Evaluation of thermal comfort in university classrooms through objective approach and subjective preference analysis

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Abstract

Assessing thermal comfort becomes more relevant when the aim is to maximize learning and productivity, like occurs in office and schools. But if in the offices the Fanger model seems well represent the thermal occupant response, differently in the schools adaptive mechanisms happen that significantly influence the occupant’s thermal preference. In this study an experimental campaign is carried out in the Polytechnic University of Bari, in the first days of March in free running conditions. Firstly the questionnaires results with the application of Fanger and adaptive model are compared; secondly using subjective scale a complete analysis on thermal preference is performed, in terms of acceptability, neutrality and preference, with a particular focus on the gender influence. The user possibility to control the indoor plant system produces a significant impact on thermal sensation and acceptability of thermal environment. Furthermore it is demonstrated that the gender can greatly influence the thermal judgment of the thermal environment when an outdoor cold climate occurs.

Keywords

Thermal comfort, Fanger's model, adaptive model, thermal sensation.

1. Introduction

Assessing the Indoor Environmental Quality (IEQ) is the first step to a low energy building design ensuring the comfort of the occupants, according to high quality standards. This aim becomes more relevant when offices or schools are taken into account; here the workers need also to be "efficient" in terms of learning and productivity.

Recent studies have analyzed the close relationship between performance and thermal comfort of the occupants in workplaces. Remarkable results [1-7] have to be considered. Preferable indoor comfort conditions are not only correlated to the best result in terms of work productivity since thermal comfort is related to several factors. Furthermore, the lack of comfort causes the "environmental stress" producing a negative trend [8]. It was proved that the office employees working in better hygrothermal conditions are more productive, less prone to absenteeism and grievances; the comfort also increases the level of attention consequently reducing the risk of accidents at work [9].

Fisk and Rosenfeld [10] have analyzed the impact on production and social costs that the comfort conditions determine in the offices in United States. The indoor comfort improvement causes a direct increase of 0.5% to 5% in U.S productivity, i.e. an economic enhancement between 12 and 125 billion U.S. $ annually [11].

Similarly, students attending scholar comfortable environments can improve performance in terms of attention, concentration and learning. In the late 60's Pepler and Warner [12] were the first researchers investigating the effects of the thermal environment on the intellectual performances of the students. The experimentations were conducted on 36 women and 36 men, in climatic chambers. They found an inverse U-shape relationship between time to complete a task and temperature, with the best performance corresponding to 26.7 °C. At this temperature the students employed the shortest time to complete the assigned work.

This paper provides an additional contribution to the investigations on thermal comfort carried out in schools, validating different thermal models according to the international standards. A correlation between hygrothermal comfort perception and the control of the climate parameters was investigated, considering the climate of Bari (Italy).

1.1 Comfort models

Physiologically, the hygrothermal comfort is achieved when the body thermoregulatory mechanisms are minimized in response to signals transmitted by thermal receptors. In moderate thermal environments the subjective individual condition must be considered significant regarding to mental as well as physical comfort.

Current European Standards dealing with the "Ergonomics of the thermal environment" provide two different approaches for evaluating comfort in moderate environments, based on different assumptions: the rational model of Fanger [13] and the adaptive approach [14].

Fanger's model is based on an energy balance of the human body, considered as a thermodynamic system that exchanges heat with the external environment. This model has been theorized in the 70s and is based on tests carried out in climatic chamber of 1,296 Danish students [15]. The model is based on three fundamental assumptions:

1. passive people: users without any possibility of controlling the environment in which they are;
2. the same result are achieved for equal values of the six input variables;
3. steady-state model: just small time variations of the environmental parameters are allowed.

This model provides results getting close to the real ones when the setted values do not vary; i.e when considering a HVAC system, the passive behavior of the occupants and a fixed wear. The best application for this model are the offices, often with a centralized HVAC, where the occupants have work schedules and fixed locations and sometimes even a standard work wear.

The adaptive approach comes from field studies began in the mid-70’s in response to the oil-shocks. This approach considers the individual user interaction with the environment, carrying out a thermal adaptation on three different levels [16]:

1. conscious or unconscious behavioral adjustment, directly connected with the human body energy balance classified as: individual (referring to wear, activity, posture, hot/cold drinks consume, moving to other rooms), technological (referring to the user possibility to change plant systems settings, opening/closing windows or window solar shadings), cultural (working time and breaks);
2. physiological; a prolonged exposure to particular environmental conditions determines a reduction in stress and an increase in tolerance, that is distinguishable in: genetic adaptation and acclimatization;

3. psychological, regarding to previous experiences, expectations or to the perception of microclimate control possibility.

The adaptive model is based on a simple correlation between the optimum internal temperature and the external reference temperature. ASHRAE standard [17] considers a reference external temperature based on no fewer than 7 and no more than 30 sequential days prior to the day in question. EN ISO standard [14] considers, accurately, a Running Mean temperature, i.e. a weighted mean value of the daily mean temperatures of the seven previous days. It has been observed, that the individual thermal sensation is more strongly influenced by the outdoor temperature recorded in the days closer to the real one than by monthly mean temperature values [18].

Experimental tests have shown that the adaptive model provides more realistic results in naturally ventilated environments, especially where the occupants can control the microclimatic parameters. It was also note that the range of comfort values in naturally ventilated environments is larger than in HVAC environments [18]. Several researchers found that fieldworks results are closer to the real judgment of the occupants than the results achieved in climatic chambers. McIntyre [19], comparing the results obtained by Fanger in climatic chambers with those achieved by fieldworks, considers that some variables of the real world cannot be reproduced in a climatic chamber. Oseland [20] and Becker et al. [21] confirm McIntyre results studying the hygrothermal comfort both in offices and in residential buildings.

However Fanger model can be considered the most reliable, and the only scientific model for the hygrothermal comfort assessment. It takes account the most important variables affecting the thermal sensation, unlike the adaptive model, which considers only an external reference temperature. In order to improve the model Fanger and Toftum [22], have introduced a correction to the model by the new PMVe model. Fanger has corrected the expectation of the occupants in warm climates in buildings without air-conditioning, introducing a factor of expectation in the comfort equation.

Several campaign surveys were been conducted in three different continents; however the PMVe model validation is ongoing before the model becomes a standard.

A totally different approach to the comfort evaluation was provided by Yao et al. [23]. He defined a theoretical adaptive model of thermal comfort, aPMV (adaptive Predicted Mean Vote), based on the theory of black-box, whereas cultural, climatic, social, psychological and behavioral adaptation factors, play an important role on the thermal sensation. Employing the aPMV model, based on the mechanisms of cybernetics, on buildings without HVAC, it can be note that the PMV predicted by Fanger overestimates the current average rating.

Recent studies on thermal comfort, taking into account the thermal preferences and people's acceptability [24-26] have analyzed the thermal judgment of the users that is more complex than a simple thermal vote.

McIntryre [27] has shown that the preferred temperature is not the neutral one, but it depends on the place where the users are. People of cold climates may prefer what they call a ‘‘slightly warm’’ environment and vice versa.

Brager and DeDear [18] have defined this aspect "semantic effect", describing the deviation between the preferred and neutral temperature in full air conditioned environments by a linear relationship depending on outdoor daily average temperature. In naturally ventilated environments it is not possible to establish a general relation, since it varies greatly depending on the geographical area because of the adaptation mechanisms of the people.

1.2 Recent studies carried out in schools

In the offices, the clothing is often fixed, the average age of the occupants is highly variable, there are centralized HVAC plants and the users can't control the microclimatic parameters (i.e opening of windows and controlling solar shadings). On the contrary, in the classrooms a greater conditioning plants control is possible adapting the indoor microclimate during the hourly lesson breaks, but it is limited during school time.

Several surveys were conducted in schools at different levels. The microclimatic parameters were put into relation with the judgment of the occupants expressed by the questionnaires, in order to validate the comfort model and analyze subjective preferences.

Mors et al. [28] in order to test the efficiency of Fanger and Adaptive models on children, have compared the real mean vote with the predicted mean vote and the limit temperatures in some classes of a primary school.

The authors have concluded that the Fanger model underestimates the thermal sensation, with a greater error in summer. Furthermore children prefer lower temperatures than those predicted by the adaptive model.

De Giuli et al. [29] evaluate the indoor environmental conditions and children's comfort levels in three Italian primary schools. Predicted mean vote and predicted percentage dissatisfied indexes were calculated and an adaptive approach was also applied, but their results did not correspond to the students' subjective evaluation of thermal comfort.

Corgnati et al. [30] have investigated the thermal preferences in some schools in Turin (Italy) using both the rational approach of Fanger and the adaptive approach. A first survey was conducted in winter with water heating system turned on, the second one in September and May in free running condition. The study shows a gradual changing trend in the thermal preference from winter to spring. During the heating period the students prefer slightly warm or warm environments, however during the mid season they prefer neutral environment. In mid-season it can be note that the percentage of students not satisfied predicted by the Fanger model (PPD) and the percentage obtained by the adaptive model are similar, both less than 10% (probably because any extreme outdoor environment conditions occurs). However, taking into account the questionnaires it can be note that the real percentage of dissatisfied (PD) is significantly higher than those predicted; this deviation increases if the indoor operative temperature is above 20.5 °C or PMV is above -0.5. Furthermore, as Mayer has argued in his studies [31], the vote +2, considered unacceptable by Fanger, is instead accepted and preferred by the occupants. Considering not satisfied people expressing a score of -3, -2 and +3 (excluding the vote +2), the index of Fanger PPD is closer to the real PD.

Von Grabe et al. [32] show that people who are voting with ASHRAE ±2 or beyond are not necessarily dissatisfied (which is the basic assumption of the classical PPD concept) and vice versa, that people who are voting between -1 and 1 are not necessarily satisfied with their thermal environment.

Buratti and Ricciardi [26] carried out a survey at Perugia, Terni and Pavia Universities, by a questionnaire given to the students and collecting data on microclimate. The purpose of the study was to compare data provided by the theoretical models of Fanger and Wray with the experimental data. Wray model [33], based on Fanger thermal balance equation, defines a new thermal index more intuitive. This model, designed for evaluating comfort in buildings with passive solar systems (so not uniform environments), introduces two indices:

- The Comfort Uniform Temperature defined as the temperature of an environment in which the heat balance in the Fanger equation is equal to zero (optimum comfort conditions);
- The Equivalent Uniform Temperature defined as the uniform temperature of an ideal environment in which the occupants would express the same degree of thermal comfort achieved in a real environment.

The study found that Fanger and Wray models converge and the results achieved by the two models are similar to the results obtained by the questionnaires.

2. Experimental study

2.1 Aim of the study

The results shown in this paper were achieved from an experimental campaign performed at the Polytechnic University of Bari (Italy). The classrooms, taken into account, had different architectural features, conditioning plants, solar exposure. The analysis was conducted in the first days of March, at the beginning of spring, during teaching timetable, involving 126 students.

The study is divided into three parts. Firstly, the models provided by the comfort technical standards were taken into account, comparing the expected results with those achieved by the questionnaires given to the students. Then a more detailed analysis was conducted on the preferences expressed by the occupants. At last, it was assessed the influence of the individual control of the environmental parameters on thermal sensation.

2.2 Climate

Bari is a town placed in southern Italy. According to Koppen world climate classification [34], it has a Mediterranean climate characterized by hot humid summers and moderate winters. The Adriatic Sea mitigates outdoor temperatures: in January, the coldest month, the average temperature is 8.6 °C, while in July, the warmest month, the temperature is 24.7 °C.

2.3 Classrooms

Two different type of classrooms were taken into account. The architectural and plant features are shown in Table 1.

Table 1 - Architectural and plant features of the classrooms

Classroom	**N. of seats**	**Floor Area (m^2)**	**Heigth (m)**	**Volume (m^3)**	**A_{window}/A_{floor}**	**Windows exposition**	**Heating plant**	**Ventilation plant**
10	110	86,25	2,70	233	0,16	Est	OFF	OFF
21	80	118,4	2,70	320	0	-	OFF	ON

The classroom 10 (Fig. 1) is located on the second floor, it borders with other classrooms with similar geometric structure. The entrance to the classrooms is from an internal corridor. The external wall has a ribbon window and it is equipped with solar shadings controlled by the users. There is an HVAC plants with ceiling diffusers, controlled by a thermostat. During the experimental measurements there were 57 students and the air conditioning system was switched off.

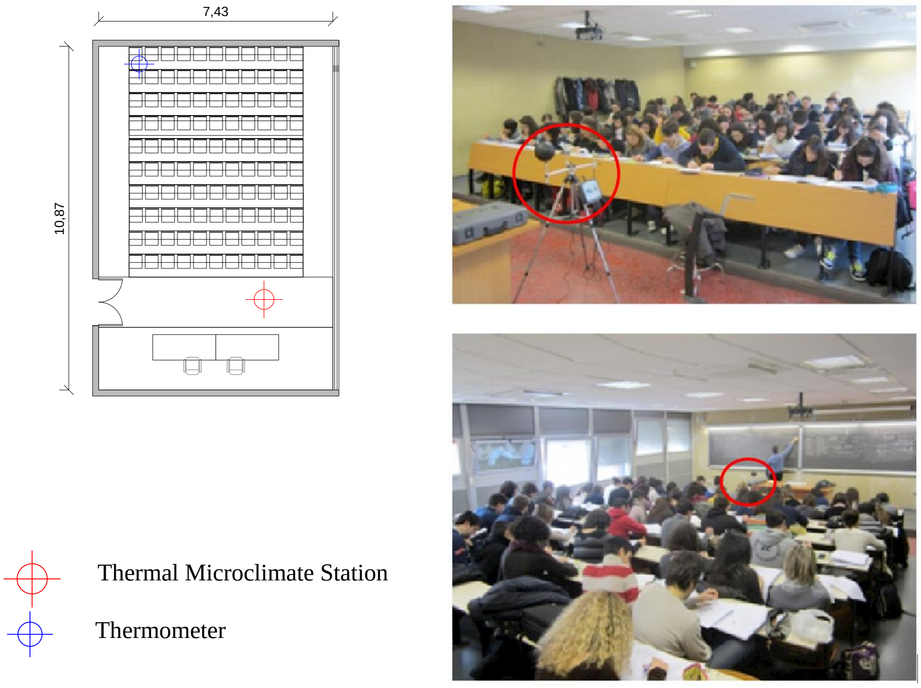

Fig. 1 - Classroom 10 (Map, view and monitoring points).

The classroom 21 (Fig. 2) is on the first floor, it develops in width and it is partially below floor level. Access is directly from the outside. The classroom has no windows; it has a ventilation system which was switched on during the test. There were 69 students during the measurements.

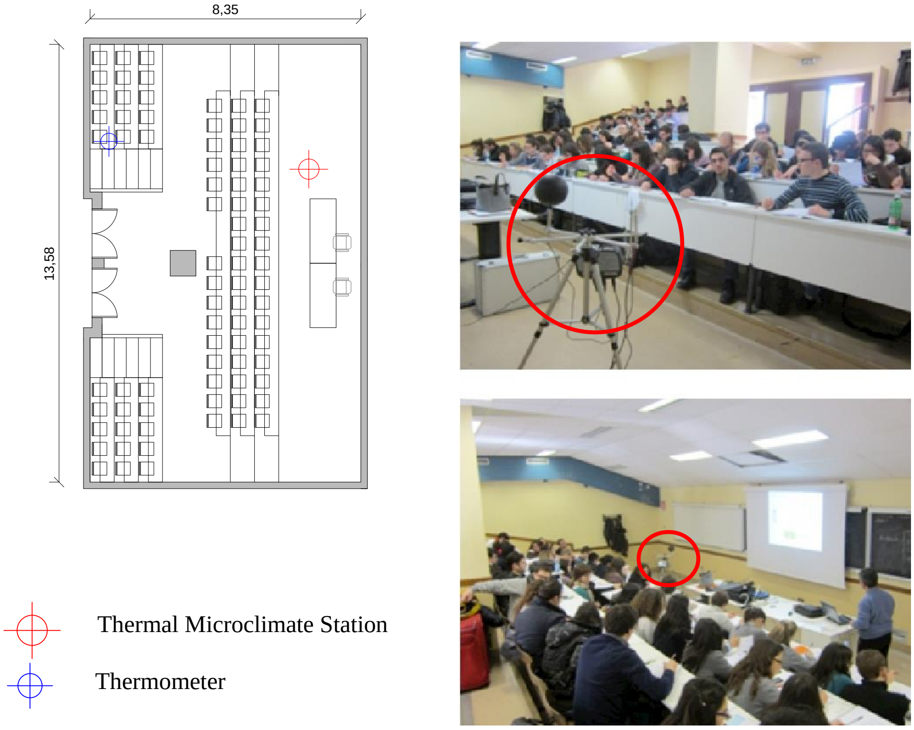

Fig. 2 - Classroom 21 (Map, view and monitoring points).

Both classrooms have seats placed on a sloping floor. As a consequence of this geometric configuration, the temperature was recorded at different positions in order to verify the presence of different thermal zones. As a result of measurement it can be note that two different thermal zones occur in classroom 21 (Fig. 3).

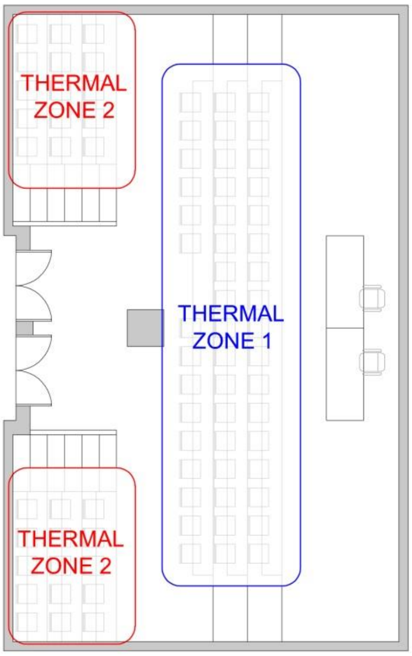

Fig. 3 - Thermal zones in classroom 21.

2.4 Measurements

In order to control indoor microclimate, the Thermal Microclimate HD32.1 Delta Ohm station was used. For the control of the environmental parameters the following probes were used:

- Globe-thermometer (Pt100, 150 mm diameter);
- Omnidirectional hot-wire anemometer (NTC 10 kOhm);
- Combined sensor with a capacitive sensor measuring temperature (Pt100) and relative humidity.

According to EN ISO 7726 [35] the parameters were constantly measured at 1.1 m height above floor level. During the lesson (1 hour and 40 minute) the measurement was performed at 2 minute intervals. Since the globe thermometer and the temperature probe have a response time of 15 minutes at least, the first 15 minutes recorded were not considered.

In order to evaluate the thermal condition of the environment, as shown in Figs. 1-2, the monitoring station was installed near the desk, in the lowest area of the classroom (coldest area), and at the same time the temperature was recorded in the highest area (warmest area) in order to evaluate the thermal uniformity of the environment. This last measurement was performed by a Delta Ohm HD 9021 device with a Pt100 thermal sensor (TP 870A) .

2.5 Questionnaires

The questionnaires were used to analyze the thermal perception by the occupants. They were distributed to the students after 30 minutes from the lesson start while measurements were carrying out.

The questionnaire is divided into four parts:

Part 1. General information: gender, age and individual student position in the classroom.

Metabolism and thermal perception depends to the age and sex. Parsons [36], showed that women have a slightly lower metabolism, so they can tolerate warm better than men.

Part 2. Individual thermal sensations: vote on thermal environment, thermal preferences, thermal satisfaction, thermal acceptability and air movement acceptability.

Thermal vote is expressed on Fanger seven-point scale, allowing the evaluation of the actual mean vote (AMV) and the dispersion regarding to the actual percentage of dissatisfied (APD). Preference, dissatisfaction, thermal unacceptability and acceptability of the air movement were analyzed by a separate and specific procedure.

Part 3. Clothing: according to EN ISO 9920 [37] check-list of clothing, in order to define thermal insulation of the occupants. According to EN ISO 7730 [13] for people seated the thermal insulation must be evaluated considering the additional contribution (0.1 clo) due to contact with the seat.

Part 4. Individual environmental parameters control: possibility to influence microclimatic conditions of the environment, perception and satisfaction of this level of control.

The correlation between these results allows to study the influence of the behavioral and psychological adaptation on comfort perception.

3. Results and discussion

Comparing the results from questionnaires and the temperature values measured (21,6°C in zone 1; 23,7°C in zone 2) in the classroom 21 it can be note that the students placed in thermal zone 1 express a vote more negative (Fig.4).

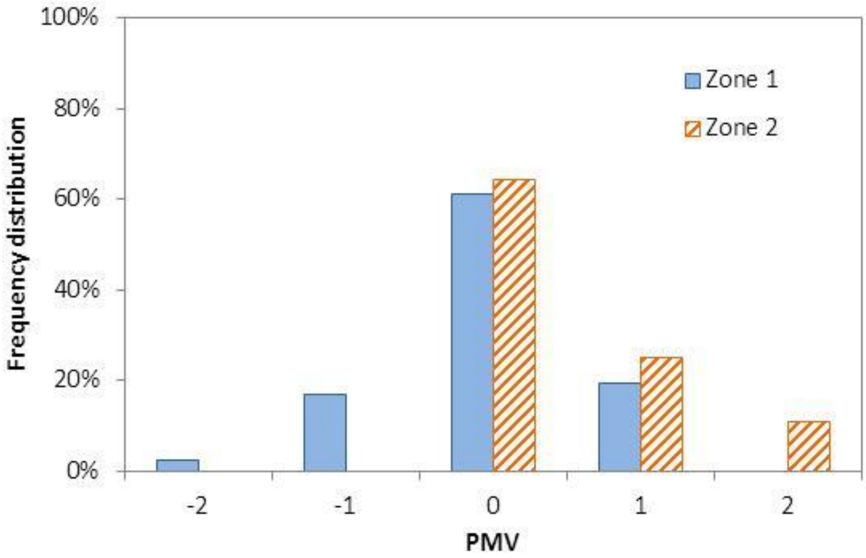

Fig. 4 - PMV expressed for each thermal zone in classroom 21.

This different thermal sensation is due to the different height of the classroom caused by the sloping floor; seats of thermal zone 2 are located higher than seats of thermal zone 1.

3.1 Rational and adaptive approach comparison

3.1.1 Fanger rational approach

The data collected from the questionnaires and the microclimate monitoring station have been processed in order to evaluate the thermal comfort according to EN ISO 7730 [13] which considers Fanger model (Table 2). In order to determine PMV and PPD values it was considered a sedentary activity (1.2 met); clothing values were drawn from the questionnaires.

Table 2 - Fanger model data and questionnaire results.

Classroom	**T. outdoor (°C)**	**T.indoor (°C)**	**Fanger indices**		**Questionnaire results**	
			PMV	**PPD**	**AMV**	**PD**
21	14.6	22.6	-0.05	5.0%	0,17	5.9%
10	13.5	22.2	0.03	5.0%	0,07	0.0%

Although by Fanger model can be appreciated values very close to the real ones, it can be note that a slight overestimation of the mean vote occurs, predicting cold sensation greater than the real one.

Figures 5 show the relationship between the thermal resistance due to clothing and the mean vote, comparing PMV to AMV. It can be note that a significant correlation between AMV and clothing does not exist. People wearing lighter clothing, who should feel colder, are warmer than people wearing heavier clothing. This is due to the human ability to adapt his body to the environment, changing the clothing according to the thermal sensation. This aspect is not taken into account by Fanger model.

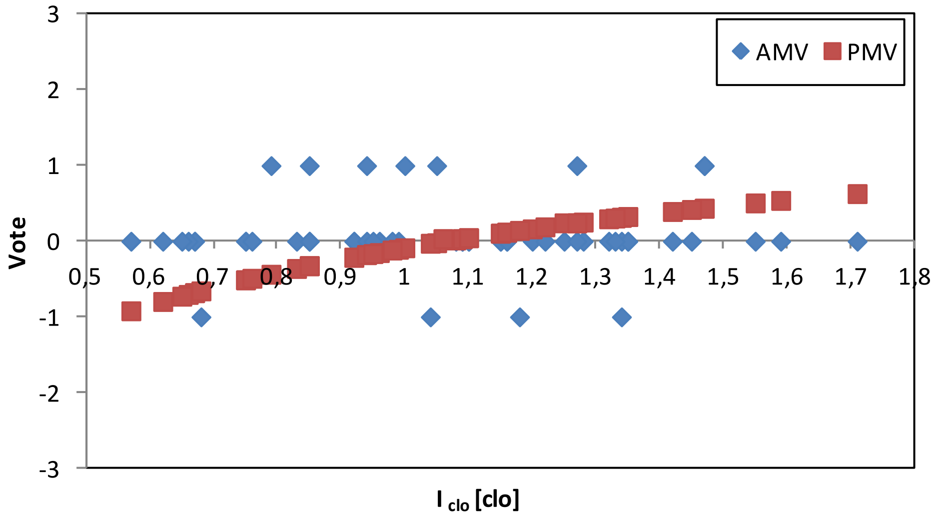

Fig. 5: Classroom 10 - AMV and PMV vs I_{clo}.

3.1.2 Adaptive approach

As previously described , the EN 15251 [14] and ASHRAE 55 [17] define the mathematical model to calculate the optimum internal operating temperature according to the adaptive approach. The Mean Monthly outdoor Temperature (T_{mm}) and the Running Mean Temperature (T_{rm}), being into the range of applicability, were also taken into account into the adaptive model (Tab. 3).

Table 3 - Adaptive model data.

Classroom	**$T_{outdoor}$** (°C)	**T_{mm}** (°C)	**T_{rm}** (°C)	**T_{indoor}** (°C)	**Adaptive model results**			**Questionnaire results**	
					PPD	**T_{op} (°C) (ASHRAE 55)**	**T_{op} (°C) (EN 15251)**	**AMV**	**PD**

21	14,6	10,0	11,5	22.6	<10%	21±2,5	22,6 ±3	0,17	5,9%
10	13,5	10,2	11,6	22.2	<10%	21±2,5	22,6±3	0,07	0,0%

Comparing the questionnaire and the adaptive approach results it can be assessed that the measured indoor temperature values (T_{indoor}) are in the optimum internal temperature range achieved by the adaptive model (T_{op}). It can be also note that the dissatisfied occupants percentage (PD) is less than 6%, according to the results from the questionnaires.

Furthermore, it can be assessed that rational approach and adaptive model results are similar, since the PPD is less than 10%, according to the results from questionnaires.

3.2 Thermal preference

The second part of the study takes into account the thermal sensation, according to Fanger seven point scale and compares it to individual preferences.

In order to compare the occupants votes to thermal preference the following indexes were taken into account:

Thermal Preference Index (I_{tp}) = (*N. of occupants willing to a change*)/(*N. of voting occupants*);

Dissatisfaction Index (I_d) = (*N. of dissatisfied occupants*)/(*N. of voting occupants*);

Thermal unacceptability Index (I_{tu}) = (*N. of occupants that feel unacceptable the environment*)/(*N. of voting occupants*);

Air movement unacceptability (I_{amu}) = (*N. of occupants that feel unacceptable the air movement*)/(*N. of voting occupants*).

From Tab. 4 it can be note there is a greater discomfort in classroom 21 than in the classroom 10: 21,7% of occupants prefer hotter or colder environment, 24,6% of occupants are dissatisfied with the thermal environment, but only the 11,6% considers the environment unacceptable. Furthermore, 36,2% of occupants considers unacceptable the air movement, produced by ventilation plant reaching an average speed of 0,10 m/s as monitored during the test.

Table 4 - Thermal sensation indexes.

Classroom	**Indexes**			
	Thermal Preference (I_{tp})	*Dissatisfaction* (I_d)	*Thermal unacceptability* (I_{tu})	*Air movement unacceptability* (I_{amu})
21	21,7	24,6	11,6	36,2
10	14,0	17,5	7,0	14,0

In order to assess the correlation between thermal vote and thermal sensation, the data collected in the two classrooms were combined and analyzed. The votes, expressed by the occupants, were then connected to Thermal Acceptability (Fig. 7), Thermal Neutrality (Fig. 8) and Thermal Preference (Fig. 9).

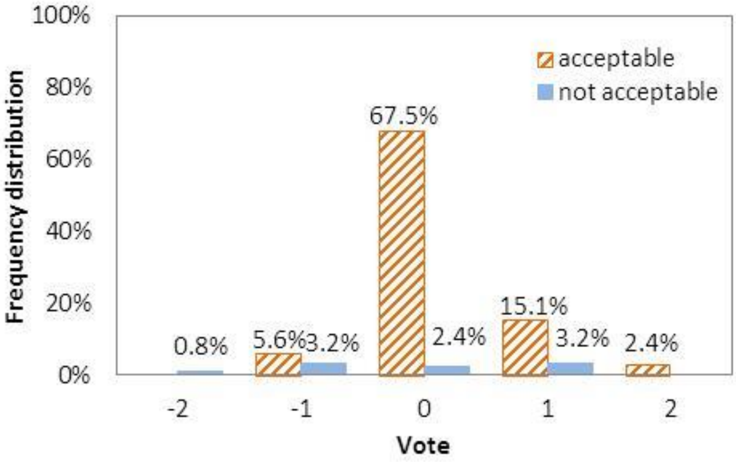

Fig.6 - Thermal Acceptability.

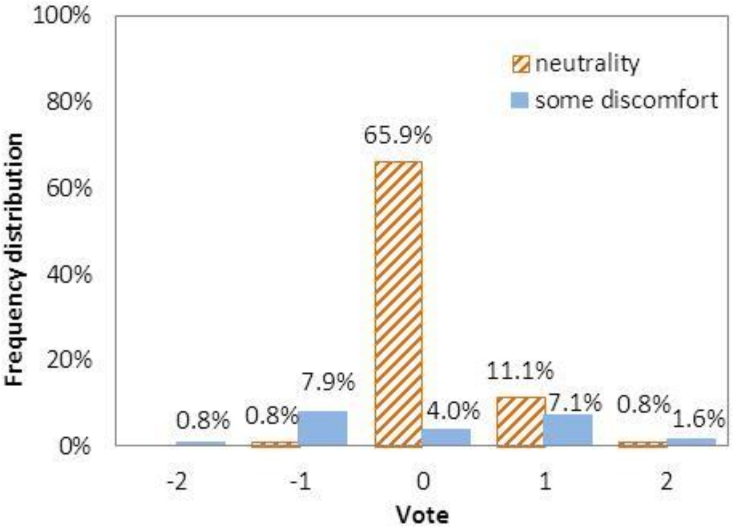

Fig.7 - Thermal Neutrality.

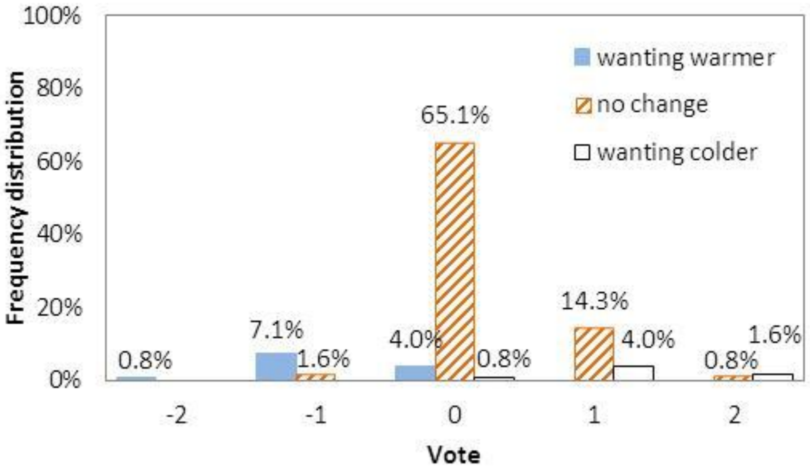

Fig. 8 - Thermal Preference.

Most occupants (96.8%) express a vote -1, 0, +1; however 9,5% considers the environment "unacceptable," and 21,4% feel a "slight discomfort". Among occupants formulating a vote of neutrality (69.9%), 2,4% of the students consider the environment unacceptable and 4,0% feels a slight discomfort. These values confirm the subjectivity of thermal comfort perception and the strictly connection of the factors involved. It can be asserted that individual expectation and plant control possibilities must be added as objective factor.

Furthermore the acceptability of the environment is connected to scale positive vote (warm sensation), as proved by Mayer [31] and Corgnati et al. [30]. All students expressing positive vote (+2) consider acceptable the environment; just half of them feel a slight discomfort. However most people expressing negative vote (-2) consider the environment unacceptable and annoying. As consequence, it can be asserted that warm environment is more acceptable than cold environment.

81% of the students expressed vote -1, 0, +1; they do not prefer a warmer or colder environment. Among people expressing vote -1 (8,7%), just 1,6% prefer not to change the environment, however 18,2% of students expressing vote +1; among them 4,0% prefer changing environment.

Intersection point between the thermal preference curves (Fig. 10) determines the mean vote corresponding to the minimum number of dissatisfied. This point does not represent the neutrality, but is slightly shifted towards positive values.

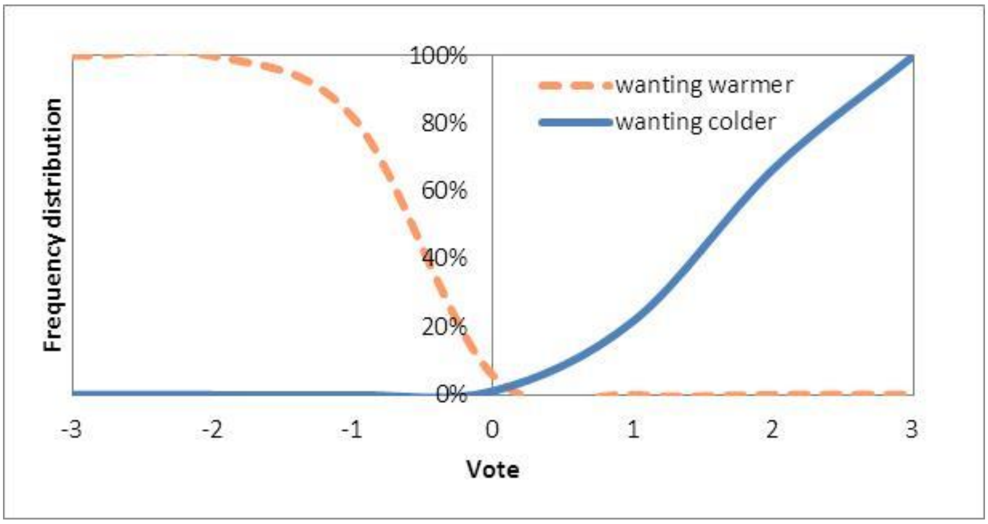

Fig. 9 - Students percentage preferring warmer/colder environment vs thermal vote.

The gender influence

Several studies have investigated the difference between males and females response in thermal comfort [36, 38-41]. Fanger [15] has proved that the women are more sensitive to a deviation from the optimum.

Studies conducted by Breslin [39] and Webb et al. [42] show that in neutral or light warm conditions any significant difference between men and women response can be appreciated. However, in cold environment a great difference in thermal perception can be note comparing men and woman response; women tend to feel cold more than men [36].

The thermal sensation in a “moderate” environment was studied. Table 5 summarizes the clothing insulation values and the AMV distinguishing men and women vote. Comparing cloth indexes of the two gender can be appreciated a difference of 0,09 clo in classroom 21 and a difference of 0,15 clo in classroom 10. It can be asserted that women are inclined to wear warmer clothing.

Table 5 - Clothing and Actual Mean Vote (women vs. men)

Classroom		**Number**	**I_{Clo} (clo)**	**AMV**
21	Men	37	0,98	0,32 ± 0.63
	Women	32	1,07	0,00 ± 0,80
10	Men	19	1,03	0,11 ± 0,32
	Women	38	1,18	0,05 ± 0,52

Fig. 11 shows the men and women votes. In the same environment 14,3% of women feels cold (vote -1); on the contrary just 1,8% of men feels cold. Considering warm sensation (vote +1) any significant difference between the two gender occurs. Also the neutrality perception is similar taking into account men and women.

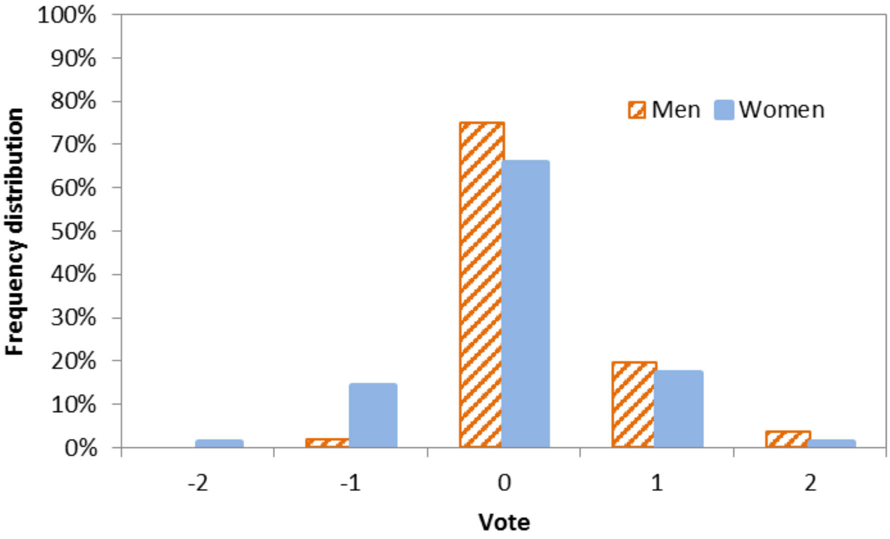

Fig. 10 - Men and women votes.

Thermal sensation, neutrality and acceptability results are shown in Fig. 11-12-13.

A greater percentage of women (31,4% of women vs 8,9% of men) consider the thermal environment conditions of discomfort. Women prefer a warmer environment (18,6% of women vs 3,6% of men), in agreement with the vote of slightly cold.

Furthermore, considering the acceptability, it can be note that an higher percentage of men (12,5% of men vs. 7,1% of women) expresses a judgment of unacceptability.

A study conducted by Karjalainen [43] in Finland and in different type of buildings (home, offices, universities) confirmed a significant gender differences in the perception of thermal comfort. Females are less satisfied with thermal environments than males and feel both cold and hot more often than males. However, Karjalainen considering the different gender clothing and the building characteristics has concluded that the gender thermal comfort perception is connected to process of human adaption.

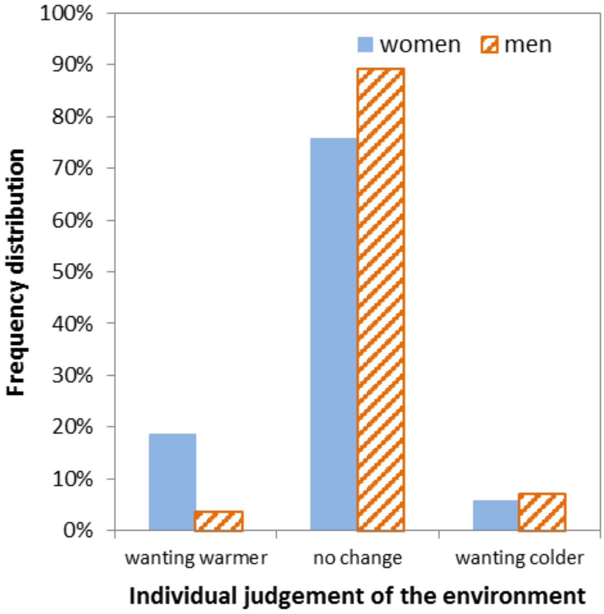

Fig. 11 - Thermal preference (women vs. men)

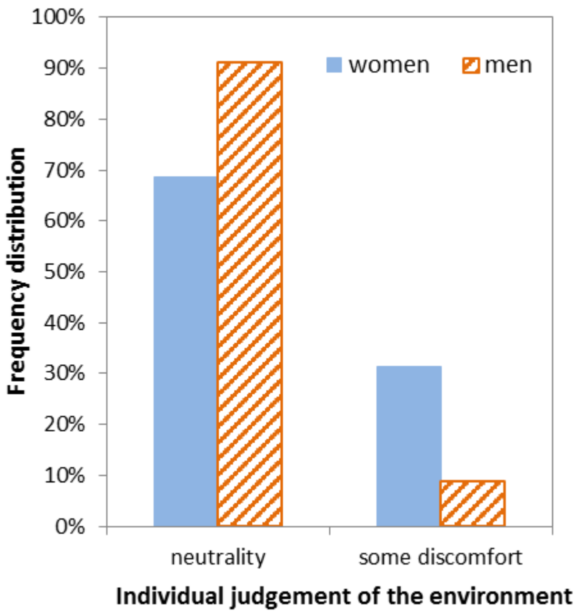

Fig. 12 – Neutrality (women vs. men)

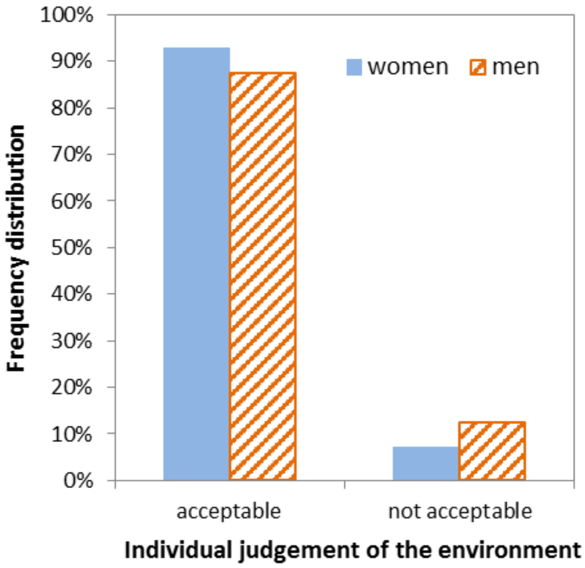

Fig. 13 – Acceptability (women vs. men)

3.2 Microclimatic controls

Luo et al. [44] investigated the thermal comfort perception in winter in residential apartments considering occupants with different personal control on heating system. He demonstrated that occupants in apartments in which the heating facilities could be controlled were more likely to report neutral thermal sensations. In this latter case the users had 2.6 °C lower neutral T_{op} than those without personal control.

By the questionnaires, the occupant adaptation activity was evaluated, analyzing the relationship between microclimate control and thermal sensation.

The two classrooms have different microclimate control levels; as consequence different results can be appreciated.

Classroom 21 has no windows and is equipped with a centralized ventilation plant, switched on during experimentation. The monitoring station recorded an average air velocity of 0.10 m /s. The 36.2% of students believed that the value of air velocity was unacceptable, too high.

By the questionnaires students expressed an opinion about their satisfaction on possibility to control the microclimatic parameters.

In classroom 21, 79,7% of the students believe to have any control on microclimate; 14,5% of them is satisfied of this condition. Figure 14 show the correlation between the perception of the occupants on controlling the microclimate and their thermal response. The increase of control perception causes the enhancement of the levels of acceptability, neutrality and vote "0".

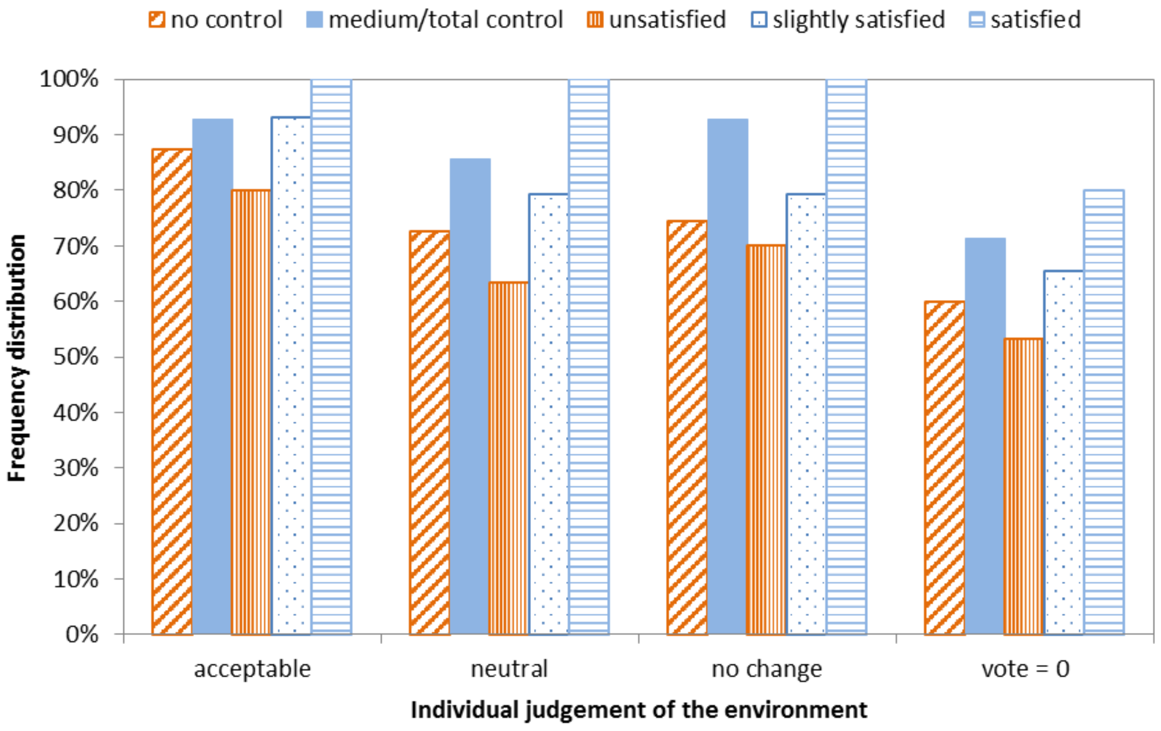

Fig. 14 - Classroom 21. Control level and satisfaction influence on acceptability, neutrality, preference and thermal vote.

In classroom 10 there was a different environmental condition. The wall opposite to the entrance has ribbon window, with fixtures and solar shadings adjustable by the user. There is also a HVAC plant with ceiling diffusers that the occupants can control by a thermostat. During the measuring campaign the HVAC plant was turned off. The questionnaires show that just 15.8% of the occupants believed to have any control on microclimate. This is due to the real impossibility of the occupants to control the microclimate during lessons. Furthermore, just 5,3% of the occupants is unsatisfied of the thermal conditions.

In Figure 15 it can be note that when increasing the microclimate control, the satisfaction feeling on environmental conditions improves. The satisfaction on control possibilities and the thermal preferences are compared. It results that just 5,3% of the occupants is unsatisfied on control level. Among them, 2/3 of the occupants would not change the environmental conditions and 1/3 of the occupants expressed a neutral condition. Students considering the environment satisfying expressed a greater positive vote.

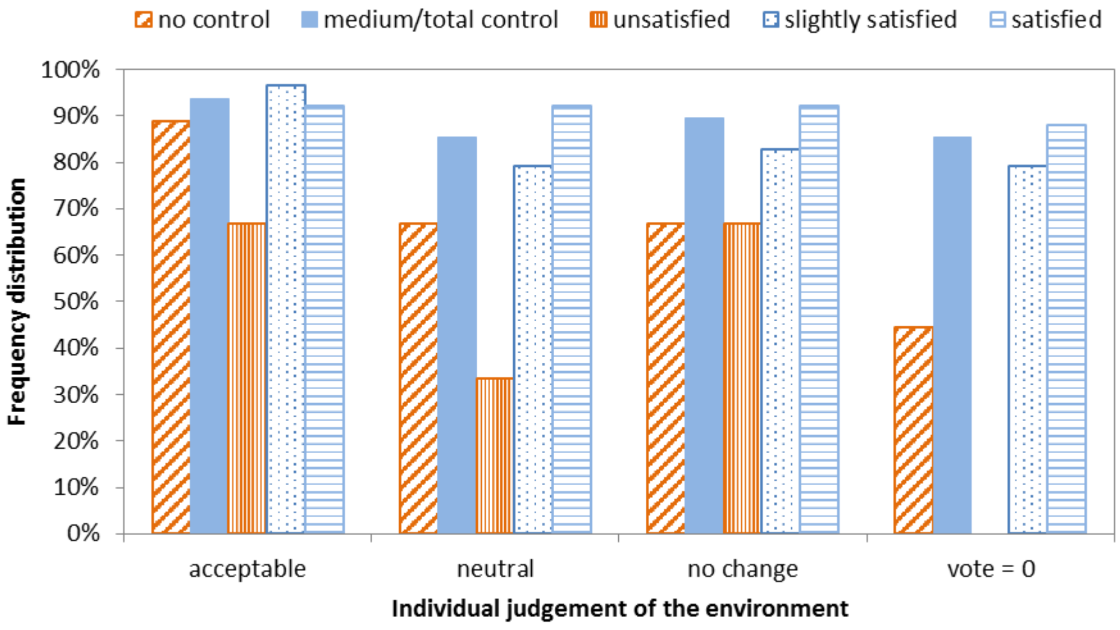

Fig. 15 - Classroom 10. Control level and satisfaction influence on acceptability, neutrality, preference and

thermal vote.

A comparison of the thermal preference expressed by students in the two classrooms, is reported in Fig. 16.

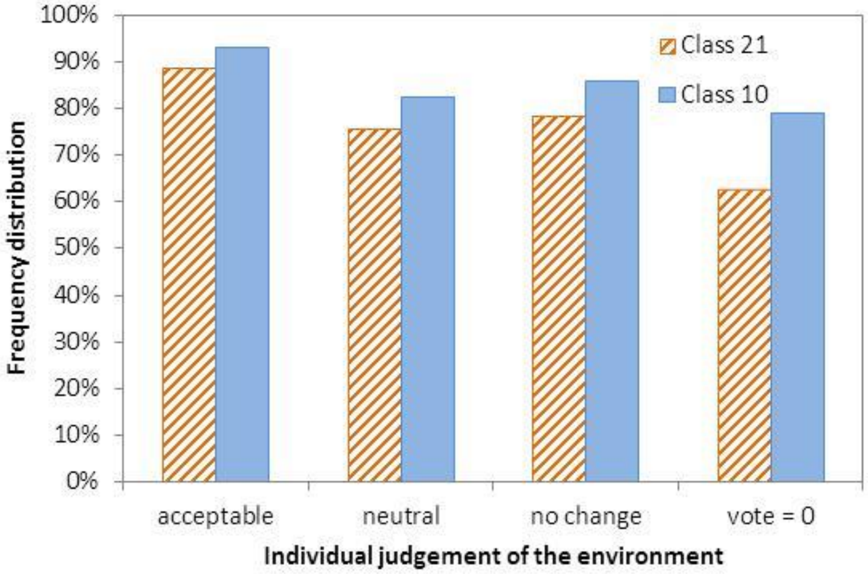

Fig. 16 - Comparison of thermal sensation in the two classrooms.

The different control possibility of indoor climate causes a great difference in comfort perception.

In classroom 21, 88% of the occupants considers acceptable the environment, 75% of the students assesses neutral the environment, 78% of the users does not change the thermal environment; just 62% expressed vote "0".

In classroom 10 the expressed preferences are higher: 93% of the occupants believe the environment acceptable, 83% considers it neutral, 86% does not want to change the microclimate and about 79% expressed a vote "0".

4. Conclusions

This study is a contribution on research about thermal comfort in universities, performed by field measurements in classrooms at Polytechnic University of Bari. The experimental analysis was divided as follows: a first comparison of Fanger's model and Adaptive approach and a comparison of these results with the real vote expressed by questionnaires; a second analysis of the thermal sensation of the occupants and a final study of the correlation between the individual possibility of control the environmental parameters and the thermal sensation.

Significant results were found. The architectural geometry of the environments has a great influence on thermal conditions, since different thermal zones exist. This influences the student's vote. PMV and PPD values are similar to the real votes, collected by the questionnaires; a slight underestimation can be appreciated when using models. Comparing optimal Operative Temperature, achieved by adaptive model, with the favorite real temperature, it can be note that this latter one is shifted toward positive range of thermal scale; this is due to an individual warmer preference of the thermal environment.

Furthermore, a slight different thermal response can be appreciated comparing women and men thermal response. It was found that women tend to feel cold more than men and they are inclined to wear warmer clothing. As consequence, woman prefer warmer environment and a greater percentage of them consider the classroom thermal conditions of discomfort.

Also the relationship between microclimate control and thermal sensation was investigated. The two classrooms have different microclimate control levels; thus different results can be appreciated. It can be note that when increasing the microclimate control, the satisfaction feeling on environmental conditions improves. Conversely, when decreasing individual control possibilities on thermal environment a worst thermal perception occurs; the occupants are more unsatisfied of the thermal environment conditions. As a consequence the neutrality sensation reduces and the user prefers a warmer or colder environment.

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