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Behavioural Perspectives of Outdoor Thermal Comfort in Urban Areas: A Critical Review

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Abstract: The thermal characteristics of outdoor urban spaces and the street networks connecting them are vital to the assessment of the liveability and sustainability of cities. When urban spaces are thermally comfortable, city dwellers spend more time outdoors. This has several benefits for human health and wellbeing, also reducing indoor energy consumption and contributing to local economy. Studies on outdoor thermal comfort have highlighted the need to develop interdisciplinary frameworks that integrate physical, physiological, psychological, and social parameters to assist urban planners and designers in design decisions. In this paper, an extensive literature review of outdoor thermal comfort studies over the past decade was undertaken, including both rational and adaptive thermal comfort approaches, from the contextualize the behaviour perspectives related to the use of urban space. Consequently, the paper suggests a comprehensive framework for evaluating the relationship between the quantitative and qualitative parameters linking the microclimatic environment with subjective thermal assessment and social behaviour. The framework aims to contribute to the development of exclusive thermal comfort standards for outdoor urban settings.

Keywords: thermal comfort; subjective thermal assessment; urban planning; urban space; microclimate; temperature; urban design

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2018) warns that anthropogenic activities have caused a rise of around 1 °C in global warming. Climate change predictions point to a high probability of a further increase in global temperatures by 1.5 °C between 2030 and 2052 if the current rate is unmanaged [1]. A further rise in global temperatures will accordingly lead to exceptional and progressively more regular and longer heat waves [2]. The week-long European heat waves of 2003 and 2017 are alarming instances, and such occurrences are likely to increase progressively, with air temperatures 20%–30% above average [3,4]. In hot climates, heat waves increase human heat stress and morbidity, and decrease productivity [5–7]. The United States Center for Disease Control (2004) states that the United States witnessed more than 8000 premature fatalities between 1979 and 1999 because of the heat waves. This figure exceeds all other natural disasters combined, including hurricanes, lightning, tornadoes, floods, and earthquakes [8]. The health implications of climate change and rising high temperatures are accompanied by high humidity levels, low wind speed, and minimal cloud cover [9,10].

Urban environments present a higher threat of thermal stress than rural environments, particularly around evening time. This phenomenon is referred to as an urban heat island (UHI) [11–15]. These occur due to accelerated urbanisation leading to changes in the natural air circulation, prevailing wind speed and course, and solar radiation levels [16,17]. In order to minimise negative climatic effects on urban communities, urban design and planning professionals should integrate atmospheric information into design strategies and create interfaces between the microclimate, outdoor thermal comfort, design guidelines, and urban planning regulations. However, the reconciliation of the climatic aspects within the planning and design process is challenging due to both the poor understanding of outdoor thermal indices, and a need for interdisciplinary collaboration between climatologists, urban planners, and urban simulation experts [18–22]. Accordingly, urban regulations and designs in hot climates, particularly in undeveloped countries, have usually been inspired by urban design principles and ideas from temperate climates. Consequently, the application of these principles fits poorly with different climatic, cultural, and economic contexts, leading to uncomfortable local outdoor conditions [23,24].

In this context, the paper critically assess the outdoor thermal comfort studies literature from a behavioural point of view, including common evaluation techniques and outdoor thermal comfort studies, paying particular attention to perceptions of outdoor thermal comfort and the use of outdoor space in the context of urban planning. The identification of knowledge gaps is followed by the proposal of a comprehensive framework for examining the behavioural aspect of outdoor thermal comfort.

1.1. Thermal Comfort Theories

Table 1 summarises studies on the theories applied to outdoor thermal comfort. Shooshtarian (2019) categorised the most well-known theories, based on how Bandura (1986) followed social cognitive theory [25,26]. The categorisation is composed of three mechanisms that shape exchanges between the urban environment, behavioural reactions, and perceptual development:

- Environmental drivers, referring to spatial features such as shade behaviour in a space, and the sociocultural dimension (e.g., the materials and equipment used in a place and the cultural background);
- Personal drivers relating to the human condition, including physical, physiological, and psychological personal aspects;
- Behavioural drivers relating to human actions, such as the type of performance and activities, in addition to a person's reaction to their thermal surroundings. The significance of these drivers within the field of thermal satisfaction has been stated in numerous studies [27–29].

Table 1. Summary of indoor thermal comfort studies as a theoretical framework [25].

	Definition of the Theory	Application
Personal	*Alliesthesia* [30]	
	This concerns the psychological (perceptual alliesthesia) and physiological (interaction with environmental stimulus) dimensions of thermal satisfaction. It potentially represents a unique way of considering comfort in thermal conditions.	The two main applications of alliesthesia are: long-term, an explanation of thermal comfort requirements in different seasons; short-term, perceptions of transient thermal environments. These applications correspond to the psychological and physiological dimensions of alliesthesia, respectively.
	Environmental perception theory [31]	
	Objects are perceived based on the meaning, action, and behaviour involved, not simply according to their physical characteristics.	The theory hypothesises that when attending open spaces, people begin to develop meteorological "images" or "schemata" about them, and these images reflect the environmental circumstances. These schemata are either based on individuals' repetitive experience of similar stimuli, or simply reflect a bias established through salient events.

Table 1. *Cont.*

	Definition of the Theory	Application
	Ecological systems theory (EST) [32]	
Environmental	EST consists of a multilayered framework that assumes that people are influenced through a set of "environments", which, together with their personal characteristics, create knowledge of reality.	EST has been adopted in many studies in which the main focus was interactions between humans (organisms) and the surrounding ecology. This study demonstrated that these layers can modify people's thermal perceptions to varying extents. The model is comprehensive and can be used in other thermal comfort studies.
	Theory of Semiotics (Charles Sanders Peirce, 1867 and Ferdinand de Saussure, 1857–1913) [33]	
Environmental	This theory is basically the study of environmental signs, or an epistemology about the actual existence of signs in societal life. Environmental signs such as smell, sound, light, and heat are the focal points of this theory and are essential for people's perceptions of their surroundings. It is the theory of meaning and how these meanings can be linked to the real environment.	Drawing on this theory, Cortesão et al. (2018) adopted a framework to study the processes of the visual interpretation of built and vegetated materials in relation to people's outdoor thermal perceptions in Porto, Portugal [34]. The visual interpretation was made by participants using a photographic comparison of environmental signs in three outdoor spaces.
	Theory of Place [35,36]	
Environmental	The theory presumes that a place's character can play a key role in shaping people's attitudes, perceptions, and behaviours. The theory distinguishes "place" and "space".	The theory is proposed as a product of two integrated frameworks [37]. The first framework involves three architectural discourses of space, form, and function [38]. These map the different types of design issues with which environmental and behavioural research must connect. The three components are then translated into the physical (form and space), psychological (cognition and emotions), and functional (activity) dimensions of an open space [39]. The second framework consists of the three paradigms in the process of a person–place transaction (i.e., the personal, social, and cultural aspects that embrace the three broad psychological processes connected to the design issues) [40].
	Theory of Rising Expectations [41]	
Environmental	The theory describes how people's unmet rising expectations lead to public dissatisfaction, or even a revolution in more extreme cases.	Shooshtarian and Rajagopalan (2017) applied the theory in Melbourne, Australia. Participants' thermal comfort requirements were represented through different indicators of thermal satisfaction. Among others, thermal preference (Tpref: representative of thermal expectations) and thermal sensation (Tn: representative of actual momentary thermal sensations) were the main indicators. The study found that participants' Tpref was lower than Tn in summer, and vice versa in autumn [42].

Table 1. *Cont.*

	Definition of the Theory	Application
Behavioural	*Theory of Public Space and Public Life* [43]	
	This theory hypothesises that typical activities in outdoor environments can be classified into the main categories of necessary, optional, and social.	The application aims to understand human–place relationships with reference to outdoor activity types.
	Environmental Behavioural Learning Theory [44]	
	This theory assumes that people in a society may adopt a behaviour present in the predominant culture and its associated social learning processes, including observation and education.	The theory functions through the concept of positive reinforcement, which states that the reception of positive feedback for certain behaviour can increase the frequency of developing similar behaviours.

1.2. Thermal Comfort: International Standards Orgainzation ISO 7730 (2005) Indices of Thermal Comfort

Thermal comfort (International Standards Orgainzation ISO 7730 (2005) [45]) is known as the state of mind that expresses satisfaction with the surrounding environment, implying that comfort is a physiological and psychological condition. Numerous researchers have argued that thermal sensations differ among individuals occupying the same place, due to the combination of a number of variables, including state of mind, culture, and social perceptions [22]. In spite of the fact that this depiction suggests psychological influences, thermal comfort has been examined exclusively from a physical point of view [46]. According to Epstein and Moran. (2006) [47], in 1905, the measurement of wet bulb temperature, first suggested by Haldane (1905) [48], was the most appropriate expression of heat stress. Ever since, a list of thermal indices has been developed, primarily dependent on combining the effect of environmental factors. Later on, other personal parameters, such as human activity and clothing level, were included. Examples are the effective temperature index (ET) [49], predicted mean vote (PMV) [50], physiological equivalent temperature (PET) [51–53], the universal thermal climate index (UTCI) [54], and the COMFA (outdoor thermal comfort model) [55], inter alia.

Although these indices provide near accurate expectations of human thermal sensation, the different approaches underlying the generation of these indices, either by relying on the principles of human thermal exchange or the human response to various environmental factors, have been progressively criticised for disregarding numerous subjective, social, and cultural dimensions. Additionally, these indices were exclusively designed on hypothetical examinations of occupant experience in the mid-latitude climates of North America and Europe, for example, American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) and the ISO [56] (Han, 2007). However, certain other investigations in various climatic regions have demonstrated a more extensive scope of adaptation and acceptance to local climate. Currently, there are two different approaches that consider the determination of thermal comfort, known as the steady-state and non-steady-state approaches, and each has its limitations and possibilities [57]. The steady-state or rational approach uses the data obtained from climate chambers to assist its hypothesis, and is best known in the work of Fanger (1970) [50]. The non-steady-state or empirical approach is based on information gathered from field investigations of people in space. These approaches will now be addressed in turn.

1.2.1. Steady-State Evaluation

This method is based on an analysis of heat exchange mechanisms, hypothesising that people's exposure to an ambient climatic environment enables a person to reach thermal equilibrium by habituation [58,59]. The approach is based on models such as the Fanger (1970) [50] heat balance equation for comfort model, which integrates both environmental (air temperature, mean radiant temperature, humidity, and wind speed) and personal factors (human activity and clothing level). In addition, the two-node model, also known as the Pierce two-node model, was developed by Gagge et al. (1986) [60]. This model deals with the human body as two isothermal parts, one representing the core and the other the skin, based on which thermoregulation is constructed between the two parts for the passive state. It takes into account the deviations of the core, skin, and mean body temperature weighted by alpha from their respective set points [61].

One of the most commonly used indices is Fanger's PMV (1970 [50], which predicts the mean response of a larger population of people based on an ASHRAE seven-point scale, varying from hot (+3) to cold (−3). In practice, PMV also leads to estimating the predicted percentage dissatisfied index (PPD), which is defined as the quantitative estimation or assumption of the percentage of thermally dissatisfied people at each PMV scale, predominantly based on climate chamber experiments with occupants. It is essential to mention that PMV was initially produced for indoor thermal comfort, and therefore its application for outdoor studies is questionable. However, it has been widely used to assess outdoor thermal comfort in research, combined with a large sample of users interviewed to assess the sociocultural influences on thermal comfort of actual outdoor inhabitants [62–64]). The latter approach reported discrepancies between predicted PMV and the votes of outdoor users [57]. Therefore, preference has generally been given to field studies and actual conditions over climate chamber experiments [65].

Table 2 below summarises the most commonly used indices. Physiological equivalent temperature (PET) is another rational index [66], in which PET is defined as the air temperature at which, in a typical indoor setting, the heat budget of a human body is maintained by the core and skin temperature under complex outdoor conditions [67]. PET is preferred over other indices, such as PMV, because of its unit of measurement (°C), making it easier for urban planners and designers to interpret without needing advanced meteorological or physiological knowledge. It translates the complexity of outdoor settings into a simple indoor setup on a physiologically equivalent basis that can realistically be comprehended and understood [52,64,68–70]. Although the validity of PMV and PET for outdoor studies has been criticised in many studies, German guidelines for urban and regional planners [59] recommend both PET and PMV to predict changes in the thermal element of regional or urban climates [71]. Moreover, while ISO 7730 (2005) [45] and ASHRAE 55 (2017) [72] both suggest PMV for indoor thermal comfort assessment, current regulations and standards contain no references regarding how to calculate outdoor neutral and preferred index temperatures [73] (Johansson et al., 2014).

Table 2. The most widely used thermal comfort indices [50,64,74,75].

Index	Definition
ET* (°C): New Effective Temperature	The temperature of a standard environment (Mean Radinat temperature (MRT) = Air Temperature ($T_{a)}$; Relative Humidity (RH) = 50%; Wind Speed (WS) < 0.15 ms^{-1}) in which a subject would experience the same skin wetness and mean skin temperature as in the actual environment. Limited to low activity and light clothing.
SET* (°C): Standard Effective Temperature	Similar to ET* but with a clothing variable. Extends to include a range of activities and clothing levels
OUT_SET* (°C): Outdoors Standard Efficient Temperature	Similar to SET* but adapted to outdoors as it takes into account solar radiation fluxes. Reference indoor conditions are: MRT = T_a; RH = 50%; WS = 0.15 ms^{-1}.
PMV: Predicted Mean Vote	Based on the human heat balance, this expresses thermal comfort on a scale from −3 to +3. Uses both environmental (air temperature, mean radiant temperature, humidity and wind speed) and personal factors (human activity and clothing level).
PET (°C): Physiological Equivalent Temperature	Temperature at which, in a typical indoor setting (MRT = T_a; vapour pressure (VP) = 12 h Pa; wind speed (WS) = 0.15 ms^{-1}), the heat balance of the human body (work metabolism 80 W of light activity, clothing of 0.9 clo_ insulation effect of clothes) is maintained, with a core and skin temperature equal to those under actual conditions.
UTCI: Universal Thermal Climate Index	Intended for outdoors; no information on the clothing insulation level of the surveyed population is required. Reference condition for activity: metabolic rate of 135 W/m^2 and a walking speed of 1.1 m/s [75].

1.2.2. Non-Steady-State Evaluation Approaches

Based on laboratory and controlled experimental conditions, the steady-state approach alone is insufficient in assessing thermal comfort conditions outdoors, as it fails to account for the dynamic aspects of the course of human thermal adaptation [76]. Therefore, it has to be combined with the non-steady-state, also known as the adaptive approach, which includes behaviour adjustment, and physiological and psychological factors. The adaptive approach was brought into field studies [77] to provide a more realistic analysis of acceptability levels in the thermal environment, as related to a specific context, and occupant behaviour and expectations [57,70,78,79]. The adaptive approach can explain the crucial discrepancies within the comfort temperature range between cities sharing the same climate, and also sometimes between two different zones located in the same city. For instance, Lin (2009) assessed human thermal sensation in the humid climate of Taiwan, and concluded that the acceptance range was 21.3–28.5 °C PET for the whole year. This approach recorded a fundamentally higher range than the European reported comfort temperature range of 18–23 °C PET [70]. In another study, Cohen et al. (2013) found that Mediterranean Tel Aviv reported a temperature 3 °C higher on the PET scale than the European boundary, and lower by 5 °C PET than Taiwan [75]. In the hot arid climate of Cairo, another study found that the thermal comfort range was 23–32 °C PET, higher than that of the temperate climates and the European range [20]. These discrepancies indicate the need for in situ questionnaires and participant observation research to collect data on outdoor users' perceptions, including their subjective sensation of urban surroundings, to reveal a wider perspective of the evaluation of outdoor thermal comfort [75,80].

Numerous researchers have, therefore, reported the unfeasibility of developing generally valid rating systems for heat stress because of the complexity and number of interrelated factors [47,81]. Recently, scholars such as De Dear (2004), Nikolopoulou and Lykoudis (2006), Lin and Matzarakis (2008), Kántor et al. (2012), and Cohen et al. (2013) have recommended that field studies are conducted in tandem with laboratory studies, to present a more comprehensive point of view regarding urban comfort and the influence of cultural and habitual variables [80,82–85].

2. Subjectivity and Context-Based Recent Outdoor Thermal Comfort Adaptive Approaches

This section critically reviews outdoor thermal comfort studies from a behavioural stance, with a focus on the link between outdoor thermal comfort and outdoor activity, and the use of outdoor space in the context of urban planning. Due to the advances in technology and enhanced techniques within the field of biometeorology and urban climatology, only those studies performed during the past decade were included, based on a desktop search for science citation index (SCI) impact journals. A total of 47 articles was found during the search, which used keywords such as outdoor thermal comfort, theoretical framework, comfort perception, open spaces, thermal sensation, thermal satisfaction, and expectations. This was followed by the application of relevant selection criteria, such as the validity of the scope, by focusing on people's outdoor thermal perception or sensation, and whether the methodological framework was clearly stated and applied in the research strategy. The following studies were excluded for being purely based on: human thermoregulation [86], computational fluid dynamic (CFD) techniques [87], meteorology [88], and design issues [89].

Lin (2009) investigated outdoor thermal perception and adaptation in relation to the use of a square in a hot and humid subtropical climate in Taichung City, Taiwan. The methodology was comprised of physical measurements, observations, and interviews. One of the most significant results was that the thermal acceptance range varied between 21.3 and 28.5 °C PET, which was higher than the European scale of 18–23 °C PET, and showed that people living in different climates might have different thermal preferences. The analytical results confirm the existence of thermal adaptation, where people preferred a cool temperature and weak sunlight, and adapted to thermal environments by seeking shelter outdoors [70]. Accordingly, in another study, Al Jawabra and Nikolopoulou (2009, 2018) investigated the complicated relationship between human behaviour and the local climate in the urban spaces in the hot climate of two cities: Phoenix in North America, and Marrakech in North Africa [90,91].

They aimed to include a variety of different users in the same climatic context, and employed field questionnaires, user activities observations, and on-site field measurements. The analysis showed that the number of individuals and outdoor activities were affected by solar radiation, particularly in summer. Additionally, individuals from various social backgrounds situated in a similar atmosphere had various means of adapting to the climatic context; this variation indicates the significance of surveying the evaluation of objective and subjective comfort in a half and half survey. Nonetheless, the study lacked a reflection on the socio-economic background of respondents and how they might regularly use mechanical cooling and heating systems to achieve thermal comfort [25]. Yahia and Johansson (2013) evaluated human behaviour using different thermal indices by investigating various thermal environments in the hot climate of Damascus, Syria, during the summer and winter [92]. They took field measurements of the main micrometeorological parameter, and also employed field questionnaires and observation. The results showed neutral temperature values in an opposing trend: in winter, a value of 28.8 °C was recorded, whereas in summer it was 22.9 °C. Although it may seem surprising that the summer neutral PET was lower than the winter, the study ignored previous thermal pleasure in the questionnaire, and this may have affected the results. Another thermal comfort study in outdoor urban spaces in Singapore was a comparative analysis conducted by Yang et al. (2013) [78]. The study explored the impact of thermal adaptation on human thermal sensation in outdoor spaces, and showed that the participants may have expected a higher temperature in outdoor conditions than in semi-outdoor or indoor conditions. This finding suggests not only that in outdoor conditions people may be more tolerant of heat stress than when indoors in a tropical climate, but also that the sun sensation (also known as solar radiation) is the most significant influence on human thermal sensation in outdoor spaces.

Studies have suggested human tolerance to a wider scale of thermal comfort temperatures in non-moderate climates, as well as typologies of urban spaces. The study by Cohen et al. (2013) evaluated the perception of human thermal sensation in the Mediterranean climate by selecting three representative types of outdoor urban spaces: an urban park, an urban square, and a street canyon [75]. The study concluded that although the most comfortable thermal conditions were found in the urban park during summer, the park visitors' tolerance of hot temperatures was lowest in comparison to respondents at other sites. In this specific case, psychological expectancy may provide a possible explanation, in that the park visitors expected better thermal conditions than those at exposed outdoor sites. Indeed, several other studies have found that such expectations can influence subjective assessment [53,83,93,94].

In particular, Chen et al. (2015) studied the role thermal comfort plays in affecting the evaluation of outdoor space and activity in an urban park in Shanghai, China [95]. The authors undertook meteorological measurements, questionnaire surveys, and unobtrusive observations, in addition to the application of PET to evaluate objective thermal comfort based on the micrometeorological conditions. The duration of human exposure and familiarity, as well as expectations of the local thermal environment, were found to affect the acceptable range of thermal comfort. The findings also revealed that the duration of stay and length of residence in Shanghai affected visitors' thermal adaptation.

In a similar study, Elnabawi et al. (2016) compared two locations no more than 1500 m apart on one of the oldest medieval streets in Cairo [20]. The first part of the street had been fully restored but the other had yet to undergo restoration, providing the opportunity to compare the impact of renovation interventions on occupant thermal adaptation. The study noted differing behaviours and ways of adapting to the microclimate in the two parts of the street, and this difference was attributed to the various methods of shading used by street occupants to avoid the intense solar radiation in the hot summer time. The study also reported a difference in the thermal adaption behaviour of the males and females based on the cultural background, highlighting the necessity of considering the socio-economic background.

Two studies on thermal comfort were also conducted by Kenawy and Elkadi (2018) and Lu et al. (2019) [96,97]. The former presented a thermal comfort benchmark study regarding the temperature in the oceanic climate zone of Australia, and the authors claimed that such a benchmark could assist in designing comfortable urban spaces. However, according to Shooshtarian (2019), studies of outdoor thermal environments must be based on participants who have long-term familiarity with the particular environment under consideration, and avoid participants whose exposure is temporary and lacks familiarity with the context, such as tourists [25]. In the study by Lu et al. (2019), there was an investigation of the outdoor thermal sensation in the severe cold climate of Harbin, China [97]. The study analysed the correlation between the actual thermal sensation outdoors and microclimate parameters. The findings concurred with similar studies in extreme climates, in that people living in extreme cold climates are physically better adapted to their environment. However, the study did not adapt other parameters, such as psychological and social or behavioural adaptions.

The configuration of the coverings and outdoor furnishings of a particular outdoor environment also need to be considered in studies of outdoor environments. Canan et al. (2019) examined the outdoor thermal comfort conditions in Konya (Central Anatolia, Turkey) during summer [98]. A transversal field survey was conducted with randomly chosen participants, and on-site field measurements were taken. The results demonstrated that the site had very unfavourable thermal conditions, possibly related to the stone-covered ground and its derived solar reflection. In addition, the orientation of benches was parallel to the main pedestrian axis. These findings highlight the importance of built material and design on meteorological conditions and thermal perceptions. However, possible limitations of the study may be that the age of the surveyed participants was young, and there was also a lack of consideration of climate background, as the sample was randomly chosen, which in turn might have affected the results.

Zacharias et al. (2004) examined the differing attitudes of urban space users before and after exposure to an extensive restoration project encouraging people to use an outdoor space [99]. The proposed design offered more seating areas, but the study showed that increasing the number of seats had a minor effect on the use of the space. The factors found to be more influential on the choice of seating location and duration of settled status were the seat location in sheltering from perceived uncomfortable climatic conditions, shelter from wind, and being shaded from direct solar radiation.

From the examples above, it can be seen that microclimate does indeed have a significant influence on the use of outdoor spaces in cities. All the reviewed studies were based on combinations of two distinct methodologies for studying urban microclimates, including the steady-state and non-steady-state (adaptive) approaches. However, recently some attempts have been made to include different theoretical frameworks to support the understanding and interpretation of comfort data. These approaches lack a valid framework for assessing the collected data, standardised measurement tools and questionnaire designs, and methods of data analysis. Such a framework would enable researchers to widen the scope and outcomes of their studies, to exceed the common protocols that only account for one or a range of thermal comfort index scales, and to expand these to include thermal perception and sensation. Table 3 reviews relevant studies and contrasts their climate, methods, and outcomes.

Table 3. Review of recent outdoor thermal comfort from a behavioural stance.

Source	Location and Climate Type	Methodology	Conclusions
Lin (2009) [70]	Taichung City, Taiwan. Hot and humid subtropical climate	Physical measurements, observations, and interviews	The results confirm the existence of thermal adaptation, as the thermal acceptance range was higher than the European scale, showing that people living in different climates might have different thermal preferences. The study lacked a standardised methodology when comparing the thermal acceptance range with a different climate zone.
Al Jawabra and Nikolopoulou (2009, 2018) [90,91]	Phoenix in North America, and Marrakech in North Africa. Hot, arid climate	Field questionnaire, user activity observations, and on-site field measurements	The analysis showed that individuals from various social backgrounds situated in a similar atmosphere have various ways of adapting. The study lacked a reflection of socio-economic background, as it could have applied a theoretical framework for data interpretation [25].
Yahia and Johansson, (2013) [92]	Damascus, Syria. Cold, arid steppe	Field measurements for the main micro meteorological parameters, in addition to field questionnaires and observations	The calculated neutral temperature values presented an opposing trend: in winter the PET value was higher than in summer. The study ignored previous thermal pleasure in the questionnaire, which might have affected the results.
Yang et al. (2013) [78]	Singapore. Tropical rainforest climate	Field measurements, observations, and social surveys	People in outdoor conditions may be more tolerant of heat stress than those indoors.
Cohen et al. (2013) [85]	Israel. Mediterranean climate	Field measurements, observations, and social surveys	Although the most objectively comfortable thermal conditions were found in the urban park site, park visitors' tolerance of hot temperatures was lowest in comparison to respondents at other sites.
Chen et al. (2015) [95]	Shanghai, China. Humid subtropical climate	Meteorological measurements, questionnaire surveys, and unobtrusive observations	Duration of stay and length of residence affected visitors' thermal adaptation.
Elnabawi et al. (2016) [20]	Cairo, Egypt. Hot, arid climate	Physical measurements, observations, and interviews	The study noted changing behaviour and adaptation to the microclimate based upon the study context.
Kenawy and Elkadi (2018) [96]	Melbourne, Australia. Temperature, oceanic climate	Field measurements, questionnaires, and observations	The results endorse the significant impact of thermal adaptation factors on the users' comfort levels and acceptability in micrometeorological environments. The study's aim might be irrelevant, and there were no criteria regarding the survey's participants, as most were tourists from different climate backgrounds visiting a Melbourne tourist destination.
Cohen et al. (2019) [100]	Beer Sheva, Israel. Hot, arid climate	Field survey, on-site measurements, and analysis of other studies on similar climates	The authors claimed that the modified comfort range for arid zones is wider than the original scale for temperate climates. The discrepancies in the PET index scale, compared to other studies on similar climates, was justified due to variations in techniques used to define neutral temperature, or variations in data collection methods.

Table 3. *Cont.*

Source	Location and Climate Type	Methodology	Conclusions
Lu et al. (2019) [97]	Severe cold climate of Harbin, China	Field measurements and field questionnaires	The findings confirmed previous studies' suggestions that people living in severe cold areas are better adapted to the cold climate, but the study linked these findings to physical adaptation only, without considering other studies, which confirmed the importance of psychological and social or behavioural parameters.
Canan et al. (2019) [98]	Konya (Central Anatolia, Turkey). Cold semi-arid climate	Field survey of randomly chosen participants, and on-site field measurements	The findings highlighted the importance of built material and design on meteorological conditions and thermal perceptions. The study sample was young, and there was a lack of consideration of climate background, as the sample was randomly chosen.
Peng et al. (2019) [101]	Eindhoven, the Netherlands. Temperate, oceanic climate	Path analysis method to examine direct and indirect effects of various factors on subjective comfort in urban public spaces	The findings stated that the incorporation of both objective indicators and individuals' subjective factors are fundamental to effective analysis of actual comfort in urban public spaces. The lack of consideration of climate background and the inability to explain thermal comfort in genders might have affected the results.
Shooshtarian and Rajagopalan (2017) [42]	Temperate setting in Australia	Questionnaire survey, field measurements, on-site observations, and a theoretical framework	The study applied a multi-model framework, including the socio-ecological system model, alliesthesia, and the theory of rising expectations, to justify the thermal satisfaction patterns of the target samples. The most interesting finding was the validity of theoretical models in calculating outdoor thermal comfort requirements.

3. Studying the Outdoor Environment: Methods and Limitations

Nevertheless, the two common methods used for thermal satisfaction assessment—whether via the heat balance approach [50], the adaptive thermal comfort model [83,102,103], or both combined—have failed to provide realistic and context-specific data on thermal satisfaction [25]. The heat balance approach can only provide a close estimation of respondents' thermal satisfaction, disregarding the context features or reasons behind the formation of their thermal satisfaction. Accordingly, the adaptive thermal approach was developed to recognise people's cultures or actions when alleviating their personal discomfort [102].

De Dear (1998) proposed a framework for adaptive comfort based on three dimensions: behaviour adaptation, physiological acclimatisation, and psychological adaption. The framework considers the human being in the centre of the process as an active recipient of environmental stimuli [29]. Later on, these adaptive methods were included in thermal comfort standards, such as ASHRAE 55, 2017, British Standard (BS EN 15251:2007, BS EN 16798-2), and other international standards, to fulfil the limitations associated with the steady-state approach. However, the adaptive approach still contains certain shortcomings; indeed, many scholars and practitioners have suggested that the adaptive approach merely links outdoor air temperature to the indoor occupant's thermal expectation, and thus the model's standards cannot be applied in every urban context [104]. According to Lin et al. (2012), all local issues related to the tested context should be taken into account [105]. Therefore, it is not possible to develop a universal comfort index range or preferred temperature [25]. For instance, in a comparative study between the two cultures of Sweden and Japan, it was found that within similar microclimate conditions, the Swedish participants tended to be more comfortable with a warm environment than the Japanese [106]. According to Shooshtarian (2019), without going deep into the contextual parameters of such a culture, the study's conclusion seems counterintuitive [25]. In another study of a crowded urban street in Cairo, Egypt, shade seeking was the predominant adaptive approach for males, accounting for 48% of behaviour, compared to 8% for females. The researchers attributed this low female percentage to cultural constraints, as females in Egypt intentionally avoid physical proximity to the men occupying the shaded parts of the street [20]. This context-based behaviour cannot be explained only be relying on the thermal comfort approaches [25].

The tools and methods used may also influence the research outcomes of outdoor thermal comfort studies. Cohen et al. (2019) used field surveys in their investigation of outdoor thermal perceptions in the hot, arid climate of Beer Sheva, Israel [100]. The study investigated the current assessment method for subjective thermal sensation, as well as sought to modify the thermal perception scale using the PET index. The study justified the occurrence of discrepancies in the PET index scale in the hot, arid areas when compared to other studies in a similar climate as being due to either variations in the techniques used to define neutral temperature [107] or variations in data collection methods, such as time of day, duration, location, and station setting. All these factors again highlight the necessity for a comprehensive valid framework that can unify the methods and procedures of data collection, and the analytical frameworks of this type of study.

A study by Peng et al. (2019) took this a step further by proposing the path analysis method to examine the direct and indirect effects of various factors on subjective comfort in urban public spaces in spring in Eindhoven, the Netherlands [101]. The paths were set up to include connections between the endogenous variables and the influences from the exogenous variables. The findings revealed that the incorporation of both objective indicators and individuals' subjective factors are fundamental to an effective analysis of actual comfort in urban public spaces. Regarding the microclimate variable, air temperature, wind velocity, and relative humidity had a significant indirect influence on comfort in this study. However, the mean radiant temperature surprisingly had no noteworthy effects. Regarding the socio-demographic characteristics, a significant negative direct connection was found between age and thermal sensation. Considering comfort perception, the findings showed that the expected thermal and wind condition had evident connections with the acceptability of outdoor activity and comfort assessment. Nevertheless, the lack of consideration of climate background and inability to explain thermal comfort based on genders might have affected the results, as the majority of the respondents were aged 16–35, and almost 23% were non-Dutch.

Another interesting approach was taken by Shooshtarian and Rajagopalan (2017), who employed the socio-ecological system model (SESM) as a theoretical model to address their research objectives [42]. This framework was built on the ecological system theory [108], which has been used to study human attitude and behaviour within an ecosystem, and the theories of alliesthesia and rising expectations. The study aimed to identify thermal expectations in attaining thermal comfort in urban spaces in a temperate setting in Australia. The study applied a multimodel framework to justify the thermal satisfaction patterns of the target sample. The findings highlight the importance of the role of thermal expectations in shaping people's judgments regarding thermal conditions, and that certain contextual factors may drive people's thermal sensations. However, the most interesting finding was the validity of the theoretical models in calculating outdoor thermal comfort requirements.

In accordance with the above, three main gaps have been identified regarding outdoor thermal comfort in comparison with the extensively investigated indoor thermal comfort, and these are as follows:

1. The integration of climatic analysis in the urban design phase is still limited in its adoption [19]. The lack of a valid climatic outdoor space design evaluation framework has been identified [18,22,109,110]. There is a need for a framework that can facilitate the relationship between quantitative and qualitative parameters, such as the local microclimate, thermal sensation votes, and human adaptation [76,109];

2. Numerous outdoor thermal comfort studies have extended indoor comfort methods to the outdoors by applying indoor thermal comfort indices, which depend on a steady-state energy balance model, and integrate physical parameters into a single measurement to evaluate human comfort and thermal stress [67]. Since these thermal indices were initially established for indoor places, their legitimacy under open-air conditions has been progressively questioned [53,62,85,111].

The existing outdoor thermal comfort common approaches fail to fully explain thermal satisfaction [42,103]. Therefore, outdoor thermal assessment methods should be accompanied by an explanatory tool that clearly states how data are interpreted and how these outcomes can be related to the study context [25].

4. Thermal Comfort: Integrating the Socio-Cultural Aspect

Outdoor (or urban thermal) comfort is an interdisciplinary study, incorporating phenomena such as meteorology, urban structure, psychology, and social behaviour. The local microclimate has environmental parameters that are of the utmost importance in the assessment of thermal sensation and comfort. However, any thermal comfort evaluation cannot solely be explained by objective parameters, as subjective responses to the environment and the urban configurations of a place also need to be considered. In addition to this, other physical and social parameters play a major role in shaping people's perceptions during their outdoor activities. Accordingly, the proposed framework is comprehensively based on the interoperability of the four different levels of assessment—namely physical, physiological, psychological, and social/behavioural—compiled in one structure (Figure 1), as well as four methodology phases: preliminary data collection, on-site field measurements, a social survey, and micro-urban performance simulation.

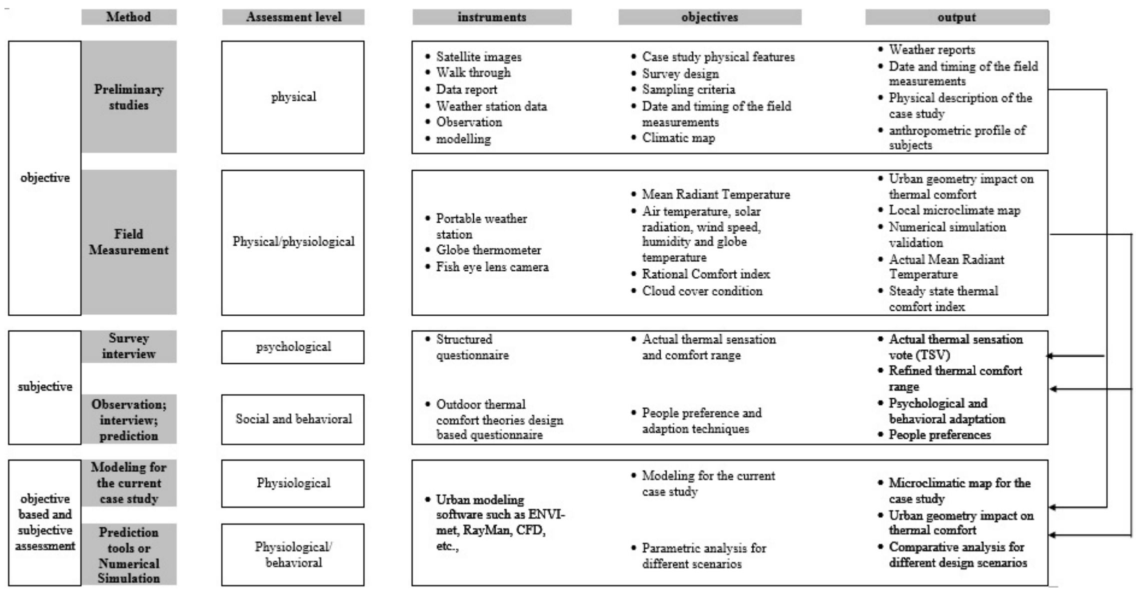

Figure 1. A proposed assessment framework for outdoor thermal comfort.

4.1. Phase One

The initial data gathering should be performed to establish background information on a particular urban context, perhaps from a site observation, walk-through, meteorological reports, weather profiles, surveys of existing building structures and their urban morphology, and types of vegetation. This phase is crucial, as it classifies the site's characteristics, and therefore certain site sampling strategies are needed. As per the World Meteorological Organization (WMO) guide to Meteorological Instruments and Methods of Observation (WMO No. 8, 2008) [112], a site's urban form can be simplified and classified based on the roughness length, aspect (height-to-width) ratio of urban canyons, and the percentage of built or hard surfaces. Accordingly, this knowledge underpins decisions on best timings and locations for on-site measurements (phase two), the anthropometric profile of subjects (questionnaire sample criteria) and observations, the questionnaire design (phase three), and the urban environmental simulations in the subsequent stages.

4.2. Phase Two

For the in situ field measurements, the main objective of a site survey is to capture the urban geometry and materials in terms of how they impact the local climate within the urban canopy layer (UCL); this cannot be extracted from meteorological weather data. A physical site survey identifies spots for measuring microclimatic variations within the urban canyon. The known microclimate parameters that are essential for human thermal comfort are: air temperature (Ta), solar radiation (W/m^2), relative humidity (RH), and air velocity (va), in addition to globe temperature (Tg) [72]. These data can then be cross-referenced to local weather station data to evaluate the current UHI status and the microclimate conditions within the urban canopy layer (UCL), along with the other different climate layers. It also helps to understand the effect of the urban geometry factors on the local climate, such as aspect ratio, vegetation, and sky view factor. Although the accuracy of the instruments and methods used are of great importance, it has been noted that measurement equipment, accuracy, and response time have often gone unstated in the majority of recent outdoor thermal comfort and microclimate studies [73]. Extensive guidelines exist on methods to measure indoor temperatures, such as ISO 7726 (1998) and the ASHRAE Handbook of Fundamentals [72,113], but care must be taken to position instruments to avoid direct solar radiation in outdoor urban environments when measuring air movement and air temperature. Therefore, meteorological instruments and their specifications must be stated according to any of the international or national standards and handbooks, such as the WMO No. 8 (2008) [112], which specifies the appropriate setup for outdoor field measurement instruments. The following section explains some specifications to increase the accuracy of the in situ meteorological method.

- Instrumental setup, measuring range, and accuracy

According to ISO 7726 (1998), the recommended heights of the sensors are 0.6 and 1.1 m for sitting and standing subjects, respectively, which is equivalent to the centre of the gravity of the human body [113]. The instruments and sensors' accuracy requirements should follow ISO 7726 (1998) recommendations, or any other well-known standards or guide recommendations.

- Air temperature and humidity

Unlike indoor thermal studies, air temperature and humidity sensors can be exposed to the sun, which may lead to overestimation of the air temperature; therefore, according to the available standards regarding Ta and humidity, the following considerations should be made:

- The use of a suitable protection or shielding for the abovementioned sensors to minimise radiative exchange between the instrument and its surroundings [112,113];
- The use of suitable ventilation for the shield to maximise convection and avoid the formation of warm air around the sensors, which in turn will affect the measurements [112];
- The allowance of one and half for the sensor response time before measurements are taken, to account for instrument thermal inertia [72,113].

- Wind speed

- Wind velocity and direction vary significantly outdoors. Sensor accuracy and the measuring instrument setup should comply with the ISO 7726 (1998) [113], or any other international or national standards;

- The interval time between the measurements should be sufficient to cover both low and high speeds, at least in locations where high wind speeds are expected;
- Hot-wire and hot-sphere anemometers can measure low wind speeds but still have some limitations for high-speed wind, in addition to omni-directional hot-wire and hot-sphere anemometers for wind direction [73,113].

- Mean radiant temperature

The mean radiant temperature (Tmrt) is one of the most critical parameters in assessing outdoor thermal comfort, especially in urban areas with warm and sunny weather conditions. According to ASHRAE (2017), "it is the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform enclosure" [72]. In other words, the Tmrt summarises the effects of all radiant heat fluxes reaching the body. There are numerous ways for outdoor Tmrt to be determined, but the most accurate is by integral radiation measurements and the calculation of angular factors (the amount of radiation falling on the human body from various directions) [69]. Short- and long-wave radiation are measured from six different directions using pyranometers and pyrgeometers, respectively, but at high angles of incidence, the orthogonal instrument settings might cause errors [69]. Tmrt outdoors can be calculated based on the Stefan–Boltzmann law, as per the following equation:

$$S_{str} = \propto_k \sum_{i=1}^{n} K_i F_i + \varepsilon_p \sum_{i=1}^{n} L_i F_i \quad (1)$$

where (K_i) are the short-wave radiation fluxes (Wm^{-2}) (i = 1–6), (L_i) are the long-wave radiation fluxes (Wm^{-2}) (i = 1–6), F_i are the angular factors (i = 1–6), and ($\propto_k$) is the absorption coefficient for short-wave radiation (standard value 0.7).

The German guideline (Association of German Engineers) VDI 3787 (2008) proposed a simpler method through mounting one pyranometer and one pyrgeometer on a moveable axis so that they are easily oriented in the six directions mentioned in the previous method, namely upward, downward, north, east, south, and west. A total observation time of ten minutes is all that is required to determine the outdoor Tmrt (VDI 3787, 2008) [59]. Another method used to determine Tmrt is a globe thermometer, which assumes that Tmrt is at equilibrium between the radiation balance and convective heat exchange of the globe [72] (ASHRAE, 2017). Put simply, if the globe temperature, air temperature, and air velocity are known, then the Tmrt can be calculated according to Equation (2) given by ASHRAE (2009) [114], with the empirical coefficient as recently refined by Thorsson et al. (2007) [115]:

$$T_{mrt} = \left[\left(T_g + 273.15 \right)^4 + \frac{1.1 \times 10^8 V_a^{0.6}}{\varepsilon_g D^{0.4}} \times (T_g - T_a) \right]^{\frac{1}{4}} - 273.15 \quad (2)$$

where (T_g) is the globe temperature (°C), (V_a) is air velocity (ms^{-1}), (T_a) is the air temperature (°C), D [mm] is the globe diameter (=152 mm), and ($\varepsilon_{\varepsilon g}$) is the emissivity of the sphere (= 0.95 for a black globe).

According to ISO 7726 (1998) and the ASHRAE Handbook of Fundamentals (ASHRAE, 2017), a medium grey globe thermometer colour is recommended for outdoors [72,113]. A table tennis ball sized 40 mm and painted grey has proven to be reliable and accurate in several outdoor studies [115,116]. According to Thorsson et al. (2007), the tone code RAL7001 (flat grey) was found to give the most accurate results, although it slightly overestimates the Tmrt during shady conditions and slightly underestimates it during sunny conditions [116]. The application of smaller globes (for example 40 mm) is common due to advantages in reducing the response time. However, sometimes it underestimates the globe temperature due to the convective heat transfer around a small globe potentially varying as a result of the small diameter [117], and thus a standard 150 mm globe might be called for in order to correct the globe temperature values [118]. Accordingly, the use of non-standard globes should be strongly discouraged in the presence of low air velocity values (e.g., under indoor conditions). On the contrary, in the presence of high velocity values (e.g., outdoors), non-standard globes provide reliable measurements if air velocity is known [117]. However, another easy method of calculating the Tmrt is by modelling, such as models recently developed with the aim of simulating the radiation field in an outdoor urban context approach, using PC software such as RayMan, ENVI-met, and SOLWEIG [115,119,120]. The main advantage of such models is the possibility of testing the microbioclimatic effects of different planning scenarios by modifying the dimensions, arrangements, and radiant properties of the buildings and vegetation within the model environment [121].

4.3. Phase Three

In the third phase, questionnaires and observations need to be implemented concurrently with physical measurements to investigate the impact of the urban space microclimate on urban duration and space usage, and gain a local understanding of adaptive behaviours to mitigate heat stress [20,25]. However, one drawback of the adaptive approach is that there is no advice on how to perform or design the field survey regarding the required number of subjects, appropriate time of the day, and minimum duration for each survey. Nevertheless, with the aim of standardisation, ISO 10551 (1995) suggests five subjective judgment scales to describe the thermal state of a person, namely thermal perception, thermal comfort (affective evaluation), thermal preference, personal acceptability, and personal tolerance [122]. ASHRAE 55 (2010;2017), which is aimed at indoor applications, includes scales for thermal perception and thermal acceptability [72,123]. Physical activity and clothing insulation are also of great importance as they strongly affect thermal perception. Numerous guidelines and standards specify information about the metabolic rate and clothing insulation, such as ISO standards 9920 (2007) and 8996 (2004), which specify methods to determine metabolic rates for working environments, and include metabolic rates for a number of different tasks [124,125].

4.4. Phase Four

In the final phase, predictive micro-urban performance simulations are required. Although an individual's subjective perception and reaction to outdoor spaces can differ according to the specifics of the context and local cultures, parametric environmental performance simulation analysis provides comparative analytical tools to assess different design proposals and their impact on human well-being. Numerous scholars have highlighted the urgent need to further develop reliable outdoor environmental predictive tools to assist in evaluating any modifications in outdoor microclimates in the design phase [18,64,109,110]. Thus, when urban planners or designers aim to encourage more users to spend time outdoors, undertaking numerical simulations facilitates their decisions based on comparative assessments of a wide range of urban configurations, by quantifying the effect of urban features (such as aspect ratio, sky view factors, and shadings) on pedestrian thermal sensation and adaptation. These factors can then be taken into consideration in their designs for creating or retrofitting an urban space. Such a tool should open the field of analysis to a wider range of temporal effects (such as daily, monthly, and annual thermal and comfort conditions) in a certain urban setting within a particular microclimate. This will then generate outcomes that can clarify the relationship between a particular urban design configuration and human thermal sensation and usage. Programs that can perform these functions are: ENVI-met, which can predict the microclimate in urban areas [126,127] RayMan [121,128,129], which is suitable for the analysis of the effect of various planning scenarios in different micro to regional scales; SOLWEIG [130], which estimates the spatial variations of 3D radiation fluxes and Tmrt in complex urban settings; and computational fluid dynamics, which predicts urban temperatures, including pedestrian-level and thermal environments in urban areas [131,132].

In addition to the factors mentioned above, other subjective aspects should also be taken into account, such as people's preferences, adaptation behaviour, cultural background, and all other social or behavioural aspects. There is, therefore, a need for a predictive tool with the capability of representing the non-steady dimension of people's behaviours according to their characteristics. In this context, Bruse [126,127] has proposed a multi agent-based system known as BOTworld, which uses virtual agents (bots) and a multi-agent simulation system (MAS) to simulate pedestrians and occupant thermal sensation and reactions during their use of an urban space. The software agents take the role of the virtual humans moving through the model environment and different microclimate conditions, while also constantly monitoring thermal comfort. In this framework, the numerical simulation has to pass through two stages. In the first, the base case model is constructed, which captures the physical and climatic characteristics of the site under consideration. It is important to validate simulation results with those measured in situ in previous phases. In addition, the places obtained from the observations and surveys where people's thermal adaption or sensation was reported or observed can be located for further analysis using one of the well-founded outdoor thermal comfort theories. The second stage of the simulation allows for scenario-based parametric assessments and analyses alternatives in order to reach optimised thermal conditions. This stage allows two types of assessments: objective and subjective. The objective assessment covers the impact of various micro-urban design interventions on local microclimates, which in turn allows for the introduction of design strategies related to vegetation or surface materials, or massing changes to urban plans to provide better Tmrt profiles and outdoor thermal comfort. However, the subjective assessment based upon data obtained from surveys and interviews, such as people preferences, adaptation behaviour, and other social or behavioural aspects, can be used to develop a context-based new design proposal; it can also be used as a set of evaluation criteria between different scenarios to achieve thermal comfort.

All four phases can then interrelated and compiled systematically within a comprehensive framework. In this way, the framework overcomes common study limitations, but also, and more importantly, permits the identification of overall human outdoor thermal comfort by proposing guidelines to improve microclimate and outdoor thermal comfort based on an examined case study (Figure 1).

5. Conclusions

The proposed framework is expected to contribute to the development and standardisation of outdoor thermal comfort studies, enabling researchers to extend the implications of their findings. By comparing results with other studies that have applied the same techniques, and developing a platform for outdoor thermal comfort studies, new knowledge can be established. The framework also opens the door for current standards and guidelines regarding outdoor thermal comfort (such as ISO 7730, ASHRAE 55, and CEN (Comité Européen de Normalisation) Standard EN 15251 [45,72,123,133], which heavily rely on the physiological and adaptive approaches) to reconsider the conventional philosophy and well-founded theories regarding outdoor thermal comfort. They can then guide the design and method of data collection and interpretation in order to build an understanding of the true relationship between the various determinants of thermal satisfaction [42,134].

The paper conducted a literature review of outdoor thermal comfort during the last decade, including both rational and adaptive thermal comfort approaches, and drew the following conclusions:

- The significant influence of the microclimate in shaping people's behaviours and usage of outdoor spaces;
- The lack of standardisation of methodology and data processing, such as comparing the thermal acceptance range with another different climate zone or study, or finding discrepancies in the comfort index scale due to either variations in techniques used to define neutral temperature or variations in data collection methods;
- The lack of incorporation of theoretical frameworks based on well-founded outdoor thermal comfort theories to support data interpretation, such as the psychological and behaviour aspects or lack of consideration of climate background during a survey.

Based on our critical review of the literature, three main gaps were identified in research on outdoor urban environments:

- The application of the climate aspect within the design process is still lacking as a result of poor interdisciplinary work, for example the incorporation of climate knowledge into urban planning is often missing [19];
- Many comfort indices and models developed to predict the perception of heat exchanges between the human body and the surrounding environment were originally developed for indoor thermal comfort analysis; after some amendment, these indices were extended for outdoor studies, but their creditability for outdoor conditions remains questionable;
- There is no framework based on a combination of qualitative and quantitative research tools that can provide a valid methodology for interpreting the data collected from physical measurements and their correlations in conjunction with subjective thermal assessments, such as social and behavioural factors.

In this context, the paper proposes a comprehensive framework that contextualizes both spatial and temporal aspects of thermal sensations, to a particular urban climate, and the usage pattern of that space. To create an effective decision-making framework for designers and planners, the comfort index used must be augmented by field measurements and thermal sensation questionnaires.

The output from the preliminary data gathering of the physical attributes of the urban space will serve to determine the locations and timings of the field measurement. Observations and questionnaires will delineate the anthropometric profile of a specific urban location.e. The proposed framework suggests that in order to assess the perception of outdoor thermal comfort in terms of behavioural aspects, an assessment framework should work on four levels: physical, physiological, psychological, and socio- behavioural aspects. This framework should allow the static and objective characteristics (physical and physiological features) to be measured and modelled effectively to provide microclimatic knowledge; at the same time, the dynamic and subjective characteristics (psychological and social or behavioural features) can be clearly identified and analysed to provide grounded theory for assessing and designing habitable outdoor spaces.

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References

1. Intergovernmental Panel on Climate Change (IPCC). Global Warming of 1.5oC: Special Report. 2018. Available online: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Summary_Volume_Low_Res.pdf (accessed on 17 October 2019).
2. Viceto, C.; Pereira, S.C.; Rocha, A. Climate Change Projections of Extreme Temperatures for the Iberian Peninsula. *Atmosphere* **2019**, *10*, 229. [CrossRef]
3. UNEP. Impacts of Summer 2003 Heat Wave in Europe. *Environment Alert Bulletin*. 2003. Available online: https://www.unisdr.org/files/1145_ewheatwave.en.pdf (accessed on 17 October 2019).
4. Otto, F.E.L.; van Oldenborgh, G.J.; Vautard, R.; Schwierz, C. Record June Temperatures in Western Europe. World Weather Attribution. 2017. Available online: www.worldweatherattribution.org/analyses/european-heat-june-2017/ (accessed on 30 March 2018).
5. Harlan, S.H.; Brazel, A.J.; Prashad, L.; Stefanov, W.L.; Larsen, L. Neighborhood microclimates and vulnerability to heat stress. *J. Soc. Sci. Med.* **2006**, *63*, 2847–2863. [CrossRef] [PubMed]
6. Kjellstrom, T.; Hogstedt, C. Global situation concerning work related injuries and diseases. In *OSH for Development*; Elgstrand, K., Pettersson, I., Eds.; Royal Institute of Technology: Stockholm, Sweden, 2009; pp. 741–761.

7. Adam-Poupart, A.; Labrèche, F.; Smargiassi, A.; Duguay, P.; Busque, M.A.; Gagné, C.; Rintamäki, H.; Kjellstrom, T.; Zayed, J. Climate change and Occupational Health and Safety in a temperate climate: Potential impacts and research priorities in Quebec, Canada. *Ind. Health* **2013**, *51*, 68–78. [CrossRef] [PubMed]
8. Borden, K.A.; Cutter, S.L. Spatial patterns of natural hazards mortality in the United States. *Int. J. Health Geogr.* **2008**, *7*, 64. [CrossRef] [PubMed]
9. De Carolis, L. The Urban Heat Island Effect in Windsor, ON: An Assessment of Vulnerability and Mitigation Strategies' Report Prepared for the City of Windsor August. City of Windsor, Ontario, 2012. Available online: https://www.citywindsor.ca/residents/environment/Environmental-Master- (accessed on 17 October 2019).
10. Forkes, J. *Urban Heat Island Mitigation in Canadian Communities*; Clean Air Partnership: Toronto, ON, Canada, 2010.
11. Oke, T.R. *Boundary Layer Climates*; Methuen & Co.: New York, NY, USA, 1978; pp. 339–390.
12. Oke, T.R. Street design and canopy layer climate. *J. Energy Build.* **1988**, *11*, 103–113. [CrossRef]
13. Santamouris, M.; Papanikolaou, N.; Koronakis, I.; Georgakis, C.; Argiriou, A.; Assimakopoulos, D.N. On the impact of urban climate on the energy consumption of buildings. *J. Sol. Energy* **2001**, *70*, 201–216. [CrossRef]
14. Streutker, D.R. Satellite-Measured Growth of the Urban Heat Island of Houston, Texas. *Remote Sens. Environ.* **2003**, *85*, 282–289. [CrossRef]
15. Gartland, L. *Heat Islands Understanding and Mitigating Heat in Urban Areas in the UK and USA in 2008*; Earthscan: London, UK, 2008.
16. Roth, M. Effects of Cities on Local Climates. In Proceedings of the IGES/APN Mega-City Project, Kitakyushu, Japan, 23–25 January 2002.
17. Givoni, B. *Climate Considerations in Building and Urban Design*; Van Nostrand Reinhold: New York, NY, USA, 1998.
18. OKE, T.R. *Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites*; IOM Report No. 81, WMO/TD No. 1250; World Meteorological Organization: Geneva, Switzerland, 2006.
19. Fahmy, M.; Sharples, S. The Need for an Urban Climatology Applied Design Model. *Online Newsl. Int. Assoc. Urban Climatol.* **2008**, *28*, 15–16.
20. Elnabawi, M.H.; Hamza, N.; Dudek, S. Thermal perception of outdoor urban spaces in the hot arid region of Cairo, Egypt. *Sustain. Cities Soc.* **2016**, *22*, 136–154. [CrossRef]
21. Nouri, A.S.; Costa, J.P.; Santamouris, M.; Matzarakis, A. Approaches to outdoor thermal comfort thresholds through public space design: A review. *Atmosphere* **2018**, *9*, 108. [CrossRef]
22. Shooshtarian, S.; Rajagopalan, P.; Sagoo, A. A comprehensive review of thermal adaptive strategies in outdoor spaces. *Sustain. Cities Soc.* **2018**, *41*, 647–665. [CrossRef]
23. Baker, L.A.; Brazel, A.J.; Selover, N.; Martin, C.; McIntyre, N.; Steiner, F.R.; Nelson, A.; Musacchio, L. Urbanization and warming of Phoenix (Arizona, USA): Impacts, feedbacks and mitigation. *Urban Ecosyst.* **2002**, *6*, 183–203. [CrossRef]
24. Johansson, E. Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco. *Build. Environ.* **2006**, *41*, 1326–1338. [CrossRef]
25. Shooshtarian, S. Theoretical dimension of outdoor thermal comfort research. *Int. J. Sustain. Cities Soc.* **2019**, *1*, 101495. [CrossRef]
26. Bandura, A. *Social Foundations of Thought and Action: A Social Cognitive Theory*; Prentice-Hall: Englewood Cliffs, NJ, USA, 1986.
27. D'oca, S.; Chen, C.F.; Hong, T.; Belafi, Z. Synthesizing building physics with social psychology: An interdisciplinary framework for context and occupant behaviour in office buildings. *Energy Res. Soc. Sci.* **2017**, *34*, 240–251. [CrossRef]
28. Shooshtarian, S. Socio-economic factors for the perception of outdoor thermal environments: Towards climate-sensitive urban design the global built environment review. *Glob. Built Environ. Rev.* **2015**, *9*, 39–53.
29. De Dear, R.J.; Brager, G.S. Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Trans.* **1998**, *104*, 145–167.
30. Cabanac, M. Physiological role of pleasure. *Science* **1971**, *173*, 1103–1107. [CrossRef]
31. Gibson, J.J. The ecological approach to the visual perception of pictures. *Leonardo* **1978**, *11*, 227–235. [CrossRef]

32. Bronfenbrenner, U. *The Ecology of Human Development: Experiments by Nature and Design*; Harvard University Press: Cambridge, MA, USA, 1979; ISBN 0-674-22457-4.
33. Peirce, C.S. *Collected Papers of Charles Sanders Peirce*; Harvard University Press: Cambridge, MA, USA, 1974.
34. Cortesão, J.; Alves, F.B.; Raaphorst, K. Photographic comparison: A method for qualitative outdoor thermal perception surveys. *Int. J. Biometeorol.* **2018**.
35. Canter, D. The facets of place. In *Toward the Integration of Theory, Methods, Research, and Utilization*; Advances in Environment, Behavior and Design, Vol 4; Springer: Boston, MA, USA, 1997.
36. Graumann, C.F. The phenomenological approach to people-environment studies. In *Handbook of Environmental Psychology*; Bechtel, R.B., Churchman, A., Eds.; John Wiley & Sons Inc.: New York, NY, USA, 2002.
37. Moore, G.T.; Marans, R.W. *Toward the Integration of Theory, Methods, Research, and Utilization*; Springer Science & Business Media: Boston, MA, USA, 2013.
38. Markus, T.A. Buildings as classifying devices. *Environ. Plan. B: Plan. Des.* **1987**, *14*, 467–484. [CrossRef]
39. Canter, D. *The Psychology of Place*; The Architectural Press Ltd.: London, UK, 1977.
40. Saegert, S.; Winkel, G.H. Environmental psychology. *Annu. Rev. Psychol.* **1990**, *41*, 441–477. [CrossRef]
41. Davies, J.C. The J-curve of rising and declining satisfactions as a cause of some great revolutions and a contained rebellion. In *The History of Violence in America: Historical and Comparative Perspectives*; Graham, H.D., Gurr, T.R., Eds.; Praeger: New York, NY, USA, 1969.
42. Shooshtarian, S.; Rajagopalan, P. Study of thermal satisfaction in an Australian educational precinct. *Build. Environ.* **2017**, *123*, 119–132. [CrossRef]
43. Gehl, J. *Life Between Buildings: Using Public Space*; Island Press: Washington, DC, USA, 2011.
44. Tung, C.H.; Chen, C.P.; Tsai, K.T.; Kántor, N.; Hwang, R.L.; Matzarakis, A. Outdoor thermal comfort characteristics in the hot and humid region from a gender perspective. *Int. J. Biometeorol.* **2014**, *58*, 1927–1939. [CrossRef]
45. ISO 7730. Ergonomics of the Thermal Environment. In *Analytical Determination and Interpretation of Thermal Comfort using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*; ISO: Geneva, Switzerland, 2005.
46. Nikolopoulou, M. Outdoor comfort. *Front. Biosci.* **2011**, 6. [CrossRef]
47. Epstein, Y.; Moran, D.S. Thermal comfort and the heat stress indices. *Ind. Health* **2006**, *44*, 388–398. [CrossRef]
48. Haldane, J. The Influence of High Air Temperatures No. I. *Epidemiol. Infect.* **1905**, *5*, 494–513. [CrossRef]
49. Missenard, A. *L'Homme et le Climat*; Librairie Plon: Paris, France, 1937; p. 270.
50. Fanger, P.O. *Thermal Comfort-Analysis and Applications in Environmental Engineering*; Danish Technical Press: Copenhagen, Denmark, 1970.
51. Mayer, H. Human Biometeorology—Urban Bioclimatology. *J. Exp.* **1993**, *49*, 957–963.
52. Matzarakis, A.; Mayer, H.; Iziomon, M.G. Applications of a universal thermal index: Physiological equivalent temperature. *Int. J. Biometeorol.* **1999**, *43*, 76–84. [CrossRef]
53. Höppe, P. Different aspects of assessing indoor and outdoor thermal comfort. *J. Energy Build.* **2002**, *34*, 661–665. [CrossRef]
54. Jendritzky, G.; de Dear, R.; Havenith, G. UTCI—Why another thermal index? *Int. J. Biometeorol.* **2012**, *56*, 421–428. [CrossRef] [PubMed]
55. Brown, R.D.; Gillespie, T.J. *Microclimatic Landscape Design—Creating Thermal Comfort and Energy Efficiency*; Wiley: New York, NY, USA, 1995; ISBN 0-471-05667-7.
56. Han, J. Field study on occupant's thermal comfort and residential thermal environment in a hot climate of China. *J. Build. Environ.* **2007**, *42*, 4043–4050. [CrossRef]
57. Djongyang, N.; Tchinda, R.; Njomo, D. Thermal comfort: A review paper. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2626–2640. [CrossRef]
58. American Society of Heating, Refrigerating and Air-Conditioning Engineers. ANSI/ASHRAE Standard 90.1—2007 Energy Standard for Buildings Except Low-Rise Residential Buildings, Atlanta, GA 30329, USA. Available online: https://www.ashrae.org/technical-resources/bookstore/standard-90-1 (accessed on 17 October 2019).
59. VDI 3787. *Part 2, Environmental Meteorology—Methods for the Human Biometeorological Evaluation of Climate and Air Quality for Urban and Regional Planning at Regional Level; Part I: Climate*; BeuthVerlag: Berlin, Germany, 2008.

60. Gagge, A.P.; Fobelets, A.P.; Berglund, L.G. A standard predictive index of human response to the thermal environment. *Am. Soc. Heat. Refrig. Air-Cond. Eng. Trans.* **1986**, *92*, 709–731.
61. Doherty, T.J.; Arens, E. Evaluation of the physiological bases of thermal comfort models. *ASHRAE Trans.* **1988**, *94*, 1.
62. Nikolopoulou, M.; Baker, N.; Steemers, K. Thermal comfort in outdoor urban spaces: Understanding the human parameter. *J. Sol. Energy* **2001**, *70*, 227–235. [CrossRef]
63. Thorsson, S.; Lindqvist, M.; Lindqvist, S. Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. *Int. J. Biometeorol.* **2004**, *48*, 149–156. [CrossRef]
64. Cheng, V.; Ng, E.; Chan, C.; Givoni, B. Outdoor thermal comfort study in a subtropical climate: A longitudinal study based in Hong Kong. *Int. J. Biometeorol.* **2012**, *56*, 43–56. [CrossRef]
65. Ealiwa, M.A.; Taki, A.H.; Howarth, A.T.; Seden, M.R. 2001. An investigation into thermalcomfort in the summer season of Ghadames, Libya. *Build. Environ.* **2001**, *36*, 231–237. [CrossRef]
66. Mayer, H.; Höppe, P. Thermal Comfort of Man in Different Urban Environments. *Theor. Appl. Climatol.* **1987**, *38*, 43–49. [CrossRef]
67. Hoppe, P. The physiological equivalent temperature—A universal index for the biometeorological assessment. *Int. J. Biometeorol.* **1999**, *43*, 71–75. [PubMed]
68. Ali-Toudert, F.; Mayer, H. Numerical study on the effects of aspect ratio and solar orientation on outdoor thermal comfort in hot and dry climate. *J. Build. Environ.* **2006**, *41*, 94–108. [CrossRef]
69. Thorsson, S.; Honjo, T.; Lindberg, F.; Eliasson, I.; Lim, E.M. Thermal comfort and outdoor activity in Japanese urban public places. *Environ. Behav.* **2007**, *39*, 660–684. [CrossRef]
70. Lin, T.P. Thermal perception, adaptation and attendance in a public square in hot and humid regions. *J. Build. Environ.* **2009**, *44*, 2017–2026. [CrossRef]
71. Matzarakis, A.; Mayer, H. Atmospheric Conditions and Human Thermal Comfort in Urban Areas. In Proceedings of the 11th Seminar on Environmental Protection Environment and Health, Thessaloniki, Greece, 20–23 November 2000; pp. 155–166.
72. ANSI/ASHRAE. *Standard 55: 2017, Thermal Environmental Conditions for Human Occupancy*; ASHRAE: Atlanta, GA, USA, 2017.
73. Johansson, E.; Thorsson, S.; Emmanuel, R.; Krüger, E. Instruments and methods in outdoor thermal comfort studies—The need for standardization. *J. Urban Clim.* **2014**, *10*, 346–366. [CrossRef]
74. Givoni, B. *Man, Climate and Architecture*, 2nd ed.; Applied Science: London, UK, 1976.
75. Cohen, P.; Potchter, O.; Matzarakis, A. Daily and seasonal climatic conditions of green urban open spaces in the Mediterranean climate and their impact on human comfort. *J. Build. Environ.* **2013**, *51*, 285–295. [CrossRef]
76. Chen, L.; Ng, E. Outdoor thermal comfort and outdoor activities: A review of research in the past decade' Cities. *Int. J. Urban Policy Plan.* **2012**, *29*, 118–125. [CrossRef]
77. Cena, K.; DeDear, R. Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. *J. Therm. Biol.* **2001**, *26*, 409–414. [CrossRef]
78. Yang, W.; Wong, N.H.; Jusuf, S.K. Thermal comfort in outdoor urban spaces in Singapore. *Build. Environ.* **2013**, *59*, 426–435. [CrossRef]
79. Inavonna, I.; Hardiman, G.; Purnomo, A.B. Outdoor Thermal Comfort and Behaviour in Urban Area. *IOP Conf. Ser: Earth Environ. Sci.* **2018**, *106*, 012061. [CrossRef]
80. Kántor, N.; Unger, J.; Gulyas, A. Subjective estimations of thermal environment in recreational urban spaces: Part 2 international comparison. *Int. J. Biometeorol.* **2012**, 56. [CrossRef] [PubMed]
81. Gagge, A.P.; Nishi, Y. Physical indices of the thermal environment. *ASHRAE J.* **1976**, *18*, 47–51.
82. De Dear, R. Thermal Comfort in Practice. In *Indoor Air*; Wiley: Hoboken, NJ, USA, 2004; Volume 14, pp. 32–39.
83. Nikolopoulou, M.; Lykoudis, S. Thermal comfort in outdoor urban spaces: Analysis across different European countries. *J. Build. Environ.* **2006**, *41*, 1455–1470. [CrossRef]
84. Lin, T.P.; Matzarakis, A. Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. *Int. J. Biometeorol.* **2008**, *52*, 281–290. [CrossRef]
85. Cohen, P.; Potchter, O.; Matzarakis, A. Human thermal perception of Coastal Mediterranean outdoor urban environments. *J. Appl. Geogr.* **2013**, *37*, 1–10. [CrossRef]
86. Katavoutas, G.; Flocas, H.A.; Matzarakis, A. Dynamic modeling of human thermal comfort after the transition from an indoor to an outdoor hot environment. *Int. J. Biometeorol.* **2015**, *59*, 205–216. [CrossRef]

87. Nilsson, H.O.; Holmer, I. Comfort Climate Evaluation with Thermal Manikin Methods and Computer Simulation Models. *Indoor Air* **2003**, *13*, 28–37. [CrossRef]
88. Pielke, R., Sr.; Beven, K.; Brasseur, G.; Calvert, J.; Chahine, M.; Dickerson, R.R.; Entekhabi, D.; Foufoula-Georgiou, E.; Gupta, H.; Gupta, V.; et al. Climate change: The need to consider human forcings besides greenhouse gases. *Eos Trans. Am. Geophys. Union* **2009**, *90*, 413. [CrossRef]
89. Cortesao, J.P.A.G. Thermal Retrofitting of Public Spaces in Compact Urban Areas: A Bioclimatic Approach. Ph.D. Thesis, Universidade do Porto, Porto, Portugal, 2013.
90. Al Jawabra, F.; Nikolopoulou, M. Outdoor Thermal Comfort in the Hot Arid Climate, the effect of socio-economic background and cultural difference. In Proceedings of the 26th Conference on Passive and Low Energy Architecture PLEA, Quebec, Canada, 22–24 June 2009.
91. Al Jawabra, F.; Nikolopoulou, M. Thermal comfort in urban spaces: A cross-cultural study in the hot arid climate. *Int. J. Biometeorol.* **2018**, *8*. [CrossRef]
92. Yahia, M.W.; Johansson, E. Influence of urban planning regulations on the microclimate in a hot dry climate: The example of Damascus, Syria. *J. House. Built Environ.* **2013**, *28*. [CrossRef]
93. Becker, S.; Potchter, O.; Yaakov, Y. Calculated and observed human thermal sensation in an extremely hot and dry climate. *Energy Build.* **2003**, *35*, 747–756. [CrossRef]
94. Yin, J.F.; Zheng, Y.F.; Wu, R.J. An analysis of influential factors on outdoor thermal comfort in summer. *Int. J. Biometeorol.* **2012**, *56*, 941–948. [CrossRef]
95. Chen, L.; Wen, Y.; Zhang, L.; Xiang, W.N. Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai. *Build. Environ.* **2015**, *94*, 644–653. [CrossRef]
96. Kenawy, I.; Elkadi, H. The outdoor thermal benchmarks in Melbourne urban climate. *Sustain. Cities Soc.* **2018**, *43*, 587–600. [CrossRef]
97. Lu, M.; Hou, T.; Fu, J.; Wei, Y. The Effects of Microclimate Parameters on Outdoor Thermal Sensation in Severe Cold Cities. *Sustainability* **2019**, *11*, 1572. [CrossRef]
98. Canan, F.; Golasib, I.; Ciancio, V.; Coppi, M.; Salata, F. Outdoor thermal comfort conditions during summer in a cold semi-arid climate. A transversal field survey in Central Anatolia (Turkey). *Build. Environ.* **2019**, *148*, 212–224. [CrossRef]
99. Zacharias, J.; Stathopoulos, T.; Wu, H. Spatial behaviour in San Francisco's plazas—The effects of microclimate, other people, and environmental design. *Environ. Behav.* **2004**, *36*, 638–658. [CrossRef]
100. Cohen, P.; Shashua-Bar, L.; Keller, R.; Gilad, R.; Yaakov, Y.; Victor, L.; Kutiel, P.B.; Tanny, J.; Cohen, S.; Potchter, O. Urban outdoor thermal perception in hot arid Beer Sheva, Israel: Methodological and gender aspects. *Build. Environ.* **2019**. [CrossRef]
101. Peng, Y.; Feng, T.; Timmermans, H. A path analysis of outdoor comfort in urban public spaces. *Build. Environ.* **2019**, *148*, 459–467. [CrossRef]
102. Humphreys, M.A. An adaptive approach to thermal comfort criteria. In *Naturally Ventilated Buildings: Buildings for the Senses, the Economy and Society*; E & FN Spon.: London, UK, 1997.
103. Nikolopoulou, M.; Steemers, K. Thermal comfort and psychological adaptation as a guide for designing urban spaces. *J. Energy Build.* **2003**, *35*, 95–101. [CrossRef]
104. Schweiker, M.; Shukuya, M. Comparative effects of building envelope improvements and occupant behavioural changes on the exergy consumption for heating and cooling. *Energy Policy* **2010**, *38*, 2976–2986. [CrossRef]
105. LIN, T.; TSAI, K.; TUNG, C.; HWANG, R.; MATZARAKIS, A. An analysis of the effects of shading factors on human bioclimate in an evolving urban context. In Proceedings of the 8th International Conference on Urban Climate, Anais, Dublin, 6–10 August 2012.
106. Knez, I.; Thorsson, S. Thermal, emotional and perceptual evaluations of a park: Crosscultural and environmental attitude comparisons. *J. Build. Environ.* **2008**, *43*, 1483–1490. [CrossRef]
107. Hadianpour, M.; Javad, M.; Bemanian, M.; Nasrollahi, F. Seasonal differences of subjective thermal sensation and neutral temperature in an outdoor shaded space in Tehran, Iran. *Sustain. Cities Soc.* **2018**, *39*, 751–764. [CrossRef]
108. Bronfenbrenner, U. Six theories of child development: Revised formulations and current issues. In *Ecological Systems Theory*; Jessica Kingsley Publishers: London, UK, 1992; pp. 187–249.
109. Eliasson, I. The use of climate knowledge in urban planning. *Landsc. Urban Plan.* **2000**, *48*, 31–44. [CrossRef]

110. Givoni, B.; Noguchi, M.; Saaroni, H.; Pochter, O.; Yaacov, Y.; Feller, N.; Becker, S. Outdoor comfort research issues. *J. Energy Build.* **2003**, *35*, 77–86. [CrossRef]
111. Spagnolo, S.; de Dear, R. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *J. Build. Environ.* **2003**, *38*, 721–738. [CrossRef]
112. WMO-No. 8. *Guide to Meteorological Instruments and Methods of Observation*, 7th ed.; World Meteorological Organization (WMO): Geneva, Switzerland, 2008.
113. ISO 7726. *Ergonomics of the Thermal Environment—Instruments for Measuring Physical Quantities*; ISO: Genava, Switzerland, 1998.
114. American Society of Heating. *2009 ASHRAE Handbook: Fundamentals*; American Society of Heating: Atlanta, GA, USA, 2009.
115. Thorsson, S.; Lindberg, F.; Eliasson, I.; Holmer, B. Different methods for estimating the mean radiant temperature in an outdoor urban setting. *Int. J. Climatol.* **2007**, *27*, 1983–1993. [CrossRef]
116. Yahia, M.W.; Johansson, E. Evaluating the behaviour of different thermal indices by investigating various outdoor urban environments in the hot dry city of Damascus, Syria. *Int. J. Biometeorol.* **2013**, *57*, 615–630. [CrossRef]
117. D'Ambrosio Alfano, F.R.; Malchaire, J.; Palella, B.I.; Riccio, G. The WBGT index revisited after 60 years of use. *Ann. Occup. Hyg.* **2014**, *58*, 955–970.
118. Oliveira, A.V.M.; Gaspar, A.R.; Raimundo, A.M.; Quintela, D.A. On the measurement of globe temperatures: Analysis of the influence of different parameters. *Extrem. Physiol. Med.* **2015**, *4*, A14. [CrossRef]
119. Bruse, M. The Influences of Local Environmental Design on Microclimate. Ph.D. Thesis, University of Bochum, Bochum, Germany, 1999.
120. Ali-Toudert, F. Dependence of Outdoor Thermal Comfort on Street Design. Ph.D. Thesis, University of Freiburg, Freiburg, Germany, 2005.
121. Matzarakis, A.; Rutz, F.; Mayer, H. Modelling radiation fluxes in simple and complex environments—Application of the RayMan model. *Int. J. Biometeorol.* **2007**, *51*, 323–334. [CrossRef] [PubMed]
122. International Organization for Standardization. *ISO 10551 Ergonomics of the Thermal Environment—Assessment of the Influence of the Thermal Environment Using Subjective Judgement Scales*; ISO: Geneva, Switzerland, 1995; pp. 1–28.
123. ASHRAE 55. *Thermal Environmental Conditions for Human Occupancy*; ASHRAE: Atlanta, GA, USA, 2010.
124. ISO. *Ergonomics of the Thermal Environment—Estimation of the Thermal Insulation and Evaporative Resistance of a Clothing Ensemble—ISO 9920 Standard*; International Organization for Standardization: Geneva, Switzerland, 2007.
125. ISO 8996. *Ergonomics of the Thermal Environment—Determination of Metabolic Rate*; International Organization for Standardization: Geneva, Switzerland, 2004.
126. Bruse, M. BOT World Homepage. 2007. Available online: http://www.botworld.info/ (accessed on 5 September 2015).
127. Bruse, M. Analysing human outdoor thermal comfort and open space usage with the multi-agent system BOTworld. In Proceedings of the 7th International Conference on Urban Climate (ICUC-7), Yokohama, Japan, 29 June–3 July 2009.
128. Matzarakis, A.; Fröhlich, D.; Gangwisch, M.; Ketterer, C.; Peer, A. Developments and applications of thermal indices in urban structures by RayMan and SkyHelios model. In Proceedings of the ICUC9 9th International Conference on the Urban Climate Jointly with the 12th Symposium on the Urban Environment, Freiburg, Germany, 23 April 2015.
129. Matzarakis, A.; Rutz, F.; Mayer, H. Modelling Radiation fluxes in simple and complex environments—Basics of the RayMan model. *Int. J. Biometeorol.* **2010**, *54*, 131–139. [CrossRef] [PubMed]
130. Lindberg, F.; Holmer, B.; Thorsson, S. SOLWEIG 1.0—Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. *Int. J. Biometeorol.* **2008**, *52*, 697–713. [CrossRef] [PubMed]
131. Allegrini, J.; Dorer, V.; Carmeliet, J. Buoyant flows in street canyons: Validation of CFD simulations with wind tunnel measurements. *Build Env.* **2014**, *72*, 63–74. [CrossRef]
132. Yang, X.; Zhao, L.; Bruse, M.; Meng, Q. Evaluation of a microclimate model for predicting the thermal behaviour of different ground surfaces. *Build. Environ.* **2013**, *60*, 93–104. [CrossRef]

133. Cen, E. CEN Standard EN 15251. In *Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics*; The publisher is European Committee for Standardization (CEN): Brussels, Belgium, 2007.
134. Lai, D.; Guo, D.; Hou, Y.; Lin, C.; Chen, Q. Studies of Outdoor Thermal Comfort in Northern China. Available online: https://doi.org/10.1016/j.buildenv.2014.03.026 (accessed on 17 October 2019).

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