Walking Behavior and Outdoor Thermal Comfort: Case Study –Abu Dhabi-

[1*] M.Sc. **Nassima Mouada**

[1] *Department of Architecture, University of Biskra, Algeria*
E-mail[1]*: nissmouada@gmaail.com*
[2] Pr. **Noureddine Zemmouri**

[2] *Department of Architecture, University of Biskra, Algeria*
E-mail[2]*: pr.zemmouri@gmail.com*
[3] Dr. **Rim Meziani**

[3]*Department of Architecture, Abu Dhabi University*
E-mail[3]*: rim.meziani@adu.ac.ae*

Abstract

The present research will focus on the concept of walkability and it is a relationship with outdoor thermal comfort. The main objective is to evaluate how far a pedestrian might be able to walk before experiencing discomfort in an outdoor environment; the thermal comfort indices used the Physiologically Equivalent Temperature (PET), calculated using Envimet 04 Software. Walking comfort indices used skin wettedness to simulate the physiological of the body that reacts to the environment. The case study located preferably in two different areas, one is a shaded area (garden), and the second one is an urban zone. The methodology adopted is based firstly on field measurement of thermal comfort and secondly on a simulation of the walking comfort of people. The findings from this research were found that shadowing affects walking behavior in Abu Dhabi during the daytime of the hot season.

Keyword: Walking behavior; Outdoor Thermal Comfort; Skin Wittedness; Envimet 04.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), global air temperatures are expected to rise by 0.2°C per decade over the next century. This phenomenon brought with it a host of serious problems, the consequence include increased occurrence of heat stress, especially at night, Moreover, uncomfortably high temperatures inhibit many forms of activity, such as walking, and has become a significant barrier to more active lifestyles. This confirms the role of outdoor thermal comfort on physical activity, measuring the level of outdoor thermal comfort is not simply due to methodological diversity and the combination of a large number of factors that affect the perception of a human. Acknowledging the significance of thermal comfort for people as they use outdoor spaces, numerous studies (Johansson. 2006, Kruger et al., 2013) have set out to investigate the different thermal sensations that can be recorded in various spatial configuration and under different climate conditions. Authors have been calculated a large number of outdoor thermal indices, such as predicted mean vote, operative temperature, mean radiant temperature and physical equivalent temperature. Walking behavior as an issue in outdoor spaces has received increased research attention. Evaluating The quality of walking environment is a difficult process mainly due to the many parameters involved in its assessment, in this context, weather conditions are shown to be the most variable that defines how convenient the area is for walking, in this purpose, the weather is hardly stated in literature that discussed about neighborhood design and walkability. Clark et al., (2013) studied the effect of climate conditions on the walkability, the study was done in Canada, they found that the use of foot as a mode of displacement might be hard to achieve in climate characterized by low temperatures and high amount of precipitation for a long period of the year. Eliasson, (2000) used a questionnaire survey; he found that most of the urban designers did not take into account climatic conditions during the design process of public spaces. Merril et al,. (2003) found that the physical activity has been affected by the season and climate for an adult in the United States.

Eves et al,. (2008) They observed the number of individuals willing to climb stairs or walk at least half of length of moving sidewalk in a hot-humid climate of Hong Kong, they found that the willingness of individuals to climb stairs or walk decreased along with humidity increased (Koerniawan et al, 2014). Brown et al., (1985) stated that solar radiation significantly could increase rates of perceived exertion and discomfort.

This paper seeks to identify design solutions that can mitigate the challenges that climate poses to creating physical activity in outdoor spaces, the city of Abu Dhabi which identifies the typical summertime weather conditions in UAE, this city was selected to be the study area because it contains a wide diversity of urban characterized. It then examines the body’s physiological response to these conditions and offers how far an average adult male can walk while maintaining thermal comfort, we suggested that thermal requirements of people and qualities of microclimate should carefully be considered during the design process of urban spaces. The thermal comfort indices used The Physiologically Equivalent Temperature (PET) calculated using Envimet 04. Walking comfort indices used skin wittedness to simulate the physiological of the body that reacts to the environment.

2. Climate Conditions

Abu Dhabi is geographically located on the north-eastern part of the Persian Gulf in the Arabian Peninsula. The island city is located just 250 meters from the mainland which consists of many other suburbs linked to the emirate. According to the climate data of Abu Dhabi, this city has a hot arid climate. Sunny blue skies can be expected throughout the year. The months of June through September are generally hot and humid with maximum temperatures averaging above 35 °C (95 °F). During this time, sandstorms occur sporadically, in some cases reducing visibility to a few meters. The weather is cooler from November to March. Temperatures range from a low of around 13°C (50°F) on a winter's night to a high of around 42 °C (118°F) on a summer's day. The cooler months, November to April, are the most pleasant time when temperatures are around 24°C (75°F) during the day and 13°C (56°F) at night. However, the dry desert air mixed with the sea breeze and cooler evenings makes it a traditional retreat from the intense summer heat and year-round humidity of the capital city. The average annual rainfall is 75 mm.

Figure 1. Overview of Abu Dhabi city and case study

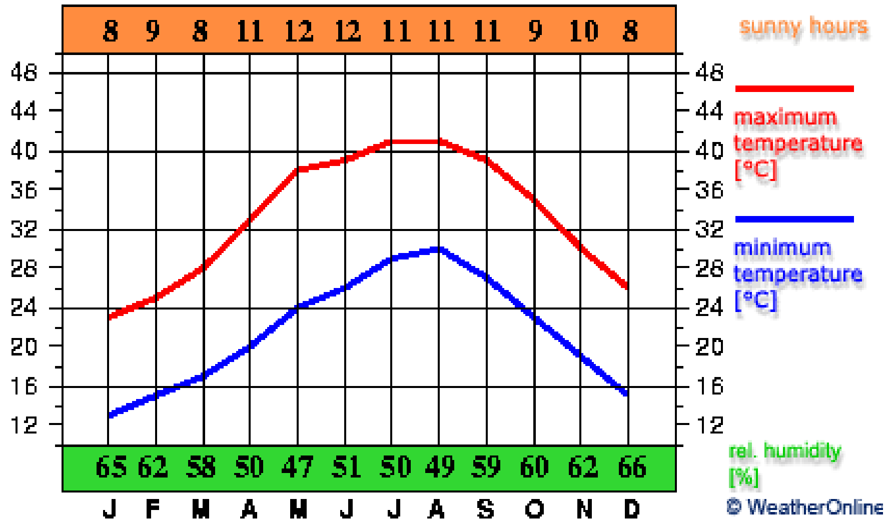


Figure 2. Weather data of Abu Dhabi
Source. www.holiday-weather.com/abu_dhabi

3. Material and Methods

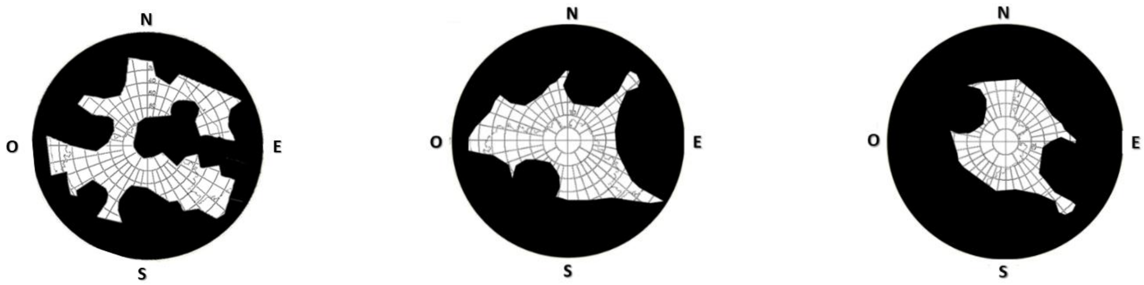
3.1 Measurement location and period

This study was carried out in two urban zones within the center city of Abu Dhabi, the first one is an urban area exposed to the sky and surrounded by buildings, the second one is a park with a large presence of treats and recreational equipment (Alkhalidiha park), this zone has different functions and recreational uses (relaxation, growing useful produce). For each zone, three points were taken as study areas (Fig.3). These points represent the most common types of environments for each zone, and they were particularly selected because they comprise a variety of physical factors, including vegetation and SVF (see Figure 5). It is possible to calculate SVF values using Rayman 1.2, developed by Andreas Matzarakis at the University of Freiberg in Germany. Within these points, we assessed the climate averages for air temperature, humidity, and wind speed in all study areas, focusing in particular on the hours when most trips are made.

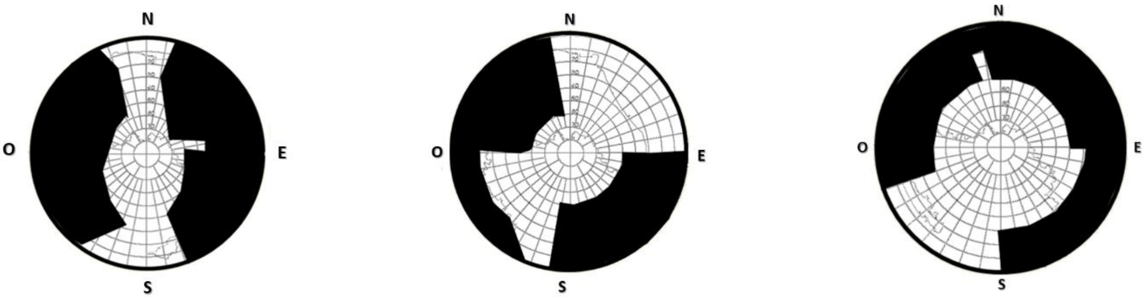
The testing period was mainly concentrated in the summer period when outdoor activity is most difficult due to climatic conditions. The improvement of the outdoor thermal comfort and the production of pleasant outdoor climate conditions contribute substantially to the ability to walk on public spaces and is planning the challenge especially in summer season, during this period of the year as temperatures hot up, we usually recommend increasing vehicle use, passenger vehicles are a major pollution contributor, producing significant amounts of air pollution which can be considered as one of the important reason behind the phenomenon of Urban Heat Island (UHI). The negative effects of UHI would double in the city of Abu Dhabi, especially in the summer season. In addition, thermal comfort represents an essential aspect of physical and psychical satisfaction in an outdoor area; however, there is a significant lack of information on thermal comfort under summer conditions in sub-tropical, arid climate, which in effect will assist the design and planning of such spaces, for these reasons, we have chosen to investigate the outdoor thermal comfort and walkability within this challenging period.

Figure 3. 3D view of the studied areas
Source: http://www.alainproperties.ae

Figure 4. Measurement locations in the two zones



Point 1 (SVF 0, 26) Point 2 (SVF 0, 44) Point 3 (SVF 0, 35)



Point 4 (SVF 0, 54) Point 5 (SVF 0, 63) Point 6 (SVF 0, 72)

Figure 5. Sky view factor for each space

According to the climate data, the summer period in Abu Dhabi is defined based on air temperature at the airport as being between May and September, over this period, Augusts is the hottest month

(Figure.1), the maximum daily temperature consistently exceeded 41,50 °C, during this period the fieldwork was scheduled at 7 am, 13 pm and 8 pm.

3.2 Thermal comfort measurement

In order to provide an accurate assessment of climates impact on thermal comfort, it makes the most sense to examine conditions at the hours' people typically travel during the months in which weather conditions are the most extreme. For this study, I selected three observation hours: 7 a.m., 5 p.m., and a midday hour of 1 p.m. Most thermal comfort calculations required to evaluate that climate data, Mean radiant temperature (MRT) is the most important meteorological parameter affecting human heat balance during sunny weather conditions (Bryan, 2001; Matzarakis, Rutz & Mayer, 2006), other parameters also are important such as : Air temperature , Relative humidity and wind speed , all these values were obtained from simulation processes by using Envimet 04, this numerical tool has proven

to be a reliable tool to simulate urban meteorological under deferent scale level. The simulation was carried out on 15 Augusts 2018. Points were chosen in this study include protected, and opened areas to promote different possibilities of thermal conditions. Shaded areas are those situated in a garden with a high level of vegetation density and low values of SVF. However, the three points situated in an urban residential zone (Point 4, point 5 and point 6) are open to the sky, with high values of SVF varied between (0, 54 and 0, 72). For the assessment of outdoor thermal comfort, PET index based on the balance of energy of the human body was used in this study. The thermal comfort model prompts point scales, from very cold to very hot, combining individual parameters (metabolism and clothing resistance) and environmental parameters mentioned above, the rate of Metabolic energy transformation (work metabolism) based on 93 W/m² for a standing and light activity of walking, the insulation factor of clothing (clo) has been standardized to 0.55.

Table 1. Climate data used in thermal comfort and walkability simulation

	Average values for Garden				**Average values for urban zone**			
	MRT (°C)	Ta (°C)	RH (%)	V (m/s)	MRT (°C)	Ta (°C)	RH (%)	V (m/s)
8 am	34,27	33,55	65.88	0,45	55,80	33,85	61,23	1,02
1 pm	62,02	39,81	63,23	0,71	61,80	37,27	56,98	1,45
5 pm	51,00	37,73	64,78	0,34	62,09	38,35	58,12	0,98

3.3 Walking comfort measurement

In terms of walking, the physiological index of Skin Wittedness is a suitable measurement to calculate walking comfort, it is defined as the ratio of the actual sweating rate to the maximum sweating rate that occurs when the skin is completely wet, and related to the skin temperature that indicates the sensation of comfort and discomfort caused by perspiration ((Koerniawana et al., 2014)), in order to calculate this index, it's important to identify subject surface area (m^2), Clothing units (Clo), and metabolic rate (W/m^2), the equation of Skin Wittedness is derived from (Fukuzawa et al, 2009) :

$$W= (Qmax/Qemax) + 0, 06 \quad \ldots \quad (1)$$

Qemax: is the maximal evaporative capacity of the environment (W/m^2)

Qmax: is required evaporative heat loss (W/m^2).

As mentioned by Hongo., (2009), 0.3 of wittedness is the limit condition of thermal comfort in the whole body; the thermal discomfort would progressively increase when the value of whiteness reaches 0.3-0.05. (Havenith, et al, 2002) confirmed that the comfortable of walkability based on skin wittedness is reliant on activity level when w is less than 0.0012 M (metabolic rate) + 0.15. The simulated average of emirate people which was met on location, i.e. male; tall 170 cm; and weights 70 kg, Clo (Clothing value) is 0.45 for all simulations, and activity (metabolic rate) is walking/light activity (93 w/m2) equal to 100 m/s, according to de Dear's calculator, the distance of walkability in all spaces can be calculated by using de Dear's calculator to calculate Qsw and Tsk values, and equation available at http://www.sportsci.org/jour/0003/ka.html to calculate Qemax, after that it was achievable to simulate skin wittedness (w) in every minute using Equation 1. The every minute result values were compared with 0.3 as the thermal comfort limitation by (Havenith et al., Parsons 2002).

4. Result and Discussion

4.1 Microclimatic variation

Analysis of the results showed microclimatic differences between the two zones (urban and garden). For air temperature (Tai) and Mean radiant temperature (MRT), the values in the garden were considerably lower than the urban zone, where the average air temperature varied between 34 °C and 36 °C, cooler than the urban environment by 0,5 °C and 2.10°C respectively.

The average MRT varied between 48°C and 50°C. This is mainly because of the combined effect of the SVF and vegetation density. In fact, the high levels of vegetation density and the low level of opening to the sky in the garden were reported to have resulted in a reduction of both incoming and outgoing solar radiation, leading to a considerable reduction of temperature values and MRT Results also illustrate that the highest values of relative humidity were recorded in the garden, reaching 63,60%, which is due to shading by trees combined with the cooling effect of evapotranspiration processes, whereas the lowest values of relative humidity were noted in the urban environment (point 4 point 6), due to the lack of vegetation (Table.2).

For the wind speed, the values are negatively affected by SVF. It is notable that all spaces with high SVF (point 4, point 5 and Point 6) recorded higher values of wind speed, varying between 0.89 m/s and 1.90 m/s.

Table 2. Climate data for all studied points

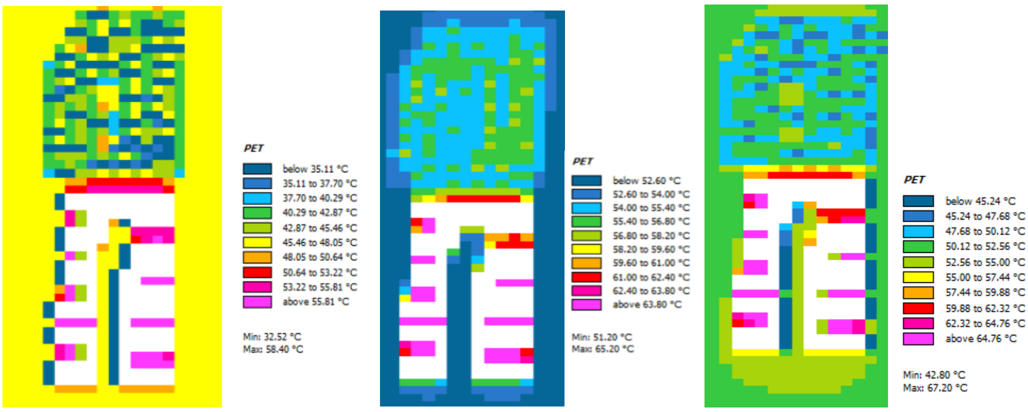
Location	Point	MRT (°C)	Ta (°C)	RH (%)	V (m/s)
Urban zone	Point 1	48,46	36,95	63,60	0,70
	Point 2	47,88	34,01	65,17	0,20
	Point 3	50,98	35,13	63,53	0,92
Garden	Point 4	62,52	36,45	60,36	1,90
	Point 5	62,71	38,54	58,69	0,89
	Point 6	61,71	37,47	57,78	0,99

4.2 Thermal Comfort

The thermal comfort model prompts point scales, from very cold to very hot. According to Lin et al, (2008) the value of 30°C for PET index represents the range of acceptable conditions in Subtropical Regions, This value can be used as the baseline in assessing the outdoor thermal comfort in all studied areas (Figure 6). Results revealed that the highest value of 57 °C was detected in the point 6 at 1 pm, whereas a minimum value of 30 °C was found in point 2 at 8 am. The results show that the highest values were noted at 1 pm, and the lowest values were found at 8 am.

Analysis of the results demonstrates that all measurement points in the garden are thermally comfortable at 8:00, which can be explained by the combined effect of low air temperature and MRT due to decreasing of SVF and the cooling effect of trees. However, the average values of the PET index are higher in all spaces with a high level of SVF. Consequently, these spaces are more exposed to solar radiation, which has a negative effect on MRT and PET index.

Through these results, it can be seen that all spaces situated in the garden are less stressful than the outdoor urban spaces of the urban zone; sufficient shading in the garden is the main reason behind the higher satisfaction of thermal conditions.



8 am **1pm** **5 pm**

Figure 6. Simulated results of PET index.

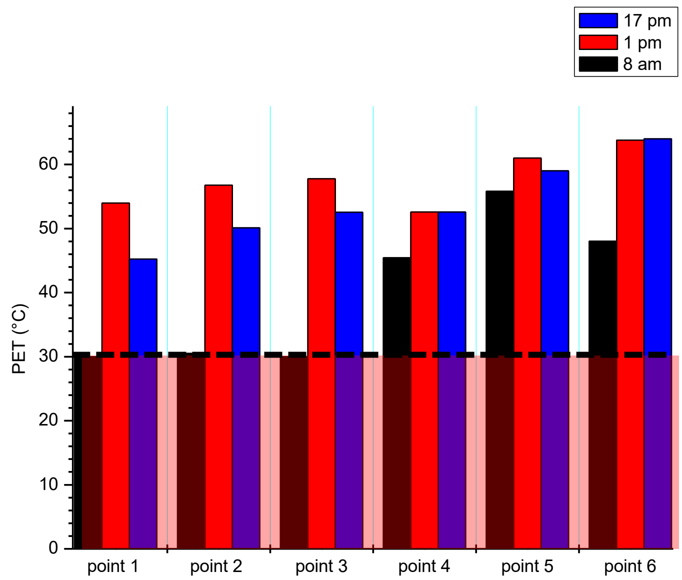


Figure 7. The result of PET index and comfortable value

4.3 Walking Comfort

All calculations assumed a male subject with a body surface area of 1.90 m², wearing clothing with a value of 0.55 (clo), and walking at a metabolic rate of 100 W/m². The air temperature, mean radiant temperature, relative humidity, and wind speed combinations used for each environment, and time are shown in Table.1. The result of walkability simulation shown in Table.2. Results show that the summer climate conditions in Abu Dhabi make walkability difficult. In the urban environment with no trees, the average adult male would experience uncomfortable skin wittedness in fewer than five minutes if walking normally affected at 8 am, in this time, comfortable walking time was five minutes, corresponding to a distance of 402 meters. Meanwhile, in the shaded areas (garden), in the morning,

people could walk about 804 m, and comfortable walking time was ten minutes. It is clear that the dense trees of the garden increased the walking time to 5 minutes, this, in turn, expanded the comfortable walking distance to 400 meters. The lowest walking time values are found at 1 p.m when the director solar radiation is more intense, this leads to increasing the ambient air temperature and the average mean radiant temperature of all tested areas. However, the shade created by trees in the garden adds just a two-minute improvement. At this time, people can walk more than 480 m
in the shaded areas. In 5 p.m. people could walk 723, 6 m in the garden, they feel uncomfortable after nine minutes. However, in the no treatment areas, they cannot walk more than 402 m before they feel discomfort.

Table.3 Result of Walkability calculation

07 am walking distance threshold values			
	Minutes where W ≤ 0,33	Walking distance in comfort W ≤ 0,33	W value at 5 minutes
Garden	10	804	0,26
Urban Zone	5	402	0,39
1 pm walking distance threshold values			
Garden	6	482,4	0,29
Urban Zone	4	321,6	0,34
5 pm walking distance threshold values			
Garden	9	723,6	0,30
Urban Zone	5	402	0,33

5. Conclusion

The findings from this research depicted that the average values of PET in the selected points were uncomfortable (PET > 30°C). However, the comfort condition occurred at 8 am. All area with the shaded of the trees is the location can be tolerated as the location most comfortable because the high wind speed was not hindered by the buildings and had the longer thermal acceptable period the uncomfortable condition occurred in 13.00 when the PET value reached its peak in 63°C while the location amongst the buildings with the high MRT occurred from the heat trapped amongst the buildings in the night time and made the temperature rise quickly in the morning (8 am) (Koerniawan et al, 2014).

In terms of walkability, results clearly proved that shade of trees has a significant impact on walking distance, in all measurement times; shaded areas contributed to reducing the skin wettedness values after five minutes of walking. This strategy of protection helps also to increase the amount of time before Skin wettedness reached the value of 0.33, which lead to creating the longest distance of comfortable walking. This result agrees well with another study, conducted by (Devo, 2011) in Miami, the Author examined the body 's physiological response to climate conditions of Miami, he found that Shadow is the main issue that makes the walking more comfortable.

Finally, in order to introduce the walking behavior as the main form of everyday travel over short distances Abu Dhabi city, it is recommended that design guidelines be applied to support all strategies of natural or artificial shadow which are more relevant to the explanation of the flow of people present in outdoor public spaces

References

Brown, S. L. & F. W. Bannister. (1985). Thermoregulation during prolonged actual and laboratory simulated bicycling. *European Journal of Applied Physiology*, 54, 125-130.

Dear R, de Dear's calculator". http://web.arch.usyd.edu.au/~rdedear/

DeVau, M. 2011, "Strategies to Address the Climatic Barriers to Walkable, Transit-Oriented Communities in Florida", Georgia Institute of Technology School of City and Regional Planning, Master Thesis, 46.

DeVeau, M. (2011). Strategies to address the climatic barriers to walkable, transit-oriented communities in Florida. SCRP Master's Thesis, Georgia Institute of Technology, School of City and Regional Planning, Atlanta, GA.

Eliasson, I., (2000) 'The use of climate knowledge in urban planning', *International Journal of Landscape and Urban Planning*, 48(1-2), 31-44.

Eves, F., Masters, R., McManus, A. Leung, A., Wong, P., & White, M. (2008). *Medicine & Science in Sport & Exercise*, 965-971.

Ewing, R., Handy, S., Brownson, R., Clemente, O. & Winston, E. (2006). Identifying and measuring urban design qualities related to walkability. *Journal of Physical Activity and Health*, 3(Suppl 1), S223-S239.

Hartog and Havenith 2009. "Analytical Study of the Heat Loss Attenuation by Clothing on Thermal Manikins Under Radiative Heat Loads". *International Journal of Occupational Safety and Ergonomics (JOSE)* 2010, Vol. 16, No. 2, 245–261.

Intergovernmental Panel on Climate Change (IPCC) Plenary XXVII (2007) Climate Change: Synthesis Report.

Johansson E., and Emmanuel R., (2006) 'The Influence of Urban Design on Outdoor Thermal Comfort In The Hot, Humid City Of Colombo, Sri Lanka', *International Journal of Biometeorology* (2006) 51:119-133.

Koerniawan, MD., 2014. "Thermal Comfort and Walkability In Three biggest Jakarta's Theme Parks" Unpublished manuscript, last modified January 28, 2014.

Krüger, E., Drach, P., Emmanuel, R. and Corbella, A. (2013) 'Assessment of daytime outdoor comfort levels in and outside the urban area of Glasgow, UK'. *International Journal of Biometeorology*, 57, 521-533.

Merrill, R., Shields, E., White, G., & Druce, D. (2003). Climate conditions and physical activity in the United States. *American Journal of Health Behavior*, 29, 371-381.