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Thesis: Assessment on outdoor thermal comfort conditions in the capital Phnom Penh

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Summary

Thermal microclimate in cities has been noticeably changed due to the rapidity of urbanization and climate change. The thermal alteration in the built environment of cities results in a number of urban problems linked with human well-being. Since heat stress is one of the serious environmental threats to human health, it can leave urban communities at a risky threshold. In particular, cities located in the hot-humid climate are more vulnerable to the mounting thermal conditions. Nonetheless, outdoor thermal conditions in the tropical climate have not been fully observed. There is much need for investigation focusing on both physiological and psychological influences to determine thermal environments on the micro-scale.

The main aim of this present study is to understand outdoor thermal conditions in the tropical climate of Phnom Penh. The investigation of outdoor thermal comfort was performed through the Physiologically Equivalent Temperature (PET) index based upon the measurement of climatic parameters. Simultaneously, a questionnaire survey was utilized to capture psychological perception with response to thermal conditions. The field survey was conducted in three different types of outdoor spaces in Phnom Penh to observe thermal circumstances. one is a low-rise area adjacent to a river with fewer shades, second is a medium-rise area and the last is a high-rise area.

Depending to the PET calculation, the results represent very low thermal comfort in the outdoor environment of the city while strong and extreme heat stress occurred all the time during the survey period. The thermal conditions far exceeded the comfortable range. Among all climatic parameters, solar radiation has the strongest influence on the physiologically thermal comfort level in the outdoor environment. Even though under the hot temperature outside, the thermal condition is still acceptable according to the psychological responses of participating outdoor users. Furthermore, the study indicates a major difference between thermal conditions from the physiological index and the psychological responses. Greater tolerance of the outdoor users to the hot environment is found, in comparison with the physiological outcomes. Besides the climate effect on the outdoor thermal comfort level, the study also shows a significant influence of physical adaptation. The proper characteristics of spatial setup are able to mitigate the individual thermal comfort. Finally, the study gives some recommendations for better outdoor thermal conditions in order to enhance urban life and promote outdoor activities in hot-humid environments.

Keywords

Outdoor thermal comfort, climatic parameters, physical adaptation, psychological perception

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Abbreviations

AT	Apparent Temperature
IHS	Institute of Housing and Urban Development Studies
MRT	Mean Radiant Temperature
Out-SET	Standard Effective Temperature for Outdoor
PET	Physiologically Equivalent Temperature
RH	Relative Humidity
SET	Standard Effective Temperature for Outdoor
SPSS	Statistical Package for Social Sciences
THI	Temperature-Humidity Discomfort Index
UHI	Urban Heat Island
UTCI	Universal Thermal Climate Index

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Chapter 1: Introduction

1.1 Background Information

The world today has undergone high rates of urbanization process, especially taking place in the developing world such as Asia and Africa. More than half of the total world population is dwelling in cities and towns in 2018, accelerating from 30 percent in 1950. Significantly, an urbanization report (United Nations, 2019) projected that the proportion would surge to 68 percent by 2050, with different urbanization levels according to particular geographic regions. Align with the accelerating of human movement from rural to urban, demands for housing, physical and social infrastructure, and industrial activities are spiking. This emerging phenomenon has changed microclimate patterns in metropolitan and urban areas.

Without proper development plans that critically consider promoting mitigation and adaptation actions, the altering phenomenon gradually results in several consequences for the urban environment (Revi and Satterthwait, 2014). The process of urbanization drastically modifies natural landscapes to urban landscapes such as roads, buildings and also supporting infrastructure. That is a remarkable development in changing urban climate that the temperatures in urban centres become different from their surroundings and rural areas (Oke, 1982) and this thermal occurrence is well-known as the formation of urban heat island (UHI). Heat island is identified as one of the most serious concerns during the rapid pace of urbanization and expansion as it causes heat stresses in built environments. The comfort of urban life, both indoor and outdoor, and liveability of urban centres could be exacerbated by higher urban temperatures (Shahmohamadi et al., 2011). Discomfort and disruption as consequences of warmer temperatures will place urban communities at higher risks in terms of increasing health concern and mortality rates, particularly elderly people and outdoor workers. Attempting to better understanding such severe consequences of urban heat on humans, this study aims at understanding outdoor thermal conditions by observing climatic parameters and gathering psychological perception.

1.2 Problem Statement

Phnom Penh, the largest and fastest growing city in Cambodia, acts as a gateway connecting to the regional and global economy. It transformed from a destructed city after civil wars to a hub of rapid urbanization and dynamic economic development (World Bank, 2017). Urbanization in Phnom Penh has grown considerably on both dimensions, horizontal and vertical. Phnom Penh's the rapidity of urbanization has spatially broadened to include surrounding areas, with a double increase of land area in 2010. Due to domestic growth and rural-urban migration, the population living in the city increased triple from 567,860 to 1,688,040 between 1998 and 2013 (UNFPA, 2014), and half of a decade later it peaked to above 2 million inhabitants (NIS, 2019).

The rapid and haphazard accumulation of people in Phnom Penh contributes to environmental deterioration, which in turn affects the city livelihood and welfare of urban dwellers (UNFPA, 2014). This accelerated growth causes a significant rise in land use modification, vehicular congestion, energy consumption and manufacturing activities. In fact, blue spaces (natural reservoirs)—which contribute to cooling effect—within the city have been filled for development purposes over the last 10 years, being replaced by buildings, roads, etc. Not only increasing extreme events like flash flooding, but it also makes this emerging city build a stronger capacity holding energy radiation in the urban structure, warmer than rural counterparts. Another consequence due to a little emphasis on the local environment in the planning process is the lack of green and open spaces across the city. While the city vibrant, yet there is a notice that green colour has been eliminated substantially from this urbanized space (David, 2014). Between 1997 and 2014, over six thousand hectares of arable and vegetated areas were converted to other types of land use despite the tripling expansion of built-up areas. Meanwhile, air pollution is also a major concern of the city as it is attributed to the rapid growth of anthropogenic activities and especially private vehicles (UNFPA, 2014). On the other hand, while the overall climate of the country is predicted a massive temperature rise attributing to global warming, within the annual range between 28.7 ^{O}C and 30.7 ^{O}C in the last 21st century, urban changes as a result of the urbanization process inevitably deteriorate the microclimate severely. It poses warmer temperatures than those of suburban and rural areas, in which the general climate is already temperate. A study from Furuuchi et al. (2006) determining the local temperature distribution found the existence of the urban heat island effect in the Phnom Penh neighbourhood, with the UHI intensity 4.6 ^{O}C comparing with the southern periphery. The elevated temperatures in the urban canopy may negative affect outdoor thermal comfort of its dwellers. Although Furruchi et al.'s finding provides the empirical evidence of elevated urban temperatures, the study did not further investigate how the warmer environment on the micro-scale affect human thermal comfort and sensation in the city centre.

For many years, numerous studies have been investigating outdoor thermal comfort in different urban spaces and climates based on the evaluation of micro-meteorological circumstances. In this regard, several thermal indices have been created to determine indoor and outdoor thermal comfort based on energy fluxes (Makaremi et al., 2012). Out Standard Effective Temperature (OUT-SET) and Physiologically Equivalent Temperature (PET) indices were essentially built for outdoor thermal comfort measurements, whereas previous studies have indicated that PET is the most applicable for assessing thermal comfort within outdoor spaces (Honjo, 2009; Johansson and Emmanuel, 2006). But most studies stressing on urban thermal comfort have been based only on these automatic physiological results, ignoring the subjective thermal perceptions of individuals which is very important to express the psychological satisfaction within a complex and populated concentration (Lenzholzer et al., 2015). Herranz-Pascual (2014) argues that taking both perspectives into account can be of great importance to mitigate heat stresses. A research investigating thermal comfort in the hot-humid city of Malaysia, in particular, shows that local respondents accepted the thermal condition above the acceptable level of PET physiological measurements (Makaremi et al., 2012). It apparently means that the local inhabitants have had more tolerance to the warm outdoor environment. Yet the study lacks a declaration which other factors influence the human judgments of their urban climate. Another concern is that very little attention to urban thermal comfort within outdoor environments has been drawn in developing countries as the availability of related data is rather limited (Ongoma, Victor; MuangeZablon, 2016a).

It is most likely to be more important for the countries with rapid and unplanned growing cities like Phnom Penh and also to support discussions about local environmental issues regarding the elevation of urban microclimate and human wellbeing. Therefore, this study stressing on the outdoor thermal comfort by concerning both climatic measurements and human perceptions, contributes meaningfully to the research efforts in environmental and personal heat exposure and helps to improve insight of how microclimate can affect urban wellbeing.

1.3 Relevance of Research Topic

With little awareness of altering urban climate caused by global warming and urbanization, the result of this investigation focusing on the assessment of outdoor thermal comfort will serve as a wakeup call to city planners and designers to pay more attention to the thermal environment in this urban communities. The present investigation, which takes into account both climatic conditions and psychological perception related to thermal conditions, will be very important for science and society. The findings of this study will show which circumstances of thermal comfort have the greatest impact on human dissatisfaction and health due to heat.

The study, furthermore, can become a basic guidance for future urban design and development towards a sustainable way how to reduce heat stress and how to improve thermal comfort conditions in the city. Meanwhile, the Cambodian government recently adopted the Phnom Penh Sustainable City Plan 2018-2020 which endeavours to improve urban resilience for every citizen to nature and climatic risks. As the study's focus is aligned with the goal of the new city plan, the study outcome will enable to offer a pragmatic support to handle heat stress in the urban spaces of Phnom Penh. With a more comfortable urban climate, Phnom Penh in the future will become a more comfortable and liveable place. In addition, the city will be enabled to encourage and attract urban communities to do more outdoor heat constitution activities and use non-automobile transport options like walking, cycling and commuting with public transports.

1.4 Research Objective

The main objectives of this research are as follows:

(1) To determine the climatic parameters which influence human thermal comfort in outdoor spaces within Phnom Penh city;
(2) To understand psychological perception of the urban thermal comfort; and
(3) To understand the differences between human thermal comfort conditions as derived from climatic parameters and from psychological perception.

1.5 Main Research Question and Research Sub-questions

In order to attain these objectives, research questions are being developed. The main research question is:

> "How are outdoor thermal comfort parameters related to the differences or similarities between climatic parameters and psychological thermal perceptions?"

There are three research sub-questions to support the main one:

(1) How do urban climatic parameters affect the outdoor thermal comfort in Phnom Penh?
(2) How do psychological thermal perceptions express outdoor comfort condition in Phnom Penh?
(3) How to explain the differences or similarities of thermal comfort conditions between climatic parameters and psychological perception?

Chapter 2: Literature review

2.1 Outdoor Thermal Comfort

2.1.1 Effects of Thermal Discomfort

Climate change and urban heat island cause more frequent and extreme weather events such as heatwaves (Smoyer et al., 2000). Cities where the urban heat island effect exists to elevate air temperatures are indicated to expose higher unfavourable or uncomfortable environments, meanwhile, climate change altering global and regional air temperatures is likely to aggravate the danger of heat to humans in metropolitan areas. In particular, countries situated in hot tropical and sub-tropical regions are expected to get more considerably impacted by these warmer weather phenomenon (Kjellstrom and McMichael, 2013). Due to the microclimate alteration, heat stress is marked as a serious environmental risk to human health. The dissatisfied thermal conditions in outdoor and indoor environments become a major problem of heat stress which results in a considerable increase in heat-related mortality (Evans, 1984). Since the 19th century, heat-related mortality has been elucidated by the physiological studies that show the association between effects connected to heat stress and uncomfortable ambient conditions of outdoor environments. Many studies carried out in a number of European and US cities found the increase in mortality and urban residents showed deteriorated health and less functionality in working performance during the duration of warmer temperature (Vanos et al., 2010). Noticing from such thermal comfort investigations through individual experiences, heat-related illnesses include heat stroke, fatigue, headaches, nausea, confusion and cramping. In a more serious situation, heat stress can cause fatal risks. Sick, young and elder people are the most vulnerable group that confronts the highest chance of mortality and heatstroke during warmer temperatures (Smoyer et al., 2000). There is no doubt the future growth of urban agglomerations brings additional problems affiliated with cardiovascular and respiratory concerns due to the mounting heat stress and air pollution in the built environment.

In addition to the health impact, heat stress also negatively affects on human wellbeing as well as reduces the productivity performance of people. The level of thermal comfort, according to Evans (1984), correlates directly to human health. Thus, the condition of comfort is a crucial factor influencing people’s day-to-day activities. People exposing in uncomfortable thermal conditions—for instance, above the neutral range of environmental comfort—are diminished their actively performance and sometimes become involved in unexpected accidents when their ability of responding tasks is being impaired or reduced. Moreover, there is an investigation emphasizing a comparison of human working activities within the different conditions of urban and rural comfort (Robba, 2011). The investigation found that the hot dissatisfaction feeling of workers operating in the urban environment can hinder their capacity of activities whereas the rural thermal condition is much more pleasant for more human activities.

Research on the thermal comfort and discomfort of human-being emphasizes the profound importance to understand the interrelationships between surrounding environments, especially in populous areas like towns and cities, and their impacts on human health and the efficiency of productivity as well as human wellbeing. Awareness of these is profoundly important for urban planning and design to solve the related problems to ensure the liveability in urban neighbourhoods (Gaitani et al., 2007). In turn, the pleasant environment can attract more outdoor users because people can enjoy with various outdoor activities with less thermal concerns.

2.1.2 Conceptions of Thermal Comfort

The beginning study of outdoor thermal comfort commenced in the early twentieth century (Nicol, 2008). The concepts of human thermal comfort have been an extremely popular and discussed topic in literature. It is, nonetheless, very complex and tough to define. Among scholars, the conception of thermal comfort has long been described according to a purely physiological phenomenon. Fanger (1970) characterizes thermal comfort as the human satisfaction of their living environment. His laboratory investigation gave special importance only to the effects of physical climatic parameters. Similar to Fanger, Olgyay (2015) delineates thermal comfort is the condition that the individual does not encounter the feeling of discomfort or dissatisfaction within the dwelling environment. He points out the differences of individual thermal neutrality under the condition of comfortable feeling because of different types of clothing and metabolism activities. Following this physiological-based concept which is concerning only the micrometeorological conditions and human metabolic activities, numerous physiological indices have been developed to assess the conditions of human thermal comfort. These physiological-base methods have solely depended on objective measures.

Other researchers indicate that these measures are inadequate to determine thermal comfort for a certain place. Benton et al. (1990), ASHARE (2004), Lenzhonler et al. (2015) and Foruzamehr (2018) describe the term of thermal comfort is the condition of mind that relies upon both physiological and psychological factors. These researchers add a subjective aspect of human thermal perception to their studies besides the influence of climatic and physiological factors. Lenzhonlzer gives an explanation that the term 'comfort' or 'satisfaction of humans' cannot be determined by solely looking at the physical aspect alone because thermal comfort is also the expression of psychological perception. In an attempt to understand and interpret thermal comfort in the real world, Benton et al. (Benton et al., 1990) assert the critical role of the non-physical or psychological aspect when defining the term of comfort. Giving a more deep and comprehensive definition as well as showing the relation between both aspects, ASHRAE states that thermal comfort is people's subjective psychological perception which also depends upon physiological thermoregulation processes as the human body is exposed to a variety of environmental influences such as air temperature, humidity, wind speed and radiation temperature. Hence, the condition of comfortable mind requires investigators to deem both physiological and psychological influences.

2.2 Climatic Parameters and Physiological Aspect of Thermal Comfort

2.2.1 Climatic Parameters

As far as thermal comfort in outdoor space is concerned, the position of microclimate is very important and it is one of the major factors directly affecting human thermal comfort (Njoku and Daramola, 2019). Users of outdoor spaces directly contact microclimate factors including air temperature, relative humidity, solar radiation and wind velocity (Ongoma et al., 2016). Such parameters highly affect thermal sensation which is regarded as the objective part of thermal comfort. The human body quickly detects and responds to environmental conditions in order to regulate the balance of internal body temperature. Relatively, Inavonna et al. (2018) proved that these environmental parameters significantly manipulate the physiological sensation of comfort.

Air Temperature

Among the various climatic parameters, air temperature is the only one that potentially contributes to thermal comfort and people's thermal sensation as it is partly determined to understand the amount of heat loss of the human body through the process of convection (Foruzanmehr, 2018). Convection is described as the energy (heat) transferring process in the form of fluid to another place or object. Human body can lose its heat through convection to cool off the surrounding air (Choudhury et al., 2011). An analysis of microclimate impacts on human thermal sensation from Park et al. (2014) reveals a strong association between air temperature and outdoor thermal comfort. Midafternoon has the highest level of heat stress as the ambient temperature climbed above 28 ^{O}C. The sunny spaces experienced mild to moderate thermal stress while a variation of heat stress from no to moderate level at shaded spaces with lower temperatures 1-2 ^{O}C. The study findings illustrate the direct connection that occurred between air temperature and human thermal comfort. Hot temperatures, in general, lead to an increase in discomfort. Cui et al. (2013) investigated the influence of air temperature on human thermal comfort. Similar to the findings of Park et al., the downward trend of thermal comfort votes was identified. The neutrality of thermal comfort occurred when air temperatures varied from 22 ^{O}C to 24 ^{O}C. Noticeably, the respondents shifted to vote for 'uncomfortable' and 'very uncomfortable' when the air temperature exceeded 32 ^{O}C. Behind the warmer urban microclimate, there is a significantly positive correlation between urban population and the trend of urban warming in China (Hua et al., 2008). After the year of 1978, the influence of urbanization and industrialization processes has contributed to a dramatic increase in air temperature (both maximum temperature and minimum temperature). The existence of high UHI effects was noticed in most cities situated in regions with rapid industrial and economic development.

Wind Velocity

The velocity and direction of wind typically have a potential effect on the comfortable state of humans (Ongoma et al., 2016), particularly in hot and dry regions. In urban fabric, air movement influences the diffusion of pollutants and complex heat transfer which induces human comfort (Mochida and Lun, 2008). Significantly, wind speed within a space above 1.0 m/s is possible to decrease warm air temperature up to more than 3 ^{O}C (Nicol, 2008). Directly affecting the internal human body, it introduces the heat loss from human body through the process of convection in case air temperature is lower than the temperature of human skin. The heat loss increases when air flow brings dry air surrounding into the skin and accelerates the greater evaporation. A study observed over an African-city of Nairobi with a rapid pace of urbanization provides a strong illustration to explain a significant modification of wind speed that has a detrimental impact on human comfort (Ongoma, V. et al., 2013). Although the urbanization process in the city had insignificance to modify wind direction during the observation period, the reduction of wind speeds is predominantly evidenced due to considerable changes in surface roughness. The surface alterity which is the result of urbanization leads to windless conditions or a decrease in air mass exchange and hence in reduced heat flow across the urban setting. This phenomenon has a negative impact on pollutant concentration inside the city as well as warm temperatures. It has a negative influence on both human comfort and the local climate in general. City planning and management should pay more attention on promoting wise land use that enables facilitate sufficient cooling effects. Vegetated and ventilated zones across cities are very important to minimize adverse threats of heat stress environments and additionally to improve adaptive capacity (Smoyer et al., 2000).

Relative Humidity

Relative humidity (RH), which plays a vital role in understanding the characteristics of urban atmospheric climates, has been described as a ratio of actual water vapor in the air, and it is commonly depicted as percentage (Mahmoud and Gan, 2018). With a significant impact of climatic conditions, the concentration of water vapour has a strong dependency on air temperature. It is an explanation of why the mathematical equation of RH can be ascertained easier than other hydro-meteorological parameters. More importantly, this form of humidity is a significant climatic element that has an effect on human physiological comfort apart from air temperature and wind speed (Adebayo, 1989; Wypych, 2010). The optimal range of RH is between 30% and 60%, with minimal effects on thermal discomfort (La Roche, 2012). According to Mahmoud and Gan (2018), their study examined the implications of rapid urbanization on urban climate and human thermal comfort in Cairo, the capital of Egypt which is a highly populated megacity with over 10 million population. Cairo has undergone radical urbanization and urban growth. This new tendency of urban development has resulted in the variation of the urban climate. Serious levels of heat stress have risen and persisted under the warming atmosphere. A collection of climatic observations from 1950 to 2017 was detected a substantial upward trend of air temperatures almost 0.2 ^{O}C per decade. Contrary to the rising air temperature, the relative humidity trend was negative from 63.61% dropped to 60.53% during the corresponding period, with the decreased average of 0.55% per decade, as a consequence of a dramatic rise in impermeable surfaces in Cairo. The statically negative correlation between RH and indices of thermal comfort lead the researchers to deduce that as the percentage of RH declines, thermal discomfort gradually elevates.

Solar Radiation

Solar radiation has been found to induce significant thermal distress through radiant flux and exchanges between subjects and the surfaces around it. People may perceive different levels of thermal sensation regarding the effect of solar radiation while standing next to windows and outdoors (Foruzanmehr, 2018). In order to ascertain the solar radiation effect, Mean Radiation Temperature (MRT), which is one of the most important elements in micro-scale climate, incorporates in its calculation. Conducted an investigation in a botanic garden of Melbourne, Lam and Hang (2017) show that higher incoming solar radiation was significantly affiliated with the hotter feeling of outdoor visitors under the same range of air temperature 25 ^{O}C - 36.9 ^{O}C. There is an important recommendation from this analysis. Apart from the solar radiation effect on human heat equilibrium, visual comfort—subjective satisfaction—can partly entail the outdoor thermal comfort in a shaded condition. The urban structure of cities from a morphological perspective has a potential impact on the increase in net radiation and also reduction of energy convection in urban canyons. Shalaby (2011) gives empirical findings from the observation in populous cities. The majority of highly dense cities are unprecedentedly growing with congestion of tall buildings and narrower sky view factor, the radio of the visible sky above a certain point. This human-built structure has a stronger capacity to trap lots of solar short-wave radiations rather than release absorbed energy (heat) back to the atmosphere. As a consequence, the warming climate in the metropolitan areas is a big challenge to comfortable zones of urban life.

2.2.2 Physiological Aspect of Thermal Comfort

Physiological comfort is characterized by maintaining thermal balance at the neutral body temperature, which typically is 37 ^{O}C (98 ^{O}F) with the range of tolerance below and above 0.5 ^{O}C within distinct microclimatic conditions, with the minimum level of thermal body regulation (Choudhury et al., 2011). The mechanisms, which are fundamental automatic thermoregulation, attempt to make a thermal balance inside the internal human body with the outside environment through accelerating and decreasing heartbeat in order to adjust blood flow and to control the distribution of heat. During comfortable conditions, heat production of human body is equivalent to heat loss without any thermal mechanisms to balance for the equilibrium state. However, under cold and hot weather conditions, people are commonly quivering to generate heat production and sweating to lower skin temperature, respectively. Notedly, there is significant notice from Greig (1965) according to his physiological study in Sydney. There is no perfect weather condition that different people all feel comfortable. The field study showed 80% of involved respondents expressed their feeling of comfort whereas the other 20% were reported too cool and too warm under the same temperature.

The feeling of thermal comfort, in this regard, is not just associated with environmental (or physical) characteristics as explained above. Types of human clothing and types of human physical activities also attribute to the state of mind, whether comfort or discomfort (Vanos et al., 2010). Vanos et al. additionally demonstrate that the effects of clothing and metabolic heat production as well as local climate measurements provide core foundation for a thorough understanding of physiological sensation in conjecture with surrounding environments. Along with this aspect, a physiological comfort model, or so-called heat balance model which is developed by Fanger (1970), also includes the parameters of clothing types and metabolic rate with environmental parameters in order to determine the condition under which the majority of people seem to be satisfied and comfortable. Metabolism is defined as a chemical reaction when heat inside the human body is discharging in order to maintain life (Choudhury et al., 2011). The metabolic process tends to increase the energy demand when the body performs extra physical activity. At that time, more internal heat is being generated. In another case, particularly even though there is just stationary activity, metabolism still rises with the intention of maintaining the internal temperature once the body persists heat loss against the outside environment.

Choudhunry et al. (2011, p. 18) state “clothing is the nearest mobile environment”. The basic function of the apparel is to insulate the body in opposition to an uncomfortable condition—cold or hot. Aside from the provision of mental comfort in terms of aesthetic styles of clothing, it constitutes a very significant part to prevail in levels of individual thermal comfort. A field survey was carried out by Yang et al. (2013) to determine the impact of thermal adaptation on human sensation in outdoor urban areas in Singapore. Following the results, some outdoor users of this tropical city indicated that ‘reducing clothing’ is a preferential measure to deal with a hot weather condition. It evidences that clothing plays a significant role in stabilizing human heat balance by regulating heat loss and moisture loss.

2.2.3 Outdoor Thermal Comfort Indices

Deep understanding of outdoor thermal comfort is acknowledged very useful, particularly in fast developing regions, to enhance human wellbeing and green space management. As that, since the beginning of the 20th century, both simple and rational indices have been developed to investigate thermal comfort in outdoors (Heng and Chow, 2019). The simple-method index refers to a measurement purely based on basic environmental parameters such as air temperature and relative humidity. Indices with the simple method include Temperature-humidity discomfort index (THI) and Apparent Temperature (AT) (Steadman, 1979; Thom, 1959).

On the other hand, rational indices take into count not only environmental parameters but also individual physiological data (clothing and metabolic activity). The Standard Effective Temperature for outdoor situations (OUT-SET), Universal Thermal Climate Index (UTCI) and Physiological Equivalent Temperature (PET) are rational indices based upon the energy fluxes between human body and surrounding environment (Höppe, 1999; Pickup and de Dear, 2000). Among these indices, Makaremie et al. (2012) claim that PET is the most applicable index for determining outdoor thermal comfort in different climate conditions. The index includes all basic thermoregulatory processes and was developed through thermo-physiological heat balance model or called MEMI model for individuals (Honjo, 2009). Later, there was a study focusing on adjusting the PET thermal comfort scale for tropical climate in comparison with the original PET range (the neutral perception between 18 ^{O}C and 23 ^{O}C) (Lin and Matzarakis, 2008). The result of the field investigation showed that local people have a higher tolerance than the original PET range, corresponded the neutral temperatures between 26 ^{O}C to 30 ^{O}C. To suit tropical and subtropical environments, Lin and Matzarakis modified a new PET thermal perception range, as shown in ***Table 1***.

Table 1: PET thermal perception classification in the European region and tropical region

PET (^{O}C) range for		Thermal perception	Grade of physiological stress
European Region	**Tropical Region**		
<4	<14	Very cold	Extreme cold stress
4-8	14-18	Cold	Strong cold stress
8-13	18-22	Cool	Moderate stress
13-18	22-26	Slightly cool	Slight cold
18-23	**26-30**	**Neutral**	**No thermal stress**
23-29	30-34	Slightly Warm	Slight heat stress
29-35	34-38	Warm	Moderate heat stress
35-41	38-42	Hot	Strong heat stress
>41	>42	Very hot	Extreme heat stress

Source: (Honjo, 2009; Lin and Matzarakis, 2008)

2.3 Psychological Aspect of Comfort

The psychological aspect of thermal comfort is characterized as a subjective character representing the state of mind that manifests satisfaction under a certain thermal environment and thus is complicated to deal with due to the complexity of energy influxes across rough surfaces and the unprecedented alteration of climatic parameters which influence individual thermal comfort directly (Höppe, 2002). In addition, the levels of thermal satisfaction may vary depending on individual sensation, experience, adaptive behavior, etc. Psychological influences, however, are key factors to understand thermal perception, particularly in open spaces. According to a solely physiological investigation by Nikolopoulou et at. (2001), the findings indicated that the applied method contributes just 50 percent to the discrepancy between objective and subjective thermal comfort in outdoor spaces. The remaining portion is needed to be determined by psychological influences. Indeed, the acquisition of a comfortable thermal condition is closely correlated with the state of neutrality. Under a neutral condition, humans do no prefer warmer or cooler temperatures because they have already been in a satisfied state. The determination of thermal comfort is needed human psychological response to the proximate environment, not purely based on the physiological energy balance model.

2.3.1 Individual characteristics

The association between human psychologies and the environment is consistent with the process of sensation reflecting the climatic surroundings. With regard to thermal comfort, the sensing starts with physical stimuli which are perceived differently by individuals according to their own characteristics (Inavonna et al., 2018). Inavonna et al. emphasize that the individual characteristics include adaptive behavior, (short or long term) experience, preference, duration of exposure in outdoors. Such factors are seen in line with a psychological study conducted by Nikolopoulou and Steemers (2003) to be aware of what extent thermo-individual adaptation as a guide for urban design.

In that research, Nikolopoulou and Steemers introduced the concept of experience—short and long-term memory—which is closely related to the temporal character of microclimate in urban spaces. The authors noted the influence of experiences on distinct thermal sensation and preferences. The findings from interviews with outdoor passers proved such influence as thermal neutrality was found a variation from 7.5 ^{O}C to 27 ^{O}C in winter and summer, respectively. Short-term (or momentary) experience is referred to as the thermal perception for a specific moment and at a particular location. A person may claim, for example, “I feel cold or it is hot in this square” which is an actual sensation. On the other hand, long-term experience seems to determine a suitable type of seasonal clothing, a preference of activities under various climatic conditions and even the selection of food to modify metabolic heat production. These adaptive behaviors are generated as the result of repetitional experiences that enable individuals to differently adapt with dissatisfied conditions. A study in Malaysia evidences that there is a significant difference between locals and international respondents with respect to climatic conditions. The local group had long-term experience adapting to the hot-humid environment, and conversely, the other group had less experience under such an environment. The findings indicated that the comfort condition was confirmed comfortable by 65% of locals and 39% of internationals, while 35% of locals and 61% of internationals voted the uncomfortable state. Hence, it is clear that the duration of experience living in such an environmental condition resulted in the discrepancy of responses from both counterparts.

2.3.2 Spatial and material Characteristics

In addition to psychologically individual characteristics (thermal sensation, experience and preference), spatial and material characteristics accommodated in outdoors have some impacts on the human thermal sensation (Lenzholzer et al., 2018; Nikolopoulou and Steemers, 2003). Urban characteristics (e.g. spatial configuration, view of landscape, vegetation and construction materials), in the context of outdoor thermal comfort, provide a function as interactive physical adaptation, indirectly making people adjust to the ambient environment in order to maintain their thermal comfort. However, this kind of physical adaptation, in the time of rapid growth in urban agglomerations, is very limited in the built environment due to a lack of the nature of open spaces and specific elements to cope with the fluctuation of microclimate (Nikolopoulou and Lykoudis, 2006). Nikolopoulou and his co-author claim that a positive evaluation of the places with natural characteristics was found in term of the thermal comfort, whereas the places with built characteristics had unfavorable outcomes (Nikolopoulou and Steemers, 2003). They add that long-term memory is unlikely to connect with spatial characters, yet people's momentary memory does. Through the latter, the diversity of designs in urban fabrics can alter human thermal perception.

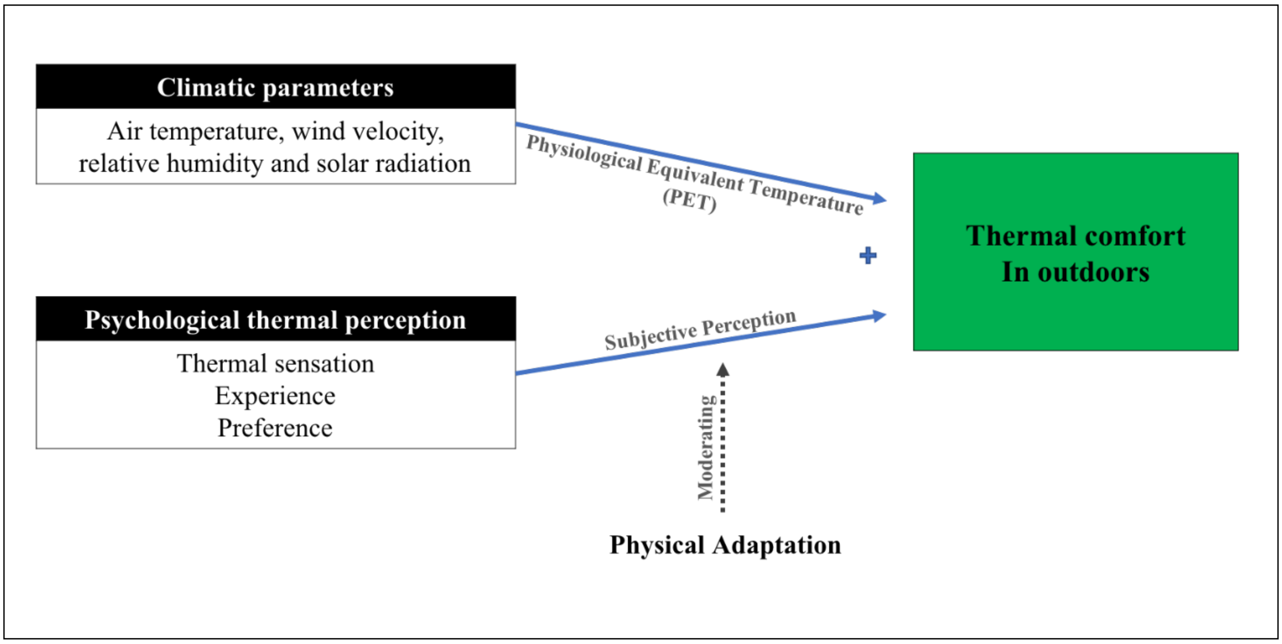
For example, a previous study focused on design issues and thermal comfort, conducting a quick-scan on people's thermal experiences at public parks (Lenzholzer, 2012). People in three Dutch squares (Spuiplein, Neckerspoel and Grote Markt) were questioned about their opinions regarding spatial characteristics, including block width, openness of the square and materials used. The goal is to determine the correlations between different spatial structures and their thermal experiences. The findings indicated that respondents were mostly unhappy with the environmental conditions in these public squares. Their problems were associated with the spatial configuration. Some answers were 'standing here doesn't differ from the inside of refrigerator' and 'this area is a stone desert'. According to the psychological results, there could be a drawn conclusion that these microclimate problems within Dutch public spaces were somehow because of the oversight of urban design which was attributed to a lack of appropriate design guidelines to improve the local climate. Concerning in the sample focus, Lenzholzer et al. (2018) prove the association between spatial setups in urban squares and people's thermal perceptions by qualitative interviews. On summer days, most respondents assessed vegetated spaces more thermally comfortable than water and built environments. Significantly, this perception is in line with the existence of cool islands shown by physical measurements. The spatial pattern amid high-rise buildings, in addition, was considered to expose small-scale squares to aggressive wind fluxes. However, there was still unclear to evidence the possible relation of colours in urban spaces and thermal comfort in factual effects. Based on these empirical findings, there is no doubt that spatial characteristics of outdoor spaces have a moderating influence on users' thermal perception by adjusting human sensation.

2.4 Conceptual Framework

According to the literature review in this chapter, there are lots of academic efforts to evidence the potential influence of climatic and psychological parameters on thermal comfort conditions in outdoor and indoor environment, particularly in the complex outdoor spaces of dense urban agglomerations which have been transformed into the built environments. Previous studies in literature review can be marked as strong ground for this study to develop a conceptual framework towards the research objective. As shown in ***Figure 1***, the conceptual framework consists of dependent, independent as well as moderating variables, and illustrates the relations among them. As the study objective is to ascertain the conditions of thermal comfort in outdoor spaces of Phnom Penh, 'thermal comfort' is defined as a dependent variable, the result of which relies upon a range of independent measures. While previous studies focused predominantly either on physical aspect (climatic parameters) or psychological aspect, both aspects have been observed and combined in this study for determining the integral human thermal comfort conditions in Phnom Penh.

In line with recent climatic investigations (Inavonna et al., 2018; Njoku and Daramola, 2019; Ongoma, Victor; MuangeZablon, 2016b), climatic parameters (i.e. air temperature, wind velocity, relative humidity and solar radiation) are included in physical-based aspect of thermal comfort. These aspects are associated with physiological factors (clothing and metabolic activities) in order to figure out outdoor thermal comfort through PET's equation. On the other hand, individual characteristics (thermal sensation, experience and preference) take place to understand psychological thermal perception. Based on an empirical finding in Singapore (Yang et al., 2013), there was not a significant difference of thermal sensation votes with different exposure time which are therefore excluded in this study. As the literature indicates, physical adaptation, which includes individual adaptive behavior (i.e. using umbrella, wearing hat or search for shade) and spatial characteristics (i.e. greenery, width or proportion of landscape), plays a role, altering the relation of the psychological thermal perception and thermal comfort. Therefore, physical adaption is used as moderating variable.

Figure 1: The conceptual framework of outdoor thermal comfort



Chapter 3: Research design, methods and limitations

This chapter describes a research design to ascertain research objectives and research questions. To be consistent with literature review and previous studies, theoretical concepts shown in the conceptualization framework in chapter 2 have been operationalized into measurable indicators for quantification. Aims of the study and research questions are noted as milestones to determine the most suitable strategy. In turn, the strategy enables to direct methods for data collection, necessary instruments and analysis techniques that can maximise reliability and (internal and external) validity. At the end of the chapter, possible limitations of the study are also identified in the research design in line with time frame and prevailing situation.

3.1 Description of the research design and methods

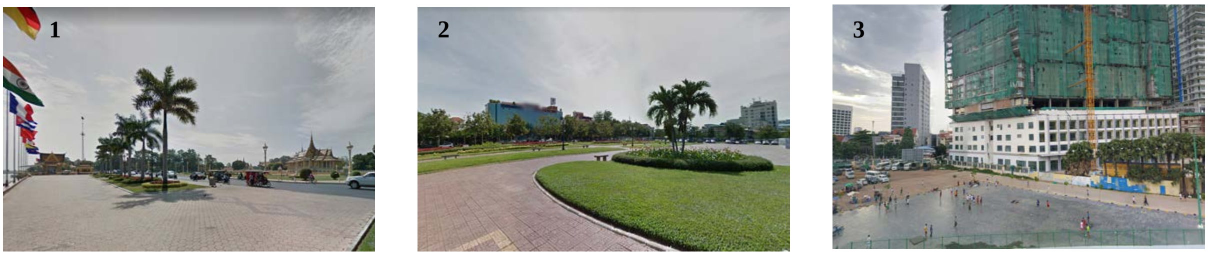
3.1.1 Research Strategy

The main objective of this research is to understand outdoor thermal comfort by considering climatic parameters and psychological perception of individuals. Van Thiel (2014) indicates the significant influence of the research aim and questions on the way to choose the most adequate research strategy. Therefore, according to the research aims—concerning psychological perception—the nature of this study requires to assess individual opinions to answer a universal question generalization of individual opinions. Without doubts the study has therefore to focus on large-scale research (population within an urban agglomeration), and not to certain groups on a small scale. Van Thiel, in addition, claims that 'Survey' employs so well for those type of studies that intend to generalize people's opinion and to gather sizable data. Thus, the survey strategy is likely to be acknowledged and is therefore the most suitable strategy used to collect new data regarding individual thermal perception in outdoors of Phnom Penh. Meanwhile, the physical observation is carried out by measuring climatic parameters and observing clothing and outdoor users' activity. This strategy, on the other hand, enable the research to statistically explore descriptive, inferential and explanatory information because it gathers standardized measurement in advance (Cohen et al., 2013).

3.1.2 Data collection methods

Data collection involves both physical measurement (climatic parameter) and subjective survey (psychological perception). These are carried out simultaneously for this investigation of outdoor thermal comfort condition. The Phnom Penh capital city (11.5564° N, 104.9282° E) is defined as a study area to observe thermal comfort conditions of outdoor spaces within the hot and humid tropical environment. This study is conducted at three open squares with different microclimatic conditions and locations in order to represent various circumstances that people may experience in their everyday life. These squares are: (1) Royal Palace park, (2) Botum Pagoda park and (3) Olympic Stadium open space. The open squares also have different spatial conditions in an objective to possibly give a generalized picture of thermal comfort conditions across the city. Royal Palace park is situated along the Tonle Sap riverside in a controlled development zone (low-rise building) with less shades. Botum Pagoda park is surrounding by medium-rise buildings (residential and commercial use), and its environment is opposed to that of Olympic Stadium open space which encompasses in the inner-city near high-rise buildings.

Photograph 1: Three open squares of the Phnom Penh city where the surveys taken place



Source: (Google Street view, 2013, 2014, 2017)

The field observations are taken on 26 June to 03 July 2020 from Friday to Sunday. Each site was visited twice from 9:00 am to 05:00 pm. The day with neither rain nor strong wind is considered a suitable weather for surveys.

<u>physical thermal condition measurements</u>

The PET index, which is depended on a simplification on the human energy balance model, is utilized to estimate the physiologically thermal environment. PET requires meteorological data and thermo-physiological data for assessing outdoor thermal comfort. The physical thermal condition measurements are conducted at the selected open squares in order to record basic climatic data for PET. Mean radiant temperature (T_{mrt}) is a key climatic parameter that regulates human energy balance. It leads the mean radiant temperature to have a strong influence on thermal physiological indices (Thorsson et al., 2006). For the PET index, T_{mrt} is the most important determining parameter while other climatic parameters—air temperature (T_a), wind velocity (V) and relative humidity (RH)—are input parameters that have very weak effect on PET (Matzarakis and Rutz, 2018). In addition, the thermo-physiological information related to metabolic rate and clothing insulation are, in addition, added into the PET model.

Heat stress WBGT (wet bulb globe temperature) meter model HT30 was employed to measure T_a, RH and T_g (globe temperature) with a basic accuracy of $\pm$ 1.0 ^{O}C, $\pm$ 3% and $\pm$ 2.0 ^{O}C respectively (Extech, 2013). Wind velocity is recorded by the UNI-T UT363 anemometer which is a mini data logger connecting with smartphone; it provides an accuracy of $\pm$ 0.1 m/s. In addition, mean radiant temperature (T_{mrt}) is derived from the WBGT meter with regard to air temperature, global temperature and also wind velocity measurements (Thorsson et al., 2006). The equation of T_{mrt} is:

$$T_{mrt} = \left[(T_g + 273.15)^4 + \frac{1.1 \times 10^8 V^{0.6}}{\varepsilon D^{0.4}}(T_g - T_a)\right]^{1/4} - 273.15$$

ε = the globe emissivity, D = globe diameter

The instruments are recommended to install 1.1 meters above ground, equivalent to the average height of adults (Mayer and Höppe, 1987). All of these parameters are manually recorded with 60 minutes measurement frequency, excluding wind velocity because the utilized windmeter can store and transfer the measurements to mobile phone via Bluetooth connection.

<u>subjective survey</u>

This current research is utilized a structured questionnaire to gather subjective responses of outdoor users with respect to thermal comfort in the city's squares. The survey strategy is commonly administered by a questionnaire (Van Thiel, 2014) because it is an efficient instrument for collecting a considerable amount of subjective information. Items in questionnaire are adopted from operationalized indicators (elaborated in the next section), based on the literature review of previous thermal comfort studies (Lenzholzer et al., 2015; Lin and Matzarakis, 2008; Makaremi et al., 2012; Yang et al., 2013). In efforts to ascertain involving variables, the questionnaire is formulated, comprising three sections: personal information, psychological perception of thermal comfort and the application of physical adaptation. The first section is about personal data or so-called control items such as age, sex, the duration living in the city, type of clothes and activities in the last 15 minutes. The second section is inquired respondents about their psychological perception linked with thermal sensation, acceptability of prevailing thermal condition and thermal preference. The investigation of individual physical adaptation and perception associated with spatial setups was elaborated in the last section. For this study, it is impossible to circulate the questionnaire through online platform as physical measurement and subjective survey are carried out at the same time. That ensures the match of both observations for a comparative assessment to understand thermal comfort conditions. Outdoor users are interviewed person by person at the open squares.

3.1.3 Sample size and selection

Probability sampling is chosen randomly outdoor users who are sitting on the benches, passing or standing at the selected open squares during the specified time frame. Indeed, this sampling method has been very suitable for the study willing to generalize human perceptions of outdoor thermal comfort since it can provide representativeness. The decision relying upon the simple random approach was attributed to eliminating bias and skewness that would occur if correspondents were intentionally drawn from non-probability sampling.

Sample size is very significant while it is used to reflect the population in a survey. The sample size equation positions to determine the number of samples that should be involved in the study. As there is no a recorded number of outdoor users at the open squares in Phnom Penh, the sample size cannot be determined by the equation with a population based. To deal with the unknown population value, Men (2014) proposes an equation of minimum sample size for unlimited population, as follows:

$$n = \frac{Z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2}$$

z : confidence level
ε : margin of error
$\hat{p}$: population proportion
n : sample size

Based on this equation, at least 97 samples are needed for the study to represent the whole outdoor users, with a confidence level of 95% (Z= $\pm$ 1.96), a margin of error 10% and a population proportion of 50% to represent the whole outdoor users.

3.2 Operationalization: Variables and Indicators

The operationalization is a transition step, translating theoretical concepts into measurable entities (Van Thiel, 2014). In the context of observing thermal comfort in outdoor spaces of the city, the operationalization of variables, *as shown in **Table 2***, has been developed in line with the conceptual framework and the research questions. To reach the study’s objectives, two independence variables (climatic parameters and psychological thermal perception) and a moderating variable (physical adaptation) are operationalized into a number of quantifiable indicators based on the definition of these variables and their role. Elaborated indicators contribute to the formulation of the questions for the survey. Hence, the operationalization forms an important ingredient for data collection.

Climatic parameters are defined to follow their measurement unit. Air temperature is in the Degree Celsius scale (^{O}C) and relative humidity in percentage (%). Metabolic rate and clothing insulation have been derived from the ASHRAE standard 55-2004 for thermal environmental condition (ASHARAE, 2004). The consensus standard of ASHARAE offers checklists of metabolic rates (W/m^2) for types of physical activities and clothing insulation values (clo).

On the other hand, indicators of psychological thermal perception (independent variable) have been elaborated in a consistency with previous interrelated studies (Makaremi et al., 2012; Yang et al., 2013) that had emphasized the significance of psychological characters such as experience, perception of thermal sensation as well as the perception of thermal preference. To evaluate overall sensation perception, Yang et al. (Yang et al., 2013) and Tung et al. (Tung et al., 2014) recommend to use a 7-point ASHARAE scale: cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3). Subsequently, respondents are asked to express their thermal sensation regarding each climatic parameter (Ta, V and RH) on a 5-point scale. Thermal preference is also asked to understand individual desire for satisfied thermal conditions, presenting in a 5-point scale for each climatic parameter. For example, air temperature: cooler (-2), slightly cooler (-1), no change (0), slightly warmer (+1) and warmer (+2).

Outdoor thermal comfort which is a state of mind expressing satisfaction of a certain environment plays a role as a dependent variable in the observation. Depending on psychological responses, acceptability of outdoor environment is involved to determine the overall thermal comfort. The responses are defined on a 5-point scale: very uncomfortable (-2), uncomfortable (-1), acceptability (0), comfortable (+1) and very comfortable (+2).

Physical adaptation, a moderator variable, is referred to interactive ways that make a person adjust to the ambient environment (Lenzholzer et al., 2018). Indicators of the moderator variable are adopted from the studies of Lenzholzer et al. (Lenzholzer et al., 2015) and Lenzholzer et al. (Lenzholzer et al., 2018). The studies of them includes individual adaptive behaviour and also the perception of spatial condition, such as greenery and proportion of the place, related to the thermal experience. Associated with that, the preference of spatial condition that may let outdoor users perceive more thermally comfortable is deemed as solutions to deal with unpleasant microclimate.

Table 2: Operationalization table of variables

Variables	Definition	Sub-variables	Indicators	Source of data
Climatic parameters (independent variable)	Major factors affecting human thermal comfort such as air temperature, wind velocity, relative humidity and mean radiant temperature, and	• Air temperature • Wind Velocity • Relative humidity • Mean radiant temperature	1. Air temperature (^{O}C) 2. Wind velocity (m/s) 3. Relative humidity (%) 4. Mean radiant temperature (^{O}C)	Primary data (physical measurements)

	manipulating the physiological comfort	• Metabolic rate • Clothing insulation	5. Individual metabolic rate (W/m^2) 6. Clothing insulation (clo)	Primary data (questionnaire)
Psychological perception (independent variable)	a subjective character representing the state of mind.	• Experience • Thermal sensation • Preference	7. Duration of experience living in the neighborhood 8. Perception of individual thermal sensation (ASHRAE's 7-point scale) 9. Perception of sensation of climatic factors (5-point scale) 10. Perception of thermal preference (5-point scale)	Primary data (questionnaire)
Outdoor thermal comfort (dependent variable)	the state of mind manifesting satisfaction under a certain thermal environment	• acceptability of outdoor environment	11. Acceptability of outdoor environment (5-point scale)	Primary data (questionnaire)
Physical adaptation (moderator variable)	interactive adaptive ways that make a person adjust to ambient environment in an effort to maintain their comfortable condition.	• Individual adaptive behavior • Spatial characteristics	12. Types of individual adaptive behavior (wearing hat, using umbrella, searching shade, etc.) 13. Perception of spatial proportion (too wide, good, too narrow) 14. Perception of greenery in the outdoor 15. Perception of a preferable spatial setup that enables them to adjust with the ambient condition	Primary data (questionnaire)

3.2.1 Data analysis methods

The study is using the Physiologically Equivalent Temperature (PET) to determine thermal comfort conditions based upon climatic parameters (first independent variable). Air temperature, relative humidity, wind velocity and mean radiant temperature are necessary input data associated with metabolic rate and clothing insultation for the PET calculation. The values of PET are computed using an open software RayMan Pro (Matzarakis et al., 2007), and the PET classification is followed the adjusted scales for the tropical regions from Lin and Matzarakis (Lin and Matzarakis, 2008). Next, multi regression of interferential analysis is administered to determine how each climatic parameter (independent variable) contributes to the PET values as this statistical technique can allow this study to examine the linear relation between more than one independent variable and the dependent variable at the same time (Lavrakas, 2008).

For the second independent variable (psychological perception), responses derived from subjective survey are analyzed by simple descriptive analyses (frequency, central tendency and variation) in a Statistic Package SPSS to give an exploratory of overall thermal sensation and acceptability of thermal conditions in the outdoors of Phnom Penh.

The data gathered from the two independent variables described above are subsequently used to calculate the dependent variable, the outdoor thermal comfort. Therefore, a statistically descriptive comparison between the PET values and overall acceptability of thermal conditions is executed to understand the similarities or differences of thermal conditions that are derived from the climatic-based observation and psychological survey. After the comparative analysis, logistic regression is applied to look at the relation between the moderator variable (physical adaptation which is a binary nature of data) and the overall acceptability of thermal comfort. The result of the logistic regression function explains to what extent the moderator variable has an effect on psychologically thermal comfort in outdoors. The research analysis methods are illustrated summarily in ***Table 3***.

Table 3: Data analysis methods

Research questions	Variables and sub-variable	Type of data	Methods	Tools
1. How do urban climatic parameters affect the outdoor thermal comfort in Phnom Penh?	Air temperature Wind velocity Relative humidity Mean radiant temperature Metabolic rate Clothing insulation	Quantitative	Physiological Equivalent Temperature (PET) index and Multi Regression	RayMan Pro and Statistic Software
2. How do psychological thermal perceptions express outdoor comfort condition in Phnom Penh?	Experience Thermal sensation Preference		Descriptive analysis	Statistic Software
3. How to explain the differences and similarities of comfort conditions between climatic parameters and psychological perceptions?	Physiological thermal comfort (obtained using methods from research question one) Psychological perception Physical adaptation		Descriptive comparison and Logistic Regression	Statistic Software

3.3 Expected Challenges and Limitation

For this thermal comfort observation, there are a few foreseen challenges that can impact on the outputs of the study. Since the schedule of the field survey have been planned, the unprecedented condition of unsuitable weather (rain and strong wind) could occur any time within the specified period. That would bring some implications which turn to affect both objective and subjective results. Another challenge is that Phnom Penh has been under the threat of the coronavirus. Surveying human perception in person during the strange situation is unlikely easy to be carried out while less people spend time in outdoors and the norm of social distancing is active. To ease the challenge, electronic questionnaire is circulated to selected respondents. Due to a lack of available climatic data and a limited time frame for the field survey, the observation of thermal comfort conditions at outdoor spaces in Phnom Penh is unable to cover a long-time span. It is limited the study to understand various thermal conditions in outdoor in different seasons (dry and rainy).

Chapter 4: Presentation of data and analysis

This chapter elaborates on the findings of physiological thermal comfort using the PET index based on the climatic parameters and psychological responses from the outdoor users regarding the outdoor thermal environment in Phnom Penh. Moreover, a comparative analysis between the PET results and the psychological perception is summarised and highlighted the differences that provide an in-depth understanding of the thermal condition in reality. Lastly, the study attempts to prove the moderating effect of physical adaptation on psychological thermal comfort in this chapter.

4.1 Results of Outdoor Climates and PET

4.1.1 Outdoor climate parameters

The research was conducted field surveys in three open squares which are Royal Palace, Botum Pagoda park and Olympic Stadium open space in the city centre of Phnom Penh, as described in the previous chapter. For these squares, physical measurement was carried out for six days (two days per place) from 9:00 am to 5:00 pm, using the heat stress WBGT meter and the anemometer to capture all necessary climatic data. Following a manual record every 60 minutes, 54 records were collected for each climatic parameter (or 216 record in total) throughout the 6 days of the field survey. The study simple attempts to present the overall microclimate in the city, without concentration upon the climatic condition of each square. Thus, the dataset collected at the three outdoors was combined and calculated to estimate the hourly average of each climatic parameter.

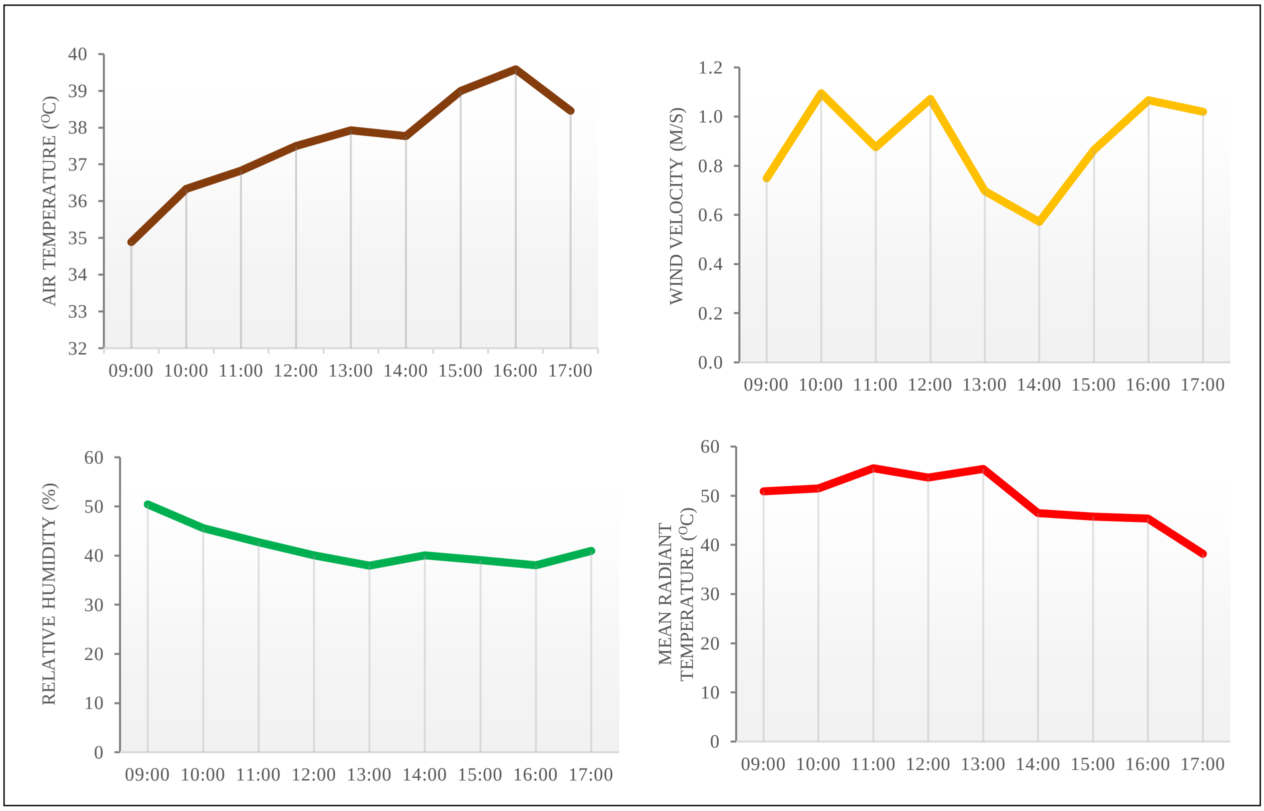
Photograph 2: Climatic measurement at the selected squares

The statistical summary of outdoor climate parameters—including air temperature, wind velocity, relative humidity and mean radiant temperature—is provided in ***Figure 2***. It is clear that the overall outdoor climate conditions in Phnom Penh were considerably hot and humid as the outdoor environment was with a high level of air temperature, mean radiant temperature and humidity. In contrast, the wind velocity during the observation was relatively low.

The four climatic parameters differed in patterns during measured days from 9:00 to 17:00. Variations of air temperature tended to slightly cool in morning then hot in afternoon, with a mean temperature around 37.5 ^{O}C. From 9:00 to 11:00 in morning, the temperature was fairly below the average, and it continued rising to 37.9 ^{O}C at 13:00. There was a big jump between 14:00 and 16:00 when it reached the hottest temperature at 39.5 ^{O}C. Then it began cooling off at 17:00. The pattern of wind velocity, on the other hand, was evidently fluctuated over the period observed. The average wind speed in the city was 0.9 m/s which is very light air. The maximum speed was up to 1.1 m/s. There were likely no light breezes flowing through the urban canopy. There is also a notice that in early afternoon, from 13:00 to 14:00, the wind was almost calm.

However, ***Figure 2*** illustrates the downward trend of humidity. At the earliest morning of recording time, the highest percentage of humidity was recorded. With the rising air temperature, it is seen that the relative humidity decreased slowly to 40%. And, the level of humidity in the atmosphere was back to slightly increase when the temperature went down in the late afternoon. The results show a negative relationship between the relative humidity and air temperature, which warming during sunrise and cooling off during sunset. As the field survey was organized in non-shade conditions and the instruments were places 1.1 meters above concrete surfaces, values of mean radiant temperature were very high, according to the MRT line graph. Most radian temperatures were greater than 50 ^{O}C. Although the decline started from 14:00, the temperatures were not down below 35 ^{O}C. With the high range of MRT, thermal distress can emerge, in particular exposing human heat equilibrium. Variations of MRT may be the result of the local urban structure which has potential for radiant flux.

Figure 2: Outdoor climatic parameters (T_a, V, RH and MRT)



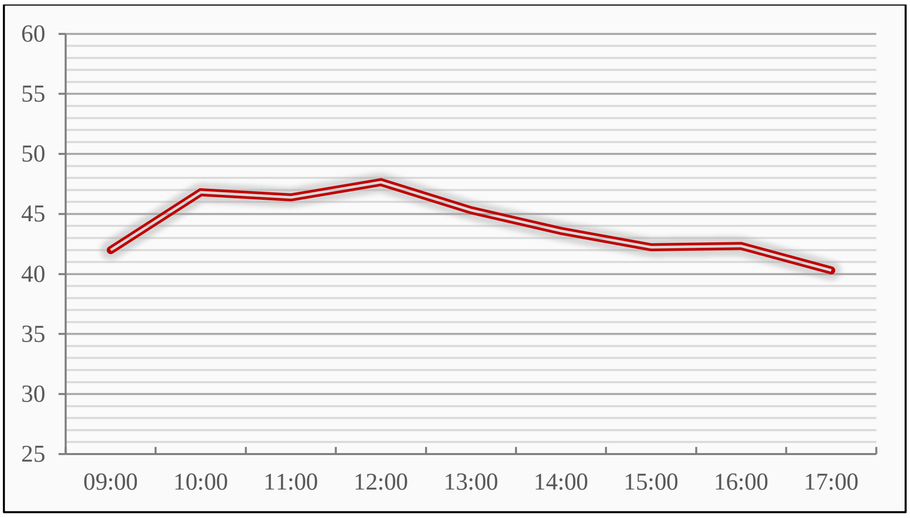
4.1.2 Thermal comfort based on PET analysis

The physical thermal condition measurements were carried out at the three locations in order to obtain the actual values of PET for the urban thermal environment. All the climatic parameters (air temperature, wind velocity, relative humidity and mean radiant temperature) were input data for calculating the Physiologically Equivalent Temperature (PET) in the Rayman Pro software.

Metabolic rate and clothing insulation were also added in this computing process while the rate of them was determined based on the consensus standard of ASHARAE 55-2004 (ASHARAE, 2004). During the interview, the majority of engaged respondents were sitting and standing to answer the questionnaire. The metabolic rate for the sort of walking and relaxing activity was, therefore, taken to be 1.2 met (or equal to 70 W/m^2). Following the field observation, almost 50% of participating outdoor users attired in trousers and long-sleeve shirt even on shining day. The average value of clothing insulation was indicated to be 0.61 clo.

PET values obtained from the PET analysis are exhibited, as seen in ***Figure 3***. During the measurement time between 9:00-17:00, the average PET value of the three locations generally exceeded the range limit of thermal comfort which is between 26 ^{O}C - 30 ^{O}C (Lin and Matzarakis, 2008). The amount of PET at each hour was not lower than 40 ^{O}C. On the comfort scale, it indicates that the thermal comfort condition of the areas was remarkably low. Moreover, it should be noticed that the PET values during the time of 10:00-12:00 reached the top of 47, greatly surpassed the rage limit of no thermal stress. Otherwise, the values fell steadily in afternoon until the lowest of 40 at 5:00 pm.

Figure 3: Result of physiologically equivalent temperature (PET)



The similarity of the PET trend and that of all climatic parameters, on the other hand, should be highlighted. As illustrated in ***Figure 2*** and ***Figure 3***, it is apparent that the pattern of PET seems to be comparable to the MRT pattern. The highest values of them were found during the period of 10:00-12:00. For instance, at midday, the highest PET value reached a peak of 46 ^{O}C, meanwhile, the MRT rose to the highest at 11:00. Likewise, both patterns started declining gradually after midday until reaching the lowest level at 5:00 pm. The similarity indicates a significant association between MRT and the physiological thermal condition depending on the PET calculation, whereas the other climatic parameters represented less consistent with the variation of PET during the measurement duration.

Although the overall condition of thermal comfort in the city was very hot and far exceed the limit range of thermal satisfaction, the duration of climatic measurements (9:00 am to 5:00 pm) should be taken into consideration. Meanwhile, this thermal observation was excluded the climatic situation during night-time, which the average temperature is normally cooler than that of daytime. The study concentrated merely on daytime because it is the most consuming time of open spaces.

4.1.3 The association between climatic parameters and the PET result

After the outdoor weather data and the outdoor PET condition were presented and described, this section would like to discuss beyond that. Correlation and multiple regression analyses were used to understand the distribution between the climatic parameters (air temperature, wind velocity, relative humidity and mean radiant temperature) and the outdoor PET values. The statistical outputs, furthermore, is able to indicate which climatic parameter has the greatest effect on the variation of physiological thermal comfort.

A significant relationship between MRT and PET was detected according the Pearson correlation matrix shown in ***Table 4***. The correlation coefficient (r) of the two variables was .514, with the significant level of < 0.001 ($p < 0.001$). $r > 0.7$ is considered a strong correlation, $r < 0.3$ are deemed a weak correlation and when r is between 0.3 and 0.7, the correlation is noted a moderate one, based on (C.Cronk, 2008). So, the correlation of 0.514 between MRT and PET was a moderate positive correlation. It means that higher MRT tends to moderately increase the value of PET. Also, it indicates a significant linear relationship between the two variables. It is interesting that the other climatic parameters (air temperature, wind velocity and relative humidity) are not statistically related to PET, However. The correlation coefficients of them with PET, in addition, have a significance level greater than 0.05. It proves that there are not statically significant.

Table 4: Correlation between climatic parameters and PET

		T_a	V	RH	MRT
PET	Pearson Correlation	.060	.031	-.163	.514**
	Sig. (2-tailed)	.669	.825	.240	.000
	N	54	54	54	54

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

A multiple linear regression analysis was performed in SPSS to seek a statistical model that predicts the variation of PET (the dependent variable) based on the climatic parameters. The four climatic parameters were denoted as predictors engaging in the regression analysis even though air temperature, wind velocity and relative humidity were found uncorrelated with the PET result. In the multiple regression, the addition of the uncorrelated predictors may improve the prediction of PET values because they can be related to other predictors (Thompson and Levine, 1997). The output of the multiple regression analysis produced three important tables, illustrating the result of the model. These tables include model summary, ANOVA and coefficients. The explanation of each table is described as follows.

The model summary shows in ***Table 5***. The value of R Square (R^2) in the prediction model is 0.32. It has known that R^2 in the regression analysis represents the proportion of the variance in the dependent variable (PET values) that can be contributed by the variation in the independent variables (climatic parameters). Therefore, it means that 32% of the variation in PET can be explained by differences in the climatic parameters in the model. In addition, the standard error of the estimate (4.44687) gives a margin of error for this prediction.

Table 5: Model summary for the prediction of PET

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate

1	.567	.321	.266	4.44687

Table 6 shows the ANOVA analysis output. It determines the overall significance level of the predictors in the model. It is apparent that the significant value is 0.001, which is less than 0.05. Therefore, it indicated that the predictors were able to account for a significant amount of the variance in PET, $F(4,49) = 5.79$, $p < 0.05$, $R^2 = 0.321$.

Table 6: ANOVA summary of PET

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	458.103	4	114.526	5.792	.001
	Residual	968.957	49	19.775		
	Total	1427.060	53			

The coefficient table was used to figure out the contribution of each predictor variable to the model. By going through the row of each predictor variables shown in ***Table 7***, it indicates that only the MRT predictor has a significant value less than 0.05 ($p < 0.05$). It means that the coefficient of the predictor is greater than zero. MRT is able to account for a statistically significant variance of PET. However, the coefficient of other predictors (air temperature, wind velocity and relative humidity) is not significantly different from 0 because the p-value of each is greater than 0.05. On the other hand, the B value of MRT in the unstandardized coefficients column shows a positive association. In other word, the value of MRT increases, the value of PET also increases. The B value of MRT (0.273) signifies how much the value of PET changes given a one-unit change in MRT, holding other variables constant. Therefore, the equation of the prediction model was performed as $Y_{PET} = 91.625 + (-1.113*\text{air temperature}) + (-7.35*\text{wind velocity}) + (-0.440*\text{relative humidity}) +(0.273*\text{MRT})$.

Table 7: Coefficients of PET

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	91.625	37.096		2.470	.017
	Air temperature	-1.113	.697	-.524	-1.597	.117
	Wind velocity	-7.35	1.664	-.060	-.442	.661
	Relative humidity	-.440	.270	-.547	-1.631	.109
	MRT	.273	.069	.516	3.992	.000

In short, a conclusion can be drawn based on the results of the statistical analyses described above. It is statistically apparent that among all climatic parameters only, the mean radiant temperature had a significant association with the variance of PET. Meanwhile, the relationship of air temperature, wind velocity and relative humidity with the PET was found no significance. Comparing with the other parameters, MRT has a major role that is able to shift (elevating or lessening) the physiological thermal comfort in outdoors, particularly the thermal comfort condition calculated through the PET model.

4.2 Results of psychological perception of the outdoor thermal comfort

4.2.1 Overview of data and respondents

A total of 172 responses were compiled via face-to-face interviews during the three-week survey at the three different open squares (Royal Palace park, Botum Pagoda park and Olympic Stadium open space) in Phnom Penh capital city. According to ***Table 8*** giving a statistical summary of outdoor respondents, 77 respondents were interviewed at Royal Palace park while a marginally smaller number of respondents were from Botum Pagoda park (50) and Olympic Stadium open space (45). A notice should be taken that although there is no equivalent number of respondents from each place, none of the sites contributes less than 25% of the total responses. The number of respondents involved in the study is considerably higher than the sample size required to represent the entire outdoor users, as detailed in chapter 3.

Moving to the gender proportion, there is a favourable contribution to this survey. the number of male and female respondents engaging in the interview are almost equal, 89 and 86 respectively; they were between the age of 16 to 60 years old, with an average of 32 years old. Over a half of all respondents, in addition, have lived in the city longer than 3 years and just 9.7% are recorded their living duration shorter than a year.

Table 8: Summary of outdoor respondents

Number of samples		**172**
	Royal Palace park	77
	Botum Pagoda park	50
	Olympic Stadium open space	45
Gender	Male	88
	Female	84
Age	Mean	32
	Minimum	16
	Maximum	60
Experience living in the city	< 1 year	9.7%
	>1 – 3 years	32.6%
	> 3 years	57.7%

4.2.2 Psychologically thermal sensation and Preference

Studying on thermal comfort has been suggested, according to the literature review, to take into account both physiological and psychological aspects. A physiological-based observation alone is likely to be difficult to offer a comprehensive insight into thermal comfort conditions. Thermal comfort literally concerns with the human satisfaction of the outdoor thermal environment. Furthermore, the degree of satisfaction can vary depending on individual experience, thermal sensation as well as adaptive behaviour. Human psychological response is also needed to investigate in order to determine outdoor thermal comfort. With this regard, this study inquired 172 outdoor users to vote the overall thermal sensation on a 7-point ASHARAE scale and specified sensation votes for each climatic parameter on a 5-point scale. In addition, thermal preference was also questioned on a 5-point scale to reveal their satisfied thermal condition. Consequently, descriptive analysis was performed in SPSS software to analyse and visualize the collected data. The purpose of this statistical test is to derive an overview of thermal sensation and preference of thermal condition in Phnom Penh.

Following the descriptive outcome of the overall thermal sensation, when all responses were asked to vote their own thermal sensation on a 7-point scale (-3 cold to +3 hot), 142 out of 172 responses (counted for 82.6%) confirmed the overall thermal sensation was above the neutral level. Meanwhile, 65 responses felt warm and other 24 said hot, reflecting their surrounding weather. On the other hand, there were 29 responses who said the condition was neutrality for them. It is surprising that one response found it slightly cool. Overall, the result of thermal sensation demonstrates a majority of responses that are on the warm side of the scale (slightly warm to hot), with a small proportion of the neutral feeling. Since the overall thermal sensation was mostly voted warm and hot, 160 responses would like a slightly cooler weather condition to help them feel pleasant during the time outside. Conversely, there was a small portion (5.8%) that responses preferred it to remain unchanged because the current climatic conditions were satisfied, and only two respondents claimed the weather was needed to be slightly warmer. Responses to thermal sensation and preference for each climatic parameter were examined for an in-depth understanding. In particular, the comparative observation about subjective responses and climatic data was taken into account.

Figure 4: Overall thermal sensation votes

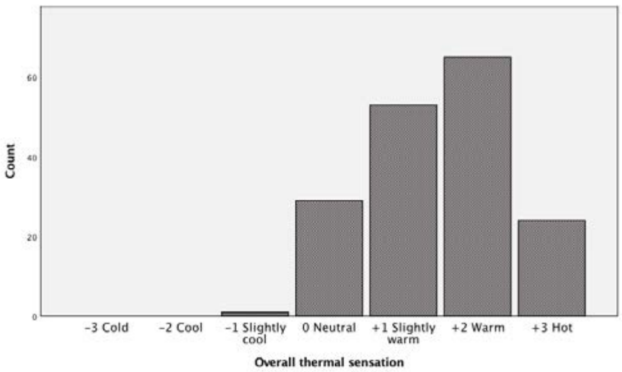
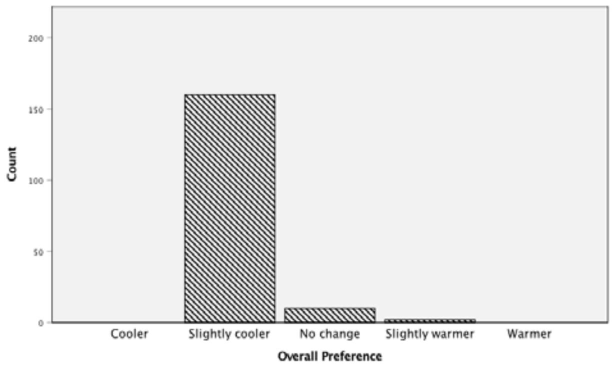


Figure 5: Overall preference votes



Air temperature

After concerning the overall thermal sensation, participants were questioned about their sensation and preference with respect to air temperature. The answer was supposed to mark on a 5-point scale. Based on the data collected, the highest proportion (72.5%) is distributed the outdoor users who experienced warm and hot, meanwhile, the percentage of respondents who felt neutral and cool are 27.9% and 0.6%, respectively. It is noted that this result is well correlated with the recorded values of air temperature. During the measurement time, the air temperature is considerably high between 35 ^{O}C and 38 ^{O}C and the mean of it is 37 ^{O}C. With the warm sensation, almost all the respondents (97.1%) wanted air temperature to be slightly cooler. The better climatic conditions will be able to make them happier during outdoor. In spite of that preference, there were 5 respondents who didn't prefer any changes as the current weather was nice for them. The number of no change votes is a small portion, compared with that for a slightly cooler condition.

Wind velocity

A 5-point scale (from -2 no wind to +2 windy) was utilized for the subjective assessment regarding wind velocity. Outdoor users were requested to identify their feeling. The survey results show that over half of the respondents (58.7%) voted little wind speed in open spaces, whereas 11% of them expressed it was windy during the survey. Moreover, the neutral level of wind speed was experienced by almost a quarter of them (29.7%). It should be noted this finding is not clustered just on the right side or the left side of the neutrality. The subjective votes are allocated all over the scale. The subjective votes were respectively scattered on the scale. Somehow it is unlikely to match with the wind speed data derived from the physical measurement, the results of which found the wind speed was very light and sometimes almost calm. Wind speed varied between 0.75 m/s and 1.02 m/s. With regard to the question of their preferential wind speed, greater than 90% stated that in order to improve the weather condition, they needed the wind speed to be slightly stronger. So, there might be light breezes flowing through the urban canopy. It would help them feel more comfortable.

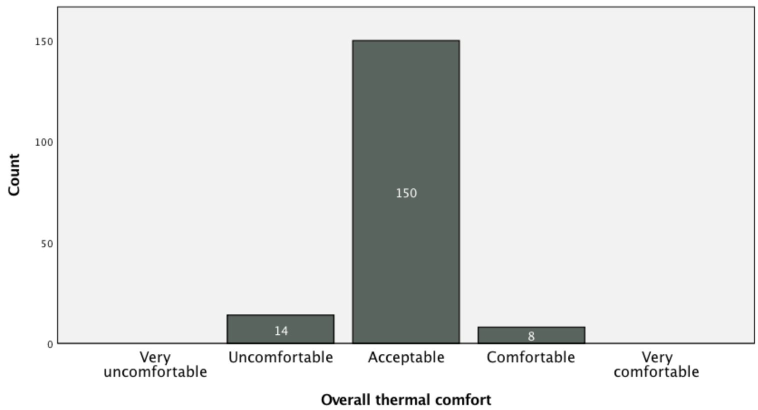
Relative Humidity

Apart from the individual sensation about air temperature and wind velocity, respondents were queried on a 5-point scale (too dry to very humid) to reveal their feeling about the humidity in the atmosphere. 64.5% of respondents expressed that the humidity condition of the areas was dry, while it opposed to a small portion of respondents (2.9%) who claimed that the condition was humid. Besides that, there were 56 voters (32.6%) who rated the humidity to be in the neutrality level. But, only 13.4% would like the humidity level to remain unchanged as they perceived the comfortable feeling under this weather condition. The highest percentage of respondents (85.5%) declared that they preferred it to be slightly damper because the low level of humidity in the surrounding atmosphere affected their comfortable sensation. The results of individual sensation regarding humidity turns out low consistency with the output from the physical measurement of recorded humidity data. The percentage of humidity in the atmosphere were between 40% and 50% which is classified in a comfort range, according to La Roche (2012).

4.2.4 Overall perception of thermal comfort in Outdoors

The level of thermal acceptability of the thermal environment in this study was signified as a dependent variable to assess the psychological perception (subjective) of outdoor thermal comfort, whereas the physiological comfort (physical) was derived through the PET model. With regard to the outdoor climatic condition, the respondents were enquired to express their overall thermal comfort. Their subjective responses were defined on a 5-point Likert scale—from -2 for very uncomfortable to -2 for very comfortable. Meanwhile, 0 (for acceptable) presents the state of neutrality that outdoor users do not prefer warmer or cooler temperatures as thermal discomfort is not detected. According to ***Figure 6*** showing overall thermal comfort, 150 respondents (87%) stated that the thermal comfort condition was accepted and 8 respondents (5%) experienced comfortable during their outdoor visit. The other 14 respondents (8%) rejected the statement that the outdoor condition was accepted and comfortable as this group encountered the uncomfortable experience. On the other hand, there was no vote for the rightmost (very comfortable) and leftmost (very uncomfortable) sides of the scale. It is apparent that thermal comfortable votes from the respondents gather only on the middle part of the scale. It indicates an accepted thermal condition although very small portions of comfortable and uncomfortable votes were identified.

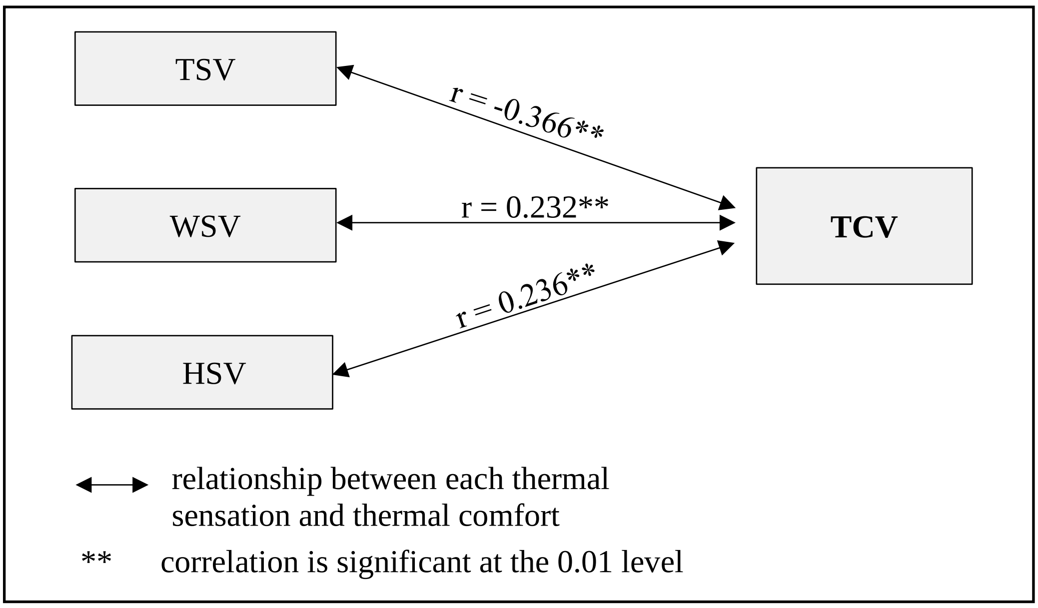
Figure 6: Responses of overall thermal comfort



After the exploration of overall thermal comfort, there was a following observation with respect to thermal sensation responses. That aimed to figure out the correlation between thermal comfort votes (TCV) and thermal sensation variables which included temperature sensation votes (TSV), wind sensation votes (WSV) and humidity sensation votes (HSV). Notedly, these variables were recorded in a form of ordinal data, so Spearman correlation analysis, which is a non-parametric procedure, was used to determine the strength of association among these ordinal variables.

The result of correlation analysis is presented in ***Figure 7***. It can be found that the thermal comfort (TCV) has significant relationships with TSV, WSV and HSV with p-value of 0.000, 0.002 and 0.002 respectively ($p < 0.05$). The temperature sensation (TSV) is noticed to have the most significant, negative relationship with a correlation coefficient of -0.366. This means that when the temperature sensation increases, the level of thermal comfort tends to decrease to uncomfortable conditions, and vice versa. The result, in addition, signifies a positive correlation of 0.236 between the thermal comfort and the humidity sensation, followed by the wind sensation with a correlation coefficient of 0.232. These relationships can be explained that the increase of the wind sensation and the humidity sensation contributes to the better thermal comfort condition.

Figure 7: Spearman correlation between thermal sensation responses and thermal comfort



4.3 Comparative analysis on the PET values and psychological perception

According to the physiological assessment of the chosen open squares in the capital Phnom Penh, using the PET index, it can be deduced that the accepted condition of outdoor thermal comfort (lower than 34 ^{O}C) was not detected during the survey timeframe (9:00 am – 5:00 pm). The physiological thermal comfort with the approximate environment was in the critical conditions that can cause strong and extreme physiological stress, whilst the results of PET persisted above 40 ^{O}C—with a thermal sensation range of hot and very hot. Relatively, the condition far exceeded the comfortable range according to the modified PET range by Lin and Matzarakis (2008). Furthermore, the statistical observation in this focus reveals that solar radiation in the atmosphere has a significant correlation with the variation of thermal comfort. Due to a high amount of solar radiation, the period from 10:00 to 13:00 was found to have the poorest thermal comfort as the climatic data shown. The lessened solar radiation between 15:00 and 17:00 resulted in the improved condition of thermal comfort (down to the lowest at 40 ^{O}C).

The questionnaire survey, on the other hand, was conducted simultaneously with the climatic measurement, aiming to observe the individual perception of thermal sensation as well as thermal comfort in the outdoors of Phnom Penh. According to the findings from the subjective evaluation, most of the participating respondents claimed that they felt warm and hot during outside. The responses expressing their own sensation appear to be in line with the actual climatic condition (hot and humid). A large number of respondents wished to be in a slightly cooler condition that would make them feel more comfortable during their outdoor visit. Following that, when they were asked to define their acceptability regarding the climatic condition, the results turned out with surprises. A considerable number of respondents (92%) expressed that the overall thermal comfort condition in the outdoors was acceptable and comfortable.

Depending on the outcomes from the subjective assessment of individuals with respect to the thermal environment in urban outdoors and from the calculated PET values based on climatic parameters, this research reveals a substantial difference between both evaluating approaches. The results of the subjective assessment indicate that, although the actual condition is proven uncomfortable by the PET analysis, the accepted thermal condition from the subjective votes do exist. The majority of participating respondents declared that the outdoor thermal environment was accepted. Therefore, a conclusion can be drawn that the accepted level of the outdoor users surpasses the PET range limit of acceptable thermal comfort, which was reclassified by Lin and Matzarakis (2008). In other word, the outdoor users are seen to be more tolerant or be intimate to the hot thermal environment, in which people have years living experience. That makes people seem familiar with the temperate weather.

Besides a pure focus on the strong influence of climatic factors on human thermal sensation, the literature review suggests the important role of physical adaptation—including individual adaptive behaviour and spatial characteristics of the areas—in outdoor human thermal comfort. Adaptive characteristics of individuals adapting to a dissatisfied microclimate, in fact, are able to adjust their psychological state of comfort differently. Spatial characteristics accommodated in local outdoor also play a role in impacting human perception regarding thermal comfort. To understand that, the following section is going to explore the moderating association between physical adaptation and human thermal comfort votes.

4.4 Moderating effects of Physical adaptation in human thermal comfort

As mentioned in the conceptual framework with the theoretical base, physical adaption in this study has a role as a moderator variable that affects the relationship between the independent variable (psychological thermal sensation, i.e. thermal sensation, experience and preference) and the dependent variable (the psychological thermal comfort). Adding to the observation of psychological perception regarding thermal comfort, this part attempts to determine the moderating effect on the relationship between the dependent variable and the independent variables. Hierarchical binary logistic regression using SPSS was performed based on the outdoor users' responses to the four questions, concerning applied solutions to maintain individuals' thermal comfort and the effects of the local spatial setup surrounding the areas (openness and greenery). All included variables in the analysing process are detailed as follows:

- The dependent variable (Y): the psychological thermal comfort
- The independent variables (X): the overall thermal sensation, preference and duration living in the capital
- The moderator variables (M): individual adaptive behaviour, the effects of openness and the effects of greenery

Binary logistic regression is a suitable method for a dichotomous dependent variable (with only two categories). However, the thermal comfort of the outdoor environment (the dependent variable) in the observation was in a type of ordinal variable with a 5-point Likert scale that, in fact, violated an assumption of binary logistic regression. In order to apply this inferential method, the dependent variable was transformed into a dummy variable, 1 for acceptable and 0 unacceptable. On a 5-point scale those responses from 0 to +2 were converted to 1 (acceptable) while the rest were coded as 0 (unacceptable). In addition, the responses about individual behaviour were also transformed into dummy variables (yes/no) as the question was set in the form of multiple choices.

In order to test the influence of the moderator variable, two blocks (or two steps) were set in the process of the hierarchical regression model. The logistic regress in Block 1 took into account only the relationship between the independent variables (X) and the dependent variable (Y). Subsequently, the moderator variables (M) entered in the regression of Block 2 that also included the independent variables to predict the value of the dependent variable. The modification in the relationship from Block 1 to Block 2 can interpret the effect of the moderating variables.

Table 9 illustrates the summarized results evaluating the model when all predictors (X and M) were involved. The table contains values of Chi-square (equivalent to f-value in linear regression), which is a test of the null hypothesis when all of the regression coefficients are equal to zero. When Block 1 and Block 2 have significant amounts of prediction ($p < 0.001$), the comparison of the Chi-square values should be considered. With the 3 degrees of freedom (3 independent variables), the Block 1 Chi-square is 21.628. Yet, the value of Chi-square increases to 55.109 in Block 2 after the moderator variables entered the model with the independent variables. It indicates that the regression in Block 2 fits the data better than the regression in Block 1 without the moderator variables.

Table 9: Omnibus tests of model coefficients

	Chi-square	df	Sig.
Block 1	21.628	3	.000
Block 2	55.109	8	.000

Modal summary, as seen in ***Table 10***, shows how well the applied logistic regression model fits the data. The table contains the value of -2 Log likelihood (-2LL) and pseudo-R2 for Block 1 and Block 2. Comparing the results in Block 1 and Block 2, there is a significant decrease in the value of -2LL, fallen from 75.436 to 41.955. Thus, the regression model in Block 2 with 8 predictors (X and M) included represents a significant improvement and fit over the regression model in Block 1 with only the independent variables.

Table 10: Modal summary of the overall acceptability of outdoor environment

Block	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	75.436	.118	.274
2	41.955	.274	.636

The value of R^2, not distinct from R^2 in linear regression, indicates the rough estimate of the variance in the psychological thermal comfort that can be predicted from the combination of predictors. Focusing on Nagelkerke R^2 which is able to achieve a range value from 0 to 1, there was an increase in the R^2 values between Block 1 and Block 2. Block 2 with the addition of physical adaptation (M) brings the value of R^2 from 0.274 to 0.636. It refers that 63.6% of the variance in the psychological thermal comfort (Y) can be explained by differences in all engaged predictors (X and M). Therefore, it can be assumed that the increased amount of R^2 results from the distribution of M in the model.

The final output of the regression analysis is presented in the table of variables in the equation, shown in ***Table 11***. Regression coefficients (B) of all predictors (X and M) are illustrated in the table to indicate the amount of change in the log odds (Y) for a one-unit change in the predictor variable, with other predictors in the model held constant. The logistic coefficients are likely similar to linear coefficients in order to generate the predicted values of a dependent variable. The amount of coefficient close to 0 indicates no effect on the variance in the dependent variable. According to Jaccard (2001), there is an interaction effect in a logistic regression model when the effect of an independent variable changes based on the amount of a third variable, known as the moderator variable.

Table 11: Variables in the binary logistic regression equation

Variables	Block 1		Block 2	
	B_1	$Sig._1$	B_2	$Sig._1$
Duration	-.075	.865	.413	.518
Thermal sensation	-1.746	.000	-2.562	0.006
Preference	-.610	.449	17.411	.998
Wearing hat	--	--	55.642	.998
Using umbrella	--	--	75.108	.998

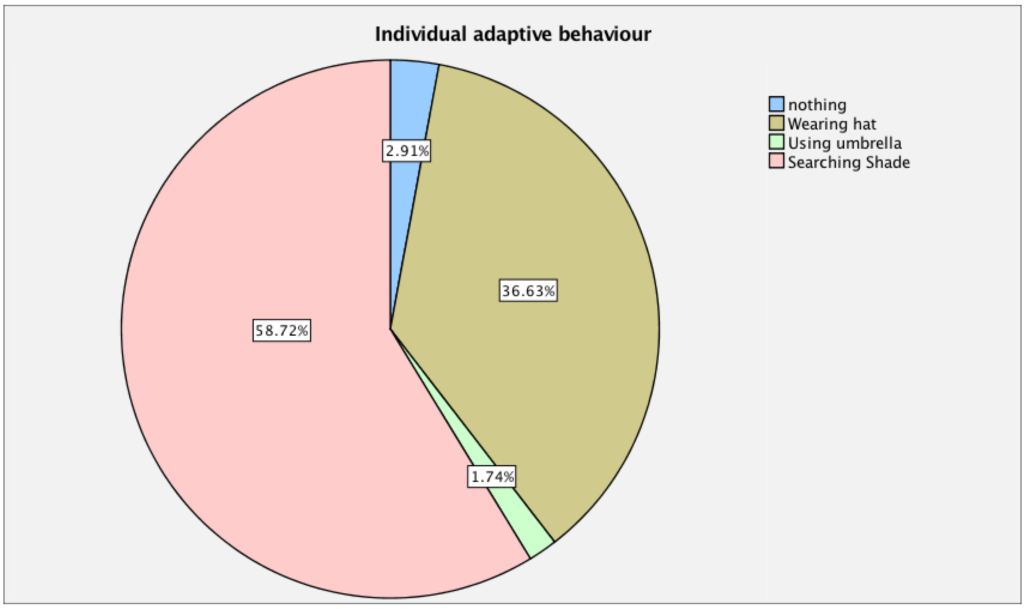
Searching shade	--	--	56.211	.998
Effects of openness	--	--	3.242	.035
Effects of greenery	--	--	1.870	.045
Constant	5.557	0.02	-35.213	.998

For instance, the logistic coefficient of thermal sensation in Block 1 (B_1) is -1.746 while it is significantly associated with the thermal comfort ($p<0.05$). After the moderator variables (M) enter Block 2, it can be seen that the coefficient value of thermal sensation (B_2) is reduced to -2.562. Besides the thermal sensation variable, the coefficient of the other predictors (duration and preference) are also moderated in Block 2. It indicates an interaction effect that does occur in the model. The coefficients of the independent variables are moderated by the moderator variables. Therefore, the statistical findings are able to prove that physical adaptation (M) significantly moderated the association between psychological thermal perception (X) and the thermal comfort of the outdoor environment (Y). The important role of physical adaptation can be recognized for enhancing the individual acceptability of the outdoor environment.

4.4.1 Impact of individual adaptive behaviour

During the survey, the adaptive behaviour of individuals was observed and noted what solution the engaged respondents applied to adjust their thermal sensation in the hot and humid environment. ***Figure 8*** reveals that searching shades (most of which are tree shades) is the largest percentage of responses as 58.72% of the respondents were sitting and standing under shades during the field survey. It was followed by the measure of wearing hat (36.63%). There was a very small portion of respondents (1.74%) who used umbrella to avoid the direct impact of sunlight which would cause heat stress. According to the field observation, 2.91% bore themselves with the outdoor weather, without applying any adaptive solutions. The findings of this investigation suggested that it is foremost important to furnish more shades in open squares for people. They may be able to enjoy more in the outdoors during their visit.

Figure 8: Percentage of individual adaptive behaviour



Depending on the statistical findings using the logistic regression model above, individual adaptive behaviour (comprising 3 dummy variables: wearing hat, using umbrella and searching shade) fails to predict the thermal acceptability of individuals, even it was alone or with the other predictors. As the p-value (represented by Sig. in ***Table 11***) of each variable was close to 1, the effect of the observed variables almost indicates the strong evidence for the null hypothesis, no relationship. It suggests that individual adaptive behaviour does not have significantly affect the outdoor thermal comfort of individuals.

4.4.2 Impact of spatial characteristics

Spatial characteristics play a role as an interactive physical adaptation in the context of outdoor thermal comfort (Lenzholzer et al., 2018). The characteristics set up in urban squares have some influences on psychological perception which, in turn, tends to modify individual thermal comfort (Nikolopoulou and Steemers, 2003). That can indirectly expose people to a worse thermal condition or make people adapt to the built environment (Nikolopoulou and Lykoudis, 2006). Without including all spatial characteristics, the study emphasises openness and greenery accommodated in the selected open squares. The respondents were asked about spatial perception regarding openness and greenery. Besides that, the survey also attempted to relate their spatial perception responses to outdoor thermal comfort.

According to the survey findings, the percentage of 88.6% of respondents stated that the openness of the open squares was good while 9.7% expressed the areas too wide for them. The too narrow openness of the places was reported by just 1.7%. With that the built environment, almost everyone (95.4%) agreed that the designed openness of the outdoors affected their thermal comfort votes. Moving to the greenery focus, the selected areas, representing the outdoor condition in the capital, were noted less green by 96% responses and 4% voted very green. In fact, there are some trees and green grasses providing shades and cooling the air through the process of evapotranspiration in the areas. 80% of the participating respondents, in addition, declared that the amount of greenery in the places can impact the level of their thermal comfort. Likewise, the responses regarding the openness and greenery of the proximate spatial setup had a positive, significant effect on outdoor thermal comfort, as seen in the statistical analysis in ***Table 11***. The findings suggest that the thermal comfort condition can be improved by providing a spatial setup with better openness and more greenery in outdoors. Therefore, people with a comfortable sensation will enjoy their outside visit and spend more time for outdoor activities.

Dwelling in the warm environment between a temperature range of 34 ^{O}C and 39 ^{O}C, the respondents were asked to know their preferable spatial setup that is able to improve the thermal comfort of individuals when they were in outdoors. Following the responses, increasing vegetation and green materials as well as providing more shades in open squares are much needed to help outdoor users adapt to the ambient condition. Meanwhile, a number of respondents would like a spatial setup accommodating with more blue spaces and aesthetic landscapes. That is expected to reduce heat stress during warm day outside. Indeed, green space and blue space (both natural and man-made) are commonly recognized as cooling effects on urban thermal environment to improve the quality of outdoor life in cities.

4.5 Discussion

The PET result based on the climatic parameters in the selected open squares representing the outdoors in Phnom Penh capital city indicates that the overall evaluation of outdoor thermal comfort is in the grade of strong and extreme heat stress. An acceptable condition of thermal comfort (PET between 20 ^{O}C to 30 ^{O}C) did not exist during the measurement time from 9 am to 5 pm. In addition, the worst thermal condition was detected over the period of 10 am to 12 pm due to the high amount of solar radiation. The thermal condition from 4 to 5 pm, however, was better compared to that of other times during a day when the PET values were down to the lowest. The thermal environment occurred in the late afternoon because of the decreased amount of solar radiation.

According to the statistical analysis of climatic parameters that affect the PET result, the study found that the change of PET values was mostly influenced by mean radiant temperature. The positive association between MRT and the physiological thermal index PET was observed (section 4.1.3). Based on the illustration of the PET result and MRT during the survey time, the both hit the peak at the same time (from 10 am to 12 pm) and they started to fall steadily to the lowest level at 5 pm. In fact, the finding is literally consistent with the findings of previous studies (Lin and Matzarakis, 2008; Makaremi et al., 2012; Mayer et al., 2008). Those studies indicate that mean radiant temperature has a strong influence on the outdoor conditions of thermal comfort, in particular the observations based on the thermal index PET. Moreover, the analysis of the present study also supports the study of Makaremi et al. (2012) which demonstrated that the significant effects of air temperature, wind speed and relative humidity on the variation of thermal comfort values were not found when using the PET. It does not fit with the theory stating that air temperature, wind speed and relative humidity have potential effects on thermal comfort (Foruzanmehr, 2018; La Roche, 2012; Ongoma et al., 2016). With this regard, there should be a note that the influence of each climatic parameter on the range of thermal comfort can vary depending on the selected thermal index.

Moreover, the overall thermal comfort of the outdoor spaces based on the psychological responses of people demonstrates the considerable difference, compared with the result derived from the physiological index PET. According to the questionnaire survey, the people using the outdoor spaces expressed that the thermal condition was acceptable, whereas they felt warm and hot and slightly cooler weather was their thermal preference to mitigate the thermal heat. However, it is noticed the psychological finding opposes the find from PET. The PET result indicated the strong and extreme heat stress of the outdoor thermal condition, yet the condition was acceptable according to most psychological responses. Therefore, the study can identify the tolerance of people to the hot-humid climate as most of them have lived in such climate for years. Similarly, the thermal observation in the city of Malaysia by Makaremi et al. (2012) also found a gap between the results of thermal comfort conditions from the PET index and the psychological sensation of individuals due to the influence of psychological adaptation.

In accordance with the literature review, the study also elucidates the influence of physical adaptation on the outdoor thermal condition. The statistical analysis using binary logistic regression proves and verifies the moderating effect of spatial characteristics on the individual vote of thermal comfort because the thermal sensation of individuals can be adjusted by the spatial setup in the chosen outdoors. In fact, a large number of respondents agreed that besides the potential influence of climatic parameters, the designed openness and greenery built in the selected outdoors can also affect the perception of thermal comfort. This result complements the finding of a past study in Dutch squares (Lenzholzer, 2012), revealing the association between different spatial structures and human thermal perception. The outdoor thermal condition can be enhanced, by adding more greenness, designing a proper openness and views of landscape within the dense urban setting. On the other hand, individual adaptive behaviour based on the field observation is found no potential effect on the variation of individual thermal comfort. The result demonstrates that individual activity such as wearing hat, using the umbrella or sitting in the shade cannot make them feel better with the surrounding thermal condition.

Chapter 5: Conclusions and recommendations

This chapter provides a concise conclusion of the study's findings that ascertain the research questions in relation to outdoor thermal comfort conditions. Furthermore, the study also brings some recommendations both for future research and urban policy.

The main objective of this research attempts to be aware of the thermal comfort condition in the Phnom Penh outdoor environment by taking into account both the physiological results based on climatic parameters (objective) and psychological thermal perception (subjective). Following literature review, both physiological and psychological influences are very relevant to uncover the thermal condition in urban squares. The research has also striven to explain the variations in thermal results derived from the objective and subjective influences. Another indication through literature review makes know that the responses of psychological thermal perception are moderated by physical adaptation. Therefore, the study has taken another step further to determine the moderating effect of physical adaption on the observation of individual adaptive behaviour and spatial characteristics.

The main research questions of the study are how do climatic parameters influence the outdoor thermal comfort, how do psychological thermal perceptions express the thermal comfort of the outdoor environment and how to explain the differences or similarities thermal conditions obtained from the physiological index and psychological perception.

5.1 Conclusion

Sub-question 1: climatic parameters and physiological thermal comfort

The finding evidenced that the overall microclimate of the outdoors in the capital Phnom Penh is hot and humid, with a high amount of air temperature (34 ^{O}C-49 ^{O}C), mean radiant temperature (38 ^{O}C-55 ^{O}C) and humidity (37%-50%). Meanwhile, the wind speed which typically has a potential effect to decrease the warm atmosphere, was almost calm and very passive, flowing through the urban canopy. With this hot-humid microclimate, the results of the Physiologically Equivalent Temperature index show that the thermal comfort condition in the outdoor environment is in the level of strong and extreme heat stress as the calculated PET values were much higher than the comfortable range reclassified for the tropical environment (PET < 30 ^{O}C). The most uncomfortable condition appeared during the time of 10:00 – 12:00. None acceptable condition existed during the survey time, but the thermal condition was gradually better at late noon (5:00 pm) after the sunset. Among all included meteorological parameters, solar radiation in the urban atmosphere can be deduced that it has a significant relationship with physiological thermal comfort. Changes of the thermal environment strongly depends on the level of solar radiation while air temperature, wind velocity as well as humidity insignificantly affect the thermal comfort.

Sub-question 2: psychological thermal perception and thermal comfort

Psychological responses from the questionnaire survey suggest that there is a noticeable difference between the thermal sensation of individuals depending on the microclimate, thermal preference and the level of thermal acceptability for the thermal environment. The subjective results of individual sensation clearly show that the weather condition in the outdoor is out of the neutral range. Most people encountered warm and hot during their outdoor visit while slightly cooler weather is anticipated to improve individual thermal sensation back to neutrality. However, even with the warm and hot sensation, the overall thermal condition of the outdoors is mostly acceptable. More than 90% of outdoor users expressed that the outdoor environment was accepted, although only 8% experienced uncomfortable. On the other, the study reveals that the psychological perception of outdoor thermal comfort is significantly distributed by sensation perception regarding climatic parameters. The thermal sensation regarding the outdoor temperature is regarded as the strongest influence on the degree of thermal comfort. It suggests that, in order to enhance the thermal comfort condition, the level of outdoor temperature should indeed be considered and contained to be in the neutral zone.

Sub-question 3: Comparation between physiological and psychological thermal comfort

There is a considerable difference between the thermal comfort condition resulting from the physiological index and the psychological perception. The comparison indicates a greater tolerance of the local outdoor users to the hot climate. Although the results of PET evidenced a critical state of thermal stress (PET > 40 ^{O}C), the thermal environment was still accepted by the local inhabitants, most of whom have lived in the capital for years. The living experience tends to make people familiar with the kind of climate. In addition to the climate effect, physical adaptation has a significant impact on the individual perception of thermal sensation as well as thermal comfort. In particular, the characteristics of spatial setup in the urban squares are capable of modifying the individual thermal comfort. Due to the surrounding spatial design, people may feel colder or warmer. In the tropical climate, the city should provide more shades, green spaces and blue spaces in open spaces as well as aesthetic landscapes in order to improve for a comfortable thermal condition that, in turn, can enhance the quality of urban life and promote outdoor activities.

5.2 Recommendations for further research

Following the limited timeframe, this research was conducted only at three open spaces selected in the capital to provide a generalized understanding of thermal comfort conditions. The selection was simply based on the difference in spatial characteristics. Further research is suggested to include a larger number of places so that the external validity of research on the overall outdoor thermal comfort can maximise. Satellite climate data can be utilized in a phase of site selection instead of a simple method for choosing interesting places. It assists to ensure that selected places with various climatic conditions are used to be representative. On the other hand, this study suggests that observing only daytime seems hard to detect a comfortable thermal condition, particularly in tropical areas. Thus, the collection of climate data for a whole day (daytime and night-time) and also in different seasons should be paid more attention. That complete observation can yield more accurate and interesting results.

It will be also interesting to conduct a further study that brings a concentration upon a comparison of thermal comfort conditions in different urban structures. In particular, determining the effects of green spaces, blue spaces and dense buildings on thermal comfort is encouraged to explore further. With this scientific evidence, findings of spatial distribution to thermal comfort in the urban environment can be very important suggestions for future urban development.

5.3 Recommendations for urban planning

The results of the study show the extreme condition of physiological heat stress in this tropical city. That level of heat stress can be marked as a serious environmental risk that negatively impacts human wellbeing. Heat-related illnesses, fatal risks and human performance reduction are possible to happen as the result of thermal discomfort in the ambient environment. From this study, solar radiation has been found to have a major cause of outdoor thermal discomfort rather than air temperature. To cope with an extreme thermal condition, this research also affirms that spatial characteristics have positive, significant impacts in moderating microclimate conditions. Therefore, adaptation strategies integrated into urban planning and design is foremost important to improve human thermal comfort as well as heat stress and additionally alleviate the unprecedented impacts of climate change.

The spatial preference that is suggested through the subjective survey leads to mitigation of the heat stress. There is much need for more greenness, shades and blue spaces in open squares where people engaged in pedestrian traffic and outdoor activities are directly exposed to hot temperatures, especially to a high radiant temperature. Indeed, the spatial preference can function as a guideline for urban planning to address the thermal-related concerns. Cities should grow with more greenery and shades because it plays a crucial role in reducing heat stress and mitigating microclimate conditions. That leads to enhance outdoor well-being. Due to evapotranspiration and shading effects, greenery has a significant influence on outdoor thermal comfort. The effect of tree shades during hot day is able to lessen radiant heat load and maintain wind movement in a favourable condition. Trees and vegetated surfaces through the evapotranspiration process can increase humidity to mitigate urban temperature while solar radiation is changed to latent heat (Perini et al., 2018). Greenspace, greenway, street tree, and urban forest can be interesting alternatives that should be considered in urban planning strategies for dealing with outdoor thermal comfort within the urban environment. But, the types and density of vegetation offer different cooling effects.

Moreover, the use of blue space in urban settings is considered a potential strategy for advancing the urban thermal environment, since blue space plays a role in the spatial distribution of heat release. With suitable solar radiation and wind flow, the water feature can facilitate the reduction of air temperature. The ambient temperature in the areas adjacent to water can be considerably decreased due to the cooling effect from the evaporative process (Mostofa and Manteghi, 2019). The cooling phenomenon will bring adverse advantages to mitigate microclimate conditions, including the enhancement of thermal comfort in the outdoor environment and the development of urban cool island. In order to boost the thermal comfort achieved, blue space in urban settings should be carefully planned because it can somehow result in reduced urban thermal comfort, especially in the hot-humid region (Ampatzidis and Kershaw, 2020).

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Annex 1: Research Instruments and Time schedule

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MSc. Urban Management and Development (UMD)
June 2020

Questionnaire for Outdoor users
Research topic: Outdoor thermal condition in the capital city Phnom Penh

I am Chandavin David, a Cambodian student in MSc. Urban Management and Development (UMD) at the Institute for Housing and Urban Development Studies (HIS) of Erasmus University of Rotterdam. The aim of the research survey is to observe thermal comfort conditions in the capital city Phnom Penh by selecting three open spaces to represent the city's microclimatic environment. The outputs of the current research will become a significant ground for urban planners and designers to manage this growing city. The sustainability of the built environment and urban wellbeing is ensured.

This current survey is a part of my master thesis in the data collection phase. To attain the research objective, I would like inquire you as an outdoor user about individual thermal sensation and relevant factors regarding the surrounding environment. It will take about 15 minutes for filling out the survey. We are ensured that all given information will be highly confidential, and it will be used for academic purpose only.

I am grateful for your understanding and cooperation.

Date: ____/____/_____ Time: ____:____ Location:

Part I: Personal Information

1. Gender: Female ☐ Male ☐ **Age**:

2. How long have you in Phnom Penh?
0.5 – 1 year ☐ >1 – 3 years ☐ >3 – 5 years ☐

3. What was your activity in the last 15 minutes? (choose one choice only)
Sitting ☐ Standing ☐ Light walking ☐
Medium activity ☐ High activity ☐

4. Respondent's clothing:
Trousers, short-sleeve shirt ☐
Trousers, long-sleeve shirt ☐
Trousers, long-sleeve shirt and plus jacket ☐
Knee-length skirt, short-sleeve shirt ☐
Knee-length skirt, long sleeve shirt ☐
Knee-length skirt, long sleeve and plus jacket ☐

Walking sports (short-sleeve shirt) ☐
Sweat Pants, long-sleeve sweatshirt ☐

Part II: Thermal Sensation

5. Please describe your current thermal sensation (7-point scale)

cold	cool	slightly cool	neutral	slightly warm	warm	hot
☐	☐	☐	☐	☐	☐	☐

6. How do you feel about

Air temperature

cold	cool	neutral	warm	hot
☐	☐	☐	☐	☐

Wind velocity

No wind	Little wind	neutral	windy	Very windy
☐	☐	☐	☐	☐

Humidity

Too dry	Dry	neural	humid	Very humid
☐	☐	☐	☐	☐

7. How would you rate the overall acceptability of the temperature now?

Very uncomfortable	Uncomfortable	Acceptable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

8. How would you prefer the climate in this place, in overall?

Cooler	Slightly cooler	No change	Slightly warmer	Warmer
☐	☐	☐	☐	☐

9. What are your preferences regarding to climatic parameters?

Air temperature

Cooler	Slightly cooler	No change	Slightly warmer	Warmer
☐	☐	☐	☐	☐

Wind velocity

Weaker	Slightly weaker	No change	Slightly stronger	Stronger
☐	☐	☐	☐	☐

Humidity

Drier	Slightly drier	No change	Slightly damper	damper
☐	☐	☐	☐	☐

Part III: Application of physical adaptation

10. To maintain your comfortable condition, which solution below is applicable to you now? (skip to another question if inapplicable)

Wearing hat ☐

Using umbrella ☐

Searching shade ☐

Other ☐ (please specify) ……………………

11. What do you think about the openness of this place?

Too narrow ☐ Good ☐ Too wide ☐

Does it affect your thermal comfort? Yes ☐ No ☐

12. What do you think about greenery within this place?

No green ☐ Less green ☐ Very green ☐

Does it affect your thermal comfort? Yes ☐ No ☐

13. What is your preferable spatial setup that make you adapt with the ambient condition?

Increasing vegetation and green materials ☐

Providing more shades ☐

Creating view on landscapes ☐

Increasing blue spaces ☐

Other ☐ (please specify) ……………………

End of questionnaire

Thank you so much!

Annex 2: Field Record of Climate Data

Date	Location	Time	Air temperature (^{O}C)	Wind velocity (m/s)	Relative humidity (%)	Global temperature (^{O}C)
26/06/2020	Wat Butum	09:00	35.50	0.61	51.40	50.30
		10:00	37.40	1.77	43.50	46.50
		11:00	35.40	1.51	46.10	46.20
		12:00	37.20	1.68	41.20	45.10
		13:00	37.50	0.83	41.10	46.30
		14:00	35.70	0.38	46.70	35.10
		15:00	35.00	0.34	47.05	34.75
		16:00	35.67	0.73	44.70	36.33
		17:00	33.73	1.69	58.87	34.03
27/06/2020	Royal Palace	09:00	33.20	0.78	53.80	37.10
		10:00	34.36	1.09	50.46	38.46
		11:00	35.93	0.41	44.83	40.50
		12:00	36.23	0.51	41.33	40.83
		13:00	37.93	0.60	36.33	44.43
		14:00	37.53	0.62	39.16	41.80
		15:00	38.96	0.83	39.33	41.10
		16:00	38.86	0.95	39.73	38.43
		17:00	37.16	0.94	41.10	35.73
28/06/2020	Olympic	09:00	35.57	0.7	46.23	40.93
		10:00	36.80	0.71	42.13	46.60
		11:00	36.67	0.92	43.17	45.90
		12:00	37.50	0.75	40.20	41.50
		13:00	38.15	0.95	35.90	46.90
		14:00	40.07	0.76	33.67	43.30
		15:00	39.03	1.4	36.53	41.43
		16:00	39.33	1.34	38.23	41.43
		17:00	38.30	1.3	40.00	44.30

Date	Location	Time	Air temperature (^{O}C)	Wind velocity (m/s)	Relative humidity (%)	Global temperature (^{O}C)
03/07/2020	Wat Butum	09:00	33.35	0.97	56.00	36.20
		10:00	33.87	1.81	53.97	37.90
		11:00	36.67	0.74	43.50	42.20
		12:00	38.37	0.90	39.97	46.00
		13:00	38.33	0.46	38.00	45.07
		14:00	37.53	0.71	44.63	41.30
		15:00	42.47	1.14	33.60	48.27
		16:00	43.17	1.62	32.13	46.77
		17:00	44.00	0.70	29.60	43.70
04/07/2020	Royal Palace	09:00	38.07	0.78	34.43	20.77
		10:00	39.47	1.09	36.67	40.83
		11:00	37.73	0.41	41.47	39.73
		12:00	37.77	0.51	40.57	40.77
		13:00	38.40	0.60	40.53	42.57
		14:00	34.10	0.62	52.40	37.70
		15:00	35.20	0.83	48.27	36.63
		16:00	34.60	0.95	49.00	38.07
		17:00	35.30	0.94	45.47	36.77
05/07/2020	Olympic	09:00	38.50	0.65	41.25	38.50
		10:00	41.20	0.1	32.85	41.20
		11:00	40.40	1.26	33.80	40.40
		12:00	39.50	2.08	36.30	39.50
		13:00	37.70	0.74	40.06	37.70
		14:00	38.25	0.34	36.85	38.25
		15:00	39.55	0.65	38.40	39.55
		16:00	41.63	0.81	33.56	41.63
		17:00	40.40	0.55	35.10	40.40

Annex 3: Output of PET Index

Date	Time	Ts	Ta	VP	RH	v	Tmrt	cloth.	activ.	PET
26.6.2020	09:00	50.8	35.5	29.6	51.4	0.61	68.8	0.61	100	53.5
26.6.2020	10:00	51.4	37.4	27.8	43.5	1.8	68.4	0.61	100	52.6
26.6.2020	11:00	52.6	35.4	26.4	46.1	1.5	69.8	0.61	100	51.8
26.6.2020	12:00	54.3	37.2	26	41.2	1.7	64.1	0.61	100	50.3
26.6.2020	13:00	58.6	37.5	26.4	41.1	0.8	60.3	0.61	100	49.7
26.6.2020	14:00	57.9	35.7	27.2	46.7	0.4	34.4	0.61	100	35.6
26.6.2020	15:00	52.9	35	26.4	47.0	0.3	34.5	0.61	100	35.2
26.6.2020	16:00	43.2	35.7	26.0	44.7	1.7	34.9	0.61	100	36.0
26.6.2020	17:00	39.7	33.7	33.7	58.9	1.7	34.9	0.61	100	34.3
27.6.2020	09:00	47.3	33.3	28.6	56.0	1.0	41.9	0.61	100	37.2
27.6.2020	10:00	47.9	33.9	28.4	54.0	1.8	49.1	0.61	100	40.1
27.6.2020	11:00	58.3	36.7	26.7	43.5	0.7	50.9	0.61	100	44.3
27.6.2020	12:00	59.7	38.4	26.9	40.0	0.9	58.8	0.61	100	49.5
27.6.2020	13:00	62.3	38.3	25.5	38.0	0.5	52.9	0.61	100	46.7
27.6.2020	14:00	57.0	37.5	28.7	44.6	0.7	47.2	0.61	100	43.1
27.6.2020	15:00	55.6	42.5	28.1	33.6	1.1	59.4	0.61	100	52.9
27.6.2020	16:00	50.6	43.2	27.9	32.1	1.6	55.5	0.61	100	51.8
27.6.2020	17:00	47.5	44.0	26.8	29.6	0.7	43.2	0.61	100	45.8
28.6.2020	09:00	50.6	35.6	26.7	46.2	0.7	49.2	0.61	100	42.7
28.6.2020	10:00	56.0	36.8	26.1	42.1	0.7	60.7	0.61	100	49.6
28.6.2020	11:00	57.1	36.7	26.5	43.2	0.9	61.5	0.61	100	49.5
28.6.2020	12:00	60.0	37.5	25.8	40.2	0.8	48.0	0.61	100	43.4
28.6.2020	13:00	58.4	38.2	23.9	35.9	0.9	61.8	0.61	100	50.7
28.6.2020	14:00	59.0	40.1	24.8	33.7	0.8	48.5	0.61	100	45.5
28.6.2020	15:00	51.4	39	25.5	36.5	1.4	47.1	0.61	100	44.2
28.6.2020	16:00	47.5	39.3	27.1	38.2	1.3	46.3	0.61	100	44.2
28.6.2020	17:00	41.4	38.3	26.8	40.0	1.3	57.1	0.61	100	48.2
3.7.2020	09:00	47.9	33.2	27.3	53.8	0.8	43.8	0.61	100	38.2
3.7.2020	10:00	51.4	34.4	27.3	50.5	1.1	40.4	0.61	100	37.2
3.7.2020	11:00	60.4	35.9	26.4	44.8	0.4	45.7	0.61	100	41.5
3.7.2020	12:00	60.8	36.2	24.8	41.3	0.5	46.8	0.61	100	42.1
3.7.2020	13:00	60.8	37.9	23.9	36.3	0.6	53.3	0.61	100	46.5
3.7.2020	14:00	57.7	37.5	25.2	39.2	0.6	48.0	0.61	100	43.5
3.7.2020	15:00	53.8	39	27.3	39.3	0.8	44.9	0.61	100	43.0
3.7.2020	16:00	48.2	38.9	27.5	39.7	0.9	37.6	0.61	100	39.7
3.7.2020	17:00	40.8	37.2	25.9	41.1	0.9	32.8	0.61	100	36.3
4.7.2020	09:00	47.9	33.2	27.3	53.8	0.8	43.8	0.61	100	38.2
4.7.2020	10:00	51.4	34.4	27.3	50.5	1.1	46.9	0.61	100	40.2
4.7.2020	11:00	60.4	35.9	26.4	44.8	0.4	45.7	0.61	100	41.5
4.7.2020	12:00	60.8	36.2	24.8	41.3	0.5	46.8	0.61	100	42.1
4.7.2020	13:00	60.8	37.9	23.9	36.3	0.6	53.3	0.61	100	46.5
4.7.2020	14:00	57.7	37.5	25.2	39.2	0.6	48.0	0.61	100	43.5
4.7.2020	15:00	53.8	39	27.3	39.3	0.8	44.9	0.61	100	43.0
4.7.2020	16:00	48.2	38.9	27.5	39.7	0.9	37.6	0.61	100	39.7
4.7.2020	17:00	40.8	37.2	25.9	41.1	0.9	32.8	0.61	100	36.3
5.7.2020	09:00	53.5	38.5	28.0	41.3	0.6	58.0	0.61	100	49.4
5.7.2020	10:00	64.8	41.2	25.7	32.8	0.1	43.4	0.61	100	42.8
5.7.2020	11:00	58.5	40.4	25.4	33.8	1.3	60.0	0.61	100	51.4
5.7.2020	12:00	54.9	39.5	26.0	36.3	2.1	57.8	0.61	100	49.4
5.7.2020	13:00	59.5	37.7	26.0	40.1	0.7	51.2	0.61	100	45.2
5.7.2020	14:00	60.6	38.3	24.7	36.8	0.3	52.7	0.61	100	46.6
5.7.2020	15:00	55.3	39.5	27.5	38.4	0.6	43.6	0.61	100	42.8
5.7.2020	16:00	51.2	41.6	26.9	33.6	0.8	57.8	0.61	100	51.4
5.7.2020	17:00	44.4	40.4	26.3	35.1	0.6	28.3	0.61	100	36.1

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