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Tehrān-Karaj

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The Dependence of Outdoor Thermal Comfort on Urban Layouts

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Abstract

The goal of this research was evaluation of effect of urban layouts on outdoor thermal comfort. Thermal comfort in outdoor Settings is a topic that, until recently, has received little research attention. Most of the researches concerning thermal comfort focused mostly on indoor spaces. The former studies—carried out by author in Iran—showed thermal comfort is the main component of comfortability in urban open space.

To analysis the effect of urban layouts on outdoor thermal comfort, Young Cities project located in Tehran region was selected. Analyses were done in two different levels and scales, including large scale, 35 hectare pilot project in Hashtgerd using ENVI-met and medium scale, Sub-neighborhood level, by Ecotect.

The result of this research would lead to optimizing sub-neighborhood layout regarding outdoor thermal comfort and energy efficiency and defining architectural guidelines for 35 hectare pilot project. Furthermore based on these outcomes optimal; form, orientation, façade, height of building and layout of open space would be suggested.

Keywords
Ecotect, ENVI-met, Outdoor Thermal Comfort, Physiological Equivalent Temperature, Simulation, Urban Layout

1 Introduction

Due to its nature; open public space involved a huge part of urban activities. One of the most important principles in designing open public spaces is considering thermal comfort in order to improve the quality of space and increase user's satisfaction (Monam 2011). Only In the last 20 years the transfer of knowledge from climatologic and biometeorologic studies to urban & architectural design tools has begun to take place (Akbari, Davis, Dorsano, Huang, & Winnett 1992; Brown 1995; Dessi 2002; Katzschner 2006; Ochoa De la Torre J.M. 1999) (Scudo 2005: 261). In urban areas, the great variety of different surfaces and sheltering obstacles produces a pattern of distinct microclimate systems. To simulate these local effects, micro scale surface–plant–air interaction schemes with a special extension to typical artificial urban boundaries are required (Bruse & Fleer 1998).

The general aim of this research is studying, analyzing and identifying Environmental elements which increase outdoor comfort that consequently influences on indoor comfort. The study is limited to the microclimate at urban open space and will be conducted in Iran, Hashtgerd. This research project proposed to investigate aspects of urban space, which could contribute to improve outdoor human thermal comfort using urban layout such as form and height. Key questions approached in this work are:

- How urban morphology (Orientation of blocks and layout of open space, scale of building) affect thermal comfortability?
- How simulation analyzes could improve thermal comfort in urban open space?

2 Outdoor Thermal Comfort

One of the most affected environmental qualities is human thermal comfort in the urban outdoors (Behzadfar & Monam 2011; Monam 2011). There are four environmental variables affecting thermal comfort of a human body: air temperature, mean radiant temperature, air humidity and air speed. Additionally, two personal variables influence thermal comfort: clothing and the level of activity. Other personal factors related to adaptation, and acclimatization has proven to affect thermal sensation (Ghazizadeh, Monam, & Mahmoodi 2010).

Since outdoor thermal environment may not be comfortable all the time, the various created microclimates offer individuals control in overcoming thermal discomfort. People tend to adapt to the ambient thermal conditions by modifying a clothing and activity patterns in order to continue their activities and routines. e.g. (Donaldson, Rintamaki, & Nayha 2001; Gehl 1987; Nasar & Yurdakul 1990; Nikolopoulou, Baker, & Steemers 2001; Parsons 2002).

There are several bio meteorological indices as indicators of thermal stress and thermal comfort. In this study one of the most widely used bioclimatic indices, the physiologically equivalent temperature (PET) is used. PET, which is expressed in °C, is based on a combination of the heat balance model MEMI (Hoppe 1999) and a parts of the two-node model used for new Effective Temperature (ET*) and Standard Effective Temperature (SET*). It is defined as "the physiologically equivalent air temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of a human body is maintained with core and skin temperatures equal to those under the conditions being assessed" (Hoppe 1999). The conditions of the indoor reference climate entail air temperature equal to MRT, wind speed of 0.1 m/s ("still" air) and vapor pressure of 12 hPa (Table 1).

To study thermal comfort the benchmarks of indices have to be considered differently depending on the regional climate and urban situation. Therefore, it is not possible to only refer to one index value worldwide. A calibration of PET, using ordinal regression analysis, applying data from Germany (Katzschner 2011) and Tehran (Monam & Ghazizadeh 2012), shows the difference in perception concerning heat stress. For a sedentary person wearing typical indoor clothing, thermal comfort is defined as PET values between 18 and 23°C in Germany and between 25 and 28.5°C in Iran (Monam 2011) (Table 2).

Variables	
individual	Metabolic heat production (M)
	Mechanical work accomplished (W)
	Clothes resistance (Iclo)
microclimatic	Air temperature (Ta)
	Vapor pressure (Pa)
	Wind velocity (Va)
	Mean radiant temperature (T_{mrt})

Tab. 1: PET index considered in the present study (Monteiro & Alucci 2006)

PET (°C) Tehran (Monam, 2011)	**PET (°C) Germany** (Katzschner, 2011)	**Thermal perception**	**Grade of physiological stress**
< 17.5	< 13	Cool	Moderate cold stress
17.5–25.0	13–17	Slightly cool	Slight cold stress
26–32.0	18–28	Comfortable	No thermal stress
33–36.0	29–34	Warm	Moderate heat stress
37–40.0	35–41	Hot	Strong heat stress
> 41.0	> 42	Very hot	Extreme heat stress

Tab. 2: Calibration of PET (°C) in Germany, Hong Kong, Brazil and Tehran (based on empirical data)

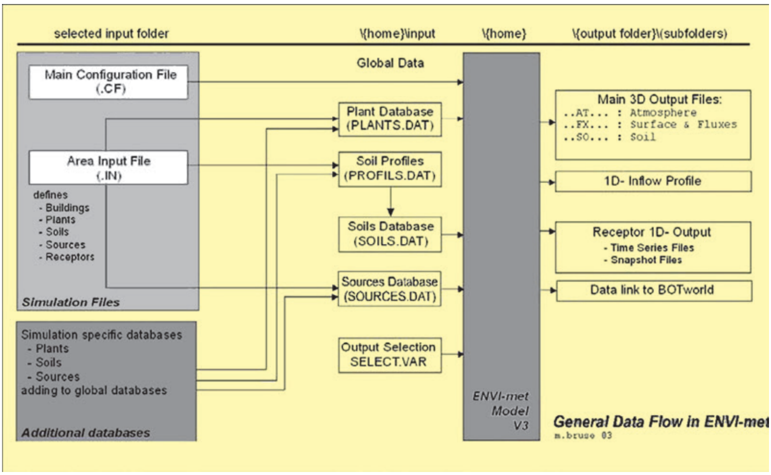

Fig. 1: Basic data structure of ENVI-met (Ozkeresteci et al. 2003)

3 Simulation with ENVI-met

In this study, the three-dimensional model ENVI-met 4, was applied. ENVI-met is a computer program that predicts microclimate in urban areas. It is based on a three-dimensional and energy balance model. According to researches (Ali-Toudert 2005; Emmanuel, Rosenlund, & Johansson 2007; Fahmy & Sharples 2009; Lahme & Bruse 2003; Ozkeresteci, Crewe, Brazel, & Bruse 2003; Yu & Hien 2006) ENVI-met software's result is more precise and reliable in comparison with other software.

This model takes into account the physical processes between atmosphere, ground, buildings and vegetation and simulates the climate within a defined urban area with a high spatial and temporal resolution, enabling a detailed study of microclimatic variations. The horizontal model size is typically from 100 m × 100 m to 1,000 m × 1,000 m with grid cell sizes of 0.5–5 m. ENVI-met allows two different types of vertical grids: an equidistant grid, where all grids, except the lowest five, have an identical vertical extension, and a telescoping grid where the grid size expands with the height (Bruse 2004). (Figure 1) The input data consist of physical properties of urban area and limited geographical and meteorological data. The required input data for the buildings are dimensions, reflectivity, U-value and indoor temperature.

The model uses detailed data on soils, including thermal and moisture properties. Both the evapotranspiration and shading from vegetation are taken into account. The required geographical and meteorological input data are longitude and latitude, initial temperature and specific humidity of the atmosphere at 2,500 m (upper model boundary), relative humidity at 2 m height, wind speed and direction at the 10 m height, and cloud cover. The model provides a large amount of output data, including wind speed, air temperature, humidity and MRT and PET in version 4.0.

4 Area of Study

To analysis, the effect on urban layout in thermal comfort, Young Cities project (35 hectares) located in Tehran—Karaj region was simulated. Two urban layouts were analyzed to include low-rise building (as a new design) and high-rise building layout (as a typical form in that area). Simulations and analyses have been done in these different levels with different scales.

- In Large scale, 35 hectares pilot project in Hashtgerd, thermal comfort in two samples of high and low rise building at nine selected points was studied (Figure 2 and Table 4).
- In Medium scale, Sub-neighborhood level, optimum orientation of building; building volume and height, façade materials, distance between buildings, yard dimension and vegetation position were studied (Figure 3).

Fig. 2: Modeled locations in high and low rise building

Low rise building				High rise building			
Location	Cover	SVF	Tertian (m)	Location	Cover	SVF	Tertian (m)
1	Asphalt	0.53	10	1	concrete	0.91	20
2	Asphalt	0.77	22	2	Asphalt	0.61	22
3	Grass	0.49	47	3	Soil	0.62	47
4	Concrete	0.74	25	4	Water	0.79	24
5	Asphalt	0.71	12	5	Grass	0.59	12
6	Concrete	0.76	27	6	Soil	0.65	32
7	Grass	0.62	20	7	Grass	0.61	32
8	Asphalt	0.66	42	8	Soil	0.75	40
9	Asphalt	0.55	52	9	Asphalt	0.73	45

Tab. 3: Description of the modeled location

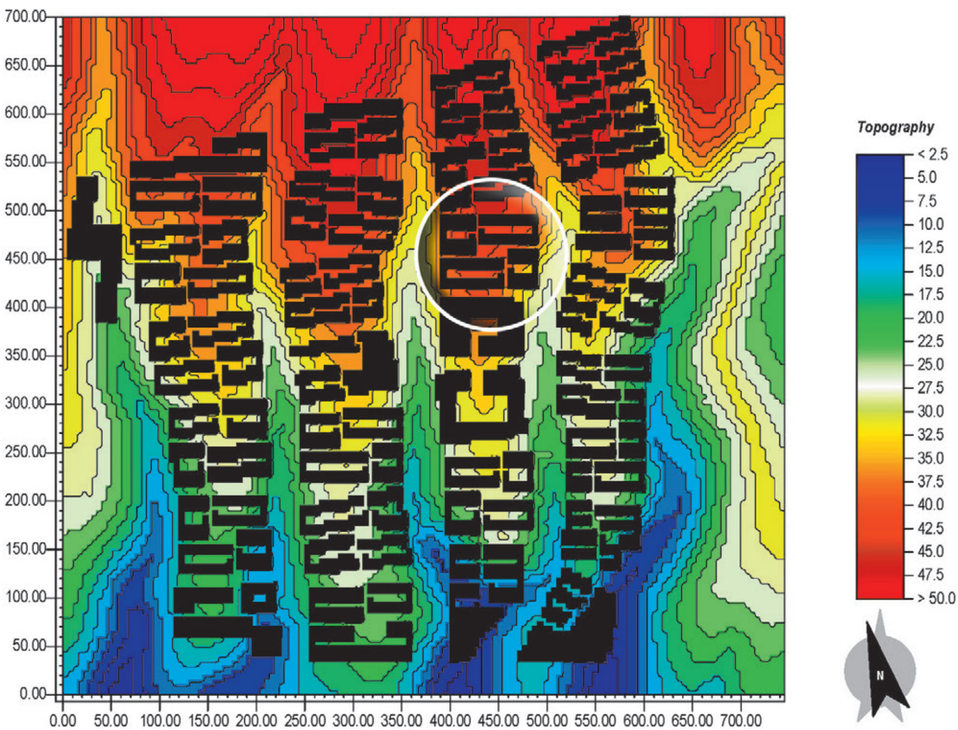

Fig. 3: Position of sub-neighborhood area in topography map

5 Simulation Process

ENVI-met has two basic steps before simulation is running. The first is editing the input of the urban area to be tested. The second step is editing the configuration file, where the information about temperature, wind speed, humidity, and databases for soil types and vegetation are entered. The simulation is then processed using both input and configuration files. ENVI-met outputs binary files which have to be imported into the visualization program LEONARDO.

The output generated files can be separated into two groups: main data files; contain the complete state of the 3D model, including the atmosphere, surface and soil. Receptor files; these files are generated if were defined receptors inside the model area to watch specific points in more detail. In this paper, the simulations were initiated using data obtained from a Hashtgerd weather database on Meteonorm software, Version 6.0, and upper air data from Tehran Mehrabad observations (Table 4).

Simulation period is the mid-day of the mid-month of spring, summer and autumn. In winter, fifth of January was selected because that day in a middle of winter has minus degree of temperature. Area around 35 ha pilot project has been transformed in the ENVI-met model grid with the dimension 149 × 140 × 34 grids with a resolution of 5 m × 5 m × 2.5 m resulting in a total area of 745 × 700 m in the horizontal extension (Table 5).

Date	Avg. Daily	5th Jan	5th May	6th Aug	6th Nov
Wind Speed (m/s)	2005–2011	3.0	1.2	1.2	3.9
Wind Direction (deg)	2005–2011	145.0	215.0	237.0	160.0
RH (%)	2005–2011	64.0	31.0	21.0	50.0
Cloud (1–8)	2005–2011	6.0	4.0	1.0	4.0
Humidity 2,500 m (K)	2001–2011	2.1	3.7	4.1	3.4
Temperature 2,500 m (G/Kh)	2001–2011	296.4	307.8	319.6	303.3

Tab. 4: Input meteorological data applied in the ENVI-met simulations (University Of Wyoming 2012; Weather Underground 2012)

Time	Start of simulation at Time (h)	00:00
	Total Simulation Time (h)	15:00
Building	Indoor Temperature (K)	294.15
	Heat Transmission Walls (W/m^2K)	0.20
	Heat Transmission Roofs (W/m^2K)	0.32
	Albedo Walls, Roofs	0.2, 0.3
Biometeorology	Age, Sex	35, male
	Weight (kg), Height (m)	75, 1.75
	Static clothing insulation (clo)	1.2, 0.8
	Energy-Exchange (Col. 2 M/A)	116
	Walking speed (m/s)	0.5

Tab. 5: Input configuration data applied in the ENVI-met simulations

6 Compare Low-rise and High-rise Building Layout

Mean radiant temperature, surface temperature and wind velocity were compared in two-sample layouts (Figure 4). The results show in the open space around the low rise building weather is cooler than the area around high-rise building. Also weather in low-rise layout is more humid than high-rise building in summer (Figure 5).

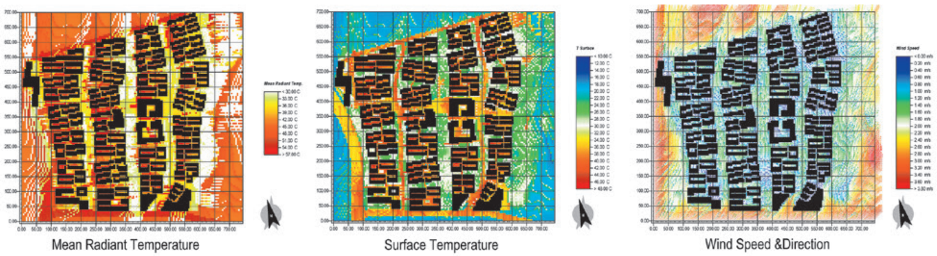

Fig. 4: Simulation of low-rise building layout by ENVI-met 4

In this study, PET index for compare outdoor thermal comfort was used. Before analyzing, local range of PET instead of universal range and thermal insulation of Iranian clothing were required. The thermal insulation of clothing is one of the important parameters used in the thermal comfort model adopted. Compare PET between low-rise and high-rise layout, shows more outdoor thermal comfort in low-rise building (Figure 6).

Fig. 5: Compare low-rise and high-rise building layout in middle point of site

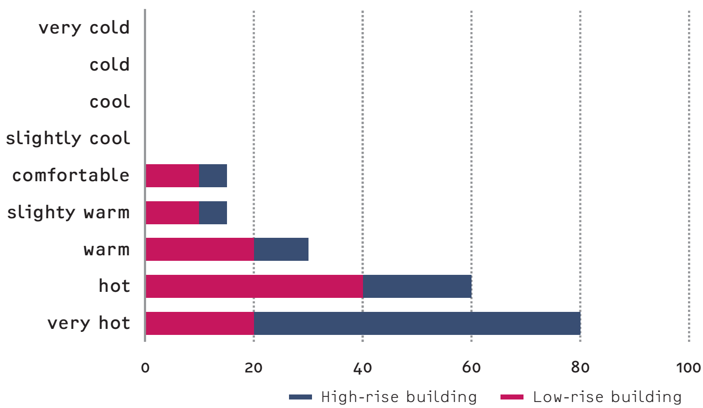

Fig. 6: Compare PET between low- and heigh-rise layout in all open space

7 Analyze of Sub-neighborhood Layout

In medium scale, a sub-neighborhood area in 35 hectares as a sample was selected. Criteria of design Sub-neighborhood based on outdoor thermal comfort includes (Figure 7):

- Increase sky view factor by architectural design
- Increase natural ventilation through open space layout
- Increase vegetation through creating green network in open space
- Attention to the tree types and position of the plants

Based on comparing solar radiation and wind flow in a difference sample, the optimum form of building was achieved in terms of volume, orientation, height and material (Figure 8). To decrease temperature and increase humidity and wind flow in summer following measures could be applied:

- Using shading trees as an overhead canopy
- Using turf or ground cover instead of paving
- Reducing close shrubs to encourage air circulation
- Encouraging overhead planting, which slows evaporation
- Adding water elements such as fountains
- Using low windbreaks to preserve moisture
- Using natural mulch under plantings

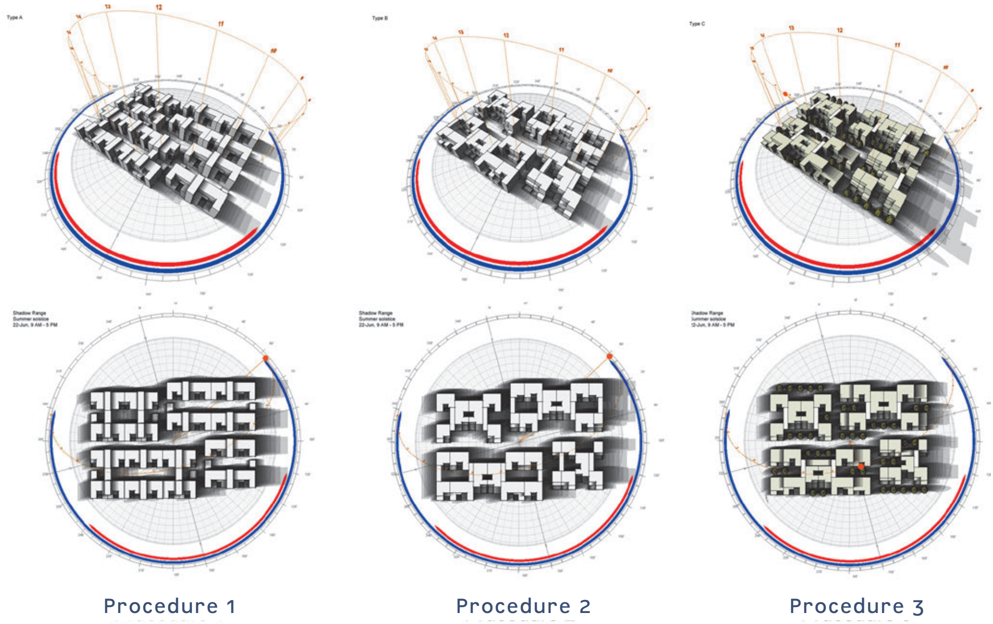

Fig. 7: Optimization sub-neighborhood layout designs

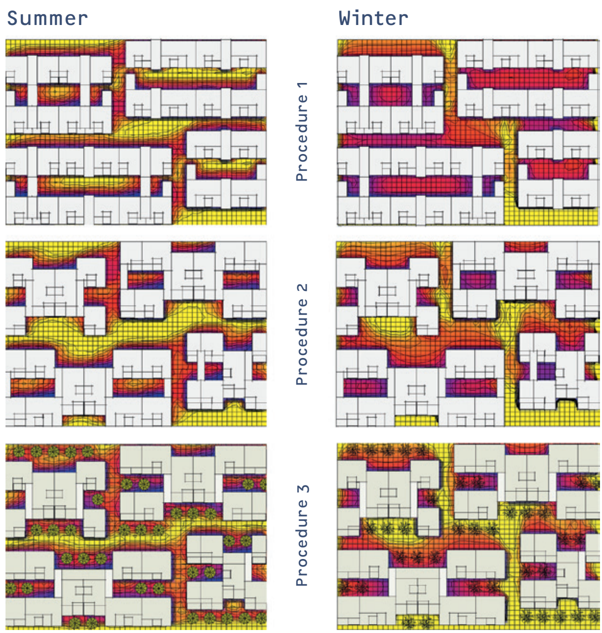

Fig. 8: Comparing solar radiation in three samples

8 Conclusion

The results of simulation showed outdoor thermal comfort in low-rise layout is higher in comparison with height-rise layout according to the PET index. The result from this research implied optimizing sub-neighborhood layout regarding outdoor thermal comfort and energy efficiency and defining architectural guideline such as form, orientation, façade and height of building for 35 hectare pilot project. The results confirmed huge modifications of thermal comfort are possible in summer with few modifications of urban layout such as planting and architectural form.

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