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# Thermal – hygrometry comfort in university classrooms: Experimental results in north and central Italy universities conducted with new methodologies based on the adaptive model

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ABSTRACT: UNI EN ISO 7730 (1997), about thermal – hygrometry comfort, is based on a static model where occupants are considered as passive subjects in thermal exchange. In the last years adaptive models were developed, where occupant acts with environment, reducing individual reaction to environmental stimuli. None of the proposed adaptive models found a full confirmation, therefore a revised version of 7730 is treating adaptation only in a generic way. In the present paper a multiple response questionnaire was elaborated, comprehensive of information for the static and adaptive model. It was applied in autumn in a classroom of the University of Perugia with 120 students and in winter in two classrooms (University of Pavia, with 130 students and University of Perugia, Terni, with 20 students). The thermal hygrometry conditions were monitored; finally questionnaire and experimental data were compared and a correlation for the static and the adaptive model is here proposed.

## 1 INTRODUCTION

Quality of life is tending to higher and higher standards, therefore an extremely punctual definition of the microclimate requirements is demanded, in order to provide thermal – hygrometric comfort conditions at global and local level, in the working and living environments.

Comfort sensation is strictly linked to metabolic heat production, energy exchange with environment and physiological body temperature variation. Nevertheless comfort is also influenced by psychological factors, such as regional or national habitudes, previous experience and personal expectations (Brasier (1993), Kant & Borm P.J.A (1990), Cohen, Evans, Stokols & Krantzs (1986), Humphryes (1978)).

In moderate environments, the international standards ASHRAE Standard 55/P (1992) and UNI EN ISO 7730 (1997) indicate limits and rules to follow for obtaining comfort conditions.

UNI EN ISO 7730 (1997), related to thermal – hygrometric comfort conditions in moderate thermal environments, is based on a static model where the human occupancy is considered as a passive subject of thermal exchange. In latest years, adaptive models were developed, in which building occupants interact at all levels with environment, tending to fulfill the satisfaction with microclimate. This is obtained trough an adaptive process based on a gradual diminishment of individual interactions to environment stimulus. The introduction of ISO-DIS 7730 (2003), as revision of the current technical norm, proposes to divide thermal environments in small categories, distinguishing more acceptable limit conditions. Nevertheless, since none of the adaptive models proposed by literature found confirmations and agreements, the revision is treating the adaptation only in a generic and informative way. Many studies are now taking place to support adaptive models, aiming to introduce quantity indexes for actions of people to enhance their comfort conditions.

Aim of the present work is the evaluation of thermal – hygrometric comfort conditions in university classrooms; the definition phase of investigation methodology and a first experimental measurement session, in autumn and winter season, is presented. The thermal environment of three university classrooms was examined:

– Classroom F of the Faculty of Engineering of University of Perugia (Italy), Perugia (called Classroom 1).

– Classroom 2 of the Faculty of Engineering of the University of Perugia (Italy), Terni (called Classroom 2).
– Classroom 8 of the Faculty of Engineering of the University of Pavia (Italy), Pavia (called Classroom 3).

Classrooms, different for architectural characteristics, dimensions, capacity and typology of building services, were investigated at the end of November 2004, in February and March 2005. Results were related to external climatic conditions.

Measurement methodology was based on the acquisition of thermal – hygrometric parameters defined by UNI-EN-ISO 7730/1994, ISO-DIS 7730/2003, UNI-EN-ISO 10551/2002 and ASHRAE Standard 55/1992, useful for an evaluation of comfort both through the traditional method and the new adaptive approach.

Data about comfort sensation were also evaluated through questionnaires distributed to the occupants. Questionnaire contains information about subjective answer to the thermal environment conditions, considering different points of view: thermal sensation, comfort, thermal preference, acceptability, tolerability, possibility of individual microclimatic control, satisfaction about individual comfort and use of different mechanisms of microclimate control. Questionnaire allows studying the behavior aspects of interaction human – thermal environment also through the adaptive approach.

Questionnaire's results were examined in compliance with UNI-EN-ISO 10551/2002 and compared to microclimate experimental values.

## 2 MEASUREMENTS

### 2.1 *The new adaptive model*

Thermal comfort is regulated in many aspects by numerous international standards. In particular, for thermal moderate environments, an important standard is UNI-EN-ISO 7730/1997, which defines the comfort indexes PMV and PPD. Another well-known standard is ASHRAE Standard 55/1992, which defines the range of optimal thermal – hygrometric comfort conditions.

The two standards are now in revision and the discussion about new versions is quite active. Some of the proposed variations are important: ISO/DIS 7730/2003 introduces classes of acceptability and concepts of thermal dynamic clothing insulation and adaptation. In ASHRAE Standard 55/2004 the index ET (Effective Correct Temperature) disappears and is replaced by PMV and PPD, representing an analytical evaluation method. It is alternative to the graphic method, already present in the 1992's version, and to the new one referred to natural ventilated environments.

UNI-EN-ISO 7730/1997 was based on a model where the human occupancy is a passive subject in the heat exchange process. The model prescribes optimal temperatures (almost constant) and values of six independent variables (temperature, relative humidity, air velocity, mean radiant temperature, clothing thermal insulation, metabolic activity level). In the latest years numerous researchers raised doubts about validity of this assumption that does not take into account climatic, cultural, social and contextual factors. They introduced the concept of adaptation, which considers the context and the thermal history of the subject and how he can modify expectations and thermal preferences of occupants (Brager & De Dear (1998), Humphreys & Nicol (1998), Corgnati & Fracastoro (2002)).

The adaptive model introduces control and answer algorithms that allow to improve the thermal comfort level and to reduce energy consumption. In the adaptive model the subject, consciously or unconsciously, plays an active role in reaching satisfaction about microclimate. The subject himself interacts in the adaptive process, by reducing his individual reactions to environmental stimulus.

Three kinds of adaptation could be distinguished:

– behavioral: changes that a person puts in practice, consciously or not, in order to modify parameters that regulate body thermal balance; it could be classified in personal, technological and cultural;
– physiological: the extended exposure to particular thermal conditions reduces stress. In typical conditions of moderate environments this adaptation has a little influence on comfort perception;
– psychological: previous experience and expectations modify the sensation of sensorial stimulus and the reaction to them.

Analysis of statistical data of Dear & Brager (1998) shows that the behavioral mechanism of adaptation gives to people an active role in maintenance of the personal comfort because it is directly linked to the thermal balance of human body.

Other researchers proposed relationships for environmental evaluations; in particular a model was analyzed, where an optimal variable temperature was introduced, as a function of the external meteorological conditions, the previous thermal experiences and the current occupants expectations (Brager & De Dear 2000).

Nevertheless none of the proposed models has yet confirmations and consensus; therefore ISO/DIS 7730/2003 considers adaptation in a qualitative way.

### 2.2 *Questionnaire*

The questionnaire used in the experimental campaign was elaborated considering the one proposed in UNI-EN-ISO 10551/2002. It was then integrated with questions about the occupant possibility of using thermal environment control and satisfaction for the evaluation of the influence of the behavioral aspect into the personal thermal adaptation. Environment was analyzed from different points of view:

– thermal sensation;
– comfort;
– thermal preference;
– acceptability;
– tolerability;
– possibility of individual control of microclimate;
– satisfaction for individual control.

The multiple responses questionnaire is divided into three parts:

– first part: personal data (age, sex);
– second part: thermal questionnaire (activity performed in the last 10, 20, 30 and 60 minutes; judgment about tolerability of thermal environment, air movement, temperature difference between head and ankle (Fanger (1970)); eventual preference for different conditions);
– third part: personal environmental control (possibility of interaction with environmental microclimate conditions through doors and windows opening, building services regulations etc. and satisfaction about possibilities of action; position inside the room, to be indicated in the classroom plan).

### 2.3 *Instruments*

The experimental campaign was carried out employing two measurement sets:

– BABUC set by LSI
– HSA DGT set by TCR Tecora.

The BABUC set is composed by a multi-acquisition system with 11 channels, memory for 20,000 samples (64 kb), called BABUC A (Fig. 1). The following probes were connected to the system:

– air temperature (accuracy ± 0.17°C);
– average air speed and intensity of turbulence (accuracy ± 5 cm for $v_a$ within 0 ÷ 0.5 m/s, ±10 cm for $v_a$ within 0.5 ÷ 1.5 m/s and 4% for $v_a$ > 1.5 m/s);
– forced ventilation psychrometric probe (accuracy on temperature ±0.13°C, relative humidity ±2%);
– globe-thermometer probe in opaque black branch (reflection <2%), with diameter of 15 cm, for the measurement of the mean radiant temperature (accuracy ±0.17°C);
– absolute barometric probe (accuracy ±1 hPa °C);
– double temperature probe (surface floor temperature and air temperature at 10 cm from the ground, accuracy ±0.17°C); it allows to obtain the percentage of dissatisfied for the floor temperature, the percentage of dissatisfied for vertical thermal gradient (when probe is linked to an air temperature probe at 1.1 m from ground) (UNI-EN-ISO 7730);
– net radiance (accuracy ±3%) which allows to obtain the radiating asymmetric temperature and the percentage of dissatisfied for radiant asymmetry;
– carbon dioxide concentration (accuracy ±3p.p.m. in interval 0–3000 p.p.m.).

Figure 1. Microclimatic measurement set BABUC A.

Figure 2. Microclimatic measurement set HAS DGT.

The HSA DGT set is equipped with four standard probes (Fig. 2):

– forced ventilation psychrometric probe (accuracy on temperature ±0.18°C, relative humidity ±3%);
– hot wire anemometer (accuracy ±5 cm for $v_a$ within 0 ÷ 0.5 m/s, ±10 cm for $v_a$ within 0.5 ÷ 1.5 m/s and 4% for $v_a$ > 1.5 m/s);
– globe-thermometer probe in opaque black branch (reflection <2%), with diameter of 15 cm, for the measurement of the mean radiant temperature (accuracy ±0.17°C);
– humid temperature naturally ventilated (accuracy on the temperature ±0.20°C, accuracy on relative humidity ±3%).

Table 1. Classroom characteristics and data of measurements.

| Classroom | 1 | 2 | 3 |
|---|---|---|---|
| Location | Perugia | Terni | Pavia |
| Capacity (seats) | 300 | 96 | 160 |
| Windows | yes | no | yes |
| Stand | no | no | yes |
| Plant | air | air-water | air |
| Surveys number | 3 | 3 | 2 |
| Survey period | autumn | winter | winter |
| Questionnaires | 349 | 52 | 169 |

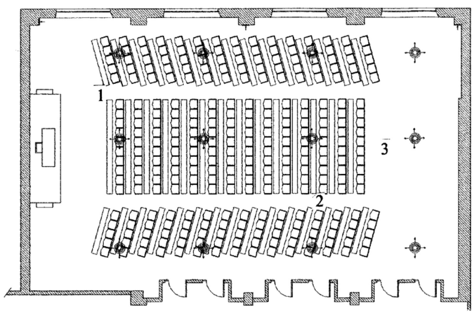


Figure 3. Classroom 1 and measurement points (1, 2 and 3).

## 3 MEASUREMENT METHODOLOGY

Measurements were carried out in three different classrooms, varying for materials, plan characteristics and geographic location. Classrooms characteristics and main measurements data are reported in Table 1.

Thermo-hygrometric conditions in the classrooms were measured in different points, in order to evaluate their spatial uniformity. A plan and a photo of classroom 1 are presented in Figure 3 and 4; the measurements points are indicated:

- point 1 and 2 for BABUC;
- point 3 for HSA DGT.

In Figures 5 and 6 a plan and a photo of classroom 2 are presented, with measurements points:

- point 1 for BABUC;
- point 2 for HSA DGT.

Figures 7 and 8 show a plan and a photo of classroom 3, with measurements points:

- points 1, 2 e 3 for BABUC;
- point 4 for HSA DGT.

Measurements points were chosen considering:

- students position in the classroom and collocation in the more crowded zones;

Figure 4. Measurements in classroom 1.

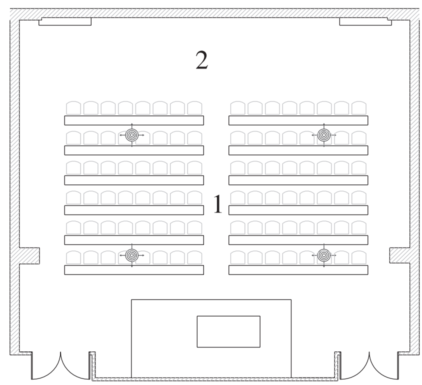


Figure 5. Classroom 2 and measurement points (1 and 2).


Figure 6. Measurements in classroom 2.

- cold or warm vertical surfaces position (i.e. windows);
- possibility to place instruments.

Measurements and questionnaire distribution took place 30 minutes after the beginning of the lesson, in

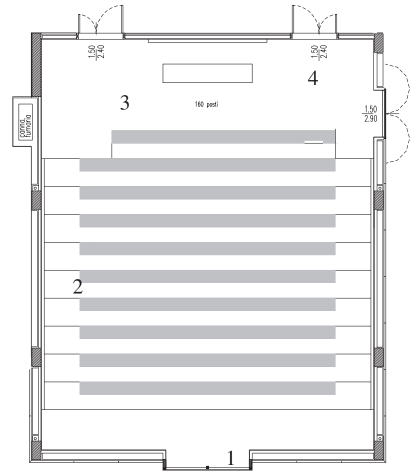


Figure 7. Classroom 3 and measurement points (1, 2, 3, 4).

Figure 8. Measurements in classroom 3.

order to allow the students and instruments to adjust to the environmental conditions. In the same day different measurements in different times and positions were carried out. Two BABUC A systems were used, in order to measure all the environmental parameters at the same time.

The following parameters were measured:

- dry bulb temperature;
- wet bulb temperature;
- air velocity;
- globe thermometer temperature;
- atmospheric pressure;
- air temperature at neck (1.10 m from floor);
- air temperature at ankles (0.10 m from floor);
- floor temperature;
- asymmetric radiant temperature;
- $CO_2$ concentration.

The following parameters were then calculated:

- air relative humidity;
- mean radiant temperature;
- operative temperature;
- PMV (Predicted Mean Vote);
- PPD (Predicted Percentage of Dissatisfied);
- turbulence intensity;
- PPD for thermal vertical gradient;
- PPD for floor temperature;
- PPD for radiant asymmetry;
- PPD for current of air.

The external conditions were also measured during surveys; in particular:

- air temperature;
- air relative humidity;
- $CO_2$ concentration;
- atmospheric pressure.

## 4 RESULTS

### 4.1 *Measurements*

A synthesis of the experimental results is reported in Table 2: the mean measured data in each survey and the mean global values for each classroom are reported.

For the sake of brevity, only the parameters related to the global comfort are reported; data related to local discomfort were omitted (vertical thermal gradient, floor temperature, radiant asymmetry, draughts): data shows in fact low values of PPD for local discomfort

Data in Table 2 show:

- air temperature is in the recommended range;
- relative humidity is in the recommended range in Classrooms 1 and 2 while it is too low in Classroom 3;
- the mean radiant temperature is near the air temperature, so no significant influence of radiant surfaces is found;
- air velocity is very low and under the maximum recommended values;
- PMV, both for men and women, is always in the range $-0.5 \div +0.5$, with PPD under 10% for Classrooms 1 and 2; PPD for Classroom 3 is in the range 10–15%, even if the mean PMV is in the $-0.5 \div +0.5$ range; it is due to the mean values of PMV, obtained from data external to the range $-0.5 \div +0.5$.

### 4.2 *Questionnaires*

In the elaboration of questionnaires the following aspects were taken into account:

- average age of the subjects;
- predicted mean vote (PMV);
- dispersion of PMV around its mean value;
- thermal dissatisfaction index (TDI) [%], defined as the ratio *dissatisfied persons/persons that express a*

Table 2. Synthesis of measured data in Classrooms 1, 2, 3.

| Classrooms | Surveys | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|---|
| | | | Average | | Average | | Average |
| | 1 | – | | 5.2 | | 6.0 | |
| $T_{ext}$ [°C] | 2 | – | 12.2 | 4.7 | 6.2 | 9.7 | 7.8 |
| | 3 | 12.2 | | 8.8 | | – | |
| | 1 | 71 | | 62 | | 47 | |
| $RH_{ext}$ [%] | 2 | 96 | 86 | 98 | 70 | 29 | 38 |
| | 3 | 91 | | 50 | | – | |
| | 1 | 22.5 | | 21.2 | | 22.6 | |
| T [°C] | 2 | 24.1 | 23.6 | 24.8 | 22.3 | 21.7 | 22.1 |
| | 3 | 24.2 | | 20.9 | | – | |
| | 1 | 50 | | 63 | | 30 | |
| RH [%] | 2 | 45 | 48 | 53 | 59 | 26 | 28 |
| | 3 | 49 | | 60 | | – | |
| | 1 | 23.6 | | 20.9 | | 24.0 | |
| $T_{mr}$ [°C] | 2 | 24.0 | 24.3 | 22.9 | 21.4 | 19.9 | 22.0 |
| | 3 | 25.2 | | 20.3 | | – | |
| | 1 | 0.090 | | 0.004 | | 0.059 | |
| va [m/s] | 2 | 0.016 | 0.046 | 0.006 | 0.007 | 0.081 | 0.070 |
| | 3 | 0.033 | | 0.012 | | – | |
| | 1 | 72 | | 72 | | 72 | |
| M [$W/m^2$] (M) | 2 | 72 | 72 | 72 | 72 | 72 | 72 |
| | 3 | 72 | | 72 | | – | |
| | 1 | 1.48 | | 1.10 | | 0.81 | |
| $I_{cl}$ [clo] (M) | 2 | 1.29 | 1.33 | 0.73 | 0.85 | 0.77 | 0.79 |
| | 3 | 1.22 | | 0.72 | | – | |
| | 1 | 69 | | 69 | | 69 | |
| M [$W/m^2$] (W) | 2 | 69 | 69 | 69 | 69 | 69 | 69 |
| | 3 | 69 | | 69 | | – | |
| | 1 | 1.45 | | 0.28 | | 0.88 | |
| $I_{cl}$ [clo] (W) | 2 | 1.40 | 1.38 | 0.73 | 0.85 | 0.74 | 0.81 |
| | 3 | 1.30 | | 0.81 | | – | |
| | 1 | 0.11 | | 0.03 | | −0.01 | |
| PMV (M) | 2 | 0.39 | 0.32 | 0.31 | −0.07 | −0.70 | −0.36 |
| | 3 | 0.45 | | −0.54 | | – | |
| | 1 | −0.02 | | −0.40 | | 0.01 | |
| PMV (W) | 2 | 0.39 | 0.26 | 0.23 | −0.22 | −0.87 | −0.43 |
| | 3 | 0.41 | | −0.48 | | – | |
| | 1 | 5.4 | | 6.2 | | 6.1 | |
| $PPD_1$ [%] (M) | 2 | 8.5 | 8.3 | 7.8 | 8.4 | 16.3 | 11.2 |
| | 3 | 11.0 | | 11.2 | | – | |
| | 1 | 5.2 | | 6.3 | | 6.4 | |
| $PPD_2$ [%] (M) | 2 | 8.1 | 7.9 | 7.6 | 8.6 | 18.1 | 12.3 |
| | 3 | 10.4 | | 11.8 | | – | |
| | 1 | 5.3 | | 5.4 | | 6.1 | |
| $PPD_1$ [%] (W) | 2 | 8.4 | 7.9 | 7.0 | 7.4 | 21.9 | 14.0 |
| | 3 | 10.1 | | 9.8 | | – | |
| | 1 | 5.4 | | 5.7 | | 6.2 | |
| $PPD_2$ [%] (W) | 2 | 8.2 | 7.8 | 7.0 | 7.6 | 24.1 | 15.1 |
| | 3 | 9.9 | | 10.0 | | – | |

*judgement* (it is evaluated as the percentage of persons that have answered “slightly annoying, annoying, very annoying”, to the question “this sensation provokes you a state of...”);

– thermal preference index (TPI) [%], defined as the ratio *persons who want to change/persons that express a judgement* (it is evaluated as the percentage of persons that have answered “a lot more cold, more cold, a bit more cold, a lot more hot, more hot, a bit more hot”, to the question “in this moment you would feel...”);

– thermal unacceptability index (TUI) [%], defined as the ratio *persons that consider unacceptable/persons that express a judgement* (it is evaluated as the percentage of persons that have answered "no, it is not acceptable" to the question "considering only your personal preferences, this environment, from a thermal point of view, is acceptable or unacceptable?");

– thermal annoying index (TAI) [%], defined as the ratio *persons that can not bear it/persons that express a judgement* (it is evaluated as the percentage of persons that have answered "a bit difficult to tolerate, rather difficult to tolerate, very difficult to tolerate, unbearable" to the question "in your opinion this environment is . . .");
– unacceptable air movement index (UAMI) [%], defined as the ratio *persons that express a negative judgement/persons that express a judgement* (it is evaluated as the percentage of persons that have answered "completely unacceptable, slightly unacceptable, unacceptable" to the question "the air movement in this moment is . . .");
– unacceptable vertical thermal gradient index (UVTGI) [%], defined as the ratio *persons that express a negative judgement/persons that express a judgement* (it is evaluated as the percentage of persons that have answered "completely unacceptable, slightly unacceptable, unacceptable" to the question "you consider the difference of temperature between head and ankles . . .") (Fanger (1970));
– preference vertical thermal gradient index (PVTGI) [%], defined as the ratio *persons that want to change/persons that express a judgement* (it is evaluated as the percentage of persons that have answered "lower, higher" to the question "you would prefer a difference of temperature between head and ankles . . .") (Fanger (1970));
– environmental control dissatisfaction index (ECDI) [%], defined as the ratio *persons that express a negative judgement/persons that express a judgement* (it is evaluated as the percentage of persons that have answered "very unsatisfied, unsatisfied, slightly unsatisfied", to the question "towards the possibilities you have, you consider yourself?");

A synthesis of results is reported in Table 3. It shows that:

– occupants feel a thermal sensation of slightly hot;
– the high values of thermal indexes of dissatisfaction, preference and annoyance put in evidence the difficulties of putting up with existing thermal conditions;
– the low air movement makes worse the discomfort of occupants, especially in Classroom 2;
– except for Classroom 2, the thermal gradient in the vertical axis does not present too high percentage of dissatisfied;
– considering the environment control, most of people, especially in Classrooms 2 and 3, present a high dissatisfaction.

It may be concluded that Classroom 2 globally presents a higher percentage of dissatisfied. This is probably due to the psychological sensation linked to the absence of windows.

## 5 CONCLUSION

The standard UNI-EN-ISO 7730/1997 regulates the indoor thermal – hygrometry comfort; the standard is now in revision. The project ISO-DIS 7730/2003 introduces three environments categories with different criteria of comfort evaluation. This modification enlarges the possibility of satisfaction of different users requirements.

The project has no structural modifications on the evaluation procedure of thermal moderate environments currently in use. Nevertheless, even though in a qualitative way, it introduces the adaptive approach, where the subject interacts with environment at all level, by means of actions that allows him to create satisfaction towards microclimate conditions (possibility of changing the microclimate conditions by opening doors and windows, by regulation of building services and consequent satisfaction for the possibility of interactions).

The present paper reports the first results of an experimental campaign carried out in classrooms of the University of Pavia and Perugia (Italy). The aim is the evaluation of microclimatic comfort conditions with the traditional approach and with an approach that takes into account the current state of art on adaptive models.

Measurements of the main environmental parameters were carried out and the comfort indexes were calculated in three classrooms, different for geographic location, typologies, architectural characteristics and types of building plants. In order to take into account the adaptive approach, a questionnaire was specifically elaborated, for the evaluation of thermal environment condition directly by the occupants.

In the three classrooms 570 questionnaires were filled up in total; results from their elaboration were compared with the ones obtained by experimental measurements.

Results show that even if experimental data are within the optimal ranges, questionnaires prove a more critical situation. In fact, although indexes comfort values are within standard limits, only a small part of occupants is satisfied about thermal environment and their judgements put in evidence a situation of light hot, present in all the examined cases. It is in part due to the low possibility of interaction occupants – environmental conditions and in part to low air movement (related to the dissatisfaction for thermal vertical gradient).

The distinction between men and women did not convey to significant results, but it is evident that

Table 3. Questionnaires analysis: synthesis of main results.

| | | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|---|
| Classrooms | Surveys | | Average | | Average | | Average |
| Questionnaires | 1 | 137 | | 17 | | 108 | |
| | 2 | 89 | – | 24 | – | 61 | – |
| | 3 | 123 | | 11 | | – | |
| Age of subjects | 1 | 20.0 | | 22.0 | | 20.0 | |
| | 2 | 20.0 | 20.0 | 22.0 | 22.0 | 20.0 | 20.0 |
| | 3 | 20.0 | | 23.0 | | – | |
| PMV | 1 | 0.34 | | −0.06 | | 0.69 | |
| | 2 | 0.33 | 0.59 | 1.63 | 0.55 | 0.02 | 0.35 |
| | 3 | 1.10 | | 0.09 | | – | |
| PMV dispersion | 1 | 0.44 | | 0.76 | | 0.95 | |
| | 2 | 0.60 | 0.96 | 1.32 | 1.08 | 0.87 | 0.91 |
| | 3 | 0.80 | | 1.17 | | – | |
| TDI [%] | 1 | 33.6 | | 82.4 | | 61.1 | |
| | 2 | 34.8 | 44.23 | 70.8 | 69.2 | 41.0 | 51.05 |
| | 3 | 64.3 | | 54.5 | | – | |
| TPI [%] | 1 | 47.4 | | 76.5 | | 67.6 | |
| | 2 | 43.8 | 54.73 | 79.2 | 70.0 | 42.6 | 55.1 |
| | 3 | 73.0 | | 54.5 | | – | |
| TUI [%] | 1 | 11.7 | | 41.2 | | 27.8 | |
| | 2 | 9.0 | 12.7 | 70.8 | 43.4 | 11.5 | 19.65 |
| | 3 | 17.4 | | 18.2 | | – | |
| TAI [%] | 1 | 38.7 | | 82.4 | | 54.6 | |
| | 2 | 36.0 | 42.0 | 91.7 | 79.2 | 32.8 | 43.7 |
| | 3 | 51.3 | | 63.6 | | – | |
| UAMI [%] | 1 | 32.8 | | 76.5 | | 56.5 | |
| | 2 | 29.2 | 39.5 | 100.0 | 83.1 | 49.2 | 52.85 |
| | 3 | 56.5 | | 72.7 | | – | |
| UVTGI [%] | 1 | 28.5 | | 64.7 | | 32.4 | |
| | 2 | 22.5 | 25.1 | 75.0 | 64.7 | 27.9 | 30.15 |
| | 3 | 24.3 | | 54.5 | | – | |
| PVTGI [%] | 1 | 40.1 | | 88.2 | | 39.8 | |
| | 2 | 38.2 | 35.9 | 79.2 | 77.0 | 31.1 | 35.45 |
| | 3 | 29.6 | | 63.6 | | – | |
| ECDI [%] | 1 | 40.9 | | 94.1 | | 69.4 | |
| | 2 | 46.1 | 45.53 | 95.8 | 87.5 | 82.0 | 75.7 |
| | 3 | 49.6 | | 72.7 | | – | |

among women, having a slightly lower metabolism, it is more easily accepted the environmental condition of light hot.

It may be concluded that psychological factors extremely influence occupants' judgment; this is confirmed by the fact that the highest values of dissatisfaction are reached in Classroom 2, characterised by absence of windows.

More exhaustive conclusions could be expressed at the end of the experimental campaign, which will be extended to different seasons.


## ACKNOWLEDGEMENTS

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## NOMENCLATURE

A: average of surveys 1, 2 and 3;
ECDI = environmental control dissatisfaction index (%);
ET* = effective correct temperature (°C);
$I_{cl}$ = clothing thermal insulation (clo, $m^2K/W$);
M = metabolism (met, $W/m^2$);
(M) = men;
PPD = Predicted Percentage of Dissatisfied (%);
PMV = Predicted Mean Vote;
PVTGI = preference vertical thermal gradient index (%);
S: survey number;
T = temperature (°C);
TAI = thermal annoying index (%);
TDI = thermal dissatisfaction index (%);
TPI = thermal preference index (%);

| | | |
|---|---|---|
| TUI | = | thermal unacceptability index (%); |
| UAMI | = | unacceptable air movement index (%); |
| UR | = | relative humidity (%); |
| UVTGI | = | unacceptable vertical thermal gradient index (%); |
| v | = | speed (m/s); |
| (W) | = | women. |

*Subscripts*

| | | |
|---|---|---|
| a | = | air; |
| ext | = | external; |
| mr | = | mean radiant; |
| 1 | = | calculations in compliance with UNI EN ISO 7730/97; |
| 2 | = | calculations in compliance with ISO DIS 7730/2003. |

## REFERENCES


Alfano, G. & D'Ambrosio, F.R. 1986. La misura della resistenza termica conduttiva equivalente dell'abbigliamento, *Condizionamento dell'aria, riscaldamento, refrigerazione*, n. 30, 109–119.

ASHRAE. 1992. Thermal environment conditions of human occupancy – ASHRAE Standard 55–92, *American Society of Heating Refrigerating and Air-Conditioning Engineers*, Atlanta, Ga., USA.

ASHRAE. 1993. Handbook. *American Society of Heating Refrigerating and Air-Conditioning Engineers*, Atlanta, Ga., USA.

ASHRAE. 2004. Thermal Environment Conditions for Human Occupancy. ASHRAE Standard 55/2004". Geneva, 2003.

ASHRAE Standard 62.1/2004. Ventilation for Acceptable Indoor Air Quality. , *American Society of Heating Refrigerating and Air-Conditioning Engineers*, Atlanta, Ga., USA.

Brasier, P. 1993. *Control of thermal comfort*, Clima 2000, London.

Cohen S., Evans G.W., Stokols D. & Krantz D.S. 1986. *Personal Control and environmental stress*, in Cohen S., Evans G.W., Stokols D. & Krantz D.S. Behavior, health and environment at stress. New York: Plenum.

Corgnati, S.P. & Fra castoro, G.V. 2002. Linee guida per la modellazione di grandi serre. *CdA*, XLV (3), 54–63.

De Dear, R.J. & Brager, G.S. 1998. Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions*, 104 (1A), 145–167.

De Dear, R.J. & Brager, G.S. 2000. A standard for natural ventilation. *ASHRAE J.*, 42 (10), 21–28.

Fanger, O.P. 1970. *Thermal comfort*, McGraw Hill, New York.

Fanger, O.P. 1986. The PMV index and the international comfort standard, Practical application", *Proc. of AICARR seminar on thermal comfort and the controlled environment*, Naples, May.

Fisher, R.A. 1973. "*Statistical methods for research workers*" (14th edition). New York.

Gagge, A.P., Stolwiijk J.A.J. & Nishi Y. 1971. An effective temperature scale based on a simple model of human physiological regulatory response, *ASHRAE Transactions*, 77(1), American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta, Ga., USA.

Havenith, G. & Holmer, I. 2002. Calculation of dynamic heat and vapour resistance. *Proceedings of Environmental Ergonomics IX.*

Humphryes M.A., 1978/ *Outdoor temperatures and comfort indoor*. Building Research and Practice, March–April 1978, 91–105.

Humphreys, M.A. & Nicol J.F. 1998. *Understanding the adaptive approach to thermal comfort*. *ASHRAE Transactions*, 104 (1B), 991–1004.

ISO. 1992. *Evaluation of thermal strain by physiological measurement*s, ISO Standard 9886, International Standardization Organization. Geneva (Swiss).

ISO. 1995. Ergonomics of the thermal environment – Estimation of the thermal insulation and evaporative resistance of a clothing ensemble, ISO Standard 9920, *International Standardization Organization*, Geneva (Swiss).

ISO. 2003. Ergonomics of thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort. ISO/DIS 7730. *International Standardization Organizatio*n. Geneva (Swiss).

Kant I.J. & Borm P.J.A. 1990. The effect of thermal activity on thermal sensation. Indoor Air, Toronto, Canada.

McCullough, E. A., Olesen, B. W. & Hong, S. 1995. Thermal insulation provided by chairs. *ASHRAE Transactions*, 110 (1), 795–802.

Nevins, R.G. & Darwish, M. A. 1977. Heat transfer through corporea", in *Trattato di fisiologia medica di Mountcastle*, second edition, vol. 2, (56), 1527–1570, Piccin, Padova (Italy).

Olesen, B.W. 1977. Thermal comfort requirements for floors, *Proc. Of Meeting of IIR*, Belgrade.

Olesen, B.W. 1985. Local thermal discomfort, *Bruel and Kjaer Technical Review,* n.1, 3–41.

UNI. 1995. Ergonomia – Determinazione della produzione di energia termica metabolica, Norma UNI-EN 28996, *Unificazione Italiana*, Milan (Italy).

UNI. 1996. Ambienti termici – Strumenti e metodi per la misura delle grandezze fisiche, Norma UNI-EN 27726, *Unificazione Italiana*, Milan (Italy).

UNI. 1997. Ambienti termici moderati. Determinazione degli indici PMV e PPD e specifica delle condizioni di benessere termico, norma UNI EN ISO 7730, *Unificazione Italiana*, Milan (Italy).

UNI. 2002. Ergonomia degli ambienti termici – Valutazione dell'influenza dell'ambiente termico mediante scale di giudizio soggettive. UNI-EN-ISO 10551. January.

UNI-EN-ISO 9920. 2004. Ergonomia degli ambienti termici – Valutazione dell'isolamento termico e della resistenza evaporativi dell'abbigliamento. March.

Siegel, S. & Castellan, N.J. 1979. *Statistica non Parametrica*", second edition, McGraw-Hill Libri Italia, Milan (Italy).

Soliani L. 2004. *Manuale di statistica*, Università di Parma, Novembre edition.

Vogt, J.J & Metz, B. 1984. Ambiente termico, in *Manuale di fisiologia del lavoro*, Scherrer e coll. Eds., cap. 7, 183–222, Masson, Milan (Italy).