REFRESHING ARCHITECTURAL SPACES BY MEANS OF LARGE-SIZED VERTICAL CERAMIC PANELS

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ABSTRACT

This paper details ambient heat conditioning using a system patented under Spanish patent number 201001626, which was developed by this research group in collaboration with ASCER and AICE. It comprises 3 mm thick, large-sized porcelain tile panels, polypropylene capillary mats, conductive paste, and a second 3 mm thick porcelain tile layer. Water is circulated at 17ºC through the capillary mat. The panels are hung vertically from the ceiling. The authors have used simulation software to determine the convection patterns of the air-streams generated in spaces with varying free headroom and the degree of air heating compared to when the same system is arranged horizontally as a suspended ceiling. Finally, the energy required by the user for radiation and convection of the circulating air has been calculated for both systems.

Radiant surfaces that use capillary mats made of polypropylene tubes provide for an extremely comfortable and energy-efficient ambience conditioning system. Apart from its use in suspended ceilings, plaster panels on walls and ceilings and flooring systems, it has a further unique application: it can be arranged as what is known as a baffle system, i.e. metallic panels hung vertically from the ceiling.

At present, ambience conditioning using radiant surfaces involves systems that distribute hot or cold water or with radiant foils (electric elements that work according to the Joule effect). The systems based on circulating hot or cold water either use thick piping or a polypropylene capillary mat with internal diameters of approximately 3 millimetres. These capillary mats have a series of fines tubes arranged in parallel with approximately 8 millimetre spacing. The tubing runs from a larger-diameter main feed tube and back to a return tube of the same larger diameter. In this way, they form parallel capillary-tube mats of variable surface areas that can be adapted to the space available. Cold or hot water is circulated through the tubes from coolers, heaters, absorption units, etc.

Energy exchange efficiency is much higher in capillary mat systems compared to thick-pipe arrangements, mainly because they provide a much larger heat-exchange area and lower tube thickness, so that it takes much less time to condition the room to the required temperature.

Recently, the "Technology and Sustainability in Architecture" research group at the University of Alicante, in collaboration with ASCER and ITC, has developed a patent as part of its '4 Senses' research project that consists of a heat-conditioning ceramic panel with built-in polypropylene capillary mats, for which it has requested Spanish patent protection under application number 201001626 [1]. The structure of the panel comprises 4 main parts:

- A ceramic piece, which can have any shape, texture, thickness or size. The ceramic piece is a low-thickness porcelain tile, specifically 3 or 4 millimetres thick to make it lighter and easier to fit and dismantle.
- An adhesive bond interlayer between the ceramic tile and the capillary mat. This consists of an adhesive material that is chemically compatible with both the ceramic tile and the polypropylene, depending on the type of capillary mat used in the thermal conditioning system. It is a material that favours thermal transmission, like, for example, a conductive paste or similar, so that it wraps itself around the entire surface of the capillary tubes.
- A polypropylene tube capillary mat. This mat has the same surface area as the ceramic tile so that each tile has its own independent mat. The mat has a main feed tube and another return tube of a suitable diameter for the total flow in the mat and which are connected to the feed and return distribution tubing by means of a flexible pipe and a 'click-and-cool' or similar connector.

- A second porcelain tile, 3 or 4 mm thick, similar to the previous one, so that the panel has a similar finish on its top and bottom sides with the same thermal performance across its entire surface area.

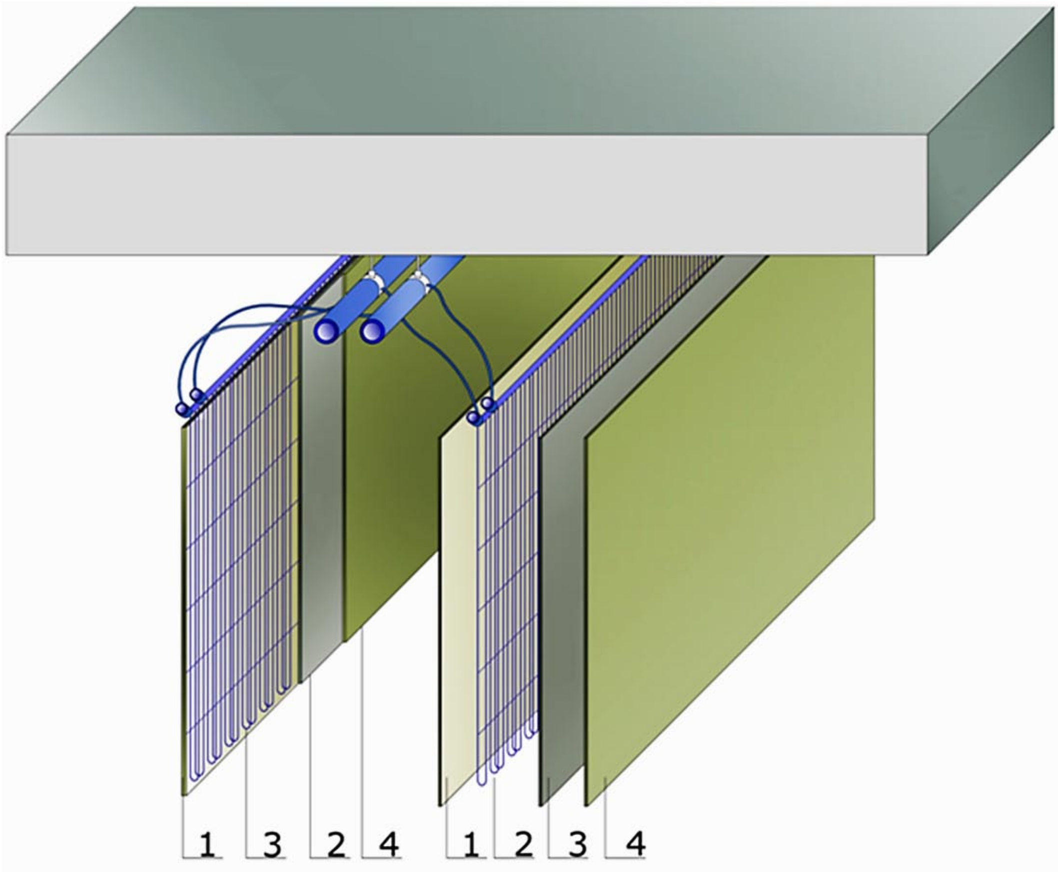

Fig. 1. Ceramic thermal conditioning panel

These panels, with an overall thickness of 15 mm, are hung vertically from the ceiling. Water is circulated at 17°C through them so that the water receives heat from the conductive paste through the walls of the polypropylene tubing and then from the large-sized, 3 mm thick ceramic tiles on each face of the mat. The heat produced inside the room by various heat sources is collected by the mass flow of water and transported to a cooler or heater, where it is returned to 17°C for subsequent recirculation.

The initial design of such an installation generally calls for different distribution circuits with thermostat valves and flow-balancing valves or flow meters on each circuit. The elements in the secondary circuit, as well as the circulation pumps, the primary circuit plate and shell heat exchanger and the expansion tank, are generally prefabricated in the workshop. In this way, proper water distribution through the tubing can be guaranteed for the design flow rates and perfect balance and control can be achieved for each zone to be conditioned.

This thermal conditioning system for architectural spaces requires a dehumidification system, firstly to counteract any latent sources produced by people and infiltrated air, and secondly to prevent relative humidity from reaching undesirable levels, which could then cause condensation on the ceramic panels if they reach a temperature close to dew point. Normally one or several slow fan-coils would be arranged for the dehumidification and to ensure that the speed of the re-circulated air is practically unnoticeable, as is the sound level produced by the fans. It is therefore a silent conditioning system, in which no cold air is impelled into the living area but which rather provides gentle air renewal [2] and dehumidification.

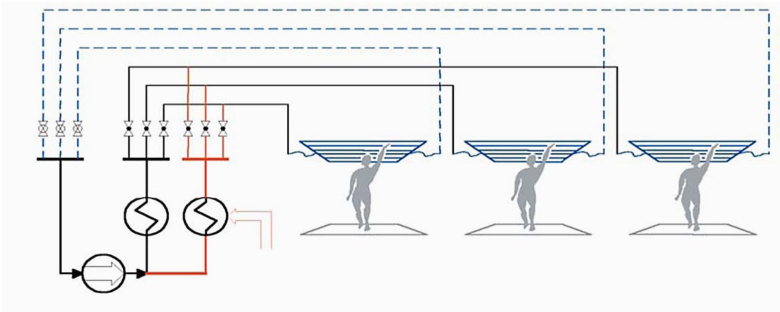

Diagram of a 3-pipe distribution sub-station
1 = Pump, 2 = cold exchanger, 3 = heat exchanger, 4 = flow regulator, 5 = cold valves, 6= hot valves, 7= hot water connection

Fig. 2. 3-pipe system

To prevent any risk of condensation moisture, which could arise in conditions of maximum latent heat sources or in periods in which the outdoor air is excessively humid, relative humidity sensors are fitted on the ceramic panels so that if they detect any condensation moisture, the sensor would order the thermostat valves to close, thereby impeding cold water from running through the relevant circuit(s). In this automatic way, any surface condensation can be prevented and once the risk of condensation has been overcome, the valve reopens automatically and cold water starts circulating again.

In thick pipe radiant floor systems, a 6 cm thick cement mortar layer with plastic additives is laid to improve thermal conductivity so that the system operates by first heating or cooling this layer of mortar. This process can last between one and two hours. Once the layer has changed its temperature, the top flooring receives the variation in heat through conduction and it is the floor surface that is responsible for the energy exchange by radiation with the rest of the walls, people, and air, thereby generating convection streams [3][4]. Thus, in such a system, thermal conditioning is performed by both radiation and convection in a ratio of about 60% to 40%. Furthermore, the system also creates significant thermal inertia, which stabilises any possible variation in thermal loads in the air, as convection accounts for less than 40% of the conditioning factor, which therefore means that the heat exchange continues to take place for a certain period of time even though water circulation through the heating circuits has been cut off.

It is more difficult to install water distribution through circuits in the ceiling than at floor level because the tubing cannot be encased in mortar but rather is fitted in an air cavity, which is what exchanges heat with the building material. However, it does have the advantage of allowing for a greater heat exchange surface area as there are no interfering items of furniture and it favours convection streams for room cooling in summertime. In the case on hand, because a 'baffle' type solution has been chosen, the panels are fitted vertically and there is no air cavity with a suspended ceiling. Once the ceramic panels are at a temperature of 17 to 18°C due to the circulation of cold water through the mat, they radiate towards the ceiling, walls and floor.

Radiant heat exchange efficiency is related to both distance and geometry. This last factor is determined by shape and is complex to calculate but which in standard building spaces is given a value of 0.4 from the ceiling to the floor and 0.15 from the ceiling to the walls. In this way, the average radiant temperature can be worked out.

The research outlined here is based on a 240 m² (12 x 20 m) and 6 m high surface area suitable for multiple purposes such as an exhibition hall, meeting room, etc. The walls in this room have the following characteristics:

Air:

Name of property	Value	Unit	Type of value
Density	1.1	kg/m^3	Constant
Thermal conductivity	0.027	W/(m.K)	Constant
Specific heat	1000	J/(kg.K)	Constant

Double glazed wall with cavity:

Name of property	Value	Unit	Type of value
Density	2457.6	kg/m^3	Constant
Coefficient of thermal expansion	9e-006	/Kelvin	Constant
Thermal conductivity	0.74976	W/(m.K)	Constant
Specific heat	834.61	J/(kg.K)	Constant

Double-leaf multilayer envelope with insulation and air cavity:

Name of property	Value	Unit	Type of value
Density	1600	kg/m^3	Constant
Coefficient of thermal expansion	1.08e-005	/Kelvin	Constant
Thermal conductivity	7.5521	W/(m.K)	Constant
Specific heat	877.96	J/(kg.K)	Constant

Ceramic panel containing capillary mats:

Name of property	Value	Unit	Type of value
Density	2300	kg/m^3	Constant
Coefficient of thermal expansion	1.08e-005	/Kelvin	Constant
Thermal conductivity	1.4949	W/(m.K)	Constant
Specific heat	877.96	J/(kg.K)	Constant

In order to research the degree of thermal conditioning in summertime, readings were taken of the radiant energy that the people in the room would receive by the average radiant temperature of the walls, and the convection currents that would be produced and that would have an effect on the conditioning were determined. For this, a tool known as 'Cosmosworks Professional' was used to define a specific room with a double glazed window across the entire surface of one wall and the temperatures of the walls depending on the specific outside temperature and conductance rates obtained according to the CTE [5]. Pattern simulation techniques were used on the air in the thermal balance to study the heat exchange in the air throughout the entire room. A comparative study of two different cases was made:

1. Cooling by means of large-sized, ceramic radiant ceiling panels with capillary mats across their entire surface area, suspended horizontally from the ceiling, creating a 1 metre high air cavity.

2. Cooling by means of large-sized ceramic panels with polypropylene capillary mats hung in a 'baffle' arrangement. The panels are spaced 1 metre apart from each other as shown in the diagram.

In order to perform a uniform technical comparison, both rooms were subjected to the same thermal load, for which the following parameters and heat conditions were set:

Temperature-1 <thermal panels -1>	Radiant ceiling at temperature of **290 Kelvin (17ºC)**
Convection-1 <glass envelope -2>	Coefficient of convection **30 W/(m^2.K)** and volumetric temperature of **308 Kelvin (surrounding temperature of 35ºC)**
Convection-2 <walls-1>	Coefficient of convection **15 W/(m^2.K)** and volumetric temperature of **299 Kelvin (surrounding temperature of 26ºC)**
Heat flow -1 <glass envelope -2>	Heat flow of 150 W/m^2

Outside temperature was assumed to be 35°C with a heat flow through the double-glazed window of 150 W/m^2 and a coefficient of convection of 30 W/m^2h, while air temperature in the top space was deemed to be 26°C with a coefficient of convection of 15 W/m^2h [6]. The surface temperature on the ceramic conditioning panels was 17°C in both cases, a temperature which must not drop in any circumstances as that would lead to conditions suitable for surface condensation to form.

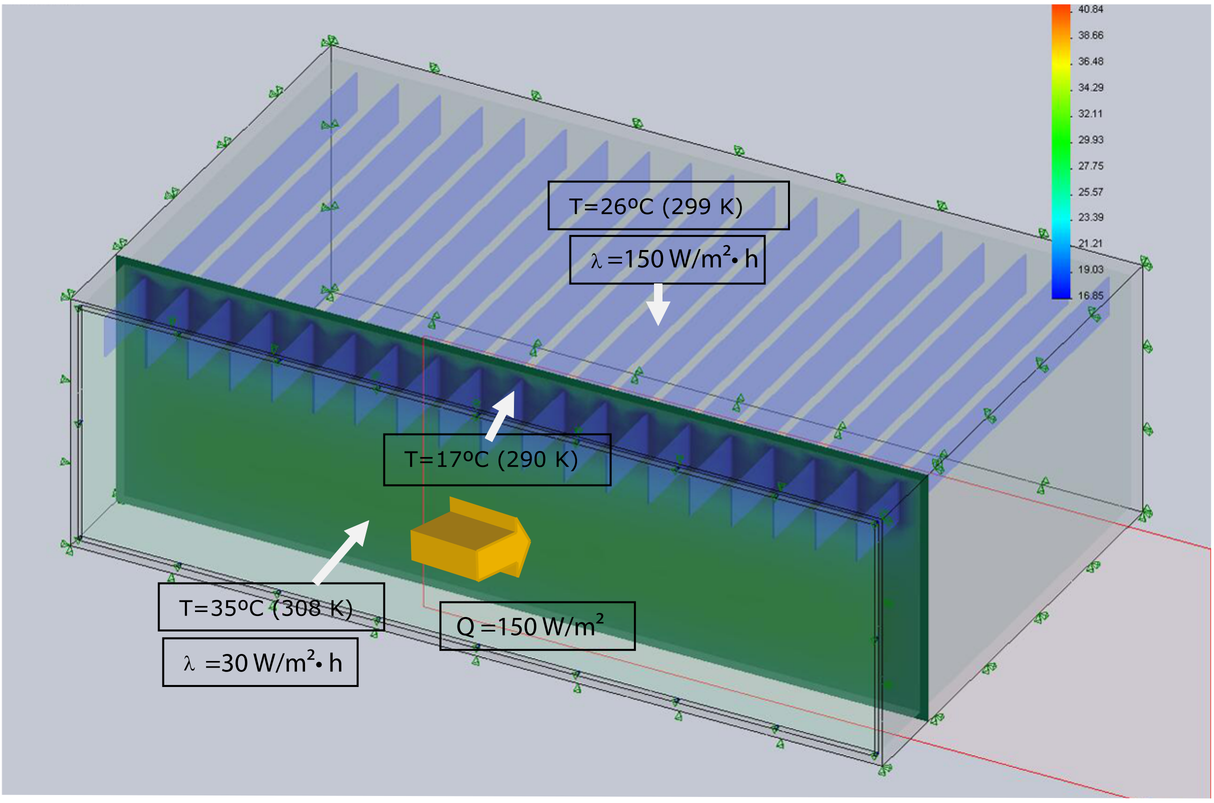

Fig. 3. Characteristics of the space and thermal conditions

Thermal behaviour calculations were made by determining the shape factor for radiated energy and the simulation tool was used to establish the isotherms and thermal gradient in the air according to the convection currents produced in both cases. Determining air temperature in the room, taking into account a convection air speed estimated according to the experimental method at 0.05 m/s, enabled the convection heat exchange to be quantified at any point of the space.

As far as radiant energy was concerned, using the following expressions:

$$q_{rd} = \sigma \mathcal{E} \left(T_1^4 - T_2^4\right) \qquad (1)$$

$$q_{rdi} = h_r \left(T_i - T_{rm}\right) \qquad (2)$$

$$T_{rm} = \frac{T_s + 0{,}15 \,.\, \left(T_{p1} + T_{p2} + T_{p3} + T_{p4}\right) + 0{,}4 \,.\, T_t}{2} \qquad (3)$$

T_{rm}: mean radiant temperature

T_s : floor surface temperature

T_p: surface temperature of walls 1, 2, 3 & 4

T_t : ceiling surface temperature

$\mathcal{E}$: surface emissivity

h_r: loss factor due to radiation from an individual

the shape factors for both panel geometries or arrangements was determined according to the experimental method of M. Ortega and A. Ortega [7], in which the shape factor for the floor to ceiling is 0.4, for ceiling to wall is 0.15, and from the ceramic panels to the wall is 0.10, taking into account that they only occupied one sixth of the full surface area of the walls. Thus, mean radiant temperature could be calculated in both cases, although it should be remembered that in the baffle-type arrangement, the radiant surface area of the panels was twice that of the suspended ceiling and that the surface that was not visible from the subject's position, which would be approximately 50%, would also emit radiation by reflection on the adjoining panels:

$$T_{rm} = \frac{T_s + 0{,}15\,.\left(T_{p1} + T_{p2} + T_{p3} + T_{p4}\right) + 0{,}4\,.\,T_t + 0{,}1\,.\left(T_{pc}.n\right)}{2} \quad (4)$$

T_{pc}: surface temperature of hanging ceramic panels

n: number of ceramic panels per linear metre of ceiling

The results obtained gave a mean radiant temperature of 21.9 ºC for the horizontal panel system and 22.8 ºC for the hanging baffles, where T_{pc} was 18 ºC and n = 1.

For the *hr* factor, of losses by an individual's radiation, we estimated a value of 4.7 W/m^2°C both for the suspended ceiling and for the baffle-type hanging panels [8]. The surface temperature of the human body was estimated as 30°C. Therefore, heat exchange through human body radiation with surrounding surfaces will be as per the following expression for each square metre of human body surface (2):

$$q_{rdi} = 4{,}7.\,(30ºC - 21{,}9ºC) = 38{,}07\ \text{W/m}^2 = 38{,}07\ \text{W/m}^2$$

$$q_{rdi} = 4{,}7.\,(30\ ºC - 22{,}8ºC) = 33{,}84\ \text{W/m}^2 = 33{,}84\ \text{W/m}^2$$

From this, it follows that the effectiveness of the baffle system as far as ambience conditioning using radiant surfaces on the user was 88% compared to the traditional suspended ceiling system, a value that is more than satisfactory bearing in mind the variation in geometrical arrangement.

With regard to heat flow as a result of convection currents in the air surrounding the individual, the following expressions:

$$q_{cv} = h_c(T_p - T_a) \quad (5)$$

$$h_c = 8{,}3\,.\,(v^{0{,}24}) \qquad (6)$$

$$q_{cvi} = h_c\,(T_i - T_a) \qquad (7)$$

q_{cv} : heat flow by convection

q_{cvi}: losses by convection per square metre of human body surface

v: air speed of 0.05 m/s

T_i : skin surface temperature.

T_a: ambient air temperature.

As the heat transfer factor *hc*, in both cases, did not depend on the positional geometry of the panels, this was determined as:

h_c = 8.3 x 0.05 $^{0.24}$ = 3.89 W/m² ºC (standing individual)

h_c = 8.3 x 0.05 $^{0.6}$ = 1.38 W/m² ºC (seated individual)

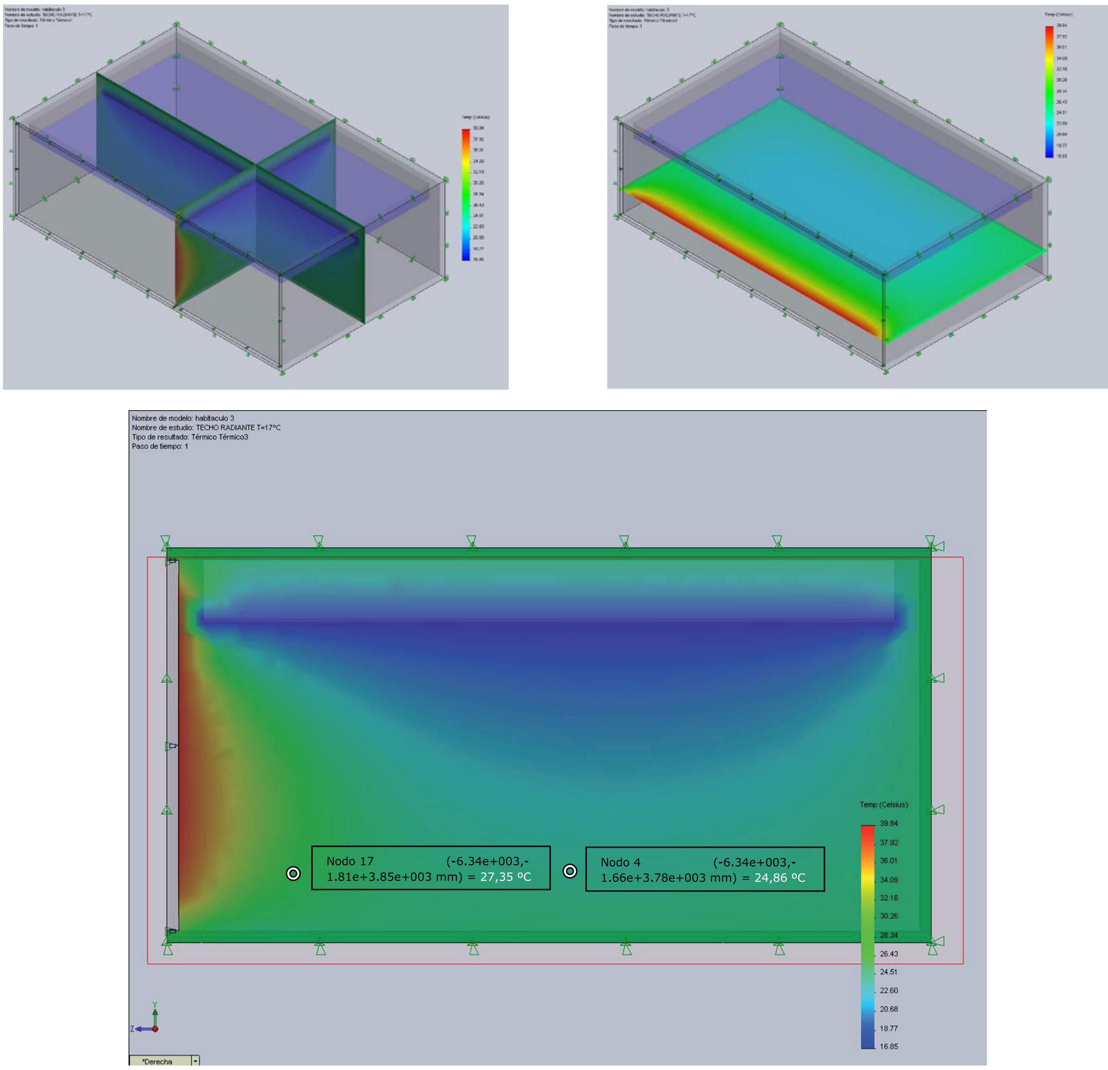

Fig. 4. Air temperatures in a cross-section of the horizontal ceramic suspended ceiling

To determine the heat flow by convection that an individual feels with the foregoing parameter , the air temperature was analysed according to the conditions outlined above, i.e., with a glass wall at 28°C temperature, an outside temperature of 35°C, a heat flow rate of 150 W/m^2 through the glass, and a temperature in the surrounding spaces of the party wall of 26°C. The resulting air temperatures are shown in figures 4 and 5.

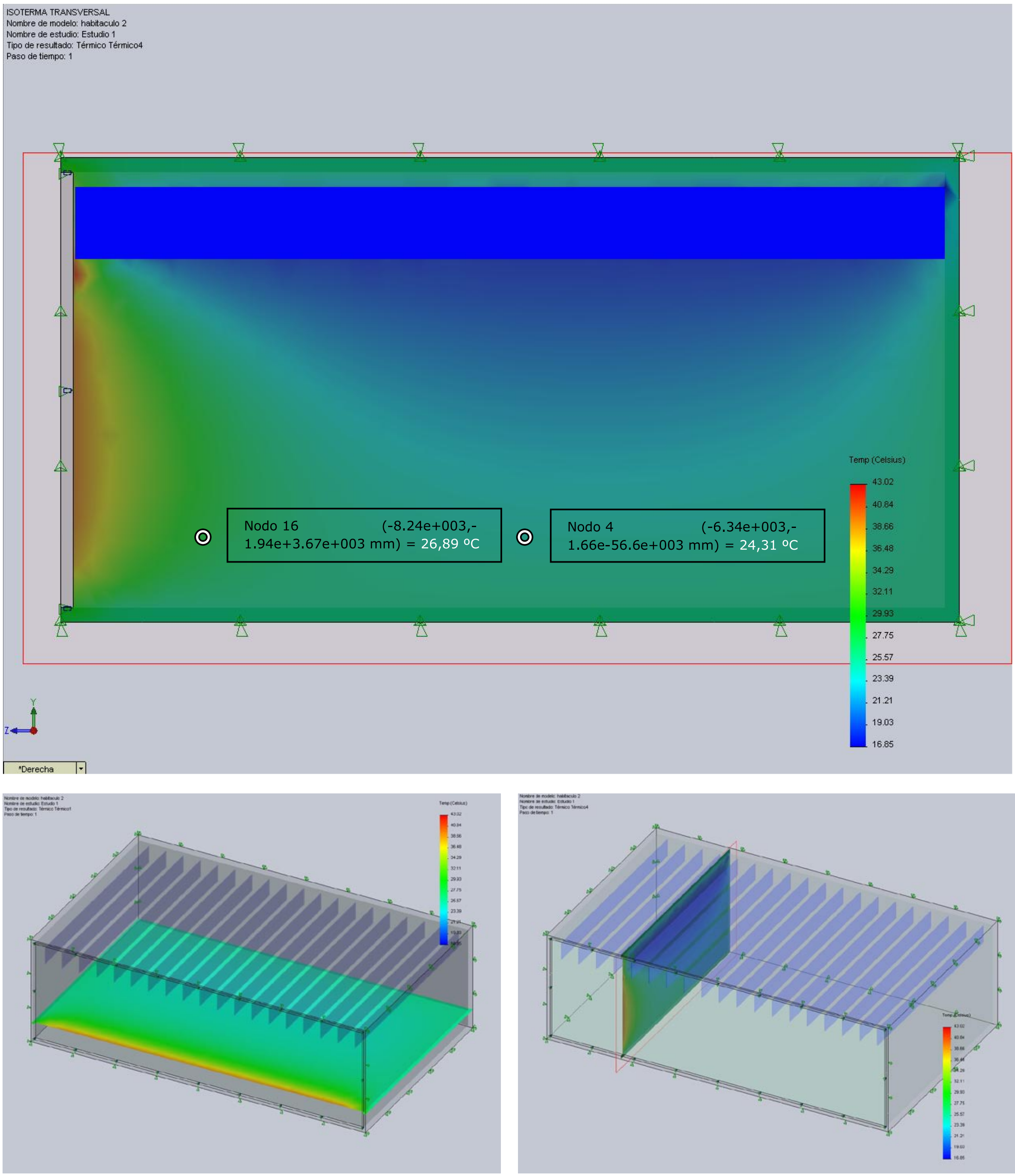

Fig. 5. Air temperatures in a cross-section of the baffle arrangement

As can be seen, the air temperatures in the occupation area were lower for the baffle type arrangement. Mean temperature in the occupation area was determined at two different positions at varying distances from the window: the first, 2 metres from the window and the second in the centre, 6 metres away. The temperatures obtained are shown in *Table 1*: at 2 metres, the temperature was 27.35°C, compared to 26.89°C for the baffle system, and 24.86°C compared to 24.31°C at 6 metres' distance from the glass window.

Taking into account the mean temperatures obtained and that body temperature is 30°C, body heat flow could be determined per square metre of body surface area by convection using the following expression (7):

$$q_{cvi} = 3{,}89\ (30ºC - 27{,}35) = 10{,}3\ \text{W/m}^2 \quad q_{cvi} = 3{,}89\ (30ºC - 26{,}89) = 12{,}1\ \text{W/m}^2$$
$$q_{cvi} = 3{,}89\ (30ºC - 24{,}86) = 19{,}9\ \text{W/m}^2 \quad q_{cvi} = 3{,}89\ (30ºC - 24{,}31) = 22{,}1\ \text{W/m}^2$$

Therefore, for a standing individual, it can be concluded that heat flow by convection was between 10% and 17% higher with the baffle system depending on whether the individual was standing closer to or further from the glass window.

Table 1 is a summary of the results obtained and shows the heat flows for an individual due to radiation and convection. It can be seen that for the type of room used in the research, the sum total of these airflows remained almost unaltered. Considering the scarce effect that heat flow by transmission had on total heat dissipation by the individual and that the effect of heat flow by evaporation – respiration and perspiration – would be similar, and also that relative humidity would be controlled by dehumidification provided by slow fan-coils, it may be concluded that the baffle system provided satisfactory ambience conditioning.

	T_t	T_s	T_{mp}	T_{rm}	v	h_c	h_r	T_a	q_{rdi}	q_{cvi}	$q_{rdi}+q_{cvi}$
Cold radiant ceiling using horizontal Ceramic Panels	17	20	24	21,9	0,05	3,89	4,7	27,3	38,0	19,9	57,9 W/m^2
Cold radiant ceiling using baffle type ceramic panels	17	20	24	22,8	0,05	3,89	4,7	26,8	33,8	22,1	55,9 W/m^2

Table 1.

CONCLUSIONS

A thermal conditioning system using large-sized ceramic panels with built-in polypropylene capillary mats hanging from the ceiling in a baffle arrangement are shown to be very effective ways of achieving silent and healthier ambience acclimatisation with proven energy savings.

The baffle position compared to a traditional horizontal suspended ceiling reveals certain differences with regard to ambience conditioning efficiency. Heat flow by radiation between the individual and the walls that make up the architecture of the rooms, in which the ceiling is at a temperature of between 17 and 18°C, is approximately 89% in the baffle system, compared to the horizontal suspended ceiling in large size rooms with high ceilings, due to the shape factor.

With regard to heat flow due to convection between a standing person and the surrounding air in the room, the result is between 10 and 17% higher in the case of the baffle arrangement, due to the fact that such a system favours convection currents, with air temperatures slightly lower in the occupation area. In this way, very similar ambience conditioning can be achieved to that of a suspended panel ceiling, because both factors – convection and radiation – balance out in the final total (96%). It should be highlighted that in both cases, a minimum amount of air dehumidification is required – as laid down by the Technical Building Code – using a fan coil driven from the cold water distribution net, as the capillary mat system is incapable of providing it on its own.

Thus, ceramics are seen as good top surface materials for the panels, as their high thermal conductivity favours heat transmission towards the water circulating through the capillary mats.

REFERENCES

[1] *Panel de Acondicionamiento Térmico Cerámico.* Referencia de solicitud de Patente Nacional 201001626. Proyecto de I+D+I "4 senses". Diciembre de 2010. Solicitantes: Universidad de Alicante, ASCER, AICE.

[2] RITE. Capítulo II. Artículo 11. UNE-EN 15251.

[3] Dong, M. N. et al., 2008, Quantitative analysis on the effect of thermal bridges on energy consumption of residential buildings in hot summer and cold winter region: Chongqing Jianzhu Daxue Xuebao/*Journal of Chongqing Jianzhu University*, v. 30, p. 5-8.

[4] F. Javier LÓPEZ RIVADULLA; Víctor ECHARRI IRIBARREN; Patricia ALONSO ALONSO; Joaquín FERNÁNDEZ MADRID. " Fachada ventilada. Pérdidas energéticas derivadas del sistema de anclaje", CONGRESO DE PATOLOGÍA Y REHABILITACIÓN DE EDIFICIOS (PATORREB), Oporto–Facultad de Ingeniería de la Universidad de Porto, Marzo 2009.

[5] CTE. DB HE. Ahorro Energético. Apéndice E. *Cálculo de los parámetros característicos de la demanda.* E1. Transmitancia térmica.

[6] Bartomeu SIGALÉS I PUEYO. *Transmissió de calor. Vol.3. Convecció sense canvi de fase.* Edicions de la UPC, Barcelona, 1990.

[7] Mario Ortega Rodríguez; Antonio Ortega Rodríguez. *Calefacción y Refrescamiento por Superficies Radiantes.* Paraninfo, Madrid, 2001, p.11.

[8] Ibídem, p.12.