The Use of Newly Developed Public Transportation System in Relation to People's Thermal Perception of Outdoor Climate

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Abstract

In the past decade, Doha the capital city of Qatar has witnessed a massive shift in various fields including economy, education, and sports sector. This flux caused rapid population growth, and as a result have led to an increase in the number of private cars in the city, leading to significant traffic congestion. The Transport Master Plan for Qatar (TMPQ) 2006-2026 included the introduction of a metro and rail system aiming to (1) solve the problem of traffic congestion, (2) meet the goals of Qatar National Vision (QNV) 2030, (3) and successfully sponsor the recently held FIFA World Cup 2022. Most of the people in Qatar have private cars, which they generally consider necessary for door-to-door trips. In addition, the existing public transportation system is mostly used by the lower class. 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 humid climate. In this research paper, the thermal comfort issue was explored by considering both, subjective and objective parameters. The outcomes of the research reveal that people are largely able to adapt successfully to the heat through behavioural adaptation, which improves people's thermal tolerance to the outdoor climate in Qatar. However, the findings indicate that people's thermal comfort could be further enhanced through minor modifications to the outdoor environment including a high Height/Width ratio, provision of vegetation, and shading street furniture.

Keywords: Outdoor thermal comfort; Behavioural adaptation; Hot-arid climate; Public transportation

1 Introduction

The public transportation (PT) system is newly developed in Doha city, the capital of Qatar, where Doha Metro started operations in 2019 supported by an extensive network of infrastructure including buses, taxis, bicycles, and pedestrians. This system was designed as a solution to the issue of high traffic congestion, to meet the goals of Qatar National Vision 2030, and successfully host the world cup 2022 (Shaaban, 2012). However, people in Qatar are used to door-to-door trips with high reliance on private cars use. In addition, it is believed that Qatar's harsh weather conditions would be an impediment to the success of this system, where using PT requires walking and waiting outdoors.

Scholars highlighted that in order to achieve outdoor thermal comfort studying the microclimatic measurements solely is not sufficient as human behavioural adaption plays a fundamental role in the same. The physical microclimatic measurements reflect only 50% of actual sensation votes, and the remaining 50% is identified by human adaptation (Nikolopoulou, 2001; Nikolopoulou, 2006).

Therefore, it is crucial to study both the microclimatic measurements and human adaptation while the relationship between them is "complementary rather than contradictory." The term "adaptive approach" refers to the fact that people may take actions to enhance their thermal comfort level, by making use of more or less clothing or activity, as well as different ways of behaving within the built environment. (Nikolopoulou, 2003; Sugawara, 2008) have specified three measures of thermal adaptation: physical, physiological, and psychological.

Multiple microclimatic studies have focused on how the physical environment would have a positive impact on enhancing people's outdoor thermal comfort in hot climates (Krüger, 2010; Pearlmutter, 2006). This can be achieved if designers considered the following aspects of street design (including aspect ratio, urban geometry, solar orientation, street orientation, shade, and vegetation) (Ali-Toudert, 2006; Giridharan, 2008; Johansson, 2006; Park, 2012; Pearlmutter, 2007; Yang, 2011).

Although, the number of thermal comfort studies has increased in the last few years, still in Qatar the research work in this area is considered humble. Based on the Qatari standards, it is suggested to follow ASHRAE standard in order to achieve thermal comfort yet this is not validated to the local climate of Qatar. It is imperative to mention that, both Fanger's Thermal Comfort Model and ASHRAE standard were criticized by several researchers for being limited to uniform comfort conditions (Indraganti, 2010). To fill the gap in this area, an outdoor field study was conducted in both warm and cool seasons in 2017 in Qatar. The objectives of this paper are to understand: (a) people's thermal perception of the outdoor microclimate in Qatar, (b) people's adaptive actions, (c) the characteristics of the outdoor built environment, and how these aspects would affect the use of PT.

2 Research Method

According to the Köppen-Geiger climate classification, Qatar's climate is considered as the following:

The main climate is arid, the precipitation is desert, and the temperature is hot arid (Kottek, 2006). The mean air temperature across the year is between 14°C and 41°C. Qatar's climate is classified into three seasons: (a) the cool season enduring from December 6 to March 6, (b) the warm season enduring before and after the hot season from March 7 to May 10 and from September 27 to December 5, and (c) the hot season enduring from May 11 to September 26 (Climatemps, 2014; ColumbusTravelMedia., 2016; weatherspark, 2016).

The criteria for selecting the time and location of field measurements were based on fundamental issues. The climatic measurement was performed during the warm and cool seasons, where the hot season was excluded because most of the people travel outside the country at this time of the year. The data collection was scheduled from 8:00 until 18:00 hrs since this is the time most of the people use their cars/ or PT. The location of the field measurements was in Doha the capital of Qatar, in Al-Waab area. This location was chosen because both groups of the studied sample (current users and non-current users) can be studied in close proximity experiencing the same climatic conditions, and the selected metro station has similar characteristics to most metro stations in Doha (surrounded by residential and mixed-use land uses).

The methodology of this research paper consolidates both qualitative and quantitative methods. In order to study outdoor thermal comfort (Nicol, 2008) level III protocol of field studies took place focusing on the adaptive approach and using prediction and causality comparing two different groups of users (Groat, 2002), incorporating physical measurements (objective) and human behaviour (subjective) to grasp the outdoor thermal perception of people in Qatar's hot arid climate and its impact on the use of PT.

2.1 Climatic Variables

Climatic measurements were conducted during warm season (November 25, 2016 to December 2, 2016), and cool season (December 30, 2016 to January 6 and February 20-22, 2017) to investigate the climatic conditions. In order, to track the changes in the weather, the measurements were planned every two hours from 8:00 until 18:00 hrs. Microclimatic data was collected by measuring air temperature (Ta), relative humidity (RH), wind speed (W), and mean radiant temperature (MRT) using data loggers measured by the two devices shown in Figure 1(a). For all measurements, equipment was placed at a height of 1.1 m, corresponding to the centre of gravity for typical adults, appropriately in locations where people are expected to sit or walk (Mayer, 1987). To calculate the PET, the climatic data was used as input into the radiation and bioclimatic model RayMan. 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.

(a) **(b)**

Fig. 1: (a) EXTECH heat stress meter HT30 (Extech Instruments, 2016), and Kestrel 4200 pocket airflow tracker (Kestrel meters, 2016). (b) Site map shows Khalifa International Stadium, Aspire park, and Villagio Mall, locations of questionnaire responses where were collected

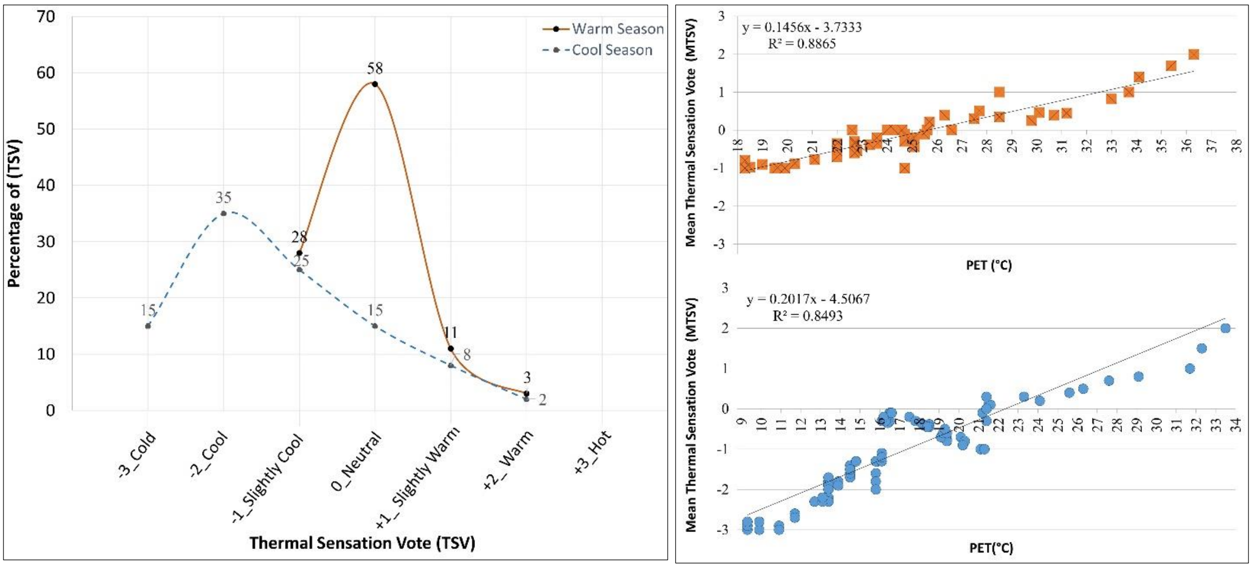
2.2 Questionnaire

Simultaneously with the climatic data measurements, the questionnaire was conducted, at the same time and in the same locations; since it was a right-now-right-here questionnaire, in order to be able to study the relationship between TSV and climatic measurements. The sample size was 200 participants; with two different groups, each constituted 100 responses (current users of PT and non-current users). The current user of PT was interviewed at bus stops and the non-current users were interviewed at Aspire Park (Figure 1(b)). In order to understand if there are any factors that affect the use of PT other than thermal comfort, it was mandatory to interview people in outdoor areas so they express their current thermal status. The sample was limited to citizens and residents who were living in Qatar for the past ten years to ensure that their thermal memory is linked to Qatar's climate. In the questionnaire, people were asked about their thermal status, thermal preference, and their use of PT in the meantime and in the future.

3 Results and Discussion

3.1 Subjective Thermal Responses

In contemplation of evaluating participants' thermal sensation votes (TSV), people from both groups were asked to express their thermal status in warm and cool seasons. Fanger's 7 points scale -3 (very cold) to +3 (very hot) was used to indicate the studied sample's thermal condition (Figure 2(a)). On one hand, in the warm season participants recorded the highest percentage of votes feeling neutral with 58%, and 97% of the votes fall within the three central categories (slightly cool= -1, neutral= 0, and slightly warm=1) on thermal sensation scale. Interestingly, this reflects that most of the people felt comfortable in the warm season. On the other hand, in the cool season the highest votes recorded 35% of feeling cool (-2 on the sensation scale). Unlike the warm season, in the cool season the majority of the votes were skewed to the left on the cooler side of the sensation scale constituting 75% of the votes.



(a) **(b)**

Fig. 2: (a) TSV percentage responses for each season. (b) Correlation between TSV and PET on right top side for warm season and right bottom side for the cool season

For the purpose of identitfying (1) people's thermal senstitivty (TSV) in realtion to Physiological Equivalent Temperature PET values, (2) people's thermal acceptable range, and (3) neutral temperature in both seasons; it was mandotry to perform a coorelation test. Using Excel's "Linear regression analysis," a test was performed. The Mean Thermal Sensation Votes (MTSV) were used as dependent variable, and the PET values served as independent variable, 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.

(Markus, 1980) stated in order to determine the thermal acceptable range it should be indicated as +0.5 to -0.5 range on the thermal sensation vote scale. With the aim of identifying the thermal acceptable range for people in Qatar, the earlier linear regression equation was used. It concludes that, the thermal acceptable range in the warm season is 22.2 to 29.1 °C, and for the cool season is 19.8 to 24.8 °C. This indicates that people tend to tolarate higher temperatures in the warm season than in the cool season. The average acceptable thermal range overall for both seasons, excluding the hot season, is 21 to 26.9 °C PET.

In an effort to compute the neutral temperature (the temperature at which people vote zero on the sensation scale, expressing a feeling of neither too cool nor too warm), we utilize the previous equation– it has been found that, the neutral temperatures for the warm and cool seasons were 25.64 °C and 22.3 °C, respectively. This finding is similar to the previous one where people's neutral temperature tends to be higher in the warm season than in the cool season. This is can be referred to the expectation factor, where people expect that the temperature should be higher in the warm season. Hence, they adapt to higher temperatures in the warm season than in the cool season.

3.2 Behavioural Adaptation

3.2.1 Location in the Environment

(Yao, 2009) stated that human behaviour in a thermal environment is one part of human adaptation process. If a person feels thermally uncomfortable, he or she might make personal, environmental or cultural modifications, which are considered behavioural adaption actions (De Dear, 1998). In the questionnaire, participants were asked about the actions they would take if they felt too hot in an outdoor space, and reactions differing based on gender were noted, as shown in Figure 3. The first clear finding is that most participants of both genders said they would "move to the shade," with response frequencies of 32% for males and 40% for females. This indicates that protection from solar radiation is considered a key means for people to improve their thermal comfort. The second notable finding is that 29% of males would choose to reduce their amount of clothing to adapt to the surrounding environment, while only 5% of females said they would do so. This is presumably due to cultural issues, as women cannot easily reduce their clothing due to the local clothing norms (e.g., they cannot take off their veil).

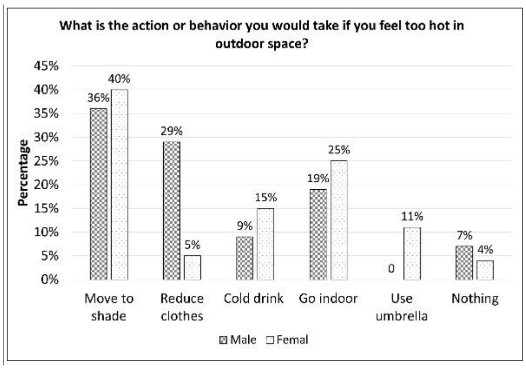


Fig. 3: People's behavior if they felt too hot in case of both genders–males and females

3.2.2 Level of Activity

One part of behavioural adaptation is level of activity, and this has a significant impact on the thermal comfort level of users (Clark, 1985). In order to gauge the influence that participants' level of activity would have on their thermal comfort, the relationship between these two factors was examined. Participants were asked how long they would enjoy walking or waiting (sitting or standing) during the warm or cool seasons. In this way, one can form a picture of how outdoor climate in the region contributes to people's activity level, which in turn is relevant in seeking to understand how people are likely to view the use of PT in Qatar (Figure 4). In the cool season, a slight majority (51%) of respondents said that the time they could comfortably wait for the next bus or metro car to arrive was 20 minutes, while 39% gave the same response during the warm season. This may be due to the impact of seasonal variation as well as people's expectations regarding thermal comfort; participants tended to express more willingness to wait outdoors during the cool season than during the warm season because of their different expectations about each season (Lin, 2009; Nikolopoulou, 2003).

The other tested activity was walking; participants were asked for how long they could enjoy walking in either of the seasons. This set of findings, shown in Figure 4, was consistent with the findings just discussed. Most participants opted for 15 or 20 minutes during both seasons, but during the cool season, people's willingness to walk for a longer period was greater than in the warm season. In the cool season, response rates of 38% and 53% were observed for the respective choices of 15 and 20 minutes as preferable walking times, while during the warm season, the corresponding respective response rates were 46% and 39%. Again, this can be explained by different seasonal expectations. However, comparing the waiting and walking time outcomes reveals that people tolerate staying in outdoor spaces for longer times when they are sitting or standing rather than walking. This shows how different activities have different influences on people's thermal conditions in outdoor spaces.

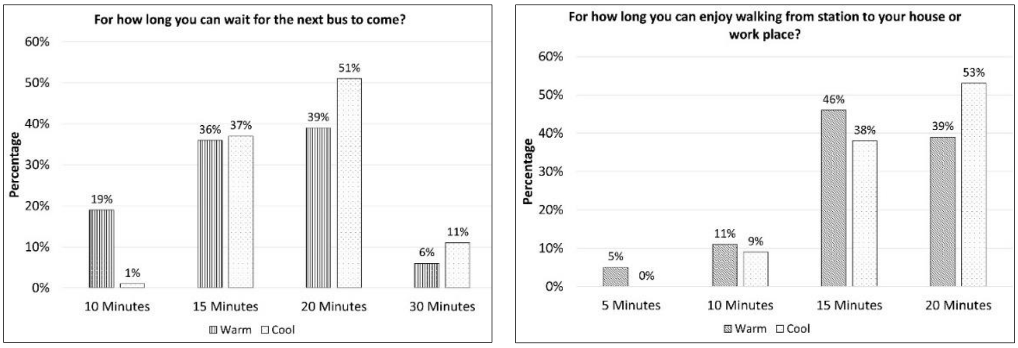


Fig. 4: People's responses regarding the waiting time in outdoors (left), and people's responses regarding their ability of walking duration outdoors (right)

3.3 Physical Built Environment and Better Outdoor Thermal Comfort

Values of PET varied between the warm and cool seasons, with values of 18.4 to 37.3 °C and 9.3 to 33.0 °C, respectively. It is noteworthy that the PET measures exceed the acceptable limit by almost 8 °C during both seasons. People's reactions when they feel uncomfortably hot were also studied; it was found that most respondents would choose to move to the shade in such a situation. This highlights the fact that an influential factor on people's thermal comfort is exposure to solar radiation. This has been found to be the case in a previous study of Qatar's Souq Waqif, where the difference in air temperatures between shaded and unshaded walkways can reach to 10 °C (Alattar, 2015). If shaded walkways are provided, the PET value can be reduced so that it falls into the acceptable range.

Shading in an outdoor area can be provided through a high H/W ratio, as well as by vegetation and other shading elements. In our case study, focusing on Villaggio Metro Station, we found the H/W ratio to be rather low, with a value of about 0.3, so that almost no shade is provided (Figure 5). Regarding vegetation, as yet no trees providing shade in the studied area have been planted. Shading devices have also not been provided. All of the above factors indicate a crucial need for vegetation and shading elements to enhance the microclimate and encourage more users to use the PT system currently being developed. The problems just discussed are evident not only around Al-Waab Street, but rather typical of the streets in Qatar more generally, even in areas with high-rise buildings like the West Bay area of Doha's Central Business District (CBD). Street orientations have generally not been taken into account, and as a result, the shade that these buildings could otherwise provide is essentially wasted, leaving the adjacent streets highly exposed to solar radiation.

A good solution to this problem is the creation of "vegetation islands" which can be used to form sheltered corridors. This concept of vegetation islands refers to the provision of shaded walkways at specifics distances, with these walkways shaded by trees. This can encourage people to spend more time in outdoor spaces and better enjoy walking there, as when people abandon one spot exposed to rain in favour of another which provides shelter.

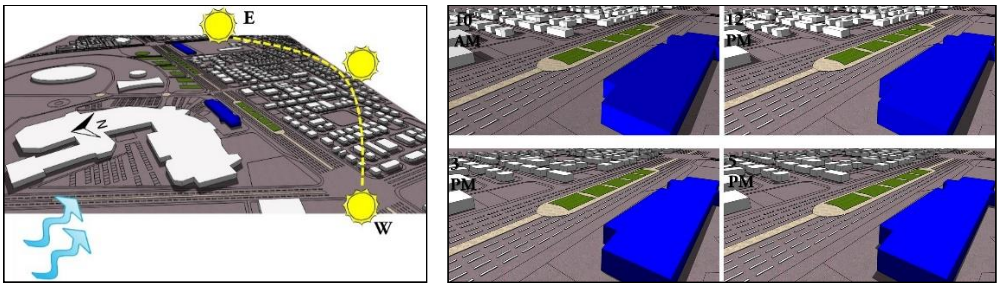


Fig. 5: To the (left), the street orientation of the studied site, to the (right), illustration to the shade and shadow created from the H/W in relation to different times of the day

4 Conclusion

A sample of 200 subjects were involved in outdoor thermal comfort study in Doha, hot arid climate of Qatar. The data collection was conducted during the warm and cool seasons using class III protocol for field study. The aim of this study was to understand if outdoor climatic conditions would be an obstacle to the use of newly developed Public Transportation System.

Following are the conclusions:

1. One of the objectives of this study was to understand people's thermal perception of the outdoor climate in Qatar. People expressed their thermal status using Fanger 7-point scale for both warm and cool seasons. It has been found that people's thermal acceptable 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 indicates that people tend to tolerate higher temperatures in the warm season than in the cool season. The average acceptable thermal range overall for both seasons, excluding the hot season, is 21 to 26.9 °C PET.
2. In addition, the neutral temperatures were identified for the warm and cool seasons 25.64 °C and 22.3 °C, respectively.
3. In order to understand the use of PT in relation to outdoor thermal comfort, people's behavioural adaption was studied. The first aspect was people's location in the environment, people were asked what action they would take if they felt too hot and most responses voted they would move

to the shade. This highlights that solar exposure is considered the most influential issue to achieve thermal comfort. The second aspect is the level of activity, in this case, people were asked about the duration of time they can enjoy waiting or walking in outdoors. Most of the respondents recorded longer waiting and walking times than required for the next bus to arrive or to reach the metro station. This emphasizes the fact that based on people's behavioural adaptation, the microclimatic conditions are not considered an impediment to the use of PT.

4. Interestingly, in accordance with our case study it has been found that the built environment is not well designed. The provision of shade is not considered in all aspects including H/W ratio, urban geometry, shading trees, shading elements, street orientation, and solar orientation.
5. The measured PET values for both warm and cool seasons exceed the thermal acceptable ranges with a value around 8 °C. This means that the PET should be decreased by 8 °C to promote a better outdoor microclimate. A previous study in Souq Waqif in Qatar found variation of 10 °C between shaded and unshaded walkways. This indicates if shade is provided in the studied area (in Doha's streets), the PET values will fall within the thermal comfort range.

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References

Alattar, D., Nafi, S. & Furlan, R. (2015). Built Form of the Souq Waqif in Doha and User's Social Engagement". *American Journal of Sociological Research, 5*(3), 73-88.

Ali-Toudert, F. & Mayer, H. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. *Building and environment, 41*(2), 94-108.

Clark, R. P. & Edholm, O. G. (1985). Man and his thermal environment, pages, Arnold, city.

Climatemps (2014). "Doha, Qatar Climate Graphs", Retrieved November 24 from http://www.qatar.climatemps.com/graph.php

ColumbusTravelMedia (2016). "Qatar Weather, climate and geography", Retrieved November 20 from http://www.worldtravelguide.net/qatar/weather-climate-geography

De Dear, et al. (1998). Developing an adaptive model of thermal comfort and preference/discussion, pages, ASHRAE transactions, city.

Extech Instruments (2016). "Extech Instruments Heat Stress WBGT Meter-HT30", Retrieved December 4 from http://www.homedepot.com/p/Extech-Instruments-Heat-Stress-WBGT-Meter

Giridharan, et al. (2008). Lowering the outdoor temperature in high-rise high-density residential developments of coastal Hong Kong: The vegetation influence. *Building and Environment, 43*(10), 1583-1595.

Groat, L. & Wang, D. (2002). Architectural research methods, pages, Wiley, city.

Indraganti, M. (2010). Behavioural adaptation and the use of environmental controls in summer for thermal comfort in apartments in India. *Energy and Buildings, 42*, 1019–1025.

Johansson, E. (2006). Influence of urban geometry on outdoor thermal comfort in a hot dry climate: a study in Fez, Morocco. *Building and environment, 41*(10), 1326-1338.

KestrelMeters.com (2016). "Kestrel 4200–Discontinued", Retrieved December 4 from https://kestrelmeters.com/products/kestrel-4200-pocket-air-flow-tracker

Kottek, et al. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorol. Z., 15*, 259-263.

Krüger, E., Pearlmutter, D. & Rasia, F. (2010). Evaluating the impact of canyon geometry and orientation on cooling loads in a high-mass building in a hot dry environment. *Applied energy*, *87*(6), 2068-2078.

Lin, T. P. (2009). Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Building and environment, 44*(10), 2017-2026.

Markus, T. A., Morris, E. N. & Reed, P. (1980). Buildings, climate and energy, pages, Pitman, city.

Mayer, H. & Höppe, P. (1987). Thermal comfort of man in different urban environments. T*heoretical and applied climatology, 38*(1), 43-49.

Nicol, J. F. (2008). A handbook of adaptive thermal comfort towards a dynamic model, pages, University of Bath, city.

Nikolopoulou, M., Baker, N. & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar energy*, *70*(3), 227-235.

Nikolopoulou, M. & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: analysis across different European countries. *Building and Environment 41*(11), 1455-1470.

Nikolopoulou, M., & Steemers, K. (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings, 35*(1), 95-101.

Park, M.Et al. (2012). Effect of urban vegetation on outdoor thermal environment: field measurement at a scale model site. *Building and Environment*, *56*, 38-46.

Pearlmutter, D., Berliner, P. & Shaviv, E. (2006). Physical modeling of pedestrian energy exchange within the urban canopy. *Building and Environment*, *41*(6), 783-795.

Pearlmutter, D., Berliner, P. & Shaviv, E. (2007). Urban climatology in arid regions: current research in the Negev desert. I*nternational Journal of Climatology, 27*(14), 1875-1886.

Shaaban, K. & Khalil, R. F. (2012). Proposed policies to support the new metro system in Qatar. *Procedia-Social and Behavioral Sciences*, *48*, 2315-2324.

Sugawara, et al. (2008). How much cool air does an urban green park produce?. Geogr Rep Tokyo Metrop Univ,), Geographical reports of Tokyo Metropolitan University, 43-89.

Weatherspark (2016). "Average Weather For Doha, Qatar", weather spark https://weatherspark.com/averages/32878/Doha-Ad-Dawhah-Qatar

Yang, F., Lau, S. S. & Qian, F. (2011). Urban design to lower summertime outdoor temperatures: An empirical study on high-rise housing in Shanghai. *Building and Environment, 46*(3), 769-785.

Yao, R., Li, B. & Liu, J. (2009). A theoretical adaptive model of thermal comfort–Adaptive Predicted Mean Vote (aPMV). *Building and environment*, *44*(10), 2089-2096.

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