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Thermal comfort evaluation in a mechanically ventilated office building located in a continental climate

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ABSTRACT

To quantify the thermal comfort achieved in an office building placed in Madrid and considering climatic variations, building designs, behaviour of inhabitants and the operation of the conditioning systems, two experimental campaigns have been carried out during the summer and the winter time. Depending on the season of the year different temperature profiles have been obtained as a consequence of meteorological variables and inhabitant concerns. Energy balance between indoors and outdoors indicate the thermal oscillation as well as the thermal deviation from the comfort bands. To analyze the daily evolution two typical days have been calculated by the Hall methodology. The quantification of thermal sensation of the occupants has been calculated by the PMV/PPD methodology. This evaluation shows low percentages of people dissatisfied with the indoor environments and low energy demands achieved inside the offices.

1. Introduction

Environmental impacts, industrial activities, urban patterns or the use of conditioning systems, have led to an intensification of the building energy demands and greenhouse gases emissions to the atmosphere [1]. Currently this sector represents more than 40% of the primary energy consumption in most countries [2] so reductions in these trends have become a global worry. With this aim, the European Union has developed new directives to improve the energy performance of new and existing buildings, reduce the energy imports and mitigate the climate change [3]. In Spain, the building sector represents about 26% of the final energy consumption but it is responsible for 25% of CO_2 emissions produced [4]. The analysis of this energy consumption by uses indicates that more than 42.5% goes for heating systems while 9% is used for cooling. These values have been increasing during the last years approaching to the energy consumption of the Northern European countries. Therefore, more efficient buildings must be constructed in order to create almost zero energy buildings. The first stage of this objective is the use of natural resources to design efficient buildings that are integrated into their environments. The second stage is to optimize the appliances and equipment, including the use of renewable systems. The implementation of these passive and active strategies must never compromise comfort and healthy requirements [5].

There are three ways to thermally conditioning an office building: centrally air-conditioning (HVAC), naturally ventilated and a mixture of both. The main differences between them are: the interaction between inhabitants and the control systems, the building adaptability to climatic conditions and the energy demands.

In the European context there have been several projects to study the comfort levels achieved in office buildings [6–9]. These projects investigate the way to quantify this thermal sensation with mathematical and statistical methods.

In the Spanish context, the Ministry of Science and Innovation has promoted a Singular Strategic Project of Research and Development, PSE-ARFRISOL (Bioclimatic Architecture and Solar Cooling, in Spanish) [10], being its main objective to demonstrate the usefulness of bioclimatic architecture and solar thermal and photovoltaic systems to save energy in future buildings. For this purpose, five office buildings were constructed or restored in different climatic zones of Spain. These prototypes were built for high-quality measurements recorded during monitoring to support research activities on thermal comfort, energy performance analysis and both active and passive systems integration in buildings. This article analyses the thermal behaviour of one of these new buildings, located in Madrid, by means of thermal balances between indoors and outdoors.

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2. Initial requirements

2.1. Building description

The analyzed case (ED70 building) is an extension of an existing building located at the CIEMAT facilities in Madrid, which maintains the same proportions, size and exterior appearance than the previous construction. This building has a rectangular shape with a total surface of 2000 m^2, distributed in three floors plus a basement. The main direction is oriented in the north-south axis with the openings distribution in façade according to local regulations. This building is mechanically conditioned to hold office rooms and laboratories. For safety reasons, the biological lab activities imply very rigorous environmental specifications with low energy saving potential. On the other hand, offices offer a great opportunity to implement energy efficiency measures. These rooms represent a 25% of the total building surface, this is, the ground floor. Office and labs air conditioning is provided by means of a two-stage system. First, a centralized AHU unit pre-treats the renovation air up to a working temperature. Then, terminal units modulate for the needs of each room. In order to reduce the conventional energy demands and increase comfort levels, a passive design has been combined with the use of active solar systems.

The techniques implemented in this building are: ventilated façades, insulation improvement in exterior walls, differential treatment of walls and shading devices. Two active solar systems have been installed: thermal collectors for domestic hot water production, heating and cooling; and photovoltaic panels for electrical production. A summary of the passive and active systems implemented in this building can be seen in Table 1.

The thermal field, composed by solar thermal flat plate collectors, is integrated at the pergola structure that shades the roof of the building. The photovoltaic field, composed by semitransparent photovoltaic modules, is integrated at the shading devices of the south façade (Fig. 1).

Although several rooms in ED70 have been monitored during the winter 2011/2012 and summer 2012, only two offices have been presented in this article to be representative of all. These rooms are located at the ground floor, one oriented to the south (P0.13) and one oriented to the north (P0.20), as shows in Fig. 2. Internal divisions among offices are made of furniture while the external divisions among offices and the corridor are made from

Table 1
Passive and active techniques implemented in ED70 building.

Passive techniques	Active techniques
Ventilated façade in South orientation Improvement of insulation in exterior walls Differential window glassing according to orientation + frame with thermal break: South: double clear North: double clear low emissivity	Solar cooling: 4 Climatewell 20 kw machines connected to cooling tower 180 m^2 of Tim flat plate solar collectors with 4 m^3 water storage Semitransparent PV panels (5′7 kWp) used also as shadowing for south façade holes
Optimized shading devices of south windows (width & incident angle)	Air-air climatization. Four-pipe installation connected to ATU's and inductors for distribution
Shading of roof	Intelligent indoors illumination system

glass. Geometry (ground area of about 22 m^2) and materials of both offices are the same but occupancy and internal gains are different. In P0.13 there are six people working with the doors open, leading to high heat and mass exchange between the office and the corridor.

In P0.20 there are usually three people, but sometimes there are two, four or five, working in a closed room for almost the workday, which means low air exchanges with the corridor. No special dress code is required, so the clothing factor has been assumed as the normal value for each season (0.5 and 1 clo for winter and summer respectively). To increase the interaction between the building and users as well as their comfort perception, all the occupants can establish set point temperatures of each office.

2.2. Experimental design

The experimental campaign has been designed and implemented to assess the energy performance of the building taking into account their thermal response to internal and external perturbations. Up to date, there is no standard procedure regarding experimental building energy performance evaluation. Several evaluation techniques at a different complexity levels coexist, such as long-term dynamic integrated analysis [11], dynamic grey box modelling [12], building simulation validation and calibration [13], among others. With this purpose, different sensors were installed in both offices (including all adjacent offices and corridor as

Fig. 1. South façade view of ED70 building.