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Simulation for Pedestrians' Thermal Comfort in Commercial Streets in Mosul-Iraq (According to Iraqi commercial building regulations)

Turki Hasan Ali[1], Ali Haider Saad Ali [2]
[1]Dpt. of Architecture Engineering, College of Engineering, Nawroz University, Duhok, Iraq
[2]Dpt. of Architecture Engineering, College of Engineering, Nawroz University, Iraq
* Corresponding author: College of Engineering, Nawroz University, Duhok, Iraq. Tel: +9647701698904.
Turki.Ali@nawroz.edu.krd; ali.saadali@nawroz.edu.krd

ABSTRACT

The shopping activity has occupied great importance within the urban activities, which have social and economic revenues for a high number of urban inhabitants. Commercial activities witnessed widespread in Mosul city, many streets changed their land use to commercial ones, reaching 11 Km in length in 2007, which formed in accordance with the applicable old and imported building regulations in Iraq. These regulations don't take into account the specificity of our hot, dry climate, which causes uncomfortable urban spaces for pedestrians and forces the building owners to roof their building facades with sheds. Studying urban micro-climate is important because of the high number of involved users. This paper aims to assess the thermal comfort of pedestrians in typical commercial streets in the city and study to what extent the proposed urban design solution will improve the thermal condition. The study will be performed with the numerical model ENVI-met, in which the influence of different street sections will be simulated. The results of this study give legislators the evidence to review building regulations in Iraq generally, and Mosul in particular, to meet the requirements of urban sustainability.

KEYWORDS: Urban design, Thermal comfort, physiologically equivalent temperature; ENVI-met

1 INTRODUCTION

Living in the era of sustainability, urban design research has taken very serious concern over human thermal comfort. However, there are many aspects of the built environment considered as factors influencing outdoor thermal comfort; this paper focuses on the role of commercial street geometry, which is a result of building regulation, in human thermal comfort. The relationship between urban geometry and thermal comfort is by far less well understood, and the number of studies in Iraqi cities is very few. Commercial activities witnessed widespread in Mosul city, many streets changed their land use to commercial ones, reaching 11 Km in length in 2007; most of them are collectors or arterial road types with a 30 meters' width or more, and some of them are built according to the old building regulation and others built to the newer version of regulations. The study aims to compare the outdoor thermal comfort of pedestrian users in different cases of commercial streets (existing and proposed) in Mosul city to bring out possible solutions to enable the urban planners, designers, developers and regulation authorities to work out strategies to enhance the urban microclimate and provide a comfortable environment for pedestrians to achieve sustainability in this respect.

2 THERMAL COMFORT IN COMMERCIAL STREETS

Commercial streets are dynamic outdoor environments that can be challenging to achieve thermal comfort. The strategies to improve thermal comfort in commercial streets can vary from providing shade and greenery, designing for airflow, reducing heat sources, providing water features, encouraging outdoor activities during cooler hours, and educating people.

One study by Ibrahim and others (Ibrahim et al., 2021) investigated the effect of shade on thermal comfort in urban streets. The study found that the use of shade structures could improve thermal comfort by reducing the ambient temperature and radiation levels. Another study by Lin and others (Lin et al., 2021) explored the impact of urban greening on thermal comfort in sidewalks within varied urban road structures. The study found that the incorporation of greenery, such as trees and grass, in commercial streets could reduce the air temperature and increase the relative humidity, improving thermal comfort. Additionally, a study by Qureshi (Qureshi,2022) investigated the effectiveness of water misting systems in improving thermal comfort in commercial streets. The study found that the use of water misting systems could reduce the air temperature by up to 5°C, improving thermal comfort for pedestrians.

These studies highlight the importance of incorporating various strategies to improve thermal comfort in commercial streets. By providing shade, greenery, and water features and designing for airflow, commercial streets can become more comfortable and inviting for pedestrians, improving their overall experience.

3 MEASURING HUMAN THERMAL COMFORT

The current research intends to use an index of comfort for calibrating outdoor thermal comfort; this is PET (Physiological Equivalent Temperature). It can be calculated by using the Software ENVI-met V4.0 BASIC version, which is made freely available by its author; this model is capable of modelling outdoor thermal environments for different climate patterns with acceptable accuracy. The values of PET enable the understanding of the influence of street urban design factors like (different setbacks, cantilevers and galleries, and vegetation) on the outdoor thermal comfort of the pedestrians. In order to exclude the role of other factors like different orientations, wind directions and material finishes, all cases were given the same values; hence, this enables exploring which urban design solution has the better performance and so to modify the existing building regulations for achieving a better outdoor thermal comfort conditions for the pedestrian users. Thermal comfort is a highly abstract idea that is easily defined. This is due to the requirement to consider a variety of environmental and individual factors. The International Standard ISO 7730 describes human thermal comfort as "that condition of mind in which satisfaction is expressed with the thermal environment" (Liu, 2008). The International Standard ISO 7730 describes human thermal comfort as "that condition of mind in which satisfaction is expressed with the thermal environment" (Liu, 2008). Six environmental and individual factors influence thermal comfort. Despite their potential independence from one another, these elements work together to support human thermal comfort.

- Environmental variables (Temperature, n.d.): Humidity, Radiant Temperature, Air Temperature, and Air Velocity.
- Personal aspects Insulation and metabolic heat in clothing

The comfort assessment techniques used outdoors have been modified from those intended for indoor use. Numerous thermal indexes fall into one of two categories: empirical or rational. The earlier-developed first group, which includes Höppe (1999) and Höppe (2002), is based on measurements with subjects or on simplified relationships that don't always correspond to theory. The most recent rational indices, supported by the current advancement of computing methods, are based on the energy balance of the human body. For instance, Physiological Equivalent Temperature (PET), Index of Thermal Stress (ITS), Heat Stress Index (HIS), Predicted Mean Vote Perceived Temperature (PMV), etc. (Ali, 2005). The (PET) index is used in this study to quantify thermal comfort.

3.1 Physiological Equivalent Temperature (PET) Index

An index that evaluates the climatic variables Mean Radiant Temperature (Tmrt), Air Temperature (Ta), Wind Speed (v), and Vapor Pressure (VP) to represent the thermal state of a person. It is "the air temperature at which the heat budget of the human body is balanced with the same core and skin temperatures as under complex outdoor conditions being assessed" in a typical indoor environment (without wind and solar radiation). (2012) and (Mohan et al. (2013), respectively.

3.2 Relevance of (PET) Index

For the assessment of urban thermal perceptions, it is necessary to utilize particular criteria for the accurate measurement of physiological equivalent temperature (PET). There are alternative indices, of course, but the PET index is more suited due to its wide distribution, adaptation to outdoor settings (Ali, 2016), and use of the (oC) unit as a measure of thermal comfort, which makes the results understandable for potential consumers. PET is based on the thermal balance of a person, which includes all heat exchange processes that take place between the human body and its surroundings (Kenawy & Mahmoud 2010). It is "defined as the air temperature at which the human energy budget for the simulated indoor conditions is balanced by the same skin temperature and sweat rate as under the simulated complex outdoor conditions to be evaluated." Mean radiant temperature, air temperature, wind speed, and vapor pressure are the meteorological input parameters. PET also takes internal heat production and clothing's ability to withstand heat transmission into account.

4 METHODS AND DATA

4.1 Study Area

Mosul city is located at (36°20′06″ N; 43°07′08″ E). This falls under semi hot, dry climate with a distinct cold rainy winter and hot-dry summer. The hot season in Mosul usually falls in August (average highest value = 43° C), and the hottest day recorded was (51° C) at July, Fig (1) shows that more than half of the year is a hotly climate, so the paper adopts the urban design for this kind of climate.

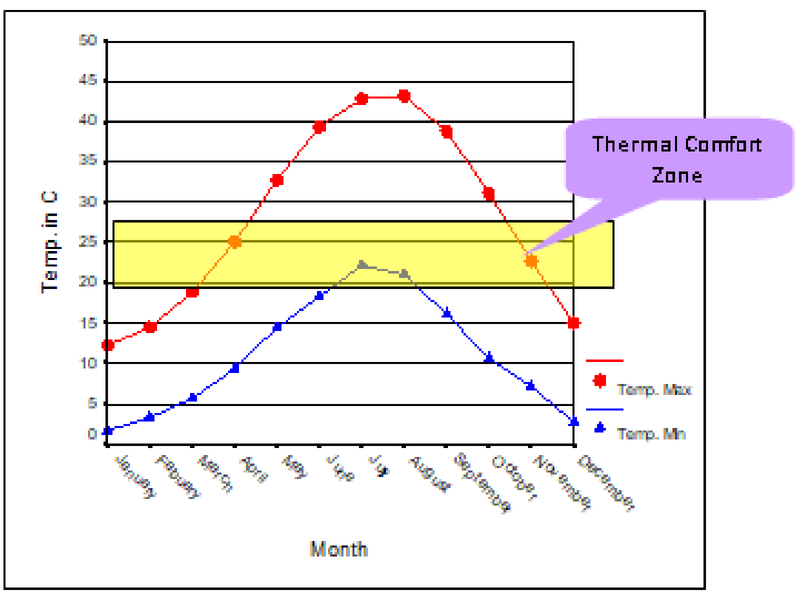

Figure 1: Average Daily Min. and Max. Temperatures in Mosul City

4.2 Commercial Building Regulations in Mosul City

In Mosul one of the Iraqi cities, two main regulations systems played the main role in determining their urban geometry. The first is the Roads and Buildings Regulation Act No. 44, 1935, and its amendments, and the second is the Municipal Administration Act No. 165 of 1964 amended; according to these two acts building regulations are determined at each city by the municipal authority. The application of those regulations varied through time and place as some of the buildings overlooking streets have been built according to the old building regulations while others have been built according to the newer version of regulations. Accordingly, three groups of streets can be recognized within the streets of all Iraqi cities generally and within Mosul City in specific. To achieve its objectives, the current research intends to study and analyze eight types or cases of streets; three cases represent the existing commercial typologies which were resulted from the application of the enforced regulations. The first case represents streets that have been formed according to the older regulations, which are mainly recognized by buildings without any setbacks with one-meter balconies. The second case represents streets of the buildings implemented according to the amended version of the first old regulations. This case is characterized geometrically by a (5.0 meters) cantilever covering the sidewalk of the street. The third case represents the last and new version of these regulations, which impose a (5.0 meters) setback of the buildings from the sidewalk of the main street and a (3.0 meters) for the side road with a cantilever covering half of these setbacks. For better results and as a part of the contribution to solving the problem of thermal comfort in commercial streets, this paper introduces five additional proposed cases (hypothetical cases) that represent urban solutions based on combinations of three strategies. The first one adopts street section geometrical parameters transformations, which may reflect different conceptualizations of the building regulations. The second strategy adopts green surfaces and planting trees, while the last strategy is a mixture of the other two strategies. Fig 2. & Table 1.

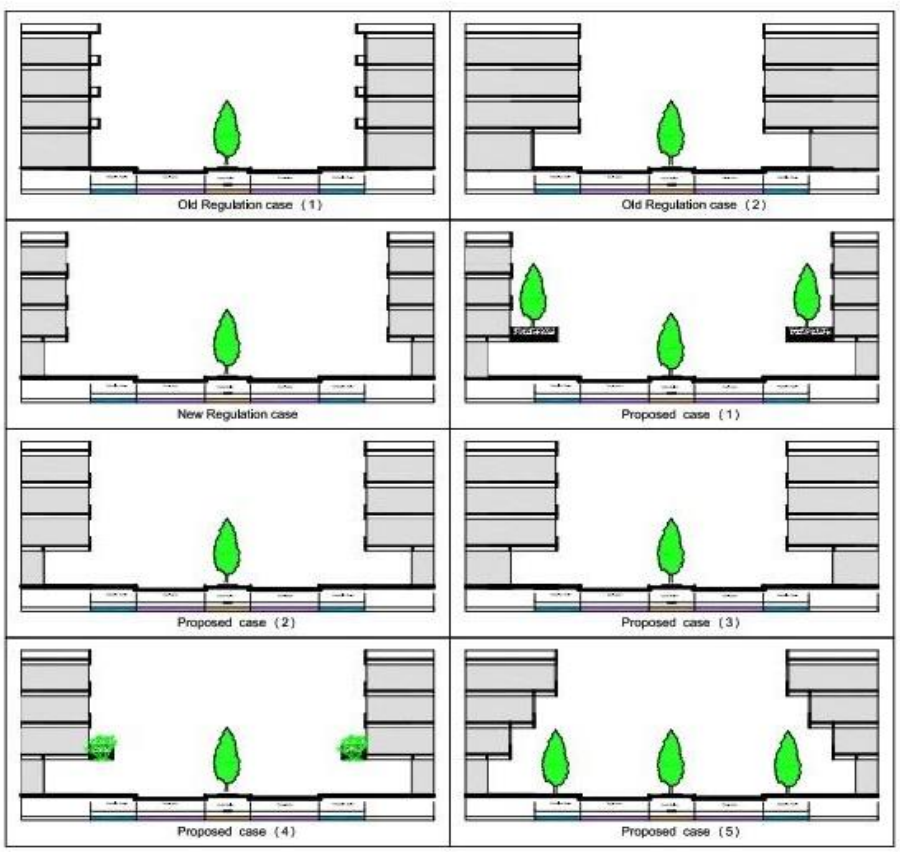

Figure 2: Street Cross Sections of the Eight Cases Under Study

Table 1. Study Cases descriptions

Study Cases	Descriptions
Case (1)/ Old Regulations (Version 1)	No setback and only one meter cantilevered for the upper levels above the Pedestrian walkway.
Case (2)/ Old Regulations (Version 2)	No setback and cantilever for the upper levels cover totally the Pedestrian walkway.
Case (3)/ New Regulation Case	Five meters setback at ground level, then half of the setback at the upper levels are cantilevered.
Case (4)/ Proposed Hypothetical Case	Five meters setback at ground level, then the setback at the upper levels is cantilevered half setback + five meters green roof (the setback and half of the pedestrian walkway are covered).
Case (5)/ Proposed Hypothetical Case	Five meters' setback at ground level, then all the setback is cantilevered at the upper levels. (The pedestrian walkway isn't covered)
Case (6)/ Proposed Hypothetical Case	Two meters and a half setback at ground level and double the setback are cantilevered at the upper levels. (Only half of the pedestrian walkway is covered)
Case (7)/ Proposed Hypothetical Case	Five meters setback at ground level and all the setbacks are cantilevered at the upper levels, plus a green roof cover half of the Pedestrian walkway.
Case (8)/ Proposed Hypothetical Case	Five meters of setback at ground level and half of the setback at the 1st level are cantilevered, another half of the setback is cantilevered at the 2nd level, and finally, half of the setback is cantilevered at the 3rd level.

To understand the influence of building regulations, which determine the street geometry, on the outdoor thermal comfort of pedestrian users in Mosul commercial streets, the eight cases mentioned above were modelled and analyzed in terms of their thermal performance. The microclimate model ENVI-met (V4) was used for predicting the effects of these different street geometry parameters on urban microclimate. Then, the post-processing Biomet tool was used to calculate PET (Physiological Equivalent Temperature) Index, which was used as an indicator of the thermal comfort of pedestrians for each case. Simulations were carried up on (the 25th of July) as the hottest day of the year. This procedure was repeated for four different periods (9.00 am, 12.00 am, 15.00 pm, 18.00 pm).

The process was carried up through the following steps:

- To conduct the simulation, the studied cases had been defined with their 2D and 3D conditions by several input data sets which represent the different street geometries, building materials, street width and materials and planting; therefore, a virtual 3D model is introduced in each case. (Fig 3)
- All the cases have the same configuration file, which includes the climatic data; Air Temperature, Relative Humidity, Wind Speed, Mosul's Geographic Location and Orientation were 'forced' in the simulation (data taken from a world weather online web site) Table 2. Parameters such as; different orientations, wind directions and material finishes were excluded.

The comfort simulations PET index was calculated using the Bio-Met tool, a post-processor tool for computing human thermal comfort indices from ENVI-met model output files. The inputs needed for the simulations—air temperature, radiant temperature, surface temperature, wind velocity, etc.—are collected from the output files, while individual parameters like attire, age, and so on are taken by default from the software.

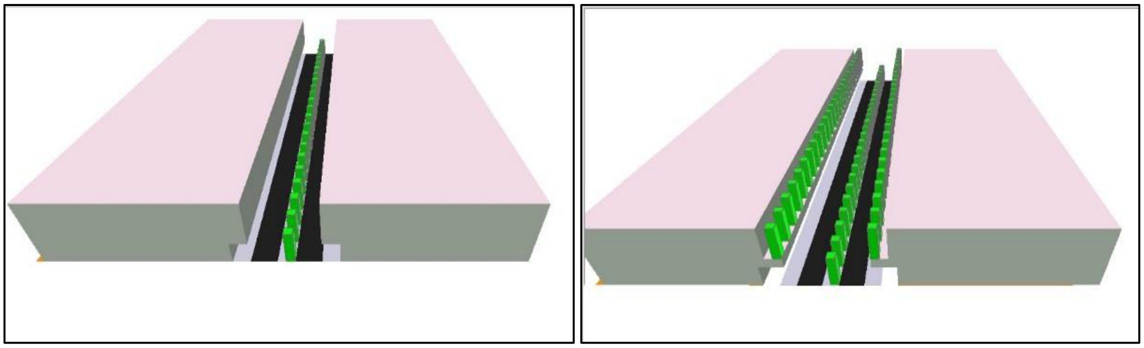

Figure 3. Examples of 3D Models of the Eight Cases under Study

Table 2. Mosul City Meteorological Data (25th Jul), (AccuWeather. (n.d.-b)

Time	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00
Temp-F	86.9	81.8	86.9	101	108.7	108.4	98	91.1
Rain	0.0 mm							
Cloud	0%	0%	0%	0%	0%	0%	0%	0%
Wind	8 mph	7 mph	7 mph	7 mph	8 mph	12 mph	8 mph	8 mph
Direction –Degree	280	300	300	270	260	250	240	250
R.H. %	18	27	24	14	8	7	11	15
Pressure-MB	973.8	973.6	974.1	973.3	971.8	969.7	969.6	970

5 RESULTS AND DISCUSSION

This part is dedicated to presenting the results of the analysis of the eight cases under study: Review Table 3 & Fig 4

- The analysis showed that all the study cases were located above the upper limit of thermal discomfort standardly defined, as the bit index for all of them was higher than 30°C during the daytime period between 07:00 am– 17:00.
- The analysis showed that there is a recurring pattern in the behavior of the values of the PET index during daylight hours for all the studied cases. The similarity of the curves of the corresponding cases Fig 5 indicates this. In this pattern, the values of the PET index start low at 9:00 am in all cases and increase upward until they reach a maximum at 15:00, then decline rapidly and with a greater tendency at 18:00. This is because all cases are affected by the increased amount of solar radiation in the middle of the day and the afternoon.
- Although the curves of the PET indices maintained a similar pattern in terms of their shapes, the analysis highlighted the variation in their locations on the chart. This indicates the variation of the study cases in the values of the PET index for each of them.
- The second case, which represents the group of streets with buildings applying the amended old regulations, had the highest closeness to the standard thermal comfort zone, although it was still above the standard thermal comfort range. In this case, the value of the PET index starts from 32.98 ℃ at 9:00 in the morning and reaches the maximum value of the index by 48.6 ℃ at 15:00, to decrease to 34.33 ℃ at 18:00.

- The third case, which represents a group of streets with buildings applying the new version of regulations, recorded the maximum distance from the thermal comfort zone, as it is the highest in terms of feeling thermal discomfort. This state starts with a PET index value of 41.69 °C at 9:00 AM, rises to 56.79 °C at 15:00, and then drops to 40.59 °C at 18:00.
- The first case, which represents a group of streets applying the old regulations before the amendment, ranked fourth in terms of its proximity to the thermal comfort zone, as the PET index value starts from 38.01 ℃ 9:00 am and rises to 52.61 ℃ at 15:00, then It drops to 38.81 ℃ at 18:00.
- The fourth and seventh cases, respectively, came in the second and third rank in terms of how close they were to the standard range of thermal comfort. For the fourth case, the value of the bit index starts from 35.62 ℃ at 9:00 in the morning, rises to 49.11 ℃ at 15:00, and then drops to 36.89 ℃ at 18:00. As for the seventh case, the PET index values start from 36.16 ℃ at 7:00 in the morning, rise to 52.60 ℃ at 15:00, and then drop to 37.60 ℃ at 18:00.
- As for the first case, which represents streets with buildings applying the old regulations before the amendment, it ranks fourth in terms of its distance from the thermal comfort range, as the index values start from 38.01 ℃ at 9:00 in the morning and rise to 52.61 ℃ at 15:00 to decrease to 38.81 ℃ at 18:00.
- Finally, the third, fifth, and second cases, which are hypothetical proposals, respectively occupied the last ranks in terms of their degree of proximity to the standard range of thermal comfort, meaning that they occupied the first ranks in terms of levels of thermal discomfort.

Table 3. Equivalent Average PET (℃) During Day Time & The Cases Ranking

Study Cases / Average PET (C°)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
	Old Regulation (1)	Old Regulation (2)	New Regulation Case	Proposed/ Hypothetical	Proposed/ Hypothetical	Proposed/ Hypothetical	Proposed/ Hypothetical	Proposed/ Hypothetical
9 O'clock	38.01	32.98	41.69	35.62	38.72	38.53	36.16	38.56
Ranking	4	1	8	2	7	5	3	6
12 O'clock	42.97	40.40	47.57	41.22	46.62	43.55	41.64	43.72
Ranking	4	1	8	2	7	5	3	6
15 O'clock	52.61	48.62	56.79	49.11	55.25	52.77	52.60	53.67
Ranking	4	1	8	2	7	5	3	6
18 O'clock	38.81	34.33	40.59	36.88	40.00	39.01	37.50	40.00
Ranking	4	1	8	2	7	5	3	6
Total Ranking	4	1	8	2	7	5	3	6

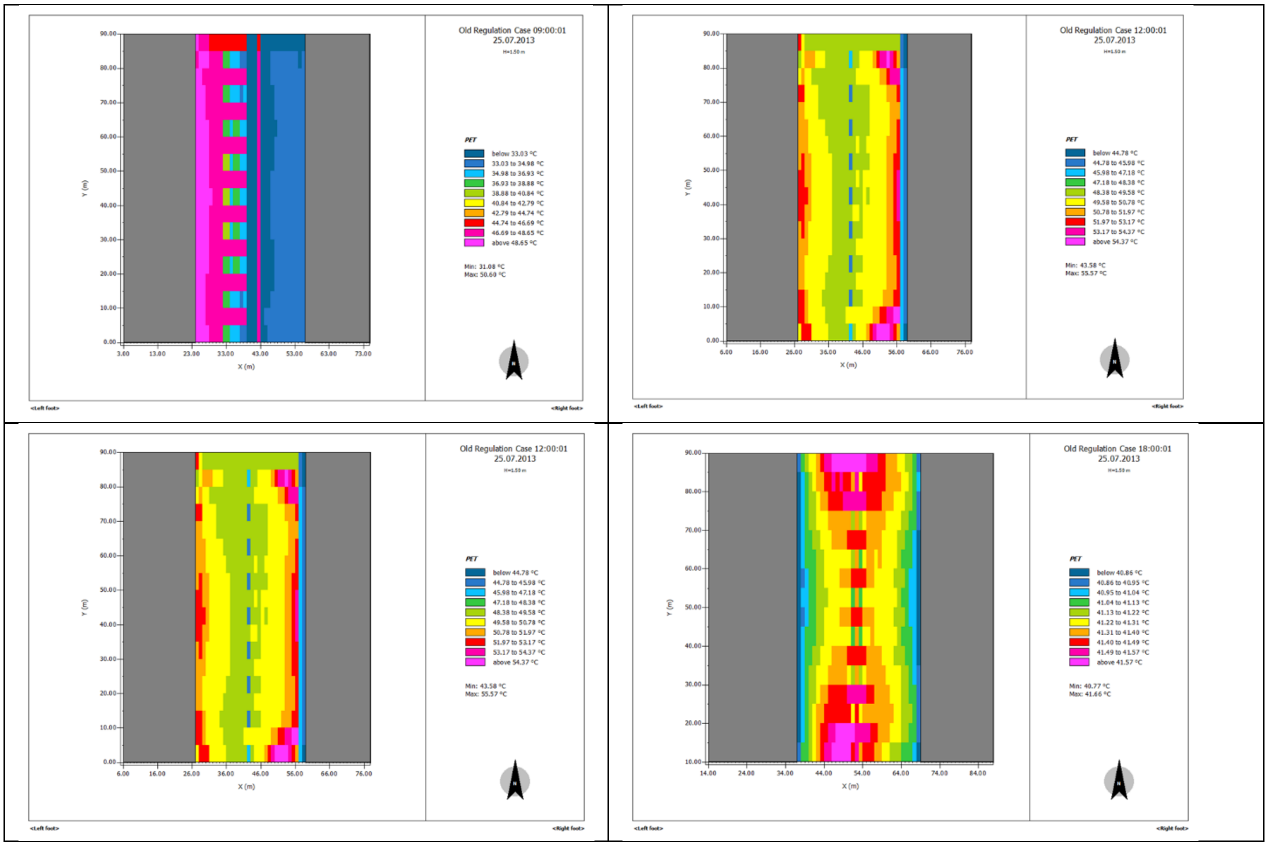

Figure 4. Examples of PET Index Heat Maps of Some Cases under Study

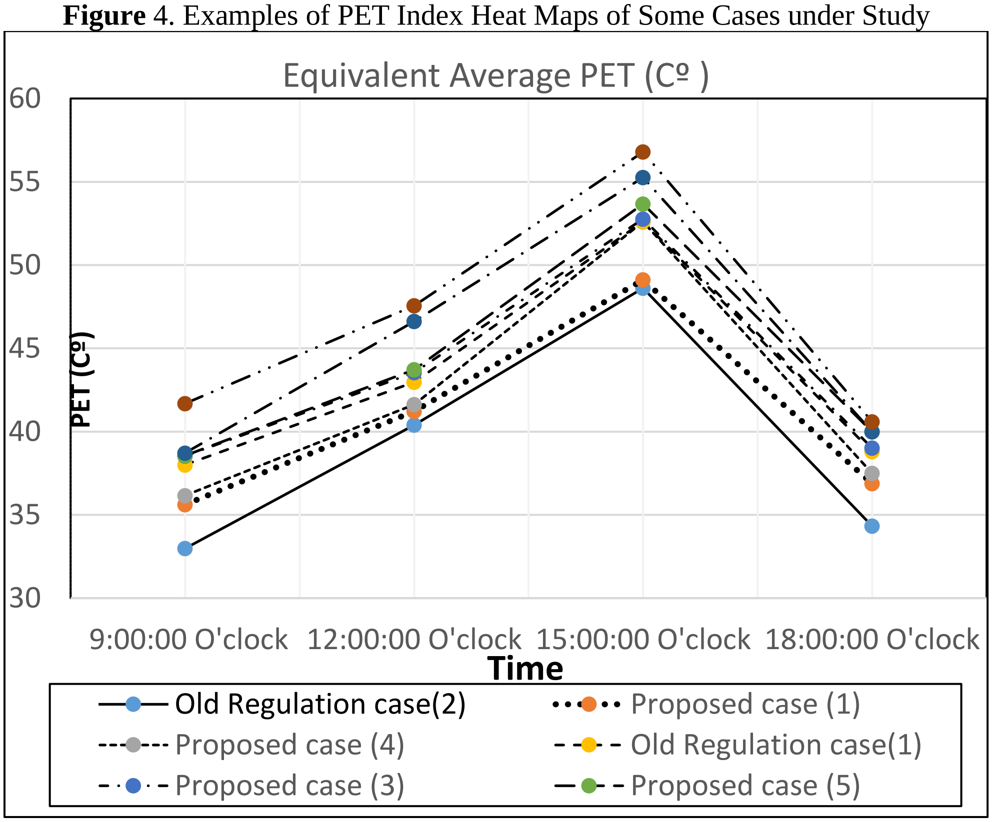

Figure 5. Average PET Indices of the Eight Cases Under Study

6 CONCLUSIONS AND RECOMMENDATIONS

The study clarified the effects that urban design parameters may have on people's thermal comfort in the urban environment.

The results of the analysis showed that the streets without setbacks from the plot front border and the upper floor projection over the entire width of the pedestrian sidewalk are the nearest for achieving thermal comfort. The streets with a 5:00m from the plot front with the upper floors projection by half the setback were the farthest from achieving thermal comfort, and thus, they are considered the worst streets in terms of thermal comfort.

Accordingly, it was clear from reading the results that the streets with buildings applied to the old amended regulations (i.e., based on the Roads and Buildings Regulation No. 44 of 1935) are relatively the most thermally comfortable for pedestrians. On the other hand, the streets with buildings applying the new regulations are the farthest from achieving thermal comfort, meaning that they are the worst places in terms of thermal comfort.

The proposed hypothetical cases provided useful explanations about the effect of the parameters specified in the current research on the feeling of thermal comfort, both positively and negatively. Achieving a five-meter setback on the ground floor and then covering half or all of the setback in addition to covering half of the pedestrian walkway (as implied in case four, case seven, and case six to some extent, respectively) had a positive effect on the feeling of thermal comfort.

On the other hand, partial or complete coverage of the setback on the ground floor had no positive effect, even negative effect, on the feeling of thermal comfort unless the pedestrian walkway was covered (implied in the fifth case)

The geometrical characteristics implied in proposing a multi-story inverted graded section after achieving a five-meter setback in the ground floor, even though the final protrusion of the last floor covering half the width of the pedestrian walkway (implied in the eighth case), were not sufficient to achieve better thermal performance. It was clear from the results that the reversed graded section towards the street, although it reduces the sky view factor, does not achieve the desired goal, and this may be due to the fact that the coverage of the pedestrian corridor was at a higher level than the first floor.

Based on the conclusions mentioned above, the research recommends the following:

- Reconsidering the new building regulations for commercial streets due to their negative impact on pedestrians' sense of thermal comfort.
- Refer to the application of the amended version of old regulations due to their positive impact on pedestrians' sense of thermal comfort.
- Or the development of those controls by the provision of significant parameters that have been studied in the current research This may be realized via achieving the integration of the geometric characteristics of the second and fourth study cases so that:
  - The projections shall be of such dimensions as to cover the entire pedestrian walkway
  - The projections are as low as possible (first or mezzanine floors)
  - In addition to providing green areas and masses that make the projections more effective in thermal comfort in a positive direction.
  - Using a water misting system at the ceiling of the projections instead of setting back regulations.

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