261.57
Pumping	0	0	48758.3	68090.15
Total	695019.65	813841.28	976974.61	1130884.77

Likewise, the total electric energy impact of the VRF system compared to the system configured in VAC mode is 30%. On the other hand, the employment impact of dedicated air units (DOAS) represents an approximate increase of 20% for the two technologies analysed. The advantage of the VRF system lies in the possibility that present of this technology, in the adjustment of the system load to the instantaneous thermal demand.

4. Conclusion

The results showed the potential reduction of 30% in total electricity consumption when the air conditioning system is configured with VRF technology. This is due to the master control system present in this technology used, thus achieving the adjustment of the load of the system of generation of cold to the thermal demands of the zones for a greater diversity. It should be noted that although the total electric energy consumption is increased by approximately 20% when the dedicated air units

(DOAS) are added for both technologies, these are guarantees for compliance with minimum air requirements per standard, and humidity control in each room.

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