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Experimental analysis of energy savings and hygrothermal conditions improvement by means of air curtains in stores with intensive pedestrian traffic

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ABSTRACT

Current worldwide building legislation requirements aim to the design and construction of technical services that reduce energy consumption and improve indoor hygrothermal conditions. The retail sector in Spain, with a lot of outdated technical systems, demands energy conservation measures in order to reduce the increasingly electrical consumption for cooling. Climatic separation with modern air curtains and advanced hygrothermal control systems enables energy savings and can keep suitable indoor air temperature and humidity of stores with intense pedestrian traffic, especially when located in hot humid climates. As stated in the article, the energy savings in commercial buildings with these systems exceeds 30%.

1. Introduction

The main reasons of high energy consumption of the air conditioning systems in partially open stores is that they have to match an important thermal load due to the infiltration air that comes into the shop through the open door [1,2].

This situation is even harder in warm humid climates, for the cooling system also has to face the latent cooling load associated to high outdoor humidity content. When air conditioning is supplied with a direct expansion system, the evaporative unit control is adjusted to maintain a set point temperature. As the total thermal load exceeds the power capacity, the desired temperature is rarely reached, though the unit is continuously working at the maximum power.

Instead of vestibules or sliding doors, air curtain systems are an accepted solution to reduce infiltration for buildings in mild and moderate climates, even when complying with very strict standard requirements [3]. It consists in a fan placed over the entry that recirculates the air of the room and blows a downward jet to create an air barrier to external heat and, what is most important, outdoors moisture.

The purpose of this study is to carry out a thorough experimental analysis of the thermal loads and the hygrothermal conditions of a store with a high pedestrian traffic under three air conditioning situations: without climatic separation, with a conventional air curtain and with a high efficiency air curtain [4]. From the analysis, the adequate strategy for energy savings [5–7] and indoor conditions improvement is proposed [8–10].

2. Material and method

The object of study is a 200 m^2 commercial store with 3.10 m. ceiling height. It is located in Javea, to the East of Spain, close to the sea shore (Mediterranean Sea).

As in most wide open premises, the entrance is affected by the conjunction of two phenomena: free convection and pressure difference. Climatic separation via a traditional air curtain system is used in this case, it being the most effective way of eliminating the otherwise associated thermal loads.

In order to reduce energy consumption and maintain indoor air temperature within a comfortable range, it was decided to change the climate separation facilities. It was intended to maintain indoor hygrothermal conditions between 22 and 23 °C with a relative humidity of 55% [11], when outdoor temperatures swung from 17 to 30 °C and the relative humidity between 60% and 90% [12]. The refurbishment of the existing air conditioning facilities would need to be done without temporarily stopping commercial activity.

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2.1. Case studies

2.1.1. Description of the original situation

As in commercial stores of the type, air conditioning is solved by a ceiling mounted direct expansion unit.

Due to the frequent door opening caused by an estimated pedestrian traffic of 100 passages per hour, a conventional air curtain establishes a necessary climate separation. Nevertheless and though the shop is fully air conditioned, almost every day during summer period, indoor air temperature occasionally raises up to 30 °C for periods of nearly an hour, with outdoor temperatures slightly over 30 °C. Indoors relative humidity in such cases was kept below 50% due to the dehumidification performance of the cooling machine.

The electrical consumption for cooling, under these conditions, mounts up to 33.7 kW h/m^2 year. According to the official Spanish rating procedure (CALENER), this electrical consumption leads to an F qualification in final energy consumption for cooling [13]. This service represents the 20% of the energy use in small retail, whose typical global final energy consumption for this climate is 89 kW h/m^2 year (181 kW h/m^2 year, for primary energy), which is similar to other European energy benchmarks [14].

To identify the reasons of such high electrical consumption and the causes of unwanted indoor air conditions, a preliminary study on the air curtains operation was conducted with the following results:

Due to an inefficient control system, jet velocity is usually inadequate. When air is supplied with low velocity, air curtain is far from isolating indoor air from the variable outside conditions, for the air stream does not reach the ground, so there are large energy losses, during winter as well as in summer conditions (Fig. 1a). Convection energy losses were produced by the flow of air through the opening at the top of the facade forced by the decrease of density of hot air.

On the contrary, an increase in jet velocity tends to produce an air collision with the ground (Fig. 1b). In this case, the mixture of air from outside to the inside also causes a significant heat loss.

This effect is strengthened due to positive pressure created by the continued use of air conditioning system. It causes a positive indoors air pressure that forces indoor air to go outside through the openings.

To effectively carry out its function of climatic separation, air curtains should maintain a proper discharge length whatever the external conditions of wind are. If the air curtain jet is too weak and the throw distance is short it does not prevent infiltrations. By contrast, excessive throw distance due to a strong jet can reduce efficiency by almost 50%. In this case, high velocity and turbulent flow make the air curtain partially mix with outside air [15].

2.1.2. Description of the proposed solution

It is proposed to replace the original air curtain system by a higher efficient one in order to analyze the energy savings and the indoor hygrothermal conditions achieved. The comparison has been made with respect to the original situation and to an intermediate case without curtains, during the substitution process, when electric consumption and indoor conditions were also evaluated.

The climate separation is achieved by means of an air curtain Indac S150 (Biddle) placed in the existing door. This advanced equipment automatically eliminates turbulence created by fans using downstream guide vanes. This solution makes possible to maintain the jet convergent and rectilinear, allowing to vary the thickness of the jet, instead of controlling the velocity of discharge, as most systems do.

It recirculates air at the room temperature throughout the year. The supplied air flow rate is fixed for each fan position and the equipment adapts its velocity of discharge by a variation of the outlet geometry. Thus, an identical download length is achieved whatever the external conditions of wind are.

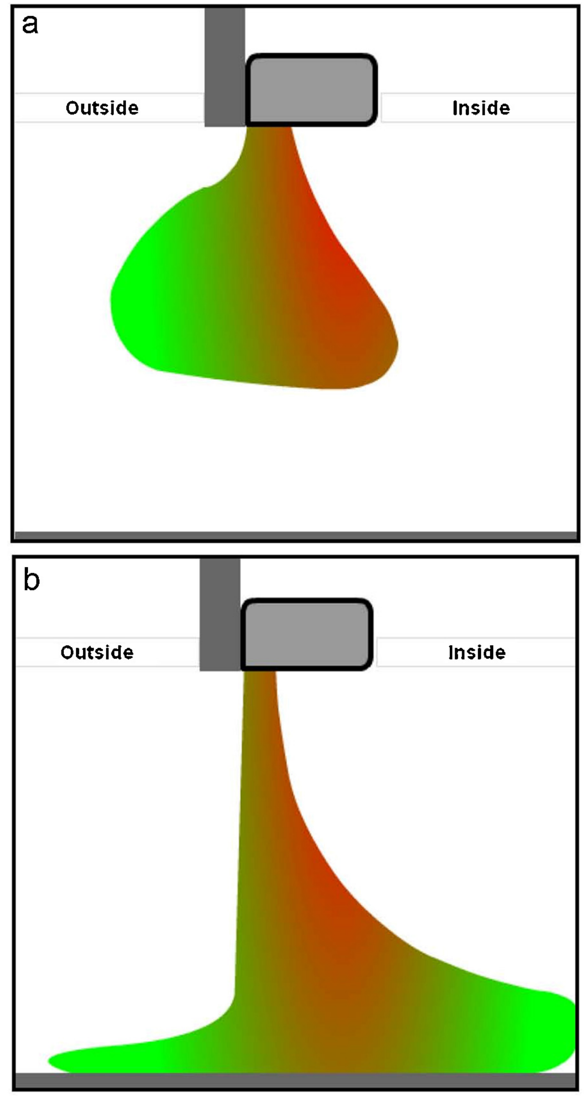

Fig. 1. (a) Short throw due to low velocity (Air flow rate: 1350 m^3/h; air velocity: 5 m/s; Jet momentum: 1.50 N/m), (b) Excessive throw when high velocity (Air flow rate: 1890 m^3/h; air velocity: 7 m/s; jet momentum: 2.95 N/m).

In summer case, the estimated electric power of the curtain is 64.6 W, according to the specifications showed below (Table 1). This is almost four times smaller than for the fan of the original air curtain.

Air curtain characteristics have been selected (Fig. 2) by using a commercial simulation program that takes into account the effect of air flowing toward the outside due to difference of density [16].

To control and automate the installation (air curtain and direct expansion unit) a remote control and metering equipment was installed. It operated on the basis of a driver that control measures provided by four energy meters (general, air curtains, lighting and chiller), an interface for exchanging information with the VRF system and the corresponding control and warning relays.

Communication with the platform is maintained via GSM modem with security protocol. As the received data are stored, it is possible to draw graphics of electric power consumption related to outdoor conditions variation, as well as indoor temperature evolution curves.

The projected air conditioning system (Fig. 3) consists an existing ceiling mounted Mitsubishi evaporative unit with 7.1 kW