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Review

Outdoor Wellbeing and Quality of Life: A Scientific Literature Review on Thermal Comfort

Ernesto Antonini *, Vincenzo Vodola, Jacopo Gaspari and Michaela De Giglio

Department di Architecture—DA, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy; vincenzo.vodola2@unibo.it (V.V.); jacopo.gaspari@unibo.it (J.G.); michaela.degiglio@unibo.it (M.D.G.)

* Correspondence: ernesto.antonini@unibo.it

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Abstract: While indoor comfort represents a widely investigated research topic with relation to sustainable development and energy-demand reduction in the built environment, outdoor comfort remains an open field of study, especially with reference to the impacts of climate change and the quality of life for inhabitants, particularly in urban contexts. Despite the relevant efforts spent in the last few decades to advance the understanding of phenomena and the knowledge in this specific field, which obtained much evidence for the topic's relevance, a comprehensive picture of the studies, as well as a classification of the interconnected subjects and outcomes, is still lacking. This paper reports the outcomes of a literature review aimed at screening the available resources dealing with outdoor thermal comfort, in order to provide a state-of-the-art review that identifies the main topics focused by the researchers, as well as the barriers in defining suitable indexes for assessing thermal comfort in outdoor environments. Although several accurate models and software are available to quantify outdoor human comfort, the evocated state of mind of the final user still remains at the core of this uncertain process.

Keywords: outdoor thermal comfort; human thermal perception; thermal comfort assessment; quality of life

1. Introduction

1.1. Review Contest and Boundaries

While indoor conditions have been the main concern for research on user comfort since the second half of 20th century, assessing outdoor comfort has emerged as a challenging field during the last few decades. Three main phenomena have pushed towards this change:

- The growth of cities, driven by the increasing movement of people to urban areas, where half of the world's population is already living, and a further expansion is expected in the near future [1].
- The consequent exposure of a huge number of people to the effects of extreme weather conditions due to both climate change and local phenomena, boosted by the high density of settlements, such as Urban Heat Islands (UHI) (peaks of temperature higher than that of the rural surroundings) [2]. The evidence on the average temperature increase and the related potential impacts are widely explored in authoritative reports from the Intergovernmental Panel on Climate Change (IPCC) [3] and the National Oceanic and Atmospheric Administration (NOAA) [4], particularly dealing with more relevant effects on urban areas [5].
- The change in lifestyles and particularly the increasing amount of time spent by inhabitants inside buildings pushed the need for high-quality outdoor spaces that provide healthy leisure facilities, and significantly contribute to the urban environment's livability and vitality. Thus, encouraging

more people to use outdoor spaces would bring greater benefits into the physical, environmental, economic and social spheres of the cities [6–9].

Scientists worldwide have thus focused their attention on this topic, making available a wide range of tools and methods to assess human thermal outdoor comfort in different climatic contexts. Over 100 biometeorological and thermal stress indexes [10] have been developed, adopting different approaches and rationales, aiming at linking the microclimatic conditions to the perceived sensations.

Since the available knowledge on human thermal perception and related evaluation protocols were mainly the ones previously developed for interior spaces and other confined spaces, the assessment of outdoor conditions initially refers to these patterns [11].

In fact, human thermal comfort and its assessment were studied since the beginning of the 20th Century, when the first simplified models were developed [12]. The two node model applied thermodynamics principles to energy exchanges between the human body and its thermal environment [13] for the first time during the 1930s, but it is only from the 1960s onwards that researchers were able to analyze the main climatic parameters connected to the perception of thermal comfort (e.g., air temperature, radiant temperature, air humidity, air flow velocity) when the first climate chambers were made available [14]. The cornerstone studies of Givoni [15] and Fanger [16] led in the following years to the identification of new parameters that are currently considered essential elements in the contemporary assessment of thermal comfort. The advances in the physics of heat exchange knowledge gained during the 1980s and the increasing availability of computer tools to support the research activity allowed relevant progress on the understanding of the human thermal environment [17–22] and the formulation of indexes based on body heat exchange [11].

In order to model human thermal comfort in outdoor environments, solar radiation was first added to the set of climatic variables in use for indoor spaces [23,24]. Olgyay assumed that solar radiation must be combined to the effects of other climatic elements, to draft a "bioclimatic chart" for the outdoor conditions [23].

Further studies have shown that outdoor thermal comfort is a more complex notion and a multilayered condition, which is very difficult to properly describe as a whole by considering biometeorological factors only [25]. Although the thermal state appears as very influential among the many factors shaping the quality of outdoor spaces, a wide range of additional social and physical aspects, however, were identified as relevant, especially those linked to behavioral variables [26].

Nonetheless, the issue remains open, especially regarding the assessment of the human variables influenced—including cultural, behavioral and psychological factors—on the perception of the environment's physical conditions [10].

The efforts spent in the last few decades to advance the understanding of these phenomena provide evidence of the topic's relevance, even if a comprehensive picture of available studies is still lacking, as well as a classification of the interconnected subjects and outcomes. A systemic overview of the available knowledge could be therefore a useful tool for identifying the different research trends and classifying their objectives, approaches, results and implications.

This paper reports the outcome of a literature review aimed at screening the available resources dealing with outdoor thermal comfort, in order to provide a state of the art that identifies the main topics focused on by the researchers, as well as the barriers in defining suitable indexes and approaches for thermal comfort assessment in outdoor environments.

1.2. Theoretical Background

The International Organization for Standardization (ISO) has released a series of international regulations for the evaluation of thermal comfort; ISO 13731:2001 defines physical quantities and provides a reference for terminology and symbols to adopt for standards on ergonomics of the thermal environment [27], while ISO 7726:1998 identifies the means and instruments for measuring the physical quantities involved [28]. ISO 7730:2005 provides an analytical determination and interpretation of thermal comfort using calculation of the Predictive Mean Vote (PMV) and Percentage of Person

Dissatisfied (PPD) indexes and local collected data [29]. Although the model was developed for indoor comfort assessment, it may be adapted for outdoor spaces by adding the radiative exchange values [30]. This ISO Standard also includes annexes providing comprehensive databases for the metabolic rates of different human activities and the thermal insulation values of clothing ensembles. Moreover, ISO 7243:2017 enables the estimation of the worker heat stress by Wet Bulb Globe Temperature Index (WBGT) [31], which can be applied for both indoor and outdoor work environments.

In addition to ISO standards, other regulations such as American National Standards Institute (ANSI) / American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55-2017 and European Standards (EN) 15251-2017 specify calculation and evaluation methods for thermal comfort. However, they are mostly addressed to indoor environments, and focused on those parameters affecting the energy performance of buildings [32].

The awareness of the topic's broad latitude has prompted some authors to focus on the possible gaps in criteria and assumptions currently in use to map the factors influencing the perceived outdoor comfort and wellbeing sensation, starting from the definition of thermal comfort itself.

ASHRAE defines thermal comfort as a state of mind that expresses satisfaction with the thermal surroundings [33], which means that human thermal comfort refers to a subjective sensation, different from one subject to another [34]. Some studies argue that this definition may appear rather vague [10]: it does not specify what that state of mind is (in terms of perception, feeling, etc.) and it does not provide any indication of how to relate this mental state into something that can be measured, nor which variables could be involved [35]. Thus, this is still an open issue from different points of view, although the definition is intended to be the most general as possible, to provide a common understanding, thus leaving each study the responsibility to state the assumptions (and limitations) in their own premises.

Additionally, when the assessment of this mental state has to be investigated, referring to the outdoor environment, the relationship between the human body and a large set of spatial and temporal variables must be also considered. Theoretically, this gap could be filled by adapting for the outdoor comfort assessment the same methodologies and indexes developed to evaluate indoor comfort. However, several authors discussed this position as unsuitable, arguing that the theoretical models developed for describing thermoregulation functions within the indoor environment are not adequate to feature the outdoor thermal comfort conditions [34,36]. This is mainly because of the outdoor environment's greater complexity, and its temporal and spatial variability [34]. Thus, the need is acknowledged for empirical data from field surveys on the subjective human perception of outdoor wellbeing, which should enable investigation of thermal comfort in open spaces from a broader and more realistic perspective [34].

In order to make the reading easier, Table 1 provides the nomenclature of the main terms and acronyms reported in the paper, as well as Table 2, which summarizes the main thermal comfort indexes.

Table 1. Nomenclature of main terms used.

Abbreviation	Definition
UHI	Urban Heat Island
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration

Table 2. Nomenclature of the main thermal comfort indexes cited.

Abbreviation	Index	Unit
ASV	Actual Sensation Vote	-
AT	Apparent Temperature	°C
COMFA	COMfort FormulA	$W{\cdot}m^{-2}$
DI	Discomfort Index	°C
ESI	Environmental Stress Index and	°C
ET	Effective Temperature	°C
ETU	Universal Effective Temperature	°C
H	Humidex	°C
HI	Heat Index	°C
ITS	Index of Thermal Stress	W
MENEX	Man ENvironmental Heat EXchange model	$W{\cdot}m^{-2}$
OUT_SET*	Outdoor Effective Temperature	°C
PE	Cooling Power Index	$kcal{\cdot}m^{-2}{\cdot}h$
PET	Physiologically Equivalent Temperature	°C
PMV	Predicted Mean Vote	-
PSI	Physiological Strain Index	°C
PT	Perceived Temperature	°C
RSI	Relative Strain Index	-
SET	New Standard Effective Temperature	°C
TS	Thermal Sensation	-
TSV	Thermal Sensation Vote	-
UTCI	Universal Thermal Climate Index	°C
WBGT	Wet Bulb Globe Temperature Index	°C
WCI	Wind Chill Index	°C

2. Methodology

Although overall human comfort involves several environmental agents acting simultaneously, including air quality and thermal, acoustic, and lighting factors [34,37], this study was limited to the thermal wellbeing, since it plays a crucial role in affecting the comfort perception in outdoor environments.

The review was based on a systematic search for peer-reviewed papers published within the last twenty years. The aim of the review was to identify the most relevant trends in studies dealing with outdoor human thermal comfort. Five main search engines were used: Science Direct, Google Scholar, Scopus, Web of Science (WOS) and Researchgate. The following keywords were used for the preliminary retrieval of papers from the sources:

- outdoor thermal comfort;
- thermal perception;
- thermal wellbeing;
- human thermal comfort;
- human thermal index;
- outdoor thermal comfort approaches;
- thermal comfort assessment.

This allowed a first selection based on the paper title and abstract. Additionally, papers referenced within the selected articles were considered as secondary sources, thus embedded in the second step of the review process.

Review Process and Outcomes

The outcome of the first search round provided more than 25,000 results, of which 1059 were retrieved from the Science Direct database, 16,600 from the Google Scholar search engine, 710 from the

Scopus database, 594 from Web of Science and 6160 from Researchgate. Duplications were deleted in a second step of the process and the results were also filtered using a combination of the proposed keywords. The results distribution from Science Direct, reported in Figure 1, indicates a growing interest in the second decade that can be certainly associated to new drivers, such as the effects of climate change and related heat waves, but also to the development of web-based solutions to share knowledge and studies that facilitated the communication and exchange among the scientific community. Furthermore, it must be noted that the increasing demand for scientific publications on the topic within the academic circuits, for both research purposes and career advancement, may have influenced the numeric growth of studies, as well as their availability in scientific journals.

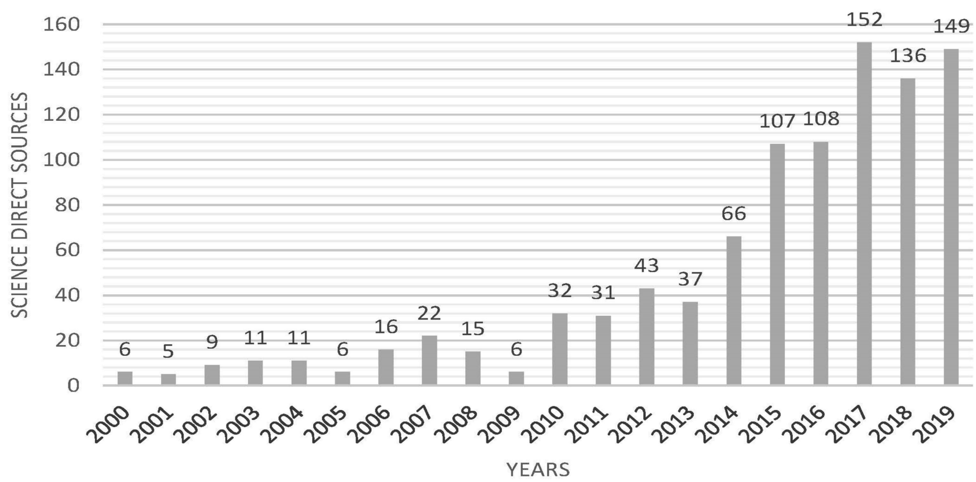

Figure 1. Results retrieved from the ScienceDirect search engine (keys: publication after 1999; text string "outdoor thermal comfort" in paper abstract and/or title).

The selection results were then refined according to the predefined set of keywords; a total of 855 sources were found at the end of the filtering process, including journal articles, book chapters, reviews and peer-reviewed conference papers. The sources matching with three or more keywords (out of six) were considered as having highly relevant contents. They were then shortlisted and their full text downloaded; 146 significant outputs were identified by selecting those focusing on the relationships between outdoor thermal comfort and microclimatic variables.

The sources referenced by the selected papers were also explored, thus increasing to 236 the final number of the surveyed articles. Figure 2 displays the incidence per year (Figure 2a) and the breakdown by issues addressed (Figure 2b).

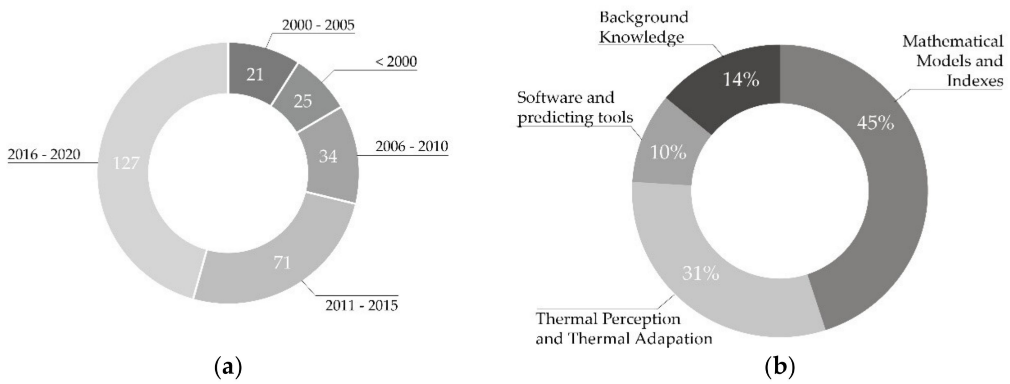

Figure 2. Distribution by year (**a**) and by topic (**b**) of the final 236 sources considered for the review purposes.

The analysis of the 236 final resources, as shown in Figure 2b, pointed out that studies on outdoor comfort could be divided into four main groups:

- The first group [1–5,11–13,16,19–24,26–29,31–33,38–47] includes papers that provide theoretical background elements as well as definitions, terminology and regulations (14% of items);
- The second group [8,14,15,17,18,22,30,48–149] collects mathematical models and indexes for the definition of new approaches in outdoor comfort assessment (45% of selected items);
- The third group [6,7,9,10,25,34–37,150–213] includes investigations of the physical, physiological and psychological human adaptability as a key for understanding thermal perception in outdoor environments (31% of items);
- The fourth group [214–236] deals with the use of software and forecasting tools to virtually reproduce complex environmental contexts, in particular with the aim of supporting the designer in understanding the effects of changes in the climatic factors that affect people's external comfort (10% of articles).

Accordingly, this review adopts the same structure, reporting the findings grouped in three sections, corresponding to the main topics to which scientific efforts were devoted toward identifying both effective methodologies and main limitations for the full comprehension of the subject. In addition, a brief introduction to standards and regulations is provided in the theoretical background paragraph of the introduction.

From the literature analysis, field studies on outdoor thermal comfort were carried out around the world in the last 20 years. Givoni et al. discussed methodological issues and deepens problems in outdoor comfort research based in Japan and Israel [164], as well as in China [74], where other studies were also conducted [51,54,57]. Other studies were performed with reference to the following geographical areas: Canada [207], Argentina [138], Sweden [147,175,218], Portugal [131], United Kingdom [187,209], Italy [214], Morocco [132], Emirates [227], Egypt [118], Malaysia [192], Bangladesh [141], Australia [142], New Zealand [208]. Among the largest research projects, the most extensive was RUROS: Rediscovering the Urban Realm and Open Spaces [37], which included field surveys carried out in seven European cities: Athens, Thessaloniki, Milan, Fribourg, Kassel, Cambridge, Sheffield.

3. Results

3.1. Mathematical Models and Indexes

Several complex thermal indexes were developed to date, describing and quantifying the thermal environment of humans and the energy fluxes between the human body and the surrounding environment. De Freitas and Grigorieva [79,80] carried out a three-stage study, providing a comprehensive register of 165 indexes suitable for the purpose, which were subsequently grouped and classified. Thus, they observed that indexes are almost designed for a specific application, so the choice depends on the context in which the index is used, as well as on the availability of the data needed to quantify it. They also found that the best performing indexes are those based on the body/atmosphere energy balance, which, however, are those needing more complicated calculation routines and more detailed input data. What emerges as an additional and more serious drawback is that body–atmosphere energy balance indexes are often based on numerical models that were not validated. This leads to the conclusions that there is not an overall best index [79] and the use of a standardized human body could introduce errors, since the characteristics of the human body vary individually [80].

A review about models and standards is provided by Coccolo et al. [157] who analyzed a number of outdoor human comfort models and the related physical variables as well as the applicability with reference to the climate, with reference to the research goals, dividing the models in the following three groups:

- Indexes based on the human's energy balance, which show the interrelation between metabolic activities, clothing and environmental parameters, and humans thermal perception. They include COMFA (COMfort FormulA), ETU (Universal Effective Temperature), ITS, MENEX, PET, PMV, PT, OUT_SET*, SET, UTCI;
- Empirical indexes, which are expressed as linear regressions based on field studies (monitoring and surveys) defining the human comfort for a specific climate or location that are set and validated for it. They consider Actual Sensation Vote (ASV), Thermal Sensation (TS), Thermal Sensation Vote (TSV);
- Indexes based on linear equations defining the comfort as function of the thermal environment, by focusing on air temperature, wind speed and relative humidity parameters, but neglecting the microclimate and human behaviour. Among these are Apparent Temperature (AT), Discomfort Index (DI), Environmental Stress Index and (ESI) and Physiological Strain Index (PSI), Effective Temperature (ET), Humidex (H), Heat Index (HI), Cooling Power Index (PE), Relative Strain Index (RSI), Wet Bulb Globe Temperature Index (WBGT), Wind Chill Index (WCI).

A selection of case studies about the different models since 2000 is organized in a graph according to the Köppen climate classification by Coccolo et al [157]. Temperate climate emerges as the most studied condition, followed by those referring to arid, cold and tropical climates, while very few studies were performed for polar environments. The outcomes of this research leads to the following conclusions:

- Thermal indexes based on energy balance enable quantification of thermal sensation from the general climate to the urban microclimate, considering the human variables.
- Empirical indexes reliably describe the thermal perception of humans and the environmental factors affecting their thermal behavior.
- Indexes based on linear equations do not allow for more comprehensive microclimate analysis, even if they can be useful for meteorological forecasting or for mapping of thermal comfort trends over the time [86].

From the literature analysis, it emerges that PMV and PET are the most widely used indexes [49,50,59,61,62,67,71,75,77,80,85,86,88,89,92,93,95,98,109,110,112,114,118,128,131,133,138,141,142,148,151,154]. However, PMV was elaborated for indoor environments by observing people sitting in climate chambers; it does not consider the dynamic adaptive response of the human body and instead references a punctual static situation. Thus, its use in outdoor environments may often give misleading results. Cheng et al. [74] clearly demonstrate that PMV generally overestimates the thermal sensation in summer and underestimates in winter.

Developed for the outdoor environment, PET is a procedure often adopted, with results that are well correlated with onsite monitoring and questionnaires [49,77,89,114,131,133,141,142,148]. The PET index can be used as an alternative to PMV; however, the main drawback is that it can underestimate the effect of latent heat fluxes and overestimate radiant heat flows [74]. By comparing the outdoor thermal environment and the thermal sensation of pedestrians in two different Chinese cities, and through the thermal unacceptability percentage and PET indexes, Yang et al. [54] observed that the thermal unacceptability expressed by people was different according to the city, despite the similar outdoor thermal conditions.

In arid climates, ITS results show high correlation with field studies [196,200], while SET [52,142,191] and OUT SET* [133,148] appear to be more applied in and reliable for temperate climates. Being more scientifically updated, UTCI is instead the only index that was applied to all climates [59,84,99], ensuring a good matching between onsite measures and simulations [70,133,157]. PE and WCI, describing thermal sensations from comfort to extreme cold stress are preferable in cold climates. ITS, H, HI and WGBT make available detailed thermal scales for hot sensations, often neglecting the cold ones [157].

From the research carried out so far in order to understand the primary models used, it seems that there are apparently a large number of indexes available for the assessment of outdoor comfort, despite each of them presenting some drawback with different levels of error or approximation.

Although energy balance based indexes are widely used, the main limitation lies in the steady-state condition that does not fully reflect people rarely experience thermal equilibrium in outdoor environments [100].

A positive note is that the scientific community seems to be aware of this limit and much effort was spent to understand the human adaptation capacity as well [25].

3.2. Human Thermal Perception and Thermal Adaptation

The term adaptation can be broadly defined as the gradual decrease of the organism's response under an iterated exposure to a stimulus, thanks to the effects of all the actions deployed by the subject to make it better suited to survive in such an environment. In the context of thermal comfort, this can involve all the processes that people perform to reduce the gap between the environmental conditions and their requirements [194]. In other words, whenever metabolic activity or environmental conditions change, the human body tends to adapt itself to those changes. According to Nikolopoulou and Steemers [194], the adaptation basically occurs in three different ways:

- Physical adaptation—namely, the changes that a person makes in order to adjust oneself to the environment (such as altering clothing layers, posture and position, or drinking) or to conform the environment to his needs;
- Physiological adaptation—also called physiological acclimatization, which implies changes in the physiological response mechanisms resulting from repeated exposure to a stimulus;
- Psychological adaptation—which involves the different ways that individual people perceive the environment, being the human response is not only direct related to the physical stimulus magnitude, but also to the information that people have regarding that situation. The familiarity with that climate, the individual expectations, experiences, time of exposure and alleged control power on the situation, significantly influence the perception of environmental stimuli. Cultural factors and personal attitudes also affect the thermal perception, thus underlining the need to connect the thermal comfort indexes to the emotional feeling individually established with the environment [175].

A large number of studies were done in the last twenty years that aimed to incorporate the human dimensions into comfort assessment methods, performed both through climate chambers and by direct field surveys. Some of these studies investigated the possible adaptation from a thermophysiological perspective [95,174], others focused on the parameters that determine the human perception of comfort [81,142,194,208].

Some links between human thermoregulation mechanisms and thermal environment conditions were established by running tests in climate chambers [149,195]. However, whether these results can be transferred to the behavior of people in external environments is still an open question, since all the aspects that influence adaptation actions in real contexts are highly complex to reproduce (providing wide temperature ranges, checking for human physical and behavioral changes, measuring temperatures of people' skin and core to evaluate thermoregulation features etc.).

Thus, the assessment of the human thermal sensation must consider the environmental stimuli, which are dynamic and perceived subjectively. The stimuli are dynamic due to the human adaptation to external climatic conditions, which is a progressive process influenced by various adaptive factors. It is subjectively perceived, since the human perception of thermal comfort is not always nor univocally dependent only on objective biometeorological conditions. This means that the individual attitude towards outdoor space is not only determined by the state of the body, but also by the state of the mind. This suggests that the ideal framework for thermal comfort assessment should work on at least four levels: physical, physiological, psychological and social/behavioral [7].

Therefore, by considering simultaneously all the factors (whether objective or subjective) influencing human thermal perception, it is possible to obtain an evaluation of outdoor comfort as coincident as possible with reality. Each of these factors can be estimated or calculated through different approaches (measurements, modeling, field interviews and observations). Thus, working on the four levels of evaluation of human outdoor thermal comfort, it should make it possible to connect the external microclimatic conditions with the perception of people who use a certain space at a specific temporal moment.

In other words, this framework should allow a linkage of "climatic knowledge" with "human knowledge" [7].

"Neuroarchitecture" seems to be opening a new research field that is able to drive some advances in this direction, combining neuroscience and architecture to better understand how space is perceived by the human brain [159,160,165]. The outcome from neuroarchitecture studies could thus enhance the effectiveness of the design of the built environment, providing a better knowledge of the relationship between the humans and their spatial wellbeing [157].

Coburn et al. [202] investigated how neuroarchitecture could mature into an experimental science by outlining the related challenges ahead and identifying the priority need for a specific framework to guide research. To date, however, relatively little work has been done on architecture neuroscience, and further studies are needed.

Therefore, the final suggestion is to apply a multidisciplinary approach, including both studies on physical phenomena and human psychology. For this reason, it is highly recommended that shared principles and definitions be included in the common framework.

3.3. Software and Predictive Tools

Givoni et al. [164] addressed the need for prediction tools in order to support designers in understanding the effect of a change in a climatic element that influences people's outdoor comfort. In fact, the availability of simulation and scenario-testing tools within an assessment framework is crucial, as they provide a platform for both the integration of knowledge from various perspectives and the comparisons of different design options.

Currently, tools for simulating virtual scenarios are becoming increasingly available and updated, allowing reproduction of even complex environmental contexts. The literature review performed identified the most used software: ENVI-Met, RayMan, SOLWEIG and the UTCI calculator (Figure 3). While ENVI-Met is based on computational fluid dynamics (CFD) and thermodynamics, RayMan and SOLWEIG are basically 3D radiation models.

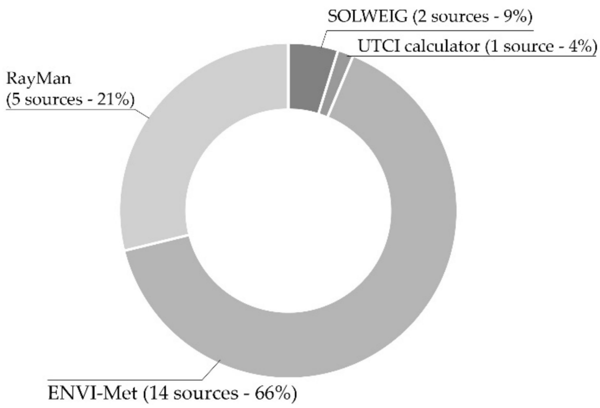

Figure 3. The most used software and tools outlined from the literature review.

ENVI-Met is a tool to simulate outdoor space microclimate by quantifying energy and mass exchanges, wind turbulence, vegetation effect on the outdoor conditions, bioclimatology data and pollution scattering. It is based on four interrelated systems: soil, vegetation, atmosphere and buildings.

Outdoor microclimate is described by air temperature, Mean Radiant Temperature (MRT), wind speed and direction, short- and long-wave radiation from a single building to an entire city [236]. It was used by Acero et al. to evaluate the differences in thermal comfort comparison models and onsite measures in four different locations [58]. The study points out that some deviations may occur in the ENVI-Met output; however, the tool provides useful and quite reliable outcomes (e.g., comparison of urban planning scenarios during typical meteorological conditions). Nevertheless, limitations must be clearly outlined in order to avoid misleading results. ENVI-Met is often used while interacting with other tools and plugins. Through the postprocessing tool called BioMet, it is possible to determine thermal comfort according to PMV, PET, UTCI [215] and MRT. Additionally, thanks to a generative algorithm called ENVI-BUG Software, it is possible to combine ENVI-Met, Rhinoceros, Grasshopper and LadyBug. Fabbri et al. effectively adapted it to obtain a 3D output, achieving a simplified method for displaying results and making them easier to read for nonexpert users [230].

Developed at the University of Freiburg, RayMan is a diagnostic microscale radiation model able to calculate radiation fluxes and thermophysiologically indexes, such as PMV, PET, SET* [222], UTCI, PT [220] and MRT. It is mainly used to compare the effect of multiple planning scenarios in different situations from micro to regional scales [220]. It allows the use of several input data such fish-eye pictures or obstacle files to obtain additional outputs like shade and sunshine duration, as well as the possibility to run long-term data sets. The major drawback is that the model cannot calculate air temperature, air humidity and calculate or adjust wind speed. These gaps are often bridged by preparing the data in the input files or running simulations with different wind speeds [222].

SOLWEIG (SOlar and LongWave Environmental Irradiance Geometry) enables quantification of PET, UTCI and MRT within complex urban settings as described by Lindberg et al. [218]. It applies the theory of radiative fluxes and mean radiant temperature, the main limitation is that it takes only building geometry into account, while vegetation is not considered when mean radiant temperature is calculated.

The UTCI calculator allows determination of a pedestrian's thermal comfort according to the Universal Thermal Climate Index [117]. Abdel-Ghany et al. demonstrated its application in combination with RayMan to evaluate UTCI index in arid climatic conditions [128], concluding that the model can be used successfully in arid environments to evaluate the thermal sensation, with the heat stress outcome very close to the PET index.

These environmental modeling tools can provide a better understanding of climatic conditions and a mean to effectively assess human thermal comfort outdoors, helping town planners and decision makers to compare and test several design alternatives in terms of attractiveness and effectiveness [232]. In addition, the development of such tools and software can solve the limitation of the different methodologies used in research.

4. Discussion

The literature review in this paper lists the main available resources dealing with outdoor thermal comfort issues. Its aims to provide a state-of-the-art review to identify the main topics on which current research focuses, and what the main barriers are that limit the identification of successful indexes for the assessment of thermal comfort in the outdoor environment, especially in urban contexts [150,170].

The main outcome is that thermal comfort in the outdoor environment is a complex issue with multiple layers and that the human state of the mind plays a key role in influencing peoples' perception on space and its utilization.

The literature review performed points out that many indexes and approaches have been developed, however they are specifically addressed to meet particular contexts with relation to specific variables. A relevant drawback deals with the limited consideration of the dynamic adaptive response of the human body, since the most frequently adopted indexes focus on the energy balance between the human body and the environment. More recent indexes seem to pay more attention to human perception and behavior, but their application is still limited and therefore a discussion on the potential outcomes is still hard and may be somehow misleading. The main suggestion is to focus on a limited and possibly shared number of procedures that adequately consider the human thermal perception and thermal adaptation.

It must be noted, despite some attempts to integrate different disciplines on the same topic, that most studies are organized by adopting a silos approach.

Moreover, many studies reveal that different people experience the environment in a different way. The human response to a physical stimulus is not in direct relationship to its intensity, but depends on the "information" that people have for a particular situation, and on the associated psychological factors influencing the thermal perception of a space and the changes occurring in it [194]. If physiological acclimatization is not sufficient to meet a comfort status, physical adaptation will be introduced to adjust oneself to the environment or alter the environment to his needs (such as altering clothing levels, modifying posture and position, or even changing metabolic heat with the consumption of hot or cool drinks).

Since the agents acting on this mechanism belong to at least four different but interconnected patterns (physical, psychological, physiological and social/behavioral), the ideal framework for thermal comfort assessment should work on all of them.

No effective methods are available today that include the human dependent factors within the outdoor thermal comfort models. However, the scientific community seems to become increasingly aware of the importance of the psychological and social/behavioral factors, as indicated by the number of recent studies exploring these fields. Integrating the physical energy balance and the human variables would allow for creation of more complete and thus more effective models, drastically improving the reliability of their results.

Despite the complexity of the above interrelations, these topics should be approached at design level. More effective simulation and modeling tools could be developed within that framework, providing designers and decision makers with a means to better achieve the thermal outdoor comfort target by integrating the factors related to climatic conditions and those belonging to the people's sensitivity to environmental stimuli; these tools could be wisely adopted in urban design. In this way, shopkeepers could be the first group to realize the benefit of such cool oases in a hot environment, and finally it would be possible to extend the positive impacts not only to the environmental domain of cities but also to the economic domain.

The highly advisable trend sketched by this scenario cannot hide the fact that shortcomings are still evident in research, concerning both the tools and the goals. Concerning tools, the systematization of all knowledge belonging to physical, physiological and psychological studies seems to be the only way forward today for the identification of an effective and shared method to evaluate the achievement of thermal comfort in outdoor spaces. Regarding goals, deeper interdisciplinary studies are needed to support with evidence the assumption that the more intense use of outdoor space will benefit the economic and social life of the city.

5. Conclusions

The literature review performed points out that many different interrelated issues drive the research on outdoor thermal comfort. The topic emerges as worthy to be further investigated, especially in relation to social and behavioral implications, requiring to possibly adopt a transdisciplinary approach. Despite the effort spent to create accurate models and software to properly assess outdoor human comfort, the evocated state of mind of the final user still remains at the core of the uncertain process. The field studies, including surveys and tests with different categories of users, highlight the need to refine the available indexes to better reflect the real perception of the human body in different conditions.

Therefore, each user has to clearly understand the basic equations of the software or tool chosen, in order to select the one that best suits the needs for the research purpose and the application context. This often generates some uncertainty that makes a comparative approach among the different outcomes more difficult.

Some relevant shortcomings can be currently detected and listed as follows, with the aim to address and prioritize the research efforts for further improving an understanding of outdoor human comfort.

Assuming that an effective assessment requires consideration of physical, physiological, psychological and behavioral levels, the detected lack of shared principles and definitions within a common framework reduces the possibility to take into account the multiple and interconnected nature of phenomena. Accordingly, the definition of a comprehensive and stable framework represents a top priority:

- The availability of several models and methods is on the one hand a true sign of interest in assuming outdoor thermal comfort as a relevant field of research, especially when connected to climate change effects (UHI, heat waves etc.), but each methodology has its own limitations and the differences make it harder to compare the outcomes. The development or the refinement of tools and software able to solve these gaps may certainly support the research activity in the future.
- The gap between models and real perception in experimental studies suggests that human sensation and behavior are central and crucial elements to further improving the quality of research.
- Understanding the outcomes is another relevant issue dealing with a proper communication of the possible social implications to nonexperts. Even if this is not a top priority, it will certainly contribute by increasing the attention towards quality of life in outdoor urban spaces.

The use of reliable predictive and simulation tools will support decision makers, designers and planners to better realize the potential impacts of their decision and strategies when transforming the built environment. Finally, a multidisciplinary approach, including studies on physical phenomena, human psychology and architecture, is highly recommended, assuming people's wellbeing is the ultimate goal.

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References

1. Population Reference Bureau 2008 WORLD POPULATION Data Sheet. *Popul. Bull.* **2008**, 10–11.
2. Akpınar, M.; Sevin, S. *Reducing Urban Heat Islands by Developing Cool Pavements*; Springer Science and Business Media LLC: Cham, Germany, 2018; pp. 43–50.
3. Hoegh-Guldberg, O.D.; Jacob, D.; Taylor, M.; Bindi, M.; Brown, S.; Camilloni, I.; Diedhiou, A.; Djalante, R.; Ebi, K.L.; Engelbrecht, F.; et al. Global Warming of 1.5 °C. *Special Report* **2014**, 177–287.
4. Rebecca, L.; Dahlman, L. Climate Change: Global Temperature|NOAA Climate.gov. Available online: https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature (accessed on 27 March 2020).
5. For Some Urban Areas, A Warming Climate is only Half The Threat–Science Daily. Available online: https://www.sciencedaily.com/releases/2019/11/191114115946.htm (accessed on 27 March 2020).
6. Gehl, J. *Life between Buildings: Using Public Space*; Island Press: Washington, DC, USA, 2011.
7. Chen, L.; Ng, E. Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities* **2012**, *29*, 118–125. [CrossRef]
8. Maruani, T.; Amit-Cohen, I. Open space planning models: A review of approaches and methods. *Landsc. Urban Plan.* **2007**, *81*, 1–13. [CrossRef]
9. Nikolopoulou, M.; Baker, N.; Steemers, K. Thermal comfort in outdoor urban spaces: Understanding the human parameter. *Sol. Energy* **2001**, *70*, 227–235. [CrossRef]

10. Nikolopoulou, M. Outdoor thermal comfort. *Front. Biosci. Sch.* **2011**, *3*, 1552–1568. [CrossRef]
11. Fabbri, K. *Indoor Thermal Comfort Perception*; Springer International Publishing: Cham, Switzerland, 2015.
12. Gagge, A.P. An effective temperature scale based on a simple model of human physiological regulatory response. *Ashrae Trans.* **1971**, *77*, 247–262.
13. Gagge, A.P. The linearity criterion as applied to partitional calorimetry. *Am. J. Physiol. Content* **1936**, *116*, 656–668. [CrossRef]
14. Honjo, T. Thermal Comfort in Outdoor Environment. *Global Environ. Res.* **2009**, *13*, 43–47.
15. Givoni, B. *Estimation of the Effects of Climate on Man: Development of a New Thermal Index*; Technion: Haifa, Israel, 1963.
16. Fanger, P. *Thermal Comfort*; McGraw-Hill: New York, NY, USA, 1972.
17. Gagge, A.P.; Fobelets, A.P.; Berglund, L.G. Standard Predictive Index of Human Response to The Thermal Environment. In *Proceedings of the ASHRAE Transactions*; ASHRAE: Portland, OR, USA, 1986; Volume 92, pp. 709–731.
18. Höppe, P. The physiological equivalent temperature—A universal index for the biometeorological assessment of the thermal environment. *Int. J. Biometeorol.* **1999**, *43*, 71–75. [CrossRef]
19. Mayer, H.; Höppe, P. Thermal comfort of man in different urban environments. *Theor. Appl. Clim.* **1987**, *38*, 43–49. [CrossRef]
20. Steadman, R.G. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proc. Am. Philos. Soc.* **1945**, *89*, 177–199.
21. Steadman, R.G. Indices of windchill of clothed persons. *J. Appl. Meteorol.* **1971**, *10*, 674–683. [CrossRef]
22. Steadman, R.G. A Universal Scale of Apparent Temperature. *J. Clim. Appl. Meteorol.* **1984**, *23*, 1674–1687. [CrossRef]
23. Olgyay, V. *Design with Climate: Bioclimatic Approach to Architectural Regionalism-New and Expanded Edition*; Princeton Univerity Press: Princeton, NJ, USA, 2015.
24. Penwarden, A. Acceptable wind speeds in towns. *Build. Sci.* **1973**, *8*, 259–267. [CrossRef]
25. Perera, K.; Schnabel, M.A.; Donn, M.; Maddewithana, H. Addressing Human Thermal Adaptation in Outdoor Comfort Research—A Literature Review. In Proceedings of the Making built environments responsive, 8th International Conference of Faculty of Architecture Research Unit (FARU), University of Moratuwa, Sri Lanka, 11–12 December 2015; pp. 477–490.
26. Parsons, K. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2014; ISBN 9781466595996.
27. ISO 13731:2001-Ergonomics of the Thermal Environment—Vocabulary and Symbols. Available online: https://www.iso.org/standard/22450.html (accessed on 19 February 2020).
28. ISO 7726:1998-Ergonomics of the Thermal Environment—Instruments for Measuring Physical Quantities. Available online: https://www.iso.org/standard/14562.html (accessed on 19 February 2020).
29. ISO 7730:2005-Ergonomics of the thermal environment—Analytical Determination and Interpretation of Thermal Comfort using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. Available online: https://www.iso.org/standard/39155.html (accessed on 29 January 2020).
30. Jendritzky, G.; Nübler, W. A model analysing the urban thermal environment in physiologically significant terms. *Theor. Appl. Clim.* **1981**, *29*, 313–326. [CrossRef]
31. ISO 7243:2017-Ergonomics of the Thermal Environment—Assessment of Heat Stress Using the WBGT (Wet Bulb Globe Temperature) Index. Available online: https://www.iso.org/standard/67188.html (accessed on 19 February 2020).
32. EN 15251:2007–Policies–IEA. Available online: https://www.iea.org/policies/7029-en-152512007 (accessed on 19 February 2020).
33. *American Society of Heating Refrigeration and Air-Conditioning Engineers ASHRAE Handbook Fundamentals*; ASHRAE: Atlanta, GA, USA, 1989.
34. Nikolopoulou, M.; Lykoudis, S. Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Build. Environ.* **2006**, *41*, 1455–1470. [CrossRef]
35. Heijs, W.J.M. The dependent variable in thermal comfort research some psychological considerations. In *Proceedings of the Thermal Comfortpast Present and Future: Proceedings of the Conference of June 1993*; Oseland, N., Humphreys, M., Eds.; Watford Building Research Establishment: Garston, UK, 1994; pp. 40–51.

36. Shooshtarian, S. Theoretical dimension of outdoor thermal comfort research. *Sustain. Cities Soc.* **2019**, *47*, 101495. [CrossRef]
37. RUROS Database: Field Survey Results. Available online: http://alpha.cres.gr/ruros/database.htm (accessed on 16 February 2020).
38. US Department of Commerce National Oceanic and Atmospheric Administration. Available online: https://www.noaa.gov/ (accessed on 30 March 2020).
39. ISO 11079:2007-Ergonomics of the Thermal Environment—Determination and Interpretation of Cold Stress When Using Required Clothing Insulation (IREQ) and Local Cooling Effects. Available online: https://www.iso.org/standard/38900.html (accessed on 29 January 2020).
40. ISO 7243:1989-Hot Environments—Estimation of the Heat Stress on Working Man, Based on the WBGT-Index (Wet Bulb Globe Temperature). Available online: https://www.iso.org/standard/13895.html (accessed on 29 January 2020).
41. Cheung, P.K.; Jim, C. Determination and application of outdoor thermal benchmarks. *Build. Environ.* **2017**, *123*, 333–350. [CrossRef]
42. Gagge, A.P.; Stolwijk, J.A.J.; Nishi, Y. An Effective Temperature Scale Based on a Simple Model of Human Physiological Regulatiry Response. *Memoirs Faculty Eng. Hokkaido Univ.* **1971**, *13*, 21–36.
43. Chun, C.; Kwok, A.; Tamura, A. Thermal comfort in transitional spaces-basic concepts: Literature review and trial measurement. *Build. Environ.* **2004**, *39*, 1187–1192. [CrossRef]
44. Thom, E.C. The Discomfort Index. *Weatherwise* **1959**, *12*, 57–61. [CrossRef]
45. EPA Heat Island Compendium. *US Environ. Prot. Agency* **2008**, 2–3.
46. Varquez, A.C.G.; Kanda, M. Global urban climatology: A meta-analysis of air temperature trends (1960–2009). *npj Clim. Atmospheric Sci.* **2018**, *1*, 32. [CrossRef]
47. Wu, H.; Wu, Y.; Sun, X.; Liu, J. Combined effects of acoustic, thermal, and illumination on human perception and performance: A review. *Build. Environ.* **2020**, *169*, 106593. [CrossRef]
48. Acero, J.A.; Arrizabalaga, J.; Kupski, S.; Katzschner, L. Urban heat island in a coastal urban area in northern Spain. *Theor. Appl. Clim.* **2012**, *113*, 137–154. [CrossRef]
49. Xi, T.; Li, Q.; Mochida, A.; Meng, Q. Study on the outdoor thermal environment and thermal comfort around campus clusters in subtropical urban areas. *Build. Environ.* **2012**, *52*, 162–170. [CrossRef]
50. Xie, Y.; Huang, T.; Li, J.; Liu, J.; Niu, J.; Mak, C.M.; Lin, Z. Evaluation of a multi-nodal thermal regulation model for assessment of outdoor thermal comfort: Sensitivity to wind speed and solar radiation. *Build. Environ.* **2018**, *132*, 45–56. [CrossRef]
51. Xie, Y.; Liu, J.; Huang, T.; Li, J.; Niu, J.; Mak, C.M.; Lee, T. cheung Outdoor thermal sensation and logistic regression analysis of comfort range of meteorological parameters in Hong Kong. *Build. Environ.* **2019**, *155*, 175–186. [CrossRef]
52. Yahia, M.; 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.* **2012**, *57*, 615–630. [CrossRef]
53. Yang, W.; Wong, N.H.; Jusuf, S.K. Thermal comfort in outdoor urban spaces in Singapore. *Build. Environ.* **2013**, *59*, 426–435. [CrossRef]
54. Yang, W.; Wong, N.H.; Zhang, G. A comparative analysis of human thermal conditions in outdoor urban spaces in the summer season in Singapore and Changsha, China. *Int. J. Biometeorol.* **2012**, *57*, 895–907. [CrossRef] [PubMed]
55. Yang, Y.; Gatto, E.; Gao, Z.; Buccolieri, R.; Morakinyo, T.E.; Lan, H. The "plant evaluation model" for the assessment of the impact of vegetation on outdoor microclimate in the urban environment. *Build. Environ.* **2019**, *159*, 106151. [CrossRef]
56. Yang, Y.; Zhou, D.; Wang, Y.; Ma, D.; Chen, W.; Xu, D.; Zhu, Z. Economical and outdoor thermal comfort analysis of greening in multistory residential areas in Xi'an. *Sustain. Cities Soc.* **2019**, *51*, 51. [CrossRef]
57. Zhao, L.; Zhou, X.; Li, L.; He, S.; Chen, R. Study on outdoor thermal comfort on a campus in a subtropical urban area in summer. *Sustain. Cities Soc.* **2016**, *22*, 164–170. [CrossRef]
58. Acero, J.A.; Herranz-Pascual, K. A comparison of thermal comfort conditions in four urban spaces by means of measurements and modelling techniques. *Build. Environ.* **2015**, *93*, 245–257. [CrossRef]
59. Achour-Younsi, S.; Kharrat, F. Influence of Urban Morphology on Outdoor Thermal Comfort in Summer: A Study in Tunis, Tunisia. *Mod. Environ. Sci. Eng.* **2016**, *2*, 251–256. [CrossRef]

60. Alfano, F.; Palella, B.I.; Riccio, G. Thermal environment assessment reliability using temperature–humidity indices. *Ind. Health* **2010**, *49*, 10081910028.
61. Ali-Toudert, F.; Djenane, M.; Bensalem, R.; Mayer, H. Outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria. *Clim. Res.* **2005**, *28*, 243–256. [CrossRef]
62. Andreou, E. Thermal comfort in outdoor spaces and urban canyon microclimate. *Renew. Energy* **2013**, *55*, 182–188. [CrossRef]
63. Athamena, K.; Sini, J.-F.; Rosant, J.-M.; Guilhot, J. Numerical coupling model to compute the microclimate parameters inside a street canyon. *Sol. Energy* **2018**, *174*, 1237–1251. [CrossRef]
64. Balaras, C.; Tselepidaki, I.; Santamouris, M.; Asimakopoulos, D. Calculations and statistical analysis of the environmental cooling power index for Athens, Greece. *Energy Convers. Manag.* **1993**, *34*, 139–146. [CrossRef]
65. Balogun, I.A.; Daramola, M.T. The outdoor thermal comfort assessment of different urban configurations within Akure City, Nigeria. *Urban Clim.* **2019**, *29*, 100489. [CrossRef]
66. Beshir, M.; Ramsey, J.D. Heat stress indices: A review paper. *Int. J. Ind. Ergon.* **1988**, *3*, 89–102. [CrossRef]
67. Binarti, F.; Koerniawan, M.D.; Triyadi, S.; Utami, S.S.; Matzarakis, A. A review of outdoor thermal comfort indices and neutral ranges for hot-humid regions. *Urban Clim.* **2020**, *31*, 31. [CrossRef]
68. MENEX_2005 The Updated Version of Man-Environment Heat Exchange Model. Available online: http://www.igipz.pan.pl/tl_files/igipz/ZGiK/opracowania/indywidualne/blazejczyk/ (accessed on 30 March 2020).
69. Blazejczyk, K.; Bröde, P.; Fiala, D.; Havenith, G.; Holmér, I.; Jendritzky, G.; Kampmann, B.; Kunert, A. Principles of the New Universal Thermal Climate Index (UTCI) and its Application to Bioclimatic Research in European Scale. *Misc. Geogr.* **2010**, *14*, 91–102.
70. Blazejczyk, K.; Epstein, Y.; Jendritzky, G.; Staiger, H.; Tinz, B. Comparison of UTCI to selected thermal indices. *Int. J. Biometeorol.* **2011**, *56*, 515–535. [CrossRef]
71. Bouyer, J.; Vinet, J.; Delpech, P.; Carré, S. Thermal comfort assessment in semi-outdoor environments: Application to comfort study in stadia. *J. Wind. Eng. Ind. Aerodyn.* **2007**, *95*, 963–976. [CrossRef]
72. Bröde, P.; Fiala, D.; Blazejczyk, K.; Holmér, I.; Jendritzky, G.; Kampmann, B.; Tinz, B.; Havenith, G. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). *Int. J. Biometeorol.* **2011**, *56*, 481–494. [CrossRef]
73. Cheng, V.; Ng, E. Thermal Comfort in Urban Open Spaces for Hong Kong. *Arch. Sci. Rev.* **2006**, *49*, 236–242. [CrossRef]
74. Cheng, V.; Ng, E.; Chan, C.; Givoni, B. Outdoor thermal comfort study in a sub-tropical climate: A longitudinal study based in Hong Kong. *Int. J. Biometeorol.* **2011**, *56*, 43–56. [CrossRef] [PubMed]
75. Cheung, P.K.; Jim, C. Comparing the cooling effects of a tree and a concrete shelter using PET and UTCI. *Build. Environ.* **2018**, *130*, 49–61. [CrossRef]
76. Chow, W.T.L.; Akbar, S.N.; Assyakirin, B.A.; Heng, S.L.; Roth, M. Assessment of measured and perceived microclimates within a tropical urban forest. *Urban For. Urban Green.* **2016**, *16*, 62–75. [CrossRef]
77. Cohen, P.; Potchter, O.; Matzarakis, A.A. Human thermal perception of Coastal Mediterranean outdoor urban environments. *Appl. Geogr.* **2013**, *37*, 1–10. [CrossRef]
78. De Dear, R.; Pickup, J. An Outdoor Thermal Comfort index (OUT-SET*)-Part I-The Model and its Assumptions SAMBA IEQ Monitoring System View Project Natural Ventilation in Buildings View. In Proceedings of the 15th International Congress of Biometeorology and International Conference on Urban Climatology, Sydney, Australia, 8–12 November 1999.
79. De Freitas, C.R.; Grigorieva, E.A. A comprehensive catalogue and classification of human thermal climate indices. *Int. J. Biometeorol.* **2014**, *59*, 109–120. [CrossRef]
80. De Freitas, C.R.; Grigorieva, E.A. A comparison and appraisal of a comprehensive range of human thermal climate indices. *Int. J. Biometeorol.* **2016**, *61*, 487–512. [CrossRef] [PubMed]
81. Deb, C.; Ramachandraiah, A. A simple technique to classify urban locations with respect to human thermal comfort: Proposing the HXG scale. *Build. Environ.* **2011**, *46*, 1321–1328. [CrossRef]
82. Dimoudi, A.; Kantzioura, A.; Zoras, S.; Pallás, C.; Kosmopoulos, P. Investigation of urban microclimate parameters in an urban center. *Energy Build.* **2013**, *64*, 1–9. [CrossRef]
83. Dimoudi, A.; Zoras, S.; Kantzioura, A.; Stogiannou, X.; Kosmopoulos, P.; Pallás, C. Use of cool materials and other bioclimatic interventions in outdoor places in order to mitigate the urban heat island in a medium size city in Greece. *Sustain. Cities Soc.* **2014**, *13*, 89–96. [CrossRef]

84. Du, J.; Sun, C.; Xiao, Q.; Chen, X.; Liu, J. Field assessment of winter outdoor 3-D radiant environment and its impact on thermal comfort in a severely cold region. *Sci. Total. Environ.* **2020**, *709*, 136175. [CrossRef]
85. Ebrahimabadi, S. Outdoor Comfort in Cold Climates: Integrating Microclimate Factors in Urban Design. Ph.D. Thesis, Luleå Univ. Technol. 1 jan 1997, Luleå, Sweden, 2015; p. 195.
86. Emmanuel, R. Thermal comfort implications of urbanization in a warm-humid city: The Colombo Metropolitan Region (CMR), Sri Lanka. *Build. Environ.* **2005**, *40*, 1591–1601. [CrossRef]
87. Epstein, Y.; Moran, D.S. Thermal comfort and the heat stress indices. *Ind. Heal.* **2006**, *44*, 388–398. [CrossRef] [PubMed]
88. Evola, G.; Gagliano, A.; Fichera, A.; Marletta, L.; Martinico, F.; Nocera, F.; Pagano, A. UHI effects and strategies to improve outdoor thermal comfort in dense and old neighbourhoods. *Energy Procedia* **2017**, *134*, 692–701. [CrossRef]
89. Fang, Z.; Xu, X.; Zhou, X.; Deng, S.; Wu, H.; Liu, J.; Lin, Z. Investigation into the thermal comfort of university students conducting outdoor training. *Build. Environ.* **2019**, *149*, 26–38. [CrossRef]
90. Fiala, D.; Havenith, G.; Bröde, P.; Kampmann, B.; Jendritzky, G. UTCI-Fiala multi-node model of human heat transfer and temperature regulation. *Int. J. Biometeorol.* **2011**, *56*, 429–441. [CrossRef]
91. Foda, E.; Sirén, K. A new approach using the Pierce two-node model for different body parts. *Int. J. Biometeorol.* **2010**, *55*, 519–532. [CrossRef]
92. Golasi, I.; Salata, F.; Vollaro, E.D.L.; Coppi, M. Complying with the demand of standardization in outdoor thermal comfort: A first approach to the Global Outdoor Comfort Index (GOCI). *Build. Environ.* **2018**, *130*, 104–119. [CrossRef]
93. Golasi, I.; Salata, F.; Vollaro, E.D.L.; Coppi, M.; Vollaro, A.D.L. Thermal Perception in the Mediterranean Area: Comparing the Mediterranean Outdoor Comfort Index (MOCI) to Other Outdoor Thermal Comfort Indices. *Energies* **2016**, *9*, 550. [CrossRef]
94. Gonçalves, A.; Ribeiro, A.; Maia, F.; Nunes, L.; Feliciano, M. Influence of Green Spaces on Outdoors Thermal Comfort—Structured Experiment in a Mediterranean Climate. *Clim.* **2019**, *7*, 20. [CrossRef]
95. Gulyás, Á.; Unger, J.; Matzarakis, A. Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. *Build. Environ.* **2006**, *41*, 1713–1722. [CrossRef]
96. Guo, H.; Aviv, D.; Loyola, M.; Teitelbaum, E.; Houchois, N.; Meggers, F. On the understanding of the mean radiant temperature within both the indoor and outdoor environment, a critical review. *Renew. Sustain. Energy Rev.* **2020**, *117*, 109207. [CrossRef]
97. Hai, Y.; Feng, Q. Thermalscape of Ecological City and its Visualized Evaluation. *Energy Procedia* **2018**, *152*, 1139–1144. [CrossRef]
98. Hami, A.; Abdi, B.; Zarehaghi, D.; Maulan, S. Bin Assessing the thermal comfort effects of green spaces: A systematic review of methods, parameters, and plants' attributes. *Sustain. Cities Soc.* **2019**, *49*, 101634. [CrossRef]
99. Hanipah, M.H.; Abdullah, A.H.; Sidik, N.A.C.; Yunus, R.; Yasin, M.N.A.; Yazid, M.N.A.W.M. Assessment of Outdoor Thermal Comfort and Wind Characteristics at Three Different Locations in Peninsular Malaysia. In *Proceedings of the MATEC Web of Conferences*; EDP Sciences: Paris, France, 2016; Volume 47, p. 4005.
100. Höppe, P. Different aspects of assessing indoor and outdoor thermal comfort. *Energy Build.* **2002**, *34*, 661–665. [CrossRef]
101. Huang, T.; Li, J.; Xie, Y.; Niu, J.; Mak, C.M. Simultaneous environmental parameter monitoring and human subject survey regarding outdoor thermal comfort and its modelling. *Build. Environ.* **2017**, *125*, 502–514. [CrossRef]
102. ISO 7730:1994-Moderate Thermal Environments—Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort. Available online: https://www.iso.org/standard/14567.html (accessed on 29 January 2020).
103. Jain, S.; Garg, V. A review of open loop control strategies for shades, blinds and integrated lighting by use of real-time daylight prediction methods. *Build. Environ.* **2018**, *135*, 352–364. [CrossRef]
104. The Perceived Temperature: The Method of the Deutscher Wetterdienst for the Assessment of Cold Stress and Heat Load for the Human Body. Available online: https://www.semanticscholar.org/paper/ (accessed on 29 January 2020).
105. Jendritzky, G.; De Dear, R.; Havenith, G. UTCI—Why another thermal index? *Int. J. Biometeorol.* **2011**, *56*, 421–428. [CrossRef]

106. 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]
107. Johansson, E.; Thorsson, S.; Emmanuel, R.; Krüger, E.L. Instruments and methods in outdoor thermal comfort studies – The need for standardization. *Urban Clim.* **2014**, *10*, 346–366. [CrossRef]
108. Jones, B.W. Capabilities and limitations of thermal models for use in thermal comfort standards. *Energy Build.* **2002**, *34*, 653–659. [CrossRef]
109. Karakounos, I.; Dimoudi, A.; Zoras, S. The influence of bioclimatic urban redevelopment on outdoor thermal comfort. *Energy Build.* **2018**, *158*, 1266–1274. [CrossRef]
110. Lai, D.; Guo, D.; Hou, Y.; Lin, C.; Chen, Q. Studies of outdoor thermal comfort in northern China. *Build. Environ.* **2014**, *77*, 110–118. [CrossRef]
111. Lai, D.; Liu, W.; Gan, T.; Liu, K.; Chen, Q. A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Sci. Total. Environ.* **2019**, *661*, 337–353. [CrossRef]
112. Lai, D.; Zhou, C.; Huang, J.; Jiang, Y.; Long, Z.; Chen, Q. Outdoor space quality: A field study in an urban residential community in central China. *Energy Build.* **2014**, *68*, 713–720. [CrossRef]
113. Li, J.; Niu, J.; Mak, C.M.; Huang, T.; Xie, Y. Assessment of outdoor thermal comfort in Hong Kong based on the individual desirability and acceptability of sun and wind conditions. *Build. Environ.* **2018**, *145*, 50–61. [CrossRef]
114. Li, L.; Zhou, X.; Yang, L. The Analysis of Outdoor Thermal Comfort in Guangzhou during Summer. *Procedia Eng.* **2017**, *205*, 1996–2002. [CrossRef]
115. Lin, P.; Gou, Z.; Lau, S.S.Y.; Qin, H. The Impact of Urban Design Descriptors on Outdoor Thermal Environment: A Literature Review. *Energies* **2017**, *10*, 2151. [CrossRef]
116. Liu, L.; Lin, Y.; Wang, L.; Cao, J.; Wang, D.; Xue, P.; Liu, J. An integrated local climatic evaluation system for green sustainable eco-city construction: A case study in Shenzhen, China. *Build. Environ.* **2017**, *114*, 82–95. [CrossRef]
117. UTCI Calculator. Available online: http://www.utci.org/utcineu/utcineu.php (accessed on 29 January 2020).
118. Mahmoud, A. An analysis of bioclimatic zones and implications for design of outdoor built environments in Egypt. *Build. Environ.* **2011**, *46*, 605–620. [CrossRef]
119. Manavvi, S.; Rajasekar, E. Estimating outdoor mean radiant temperature in a humid subtropical climate. *Build. Environ.* **2020**, *171*, 106658. [CrossRef]
120. Masterton, J.; Richardson, F. *Humidex: A Method of Quantifying Human Discomfort due to Excessive Heat and Humidity*; Environment Canada: Downsview, ON, Canada, 1979.
121. Memon, R.A.; Chirarattananon, S.; Vangtook, P. Thermal comfort assessment and application of radiant cooling: A case study. *Build. Environ.* **2008**, *43*, 1185–1196. [CrossRef]
122. Miao, C.; Yu, S.; Hu, Y.; Zhang, H.; He, X.; Chen, W. Review of methods used to estimate the sky view factor in urban street canyons. *Build. Environ.* **2020**, *168*, 106497. [CrossRef]
123. Middel, A.; Selover, N.; Hagen, B.; Chhetri, N. Impact of shade on outdoor thermal comfort-a seasonal field study in Tempe, Arizona. *Int. J. Biometeorol.* **2016**, *60*, 1849–1861. [CrossRef]
124. Mijorski, S.; Cammelli, S.; Green, J. A hybrid approach for the assessment of outdoor thermal comfort. *J. Build. Eng.* **2019**, *22*, 147–153. [CrossRef]
125. Mittal, H.; Sharma, A.; Gairola, A. A review on the study of urban wind at the pedestrian level around buildings. *J. Build. Eng.* **2018**, *18*, 154–163. [CrossRef]
126. Moran, D.; Health, Y.E.-I. Undefined Evaluation of the environmental stress index (ESI) for hot/dry and hot/wet climates. *Ind. Health* **2006**, *43*, 399–403. [CrossRef]
127. Gonzalez, C.M.; Leon-Rodriguez, A.L.; Navarro-Casas, J. Air conditioning and passive environmental techniques in historic churches in Mediterranean climate. A proposed method to assess damage risk and thermal comfort pre-intervention, simulation-based. *Energy Build.* **2016**, *130*, 567–577. [CrossRef]
128. Abdel-Ghany, A.M.; Al-Helal, I.M.; Shady, M. Human Thermal Comfort and Heat Stress in an Outdoor Urban Arid Environment: A Case Study. *Adv. Meteorol.* **2013**, *2013*, 1–7. [CrossRef]
129. Nagano, K.; Horikoshi, T. New index indicating the universal and separate effects on human comfort under outdoor and non-uniform thermal conditions. *Energy Build.* **2011**, *43*, 1694–1701. [CrossRef]
130. Oh, H.-J.; Jeong, N.-N.; Sohn, J.-R.; Kim, J. Personal exposure to indoor aerosols as actual concern: Perceived indoor and outdoor air quality, and health performances. *Build. Environ.* **2019**, *165*, 106403. [CrossRef]

131. Oliveira, S.; Andrade, H. An initial assessment of the bioclimatic comfort in an outdoor public space in Lisbon. *Int. J. Biometeorol.* **2007**, *52*, 69–84. [CrossRef] [PubMed]
132. Ouali, K.; El Harrouni, K.; Abidi, M.L.; Diab, Y. Analysis of Open Urban Design as a tool for pedestrian thermal comfort enhancement in Moroccan climate. *J. Build. Eng.* **2020**, *28*, 101042. [CrossRef]
133. Pantavou, K.; Santamouris, M.; Asimakopoulos, D.; Theoharatos, G.; Santamouris, M. Empirical calibration of thermal indices in an urban outdoor Mediterranean environment. *Build. Environ.* **2014**, *80*, 283–292. [CrossRef]
134. Pearlmutter, D.; Berliner, P.; Shaviv, E. Integrated modeling of pedestrian energy exchange and thermal comfort in urban street canyons. *Build. Environ.* **2007**, *42*, 2396–2409. [CrossRef]
135. Pearlmutter, D.; Berliner, P.; Shaviv, E. Urban climatology in arid regions: Current research in the Negev desert. *Int. J. Clim.* **2007**, *27*, 1875–1885. [CrossRef]
136. Pickup, J.; Dear, R.D. *An Outdoor Thermal Comfort Index (OUT-SET*)*; 15th ICB ICUC; Macquarie University: Sydney, Australia, 1999.
137. The Heat Index Equation. Available online: https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml (accessed on 29 January 2020).
138. Ruiz, M.A.; Correa, E.N. Adaptive model for outdoor thermal comfort assessment in an Oasis city of arid climate. *Build. Environ.* **2015**, *85*, 40–51. [CrossRef]
139. Abu Bakar, A.; Gadi, M.B. Urban Outdoor Thermal Comfort of The Hot-Humid Region. In *Proceedings of the MATEC Web of Conferences*; EDP Sciences: Paris, France, 2016; Volume 66, p. 84.
140. Salata, F.; Golasi, I.; Treiani, N.; Plos, R.; Vollaro, A.D.L. On the outdoor thermal perception and comfort of a Mediterranean subject across other Koppen-Geiger's climate zones. *Environ. Res.* **2018**, *167*, 115–128. [CrossRef]
141. Sharmin, T.; Steemers, K.; Humphreys, M. Outdoor thermal comfort and summer PET range: A field study in tropical city Dhaka. *Energy Build.* **2019**, *198*, 149–159. [CrossRef]
142. Spagnolo, J.; De Dear, R. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *Build. Environ.* **2003**, *38*, 721–738. [CrossRef]
143. Staiger, H.; Laschewski, G.; Grätz, A. The perceived temperature —A versatile index for the assessment of the human thermal environment. Part A: Scientific basics. *Int. J. Biometeorol.* **2012**, *56*, 165–176. [CrossRef]
144. Sulaiman, H.; Olsina, F. Comfort reliability evaluation of building designs by stochastic hygrothermal simulation. *Renew. Sustain. Energy Rev.* **2014**, *40*, 171–184. [CrossRef]
145. Taleghani, M. Outdoor thermal comfort by different heat mitigation strategies- A review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2011–2018. [CrossRef]
146. González, A.T.; Chicote, M.A.; García-Ibáñez, P.; Velasco, E.; Rey-Martínez, F.J. Assessing the applicability of passive cooling and heating techniques through climate factors: An overview. *Renew. Sustain. Energy Rev.* **2016**, *65*, 727–742. [CrossRef]
147. 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] [PubMed]
148. Tsitoura, M.; Tsoutsos, T.; Daras, T. Evaluation of comfort conditions in urban open spaces. Application in the island of Crete. *Energy Convers. Manag.* **2014**, *86*, 250–258. [CrossRef]
149. Wan, J.; Yang, K.; Zhang, W.; Zhang, J. A new method of determination of indoor temperature and relative humidity with consideration of human thermal comfort. *Build. Environ.* **2009**, *44*, 411–417. [CrossRef]
150. Ahmed, K.S. Comfort in urban spaces: Defining the boundaries of outdoor thermal comfort for the tropical urban environments. *Energy Build.* **2003**, *35*, 103–110. [CrossRef]
151. Ali, S.B.; Patnaik, S. Thermal comfort in urban open spaces: Objective assessment and subjective perception study in tropical city of Bhopal, India. *Urban Clim.* **2018**, *24*, 954–967. [CrossRef]
152. Aljawabra, F.; Nikolopoulou, M. Influence of hot arid climate on the use of outdoor urban spaces and thermal comfort: Do cultural and social backgrounds matter? *Intell. Build. Int.* **2010**, *2*, 198–217.
153. Amindeldar, S.; Heidari, S.; Khalili, M. The effect of personal and microclimatic variables on outdoor thermal comfort: A field study in Tehran in cold season. *Sustain. Cities Soc.* **2017**, *32*, 153–159. [CrossRef]
154. Baruti, M.; Johansson, E.; Åstrand, J. Review of studies on outdoor thermal comfort in warm humid climates: Challenges of informal urban fabric. *Int. J. Biometeorol.* **2019**, *63*, 1449–1462. [CrossRef]
155. Brager, G.S.; De Dear, R. Thermal adaptation in the built environment: A literature review. *Energy Build.* **1998**, *27*, 83–96. [CrossRef]

156. Brychkov, D.; Garb, Y.; Pearlmutter, D. The influence of climatocultural background on outdoor thermal perception. *Int. J. Biometeorol.* **2018**, *62*, 1873–1886. [CrossRef] [PubMed]
157. Coccolo, S.; Kämpf, J.; Scartezzini, J.-L.; Pearlmutter, D. Outdoor human comfort and thermal stress: A comprehensive review on models and standards. *Urban Clim.* **2016**, *18*, 33–57. [CrossRef]
158. Cohen, P.; Shashua-Bar, L.; Keller, R.; Gil-Ad, R.; Yaakov, Y.; Lukyanov, V.; Bar (Kutiel), P.; Tanny, J.; Cohen, S.; Potchter, O.; et al. Urban outdoor thermal perception in hot arid Beer Sheva, Israel: Methodological and gender aspects. *Build. Environ.* **2019**, *160*, 106169. [CrossRef]
159. Eberhard, J.P. Applying Neuroscience to Architecture. *Neuron* **2009**, *62*, 753–756. [CrossRef]
160. Eberhard, J. *Brain Landscape the Coexistence of Neuroscience and Architecture*; Oxford University Press: New York, NY, USA, 2009.
161. Eliasson, I. The use of climate knowledge in urban planning. *Landsc. Urban Plan.* **2000**, *48*, 31–44. [CrossRef]
162. Fong, C.S.; Aghamohammadi, N.; Ramakreshnan, L.; Sulaiman, N.M.; Mohammadi, P. Holistic recommendations for future outdoor thermal comfort assessment in tropical Southeast Asia: A critical appraisal. *Sustain. Cities Soc.* **2019**, *46*, 101428. [CrossRef]
163. Jabbari, S.G.; Maleki, A.; Kaynezhad, M.A.; Olesen, B.W. Inter-personal factors affecting building occupants' thermal tolerance at cold outdoor condition during an autumn–winter period. *Indoor Built Environ.* **2019**, 1420326X1986799. [CrossRef]
164. Givoni, B.; Noguchi, M.; Saaroni, H.; Pochter, O.; Yaacov, Y.; Feller, N.; Becker, S. Outdoor comfort research issues. *Energy Build.* **2003**, *35*, 77–86. [CrossRef]
165. Groh, J. *Making Space: How the Brain Knows Where Things Are*; Harvard University Press: London, UK, 2014.
166. Haddad, S.; Osmond, P.; King, S. Application of adaptive thermal comfort methods for Iranian schoolchildren. *Build. Res. Inf.* **2016**, *47*, 173–189. [CrossRef]
167. Halawa, E.; Van Hoof, J. The adaptive approach to thermal comfort: A critical overview. *Energy Build.* **2012**, *51*, 101–110. [CrossRef]
168. Hanzl, M.; Ledwoń, S. Analyses of human behaviour in public spaces. Smart Communities. In Proceedings of the ISOCARP/OAPA Congr., Portland, OR, USA, 24–27 October 2017; pp. 653–666.
169. Humphreys, M.; Hancock, M. Do people like to feel 'neutral'? *Energy Build.* **2007**, *39*, 867–874. [CrossRef]
170. Inavonna, I.; Hardiman, G.; Purnomo, A.B. Outdoor thermal comfort and behaviour in urban area. *IOP Conf. Series: Earth Environ. Sci.* **2018**, *106*, 12061. [CrossRef]
171. Jamei, E.; Rajagopalan, P.; Seyedmahmoudian, M.; Jamei, Y. Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. *Renew. Sustain. Energy Rev.* **2016**, *54*, 1002–1017. [CrossRef]
172. Ji, W.; Zhu, Y.; Cao, B. Development of the Predicted Thermal Sensation (PTS) model using the ASHRAE Global Thermal Comfort Database. *Energy Build.* **2020**, *211*, 109780. [CrossRef]
173. Ji, Y.; Wang, Z. Thermal adaptations and logistic regression analysis of thermal comfort in severe cold area based on two case studies. *Energy Build.* **2019**, *205*, 109560. [CrossRef]
174. Ketterer, C.; Matzarakis, A.A. Human-biometeorological assessment of heat stress reduction by replanning measures in Stuttgart, Germany. *Landsc. Urban Plan.* **2014**, *122*, 78–88. [CrossRef]
175. Knez, I.; Thorsson, S. Thermal, emotional and perceptual evaluations of a park: Cross-cultural and environmental attitude comparisons. *Build. Environ.* **2008**, *43*, 1483–1490. [CrossRef]
176. Krüger, E.L.; Kr?ger, E. Impact of site-specific morphology on outdoor thermal perception: A case-study in a subtropical location. *Urban Clim.* **2017**, *21*, 123–135. [CrossRef]
177. Krüger, E.L.; Rossi, F.A. Effect of personal and microclimatic variables on observed thermal sensation from a field study in southern Brazil. *Build. Environ.* **2011**, *46*, 690–697. [CrossRef]
178. Lam, C.K.C.; Lau, K.K.-L. Effect of long-term acclimatization on summer thermal comfort in outdoor spaces: A comparative study between Melbourne and Hong Kong. *Int. J. Biometeorol.* **2018**, *62*, 1311–1324. [CrossRef] [PubMed]
179. Lau, K.K.-L.; Chung, S.C.; Ren, C. Outdoor thermal comfort in different urban settings of sub-tropical high-density cities: An approach of adopting local climate zone (LCZ) classification. *Build. Environ.* **2019**, *154*, 227–238. [CrossRef]
180. Lenzholzer, S.; Klemm, W.; Vasilikou, C. Qualitative methods to explore thermo-spatial perception in outdoor urban spaces. *Urban Clim.* **2018**, *23*, 231–249. [CrossRef]

181. Li, J.; Liu, N. The perception, optimization strategies and prospects of outdoor thermal comfort in China: A review. *Build. Environ.* **2020**, *170*, 106614. [CrossRef]
182. Li, K.; Zhang, Y.; Zhao, L. Outdoor thermal comfort and activities in the urban residential community in a humid subtropical area of China. *Energy Build.* **2016**, *133*, 498–511. [CrossRef]
183. Lin, T.-P. Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Build. Environ.* **2009**, *44*, 2017–2026. [CrossRef]
184. Liu, Z.; Zhao, X.; Jin, Y.; Jin, H.; Xu, X. Prediction of Outdoor Human Thermal Sensation at the Pedestrian Level in High-rise Residential Areas in Severe Cold Regions of China. *Energy Procedia* **2019**, *157*, 51–58. [CrossRef]
185. Malgoyre, A.; Tardo-Dino, P.-E.; Koulmann, N.; Lepetit, B.; Jousseaume, L.; Charlot, K. Uncoupling psychological from physiological markers of heat acclimatization in a military context. *J. Therm. Boil.* **2018**, *77*, 145–156. [CrossRef]
186. Mauree, D.; Naboni, E.; Coccolo, S.; Perera, A.T.D.; Nik, V.M.; Scartezzini, J.-L. A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities. *Renew. Sustain. Energy Rev.* **2019**, *112*, 733–746. [CrossRef]
187. Metje, N.; Sterling, M.; Baker, C. Pedestrian comfort using clothing values and body temperatures. *J. Wind. Eng. Ind. Aerodyn.* **2008**, *96*, 412–435. [CrossRef]
188. Mi, J.; Hong, B.; Zhang, T.; Huang, B.; Niu, J. Outdoor thermal benchmarks and their application to climate-responsive designs of residential open spaces in a cold region of China. *Build. Environ.* **2020**, *169*, 106592. [CrossRef]
189. Mishra, A.K.; Derks, M.; Kooi, L.; Loomans, M.; Kort, H. Analysing thermal comfort perception of students through the class hour, during heating season, in a university classroom. *Build. Environ.* **2017**, *125*, 464–474. [CrossRef]
190. Mishra, A.K.; Ramgopal, M. Field studies on human thermal comfort—An overview. *Build. Environ.* **2013**, *64*, 94–106. [CrossRef]
191. Nakayoshi, M.; Kanda, M.; Shi, R.; De Dear, R. Outdoor thermal physiology along human pathways: A study using a wearable measurement system. *Int. J. Biometeorol.* **2014**, *59*, 503–515. [CrossRef]
192. Nasir, R.A.; Ahmad, S.; Ahmed, A.Z. Physical Activity and Human Comfort Correlation in an Urban Park in Hot and Humid Conditions. *Procedia Soc. Behav. Sci.* **2013**, *105*, 598–609. [CrossRef]
193. Nikolopoulou, M.; Lykoudis, S. Use of outdoor spaces and microclimate in a Mediterranean urban area. *Build. Environ.* **2007**, *42*, 3691–3707. [CrossRef]
194. Nikolopoulou, M.; Steemers, K. Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy Build.* **2003**, *35*, 95–101. [CrossRef]
195. Parkinson, T.; De Dear, R. Thermal pleasure in built environments: Physiology of alliesthesia. *Build. Res. Inf.* **2014**, *43*, 288–301. [CrossRef]
196. Pearlmutter, D.; Jiao, D.; Garb, Y. The relationship between bioclimatic thermal stress and subjective thermal sensation in pedestrian spaces. *Int. J. Biometeorol.* **2014**, *58*, 2111–2127. [CrossRef]
197. Peng, Y.; Feng, T.; Timmermans, H.J.; Nuaa, A. Path analysis of outdoor comfort in urban public spaces. *Build. Environ.* **2019**, *148*, 459–467. [CrossRef]
198. Piselli, C.; Castaldo, V.; Pigliautile, I.; Cabeza, L.F.; Cotana, F. Outdoor comfort conditions in urban areas: On citizens' perspective about microclimate mitigation of urban transit areas. *Sustain. Cities Soc.* **2018**, *39*, 16–36. [CrossRef]
199. Potchter, O.; Cohen, P.; Lin, T.-P.; Matzarakis, A.A. Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. *Sci. Total. Environ.* **2018**, 390–406. [CrossRef] [PubMed]
200. Saaroni, H.; Pearlmutter, D.; Hatuka, T. Human-biometeorological conditions and thermal perception in a Mediterranean coastal park. *Int. J. Biometeorol.* **2014**, *59*, 1347–1362. [CrossRef] [PubMed]
201. Salata, F.; Golasi, I.; Proietti, R.; Vollaro, A.D.L. Implications of climate and outdoor thermal comfort on tourism: The case of Italy. *Int. J. Biometeorol.* **2017**, *61*, 2229–2244. [CrossRef]
202. Coburn, A.; Vartanian, O.; Chatterjee, A. Buildings, Beauty, and the Brain: A Neuroscience of Architectural Experience. *J. Cogn. Neurosci.* **2017**, *29*, 1521–1531. [CrossRef]
203. Schweiker, M.; Rissetto, R.; Wagner, A. Thermal expectation: Influencing factors and its effect on thermal perception. *Energy Build.* **2020**, *210*, 109729. [CrossRef]

204. Sharifi, E.; Boland, J. Limits of thermal adaptation in cities: Outdoor heat-activity dynamics in Sydney, Melbourne and Adelaide. *Arch. Sci. Rev.* **2018**, *61*, 191–201. [CrossRef]
205. Sharifi, E.; Boland, J. Passive activity observation (PAO) method to estimate outdoor thermal adaptation in public space: Case studies in Australian cities. *Int. J. Biometeorol.* **2018**, *64*, 231–242. [CrossRef]
206. Shooshtarian, S.; Ridley, I. The effect of physical and psychological environments on the users thermal perceptions of educational urban precincts. *Build. Environ.* **2017**, *115*, 182–198. [CrossRef]
207. Stathopoulos, T.; Wu, H.; Zacharias, J. Outdoor human comfort in an urban climate. *Build. Environ.* **2004**, *39*, 297–305. [CrossRef]
208. Walton, D.; Dravitzki, V.; Donn, M. The relative influence of wind, sunlight and temperature on user comfort in urban outdoor spaces. *Build. Environ.* **2007**, *42*, 3166–3175. [CrossRef]
209. Wilson, E.; Nicol, F.; Nanayakkara, L.; Ueberjahn-Tritta, A. Public Urban Open Space and Human Thermal Comfort: The Implications of Alternative Climate Change and Socio-economic Scenarios. *J. Environ. Policy Plan.* **2008**, *10*, 31–45. [CrossRef]
210. Xi, T.; Wang, Q.; Qin, H.; Jin, H. Influence of outdoor thermal environment on clothing and activity of tourists and local people in a severely cold climate city. *Build. Environ.* **2020**, *173*, 106757. [CrossRef]
211. Xi, T.; Wang, Q.; Wang, S.; Lv, X. Adaptation to outdoor thermal environment of tourists and local people in winter in Harbin. In *Proceedings of the AIP Conference Proceedings*; American Institute of Physics Inc.: College Park, MD, USA, 2019; Volume 2123, p. 020021.
212. Xi, T.; Wang, S.; Wang, Q.; Lv, X. College students' subjective response to outdoor thermal environment in a severely cold climate city. In *Proceedings of the AIP Conference Proceedings*; American Institute of Physics Inc.: College Park, MD, USA, 2019; Volume 2123, p. 020023.
213. Yau, Y.H.; Chew, B.T.; Saifullah, A.Z.A. A Field Study on Thermal Comfort of Occupants and Acceptable Neutral Temperature at the National Museum in Malaysia. *Indoor Built Environ.* **2011**, *22*, 433–444. [CrossRef]
214. Battista, G.; Vollaro, R.D.L.; Zinzi, M. Assessment of urban overheating mitigation strategies in a square in Rome, Italy. *Sol. Energy* **2019**, *180*, 608–621. [CrossRef]
215. Using ENVI-met met BioMet. Available online: http://www.envi-met.info/doku.php. (accessed on 13 April 2020).
216. Imbert, C.; Bhattacharjee, S.; Tencar, J. Simulation of urban microclimate with SOLENE-microclimat —An outdoor comfort case study. *Simul. Ser.* **2018**, *50*, 198–205.
217. Liang, X.; Tian, W.; Li, R.; Niu, Z.; Yang, X.; Meng, X.; Jin, L.; Yan, J. Numerical investigations on outdoor thermal comfort for built environment: Case study of a Northwest campus in China. In *Proceedings of the Energy Procedia*; Elsevier Ltd.: Amsterdam, The Netherlands, 2019; Volume 158, pp. 6557–6563.
218. 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]
219. Mackey, C.; Galanos, T.; Norford, L.; Roudsari, M.S.; Bhd, N.S. Wind, Sun, Surface Temperature, and Heat Island: Critical Variables for High-Resolution Outdoor Thermal Comfort Payette Architects. *Proc. 15th IBPSA Conf.* **2017**, 985–993.
220. Matzarakis, A.; Fröhlich, D.; Gangwisch, M.; Ketterer, C.; Peer, A.; Freiburg, A.; Freiburg, D. Developments and applications of thermal indices in urban structures by RayMan and SkyHelios model. In Proceedings of the 9th International Conference on Urban Climate, Toulouse, France, 20–24 July 2015.
221. Matzarakis, A.A.; Rutz, F.; Mayer, H. Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model. *Int. J. Biometeorol.* **2009**, *54*, 131–139. [CrossRef]
222. Matzarakis, A.A.; Rutz, F.; Mayer, H. Modelling radiation fluxes in simple and complex environments—application of the RayMan model. *Int. J. Biometeorol.* **2006**, *51*, 323–334. [CrossRef] [PubMed]
223. Naboni, E.; Coccolo, S.; Meloni, M.; Scartezzini, J.-L. Outdoor Comfort Simulation of Complex Architectural Designs a Review of Simulation Tools from the Designer Perspective. *Build. Perform. Anal. Conf. SimBuild* **2018**, 659–666.
224. Perini, K.; Chokhachian, A.; Dong, S.; Auer, T. Modeling and simulating urban outdoor comfort: Coupling ENVI-Met and TRNSYS by grasshopper. *Energy Build.* **2017**, *152*, 373–384. [CrossRef]
225. Salata, F.; Golasi, I.; Vollaro, R.D.L.; Vollaro, A.D.L. Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. *Sustain. Cities Soc.* **2016**, *26*, 318–343. [CrossRef]

226. Coccolo, S.; Mauree, D.; Naboni, E.; Kaempf, J.; Scartezzini, J.-L. On the impact of the wind speed on the outdoor human comfort: A sensitivity analysis. *Energy Procedia* **2017**, *122*, 481–486. [CrossRef]
227. Taleb, H.; Taleb, D. Enhancing the thermal comfort on urban level in a desert area: Case study of Dubai, United Arab Emirates. *Urban For. Urban Green.* **2014**, *13*, 253–260. [CrossRef]
228. Tsitoura, M.; Michailidou, M.; Tsoutsos, T. A bioclimatic outdoor design tool in urban open space design. *Energy Build.* **2017**, *153*, 368–381. [CrossRef]
229. Tsoka, S.; Tsikaloudaki, K.; Theodosiou, T. Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review. *Sustain. Cities Soc.* **2018**, *43*, 55–76. [CrossRef]
230. Fabbri, K.; Di Nunzio, A.; Gaspari, J.; Antonini, E.; Boeri, A. Outdoor Comfort: The ENVI-BUG tool to Evaluate PMV Values Output Comfort Point by Point. *Energy Procedia* **2017**, *111*, 510–519. [CrossRef]
231. Fabbri, K.; Gaspari, J.; Bartoletti, S.; Antonini, E. Effect of facade reflectance on outdoor microclimate: An Italian case study. *Sustain. Cities Soc.* **2020**, *54*, 101984. [CrossRef]
232. Gaspari, J.; Fabbri, K.; Lucchi, M. The use of outdoor microclimate analysis to support decision making process: Case study of Bufalini square in Cesena. *Sustain. Cities Soc.* **2018**, *42*, 206–215. [CrossRef]
233. GhaffarianHoseini, A.; Berardi, U.; GhaffarianHoseini, A.; Al-Obaidi, K. Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia. *Sci. Total. Environ.* **2019**, *666*, 1327–1345. [CrossRef] [PubMed]
234. Guan, L.; Bennett, M.; Bell, J. Development of a climate assessment tool for hybrid air conditioner. *Build. Environ.* **2014**, *82*, 371–380. [CrossRef]
235. Huang, K.-T.; Yang, S.-R.; Matzarakis, A.A.; Lin, T.-P. Identifying outdoor thermal risk areas and evaluation of future thermal comfort concerning shading orientation in a traditional settlement. *Sci. Total. Environ.* **2018**, *626*, 567–580. [CrossRef]
236. Huttner, S.; Bruse, M.; Dostal, P. Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities. In Proceedings of the 5th Japanese-German Meeting on Urban Climatology, Freiburg, Germany, 6–8 October 2008.