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Effect of Thermal Comfort in Different Buildings Specifications

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ABSTRACT
A thermal comfort study has been conducted in two towns from two climatic zones in Libya. Some persons were concerned by this survey. They have been asked once each month during one year and the buildings were without air conditioning systems. The study results have been processed and correlations between sensations and globe temperatures have been found. The comfort temperatures calculated PMV/PPD (Predicted Mean Vote / Predicted Percentage of Dissatisfied) for each location. The description of this survey and the methodology of data analysis are described in details in this paper. The main results are discussed and compared with those of similar surveys conducted in different geographic locations and very close to the correlation between comfort temperature and mean outdoor temperature
Keywords: Ventilation& air conditioning, thermal comfort, Libya climate.

I. INTRODUCTION

A control system is maintaining the indoor in most of developed countries, the central heating systems are commonly used in winter. Air temperature at a set value according to thermal comfort standards [1] the use of thermal insulation, multiple glazing and controlled ventilation systems are necessary. In the North African countries, the climate is mild, but the needs to heating in winter and cooling in summer are certain, especially in coast areas where the humidity is high. The traditional buildings provided a relatively acceptable thermal comfort in winter and particularly in summer. These buildings are naturally ventilated and have a high thermal capacity. They are equipped with a courtyard; in those houses, adapted shadowing devices and appropriate orientations of the openings facilitate the control of the solar gains. During summer in the night, when the outdoor air is cooler, people enjoy opening the windows and doors, the building is then cooled by natural ventilation and coolness is stored in the building thermal mass for the next day. This traditional way of construction is not any more possible because of its cost and the change of people's standard of life and behaviors; courtyard houses are replaced with flat or terrace houses. The development of "modern" construction was very fast and no care was paid to the thermal quality of the buildings. Most of the recent buildings are not equipped with thermal insulation and their tightness to air is very poor, this is due to the lack of appropriate standards. These standards are deduced from the experiments done by Fanger [2] in climatic chambers and use the predicted mean vote (PMV) equation to estimate the human mean response to the thermal environment from the knowledge of three thermal variables. Two among them are related to the ambience, they are the air temperature (Ta), the radiant temperature (Tr) or the globe temperature (Tg), the air velocity (va) and the air relative humidity (RH) or vapour pressure (Pv). Two remaining parameters are related to the occupant's adaptability to the local climate; these are the metabolic rate (M) and the clothing insulation (Icl). The steady state conditions are not reflecting the real life conditions particularly in North Africa where the indoor temperature is free running and the control is done manually by the occupant according to his feeling. People are used to adapt themselves to climate using clothing, posture, kind of activity, natural ventilation, etc. An assessment of the thermal comfort level as felt by the building's occupants must be done under real occupation conditions.

II. DATABASE AND ANALYSIS

The responses from the questionnaires were entered in excel for analysis. A database has been built to filter the data according to any fixed criteria. During a preliminary data processing, we eliminated the records for which relevant information were missing or inconsistent responses are encountered. The air velocity was than calculated from the cooling time of the Kata thermometer, according to the appropriate equation for each thermometer. Each of these three zones has its own cultural heritage and traditional architecture reflecting its own particular climate. In addition, there are wide seasonal changes in the weather between summer and winter.

In summer, midday temperature can exceed 43 °C in some regions in the south. In winter, temperature can fall down to around 0 °C in the North Mountains. In the desert, at the country south, the freezing winter nights are also very common. Thermal comfort and temperature standards[3] take no account of climatic variations and people adaptive behaviors. Analysis of thermal comfort field studies have shown that indoor comfort temperature as felt by the occupants is function of mean outdoor temperature [4], [2], [5] and [6]. This means that we can relate indoor comfort temperature to climate, region and seasons. For free running buildings and according to different surveys held under different climatic conditions, Humphreys [4] has found that the comfort temperature can be obtained from
The mean outdoor temperature with Eq 1.

$$Tc = 0.534To + 11 \quad (1)$$

Auliciems revised Humphreys equation by deleting some fields studies such those with children as the subjects, and adding more information from other studies not included by Humphreys [7], [8]. These revisions increased the database to 53 separate field studies in various climatic zones covering more countries and more climates. After combining the data for naturally ventilated buildings and air-conditioned buildings, the analysis led to an equation involving the outdoors air temperature (To) and the indoor air temperature (Ti), this resulting equation is Eq. 2

$$Tc = 0.48\ T_i + 0.14 + T_o + 9.22 \quad (2)$$

Auliciems [3] has also proposed a single line for all buildings, which covered the naturally ventilated buildings and air conditioned buildings. This relation is given by Eq. 3

$$Tc = 0.31\ T_o + 17.6 \quad (3)$$

Nicol has conducted several surveys under different climatic conditions. In a first survey in Nicol [9], he has established relation between comfort temperature and outdoor temperature given by Eq. 4

$$Tc = 0.38\ T_o + 17.0 \quad (4)$$

In a second survey in Pakistan [18], he has found a second regression given by Eq. 5

$$Tc = 0.36T_o + 18.5 \quad (5)$$

Those relations show clearly that the comfort temperature is related to the outdoor temperature and so to the climate. The difference between those relations confirms that there is no universal comfort temperature.

III. CONDUCT OF THE SURVEY AND EXPERIMENTAL METHOD

1. Methodology

A cross-sectional investigation has been carried out monthly during a complete year in three different towns covering two climatic zones. In each town, 40 persons have been selected20 among them have been interviewed in their houses and the 20 other persons have been interviewed in their working places. The total number of subjects was 200 persons spread in three cities. Each person was visited 12 times, once in each month of the year.Equilibrium between males and females has been respected during the selection of the survey subjects; Table 1 gives the subjects three repartition for the different towns.The subjects have been selected by the researchers, who are in charge of the survey in each town. No more than two different persons were interviewed in the same building; hence, a larger number of different buildings were covered.

2. Experimental method

Four environmental variables were measured at the moment of the survey: the air temperature (Ta) in (°C), the globe temperature (Tg) in (°C), the relative humidity (RH) in (%) and thecooling time of a Kata thermometer (t) in (s). All sensors were positioned in the vicinity of the subject along the time during which the survey sheet was being filled.The subject sensation and preference about which he had to answer in a seven steps scale according to Bedford scale.Her preference to be warmer or cooler, His skin moisture, His feeling and preference about the air velocity, His activity at the moment of the survey and 30 min before.

A full description of the conduct of the survey and the results obtained from it is given in References. [10,11].

2.1.Calculation of the clothing insulation

Individual clothing articles indicated in the survey responses were converted into their respective thermal insulation value (Ic) in units of Clo as tabulated by McIntyre [12]
(1 Clo = 0.155 m2 C/W).
The overall Clo value for each subject entire clothing ensemble has been calculated using the following equations from McIntyre [14] Eqs. 6 and 7:

$$I\ Clo,\ men = 0.113 + 0.727 \times \sum Ic \quad (6)$$

$$I\ Clo,\ women = 0.05 + 0.77 \times \sum Ic \quad (7)$$

2.2. Calculation of the metabolic rate

The metabolic rate has been calculated from the activity level of each respondent at the moment in which the questionnaire sheet is being filled and his activity level 30 min before according to the following relation Eq. 8:

M = ADu58 (0.71I act0 + 0.3I act-30) (8)
where I act (0) and I act (−30), act are the activity levels at the moment of the survey and respectively 30 min before the time during which the survey sheet has been filled; ADu is the subject body surface area calculated according to Dubois formula as function of the subject weight (W) and height (H) (see Eq. 9 from McIntyre [12]
ADu = 0.202 W 0.425 H 0.725 (9)

IV. DATA SUMMARY

Table 1 shows summarizes the distribution of the physical measured data two cities in Libya. It seems reasonable to expect that the activity at the moment of the survey would be more influential than 30 min earlier. As far as it is known, no other investigators gave indication of appropriate weightings. Rowe [13] conducted a similar survey in which he asked about the activity at the moment of the survey, 10 min before, 20 min before, 30 min before and 60 min before. He took the following ad hoc weighting factors: 50% for the 10 min proceeding the moment of the survey, 25% for the 10 min before, 15% for the time corresponding to 30 min before the survey time.

Table I. The distribution of the physical measured data by city

City / level	T_{air}	T_{glo}	Humidity	ET	Clo	Met
Tripoli						
Max	29.5	29.2	77	25.9	1.22	2
Min	15	15.2	34	15.6	0.07	0.7
Average	23.5	24.1	56	21.2	0.55	1.23
Gharian						
Max	35.5	28.1	70	23.3	1.43	2
Min	11.9	12.4	22	14.3	14.3	0.16
Average	21.6	21.8	52	19.6	0.62	1.19

V. COMFORT VOTES AND THERMAL ACCEPTABILITY

Referring to previous research, the comfort temperature has been linearly related to outdoor temperature. The survey data have been used to generate the comfort temperature as felt bythe subjects in their real living conditions, then the comfort temperatures have been correlated to the outdoor temperatures and to running mean temperatures.

1. Thermal acceptability

The comfort votes of the population have been sorted in ascending order. The votes equal to (-1), (0) and (1) are considered as those who take the operative temperature as acceptable.
For each value of the globe temperature, the total number of the votes and the percentage of the votes that are stating the acceptability have been calculated.
1. For temperatures between 16 and 26.5 °C, more than 80% are voting acceptable. This result shows that there is a high adaptation potential for a so wide temperature range.
2. The distribution is multi-modal. This result can be explained by the fact that for some values of low and some values of high temperatures, the total number of observations is verysmall, a unique vote stating acceptability will generate a high percentage for the corresponding value of the temperature. Those side percentages of acceptability made that a probity or logit regression is impossible. A polynomial regression has been tested. Two different equations have been found and their plots are shown in FigureI. The function represented by an order 4 polynomial fits better the data scatter for the acceptable zone, unfortunately, this function deviates from the data for low and high temperatures, and this is to fit the marginal points caused by the small number of votes that have occurred in these temperatures. This function is also more robust, we can adopt it for lack of a better function as probity and we must pay attention to not use it for globe temperatures lower than 10 °C or higher than 35 °C.

2. Relation between PMV and sensation

Using the measured parameters, the PMV has been calculated for each subject according to Fanger [2]. The values of the PMV have compared to those of comfort votes (S) as described by the subjects. Figure II given the plot of the PMV as function of the comfort vote. This figure shows that each value of the sensation (comfort vote), the scatter of the PMV is very large. The regression line dose not correspond to the line y = x
For the value of S = -3, the value of the PMV from the regression is also equal to -3.
For S = 0 , the PMV (from the regression) is equal to -3 .
For S = -3, the PMV (from the regression) is equal to (- 0.87) which is very far from the comfort vote.

For S = +3, the PMV (from the regression) is equal to (1.28) which is very far from the comfort vote.

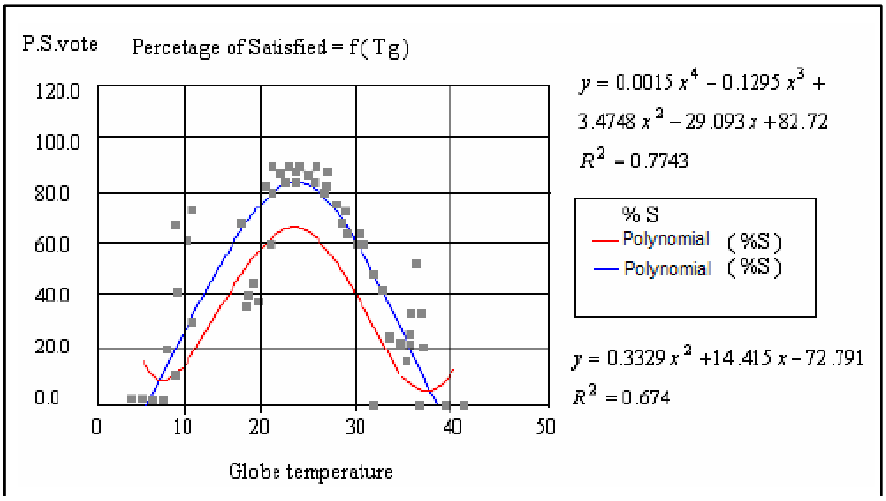

Figure I. Acceptable comfort votes as function of the globe temperature

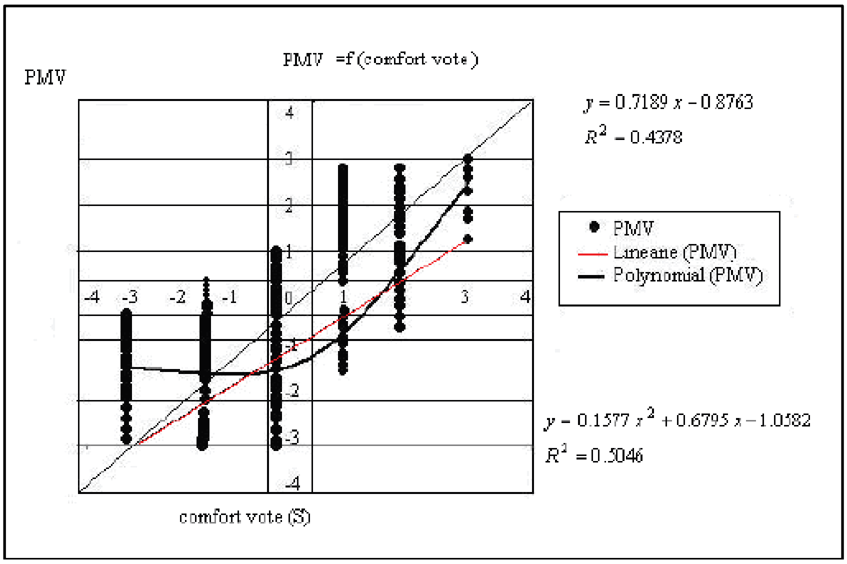

Figure II. PMV Calculation as function of comfort votes

VI. RESULT

Referring to Nicol and Raja [9], the running mean temperature was calculated with a coefficient C = 0.8. The Griffiths comfort temperatures have been correlated to the daily running mean temperatures. The resulting correlation is given by the expression in Eq. 10

$$T_{c\text{-}Griffiths} = 0.532\ T_{RM} + 11.56 \quad (R2 = 0.6262) \qquad (10)$$

This result is very close to the correlation between comfort temperature and mean outdoor temperature, but has a slightly higher determination coefficient. Compared to the results of Nicol and Raja [9], this equation shows that the Libya population is having a higher adaptation capacity than the average European population that was Involved in the SCATs project. This difference can be explained by the fact that the SCATs project has been held in air-conditioned buildings while the Libya survey covered only naturally ventilated buildings.The correlation is very close to the one found by Humphreys in [4]. The determination coefficient found for the running mean temperature regression was 35% lower than that found for the mean outdoor temperature regression.

VII. CONCLUSION

Building standards have been based on fixed comfort temperatures found from tests held in climatic chambers. The indoor temperature is fixed to a set value and controlled by heating and air conditioning systems. The thermal sensation of the building occupants is the only controller of the ventilation, the heating or the cooling of the building. Unlike the conventional thermal regulations, which are based on energy consumption, the special feature of the future Libya thermal regulation is related to the fact that it must ensure a minimum level of thermal comfort when the building is free running without any heating or cooling system. The comfort temperature can be correlated to the monthly mean outdoor temperature. Such concept can be used to design comfortable buildings. The comparison between the comfort temperature and the maximum and minimum outdoors temperatures can help designer to judge whether passive heating and cooling techniques are appropriate for the climate under consideration. The relationship between the indoor comfort temperature and the range of outdoor temperatures shows whether for example night ventilation can be or not a way to keep the building cool in summer and help the designer to select the appropriate thermal capacity for the building. The study suggests that in Libya, the thermal comfort temperature can be calculated from one of the expressions in Eq. 11 and 12.

$$T_{c\text{-}Griffiths} = 0.518\ _{to-Avg} + 10.35 \qquad (11)$$

$$T_{c\text{-}Brager} = 0.680\ _{to-Avg} + 6.88 \qquad (12)$$

where Tc-Griffiths (°C) is the comfort temperature calculated using the Griffiths method, Tc-Brager (°C) is the comfort temperature found according to [8], To-Avg (°C) is the monthly mean outdoor temperature. The correlations found in the case of our study are in good agreement with those found in the literature particularly the one found by Humphreys. For buildings equipped with heating and air conditioning systems, a variable indoor temperature has to be taken according to the comfort temperature calculated from the above equation. This is in agreement with the common way people used to run their heating or cooling systems. Such method of running will allow an important energy saving compared with the existing standards.

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