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A Review of Effective Urban Strategies for Enhancing Pedestrian Thermal Comfort in High-Temperature Urban Environments

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I. INTRODUCTION

As cities continue to expand into mega cities, characterized by higher population density, narrower urban corridors, and increased tall buildings, the urban environment undergoes degradation [1]. This urbanization process often leads to a phenomenon known as Urban Heat Island (UHI), where cities experience higher temperatures compared to their surrounding non-urbanized areas [2,3]. (UHI) effect is the most evident climatic outcome of urbanization. It leads to increased air and surface temperatures in cities relative to the adjacent rural regions[4-6]. Numerous studies have been carried out to investigate the characteristics, importance, causes, and impacts of (UHI), as well as to document its intensity across different geographical regions around the world [3,7,8]. Consequently, the heightened urban air temperature significantly impacts the thermal comfort level of city residents [9,10]. Outdoor spaces play a vital role in sustainable cities as they accommodate pedestrian traffic, outdoor activities, and contribute to the overall liveability and vibrancy of urban areas. In the global context of climate change, outdoor spaces that offer a pleasant thermal comfort experience for pedestrians effectively enhance the quality of urban living [11-14]. Thermal comfort stands as a crucial factor influencing the quality of outdoor environments for pedestrians. Therefore, ensuring thermal comfort during both hot and cold seasons is essential for users of outdoor spaces. The consideration of thermal comfort in open spaces becomes paramount during the design process, as it is influenced by a wide range of variables [15]. This paper examines the latest research on heat mitigation strategies employed in hot regions and offers a critical evaluation of various urban design approaches that significantly impact the urban climate of cities with high temperatures. Additionally, this study focuses on the different urban design parameters that affect (UHI) and pedestrian thermal comfort in hot and humid climates.

II. LITERATURE REVIEW

Urbanization has a detrimental impact on the environment, notably through (UHI) effect, where air and surface temperatures in urban areas rise substantially higher than those in surrounding rural regions. This temperature increase is primarily due to the accumulation of heat in densely built environments and the replacement of vegetated areas with impervious surfaces [3]. UHI effect poses several challenges for cities and their inhabitants, including a direct correlation with increased electricity demand during hot summer days. Recent research indicates that each degree of temperature rise can lead to a 0.45% to 4.6% increase in electricity consumption [16].

Thermal comfort is the state of mind reflecting satisfaction with the surrounding thermal conditions. It is commonly defined as the absence of discomfort from feeling too hot or too cold. Outdoor thermal comfort depends on meteorological factors like air temperature, humidity, solar radiation, wind speed, and wind direction as well as personal factors such as clothing, insulation, and individual metabolic rates, which are influenced by factors like body shape, age, and gender. These factors affect thermal comfort by modifying how the body exchanges heat through convection, conduction, and radiation [17-25].

Given the significant effects of UHI on public health, energy consumption, and environmental conditions in various hot cities, it is imperative to propose mitigation strategies that promote sustainable urban development. Comprehensive mitigation approaches, such as the implementation of shading, the use of highly reflective materials, enhanced ventilation, and the use of green surfaces, have been suggested to alleviate UHI effect. on this context, the present paper examines the factors influencing pedestrian thermal comfort and presents strategies that enhance outdoor thermal comfort.

III. METHODOLOGY

The following steps were followed to prepare the research:

A. *Data Acquisition*: The research commenced with the collection of peer-reviewed articles published in English, sourced from ScienceDirect, Scopus, Wiley, and Springer databases.

B. *Data Processing*: The gathered articles were systematically categorized according to their overarching themes, which subsequently formed the main sections of the research.

C. *Classification*: Within each section, corresponding to specific heat-mitigation strategies, the papers were thoroughly analysed, and the findings of each study were documented.

D. *Composition of the Main Body*: Each section was extensively composed, incorporating studies from diverse climatic contexts pertaining to the respective heat-mitigation strategy.

E. *Conclusion*: The conclusion was crafted with a focus on addressing the reviewed literature in terms of prevalent research methodologies, employed software, studied climatic conditions, and other relevant factors.

IV. EFFECTIVE STRATIGES FOR ACHIEVING PEDESTRIAN THERMAL COMFORT IN HOT REGIONS

Several studies have identified specific strategies for enhancing thermal comfort in urban areas as the following:

A. Urban Geometry Strategy Affecting Pedestrian Thermal Comfort

This strategy examines how pedestrian-level interventions impact outdoor human thermal comfort, focusing on the manipulation of urban geometry parameters such as aspect ratio (H/W), sky view factor (SVF), street orientation, and neighbourhood configuration.

The aspect ratio, a key factor in urban canyon geometry, is defined as the ratio between the height (H) and width (W) of canyon walls [26] as shown in “Fig.1”. Research consistently links aspect ratio to pedestrian thermal comfort, emphasizing its influence on thermal radiation within cities [27]. Appropriate aspect ratios contribute to more effective shading, resulting in notable reductions in physiological equivalent temperature (PET), and consequent improvements in comfort levels [28]. Typically, narrower streets, characterized by increased building shading due to higher aspect ratios, generally provide better thermal comfort for sidewalk pedestrians compared to wider streets [29].

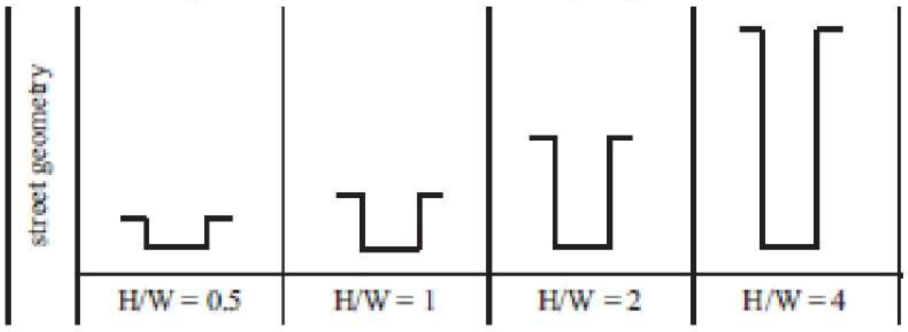


Fig.1 The aspect ratio (H/W) - the ratio between the height (H) and width (W) of canyon walls

Shashua-Bar et al. [30] reported that increasing the spacing between buildings can result in a rise of daytime air temperature by 4.7K. Similarly, research conducted in hot-dry climates, such as Fez, Morocco, demonstrated that deep street canyons experience significantly lower daytime air temperatures compared to shallower canyons [31]. In addition, a study in a highly dense urban area of Athens, Greece, investigated the influence of aspect ratio on air temperature across three urban canyons with varying aspect ratios (H/W¼3, 2.1,1.7), revealing a marked increase in air temperature as the aspect ratio decreased [32].

SVF is another critical urban geometry parameter. SVF is defined as “the ratio of the amount of the sky which can be seen from a given point on a surface to that potentially available [33]. Studies indicate that lower SVF values in urban settings, coupled with abundant green coverage, improve bioclimatic conditions. Conversely, areas with higher SVF values and surrounded by buildings tend to exhibit the least thermal comfort [34-38]. A study conducted in Beijing, China, revealed a direct relationship between daytime air temperature and sky view factor (SVF) in urban areas, indicating that an increase in SVF leads to higher daytime air temperatures, while the temperature reverses at night [39]. Similarly, research in Athens, Greece, examined the impact of six different urban layouts with varying SVFs on outdoor thermal comfort, finding a significant correlation between SVF and air temperature [40].

Street orientation is critical for enhancing pedestrian thermal comfort “Fig.2”. Selecting the most suitable orientation, particularly in temperate climates faces more challenges where it is important to balance the needs of both hot and cold seasons [41]. Research by Targhi and Van Dessel, examining Winchester, USA, during peak heat conditions, reveals that north–south streets offer greater thermal comfort due to solar radiation management [42]. Achour-Younsi and Kharrat investigated three streets in Tunis with fixed ratio, finding that north–south orientations provided the best thermal conditions, while east–west orientations were the least effective [43]. Another study in São Paulo's humid climate showed that, streets-oriented northwest–southeast and southwest–northeast had better thermal performance compared to north–south and east–west orientations [44].

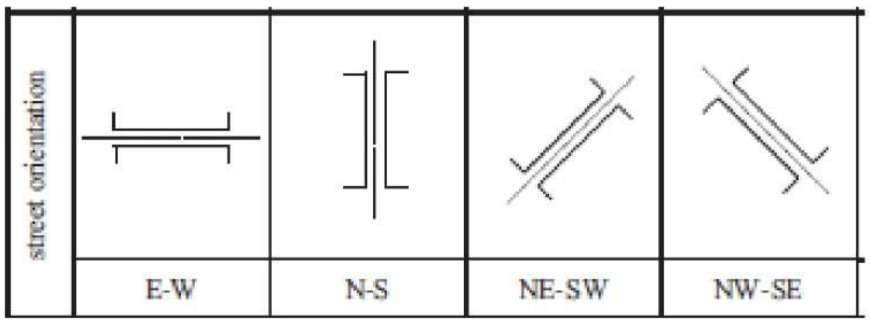


Fig.2 Street orientation is critical for enhancing pedestrian thermal comfort

Urban forms, defined as the spatial arrangement of buildings, profoundly affect thermal comfort at the pedestrian level. They manage solar radiation absorption and airflow, critical factors for thermal comfort. Compact urban designs can mitigate solar exposure during hot summers but might hinder airflow, potentially compromising thermal comfort. Finally, strategic urban planning at the Neighbourhood level within cities can provide urban spaces that prioritize comfort, harmonizing with the unique climatic attributes of the region [41].

B. Urban Greening Strategy Affecting Pedestrian Thermal Comfort

Urban greening has been recognized as a vital adaptive strategy and an essential method for mitigating (UHI) effect and minimizing health-related impacts associated with elevated air temperatures [45,46]. Comprehensive field-measurements have consistently shown that green spaces generally maintain lower temperatures relative to their surrounding urbanized areas, with observed temperature differences ranging between 1°C and 7°C [47-49]. Vegetation contributes to urban cooling through mechanisms such as shading, evapotranspiration, and the alteration of wind patterns [50].

Trees are regarded as a vital strategy for enhancing thermal comfort in outdoor environments due to several factors, including their shading effect [51-55]. Various studies have identified trees as the most effective strategy for improving thermal comfort in outdoor spaces when compared to other methods [56-60]. However, it is essential to consider the position of the tree relative to buildings, the distance between trees and building, as well as the height, form, and structure of the tree canopy. The cooling potential of trees is not solely dependent on the attributes of trees, but is also influenced by the surrounding environment factors, such as geometry, prevailing wind conditions, building heights and density, and surface materials [61]. In the tropical city of Bangalore, India, street segments with trees exhibited lower ambient air temperatures by an average of 5.6°C [62]. Similarly, a study conducted on an institutional campus at Saga University, Japan, found that increasing the number of trees by 20% could reduce the average maximum temperature by 2.27°C during the hottest hour of a summer day. In a high-rise residential area in Hong Kong, increasing the tree cover from 25% to 40% resulted in a 0.5°C reduction in the daytime heat intensity. Akbari, Pomerantz, and Taha have noted that shade trees cool the environment by reducing air temperatures [63]. Field measurements collected in Singapore's hot-humid climate demonstrated a temperature variation of 1.5–2.8°C between areas covered by trees and the areas surrounding them [64].

Roofs constitute approximately 20%–25% of urban surfaces. Green roofs and green walls are two approaches to integrating vegetation into urban environments [65]. A study on Melbourne's urban design incorporating vegetation revealed that green roofs did not enhance PET index for pedestrians [66]. Perini and Magliocco analysed the cooling effects of green roofs and ground-level green surfaces in the Mediterranean climates of three Italian cities: Genoa, Rome, and Milan. They found that ground-level vegetated surfaces were more effective than green roofs in reducing air temperature and mean radiant temperature at a pedestrian height of 1.6 meters. However, green roofs were beneficial in reducing the cooling load of buildings [67].

Green walls also serve as a heat mitigation strategy affecting both the indoor and outdoor environments of buildings. Bartfelder and Köhler measured air temperatures in front of bare and green walls in Berlin, Germany, and found that the cooling effect of green walls varied with outdoor temperatures, showing a reduction of 0.4°C on cool days and 5.8°C on hot days [68]. Wong et al. investigated the surface temperatures of eight different green wall systems in Singapore, finding that on June 21, green walls exhibited an average cooling effect of 4.36°C compared to exposed bare walls. They also measured the ambient temperature proximate to these walls, observing reductions of up to 3.33°C at 0.15 meters, with minimal effect at 0.60 meters away [69].

C. Surfaces Strategy (Materials, and albedo)

Among the various strategies to enhance thermal comfort in outdoor environments, the selection of surface materials for urban streets, such as pavements and building facades, is crucial. Numerous studies have explored the significance of white or high-reflection surfaces in this context.

Pavement materials absorb solar and infrared radiation, subsequently dissipating a portion of the accumulated heat into the atmosphere through convection and radiation, which leads to elevated air temperatures [70]. According to existing literature, high-albedo pavements play a significant role in improving the urban climate [63]. High-albedo materials are characterized by their high reflectivity to solar radiation and increased spectral emissivity. These materials, which exhibit a high coefficient of reflection for shortwave radiation and a high level of emissivity for longwave radiation, reduce the amount of solar radiation absorbed by urban canyon materials, thereby lowering surface temperatures and decreasing indoor temperatures [71]. The effects of 93 commonly used pavement materials, varying in colour, surface roughness, and sizing, have been investigated concerning their potential to reduce ambient temperatures and mitigate the urban heat island effect [72]. Replacing dark-coloured asphalt with white-painted surfaces has been shown to reduce daily surface temperatures by 7 K [73]. Similarly, it was found that the surface temperature of asphalt can be approximately 35 K higher than the air temperature, whereas light-coloured paving tiles are only 5–7 K warmer under identical conditions [72]. In a study conducted in Greece, a maximum surface temperature difference of 7.6°C was observed between conventional tiles and cool pavements on a hot summer day [74].

Numerous studies indicated that highly reflective surfaces, despite reducing air temperature, have an adverse effect in terms of a greater reflection of sun rays in urban canyons, which ultimately increases the thermal discomfort of pedestrians [75–77]. In general, it is recommended to use surfaces with high reflectivity on the roofs of buildings to reduce the energy consumption of the buildings [63,78,79].

D. Water bodies strategy

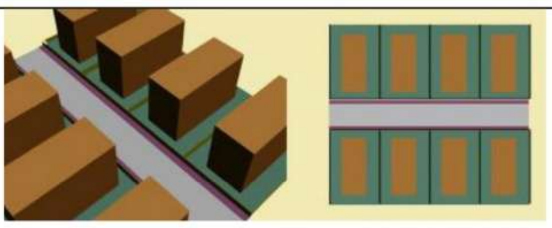
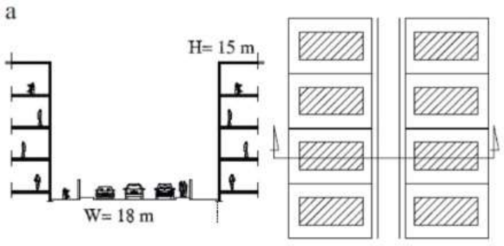
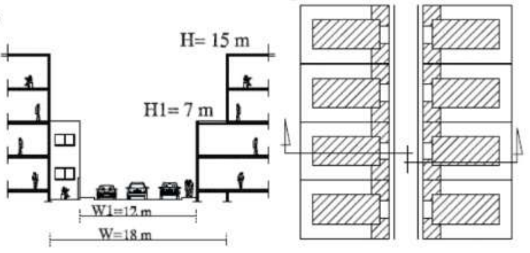
Water bodies are recognized as an effective strategy for enhancing thermal comfort in outdoor environments due to their ability to balance humidity and lower air temperatures in urban areas [80–82].

Martins et al. [83] employed ENVI-met simulations to assess thermal comfort in a newly developed urban area in Toulouse, France, concluding that the expansion of water surfaces resulted in a 2°C reduction in PET. In another study, the current climate conditions in Athens, Greece (characterized by a Mediterranean climate) were compared with scenarios where green, water, and white surfaces were integrated into the urban landscape [84]. It was found that the scenario with an increased presence of water bodies provided the most significant improvement in outdoor thermal comfort. Research conducted in Japan, focusing on the thermal comfort around water bodies, suggested that larger ponds aligned with prevailing winds can more effectively enhance thermal comfort [85]. Furthermore, Xu et al.

[86] investigated human comfort in the design of littoral zones around urban water bodies in China, aiming to maximize the temperature regulation function of these water bodies and create a more comfortable environment during the summer. By utilizing the Standard Effective Temperature (SET) and the heat index, their study revealed that the evaporation of surface water plays a crucial role in reducing temperature and increasing humidity, thereby improving human comfort in littoral zones during hot summer days.

V. ANALYTICAL EXAMPLES

Table.1 shows Example NO.1 [87]

location	Rural Area (IRA), Damascus, Syria	 Perspective and plans of the studied zone IRA (New Planning Area)
Climate zone	Hot & dry	
The aim	Exploring how vegetation and landscape elements affect the outdoor thermal comfort for detached buildings	
Simulation Tools	ENVI-met	
Simulation procedure time	Both the summer and winter seasons (21st of July - 15th of January) 5:00 AM UNTIL 16:00 PM	
Parameters	H/W ratio, street orientation, spacing between buildings, vegetation and shading devices	
Indices used	Physiologically Equivalent Temperature (PET)	
Cases (strategies used)	Consisted of a base case and three additional cases • Base case: 600 m2(20 m × 30 m), plot coverage 40%, maximum building height 15 m, street width 18 m. Fig a • Case 1: Urban morphology - a new extension with a height of 7 m was added in the front block side (affects H/W ratio). Fig b a  b  • Case 2: Vegetation - a continuous row of street trees was added along the pavements. Fig c • Case 3: Vegetation and shading devices - a mixture of horizontal shading devices and street trees were added. Fig d	

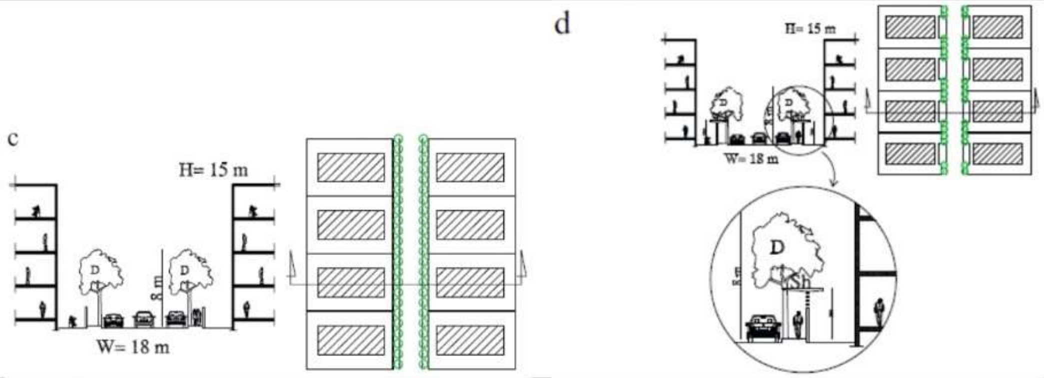
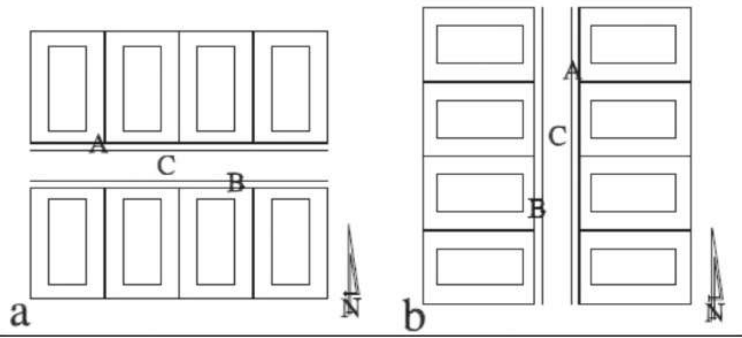
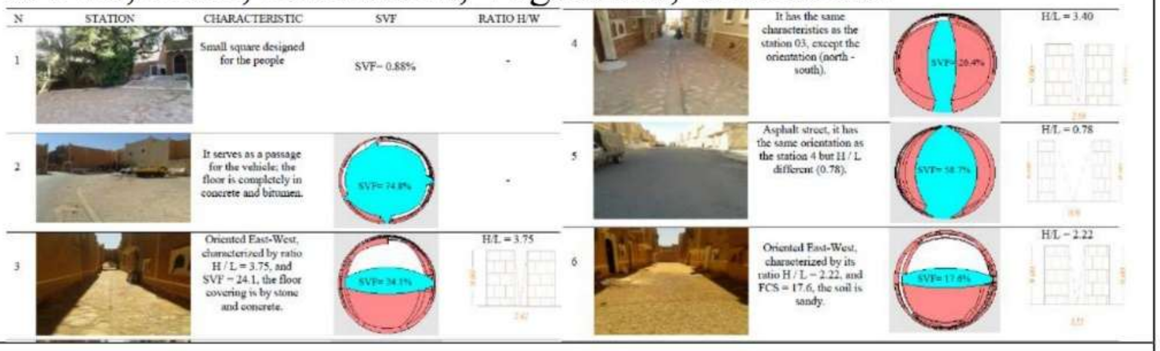
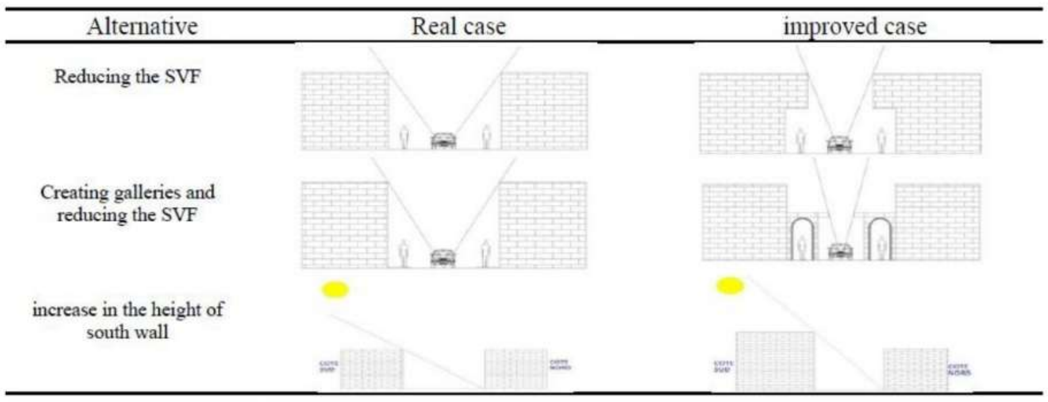
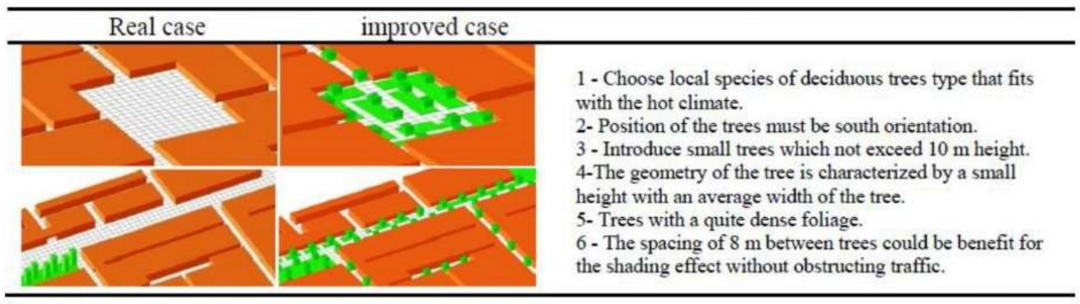
	
Measurement points	Dividing the public space into zones A, B, C for E-W and N-S orientations 
Results	The PET index results at 14:00 for the E-W street orientation: 1- **Base case:** (pavements and the street) (PET is between 51 and 58◦C) 2- **Case 1: Urban morphology** – the southern pavement where PET is about 36◦C 3- **Case 2: Vegetation** – (PET is between 35 and 50◦C) 4- **Case 3: Vegetation and shading devices** – (PET is between 32◦C and 48◦C) Further results • **Base case: N-S orientation** is more comfortable than E-W mainly for the west pavement due to the shade created by the buildings. Although N-S is a bit more stressful than E-W, especially in the spaces between buildings where the E-W orientation provides plenty of shade due to the self-shading. • **Case 3: Vegetation and shading devices** – The street space – in both orientations – is less stressful when trees and shading devices are used over the pavements, and this is because the trees and shading devices help to prevent the solar radiation to heat up the street when sun angles are low. • The results indicate that the last case is clearly better than the other cases regarding outdoor thermal comfort. In addition, it is shown that the idea of using a mixture of shading devices and trees is a good strategy to have less stressful urban spaces.

Table.2 shows Example NO.2 [88]

<table>
<tr><td>location</td><td>
The city of Tafilelt (Ghardaia, Algeria)</td></tr>
<tr><td>Climate zone</td><td>Hot and Dry</td></tr>
<tr><td>The aim</td><td>Discussing and assessing the impact of geometry and shade trees on open spaces climate</td></tr>
<tr><td>Simulation Tools</td><td>ENVI-met & COMFA</td></tr>
<tr><td>Simulation procedure time</td><td>Summer season (15 of Jun 2013 conditions), during 13 hours per day</td></tr>
<tr><td>parameters</td><td>SVF, RATIO, Orientation, Vegetation, Albedo</td></tr>
<tr><td>Indices used</td><td>PMV & TB presented by the budget (is calculated from the COMFA method)</td></tr>
<tr><td>Measurement points</td><td>Selection is based on a course that passes through several outdoor spaces of different shape and orientation. Six points are different in SVF, Ratio, Orientation, Vegetation, and Albedo

<table>
<tr><th>N</th><th>STATION</th><th>CHARACTERISTIC</th><th>SVF</th><th>RATIO H/W</th></tr>
<tr><td>1</td><td></td><td>Small square designed for the people</td><td>SVF~ 0.88%</td><td>-</td></tr>
<tr><td>2</td><td></td><td>It serves as a passage for the vehicle; the floor is completely in concrete and bitumen.</td><td>SVF= 74.8%</td><td>-</td></tr>
<tr><td>3</td><td></td><td>Oriented East-West, characterized by ratio H / L = 3.75, and SVF = 24.1, the floor covering is by stone and concrete.</td><td>SVF= 24.1%</td><td>H/L = 3.75</td></tr>
<tr><td>4</td><td></td><td>It has the same characteristics as the station 03, except the orientation (north - south).</td><td>SVF= 20.4%</td><td>H/L = 3.40</td></tr>
<tr><td>5</td><td></td><td>Asphalt street, it has the same orientation as the station 4 but H / L different (0.78).</td><td>SVF= 58.7%</td><td>H/L = 0.78</td></tr>
<tr><td>6</td><td></td><td>Oriented East-West, characterized by its ratio H / L = 2.22, and FCS = 17.6, the soil is sandy.</td><td>SVF= 17.6%</td><td>H/L = 2.22</td></tr>
</table></td></tr>
<tr><td>Cases (strategies used)</td><td><u>Base case</u>
The evaluation of outdoor thermal comfort for these six considered stations were done using the two methods PMV which is measured and TB presented by the budget, which is calculated from the COMFA method.
<u>After improvement</u>
This effect can be moderated by controlling the SVF, including vegetation, improvement in the morphology and the albedo. Therefore, the Envi-met software was used to simulate and assess the external thermal comfort Using (PMV) and (TB).</td></tr>
</table>





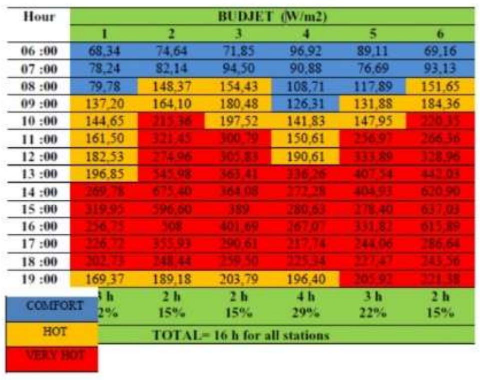
1 - Choose local species of deciduous trees type that fits with the hot climate.
2- Position of the trees must be south orientation.
3 - Introduce small trees which not exceed 10 m height.
4-The geometry of the tree is characterized by a small height with an average width of the tree.
5- Trees with a quite dense foliage.
6 - The spacing of 8 m between trees could be benefit for the shading effect without obstructing traffic.

All the parameters listed above were combined to improve the thermal comfort level in the studied stations.

Results

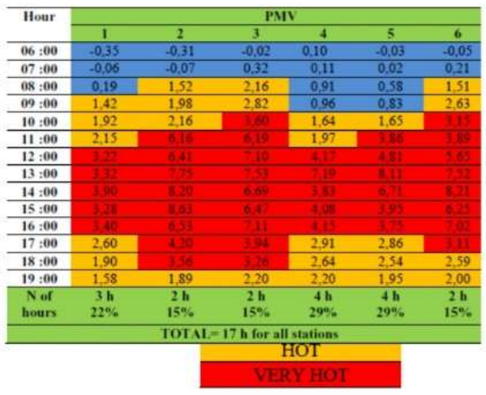
Base case:

The results of TB and PMV on six points during 13 hours of calculation, the blue boxes show the effective hours for thermal comfort and red boxes show the extremely hot hours were the thermal conditions are critical.



Hour	BUDJET (W/m2)					
	1	2	3	4	5	6
06 :00	68,34	74,64	71,85	96,92	89,11	69,16
07 :00	78,24	82,14	94,50	90,88	76,69	93,13
08 :00	79,78	148,37	154,43	108,71	117,89	151,65
09 :00	137,20	164,10	180,48	126,31	131,88	184,36
10 :00	144,65	215,36	197,52	141,83	147,95	220,35
11 :00	161,50	321,45	300,79	150,61	256,97	266,36
12 :00	182,53	274,96	305,83	190,61	333,89	328,96
13 :00	196,85	545,98	363,41	336,26	407,54	442,03
14 :00	269,78	675,40	364,08	272,28	404,93	620,90
15 :00	319,95	596,60	389	280,63	278,40	637,03
16 :00	256,75	508	401,69	267,07	331,82	615,89
17 :00	226,72	355,93	290,61	217,74	244,06	286,64
18 :00	202,73	248,44	259,50	225,34	227,47	243,56
19 :00	169,37	189,18	203,79	196,40	205,92	221,38
	h 2%	2 h 15%	2 h 15%	4 h 29%	3 h 22%	2 h 15%
	TOTAL= 16 h for all stations					

🟦 COMFORT
🟨 HOT
🟥 VERY HOT



Hour	PMV					
	1	2	3	4	5	6
06 :00	-0,35	-0,31	-0,02	0,10	-0,03	-0,05
07 :00	-0,06	-0,07	0,32	0,11	0,02	0,21
08 :00	0,19	1,52	2,16	0,91	0,58	1,51
09 :00	1,42	1,98	2,82	0,96	0,83	2,63
10 :00	1,92	2,16	3,60	1,64	1,65	3,15
11 :00	2,15	6,16	6,19	1,97	3,88	3,89
12 :00	3,22	6,41	7,10	4,17	4,81	5,65
13 :00	3,32	7,75	7,53	7,19	8,11	7,52
14 :00	3,90	8,20	6,69	3,83	6,71	8,21
15 :00	3,28	8,63	6,47	4,08	3,95	6,25
16 :00	3,40	6,53	7,11	4,15	3,75	7,02
17 :00	2,60	4,20	3,94	2,91	2,86	3,11
18 :00	1,90	3,56	3,26	2,64	2,54	2,59
19 :00	1,58	1,89	2,20	2,20	1,95	2,00
N of hours	3 h 22%	2 h 15%	2 h 15%	4 h 29%	4 h 29%	2 h 15%
	TOTAL= 17 h for all stations					

🟨 HOT
🟥 VERY HOT

After improvement

This effect can be moderated by controlling the SVF, including vegetation, improvement in the morphology and the albedo. Therefore, the Envi-met software was used to simulate and assess the external thermal comfort Using (PMV) and (TB).

The tables below show the results of BUDJET and PMV for six stations after improvement.

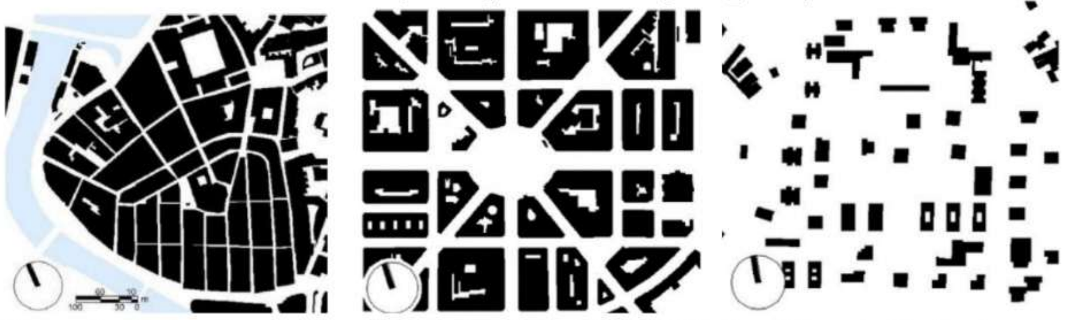
Hour	BUDJET (W/m2)					
	1	2	3	4	5	6
06 :00	109,49	110,62	108,86	112,50	110,26	108,80
07 :00	53,10	70,94	81,54	86,18	75,70	66,68
08 :00	97,85	88,15	90,15	97,61	95,71	87,90
09 :00	101,31	101,34	101	105,68	101,68	100,55
10 :00	113,27	108,83	113,07	116,82	115,31	112,44
11 :00	117,29	118,48	119,78	122,00	124,73	118,07
12 :00	139,99	137,43	137,34	142,04	140,27	137,15
13 :00	151,87	147,58	148,01	151,92	150,39	148,39
14 :00	154,67	153,66	153,43	155,25	155,31	153,85
15 :00	157,41	156,33	156,83	157,99	158,05	157,07
16 :00	156,31	155,11	156,65	157,15	157,19	155,59
17 :00	136,99	133,63	136,46	139,29	138,55	133,18
18 :00	116,99	123,63	116,46	119,29	118,55	123,18
19 :00	107,99	102,34	105,40	109,71	107,94	103,97
N of hours	8 62 %	8 62 %	8 62 %	8 62 %	8 62 %	8 62 %
TOTAL= 48 h for all stations						

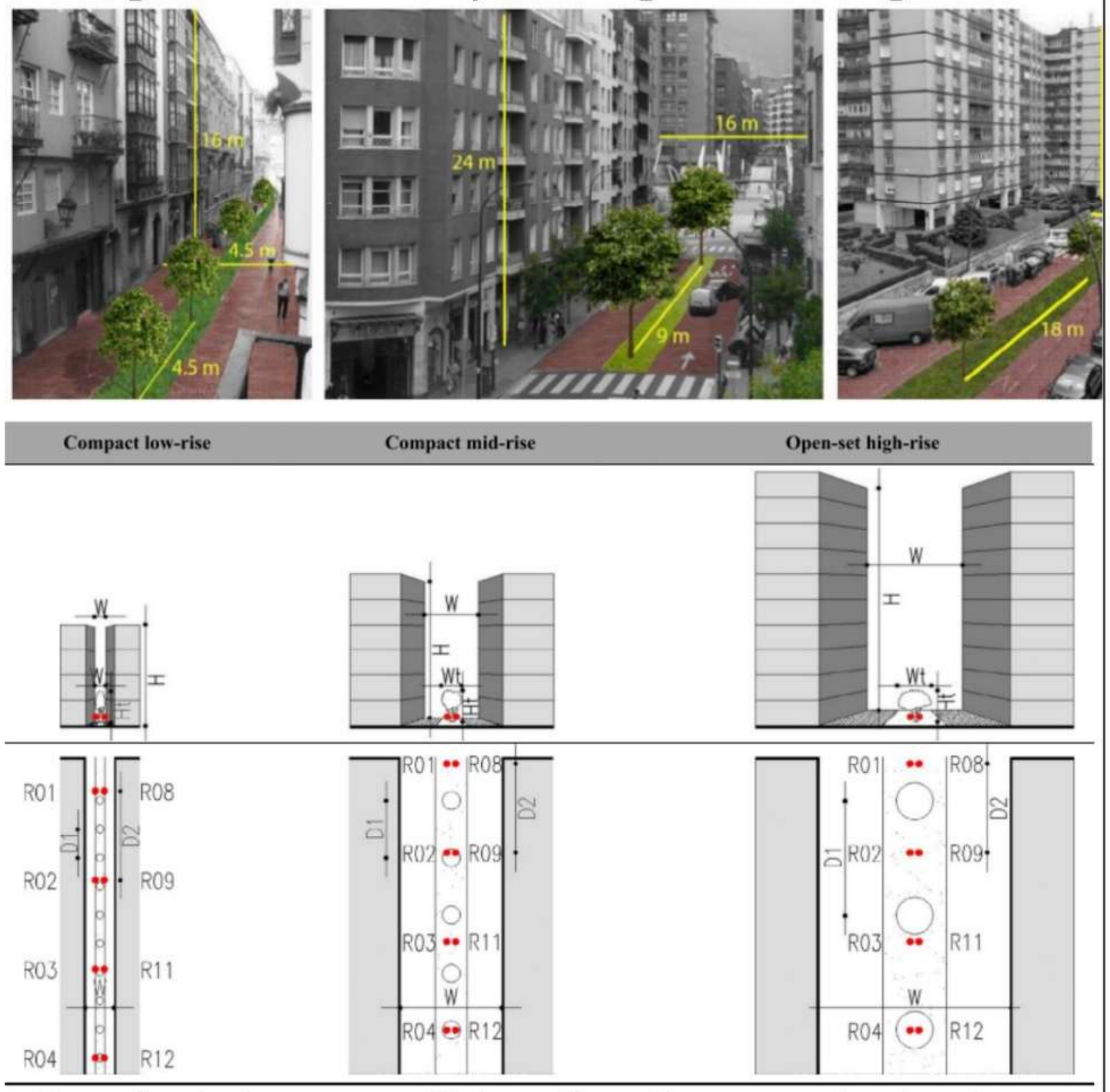
🟦	COMFORT
🟨	HOT
🟥	VERY HOT

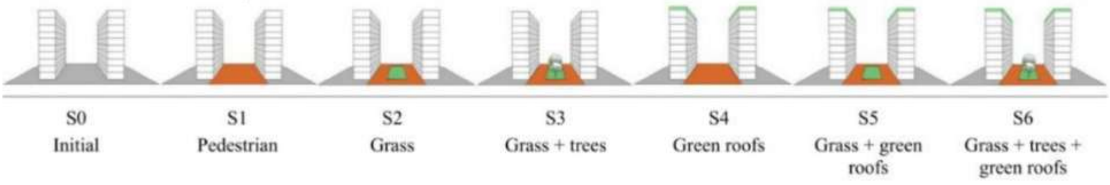
Hour	PMV					
	1	2	3	4	5	6
06 :00	0,47	0,17	0,76	1,20	0,58	0,64
07 :00	0,54	0,03	0,44	0,63	-0,22	0,13
08 :00	0,95	0,58	1,10	1,06	0,76	0,83
09 :00	0,88	0,92	1,51	1,46	0,99	0,95
10 :00	0,97	1,00	1,92	1,85	1,56	1,60
11 :00	1,94	1,75	2,65	[illegible]	1,91	2,30
12 :00	2,20	2,27	2,86	[illegible]	2,25	2,66
13 :00	2,57	2,49	[illegible]	[illegible]	2,50	3,00
14 :00	2,57	2,44	2,67	3,00	2,30	2,43
15 :00	2,60	2,48	2,60	3,00	2,37	2,47
16 :00	2,67	1,94	2,45	2,87	2,16	2,34
17 :00	[illegible]	1,78	1,92	2,54	1,90	1,74
18 :00	2,78	0,98	1,33	1,96	1,59	1,00
19 :00	0,66	0,65	0,59	0,89	0,95	0,61
N of hours	6 47 %	7 54 %	4 31 %	4 31%	5 39 %	6 47 %
TOTAL= 32 h for all stations						

This study demonstrates that in a hot arid environment, thermal comfort can be enhanced by the geometry of the street, orientation, vegetation, building materials and albedo. Development of urban design for the arid is needed by achieving the objectives of thermal comfort, energy saving and reduction of the urban heat island through an urban design high quality environmental in time (management).

Table.3 shows Example NO.3 [89]

location	Bilbao (Basque Country, Spain)  The selected urban areas. From the left: Casco Viejo, Abando/Indautxu and the Txurdinaga
Climate zone	Humid temperate climate with no dry season
The aim	Presents a comparative analysis of green actions to improve outdoor thermal comfort conditions in three urban districts: 1- Casco Viejo (H/W= 3.5) representing the compact low-rise class 2- Abando/Indautxu (H/W= 1.5) representing the compact mid-rise class 3- Txurdinaga/Miribilla (H/W= 1.3) representing the open-set high-rise class
Simulation Tools	using ENVI-met model
Simulation procedure time	7th of August 2010, simulations were launched at 4:00 am and the total modeling time was 44 h.
Parameters	Ground surface materials and green elements, such as grass, green roofs and trees
Indices used	Physiologically Equivalent Temperature (PET)

Measurement points	In the typical selected districts, the urban street canyons are mainly oriented as follows: 24° North–NorthEast in Casco Viejo;17° North NorthEast in Abando/Indautxu; and 9° North–NorthEast in Txurdinaga/Miribilla. Therefore, the orientations of the models have been set according to the specific prevalent orientation of the urban canyons of these districts. The height of the buildings and the width of the streets have been set according to the aspect ratio of the urban street canyons. The distance between the aligned trees (D1) was set equal to 4.5 m in the compact low-rise buildings, 9 m in the compact mid-rise buildings and 18 m in the open-set high-rise buildings.  The analyzed urban canyons with the position of the receptors, location of trees, distance between the trees (D1), and distance between the receptors (D2)
Cases (strategies used)	For each of the three urban canyon types selected, there were seven scenarios: the scenario of the current initial situation (S0 – Initial), the scenario in which the ordinary traffic road was converted to a pedestrian promenade (S1 – Pedestrian) and five scenarios using green actions (S2 – Grass, S3 – Grass + Trees,

	S4 – Green roofs, S5 – Grass + Green roofs, S6 – Grass + Trees + Green roofs).  The seven scenarios and the green actions analyzed in this work
Results	• The urban microclimate analyses conducted for this work demonstrated that the maximum daily temperature within the urban canyon decreases as the aspect ratio increases, but at the same time, a higher H/W ratio may reduce the wind benefit at the pedestrian level. • The benefit of using materials with a high albedo is reducing the surface temperatures. In this study, the analyses conducted (S1) in the compact mid-rise and open-set high-rise urban areas confirm a significant reduction in terms of maximum peak of PET level. • The benefit given by the presence of the grass (S2), is relevant only in the open-set high-rise urban areas in which the level of PET is reduced from the warm range (29 °C < PET < 35 °C) to the slightly warm range (23 °C < PET < 29 °C). • The effect of combining trees and grass (S3) gives benefits in terms of heat stress. The maximum reduction of the PET index registered in this study was 10 °C in the compact low-rise and mid-rise areas and 8 °C in the open-set high-rise area in scenario S3. • The range of influence of green roofs (S4) in thermal comfort at pedestrian level can be considered low.

VI. DISCUSSION & CONCLUSIONS

The main purpose of this study was to identify parameters affecting the thermal comfort of pedestrians in outdoor environments. Over 80 studies were reviewed, selected for their focus on enhancing outdoor thermal comfort across various climates. These studies utilized different human thermal comfort indices and employed a range of research methods, including field measurements, computer simulations, or a combination of both. The reviewed heat-mitigation strategies were divided into four sections: Urban Geometry Strategy; Urban Greening Strategy; Surfaces Strategy; and Water bodies strategy. Here, the most important lessons learnt from these studies are summarized:

1. The studies employed various data collection methods, with field measurements and computer simulations being the most common for analyzing thermal environments. Key strategies to enhance pedestrian thermal comfort often focus on climatic design solutions related to the physical characteristics of urban spaces, such as shading (from buildings and trees), street orientation, urban canyon geometry, vegetation, water surfaces, and the use of highly reflective materials. However, many studies also emphasize that psychological factors, including people's perceptions of their thermal environment and their thermal expectations, are crucial for achieving optimal thermal conditions.
2. Among climatic factors influencing outdoor thermal comfort, mean radiant temperature has the most significant impact, followed by wind speed and direction. Consequently, strategies that reduce mean radiant temperature, such as shading, are particularly effective. Increasing the (H/W) ratio in urban canyons also improves outdoor thermal comfort.
3. Many studies highlight vegetation, particularly trees, as the most effective strategy for enhancing thermal comfort. While green roofs reduce building energy consumption, they have minimal impact on pedestrian thermal comfort. In contrast, green walls are more effective in improving thermal conditions within urban canyons.
4. The use of highly reflective materials in urban canyons is generally discouraged as they can increase thermal discomfort by reflecting solar radiation, despite lowering air temperatures. However, these materials are suitable for roofs to reduce air temperatures and overall building energy consumption.
5. The orientation and geometry of urban canyons also play a crucial role in creating favourable thermal conditions. Orientation with respect to sunlight and prevailing winds, as well as the density and form of urban areas, significantly influence microclimatic and thermal conditions for pedestrians. Dense areas with limited ventilation tend to trap heat, while courtyards are identified as the most thermally comfortable and energy-efficient urban form.
6. Planning policies and design strategies dictate the structure of the cities. Therefore, the strategic manipulation of urban design parameters could mitigate the increased urban air temperature and improve the thermal comfort of city dwellers. Integration of climatic considerations into city planning and design can contribute to sustainable urban development and mitigate the adverse impacts of climate change on public health.

Conflicts of Interest: The authors declare no conflict of interest.

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