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A Systematic Approach to Achieve Thermal Comfort in Residential Urban Clusters Through Sustainable Urbanization

Marwa Mohamed abbas [1, a, *], **Ahmed Nour Eldin** [2, b]

[1] Architecture Department, Modern Academy for Engineering & Technology, Cairo, Egypt
[2] Architecture Department, Modern Academy for Engineering & Technology, Cairo, Egypt
E-mail: [a, *] miroda2020@gmail.com (Corresponding author),
[b] dr.ahmed.nour020@gmail.com

Abstract

The research has studied the relationship between the quality of thermal comfort in the outdoor spaces of the residential urban clusters on the quality of thermal comfort in the indoor spaces in order to provide a proposed approach for the designs of the outdoor spaces that work to raise the thermal comfort efficiency of the indoor spaces overlooking them, by studying the extent of the impact of these design variables on the thermal comfort in the outdoor urban space , by measuring the predictive average value of PMV as an indicator of outdoor thermal comfort, that is by using the results of previous studies to measure the thermal comfort of the external spaces of buildings through the inputs of climatic determinants and urban variables such as the geometric shape and orientation of the building block with the fixation of the other influential urban factors, by conducting a simulation using ENVI- MET for the outdoor spaces of the commonly designed residential urban clusters in the New Cairo area, and measuring the value of PMV as an indicator of the thermal comfort value of the indoor spaces, using DESIGN BUILDER for the indoor spaces, then comparing the results of the thermal comfort.

Keywords: Thermal Comfort, Urban Sustainability, Passive Techniques, Residential Urban Clusters, Predictive Main Vote (P.M.V).

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1. Introduction

The indoor spaces of residential buildings are places where people go to get rid of the trouble of hard work throughout the day. Thermal comfort is considered one of the most important factors for people to feel comfortable. Global warming is afflicting humanity with its serious core damages, Therefore, architectural designers adopted environmentally friendly green architecture methods that provide appropriate thermal comfort for humans through the development of urban designs for the outdoor and indoor spaces of buildings, which helps to reduce the use of industrial air conditioners and reduce heat emissions. [1]

The designs of the outdoor spaces of the residential urban clusters play a key role in determining the value of the thermal comfort of these outdoor spaces.

This prompted the researchers in this paper to develop a proposed methodology for the relationship between the value of PMV for outdoor spaces and its value for indoor spaces. That is through selecting five models from the common designs of residential urban clusters in New Cairo [2], and using the results of previous studies to determine the value of the PMV for each of them, then selecting only two samples, which are "the best residential group of Where PMV and the residential group is the lowest so that the differences are clear during the study of comparing the results of PMV measurements at two points specified in the outdoor space of the two selected samples with their results at three points specified in the “indoor space of the residential buildings overlooking those spaces, That is through by using specialized computer programs (ENVI-MET and DESIGN BUILDER) through

which these measurements are simulated to obtain results that help to propose a methodology to raise the thermal comfort efficiency of the indoor spaces. [3]

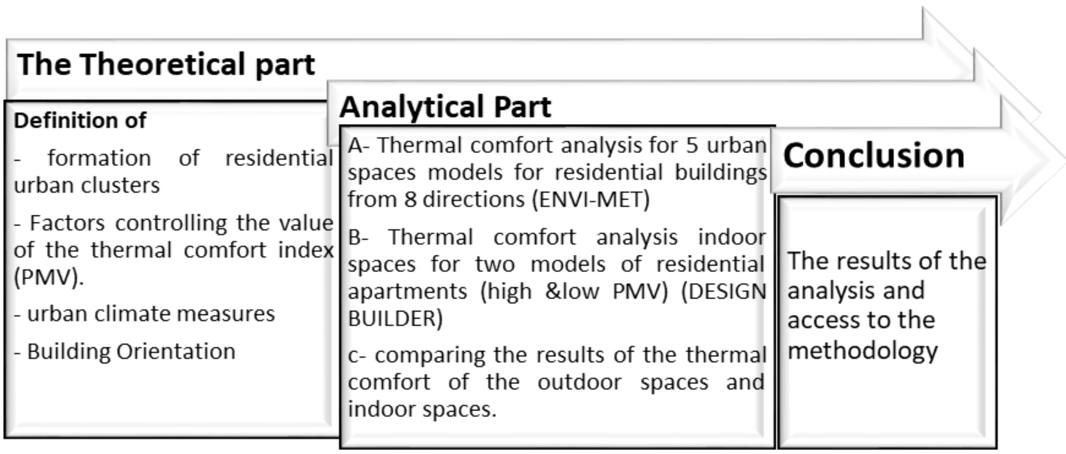


Fig. 1 showing the methodology of the structure of the research steps, (Researchers)

2. Methodology

The study followed the descriptive analytical approach, followed by using simulation programs to compare the results and develop a proposed methodology to raise the thermal comfort efficiency of the interior spaces of residential buildings, And that through two parts:

The Theoretical Part: A study of "components of residential urban clusters - thermal comfort PMV - urban climate scale - orientation of blocks - the necessary data to simulate the thermal comfort of outdoor spaces with indoor spaces**.** [4]

The Analytical Part: A study of the thermal comfort measurements of the outdoor spaces as well as the indoor spaces overlooking them for 5 buildings in the New Cairo area are from the commonly used forms from eight directions, recording the measurements and simulating them using specialized computer programs, to determine the best shapes and directions that provide the best thermal comfort for the indoor spaces.

3. The Theoretical Part

3.1. Style Formation of Residential Spaces

The residential urban space consists of two configurations, the first is building facilities with indoor spaces designed to provide basic needs for human comfort, **and** the second configuration is the space surrounding the facilities and is called the outdoor spaces. The residential environment, which is a key factor in the formation of outdoor spaces. [5]

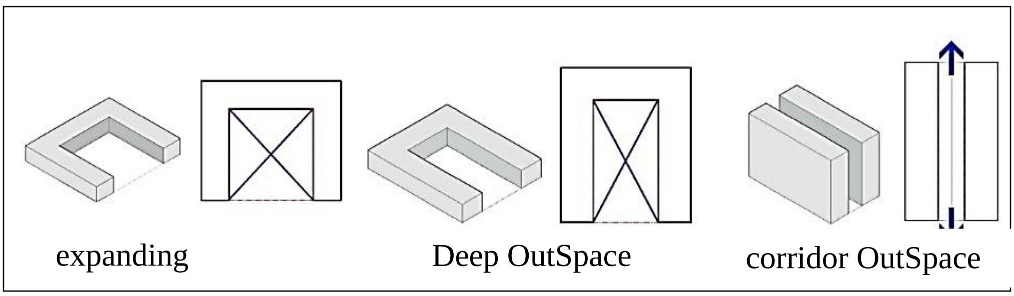


Fig. 2 showing the Urban types in ratios of proportions, Source: (Authors)

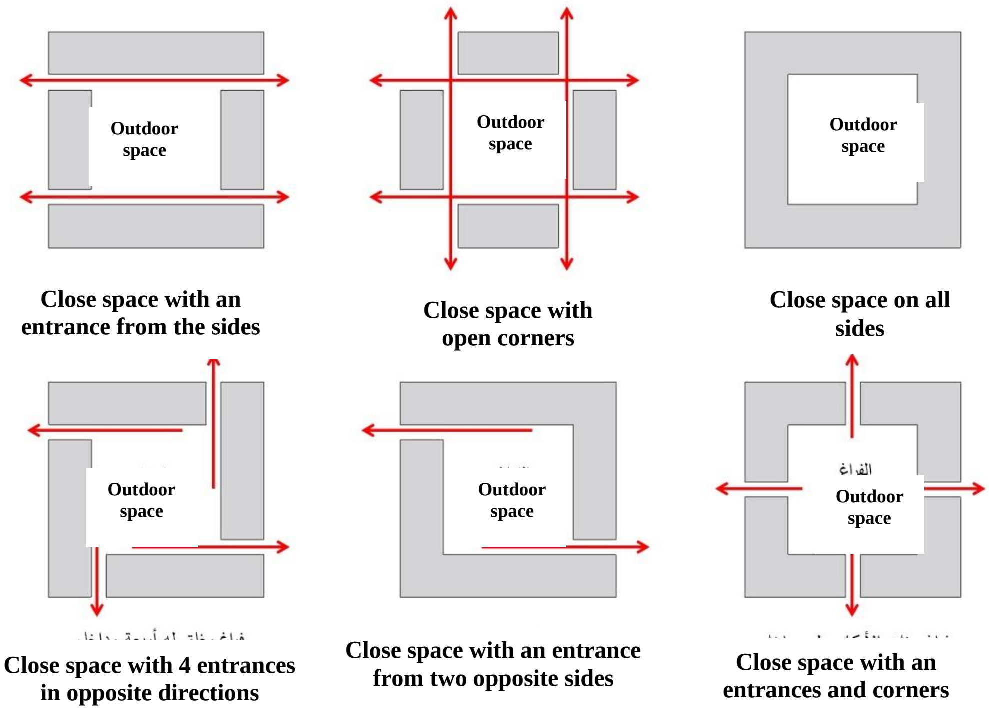


Fig.3 Types of closed urban spaces for residential buildings, source: (Authors)

3.2. Factors controlling the value of the thermal comfort index (PMV).

The expected PMV value depends on the influencing factors "temperature - wind speed". Indoor thermal comfort can be calculated by feeding that data to the ENVI-MET simulation program, which solves the equation. [6], [7]

Equ.1 PMV=[0.028+0.303·exp(−0.036·M/ADu)] (H/ADu−Ed−Esw−Ere−L−R−C)

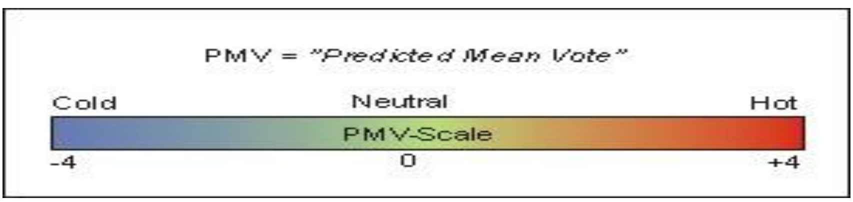


Fig. 4 PMV predictive rating scale,
Source:http://www.envimet.info/doku.php?id=apps:biometpmv

3.3. Urban Climate Measures

Scientists classified the urban climate in terms of the size of the scale into three scales, as shown in **Fig. 5**

A- The meso-climate: This scale is the urban scale (10 km).

B- The local climate: This scale is the neighborhood scale (100m-10km).

D- Microclimate: This scale is the scale of residential buildings and urban spaces (street canyon) (200m-300m). [9]

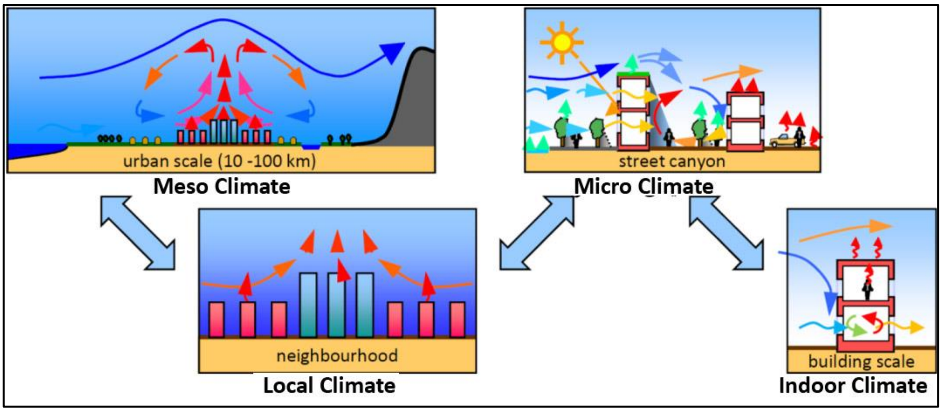


Fig.5 The different measures of the urban climate, Source: Viktor Dorer,Urban Climate & Energy Demand in Buildings, Empa, Building Science and Technology Laboratory.

3.4. The effect of orienting the architectural block on the thermal comfort of the outer urban space

The architectural building is the urban fabric that is classified according to the method of assembling it into "separate - semi-detached - connected blocks", and the blocks differ in their characteristics in terms of size, formation, orientation, and their compatibility with the climate. [11]

Building Orientation: The best value of thermal comfort for the outgoing void can be obtained by orienting the buildings in proportion to the movement of the sun and the direction of the wind Northeast or southwest, it was found that the northern facades get the least amount of solar radiation throughout the year, and the southern facades get the least amount of it in summer, when the sun is almost vertical, while they get the highest solar radiation in winter, as the angle of its elevation above the horizon is small, [12] shown in **Fig. 6**

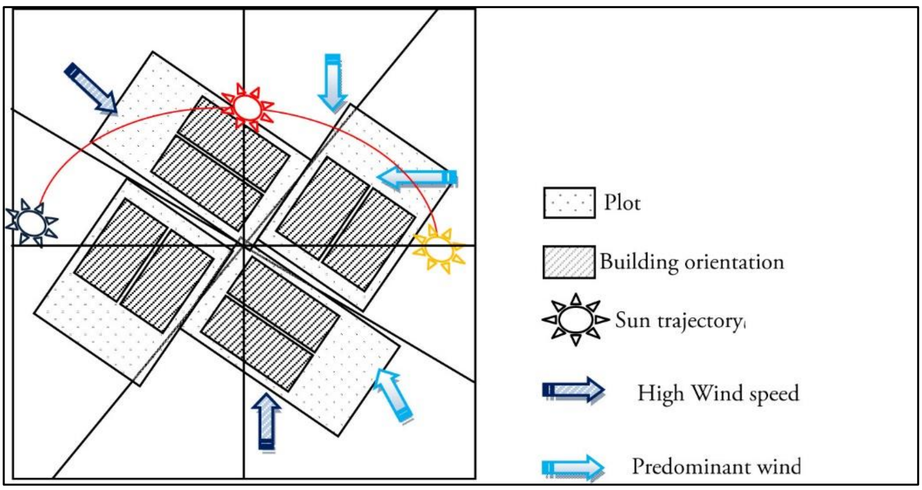


Fig.6 The orientation of the buildings, the path of the sun, the direction of the prevailing winds and the direction of the high wind speed, Source: Marcelino Januário Rodriguês, Influence of Solar Shading and Orientation on Indoor Climate, Faculty of Engineering, Department of Construction Sciences, Lund University, Published in 2010

4. The Analytical Part: Data used in simulating the thermal comfort of the outdoor and indoor spaces of Residential Urban Clusters:

The analytical part aims to study of the effect of the quality of thermal comfort in the outdoor spaces of the residential urban clusters "on the quality of thermal comfort in the indoor spaces, as well as studying the extent of the impact of these design variables on the thermal comfort in the outdoor urban space, by measuring the value of the average predictive vote (PMV) as an indicator of outdoor thermal comfort through inputs Climate determinants and urban variables, such as the geometric shape and orientation of the building block, with fixing the rest of the other influential urban factors.

In order to achieve this goal, a simulated model of the urban and residential architectural space is created in its physical nature (dimensions, building materials and floors), using computer programs, ENVI – MET SPACES and DESIGN BUILDER programs, through three steps:

4.1. The First Axis: Envi -Met spaces Analysis:

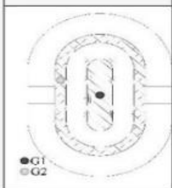
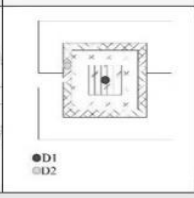
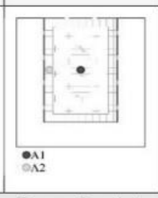
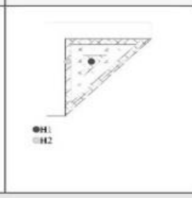
Selecting five residential urban clusters of common different shapes designed in the New Cairo area, and evaluating the quality of thermal comfort for its outdoor space by recording thermal comfort measurements for two external points for each group from residential urban clusters and its variable value at eight different directions for those buildings, using the ENVI- MET SPACES simulation program for outdoor spaces, from which detailed data can be obtained for all data Inferred and standing on the best shapes and directions that provide the best thermal comfort for the external spaces, [14]With fixing the rest of the other influencing urban factors:

1. The month of July was chosen to enter the average values of climatic factors during this month "temperature - relative humidity - wind speed and direction" to conduct simulations of outdoor and indoor urban spaces.
2. Unifying the heights of the residential buildings surrounding the urban and architectural space to be 15 meters high.
3. That the ratio of containment to the outdoor urban void be 2:1 at an angle of 30 "ideal containment".
4. The area of the outdoor urban space should be 2500 square meters and contain two points for recording climatic data.
5. The urban space should consist of 50% hardscape, 50% softscape
6. The locations for selecting the measurement points for thermal comfort are unified in the second floor above the ground for the indoor spaces overlooking the outdoor spaces of the two selected models using the Design Builder program.

4.1.1. Table 1. Data recorded for simulating urban and architectural spaces in the selected residential community:

To measure the outdoor thermal comfort using its inputs "climatic determinants - urban variables in the geometric shape and orientation of the building block and the outdoor space of the residential community" with fixing the rest of the influencing urban factors using the ENVI-MET SPACES program to measure the value of PMV in two outdoor points as an indicator of the thermal comfort value of the outdoor space Through which detailed data can be obtained for all the inferred data after the simulation. [15], [16]

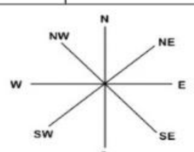
Table.1 Data used in simulating thermal comfort for outdoor spaces, source: (4)

Residential Urban Clusters	Model (G)		Model (D)		Model (A)		Model (H)		Model (N)	
										
	Record points									
	G1	G2	D1	D2	A1	A2	H1	H2	N1	N2

Data recorded for the ENVI-MET BIOMET program							
	Input	Type	Weight KG	Age	Movement Speed M/S	Clothes (CLO)	Output Height Level
	Value	MALE	75	35	1.21	0.5	`1.5

Data recorded for the Simulation ENVI-MET GUIDE						
	Input	Temperature ºC Min	Temperature ºC MAX	% Relative humidity	Wind speed M/S	located
	Value	22	32	15 MIN 70MAX	3.5	New Cairo – Egypt

The Clusters are directed in 8 directions



4.1.2. Simulation results of the measuring the thermal comfort index (PMV) in the outdoor space for the selected residential urban clusters:

By recording PMV measurements of two points of the outer space for each of the two selected models, "by directing them to eight consecutive directions by rotating the model horizontally around the axis of a full rotation of 360 within 24 hours" from 1 am to 12 pm.

The timing of the measurement was standardized to be 4:00 pm as a unified fixed time for all measurements, as the PMV reading was the highest at this time in most of the curves for the two measurement points (A1 & A2) for five residential urban clusters (G, D, A, N, H) in residential urban, the high recording value means the low thermal comfort and vice versa.

1- <u>Residential Urban Cluster (G):</u> Average PMV at the two recording points in the outer urban space of the residential group (G) for eight direction over 360 degrees at 4 pm. The figure shows the high score in point (G-90) recording value 4.2191 - Low score in point (G-0) recording value 3.49

Fig.7 Shape of the residential urban cluster - model (G), sorce: google earth & Authores

Table2. Average PMV at the two recording points in the outer urban space & average pmv of the residential cluster group (G) at 4:00 pm

Orientation Cases	(G-0)	(G-45)	(G-90)	(G-135)	(G-180)	(G-225)	(G-270)	(G-315)
PMV (G1)	3.7307	3.7749	4.2191	3.9812	3.7502	3.7498	4.1586	3.9373
PMV (G2)	3.2611	3.3725	5.586	5.7045	4.9749	5.3047	3.197	3.2965
Average PMV (G)	3.4959	3.5737	4.90255	4.84285	4.36255	4.52725	3.6778	3.6169

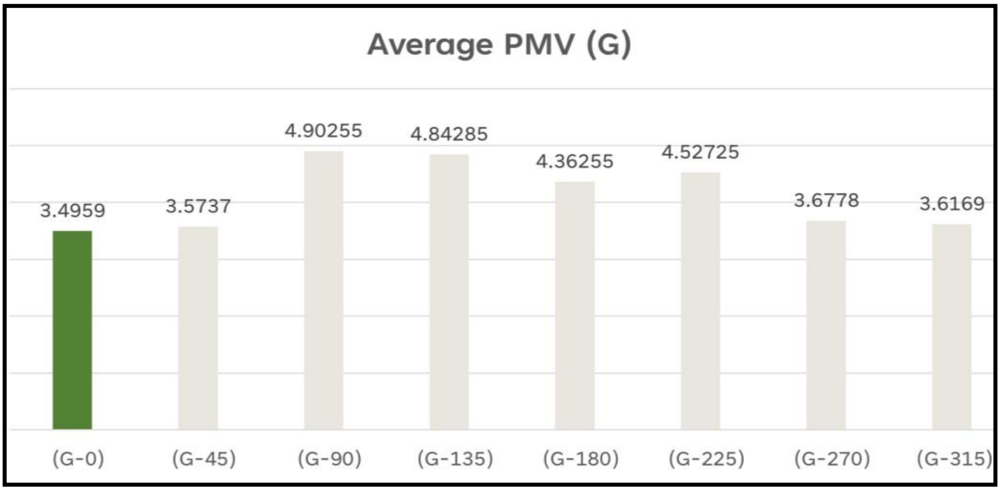


Fig.8 Average PMV at the two recording points in the outer urban space of the residential group (G) at 4:00 pm, source: Authors by Envi-met program

2- <u>Residential Urban Cluster (D):</u> Average PMV at the two recording points in the outer urban space of the residential group (D) for eight direction over 360 degrees at 4 pm. the high score in point (D-135) recording value 5.592 – Low score in point (D-270) recording value 3.886

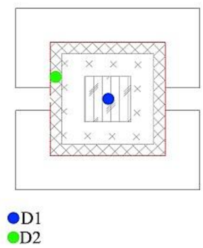


Fig.9 Shape of the residential urban cluster - model (D), sorce: google earth & Authores

Table3. Average PMV at the two recording points in the outer urban space & average pmv of the residential cluster group (D) at 4:00 pm

Orientation Cases	(D-0)	(D-45)	(D-90)	(D-135)	(D-180)	(D-225)	(D-270)	(D-315)
PMV (D1)	5.3656	4.9427	5.3429	5.3326	5.3983	5.3416	4.6056	5.2865
PMV (D2)	3.1058	3.2773	5.7979	5.8525	5.1069	5.442	3.1668	3.2056
Average PMV	4.2357	4.11	5.5704	5.59255	5.2526	5.3918	**3.8862**	4.24605

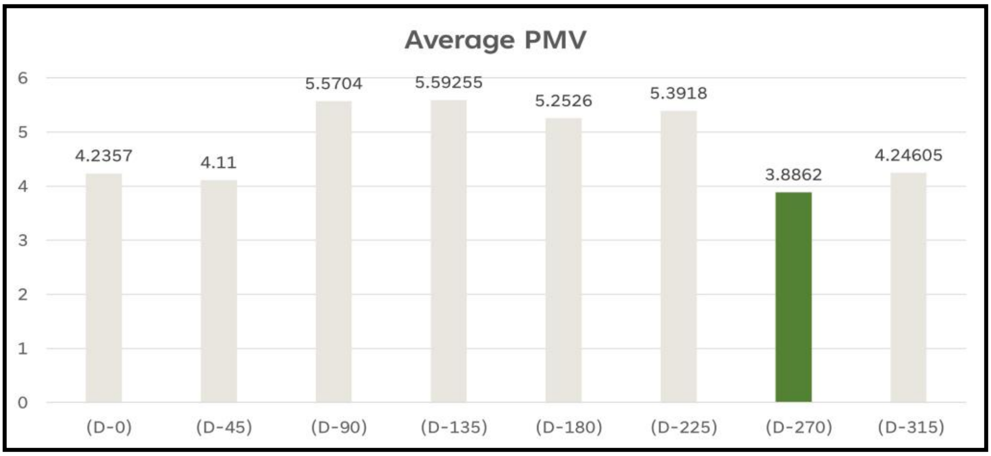


Fig.10 Average PMV at the two recording points in the outer urban space of the residential group (D) at 4:00 pm.

3- <u>Residential Urban Cluster (A):</u> Average PMV at the two recording points in the outer urban space of the residential group (A) for eight directions over 360 degrees at 4 pm. the highest score in point (A-225) recording value 6.4858 (the lowest thermal comfort in the selected residential urban cluster) – Low score in point (A-0) recording value 3.2351

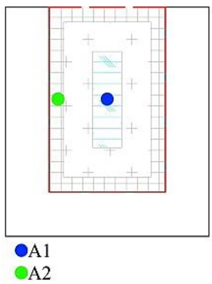



Fig.11 Shape of the residential urban cluster - model (A), sorce: google earth & Authores

Table4. Average PMV at the two recording points in the outer urban space & average pmv of the residential cluster group (A) at 4:00 pm

Orientation Cases	(A-0)	(A-45)	(A-90)	(A-135)	(A-180)	(A-225)	(A-270)	(A-315)
PMV (A1)	3.128	5.5922	6.2167	6.1783	3.1284	6.2647	6.2515	6.2685
PMV (A2)	3.3422	3.3149	6.3734	6.7128	5.5957	6.7069	6.4999	3.4103
Average PMV	3.2351	4.45355	6.29505	6.44555	4.36205	6.4858	6.3757	4.8394

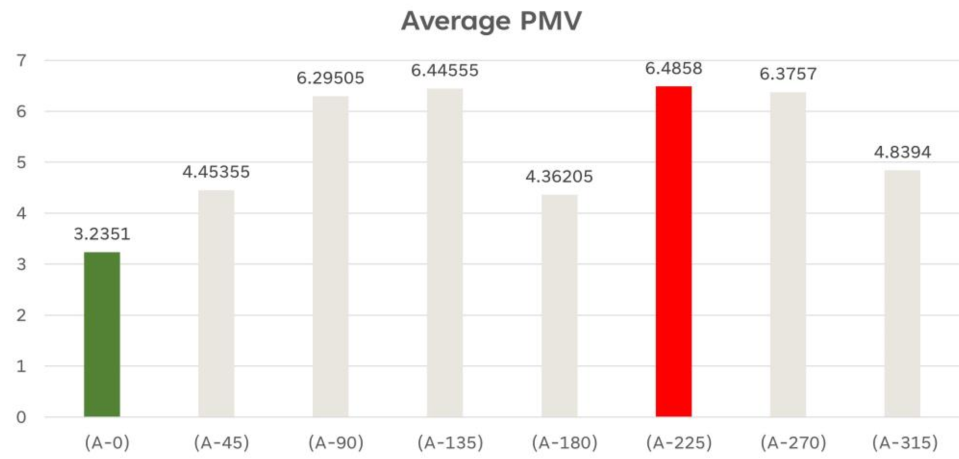


Fig.12 Average PMV at the two recording points in the outer urban space of the residential group (A) at 4:00 pm.

4- Residential Urban Cluster (N): Average PMV at the two recording points in the outer urban space of the residential group (N) for eight direction over 360 degrees at 4 pm. the high score in point (N-135) recording value 6.035 – Lowest score in point (N-45) recording value 2.951 (the best thermal comfort in the selected residential urban cluster)

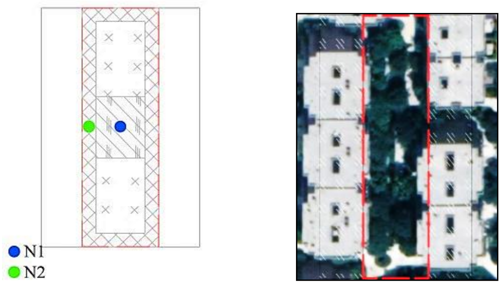


Fig.13 Shape of the residential urban cluster - model (N), source: google earth & Authores

Table5. Average PMV at the two recording points in the outer urban space & average pmv of the residential cluster group (N) at 4:00 pm

Orientation Cases	(N-0)	(N-45)	(N-90)	(N-135)	(N-180)	(N-225)	(N-270)	(N-315)
PMV (N1)	2.9917	2.9316	5.9537	6.0709	2.9171	2.9925	6.0032	6.016
PMV (N2)	3.0548	2.9723	5.6873	6.0008	5.1572	5.511	5.735	3.0307
Average PMV	3.02325	2.95195	5.8205	6.03585	4.03715	4.25175	5.8691	4.52335

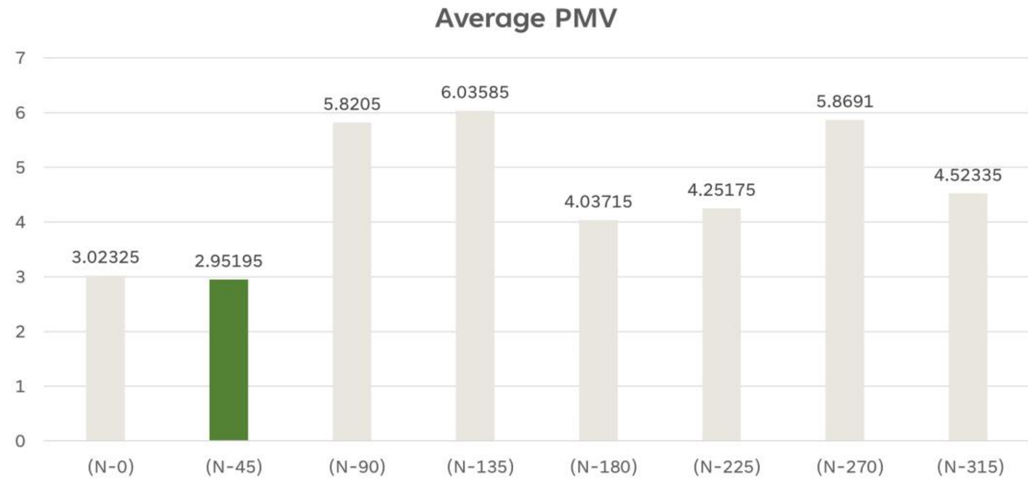


Fig.14 Average PMV at the two recording points in the outer urban space of the residential group (N) at 4:00 pm.

5- <u>Residential Urban Cluster (H):</u> Average PMV at the two recording points in the outer urban space of the residential group (H) for eight direction over 360 degrees at 4 pm. the high score in point (H-135) recording value 5.698 – Low score in point (H-0) recording value 3.191

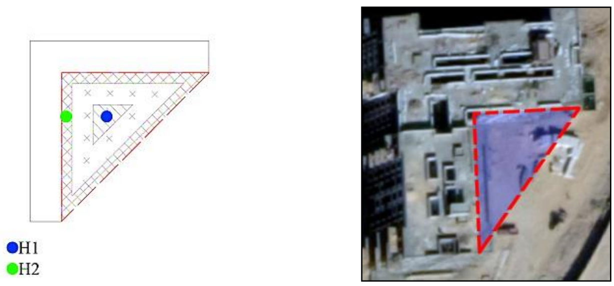


Fig.15 Shape of the residential urban cluster - model (H), source: google earth & Authores

Table6. Average PMV at the two recording points in the outer urban space & average pmv of the residential cluster group (H) at 4:00 pm

Orientation Cases	(H-0)	(H-45)	(H-90)	(H-135)	(H-180)	(H-225)	(H-270)	(H-315)
PMV (H1)	3.0808	5.4705	5.5152	5.5463	5.5285	5.455	3.043	5.7236
PMV (H2)	3.3025	3.4392	5.7305	5.8507	5.0856	5.3656	3.3581	3.7049
Average PMV	3.19165	4.45485	5.62285	5.6985	5.30705	5.4103	3.20055	4.71425

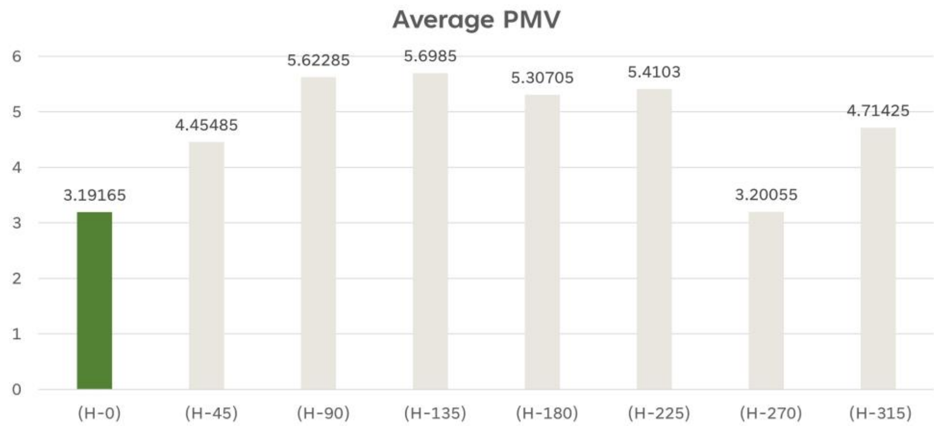


Fig.16 Average PMV at the two recording points in the outer urban space of the residential group (H) at 4:00 pm.

4.1.3. Comparing the average PMV reading at the two registration points in the outdoor urban space for each of the five selected residential urban clusters

we find that the A225 model achieves the lowest thermal comfort degree " as the highest measurement of PMV = 6.4858 (That is the worst result) , the N45 model also achieves the highest thermal comfort degree as the lowest measurement of PMV = 2.951 (That is the best result)

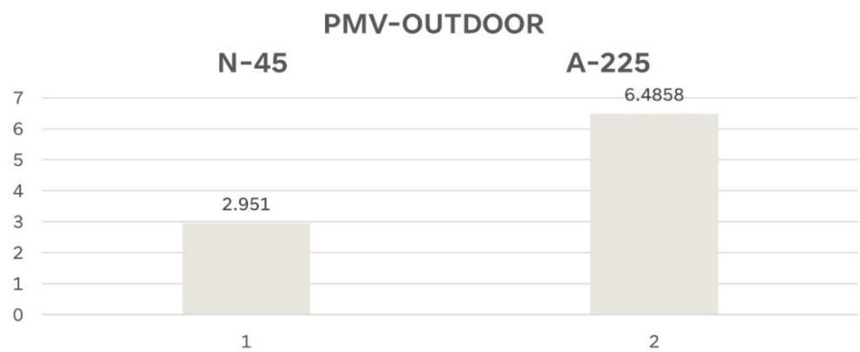


Fig.17 shows a comparison between the PMV of the outer space of the two models.

4.2. The Second Axis: Design Builder Analysis:

Through the simulation results, the residential urban clusters are arranged according to the simulation results in descending order "according to preference" in achieving outdoor thermal comfort. From these arranged groups, the first group (the best) and the last group (the least) are chosen so that the quality difference in thermal comfort is clear.

Three points for the indoor spaces of the residential buildings overlooking the selected indoor spaces are selected and determined, and the PMV value of those points is measured as an indicator of the thermal comfort value for them, using the BUILDER DESIGN simulation program for the internal spaces.

4.2.1.PMV thermal comfort measurement results:

The research will deal with measurements of PMV thermal comfort in the indoor space A225 "which achieved the least thermal comfort and N45 that achieved the best thermal comfort" by recording PMV measurements for three different points inside the internal spaces overlooking the space of each model and through the DESIGN BUILDER program the relationship between changes in comfort is studied The thermal comfort of the external spaces and the extent to which the thermal comfort of the internal spaces is affected.

A- The first model: Residential urban cluster A in the direction of 255 degrees from the Design Builder:

Analysis of the First residential group (A-225), which is the worst orientation and shape of the residential group and the worst thermal comfort result from the Envi-Met Program:

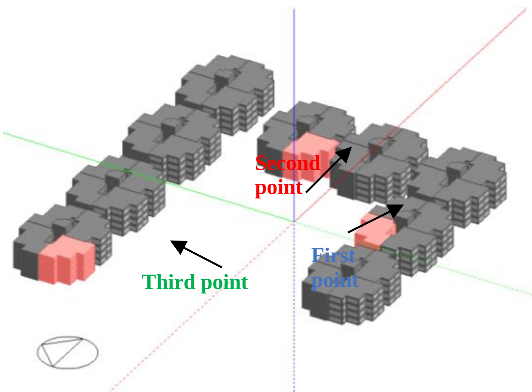


Fig.19 shows the A-225 models on the Design builder program

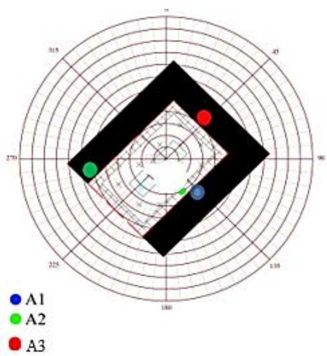
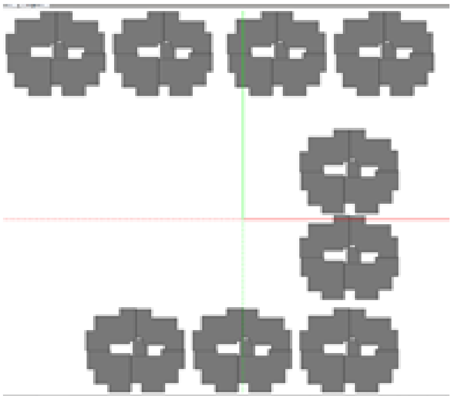


Fig.20 A figure showing the locations of the three measurement points for the spaces that overlook the outer spaces



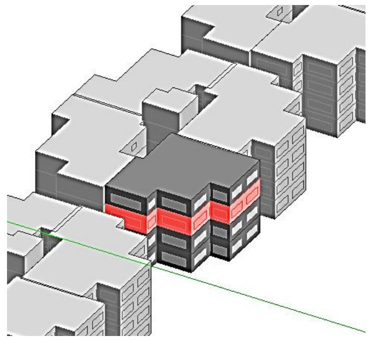


Fig27. shows the N-45 layout and 3D model (Third floor) on the Design Builder Program

- The three graphs (Figure 21, 22, 23) show the recording of the PMV thermal comfort index measurements for three different points in the indoor spaces of the buildings overlooking the outdoor space of Model A-225 during the hours of the day, and the results were as shown in the three curves of points A1, A2, A3, which is compared by integrating it into Figure 24, which includes the three structural measurements of the three points.
- As a result of measuring the thermal comfort value of first point at 4 pm for point A-225, the thermal comfort value is PMV 5.01 (this is lowest value), and its value increases with each night hours.

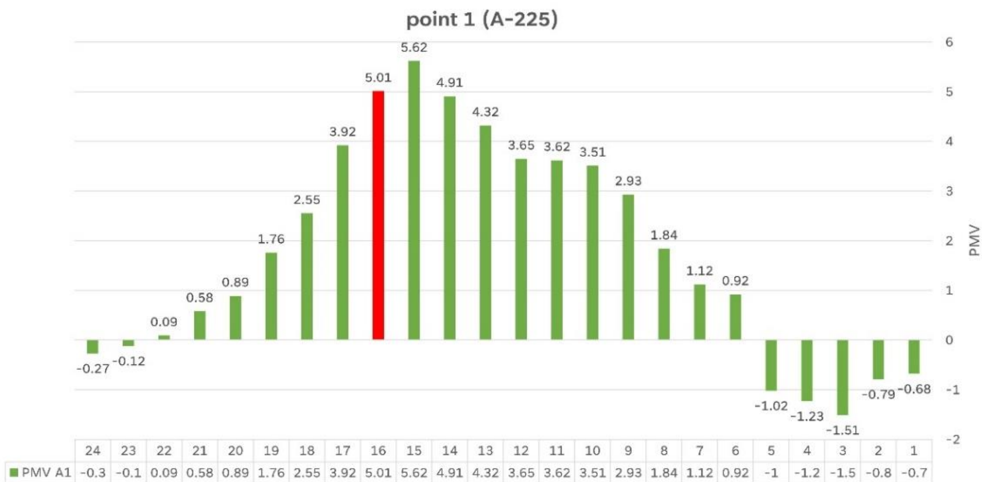


Fig.21 shows the PMV measurements of point at 4:00 pm.

- As a result of measuring the thermal comfort value of second point at 4 pm for point A-225, the thermal comfort value is PMV 5.62, and its value increases with each night hours.

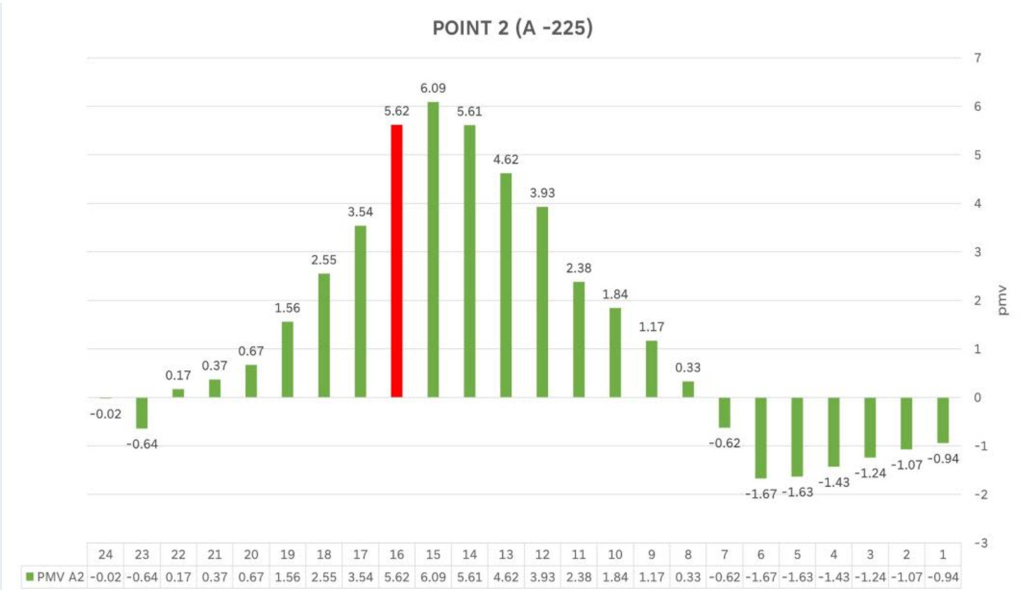


Fig. 22 shows the PMV measurements of point A2 at 4:00 pm.

- As a result of measuring the thermal comfort value of second point at 4 pm for point A-225, the thermal comfort value is PMV 6.31 (That is the worst value), and its value increases with each night hours.

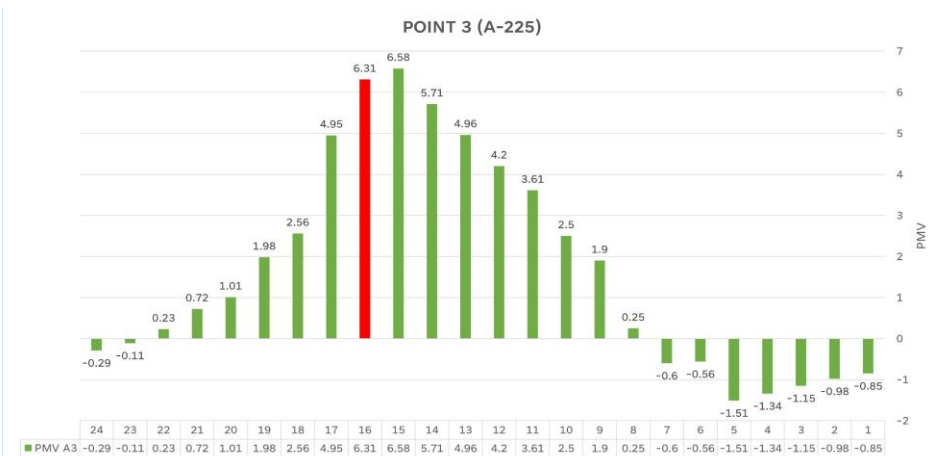


Fig. 23 shows the PMV measurements of point A3 at 4:00 pm.

- Comparison between the PMV measurements for the three points A1, A2, A3, in the model A-225 at 4 pm, where we find that point A1 achieves the best thermal comfort PMV "5.01" and that point A3 achieves the least thermal comfort PMV 6.31

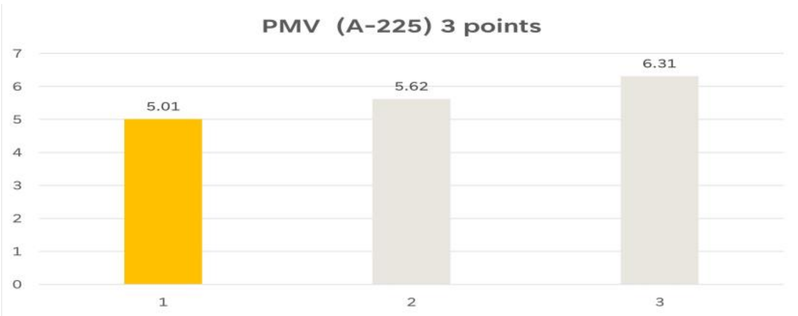
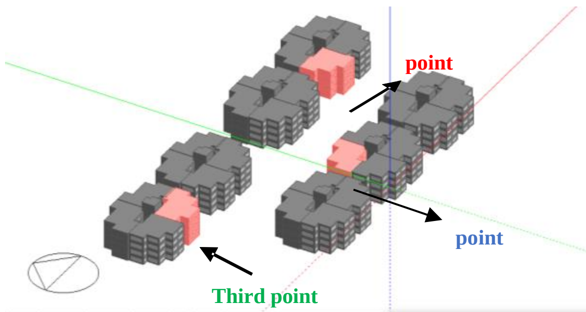


Fig.24 shows a Comparison between the PMV measurements for the three points A1, A2, A3, at 4 pm

B- The second model: Residential urban cluster N in the direction of 45 degrees from the Design Builder:

Analysis of the First residential group (N-45), which is the best orientation and shape of the residential group and the best thermal comfort result from the Envi-Met Program:



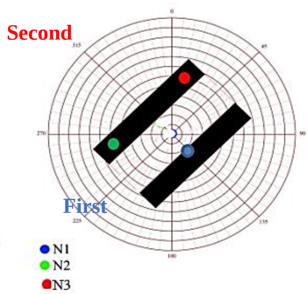
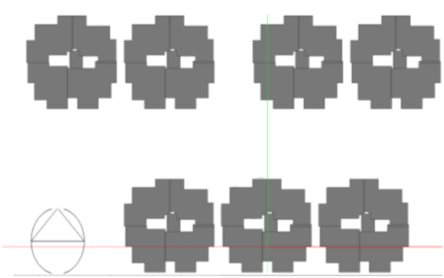


Fig25. shows the N-45 models on the Design Builder Program

Fig 26. A figure showing the locations of the three measurement points for the spaces that overlook the outer spaces



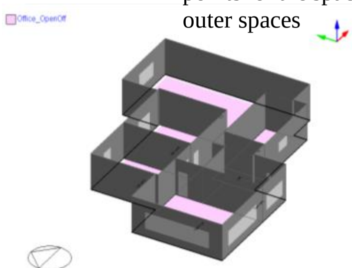


Fig27. shows the N-45 layout and 3D plan model (indoor) on the Design Builder Program

- The three graphs (Figure 28, 29, 30) show the recording of the PMV thermal comfort index measurements for three different points in the indoor spaces of the buildings overlooking the outdoor space of Model N-45 during the hours of the day, and the results were as shown in the three curves of points N1, N2, N3, which is compared by integrating it into Figure 31, which includes the three structural measurements of the three points.
- As a result of measuring the thermal comfort value of first point at 4 pm for point N-45, the thermal comfort value is PMV= 1.64 (That is the Best value), and its value increases with each night hours.

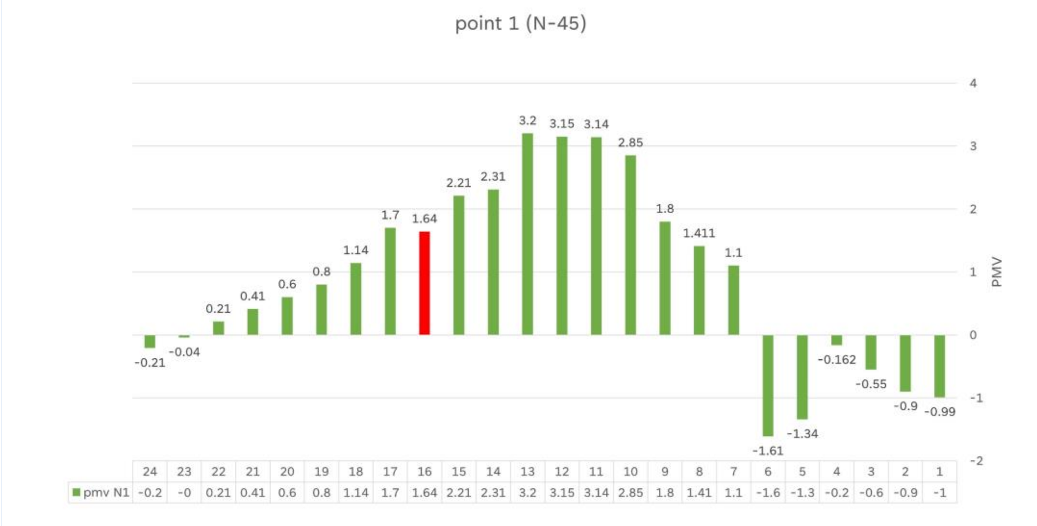


Fig.28 shows PMV measurement for point 1(N45-N1) at 4pm

- As a result of measuring the thermal comfort value of second point at 4 pm for point N-45, the thermal comfort value is PMV= 2.14, and its value increases with each night hours.

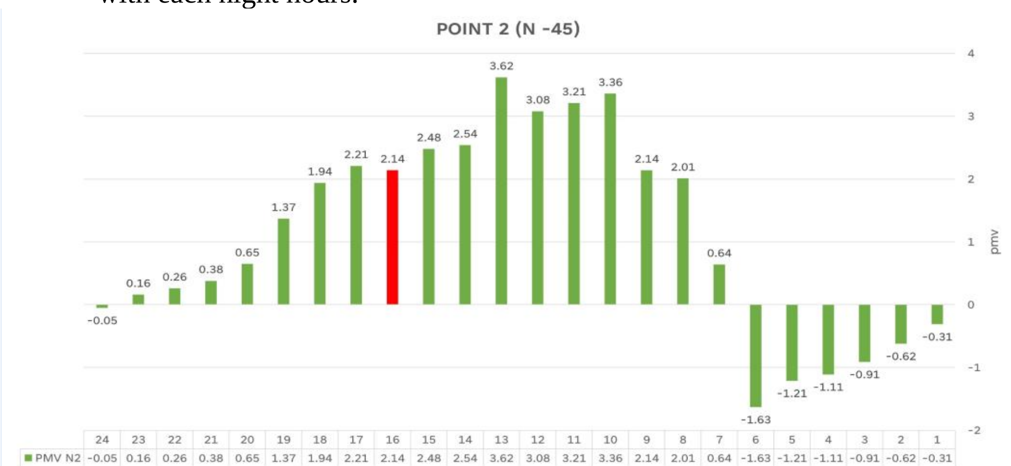


Fig.29 shows PMV measurement for point 1(N45-N2) at 4pm

- As a result of measuring the thermal comfort value of second point at 4 pm for point A-225, the thermal comfort value is PMV= 2.31, and its value increases with each night hours.

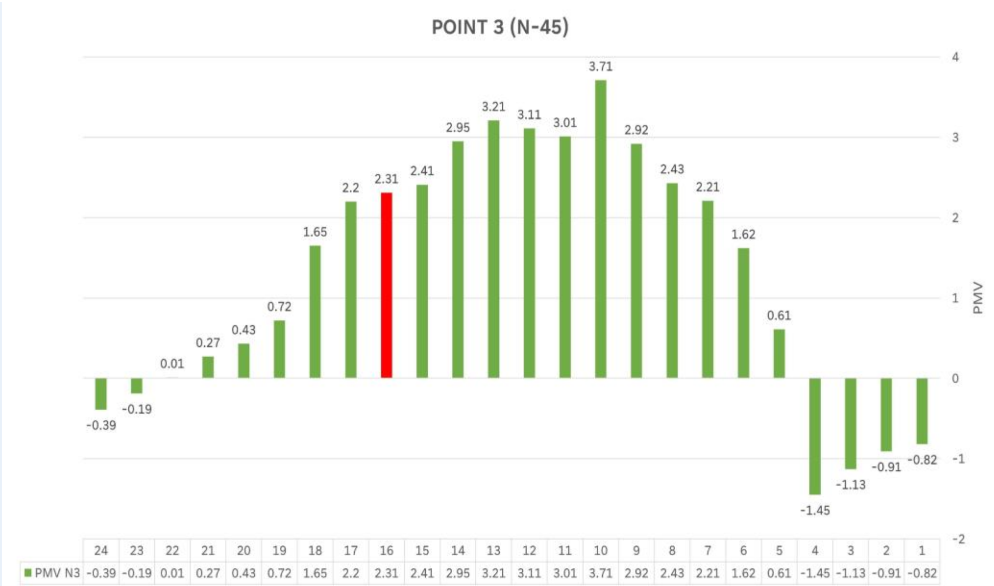


Fig.30 shows PMV measurement for point 1(N45-N23) at 4pm

- A Comparison between the PMV measurements of the three points (N1, N2, N3) in the model N-45 at 4 pm, where we find that point N1 achieves the best thermal comfort, PMV 1.64, and point N45-N3 achieves the least thermal comfort, PMV 2.31

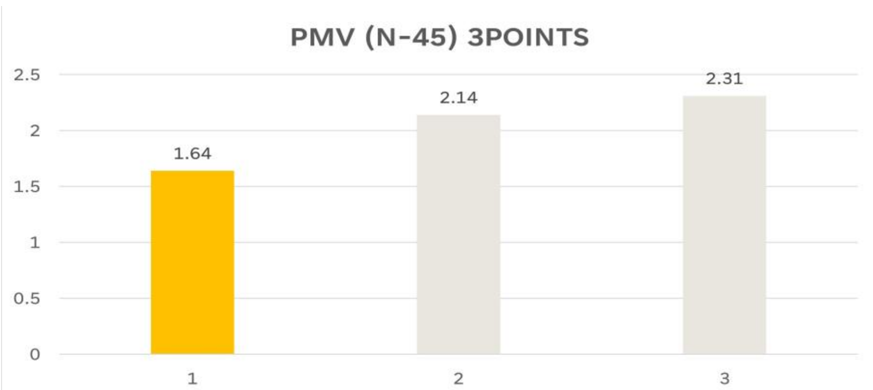


Fig.31 shows a Comparison between the PMV measurements for the three points (N-45 module) N1, N2, N3, at 4 pm.

C- Comparison between results of Residential urban clusters for indoor spaces of two modules (A) in the direction of 225 degree and module (N) in the direction 45 degree from the Design Builder:

The results showed that the N-45 model recorded the lowest value of PMV, which means that the best degree of thermal comfort PMV 1.64 indoor space, while the PMV of the A-225 model recorded the lowest value of thermal comfort PMV 5.01 indoor space, and here the big difference between the two models appears.

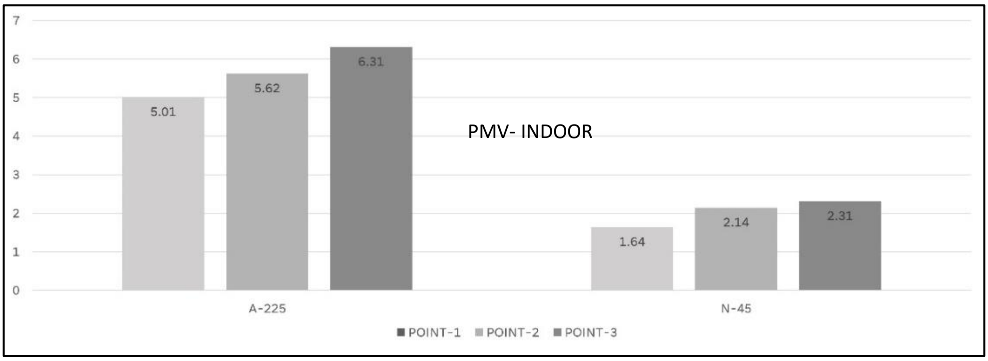


Fig. 32 shows a comparison chart between the three-point recording of thermal comfort PMV from within the spaces that overlook the outer space of the two models.

4.3. The Third Axis: compare the results: Design Builder Analysis:

Comparing the results of thermal comfort for the outdoor spaces and the results of the thermal comfort for the indoor spaces, through which these measurements are simulated to obtain results that help suggest a methodology to raise the efficiency of thermal comfort for the indoor and outdoor spaces

- The comparison chart between the two models shows the PMV score for indoor thermal comfort and outdoor thermal comfort and shows the direct effect and the direct relationship between them, as when the PMV of the outdoor space increases, it increases from the indoor space and vice versa.

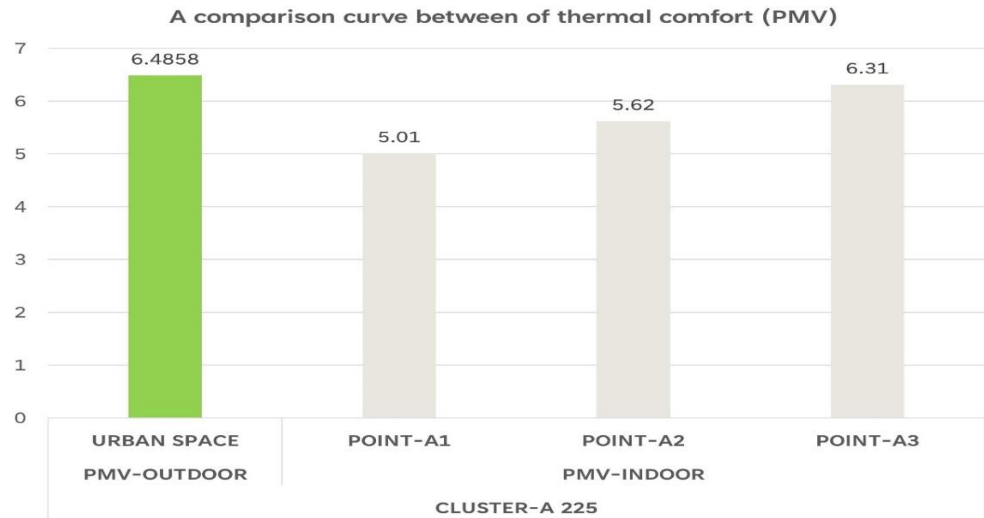


Fig. 33 shows a comparison chart between outdoor & indoor recordings of thermal comfort PMV of cluster A-225.

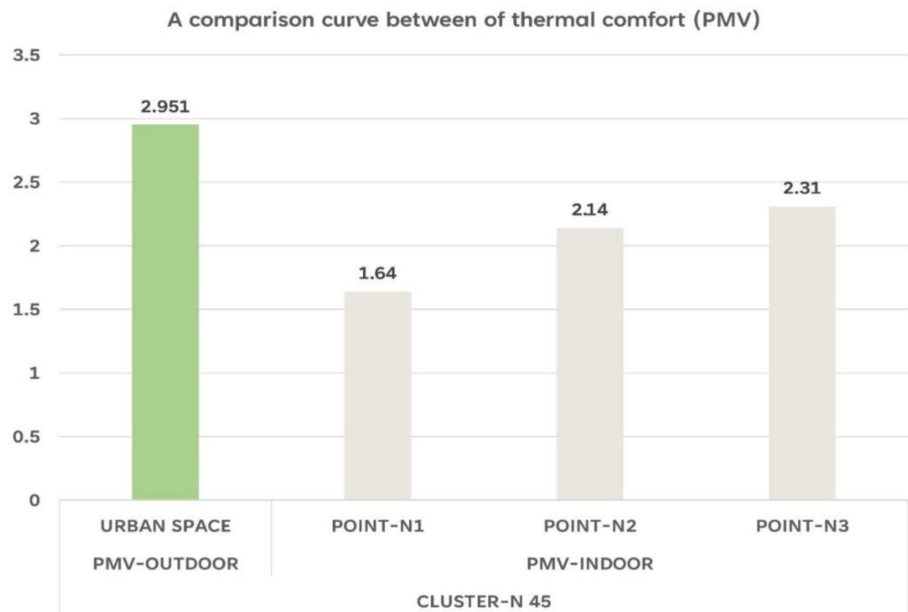


Fig. 34 shows a comparison chart between outdoor & indoor recordings of thermal comfort PMV of cluster N-45.

- The results of the PMV curve shows that the relationship is proportional between the indoor and outdoor spaces.

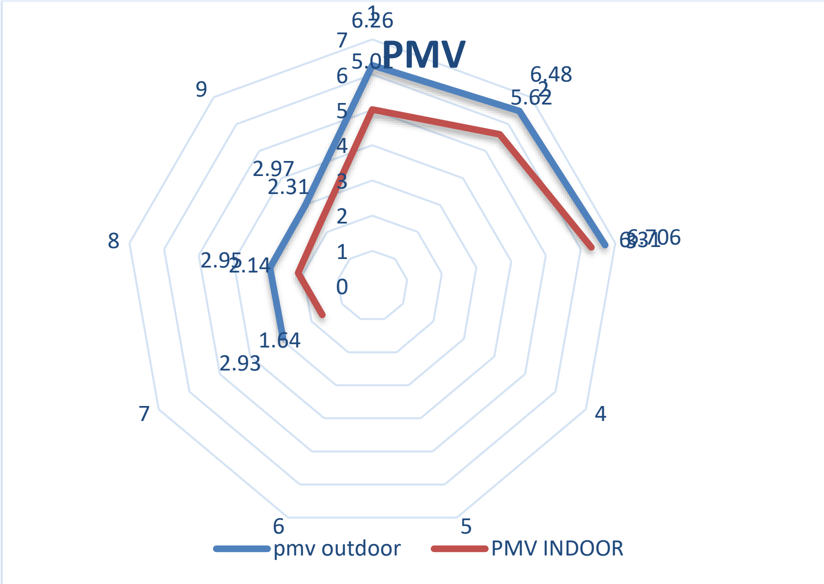


Fig. 34 shows a comparison curve between of thermal comfort PMV from indoor and outdoor the spaces of the two models.

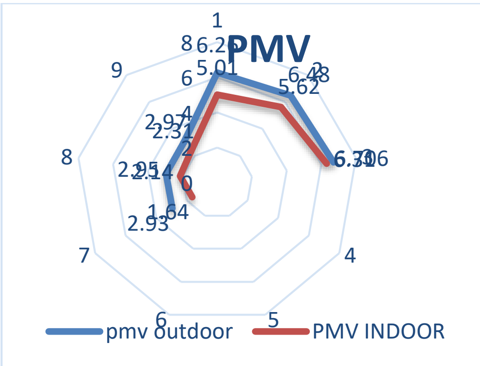
5. Conclusion

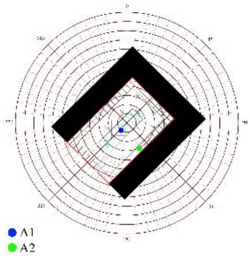
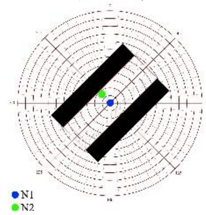
Through the research, the following results were reached:

- After recording the simulation results with the urban spaces in the selected groups through the first registration points in the middle of the space and the second next to the building blocks surrounding it, we took the average PMV value and arranged each space in the group in terms of preference and monitored the best value of them to contribute.
- It was noted in the results that there are urban voids in the same residential group that achieve better PMV values than those in other residential groups, , but in this research we arranged preference by taking the best value from each residential group, and exiting In order to achieve the goal of the research to achieve the requirements of external thermal comfort in the urban space in terms of guidance and group formation in order to be a proposed model that contributes to the provision of residential urban clusters

- The result of PMV of residential urban cluster model (N) at an angle of 45° direction and shape achieve the best thermal comfort for the indoor spaces, as it achieved the best result, the value of PMV 1.64
- The result of PMV of residential urban cluster model (A) at an angle of 225° direction and shape achieve the worst thermal comfort for the indoor spaces, as it achieved the worst result, the value of PMV 5.01

- Compares the results of the PMV curve shows that the relationship is proportional between the indoor and outdoor spaces



Residential cluster (A) (A-225)	Residential cluster (N) (N-45)
	
6.4858	**2.951**

6. Recommendations

- Attention to the stages of urban design and the use of all methods of simulation and research programs to achieve compatibility with the surrounding environment and provide thermal comfort for the humans
- It is necessary for the architects designing the indoor architectural spaces to consider the importance of the mutual climatic relationship between the indoor architectural space and the outdoor urban space, and thus try to influence and benefit from it in a climate-friendly and thermally comfortable design.
- Considering when planning and designing the construction of new urban residential urban clusters, that the results of the research must be considered as a top priority for the building directives, the building configuration and other outdoor factors as they have a significant impact on the indoor thermal comfort.

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