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An investigation into thermal comfort in the summer season of Ghadames, Libya

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Abstract

This paper reviews the results from a field survey of thermal comfort within two types of buildings; old (traditional) and new (contemporary), in Ghadames oasis in Libya. The survey was undertaken in the summer seasons 1997 and 1998, which were typical of the hot–dry climate of North Africa. It shows how the 237 residents responded to the environmental conditions. Questionnaires were collected from the residents of 51 buildings: 24 old buildings that employ natural ventilation systems with courtyards and 27 new buildings that employ air-conditioning systems. In addition the environmental parameters were measured in 11 buildings (5 old, 6 new) representing 50 subjects, to calculate the predicted mean vote value of the subject using Fanger's model as presented in ISO 7730 standard 1995. The survey has shown that the measurements of predicted mean vote (PMV) in new air-conditioned buildings provide satisfactory comfort conditions according to ISO 7730 and the occupants agree by indicating a satisfactory actual mean vote (AMV). The equivalent measurements and survey results in old traditional buildings indicated that although the PMV, based on measurements and ISO 7730, implied discomfort (hot), the occupants expressed their thermal satisfaction with the indoor comfort conditions. The field study also investigated occupants' overall impression of the indoor thermal environments; the results suggest that people have an overall impression of higher standard of thermal comfort in old buildings than in new buildings.

Keywords: Thermal comfort; Hot–dry climate; Case study; Naturally ventilated building; Air-conditioned building

1. Introduction

This paper seeks to determine the extent to which existing research findings, and the ISO 7730 standard which is based on the Fanger model [1], could be applied when designing for thermal comfort in a hot–dry climate. Since 1987, UNESCO has listed the old town of Ghadames oasis as a historic site in the World Heritage List. As such this makes Ghadames an important area and to be chosen as a case study in shaping the values of traditional dwellings in Libyan towns and cities. Ghadames lies 630 km south-west of Tripoli, close to the border of Algeria and Tunisia (see Fig. 1). It is located in the Libyan Sahara Desert, and situated at an altitude of 350 m above sea level.

It is nearly 82 ha in area with a total population of 7000 in 1850, dropping to 1900 by 1952, due to emigration to the biggest cities such as Tripoli and Benghazi, and sometimes to Algeria and Tunisia.

However, the population by 1990 had increased to 14,700 as a result of the improved economic condition of the country. The Ghadames soil is clay and stone, which is not suitable for agricultural use, but good use has been made of existing local materials, such as palm trees, clay and stones (i.e. limestone, gypsum, etc.) to construct the traditional buildings. The old town was originally protected from the drifting sand and from the high air temperature of the surrounding desert by date palm trees. The desert climate of Ghadames is one of the most extreme climatic conditions

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within the whole country. The climate is characterised by high air temperature, high solar radiation, low rainfall, low humidity and many sandstorms. The weather in summer is hot throughout the day, the air temperature sometimes rising to more than 47°C, falling to 30°C during the nights. In winter, the weather is cold at night, falling to 0°C temperature in the night. The old town of Ghadames provides a unique opportunity to investigate the differences between traditional and contemporary architecture.

2. Overview of thermal comfort

Thermal comfort has been defined by ASHRAE [2] as "that condition of mind which expresses satisfaction with the thermal environment" and as such will be influenced by personal differences in mood, culture and other individual, organisational and social factors. Thus thermal discomfort within building environments is a prevalent and significant issue throughout the developed and developing countries. The thermal comfort standards prescribed by ISO 7730 [3] are the first that have been used on a world-wide basis. They are based on Fanger's work in climate chamber experiments on young Danish students and to the PMV model. There have been extensive studies to measure thermal comfort using test chambers; e.g. Fanger [1] in Denmark, Tanabe et al. [4] in Japan, Chung and Tong [5] in Hong Kong. Other studies in thermal comfort have used field surveys such as Auliciems and De Dear [6], Nicol [7] in Pakistan, and Karyono [8] in Indonesia. In addition, McIntyre [9] presented a comparison of Fanger's climate chamber work with field studies reviewed by Humphreys [10], suspecting that certain intervening variables that occur in the "real" world might not be reproducible in the climatic chamber. Oseland [11] has reported on significant discrepancies occurring between predicted mean votes (PMV) and actual mean votes (AMV) values obtained in offices and homes as compared with climate chamber studies, attributing the differences to contextual and adaptation effects. Thus, the field studies closer to the "real" world may be preferable to climate chamber ones. A field study on thermal comfort of the above type has not previously been attempted in Libya specifically or North Africa generally. The present paper discusses the practical application of ISO 7730 Standard based on field work carried out at Ghadames oasis in Libya.

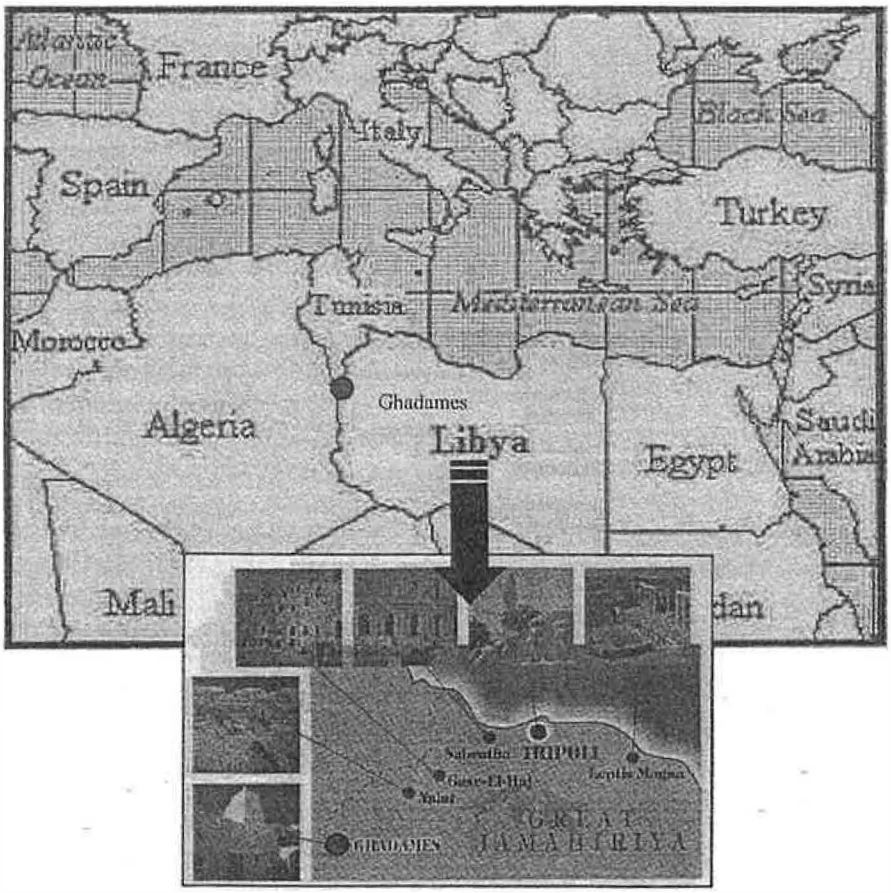

Fig. 1. Location maps.

Fig. 2. Old type of buildings in Ghadames, 1997.

It also presents human thermal sensation votes in both naturally ventilated and air-conditioned buildings.

3. Field survey

A thermal comfort field survey was carried out in 51 buildings in the Ghadames oasis, Libya in summer 1997. These buildings employ natural ventilation systems (old traditional buildings), and air conditioning systems (new contemporary buildings). Figs. 2 and 3 show typical examples of these two types. It was impossible to cover all the buildings in Ghadames, due to the limited time, but the survey was planned to select buildings that represent: (a) different locations in Ghadames; and (b) typical types and sizes (i.e. private and public, one story building, flats or two story building, etc.). All 237 responding subjects (male and female), who lived in the buildings surveyed, were Ghadamesian tribe's people in age from 19 to 70 years, and with an average occupancy of 4.5 persons for an old building and 4.8 persons for a new building. The work was divided into two kinds of surveys: (i) subjective survey, which involved collecting data from a total of 24 old buildings, effectively representing 108 (24×4.5) subjects and 27 new buildings representing 129 (27×4.8) subjects, in order to represent the actual mean vote (AMV) of the resident in Ghadames. (ii) Subjective and objective survey, which involved measuring the environmental variables in 11 buildings, representing 22 (5×4.5) subjects in old buildings and 28 (6×4.8) subjects in new buildings, in order to calculate the PMV of the subjects using Fanger's model as presented in ISO 7730 [3].

3.1. The equipment

In order to calculate the PMV and predicted percentage dissatisfied (PPD) values as presented in the ISO 7730 standard, four basic environmental parameters were measured, and two personal parameters were estimated. Air temperatures were recorded using radiation-shielded thermocouples (Type T, copper/constantan). These values were logged every 15 min and average values were calculated every hour. Air velocities were measured using an omni-directional anemometer. The mean globe temperatures were measured, using a standard globe thermometer and mean radiant temperatures were then calculated. The equipment used in this study complied with the criteria given in ISO 7726 standard [12].

3.2. The questionnaire

Subjects were asked to complete a questionnaire at the same time as the environmental variables (air tem-

Fig. 3. New type of buildings in Ghadames, 1997.

perature, globe temperature, surface temperature, air velocity and relative humidity) were being recorded. Details of clothing and activities were noted for each subject. The subjective study involved collecting data using questionnaires. The questionnaire is based on six sections: background and personal information; social interaction; thermal environment and personal influences; occupants' perceptions of the environmental conditions in the whole building; occupants' thermal comfort; and people's general feeling and personal well being. For the purpose of this paper, only the personal information and occupants' thermal sensation data have been presented including data about the age and gender of the subjects and his/her family; hours/days spent inside the building including sleeping time; presence of air-conditioning units; etc. The occupants' thermal comfort has been tested using 7-point ASHRAE sensation scale, ranges from −3 as cold to +3 as hot and 0 as neutral. In addition, preference and satisfaction scales have been used. The questionnaire has been translated into the Arabic language and distributed among the residents in Ghadames oasis. The subjects were selected randomly from different groups of people in Ghadames (i.e. Educated, Administrative, Architects and Elite groups) to represent typical range of samples. Care was taken to minimise the risks of mis-understandings arising from translations of the words describing the points on the various scales by interviewing the respondents and assisting them with completion of the questionnaires.

4. Findings

4.1. Subjective votes

Questionnaires were collected from 51 buildings representing 237 subjects, from both old and new buildings, as mentioned earlier. Fig. 4 shows the overall thermal comfort sensation for a summer season of

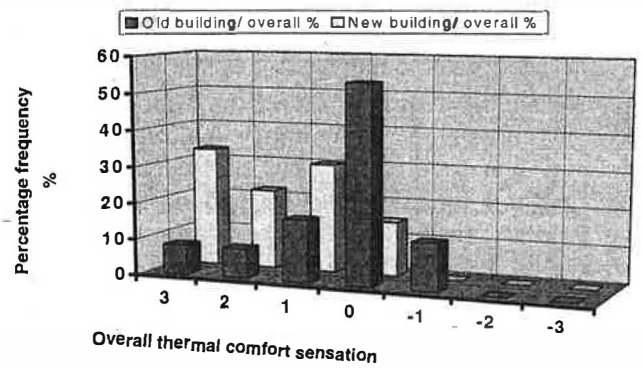

Fig. 4. Comparison of the overall thermal comfort sensation for old buildings and new buildings.

the respondents in old naturally ventilated buildings and new air-conditioned buildings. These results convey the occupants' overall impressions of the building types in terms of their comfort conditions.

It illustrates that 54% of the respondents are feeling neutral (0) in the old buildings and only 15% of the respondents in new buildings are feeling neutral. In addition, 13% of people reported as being slightly cool (−1) in the old buildings compared with 0% in the new buildings, with 8% of them feeling hot (3) in the old buildings, and 33% feeling hot in new buildings. This results therefore suggest that the occupants have an overall impression of higher standards of thermal comfort in old buildings than in new buildings.

Furthermore, the survey showed, from the preference scale, that 62% of the residents in old buildings did not want a change in their indoor environment, while 38% wanted to be cooler. By comparison, only 41% of new building occupants voted for no change with 59% who wanted to be cooler. At the same time there were 96% who were generally satisfied with their environment of the old buildings, compared with 77% of occupants of the new buildings.

4.2. Physical measurements

In addition to the subjective study, an objective survey was carried out in 11 buildings (5 old, 6 new), representing 50 subjects. All subjects were sitting on the floor, and they were wearing their traditional uniform of 0.6 clo. The sensors to measure the four basic environmental parameters were placed at a height of 0.3 m above the floor, representing the centre of gravity of the subject. The measurements were made at the same time as the respondents were completing the questionnaires. A sample of the results of the measurements of each type of building is illustrated in Table 1. Only 11 buildings (5 old and 6 new) were involved in both the subjective and objective studies. The reasons for having only that number of buildings in this survey are due to the problems encountered in Libya, which can be categorised as: (i) access — due to the former sanctions and distance from England to Libya, (ii) time-scale — the study was undertaken in four weeks in each summer season, therefore it was only possible to survey 11 buildings, and (iii) nature of the research — had to make prior-arrangements with local authorities in Ghadames; introduce and interview residents, and finally, select buildings whose residents agreed to participate in the survey. All of these issues together with the usual technical and logistic problems of site-work limited the sample size. Nevertheless the sample was selected in such a way that a reasonable cross section of house-holds was involved.

Table 1
Sample of the measurement results of old and new buildings in Ghadames, 1997

Building No. — Type	t_{out} (°C)	t_a (°C)	t_g (°C)	v_a (m/s)	Rh (%)	t_{mr} (°C)	Activity[a] (Met)	Rcl[a] (clo)	PMV	AMV
3 — Old	43.0	33.6	34	0.04	45.9	34.1	1.1	0.6	2.9	0
5 — Old	40.0	33.8	34	0.05	35.3	34.1	1.1	0.6	2.7	1
7 — New	36.2	28.0	29.0	0.20	20.0	30.0	1.1	0.6	0.7	0
10 — New	39.1	33.0	32.0	0.19	29.0	33.6	1.1	0.6	1.8	1

[a] Values were taken from ISO 7730 standard to represent the thermal insulation of clothing and the activity. t_a, Inside air temperature; t_g, inside globe temperature; v_a, air velocity; Rh, relative humidity; t_{mr}, mean radiant temperature; t_{out}, outside air temperature; Rcl, thermal resistance of the clothing.

4.3. Applicability of ISO 7730

The thermal comfort index PMV, is considered to be applicable in the Ghadames environment, for the following main reasons; (a) Fanger's work investigated about 1296 subjects, with wide range of environmental conditions, including conditions when air temperature >30°C, and relative humidity up to 70%; and (b) a moderate thermal environment is deemed to have been achieved when PMV values range from −3 as cold to +3 as hot. Therefore, the Ghadames' environment is considered as a moderate thermal environment and the ISO 7730 standard is expected to be applicable in such environments. In the present survey 50 subjects in good health (22 residents from 5 old buildings and 28 residents from 6 new buildings), in the age range 19–70 years, were asked to complete the questionnaire to determine the AMV. In the objective tests, measurements of environmental variables were used to calculate the PMV of the subjects using Fanger's model as presented in ISO 7730 [3]. The thermal comfort programme developed by Loveday et al. [13] has been used to calculate PMV values. The measurements in the new buildings were conducted with the air-conditioning system operating, whilst the old buildings depended on natural ventilation. The metabolic rate was viewed to be 1.1 met (63.8 W/m^2) to represent a sedentary activity, and clothing value, Rcl, was estimated to be 0.85 m^{2}K/W or 0.6 clo representing the thermal resistance of a traditional uniform.

Figs. 5(a) and (b) show the comparison of PMV and AMV for both old buildings and new buildings. Each point in Fig. 5(a) and (b) represents an average vote of 4.5 and 4.8 subjects respectively. Fig. 5(a) shows that the subjects were feeling neutral to slightly warm in old buildings, even when the indoor air-temperature ranged from 30 to 35°C. It can be seen that there are clear discrepancies between PMV and AMV for the old buildings. This shows that Fanger's model is invalid for predicting the thermal comfort in such environments. Adaptation effects could explain this.

Fig. 5(b) shows good agreement between the PMV values and the AMV of the occupants in new air-conditioned buildings. It shows that 67% of subjects in four new buildings were feeling neutral, while 33% were feeling slightly warm. The occupants in the new constructed buildings relied more on air-conditioning being turned on, to achieve the indoor air temperature between 25–31°C.

In addition to the physical measurements two personal parameters need to be estimated; clothing value and metabolic rate. For such estimation, it is important to take account of the uncertainties that are associated with these two parameters within the ranges normally found in the conditions of the field measurement. Thus, clothing values between 0.6–0.7 clo would be normally found on the population in Ghadames, with metabolic rates between 1.0 and 1.2 met in the sedentary posture adopted during the survey. Thus, a recalculation of the PMV values was carried out for the additional values of clothing and metabolic rate.

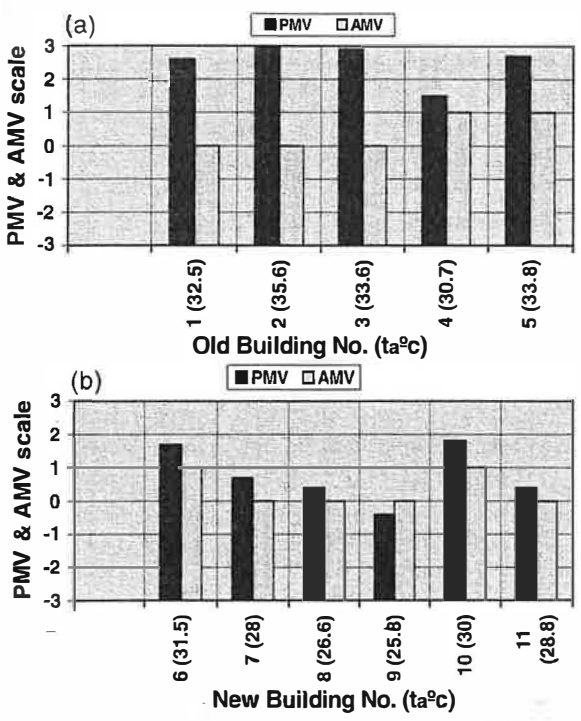

Fig. 5. (a) Comparison of PMV and AMV at 18:45 p.m. in five old buildings, 1997. (b) Comparison of PMV and AMV at 18:45 p.m. in six new buildings, 1997 (air-conditioning systems turned on).

Table 2
Effect of different Rcl and met values on the PMV

Building No. as example	Rcl values (m^2K/W) (clo)	Metabolic rate (W/m^2) (met)	PMV value	Metabolic rate (W/m^2) (met)	Rcl values (m^2K/W) (clo)	PMV value
Old building No. (5)	0.095 (0.7)	63.8 (1.1)	2.7	58.15 (1.0)	0.085 (0.6)	2.8
	0.085 (0.6)	63.8 (1.1)	2.7	63.8 (1.1)	0.085 (0.6)	2.7
	0.08 (0.5)	63.8 (1.1)	2.7	70.0 (1.2)	0.085 (0.6)	2.7
New building No. (11)	0.095 (0.7)	63.8 (1.1)	0.5	58.15 (1.0)	0.085 (0.6)	0.1
	0.085 (0.6)	63.8 (1.1)	0.4	63.8 (1.1)	0.085 (0.6)	0.4
	0.08 (0.5)	63.8 (1.1)	0.3	70.0 (1.2)	0.085 (0.6)	0.5

These new values of PMV, as shown in Table 2, suggested that those possible different values of Rcl and metabolic rates had no significant effect. Thermal resistance of the clothing is not important when the temperature differences between the body surface and air is small, and heat loss is mainly by evaporation because the climate is dry.

It is concluded that the PMV values from ISO 7730 still show disagreement with AMV values reported by the occupants in old buildings. However, if in new air-conditioned buildings, PMV values would change by the maximum +0.4 scale value for all conditions. The new values of PMV still show agreement with the AMV values reported by the occupants in new buildings.

5. Conclusions

Full-scale measurements have been carried out involving environmental parameters and human thermal comfort responses from 51 buildings in Ghadames, Libya. These buildings are either naturally ventilated with courtyards or mechanically ventilated with air-conditioning systems. This field survey was conducted in the summer of 1997, representing a typical hot–dry climate in North Africa. It forms the first stage of a research programme investigating the appropriate thermal comfort requirements for such a climate. The following conclusions can be drawn:

1. The PMV model in the form of ISO 7730 [3] cannot be used, without modifications, for predicting the overall thermal comfort of the occupants in old naturally ventilated buildings. However, the ISO 7730 standard can be used to measure human thermal comfort in new air-conditioned buildings without modifications.
2. The overall feeling of the occupants in Ghadames in the summer seasons, reported that they are more satisfied and thermally neutral in old naturally ventilated buildings than in new air-conditioned buildings. In the old buildings, about 54% of the occupants are feeling neutral and 8% are feeling hot, compared to only 15% of the occupants feeling neutral and 33% feeling hot in the new air-conditioned buildings.
3. These modifications would have to address issues related to adaptive effects.

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