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## Analysis of thermal emissions from radiators in classrooms in Mediterranean climates

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### Abstract

Using computational fluid dynamics (CFD), this study focuses on the analysis of the thermal emissions of a typical classroom in an educational establishment in the south of Spain, and heated by radiators situated under the windows. It aims to study the way to exchange energy within the venue with this system.

In order to do so a work methodology is developed which applies the Fanger method (PMV and PPD indicators) and the local thermal discomfort method to the isothermal curve sections generated by the CFD calculations, drawing up a series of lineal variation graphs on the temperature. This allows us to not only evaluate the degree of thermal comfort of the occupants in accordance with ASHRAE standards but also to carry out future comparisons between different thermal exchange system variants arising from the HVAC system. Following the application of this analysis the paper concludes that efficiency of the traditional radiator system to cope with the energy demand of the location is limited, given its incapacity to carry out a uniform exchange of energy between itself, the convective phenomena it generates, and the low relation between air volume/emitting surface, which translates into a lack of energy efficiency in the system, an aspect which is not usually contemplated in traditional analysis methods.

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### 1. Introduction

In the choice of system of HVAC planned for the hygrothermal and air quality conditioning of buildings there is usually some uncertainty as to how the system for the diffusion/emission of energy will behave in reality in the venues tested, as well as how energy-efficient it is in relation to other alternative

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systems with similar characteristics. There are many measurements, simulations, and verifications of the form of operation of each of these HVAC systems in generic locations, but there is also a certain lack of knowledge as to whether the energy use in the building is correct, given its transmission efficiency in habitable venues considered as tridimensional spaces, with occupants, furniture, equipment, and other sources of warmth that actively intervene in the system.

In order to predict the behaviour of these exchange systems it is necessary to resort to computational fluid dynamics (CFD), a branch of fluid mechanics which up until now has not been applied to construction much, with the exception of studies like those of Qiong Li *et al* [1] on the simulation of climatized train stations, or the design by Yingchun Ji *et al* [2] of a building with many passive and active measures for thermal control, carried out with the help of CFD calculations, and subsequently contrasted when it was monitored after construction. Nevertheless, CFD has been widely developed in the fields of aeronautical engineering, chemistry, biology, meteorology, oceanography, etc.

Within this general context we propose to study research in the field of school buildings, as they are presented as one of the most common and widespread building typologies, constantly in use and with major internal loads (occupancy, lighting and particularly, computer equipment, which generate distortions in the distribution of energy) and the elevated degree of comfort demanded by the occupants. Our methodologies will be based on the work carried out by Stamou *et al* [3] on a typical office module with one occupant and one desktop computer, the studies of T. Karimipناه *et al* [4], which simultaneously carried out CFD simulations and measurements in teaching classrooms with different systems to demonstrate the precision of these simulations, and finally the comfort criteria established by the Fanger method and included in EN 7730 on Ergonomics of the thermal environment [5].

This work and its methodology pave the way for comparative studies with other alternative systems, mainly with the introduction of controlled mechanical ventilation.

## 2. Methodology

### 2.1. Definition of the model under study

The model under study is a typical 50 m<sup>2</sup> classroom in a non-university teaching centre, designed to accommodate 25 students and their teacher [6], and fitted with a radiator heating system without combined mechanical ventilation, leaving the task of ventilation to the uncontrolled infiltration through the envelope, an example of the most common installation in the regions of Southern Europe.

The measurements of the classroom are 7.25 metres in length, 6.4 metres in depth and 3 metres in height. The placement of desks in the interior leaves the windows to the left, to ensure natural light for writing (fig. 1(a)). This venue is delimited by its north-facing façade (a desirable orientation for this study), and by (horizontal and vertical) partitions common to classrooms of a similar size and sharing an indoor access corridor. We considered this typical classroom to belong to the Spanish programme ‘Escuela T.I.C. 2.0’ [7], which establishes that all students and the teacher will have ‘netbook’ portable computers.

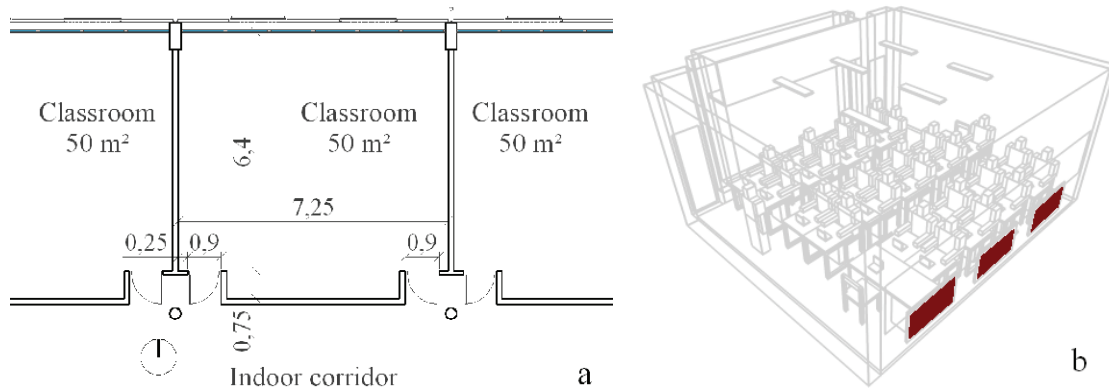


Fig. 1. (a) Floor plan of the classroom under study; (b) Positioning of elements and the system of thermal exchange (radiators) in the model.

The building data of the envelope are shown in table 1.

Table 1. Envelope

Element	Transmittance (W/m <sup>2</sup> ·K)	Element	Transmittance (W/m <sup>2</sup> ·K)
Façade	0.45	Slab	1.98
Vertical partitions	2.09	Insulated door	0.84
Fenestration	Double glazed window (4/6/4 mm) with thermal break		3.4

Solar protection: 20 cm horizontal slats at 45° every 20 cm

The building housing this classroom is located in Granada, where the climate conditions are similar to many other locations in Southern Europe (table 2), thus making it highly representative. The static calculation hypothesis was executed at 8:00 am on the 21<sup>st</sup> of January.

Table 2..Location data

Location	Granada (Spain)	Time zone	GTM + 1:00
Latitude	37.18°	Longitude	-3.78°
Elevation above ground level	559.0 m	Climatic data template	ESP_Granada.swec
Exterior calculation temperature	1.9 °C	Relative humidity for calculation	90 %
Wind speed	10.1 m/s	Wind direction	0.0° (North)

## 2.2. Description of the system studied

The energy exchange system that will be used as an example in this study is that of radiators, placing three steel radiator panels under the windows, with an average emission temperature of 70 °C and a

thermal difference of 20 °C in the water I/O.

### 2.3. Conditions for use and operation

The elements included in this study are those included in table 3, and displayed in the model as they appear in figure 1(b):

Table 3. Elements included in the calculations.

Thermal control	21 °C set temperature
Tables and chairs	26 (table and chair per occupant).
Lighting	6 overhead lights, measuring 30x100x5 cm, individual emission of 58 W (convective component only).
Netbooks	One per occupant, with an individual flow emission of 30 W (E. Lim <i>et al</i> [8] and Jung-Mi Lee <i>et al</i> [9]).
Occupants	Teacher, standing, and 25 students, sitting, with an individual flow emission of 45 W (convective component only) and clothing 1.2 clo. 0.52 persons/m <sup>2</sup> .
Openings	Infiltration rate of 0.5 renovations per hour.
Radiators	Individual flow emission equal to the power required by the location divided by the number of elements placed.
Area occupied	According to EN 13779 on ventilation for non-residential buildings [10] (fig 2(a)).

### 2.4. Tool for energy simulation

The software chosen to carry out node calculations and the CFD to which this work methodology ought to be applied is the Design Builder, following the recommendations of Z. J. Zhai [11], who established that for a model of these characteristics (simple, without continuous temporal evolutions and applied to architecture), the use of a pure CFD tool is not necessary as it is possible to use mixed calculation methods or even a single exchange of information between traditional node calculation and fluid dynamics (one-step static interaction).

### 2.5. Method of comparison of results

In order to assess the results of the calculations it is necessary to establish a comparison method, following EN ISO 7730 on Ergonomics of the thermal environment [5], which sets common analysis parameters depending on the thermal sensation experienced by a typical human being. The Fanger method and the local thermal discomfort method, both included in this norm, will be used to obtain the following indicators:

- Predicted Mean Vote (PMV).
- Predicted Percentage Dissatisfied (PPD).
- Level of local thermal discomfort due to Draught Rate (DR).
- Level of local thermal discomfort due to vertical air temperature difference (PD).

A series of lineal graphs of thermal variations are generated as aids for these indicators and to facilitate analysis using a series of isothermal curve cuts in the sections we wish to study (fig. 2(b)). In this way these graphs can be superimposed on each other for a comparative analysis with other thermal exchange systems.

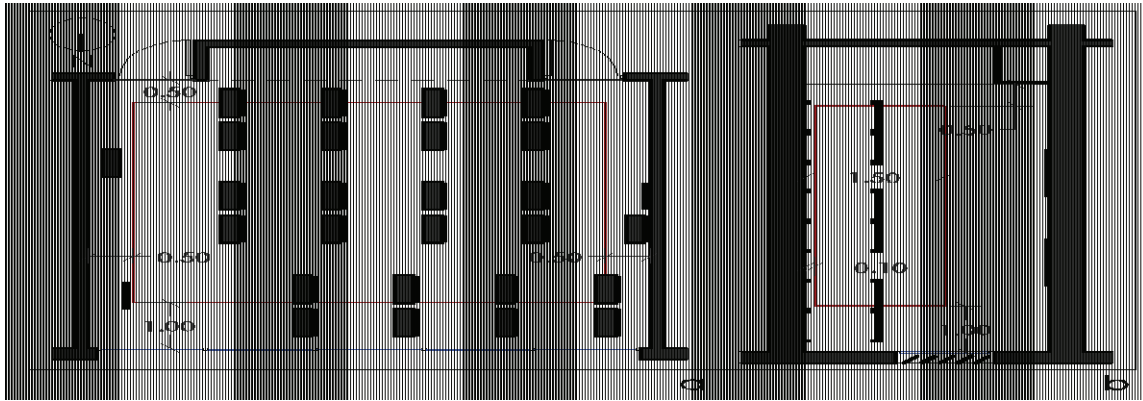


Fig. 2. (a) Zone occupied in horizontal and vertical section of the classroom (EN 13779);

(b) Cuts in horizontal and vertical section of the model selected for temperature variation graphs.

### 3. Result analysis

#### 3.1. Node calculations

The thermal demand of the venue is 5,073 W, so 3 radiators of 1,690 W were used, with a  $\Delta t=20\text{ }^\circ\text{C}$  thermal difference, and each of them measured 5 x 80 x 135 cm. Air temperatures and the temperatures radiating from walls for the 21st January, at 8:00 (zero instant), are included in table 4.

Table 4. Average temperatures of air and wall radiants (21st Jan at 8:00)

	Air of the venue	Outdoor air	External wall	Windows	Partition 1	Partition 2	Door 1	Door 2	Partition 3	Partition 4	Floor	Ceiling	Total
Surfaces (m <sup>2</sup> )	-	-	23.8	7.3	18.1	5,7	1.3	1.3	21.5	21.5	45.1	45.1	190.8
Average temperature (°C)	11.0	1.7	14.0	8.5	13.6	13.8	11.6	11.6	14.2	14.2	14.5	15.4	14.3

Note: *Partition 1* is a partition with corridor. *Partition 2* is a partition set back between doors. *Partition 3* is a partition with right-hand classroom. *Partition 4* is a partition with left-hand classroom. *Door 1* is door 1 to corridor. *Door 2* is door 2 to corridor

#### 3.2. CFD Calculations

From the model we take the two most significant sections, which must show the energy status of the entire venue, without distortions caused by the excessive proximity of occupants or equipment, or by the

operation of possible systems. We will therefore use a vertical section cutting across the classroom transversally, and another horizontal one (figs. 3(a) and 3(b)). The results of the calculations are represented in figure 3(c) and table 5.

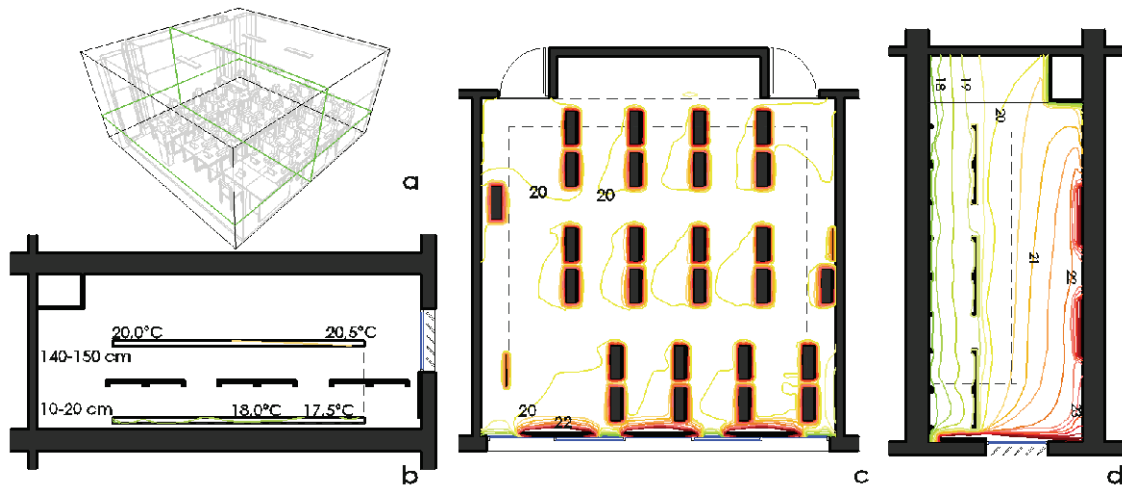


Fig. 3. (a) Position of the study sections in the model; (b) Section A of the model with a 10 cm double strip in an area occupied at heights of 10 and 140 cm, with isothermal lines; (c) Section B of the model with isothermal lines; (d) Section A of the model with isothermal lines.

Table 5. Results of thermal distribution in section A for the air of the model from 21st January at 8:00 (zero instant).

Section A (vertical transversal): 6.24 m <sup>2</sup>										
Temperature (°C)	17.5	18.0	18.5	19.0	19.5	20.0	20.5			
Surface (m <sup>2</sup> )	0.25	1.23	1.54	0.56	0.59	1.96	0.12			
Average temperature section A: 19.00 °C										
Section B (horizontal): 20.55 m <sup>2</sup>										
Temperature (°C)	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0
Surface (m <sup>2</sup> )	13.89	4.75	0.47	0.28	0.15	0.15	0.18	0.20	0.17	0.31
Average temperature section B: 19.86 °C										

The average air temperature in the venue is obtained through the weighted average of both sections, depending on the surface of each of them, and this gives a result of 19.7 °C.

### 3.3. Applying the Ergonomics of the Thermal Environment regulation

With this average temperature of 19.7 °C for the dry air contained in the occupied volume of the venue, and with an average temperature of 14.3 °C (table 4) radiated from the walls, we obtained an operational temperature of 17 °C. The average speed of air in these sections is 0.10 m/s according to the CFD model

results. The difference between the average temperature values of both horizontal strips measuring 10 cm and placed at heights of 10 and 140 cm (figure 4(b)) is 2.5 °C (from 17.6 °C to 20.1 °C). Using this data, we applied the indicator calculations of the Fanger and the local thermal discomfort methods, described in EN ISO 7730, obtaining the following values and categories (table 6):

Table 6. Thermal environment categories

Thermal status of the body in its ensemble				Local discomfort				Global class	
PMV		PPD		DR (air currents)		$\Delta T$ (air vertical)			
Value	class	Meaning	%	class	%	class	%	Class	
-0.68	C	slightly cool	15	C	8.4	A	2.6	A	C

### 3.4. Lineal graph analysis of thermal variations according to section

The resulting graphs are shown in figure 4, according to the previously selected cuts included in figure 2(b).

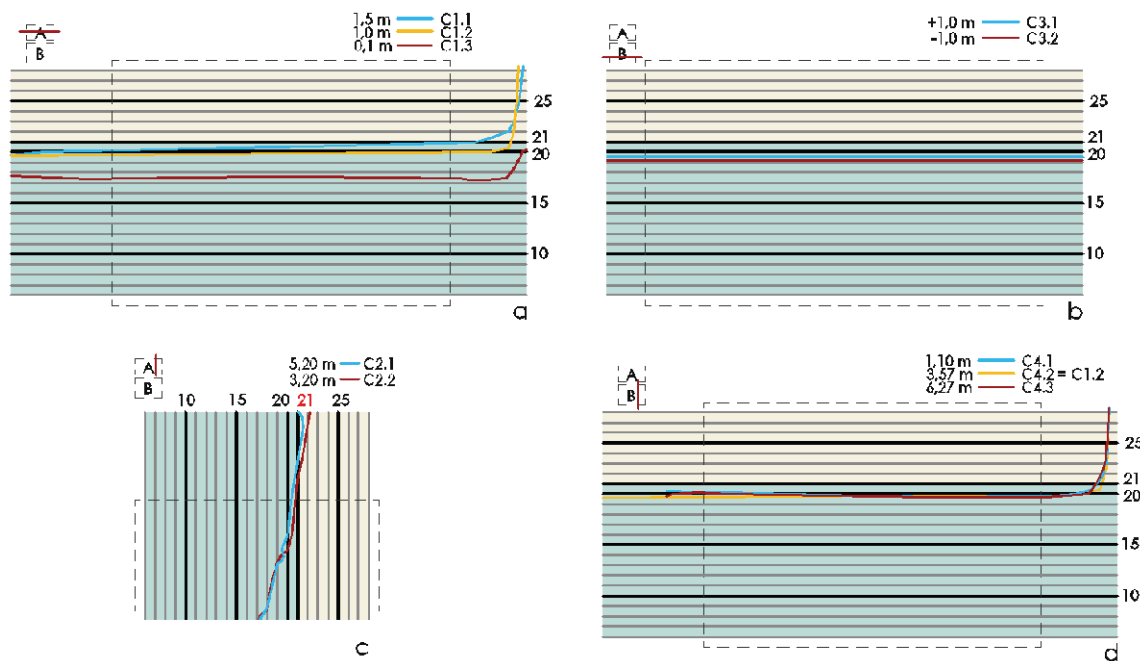


Fig. 4. Results of temperatures in the cuts in sections A and B of the model under study

From these graphs, thermal homogeneity can be observed in each of the horizontal cuts, and this only disappears as we approach the emission zone of the radiators (series C1 and C4). This thermal regularity can be noted especially when comparing cut C1.2 and the C3 and C4 series, all obtained at a height of one metre, with a practically constant temperature value of 20 °C.

In contrast, when we consider the horizontal graphs for the different heights (series C1), and especially in the vertical cuts (series C2), the thermal stratification within the 3-metre-high enclosure is clearly visible and ranges from 17 °C at floor level to 21 °C at ceiling level, a total difference of 4 °C. In the

occupied zone, from 10 to 150 cm, we find a difference of 2.5 °C.

#### 4. Conclusions

The radiator system under the windows attains category C in terms of thermal comfort, given that the system is not capable of uniformly exchanging the energy required according to node calculations for the location studied, as inevitably convective and stratification phenomena reduce efficiency to the point where heating needs are not resolved and comfort is not attained. The reason for this inability to reach the required operational temperature values is a result of the need to reach high air temperatures to compensate for the lower temperatures radiating from facings, and increased with the low correlation between the volume of air to be conditioned and the emitting surface. Given the above, the use of this system forces an increase in the energy consumption of the venue and increases discomfort in the heated area. The system also generates an area of discomfort within a radius of one metre from each of the exchange elements, and therefore occupying this area is discouraged as comfort within it cannot be guaranteed.

The above approach allows us to make progress in terms of the traditional calculations in the assessment of how energy is actually used in spaces and paves the way for the establishment of a methodology for the analysis of the efficiency of systems for the treatment of high-density enclosures.

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