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A field study on building inertia and its effects on indoor thermal environment

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ABSTRACT

Energy consumption in Spanish school buildings is higher during spring seasons. Thermal inertia of buildings can help to reduce such consumption, improve comfort, and even replace HVAC systems. This thermal inertia is usually associated to heavy wall construction, but the truth is there are other parameters that can have a significant effect on this property. This paper describes a field case study of school buildings with different types of wall construction, aimed at demonstrating real thermal inertia effects on indoor conditions. Besides air temperature measurements, HAM tools were used to simulate indoor air conditions. Results showed a good agreement between simulated and experimental air temperature results, and that other building construction parameters, such as the use of permeable coverings, may have a large impact on indoor thermal conditions and energy consumption.

1. Introduction

Nowadays in many schools, there is a great deal of interest in passive climate control systems, because of high energy costs and the impracticality of HVAC systems. These passive methods provide a good microclimate and are designed to regulate heat gain and loss and to improve air circulation. When designing a sustainable building, the important issues to consider are location, natural shade, shelter, and building materials. Construction materials and their coverings affect both the indoor thermal environment and the potential to save energy. They can be taken into account in a parameter called building thermal inertia, that could help us compare indoor ambiences and assess the potential to save energy.

A system with the highest thermal inertia has the lowest energy requirement [1]. In times of abundance, heat from solar irradiation and from internal heating appliances is stored in internal and external building elements. This energy is transferred back to the indoor zone when the indoor temperature decreases, thus reducing the heat needed from the heating system without significantly affecting thermal comfort [1]. The fact that natural thermal processes in a building may reduce the energy requirement for heating, makes it possible to choose a lower design temperature for winter, and this proposition was accepted in the Swedish Standards for design of heating systems. It may also affect the choice between continuously operated heat pumps and intermittently operated heat pumps [2]. Other investigations focused on the characterization of thermal inertia as a part of the installation of a system of summer refreshment by means of night time cooling ventilation [3].

On the other hand, old buildings tended to be constructed with heavy stonewalls, with a higher thermal mass than present day wall constructions that consist of concrete, insulation, and brick layers. But this does not imply that indoor ambience, which is the final objective of indoor environment control, presents a higher thermal inertia. In the past, wall constructions of heavy materials were considered the major passive method to control indoor ambience behaviour; however, recent studies [4–6] have shown that other parameters like solar gain and rate of air change influence this indoor ambience. Consequently, research groups [7,8] have lately shown a distinct trend to simulate heat and mass transfer of building envelopes with the aim of predicting indoor conditions [9–16] and to understand in which proportion each parameter influences changes. This software must be tested in real buildings to detect its reliability and arrive at new conclusions.

Spanish school buildings have shown high energy consumption in air-conditioning during the short cold period of the winter season, but during spring the heating system is employed if indoor conditions are below certain temperature values, despite the fact that it is not the coldest season of the year. This is due to design and application of HVAC systems, which only work when indoor conditions fall below the conditions of habitability, to indoor activity patterns, and to materials of building construction. In this sense, the heating system only works in the first few hours of the morning, because during the rest of the occupied period passive heat gains are

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enough to supply the required indoor ambience. Consequently, the heating system presents a longer operating period under a low load during the spring and autumn seasons. During these mild seasons, indoor ambiences could be controlled by passive methods leading to energy saving and better conditions of comfort [1].

In this paper, the real effect of building thermal inertia on the indoor ambience of two different Spanish school buildings is analysed.

2. Buildings and instrumentation

2.1. School buildings

Two schools were analysed and simulated. One portion of the older school was built in 1890, and the other part in 1960. The new school was built in 1999. As a consequence, the old school has thick stonewalls, while the other is constructed with brick walls. Table 1 shows the main construction characteristics of both school buildings. The classroom in the old building where the measurements were taken was located on the second floor, and has a volume of 210 m^3, while the classroom in the new building was located on the first floor, with a volume of 150 m^3.

All these buildings are occupied from February to June, when the schools are functioning, and unoccupied during weekends. In these periods, classrooms use natural ventilation and a heating system is not employed. Their active period ends in June and, therefore, indoor conditions during the summer period are not of interest. Furthermore, during extreme winter conditions these schools do not work, and as a result the heating system only works when indoor conditions exceed thermal comfort limits during winter and spring. Central heating systems are installed in both buildings.

2.2. Tiny tag data loggers

Temperature and humidity were measured using an Innova 1221 data logger equipped with a MM0034 temperature transducer, based on thermistor technology, equipped with a MM0037 humidity transducer, and incorporating a light emitting diode (LED), a light sensitive transistor, a mirror, a cooling element, and a thermistor. The accuracies obtained were ± 0.2 and ± 0.3 °C (dew point temperature), respectively. Tinytag Plus 2 dual channel data loggers equipped with thermistors and capacitive sensors were also installed to record temperature and relative humidity values with accuracies of ± 0.2 °C and $\pm 3\%$ RH, respectively.

2.3. Air change rate

One of the components of the measuring apparatus was a multi-gas analyser. The ventilation rate was monitored using the concentration decay method, using SF_6 as tracer gas, with a Brüel & Kjaer multi-sampler comprising the following main components: (a) a photo-acoustic infrared detection microprocessor-controlled gas analyser; (b) an air multi-sampler with six sampling ports; (c) application software to remotely control the gas analyser and a PC. The apparatus was equipped with a transducer to measure air temperature at the sampling point and a U0988 SF_6 filter with an accuracy of ± 0.01 ppm, that was single-point calibrated with a certified calibration gas of 10 ppm concentration.

Table 1
Constitution and characteristics of external walls of the old and new school buildings.

Layer	Dry Conductivity (W/mK)	Dry Density (kg/m^3)	Specific heat (J/kgK)
Old school			
0.5 cm Plaster	0.1600	950	840
0.5 cm concrete	0.5100	1400	1000
0.43 m Stone	1.1300	2300	840
New school			
0.5 cm Plaster	0.1600	950	840
0.5 cm concrete	0.5100	1400	1000
12 cm Brick	0.8940	1222	795
4 cm Insulation	0.0289	42.45	1214
12 cm Brick	0.8940	1222	795
0.5 concrete	0.5100	1400	1000
0.5 plaster	0.1600	950	840

3. Methodology

HAM tool simulations of internal conditions with respect to outdoor weather were to be compared with real measured data, during two days of the unoccupied period. Both buildings were also simulated under constant weather conditions, in order to obtain the building time constants.

3.1. Indoor and outdoor sampling conditions

The indoor and outdoor humidity and temperature were monitored in the two schools. The indoor measurements were taken between the months of February and June in one classroom of each school, during part of winter and spring seasons. Both schools have purely natural ventilation. The most representative classroom of each school was selected for monitoring. Transducers were suspended in the middle of the classrooms.

Outdoor temperature and relative humidity were assessed in 50 weather stations located in main interesting points in Galicia. These meteorological stations measure variables such as air temperature, relative humidity and wind speed, among others, with a sampling frequency from about five to 10 min. Their temperature, relative humidity and wind velocity margins of error are of 0.1 °C, 0.2% and 0.1 m/s, respectively. These weather stations have been chosen for this study due to the fact that they avoid buildings and other parameters that could interfere with sample data, according to ASHRAE.

3.2. HAM tool simulations

The mathematical model employed in this simulation is the result of whole building Heat, Air and Moisture (HAM) [12–14] balance, which depends on the moisture generated from occupants' activities, moisture inputs or moisture removed by ventilation, and that transported and exchanged between indoor air and the envelope [8].

The mathematical model is based on the numerical resolution of the energy and moisture balance all through the building. In accordance with the following equations, the heat flow comprises a conductive and a convective part:

$$q = q_{conductive} + q_{convective} \tag{1}$$

$$q_{conductive} = -\lambda \frac{\partial T}{\partial x} \tag{2}$$

$$q_{convective} = m_a \cdot c_{pa} \cdot T + h_{evap} \tag{3}$$

where, λ is the wall thermal conductivity (W/mK); T is the temperature (°C); m_a is the density of moisture flow rate of dry air (kg/m^2s); c_{pa} is the specific heat capacity of dry air (J/kg K); h_{evap} is the latent heat of evaporation (J/kg).

The moisture flow rate was separated into liquid and vapour phases as represented through Equations (4) and (5):