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RELATIONSHIPS BETWEEN THE THERMAL COMFORT AND EDUCATION

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ABSTRACT

In the Sustainable development's implementation process, the education is a tool that must be valued. The curricular orientations must suggest the energetic problems approach. One of the proposals looks for the need of evaluating the weather effect in working places and in the human being. Many studies made in the laboratory and in the field show relationship between thermal comfort and the human being performance (worker/student). Thermal conditions are necessary to provide a pleasant environmental that favours the teaching and the learning. In this paper we are particularly interested with the performance of a teaching environment that may be adjusted (better comfort) to students and/or workers (maintain the energy balance, both physical and psychic, without such an effort of adaption). The first results are shown in an investigation that was made, identified as different thermal comfort spaces and analysed some biometeorological indices.

INTRODUCTION

In the Sustainable development's implementation process, the education is a tool that must be valued. During the creation of the Decade of United Nations of the Education for the Sustainable development (2005-2015) was revealed the worries about the development and intends to improve the quality of education, facilitating the exchange of experiences between the different actors involved and searching for public interest in this issue. The apparent lack of strategies of environment protection with educative politics, formal and informal, are understood in some results of the Attitudes of European citizens towards the environment Eurobarometer [1].

The curricular orientations must suggest the energetic problems approach. One of the proposals looks for the need of evaluating the weather effect in working places and in the human being. During practice, the study of thermal comfort has a strong economic importance (the control of meteorology variables allows the optimization of thermal environment and, consequently, an increase in the production levels).

The human being is an open thermal system which produces energy under the form of heat interacting with the evolving environment to keep the internal temperature within certain break – homeothermal being. Many studies made in the laboratory and in the field show relationship between thermal comfort and the human being performance (worker/student).

The personal and human influence, in the satisfaction evaluation with the environment and, later on, with the relation with productive levels, depends of different factors non measurable, such as their psychological state, expectations and the social posture in the working place. Discomfort areas can induce thermal stress due to bad environmental conditions, such as heat and noise excess (some accidents and health damaging can occur). Some studies show the need of thermal stimulation to establish a healthy way of life in a long term period; however the thermal stimulation does not match in the scientific community.

Nowadays, when spoken about psychological development and the education processes of learning of our student must consider important aspects connected with motivation, stimulation and the environment, social relationships and received education, between others. The appearance of new teaching environments and the almost obliged informatics' inclusion in school, brings a new factor directly that can interfere directly in the performance, motivation and in the students learning skills, the environmental comfort (involves variables such as: noise, illumination, temperature, relative humidity, purity, air speed, radiation, physical activities and types of ventilation. Many scholar buildings show the same pattern of arquitecture, not depending of the location (the weather is determinant in the indoor thermal comfort). They're spaces that can influence negatively the motivation and concentration of the students. Thermal conditions are necessary to provide a pleasant environmental that favours the teaching and the learning.

In this paper are used biometeorological indexes which exist to know the performance of interior environments, such as the temperature – humidity index, *PPD* indexes (Predicted Percentage of Dissatisfied Vote) *PMV* (Predicted Mean Vote) determined by the standard application ISO 7730 [2] and the comfort diagram / discomfort of WMO [3].

NOMENCLATURE

A_{ef}	[m^2]	Effective body area
A_{DU}	[m^2]	Body area Dubois
C	[ºC]	Value of (11)
$e(T_d)$	[Pa]	Partial water vapour pressure at temperature of the dew point
f_{CL}	[-]	Adimensional: rate of area of human body
h_C	[W/m^{2}ºC]	Energy transfer coefficient in the form of heat by convection
HR	[%]	Relative air humidity
I_{CL}	[m^{2}ºC/W]	Thermal clothing resistance
m	[kg]	Mass of human body
M	[W/m^2]	Metabolic rate
T	[K]	Temperature
T	[ºC]	Air temperature
T_d	[ºC]	Temperature of the dew point
T_{CL}	[ºC]	Exterior temperature of the clothing
T_{MR}	[ºC]	Mean radiant temperature
T_{skin}	[ºC]	Skin temperature
T_{wn}	[ºC]	Natural wet bulb temperature
v	[m/s]	Air velocity
Z	[m]	height
W	[W/m^2]	External work

Special characters

ε	[-]	Spectral emissivity
σ	[W/m^{2}K^4]	Stefan-Boltzmann constant

Subscripts

CL	clothing
DU	Dubois
ef	effective
skin	skin
wn	natural wet bulb

THEORY

The ISO 7730 [2] regulation defines thermal comfort as being "the expressed satisfaction when someone is subjugated to a determined thermal environment". However the definition suggests some subjectivity, due to the analysis of two aspects: physical aspects (thermal environment) and subjective aspects (the individual state of mind) [4].

The thermal comfort is a sensation that depends of the singular opinion of each and everyone. A comfortable thermal environment for someone can be uncomfortable for another. It is almost impossible to make everybody satisfied about a determined thermal environment [5]. The main goal is to create a thermal environment that can please as many as it can.

According to ISO 7730 [2], the dissatisfaction can be a result of thermal discomfort due to an environment which is cold or hot, or a specified thermal discomfort in a certain part of the body.

The *ITH* index, Temperature Humidity Index, was initially developed by Thom [6] and combined the temperature in a natural wet bulb thermometer T_{wn} (ºC) with the air temperature T (ºC).

Nieuwolt [7] changed the *ITH* index established by Thom [6] using the air temperature T (ºC) and the relative humidity HR (%). This change managed to facilitate its application and evaluation because the relative humidity values of the air HR are frequently more available than the temperature of the wet bulb.

According Nieuwolt [7] the *ITH* index is determined by

$$ITH = 0{,}8T + T\frac{HR}{500} \quad (1)$$

in which T represents air temperature (ºC) and HR the relative air humidity (%).

Throughout these empiric tests, Nieuwolt [7] established reference values which bounded thermal and stress situations for human beings.

It was also applied an index that is based on the energetic balance and on a satisfaction or dissatisfaction statistic.

There are factors that influence the applicability of the thermal balance equation and the thermal regulation, such as: *geographic Localization* – according to Fanger [8], there isn't any major difference in comfort conditions between different people which lived in different areas characterized by soft weather, and comparing to other studies realized to people who live in the tropics, there isn't big differences between the preferred comfort conditions, so the equation comfort can be applied to people who live in different weathers; *acclimatization* – characterized by a serious number of physiological adjusts which occur when people are exposed to a certain thermal weather. Long lasting exposures allow man to tolerate better heat than cold. This acclimatization is achieved in 9 to 12 days. According to Martinet and Meyer [9], in a hot to moderate weather, an acclimatized person shows an efficient sweat. The sweat is common for the same central temperature and better distributed by the torso and limbs. The blood peripheral and coetaneous debt is more adopted. The increase of the cardiac frequency is less significant. The blood volume that circulates through the muscles is bigger in an acclimatized person. In cold weathers is also verified that acclimatization influences the thermal regulation. Studies realized by Prosser [10] show that the long term adaptation can become irreversible instead of what happens in a short term adaptation. For example, people who live in hot and humid weathers have a different distribution of sweat glands comparing to people who live in a moderate weather; *gender* – in studies realized by Fanger [8] was verified that women prefer hot weather as in men don't, however this difference is statistically irrelevant (5%) and without big consequences in terms of strategies to adopt when the thermal comfort is being studied by engineering and arquiteture. These results where proved by Morrisey [11]. According to Nielsen and Meyer [12], women tolerate humidity better than men. Women have proportion of body surface/mass bigger than men. Because in humid environments the sweat evaporation is lower, women tolerate better humid environments [13]; *index of corporal mass* – in sedentary conditions there aren't any differences in the adaptation to a thermal environment between people with different indexes of corporal mass. However the metabolic taxes of activities estimate body movement to be superior in obese people, so the thermal comfort temperature tends to be inferior for people with bigger index of corporal mass [8] and *age* – in average every single man and woman with more than 40 years old prefer an effective higher temperature than younger people [8]. One of the reasons mentioned for the transference of a comfort temperature higher for older people is the reduction of metabolic taxes with age. However it is verified that sweat is lower for older people, so the heat loss by evaporation is reduced with age.

Thermal environments that are hot are those for which the thermal balance, calculated in the base of heat exchanges by radiation, evaporation and convection, is positive [14]. Thermal stress due to heat can occur because of a metabolic taxes increase; air temperature increase; air humidity increase; average radiant temperature increase and, air velocity changed when the air temperature is superior to average coetaneous temperature

According to ISO 7730 [2] there are two indexes used: *PMV* and *PPD*.

The *PMV* index was developed in 1970 through laboratorial experiments in acclimatized rooms made by Fanger [8]. In their experiments, the people were dressed with certain clothes, previously chosen, making certain activities in certain thermal conditions. In determined experiments the thermal environment was controlled by the researcher and the people would show there satisfaction or dissatisfaction with the weather used according to a seventh scale of ASHRAE [15,16]. In other experiments the environment was adjusted by the people corresponding to “0” in the ASHRAE scale so it was considered a neuter thermal environment [17].

The seventh ASHRAE scale [15,16] is symmetric in relation to “0”, which corresponds to thermal comfort and shows values between 1 to 3 that can be positive, according to heat sensations, or negatives, according to cold sensations, as it is shown in **Figure 1**.

Figure 1 The seventh ASHRAE scale [15,16]

The determination of the thermal stress indexes has, as its main goal, the verification of the thermal acceptability of a certain environment establishing the limits.

Fixing the *PMV* to the value “0” is possible to determinate the possible combinations in different variables that promote a neutral thermal sensation [2].

The *PMV* index provides the estimated average vote of a large group of people exposed to the same thermal environment, and is based on the equation of thermal balance and the theories of thermoregulation. According to this, the human body develops various physiological processes such as vasodilation and peripheral vasoconstriction, sweating and muscle tremors in order to keep the body heat balanced, so the heat produced by metabolism is equal to the lost through the skin and breath. The definition of *PMV* index went on statistically combining the physiological responses of the thermoregulatory system with the votes of 1300 subjects according to the seventh ASHRAE scale [18].

According to ISO 7730 [2], the application of the *PMV* index is only recommended when the weather and personal variables are within certain ranges. There are two types of parameters that can be considered: estimated values, including metabolic rate, M and thermal clothing resistance, I_{CL} and meteorological variables including air temperature T, mean radiant temperature T_{MR}, air velocity v, the partial water vapour pressure at the temperature of the dew point $e(T_d)$.

According to ISO 7730 [2], the heat stress index *PMV* is calculated from an energy balance general equation that is the utility of several intermediate terms, including:

$$+(M-W) \tag{2}$$

that represents the metabolic rate and external work,

$$-3{,}05\times10^{-3}\left[5733-6{,}99\times(M-W)-e(T_d)\right] \tag{3}$$

the vapor diffusion namely a term related to evaporation,

$$-0{,}42\left[(M-W)-58{,}15\right] \tag{4}$$

the transpiration namely a term related to evaporation,

$$-1{,}7\times10^{-5}M\left[5867-e(T_d)\right] \tag{5}$$

the hidden breathing namely a term related to breathing,

$$-0{,}0014M(34-T) \tag{6}$$

the sensitive breathing namely a term related to breathing,

$$-3{,}96\times10^{-8}f_{CL}\times\left[(T_{CL}+273)^4-(T_{MR}+273)^4\right] \tag{7}$$

the radiation namely the loss of energy as heat by radiation (Stefan-Boltzmann law),

$$+f_{CL}h_C(T_{CL}-T) \tag{8}$$

the convection namely the loss of energy as heat by convection.

Energy balance also should show a term that represents the heat accumulation.

The constant expression given in (7) $3{,}96\times10^{-8}$ was determined based on the expression

$$\varepsilon\sigma\frac{A_{ef}}{A_{DU}} \tag{9}$$

in which ε indicates the emissivity (0,97, in this paper), σ the Stefan-Boltzmann constant $5{,}67\times10^{-8}$ W.m^{-2}.K^{-4}), A_{ef} the effective body area necessary to transfer energy as heat by radiation and A_{DU} the body area namely the area of the outer surface in a naked human body.

The naked body extended surface area evaluation was originally proposed by Dubois and Dubois [19] as follows

$$A_{DU}=0{,}203m^{0{,}425}Z^{0{,}725} \tag{10}$$

in which m represents the mass (kg) and Z the height (m) of the person. For an adult, the accepted typical value for the body surface is 1,7m2. Was considered $A_{ef}/A_{DU}\cong0{,}71$.

The exterior temperature of the clothing T_{CL} is determined by

$$T_{CL} = T_{skin} - C \tag{11}$$

in which the last expression,

$$T_{skin} = 35{,}7 - 0{,}028(M - W) \tag{12}$$

and

$$C = -I_{CL}\begin{bmatrix} 3{,}96\times10^{-8} f_{CL} \times \\ \left[(T_{CL}+273)^4 - (T_{MR}+273)^4\right] + \\ f_{CL} h_C (T_{CL} - T) \end{bmatrix} \tag{13}$$

The clothing factor I_{CL} depends on the clothing exterior and on the body area. The clothing factor correlates to the clothing thermal resistance, has no dimension and is greater than the unit. The value of h_C represents the energy transfer coefficient in the form of heat by convection.

In general, the expressions quantification submitted suggest that the heat amount due to evaporation can represent, on average, about 32% of the total brought into play, the heat amount due to radiation is about 42% of the total station at stake, the heat amount due to conduction is about 0% of the total brought to play and the heat amount due to convection is about 26% of total jeopardized.

According to ISO 7730 [2], the thermal stress index *PPD* is determined by the knowledge of the *PMV* index.

Index *PPD*, Predicted Percentage of Dissatisfied Vote, establishes the percentage of thermal dissatisfied people with the environment. This is based on the percentage of a large group of people who would like the weather to be warmer or colder, voting +3, +2 or -2 and -3, on the seventh ASHRAE scale.

The *PPD* index can be analytically determined by the expression

$$PPD = 100 - 95 \times e^{-\left(0{,}03353 PMV^4 + 0{,}2179 PMV^2\right)} \tag{14}$$

The relation between the *PPD* index and the *PMV* index can be analysed. It is impossible to obtain in an environment that fully meets all individuals of a large group; the *PPD* index value is never less than 5%. The minimum *PPD* value corresponds to the condition of thermal neutrality. The thermal neutrality is achieved by different air temperature values, relative humidity and air velocity, depending on the person and on their acclimate ability.

The maximum permissible values for *PMV* and *PPD* indexes, in order to consider the studied area as a comfort zone respectively.

$$-0{,}5 < PMV < +0{,}5$$
$$PPP < 10\% \tag{15}$$

METHODOLOGY

For different locations and days of different months (October and November) were registered temperature values, relative humidity and wind velocity. The sites are at a distance of about 60km.

It was used the seventh ASHRAE scale [16] and a range of colours (this allowed to know the real thermal sensation of the person).

It was applied *PMV* and *PPD* indexes, as well as *ITH* index.

The results were compared to the information obtained from the diagram of WMO (1987).

It was considered intervention strategies.

The data led to an exploratory investigation of the indoor environments conditions and the applicability of the adopted methodology.

RESULTS

A questionnaire was filled in each moment of registration data and it was written down any type of intervention to improve the environment.

In the colour scale, as shown in **Figure 2**, was indicated, in every moment of observation, the thermal sensation that the individual was experiencing by marking (tick).

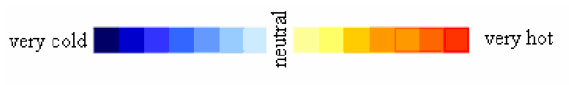

Figure 2 Thermal colour scale

The implementation of ISO 7730 [2], for selected and investigated sites, allowed us to construct the graph in **Figure 3**.

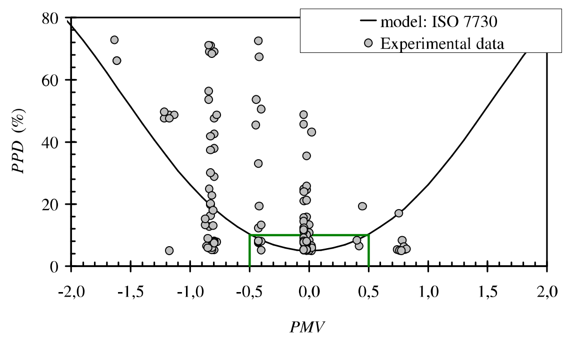

Figure 3 ISO 7730 [2]: Model and experimental data

The observation of the graph in **Figure 3** suggests that only a few registered data is included in the area under the considerated as thermal comfort. The values close to (-2) indicate the situation of feeling cold and the data close to the value (+2) indicate the situation of feeling hot.

The conclusions taken by the observation of **Figure 3** are confirmed when using the WMO diagram, as it is shown in **Figure 4**. Note that this diagram, of only two entries, shows the prevention strategies.

In **Figure 4**, as expected, few experimental points are in the comfort zone. None needs ventilation. There is a need to reduce the partial vapour pressure of moist air and heating.

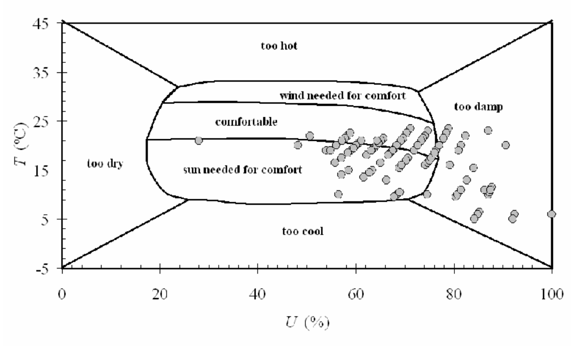

Figure 4 Experimental data and WMO [3]

The type of clothing was considered in the influence of thermal comfort. The operative temperature, defined as an uniform temperature of a black imaginary environment in which the individual could exchange the same amount oh heat by radiation and convection as in the real non uniform environment, was considered. In practice, the chosen activity (an intellectual activity – in terms of study) and the clothing (in unit clo) are related and can influence the thermal sensation of a person. Thus, for the same activity, clothing influences the operative temperature. A higher clo value (measure of clothing) determines a lower operating temperature.

It was applied *ITH* index, to the experimental data.

In **Figure 5**, it is shown the registered data values in the colour scale (sensations of emotional character) and the determined *ITH* values and evaluated according to ISO 7730 [2].

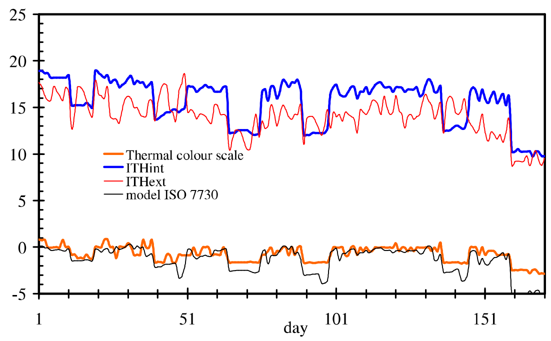

Figure 5 Indexes and experimental data: their relation

The observation of the graph in Figure 5 clearly shows that the registered values in the colours scale of thermal perception follow the trend of the *ITH* index for indoor sites. The registered values in the colours scale of thermal perception for the interior of places are completely different from the values of the indexes for exterior places. This situation shows that the atmospheric conditions (outside the buildings) determine the thermal sensation that takes place inside the buildings. There is a good correlation between the registered values by the colours scale and the estimated values according to ISO 7730 [2]. The evolution of the results in the colours scale shows an excellent correlation with the *ITH* index "indoor" values.

ONGOING RESEARCH

The exploratory study considered the used methodology as valid.

The colours scale adopted seemed to be an excellent tool to be valued. In practice, each individual reports about the thermal sensation in which is involved, namely the colours scale has two colour extremes. The "dark blue" indicates the feeling of being very cold and the colour "dark red" indicates the feeling of being very hot.

To know the influences of thermal sensation during learning (the educational context) are being prepared questionnaires to be answered by each student at the end of different classes and on different days. The students are unaware of the questionnaires passage.

It is expected that the results may help to understand the influence of thermal comfort in learning.

FINAL CONSIDERATIONS

The research made led to the conclusion, as expected, that the interior atmospheric conditions "indoor" are conditioned by the exterior weather conditions "outdoor".

The obtained results allowed knowing the feelings of comfort and discomfort during the analysis period for two different places of study.

In every place were discussed strategies to improve the environment surrounding people.

The diagram of the World Meteorological Organization (WMO) seems to be simple to use and with objective information about the improvement of the environment.

In the current issue of climate change, in which global warming is accepted [20,21], studies like this are important.

Finally, would it be nice to understand at what level is the baseline of tolerance, in terms of thermal comfort, for a better teaching and learning?

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