23. Analysis of comfort levels through the study of a ceramic pavement in a passive solar heating system

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Abstract Today there is a growing trend in energy saving applied in designing, constructing and operating buildings, which has caused an increase of interest in passive solar systems.

Reducing energy consumption in buildings is not only a lower cost for its users, but it also involves the reduction of pollution associated with their production and it reduces dependence on non-renewable energy sources.

This paper shows the study of a passive solar heating system by direct solar gain, and analyzes the performance of the pavement as a sensor system, and as an energy tank-heat dissipating sink.

The design of the experiment, monitoring and the analysis of the outcomes have allowed assessing the thermal performance of the pavement as a heat energy sensor, to check whether levels of thermal comfort achieved are acceptable. Said checking of the comfort levels tab has been performed by analyzing both the operating temperature and PD index.

Keywords: Construction; Building; Bioclimatic; Ceramic Pavement; Thermal Comfort

1 Introduction

The current energy crisis is also reflected in the field of construction (LÓPEZ-MORENO et al.2015), and factors of energy saving and greater attention to the selection of materials -taking into account their environmental impact- are taken increasingly into account on designing and constructing of buildings.

This isn't but a return to the origins, as in antiquity, technological, energy and logistical constraints imposed that buildings make maximum use of the resources of the area where they were located, taking into account also factors as typical climate of the area and the orientation of buildings.

This trend of creating an architecture suitable to its environment, reducing its energy dependence, is known as Bioclimatic Architecture, and its principles are: Consideration of the ecosystem of the environment, efficiency and rational use of materials, reduced energy consumption, compliance with comfort requirements and overall energy efficiency of the building process (Soares et al.2013).

The passive solar heating systems allow to increase comfort of people inside buildings (Esteban 1991), producing significant energy savings (Woloszyn et al. 2009) and a reduction of dependence on non-renewable energy sources (Manzano-Agugliaro et al. 2015). The assessment of comfort in moderate thermal environments is ruled by the UNE-EN ISO 7730: 2006, which presents methods to measure the degree of discomfort experienced by people through the index calculation, one of them being the PD index (Percentage Dissatisfied).

After a thorough search and analysis of academics works, it was found many scientific production on passive solar heating, however we have not found works related with the importance of pavements as energy sensors in these systems, which justifies the realization of this study.

The goal of this work is to analyze through an experimental study the influence of pavement as a heating system and to asses the degree of comfort achieved (Barrios et al. 2010) through the calculation of the operating temperature and the PD index.

Fig.1 Exterior view of the classroom

A biocimatic building called "Environmental Education Classroom" (Figure 1), located in the vicinity of Forest Park Somosaguas in the Madrid suburb of Pozuelo de Alarcón- has been chosen to conduct this study.

In winter solar radiation heats the ground of much of the classroom; constituted by a surface layer of 5cm thick ceramic pavers. Thus, this material is intended to store the heat until return to the environment is needed. In summer, as the solar trajectory is higher, the sun does not reach the inner masses, so they remain in temperatures similar to those of the land surrounding the building, which is lower than the ambient (Ayuntamiento Pozuelo de Alarcón. 2014) temperatures.

2 Methods

2.1 Description of the experimental model

The building on which the experiment was performed belongs to the bioclimatic complex called "Environmental Education Classroom." This building is located on the southern slope of a small hill whose height is 650 m above sea level, and 2.7 km from the Madrid suburb of Pozuelo de Alarcón, in the vicinity of Húmera. The classroom where the pavement has been monitored has an useful area of 51.60 square meters and capacity for 50 students, and it has a glass wall on the south facade, on top of which features a canopy that enhances the sun shading during the summer months (Figure 2).

The thermal mass is arranged on the floor of the studied building , it is 12 cm thick, spread on a layer of mortar, covering the lining ducts of the radiating floor, a bed of sand and clay pavers. This ceramic tiling 5 cm thick, is placed linearly with dry joint on a sandbed.

All this floor is arranged on a floor of honeycomb slab bricks, with a sanitary chamber of an approximate height of 1.20m.

Fig.2 Installation thermocouples

2.2 *Monitoring design*

To obtain the pavement temperatures, 20 type K thermocouples were placed on the surface of the flooring, forming a grid (Figure 3), each of them was placed in a 1.5 meters interval where in the nearest part to the glass, and every 2 meters in the rest of the classroom. These thermocouples were continuously recording sensor measures of the surface temperatura (Varela Luján et al. 2015).

Temperature measurements were taken every 10 seconds at each point and stored every 10 minutes.

We collected the data recorded during nine days of November 2015, reaching a total of 1,440 recollected data for each thermocouple placed on the pavement, so that there were collected a total of 28,800 lectures.

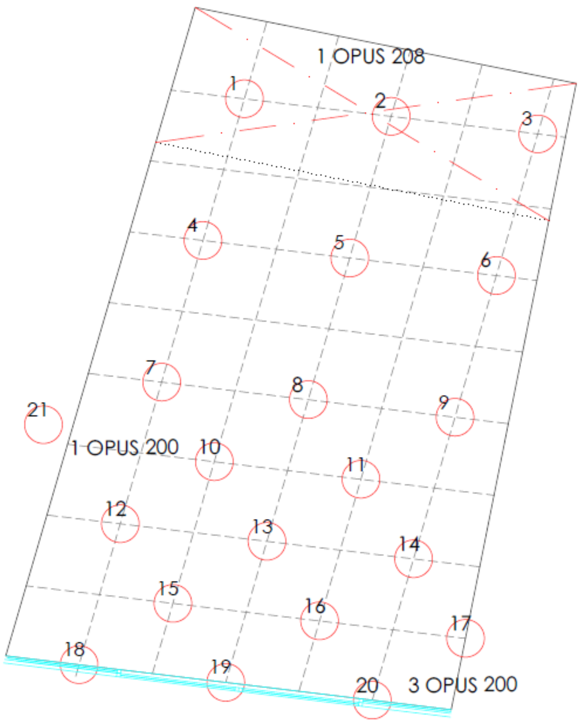

Fig.3 Location thermocouples

2.3 *Heat flow calculation*

To make a detailed study of soil behavior, we have evaluated the convective heat flows between the pavement and the classroom environment. First it has been obtained the difference between the temperature of the screed and the ambient temperature, and secondly it has been used as the transmittance value of the object of the experiment 0.30 W / m²K.After calculating heat flows, its evolution is analyzed over the studied period of time.

Also, it was performed the analysis of the evolution of the collected data of ambient and surface temperature, outside temperature and solar radiation.

2.4 Calculating comfort variables

To perform the analysis of the existing comfort (Blasco et al. 2007) in the classroom during occupational hours, there was determined the operating temperature of the classroom for the entire period.

This operating temperature, or resulting temperature is the average temperature between the radiant temperature and the air temperature (or dry temperature) (Ec. 1).

$$t_{op} = \frac{t_a + t_r}{2} \quad si\ la\ V < 2\ {}^{m}\!/_{s}\ \ y\ \left(t_a - t_r\right) < 4\,°C \tag{1}$$

Where:
ta: dry air temperature (° C)
ta: radiant surface temperature of the room (° C)

Later, to assess the possible thermal dissatisfaction motivated by heating or cooling of parts of the body, which may have cause local discomfort to people in the analyzed period, it has been calculated the PD (Percentage Dissatisfied) index measuring discomfort due to the vertical air temperature difference, which is of interest in this case study (Ec. 2).

$$PD = \frac{100}{1 + \exp\left(5{,}76 - 0{,}856 \cdot \Delta t_{a,v}\right)} \tag{2}$$

Where:
Δt ir the vertical temperature difference between head and feet, ºC.

The above expression should only be used if C t v a º 8, <Δ as it is the case.

3 Results and Discussion

From the results obtained in the analysis of the heat flow (Figure 4) it is observed that this flow is between -0.7 terms average W / m and 1.0 W / m, where the sign (-) indicates a change in heat flow. Therefore, in these cases the heat is captured by the pavement.This range of heat flow remains virtually unchanged throughout the study period, which is what matters in the performance of a passive solar heating system.

The average flow value of the pavement is positive, ie is emitted from the pavement to the environment and of an average value of 0.30 W/m², so we can confirm that the pavement is acting as an emitter.

The behavior of the flooring as a heater can be analyzed observing its performance after sunset, noting how long it takes to begin releasing heat to the environment and how long this releasing is.

Beginning 19:00h, the sun sets during this period, and it is noted that the pavement is receiving positive heat flows until 21:00h, the time when the pavement begins releasing heat to the environment that has been already cooled down. It is observed that the pavement is emitting heat until 12:30h in the morning. Then, although in the first hours of the morning this flow is insufficient to achieve comfort in the classroom, the pavement is emitting heat during all hours lacking solar radiation.

During cloudy days it is observed that the pavement acts as an emitter at every hour of day and night, but it is not capable of emitting heat more than a day if deprived of solar radiation.So it can be deduced that the heat accumulated on the pavement for a day of radiation, can be broadcasted during night time and while a one day only cycle. The pavement would not work as a passive solar heating system in longer periods of time.

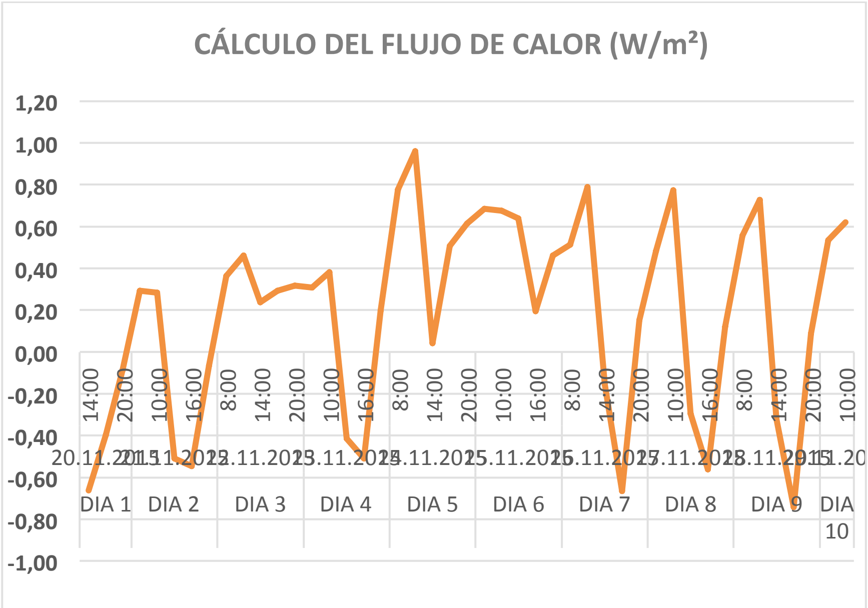

Fig. 4 Flow of heat

In analyzing the operating temperature it has been observed (Figure 5) which daylight hours are outside the limits of confort (RITE 2007), and generally average value are few degrees below it.

From these results it is observed that there are times -when the room is in use- below the comfort limits established, ir is in those hours when it would be necessary to heat the room by a heating system to meet the energy demand .

Analyzing these data it can be said that it would take an average of less than half an hour a day on to heat the room in November, so that in all occupational hours of classroom comfort temperature would be reached.

Therefore, in terms of energy consumption during the analyzed month average it would take an hour and a half a day to provide extra heating, which is a meager energy and economic expenditure.

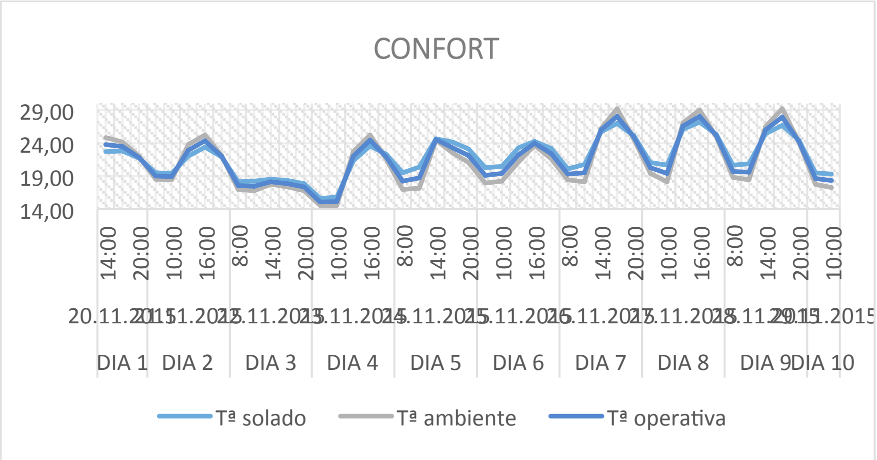

Fig. 5 Temperature of comfort

Analyzing the calculation of PD index throughout the study period, it is noted that the maximum value is 4.11% (Table 1) so it would be less than 5% in all cases, what is considered as acceptable by the norm. This means that less than 5% of people into the classroom would be unsatisfied by vertical temperature difference air.

Table 1 Maximum and minimum values of the DR

PD	FEHA Y HORA	TªAMBIENTE (°C)	Tª SOLADO (°C)	ΔTª (°C)	PD (%)
Máximo	28.11.2015 17:00	29,21	26,16	3,05	4,11
Mínimo	24.11.2015 09:50	16,78	20,18	-3,40	0,02

However, the average value of the PD index has been 0.4%, so we can say that less than 1% of people in the classroom would be dissatisfied by vertical difference of air temperature. As the analyzed classroom capacity is of 50 people, this would mean that, on average, less than 1 person would experience thermal dissatisfaction for this reason (Corgnati et al. 2009).

4 Conclusions

The conclussions of this work are:

- The analysis of data from sensors in the pavement, indicates that the design of the monitoring is appropriate, as it provides information of temperatures in all of it.Also the intervals set for sensor measuring and recording data in the datalogger are suitable for the analysis of the thermal behavior of the flooring in the period studied.

- From the analysis of the balance of heat flows in the classroom, throughout the study period, it is revealed that, during the hours lacking of radiation and during cloudy days, the pavement acts as an emitter with constant values.It is found that the pavement can not function properly as a passive solar heating system for periods longer than a cloudy day.

- It is found that the ceramic floor analyzed is a good accumulator of heat energy -where the heat source is solar radiation- to continental climate, characterized by having cold and sunny days between the months of November and February.

- Se It is verified that the floor tiles examined had a good performance as thermal mass for passive solar heating systems, possessing high thermal storage capacity and a slow thermal diffusivity.

- The use of ceramic tiles objective of the study as a passive heating system contributes to achieve comfort temperatures in most daylight hours inside the building. Furthermore, it is the cause of avoiding discomfort due to temperature differences in vertical air.

- In terms of energy consumption during the analyzed month it would take, on average, an hour and a half a day to provide extra heating, representing significant energy and cost savings.

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