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Factors Affecting Microclimate and Thermal Comfort in Outdoor Spaces: a literature review

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Abstract
Rapid urban development is a contributor to the ongoing climate change, leading to rising temperatures, frequent heat waves, and various environmental impacts. This created a pressing need for urban planning to consider the effects of thermal comfort, which greatly affects the outdoor activities as well as the quality and the mental health of the residents, in order to promote the development of more resilient and sustainable cities. The consequences of climate change result in thermal stress for urban residents, making it important to consider a wide range of factors, including climatic conditions (temperature, humidity, precipitation.), urban design (street width and orientation, vegetation, building materials...) when addressing outdoor thermal comfort. This led to the gain of interest of researchers to analyze and assess this phenomenon and provide solutions to improve people's thermal comfort, particularly in outdoor spaces. This work highlights the key factors influencing thermal comfort in outdoor spaces, drawing upon a set of previous studies to address these challenges for the creation of urban environments that enhance the well-being of users and assist in the process of creating new public spaces to ensure their thermal adaptation with their environment. This review can provide a reference for scientific planning and construction of urban outdoor spaces to improve people's thermal comfort.
Keywords*:* climate change; microclimate; urban climate; thermal comfort; outdoor spaces.

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1. Introduction

The increasing population in cities is leading to an increased load on the built environment (Dissanayake, LWG, & UGD, 2023). The global urban population has grown from 751 million in 1950 to 4.2 billion in 2018 due to the overall population growth and the mass movement of people from rural areas to cities, it is

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projected to further increase by another 2.5 billion by 2050 (Marando, Salvatori, & al., 2019). Which induces effects such as the decline of environmental quality and ultimately results in thermal discomfort in cities (Nasrollahi, Ghosouri, Khodakarami, & Tleghani, 2020). In addition, the various effects of climate change are causing thermal stress for the cities' residents, such as global warming, the heat-island effect, and therefore reduced thermal comfort. This urban Climate change and increase in ambient temperature are extremely urgent issues to be addressed by urban policymakers (Lamarca, Qüense, & al, 2018). The urban heat island (UHI) effect is one of the most crucial phenomena caused by the alteration of energy balance and thermal properties of the built environment in urban cores compared to rural areas (Marando, Salvatori, & al., 2019).

Local climatic conditions in cities often referred to as urban microclimates, result from the complex interactions between geographical, architectural, and human characteristics specific to urban environments. It is distinguished from regional or global climate by the presence of several factors that combine to create specific atmospheric conditions in restricted spaces (Dimoudi A, Kantzioura A, Zoras S, Pallas S, & P, 2013).

Understanding the importance of these factors affecting urban climate and managing them effectively is at the heart of sustainable urban planning, which results in the creation of comfortable, livable living spaces for city dwellers (Brahimi, Djaghrouri, & Benabbas, Setting up the ENVI-met digital tool to evaluate climatic conditions at an urban scale: a case study of Djelfa, Algeria, 2023).

The outdoor environment is of high importance in cities, since it also includes various pedestrian activities, the comfort level of pedestrians in such spaces has a direct impact on the presence of people in outdoor environments (Coccolo, Kampf, Scartezzini, & Pearlmutter, 2016). Due to the complexity of outdoor environments (compared to indoor environments), thermal comfort in open spaces is less studied. The beginning of such studies dates back to the last few decades of the 20th century. However, in recent years, the development of simulation software has led to a rapid growth in the number of simulation-based studies in combination with fieldwork (Nasrollahi, Ghosouri, Khodakarami, & Tleghani, 2020).

Outdoor thermal comfort is dependent on many factors, besides the climatological conditions (temperature, humidity, wind, solar radiation…), the street design and orientation, the vegetation…etc. In recent years, the focus on outdoor thermal comfort has become an important aspect. In this line, several studies have been conducted on outdoor thermal comfort, since it is an issue strongly related to health and well-being.

This work highlights the essential factors that influence thermal comfort in outdoor spaces, particularly, through the collected studies by investigating thermal comfort using both environmental and human-based parameters. It answers the following questions: What are the main factors that influence outdoor thermal comfort? Do human-based parameters affect outdoor thermal comfort as much as environmental and climatic parameters?

Furthermore, this study aims to determine the main factors that influence urban comfort within public spaces of all types. Also, to highlight the fact that most studies concerning outdoor thermal comfort mainly consider the environmental and physical parameters influencing the well-being of users; neglecting the human and psychological factors that also influence outdoor thermal comfort. To establish the conditions of thermal comfort in outdoor spaces for the users and the overall quality of life in urban areas. It is found that there exists a strong interrelationship between these factors of human interaction, but it is not clearly defined. This paper's objective is also to deepen the knowledge of the diversity of the parameters influencing outdoor thermal comfort and the importance that should be given to it compared to the studies of indoor environments.

Previous reviews focus on the classification of studies about OTC according to their methods or approaches, this paper constitutes a simplified review where we propose results and conclusions achieved in previous studies concerning every parameter influencing outdoor thermal comfort. This can allow researchers to have a general idea about the variety of these factors and their impact on people's well-being in cities, specifically in open spaces.

To achieve the above-mentioned objectives, we must define a set of concepts that this study is based on, which are: climate change, thermal comfort, microclimate, and public spaces. These concepts intersect in urban areas, where the impacts of climate change are particularly acute, and the management of microclimate and thermal comfort is critical to improving the quality of life in public spaces.

1.1. Climate change

Climate change has emerged as one of the most pressing global challenges of the first century, it refers to significant and lasting changes in the Earth's climate, primarily driven by human activities, particularly the burning of fossil fuels, deforestation, and industrial processes. These activities increase the concentration of greenhouse gases in the atmosphere, leading to a rise in global temperatures, known as global warming (IPCC, 2021).

The consequences of climate change are far-reaching. Increased frequency and severity of extreme weather events, such as hurricanes, heatwaves, and floods, pose significant risks to human health, infrastructure, and ecosystems (WMO, 2020), it can exacerbate existing environmental stresses, particularly for vulnerable populations (Allen & al, 2013). Moreover, climate change is contributing to rising sea levels, with projections indicating a potential increase of up to 1.1 meters by the end of the century, threatening coastal communities and biodiversity (Nicholls & al, 2021). Through diverse studies, it is found that the influence of climate change on outdoor thermal comfort differs from one region to another according to the climate zone that they belong to and its climatic characteristics (Huang, Lai, Liu, & Xuan, 2020).
The socio-economic implications of climate change are profound. Vulnerable populations, particularly in developing countries, are at a heightened risk of food insecurity, health issues, and displacement due to changing climatic conditions (World Bank, 2019). As such, the need for robust adaptation and mitigation strategies is critical to ensure sustainable development and the protection of public health and safety.

1.2. Microclimate

Microclimates are localized atmospheric zones where the climate differs from the surrounding areas. This can occur due to variations in surface materials, vegetation, topography, or human activities. In urban areas, microclimates are significantly influenced by the built environment, including buildings, roads, and urban vegetation. A good microclimate can improve pedestrian comfort, motivate walking, and contribute to sustainability (Louafi Bellara & Abdou, 2023).
Urban microclimates can create "urban heat islands" (UHIs), where temperatures are higher than in rural surroundings due to heat retention by buildings and pavements. Microclimate modifications can enhance thermal comfort in public spaces, reduce energy consumption, and improve public health.

1.3. Public spaces

Public spaces are areas such as parks, plazas, streets, and pedestrian zones that are open and accessible to all people, regardless of gender, race, ethnicity, or socioeconomic status (Gehl, 2011). They promote urban life quality in cities (Louafi Bellara & Abdou, 2023).
Public spaces are particularly vulnerable to climate change and urban heat. Design interventions, like increasing greenery or using cool materials, can mitigate the impact of urban heat islands and improve thermal comfort, making public spaces more livable and attractive in warmer climates.

1.4. Thermal comfort

Thermal comfort has been demonstrated to be the fundamental component of a vital and functional outdoor environment Achieving thermal comfort is essential in-built environments to ensure the well-being and productivity of occupants (Louafi Bellara & Abdou, 2023). As a concept, thermal comfort has been defined by various researchers, according to the factors that define it.
ASHRAE Standard 55 defines thermal comfort as the condition of mind that expresses satisfaction with the thermal environment and emphasizes that individual responses to thermal conditions vary based on six primary factors: air temperature, relative humidity, air velocity, radiant temperature, clothing insulation, and metabolic rate. Among these 6, metabolic rates and clothing are individual/ personal parameters and the rest of the factors are environmental factors. These are the factors that influence energy exchange between the human body and surrounding environments and altogether define a person's thermal comfort. All these factors altogether define a person's thermal comfort (ASHRAE, 2020) (Hoppe, 1999). The standard has been widely adopted for its precise criteria in determining thermal comfort in buildings (ASHRAE, 2020).
Parsons highlights that thermal comfort depends not only on the temperature but also on various environmental and personal factors that contribute to human comfort. The balance between heat generated by human metabolism and heat lost to the environment is a key consideration (Parsons, 2020).
Also, Fabbri emphasizes that thermal comfort in buildings is influenced by both environmental factors (e.g., temperature, humidity) and personal factors (e.g., clothing, activity level), and should be considered in urban design and building management (Fabbri, 2021).

1.4.1. Outdoor thermal comfort evaluation

Thermal indices are supplied to architects and urban designers to assist them in making better design decisions. They may assess both cold and hot outdoor temperatures. (Louafi Bellara & Abdou, 2023), which allows designers to create outdoor environments that promote thermal comfort even in challenging climatic conditions.
Thermal comfort is usually expressed with specific indices, the two most widely used of which are the physiological Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI) (Antoniou, Montazeri , Blocken , & Neophytou, 2024). Thermal comfort indices can be categorized based on the factors they account for, such as physiological, environmental, or adaptive responses.

• Physiologically based indices that assess thermal comfort based on human physiological responses considering metabolic rate, skin temperature, and heat transfer mechanisms such as PMV, PET, SET, ET
• Environmental-based indices that depend on factors like air temperature, humidity, wind speed, and radiant heat, such as UTCI, WBGT, HI, and WCI.
• Radiant-based indices which focus on the impact of radiant heat transfer between the human body and the environment, such as MRT, and RTA.
• Clothing-based index, this index accounts for thermal insulation provided by clothing, Clo units constitute a critical factor in determining thermal comfort.
• Adaptive indices account for behavioral and physiological adaptations to changes in the thermal conditions such as the adaptive thermal comfort model. Classifying these indices provides researchers and designers with a framework to understand thermal comfort indices based on their corresponding focus areas and application contexts, Table.1 includes a list of some indices that reflect a portion of the diversity of thermal comfort measures available, it won't be an exhaustive list of all the above-mentioned indices, as not all of them concern all climates and the outdoor thermal comfort specifically.

Table1: The most used thermal comfort indices (By Authors).

Indices	Definition	Integrated parameters
PET: Physiological Equivalent Temperature	It is suitable for evaluating thermal comfort in urban microclimates (Brahimi, Benabbas, Altan, Nocera, & Costanzo, 2023). It considers complex interactions between climatic conditions and human responses, incorporating meteorological and thermo-physical parameters. It would provide the equivalent temperature at which a person would feel comfortable under given outdoor conditions. It expresses the perceived temperature in a standard indoor setting (Höppe, 1999).	Air temperature, mean radiant temperature, relative humidity, wind speed, activity level, clothing insulation. Other factors may interfere with the heat exchange mechanisms.
UTCI: Universal Thermal Climate Index	Considered the most advanced thermoregulation model, as it considers a comprehensive range of parameters to provide a holistic assessment of thermal conditions (Brahimi, Benabbas, Altan, Nocera, & Costanzo, 2023). It reflects how the human body responds to different climatic conditions. It is used in all climates from cold to hot environments.	Air temperature, mean radiant temperature, wind speed, humidity, physical activity, and clothing isolation.
PMV: Predicted Mean Vote	Developed by Fanger, it evaluates thermal comfort by considering a combination of environmental and human factors, as it predicts the average thermal sensation of a large group on a 7-point scale (Elnabawi & Naveen, 2019).	Air temperature, mean radiant temperature, relative humidity, air velocity, Metabolic rate, and clothing insulation.
ET and ET*: Effective Temperature	ET is a thermal comfort index that combines air temperature and humidity to express the perceived temperature felt by humans. The New Effective Temperature ET* also accounts for air velocity-making it more comprehensive for assessing thermal comfort in both outdoor and indoor environments (De Dear & Brager, 2002).	Air temperature, relative humidity, wind speed (in ET*), and mean radiant temperature (in some extended models).
SET: Standard Effective Temperature	It is a comprehensive measure used in thermal comfort studies, representing the human's thermal experience and the temperature of a hypothetical, isothermal indoor environment (Nicol, Humphreys, & Roaf, 2012). Particularly used in studies evaluating the impact of thermal stress on humans in various climates for both outdoor and indoor environments (Kumar & Kurian, 2023).	Air temperature, humidity, clothing insulation, and metabolic rate.

Applying international OTC indices and standards in different locations without addressing social and cultural backgrounds results in inaccurate results, due to the complex nature and the uncertainties of the existing subjective assessment parameters and the number of different factors affecting the thermal comfort results (Aghamolaei, Azizi, Aminzadeh, & O'Donnell, 2023). Also, the influence of some factors varies, some are major, while others exert minor or negligible influences, priority should be given to factors with greater impact when researchers develop or refine their designs.

2. Material and Methods

This study on factors influencing outdoor thermal comfort is based on a set of previous studies that have addressed various activities in different outdoor spaces and have been performed in cities with diverse climates. These studies have accumulated valuable knowledge about outdoor thermal comfort including benchmarks, data collection methods, and models of outdoor thermal comfort.

The studies have identified various factors that influence outdoor thermal comfort and classified them according to different approaches such as physical, physiological, and psychological aspects, as well as behavioral, personal, social, and cultural factors…etc. Interactions among various factors have also been discussed, providing researchers with a comprehensive understanding of outdoor thermal comfort and guiding designers and planners in creating thermally comfortable urban open spaces.

Science Direct, Web of Science, Research Gate…and other search engines were used to collect and review research on microclimate and thermal comfort in outdoor spaces, including consideration of influencing factors and optimization. The collected documents were mainly in English.

Classification and analysis of the collected documents, according to the approaches and chosen parameters in the study, also according to the used methods such as the investigation, the simulation, the surveys…etc. Papers were chosen based on their general topic, forming the main sections of the paper.

Then, the focus was placed on studies that addressed the parameters that greatly influenced outdoor thermal comfort in different cities and climates, as presented in the scheme in Figure 1.

The used keywords for our research were: thermal comfort, outdoor spaces, and factors influencing outdoor thermal comfort. This will help to better understand the different outdoor thermal comfort factors and their interaction in different climates and different urban areas.

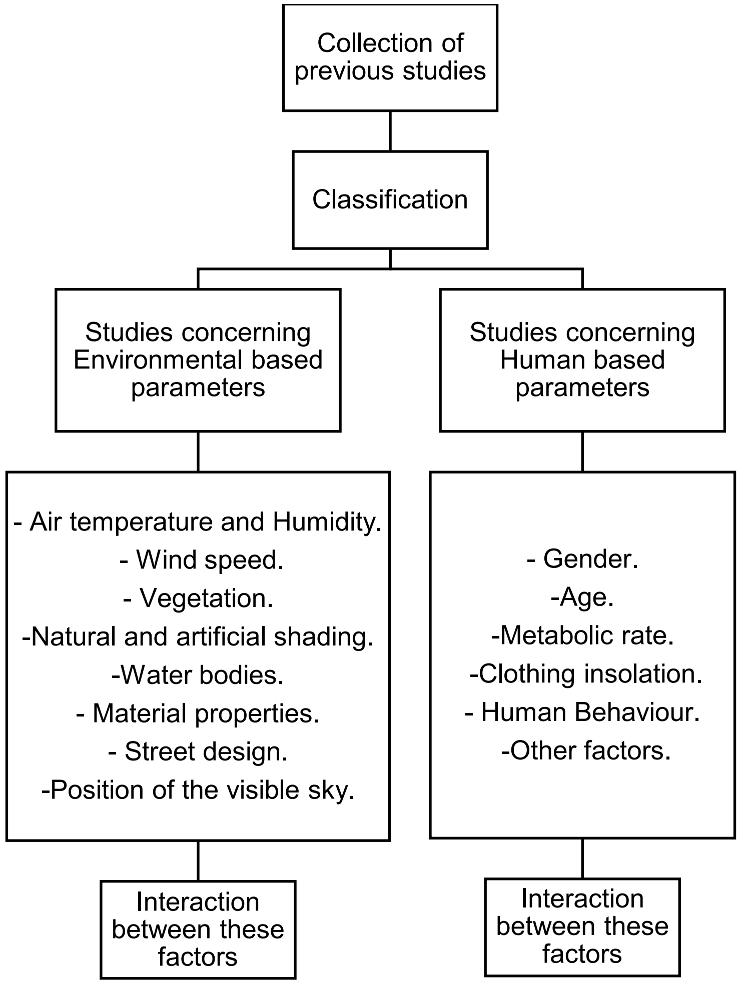

Figure 1. Research methodology Scheme (Author).

3. Analysis and Discussion

Thermal comfort is an ambiguous concept that has various definitions due to the variety of factors that influence it, it is defined as the condition of mind, which expresses satisfaction with the surrounding thermal environment, and it is assessed by subjective evaluation (ASHRAE Standard 55-2023, 2023). It has been also defined as the satisfaction level of the human condition in responding to the thermal environment, both physically and psychologically (Inavonna, Hardiman, & Purnomo, 2018).

Thermal comfort depends on a variety of factors, according to the ASHRAE standards, it depends on six primary factors: air temperature, mean radiant temperature, air velocity, relative humidity, activity level, and clothing insulation (Elvin & Godfried, 2018).

As such, it is influenced by psychological and behavioral factors in addition to the physical condition of outdoor spaces. In this regard, two categories are defined based on the main assessment approaches of outdoor thermal comfort, as shown in Figure 2 each category Is composed of a set of parameters.

Figure 2. Scheme of factors influencing thermal comfort (Aghamolaei, Azizi, Aminzadeh, & O'Donnell, 2023).

3.1. Environment based parameters

It includes the climatic and meteorological elements such as air temperature, wind speed…, and the physical characteristics, that concern the design of the city and its physical elements, which include the urban geometry, landscape planning, and material properties, etc., these elements influence and effect directly the thermal comfort indices in the outdoors.

a) Air temperature & humidity:

According to (Sachindra & Nowosad, 2022), outdoor thermal comfort is highly affected by relative humidity, wind speed, and air temperature, as they affect the daily uses of city residents. They investigated the variations in relative humidity (RH) and its impacts on outdoor thermal comfort in Poland. In Figure 3 the distribution of these variations is explained within the years. According to the results, the outdoor warm thermal comfort in Poland has declined due to high temperatures and high humidity. The interaction of these elements with other parameters is the interest of most OTC studies.

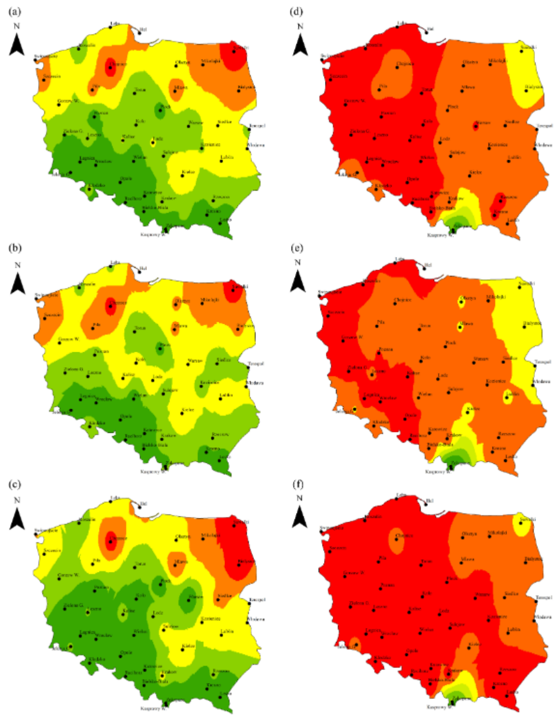

Figure 3. Spatial distribution of average RH and T air in autumn, % refer to average RH % in periods 19995-2020, 1995-2007, and 2008-2020 respectively (Sachindra & Nowosad, 2022).

b) Wind speed:

Wind speed significantly affects outdoor thermal comfort, influencing how individuals perceive temperature and overall comfort in outdoor environments. Wind speed is a vital factor in determining outdoor thermal comfort, with its effects varying by climate and context. While it plays a cooling role, its influence is often overshadowed by other environmental factors, particularly solar radiation.

Based on the correlation analyses, (Wei , et al., 2023) conclude that solar radiation and wind speed are important outdoor environmental parameters that affect human outdoor thermal comfort in spring and summer. Therefore, by reasonably installing vegetation and shading devices to block the strong solar radiation and directing the outdoor ventilation to create a comfortable wind environment, human outdoor thermal comfort in summer can be improved in the studied area.

In His study about the effect of wind speed on thermal comfort, (Rijal, 2012) confirmed that the higher wind velocity raises the upper limit of the comfort zone when the relative humidity is high. He observed that generally, wind velocity outdoors is higher than indoors and thus might raise the outdoor thermal temperature, which would be beneficial in hot and humid climates.

Due to its significance, it has been recognized in San Francisco, whereby legislation, new buildings have to be sited so that winds at ground level are limited to 5 m/s in areas where people sit for 90% of daylight hours (Bosselmann, et al., 1984).This proves the importance and the great impact the wind can have on urban space.

The basic effect of urban geometry on the thermal performance of the environment is to regulate the heat exchange in outdoor spaces. As such, they influence the heat removal from the surfaces of buildings and consequently affect the microclimate condition and outdoor thermal comfort in urban environments.

c) Vegetation:

Vegetation plays a crucial role in improving outdoor thermal comfort through several mechanisms.

- Temperature regulation:

According to (Dohsi, D, & M, 2022) studies, Landscape planning can regulate the urban microclimate condition. The vegetation reduces the most important thermal comfort indices: PMV, and PET. The aim of this research was to evaluate the effect of vegetation on local microclimate and outdoor thermal conditions in the old Ksour of the Saharan Atlas.

According to the in-situ measurements, the presence of vegetation results in a decrease in air temperature and an increase in relative humidity. The simulation results show the impact of the plant element (e.g., palm tree) on several parameters of the microclimate and outdoor thermal comfort, such as the reduction in solar radiation by absorbing it, the shade created has a great effect on the cooling of the ambient air (Dohsi, D, & M, 2022). The results show that the vegetation reduces the most important thermal comfort indices (PMV, PET) thus minimizing the dissatisfaction of the users. Fig.4 represents the study case and the modeling version via Rayman, one of the most frequently used software in this field.

Figure 4. Study case modeling via the Rayman software (Dohsi, D, & M, 2022).

Vegetation significantly reduces air temperature and mean radiant temperature (MRT) in urban environments. Studies show that scenarios with higher percentages of trees can lower air temperatures by up to 0.92°C and reduce physiologically equivalent temperature (PET) by an average of 7.5°C. The optimal configuration includes a combination of trees and grass, with 75% trees and 50% grass providing the best thermal performance (Gomaa, El Menshawy, Nabil, & Ragab, 2024). They also highlighted the urban greenery's potential to minimize heat stress passively but suggest the need for careful vegetative planning tailored to local climate and morphology.

- Shading and cooling effects:

Trees and other vegetation provide shade, which directly impacts thermal comfort by blocking solar radiation. This shading effect is particularly important in urban areas where hard surfaces can exacerbate heat. The cooling performance of vegetation is influenced by factors such as foliage density, tree height, and arrangement, which can enhance the shading and cooling effects (Dissanayake, LWG, & UGD, 2023). The densification of vegetation intensifies the cooling effect during the day, offering enhanced shade and protection against the sun's rays (Brahimi, Djaghrouri, & Benabbas, Setting up the ENVI-met digital tool to evaluate climatic conditions at an urban scale: a case study of Djelfa, Algeria, 2023).

Green design has also shown a significant impact on reducing direct solar radiation and providing shade, where trees with good positioning and large canopies provide more shade, which results in an improvement in human thermal comfort, however, the absence of tree cover results in feelings of discomfort and unpleasant perception of the environment (Louafi Bellara & Abdou, 2023).

- Microclimate improvement:

Vegetation alters urban microclimate by affecting humidity and wind patterns. Properly arranged planting can enhance ventilation and reduce heat buildup, contributing to a more comfortable outdoor environment. For instance, evenly distributed planting arrangements have been shown to improve thermal comfort significantly, with reductions in PET observed (Dissanayake, LWG, & UGD, 2023). The vegetation correlates with wind speed, as it can alter the wind speed distribution at the pedestrian level by completely

changing the wind flow pattern. Planting trees can accelerate airflow and improve local ventilation, especially by increasing wind speed under the tree canopy (Shen, Li, Wang, Su, & Li, 2023).
According to (Djaghrouri, Boudjellal, Afren, & Benabbas, 2023) trees and vegetation in general prove to be essential parameters having a significant influence on the microclimate. The study indicates that the denser the plant cover, the lower the temperatures of air and shaded surfaces, therefore the better thermal comfort, especially in the case of arid and semi-arid climates. Incorporating vegetation into urban planning is essential for enhancing outdoor thermal comfort. Strategic placement and selection of plant species can maximize these benefits, making urban areas more livable and sustainable.

d) The natural and artificial shading:

Shading is one of the most critical strategies for enhancing the outdoor thermal environment during hot periods. Adequate attention to shading and vegetation results in enhancing outdoor thermal comfort, and the interaction between urban morphology (buildings and shading device) and sun rays impacts the exposure of pedestrian paths to solar radiation. Recommended positions of natural and artificial devices to shade pedestrian paths were assessed based on location, urban canyon geometry, and orientation (Tomasi, Nikolopoulou, Giridharan, & Löve, 2024). Also, it is found that design strategies, such as shading…. may improve urban environments and pedestrians' experience in cities (Hirashima, Assis, & Nikolopoulou, 2016).
According to (Tola, Veleshnja, & Bisha, 2023), natural/artificial shading can provide effective advantages such as cooling the high-density urban areas. According to the results of the simulations, proper consideration of the types and position of greenery and the types and position of artificial shading during the planning phase would improve the thermal comfort at pedestrian level in the built environment of the Durres coastal promenade by between 12 and 45%. It can also alleviate UHI effects and provide thermal comfort (Peeters, et al., 2020).
However, as shading can reduce pedestrians' access to the winter sun for warmth contributing to discomfort, to ensure its effective application, it is important to analyze the potential shade benefits along with periods when shade becomes disadvantageous throughout the year. The new methodology called OSAM (outdoor shading assessment method) used by (Elrefai & Nikolopoulou, 2023) was assessed in two different climatic contexts; the results highlighted the variations in the shading requirements throughout the year for each studied case. This shows how the advanced capabilities of the simulation tools can be utilized for the analysis of outdoor environments in terms of shading requirements.
Other studies focus on shading and cooling provided by trees, e.g., (Wang, Wang, & Yang, 2018) highlighted how thermal comfort influences pedestrian path choices, suggesting that people tend to avoid areas with high temperatures when selecting routes. However, there are limited studies and guidance on the process of identifying the outdoor shading requirements within an urban context; from, identifying the required shading periods, to efficiently locating the shade elements, and eventually increasing the overall efficiency of the shade application, especially on larger scales, such as shading an entire urban canyon. As (Mackey, Sadeghipour, & Samaras, 2015)stated "… there are virtually no agreed-upon methods currently available to assist in the design of outdoor shades to keep people comfortable."

e) Water bodies:

Water bodies significantly influence outdoor thermal comfort by moderating microclimate and enhancing environmental conditions. Several studies have explored this relationship, highlighting the cooling effects of water bodies in various settings.
Water bodies are considered to be a strategy to improve thermal comfort in outdoor environments due to their ability to increase humidity and reduce air temperature in urban areas (Broadbent & Coutts, 2017).
The temperature-mitigating capacity of bodies of water in urban areas has many potential benefits, such as reducing energy consumption, improving pedestrian thermal comfort in outdoor environments, and creating urban cool islands (UCIs) (Syafii, et al., 2017). However, within urban areas, the climatic effectiveness of a body of water seems to depend on the speed and direction of the prevailing wind, as well as the surface area of the water. The wind carries cooler air from above the body of water and extends the temperature reduction downwind.

f) Material properties:

The relationship between material properties and outdoor thermal comfort is critical in urban design, influencing how outdoor spaces are experienced by individuals. Key factors include surface materials, albedo, and the thermal properties of building facades.
The concept of urban albedo (UA) was introduced in climatology to characterize the ability of the urban surface to reflect radiation to the sky, considering the combined effect of materials' reflectance and urban

form occlusivity, to the incoming radiation at the eaves level of street canyons, corresponding to the intersection of the roof plane with the external walls (Oke, Mills, Christen, & Voogt, 2017).
Also, a similar study results indicate that increasing the reflectivity of roads has the highest impact on the increase of urban albedo in low-rise urban canyon configurations. Instead, in the canyon with a higher aspect ratio, increasing the reflectivity of the top half of the canyon' facades allow the highest increase of urban albedo (Salvati, et al., Impact of urban albedo on microclimate: omputational investigation in London, 2020).
Another study conducted by (Salvati, et al., Impact of reflective materials on urban canyon albedo, outdoor and, 2022) investigated the multiple impacts of reflective materials on outdoor and indoor microclimates in London. It highlighted the varying impact of reflective materials in urban settings. The results highlighted that high reflectance materials may have an opposite impact on urban canyon albedo and outdoor thermal comfort depending on the urban canyon geometry. Increasing the solar reflectance of roads has the highest potential to increase urban canyon albedo (in the typical canyon geometry of residential neighborhoods in London). However, it also worsens outdoor thermal comfort at street level, due to the increase of interreflections leading to a higher mean radiant temperature, despite the beneficial effect on air temperature.
Material properties such as albedo and reflectivity change the reflection of solar radiation, reduce the absorbed and released heat, and finally improve OTC conditions (Alzate-Gaviria, Lopez-Cabeza, Diz-Mellado, RiveraGomez, & Galan-Marin, 2021). The results of the study and the simulations show that the albedo has a low influence on the air temperature, a higher effect on the temperature of surfaces, as well as the mean radiant temperature of the public space (e.g., the courtyard in Seville) affected by the solar radiation and surface temperature radiation.

g) The street design:

Urban geometry has largely emerged in urban climatology research (Swaid, Bar-El, & Hoffman, 1993). Many studies identify that street orientation and geometry can cause lower differences in air temperature.
Street design plays a crucial role in determining the outdoor thermal comfort of urban spaces. Several studies have investigated the relationship between street configuration and human thermal comfort in different climates.
This study contributes to urban human-biometeorology knowledge by conducting detailed radiation condition analysis and Tmrt differences within a medium-sized square in Szeged, Hungary. It emphasizes the importance of sidewalk exposure to direct irradiation based on facade orientation and the role of woody vegetation in mitigating heat stress (Kántor, 2018).
The urban configurations of the streets highly affect the thermal comfort in open spaces, the narrow and covered streets, at the orientations north-south, and northwest-southeast, provide better shading by buildings, desirable in the region of Biskra in the summer, with its hot and arid climate, to ensure human thermal balance and guaranteed an optimal level of thermal comfort (Sedira & Mazouz, 2023). This study demonstrates the considerable effect of SVF, the ratio H/W, and the solar orientation on thermal fluctuations in the street by affecting mainly the wind conditions that contribute to moderate air temperature, sun, and shade in streets. The opening to the sun is defined by a controlled SVF and an optimal H /W ratio combined with a controlled solar orientation, favoring the North-South, Northwest-Southeast orientation which offers acceptable conditions in terms of comfort Compared with other solar orientations.
It is also proven that the less dense urban fabric has higher air temperatures and mean radiant temperature compared to the denser urban fabrics, the density, in this case, contributes to the improvement of thermal comfort during the day, therefore it can be seen that the urban morphology influences the neutral values of the comfort indices (Boussaidi, Djaghrouri, Benabbas, & Altan, 2023). Appropriate modifications to the geometry of the urban area can improve the outdoor thermal comfort conditions (Lee, Mayer, & Kuttler, 2020).
According to (Ali-Toudert & Mayer, 2006) the orientation and street design (H/W ratio) can mitigate extreme heat stress if appropriately combined and so they lead to the development of a comfortable climate for pedestrians. The study discusses the contribution of street design, i.e., aspect ratio (or height-to-width ratio, H/W) and solar orientation, towards the development of a comfortable microclimate at street level for pedestrians. The results reveal that the time and period of day during which extreme heat stress occurs, as well as the spatial distribution of PETs at street level, depend strongly on aspect ratio and street orientation. These two urban factors can mitigate extreme heat stress if appropriately combined.

h) The position of the visible sky (SVF):

In his study, (Qaid, Lamit, Ossen, & Rasidi, 2017) achieved the outcome of his study that the position of the visible sky (or the sky view factor SVF) has a greater influence on the street's meteorological and human

thermal comfort conditions. The study results show that the position of the visible sky has a greater influence on the street's meteorological and human thermal comfort conditions than the SVF value.
Also, SVF has a significant impact on thermal storage in buildings, as it reduces the storage of heat and active air conditioning. For example, for hot and dry climates, the urban fabric should be dense, allowing an SVF between 0.25 and 0.45 to achieve an appropriate morphology to reduce heat storage (Benamor & Benabbas, 2019).
However, these two elements must be considered during urban street planning to better understand the resultant micrometeorological and human thermal comfort conditions. In addition, Researchers studying the micrometeorological and human thermal comfort conditions of streets should consider the position of the visible sky in their field measurements to obtain accurate results during the analysis process.

3.2. Human-based parameters

Due to its complexity, outdoor thermal comfort is not only determined by the physical state but also by the state of mind, where its assessment is also subjective given that thermal comfort does not always refer to climatic conditions but also to other individual and social characteristics such as the level of adaptation psychological control and social connections with the community.
Recent studies showed that people in different regions have various thermal preferences resulting from the adaptation procedure so their responses to the international OTC models and indices will be different.

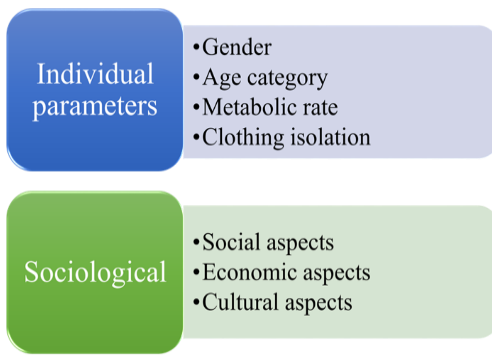

Figure 5. Scheme of human factors influencing thermal comfort (Author).

As shown in Figure 5, the human factors influencing thermal comfort can be divided into two main categories, Individual parameters, and sociological parameters.

3.2.1. Individual parameter

In his study, (Leng, Liang, & Yuan, 2019) stated that gender is an important factor for outdoor thermal comfort, as thermal perceptions and preferences of males and females differ significantly. The psychological state of people may influence their thermal satisfaction, which is considered a part of adaptation strategies in the adaptive thermal comfort approach. In this study, user's thermal comfort and adaptive behaviors during the spring marginal season in a winter city were investigated. Sensitivity to the thermal environment varies between activity types and the use of public space. User behaviors are affected by not only the microclimate environment but also by demographic factors (gender, age), daily life habits and activities, and other environmental factors such as noise levels and air quality.
• Concerning the gender effect, studies show that women tend to have a lower tolerance for heat and sunlight exposure than men. However, some research indicates that physiologically, women may have a higher thermal tolerance than men. This contradiction can be explained by psychological factors, as women's preferences for radiant skin tone are influenced by social learning processes (Inavonna, Hardiman, & Purnomo, 2018).
• Concerning age differences, young age groups tend to have higher sensitivity to cold temperatures compared to older adults. They tend to have higher thresholds for heat sensations and can withstand warmer conditions before feeling discomfort compared to younger adults (Wang, Zhao, Han, & Jiang, 2023).

- Metabolic rate:

Metabolic rate, which represents the heat generated within the body, is one of the important factors affecting human thermal comfort in outdoor environments. It varies significantly on an individual's physical activity level. Higher activity levels lead to heat production and therefore lead to discomfort in warm conditions. It also tends to be lower within older adults compared you younger individuals, which impacts their thermal preferences in outdoor spaces (Tao, Zhu, Xu, Zou, & Li, 2023).

- Clothing insulation:

Occupants have adaptively used clothing in response to the temperature change, to adapt to the varying thermal regime.
In his study, (Wei Zhao et al , 2019) found that clothing insulation varies between the two genders, and its value is positively correlated with age, that it grows with the increase of age significantly. Also, proved that adaptive clothing insulation has a higher influence on heating energy consumption indoors.
Also, there is an assumption that there are other influential psychological factors such as naturalness, experience, perceived control, time of exposure, environmental stimulation, and expectations (Inavonna, Hardiman, & Purnomo, 2018).

3.2.2. Sociological parameters

Related to the relationship between people and the society they are living in. The application of thermal comfort indices in different climates and cultural zones is not accurate without considering the social and cultural differences and economic status. They have a significant impact on participants' psychological assessments of public spaces and can change the quality of thermal judgment and their tolerance rate for thermal comfort and heat stress in outdoor spaces.
Human behavior is a form of coping with environmental stress, including open and closed behavior. Open behavior is behavior that can be observed visually, while closed behavior is the opposite - cannot be examined visually - such as attitudes, tendencies, and preferences that can be assessed through direct or indirect inquiries (Inavonna, Hardiman, & Purnomo, 2018).
Moreover, cultural constraints and context-based behavior proved to have some influences on people's levels of adaptation and their thermal behavior (Elnabawi & Naveen, 2022). The study's result suggests that people may be more willing to tolerate higher temperatures despite the decrease in comfort in such spaces, as women tend to use non-shaded public spaces to avoid the crowded places by men, also they keep a modest style with multiple clothing layers despite the high temperatures because of their religious and cultural context.
Also, thermal comfort indices may not be applicable in different cultural/climate zones without modifications, and they may not be appropriate if we do not consider the psychological and social processes involved in environmental assessments (Knez & Thorsson, 2006).
As proven in many previous studies, the physiological approach alone is not sufficient to be able to determine the exact value of outdoor thermal comfort since many other factors are affecting this value. Thus, it is required to assess the psychological aspect of individuals toward environmental conditions. A previous study stated that regard to the "thermal history" as well as "memory and expectation" are recommended besides paying attention to the physiological elements (Tung, et al., 2014).

4. Conclusion

"Cities are places, where people are impacted by multiple factors and multidisciplinary approaches, are key to improving livability" (Tomasi, Nikolopoulou, Giridharan, & Löve, 2024), therefore designers need specific instruments to implement them in practice, to achieve the optimal conditions for people's well-being and quality of life within urban spaces. Microclimatic conditions can affect the health and well-being of people and accordingly, studies investigating OTC's impact on people have gained more attention in recent years. Healthy urban planning focuses on creating healthy and sustainable cities and as such; climate-based planning strategies have to consider their application's adverse effect on the health and well-being of people.
According to previous studies, the existing comfort models are not fully developed to consider the effects of both environment- and human-based parameters for the assessment of outdoor thermal comfort performance. Most studies are based on environmental parameters, neglecting the human-based approaches. More sophisticated techniques are necessary to include these two groups in reporting outdoor thermal comfort. The development of comprehensive analysis tools that can include the results of simulations, field measurements, and surveys is necessary for this.
These studies collectively illustrate the complex interplay between different meteorological, physiological, and psychological parameters and their influence on outdoor thermal comfort, emphasizing the need for urban design strategies that account for all factors to enhance comfort in public spaces. Highlighting different aspects of OTC will aid in the decision-making process for future thermal comfort projects in urban environments. Future OTC research ought to prioritize assessing and ranking the effects of these two groups of parameters, as well as their relative significance and combined effects.
The study finding highlights the impact of the various parameters on the thermal comfort of people and their quality of life within outdoor spaces in a simplified way through a set of previous studies concerning each factor and from various climates and zones. This study's conclusions resume in the variety of the effecting

factors, and the interaction of physical, physiological, and psychological parameters, the current studies weren’t able to realize the assessment of all these parameters at once, the difficulty lies in the fact that some of these parameters are objective (such as physical parameters) and other are subjective (such as psychological parameter i.e., people’s behaviors, adaptation…etc.). These findings highlight the complexity of assessing outdoor thermal comfort, as psychological factors interact with one another and with environmental factors. Understanding these individual parameters is crucial for designing urban spaces that promote comfort and well-being in outdoor environments. Accordingly, when assessing human thermal comfort, it is imperative to consider not only environmental factors but also subjective elements such as metabolic rate and clothing insulation. These influencing variables have been incorporated into multiple linear regression equations (Zhang, Zhou, Zheng, Oladokun, & Fang, 2020).

The results obtained in this review from the previous studies allow us to answer the above-mentioned questions, therefore the climatic and physical parameters affect the thermal comfort in public spaces and people’s perception of their environment depending on the climate and the characteristics of each environment, but personal and subjective parameters also have a significant impact that must be taken into consideration.

Recommendations for urban planners and designers are proposed, to achieve optimal thermal comfort within outdoor spaces knowing that creating a comfortable thermal environment has several dimensions, from mitigation of the heat island effect and urban energy saving to the inhabitants' health and well-being as the ultimate goal (Binarti, Koerniawan, Tryadu, Utami, & Matzarakis, 2020), emphasizing for taking into consideration areas with extreme climatic conditions, developing effective strategies for optimizing urban design, integrating green solutions (such as increased vegetation and shaded areas for arid zones for example), adapting assessment models with their characteristics and conditions to improve the human comfort, and proposing optimal design strategies that will maintain the thermal comfort and human adaptation mechanisms in public urban spaces and aiming for sustainable urban development.

This research aimed to summarize and highlight some of the main factors that influence outdoor thermal comfort, as well as studies that introduced them, though the diversity of cases mentioned in this study is still not enough to fully comprehend the complexity of this subject, future studies will consider the classification of all studies concerning factors influencing thermal comfort and the followed approaches in these studies. Also, the study will be extended to the study of the interaction of these factors according to the type of climate in each case study.

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Conflicts of interest

The Authors declare that there is no conflict of interest.

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