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Thermal comfort and adaptive capacities: Differences among students at various school stages

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ABSTRACT

In educational buildings, ensuring thermal comfort is crucial in guaranteeing pupils' health and high learning. Previous studies show different thermal comfort expectations in the educational stage. However, only a few studies have simultaneously investigated all educational stages and considered schools and universities in different areas. In this study, data collected from 24 classrooms in the winter and 1548 questionnaires were used to analyse all the educational stages in one region, thus minimising the possible bias associated with the climate zone, operation mode, and cultural adaptation. Hence, all differences in the perception of the thermal environment were likely to be due to only the educational stage. The results showed that adaptive capacities, such as clothing insulation and window operation, decrease at lower educational stages. Neutral, comfort and preferred temperatures are largely dependent on the educational stage and increase with it (e.g. 20.6, 21.7, 23.1, and 23.6 °C for primary school, middle school, high school, and university, respectively). Furthermore, a linear relationship between students' age and neutral temperature was derived. These differences in thermal comfort expectations were reflected in the variable predictive capability of the predicted mean vote (the greatest difference between predicted and actual thermal sensations in primary school). Overall, this study provides evidence of the necessity for thermal comfort models that can capture variations depending on the educational stage.

1. Introduction

Students spend a considerable amount of time in schools, which implies that they can be exposed to unfavourable Indoor Environmental Quality (IEQ) [1]. As the purpose of educational buildings is to provide the best learning conditions for students and teachers, classrooms should be designed to improve concentration and stimulate the learning process [2–4].

Current comfort standards, such as ISO (International Organization for Standardization) 7730 [5], EN (European Norm) 16798-1 [6], and ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) Standard 55 [7], determine the design values for operative temperatures and comfort equations based on two main approaches: the heat balance [8] and the adaptive [9,10] ones. The first approach involves the predicted mean vote (PMV) model, which is based on the heat exchange between the human body and the surrounding thermal environment and does not consider the hypothesis that people can adapt to their surroundings for achieving comfort (e.g. opening a window or changing clothing insulation). The second approach involves an adaptive model, which assumes that indoor comfort depends on the relationship between indoor operative temperature and outdoor temperature [11].

In these standards, different perceptions at diverse educational stages are not considered. However, several studies have shown that students' thermal preferences are typically outside the comfort range provided by the standards [12] and that their requirements and preferences cannot be generalised but should be investigated based on age.

At different educational stages, students exhibit different metabolic rates, perform different activities, and have different adaptive capacities [12]. Since the age of students is an important aspect to evaluate, researchers have analysed thermal comfort in school buildings based on the educational stage, where the peculiarities of primary [13,14], secondary [15,16], or university levels [17,18] were evaluated. Ter Mors et al. [13] investigated three free-running primary schools in the Netherlands and reported that the PMV–Predicted Percentage of Dissatisfied (PPD) method underestimated the thermal sensation for

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children by up to 1.5 points. Dias Pereira et al. [16] conducted a field study in Portuguese secondary classrooms during mid-season under free-running conditions and discovered that students accepted a temperature of up to 25.2 °C and that, in general, students accepted temperature ranges higher than the normal ranges. Nico et al. [17] evaluated thermal comfort in university classrooms in Bari during winter and discovered that the PMV values were consistent with the actual thermal sensation reported in the questionnaires.

Only a few studies investigated all the educational stages simultaneously and, generally, the different schools and universities were located in different areas, thus limiting the possibility of distinguishing between the effects of the educational stage (e.g. age and activity type) and other aspects such as climate or cultural habits. In fact, the climate zone can modify the perception of thermal comfort significantly, since the thermal history can affect the students' acclimatisation ability, and the external conditions can affect the indoor environment and thermal insulation of the clothing worn by the students [13]. Furthermore, because field studies are typically based on school buildings with different operation modes, this factor can also affect students' thermal perception. Different operation modes and systems are likely to generate different thermal environments (e.g. more steady state and uniform in air-conditioned buildings and transient in free-running buildings) as well as affect the occupants' actual and perceived control over the thermal environment, which may alter their thermal expectation [19].

Differences due to the different geographic areas and operation modes might explain the different results obtained by studies that compare the thermal comfort temperatures among the different educational stages [12,20,21]. Lamberti et al. [20] extensively analysed existing studies and highlighted comfort temperature intervals of 14.7–30 °C, 14.7–35 °C, and 15.5–31.5 °C for primary schools, secondary schools, and universities, respectively.

In this study, buildings from all educational stages (from primary to university level) were investigated under the same operation mode and climate. Hence, all differences in the perception of the thermal environment were more likely to be due to only the educational stage.

Thus, this study aimed to (i) develop a better understanding of students' perception of the thermal environment at different educational stages based on different adaptive behaviours and thermal comfort; (ii) define quantitative relationships between thermal expectations and educational stage; and (iii) evaluate whether the predictive performance of the PMV–PPD model varies with the educational stage.

2. Methodology

The survey included a field study involving 24 classrooms in 11 school buildings from different educational stages in Pisa province during winter. Field environmental measurements and questionnaire surveys were conducted simultaneously.

2.1. School buildings

Case studies in the same location were performed to analyse different educational stages in the same climate zone of Pisa (which is part of 'group Csa' in the Köppen–Geiger classification and 'climate D' in the Italian classification), characterised using a Mediterranean climate with a number of degree days during the heating period of 1694.

The location of the case studies is shown in Fig. 1.

To select the buildings to be surveyed, the following criteria were considered: (1) educational stage (primary, middle, high school, or university), (2) year of construction/renovation, (3) operation mode, and (4) construction type. A diverse sample from an educational stage point of view was selected.

2.1.1. Description of surveyed buildings

In total, 11 schools and 24 classrooms were selected for the case study, which included:

- five classrooms in three primary schools (6–10 years);
- eight classrooms in two middle schools (11–13 years);
- two classrooms in one high school (14–18 years);
- nine classrooms in five university buildings (18+ years).

All the classrooms, which were equipped with a natural ventilation system, were surveyed during the heating period. Information regarding the schools is shown in Appendix A. Fig. 2 shows one surveyed school building for each educational stage.

2.1.2. Duration of monitoring

Monitoring was conducted during the heating period in Pisa (1 November–15 March) between 2018 and 2021.

Fig. 1. Location where case studies are performed in Pisa province: P1, P2, and P3 (primary schools); M1 and M2 (middle schools); H1 (high school); and U1 (university).

Fig. 2. Surveyed schools: buildings and classrooms from different educational stages: primary school (P1), middle school (M1), high school (H1), and university (U1).

2.2. *Onsite measurement*

2.2.1. *Environmental measurements*

The environmental parameters obtained during the monitoring period were the air and globe thermometer temperatures, relative humidity, and air velocity. Objective measurements were performed using a microclimate data logger (DeltaOhm HD 32.3) equipped with the following probes: a globe-thermometer TP3275, a hot-wire anemometer AP3203, and a temperature and humidity probe HP3217R. A PCE-HT110 instrument was used to monitor the outdoor air temperature and relative humidity. Specific information regarding the probes is provided in Appendix B.

The probes were positioned 1.1 m from the ground to simulate the sitting position of the student, and at least 1.5 m from the external walls and doors. The instruments were shielded from direct solar radiation, cleaned, and periodically calibrated.

2.2.2. Survey study

Students were instructed to fill out a questionnaire while objective measurements were performed. The occupants answered the surveys 110 min after entering the classroom, i.e. after they were acclimatised to the environment (Fig. 3).

The questionnaire was composed of three sections, and the questions complied with the ISO 28802 standard [22] (for details regarding the original Italian questionnaire, please see Appendix C).

In the first section, the students' information, such as age, gender, height, weight, and location occupied in the classroom, was enquired.

The second section was used to assess each student's clothing insulation based on ISO 9920 [23].

The third part was intended for evaluating the thermal environment and included the following questions:

- Thermal Sensation Vote (TSV): "With reference to the temperature, how are you feeling now?" – From [−3] "very cold" to [+3] "very hot";
- Thermal Preference Vote (TPV): "Please state how you would prefer to be now:" – From [−3] "much colder" to [+3] "much warmer";
- Thermal Acceptability Vote (TAV): "On a personal level, this environment is for me:" – From [1] "perfectly acceptable" to [5] "unacceptable".

To ease the understanding of the scales for the younger students, the questionnaire for the primary schools was provided in multiple colours and included pictures. This is in accordance with previous studies such as the field study by Aparicio-Ruiz et al. [24].

2.3. Calculations

The indoor operative temperature Top and mean radiant temperature MRT were calculated according to the ISO 7726 standard [25].

$$T_{op} = \frac{T_a + MRT}{2} \tag{1}$$

$$MRT = \left[(T_g + 253)^4 + \frac{0.25 \bullet 10^8}{\varepsilon_g} \left(\frac{|T_g - T_a|}{D} \right)^{1/4} \bullet (T_g - T_a) \right]^{1/4} - 273 \tag{2}$$

Where:

- T_a is the indoor air dry-bulb temperature;
- T_g is the black globe temperature;
- D is the black globe diameter;
- ε_g is the black-globe emissivity;
- v_a is the indoor air velocity.

Clothing insulation was evaluated from the questionnaires, listing participants with a selection of garments whose thermal insulation was

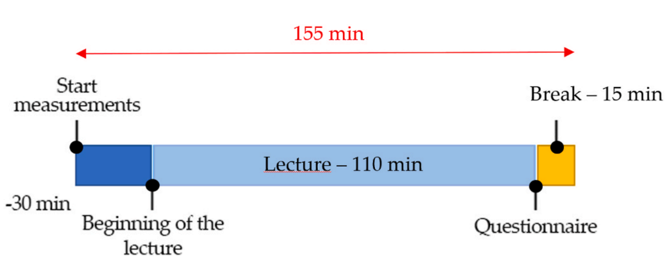

Fig. 3. Measurement procedure.

defined based on the ISO 9920 standard [23]. Clothing insulation I_{cl} was calculated according to the ISO 7730 standard as follows [5]:

$$I_{cl} = 0.83 \bullet \sum_i I_{cl,i} + 0.161 \tag{3}$$

Where $I_{cl,i}$ is the thermal insulation supplied by each garment.

The students' metabolic rate (Met) was initially estimated to be 1.2 met, based on the ISO 8996 standard [26]. Subsequently, the value was corrected by considering the different body surfaces of each student [13, 27,28]. Each student's body surface area was calculated using the Du Bois and Du Bois equation [29], as follows:

$$A_{Du} = 0.202 \bullet W_b^{0.425} \bullet H_b^{0.725} \tag{4}$$

Where:

- W_b is the body weight (kg);
- H is the height (cm).

Therefore, the metabolic rate provided by the international standard was multiplied by the ratio between the body surface of each student and the surface area of an average adult, which was estimated to be 1.8 m^2.

Meanwhile, Fanger's indices (PMV and PPD) were calculated according to the ISO 7730 standard [5].

The values of the environmental parameters were combined with the subjective responses. For each student, the responses were associated with environmental parameters monitored by the instrument closest to the student. A total of 1548 samples were obtained.

The running mean outdoor temperature (T_{rm}) was calculated from the seven days prior to the measurements based on EN 16798-1 using all the 1548 samples [6]. T_{rm} was calculated as follows:

$$T_{rm} = (1 - \alpha) \bullet \left(T_{od-1} + \alpha \bullet T_{od-2} + \alpha^2 \bullet T_{od-3} + \alpha^3 \bullet T_{od-4} + \alpha^4 \bullet T_{od-5} + \alpha^5 \bullet T_{od-6} + \alpha^6 \bullet T_{od-7} \right), \tag{5}$$

where α is a constant (assumed to be equal to 0.8), T_{od-1} is the mean outdoor temperature for the prior day, T_{od-2} the mean outdoor temperature for two days prior, T_{od-3} the mean outdoor temperature for three days prior, etc.

Based on the results of the questionnaire survey, a typically used binning method was adopted for data analysis [30–32]. The indoor operative temperatures were binned into 0.5 °C increments to calculate the average value of the subjective answers. Subsequently, to incorporate the size of each bin into the regression model, a weighted linear regression between the subjective answers and the T_{op} was fitted. This practise is of fundamental importance because it allows the thermal sensation of a group of individuals subjected to certain environmental conditions to be considered, in line with global thermal comfort analyses.

3. Results

3.1. Objective and subjective measurements

A statistical summary of the indoor and outdoor objective measurements is shown in Table 1, in addition to the mean and standard deviation of the responses.

The mean T_{rm} was the highest for the universities (13.1 °C) and lowest for the middle schools (10.9 °C). The highest variability of outdoor temperatures was reported for the universities (T_{rm} between 5 and 18.7 °C), which might be due to the higher number of samples, whereas the lowest variability was recorded for the primary schools (T_{rm} between 6.9 and 14.6 °C).

The mean indoor temperatures (T_a, T_{op}, and MRT) of the primary

Table 1

Minimum, maximum, mean, and standard deviation of the objective measurements and the mean and standard deviation of the responses from the questionnaires considering all the data (total) and those from primary schools, middle schools, high school, and university.

		Objective measurements											
		T_a (°C)	T_{op} (°C)	MRT (°C)	RH (%)	V_a (m/s)	I_{cl} (clo)	Met (met)	PMV	PPD	$T_{a,ext}$ (°C)	RH_{ext} (%)	T_{rm} (°C)
Total	**Min**	15.7	15.3	14.8	25.4	0.00	0.5	1.2	−2.6	5.0	7.3	50.2	5.0
	Max	27.1	30.9	27.1	75.6	0.76	1.8	2.1	1.0	94.7	18.1	77.3	18.7
	Mean	22.6	22.7	22.7	50.8	0.02	0.9	1.6	−0.4	16.3	13.9	67.0	12.4
	SD	2.1	2.2	2.2	10.7	0.05	0.1	0.3	0.6	16.7	2.8	6.1	3.8
Primary school	**Min**	15.7	15.3	14.8	39.4	0.00	0.6	1.9	−1.4	5.2	7.3	47.5	6.9
	Max	25.1	25.2	27.1	58.9	0.02	1.1	2.3	1.4	47.1	17.6	73.0	14.6
	Mean	21.9	22.0	22.2	48.3	0.00	0.9	2.1	0.7	22.1	13.1	65.4	11.6
	SD	2.8	3.1	3.6	5.8	0.00	0.1	0.1	0.6	13.2	2.4	7.4	3.0
Middle school	**Min**	19.5	20.0	20.0	31.3	0.00	0.5	1.3	−2.4	5.0	8.9	46.4	5.6
	Max	25.2	30.9	25.7	64.8	0.20	1.1	2.1	0.5	90.5	19.6	74.4	15.9
	Mean	21.8	22.1	22.0	48.8	0.01	0.8	1.9	−0.8	20.7	14.2	64.2	10.9
	SD	1.4	1.8	1.4	8.8	0.02	0.1	0.2	0.4	13.7	3.1	5.8	4.1
High school	**Min**	17.6	17.8	17.9	31.3	0.03	0.5	1.3	−2.4	5.0	8.9	48.6	6.8
	Max	24.8	24.7	24.6	69.0	0.52	1.1	1.8	0.3	91.7	20.9	83.4	16.5
	Mean	21.6	21.5	21.4	52.0	0.00	0.8	1.7	−0.9	27.5	15.1	68.7	12.4
	SD	1.8	1.8	1.8	12.9	0.00	0.1	0.1	0.6	22.0	3.8	10.1	3.6
University	**Min**	16.9	16.9	16.9	25.4	0.00	0.5	1.2	−2.6	5.0	11.7	2.6	5.0
	Max	27.1	26.95	26.8	75.6	0.76	1.8	1.2	1.0	94.7	15.4	78.5	18.7
	Mean	23.1	23.2	23.2	51.8	0.03	0.9	1.2	−0.2	11.8	13.8	69.7	13.1
	SD	2.0	2.0	2.0	11.5	0.05	0.1	0.0	0.6	12.3	2.8	6.2	3.6

Subjective measurements	Total		Primary school		Middle school		High school		University	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Personal information										
Sex	766 males 689 females		72 males 77 females		195 males 147 females		35 males 114 females		464 males 351 females	
Age	20	7.99	9	0.8	12	2.16	16	6.73	23	4.5
Thermal environment										
TSV	−0.09	1.05	−0.34	1.22	0.07	1.19	−0.36	1.05	−0.06	0.94
TPV	0.19	1.02	0.10	1.07	−0.03	1.16	0.31	1.03	0.26	0.94
TAV	0.39	0.52	–	–	0.32	0.63	0.41	0.65	0.45	0.84

schools were lower than those of the universities. The indoor air temperatures ranged from 15.7 to 27.1 °C and these variations are likely due to the different characteristics of the surveyed buildings, specifically the different hours of the day in which the measurements were performed and the variation in the outdoor meteorological conditions (the outdoor air temperatures were primarily distributed from 2.8 to 20.9 °C). The mean relative humidity was approximately 50%, which was within the healthy range. The air velocity remained low despite the classrooms being naturally ventilated (mean V_a between 0.00 and 0.03 m/s), which implies that discomfort due to draughts is unlikely to occur. The mean clothing insulation was approximately 0.9 clo and slightly lower for the middle and high schools (I_{cl} = 0.8 clo). On average, the metabolic rate was higher than that proposed by the standards for sedentary activities [26]. The mean PMV was attested by cool sensations (mean PMV = −0.4), and the most critical conditions were reported in the high schools, with a mean percentage of dissatisfaction of 24.5%.

The sample was equally distributed between boys and girls, where the number of girls exceeded the number of boys only in the high schools. The mean age considering all the data was 20 years: 9 years for primary schools, 12 for middle schools, 16 for high schools, and 26 for universities.

Regarding the thermal environment, on average, students felt slightly cool (TSV = −0.09 for the total data), with slightly colder sensations reported for primary and high schools (TSV = −0.34 and −0.36, respectively), neutral warm sensations for middle schools (TSV = 0.07), and neutral-cold sensations for universities (TSV = −0.06).

Students generally preferred slightly warmer environments (TPV = 0.19 for the total data) but middle school students preferred neutral to colder environments, which is consistent with the TSV response.

The thermal environment was generally acceptable considering all data (TAV = 0.39), and the middle school children showed higher tolerance compared with the high school and university students (TAV = 0.32, 0.41, and 0.45, respectively).

3.2. *Evidence of adaptation at each educational stage*

The adaptive capacities of students may vary depending on the educational stage, their adaptive ability, and their perception of the environment. In this section, the adaptive behaviour of students is analysed based on the educational stage. Since the students could not regulate the set point temperatures, they could only adapt by adjusting their clothing insulation and opening windows.

3.2.1. *Clothing adaptive behaviours*

Clothing insulation is highly correlated with temperature, and achieving thermal comfort through clothing insulation is important [9].

To understand the adaptive opportunities of students at different educational stages, the relationship between clothing insulation and indoor operative temperature (Fig. 4) was analysed. The regression between clothing insulation and the outdoor running mean temperature was not statistically significant.

In general, clothing insulation decreased as the operative temperature increased. However, different adaptive behaviours were indicated at different educational stages. In the case of primary schools, the students presented rather high thermal insulation and low adaptive capacity, as shown by the slope of the regression equation (Table 2). Among the results obtained, those from the middle and high schools showed the lowest clothing insulation with a higher adaptive capacity, particularly for middle schools. The highest clothing insulation and adaptive capacity were recorded for the universities.

The equations, R^2, and p-values of the regressions are shown in Table 2. All the regressions were significant ($p < 0.05$), and the

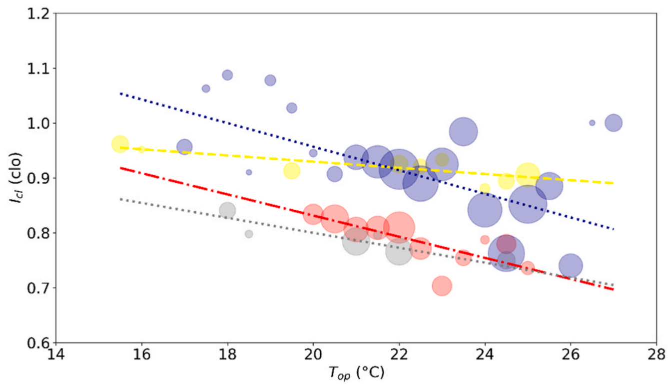

Fig. 4. Relationship between clothing insulation (I_{cl}) and operative temperature (T_{op}) for primary (in yellow), middle (in red), high (in grey) schools, and university (in blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Regression analysis, R^2, and p-value for primary, middle, high schools, and university.

Educational stage	Regression	R^2	p-value
Primary school	$I_{cl} = -0.0056 \bullet T_{op} + 1.0421$	0.70	<0.05
Middle school	$I_{cl} = -0.0193 \bullet T_{op} + 1.2165$	0.55	<0.05
High school	$I_{cl} = -0.0136 \bullet T_{op} + 1.0718$	0.88	<0.05
University	$I_{cl} = -0.0215 \bullet T_{op} + 1.3862$	0.34	<0.05

regression was particularly accurate for primary and high schools ($R^2 =$ 0.70 and 0.88, respectively). In the case of middle schools and universities, the coefficient of determination was lower, which is to be expected when individual parameters such as clothing insulation are considered, as they depend on personal preferences [33,34].

3.2.2. Window operation

In this section, window operation is correlated to indoor operative temperature and running mean outdoor temperature to show how adaptation can occur at different educational stages. In the classrooms analysed, the participants were allowed to adapt freely by opening and closing windows to restore their thermal comfort.

Logistic regression analysis was used to analyse students' behaviour during the window operation. The logit can be defined as follows [33]:

$$Logit\ p_c = Log\left(\frac{p_c}{1-p_c}\right) = c + d \bullet T \tag{6}$$

Where p_c is the probability that the windows are opened as a function of the temperature index, which is T_{op} for indoor and T_{rm} for outdoor; c is the intercept; and d is the slope of the logit line.

The values of c and d were derived from the data obtained during the monitoring period via logistic regression. Subsequently, p_c is expressed as [33].

$$p_c = \frac{\exp\ (c + d \bullet T)}{1 + \exp\ (c + d \bullet T)} \tag{7}$$

Fig. 5 shows the proportion of windows opened and the probability of windows being opened (p_c) as a function of T_{op} and T_{rm}. The windows were considered open if at least one of them was open regardless of the opening degree. This is because this analysis aimed to understand whether an interaction occurred between the occupants and window/door operation, regardless of how they were opened.

No relationship could be derived in the case of the middle schools because in all cases investigated during the measurement period, the windows were opened regardless of the indoor and outdoor conditions. This may be a constraint that occurred due to the coronavirus disease (COVID-19) pandemic period, as ventilation had to be increased by having the windows opened, and some schools had stricter rules than others.

Additionally, no clear relationship was indicated between the windows' operation and indoor operative temperature. In the case of primary and high schools, the windows were generally opened, regardless of the indoor conditions, whereas in the case of universities, they were closed. This might be related to other constraints in the universities, such as acoustic problems or reduced awareness of the necessity for ventilation.

However, the relationship between window operation and T_{rm} was more evident, where windows were opened only when the running mean outdoor temperature increased. The logistic regression trend was similar between the primary and high schools, with windows expected to be open when the T_{rm} was between 10 and 11 °C. By contrast, in the university classrooms, windows were opened at higher T_{rm} near 16 °C. Table 3 presents the characteristics of the regressions.

3.3. Thermal comfort based on the educational stage

3.3.1. Calculation of neutral, preferred, and acceptable temperatures

To highlight that thermal comfort is a function of the educational stage, as students may present different requirements and preferences, comfort temperatures were derived based on the different educational stages according to the objective and subjective responses of the students.

The neutral temperature (T_n) is the operative temperature at which

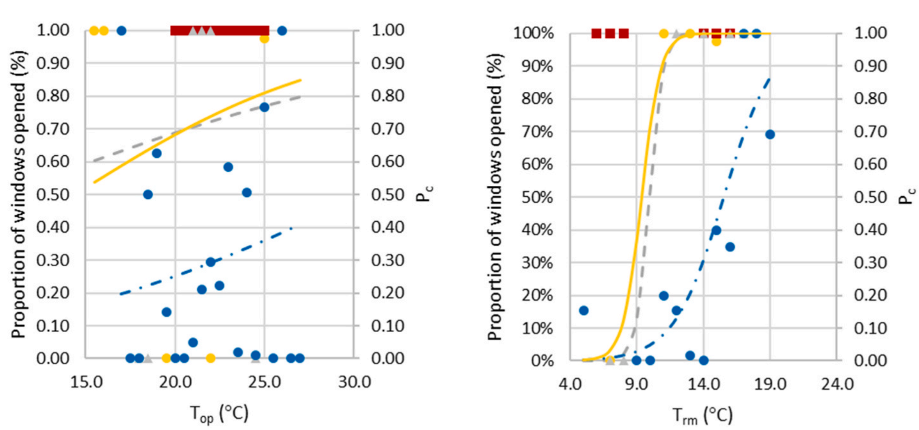

Fig. 5. Proportion of windows opened and p_c as a function of T_{op} (a) and T_{rm} (b) for primary (in yellow), middle (in red), high (in grey) schools, and university (in blue). Proportions of 0% and 100% imply that the windows were closed and opened, respectively; p_c=0 and p_c=1 imply that the model predicts the windows to be closed and opened, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Logistic regression analysis of window operation for primary school, high school, and university. No relationship was derived for the case of the middle school since the windows were opened in all cases during the measurement period.

Location	Logistic regression for window opening	Model performance
Indoor temperature		
Primary school	$p_c = \frac{\exp(1.96 - 0.14 \bullet T_{op})}{1 + \exp(1.96 - 0.14 \bullet T_{op})}$	Accuracy = 0.73
Middle school	–	–
High school	$p_c = \frac{\exp(0.87 - 0.08 \bullet T_{op})}{1 + \exp(0.87 - 0.08 \bullet T_{op})}$	Accuracy = 0.71
University	$p_c = \frac{\exp(3.11 - 0.10 \bullet T_{op})}{1 + \exp(3.11 - 0.10 \bullet T_{op})}$	Accuracy = 0.67
Outdoor temperature		
Primary school	$p_c = \frac{\exp(13.53 - 1.44 \bullet T_{rm})}{1 + \exp(13.53 - 1.44 \bullet T_{rm})}$	Accuracy = 0.99
Middle school	–	–
High school	$p_c = \frac{\exp(19.86 - 1.99 \bullet T_{rm})}{1 + \exp(19.86 - 1.99 \bullet T_{rm})}$	Accuracy = 1.00
University	$p_c = \frac{\exp(8.32 - 0.54 \bullet T_{rm})}{1 + \exp(8.32 - 0.54 \bullet T_{rm})}$	Accuracy = 0.85

the thermal sensation is neutral (TSV = 0); the preferred temperature (T_p) is the operative temperature at which no change in the thermal environment is expressed (TPV = 0); and the acceptable temperature is the operative temperature at which maximum satisfaction is achieved [10].

The neutral (T_n), preferred (T_p), and acceptable (T_{ac}) temperatures were calculated via the weighted regressions shown in Fig. 6 (linear regressions for TSV and TPV, and quadratic regressions for the percentage of satisfied according to the indoor operative temperature).

All regressions show statistical significance (Table 4) and indicate the neutral temperature (T_n), preferred temperature (T_p), and acceptable temperature (T_{ac}).

T_n and T_p were calculated by setting TSV and TPV to zero, respectively. T_{ac} was derived based on the TAV by considering occupants who voted 'perfectly acceptable' or 'slightly unacceptable'. In particular, T_{ac} was derived as the maximum of the quadratic regression, i.e. the point at which the percentage satisfied was the maximum.

An analysis of the neutral and preferred temperatures showed that both increased as a function of the educational stage (Table 4). For the primary schools, T_p was lower than T_n (18.5 against 20.6 °C), whereas they were similar for the middle and high schools, with a difference of only 0.1 °C. By contrast, the T_p for the university students was higher than the T_n (24.1 vs. 23.6 °C), which indicates that older students prefer warmer environments.

The middle school children indicated a T_{ac} of 21.2 °C, which is similar to the neutral temperature (T_n = 21.7 °C). This implies that the middle-school children were satisfied with their thermal neutrality. However, a different behaviour was indicated by the primary and university students, where T_{ac} was higher than T_n, whereas for the high school students, T_{ac} was lower than T_n.

3.3.2. Relationship between neutral temperatures and student age

Thus far, differences in adaptive behaviour, sensation, preference, and thermal acceptability have been shown as a function of the educational stage, where possible biases resulting from studies conducted in different climates and contexts were eliminated.

However, once these differences are highlighted, they must be quantified. Therefore, the relationship between neutral temperatures and student age was analysed.

To calculate T_n, Griffiths' method was applied to the responses of individuals (1548 samples) as follows [35]:

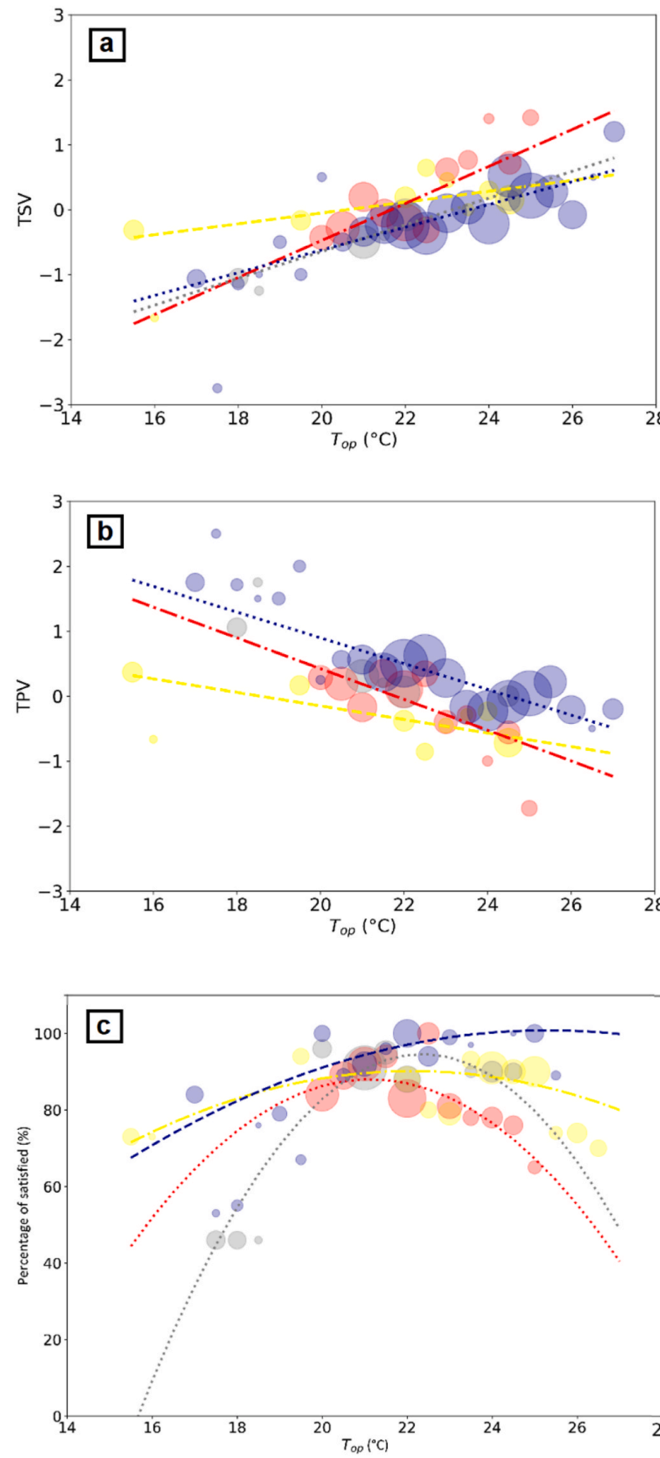

Fig. 6. Relationship between indoor operative temperature (T_{op}) and occupants' perception (TSV chart (a), TPV chart (b), percentage of satisfied chart (c)) for primary (in yellow), middle (in red), and high (in grey) schools, and university (in blue)). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

$$T_n = T_{op} + \frac{TSV}{G} \quad (8)$$

Where G is the Griffiths' constant.

In this case, G was assumed to be 0.5 °C^{-1}, which is consistent with the results derived from SCATs (Smart Controls And Thermal Comfort) and ASHRAE databases [36]. This value was selected as a reference

Table 4
Proposed regression equations and neutral, preferred, and acceptable temperatures in naturally ventilated classrooms for primary, middle, and high schools, and university.

Educational stage	Regression	R^2	p-value	T_n (°C)	T_p (°C)	T_{ac} (°C)
Primary school	$TSV = 0.0835 \bullet T_{op} - 1.7225$	0.47	<0.05	20.6	18.5	21.9
	$TPV = -0.1044 \bullet T_{op} + 1.9364$	0.61	<0.05			
	$\% = -0.0067\ T_{op}^2 + 0.2822\ T_{op} - 2.0494$	0.69	0.01			
Middle school	$TSV = 0.2850 \bullet T_{op} - 6.1742$	0.64	<0.05	21.7	21.8	21.2
	$TPV = -0.2368 \bullet T_{op} + 5.1575$	0.52	<0.05			
	$\% = -0.0215\ T_{op}^2 + 0.9266\ T_{op} - 9.0754$	0.74	0.01			
High school	$TSV = 0.2059 \bullet T_{op} - 4.7649$	0.91	<0.05	23.1	23.0	22.2
	$TPV = -0.1913 \bullet T_{op} + 4.4049$	0.73	<0.05			
	$\% = -0.0226\ T_{op}^2 + 1.019\ T_{op} - 10.516$	0.88	0.02			
University	$TSV = 0.1751 \bullet T_{op} - 4.1234$	0.63	<0.05	23.6	24.1	25.0
	$TPV = -0.2454 \bullet T_{op} + 6.0165$	0.79	<0.05			
	$\% = -0.0076\ T_{op}^2 + 0.3659\ T_{op} - 3.402$	0.60	0.01			

regarding the thermal sensitivity of schools at different educational stages. Hence, 0.5 $^\circ C^{-1}$ is a representative value that can provide a preliminary indication for the analysis.

Once T_n was derived for each of the 1548 samples, the data were binned by the student's age. This was performed to analyse the effect of the neutral temperature of each student (which varies from each individual) on their educational stage, and hence age. Fig. 7 shows the linear relationship between age and neutral temperature.

$$T_n = 0.1139 \bullet Age + 20.5146\ \left(R^2 = 0.60,\ p - value < 0.05\right) \tag{9}$$

Considering that it involves thermal sensations, thus implying a certain inter-individual variability, the regression appears promising. Clearly, this relationship is valid in the range considered (8–32 years), which practically corresponds to school-age limits.

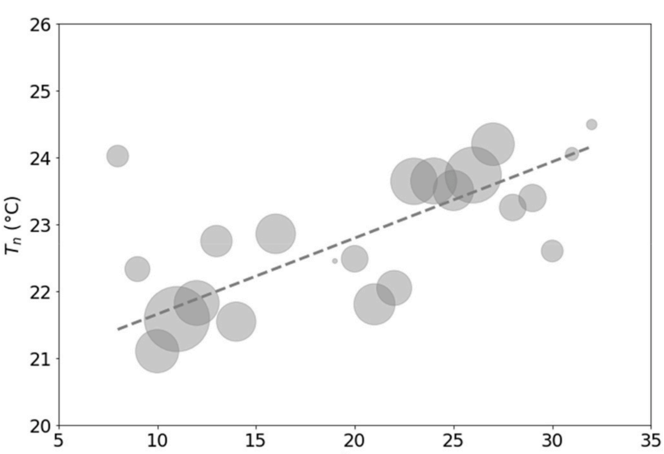

Fig. 7. Relationship between student age and neutral temperature (T_n).

3.4. Applicability of Fanger's rational model to predict thermal comfort at different educational stages

In this study, the ability of Fanger's model in evaluating the thermal sensation of students at every educational stage was investigated.

First, the relationship between the thermal sensation and the percentage of dissatisfaction calculated from the TAV, as previously shown, was analysed and compared with the original PMV–PPD relationship (Fig. 8).

The relationship between thermal sensation and satisfaction was different at each educational stage and, in general, not perfectly symmetrical compared with the original PMV–PPD relationship. For the primary schools, the minimum percentage of dissatisfaction exceeded 5% but included towards cold sensations, which implies that the children were more accepting of cold than warm sensations. The middle school students presented a very asymmetrical curve, with a higher percentage showing dissatisfaction with cold sensations and only a few preferring warm sensations. The high school students did not prefer slightly cold sensations and exhibited a quite symmetrical relationship between thermal sensation and satisfaction. By contrast, the curve for the university students was asymmetrical, with the minimum region shifting towards warm sensations, indicating that university students prefer warmer environments.

Subsequently, the Bias and Mean Absolute Error (MAE) were calculated to assess the performance of the PMV model in predicting thermal sensation. These two indices were calculated as follows:

$$MAE = \frac{\sum_{i=1}^{n} |p_i - a_i|}{n} \tag{10}$$

$$Bias = \frac{\sum_{i=1}^{n} (p_i - a_i)}{n} \tag{11}$$

Where p_i is the predicted value (PMV), a_i is the target value (TSV), and n is the number of samples.

The Bias showed negative values for all the cases except for the primary schools (0.61 for primary school, −0.82 for middle school, −0.60 for high school, and −0.10 for university), where correction to the metabolic rate was applied. This implies that, generally, the PMV tends to underestimate the thermal sensation of the students, even if the overestimation decreases as the educational stage advances. Moreover,

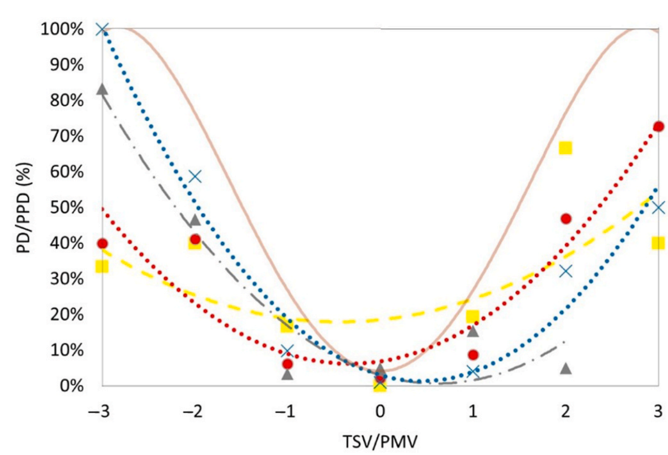

Fig. 8. Relationship between occupants' TSV and percentage of dissatisfied (PD) compared with the classic PMV–PPD curve (solid orange line) for primary (dashed yellow line), middle (dotted red line), and high schools (dash-dotted grey line), and university (dotted blue line). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the error in the prediction, defined by the MAE, decreased as the educational stage advanced (1.02 for primary schools, 1.11 for middle schools, 0.90 for high school, and 0.72 for university).

Finally, the differences between the predicted and actual neutral temperatures were analysed. Weighted regression analysis between the operative temperature (T_{op}) and each of the predicted (PMV) and actual thermal sensation (TSV) was performed.

Fig. 9 shows a comparison of the relationship between the operative temperature and thermal sensation for all educational stages. Meanwhile, the characteristics of the regressions and the neutral temperatures calculated for the PMV and TSV are reported in Table 5. All the regressions were significant ($p < 0.05$).

For the primary schools, the regression slope of the TSV was much lower than that of the PMV, which implies that the children were much less sensitive to temperature changes as compared with predictions based on the PMV. Furthermore, the neutral temperature calculated based on the PMV was lower than the actual neutral temperature (17.0 vs. 20.6 °C), which can occur in cases of thermal discomfort.

For the middle schools, the regression slope for the PMV was similar to that for the TSV (0.26 and 0.29, respectively), which implies that the predicted and actual thermal sensibilities were similar, even when the neutral temperature calculated based on the PMV was much higher (24.4 vs. 21.7 °C).

The high school and university cases present similar behaviours, with similar slopes and thus thermal sensitivity. At these educational stages, the T_n calculated based on the PMV was the same (24.4 °C) but higher than that calculated based on the TSV (23.1 °C for high school and 23.6 °C for university).

4. Discussion

In this study, the specific comfort temperatures were identified and the adaptive behaviours were investigated based on the microclimate of Pisa and thus cannot be generalised for all students worldwide owing to cultural and climate adaptation differences.

Table 5
Regression equation, R^2, p-value, and T_n calculated based on predicted and real thermal sensation T_{op} for primary, middle, and high schools, and university.

Educational stage	Regression	R^2	p-value	T_n (°C)
Primary school	$PMV = 0.17 \bullet T_{op} - 2.89$	0.97	<0.05	17.0
	$TSV = 0.08 \bullet T_{op} - 1.72$	0.47	<0.05	20.6
Middle school	$PMV = 0.26 \bullet T_{op} - 6.35$	0.95	<0.05	24.4
	$TSV = 0.29 \bullet T_{op} - 6.17$	0.64	<0.05	21.7
High school	$PMV = 0.30 \bullet T_{op} - 7.33$	0.99	<0.05	24.4
	$TSV = 0.21 \bullet T_{op} - 4.77$	0.91	<0.05	23.1
University	$PMV = 0.25 \bullet T_{op} - 6.09$	0.94	<0.05	24.4
	$TSV = 0.18 \bullet T_{op} - 4.12$	0.63	<0.05	23.6

The main contributions of this study are thermal comfort trends based on student age as well as the relevant quantitative relationships (e.g. the neutral temperature increased by 0.11 °C on average per year of age). This quantification was not possible in previous studies because the role of other factors such as climatic conditions, different countries, and social backgrounds could not be eliminated. Thus, this study provides clear evidence of the necessity for models and standards that include specific variations based on educational stage.

The following subsections discuss the variations in the adaptive capacities and comfort temperatures, as well as the accuracy of predictive models based on the educational stage.

4.1. Adaptive capacities based on the educational stage

A better understanding of students' adaptive behaviours based on their educational stage is important for creating a comfortable indoor thermal environment. The fundamental assumption of the adaptive principle is that, if a change occurs and causes discomfort, people typically react to restore their comfort [9]. In this study, the differences in terms of clothing insulation and window interaction can be reasonably attributed to the educational stage only, thus eliminating possible biases such as the different outdoor climates or different operational

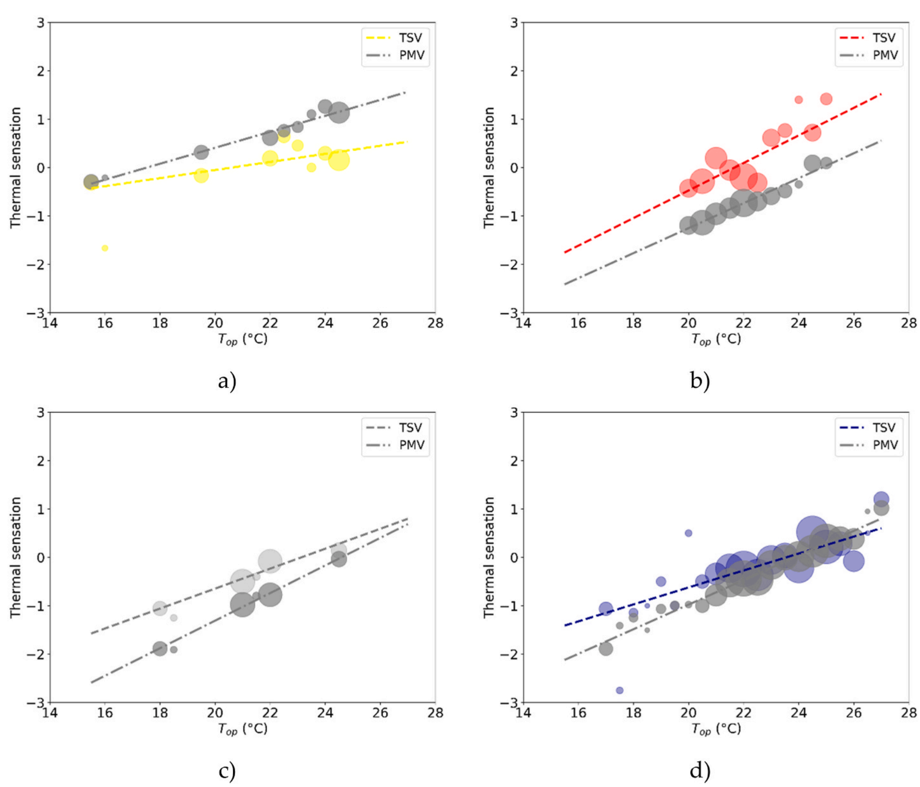

Fig. 9. Relationship between indoor operative temperature (T_{op}) and occupants' TSV and PMV for primary (a), middle (b), high schools (c), and university (d).

modes.

Regarding clothing insulation, the adaptive behaviours shown by middle school, high school, and university students were similar, whereas younger students indicated lower adaptive capacities. As the indoor operative temperature increased, the older students reduced their clothing insulation at a pace comparable to those of the other students (regression curve slopes of −0.0193, −0.0136, and −0.0215 for the middle school, high school, and university students, respectively), whereas the primary school students were slower in regulating their clothing insulation (slope = −0.0056). This might be due to the requirement of wearing the school uniform in primary schools and younger students being less aware of the adaptive opportunities.

Previous studies have investigated students' clothing insulation during the heating season. Korsavi and Montazami [37] investigated primary schools in the UK and highlighted the difficulty in adopting adaptive behaviours due to school uniforms. Jiang et al. [38] investigated high schools in China and correlated clothing insulation with indoor operative temperature, highlighting a slope close to that identified in the present study (slope = 0.013). Regarding universities, the slope identified in this study was similar to those of Jowkar et al. for the UK [39] (s = 0.03) and Corgnati et al. [15] for Italy (s = 0.022). These studies highlighted the increase in adaptation capacity with student age. Therefore, the results of this study confirm the trends observed in different locations, where the educational stage is shown to be a prevailing factor affecting the clothing adjustment of students.

Regarding window operation, although studies regarding adaptive thermal comfort in school buildings are abundant, only a few studies investigated the adaptive behaviour of window operation [40]. In this study, a clear relationship was indicated between window operation and running mean outdoor temperature. A similar trend was reported by Aparicio-Ruiz et al. [24], who showed that adaptive strategies are a function of outdoor temperature.

Moreover, Wang et al. [18] analysed window openings for university classrooms in China and discovered that the ratio of opened windows was lower than 50% when the outdoor temperature continued to decrease below 17 °C. In this study, the ratio of opened windows was less than 50% for T_{rm} below 9 °C. This implies that in the present study, the windows were opened when the temperature was lower than that indicated in Wang et al.'s study. This is attributable to the adaptation of students during the COVID-19 period, in which classrooms were considerably more ventilated (even when the outdoor temperature was low).

In the university classrooms, windows were opened at higher T_{rm} (approximately 5 °C higher than those of the other educational stages). This shows a lower tolerance to thermal discomfort caused by cold among university students compared with the case at lower educational stages.

In general, younger students show lower adaptive capacities to window operations, as the teachers undertake most of the window adjustments. This is consistent with the results obtained from the study performed by Korsavi and Montazami [37], which showed that primary school students only performed 16% of window adjustments.

4.2. Differences in neutral, preferred, and acceptable temperatures based on the educational stage

Regarding comfort temperatures, the results of this study indicate that younger students show higher tolerance than older students. Based on the regression model between T_{op} and TSV (Table 4), the regression slope for primary schools is much lower than that for the other educational stages (s = 0.0835 for primary schools, s = 0.285 for middle schools, s = 0.2059 for high schools, and s = 0.1751 for universities). The same behaviour is shown for the regression model between T_{op} and TPV (s = −0.1044 for primary schools, s = −0.2368 for middle schools, s = −0.1913 for high school, and s = −0.2454 for university).

Furthermore, for all the surveyed T_{op}, at least 70% of the younger students reported satisfaction. Finally, the primary school children generally preferred lower temperatures (T_p = 18.5 °C vs. T_n = 20.6 °C), which implies that at this educational stage, the children are less sensitive to temperature changes and tend to feel thermally neutral at different T_{op}.

These results are consistent with the results of Kim and de Dear [41], who highlighted that the sensation preferred by children occurred at 2–3 °C lower than the neutral temperature (i.e. children preferred to feel cool than to feel neutral) and that the range of thermal acceptance indicated by children was wider than that of adults under comparable occupancies.

Regarding older students, the middle school students were the most sensitive to variations in the operative temperature, as indicated by higher regression slopes. The high school and university students presented a similar response, which might be because their thermal perception is much closer to that of adults.

Concerning neutral temperatures, the older students indicated higher values (20.6 °C for primary schools, 21.7 °C for middle schools, 23.1 °C for high school, and 23.6 °C for university). A similar pattern was observed for the preferred and acceptable temperatures.

This precise trend is not easily observable when comparing neutral temperatures obtained from studies conducted in different countries. In the present study, a relationship was indicated between the students' age and neutral temperature. The regression expressed in Eq. (9) appears promising as it allows precise growth (slope = 0.1139) to be estimated at neutral temperatures based on student age.

The results above are important as they show that assuming a unique comfort temperature and hence set point temperature at all educational stages may not ensure comfortable conditions and may consequently increase energy consumption.

The variability in comfort temperatures at different ages might be caused by physiological (i.e. different metabolic activity) and psychological (i.e. different perception of the thermal environment) adaptations [42]. Regarding behavioural adaptation (i.e. different types of activities performed at different educational stages and different adaptive capacities), although younger students had less adaptive capacities, they were more satisfied with the thermal environment. These differences were not considered in the PMV–PPD model, which showed different accuracy degrees in the prediction of thermal comfort at different educational stages (more details are discussed in the following section).

4.3. Failure of PMV–PPD model in predicting thermal comfort at different educational stages

Because differences in thermal perception were indicated based on the educational stage, the ability of the PMV–PPD model to evaluate the thermal sensation of students was analysed in this study. In contrast to Fanger's theory [8], this study shows that the relationship between thermal sensation and the percentage of dissatisfaction is asymmetrical. The most significant difference was indicated between primary school students and other educational stages. Children in primary schools were more likely to accept colder sensations than those in other educational stages.

Furthermore, the PMV generally showed low accuracy in estimating the thermal sensation of the students. The prediction error based on the MAE between the TSV and PMV decreased with the educational stage (from 1.02 for primary school to 0.72 for university), which implies that, in general, the prediction of thermal sensation for university students and high schools is more accurate. This may be because the PMV was developed for adults and, even if the correction developed for children for the metabolic rate is applied, the prediction error will remain large.

Moreover, at the primary level, the PMV underestimated the thermal sensation, whereas overestimation was observed at the middle and high school levels, and better compatibility was reported in university classrooms. This is consistent with the result of Zomorodian et al. [12], who reported consistency between actual and predicted thermal sensations in university classrooms and underestimation at primary levels.

This study showed that the relationship between thermal sensation and percentage of dissatisfaction cannot be predicted using the rational model and that it varies with the variation in the educational stage; the lowest dissatisfaction occurred at temperatures that increased steadily with increasing age (Fig. 5).

Thus, this study provides evidence that different thermal perceptions are due to different ages (as well as different adaptive behaviours), which is not considered in the PMV–PPD method. The rational method does not consider the age factor in the calculations. These differences cannot be attributed to bodily differences alone because the metabolic rate was corrected in this study by applying the correction to the body surface area. Furthermore, these differences cannot be explained by heat balance, but through adaptation. These differentiations are similarly reflected in the different relationships between TSV and PD depending on the educational stages, and they should be considered when formulating adjustment coefficients for the Fanger method.

5. Conclusions

In this study, the effect of the educational stage on the perception of the thermal environment was investigated. Based on a review of the literature, this is the first study that involves buildings used for different educational stages (from primary schools to universities) under the same period, geographical area, and operation modes. This aspect is particularly relevant as it allows one to understand the differences in the various educational stages more clearly by reducing other confounding parameters. The main conclusions of this study are as follows:

(1) The ability to adapt to the environment increased with the educational stage, and children in primary schools were generally more passive in terms of adaptation.
(2) The different perceptions of the thermal environment and adaptive capacities between different educational stages resulted in different neutral, preferred, and acceptable temperatures, which increased with student age. In particular, a linear regression between age and the neutral temperature was derived. The neutral temperature increased by 1 °C on average at every educational stage.
(3) Despite having less adaptive capacities, younger students were more tolerant and satisfied than older ones, less sensitive to temperature changes, and felt thermally neutral at different T_{op}. High school and university students presented similar behaviours, which is likely because high school students began to perceive the environment as university students.
(4) The PMV–PPD method was not accurate in predicting the thermal sensations of students. The prediction error, defined by the MAE between the TSV and PMV, decreased with the educational stage (from 1.02 for primary school to 0.72 for university), which implies that, in general, the prediction of thermal sensation for university students is more accurate than that for primary school students.
(5) Correcting the metabolic rate was insufficient to achieve a better agreement between the actual thermal sensation and the PMV, the latter of which does not consider the different adaptive opportunities and thermal perceptions based on the educational stage. These differences should be considered when formulating the adjustment coefficients for Fanger's method.

5.1. Limitations and future studies

This study highlighted that the 'comfort for all' guidelines for all educational stages is not sufficient to guarantee comfort in schools. Although comparable with the sample size of previous studies, the sample size for primary and high schools was quite small (149 for each). As discussed above, the trends obtained from the present analysis were supported by several studies; however, these results should be further validated using larger samples in future studies.

The relationship among thermal neutrality, comfort, and preference should be investigated in further studies to provide a set point temperature that is effective for occupants. In fact, some differences occurred among these three aspects, even though comfort and preferred temperatures showed the same trend of thermal neutrality, i.e. increasing with the educational stage.

To assess the thermal perception of students in the four educational stages, a uniform thermal comfort evaluation scale was adopted. Future studies should focus on determining the best evaluation scale for students of different ages. Furthermore, clothing insulation was assessed by considering the standard values specified for adults. The most effective method for calculating clothing insulation for younger students should be identified in future studies.

The neutral temperatures were derived using Griffiths' method by considering a constant G of 0.5 $°C^{-1}$ as researchers have not derived it for school buildings as a function of the educational stage. This assumed value is widely accepted by the scientific community, although recent studies show that G is a variable instead of a constant [43]. Hence, future studies should focus on deriving G for different educational stages, since this study showed that thermal sensitivity depends significantly on G.

In this study, measurement was performed during the COVID-19 pandemic. This might have affected the adaptive capacities of the students, particularly regarding window opening.

Finally, the different adaptive opportunities and thermal perceptions of every educational stage highlighted the necessity to identify adjustment coefficients for predictive models that consider the peculiarities of the different educational stages.

CRediT authorship contribution statement

Giulia Torriani: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giulia Lamberti:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giacomo Salvadori:** Writing – review & editing, Supervision, Funding acquisition. **Fabio Fantozzi:** Supervision, Conceptualization, Funding acquisition, Writing - review & editing. **Francesco Babich:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Basic information of the surveyed buildings

Table A.1
Characteristics of the selected classrooms. HS = Heating System (CA = Central Air System; CR = Central Radiator System; SA = Split Air System); EXP = Exposure; H = Height; A = Area; V = Volume. All classrooms were naturally ventilated.

	School	Class	Type	Year	HS	Floor	EXP	H (m)	A (m^2)	V (m^3)
Primary schools	P1	ID1	Teaching room	1970	CR	Ground	South	3.1	44.0	136.4
	P2	ID2	Teaching room	2018	SA	Ground	North	3.1	45.0	144.0
	P2	ID3	Teaching room	2018	SA	Ground	North	3.1	45.0	144.0
	P3	ID4	Teaching room	1970	CR	Ground	South	3.1	50.0	155.0
	P3	ID5	Teaching room	1970	CR	First	South	3.1	50.0	155.0
Middle schools	M1	ID6	Teaching room	1970	CR	Ground	South	3.1	36.0	111.6
	M1	ID7	Teaching room	1970	CR	First	North	3.1	45.0	139.5
	M1	ID8	Teaching room	1970	CR	First	South	3.1	36.0	111.6
	M1	ID9	Teaching room	1970	CR	Ground	South	3.1	36.0	111.6
	M2	ID10	Teaching room	2020	CR	Ground	South East	3.1	44.0	136.4
	M2	ID11	Teaching room	2020	CR	Ground	North West	3.1	44.0	136.4
	M2	ID12	Teaching room	2020	CR	First	North West	3.1	44.0	136.4
	M2	ID13	Teaching room	2020	CR	First	South East	3.1	44.0	136.4
High school	H1	ID14	Multipurpose room	2018	CR	Third	North	3.0	100.0	300.0
	H1	ID15	Multipurpose room	2018	CR	Third	South East	3.0	100.0	300.0
University	U1	ID16	Teaching room	1936	CR	Second	South East	6.0	62.0	371.0
	U1	ID17	Teaching room	1936	CR	First	South East	6.0	80.0	476.0
	U1	ID18	Teaching room	1936	CR	Second	East	3.2	66.0	199.0
	U1	ID19	Teaching room	1936	CR	Second	East	3.2	61.0	182.0
	U2	ID20	Teaching room	1970	CR	Second	South	3.2	36.0	116.0
	U2	ID21	Teaching room	1970	CR	Second	North	3.2	85.0	270.0
	U3	ID22	Teaching room	1970	CR	Third	East	3.2	42.0	124.7
	U4	ID23	Teaching room	1980	CA	Ground	North	3.6	126.1	438.0
	U5	ID24	Drawing room	2015	CA	Ground	South	15.8	210.4	955.0
		ID25	Teaching room	2015	CA	Ground	North	7.5	142.1	1000.0

Appendix B. Technical information of the instruments

Table B.1
Detailed information of instruments.

Physical quantity	Instrument	Range	Accuracy
Indoor air temperature	HP3217R temperature and humidity probe	−40–100 °C	±1/3 DIN
Outdoor air temperature	PCE-HT110 probe	0–50 °C	±0.8 °C
Globe-thermometer temperature	Globe-thermometer TP3275	−30–120 °C	±2 °C
Relative humidity	HP3217R temperature and humidity probe	0%–100%	±1.5%
	PCE-HT110 probe	10%–90%	±1%
Air velocity	AP3203 hot-wire anemometer	0.02–5 m/s	± (0.05 + 5% of the measure) m/s

Appendix C. Original Italian questionnaire

Table C.1
Original Italian questions.

Question	Scale	Label
Parte A - Informazioni personali		
Sesso	Multiple choice	Maschio; Femmina
Indica la posizione da te occupata all'interno dell'aula, disegnando una croce nella pianta affianco.	–	–
Altezza (cm)	–	–
Peso (Kg)	–	–
Parte B - Abbigliamento		
Indica l'abbigliamento che indossi in questo memento.	Multiple choice	Maglia/Camicia: maglia maniche corte; maglia leggera, maniche lunghe; maglia normale, maniche lunghe; nessuna delle precedenti; altro. Etc.
Parte C - Comfort termico		
Con riferimento alla temperatura, in questo memento hai:	Likert	Molto freddo; freddo; leggermente freddo; né caldo né freddo; leggermente caldo; caldo; molto caldo
In questo memento vorresti avere:	Likert	Molto più caldo; più caldo; leggermente più caldo; né più caldo né più freddo; leggermente più freddo; più freddo; molto più freddo
Come consideri questo ambiente in questo memento?	Likert	Perfettamente sopportabile; leggermente difficile da sopportare; difficile da sopportare; molto difficile da sopportare; insopportabile

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