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Experimental analysis of performance, greenhouse gas emissions and economic parameters for two cooling systems in a public administration building

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ABSTRACT

More than a quarter of the non-residential buildings in Europe are public buildings and their energy consumption is forty percent higher than that of residential buildings. Therefore, promoting a public policy to increase energy efficiency of the HVAC systems in public buildings will have a significant impact in reducing global energy consumption.

In order to have a precise estimation of the impact of the substitution of the HVAC systems in a large number of public buildings, it is essential to have accurate data of the performance of these systems in specific buildings, beyond the technical specifications stated by the manufacturers. In this paper the substitution of the wide-spread, conventional air-condensed chiller (ACC) for a water-condensed chiller (WCC) with a dry-adiabatic cooler in a public administration building is analyzed in terms of energy efficiency, economic return of the required investment and environmental implications. The influence of external factors as well as the load effect are quantified. The results show that the seasonal Energy Efficiency Ratio of the WCC is near twice that of the ACC, making the replacement of the ACC for the WCC an interesting option. The results obtained in this study could be extrapolated to other non-residential public buildings.

1. Introduction

Buildings are central to the European Union energy efficiency policy, as nearly 40% of final energy consumption and 36% of greenhouse gas emissions are associated with houses, offices, shops and other buildings [1,2]. Especially important is the intensification of energy consumption in heating, ventilation, and air conditioning systems (HVAC), the largest energy end-use both in the residential and non-residential sectors [3]. In recent years, a significant increase in the use of air conditioning for cooling purposes, especially in southern European countries, is moving the energy peak demand from winter to summer. Thus, the improvement of the energy efficiency of the cooling systems in buildings is crucial to achieve the EU's 2020 climate-change and energy targets: reduction of greenhouse gas emissions by 20% with respect to those of 1990, 20% of energy from renewables, and a 20% increase in energy efficiency [4].

Even more, improving the energy performance of the HVAC systems of public buildings is crucial, not only to achieve the 2020 targets but also to meet the longer term objectives of the climate strategy as laid down in the low carbon economy roadmap 2050, when Europe aims at drastic greenhouse gas emission reductions in the building sector of 88–91% compared to 1990.

The most commonly used systems to produce chilled water for cooling purposes in buildings, both in the residential and non-residential sectors, are the vapor-compression refrigeration systems. The condenser performance is one of the most important factors to improve the efficiency of these refrigeration systems [5]. Regarding the medium used to reject the heat in the condenser of the vapor-compression refrigeration cycle we can consider two main cooling systems: air-condensed chillers and water-condensed chillers. It is well known that water-condensed chillers are significantly more efficient than air-condensed chillers [6]. Most of the air conditioning systems in the HVAC installations of big tertiary buildings in Spain in the 80s and 90s used water-condensed chillers with open cooling towers. However, in recent years, the air-condensed chillers have increased their presence in the HVAC market, mainly due to the problems associated with legionella in the cooling towers of water-condensed chillers.

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Legionella are bacteria that live in water or in the dirt in wet parts of some machines. These bacteria are inactive under 20 °C but become active between 20 °C and 40 °C, which is the usual working temperature range of the water-condensed systems. These bacteria are extremely dangerous for human health when breathed in aerosol form. There are different methods to avoid these bacteria: chemicals, cleaning the parts of the machine where they grow, not releasing aerosols to the atmosphere, etc.

To avoid the legionella risk in water-condensed chiller systems, the technology to cool down the water used to reject the heat from the condenser has evolved from the open-circuit cooling towers to other systems [5,7–9]. One of the most efficient systems is the so-called dry and adiabatic fluid cooler. The principal advantage of this system is the practical absence of water droplets in the air, so with a regular maintenance program, the legionella risk is very low [10].

In this paper, a water-condensed chiller (WCC) with a dry-adiabatic cooler is compared to a conventional air-condensed chiller (ACC) in terms of energy efficiency, reduction of greenhouse gas emissions and economic parameters. Both chillers form part of the HVAC system of a singular governmental building in Spain, so the comparison is made under actual working conditions, and the results could be extrapolated to other big buildings of the tertiary sector, such as administration buildings, hospitals, hotels, etc. It is worth noting that the energy consumption of non-residential buildings is 40% higher than residential buildings, and 30% of non-residential buildings in Europe are public buildings.

2. Methods

More than a quarter of the non-residential buildings in Europe are public buildings. Energy consumption of these public buildings, as for the rest of non-residential buildings, is forty percent higher than energy consumption in residential buildings. Therefore, promoting a public policy to increase energy efficiency of the heating, ventilation, and air conditioning systems in public buildings will have a significant impact in reducing global energy consumption, reducing as well the energy dependency from foreign countries and the greenhouse gas emissions at a regional level. The alternatives to increase energy efficiency of HVAC systems in public buildings are manifold. In this paper, we analyze a very simple alternative as is the substitution of the wide-spread, conventional air-condensed chiller (ACC) for a water-condensed chiller (WCC) with a dry-adiabatic cooler. The comparison is made in terms of energy efficiency, economic return of the required investment and environmental implications.

In order to have a precise estimation of the impact of the substitution of the HVAC systems in a large number of public buildings at a regional level, it is essential to have accurate data of the performance of both systems, beyond the technical specifications stated by the manufacturers. Preferably, these data of performance should be obtained in actual working conditions for buildings with similar characteristics, similar use and similar energy demands. Most of the chillers used as cooling devices in the HVAC systems of non-residential buildings, work at off-design conditions: either at part load, or at changing ambient conditions, so the performance stated by the manufacturers in the technical specifications of the equipment, calculated at design conditions, are not the best indicator of the actual performance of the chiller at off-design conditions.

With this aim, the HVAC system of a singular governmental building in Spain is analyzed in deep detail. The most important aspect of the HVAC system of this public building is that the cooling system is duplicated: a new water-condensed chiller (WCC) with a dry-adiabatic cooler is installed in parallel with a conventional air-condensed chiller (ACC), which was the original cooling system of the HVAC system of the building. So the comparison of both systems is made under actual working conditions, and the results could be extrapolated to other big non-residential buildings of the tertiary sector, such as administration buildings, hospitals, hotels, etc.

It is not very usual to find the two types of cooling machines (the water-condensed chiller (WCC) with a dry-adiabatic cooler and the conventional air-condensed chiller (ACC)) in the same building. At the same time, the HVAC system presented in this work has a complete instrumentation, which allows the measurement and data acquisition of temperature, mass flow rate and electric consumption at different points of the system. These two characteristics turn the HVAC system presented in this work, into a true experimental plant which allows the two cooling systems to be compared under actual working conditions in a big, non-residential, public building. This paper studies the influence of such external factors as outdoor temperature, relative humidity and absolute humidity on the energy efficiency of both systems. The effect of the chiller operating under partial or full load on the energy efficiency is also studied.

2.1. Building description

The installation studied in this work is located in the *Cortes de Castilla y León* building, an institutional building where the Legislative Assembly of the regional government of the Spanish autonomous community of Castilla y León is located. The building is situated in Valladolid, Spain (41.643859 N, 4.744645 W, elevation: 700 m amsl). Valladolid is a location with a climate that some authors describe as *Continental Mediterranean*, which is basically a *Mediterranean* climate with colder winters and hotter summers due to the inland condition and the city's relatively high elevation above sea level. The monthly mean daily minimum temperature is 0.2 °C in January and the monthly mean daily maximum temperature is 30.7 °C in July [11]. Valladolid's climate is type *Csb* [12,13] according to the classical, widely used Köppen–Geiger climate classification system [14,15].

The *Cortes de Castilla y León* building [16] was built in 2007 with a singular architectural design of white concrete and glass. It has an area of 35,200 m^2 distributed in three main floors plus a basement. The Plenary Meeting Chamber occupies a prominent place in the building, having an external cubic shape that rises above the flat roofline of the main body of the building. An exhibition room, a reception hall, a cafeteria and some offices complete the main body of the building. A secondary five-story wing of the building contains most of the offices of the employees. The basement hosts the HVAC systems, store rooms and parking.

The normal occupancy of the building is 150 people and the usual occupancy hours are from 8:00 to 16:00. However, on special political events, such as plenary meetings of the legislative assembly, the total occupancy rises to 350 people and the time schedule may be extended until 20:00 or 21:00.

2.2. Initial HVAC system

The initial HVAC system of the building consists of two natural gas boilers (1046 kW each) for heating and two conventional air-condensed chillers (McQuay ALS E 229.2 XE XN, 834 kW each) for cooling. The air-condensed chillers have a nominal Energy Efficiency Ratio (EER) of 3.08, according to the technical specifications of the manufacturer, and they use a charge of 136 kg of R134a as refrigerant.

The building HVAC distribution system has 250 fan coils and 27 Air Handling Units (AHU) grouped in three different four-pipe-line distribution circuits. Circuit 1 groups the ground, first and second floor fan coils, Circuit 2 groups the third and fourth floor fan coils, and finally Circuit 3 groups the AHUs.