Human Thermal Comfort Evaluation in Open Spaces of Two Multi-Story Residential Complexes Having Different Design Settings, Duhok-Iraq

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ABSTRACT

To achieve a sustainable residential area, open spaces must promote comfort and invite people to stay outdoors and prolonging their stays, which will contribute to a more lively residential areas offering greater interaction between its inhabitants. Thermal comfort is an essential factor that should be considered in any urban design process, urban design characteristics of any project have a strong influence on human thermal comfort at outdoor spaces, like its spatial organization and landscape elements, the paper aims to assess the impact of spatial organization differentiation on thermal comfort of inhabitants in two different residential multi-story complexes in Duhok city. Thermal comfort for an urban context in hot and semi-dry climate zone based on the physiologically equivalent temperature (PET) index have been adopted and simulated by ENVI-met program, two simulations were conducted for each complex through climatic data of the hottest day in summer and coldest day in winter of 2013. The results reveal that the two complexes have not provided a comfortable space during the two seasons in general, but it showed that the second complex has a better performance in this respect for the two seasons, in spite of the poor landscaping it has, the paper concludes the importance of the urban design characteristics represented by the spatial organization on thermal comfort of the inhabitants at open spaces at such kind of projects and climate, and the necessity of adopting more compact and close spaces.

Keywords: Urban design, Thermal comfort, physiologically equivalent temperature, ENVI-met.

INTRODUCTION

Climate as an important urban design element which serves achieving sustainability through providing desired microclimate encourages walking and facilitate social interaction in public spaces. Achieving a livable environment considered one of urban design principles concerning people who need to feels comfortable to walk through, sit, stand, play, talk, read, or just relax and contemplate [1], and not too exposed to unpleasant noise, wind, heat, rain, traffic or pollution, thermal comfort is an essential factor that should be considered in any urban design process of open public spaces, which can have a beneficial impact on the social and economic behavior aspects of people using these places [2]. Thermal comfort is

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considered as one of the three thermal environment components and it is divided into three categories; Thermal comfort, where people feel neither too hot nor too cold, and do not perceive the temperature to be a problem, [3]. Thermal stress, where the thermal environment will cause clearly defined medical conditions, and can prove fatal. And Thermal discomfort, which is the area between the first two. People can feel too hot or too cold, but do not display medical symptoms beyond irritability and fatigue.

Human thermal comfort:

Thermal comfort is a very complex concept that could be easily defined. This is because of the need to take into account a range of environmental and personal factors. Human thermal comfort is defined by the International Standard ISO 7730 as being ‘‘that condition of mind in which satisfaction is expressed with the thermal environment’’ [4].

Human thermal comfort is defined by the International Standard ISO 7730 as being ‘‘that condition of mind in which satisfaction is expressed with the thermal environment’’ [4]. The six factors affecting thermal comfort are both environmental and personal. These factors may be independent of each other, but together contribute to human thermal comfort.

- Environmental factors [5]: Air temperature, Radiant temperature, Air velocity and Humidity
- Personal factors: Clothing Insulation and Metabolic heat

Comfort assessment methods applied outdoors have been adjusted from those originally conceived for indoors. A large number of thermal indices exist which can be classified in two groups: empirical or rational. The former group, generally developed earlier, is based on measurements with subjects or on simplified relationships that do not necessarily follow theory [6, 7]. Rational indices are more recent, promoted by the lately development of computing techniques, and rely on the human energy balance. For ex. Index of Thermal Stress (ITS), Heat Stress Index (HIS), Predicted mean vote Perceived Temp (PMV), Physiological Equivalent Temperature (PET) etc. [8]. In this paper, thermal comfort is expressed by means of the (PET) index.

Evaluating thermal comfort using the PET index:

The use of specific criteria for the precise measurement of physiological equivalent temperature (PET) is needed for urban thermal sensations assessment. Of course there are other indices, but PET index is more suitable because it was adapted to outdoor settings [9], its wide distribution, and the use of (ºC) unit as an indicator of thermal comfort makes the results comprehensible for potential users. PET is based on the heat balance of man [10], involving all heat exchange processes between the human body and its environment. It “is defined as the air temperature at which the human energy budget for the assumed indoor conditions is balanced by the same skin temperature and sweat rate as under the actual complex outdoor conditions to be assessed” [9]. The meteorological input parameters are mean radiant temperature, air temperature, wind speed and vapor pressure. PET also considers the heat transfer resistance of clothing and the internal heat production.

Physiological Equivalent Temperature (PET):

An index used to describe the thermal situation of a person including the meteorological parameters Mean Radiant Temperature (Tmrt), Air Temperature (Ta), Wind Speed (v) and Vapor Pressure (VP). It ‘is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed. [11, 12].

Methods and Data:

The urban micro climate is strongly subjected to the effects of the design settings such as spatial organization and landscaping elements which shift wind patterns and limit solar radiation exposure. The paper focuses on the physical structure of the built environment and on how this affects inhabitant’s thermal comfort in open spaces, two residential complexes was selected in Duhok city, Duhok was selected as an exemplar city of the semi-hot dry climate zone of the northern region of Iraq.

Duhok city is located at (36° 51' 56" N; 42° 59' 58" E). This falls under semi hot dry climate with a distinct cold rainy winter and hot-dry summer [13]. The hot season in Duhok usually falls in July (average highest value = 41.22 o C), the minimum dry bulb temperature usually falls in January (average lowest value = 3.65 o C). So the weather data for the coldest (15th Jan, 2013) and hottest day (13th Jul, 2013) in Duhok needed for simulations are chosen in this two months, Table 1, 2 [14].

Table(1).Duhok METEOROLOGICAL Data(13th Jul, 2013), [14].

Time	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00
Temp	27 °c	25 °c	26 °c	35 °c	40 °c	41 °c	40 °c	32 °c
Rain	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm
Cloud	0%	0%	0%	0%	0%	0%	0%	0%
Wind	4 mph	3 mph	2 mph	3 mph	6 mph	6 mph	5 mph	2 mph
	NNW	NNE	NE	SSW	SSW	SW	WSW	W
R.H.	23%	27%	28%	15%	11%	8%	9%	17%
Pressure	1001 mb	1000 mb	1002 mb	1001 mb	1001 mb	999 mb	998 mb	999 mb

Table(2)Duhok METEOROLOGICAL Data(15th Jan, 2013), [14].

Time	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00
Temp	-1 °c	-2 °c	-2 °c	0 °c	7 °c	11 °c	5 °c	0 °c
Rain	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm
Wind	3 mph	4 mph	5 mph	4 mph	2 mph	2 mph	3 mph	4 mph
	NNW	N	N	NNE	N	WNW	NNW	NNE
Rain	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	0%	0%	0%	0%	0%	0%	0%	0%
R.H	80%	75%	69%	59%	51%	54%	67%	63%
Pressure(mb)	1026	1027	1028	1029	1029	1028	1031	1032

In order to assess the impact of spatial organization differentiation on inhabitant's thermal comfort, two different case study areas with different urban design characteristics are selected, the first is a residential complex called (Avro City), which has a continuous, unbounded open space layout and repetitive eight-story residential point system buildings with a rich landscaping, the other, (Zery Land) has a linear layout and semi-court organization, attached eight-story residential segment system buildings with poor landscaping. Table (3) shows the difference in urban design characteristics between the two complex results open spaces with different densities and sky view factor (SVF), Zery-Land has more compact (compactness factor equal 31% [15]) semi-closed open spaces compared with a lower compactness (compactness factor equal 11%) and unbounded open spaces at Avro-City, for SVF at typical Zery-Land open spaces was 59.427%, while at the other equal 76.291%

Table(3)Urban Design Characteristic Comparism Between The Two Residential Complex

Urban Elements	urban design characteristics	AVRO-CITY	ZERY-LAND
urban space	closure	continuous, unbounded open space	semi-closed open spaces (semi-court)
	sky view factor(SVF)	76.291%.	59.427%
urban form (buildings)	architectural design typology	point system buildings	segment system buildings
	form typology	free standing buildings in space	semi-continuous linear form
	compactness factor	11%	31%
landscape and urban furniture	landscaping	rich landscaping (planting trees, fountains, grass)	poor landscaping (only grass)

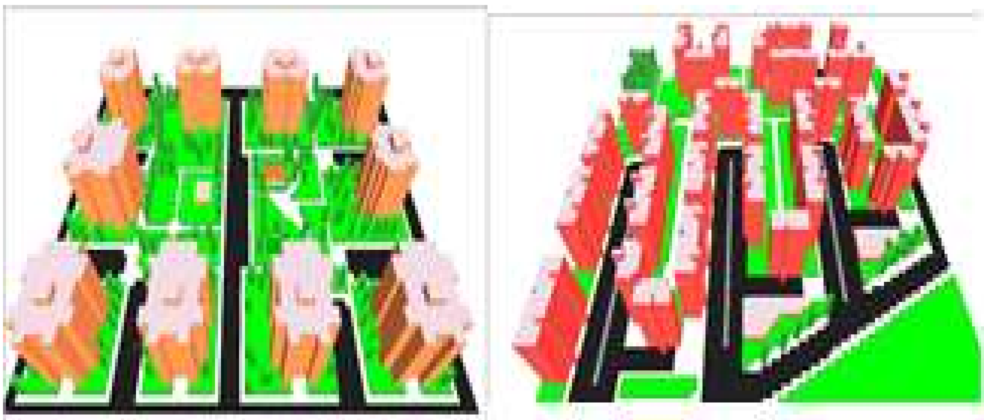
To acquire the results two simulations are needed; urban microclimate and thermal comfort simulations.

Figure (1)Case study areas

Urban microclimate simulations:

The micro-simulations are carried out for a typical part of the two residential complexes with a spatial resolution of 2.5 meters. The applied model, ENVI-met V4, which is a freeware program based on different scientific research projects under

constant development [16, 17], it is a micro-climate modeling tool which is able to simulate and analyze small scale interactions between urban design and the immediate climatic surroundings, with high resolutions [18]. The model simulates fluid and thermodynamic processes taking place at walls, roofs, ground surface, interacting with soil, plants and the atmospheric boundary conditions which deliver local atmosphere dynamics like wind flow, radiation, fluxes, temperature and humidity during one day or a few days. To conduct the simulation, using satellite images and field survey, the study areas have defined with their 2D- and 3D conditions by several input data sets represent its urban forms like; building shapes, heights and materials, and open spaces like; streets, car parks, pedestrians, play grounds and gardens with their surface materials and plants kinds and locations. Therefore a virtual 3D-model is introduced to consider the impact of urban design characteristics of the two projects, in particular their spatial organization differentiation and their land scape elements. Fig 2.
Air temperature and relative humidity was 'forced' in the simulation with the data taken from a world weather online web site. The input data for other parameters are shown in Table 1



Figure(2)3D-model of two residential complexes

TABLE(4) INPUT DATA FOR SIMULATION

Date of start of simulation	13th Jul, 2013	15th Jan, 2013
Time of start of simulation	9:00 am	9:00 am
Simulation period	09 hours	09 hours
Wind speed at 10 m height (m/s)	2.0	2.0
Wind direction	315	315
Roughness length	0.1	0.1
Initial air temperature (°C)	32.85 °C	5.35 °C
Specific humidity (g/kg)	0.01	0.5
Relative humidity at 2 m height (%)	11	55

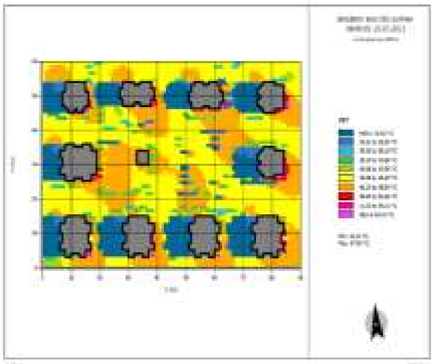
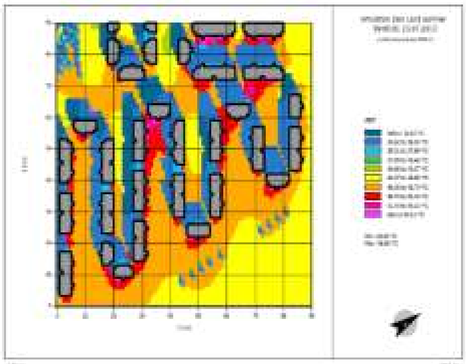
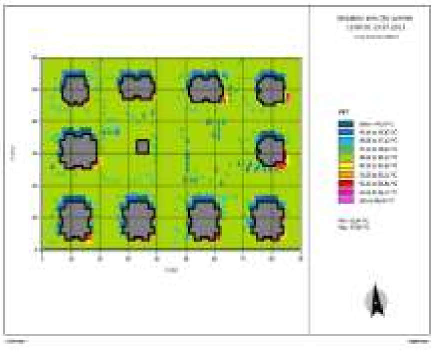
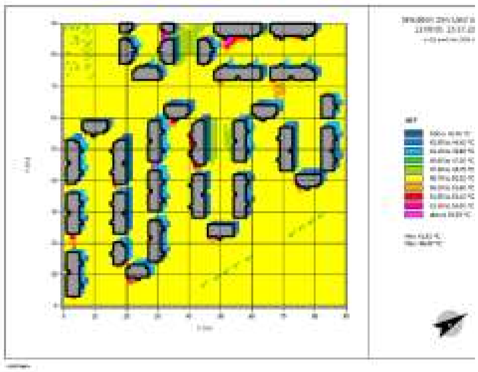
Thermal comfort simulations using Bio-met:

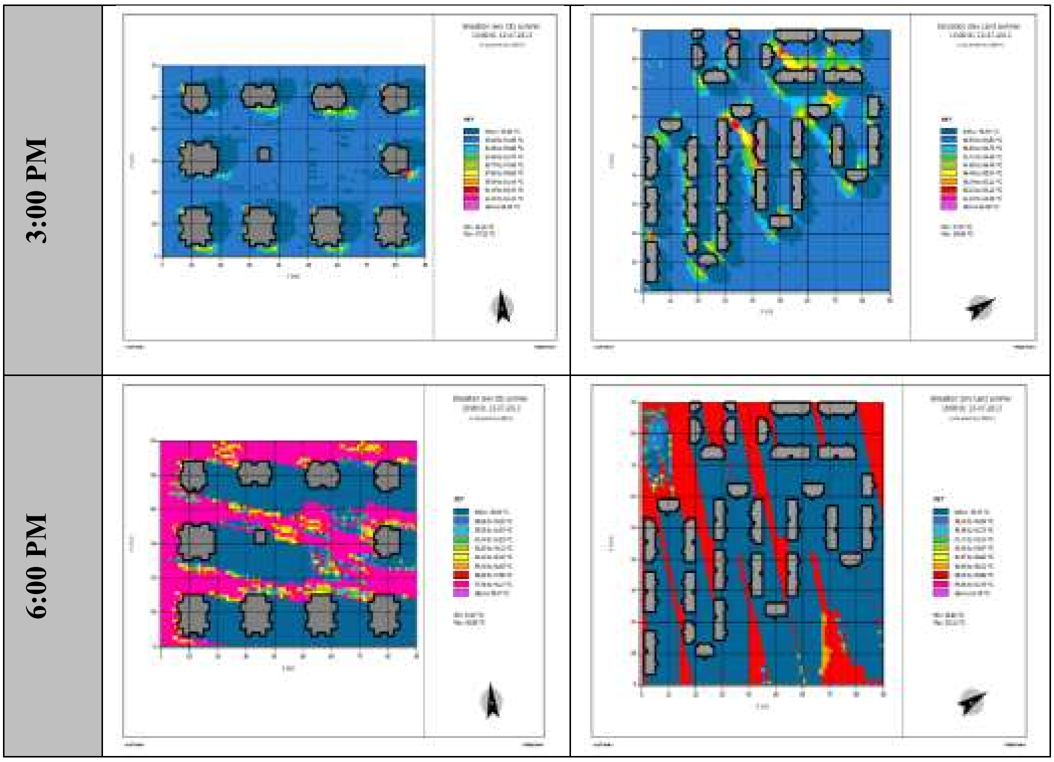
Bio-Met tool, which is a post-processor tool for calculating human thermal comfort indices from ENVI-met model output files, was used for the comfort simulations PET index. The inputs required for the simulations; air temperature, radiant temperature, surface temperature, wind velocity, etc., are taken from the output files and personal parameters like clothes, age etc. are taken by program defaults.

Results and Discussion:

Summer:

Fig. 3 shows a comparison between the two residential complexes thermal comfort index (PET) maps at 9:00 AM, 12:00 PM, 15:00 PM and 18:00 PM o'clock, the two case study haven't provide a thermally comfortable open spaces, but it's clear that there is a deference in the performance in this regard. Zery-Land residential complex have better results compared with Avro-City complex, for example PET index at 9:00 AM o'clock 26% of the open spaces was (31-35°C) and 65% (43-49°C) while at Avro-City just 12% of the open spaces was (32°C) and 60% (43-47°C), at 12:00 PM o'clock 83% of the open spaces was (48-50°C) and 10% (42-44°C) while at Avro-City 90% of the open spaces was (45-49°C), at 15:00 PM o'clock 71% of the open spaces was (48-52°C) and 19% (46-48°C) while at Avro-City 92% of the open spaces was (48-52°C) and at 18:00 PM o'clock 70% of the open spaces was (36-38°C) and 24% (48-50°C) while at Avro-City 46% of the open spaces was (37-39°C) and 41% (47-49°C).

Time	Avro City Summer (13.07.2013) PET (°C) Maps	Zery Land Summer (13.07.2013) PET (°C) Maps
9:00 AM		
12:00 PM		



Figure(3)PET maps result at summer

Winter:

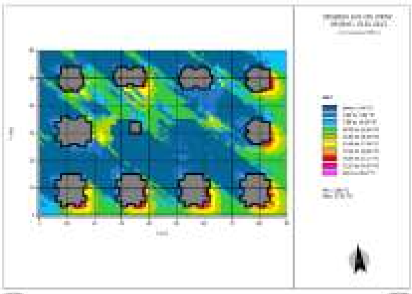
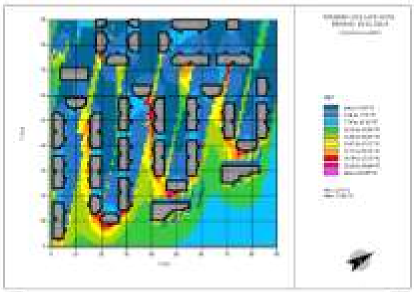
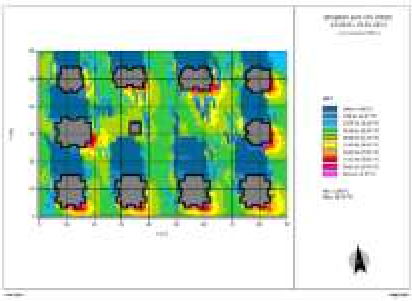
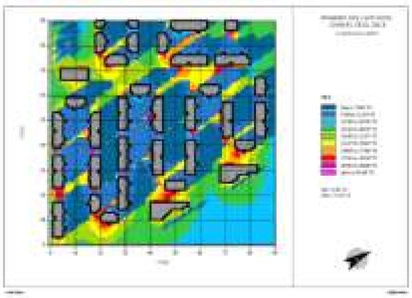
Fig. 4 also shows a comparison between the two residential complexes thermal comfort index (PET) maps at 9:00 AM, 12:00 PM, 15:00 PM and 18:00 PM o'clock at the coldest day of winter, and one more time the two study area haven't provide a thermally comfortable open spaces, but there is a deference in the performance. Zery-Land residential complex have slightly better results at the beginning and the end of the day compared with Avro-City complex, for example PET index at 9:00 AM o'clock 39% of the open spaces was (3-7°C), 32% (7-11°C) and 18% (11-15°C) while at Avro-City 52% of the open spaces was (3-7°C), 20% (7-11°C), 20% (11-15°C) and at 18:00 PM o'clock 54% of the open spaces was (3-5°C) and 44% (5-7°C) while at Avro-City 75% of the open spaces was (3-5°C) and 23% (5-7°C).), in contrast Avro-City has better performance at day hours, for example; at 12:00 PM o'clock 34% of its open spaces was (17-25°C) on other hand 19% of Zery-Land's open spaces was (17-25°C) and 15:00 PM o'clock 38% of its open spaces was (10-17°C) and 16% (17-25°C) while at Zery-Land 35% of its open spaces was (10-17°C) and 14% (17-25°C).

Difference in urban design characteristics between the two complex results open spaces with different densities and sky view factor (SVF), Zery-Land is more compacted and has lower SVF than Avro-City, due to its urban design characteristic mentioned above, and this means less radiation fluxes, and thus the radiation budget. All these factors interpret the variance in microclimatic and thermal comfort between the two complexes, orientation, size and shape of buildings determine the proportion of the shaded spaces, so these characters haven't play effective role when buildings are just an isolated towers (Avro-City) floating at unbounded space, in contrast linear buildings typology constituting semi-closed spaces have an effective role and present better performance

In order to find out precisely the causes behind this deference in performance between the two residential complexes, three points were selected at each complex as follow:

- L means a point at left hand of the typical open space and shaded at 3:00 o'clock.
- M means a point at the center of the typical open space.
- R means a point at right hand of the typical open space and shaded at 9:00 o'clock.

Table 5, Fig. 5 and table 6, Fig 6 showed that the most effective factor on PET is the mean radiant temperature, air temperature and wind speed are secondary factors with respect to comfort as they vary lesser. And this means that shading plays the major role in this regard, the deference in PET index between shaded and sunny places (L and R points) may reach to 14 °C, but this role has disappeared at noon and afternoon and appear clearly in morning, 9:00 o'clock, and at the end of the day at 6:00 PM o'clock due to solar incidence angle. M points microclimatic and thermal comfort factors are constant in nature due to the absence of shading factor, but the results showed that point at Zery-land has a higher mean radiant temperature 63.756 °C compared with 57.568°C, at Avro-City, this resulted by direct solar radiation and a higher reflection of diffused short-wave radiation from both vertical and horizontal surfaces, and trapping of long-wave radiation due to its geometrical properties (H/W ratio equal 1). The low wind speed for the two complexes accentuates the sensation of discomfort.

Time	Avro City Winter (15.01.2013) PET (°C) Maps	Zery Land Winter (15.01.2013) PET (°C) Maps
9:00 AM		
12:00 PM		

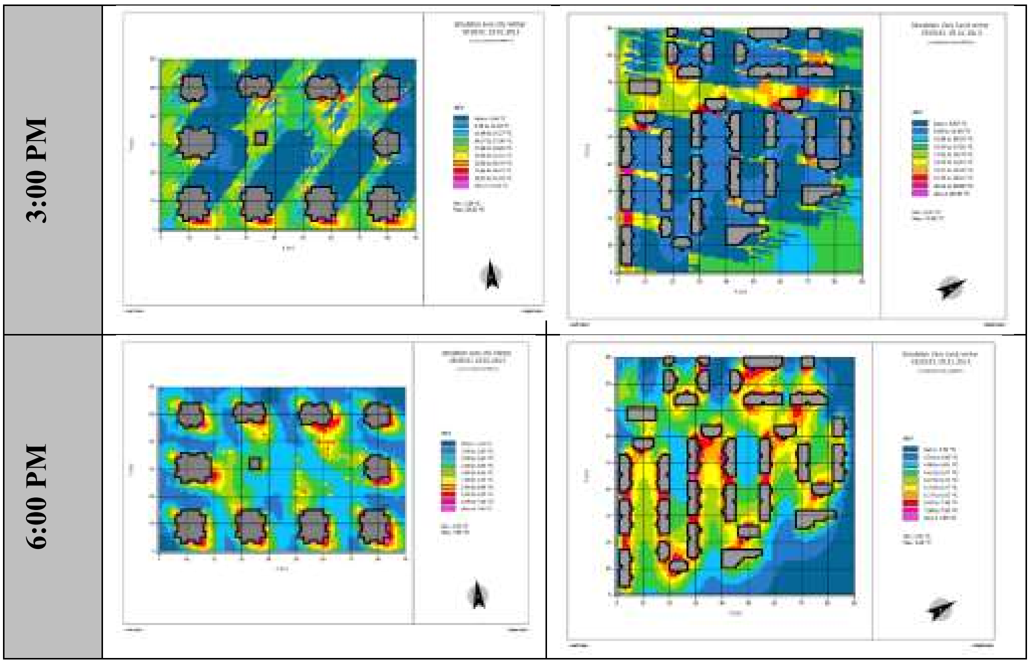


Figure (4)PET maps result at winter

Table(5)Pet, Air Temperature And Mean Radiant Temperature Of (3) Points At Avro-City (Summer)

Time	PET (°C)			Air temperature (°C)			Mean Radiant Temperature (°C)		
	L	*M*	*R*	*L*	*M*	*R*	*L*	*M*	*R*
9:00 AM	47.572	47.124	33.105	31.342	31.274	31.067	68.063	68.014	39.366
12:00 PM	42.78	48.825	48.85	35.512	35.548	35.528	52.724	66.494	66.226
3:00 PM	47.468	47.519	50.397	38.609	38.653	38.789	57.302	57.512	81.232
6:00 PM	36.925	36.994	48.866	36.678	36.712	36.83	38.161	38.251	63.079
Avg.	43.686	45.116	45.305	35.535	35.547	35.554	54.063	57.568	62.476
Avg. Wind Speed m/s							0.57	1.41	1.24

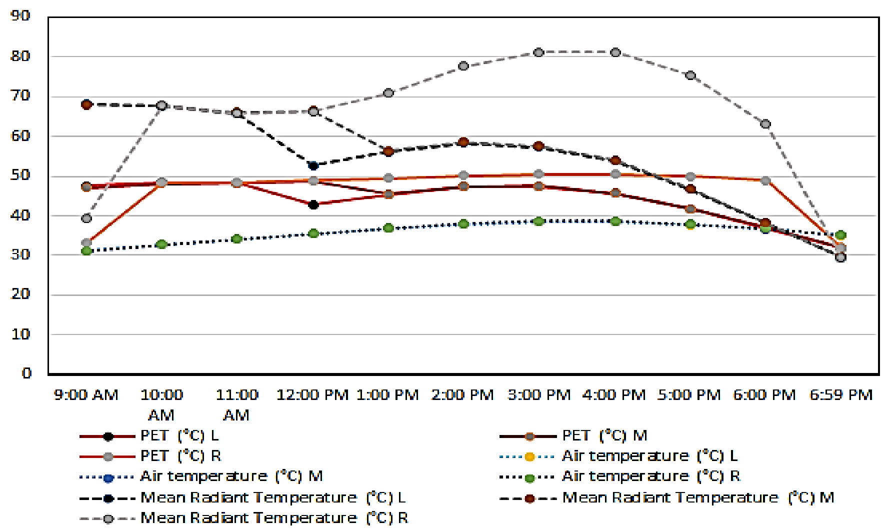


Figure (5) PET, Air temperature, Mean radiant temperature of (3) points at Avro-City (summer)

Table (6)Pet,Air Temperature And Mean Radiant Temperature Of (3) Points At Zery-Land (Summer)

Time	PET (°C)			Air temperature (°C)			Mean Radiant Temperature (°C)		
	L	M	R	L	M	R	L	M	R
9:00 AM	46.840	47.211	32.348	30.788	31.195	30.521	68.175	68.062	39.547
12:00 PM	48.863	48.874	48.802	35.642	35.566	35.684	66.883	66.935	66.513
3:00 PM	47.873	50.385	47.847	38.784	38.711	38.982	58.046	81.664	57.825
6:00 PM	37.148	37.088	37.222	36.835	36.766	36.953	38.358	38.364	38.271
Avg.	45.181	45.890	41.555	35.512	35.560	35.535	57.866	63.756	50.539
Avg. Wind Speed m/s							0.949	1.123	0.955

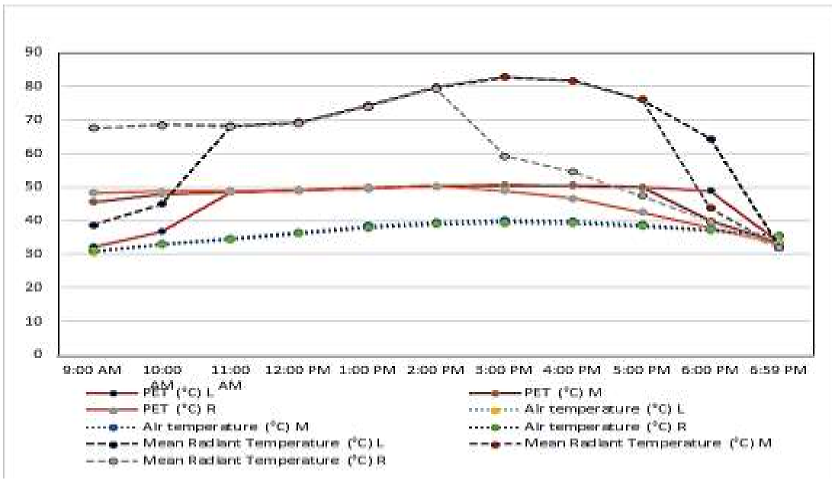


Figure (6) PET, Air temperature, Mean radiant temperature of (3) points at Zery-Land (summer)

In such climate, normally the priority of urban design aiming thermal comfort should be given to the hot period which last six months, but for better understanding of role of urban design setting in comprehensive thermal comfort, the paper explore this subject at winter season which last three months, Table 7, Fig. 7 and table 8, Fig 8 showed the two complexes hadn't provide a comfortable open spaces through day time with exception of 12:00 at Avro-City, where PET between (18-26), the rest of PET results indicate to cold sensation. Never the less, Avro-City had better PET indices compared with Zery- land complex, due to its open and unclosed spaces which permit the exposing of direct sun radiation, in contrast to the other complex which prevent the solar radiation to reach the open spaces due to its urban design properties mentioned above. In contrast to summer, thermally comfortable conditions in winter are mostly caused by a reduction in shading, which increases areas exposed to direct solar radiation. And one more time mean radiant temperature factor plays the main role in sensation of thermal comfort, but this factor is not available all the times because of the limited number of sunny days in winter. For wind speed, Zery-Land provides better shelter from the cold wind comparing with Avro-City due to the higher compactness which it has.

Table (7)Pet, Air Temperature And Mean Radiant Temperature Of (3) Points At Avro-City (Winter)

Time	PET (°C)			Air temperature (°C)			Mean Radiant Temperature (°C)		
	L	M	R	L	M	R	L	M	R
9:00 AM	9.178	4.147	4.586	5.347	5.367	5.195	13.374	4.024	4.673
12:00 PM	26.800	17.800	18.800	7.270	7.506	7.311	52.754	50.264	49.974
3:00 PM	10.692	16.800	7.796	8.448	8.645	8.462	15.274	45.261	11.776
6:00 PM	6.320	4.224	4.547	7.294	7.322	7.215	-0.766	-1.739	-1.046
Average	9.178	4.147	4.586	5.347	5.367	5.195	13.374	4.024	4.673
Avg. Wind Speed m/s							0.516	1.113	0.925

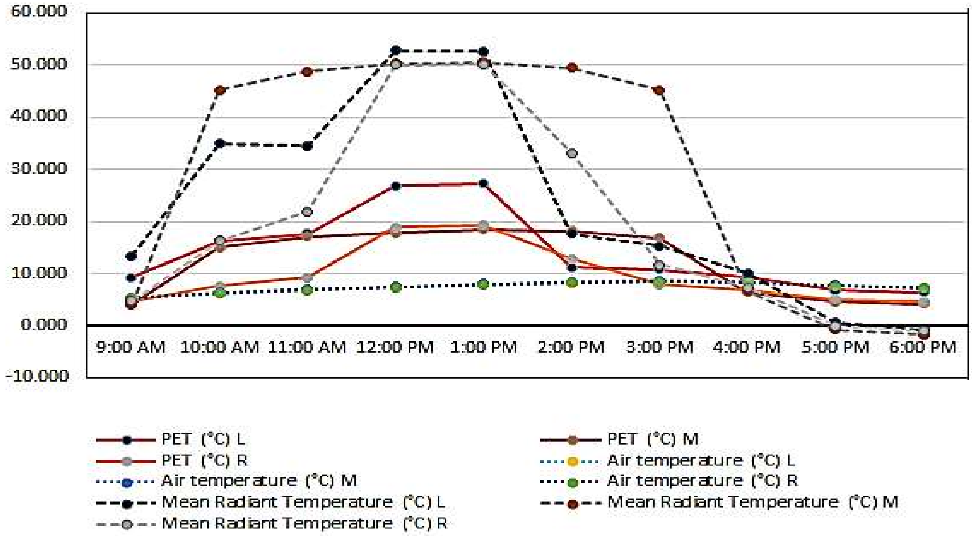


Figure (7) PET, Air temperature, Mean radiant temperature of (3) points at Avro-City (winter)

Table (8)Pet, Air Temperature And Mean Radiant Temperature Of (3) Points At Zery-Land (Winter)

Time	PET (°C)			Air temperature (°C)			Mean Radiant Temperature (°C)		
	L	*M*	*R*	*L*	*M*	*R*	*L*	*M*	*R*
9:00 AM	5.5428	5.599	5.614	5.109	5.177	5.087	7.486	7.584	7.505
12:00 PM	8.7788	8.821	8.922	6.754	6.797	6.846	18.683	18.853	18.722
3:00 PM	8.5952	8.613	8.691	8.318	8.340	8.343	14.339	14.455	14.362
6:00 PM	5.0367	5.063	5.112	7.372	7.421	7.395	-0.102	-0.010	-0.100
Average	5.5428	5.599	5.614	5.109	5.177	5.087	7.486	7.584	7.505
Avg. Wind Speed m/s							0.858	0.822	0.786

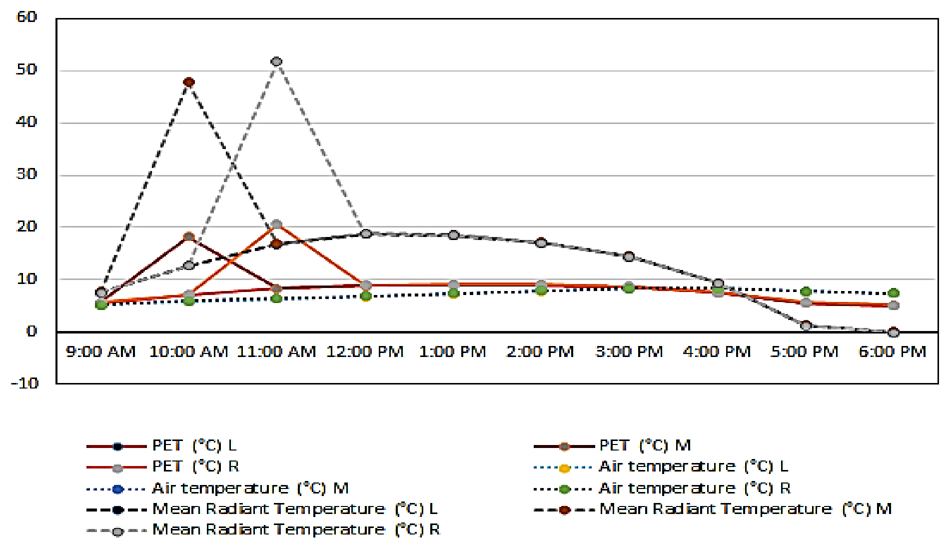


Figure (8)PET, Air temperature, Mean radiant temperature of (3) points at Zery-land (winter)

Conclusions and Recommendations:

- The study shed light on the consequences of urban design characters which can have on human thermal comfort in urban environment.
- The poor landscape at Zery-Land residential complex didn't prevent it from providing better performance compared with Avro-City complex due to its urban design characters; linear urban forms constituting semi-closed open spaces, more compact and low sky view factor.
- The idea of studying human thermal comfort at open spaces incorporates the aim of raising attention to available methods and tools that facilitate designing and evaluating alternative before taking action in implementation.
- Mean radiant temperature is the main factor influencing human thermal comfort, so shading is deemed the best strategy to achieve this goal.
- Means of shading should not excluded to the vertical building forms, but there is a necessity for integration of vertical and horizontal means, like arcades, covered walkways, pergolas, elevated buildings etc., which will enhance the environmental conditions that the body is exposed.
- Closed and semi-closed open spaces should be adopted in such harsh climate in order to create a controlled microclimate, so the linear urban form, which can be achieved by segment, corridor and gallery residential systems, deemed better than isolated tower building provide by point system, but that's not prevent from using mixed systems.

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Appendix: Samples of Simulation maps results

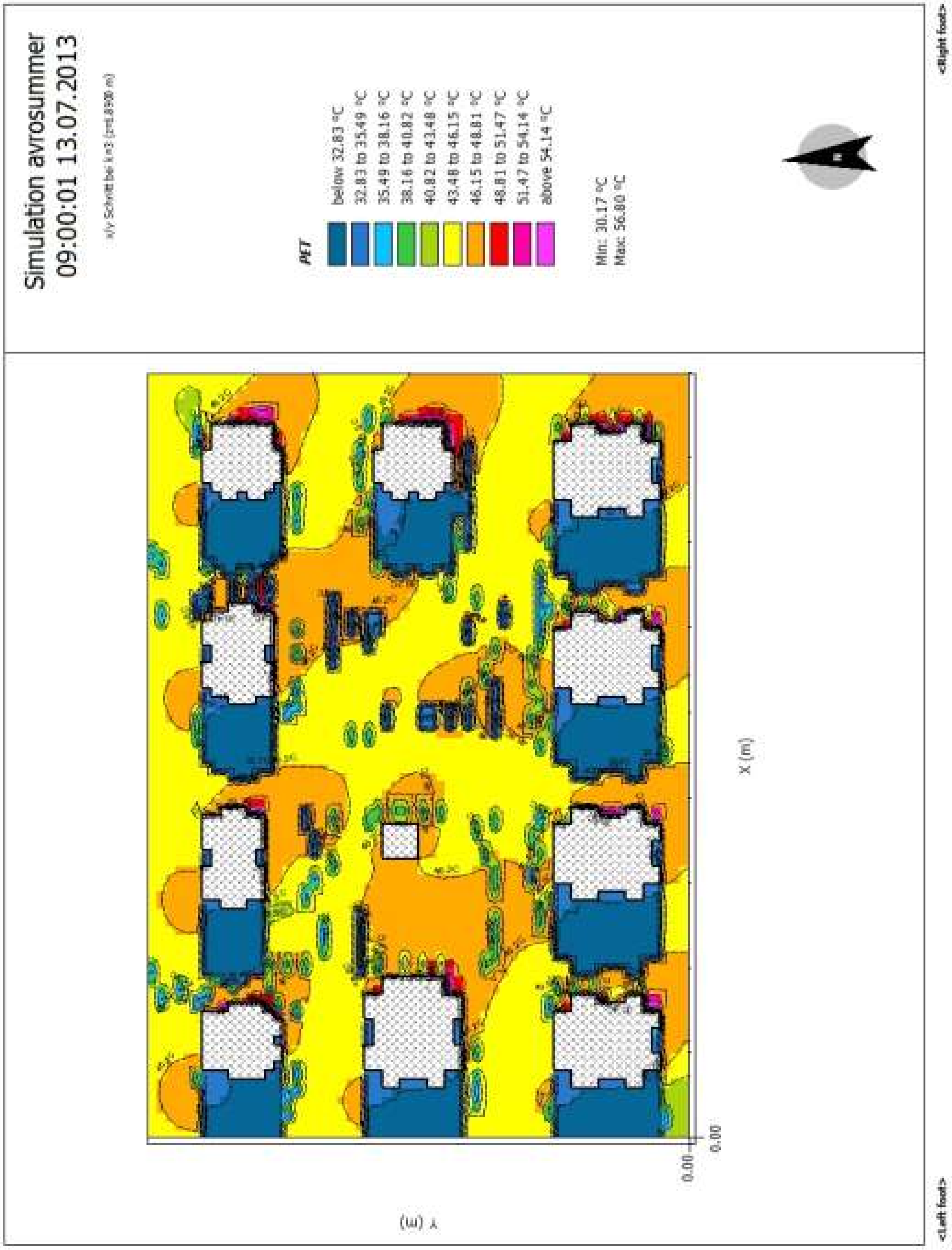
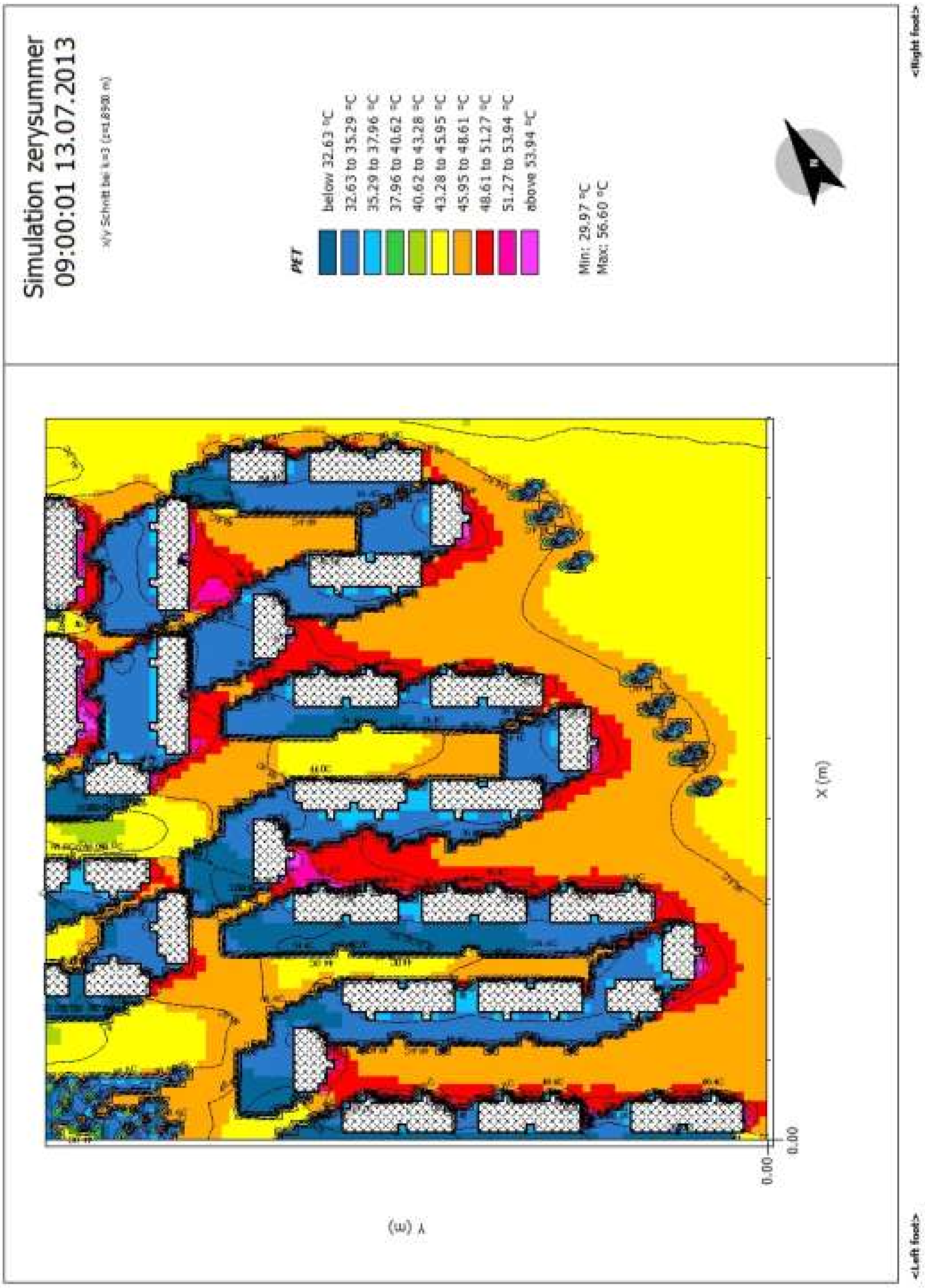


Figure (1) PET (°C) Simulation map of Avro-city at summer 9:00 O'clock Results are at 1.89 meter height



Figure(2)PET (°C) Simulation map of Zery-land at summer 9:00 O'clock Results are at 1.89 meter height