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The Street Walkability and Thermal Comfort Index (SWTCI): A new assessment tool combining street design measurements and thermal comfort

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Abstract

In recent years, walkability is increasingly integrated into sustainability strategies, considering its many health and environmental benefits. Besides, thermal comfort also has been progressively promoted as a critical measure for pedestrian comfort and wellbeing. Despite the relevance of the two concepts, few studies combined them in a comprehensive model. This study considers thermal comfort in assessing walkability by developing a new measurement tool, the Street Walkability and Thermal Comfort index (SWTCI), which focuses on comfort facilities and Physiological Equivalent Temperature (PET), at the street scale. The applied point system method requires combining a questionnaire survey, observations, and in situ measurements (air temperature, wind velocity, and relative humidity). The questionnaire survey (330 responders) measured 21 street design indicators' importance, using a five-point Liker scale ranging from 1 (least important) to 5 (very important). The observation technique seeks to evaluate every pedestrian comfort indicator score (Si_s). The in situ measurements permit Envi-met's calibrated data validation and getting the mean radian temperature (T_{mrt}). Those were considered in the PET's calculation using Rayman software. Three distinct streets have been chosen in Annaba city, Algeria, within the Mediterranean climate (Csa). The results show that the SWTCI achieves its highest score on the three streets when the thermal perception is neutral (20<PET<26), and its lowest score, with a warm thermal sensation (28<PET<31). Despite the divergence in PET values, the highest score of SWTCI was 33%, reflecting a low comfort quality and minimal pedestrian facilities. Applying the SWTCI method can transform uncomfortable streets into an ideal walkable and pleasant path by finding the problems and proposing improvements.

Keywords: Mediterranean climate (Csa), Street level, Street Walkability Thermal Comfort index (SWTCI), Thermal comfort, the Physiological Equivalent Temperature (PET), Walkability.

1. Introduction

Walking is considered the primary transport mode for people (Asadi-Shekari et al., 2019). It is also crucial in promoting a healthier and sustainable environment by reducing traffic congestion, obesity rate and improving liveability (Moura et al., 2017).The urban environment components (e.g., streets, parks, squares) have a critical role in enhancing the waking experience (Ruiz-Padillo et al., 2018).Various studies focused on evaluating walkability at the street level (Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2015) since it is the main pedestrian activity space. The street design and facilities can encourage and discourage walking. For example, urban design features such as shade trees and benches offer a pleasant walking experience (Battista and Manaugh, 2018). Drinking fountains, lighting, benches and seating area, and landscape and trees (Asadi-Shekari et al., 2013a, 2014) provide usability, safety, and attractiveness for pedestrians (Aghaabbasi et al., 2019).

According to Asadi-Shekari et al.(2019), walking rates depend on pedestrian facilities (Rodríguez et al., 2008). Designing a comfortable pedestrian environment could be achieved by operational assessment tools that involved sustained measurement and analysis of the sidewalk facilities and thermal comfort. Many studies explored walkability assessment tools at the street scale. The Level of Service(LOS) is a measurement tool for evaluating the quality of service, street facilities, and infrastructure (Asadi-Shekari et al., 2014, 2019; Moeinaddini et al., 2013). Sarkar (1993) proposed a (LOS) for the pedestrian. Based on factors that affect safety, security, comfort, system coherence, and attractiveness (Nilles and Kaparias, 2018). However, the LOS models have not included many comfort facilities besides pedestrian's characteristics such as age categories and abilities.

The pedestrian level of service (PLOS) is an essential tool for promoting existing infrastructure, managing new investments, and guiding appropriate contributions

(Christopoulou and Pitsiava-Latinopoulou, 2012). By identifying the deficiency in the pedestrian street environment and suggesting upgrading for solving the problems. Various studies proved the PLOS usefulness in assessing street facilities by considering attractiveness, safety, and convenience design factors, such as slope, sidewalk width, material, and surface condition (Asadi-Shekari et al., 2013a, 2014; Christopoulou and Pitsiava-Latinopoulou, 2012; Kang et al., 2013). However, despite the relevance of these assessment tools, they didn't consider thermal comfort in the walkability assessment. Thus, adding thermal comfort makes up an essential factor to be included in the PLOS.

From another perspective, an increasing number of studies focused on improving thermal comfort in outdoor urban spaces to enhance citizens' health, wellbeing and to promote outdoor activities (e.g., walkability, cycling). Moreover, thermal comfort defines the users' satisfaction level regarding the thermal environment (ASHRAE Standard, 2004; Potchter et al., 2018), based on the neutral temperature (Elnabawi et al., 2016).

Thermal comfort assessment requires combining meteorological variables with thermo-physiological parameters (Mayer, 1993; VDI, 1998). According to Potchter et al.(2018), the Physiological Equivalent Temperature (PET) (Matzarakis et al., 1999; Mayer and Höppe,1987) and the Universal Thermal Climate Index (UTCI) (Jendritzky, G et al., 2012) are the most used indexes for the assessment of outdoor thermal environments. PET had been applied and validated in several climates zones (Gulyás et al., 2006; Johansson et al., 2014; Matzarakis et al., 1999; Thorsson et al., 2007) as well as different outdoors environments (Ali-Toudert and Mayer, 2007; Andrade et al., 2011; Charalampopoulos et al., 2013; Knez and Thorsson, 2006; Lai et al., 2014; Lin et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 2007; Thorsson et al., 2007). Many studies applied a numerical simulation model of the climatic variable at the street level (Acero and Herranz-Pascual, 2015; Klemm et al., 2015; Lee et al., 2016; Morakinyo et al., 2017) using software to optimize thermal comfort index accuracy. For example, ENVI-met and Rayman are well-known software used to calculate outdoor thermal comfort. Envi-met simulation allows predicting the mean radiant temperature (T_{mrt}), relative humidity, air temperature, wind speed and surface temperature (Acero and Herranz-Pascual, 2015). These four microclimatic variables are essential to calculate outdoor thermal comfort, besides metabolic rate and clothing insulation (Watanabe et al., 2014).Thus, different scholars Cohen et al. (2013); Elnabawi et al. (2016); Kántor et al.(2012); Lai et al.(2014); Tseliou et al. (2010) combined simulation and field surveys in outdoor environments. To provide an extensive perspective concerning the impact of micro climate on outdoor thermal comfort and urban space use.

Based on the current literature, the thermal conditions of the walking environment have been under-investigated, despite the importance of the outdoor thermal environment for pedestrians. Indeed, thermal stress could debase the walking experience and indirectly hinder walkability and PLOS. Only a few recent studies associated walkability and thermal comfort. Lee et al. (2020) explored the influence of biometeorological related factors on pedestrian behavior by calculating PET and UTCI to express thermal stress in Hong Kong, China. The findings highlighted the correlation between thermal sensation and pedestrian choice of the shaded zone. However, the selected comfort indices have not been included in the walkability assessment. Labdaoui et al. (2021) developed a measurement tool by considering PET as a walkability indicator in the Csa climate. However, despite considering climatic variables such as air temperature, wind velocity, and relative humidity, the T_{mrt} was not included in the PET assessment. This paper fills this knowledge research gap by proposing the Street Walkability and Thermal Comfort Street Index (SWTCI). This innovative method is based on PLOS system that combines thermal comfort and walkability at the street scale.

2. Method

The current study aims to measure walkability at the street level by considering pedestrian comfort-related facilities and thermal comfort. For this purpose, we developed a new assessment tool, the Street Walkabilllity and Thermal Comfort Index (SWTCI). The presented method comprises some main steps that are summarised in Fig 1. The first one is reviewing effective indicators to identify pedestrian facilities and thermal comfort variables in research papers and standard guidelines, using Google Scholar, the Web of Science. Keywords included walkability, thermal comfort, street, Envi-met, simulation, assessment tools, street's furniture policy, and Csa. This research was conducted between 2002 and 2019 to select all the indicators that improve the walking experience. The finding emphasizes the lack of consideration for thermal comfort in the walkability assessment at the street scale. The microclimatic variables are also missing in the evaluation of walkability comfort.

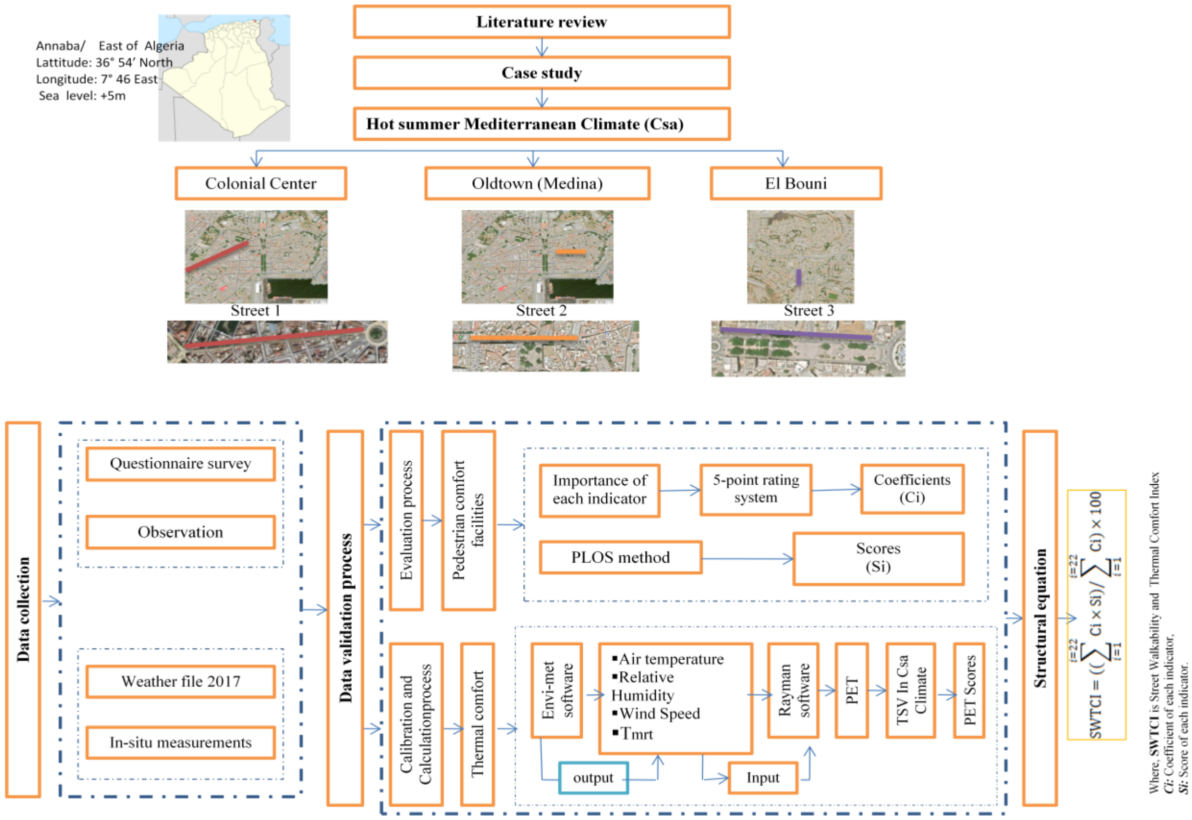


Fig.1. Conceptual framework of the STWCI

The proposed SWTCI tool is based on compiling 21 pedestrian comfort facilities extracted from the current literature (**Table 1**). That includes a wide range of sidewalk-related factors and facilities, considering people with different needs and abilities.

Table 1 Pedestrian comfort facilities on street level

Pedestrian comfortfacilities	References
Slower traffic speed	Asadi-Shekari et al. 2015, 2014; Lee and Kim, 2019; Retting et al. 2003)
Buffer and barriers (curb and furnishing zone)	Asadi-Shekari et al. 2015; Jaskiewicz 2000; Labdaoui et al. 2021
Fewer traffic lanes,	Asadi-Shekari et al., 2015, 2014; Labdaoui et al. 2021
Mid-block crossing	Diogenes and Lindau, 2010; King et al. 2009
Landscape and tree	Aghaabbasi et al. 2019; Labdaoui et al. 2021; Lee et al. 2016; Todorova et al. 2004
Furniture (trash receptacles)	Aghaabbasi et al. 2019, 2017; Asadi-Shekari et al. 2019, 2014; Labdaoui et al. 2021
Footpath pavement	Kelly et al. 2011; Moura et al. 2017; Nilles and Kaparias, 2018
Marking (crosswalk)	Kelly et al. 2011; Labdaoui et al. 2021; Moura et al. 2017; Ruiz-Padillo et al. 2018
Sidewalk on bothsides	Asadi-Shekari et al. 2015; Cain et al. 2014; Labdaoui et al. 2021
Width of footpath	Landis et al. 2001; Nilles and Kaparias, 2018
Slope	Asadi-Shekari et al. 2014; Kim et al. 2014; Koh and Wong, 2013; Labdaoui et al. 2021
Lighting	Asadi-Shekari et al. 2019; Crews and Zavotka, 2006; Nilles and Kaparias, 2018
Ramp	Aghaabbasi et al. 2019; Christopoulou and Pitsiava-Latinopoulou, 2012
Park and space for playing	Gehl et al. 2006; Labdaoui et al. 2021; Lamour et al. 2019
Social space (café)	Gunn et al. 2017; Koh and Wong, 2013; Labdaoui et al. 2021; Moura et al. 2017
Shade	Clifton et al., 2007; Jaskiewicz, 2000; Taleai and Taheri Amiri, 2017
Bench and seating area	Asadi-Shekari et al. 2019; Galanis and Eliou, 2011; Kihl et al. 2005; Troped et al., 2006
Toilet	Aghaabbasi et al. 2018; Asadi-Shekari et al. 2019; Labdaoui et al. 2021
Pedestrian signal	Aghaabbasi et al. 2018; Asadi-Shekari et al. 2014; Boisseau, 1999
Shorter crossing distance (curb extension)	Asadi-Shekari et al. 2015; Johnson, 2005; Labdaoui et al. 2021

The second step included the online survey conducted between June and August 2019 via Survey Monkey and Google Forms with 330 participants. The purpose of this survey was to measure the importance of pedestrian facilities according to people's perceptions. It included general information (age, gender, education) and highlighted street facilities' importance. People were asked to classify the importance of the selected indicators according to a scale of less important (1) to very important (5). Before the accurate data collection in June-august 2019, a pilot test with ten persons was carried out to verify the process and ensure the straightforwardness and clarity of all questions. The sample size is 330, based on the city population of 640,050, with a 95% confidence level and 5.4% margin of error. The survey's main purpose was to estimate the importance of pedestrian comfort features in general and not specially related to a specific street.

2.1 Microclimatic measurements

Three different streets were selected according to the following criteria: street morphology, slight slope, buildings' height, street orientation, length of the sidewalk, vegetative species, and distribution. We used microclimate monitoring instruments LM 8000 (Thermo-Anemometer, Hygrometer, Thermometer & Illuminometer) at the height of 1.10 m from the ground, at specific points on the 26th and 28th of August 2017. Air temperature (Ta), relative humidity (Rh), and wind speed (v) were measured and recorded at the one-second interlude. The measurement precision of microclimatic variables was ± 0.2 °C, 3% (%) and 0.2 (m/s). Every street has a specific measurement point near the sidewalk border to reduce the effect of unmeasured parameters and curtail interference with pedestrian observation and behavior. Finally, the third step involves the assessment of street facilities and PET.

To estimate these indicators, we calculated the coefficients using the survey results, scores with observation results, and PET based on the in situ measurement (to validate simulation by Envi-met tool and to get T_{mrt}). The calibration process results allowed air temperature, wind speed, relative humidity, and T_{mrt} considered in the PET calculation with the RayMan program. The SWTCI is based on the PLOS method. It can be calculated from Eq (1) (Labdaoui et al., 2021) :

$$\text{SWTCI} = ((\textstyle\sum_{i=1}^{i=22} \text{Ci} \times \text{Si}) / \sum_{i=1}^{i=22} \text{Ci}) \times 100 \text{............Eq. (1)}$$

Where ***Ci:*** *Coefficient of each indicator,* ***Si:*** *Score of each indicator.*

Table 2 shows the suggested categories of (SWTCI) from A to F,in line with other point system studies related to pedestrians(Aghaabbasi et al., 2017; Asadi-Shekari et al., 2014; Moeinaddini et al., 2015). Thus, class (A) presents the highest comfort quality with 80-100 scores while the (F) category is the lowest class, estimated very uncomfortable with 1-19 scores.

Table 2 CWTCI % interpretation

SWTCI % rating	Model score	Interpretation
A	80-100	The highest quality (very comfortable); reflecting the existence of many comfort pedestrian facilities.
B	60-79	High-quality (acceptable), some comfort pedestrian facilities present.
C	40-59	Average quality (rarely comfortable), pedestrian comfort facilities present. However, the potential to improve pedestrian comfort conditions is omnipresent.
D	20-39	Low-quality (uncomfortable), minimal pedestrian facilities.
E	1-19	Lowestquality (unpleasant).
F	0	There are no standard pedestrian amenities (very uncomfortable).

2.2 Sidewalk measurement in the pedestrian level of service (PLOS) methods

Pedestrian level of service (PLOS) methods are extensively used in urban and transportation models. The macro and micro design methods are relevant in measuring pedestrian environments (Aghaabbasi et al., 2017). Although the micro design factors are crucial to analyze the walking environment's quality (Asadi-Shekari et al., 2019; Southworth, 2005), many existing PLOS models explored just the macro-scale approach. The latter approach considers macro design factors such as density, diversity, design, destination accessibility, and distance to transit (Kim et al., 2014).

Since the current study's scope is street level, the focus is on PLOS models at the street scale (considering micro design factors). These PLOS models have different techniques and characteristics. However, each one has its benefits and drawbacks regarding sidewalk measurement. Fig 2 shows the primary types of indicators and scopes included in these PLOS models for the sidewalk assessment.

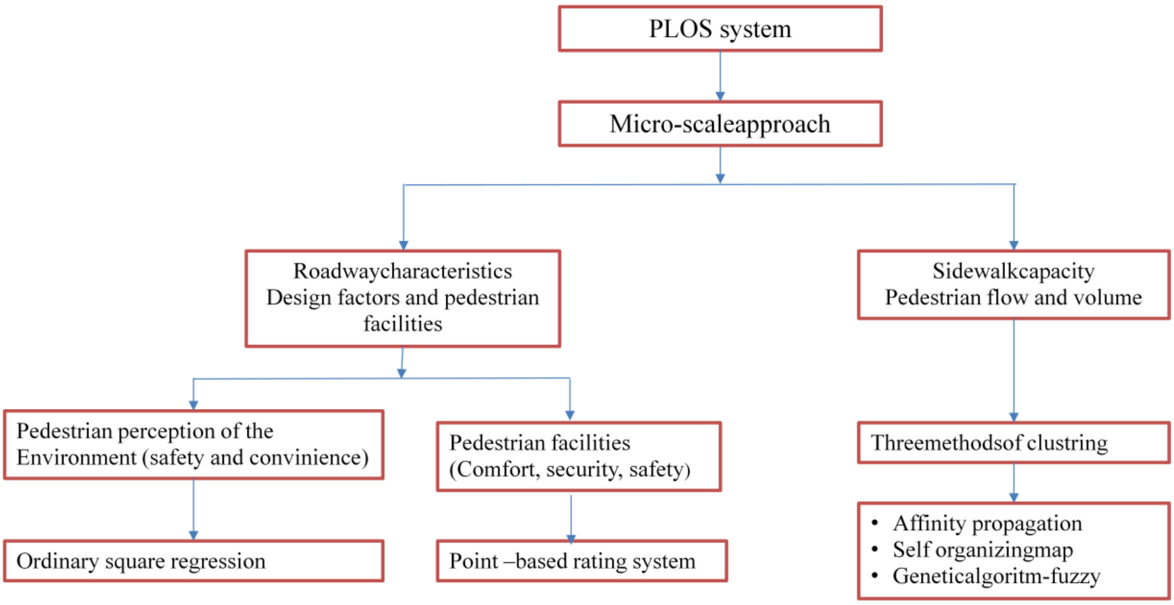


Fig. 2. Main scopes for PLOS models at the street level (Asadi-Shekari et al., 2013)

Some studies characterized the PLOS as a classification question. For example, Sahani and Bhuyan (2014) investigated three clustering methods, counting affinity propagation, self-coordinating map in artificial neural networks, and genetic algorithm-fuzzy (GA-Fuzzy) approach. Despite clarifying that GA-Fuzzy the most relevant clustering, this method only focused on capacity and met some related indicators such as pedestrian space, flow, volume to capacity ratio, and pedestrian speed, rather than the principal aim of PLOS for sidewalk facilities (Asadi-Shekari et al., 2019).

According to Asadi-Shekari et al.(2019), the PLOS method at the street level could be categorized into two major categories (Asadi-Shekari et al., 2013b, 2013a). The first category includes capacity-based tools that concentrate on sidewalk capacity, pedestrian flow, and volume. Ignoring micro-level design factors in walkability evaluation (e.g., Fruin, 1971; Manual, 2000), such as curb ramp, accessible drinking fountain, lighting, seating area, landscape, and trees. The second category includes the roadway aspects-based model that emphasizes design factors and pedestrian facilities (e.g., Asadi-Shekari et al., 2014, 2013b, 2013a; Landis et al., 2001; Sarkar S., 1993; Tan et al., 2007). The first method was criticized because pedestrians were comparable to cars and not users with special needs (Asadi-Shekari et al., 2013b, 2013a). Therefore, the second approach is more suitable for measuring walkability based on comfort-related factors that focus on this study.

Miller et al. (2000) suggested a point system in their PLOS evaluation. However, the restrained number of street facilities and users was inadequate for assessing inclusive streets. Landis et al. (2001) and Jensen (2007)explored more street factors to measure the PLOS. However, they applied an ordinary squares regression and found a few significant indicators that exclude people with disabilities. Asadi-Shekari et al. (2013b) suggested a point system as a suitable method for their PLOS model to explore micro-level design factors for all people, including people with disabilities. Although they consider weights and different measurement scores to include all possible conditions and avoid subjectivity in their evaluation, they did not consider PET in their proposed point system.

2.3Thermal comfort indices

We selected PET to represent thermal comfort because it was applied and validated in multiple climates and urban areas (Gulyás et al., 2006; Johansson et al., 2014; Matzarakis et al., 2007; Thorsson et al., 2007) based on field surveys (Elnabawi et al., 2016; Lin et al., 2013; Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006). Besides, PET was associated with the Mean Thermal Sensation Vote (MTSV) within the hot and cold climate. Therefore, the assignment scores of PET are related to the human thermal sensation scale in the Mediterranean climate based on Potchter et al. (2018) findings.

Many studies explored PET based on in situ measurements using Envi-met or RayMan software. The Envi-met model is a three-dimensional micro-meteorological program (Bruse and Fleer, 1998) and is considered one of the few micro-scale models that meet the required precise simulation standards. It verifies the correlation between the physical processes and the resulting micro-meteorological conditions in the urban canopy and thermal boundary layer (Lee et al., 2016). Also, it has been applied in simulations of the micro-climate and human-bio-meteorological influence of street design, building, and urban greening (Ali-Toudert and Mayer, 2007, 2006; Lee et al., 2016). Therefore, Envi-met was used in our study to calibrate data and get the Mean radiant temperature (T_{mrt}).

RayMan is considered one of the most successful radiations and bio-climate models (Cohen et al., 2013; Elnabawi et al., 2016). This software was developed according to the German Engineering Society's guidelines (VDI, 1998), University of Freiburg, Germany. It assesses PET according to different parameters (e.g., air temperature, air humidity, wind velocity, cloud cover, time of the day and year), and human clothing (0.9 clo), and activity (80 W) (Matzarakis et al., 2010, 2007).

Few studies combined the two programs to get more accurate results. Recent works adopt this approach in distinct outdoor environments (e.g., streets, parks, squares) within different climate zones, despite their rarity in the Mediterranean climate (Table 3).

Table3 Overview of PET calculations method in outdoor environments

Authors	Thermal comfort indices	Area/climate	Urbanlayout	Climatic /Microclimaticindicators	Method
Andreou, 2013	PET	Tinos, Greece	Streets (geometry, orientation)	Basic meteorological data	Calculation of PET using the Rayman v.1.2 tool Calculation of T_{mrt} Calculation Solar access and shading Calculating PET
Salata et al. 2016	PET	The Mediterranean climate, Csa	Street, square.	In-situ measurements	Calculating T_{mrt} Questionnaire for (MTSVs)
Klemm et al. 2015	PET	Netherlands	Parks (size, tree canopy, upwind vegetation cover)	In-situ measurements	PET Calculation using Rayman software. Calculating T_{mrt} Questionnaire for inhabitants' long-term perception of thermal comfort on warm summer days
Taleghani and Berardi, 2018	PET	Toronto	square	Climatic data In-situ measurements	ENVI-met simulations Simulated results (Air temperature, $T_{mrt,}$ and surface temperature)
Liu et al. 2016	PET	Changsha, China	Park, square, grassland, 3kind of the sidewalk.	In-situ measurements	PET Calculation using Rayman software. Surveys during 4 seasons
Lee et al. 2016	PET	Freiburg, Germany	Residential district	In-situ measurements Climatic data	PET and T_{mrt} are calculated using ENVI-met
Cohen et al. 2013	PET	The Mediterranean climate	Park, Square, Street	In-situ measurements	Calculating PET using Rayman Statistical data analysis of the in-situ Subjective thermal sensation voter records on the questionnaires with PET values
Elnabawi et al. 2016	PET	Hot Arid Climate of Egypt	Streets In Medieval Cairo	In-situ measurements	Calculating PET using Rayman Subjective thermal sensation records the questionnaires with PET values
Morakinyo et al. 2017	PET	Hong Kong	Street canyon.	In-situ measurements	Calculating PET using Rayman Calculating T_{mrt}using Envi-met software Shades ENVI-met simulations, its impact on thermal comfort

The main aim of this study is the application of the SWTCI at different street morphologies. The survey is also designed to estimate the importance of the indicators for available street types. However, for particular street types like tiny streets, some indicators such as slower traffic speed, marking (crosswalk), mid-block crossing, and slower traffic speed, could be freeze. Therefore, the proposed method can be used for general street types in different cities and particular streets and cities. The included indicators and weights need to be justified and localized.The SWTCI within Csa is applied according to the following method.

2.4Assessing indicators

One of the main limitations for PLOS point systems like Asadi-Shekari et al. (2013b)is ignoring the perceptions and PET. This study fills this gap by using people's perceptions and viewpoints as weights and coefficients for the indicators and including the PET effects. In addition, a series of in situ observations is also used to evaluate each comfort indicator's state objectively and measure their scores (Asadi-Shekari et al., 2014).

2.4.1 Pedestrian comfort facilities coefficients and scores

The questionnaire survey measured 21 street design indicators' importance, using a five-point Liker scale ranging from 1 (least important) to 5 (very important). This survey explored people's perceptions regarding the matter of pedestrian facilities. In total, 330 respondents in Annaba completed the survey online. The survey data are used to achieve each comfort indicator's relative weight (coefficient) (Cis).

Using the observation technique seeks to quantify every pedestrian comfort indicator as a score (Sis), indicating a number between 0 and 1. The score (1), considered the best score, reveals a relevant match between the existing street condition and the guideline requirements. In contrast, the score (0) means no link or the indicator is not existing in the case study. There are also some scores between 0 and 1 to cover the semi-fitness situations. For more details, refer to Appendix A and B.

2.4.2 Calculating and scoring PET

To understand thermal comfort impact on pedestrians, PET was computed on the selected streets using RayMan (Matzarakis et al., 2010, 2007). This study also used the spatial height performance and temporal microclimate resolution model, the Envi-met 4 software that can generate simulations by designing the building's architecture and vegetation model (Wu and Chen, 2017). Before PET calculation, the T_{mrt} was measured through the calibration process using the full forcing command (24h) with Annaba weather records data (26^{th} and 28^{th} of August 2017).

We validated the calibrated model based on the difference between simulated and measured air temperature, which showed a good performance between the two data sets (Elnabawi et al., 2013; Taleghani and Berardi, 2018) $Y=0.862x+3.909$, $R^2=0.84$ (Fig3). Consequently, we got four calibrated data: air temperature, wind velocity, relative humidity, and T_{mrt}. Therefore, based on these calibrated data (Klemm et al., 2015; Lobaccaro and Acero, 2015; Morakinyo et al., 2017; Taleghani and Berardi, 2018), we calculate PET from 8 am to 8 pm (Fig 1).

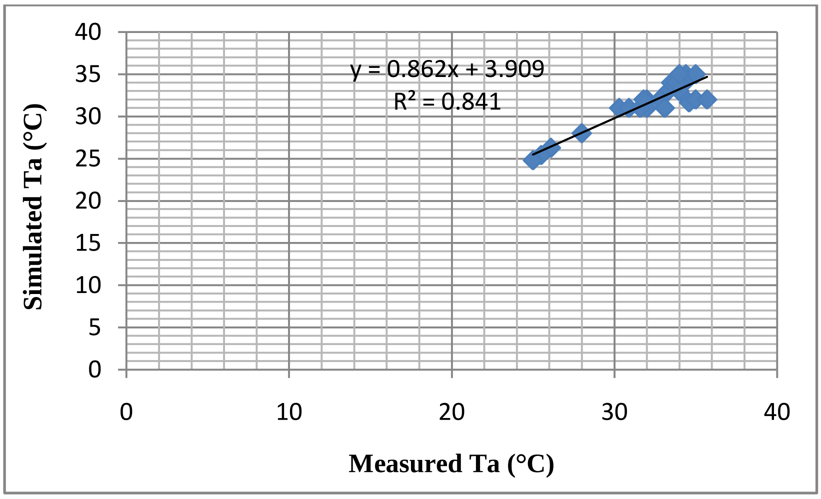


Fig.3. Correlation between simulated and measured air temperature.

To score PET in the Mediterranean climate, we applied a scale from 0 to 1 (Labdaoui et al., 2021), considering the defined thermal sensation vote (TSV) in Tel Aviv, characterized by a Csa. Thus, despite the same climate classification, both cities have the same level from the sea +5m. According to Potchter et al. (2018), the thermal comfort range in TelAviv is between 19°C -25°C in winter and 20°C - 26°C in summer. Therefore, for cold, hot, and very hot thermal sensations, the PET score is 0. For cool and warm thermal perception, the score is 0.25; for slightly cool and slightly warm, the score is 0.5. Finally, the neutral thermal sensation reaches the score of 1. (Refer to Tables 4 and 5).

Table 4 Thermal sensation and PET range for Tel Aviv (Csa climate) (Cohen et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 1999; Potchter et al., 2018)

TSV	Thermal sensation	PET range for Tel Aviv (°C)	Tel AvivClimatic zone (Koppen classification)
-4	Very cold	-	
-3	Cold	8	
-2	Cool	12	
-1	Slightly cool	15	
0	Neutral	19	Csa
1	Slightly warm	26	
2	Warm	28	
3	Hot	34	
4	Very hot	40	

[a]Vote scale (TSV), Warm Mediterranean Climate (Csa).

Table 5 PET scores according to the Thermal sensation and PET range in Csa Climate (Labdaoui et al., 2021).

PET range	PET scores
>8°C	0
8° C-12° C	0.25
12.1°C-15°C	0.5
19.1° C-26°C	1
26.1°C-28° C	0.5
28.1° C-34° C	0.25
34.1° C-40° C	0

2.5Case Study

The field study was conducted in Annaba city, Algeria, located between (Lattitude 36° 54' North, Longitude: 7° 46' East, Sea level: +5m). Annaba is defined by the Hot Summer Mediterranean climate (Csa), according to Köppen (2020) classification. Annaba city gathers a population of 640,050 inhabitants, according to The National office of statistics (2008). We selected three different streets in three diverse neighborhoods in Annaba city (Fig 4). The first segment in Colonial Centre is a regular and furnished street (Having minimum pedestrian features) with North-East, South-West orientation, and h/w=2. The second case in the medieval neighborhood (Medina) with East West orientation has an irregular morphology and has a ratio h/w equivalent to 1.83. The last street was in El Bouni neighborhood (Suburban area), with a North-South direction characterized by a regular morphology with h/w=0.29, but it is unfurnished (Table 6). These selections are just for testing the proposed STWCI in different types of streets, and the proposed STWCI can be used to measure walkability for other streets.

Table 6 The characteristics of the selected streets

Streets' characteristics	**Street1**	**Street2**	**Street3**
Length	512.9 m	323.22m	299.68m
Orientation	NE/SW	E/W	N/S
High of building	16m	11m-13m	12m - 15.5m
Ratio h/w	2	1.83	0.29
Vegetative elements (Trees)	0	3	0
Building's material	stones	Stones/Solid bricks	Precast concrete walls
Building's color	White	White	Yellow
Footpath material	Pavement	Concrete	Unfurnished+ concrete stranded tiles.

NE/SW: North East/South West, E/W: East/West, N/S: North/South

Street 1 in Colonial Center, Street 2 in Medieval neighbourhood, Street3 in El Bouni

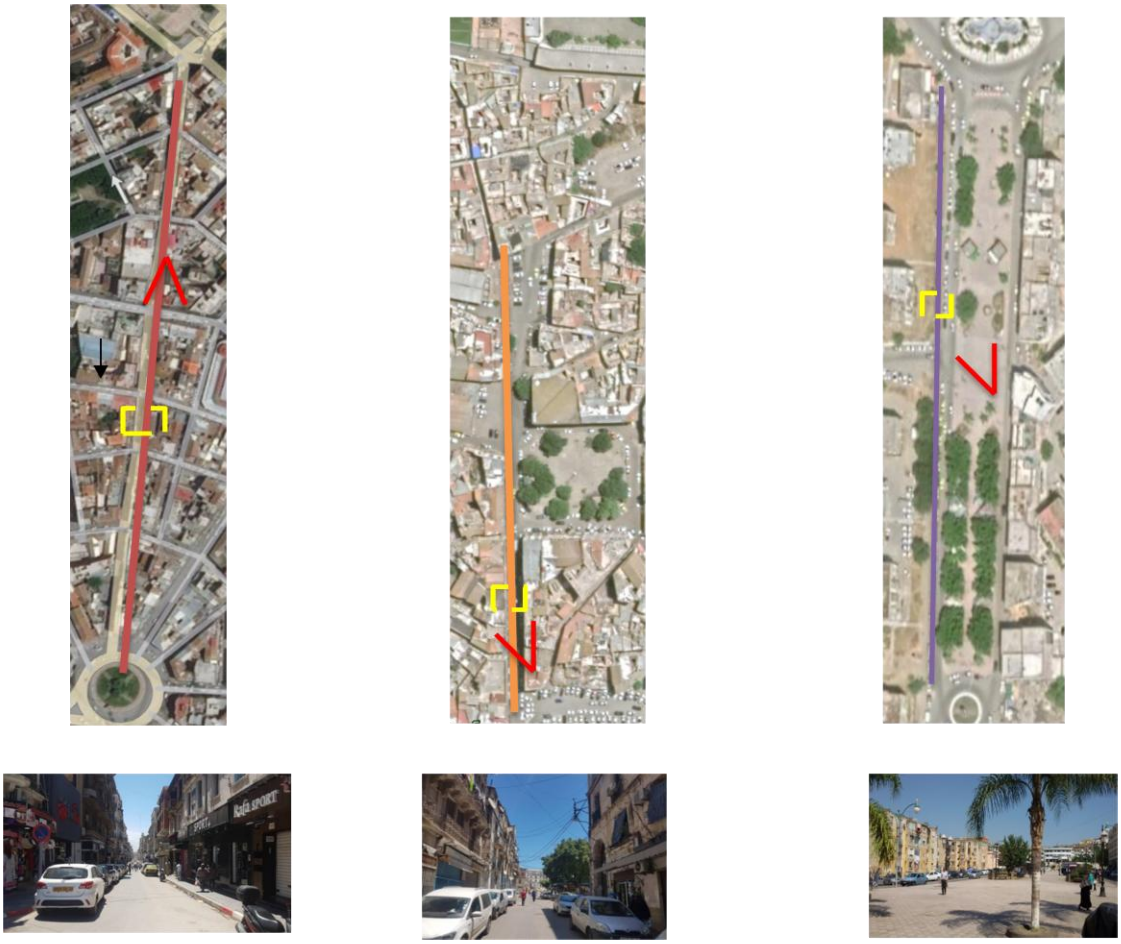


Fig.4. Location of selected streets at three distinct neighbourhoods.

Source: Google images, 2020

3. Results

3.1 Pedestrian comfort facilities coefficients and observation scores

3.1.1 Sample characteristics

The sample comprised 330 respondents, 53% male and 47% female. Some age categories were more involved than others. The results showed 64% of the response are related to the 25-34 category, followed by the 35-44 years group. In comparison, the youngest group (18-24 years old), and 45-54 years and 55-64 years, represented only 8%, 3%, 5% survey responses. Two categories, 65-74 years and +75years old, didn't take part in the survey. Since this survey's main purpose is to estimate just the importance of the indicators, the scores are calculated using objective measurement methods. Therefore, the differences in age categories, mainly because of the online data collection, cannot affect the scores. In addition, the 25-44 age categories can represent the majority of the pedestrian population in the city, and the estimated weights can represent the opinions of the majority of the pedestrian population.

3.1.2 Coefficient results

The first column in Table 6 presents the coefficients of comfort walkability indicators. Over 95% of the suggested factors such as landscape and trees, footpath pavement, shade, bench and seating area, and social space(café) are considered very important and highly significant (0.80 and 0.93). Other indicators such as the ramp, pedestrian signals, footpath width, and slope are estimated as essential (0.67-0.77). However, a single indicator (trash receptacle) was supposed less critical, having a score of 0.32.

3.1.3 Observation scores result

From the data presented in the second column of Table 7, six pedestrian comfort indicators had a score of 1. This value demonstrated an actual presence of factors on the street1in Colonial center (e.g., social space (café), the sidewalk on both sides, slower traffic speed, few traffic lanes). On the other hand, footpath pavement, the width of the footpath, and buffer/barriers (curb and furnishing zone) has 0.8, 0.8, and 0.5 scores, respectively, estimated present on the street. Still, they are not meeting the recommended standard. However, a score of 0 suggests the non-existence of the pedestrian comfort facilities in the street segment.

The third column shows the observation scores of Street 2 in the medieval neighborhood (medina). The highest score (1) is assigned to social space (café), slower traffic speed, few traffic lanes, so they are available and correspond to the referred methodological calculations. Alternatively, the ramp and standard driveway are not existing in the street. Other indicators to which scores are 0.13, 0.12 reflect no weight (e.g., footpath pavement and width of the footpath). In comparison, the sidewalk on both sides and buffer/barriers (curb and furnishing zone) indicators, with respectively 0.39 and 0.5 scores, highlight a failure with the required standards. However, the rest of the comfort walkability indicators having a score equivalent to 0 showed their total absence on the street.

The last column exhibits the observation scores at street 3 (El Bouni neighborhood). Most of the street comfort facilities had a 0 score, reflecting their lack on the street. Other indicators such as buffer and barriers, having a score of 0.5, indicated a deficiency with the recommended standard. However, social space (café), slower traffic speed, fewer traffic lanes scored the highest value 1, which implies their standard appearance on the street, while ramp and standard driveway are not available.

Table7 The scores and coefficients of street comfort indicators

		Street1	**Street2**	**Stree3**
	Length	512.9 m	323.22m	299.68m
	Orientation	NE/SW	East/West	N/S
Indicators	**Coefficients**	**Scores**	**Scores**	**Scores**
Landscape and trees	0.93	0	0.13	0
Footpath pavement	0.93	0.8	0.12	0
Marking (crosswalk)	0.85	0	0	0
Park and space for playing	0.85	0	0	0
Shade/Thermal comfort	0.85	1	1	1
		1	1	1
		0.5	0.5	0.25
		0.25	0.25	0.5
		0.25	0.25	0.25
		0.5	0.5	0.25
		1	1	1
Benches and seating area	0.84	0	0	0
Toilet	0.82	0	0	0
Buffer and barriers (curb and furnishing zone)	0.81	0.5	0.5	0.5
Social space (café)	0.8	1	1	1
Sidewalk on both sides	0.8	1	0.39	0
Ramp	0.77	1	1	1
Mid-block crossing	0.76	0	0	0
Pedestrian signal	0.76	0	0	0
Width of footpath	0.75	0.8	0.12	0
Shorter crossing distance (curb extension)	0.73	0	0	0
Slower traffic speed	0.72	1	1	1
Slope	0.71	0	0	0
Lighting	0.69	0	0	0
Fewer traffic lanes	0.68	1	1	1
Standard driveway	0.67	1	1	1
Furniture and facilities (trash receptacle)	0.32	0	0	0

NE/SW: North East/South West, E/W: East/West, N/S: North/South

3.2 Thermal comfort results and scores

It is essential to mention that PET was computed based on four calibrated microclimatic data (Air temperature, Relative humidity, wind velocity, and Mean radiant temperature) at the three selected streets on the 26th and 28th of August 2017 (Table 8).The purpose of this study is to estimate PET for the general population and not individuals.

Therefore, some parameters like clothing and activity are used to represent the general population (clothing: 0.9 clo and activity: 80 W).

Table 8 Microclimatic data and PET results using Envi-met and RayMan software.

Time (H)	Calibrated data (Envi-met)				RayMan	Calibrated data (Envi-met)				RayMan	Calibrated data (Envi-met)				RayMan
	Ta1 (°C)	Rh1 (%)	V1 (m/s)	Tmrt1 (°C)	PET1 (°C)	Ta 2 (°C)	Rh 2 (%)	V 2 (m/s)	T_{mrt} 2 (°C)	PET2 (°C)	Ta 3 (°C)	Rh 3 (%)	V 3 (m/s)	T_{mrt} (°C)	PET3 (°C)
8:00 AM	25.2-25.3	below 94%	0.2-0.4	13.3-13.5	20.1	24.9-25.1	96%	0.3-0.4	13.6-13.8	20	26	48%	0	12.8	19.9
10:00 AM	30.5-30.6	68%	0.5-0.9	17.7-17.9	25.2	30.5-30.6	below 73%	0.9-1.2	18.3-18.5	25.6	33.4	32%	0	19.9	26
12:00 PM	31.6-32	57%-59%	0.9-1.9	18.7-19	26.5	31.1-31.5	58%-61%	2-2.6	19.1-19.3	26.4	34.7	28.50%	0.2	21.6	28.4
2:00 PM	33.9-34.2	71%	0.8-1.5	21.2-21.5	29.4	33.2-33.5	70%-74%	1.6-1.9	21.7-22	29.5	31.6	50%	2.4	20.5	27.3
4:00 PM	34.6-34.9	31%-32%	1-2.	23.9-24.3	30.5	34.3-34.5	below 33%	2.4-2.9	24.5-24.8	31	33.2	25%	2.6	23.8	29.5
6:00 PM	31-31.2	65%	1-1.97	22.6-22.8	27.5	30.9-31.1	65%-69%	2.1-2.5	22.5-22.8	26.6	31.6	44%	0.5	23.6	28
8:00 PM	27.5-27.6	81%-83%	0.7-1.4	19	23.6	27.3-27.4	below 83%	1-1.3	below 19.07	23.1	28.8	57%	0.5	20.1	24.8

3.2.1 Microclimatic data

The results show a significant difference in air temperature in the three streets. The lowest temperature was recorded in Street 2 (Medina) at 8 am, 24.9 °C, compared to Street 1 (25.2°C) and Street 3 with 26°C. Although many hours reflected a high temperature (12 pm, 2 pm, 4 pm), the T (a) at Streets 1 and 2 are similar at 10 am (30.5°C-30.6°C). However, Street 2 showed the lower temperature at noon (31.1°C-31.5°C), 2 pm (33.2°C-33.5°C), 4 pm (34.3°C-34.5°C) in comparison to Street1 with (31.6°C-32°C), (33.9°C -34.2°C), and (34.6°C -34.9°C). At the same time, the highest temperature was recorded in Street 3 at noon (34.7°C). Considering relative humidity, Streets 1 and 2 recorded a higher percentage during the entire hours of the day. For example, at 8 pm, Street 1 has (81%-83%), Street 2 (below 83%) while Street 3 has 57% (Table 8).

The T_{mrt} emphasized noticeable differences. The lowest values were recorded at 8 am for the three streets. For example, Street 1 has 13.3°C -13.5°C, Street 2 recorded 13.6°C - 13.8°C, and Street 3 has 12.8°C. However, at noon, street 1 has a lower T_{mrt} value than Street 2 (19.1°C -19.3°C) and Street 3 with 21.6°C. Finally, the wind velocity recorded common low values at the three streets (Table 8).

The PET values at Streets1 and 2 are almost the same, especially during the hottest hours of the day. For example, at noon, the PET at Street 1 is 26.5°C, compared to Street 2 (26.4°C). However, at 8 pm, Street 2 recorded a lower temperature (23.1°C) than Street 1 (23.6°C). However, Street 3 registered the highest values of PET at all the hours of the day, compared to Street 1 and Street 2 (Table 7), except for 8 am where PET (19.9°C) was like Street 1 (20.1°C), and Street 2 (20°C). The results also showed a positive correlation between street orientation PET values and H/W. Indeed, Street 1 and Street 2 showed relative values of PET at the hottest hours of the day despite the difference in orientation (Street 1 NE/SW, Street 2 E/W). However, the H/W at Street 2 (1.89) is lower than Street 1 (equivalent to 2), showing a good level of shade. In contrast, Street 3 has N/S orientation, with H/W equivalent to 0.29, highlighting a deficient shade level.

3.2.2 PET coefficient and scores

The PET coefficient was derived from the questionnaire survey.There is a specific question about indicating the importance of thermal comfort for people during the walking experience in the questionnaire. To define an "acceptable thermal range" for PET in summer, TSVs were within the three major categories (Neutral, slightly warm, warm). We summarised PET values and scores from 8am to 8pm according to thermal comfort ranking in Tel Aviv with a Csa climate (Table 9). The PET is reaching its highest score (1) at 8 am, 10 am, and 8 pm, denoting a neutral thermal sensation. The lowest score is 0.25 at 4 pm on the three streets, showing a warm thermal perception. PET had the same score of 0.5 and 0.25 at noon and 6 pm on Streets 1 and 2. Versus a warm thermal perception, with a score of 0.25 simultaneously on Street 3 (See Fig 5).

Table 9 PET values and score results in the selected streets.

Time	PET Street1	Scores	PET Street2	Scores	PET Street 3	Scores
8:00 AM	20.1	1	20	1	19.9	1
10:00 AM	25.2	1	25.6	1	26	1
12:00 PM	26.5	0.5	26.4	0.5	28.4	0.25
2:00 PM	29.4	0.25	29.5	0.25	27.3	0.5
4:00 PM	30.5	0.25	31	0.25	29.5	0.25
6:00 PM	27.5	0.5	26.6	0.5	28	0.25
8:00 PM	23.6	1	23.1	1	24.8	1

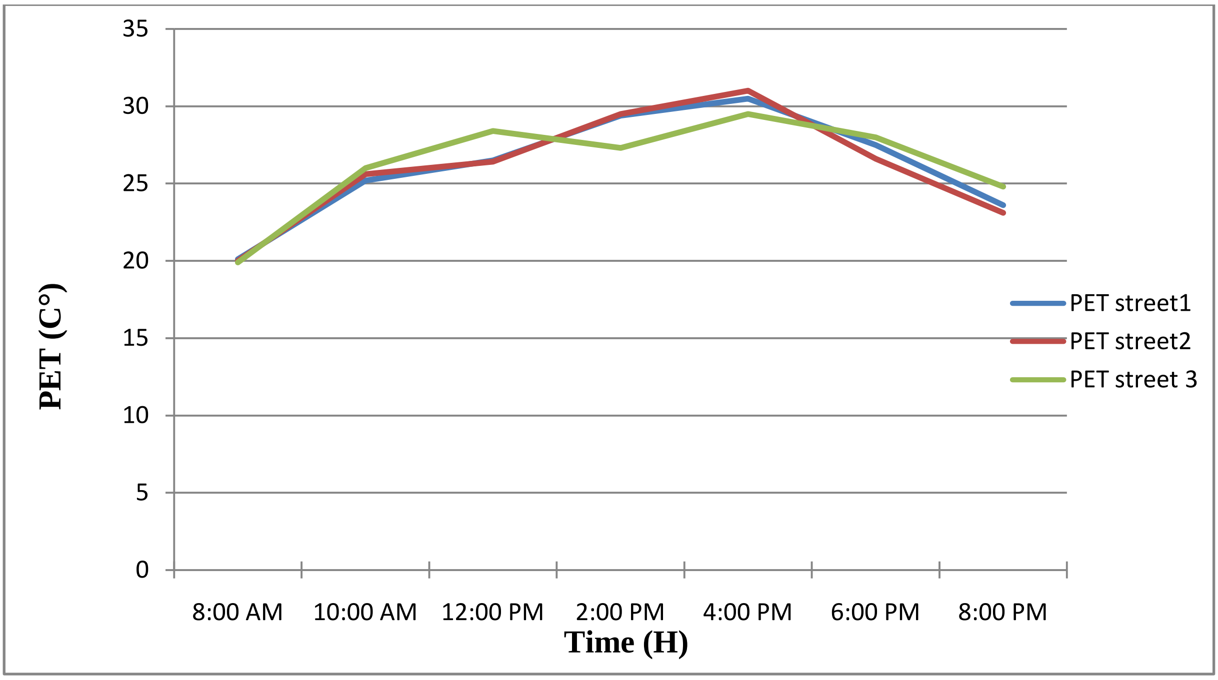


Fig. 5. Comparative analyses of PET results on three selected streets.

A straightforward analysis of the scores reveals that the same pedestrian facilities (e.g., social space (café), slower traffic speed, and fewer traffic lanes) besides PET reached the maximum scores of 1 at the three selected streets. However, the minimum values for the street facilities (e.g., parks and spaces for playing, toilet, benches and seating area) were equivalent to 0, while for the PET, the lowest score was 0.25 (See Fig 6).

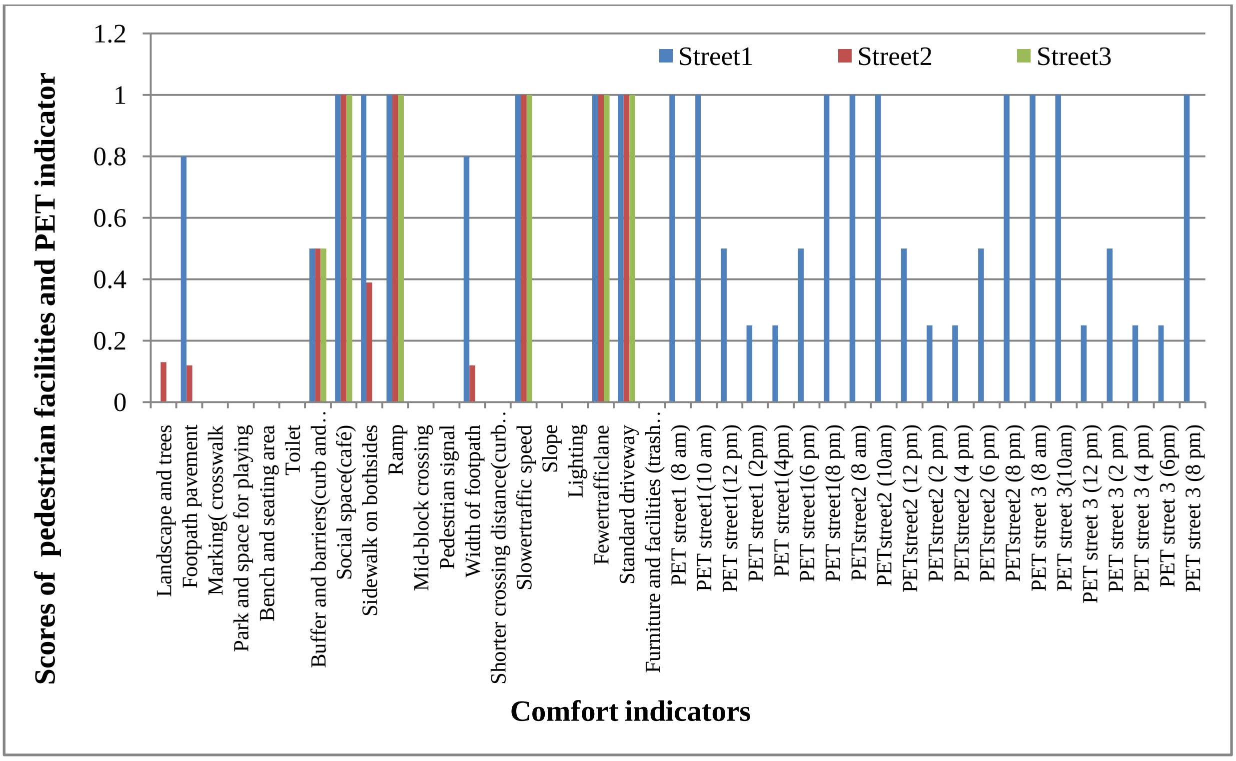


Fig. 6. Comparative analysis of comfort indicator scores on street level.

3.3 Street Walkability Thermal Comfort Index (SWTC)

The application of equation (1) allowed us to have the (SWTCI). The comparative analysis of SWTCI outcomes showed low-quality comfort walkability indicators specified by minimal pedestrian street design, which does not comply with international standards (Table10). For example, the SWTCI in Street1 was between 30%-33%.In street 2, SWTCI was included in the average of 23%-26%, and finally, the lowest scores were at Street 3(20 %< CWTCI< 23%) (Fig 8). Most of the comfort walkability indicators are not existing. The selected streets are considered uncomfortable to use and unpleasant to walk (Table1).

Table 10 SWTCI average and significance in the selected area.

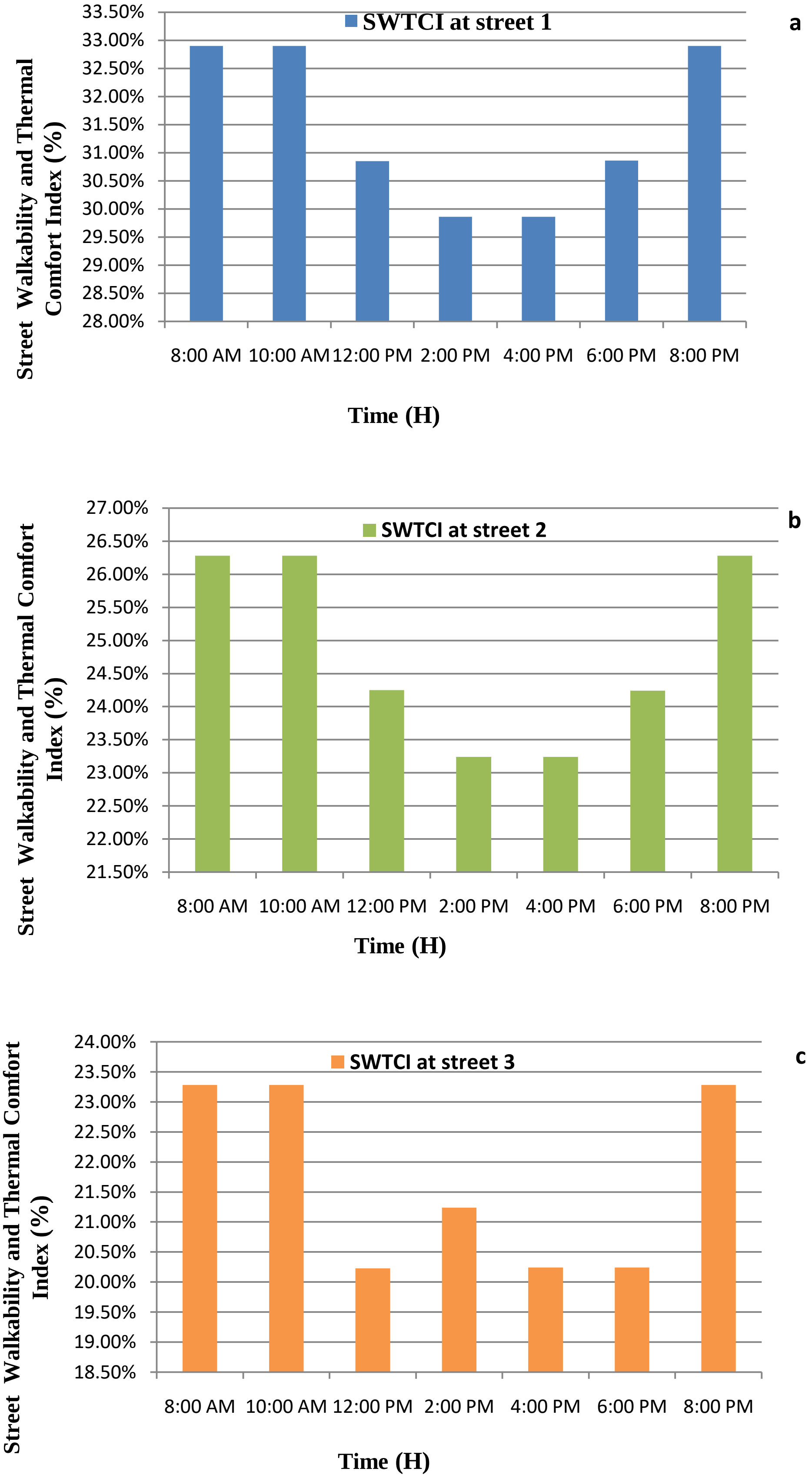
Climate	Area	Streets	**SWTCI average in the selected streets**																																							
			F	E (1%-19%)																			D (20%-39%)																			
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Csa	Colonial .C	Street 1																																								
	Medina	Street 2																																								
	El Bouni	Street 3																																								

F(0%) There are no standard pedestrian amenities (very uncomfortable), E (1%-19%) Lowest quality (unpleasant), D (20%-39%) Low quality (uncomfortable), minimal pedestrian facilities.

According to the results, SWTCI reaches its highest score on the three streets at three hours a day, 8 am, 10 am, and 8 pm, when the thermal sensation is neutral with 32.90%, 26.28%, and 23.28%, respectively. However, SWTCI gets the minimum rating at 4 pm when the thermal perception is warm, showing 29.86%, 23.24%, and 20.23%, respectively (Fig 8).

The corresponding SWTCI values at street1 got 30.85% and 29.86% by increasing from noon to 4 pm. That is reflecting a slightly warm and warm thermal sensation, respectively. STCWI was rising from 6 pm to 8 pm with 30.8% and 32.90% (Fig 7.a). The variation of STCWI was similar in the two streets (Colonial Center and Medina)(Fig7.a, b); however, the STCWI rating on Street 1 was higher than Street 2 (Fig 8).

Regarding Street 3 (El Bouni neighborhood), the results show a noticeable difference comparing to the previous STCWI rating. Three hours a day (12 am, 4 pm, and 6 pm) characterized by a warm thermal sensation get the lowest STCWI rating (20.23%, 20.24%) respectively (Fig 7.c). However, STCWI ranking at Street 3 is inferior to both previous STCWI results (Fig 8).



Street 1 in the Colonial center, **Street 2** in Medievalneighborhood (Medina), **Street 3** in El Bouni

Fig. 7. Street walkability Thermal Comfort Index at the selected streets

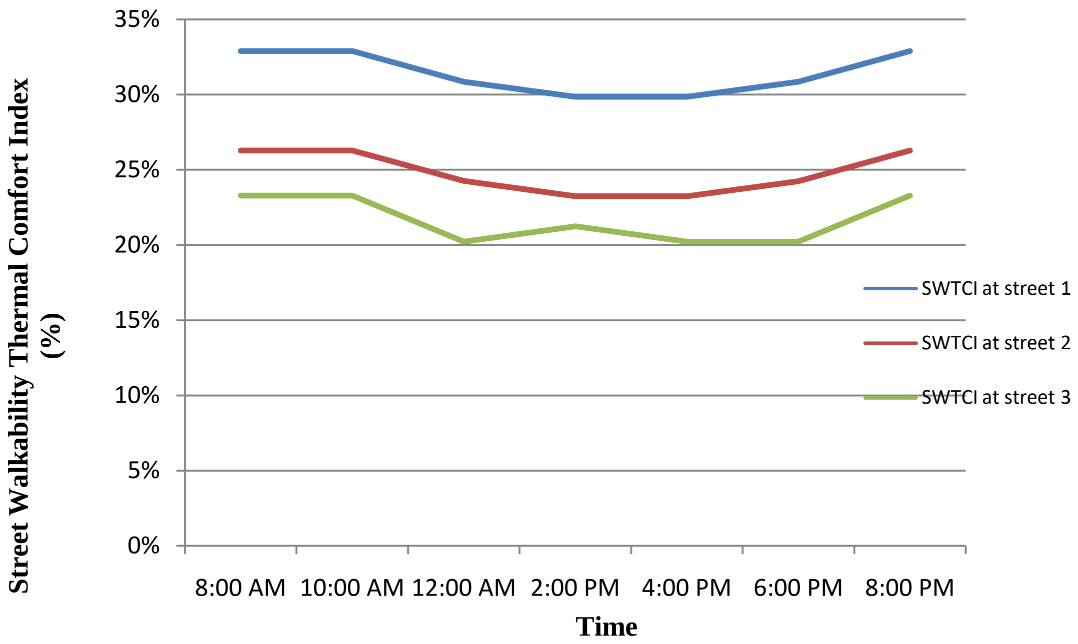


Fig. 8. Comparatives analysis of the Street Walkability Thermal Comfort Index on the selected streets

4. Discussion

To make the walking experience pleasant and more suitable, we need a pertinent rating system that can evaluate the existing pedestrian comfort environment and identify the problems that can be used for suggesting solutions. In this aim, the current research intended to examine 22 comfort walkability indicators on the sidewalk scale, using an innovative method including pedestrian comfort facilities and PET. The proposed model was tested in Annaba; Algeria. This model fulfilled the need for rating pedestrian comfort and enhancing walkability scores by combining street comfort design and thermal comfort.

4.1 Impact of the pedestrian comfort facilities

This study's findings showed the relevance of the selected indicators. Indeed, most themes are valued as very relevant for pedestrian comfort. Besides offering convenience, the requested factors included a potential sign of safety, attractiveness, and usability. For example, besides suitable signage and sufficient time for crossings, the speed limit provides comfort and safety (Lamour et al., 2019; Mateo-Babiano, 2016). Street lighting provides a pleasant and secure pedestrian setting at night (Loukaitou-Sideris, 2006). Also, the results reveal some other crucial comfort attributes such as a sidewalk on sides, foot pavement, the width of the footpath, benches, and seating area. Those define pedestrian convenience and ensure a pleasant walking experience (Aghaabbasi et al., 2018) for all categories, including children, older adults, and people with disabilities. Moreover, these indicators allowed enjoying the social life (Jacobs, 1993; Marcus and Francis, 1997). Slope, toilets, curb ramps are necessary for pedestrian comfort and ensure usability and accessibility (Asadi-Shekari et al., 2019).

4.2 The PET effect on walking comfort

The Envi-met model allows human thermal comfort simulation for the current and future climatic conditions estimated by regional climate models. The calibrated model was successfully validated based on the difference between measured and simulated air temperature, showing a good correlation between set data (Acero and Herranz-Pascual, 2015; Chen and Ng, 2013; Müller et al., 2014). This study also used the Rayman software to calculate the PET based on calibrated data to provide more accurate data of the existing thermal comfort model. For example, simulated T_a and T_{mrt} values agree much better with measurement data(Lee et al., 2016; Tan et al., 2016). Moreover, the results highlighted the h/w ratio and orientation on thermal comfort conditions (Andreou, 2013). For example, Street 3 (h/w of 4) has higher air temperature, $T_{mrt,}$ and PET values in comparison to Street1 (h/w of 2) and Street 2 (h/w of 1.83).

As introduced in Tables 4 and 5, the thermal sensation advised for the summer time in the Csa climate are neutral, slightly warm, and warm. Formerly PET ranking amid 19.9°C and 31°C. The inquiry of results PET scores was fluctuating according to the time of day in summer. The PET results at the three selected streets showed the similarity of PET ratings in Street1 and Street 2 from 8 am to 4 pm. However, PET in Street 2 is lower than PET at Street1 from 6 pm to 8 pm. We noted that the thermal sensation in both streets (Streets 1 and 2) is almost the same (Table 9, Fig 6). Alternatively, PET at Street 3 is higher than the previous streets, which involve a warm sensation in three significant hours of the day (12 am, 4 pm; 6 pm) with a harmful effect on pedestrian comfort.

Those findings are strongly supported by Wu and Chen (2017), confirming the importance of the High-rise building on both sides of streets; their shades significantly impact the thermal near-surface surrounding environment. Indeed, the concrete pavement surface temperatures shaded by buildings were relatively 16 °C lower than those bared to solar radiation during mid-day in the summer. Besides being significantly crucial to citizens, trees provide shade, allowed walking during the hottest hours of the day. Indeed trees generate the cooling effect by reducing air temperature and T_{mrt} (Bowler et al., 2010; Lee et al., 2016, 2013; Lee and Mayer, 2015; Mullaney et al., 2015). Moreover, the urban green cover can massively absorb high amounts of solar radiation (Shortwave and long-wave radiation) (Oke, 1982) and adding aesthetic value (Sousa et al., 2016).

4.1.2 Interactivity of PET and pedestrian comfort facilities on SWTCI

Among the many output possibilities derived from the SWTCI tool, we extracted those aiming to illustrate the PET assessment's usefulness.

The highest SWTCI at the three streets (33%,26%, and 23%) was correlated to neutral thermal sensation, reflecting the lowest amounts of PET followed by slightly warm. On the other hand, the lowest SWTCI rate in the selected streets (30%, 23%, and 20%) was related to the warm category of thermal sensation. In this optic, we can confirm the importance of PET in the assessment of the SWTCI process. Thermal comfort is considered a vital comfort walkability factor in improving pedestrian activity and a healthy environment, confirming the importance of the climatic conditions in outdoor urban spaces and the quality of life and wellbeing in cities(Cohen et al., 2013; Givoni, B et al., 2003).

Furthermore, the results recommended walking hours activity at 8 am,10 am, and 8 pm defined as thermally comfortable hours in summer with a neutral thermal sensation (20<PET<26), followed by 6 pm with a slightly warm thermal perception (26.84<PET<27.5). However, the warm thermal sensation is not recommended for walking and made an uncomfortable condition (28<PET<31) at 12 am and 2 pm. Thus, the pedestrians walking in the shaded zone could improve thermal sensation (Lee et al., 2020). For example, the thermal sensation scale is expressed as slightly warm instead of warm for subtropical climates (Huang et al., 2017).

The proposed model can improve the pedestrian street comfort design by suggesting enhancing the indicators scores and comparing existing conditions with standards. Some pedestrian facilities such as landscape and trees and footpath pavement have a dual role; first, they improve the sidewalk's comfort conditions, and second; they increase pedestrians' thermal comfort. Landscape and trees are considered the principal component of attractiveness, safety, and usability on street level (Aghaabbasi et al., 2019, 2017).Adding vegetation can reduce mid-daytime heat by shading ground and evapotranspiration (Donovan and Butry, 2009; Gillner et al., 2015; Wu and Chen, 2017) and promoting walking hot hours of the day. Also, some paving materials such as cement tiles facilitate the accessibility of wheelchairs and stroller. The tiles with lighter pigmentation can absorb less heat and permit better thermal comfort (Synnefa et al., 2006).

Regarding the evaluated streets in this study, enhancing some pedestrian comfort facilities scores such as landscape and trees, benches and seating area, lighting, the width of the footpath, footpath materials can significantly improve the SWTCI rates. We can enhance the pedestrians' comfort by analyzing the existing variable's quality standards (See Table 7 and Appendices A and B and C). The comfort indicators could achieve the ideal score of 1 by performing current scores. Thus, applying the suggested improvements in Appendix C leads to a relevant upgrade to SWTCI3. Indeed, it increased from 23% to 38% but still included in the same category (D).

Although the SWTCI results correlate to the PET, improving other pedestrian comfort indicators can significantly affect the SWTCI. For example, for a street without a sidewalk, most of the scores will be zero regardless of PET. In addition, some pedestrian facilities, such as footpath pavement (pavement type material) as well as landscape and trees, could have a dual role in improving the walkability and thermal comfort scores. Furthermore, including additional parameters such as building material and color, besides analyzing the effect of adding vegetation and comparing the pavement material on thermal comfort, could be other interesting perspectives on the dual role factors for future research.

It is worthy to note the possibility of improving all the pedestrian comfort indicators by considering the standard guidelines (See Appendix A) and following the same method of Asadi-Shekari et al.(2019) (See Appendix B).Using the SWTCI method would help authorities improve comfort walkability conditions on the street level and enhance citizens' comfort potential. This design model can transform uncomfortable streets into pleasant and convenient environments within different street morphology and length. Indeed, the selected streets have fulfilled these requirements, proving the SWTCI high prospective and reliable applicability.

4. Conclusion

This paper explored a new assessment model, the SWTCI within Csa. By considering PETas a comfort walkability indicator. This method is an innovative approach to combining pedestrian comfort facilities and thermal comfort on the street scale. The current process involved using a questionnaire survey, observations and in situ measurements. Using Envi-met and Rayman allowed obtaining current PET besides identifying the thermal comfort range. Thus, the SWTCI met the recent walkability audit tool (PLOS) and the successful thermal comfort approaches.

Urban designers and architects can use this model to improve comfort walkability conditions for all street morphology. Moreover, it is helpful to evaluate the existing sidewalk condition by following an easy process assessment. Applying this model can improve the existing street features and transform the streets into ideal comfortable pedestrian environments. This promising initiative can be part of a sustainable development process and healthy living strategies. The SWTCI could be explored in the Mediterranean area and other climate zones.

Despite the novelty of the proposed method, there are some limitations, such as using the fisheye technique to facilitate the quantitative interpretation of results, the absence of some comfort indicators (e.g., drinking fountains, tactile pavements, elevators next to a sky-bridge) considering their rareness in the selected area, besides the lack of building's characteristics (e.g., materials, colors). Thus, combining these factors in people's perceptions and analyzing the vegetation and footpath material effects on thermal comfort could be an added value for the SWTCI. Moreover, improving the SWTCI tool for each type of street, besides comparing different cities with different climates, could be an interesting topic for future research. In addition, further studies can use similar methodologies to develop user-friendly software for the SWTCI estimation.

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AppendixA *The pedestrian comfort facilities standards*

Sources *Asadi-Shekari et al.(2019, 2014),Ellen Vanderslice (1998), and Centre (n.d.)*

Pedestrian comfort facilities	Standards
Slower traffic speed	*30km /H based on the street standard.*
Buffer and barriers (curb and furnishing zone)	✓ *Curb standard: the lowest width of curb is equal to 0.15m, the minimal high is equivalent to 0.10-0.15m* ✓ *Furnishing zone: the lowest acceptable width is 1.2m; however, the Interval (1.8m-2.4m) is recommended.*
Fewer traffic lanes,	✓ *Standard 2 lanes.*
Mid-block crossing	✓ *1. Crosswalk number is changing, but not farther apart 60-90m, besides not contiguous than 45m and does not ban crossing further than 120m.* ✓ *2. The representative width of the mid-block crossing is 3 m. However, if the sidewalk is more extended than 3.7 m, the crosswalk should be larger than the width.*
Landscape and trees	✓ *Trees Limb must have a clear vertical high of a minimum of 2.4 m (1)* ✓ *Trees must be distant from intersections with a minimum of 7.6 m (2)* ✓ *Trees interval must not exceed 9 m to ensure an extended trees canopy.* ✓ *Trees must be implanted on both sides of the sidewalk*
Furniture (trash receptacles)	✓ *It must be in the furnishing zone within 0.9 m wide or more extensive.* ✓ *It must be far from the intersection with 9m of distance.* ✓ *A distance of 0.6m, at least from the curb border, should be respected.* ✓ *One receptacle should be provided in each playground, which has to be near benches.* ✓ *It must have at least 1.2 m clear out concerning bus facilities.* ✓ *It must be placed every 200-400 m.*
Footpath pavement	✓ *It must be solid, anti-slip, not rough, and extended.* ✓ *The area of discontinuities should not be more than 1.25 cm; besides, the thickness differences must be including 0.6-1.25*
Marking (crosswalk)	*The first type (Ladder or longitudinal)* ✓ *The minimal width of a crosswalk is 3 m, but the suggested width is 5 m* ✓ *The strips interval is 0.3-1.5 m* ✓ *The width of the bands is between 0.3-0.6m* *The second type(Parallel or standard transverse)* ✓ *The minimal crosswalk width is 1.9m, but the suggested width is between 3-4.5 m* ✓ *The width of the two bands is 0.15-0.30m*
Sidewalk on bothsides	✓ *Every side of the street must have a sidewalk.*
Width of footpath	*The footpath zone must be at least 1.5 m. However, the preferred width is between 1.8m-2.4m*
Slope	*The sidewalk slope ≤2%*
Lighting	✓ *Sufficient light must be furnished.* ✓ *The pedestrian dimension is relevant for providing lighting.* ✓ *The light pole must be based at least 0.9 m from the curb beside any other approachable structure (e.g., shelter).* ✓ *The lighting fixtures with full-cut off must provide a descended light in the streets.* ✓ *The light pole interval must be 9 m maximum to ensure sufficient light.*

Continued Pedestrian comfort facilities	Standards
Ramp	*A pedestrian surface characterised by a running slope superior to 5%* ✓ *Maximal value of the slope is 8.3%* ✓ *The minimal width is 1.2m* ✓ *An appropriate handrail must be furnished.*
Park and space for playing	✓ *Parks and the public area must be effortlessly accessible on foot or by bike for the user's categories (e.g., people with different abilities besides children and alder).* ✓ *Parks and public spaces require to be safe, accessible, and age-friendly.*
Social space (café)	✓ *They should be located every 200-400 m*
Benches and seating area	✓ *They must be provided in the frontage zone.* ✓ *They must be implanted with a minimal distance of 0.6m from the curb.* ✓ *They must be implanted with a minimal distance of 9m from the intersection.* ✓ *They must be furnished at all bus stops.* ✓ *They should be implanted every 200-400 m.* ✓ *An area of 1.2 m should be given at the end of the seats to allow strollers and wheelchairs station.* ✓ *Every seat must be furnished with a minimal distance of 0.6 m from the pedestrian traffic roads.* ✓ *A distance of 1.5 m should be respected between the seat and any immobile furniture such as a drinking fountain, trash receptacle or signpost.*
Toilet	✓ *The public toilet must be implanted close to the bus stop and at each Rapid Transit Station. Besides being adjoining to parks and playing area.* ✓ *Toilet interval implementation must be every 500- 800m.* ✓ *For wheelchair users, a minimal distance of 1.7*1.8 m should be respected.*
Pedestrian signal	✓ *Reachable pedestrian signals should have an interval of 3m at a crossing besides respecting a distance of 1.5 m from other signals (1)* ✓ *The pedestrian signal must be implanted no closer than 0.75m and with a maximal distance of 3m from the curb (2)* ✓ *It must be far less than 1.5 m from the crosswalk (3)* ✓ *An appropriate countdown must be furnished (4)* ✓ *People with disabilities (wheelchair user) must be able to achieve the button (5)* ✓ *An audio signal is necessary (6)*
Shorter crossing distance(curb extension)	✓ *Curb extension reduces the crossing distance, furnishes an additional area to the corner, and permits pedestrians' visibility before crossing.* ✓ *They should be at any mid-block crossing or marked crosswalk defined by a parking lane (where the curb could be extended).* ✓ *They are the favoured elements for corner except in extenuating design consideration (e.g., turning radius of the design vehicle).* ✓ *The curb extension could comprise transit stops, which can omit buses need to pull out of the travel lane for loading and unloading pass.*

Appendix B *Scores calculation*

Source Asadi-Shekari et al. (2019, 2015, 2014, 2013b)

Facilities	scores
Slower traffic speed	*S =1 if the speed of 30km/h (pedestrian zone) is respected* *=0 if the of 30km/h is not mentioned and respected.*
Buffer and barriers (curb and furnishing zone)	*C = Number of standard curb ramps* *N = Total number of curb ramps the street needs* *P = C/N* *S = 1 if P≥1* *= P if P<1* *=0 if the curbs are not required*
Fewer traffic lanes,	*S = 0 if N° of lanes >2* *= if N° of lanes ≤2*
Mid-block crossing	*S =∑Pi/The entire number of sections with an extend over 120m* *= 0if, the whole extend of the street, is under 120m and ci=0* *P i=1 if Pci ≥1* *= Pci if Pci<1* *Pci= ci/ni* *i=1,2,3……k (Various segments of streets between crossroads greater than 120m)* *ci=Numeral of standard mid-block crossing in segment i)* *ni=extend of trees in segment/120.*
Landscape and trees	*D = Interval of the distance between trees (m)* *C =(Extend of a street with trees –entire extend of crossroads and their considered standard restrictions)9/D If D>9* *= Extend of a street with trees –entire extend of crossroads and their considered standard restrictions if D≤9* *N=Extend of the street (both sides)-entire extend of crossroads and their considered standard restrictions)* *P1=C/N* *If D is varying within different segments of the street* *Ci = Extend of a street with trees in segmenti–entire extend of crossroads and their considered standard restrictions)9/D If D>9* *= Extend of street with trees in segmenti –complete distance of intersections and their considered standard restrictions if D≤9* *i=1,2,3……k (Various segments of streets with a different interval of trees)* *Ni = Extend of a street (in segment i) – considered standard restrictions (m)* $P1 = \sum_{i=1}^{k} Ci / \sum_{i=1}^{k} Ni$ *F = C – Extend of a street that does not have a clear vertical height* *N=Extend of the street (both sides)-entire extend of intersections and their considered standard restrictions)* *P2 = F/N* *If D is varying in different segments of the street.* *Fi = Ci – Extend of a street that does not have clear vertical height in section i* *Ni = Extend of the street (section i)- considered standard restrictions (m)* $P2 = \sum_{i=1}^{k} Ci / \sum_{i=1}^{k} Ni$ *NI = Number of crossroads with considered standard restrictions for trees).* *I = Number of the hole crossroads* *P3 = NI/I* *S= (P1+P2+P3)/3*
Furniture (trash receptacles)	*C = Extend of a street with guideline trash receptacle area + their support distance (m)* *N = Extend of street (both sides) (m)* *S = C/N*
Footpath pavement	*W = Width of footpath (m)* *C = Area of standard pavement (m2)* *N = (Extend of street (both sides) - extend of crossroads) 1.8 if W <1.80 m* *= (Extend of a street (both sides) - extend of crossroads) W if W ≥ 1.80 m* *S = C/N* ***If W is varying in a different segment of street*** *Wi = Width of footpath in segment i* *i= 1, 2, 3, …, k (various segments of a street with different width of the footpath)* *Ci = Area of guideline pavement in segment i(m2)* *Ni = (Extend of a street (in segment i)×1.8 if Wi<1.80 m* *= (Extend of a street (in segment i)×Wi if Wi ≥ 1.80 m* *PCi= Ci/Ni* *Li =Extend of street in segment i(m)* $S = \sum_{i=1}^{k} PCi \times Li /$ *(Extend of a street (both sides)-extend of crossroads).*

Continued Facilities	**scores**
Marking (crosswalk)	*C = Number of guideline crosswalk markings* *N = Number of crosswalks that street requires(mid-block and cross walk at intersections)* *P = C/N* $S \begin{cases} =1 \text{ If } P1 \geq 1 \\ =P \text{ If } P < 1 \end{cases}$
Sidewalk on bothsides	$a \begin{cases} =1 \text{ if } P1 \geq 1 \\ =P1 \text{ If } P < 1 \end{cases}$ *P1 = l1/N1* *l1 =Extend of sidewalk in one side (m)* *N1 = Extend of street – Extend of crossroads in one side (m)* $m \begin{cases} = 1 \text{ if } P2 \geq 1 \\ = P2 \text{ If } P2 < 1 \end{cases}$ *P2 = l2/N2* *l2 = Extend of footpath in opposite side (m)* *N2 = Extend of street – Extend of crossroads in other side (m)* *S = (a + m)/2*
Width of footpath	*W = Width of sidewalk (m)* *C = Area of guideline sidewalk (m2)* $N \begin{cases} =(\text{Extend of street (both sides) - extend of crossroads}) \ 1.8 \text{ if } W < 1.80 \text{ m} \\ = (\text{Extend of a street (both sides) - extend of crossroads}) \ W \text{ if } W \geq 1.80 \text{ m} \end{cases}$ *S = C/N* ***If W is varying in a different segment of street*** *Wi = Width of sidewalk in segment i* *i= 1, 2, 3, …, k (various segments of street with different width of the sidewalk)* *Ci = Area of guideline sidewalk in segment i(m2)* $Ni \begin{cases} = (\text{Extend of a street (in segment i)}) \times 1.8 \text{ if } Wi < 1.80 \text{ m} \\ =(\text{Extend of a street (in segment i)}) \times Wi \text{ if } Wi \geq 1.80 \text{ m} \end{cases}$ *PCi = Ci/Ni* *Li =Extend of street in segment i(m)* $S = \sum_{i=1}^{k} PCi \times Li /$ *(Extend of a street (both sides)-extend of crossroads).*
Slope	*C = Area of footpath with the guideline slope (m2)* $N \begin{cases} = (\text{Extend of street (both sides) - extend of crossroads}) \ 1.8 \text{ if } W < 1.80 \text{ m} \\ = (\text{Extend of a street (both sides) - extend of crossroads}) \ W \text{ if } W \geq 1.80 \text{ m} \end{cases}$ *W = Width of the footpath (m)* *S = C/N* ***If W is varying in a different segment of street*** *Wi = Width of footpath in segment i* *i= 1, 2, 3, …, k (various segments of street with different width of the sidewalk)* *Ci = Area of the footpath with guideline slope in segment i(m2)* $Ni \begin{cases} =(\text{Extend of a street (in segment i)}) \times 1.8 \text{ if } Wi < 1.80 \text{ m} \\ = (\text{Extend of a street (in segment i)}) \times Wi \text{ if } Wi \geq 1.80 \text{ m} \end{cases}$ *DCi= Ci/Ni* *Li = Extend of footpath (in segment i) (m)* $S = \sum_{i=1}^{k} DCi \times Li /$ *(Extend of a street (both sides)-extend of crossroads).*
Lighting	*D = interval of distance between light poles (m)* $C \begin{cases} = (\text{Extend of street with pedestrian lighting – entire extend of crossroads}) \times 9 / D \text{ if } D > 9m \\ = \text{Extend of street with pedestrian lighting – entire extend of crossroads if } D \leq 9m. \end{cases}$ *N = (Extend of street (both sides) –crossroads extend) (m)* *P = C/N* $S \begin{cases} =1 \text{ if } P \geq 1 \\ = P \text{ if } P < 1 \end{cases}$ ***If D is varying in a different segment of street*** $S = \sum_{i=1}^{k} Ci / \sum_{i=1}^{k} Ni$ *i= 1, 2, 3,…k (various segments of street with different Interval of distances between light poles)* $C \begin{cases} = (\text{Extend of street with pedestrian lighting in segment i}) \times 9 / D \text{ if } D > 9m \\ = (\text{Extend of street with pedestrian lighting in segment i}) \text{ if } D \leq 9m. \end{cases}$ *Ni = Extend of street in segment i(m)*

Continued Facilities	Scores
Ramp	*C = Number of guideline ramps* *N = Number of ramps that street requires* $P = C/N$ $S \begin{cases} =1 \text{ if } P \geq 1 \\ = P \text{ if } P<1 \end{cases}$ *1 if the street does not require ramp.*
Park and space for playing	$S \begin{cases} = 1 \text{ If there are a park and space for playing} \\ = 0 \text{ If there is no park and space for playing} \end{cases}$
Social space (café)	*C = Extend of a street with social spaces + their support distance (m)* *N = Extend of a street (in both sides) (m)* $S = C/N$
Bench and seating area	*C = Extend of a street with guideline seating area + their support distance (m)* *N = Extend of a street (in both sides) (m)* $S = C/N$
Toilet	*C = Extend of a street with guideline toilets + their support distance (m)* *N = Extend of a street (m)* $S = C/N$
Pedestrian signal	$SPI \begin{cases} =1 \text{ if } P1 \geq 1 \\ = P1 \quad P1<1 \end{cases}$ $P1 = SP/N$ *SP = Signals with first, second and third quality* *N = Entire number of signals that street requires.* $CPI \begin{cases} =1 \text{ if } P2 \geq 1 \\ = P1 \quad P2 <1 \end{cases}$ $P2 = C/N$ *C = Signals with fourth quality* $WPI \begin{cases} =1 \text{ if } P3 \geq 1 \\ = P1 \quad P3<1 \end{cases}$ $P3 = W/N$ *W = Signals with fifth quality* $AP \begin{cases} I=1 \text{ if } P4 \geq 1 \\ = P4 \text{ if } P4<1 \end{cases}$ $P4 = A/N$ *A = Signals with sixth quality* $S = (SPI + CPI + WPI + API)/4$ *S= 0 If there is no signal*
Shorter crossing distance(curb extension)	$P = C/N$ *C = Number of guidelines curb extensions* *N =Entire number of curb extensions that street requires* $S \begin{cases} =1 \text{ if } P \geq 1 \\ =P \text{ if } P <1 \\ =0 \text{ if there is no point in requiring curb extension and there is no footpath.} \end{cases}$

Appendix C *Improving scores*

We can improve the pedestrians' comfort condition by analyzing the existing variable's qualities with standards (See Table 7 and Appendices A, B). The comfort indicators could achieve the ideal score of 1 by performing current scores.

Example 1 *Developing pedestrian facilities scores at street 1*

1.1 Landscape and trees (current score S=0, improved score S1=0.62 with trees interval distance of 15 m, S2= 1 with trees interval distance of 9 m).

Where:

$$C=\begin{cases}\text{(Extend of a street with trees-entire extend of crossroads and their considered standard restrictions)}\times 9/D & \text{If } D>9\\ \text{(Extend of a street with trees-entire extend of crossroads and their considered standard restrictions) }/D & \text{If } D\leq 9\end{cases}$$

N=Extend of the street (both sides)-entire extend of crossroads and their considered standard restrictions)
F = C – Extend of a street that does not have a clear vertical height
NI = Number of crossroads with considered standard restrictions for trees).
I = Number of the hole crossroads.
P1=C/N
P2 = F/N
P3 = NI/I
S=(P1+P2+P3)/3

***1. D*=15**

C = ((515×2) −72) ×9/15=574.8, N = (515×2) −72=958, $P1$=574.8/958=0.60, F=958−0=958, $P2$=974.8/958=0.60, NI=8, I=12, $P3$=8/12=0.66; so, S_1= (0.60+0.60+0.66)/3=0.62)

2. ***D=9***

We can have the ideal score of 1 *(S_2=1)* of landscape and trees by considering the interval distance between trees 9m instead of 15 m, besides eliminating the standard length at two intersections.

1.2 Benches *and seating area*

C = Extend of a street with guideline seating area + their support distance (m)

N = Extend of a street (in both sides) (m)

S = C/N

1. The minimal required distance between benches (D=200m)

(C= 500+200=700, N= (515×2) =1030, S=700/1030=0.67

2. It is also possible to achieve the ideal score of 1 by considering the benches' furniture along 330m (Which included 200-400 m).

By improving only these two factors scores and maintaining PET scores, the SWTCI (at Street1) increases from 33% (category D) to 42% (category C). That allows a better comfort level.

Example 2 *Developing pedestrian facilities scores at Street 3*

Street 3 recorded the lowest scores. However, developing some pedestrian facilities scores such as landscaping and trees, footpath pavement can enhance the scores and improve the walking experience.

2.1 Width of the footpath (current score S= 0, improved score S1'0.83= with W=1.5 m, S2'= 1 with W=2.4 m or 1.80 m).

Where:

W = Width of sidewalk (m)

C = Area of guideline sidewalk (m2)

N = (Extend of street (both sides) - extend of crossroads) 1.8 if W <1.80 m

= (Extend of a street (both sides) - extend of crossroads) W if W ≥ 1.80 m

S = C/N

1. W=1.50

C= (299.68-5) ×1.50, N= (299.68-5) ×1.80, S=C/N,S2'=442.02/530.42=0.83

2. W=2.40 m or 1.80m

C= (299.68-5) ×2.40, N= (299.68-5) ×2.40, S=C/N,S2’=707.23/707.23=1.

Combining footpath pavement and width of the footpath could be an excellent choice for enhancing the pedestrian comfort facilities scores. In this case, it is easy to enhance the footpath pavement because it is not existing. So it is possible to reach the score (1) directly.

Where

W = Width of footpath (m)
C = Area of standard pavement (m2)

$$N \begin{cases} = \text{(Extend of street (both sides) - extend of crossroads) } 1.8 \text{ if } W < 1.80\text{ m} \\ = \text{(Extend of a street (both sides) - extend of crossroads) } W \text{ if } W \geq 1.80\text{ m} \end{cases}$$

S = C/N

1. W=2.40 m or 1.80m

C= (299.68-5) ×2.40, N= (299.68-5) ×2.40, S=C/N,S2’=707.23/707.23=1.

However, proposing a specific type of footpath pavement material such as tiles with a lighter is an interesting alternative to enhance thermal comfort.

2.2 Lighting (Current score S= 0, improved score S1’’=0.64 with D =14 m, S2’’= 1 with D =9 m).

Where:

D = interval of distance between light poles (m)

$$C \begin{cases} = \text{(Extend of street with pedestrian lighting – entire extend of crossroads)} \times 9 / D \text{ if } D > 9\text{m} \\ = \text{(Extend of street with pedestrian lighting – entire extend of crossroads) if } D \leq 9\text{m.} \end{cases}$$

N = (Extend of street (both sides) –crossroads extend) (m)

P = C/N

$$S \begin{cases} =1 \text{ if } P \geq 1 \\ = P \text{ if } P < 1 \end{cases}$$

1. D=14 m

***C*= (**299.68-5×9)/14, N= (299.68-5), P=C/N, P=0.63*

2. D=9

***C*= (**299.68-5×9)/9, N= (299.68-5), P=C/N, P=1*

***Appendix D** Questionnaire survey*

***PART B** General Importance*

Please rank the importance of the following walking indicators by selecting one number from 1 to 5 (1 not very important, 5 very important**)**

Indictors	1	2	3	4	5
Slower traffic speed					
Buffer and barriers (curb and furnishing zone)					
Fewer raffic lane					
Shorter crossing distance(curb extension)					
Mid-block crossing					
Social space (café)					
Landscape and trees					
Furniture and facilities (trash receptacle)					
Footpath pavement					
Marking (crosswalk)					
Sidewalk on bothsides					
Width of footpath					
Standard driveway					
Lighting					
Slope					
Ramp					
toilet					
grad					
Pedestrian signal					
Bench and seating area					
Park and space for playing					
Shade/ Thermal comfort					