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Thermal judgements and adaptive behaviours: a study on the subjective side of thermal comfort in two University buildings in France.

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Abstract

This paper presents some of the results of a field study carried out in 2013 in two University buildings in Paris and in Champs-sur-Marne, nearby Paris. The aim of the study was to examine students' thermal judgements and thermal adaptation by combining an objective and a subjective approach. First is presented a comparison between "real" thermal responses (thermal sensation, preference, acceptability) and predicted ones (Predicted Mean Vote, Predicted Percentage of Dissatisfied), after which follows an analysis of students' actions to improve their thermal comfort. Results reveal the significance of looking at thermal comfort in naturalistic settings. They also invite to address thermal responses, behaviours and opinions in an integrated protocol based on rich information on the "subjective side" of thermal comfort.

Keywords: thermal judgements, adaptive comfort, practices and behaviours, subjective and objective approach.

1. Introduction

The first codified methodology for determining thermal comfort range was introduced by Fanger (Fanger, 1972), with the support of ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). Fanger constructed from a fully controlled climate chamber a comfort index (PMV) expressed in an equation. This index is accurately calculable in any geographical context, and it suits very well fully conditioned and mechanically ventilated buildings. Numerous studies since 1970 have shown that this model is not able to properly assess the human response in naturally ventilated buildings. Models developed around the concept of Adaptive Comfort are implemented on the assumption that persons play an active role in determining their own conditions of comfort, instead of suffering passively the surrounding environmental conditions (Humphreys and Nicol, 1998; Brager and de Dear, 1998). A model developed by Dear and Brager (de Dear and Brager, 2002) from the international database ASHRAE proposes a new algorithm for predicting thermal comfort that relates the internal temperature of comfort to the average outdoor temperature. A similar model has been developed by the European project SCAT and integrated in the standard EN 15251 (Nicol and Humphreys, 2010).
Following the Adaptive Comfort principles, we attempt in this paper to approach the "subjective side" of thermal comfort in two University buildings, thus focusing on personal thermal judgments and adaptive behaviours in this important context.

2. Aims of the study

This paper presents some results of a field study carried out in 2013 in two University buildings in Paris and in Champs-sur-Marne, nearby Paris. The aim of the study was to investigate thermal sensation, thermal adaptation and thermal representation of university students by means of both an objective and a subjective approach.

A large amount of data was collected; this paper presents a part of the results. Two are the topics addressed by this paper. The first one focuses on the comparison between actually measured thermal responses (from data collected during the surveys, i.e. thermal sensation, preference, acceptability) and hypothesized/deduced ones (Predicted Mean Vote, Predicted Percentage of Dissatisfied). This comparison is carried out by the means of different thermal scales used in a questionnaire that was submitted to a number of students. It was decided not to focus on the direct correlation between votes and environmental data, such as temperature humidity etc., and that is the reason why calculation of neutral temperature is not presented in this paper. The objective here is to better understand the relation between thermal sensation, preference and acceptability, evaluating at the same time the correspondence between collected and measured votes on thermal comfort.

The second topic addressed in this paper concerns thermal adaptation. By "thermal adaptation" we mean in this context a set of actions that the surveyed subjects perform to improve their thermal comfort. We explored the opinions on the effectiveness of those practices, since one of the aims was to examine the students' ability to evaluate the adaptation opportunities that classrooms afford. We tried to understand their aptitude for carrying out different activities with a thermal implication (opening a window, drinking, etc). Finally, we wanted to see if any link could be found between students' thermal responses (sensation, preference etc.) and their degree of thermal adaptability measured through the implementation of those practices.

3. Context

3.1 Buildings

Two university buildings were surveyed. The first one (EVS) is the Architecture School in Paris-Val de Seine (Figure 1a and 1b). It's a seven storey building recently edified (2007) by F. Borel, Grand National Prize for Architecture 2010. His *silhouette* faces the Seine River in the 13th department of Paris, participating in the renovation of the ancient industrial neighborhood. The school welcomes over 1.800 students, 230 teachers and 70 administrative staff. Since the purpose of the study was the investigation of students' thermal comfort conditions, the choice was made to focus on three different classrooms. The first one is an amphitheatre (Amphi), located at the 1st floor, East-oriented, mechanically ventilated and equipped with a ceiling air-heating system. Some very small windows are located at the highest position of the wall, and students cannot either reach or open them. Windows are permanently covered by internal black curtains. The second and the third ones are two rooms that are similar in size, use and equipment. They are naturally ventilated and air-heated. One (room 411) is located at the 4th floor, North facing; while the other one (room 504) is located on the 5th floor and is West-oriented. No curtain or shading system is installed. The second university building (UPEM) is called Lavoisier and it is part of the Marne-la-Vallée university campus in Champs-sur-Marne, close to Paris (Figure 1.c). Built in 1993 by architects F.-H. Jourda and G. Perraudin, the building is a totally glazed and squared volume. One classroom was chosen (room 211) on the first floor, South facing, naturally ventilated and heated by wall radiators.

Figure 1a, b: North and East view of EVS. Figure 1.c : UPEM building

3.2 Subjects

A total of 183 students participated in the surveys. Table 1 specifies the sample size, age, weight and height for the different classrooms and buildings. Similar characteristics can be found concerning age, weight and height, whereas gender is inversed from EVS (female majority) to UPEM (male majority)

Table 1. Summary of sample

Place	EVS				UPEM	ALL
	All	Amphi	411	504	211	
Sample size	146	37	68	41	37	183
Gender						
Female	91	28	37	26	10	101
Male	50	7	29	14	22	72
Age (years)						
Mean	22,7	25,7	21,2	22,43	22,2	22,6
S.D.	4,33	6,8	1,32	3,5	1,71	3,9
Min.	19	21	19	20	20	19
Max.	52	52	26	40	28	52
Weight (kg)						
Mean	63,2	62,3	64,1	62,6	65,8	63,7
S.D.	11,7	9,4	12,4	12,6	8,9	11,3
Min.	43	43	45	44	48,5	43
Max.	90	85	90	90	80	90
Height (cm)						
Mean	170,7	169,3	171,8	170	174,6	171,4
S.D.	10,36	8	10,4	12,2	9,3	10,3
Min.	120	153	151	120	157	120
Max.	194	185	194	191	190	194

3.3 Climate

Paris has a mild humid temperate climate with warm summers and no dry season. Located in the western side of Europe and in a plain relatively close to the sea, Paris benefits from the balmy influences of the Gulf Stream. However, the weather can be very changeable especially in winter and spring, when the wind can be sharp and cold. Over the course of a year, the temperature typically varies from 1°C to 25°C and is rarely below -5°C or above

31°C. The annual average temperature is in the lower 12 °C; the July average is in the upper 19 °C, and the January average is in the upper 3 °C.

4. Methods and survey presentation.

Surveys were carried out during 2013 at different periods of the year. For EVS, 7 days of field work were organized from the 7th of March to the 16th of May 2013. UPEM students participated in the surveys 5 times from the 3rd of October to the 4th of December 2013. Students were expected to be questioned twice a day, at the beginning and at the end of the lesson during the regular lesson time, i.e. in the morning or in the first part of the afternoon (before 5 pm).

As suggested above, the present paper addresses the specific topics of thermal responses and thermal adaptation. However, the survey protocol is presented in what follows in its entirety, in order to give a more complete idea of the structure of the study. The aim of investigating thermal comfort inside university classrooms led us to set up a protocol based both on an objective and a subjective approach, starting from the hypothesis that the two are complementary and necessary for a deeper understanding of thermal comfort.

4.1 The subjective approach

The subjective approach was mainly intended to provide three different sets of information. The first one concerned the subjective thermal responses, i.e. judgements about the thermal sensation, perception, preference and acceptability of the environment. The second one focused on behaviours and practices and the third one on social representations. They were investigated through a questionnaire that was delivered and filled by the students while measurements (see 4.2) proceeded simultaneously. All efforts were put in trying to capture a "realistic" moment in the scholar daytime, neither breaking the situation continuity nor requiring any additional time, but attempting, with the help of the faculty, to integrate the task with the other usual tasks of the day (Corgnati et al., 2007). The questionnaire was devised on the basis of the author's previous experiences (Pellegrino, 2012) and it was furthermore inspired by other literature (Indraganti, 2010; Wong, 2003; Kwok, 2003; Raja et al., 2001).. It was divided in different sections, some of them being fixed, and thus repeated at each step of the survey, which means at least once a day for the 13 days of survey, others being proposed only once.

- Fixed sections:
    a. Thermal comfort judgements. 10 evaluation scales were proposed, enquiring how the thermal environment was felt. The seven-points ASHRAE scale was the first one (ASHRAE, 2005), based on the identification of the thermal sensation votes (TSV ASHRAE) answering to the question "What is your thermal sensation now?" using a scale going from "cold" (-3) to "hot"(3). The second one was the seven-points Bedford scale (TSV Bedford) answering again to the previous question but using a scale going from "much too cool" (-3) to "much too warm" (3). The third one was a seven-points perception scale (TPER) intended to measure the personal opinion on the environment climate. As much as one could ask, walking outside, "what's the weather like today?", we asked for an indoor condition such as the one in the classrooms "how could you describe the indoor climate conditions now?". Answers were the same as in the ASHRAE scale. The fourth (Nicol and Humphreys) (TP1) and the fifth (McIntyre) (TP2) scales concerned thermal preferences, asking "At the moment, would you prefer to feel…" and answering, for the Nicol one, using a five-points scale going from "much warmer"(-2) to "much cooler" (2), and for the McIntyre one, using a three-points scale from "warmer" (-1) to "cooler" (1). The sixth scale is a three-points

acceptability scale (TA), asking "At the moment, do you consider the thermal environment…" and answering "acceptable", "slightly unacceptable" and "unacceptable". The last four scales concern the evaluation, on a seven-points scale, of air speed and flow and humidity, in both cases asking an opinion about the intensity of those phenomena (AV; HV) and a personal preference ("Would you prefer…", "no change", "less humidity", "more air", etc) (AP; HP).

b. Weather and clothes. Some questions were introduced in order to investigate the subjective perception of the weather the day of the survey and the day before. Seven symbols (sun, more sun than shadows, more shadow than sun, variable with rain, shadow, rainy, snowing) were reproduced on the sheets. For another question, students were requested to guess how many degrees there were in the room. And they had to describe how they were dressed (in order to calculate CLO value for PMV, ASHRAE, 2009); but they also had to report if their choice was determined by the weather and, if so, by which specific condition (temperature, wind, rain, other).

- Questions introduced only once in the surveys.
  a. General information. "Classic" questions concerning name and surname, gender, age, weight and height of the subjects.
  b. General judgements. Students were asked to give a general description of the indoor environment of the classrooms both in winter and summer using two seven points scales going from "always too hot" to "never too hot" and from "always too cold" to "never too cold". They also had to provide an evaluation in terms of general quality (from "excellent" to "very bad"). Some other questions concerned the amount of time spent in A/C environments (in the car, in their house, in other houses and in the *loisir* spaces). Finally, they were asked to describe their subjective "approach" to climate, having to tell if they considered themselves a sensitive-to-cold person, a sensitive-to-hot person, an insensitive-to-climate person or someone who is very sensitive to both cold, hot and, in general, to all weather phenomena.
  c. Behaviour and actions. One question was introduced asking to describe the activities performed in the previous 30 minutes. These data allowed to estimate MET value on the basis of the ASHRAE parameters (ASHRAE, 2009). They were used to calculate PMV at the beginning of the lesson; we used a fixed value of 1,3 MET to calculate PMV at the end, assuming a similar metabolic condition for all the students already sitting and listening to the lesson since at least one hour. Then a list of actions ("Modify the position of louvers, curtains, etc", "Regulate the heating systems", "Regulate the AC", "Open and close a window", "Open and close a door", "Put or remove clothes", "Drink", "Have an air flow") was made. For each of these actions, students were asked to describe: i) a "possibility" evaluation, telling if such an action was possible to be carried out, impossible, or possible only in the timeframe between two lessons; ii) an "effectiveness" evaluation, telling if an action was deemed to be effective to improve the thermal comfort in the classroom, ineffective, or effective but only on a long period; iii) a "direct" activities description, telling which or whose actions were directly carried out by themselves ("never carried out", "carried out, but not today", "carried out, today too"). This last question concerning "practical" observations was proposed at each step of the survey.
  d. Social representations. The subjective approach was completed by a series of questions concerning social representations of comfort, thermal comfort and thermal adaptability. The term "social representation" was originally proposed by S. Moscovici (Moscovici, 1973). Recent developments of the original theory, known as *Central Nucleus Theory* (CNT) (Abric, 1994), led to explore the structural elements of

social representations, distinguishing between *core* and *peripheral* elements in terms of the centrality and stability of certain beliefs.

4.2 The objective approach.

The purpose here was to collect a dataset about the context of the survey. We focused on building and classroom characteristics, such as typology, orientation, exposition, number of floors, materials, heating and cooling systems, thickness of walls, double gazing, shading systems, openings dimension and position, presence of balcony.

Concerning weather conditions, we collected from the Météo France database a series of data on temperature in order to calculate the running outdoor mean temperature for the 30 and for the 3 previous days of each survey, and the mean temperature for the previous 24 hours (table 3).

The thermal environment of the four classrooms was analysed by means of field measurements campaigns carried out simultaneously with the questionnaires. Air temperature (T), globe temperature (Tg), air relative humidity (RH) and air velocity (Av) were measured (table 2) with the Sper Scientific WBGT SD Card Datalogger and the Testo 405 Anemometer at a height of 1.1 m above the floor, according to the Standard ISO 7726:1998 [ ]. The instruments remained stationary in the classrooms for the duration of the survey.

Table 2. Summary of indoor and outdoor climatic data

Place	**ALL**				**EVS**				**EVS Amphi**				**EVS 411**				**EVS 504**				**UPEM**			
Statistic	**Mean**	S.D.	Min.	Max.	**Mean**	S.D.	Min.	Max.	**Mean**	S.D.	Min.	Max.	**Mean**	S.D.	Min.	Max.	**Mean**	S.D.	Min.	Max.	**Mean**	S.D.	Min.	Max.
Indoor air temperature °C	**24**	1,5	20,5	25,7	**23**	1,6	20,5	25,7	**22**	0,5	20,5	22,1	**24**	1,5	20,9	25,7	**24**	0,9	20,9	25,7	**24**	1,1	22	25,7
Indoor relative humiduty %	**36**	12,1	18,8	63,2	**30**	9,1	18,8	48,7	**34**	10,6	24,1	48,7	**27**	6,6	18,8	40,8	**29**	7,6	18,8	42,5	**46**	9,8	31,5	63,2
Indoor globe temperature °C	**23**	1,7	19,6	26	**23**	1,9	19,6	26	**21**	0,7	19,6	22	**24**	1,7	20,4	26	**24**	1,2	20,4	26	**24**	0,9	22,1	25,6
Indoor air speed m/s	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0,1**	0,1	0	0,4
Running outdoor mean temperature (30 days) °C	**8,8**	4,7	4,1	17	**7,2**	3,5	4,1	14,6	**5,5**	0,9	4,1	6,7	**8,2**	3,8	4,1	14,6	**8,2**	4,2	4,1	14,6	**11**	5,2	5	17
Running outdoor mean temperature (3 days) °C	**8,1**	6	-0,7	18,4	**6,9**	5,9	-0,7	18,4	**5,9**	4,9	-0,7	12	**7,6**	7	-0,7	18,4	**7,1**	5,6	-0,7	18,4	**10**	5,5	2,8	16,7
Mean outdoor temperature (24 hours) °C	**9,5**	5,19	3	18	**9,7**	5,1	3	17,4	**6,9**	4,25	3	12,3	**9,6**	6,02	3	17,4	**8,9**	5,94	4	17,4	**9,2**	5,95	3,6	18

5. Results and discussion

5.1 Subjective thermal responses

Analyzing the comfort votes obtained via the previously quoted scales can help understanding thermal sensation, preference, neutrality and acceptability of the surveyed population, along with the evaluation of air velocity and humidity. Before starting these analyses, we compared the answers on scales through simple regression in order to get the determination coefficients that explain the correlations fit (I don't understand this subordinate). The results are shown in table 3. Colour intensity is proportional to correlation strength. The best correlations ($R^2 > 0.6$) were found between TSV ASHRAE scale and

Bedford and Thermal perception (TPER) scales, and between the two Thermal preference scales TP1 and TP2. Good correlations (0.4 < R^2 <0,55) were found between TSV ASHRAE scale, TP1 and TP2; between Bedford scale, TP1 and TP2; between TPER and TP1; and between HV and HP. Modest correlations (0.15 <R^2 < 0.35) were found between Bedford, TP1, TP2, AV and AP. The same procedure was applied for the EVS and the UPEM sub-populations (table 4) for the relevant correlations. Results show that R^2 is always better for EVS population, with the only exception of the HP/HV correlation.
It may be recalled that students were requested to use thermal scales twice a day, at the beginning and at the end of the lesson. Or, perception of thermal conditions is known to be influenced by various factors such as activity, clothes, etc. which is the reason why we run a last series of correlations for every room for T (votes at the beginning) and for T+1 (votes at the end of the lesson). In most all of the cases, correlations between scales at T+1 were better than at T. This may be due to the stabilization of contour conditions, i.e. metabolism, leading to a more coherent evaluation of thermal responses by subjects.

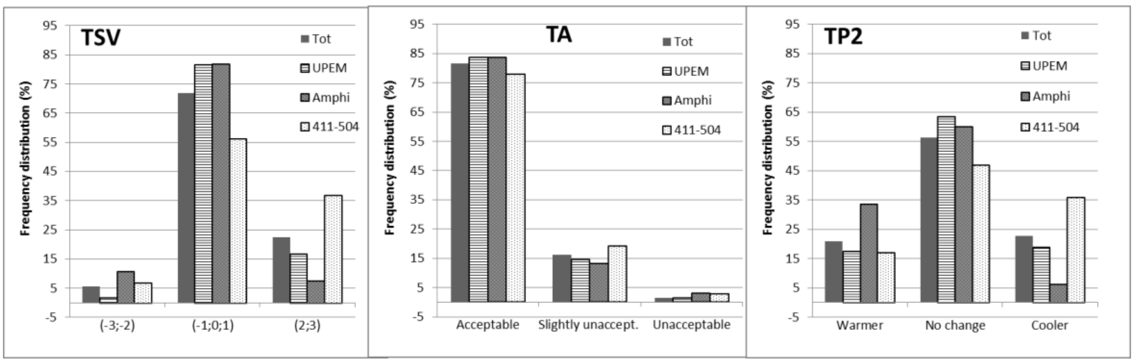
Table 3. Simple regression between scales.
Table 4. Simple regression between scales for the EVS (in red) and the UPEM (in blue) populations

R^2	TSV ASHRAE	TSV Bedford	TPER	TP1	TP2	TA	AV	AP	HV	HP
TSV ASHRAE	1	0,6	0,6	0,4	0,4	0	0,1	0,2	0	0
TSV Bedford	0,6	1	0,5	0,4	0,4	0	0,1	0,2	0	0
TPER	0,6	0,5	1	0,4	0,3	0	0,4	0,2	0	0
TP1	0,4	0,4	0,4	1	0,8	0	0	0,3	0	0
TP2	0,4	0,4	0,3	0,8	1	0	0	0,3	0	0
TA	0	0	0	0	0	1	0	0	0	0
AV	0,1	0,1	0,4	0	0	0	1	0,2	0	0
AP	0,2	0,2	0,2	0,3	0,3	0	0,2	1	0	0
HV	0	0	0	0	0	0	0	0	1	0,4
HP	0	0	0	0	0	0	0	0	0,4	1

R^2	TSV ASHRAE	TSV Bedford	TPER	TP1	TP2	TA	AV	AP	HV	HP
TSV ASHRAE	1	0,7	0,7	0,5	0,5					
TSV Bedford	0,6	1	0,6	0,5	0,4			0,4		
TPER	0,6	0,5	1	0,5	0,4					
TP1	0,3	0,4	0,3	1	0,8			0,4		
TP2	0,4	0,4	0,3	0,7	1			0,3		
TA						1				
AV							1			
AP		0,1		0,2	0,2			1		
HV									1	0,4
HP									0,5	1

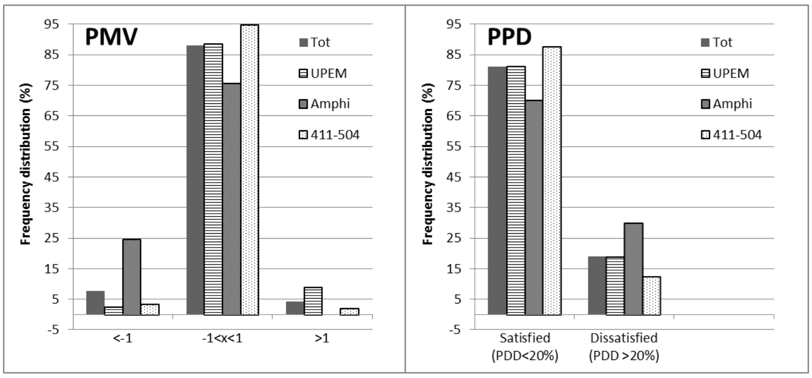
In the next analyses we will focus on thermal responses collected during the survey, and specifically on TSV ASHRAE, TP2 and TA scales. Figures 2, 3 and 4 show the frequency distribution of votes for the total population, the EVS population in Amphitheatre, the EVS population in rooms 411-504 (considered together for their similarities in floor area, openings and heating and ventilation systems) and the UPEM population. The TSV variable was reorganized in three classes (-3, -2; -1, 0, 1; 2, 3), assuming, as the ASHRAE Standards does, that the three central votes (-1, 0, 1) express acceptance and that votes outside this range express dissatisfaction.

Figures 2, 3, 4. Frequency distributions of TSV, TA and TP2 votes



Some remarks can be made. First, focusing on the total population, it can be seen that in every scale the majority of votes centered on 0, i.e. on the central class for TSV, on "acceptable" class for TA and on "no change" class for TP2. Second, looking at the samples separately, some differences can be found both in scale and population comparison. It is possible to observe that, in TA scale, populations reacted very similarly. All values are aligned, with the exception of the population of rooms 411-504, where the environment was found to be slightly unacceptable by 19.2%, as against the total value of 16.1% and the lowest value of 13.3% (Amphi). The situation is clearly different if we consider the votes on TSV and TP2, where variances between populations are significant. In TSV, in the central class, there is a difference of 25.5% between the highest values (UPEM and Amphi) and the lowest ones (rooms 411-504). This affects the (2, 3) class values, where the gap is even wider (29.3%). In the TP2 scale it can be observed for the "no change" class the same situation as in TSV, with UPEM and Amphi values higher than the 411-505 ones. But when we focus on the external classes, we can see that while UPEM votes are symmetrically distributed (nearly the same percentage of population votes "wanting warmer" and "wanting cooler"), Amphi population voted mostly "wanting warmer" (33.5% against 6.3%) and the 411-504 population mostly votes "wanting cooler" (17.1% against 36%). This last result is coherent with the high percentage (36.8%) of 411-504 individuals voting "warm" and "hot" (2, 3) in TSV scale.
Previous scales showed the "real" votes of the suveyed populations. But thermal votes can also be predicted following a specific method. In Figures 5 and 6, PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) values are shown. These parameters were calculated starting from measured data (T, RH, Top, Av) and subjective data on clothes and metabolism according to the ASHRAE Standard (ASHRAE, 2009). PMV was organised in three classes, while PPD values were split in two classes, one grouping all the values lower then 20% and the other gathering all the upper values. This was done according to ASHRAE Standard 55-2009 prescriptions, using the PMV model to set the requirements for indoor thermal conditions so as to ensure satisfaction of at least 80% of the occupants.
If we compare those graphs with the previous ones we note a striking difference, namely the highest percentage of votes for 411-504 population in the central PMV class and in "satisfied" class of PPD, while we previously observed that votes for this population were always lower than the others. In the (>1) PMV class, 411-504 population only has 1.9% of votes, while in the (2, 3) TSV class it has 36.8% of votes. Similarly, 24.5% of Amphi population votes belong in the (<-1) PMV class, while 10.7% votes are included in the (-2, -3) TSV class.

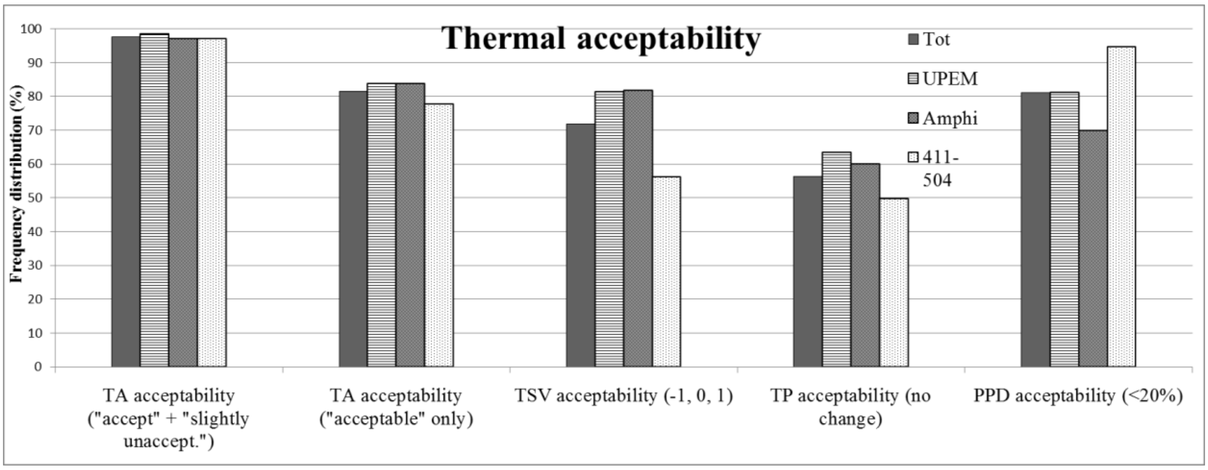
Figures 5, 6. Frequency distribution of PMV and PDD



To summarize and better compare thermal acceptability we plotted on Figure 7 the correspondent classes of all the proposed scales and votes, i.e. "acceptable" and "acceptable" + "slightly unacceptable" for TA, (-1, 0, 1) for TSV, "no change" for TP2 and (<20%) for

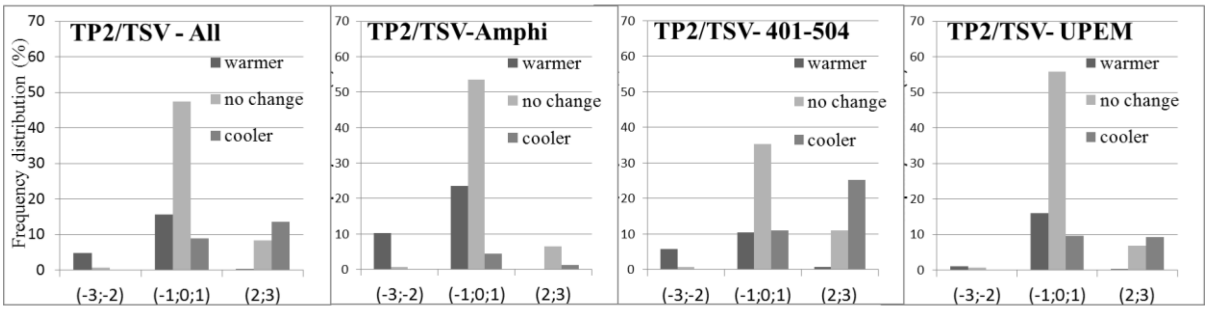
PPD. Highest frequency distribution can be observed for both the TA classifications, where values nearly reach 100% in the first case and 81.5% in the second case. Results are homogeneous for all the populations. Ranking the frequency distributions for the total population, PPD follows (81.1%); then come TSV (71.8%) and TP2 (56.4%). TP2 shows the lowest values for all the population, with votes of 411-504 students on “no change” approach 50%, while they reach 94.8% in the PPD scale.

Figure 7. Comparing various methods of acceptability



The previous analyses focus mainly on thermal acceptability. The results call for a deeper comparison in order to better understand vote distribution on different scales. That is the reason why we plotted TP1 and PMV votes on TSV for the total and the split populations (Figures 8 to 15). Concerning TP2, it can be seen that 15.5% of individuals voting in the central TSV class chose “wanting warmer” in the TP2 scale, and 9% voted “wanting cooler”. In Amphi this tendency is still more apparent, since 23.6% of individuals voting in the central TSV class chose “wanting warmer” in the TP2 scale (but only 4.5% chose “wanting cooler”). In rooms 411-504 10.5% of individuals voting in the central TSV class chose “wanting warmer” in the TP2 scale and 10.5% chose “wanting cooler”. Furthermore, in this population there is a 10.9% voting in (2, 3) TSV class that chose “no change” in the TP2 scale . In UPEM, more than 55% of individuals voting in the central TSV class chose “no change” on TP2 scale, which is the highest value overall; 16.1% chose “wanting warmer” and 9.7% chose “wanting cooler”.

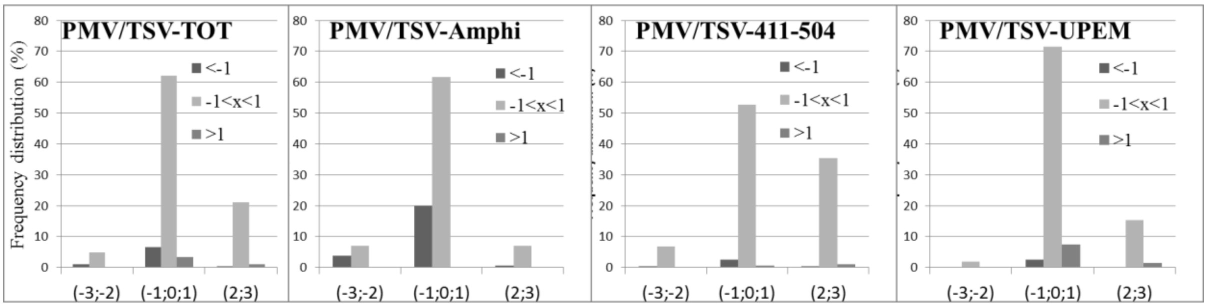
Figure 8 to 11. Diagrams of cross-tabulation, TP2 plotted on TSV



Plotting PMV on TSV similar remarks can be made, appeasing the conflict between “real”, measured votes and predicted ones. Regarding the total population, we can observe that 21.1% of individuals voting (2, 3) on TSV scales has a predicted mean vote that lies in the central

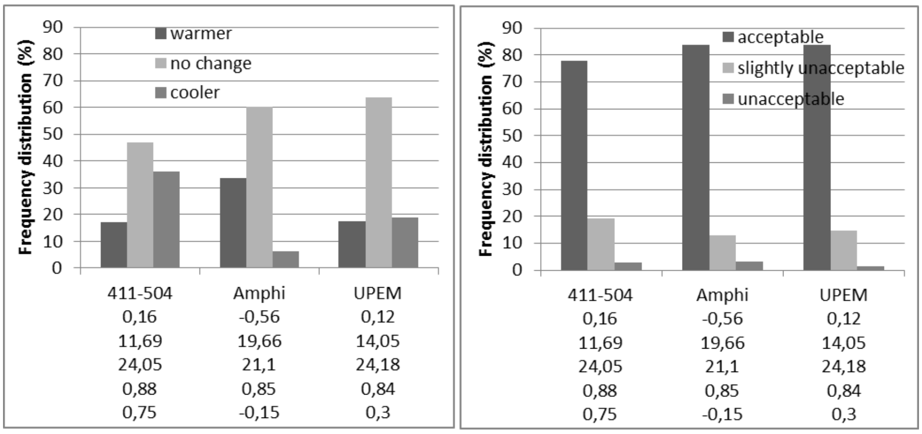
PMV class (-1<0<1), a percentage that becomes 35.4% for the 411-504 population. For the case of Amphi population, 20.1% of individuals voting (-1, 0, 1) in the TSV scale has a predicted mean vote that lies in the (>1) PMV class.

Figure 12 to 15. Diagrams of cross-tabulation, PMV plotted on TSV



For each population Figures 16 and 17 show the mean PMV, PPD, globe temperature, clothing resistance and TSV, associated with the frequency distribution of thermal preference (TP2) and thermal acceptability (TA).

Figure 16 and 17. Percentage of preference (16) and acceptability (17) *vs* mean of PMV, PPD, Tg, CLO and TSV for each classroom.



5.2 Practices and behaviours

As previously explained (see 4.1), a list of actions ("Modify the position of louvers, curtains, etc", "Regulate the heating systems", "Regulate the AC", "Open and close a window", "Open and close a door", "Put or remove clothes", "Drink", "Have an air flow") was made and students were requested to provide three descriptions regarding the following aspects.

The first one was a "possibility" evaluation, telling whether the action was deemed to be possible, impossible, or possible only in the interval between two lessons. Through this question we sought to apprehend what level of "knowledge" of the surrounding space students had, and the actions with a view to improving their thermal comfort (and maybe reduce an uncomfortable sensation) they considered possible or impossible during a lesson. In order to analyze the date, we identified different patterns or groups on the basis of similar answers, and we "typified" each group with an allusive designation.

Table 5 summarizes the results. We can identify a first group of individuals, that we can call "*misunderstanders*". For example, something intriguing could be found looking at the Amphi percentage of answers to the questions “Modify the position of louvers, curtains, etc”, and “Open and close a window”, namely a 20% and a 40% on “possible”, respectively. In this space windows and curtains are in the upper portion of the wall and students cannot reach them. Now in general windows can be opened and curtains moved, but in fact nobody can accomplish this operation without a staircase or a particular instrument. Back in the Amphi, 44% thinks that the heating system can be regulated - but it is an air-heating system, on which students do not have any control. The precise formulation of the question was: “Among the following actions, which ones are possible in this classroom?”. This is probably a drawback of the survey that led to some misunderstandings. Indeed, it was not clear to respondents *for whom* these actions were possible. The heating system can obviously regulated by somebody, namely the technical staff. Hence, we can speculate that students’ answers generally referred more to an abstract possibility than to a concrete here-and-now possibility. On that assumption, the corresponding answers are not reliable.

A second group can be identified that we shall call the “*distracted*”. It is a mixed group, composed by members of the three populations. For example, 17.2% of 411-504 students said that it was possible to modify the position of louvers and curtains, and 20.3% that it was possible but not during the lesson. In this case misunderstanding is ruled out because no louver and no curtain can be found in these classrooms. Similarly, 14.1% and 32% of 411-504 and Amphi, respectively, reported that it was possible to control the AC, and yet the AC is not installed. Finally, 63.6% of UPEM students answered that it was not possible to regulate the heating system, while operable radiators were as a matter of fact installed.

The third group includes the “*possibilists*”. For an action equally feasible for the three populations (e.g. in all the cases it was possible to open and close the door), we can see that a higher percentage of UPEM noticed the action opportunity as compared to the other populations . For example, 100% of UPEM population answered that it was possible to open and close the door, as compared to 81.3% and 80% of 411-504 and Amphi; 97% answered that it was possible to open and close the windows compared to 37.5% of 411-504; 93.9% answered that it was possible to put or remove clothes compared to 79.7% of 411-504 and 84% of Amphi; finally, 93.9% thought that it was possible to have an air flow compared to 64.1% and 40%. A fourth group, called the “*pessimists*”, is mainly composed by Amphi individuals, who frequently had the highest percentage of “not possible” answers, especially if compared to 411-504. A last group can be identified assembling the “*shies*”, mostly belonging to 411-504, who often had the highest percentage of “possible, but not during lessons” answers, with the exception of the “drink” answer, where UPEM featured the highest score.

Table 5. “Possibility” evaluation (%) for 411-504, Amphi and UPEM populations.

ACTIVITY	Possible			Not Possible			Not possible during lessons		
	411+504	Amphi	UPEM	411+504	Amphi	UPEM	411+504	Amphi	UPEM
Modify the position of louvers, etc	17,2	20	69,7	57,8	68	12,1	20,3	4	18,2
Open and close a door	81,3	80	100	7,8	16	0	6,3	4	0
Regulate the heating systems	39,1	44	15,2	42,2	52	63,6	12,5	4	21,2
Regulate the AC	14,1	32	0	70,3	68	97	12,5	0	3
Open and close a window	37,5	40	97	45,3	44	0	14,1	12	0
Put or remove clothes	79,7	84	93,9	6,3	12	0	6,3	0	6,1
Drink	78,1	76	69,7	9,4	16	12,1	7,8	8	15,2
Have an air flow	64,1	40	93,9	23,4	36	0	9,4	20	6,1

The second question asked to students concerned the "effectiveness" evaluation, in order to understand if an action was deemed to be effective to improve thermal comfort, ineffective, or effective but only on (for, in??) a long period. In this case, the question was not specifically referred to the classroom context, but to a general opinion of the subjects. The results are shown in table 6.

The most effective action is "put or remove clothes", which is the only consensual one (the three percentages are above 80%). UPEM population, consistently with the "*possibilists*", is characterized by high percentages of "effective" for many other answers: open and close the door, the window, have an air flow (all upper 85%); modify the position of louvers and drink (around 65%). In contrast, UPEM students have the lowest score on the effectiveness evaluation of the heating systems and the AC. Even if this question and the previous one are not directly related, this result may be explained by table 6, where it can be seen that they thought it was not possible to do those actions in their classroom. For the Amphi population the most effective actions are to put or remove clothes (91.3%), open and close a door, regulate the AC and regulate the heating system (around 65%-73%). For the 411-504 population, such actions are to put or remove clothes (80%), open and close a door or a window, and have an air flow (around 70-75%).

Table 6. "Effectiveness" evaluation (%) for 411-504, Amphi and UPEM populations.

ACTIVITY	Effective			Not effective			Effective, but it'll take time		
	411+504	Amphi	UPEM	411+504	Amphi	UPEM	411+504	Amphi	UPEM
Modify the position of louvers, etc	27,3	39,1	65,6	49,1	30,4	34,4	3,6	4,3	0
Open and close a door	72,7	65,2	90,6	20	21,7	9,4	1,8	8,7	0
Regulate the heating systems	58,2	73,9	50	25,5	8,7	43,8	1,8	8,7	0
Regulate the AC	52,7	65,2	43,8	16,4	13	50	1,8	13	0
Open and close a window	74,5	56,5	96,9	14,5	21,7	3,1	0	4,3	0
Put or remove clothes	80	91,3	96,9	12,7	0	0	1,8	0	0
Drink	63,6	60,9	65,6	27,3	21,7	31,3	0	0	0
Have an air flow	70,9	47,8	87,5	18,2	21,7	9,4	0	0	0

The last question concerned "direct" activities, describing which actions students directly performed in the classroom ("never carried out", "carried out, but not today", "carried out, also today"). This question was asked at each day of the survey. The data processing aimed to compare the answers and to assess their reliability. We analysed the "not, never" answers to test their consistency across questionnaires filled in different days. An acceptable consistency level was found; we proceeded by calculating the frequency of answers for all the days of the survey. A final result was obtained calculating the mean value. For "yes, but not today" and "yes, today too" answer we proceeded in a similar way, calculating a mean value of all the answers on different days (table 7). UPEM population is in general more "active" than the others, and Amphi is the less "active" one. Putting or removing clothes and drinking are the most practiced actions, followed by opening and closing a window. Some "never-carried-out" actions, such as regulating the AC, probably indicate that they are impossible. Again, AC is not installed in classrooms. We can speculate that students were more “distracted” when they answered about possibilities (table 6), and answered without examining the real equipment. But in this case, since subjects had to think about their own actions and practices, their answers were more relevant, and, in an indirect way, they provide complementary information on space characteristics.

Table 7. “Direct” activities (%) for 411-504, Amphi and UPEM populations.

ACTIVITY	Not, never			Yes, but not today			Yes, today too		
	411+504	Amphi	UPEM	411+504	Amphi	UPEM	411+504	Amphi	UPEM
Modify the position of louvers, etc	61,1	92,9	21,9	38,9	7,1	71,9	0	0	6,3
Open and close a door	33,3	42,9	6,3	61,1	57,1	68,8	5,6	0	25
Regulate the heating systems	83,3	85,7	78,1	16,7	7,1	18,8	0	14,3	3,1
Regulate the AC	100	85,7	90,6	0	7,1	6,3	0	7,1	3,1
Open and close a window	11,1	78,6	0	72,2	14,3	75	16,7	0	25
Put or remove clothes	0	7,1	0	33,3	42,9	40,6	66,7	50	59,4
Drink	5,6	7,1	12,5	61,1	42,9	50	33,3	50	37,5
Have an air flow	33,3	64,3	12,5	66,7	35,7	65,6	0	0	21,9

6. Conclusion

In this paper we approached thermal comfort in classrooms by analyzing individuals’ thermal responses and adaptive practices. By focusing on personal sensations, perceptions, opinions and behaviours, we put individuals at the centre of the stage. In accordance with recent literature that has been developing an adaptive approach, the paper underscored the significance of examining thermal comfort within natural settings. It also claims that thermal research should address thermal responses, behaviours and opinions in an integrated protocol providing maximally exhaustive information on the “subjective side” of thermal comfort.

The key findings of the survey are as follows:

A) First part on thermal responses.

- When we consider frequency distributions, we can see that thermal scales lead to varied individual interpretations of comfort. In our case, thermal acceptability indicates a very high percentage of satisfaction, while thermal sensation and mainly thermal preference present lower values.
- When we map thermal preference votes on thermal sensation votes, they do not overlap. This suggests that neutral sensation is not always the preferred thermal state for the surveyed students.
- Predicted Mean Votes and Predicted Percentage of Dissatisfied show a very high percentage of satisfaction, which surpass the ones measured by thermal sensation and preference. In other words, in our case PMV and PPD underestimate subjective thermal dissatisfaction.
- PMV shows some amount of inconsistency with thermal sensations votes. Low agreement ratios can be observed when people voting (2, 3) on TSV are considered satisfied (calculated

votes in the central class). Similarly, some people voting in the central class (satisfied) on TSV are considered unsatisfied by PMV (<-1 class).
- When we consider the three populations in detail, it is possible to observe that thermal scales behave differently. Thermal acceptability shows similar values, while the other scales display consistent differences between comfort votes in the three places. It results that UPEM population is the most and 411-504 the less comfortable one. UPEM population is also the best distributed on TSV, with a similar percentage of (2, 3) and (-3, -2) votes. Those results are contradicted by PMV and PPD, regarding which the 411-504 population has the highest percentage of satisfaction.
B) Second part on thermal adaption.
- "*Possibilities"* question. Issues of reliability were discussed in this regard. Referring to the question on possibilities, a considerable part of the population (the "*distracted*" ones) gave a wrong answer, for example reporting that in the classroom it was possible to regulate the AC when the latter was in fact not even installed. Probably the students were not paying much attention while filling the questionnaire; but more generaly, probably students do not pay much attention to "thermal" equipment such as AC, heating systems, curtains etc. either. We may speculate that they have limited interest in the environment or a weak inclination for observation.
- Apart from the "*misunderstanders*", four other groups of students were identified: the *"distracted*", the "*possibilists*" (mostly UPEM), the "*pessimists*" (mostly Amphi) and the "*shies*" (mostly 411-504).
- *"Effectiveness question".* The most effective action is "putting or removing clothes", which is the only one that is also consensual. The UPEM population is characterized by high percentages of "effective" answers. For Amphi population the most effective actions are putting or removing clothes, opening and closing a door, regulating the AC and regulating the heating system. For the 411-504 population, such actions are puting or removing clothes, opening and closing a door or a window and having an air flow.
-*"Direct" activities* question. Puting or removing clothes and drinking are the most practiced actions, followed by opening and closing a window. in general the UPEM population is more "active" than the other ones, whereas Amphi proves the less "active" one.
C) Crossing thermal responses and adaptation.
- Deeper analyses should examine if any correlation exists between thermal responses and adaptation. At this stage of the study, we can notice that the UPEM population (which turns out to be the most satisfied one on TSV, TA and TP2 scales) is also the one who has the highest percentages on "*possibilist*", "*effective*" and "*direct activities*" answers. We think this is an encouraging result that calls for new studies on the "subjective side" of comfort analysis.

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