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Thermal comfort in urban spaces: a cross-cultural study in the hot arid climate

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Abstract

This cross-cultural research is an inaugural attempt to investigate the outdoor thermal comfort and the effect of cultural and social differences in hot arid climates. Case studies were carefully selected in two different parts of the world (Marrakech in North Africa and Phoenix-Arizona in North America) to represent two different cultures in similar climatic context. Field surveys, carried out during winter and summer, included structured interviews with a standard questionnaire; observations; and microclimatic monitoring. The results demonstrate a wide thermal comfort zone and prevalence of air-conditioning influencing thermal comfort requirements. The work also provides evidence of substantial cross-cultural differences in thermal comfort requirements between residents in Marrakech and Phoenix. It shows that adaptive measures, such as level of clothing, changing place, cold drinks consumption, and thermal experience, varies between cultures and this influences the thermal evaluation of visitors in outdoor spaces in the hot arid climate. Evidence between the time spent in outdoor spaces and thermal expectations has been found. Moreover, environmental variables such as air temperature and solar radiation, have a great impact on the use of the outdoor spaces in the hot arid climate, and may determine the number of people in urban spaces. The study also identified significant differences in thermal comfort requirements between different socio-economic groups, highlighting the need for comfortable open spaces.

Keywords: Outdoor thermal comfort; Culture; Thermal adaptation; Hot arid climate; Urban space.

Introduction

Outdoor public spaces play a significant role in improving public health and wellbeing of people and reduce government expenditure Roberst-Hughes (2013). The demand is greater than before for adequate outdoor public spaces that meet the social, cultural and comfort needs of the increasing population of urban areas. Fulfilling this demand will encourage people to stay longer outdoors socialising, exercising and enjoying nature, hence improving their health and wellbeing.

A considerable number of studies in the hot arid climate (Ali-Toudert and Mayer 2007; Dalman et al. 2011; Krüger et al. 2010; Salizzoni et al. 2011; Shashua-Bar et al. 2004; Tsiros 2010; Yahia and Johansson 2014) have followed the urban climatology and simulation approach where the focal point of the research is likely to be on the interaction between the environmental elements and the physical settings of the space, with fairly little consideration given to the human factor. On the other hand, field surveys, on the whole, are arguably the preferable method for studying the relationship between the spatial behaviour of people and their thermal comfort in outdoors. Makaremi et al. (2012) and Johansson (2006) have highlighted the need for more studies on thermal comfort and human behaviour to be conducted in the hot arid climate, where there has been very limited work. Recent studies in the hot arid climate have utilised field surveys to examine the effect of thermal expectation on

outdoor thermal comfort (Shooshtarian and Rajagopalan 2017), and the effect of urban microclimate on activities (Sharifi et al. 2017), as well as applicability of the range of thermal indices. Some studies have combined field surveys with CFD simulations to study thermal comfort in air-conditioned outdoor spaces (Ghani et al. 2017) and new indices, such as IZA, have been developed particularly for cities in arid climates (Ruiz and Correa 2015).

Initial results by Aljawabra and Nikolopoulou (2009) aimed to develop a better understanding of the complex relationship between the microclimate and human behaviour in open public spaces in hot arid climates, focusing on activities and use of open spaces and the influence of microclimatic parameters, thermal sensation and preference along with the importance of open spaces for people of different socio-cultural backgrounds.

Failed open public spaces can be a result of the lack of understanding of the adaptive opportunities a public space can offer to visitors, and the negligence of cultural and social aspects when designing outdoor public spaces. The current paper proceeds to investigate how people from different cultures in the hot arid climate evaluate their thermal environment along with relationships between microclimatic and comfort conditions. It also seeks to identify adaptive measures influencing thermal comfort, and differences between different socio-economic groups in the hot arid climate.

Materials and methods

Culture can be defined as “The system of information that codes the manner in which people in an organized group, society or nation interact with their social and physical environment.” (Reber 1985). In a previous study that investigated the influence of culture and environmental attitude on participants’ thermal assessment of a square in Sweden and Japan, Knez and Thorsson (2006) defined cultural groups as “two groups of participants visiting the Swedish and the Japanese square, respectively. The two groups were considered as living in two different cultures”. In the current study two cultural groups were selected from countries in different geographical locations, North Africa and North America; different level of development, developing and developed countries; and different dominant values. Hence the groups of participants who were visiting open spaces in Marrakech are representing one culture and those in Phoenix another.

Only people who were sitting or standing in the studied spaces were considered for interviews, since these optional, as opposed to the necessary activities, have a close relationship with the quality of urban open spaces Gehl (1996). Moreover, only local individuals were considered; tourists and other visitors were excluded from the analysis to ensure that the sample represents the local culture of the studied area.

Human Monitoring

People were studied through questionnaire-guided interviews and observations. The questionnaire included four parts (Online Resource 1). The first part investigates the evaluation of different climatic parameters, thermal sensation and preference of subjects. Sensations were evaluated on a 5-pt scale and preferences on a 3-pt scale. The second part investigates potential aspects of physical and psychological adaptation as well as evaluation and use of the space. It also included wider aspects, such as the effect of the climatic context in childhood, recent thermal history, etc. The third part of the questionnaire was designed to evaluate the subject’s socio-economic conditions. Three questions about educational level, job type, and financial abilities (Platt, 2006) were used to rank subjects according to their socio-economic background. Observation data such as age, gender, clothing, etc., were also included.

Environmental Monitoring

The environmental monitoring focused on measuring local air temperature, wind speed, solar radiation and relative humidity and their variation, which directly affect human comfort and behaviour in the study areas. The sensors used (Online Resource 2), selected to conform to ISO 7726 (1985), were fixed on the top of a portable case with the data logger and power supply located inside it. The portable case was placed next to the subjects during the interviews, aiming to monitor the conditions experienced. The microclimatic data were sampled and stored every 10 seconds, an observation form was filled every 30 minutes and interviews were carried out with people according to their presence and willing to participate. The meteorological parameters were also measured almost every 30 minutes at the end of each survey session in the middle of each site to obtain the overall microclimatic reading for use of space analysis.

Study areas

Marrakech is located in the western part of North Africa $31^{\circ}62'N$ $8^{\circ}03'W$, in the area between the dry semi-arid and the dry arid zone and its altitude is 450m. The two sites in Marrakech, park and plaza (Online Resource 3), are located close to the historical Mosque of Al Koutoubia near the centre of the old city of Marrakech. Site (a) Al Koutoubia Garden offers more shaded benches, whereas site (b) Al Koutoubia Plaza has very few number most of which are not shaded. People meeting and talking are the most frequent activities for site (a), while in site (b) people gather predominantly to watch other people and chatting.

Phoenix is located in the Salt River Valley in central Arizona $33^{\circ}26'N$ $112^{\circ}1'W$, in the dry arid climatic zone and its altitude is 342m. Three sites were selected in Phoenix, site (c) Chaparral Park in Scottsdale, site (d) Tempe Beach Park and site (e) Tempe Marketplace in Tempe (Online Resource 2). Sites (c) and (d) are parks, suitable for sports and physical exercises as well as recreational activities (e.g. cycling, jogging, skating, picnics, etc.). Site (c) offers shaded areas and site (d) water-related activities (e.g. fishing, water slides, canoeing, etc.). Site (e), Tempe Marketplace, is a modern outdoor shopping mall, opened in 2007. It was designed to provide visitors with improved microclimatic conditions in the very hot summer. Dates and times in which field surveys were taking place are shown in Online Resource 4.

Results and Discussion

Description of the sample profile

A total of 431 interviews were carried out, 247 in the winter and 182 in the summer, including 86 females and 343 males. In Marrakech, there were 186 interviews in the winter and 117 in the summer, while in Phoenix; there were 65 in the summer and 61 in the winter. The number of interviews in Phoenix was lower than in Marrakech since fewer people were present during the field surveys. The sites studied were used by different age groups and gender (Online Resource 5).

Description of the microclimatic profile

Historical air temperature records of Marrakech and Phoenix for 30 years were obtained from the World Meteorological Organisation for the stations GMMX Marrakech/Ménara and KPHX Phoenix/Sky Harbor International (WMO 2011). The analysis of the climatic files shows that air temperature reaches maximum values in July and minimum in January in both cities. In winter, air temperatures are similar in Marrakech and Phoenix. However, in summer

the mean value of air temperature in Phoenix is around 5°C higher than in Marrakech. Throughout the winter months, from November until early March, Marrakesh gets mild temperatures, with the average high of 18°C; the average low drops below 6°C during this time. During the summer months, late May until September, the temperature in Marrakesh remains high. July is the hottest month of the year, when the temperature climbs to 38°C. In Phoenix, the average high is 20°C and the average low drops below 8°C during winter. During the summer months, the temperature in Phoenix remains high. July is the hottest month of the year, when the temperature climbs to over 39°C. The means of the microclimatic variables measured on site are presented in Online Resource 6.

Cross-cultural evaluation of thermal sensation

Comparing the environmental variables in the two cities

Statistical analysis was employed to identify differences between the environmental variables recorded during the surveys for the two cultural groups, using the independent-sample t-test (Online Resource 7). Comparing the means of air temperature, solar radiation, wind speed, and the relative humidity, the results showed weak differences in the solar radiation intensity S and the relative humidity RH between the two cities in winter. More specifically, Eta squared (η^2), the effect size associated with t-test (Jaccard 1990), of the S and RH were calculated as $\eta^2(S) = 0.09$ ($p < 0.01$) and $\eta^2(RH) = 0.02$ ($p < 0.05$), both indicating a weak association.

In summer, a weak difference was also found between the two cities in wind speed W_s , $\eta^2(W_s) = 0.07$ ($p < 0.01$), while for air temperature T_{air} , the effect size of t-test associated was strong $\eta^2(T_{air}) = 0.21$ ($p < 0.01$). This highlights that most of the environmental variables measured in the two cities were similar, the exception being air temperature in the summer, where there were differences, although this difference was as little as 3°C.

Comparing the subjective thermal evaluation in the two cities

i. The thermal sensation

To examine how the thermal conditions are evaluated in the two cities in the hot arid climate, the subjective thermal evaluations of all the interviewees, in Marrakech and Phoenix, were compared against each other. Chi-square (χ^2) test of independence was conducted seasonally to compare the actual thermal sensation vote (ASV) of the participants in Marrakech and Phoenix.

In winter, the Chi-square test results are $\chi^2(4, N=249) = 33.73$, $p < 0.001$ with the effect size Somers' d was -0.25. In summer, Fisher Exact test was used to meet the Chi-square test assumption requirements; the test results are $\chi^2(4, N=182) = 9.37$, $p < 0.05$ and the effect size Somers' d of 0.21. The effect size of association between ASV and the participants in the two cities was weak in both seasons. The results therefore suggest that people in the Marrakech group evaluated their thermal environment in a different way to the Phoenix group. Considering that no significant differences were found between the main environmental variables monitored in the two cities, it appears that the reason why people evaluated their thermal sensation differently is not due to differences in the environmental variables between the two cities, but other non-environmental factors influence this relationship.

Despite having 40% of participants feeling neutral (ASV=0) towards their thermal environment in Marrakech and 20% in Phoenix (Fig.1), there were 50% of the participants in

Marrakech and 30% in Phoenix who preferred to maintain their thermal conditions (Fig.2). This means that 10% of those who preferred to maintain their thermal conditions in both cities were feeling warmer or cooler than neutral, suggesting the occurrence of adaptation.

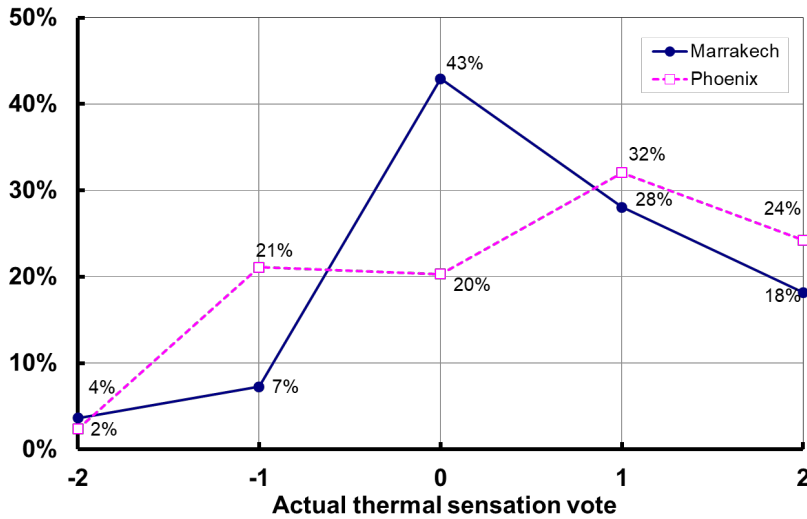


Fig.1 Percentage frequency distribution of actual thermal sensation votes (ASV) in Marrakech and Phoenix. (-2=cold, +1=cool, 0=neither warm nor cool, +1=warm, 2=hot)

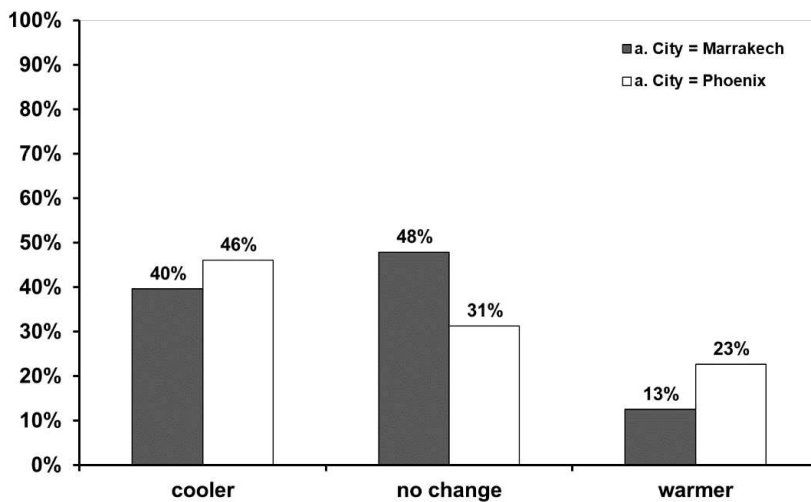


Fig.2 Percentage distribution of votes on the thermal preference scale in Marrakech and in Phoenix

ii. The wind sensation

The results of Chi-square test between the two cities and wind speed are $\chi^2(4, N=431) = 71.68, p < 0.001$ with the effect size Somers' d was 0.24. The effect size of association between wind sensation and the two cities is weak. The t-test results mentioned above indicate weak differences in wind speed measurements between the two groups in Marrakech and Phoenix. Therefore, it appears that people from the two groups have different evaluations of wind sensations.

The analysis of wind sensation scale in Marrakech and Phoenix during the two seasons revealed that the largest percentage of participants in Marrakech, around 40%, felt the wind was neutral, i.e. neither windy nor calm. Alternatively, the largest percentage of participants in Phoenix, around 50%, described it as calm. This explains the weak association between wind sensation and the cultural groups and therefore, the wind sensation is differently evaluated by people in Marrakech and in Phoenix. It is interesting, however, that the wind preferences of participants are similar in both cities. The majority of people in both groups preferred no change in the wind situation (60%) and almost (30%) wanted more wind.

iii. The humidity sensations

The Chi-square test between participants in the two cities and the relative humidity shows that $\chi^2(4, N=431) = 23.64, p < 0.001$ with the effect size of Somers' d being 0.21. The effect size of association of the relative humidity between participants in the two cities is weak. More participants felt dry in Phoenix (40%) compared with Marrakech (20%). The effect of trees and shaded areas in Al Koutoubia Park, where most participants in Marrakech were observed during noon time, could explain this difference.

The relationship between the microclimatic parameters and ASV

To quantify the relative contribution of microclimatic parameters to thermal perception correlation analysis was carried out and complemented by ordinal regression analysis. The results show that T_g, T_{air}, R_H, W_s are correlated with ASV in both cities, hence these variables may be analysed by using the ordinal regression analysis (Online Resource 8). The globe temperature T_g is used as an indicator of solar radiation in addition to air temperature. Moreover, as T_g has the property of reacting to the environment in much the same way as a human person, it is a useful indicator for thermal comfort studies (Nicol 2008). Therefore T_g, R_H, W_s were used in the ordinal regression.

As expected wind speed is negatively correlated with ASV in Marrakech, while a positive correlation was found in Phoenix. This could be attributed to the wind causing warmer wind sensations under high air temperatures in summer, particularly as earlier analysis identified higher mean T_{air} in Phoenix in the summer, although further analysis would be required. Ordinal regression, selected as ASV is an ordinal variable measured using a scale, was performed to predict the criterion variable (ASV). Three variables, globe temperature ($p < 0.001$), wind speed ($p < 0.05$), and the relative humidity ($p < 0.05$) were found to be significant and accounted for almost 23% of the variation in the actual sensation vote (ASV). However, $R^2 = 0.23$ indicates weakness in the ability of the predicted model to fit that data. By comparing Wald values for these variables (predictors), globe temperature T_g (Wald = 14.4, $p < 0.001$) is the most important predictor that influences the actual thermal sensation votes of Marrakech participants followed by wind speed W_s (Wald = 6.86, $p < 0.05$). The outcome model is presented in equation (1)

$$ASV_{Marrakech} = 0.11T_g - 0.71W_s - 0.02RH \quad R^2 = 0.23 \quad \text{eq. (1)}$$

In Phoenix, the ordinal regression shows that there are three significant variables, globe temperature ($p < 0.001$), wind speed ($p < 0.001$), and the relative humidity ($p < 0.05$), which accounted for almost 60% of the variation in the thermal sensation (ASV), (Cox and Snell $R^2 = 0.59$). By comparing Wald values for these variables (predictors), globe temperature T_g (Wald= 50.66, $p < 0.01$) is the most important predictor that influences the actual thermal sensation votes of Phoenix participants. The outcome model is presented in equation (2).

$$ASV_{Phoenix} = 0.30 T_g - 0.89Ws + 0.07RH \quad R^2 = 0.58 \quad \text{eq. (2)}$$

Thermal neutrality and thermal sensitivity

This study sought to identify whether there are any differences in thermal comfort requirements, particularly thermal sensitivity and thermal neutrality, between the different cities in the hot arid climate. Thermal neutrality is defined as the temperature which gives a neutral thermal sensation, i.e. neither warm nor cool (Humphreys 1975), or the thermal index value (temperature) corresponding with a maximum number of people voting neutral on a thermal sensation scale (Brager 1998). The average neutral temperature has been used extensively in thermal comfort research to study the effects of experience on respondents' thermal perception (e.g. Lin (2009)). To calculate the neutral temperatures in the two cities a bundle or a "bin mean thermal sensation vote" was used, rather than the individual actual votes to reduce individual differences, as recommended by De Dear and Brager (2002), Hwang and Lin (2007).

Because of the significance of the globe temperature T_g , as a predictor of thermal sensation in the context of this study, it was used to predict neutral temperature and examine thermal sensitivity. Mean thermal sensation vote responses for each three-degree interval of T_g are presented in Fig.3, with the following fitted regression lines for the two cities including the whole dataset:

$$\text{Marrakech: } ASV = 0.072 \cdot T_g - 1.6 \quad (R^2 = 0.96) \quad \text{eq. (3)}$$

$$\text{Phoenix: } ASV = 0.112 \cdot T_g - 2.7 \quad (R^2 = 0.96) \quad \text{eq. (4)}$$

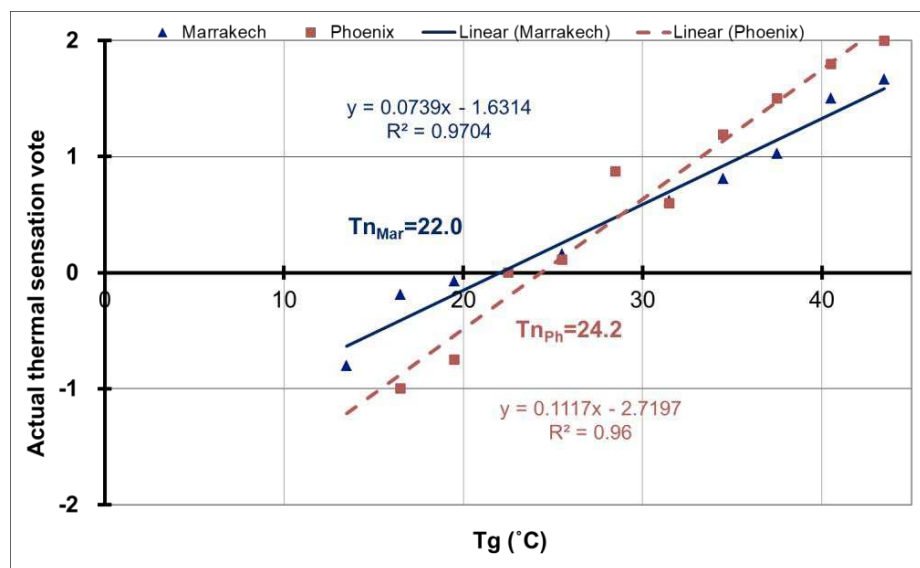


Fig.3 Neutral temperatures calculated using linear regression model for the two cities

From Equations (3) and (4), both thermal sensitivity and degree of adaptation can be investigated. The slope of the fitted lines indicates the thermal sensitivity of subjects; the

lower the value of the slope the less thermally sensitive the participants are. The slope value 0.072 corresponds to 14 °C T_g per sensation unit in Marrakech, while the slope value 0.112, corresponds to 9 °C T_g per sensation unit in Phoenix. This means that people in Marrakech were thermally comfortable at a wider range of T_g , being less sensitive to variations in air temperature and solar radiation than participants in Phoenix. The higher thermal sensitivity in Phoenix may be attributed to the fact be that the majority of participants were indoors just before coming to the open space, which are predominantly air-conditioned spaces, unlike Marrakech, where most indoor spaces are naturally ventilated. In fact, 86% of participants in Phoenix were indoors just before visiting the outdoor space, where they were interviewed, compared to 60% in Marrakech (Online Resource 9).

The neutral temperatures (T_n), calculated using equations (3) and (4) for ASV= 0, are 22.0°C and 24.0°C T_g , for Marrakech and Phoenix respectively. It is noticeable that the neutral temperature for Marrakech is 2°C lower than for Phoenix, which is likely due to the difference in clothing insulation between the two groups (see next section). The results above highlight significant differences in thermal sensitivity and neutrality between the two different cultural groups. This finding together with results of the subjective evaluation of thermal sensation presented earlier confirm that the thermal requirements of people in Marrakech and Phoenix are different despite the similarity in the prevailing climate in both locations.

Thermal adaptation

There is now extensive evidence that people adapt to their environment, and in the context of thermal comfort this enables them to achieve thermal comfort in a wide range of conditions. Nikolopoulou and Steemers (2003) identified three levels of thermal adaptation, physical, physiological, and psychological. The former referred to the changes made, in order to adjust oneself to the environment, or alter the environment to his needs, while the latter referred to the various psychological factors influencing the thermal perception of a space. They also highlighted that these should be viewed as complementary rather than contradictory.

Clothing

An important behaviour to improve thermal comfort is through clothing adjustments. In hot climates, clothing should allow the cooling effect of air movement. For example, a western outfit has a thermal insulation value of 0.3 clo while a North African traditional loose dress in bright colours clo value of up to 0.5 (Clark and Edholm 1985).

It was observed that people in Marrakech tend to wear clothes that cover most of their bodies in winter and in summer for both genders, predominantly due to cultural norms. In Phoenix, on the other hand, people have fewer cultural restrictions on what they wear, particularly in summer e.g. T-shirts, shorts, short skirts, etc. As a result, the level of clothing insulation was significantly higher in Marrakech throughout the year, which was twice as much as the value in Phoenix in winter, i.e. 0.87 and 0.43 clo respectively. The difference in clothing insulation values between the two groups was also significant in summer (Fig.4).

The minimum value of clothing insulation recorded during this study was 0.35 clo at 38°C in Marrakech and 0.25 clo at 39°C in Phoenix. The maximum value of clothing insulation recorded in Marrakech was 0.95 at 12°C while the maximum value of clothing insulation in Phoenix was 0.70 at 5°C (Fig.5).

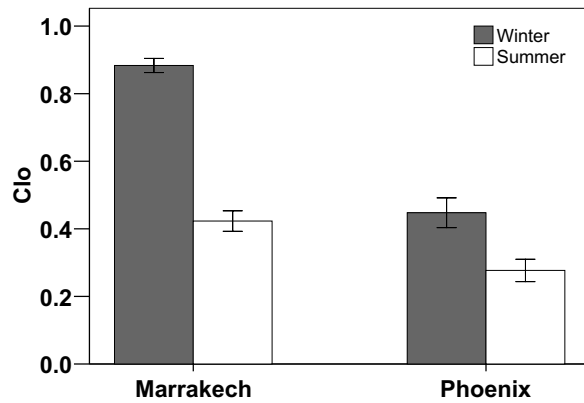


Fig.4 Clothing insulation values of both groups in Marrakech and Phoenix in winter and summer

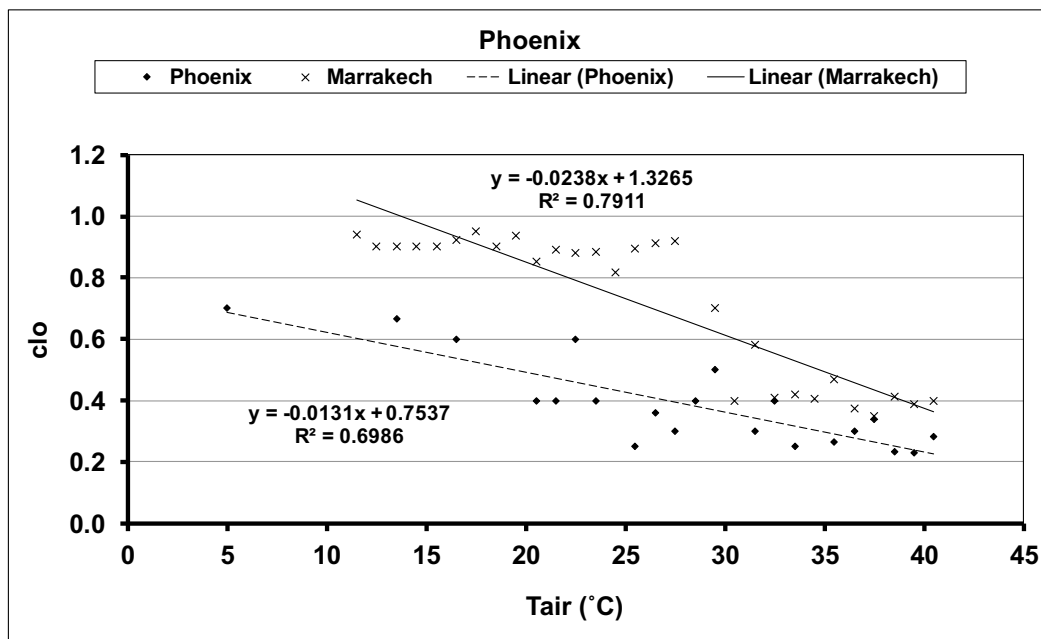


Fig.5 Clothing insulation as a function of air temperature in Marrakech and Phoenix in both seasons.

Changing place

Since very little can be done to mitigate high air temperatures outdoors, people tend to maintain their thermal comfort by reducing the solar gain and moving to shade. Seeking shade can be seen as an adaptive action to reduce the effect of direct solar radiation on their bodies in outdoor environments. Locals tend to avoid sitting in the direct sunlight in Marrakech even in winter, when tourists would sit in the sun.

In winter, 50% of the total number of people in Marrakech were in shade, and the maximum number of people were found when the air temperature was around 19°C. On the other hand, the percentage of people in shade was less than 50% in Phoenix when the temperature was less than 28°C. When the temperature exceeded 28°C, 83% of the people were found in shade. In summer, the percentage of the number of people in shade was always more than 70% of the total number of people in Marrakech. The number of people decreased when the temperature exceeded 37°C. In Phoenix, the number of people appears to be increasing with higher air temperatures. This is due to the high number of people found in Tempe Beach Park, at the water play area in the middle of the day when air temperatures were high. Although the number of people in shade was increasing, the percentage of people who were in shade was less than 50% (Online Resource 10)

Cold drinks

Consuming cold or hot drinks is one way to alter the metabolic rate as a behavioural action to improve thermal comfort (Baker and Standeven 1996). In fact, almost 60% of participants in Phoenix consumed cold drinks, with only 30% in Marrakech. Consumption of cool drinks to reduce metabolic heat is considered as an action of coping with variable thermal comfort and can be related to the long-term experience that people have gained through years of experiencing similar conditions (Nikolopoulou and Steemers (2003). Since people in both cities have experienced similar conditions, the difference in cold drink consumption could be linked to cultural differences. It is unusual to see locals in Marrakech carrying a bottle of water or cold drink. On the other hand, it is typical for people in Phoenix to have water bottles, ice creams and iced soft drinks.

Experience and Expectations

Past experiences influence expectations of the thermal environment (Nikolopoulou and Steemers 2003). When these expectations do not match the actual conditions in an urban open space this can also influence thermal perceptions and consequently the time spent in the outdoor space. The average time spent outdoors by users who considered the weather conditions to be typical for the time of year was longer by about 10% in both cities, compared with the time spent by those who considered the weather atypical (Fig. 6). This indicates that participants’ expectations appear to influence the time they spend in outdoor spaces.

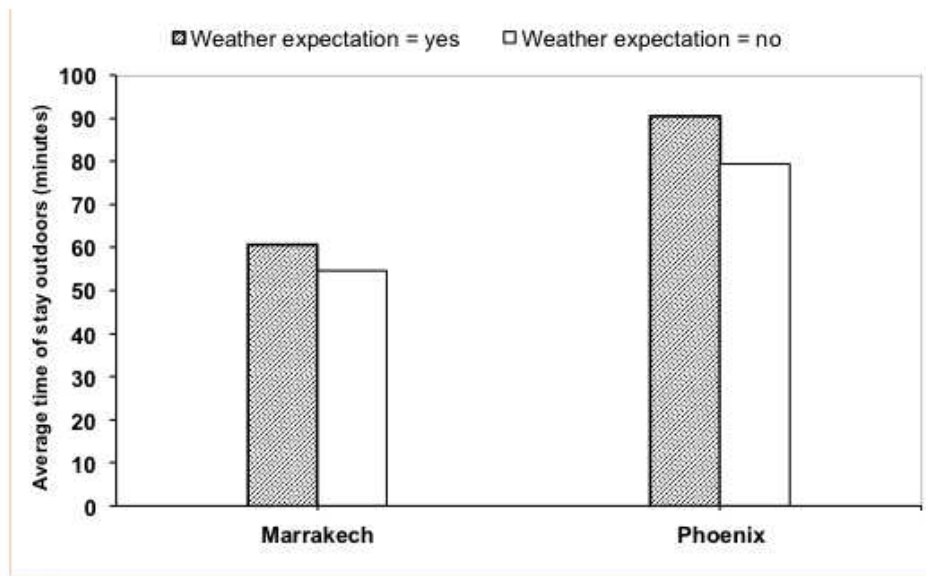


Fig 6 Time spent outdoors for different weather expectations in Marrakech and Phoenix.

Table 1 Seasonal neutral temperatures for Marrakech and Phoenix.

| | T_n winter (°C) | R^2 | T_n summer (°C) | R^2 |
|---------------------------|-------------------|-------|-------------------|-------|
| Marrakech | 19.5 | 0.96 | 25.5 | 0.92 |
| Phoenix | 23.5 | 0.97 | 26.5 | 0.99 |
| ΔT between cities | 1 | | 1 | |

Neutral temperatures can also be viewed as a result of long-term experiences. The differences in neutral temperatures in the different cities were discussed earlier, but it is also worth highlighting seasonal differences. In winter the two groups vary the most with a 4 °C difference, while they had similar thermal neutrality in summer (Table 1). This indicates that participants from the two cities may have similar expectations of weather conditions in summer but not in winter. Since the clothing insulation parameter clo is not accounted for by T_g unlike other thermal indices such as SET^* (Lin et al. 2011), the higher levels of clothing insulation clo in Marrakech, particularly in winter as was mentioned earlier, can also be contributing to the big differences in thermal neutrality between the two groups in winter.

Thermal comfort and socio-economic background

This study also investigated whether socio-economic background can be influencing thermal comfort requirements in the hot arid climate. For that, three factors were chosen to classify subjects into three groups based on their education, job, and self-assessment of their own financial circumstances (Platt, 2006). The “low group” represents individuals with a basic education, who were jobless or had a low income and their financial situation was described as ‘quite or very difficult’. The “high group” consists of people who had a higher education, highly skilled jobs and their financial situation was described as ‘all right’ or ‘living comfortably’. Those in between these two groups were included in the “medium group” (Aljawabra and Nikolopoulou 2010).

Combining the population from the two cities together, the neutral temperatures for the three socio-economic groups were calculated using the fitted equations (3) (4) and (5) when $ASV=0$:

$$\text{High: } ASV = 0.090 \cdot T_g - 2.10 \quad (R^2 = 0.95, p < 0.001) \quad 23.5 \text{ } ^\circ\text{C} \quad \text{eq. (5)}$$

$$\text{Medium: } ASV = 0.065 \cdot T_g - 1.40 \quad (R^2 = 0.84, p < 0.001) \quad 21.5 \text{ } ^\circ\text{C} \quad \text{eq. (6)}$$

$$\text{Low: } ASV = 0.054 \cdot T_g - 1.06 \quad (R^2 = 0.70, p < 0.001) \quad 19.5 \text{ } ^\circ\text{C} \quad \text{eq. (7)}$$

The relevant (T_n) temperatures of high, medium, and low groups were 23.5 °C, 21.5 °C and 19.5 °C T_g . The social group “high” is the most sensitive to the variation in T_g with the slope value of 0.107, corresponding to 9 °C T_g per sensation unit; the “medium” group with the slope value of 0.083, corresponding to 12 °C T_g per sensation unit; and finally, the group labelled “low” with the slope value of 0.054, corresponding to 18 °C T_g per sensation unit. A possible explanation of why people in the lower socio-economic group found to be thermally comfortable at a wider range on the thermal index might be attributed to their life circumstances. For example, participants from the higher socio-economic group were spending their time predominantly in air-conditioned buildings, driving air-conditioned cars. On the contrary those from the lower socio-economic group, reported they cannot afford installing air conditioning units in their dwellings. Instead they escape the undesirable indoor conditions visiting the outdoor public spaces. Having limited options to choose from, people from this group are likely to better tolerate outdoor thermal conditions.

Conclusions

The current study has provided evidence of cross-cultural differences in thermal comfort conditions between residents in Marrakech and Phoenix, similar to differences identified by Thorsson et al. (2007) for Sweden and Japan. As with various studies in outdoor contexts, the results confirmed a wide thermal comfort zone and different types of adaptation enabling this, as it has been demonstrated for temperate (Nikolopoulou and Steemers 2003; Nikolopoulou and Lykoudis 2006) as well as hot-humid climates (Lin 2009; Lin et al 2011). However, there

were significant differences in thermal sensitivity and neutrality between the two cultural groups in Marrakech and Phoenix, and people evaluated their thermal environment differently.

More specifically, people in Marrakech were thermally comfortable at a wider range of temperatures, and they were less sensitive to variations in air temperature and solar radiation than participants in Phoenix. Considering that the main environmental variables were similar in the two cities, the reason for such differences are due to non-environmental factors influencing the participants' thermal evaluation. The higher thermal sensitivity in Phoenix may be attributed to the fact be that the majority of participants are exposed to more air-conditioned spaces, unlike Marrakech, where most indoor spaces are naturally ventilated. This influence of air-conditioning on adaptation was also demonstrated by Yahia and Johansson (2013) in the context of Damascus.

Other forms of adaptation include clothing, which is also an important cultural influence (Yahia and Johansson 2013), with the higher clothing insulation in Marrakesh being responsible for a 2°C lower neutral temperature than for Phoenix. Adaptive measures, such as changing location, with natives in Marrakech found predominantly in shade, and consumption of cools drinks more prevalent in Phoenix, mark further differences between the two cultures.

A notable influence of expectations was also evidenced by the time spent in the outdoor spaces, when comparing the average time spent in Marrakech and Phoenix by those who estimated the weather conditions as typical for the time of year or otherwise. The time spent outdoors by the first group was relatively longer in both cities.

Crucially, significant differences in thermal comfort requirements were found between different socio-economic groups. Subjects in the lower socio-economic group found to be thermally comfortable at a wider range of temperatures compared to the higher socio-economic group. Participants from the lower group often could not afford installing air conditioning units, escaping the undesirable indoor conditions by visiting outdoor public spaces. Having limited options to choose from, people from this group are likely to tolerate outdoor thermal conditions more than individuals who have more mitigating options.

In summary, the work evidenced the importance of understanding cultural differences, through identifying different thermal requirements of people in Marrakech and Phoenix, despite the similarities in the prevailing climate. It also highlighted the societal need for comfortable outdoor open spaces for the wider population not just for recreation but also for survival, particularly for those from lower socio-economic background, which will become even more of a priority with a changing climate.

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