Investigation of outdoor thermal comfort and psychological adaptation in hot-humid climate of Qatar

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Abstract. In the last few years, tremendous changes have taken place in Doha, the capital city of Qatar. These include rapid population growth, great improvements in education, the hosting of international events, and diverse economic development. All of these factors have led to an increase in the number of private cars in the city, leading to significant traffic congestion. To solve this problem, meet the goals of Qatar National Vision (QNV) 2030, and successfully sponsor the FIFA World Cup 2022, the Transport Master Plan for Qatar (TMPQ) 2006-2026 was developed. This includes introduction of a metro and rail system. Most of the people in Qatar have private cars, which they generally consider necessary for door-to-door trips. The currently existing public transportation system is mostly used by blue-collar workers. Therefore, in order to develop a successful public transportation system, it is crucial to examine people's thermal perception of outdoor spaces, particularly in terms of microclimate, and people's adaptive actions in response to Qatar's hot climate. In this research paper, the thermal comfort issue was explored by considering both microclimatic measurements and people's self-described perception of microclimate, as determined via questionnaire. The outcomes of the research reveal that psychological adaptation improves people's thermal tolerance to the outdoor climate in Qatar, so that they are largely able to adapt successfully to the heat. However, the findings also show that people's thermal comfort could be further enhanced through minor modifications to the outdoor environment.

1 Introduction

In the past three decades, Qatar has experienced gigantic changes due to its movement to transform into a global country[1, 2]. As a result of this development, the number of private cars has increased enormously grounding to serious traffic congestion. It is increasingly recognized that in order to accommodate the needs of a growing population, meet the goals of QNV 2030, and host the World Cup 2022; a successful public transportation system is mandatory. Therefore, the metro project evolved and the operation started in 2019[3]. However, People in Qatar are used to door-to-door trips using private cars and labor workers mostly used the previous public transportation system.

The success of the public transportation system is directly linked to the outdoor thermal comfort of users. Owing to the fact, to use the public transportation system passengers are obligated to spend time outdoors (waiting for the next bus, walking from the metro station to the bus stop). Despite the fact that the number of thermal comfort studies has increased in the last few decades. Nevertheless, there is a dearth in thermal comfort studies in Qatar and GCC region. Recent research studies in Qatar have highlighted, that outdoor spaces and streets are not vibrant due to harsh climatic conditions and flaws in the design of the built environment [1, 4, 5]. Consequently, this research paper aims to study the outdoor thermal comfort in Doha city the capital of Qatar, and its impact on the ridership of the newly developed public transportation system.

The term "thermal comfort" has been defined in several ways. Fanger defined the term with respect to environmental and physiological conditions[6]. On the other hand, ASHRAE defined it from the viewpoint, it is not a fixed standard but rather can vary according to social and psychological dimensions[7]. ASHRAE standard have been criticized for their straightforward application of Fanger approach.

The adaptive approach is indispensable in studying outdoor thermal comfort for a number of reasons[8]. First, it is doubtful that the data obtained in laboratory studies can accurately capture the range of real-world experiences. [9, 10] It is also apparent that because people tend to adapt to their local climate, they can often accept different thermal conditions than those that would be predicted solely from laboratory-based thermal models. Therefore, field surveys are crucial in the study of outdoor thermal comfort where users are less able to control the surrounding environment. As a result, users have little choice but to adapt to the prevailing outdoor thermal conditions.

The population living in Qatar is a mixture between locals and multi-nationalities. Consequently, this leads to variations in socioeconomic factors and cultural

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backgrounds. All of the mentioned variables have an impact on thermal comfort and adaptation attitudes. Subsequently, one of the objectives of this paper is study the outdoor thermal comfort and adaptation of various socio-economic groups and its relation to the ridership of PT in Qatar's hot climate.

2 Research Methods

2.1 Study Location

According to Köppen climate classification Qatar climate is hot desert climate. The mean air temperature varies from 14°C to 41°C across the year. Qatar's climate is characterized by three different seasons known as hot, warm and cool as illustrated in figure 1 [11, 12]. To assess people thermal perception in outdoor spaces and its role in the use of public transportation systems field measurements took place during the warm and cool seasons. The hot season was excluded because most of the population travel for vacation in this time of the year.

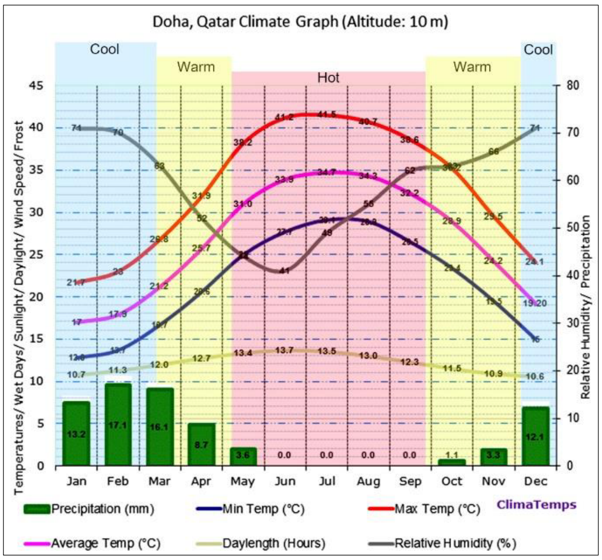

Figure 1: Minimum, average and maximum air temperature, relative humidity, and precipitation over the year in Qatar[13].

Figure 2: Notable features in the vicinity of Al-Aziziyah metro station area, illustrating the station's physical context (Source: developed by Author).

It will be necessary to refer to a specific metro station as a case study, as part of understanding the overall system of public transportation. To this end, the Al-Aziziyah metro station has been selected to serve as case study for this research; for multiple reasons (Figure 2):

a) It's built environment has the same general characteristics as most of metro stations in Doha; it is surrounded by mixed-use land with mostly residential development.
b) It is surrounded by multiple highly appealing destinations including both indoor and outdoor spaces.
c) Aspire Park is adjacent to Villaggio metro station, and was therefore a good location to present questionnaires to non-current users of PT.

Figure 3: Aspire Zone site map including Villaggio Mall, highlighting the locations where people were asked to respond to the questionnaire [14].

2.2 Data Collection

This section explains the methodology used in this research paper, which combines qualitative and quantitative methods. The recent study of thermal comfort focuses on the adaptive approach. The design of this research is based on prediction and causality. Such a design relies on field surveys, considered the most suitable way to study human thermal comfort within a specific climatic zone [15]. Following Nicol[8], a level III field survey took place; this type of survey is considered appropriate to measure both climatic variables and people's responses, and is therefore very useful in studying outdoor thermal comfort. In this research, comparing different groups of users and considering different climatic variables and physical elements leads to the study outcomes that will be presented. The data collected was as follows:

a) Measurements of climatic variables.
b) People's responses to an on-site questionnaire.
c) Observations of other relevant factors like clothing and activity level.

To measure people's thermal comfort in particular outdoor spaces, a combination of physical measurements (objective) and human behavior (subjective) measurements were incorporated, as shown in Figure 4.

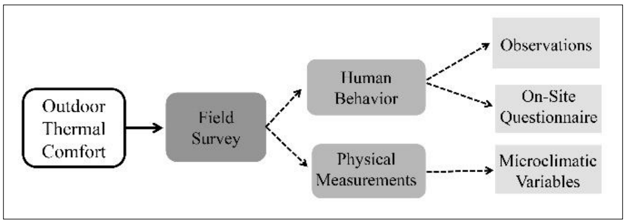

Figure 4: Logical flow of climatic data collection (Source: Author).

To assess users' thermal perceptions, a combination of microclimatic measurements and structured interviews took place. To investigate the climatic conditions, data devices were used during two different seasons; warm season (November 25, 2016 to December 2, 2017), and cool season (December 30, 2016 to January 6 and February 20-22, 2017). The fieldwork was scheduled from 8:00 to 18:00, with measurements taken every two hours to track changes in weather conditions. These times of day were selected because these are times when public transportation is most used.

Microclimatic data was collected by measuring air temperature (Ta), relative humidity (RH), wind speed (W), and mean radiant temperature (MRT) using data loggers. Later this data was used as input into the radiation and bioclimatic model RayMan to calculate the PET. The PET is the main index for thermal comfort assessment, in contrast with the thermal sensation vote (TSV), which is an indicator of human thermal adaptation.

For all measurements, equipment was placed at a height of 1.1 m, corresponding to the center of gravity for typical adults, appropriate in locations where people are expected sit or walk [16]. The PET calculation performed by the radiation and bioclimatic model RayMan used data measured by the two devices shown in Figure 5.

As noted earlier, the questionnaire was right-now-right here collected simultaneously with microclimatic measurement to collect the data used in this study. The questionnaire consisted of three sections: (a) background questions, asking participants about their gender, age, level of education, level of income, occupation, and reason of visit. (b) Thermal perception and thermal preference of air temperature, wind speed, and solar radiation. (c) Previous, current, and future use of PT.

Figure 5: Kestrel 4200 pocket air flow tracker (at left)[17], and EXTECH heat stress meter HT30 (at right) [18].

Data was collected during the same time periods and at the same locations as for the climatic measurements, in order to relate people’s thermal perceptions with the calculated thermal indices. The first step was to choose different samples of potential public transportation users. Therefore, the questionnaire with a 200-sample size was targeted as follows: the first category of respondents, representing 50% of the sample size, consisted of current users of public transportation, while the remaining 50% of respondents consisted of people who do not currently use public transportation. The current PT users were interviewed at a bus stop while waiting for their next bus, and the other respondents were interviewed in the outdoor space of Aspire Park (Figure 2). The questionnaire sample was limited to citizens and residents, temporary visitors were excluded because they would not be expected to have personal memory of Qatar’s climate or an understanding of the cultural background of the country.

According to Gehl [19], people who are standing or sitting are exercising a choice; therefore in the present study, at both studied sites the sample included people who were standing or sitting, in addition to people walking in the park. Both groups were interviewed in an outdoor environment to ensure that their answers would reflect their current thermal perceptions.

Qualitative data was collected through Field observations took place during which photos were taken and notes made; these observations were made to better inform the case study of Al-Aziziyah metro station.

3 Results and Discussion

This section covers findings related to people’s thermal perception of the outdoor climate in two different seasons (warm and cool) in Doha, and focusing on two different groups (current users and non-users of public transportation).

3.1 Thermal Sensation Vote (TSV) and PET

In the questionnaire, participants from both groups were asked about their thermal perceptions, expressed on a scale from -3 (very cold) to +3 (very hot). In order to evaluate the participants’ thermal sensation votes (TSV) Figure 6. In the warm season, 58% of respondents perceived the outdoor climate as neutral (TSV=0). In contrast, during the cool season, most of the participants felt cool (TSV=-2) or slightly cool (TSV=-1), with response rates of 35% and 25% respectively. In the warm season, 97% of the reported TSV values fell into the three central categories (slightly cool= -1, neutral= 0, and slightly warm=1), with the remaining 3% indicating that a few people felt warm. Unlike the warm season, in the cool season the TSV values that fell within the three central categories accounted for 48% of the responses, only about half of the value for the warm season.

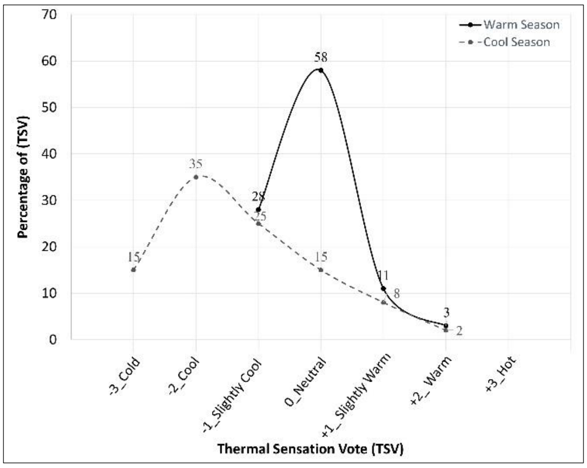

Figure 6: Percentage of responses for each TSV rank in the warm and cool seasons (Source: Author).

The Physiological Equivalent Temperature (PET) was used as a thermal index because, as explained earlier, it was considered the most suitable measure for the purposes of this study. Together with measurements of air temperature, relative humidity, wind speed, and globe temperature, participants' level of activity and amount of clothing were established, as determined via face-to-face questioning. All of these measures were fed as input into the RayMan model to calculate PET values.

The PET values obtained are shown in Table 1 for both the cool and warm seasons. Values during the cool season were as low as 12.4 °C, while the minimum value during the warm season was 21.3 °C.

Table 1: Average values of PET for both seasons (Source: Author).

Day of Measurement	PET(°C)	
	Warm Season	Cool Season
Day 1	21.6	26.6
Day 2	21.3	24.2
Day 3	28.1	21.7
Day 4	26.5	18.1
Day 5	28.1	16.6
Day 6	29.8	12.4
Day 7	29.1	14.1
Day 8	25.9	17.5

3.2 Psychological Adaptation

Thermal adaption plays a fundamental role in users' thermal comfort in outdoor spaces, since adaptation is how the human body attempts to maintain comfort [20]. Moreover, psychological adaptation is believed to have a greater such effect than physiological adaptation. Therefore, this section focuses on psychological adaptation.

3.2.1 Experience Factor

People's attitudes and thought processes are often based on their previous long-term experiences. In this way, people's past environmental exposure will tend to influence their level of adaption to their surrounding environment and influence their perceptions accordingly [21].

To investigate to what extent such influences might be at work in the context of the present study, it was necessary to ascertain at which PET temperatures people feel comfortable during both the warm and cool seasons. To test thermal sensitivity, subjective values -- namely, participants' thermal sensation votes (TSV) -- were compared with objective values of Physiological Equivalent Temperature (PET) using Excel's a "Linear regression analysis" test was performed. For both seasons, the correlation of mean thermal sensation vote (MTSV) with the measured climatic data was assessed in order to calculate the PET, which is described in the following equations:

In the warm season:

$$y = 0.1456\ (PET) - 3.7333 \qquad R^2 = 0.8865 \qquad (1)$$

In the cool season:

$$y = 0.2017\ (PET) - 4.5067 \qquad R^2 = 0.8493 \qquad (2)$$

In the warm season, the value determined for the slope of the fitted line, namely 0.1456, indicates participants' overall thermal sensitivity to PET variables; this in turn indicates that a shift from one sensation category to the next corresponds to approximately 5 °C. The linear regression result indicates that 88.65% of the variation in participants' TSV is explained by the PET. In the cool season, the corresponding linear regression value is 0.2017, and the results there indicate that 84.93% of the variation in participants' thermal sensation is similarly explained, with each category of TSV representing about a 6.8 °C shift as measured by the PET. This difference in results between seasons indicates that participants' thermal sensation tends to be more sensitive during the warm season than in the cool season.

To find out how participants' previous experience influences their thermal sensation in the Al-Waab area, a "neutral temperature" was determined. The neutral temperature is the one at which participants feel thermally neutral, neither too cool nor too warm. To assess the neutral temperature for each season, the just-discussed fitted equations were utilized, considering the cases at which MTSV=0. The neutral temperatures so calculated for the warm and cool seasons were 25.64 °C and 22.3 °C, respectively. This shows that people tolerate higher temperature in the warm season than they do in the cool season.

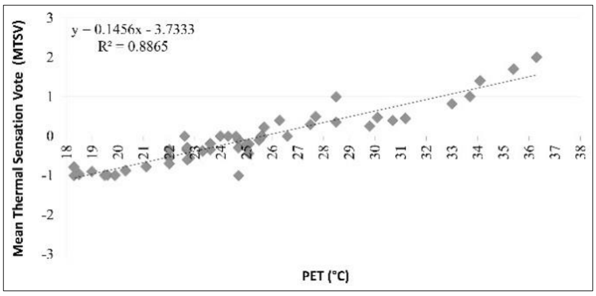

Figure 7: Correlation between PET and TSV, warm season (Source: Author).

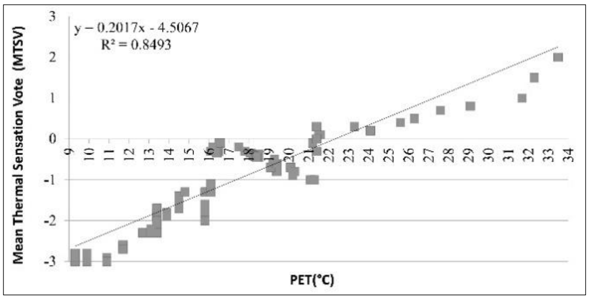

Figure 8: Correlation between PET and TSV, cool season (Source: Author).

These outcomes highlight the fact that people can modify their thermal perceptions according to experience. Because of their previous experiences, they know that in the warm season the air temperature is generally higher than during the cool season [22].

According to ASHRAE Standard 55 (2009), for a thermal condition to be considered acceptable, it should be accepted by at least 80% of users in a specific location [23]. Another concept put forward by Markus and Morris [24], identified the acceptable thermal range as being +0.5 to -0.5 range on the thermal sensation vote scale. As seen in Figures 7 and 8, the acceptable thermal range for the warm season is 22.2 to 29.1 °C, and for the cool season is 19.8 to 24.8 °C. This finding is similar to the one just presented for neutral temperature; the acceptable thermal range for the warm season corresponds to higher temperatures than that of the cool season. Presumably, this again is because of the experience factor. The average acceptable thermal range overall for both seasons, excluding the hot season, is 21 to 26.9 °C PET.

Table 2: Values of PET for different levels of TSV for the warm and cool seasons, based on equations (1) and (2) (Source: Author).

Thermal Sensation	PET (°C)	
	Warm	Cool
-3 Cold	-	7
-2 Cool	12	12
-1 Slightly cool	18	17
0 Neutral	25.6	22.3
1 Slightly warm	32	27.3
2 Warm	39	-
3 Hot	-	-

3.2.2 Expectation Factor

People's thermal perceptions are highly affected by their expectations concerning the surrounding environment [22]. To investigate the effect of expectation on thermal perception, the relationship between people's expectations and objective thermal/environmental variables (air temperature, wind speed, and solar radiation) was studied.

Although most respondents felt thermally comfortable during both seasons, it was nevertheless the case that a good percentage (46%) of them would have preferred a cooler environment during the warm season (Figure 9a). Findings for wind speed were similar (Figure 9b); most participants voiced a preference for no change during both the warm and cool seasons (59% and 54%, respectively), but many did indicate a preference for stronger winds during the warm season (38%) and weaker winds during the cool season (39%). With respect to solar exposure, during the warm and cool seasons, 57% and 73% of the respective participants indicated a preference for no change. During the warm season 39% would have liked less sun, and 18% would have liked more sun during the cool season (Figure 9c).

This variation in environmental factors from season to season affects people's expectations, so that, for example, people tend to voice a preference for less sun exposure and higher wind speeds during the warm season [22, 25].

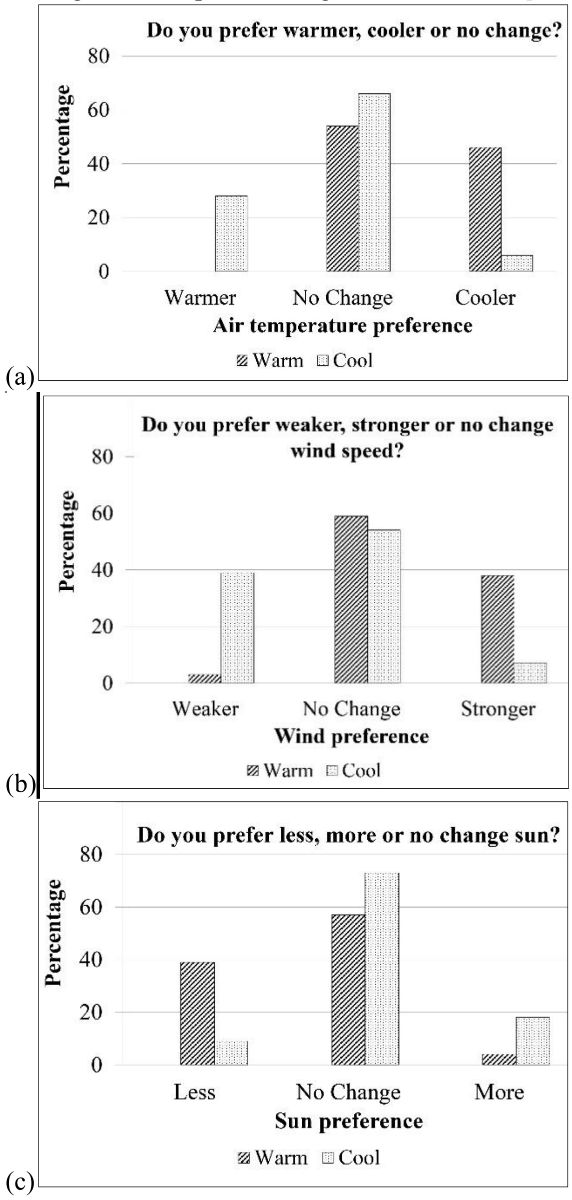

Figure 9: (a) Percentages of votes for air temperature preferences, (b) percentages of votes for wind speed preferences, and (c) percentages of votes for sun exposure preferences (Source: Author).

3.2.3 Perceived Control

Nikolopoulou and Steemers [22] found that people who are able to accept their surrounding environment are able to adapt to a wide range of thermal conditions. For instance, people who live in traditional houses that are naturally ventilated can accept a wider range of thermal comfort because they adjust their neutral temperature according to their experience [26]. To study the impact of perceived control on participants' thermal comfort, an investigation was made of the relationship between (a) their reasons for coming to a particular location, and (b) their thermal satisfaction.

Two groups of people were asked about their thermal status in an outdoor space (Figure 10). The first group of people were in a park, and indicated that they had come to relax and socialize. The second group of people were waiting at a bus stop for the next bus to arrive. To measure people's satisfaction and thermal comfort, a thermal comfort range was specified (21 to 26.9 °C PET), while any temperature outside of that comfort range would be deemed uncomfortable.

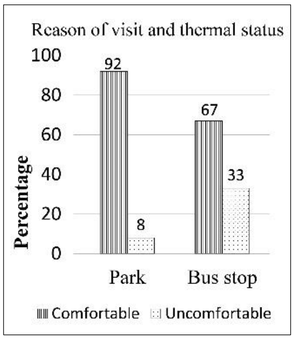

Figure 10: Breakdown of thermal satisfaction responses (comfortable vs. uncomfortable) of users in the park and at the bus stop.

The findings revealed that the largest percentage of people who felt thermally comfortable were those who were in the park (92%); at the bus stop was much lesser (67%). Nikolopoulou and Steemers [22] noted that people's thermal sensations are greatly affected by the reason for their coming to a specific place.

3.3 Socio-Economic Factors

In order to better understand the relationship between the use of public transportation and thermal comfort in outdoor spaces, both subjective data (via climatic measurements) and objective data (via questionnaire) were collected, the latter from two groups of participants (current users and non-users of public transportation). The outcomes of the questionnaire showed that both groups have almost the same thermal perceptions and preferences, so in the analysis presented here, there was no added value in breaking down these outcomes by participant group. However, there was between-group variation in the outcomes for other factors that influence the use of PT; these factors include level of education, income, social class, and cultural background.

The data showed that 72% of current users of PT had a primary or secondary school education level, while 78% of the non-current users held a bachelor's degree (Figure 11). These findings are similar to those related to level of income. The proportions of current PT users reporting a level of income of under 5000 QR were 94%, while among non-current users the response rates for incomes between 10 or over 30 thousand QR were 84% (Figure 12). These results show that level of education and level of income are correlate and that the majority of current PT users have lower levels of education and income than do non-current users of PT.

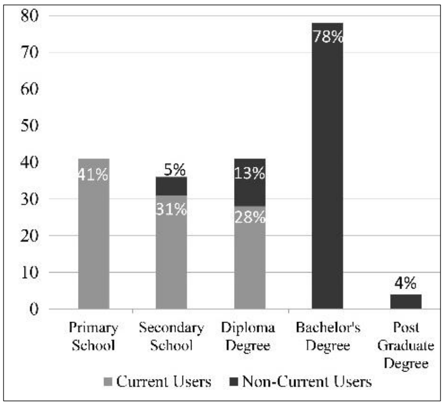

Figure 11: Education level, shown for current users and non-users of public transportation (Source: Author).

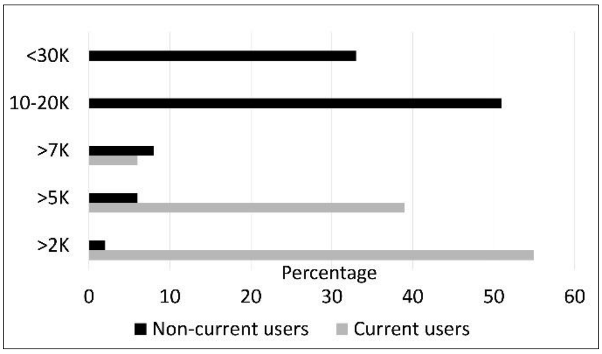

Figure 12: Income levels of current users and non-users of public transportation (Source: Author).

This is because of socioeconomic and cultural aspects that were explored further in the present study by asking people about their experiences using PT abroad. When people were asked if they would use PT in Qatar in the future, when the metro is fully implemented, most current users (67%) responded "yes, all the time," while only 26% of the non-current users made that same response (Figure 13). Interestingly, a greater percentage of non-current users said that they use PT when they travel abroad (44%), while only 8% of current users said the same (Figure 14). Respondents were also asked about their reasons for choosing their usual mode of transit. Most non-current users of PT their choice of private cars to the social status associated with this mode of transport, and to privacy reasons as well. While most of the PT users (73%) explained their choice as being due to their level of income (i.e. not being able to afford owning a private car).

It is clear from this that many people in Doha think that public transportation is designed for low-income people constituting a lower social class. To find out what would make this category of people change their opinion on this matter, they were asked what would encourage them to use PT in the future. As shown in Figure 15, the results showed that the most frequent response (36% of respondents) is that the status associated with being a PT user should be boosted.

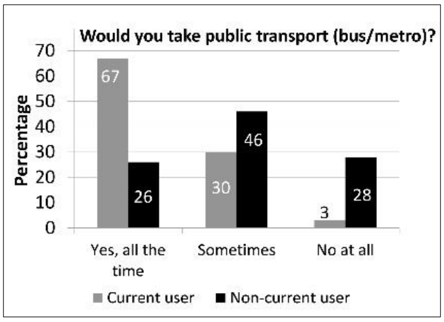

Figure 13: Summary of responses by current users and non-users regarding future use of PT (Source: Author).

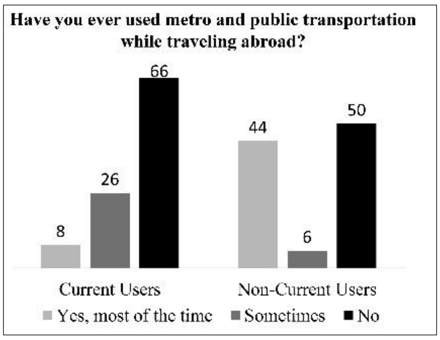

Figure 14: Summary of responses by current users and non-users of PT when asked whether they had ever used public transportation abroad (Source: Author).

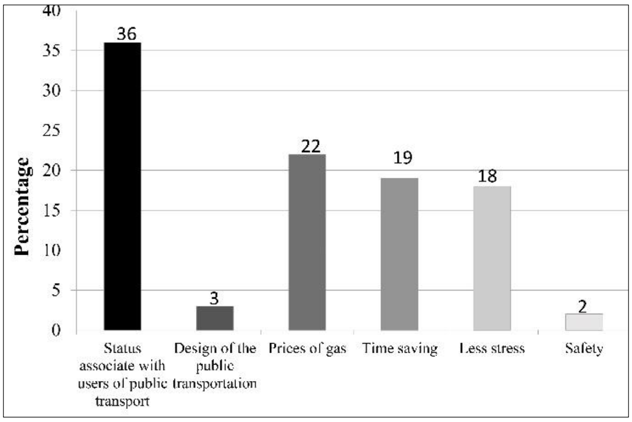

Figure 15: Summary of responses by non- current users of PT, when asked what would change their opinion about using PT in Qatar (Source: Author).

4 Conclusions and Recommendations

This research found that in studying outdoor thermal comfort in a hot arid climate, the physiological approach alone is not enough. The actual thermal sensation votes of users (subjective) were compared with physiological equivalent temperature (PET) values (objective). The outcome shows a lack of consistency between ASV and PET values, showing that heat balance indices alone do not reflect people's thermal preferences in this kind of climate. It has been found that psychological adaptation can prove influential impact on people thermal comfort in the hot arid climate of the studied area (Al-Waab) in Doha.

However, in this research paper another factor was on top of the previously mentioned factors influencing the ridership of PT. This was explored through Data collection of two different groups -- current users and non-users of public transportation. The responses to the questionnaire showed that both groups have almost the same thermal perception and preferences. However, there was variation in other factors that influence the use of public transportation and should therefore be considered; these include level of education, income, social class, and cultural background.

The findings showed that almost 75% of the current users of PT had completed at most a primary or secondary school level of education and had low monthly incomes (less than 5000 QR), while more than 75% of non-current users had obtained at least a bachelor degree and had a monthly income of at least 10,000 QR.

Interestingly, half of the non-current users have used PT abroad and enjoyed the experience. The reason that the non-current users generally prefer to use private cars is that this reflects their social class, while the current PT users indicated that the low cost of using PT suits their income level, and that the current PT network meets their needs. In addition, based on the responses to the questionnaire, the best way to encourage non-current users to change their attitudes about the use of PT is an increase in the status associated with using PT.

Figure 16: David Cameron, former Prime Minister of the United Kingdom, using the London metro (left) [27], and Mark Rutte, Prime Minister of the Netherlands, traveling by bike(right) [28].

How this scenario can be changed? A good example of action taken to encourage people to use PT is when a country's VIPs are seen using the PT system, as this can change preconceptions about the suitability of PT use for all socio-economic groups. For instance, as shown in Figure 16, the former Prime Minister of the United Kingdom, David Cameron, used the London metro to reach his office, and the Prime Minister of the Netherlands, Mark Rutte, mostly travels by bike. Similar role models could help solve the issues associated with social class and PT use in Qatar.

Another remarkable outcome from the Measurements of environmental variables in both the warm and cool seasons yielded PET values for each season were almost 8 °C higher than the acceptable range. Presumably that is why people indicated they would prefer less solar exposure and greater wind speeds during the warm season, and most participants would move to the shade when they felt thermally uncomfortable. This indicates that solar radiation is the most influential environmental variable affecting thermal comfort. From these outcomes, it is suggested that providing shaded walkways and waiting areas is an effective way to improve people's thermal comfort.

Shading can be provided through a high H/W ratio, as well as with vegetation and shading elements. In addition, there have been no trees planted in the studied area to provide shade, and shading devices are not provided.

A good way to solve this problem is by creating vegetation islands acting as shelter corridors. This concept of *vegetation islands* refers to the provision of shaded walkways at specific distances, the effect is similar to what occurs when people run from an area exposed to rain to another which provides shelter.

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