POST-OCCUPANCY EVALUATION OF A HISTORIC PRIMARY SCHOOL IN SPAIN: COMPARING PMV, TSV AND PD FOR TEACHERS' AND PUPILS' THERMAL COMFORT

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Abstract: With attention increasingly shifting toward adaptation and energy upgrade of existing and historic buildings, research on Post-Occupancy Evaluation (POE) has grown notably in recent years. School buildings are a significant asset to the European building stock and an important field of investigation because of the peculiarities of the end users and the impact of indoor environmental conditions on their health and productivity. Building on recent literature, particularly the method of Povl Ole Fanger, this research presents the results of a quantitative and qualitative study performed to assess the thermal comfort conditions of a primary school located in a historic building in Villar del Arzobispo, Spain. As the study involves six and seven-year-old pupils, appropriate questionnaires for subjective thermal comfort evaluation were defined with the pedagogical support of the teachers, who also took part in the research and helped deliver the surveys to the children. The Predicted Mean Vote (PMV) and Percentage of Dissatisfied (PD) were then calculated for the evaluation of thermal comfort from measurements and questionnaires, for both pupils and teachers, using the classroom as a sample size. The results show a difference between pupils' and teachers' subjective opinions, with the children displaying a higher and more-difficult-to-reach threshold for indoor thermal comfort.

Keywords: Post-Occupancy Evaluation, Thermal Comfort, Indoor Environmental Quality, Historic Buildings, School Buildings.

Nomenclature

A_{Du}	Du Bois Surface Area
clo	Clothing Insulation (clo)
H	Height
PD	Percentage Dissatisfied
PEPD	Prevalent Environment Perception of Dissatisfaction
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity (%)

t	Temperature (ºC)
TPV	Thermal Predicted Vote
TSV	Thermal Sensation Vote
V	Air Velocity (m/s)
W	Weight

Superscripts

c	Calculated value
e	Estimated value
m	Measured value
s	Simulated value

Subscripts

a	Air
b	Body
p	Pupils
t	Teachers

1. Introduction

Numerous researches have focused on the assessment of indoor thermal comfort, proving the difficulty in calculating and predicting such comfort due to the importance of subjective perception for the analysis. By definition, thermal comfort is "[t]hat condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation" [1]. The engineer Tom DeMarco said that "[y]ou can't control what you can't measure" [2]; therefore, two methods exist to control indoor thermal comfort, which are the most commonly internationally used. Firstly, Povl Ole Fanger developed a statistical "rational" method that presents the Predicted Mean Vote (PMV), an index that predicts the mean value of the votes of a large group of persons on a 7-point thermal sensation scale according to the heat balance of the human body. He also developed the concept of the Predicted Percentage of Dissatisfied (PPD), an index that predicts the mean value of the thermal votes of a large group of people exposed to the same environment [3]. Secondly, the "adaptive" method [4] introduces the idea that occupants can adapt to different temperatures by interacting with the surrounding conditions, such as adding or removing insulation (clothing) and using operable windows. Both thermal comfort assessment procedures have been accepted as the basis of current international standards, such as the ASHRAE Standard 55 [1], the ISO 7730 [5] and the EN 15251 [6]. While these standards have been used in many Post-Occupancy Evaluation (POE) studies, they have proved to be quite inaccurate when applied to certain types of building uses and users [7–11]. For instance, some papers have recently pointed out that Fanger's method is not very accurate when applied to classrooms and to children [8,9,12].

Research on POE has grown dramatically, especially in the last two decades [13]. Additionally, the scientific community has found a research niche analyzing indoor environmental conditions of school buildings due to the number, distribution, occupancy rate and environmental quality of the existing schools. As an example, more than 65% of the current school buildings in Italy were built before 1975 and they do not meet the modern international performance requirements for energy efficiency and thermal comfort [14]. Most of the papers about this topic have been published in the last decade and Fanger's method is commonly used. Most of these articles also follow the same methodology: the monitoring of indoor and environmental conditions and the assessment of the occupants' thermal comfort levels through qualitative surveys. However, these papers have very different approaches. Katafygiotou et al. [15] found remarkable differences between thermal sensations based on gender, where females are more sensitive to low temperatures while males feel less thermal comfort at higher temperatures. In their work, De Giuli et al. [16] pointed out the relevance of the relationship between thermal comfort satisfaction and the physical position of pupils inside the classroom. Taking a step forward on Fanger's model [3] and following the adaptive approach [4], Liang et al. [17] published their study on how the level of thermal comfort in a non-ventilated classroom changes as a function of Average Window Solar Gain (SWSG). Additionally, Teli et al. [8] presented results stating that young students are more sensitive to higher temperatures than adults: 4ºC in the PMV and 2ºC on the adaptive comfort model predictions.

According to Mors et al. [9], Fanger's model is not accurate for predicting the thermal sensation in pupils. A number of further studies, have found that children prefer lower temperatures than predicted in both Fanger's method and adaptive models. Based on these studies and doubting that the mentioned models are applicable to children, Fabbri [18] introduced categories based on age for thermal comfort studies (children, young people, elderly people, the infirm, etc.). D'Ambrosio et al. [19] proposed an expectancy factor for the Mediterranean climate based on a study of 4,000 students in 200 naturally-ventilated classrooms. Two studies introduced building energy simulations in addition to the POE, which turned out to be a very useful tool in this kind of study [20,21]. Furthermore, the analysis of the Indoor Environmental Quality (IEQ) in school buildings, as a global concept, is also a very common approach among this research topic [12,22,23]. Moreover, papers have used IEQ evaluations in order to assess the potential of several energy efficiency measures [24] and CO_2 concentration limits in classrooms [25]. A very important outcome of this group of publications is the identification of the relationship between thermal comfort and student performance. Authors like Corgnati et al. [26] and Puteh et al. [27] published a number of investigations supporting this argument in relation to secondary and university classrooms. In 2016, a very complete review paper about thermal comfort in educational buildings was published [13], highlighting that the current thermal comfort standards are inappropriate for the assessment of classrooms.

Within these studies, however, historic buildings are not mentioned, mainly due to the difficulties in investigating their technological and thermal characteristics and their impacts on indoor environmental quality. This has recently stimulated researchers' interest in studying indoor environmental conditions of this type of construction. Li et al. [28,29] carried out two studies comparing occupants´ thermal comfort sensations in historic and new rural buildings in China. The results showed better thermal satisfaction in the historic buildings when compared with the modern buildings. Following the same line, Ealiwa et al. [10] concluded that ISO 7730 [5] cannot be used for old naturally ventilated buildings and found better overall indoor environmental conditions in old buildings (naturally ventilated) than in new buildings (air conditioned). Calis et al. [11] found that the regulations may not represent the real situation in buildings that have intermittent operational schedules (i.e., mosques). Buhagiar [30] carried out an investigation that included a POE and found that the occupants preferred to rely on the in-built physical features of the buildings rather than using the air-conditioning systems.

Despite the plethora of research focused on school buildings and historic constructions, there are only a few papers that merge the three concepts this article is focused on, that is, POE, historic constructions and school buildings. Lassandro et al. [31] introduced a new methodology combining POE, environmental monitoring, energy simulations and, as an innovative concept, a virtual tour to make audit results more friendly to the school community. IEQ analysis has also become a very important asset for POE investigations, as depicted by Hanna [32] who ran a wide study about daylighting, acoustics and thermal comfort using students' satisfaction responses at the Glasgow School of Art. Similarly, Kamaruzzaman et al. [33] investigated six historic buildings in Malaysia (only one of them was a school), where the results were used to make potential refurbishments aiming at improving IEQ. One of the first international projects funded by the International Energy Agency (IEA-ECBCS) is "Annex 36 - Energy Retrofit of Educational Buildings". A number of historic buildings have been assessed as case studies from the indoor environmental comfort point of view for the implementation of tools and guidelines for decision makers and designers to improve the learning and teaching environment of educational facilities through energy-efficient retrofitting [34]. A paper published by Buvik et al. [35] focused on energy efficiency and IEQ improvements in a historic school building and was the first part of a bigger European Union project called "School of the Future – Towards Zero Emission with High Performance Indoor Environment". Lastly, Teli et al. [7] conducted a research comparing thermal comfort satisfaction in two old school buildings and concluded that further investigation is required in school building design and refurbishment based on thermal comfort research with pupils in order to achieve environmental conditions which reflect children's thermal preferences.

While several thermal comfort studies have focused on historic school buildings [36], there are many questions that still need to be answered regarding this particular end-use. For example, kindergartens and primary school buildings are almost completely excluded from these types of investigations [13]. In addition, the negative effect on students' learning and teachers' performance in an unsatisfactory thermal environment is a real phenomenon that has been demonstrated by many investigations [37–39].

In Spain, until the 20th century, schools were often placed in buildings that were not built for this purpose and haylofts, private homes and inappropriate parts of public buildings (such as the cells of town halls) were commonly used as classrooms. This tendency has changed in the beginning of the 20th century, when a surge in the construction of school buildings occurred because of the increase of literacy nationwide. These constructions show many typological and technological similarities throughout the country due to the short period during which they were built (mainly between 1925 and the end of the Spanish Civil War in 1939) and because all schools were developed by (or the project was coordinated by) one single entity, that is the central Government. To this regard, Primo de Rivera's administrations developed an ambitious plan for building new schools throughout Spain. His project was further implemented during the 2nd Spanish Republic (1931-1939), with the main goal of eradicating illiteracy (almost 50% in 1931), leading to a relevant increase in the number of school buildings in Spain, many of which are still in use today [40]. These buildings do not meet the indoor environmental quality criteria defined for school buildings, starting with thermal comfort, which is considered an important factor for students' learning performance [13].

2. Goals of the research

The paper presents the results of a POE carried out on a 1927 historic primary school in Villar del Arzobispo, a small village nearby the city of Valencia, Spain.

The objectives of this research are:

- to perform a POE of a historic primary school, using both a quantitative (measurement of microclimate conditions) and a qualitative (questionnaires) approach;
- to define the appropriate questionnaire design for the subjective thermal comfort evaluation of pupils and teachers;
- to calculate the PMV and PD for the evaluation of thermal comfort from measurement and questionnaires, for both pupils and teachers, using the classroom as a sample;
- to compare variations between the pupils' and teachers' subjective opinions.

3. Methodology

3.1. Building Description

The building analyzed is "The School of Primary Education Fabián y Fuero" located in Villar del Arzobispo, Valencia, 50 kilometers inland from the Spanish Mediterranean coast. Villar del Arzobispo is 520 meters above sea level and its climate, according to Köppen classification [41], is Csa-Mediterranean Climate. The school, completed in 1927, was part of an educational building construction campaign; it was also used as a hospital during the Spanish Civil War (1936-1939).

Architecturally, the school is a magnificent example of the time, as the structure was first built in revoked stone in 1927. To separate the students by gender, the school building was originally designed as two independent structures. The two-story C-shaped building that stands today (Figure 1) emerged in 1930 when the two parts were connected to yield more space. It is a freestanding construction surrounded by a low-density urban environment, with the main façade facing South-West. The uninsulated building envelope is composed of a 60-centimeter thick revoked stone, finished with an approximately one-centimeter thick cement-based tinted plaster layer on both sides. A brick veneer molding surrounds the upper part of all windows and external doors, on the outer side. Additionally, part of the South-West wings façades shows decorated ceramic tiles elements between the coupled windows, which are a typical architectural expression of the construction period. All windows are original and are made of single-pane glazing and wooden frames with no blinds. A clay-tiles sloppy uninsulated roof with wooden structure covers the building. The components' thermal transmittances have been calculated by using an energy simulation software (DesignBuilder/Energyplus [42]), based on the data gathered on the field, and then compared with the thermal properties of building with similar technological features and built in the same period across the Country [43]. Table 1 summarizes the thicknesses and thermal transmittance of the building envelope. The building is naturally ventilated and there is no air conditioning system; however, windows are only opened after teaching hours, during cleaning, because teachers cannot reach the handles, which are 3.02 meters from the floor. A fuel-fed heating system with radiators is distributed throughout the building.

The school houses 10 classrooms with pupils between four and seven years of age. Thirteen teachers (12 women and one man) and 120 pupils occupy the building daily. The teaching schedule is from 9:00am to 5:00pm Monday through Friday, from October until May; a reduced teaching schedule is followed in September and June to avoid the summer heat (8:30am to 2:30pm).

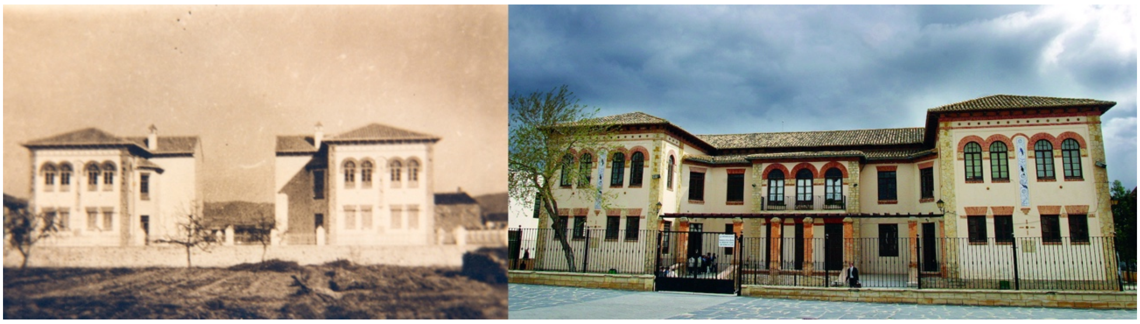

Figure 1. Original (left) and current (right) building appearance (source: City Council of Villar del Arzobispo).

Table 1. Thickness and thermal transmittance of the building envelope and openings.

Building component	Thickness [m]	U-value [W/m^{2}K]
External wall	0.60	0.352
Roof	0.50	2.930
Ground	0.30	1.062
External doors	0.04	3.633
Windows (glazing and frame)	0.06	5.778

3.2. Environmental monitoring

Meteorological and indoor environmental conditions of the school building were monitored for the duration of three months and data were gathered at one-hour intervals from October to December 2015 (Table 2). Four measuring instruments were strategically distributed (Figure 2) to measure the indoor environment characteristics such as air temperature, relative humidity and dew point. The choice of the measuring tools location depended on the following factors:

- the prescriptions of ISO 7726 [44], with particular attention to the precautions to be taken when using the monitoring tools;
- the types of teaching activity occurring inside the selected classes during the monitoring campaign, in order to limit as much as possible the mutual interferences between the pedagogical approach and the data loggers;
- the architectural, morphological and technological features (including the materiality) of the historic building, with particular attention to the historic surfaces and thermal effects caused by the presence of the wide single-pane windows.

Data logger #3 was the one placed in the classroom occupied by six and seven-year-old pupils; therefore, those are the measurements that were used for the thermal comfort calculations.

Table 3 shows the specifications of the devices used.

Table 2. Indoor and outdoor average conditions during the survey period for the days analyzed.

Date	Indoor conditions			Outdoor conditions					
	Air temperature [ºC]	Relative humidity [%]	Dew point [ºC]	Air temperature [ºC]	Relative humidity [%]	Solar radiation [W/m²]	Wind speed [Km/h]	Wind direction (prevalent)	Rain [mm]
06/11/15	18.7	69.8	13.0	19.1	69.2	374.1	7.3	West	0
13/11/15	18.1	72.9	13.1	15.9	70.3	242.3	5.2	West	0
20/11/15	18.5	67.5	12.4	18.8	49.6	350.4	9.9	West	0
27/11/15	20.2	44.8	7.8	13.6	58.7	288.3	3.7	East	0
04/12/15	20.8	48.4	9.4	13.4	50.8	334.0	8.9	West	0
11/12/15	20.7	49.5	9.7	12.3	57.7	300.7	6.7	West	0
18/12/15	22.1	45.0	9.6	18.9	30.6	218.1	12.1	West	0

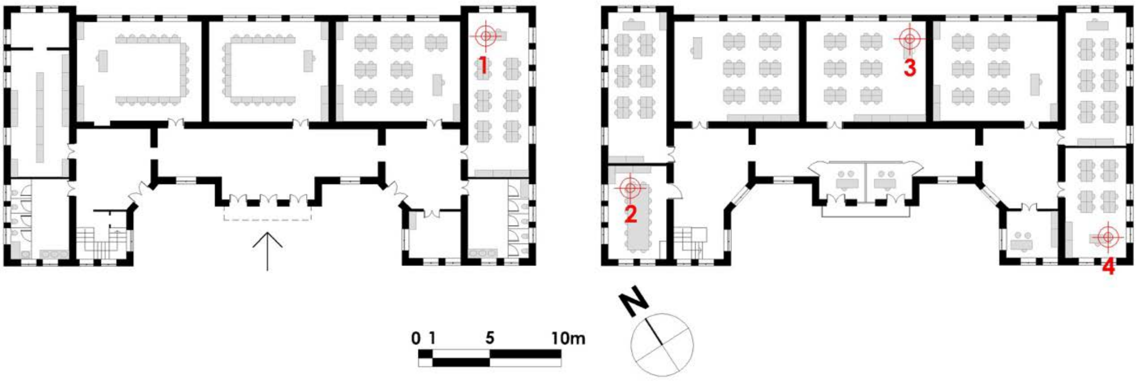

Figure 2 Building plans and dataloggers locations (ground floor on the left and first floor on the right).

Table 3. Specifications of the measuring equipment.

Probe	Measuring range	Resolution	Accuracy	Response time
Air temperature	-40 to +105ºC	0.1ºC	±1ºC (-10 to 55ºC)	60 sec.
Humidity	0 to 100%	0.1%	± 3% (3 to 97%)	60 sec.

3.3. Thermal comfort survey

The World Health Organization (WHO) defines thermal comfort as “a condition when people are satisfied with the thermal environment” and also declares that “health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” [45]. There is no doubt, therefore, that thermal comfort, also known as human comfort, needs to be assessed and taken into account in building rehabilitation.

In the case of the Primary School in Villar del Arzobispo, 10 teachers and 50 of the seven-year-old pupils participated to the study. Two full-time teachers and a classroom of students were the subjects used to compare thermal opinions under identical indoor environmental conditions. Two different surveys, one for adults and one for children, were designed and adapted to the classroom setting, making them easy to understand

and allowing for quick replies in order to avoid disrupting the regular dynamic of the class. Based on the six parameters for measuring thermal comfort described by the ASHRAE 55 [1] (air temperature, radiant temperature, air velocity, humidity, metabolic rate and clothing insulation), the questionnaires aimed at obtaining the necessary data needed to apply Fanger's method, including only the metabolic rate and clothing insulation, since the other parameters were either measured or estimated.

3.3.1. Teachers' questionnaire

The survey given to the teachers was designed to obtain all the necessary data for the PMV_t and PD_t calculation, according to Fanger's method. The teachers that were in the same room with the students answered the survey almost daily from October 1st to December 21st, with a total number of 104 completed questionnaires.

This teacher's survey included questions about:

- Thermal Sensation Vote (TSV_t) regarding the indoor thermal ambient, based on the ASHRAE 55's seven-point sensation scale [1] (Table 4);
- Clothing Insulation, where the most typical clothing items (based on ISO 7730 [5]) were provided on the questionnaire in order for the teachers to choose according to their outfit;
- subjects' Metabolic Rate, thermal perception of outdoors temperature and indoor air quality through a series of simplified questions.

3.3.2. Pupils' questionnaire

In order to evaluate the thermal comfort levels of primary school pupils (six – seven-year-olds), a subjective thermal satisfaction survey was designed by adapting the survey used for the teachers and taking into account the educators' recommendations to make the questions legible and child-friendly. Fifty pupils filled the survey biweekly from November 6th to December 18th, with the final sample consisting of 188 questionnaires. Pupils began filling out the questionnaires one month after the monitoring period began because, since the pupils were very young, an adaptation period for clarifying the task and creating a habit was requested by the teachers. The teachers working with the class to be surveyed defined a brand new pedagogical programme in order to explain the thermal sensations and the different thermal gradients to the children. This approach is based on cognitive factors that children of that age can understand because they pertain to their every-day world, such as a preferred season or an outdoor condition, and associating them with a personal feeling or emotion, such as happiness. With the guidance and the help of the teachers, this process of understanding the thermal preference was then translated into children-friendly symbols and pictures that the students could recognise and associate to the previously defined thermal sensations. To this regard, the teachers suggested that the use of a visual method would have been the most suitable way to avoid the students to repeat a previously heard answer, as the association between a sensation and a visual item is more immediate than the association between a sensation and a description in words, as this latter one needs to be processed in the students' mind. On the other side, using a visual support would have limited the teachers' influence in delivering the questionnaires, as the children were independent in their answers. The so-defined symbols and figures were then included into the questionnaire which was tested and further fine-tuned by the researchers before starting to record the children's answers. This solution guaranteed results that were more accurate and reliable by ensuring that the pupils received an induction to the questionnaires and understood the ~~process~~ meaning of the questions ahead of the survey campaign. Besides, the teachers had the opportunity to implement the cognitive aspects related to thermal comfort in their pedagogical programme.

This pupils' survey included questions about:

- Thermal Sensation Vote (TSV_p) as in the teachers' question, but adapted to make the language clearer for the children (Table 4);
- Thermal Preference Vote (TPV_p), based on the seven-point thermal sensation scale instead of the ASHRAE 55's three-point scale [1];
- Clothing Insulation. For this topic, the teachers suggested that details about the clothing should be omitted because this would have been difficult for children and would have taken them too much time to consider. It was therefore decided to ask a simple question about the most important clothes they were wearing from the point of view of insulation, that is whether a sweater or sweatshirt was worn;
- activity that the children had completed just before filling out the questionnaire; this information was used for the pupils' metabolic rate calculations.

Pupils were not asked about air quality or humidity (as in most of the surveys for adults) because the teachers thought that these questions would have been too difficult to understand.

Table 4. TSV_t and TSV_p values from Fanger's approach used for the pupils' and teachers' questionnaires.

Value	Thermal Sensation Vote (TSV_t)	Thermal Sensation Vote (TSV_p)
-3	Cold	Very cold
-2	Cool	Cold
-1	Slightly cool	A little cold
0	Neutral	Good
+1	Slightly warm	A little hot
+2	Warm	Hot
+3	Hot	Very hot

3.3.3. Clothing Insulation

Clothing insulation (clo) was measured differently for teachers and pupils. Teachers were given the most typical clothing options in their questionnaires, as indicated in ISO 7730 [5], so the values were calculated for each filled survey. On the other hand, the pupils' insulation question was simplified to only two options: whether or not they had a sweatshirt/sweater on. A typical outfit for summer and winter was also considered for boys and girls (also based on ISO 7730 [5]) according to teachers' opinion within the range of 0.34 clo for boys and 0.32 clo for girls. However, the main difference was whether or not the students had a jumper/sweater on (0.25 clo) since that was the only adaptive choice that the pupils were allowed to make (Table 5).

Table 5. Pupils' main clothing combinations according to teachers' opinion (all include underwear), based on ISO 7730 [5].

Garment description	Girls I_{clo}	Boys I_{clo}
Sleeveless dress, Sandals/shoes	0.28	N/A
Short-sleeve dress, Sandals/shoes	0.34	N/A

Sleeveless/scoop-neck blouse, Short shorts, Sandals/shoes	0.23	0.24
Short sleeve knit sport shirt, Short shorts, Sandals/shoes	0.28	0.29
Short-sleeve dress shirt, short shorts, Sandals/shoes	0.30	0.31
Short-sleeve dress shirt, Straight trousers, Sandals/shoes	0.39	0.40
Long-sleeve dress shirt, Straight trousers, Sandals/shoes	0.45	0.46
Average (sweater/sweatshirt OFF)	**0.32**	**0.34**
Average (sweater/sweatshirt ON)	**0.57**	**0.59**

3.3.4. Calculation of the metabolic rate for pupils' activities

The metabolic rates for different activities suggested by ISO 7730 [5] refer to the 'average' individual as defined in ISO 8996 [46]. When used for the calculation of the PMV, these values for the metabolic rate do not reflect the pupils' real physiological characteristics, with an evident error when calculating the thermal comfort conditions, as extensively discussed in Teli et al. [8]. There are a few examples of metabolic rate values evaluation for classroom activities [47]; however these are not specifically focused on six and seven-year-old pupils. Therefore, there is an overall need for studies related to comfort perception for children of a young age. Using the method suggested by Teli et al. [8] for the adjustment of adults' metabolic rate to pupils' physiological characteristics, this research evaluated the metabolic rate for the school activities observed in the case study.

In order to compare the metabolic rates with those of the adults, the 'average' child's characteristics had to be defined with consideration of the components affecting the body surface area according to the following Du Bois formula [46]:

$$A_{Du} = 0.202 \cdot W_b^{0.425} \cdot H_b^{0.725} \qquad (1)$$

in which

W_b is the body weight, in kilograms;

H_b is the body height, in meters.

Table 6 shows the growth reference data (age, weight, height) for boys and girls between six and seven years of age, according to the WHO [45] and a calculation of the Du Bois surface area, according to (1).

Table 6. Physiological characteristics and Du Bois surface area for six and seven-year-old pupils of the surveyed school.

Age [year:month]	**Boys**		**Girls**	
	Weight [kg]	**Height [m]**	**Weight [kg]**	**Height [m]**
6:0	20.50	1.160	20.20	1.151
6:1	20.70	1.164	20.30	1.156
6:2	20.90	1.169	20.50	1.161
6:3	21.10	1.174	20.70	1.166
6:4	21.30	1.179	20.90	1.170
6:5	21.50	1.140	21.00	1.175
6:6	21.70	1.189	21.20	1.180
6:7	21.90	1.194	21.40	1.184
6:8	22.10	1.198	21.60	1.189
6:9	22.30	1.203	21.80	1.194
6:10	22.50	1.208	22.00	1.199
6:11	22.70	1.213	22.20	1.203

7:0	22.90	1.210	22.40	1.208
7:1	23.10	1.222	22.60	1.213
7:2	23.30	1.227	22.80	1.218
7:3	23.50	1.231	23.00	1.222
7:4	23.70	1.236	23.20	1.227
7:5	23.90	1.241	23.40	1.232
7:6	24.10	1.245	23.60	1.237
7:7	24.30	1.250	23.90	1.241
7:8	24.60	1.255	24.10	1.246
7:9	24.80	1.259	24.30	1.251
7:10	25.00	1.264	24.50	1.256
7:11	25.20	1.268	24.80	1.261
Mean by gender	**22.82**	**1.212**	**22.350**	**1.157**
$A_{Du,children}$ by gender [m^2]	**0.878**		**0.841**	
$A_{Du,children}$ mean [m^2]	**0.859**			

The standard individual physiological characteristics, according to ISO 8996 [46] and Du Bois surface area (1) for adults, were calculated, as shown in Table 7.

Table 7. Physiological characteristics and Du Bois surface area for the 'average adult'.

Age [years]	**Male**		**Female**	
	Weight [kg]	**Height [m]**	**Weight [kg]**	**Height [m]**
30	70.00	1.750	60.00	1.700
$A_{Du,adults}$ by gender [m^2]	**1.844**		**1.691**	
$A_{Du,adults}$ mean [m^2]	**1.767**			

In the approach suggested by Teli et al. [8], the input activity metabolic rate is corrected for the reduced area of a child, a method that, amongst those presented in the paper, was demonstrated as the most reasonable to predict the thermal sensation of pupils under the PMV model and, therefore, used also for the case study in this research. First, a correspondence between the standard activities listed in ISO 7730 [5] and the school activities was defined based on the observations while accounting for the pedagogical approach adopted in the school for the monitored class. Then, the associated metabolic rates were corrected with consideration of the ratio between the adults' and the children's body surface areas (1.767/0.859=2.06). The related met was calculated from the metabolic rate of the sedentary person (seated, relaxed), according to the ISO 7730 [5] definition (where 1 met=58.2 W/m^2). Table 8 shows the correspondence between activities and the results of the corrections on the metabolic rates. The values were then associated with the clothing insulation for each activity and used to determine the PMV_p. It is to be noted that these values were used only as an adjustment factor for the PMV_p calculation in order to achieve results that took into account the physiological characteristics of pupils of young age.

Table 8. Comparison between the standard activities (and related metabolic rates) according to ISO 7730 [5] and the activities (and related corrected metabolic rates) monitored in the case study during the survey.

Activity (according to ISO 7730 [5]**)**	**Metabolic rate, adults (according to ISO 7730** [5]**)**		**Activity (correspondence with surveyed school activities)**	**Metabolic rate, pupils (corrected with the reduced Du Bois surface area)**	
	[W/m^2]	**met**		**[W/m^2]**	**met**

Seated, relaxed	58	1.0	Resting in the playground	119	2.1
Sedentary activity (office, dwelling, school, laboratory)	70	1.2	Classroom activity	144	2.5
			Eating seated		
Walking on level ground (2 km/h)	110	1.9	Physical education	226	3.9
Standing, medium activity (shop assistant, domestic work)	116	2.0	Playing/Running in playground	239	4.1

4. Results of the research

This section presents the results of the quantitative objective monitoring through data logger and the results of the qualitative investigation through questionnaires, in order to assess both pupils' and teachers' satisfaction with the thermal environment.

Three comparisons were made:

- comparison of TSV and PD values between teachers and pupils corresponding to the surveys;
- comparison between TSV and PMV for teachers using Fanger's model;
- comparison between TSV and PMV for pupils, using the method suggested by Teli et al. [8] for the calculation of the adjusted metabolic rate.

The recorded data were elaborated in order to evaluate Fanger's thermal comfort indices, PMV and PD, according to ISO 7730 [5]. Thermal comfort indices were calculated using MATLAB, according to Annex D of ISO 7730 [5].

In the presented case study, data input relating to environmental conditions were:

- Air Temperature (t_a);
- Radiant Temperature (t_a ± 1 ºC, according to [25]);
- Air Velocity (V_a, according to [5]);
- Relative Humidity (RH).

The other considered parameters were:

- Clothing Insulation (clo, obtained from the questionnaires and calculated according to [5]);
- Metabolic Rate (met, considering activity, according to [5] and according to Table 8, depending on the comparison considered);
- Mechanical Power or External Work (according to [5]);

Table 9 summarizes the data input considered for the three simulations.

Table 9. Summary of the parameters used in the three simulations. The bold values are variable in each simulation.

Parameters	**Simulation classroom**			**Mean**
	I	**II**	**III**	
Air Temperature [ºC]^{m}	t_a	t_a	t_a	
Radiant Temperature [ºC]^{s}	t_a	$t_a - 1$	$t_a + 1$	
Air Velocity [m/s]^{e}	0.1	0.1	0.1	
Relative Humidity [%]^{m}	RH	RH	RH	
Clothing Insulation [clo]^{c}	clo	clo	clo	
Metabolic Rate [met]^{e}	met	met	met	
Mechanical Power [W/m^2] ^{e}	0	0	0	

PMV	PMV_I	PMV_{II}	PMV_{III}	PMV_m
PD	PD_I	PD_{II}	PD_{III}	PD_m

[c]Calculated Value [5]; [e] Estimated Value [5]; [m] Measured Value [44]; [s] Simulated Value [25];.

4.1. Comparison of TSV and PD values between teachers and pupils

The first approach focused on comparing values between teachers and pupils. The ASHRAE 55 scales [1] were used as benchmarks for all values.

The dissatisfied pupils first assessed were those who voted (–3;–2) and (+2;+3) on the seven-point thermal sensation scale, following the approach used by Fanger in his experiments [3] (PD_p in Table 10). Then, the dissatisfied pupils who voted (–3;–2) and (+3) on the seven-point thermal sensation scale were assessed (PD_p* in Table 10). The analysis of the elaborated data from the questionnaires showed that the discordance among the PD values could have been a result of subjective thermal environment perceptions. A vote of (+2) is considered unacceptable by Fanger's approach; however in this study, environments receiving a vote of (+2) were acceptable, as evidenced by the analysis of the subjective feedback regarding the acceptability of a thermal environment. In fact, since pupils voting (–3;–2) and (+3) were considered dissatisfied, and pupils voting (+2) were considered satisfied, the PD_p* was well aligned. This approach was also used by Corgnati et al. [26], who highlighted a lack of agreement between the measured PD_p and PD_p* when people were voting (–3;–2) and (+2;+3) on the seven-point thermal sensation scale. Therefore, the correspondent values were considered as showing dissatisfaction.

In the pupils' Thermal Sensation Votes (TSV_p) (Table 10), 30% of answers reflected pupils' dissatisfaction (PD_p); however, this minimum decreased to 18% when PD_p* values were calculated. The maximum PD_p value was obtained with 63% of dissatisfied pupils (6th November). The same profile was observed in the PD_p* values, except for 11th December (41%) when the PD_p value increased compared to the previous week (30%), and the PD_p* value remained similar (20% and 18%).

The teachers' Thermal Sensation Votes (TSV_t) (Table 11) accounted for one day (27th November), with dissatisfied values corresponding to a prevalent environment perceived as cold, which corresponded to pupils' perception for PD*.

Table 10. Pupils' Thermal Sensation Vote (TSV_p), Percentage of Dissatisfied pupils from questionnaires (PD_p), Prevalent Environment Perception of Dissatisfaction ($PEPD_p$) from questionnaires for the days analyzed.

Date	**TSV_p**	**PD_p (%)**	**$PEPD_p$**	**PD_p* (%)**	**$PEPD_p$***
06/11/2015	+0.42	63%	Hot	53%	Hot
13/11/2015	-0.12	35%	No Preference	29%	Cold
20/11/2015	+0.70	39%	Hot	30%	Hot
27/11/2015	-0.24	32%	Cold	24%	Cold
04/12/2015	-0.25	30%	Cold	20%	Cold
11/12/2015	+0.94	41%	Hot	18%	Hot
18/12/2015	+0.22	39%	Hot	22%	No Preference

Table 11. Teachers' Thermal Sensation Vote (TSV_t), Percentage of Dissatisfied teachers from questionnaires (PD_t), Prevalent Environment Perception of Dissatisfaction ($PEPD_t$) from questionnaires for the days analyzed.

Date	**TSV_t**	**PD_t (%)**	**$PEPD_t$**	**PD_t* (%)**	**$PEPD_t$***

06/11/2015	-0.50	0%	No Preference	0%	No Preference
13/11/2015	0.00	0%	No Preference	0%	No Preference
20/11/2015	0.00	0%	No Preference	0%	No Preference
27/11/2015	-1.00	50%	Cold	50%	Cold
04/12/2015	0.50	0%	No Preference	0%	No Preference
11/12/2015	0.00	0%	No Preference	0%	No Preference
18/12/2015	0.00	0%	No Preference	0%	No Preference

Figure 3 shows the TSV_p values for pupils, summarizing the whole data per day using the mean and standard deviation. Although the mean values in each day indicated that the children were comfortable with the thermal environment, the range indicates that an important number of pupils were not comfortable, in alignment with the PD values in Table 10.

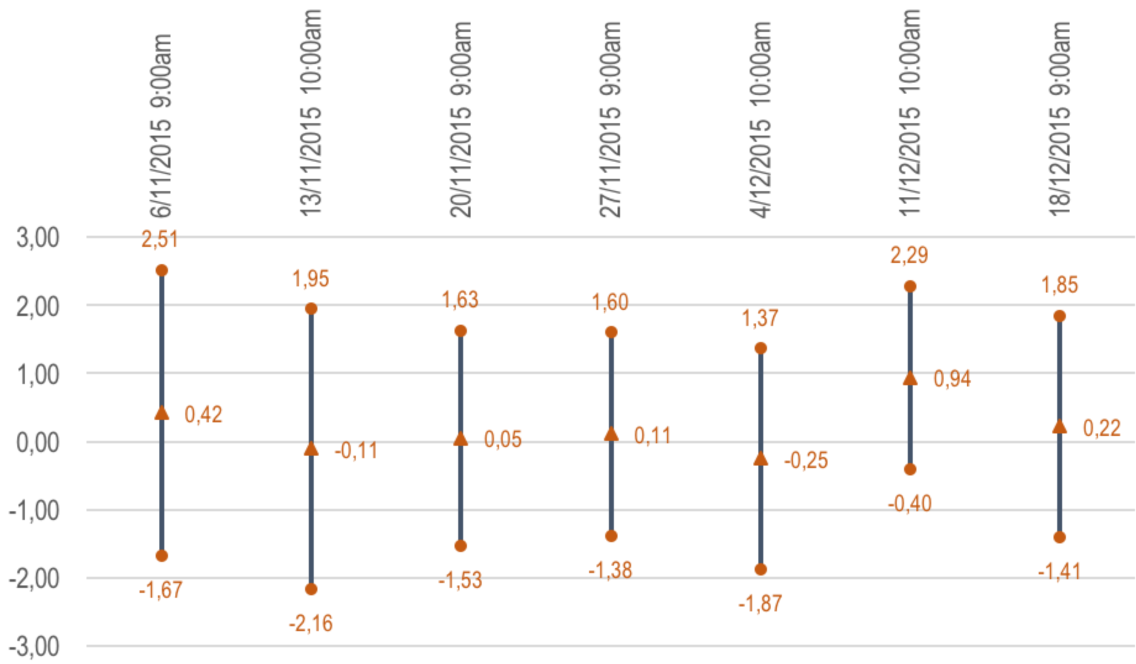

Figure 3. Subjective responses (TSV_p) for pupils (mean and standard deviation votes).

Table 12 compares the Thermal Sensation Vote indexes for pupils (TSV_p) and teachers (TSV_t). The maximum correlation between pupils and teachers was evident in the case of satisfaction, or value 0 in the ASHRAE 55's scale [1] (30%).

Table 12. Matrix of Thermal Sensation Vote indexes for pupils (TSV_p) and teachers (TSV_t).

		TSV_t						
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**
TSV_p	**-3**	0	5	0	12	0	0	0
	-2	0	0	0	10	0	0	0
	-1	0	2	0	27	0	0	0
	0	0	4	0	57	0	0	0
	1	0	4	0	21	0	0	0
	2	0	0	0	20	0	0	0
	3	0	1	0	25	0	0	0

Figure 4 and Figure 5 show the correlation between the Thermal Sensation Vote indexes for pupils (TSV_p) and teachers (TSV_t), highlighting that a correspondence was present only between the TSV_p interval (–1;+1) and the TSV_t interval (0) in the ASHRAE 55's scale [1].

The judgments on the seven-point thermal sensation scale were then correlated to their acceptability, as shown in Figure 5. The subjective judgments on the seven-point thermal sensation scale were then divided into three intervals, namely: i) (–3;–2); ii) (+2;+3); and iii) (–1;+1). According to Fanger's theory, the microclimate is not acceptable in the first and second intervals, while votes of (–1), (0) and (+1) describe acceptable thermal environments.

The pupils' answers, in terms of acceptability, were plotted by grouping the results into the three intervals previously defined. While teachers mostly (92%) expressed a vote within the interval (–1;+1), about 60% of the pupils considered this thermal environment 'acceptable'. Therefore, pupils and teachers agreed on the acceptability of the thermal environment only 57% of the time (Figure 4 and Table 12).

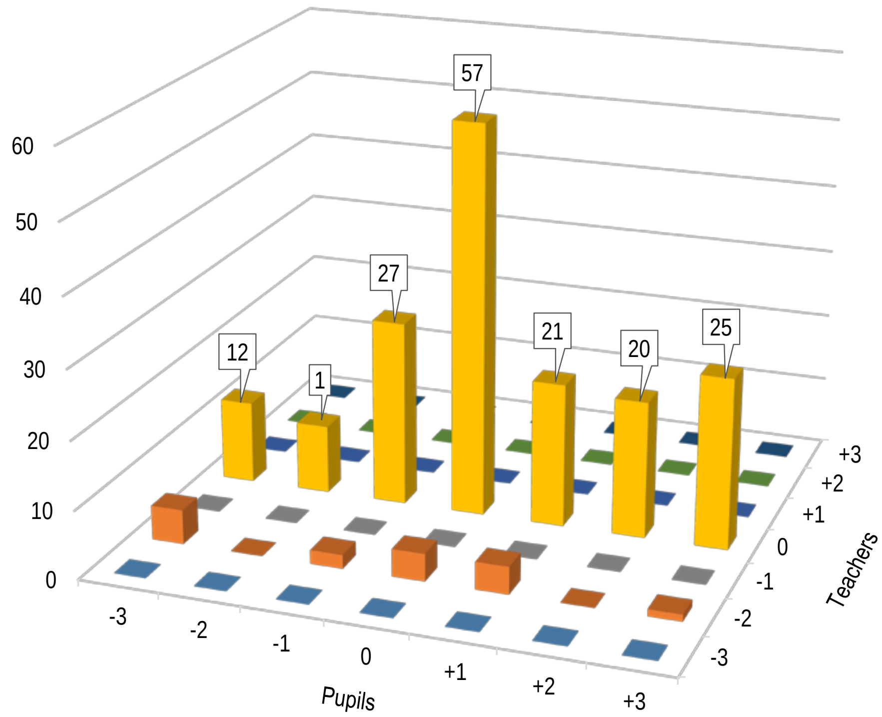

Figure 4. Correlation between Thermal Sensation Vote indexes for pupils (TSV_p) and teachers (TSV_t).

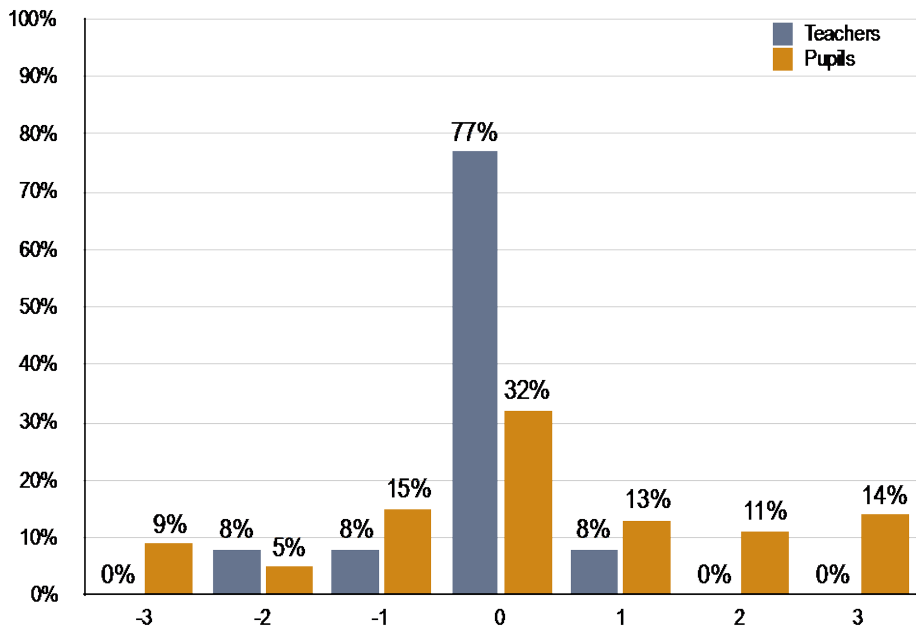

Figure 5. Total Thermal Sensation Vote indexes for pupils (TSV_p) and teachers (TSV_t) during the period analyzed registered by surveys.

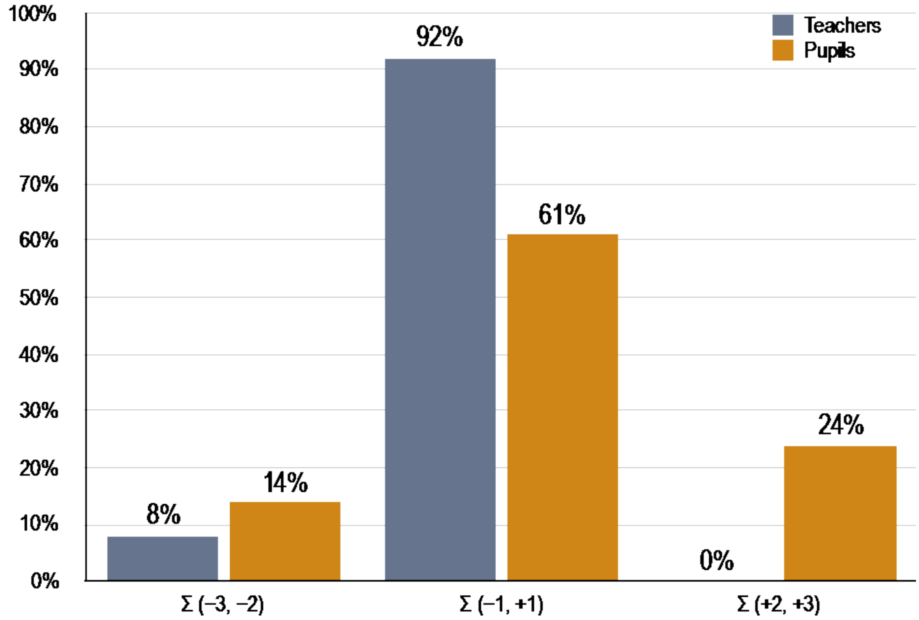

Figure 6. Subjective judgment about the acceptability of the thermal environment grouped in (–3;–2), (–1;+1) and (+2;+3) for pupils and teachers during the period analyzed registered by surveys.

Table 13. Matrix of Predicted Mean Vote indexes for pupils (PMV_p) and teachers (PMV_t) grouped in (–3;–2), (–1;+1) and (+2;+3).

		PMV_t		
		Σ (−3,−2)	**Σ (−1,+1)**	**Σ (+2,+3)**
PMVp	**Σ (−3,−2)**	5	22	0
	Σ (−1,+1)	10	105	0
	Σ (+2,+3)	1	45	0

4.2. Comparison between TSV_t and PMV_t for teachers using Fanger's model

PMV values for the teachers were obtained using Fanger's thermal comfort model, calculated with MATLAB and according to Annex D of ISO 7730 [5]. In this case, indoor values were used for data input, i.e. air temperature, air velocity (0.1 m/s) [5] and relative humidity. Radiant temperature was estimated based on air temperature (t_a ± 1 ºC) [25]. Clothing Insulation values (clo) were obtained from the questionnaires (calculated according to [5]). Finally, the teachers' metabolic rate (met) was estimated considering teaching as a light activity; therefore, 1.6 met was the established rate (also according to [5]). In order to calculate PMV_t, three simulations were run for each indoor condition (due to the three options of radiant temperature, $t_a, t_a - 1,\ t_a + 1$). The mean results of these simulations were taken as PMV_t.

Figure 7 shows the indoor Thermal Sensation Vote (TSV_t), which is plotted along with the PMV_t values calculated in the classroom (as previously presented in Table 9). PMV_t values were slightly higher than the TSV_t votes. Additionally, most of the time teachers expressed a vote within the interval –1 and +1. The same result was obtained using Fanger's model and the prediction was therefore aligned. Both votes, measured and calculated, varied between "slightly cool" and "slightly warm".

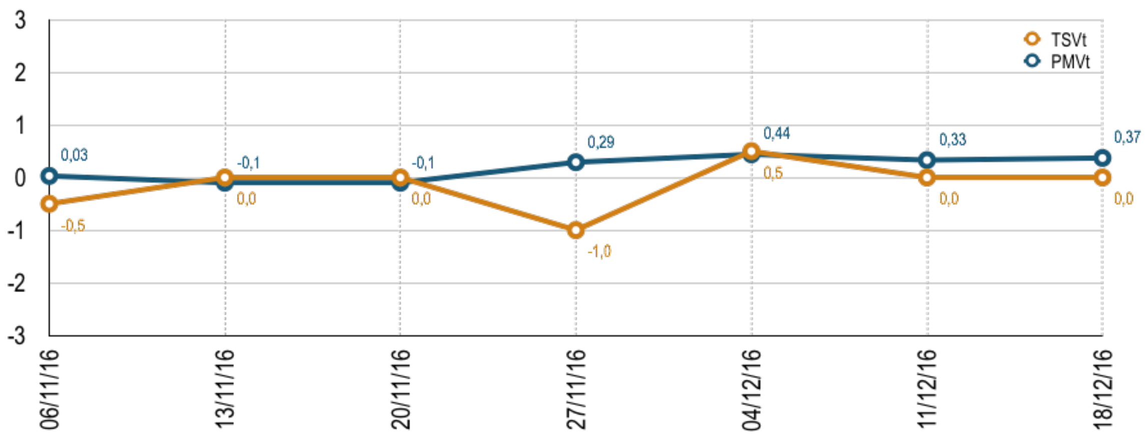

Figure 7. Subjective responses (TSV_t) and Predicted Mean Vote indexes for teachers (PMV_t) per day.

4.3. Comparison of TSV_p values versus PMV_p for pupils, using the method suggested by Teli et al. [8] *for the calculation of the adjusted metabolic rate*

PMV_p values for pupils were obtained using the method suggested by Teli et al. [8] for the adjusted metabolic rate. As calculated for teachers, indoor values were used for data input, i.e., air temperature, air velocity (0.1 m/s) and relative humidity. Again, radiant temperature was estimated based on air temperature (ta ± 1 ºC) and clothing Insulation (clo) was measured from the questionnaires (according to [5]). The metabolic rate (met) for pupils was obtained from questionnaires considering the correction based on the reduced Du Bois surface area according to Table 8. To calculate the Predicted Mean Vote for pupils, three simulations were run and their mean values were used as PMV_t.

Figure 8 shows PMV_p values. PMV_p averages were generally higher than the TSV_p averages of the pupils (Figure 6). However, PMV_p values (range) were mostly within the range of the TSV_p values except for 13th November and 27th November. In terms of the deviation values, the PMV_p rates were always lower than the TSV_p deviation values except for 13th November.

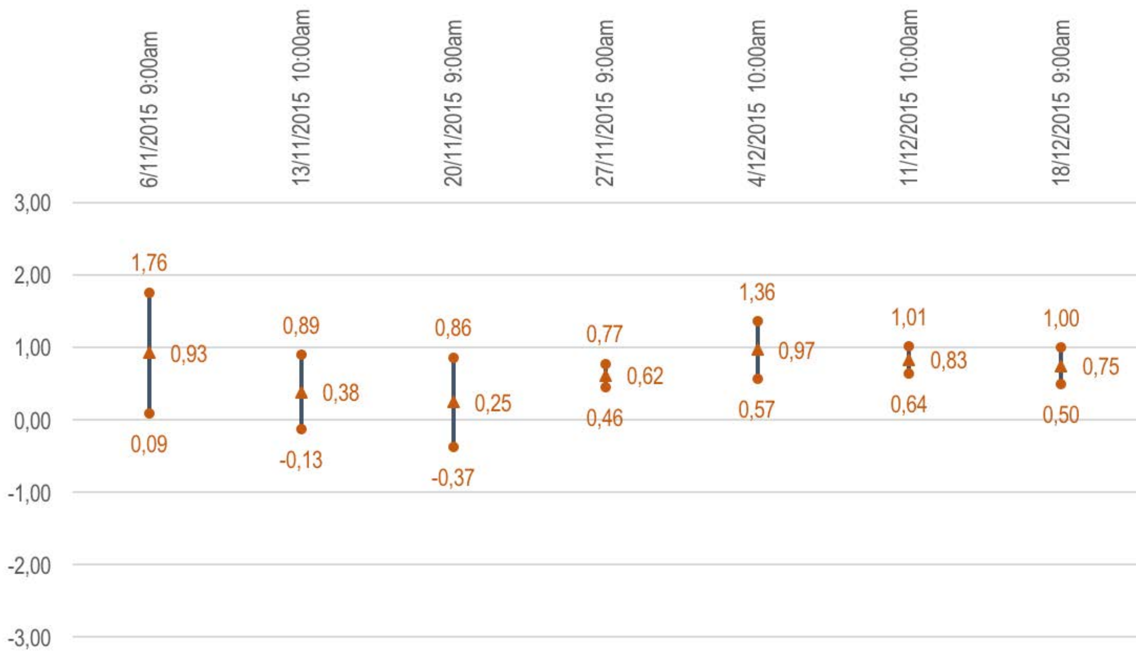

Figure 8. PMV_p calculated votes (mean and standard deviation votes) for pupils.

5. Discussion

As discussed in the introduction, the research originated by Fanger did not include children in the sample of occupants for the evaluation of thermal comfort [48]; in fact, only a few studies have begun to focus on young children for the purpose of assessing indoor thermal comfort conditions or a wider IEQ [9,12,18]. In terms of qualitative assessment through questionnaires, kindergarten and primary schools represent the most critical and difficult fields of analysis due to the characteristics of the occupants. For example, the thermal comfort perception of children is different from adults (due to a different metabolic rate, skin temperature and the production of sweat for temperature regulation) and can be affected also by non-environmental factors, requiring a psychological and pedagogical approach. Furthermore, it is relevant to highlight that children of a young age are not always able to understand the concept of thermal comfort or to describe their personal perception according to the seven-point thermal sensation scale. Likewise, interactions with other classmates can potentially influence the responses from those pupils who tend to align their answers with the general feedback. In order to tackle these threats, this study developed a questionnaire for the evaluation of thermal comfort that was specifically designed to address the level of understanding of young students. As such, the questionnaire utilizes both figures and colors that are familiar to the pupils, as they pertain to their field of knowledge, trigging a correspondent personal perception and feeling about the surrounding environment. The questionnaires were designed together with the teachers, in order to ensure that the language and the information asked were understandable by the pupils.

The simplification adopted for the investigation of the pupils' thermal comfort was also required for the analysis of the level of clothing worn by the children and their metabolic rates at the time the questionnaire was taken. The teachers advised that pupils would not have been able to keep the necessary level of attention for listing all the clothes they were wearing when the questionnaires were distributed. To assess the metabolic rates, the same approach and simplification was taken and the children were asked to describe their activity, choosing from a simple list of the more recurrent activities during a typical school day, depicted by basic figures and drawings.

Besides the fine-tuning of the pedagogical approach for the questionnaire, the co-operation with the teachers was also important for carrying out the question time with the pupils. Their presence and assistance was necessary in order to ensure that the pupils could express their true perception about the thermal environment, avoiding psychological pressures resulting from the presence of strangers and thereby leading to false or insincere answers, which could be potentially misleading for the investigation. Teachers knew the pupils very well and they could immediately determine whether they were answering truthfully or if they were influenced by external factors (for instance, the presence of the researcher), thus helping the process of information gathering.

In terms of the assessment of the occupants' satisfaction with the thermal environment, it is relevant to highlight that both pupils and teachers showed dissatisfaction on 27th November. According to the monitoring of outdoor conditions (Table 2), the outdoor air temperature was 13.6°C and the relative humidity was 58.7%, with light easterly winds and a moderate solar radiation. Although the indoor air temperature registered as 20.2°C, both pupils and teachers expressed a sensation of cold. It is to be noted that the thermal heating was not working on that day as the beginning of the heating period was 1st December. This condition could have been caused by radiant temperature asymmetry due to the thermal qualities of the historic building, where the original wide single-pane windows together with the high thermal mass of the opaque enclosures produced local discomfort and reduced the thermal acceptability of the space. This aspect is to be considered together with the overall thermal performances of the opaque envelope, which had very high thermal transmittance for the pitched roof (2.930 W/m^{2}K) and the floor towards the ground (1.062 W/m^{2}K). The vertical walls had acceptable thermal transmittance; however, the window-to-wall ratio was very high and thus did not contribute effectively to the containment of thermal losses.

Windows are a very peculiar feature in historic schools built in the early 20th Century in Spain and number, size, location, materials, opening methods and thermal transmittance can be a critical point to be tackled. On one side, the very wide dimensions (2,66 m high and 1,73 m width) and the numerous window units were originally designed to allow the natural light to enter the classes as much as possible, thus promoting visual comfort and healthy conditions for pupils and teachers, mainly in juxtaposition with the poor conditions of the previous period's schools. However, the same feature represents a significant issue in terms of energy loss (because of the very high U-values, mainly due to the lack of maintenance and technological upgrades by the property managers over time) and thermal comfort (mainly causing radiant temperature asymmetry). On the other side, the dimensions and opening mechanisms of such windows do not allow an effective natural ventilation inside the classrooms. In fact, similarly to the other historic schools pertaining to the same period, the windows of the case study analyzed in this research presented a very high sill and the position of the window's handle was placed in a very high point of the wide glazed panes (more than 3 m from the floor), not reachable by the majority of the teachers in the schools, who commonly decided not to open the windows because difficult and not safe for the children. This architectural and morphological connotation, together with the lack of any mechanical ventilation units in the building, affects the classrooms ventilation (which happens only at the end of the school day and it is performed by the cleaning team) and the indoor environmental quality in general. Another issue related to the windows was the lack of solar shading (only internal light curtains are present, but are not an efficient solution for protecting from overheating and glare inside the classrooms). In fact, the adult occupants reported very hot days in both the summer and winter school seasons, which could be attributed to solar gains due to the building orientation, the high thermal inertia and the fact that a large percentage of the external envelope consisted of unprotected single pane windows. To this regard, the difficulties in opening the windows during the hot season or during the days with high irradiation, due to both the dimension of the panes (safety issues) and the position of the handle (operability of the device), represent a critical issue which is very common in historic school buildings. Since natural ventilation is the only mean for cooling down the indoor temperature, this lack of control over the windowpanes contributes to the increase of thermal discomfort, thus avoiding the possibility of an interaction between the users and the surrounding environment and, therefore, of an adaptive comfort.

Additional environmental monitoring and more research are required to understand the dynamics of overheating beyond the period surveyed in this research, thus contributing to the definition of possible effective solutions for such typology of buildings.

6. Conclusions

This paper analyzed and summarized the results of the investigation on a historic primary school building in Spain, where both students and teachers were actively involved in gaining an understanding of their satisfaction with the thermal environment during the daily activities inside a sample of classrooms. A quantitative objective method with data logger was used to gather micro-environmental data in order to support the calculation of the Predicted Mean Vote (PMV) and the Percentage of Dissatisfied (PD) for teachers' and pupils' thermal comfort from measurement. Then, these indices were compared with the feedback from the questionnaires (the qualitative subjective method). The study showed the differences between pupils and teachers in terms of satisfaction with the thermal environment, demonstrating that the children perceived thermal comfort in a different way than the adults when applying Fanger's model. These disparities between adults and children are supported by some researchers; however, this study also shows that the indoor environmental peculiarities of a historic building do not affect the expected alterations in the comparison. Therefore, an alternative comparison was made by adjusting the values for children's metabolic rate according to the data on weight and height provided by the World Health Organization for typical six and seven-year-old pupils.

The design of the questionnaire was customized for children of a young age in order to perform a qualitative evaluation of thermal comfort in classrooms. Teachers co-operated closely with the researchers, both in the pedagogical approach and the assisted delivery phase. This was an important part of the research and represented an original contribution to a field where there is still a lack of data.

Moreover, this study investigated feedback on thermal comfort in a historic school building, where an accurate assessment of the current thermal environment, according to the building's use and the type of occupant, could positively contribute to the definition of potential future retrofit activities, thus respecting and protecting the existing building's heritage values. Post-Occupancy Evaluation, through a combined quantitative and qualitative assessment (including users' feedback), is an important method for determining which factors affect a school's thermal environment, energy performance and indoor environmental quality [49] and for understanding the opportunities for performance upgrading [50]. Although providing a roadmap for the improvement of a building's thermal quality is an important initiative for delivering indoor thermal comfort [51], the historic significance of the building needs to be taken into account in order to achieve a heritage-sensitive upgrading.

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