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Urban Morphology and Energy Performances: Investigating the Impacts of Urban Openness Factor on Theoretical Energy Demand, Case Study: Isfahan Urban Morphological Types

Yones Changalvaiee[1*], Mostafa Behzadfar[2], Mahmud Mohammadi[3] and Zahra Sadat Saeideh Zarabadi[4]**

[1] Ph.D. in Urban Design and Planning, Faculty of Art and Architecture, Science and Research Branch, Islamic Azad University, Tehran, Iran.

[2] Professor in Urban Design, Faculty of Architecture & Urban Planning, Iran University of Science and Technology, Tehran, Iran.

[3] Assistant Professor in Urban planning, Faculty of Architecture and Urban Development, Isfahan Art University, Isfahan, Iran.

[4]Associate Professor in Urban Design and Planning, Faculty of Art and Architecture, Science and Research Branch, Islamic Azad University, Tehran, Iran.

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ABSTRACT: The serious environmental challenges that the human settlements are faced with, such as climate change, resource crisis, greenhouse gas emissions and water crisis are necessitated changing the perspectives and adopting the adaptive policies of guiding and controlling the human settlements towards responsiveness of the above challenges. Accordingly, the present research aims at investigating the effective aspects of urban form on environmental performances while focusing on urban openness as one of the important general factors of built form. The methodological framework of the research has been founded on the analytical-comparative studies of the impacts of urban form on the theoretical energy demands according to the specific morphological units in the general morphological context of the Isfahan. On this basis, five tissue types (morphological units) have been selected arising from urban morphological approaches and methods as the comparative and analytical basis of the study. The results and findings demonstrate that there is a strong and significant correlation between energy demands and urban openness in general while the two classes of measures in terms of levels of complexity are classified as the analytical basis of the research. Results demonstrate that geometrical and configurational aspects of urban form are in compliance with the climatic conditions in environmental performances studies. Finally, indicating the paradoxical behaviors of heating energy demands in cold seasons and cooling energy demands in hot seasons especially in the case of hot and arid climate conditions in relation with urban morphological characteristics (focusing on urban openness factor) has been considered as the most important achievement of this research.

Keywords: Urban Openness, Morphology, Energy Demand.

INTRODUCTION AND FRAMEWORK

The recent Intergovernmental Panel on Climate Change (2015) again highlighted the need for a drastic change in national and international policies regarding the mitigation of climate change due to greenhouse gas emissions. Buildings account for almost 40% of energy consumption in European countries and hence are responsible for a significant part of greenhouse gas

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** Corresponding Author Email. Behzadfar@iust.ac.ir.

emissions. In the case of developing countries, especially in the case of Iran, regarding to the cities and climate changes report (UN, 2011) Iran's share of global CO_2 emissions is 1.55%, which is a significant rate in the global scale and building sector is also the main resource for GHG emissions in Iran by 26.4% of total CO_2 emissions (Nasrollahi, 2010). Furthermore, over the 98% of energy consumption in building sector provided from fossil fuel productions in Iran and the building sector by consuming more than 40% of total energy is the largest energy consumption sector (IMG, 2012). On the other hand, Today about 50% of the world's population lives in urban areas and is expected to grow to 66% by 2050 (UN, 2014).

Cities represent concentrations of economic and social activities that produce GHG emissions and they produce between 40 and 70 percent of global anthropogenic GHG emissions. On this basis, by 2030, over 80 per cent of the increase in global annual energy Demand above 2006 levels will come from cities in developing countries and on the other hand, In a more global picture, 20% to 40% of the total final energy consumption in developed countries can be attributed to buildings in urban zones, and the urban population is increasing (Perez et al., 2008).

Accordingly, Cities and energy are fundamentally connected, as Girardet noted that Consumption takes place within urban settlements, which cover only 2% of the earth's surface (Girardet, 1999). While urban area account for roughly 2% of the earth's surface area, they account for three-quarters of the world's energy consumption (Salat, 2009), on this basis, more than 50% of energy consumed in urban areas is used in the operation of buildings, resulting in over 35% of the world's greenhouse gas (GHG) emissions (Price et al., 2006).

Forasmuch as the great amount of energy consumption in cities is related to the building sector, scrutiny on areas of knowledge which can be connected robust nexuses between two important macro variables of energy consumption and the city as their interactions is significant.

In this study the relations of the two main macro variables of the research will be discussed by using the interdisciplinary framework of urban morphology because one of the roles of urban morphology is to identify the repeating patterns in the structure, formation and transformation of the built environment to help comprehend how the elements work together, notably to meet human needs and accommodate human culture (Kropf, 2014).

On this basis, the present research has been considered the primitive aspects of confluences of urban form with human needs in the form of environmental performances of theoretical cooling and heating energy demands towards thermal comfort. Theoretical energy demand is an estimation basis for energy demand in terms of merely morphological aspects which have significant impacts on energy demands such as geometry, configuration, shape and etc. (Salat, 2009; Swan an Ugarsal, 2009, Rode et al., 2014).

Accordingly, all non-morphological factors impacting on heating and cooling energy demands such as the insulation factor (u-value), façade details, building age, utilizing factor (consumption behavior), materials, vegetation and etc. were kept constant. The climatic context according to the hot and aired climate of Isfahan has been included the temperature, wind speed, wind direction, relative humidity, nebulosity, rain fall and horizontal global irradiance features.

Regarding the general subject of the research, urban openness as one of the general urban form factors, has been fragmented to specific analytical measures for studying morphological aspects of energy performances. The measures then, have been classified from simple levels to complicated levels and their correlations with energy demand have been investigated.

The objectives of the research therefore, have been considered as an analytical framework for investigating the relations and correlations between urban openness measures and theoretical heating and cooling energy demands.

For this purpose, the CitySim urban scale energy estimation program has been utilized for calculating and estimating heating and cooling energy demands. The main important advantage of the model comparing with the other models especially in the field of building energy estimation is its ability in simulating urban scales based on urban geometry and specific climatic conditions. Hence, specific methodology of the research could be described as the following steps:

- Selecting morphological context, and corresponding dataset (climate and related information). The case of Isfahan morphological context and its meteorological characteristics.
- Providing 3-D geometry modeler and models (compose building envelopes, volume and surfaces). Keeping these aspects as constant for all morphological samples: material, wall thickness, glazing ratio, U-value, Land use, and neutralizing of the vegetation structure impacts on thermal model.
- Adopting the CitySim Simulator transient heat flow solver the based on given thermal and radiation models and stablishing, modifying the CitySim dataset according to the Isfahan energy profile.

- Plant and equipment models-keep constant for all samples.
- Stochastic occupancy related models (presence, appliances, windows, lighting & shading, refuse)-keep constant for all samples.
- Microclimate models

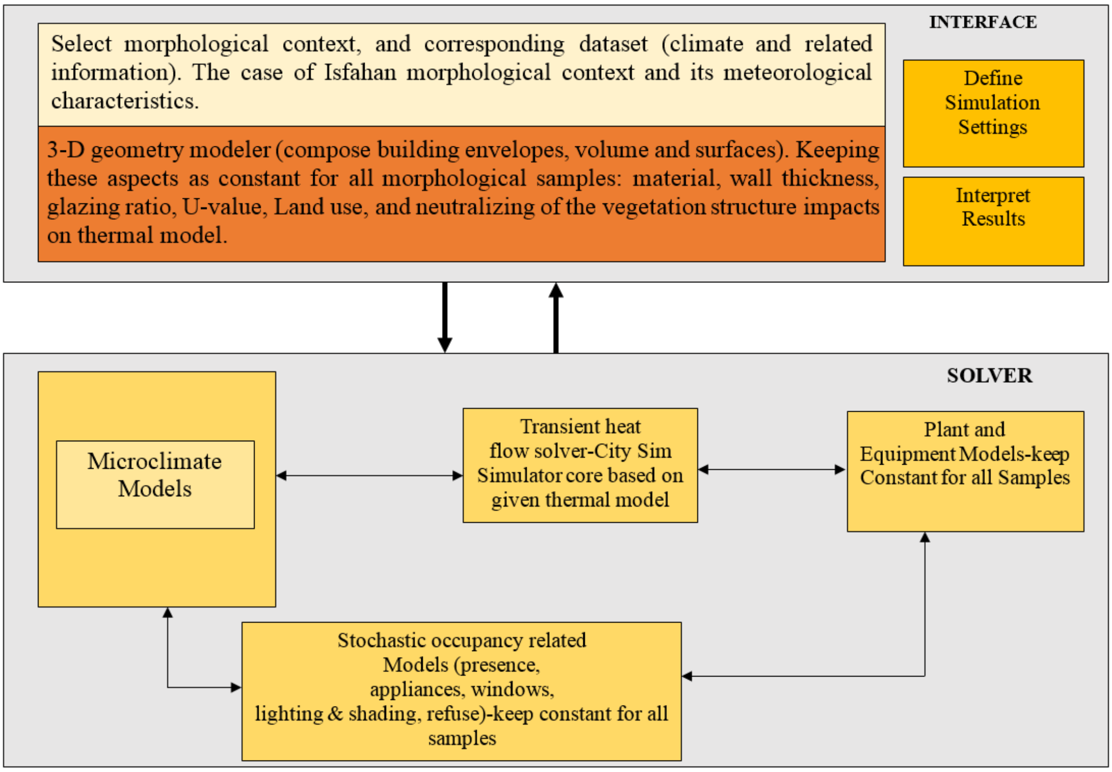


Fig. 1. Workflow of Energy Demand Estimation in the Case of Isfahan Morphological Types

URBAN MORPHOLOGICAL CONTEXT (SPATIAL SCALE OF ANALYTICAL MORPHOLOGICAL UNITS)

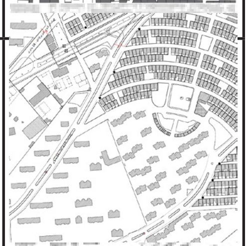
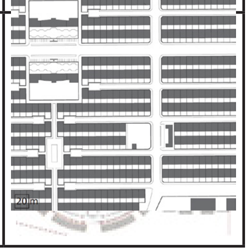
One of the important parts of the research is case study selecting methodology. As Batty mentioned: one of the major themes to support a research program for urban morphology: is establishing basic units of morphological description (Batty, 1999, p. 2). At present research “urban tissue” derived from Caniggia, and Maffei (1979, 2001) and Kropf (1993, 2011, and 2014) has been considered as urban morphological unit of the research.

Most urban analyses are carried out within defined physical boundaries or specific spatial scale of urban tissue as an urban spatial unit of analysis. Accordingly, most urban environmental performance studies have considered different scales of urban tissue ranging from 100 m x 100 m to 4 km x 4 km for urban analyses: 1km x 1km grid and 1km radius (Theurer, 1999); 400 m x 500 m urban fabric (Adolphe, 2001); 100 m x 100m urban grid (Cionco & Ellefen, 1998) and 4 km x 4 km urban grid (Long et al., 2003).

On the other hand, identification of distinct types of morphological units (urban tissue) have important role in the large morphological context of the city or town. According to the process of typological approach of urban morphology (Kropf, 2011; Caniggia and Maffie, 2001) and its related methods and principles, five tissue types have been classified in morphological context of the Isfahan (see table (1)). For this purpose, the typo-morphological method which was used and approved by Kropf and Changalvaiee (2014), has been considered to this study for presenting a holistic and inclusive perspective of urban morphological states of Isfahan urban morphological patterns. Therefore, five tissue types were selected as morphological units. Therefore, regarding the geometry simulation process of each tissue and selecting a viable scale according to the nature of a simple tissue which contains heterogeneous aspects of morphological levels in a specific hierarchy such as building patterns, plot patterns and street patterns, 100m x 100m spatial unit area has been selected for analytical process of the research.

Accordingly, one sample (100meter × 100meter) was selected from each type as the final analytical units of the research. As a general classification of the table (1), morphological types of Isfahan are classified into two general categories: 1- old and organic patterns (tissue types 1, 2 and 4) 2- modern, fragmented and grid pattern (tissue types 3 and 5).

Table. 1. Morphological Unit Definitions and Characteristics

Tissue Type	Plot Type	General Characteristics	General Aspects	[illegible]
Tissue Type 1	• Central Courtyard	Old Historical Core	• Organic Structure and Configuration • Compact Blocks	
Tissue Type 2	• Central Courtyard • Multi-Story Front Court	The Transformed Centre	• Grid Structure • Compact Blocks	
Tissue Type 3	• Multi-Story Front Court • Isolated Apartment	The Transformed Extensions	• Fragmented Structure • Isolated Block Apartments	
Tissue Type 4	• Informal Settlements • Central Courtyard • Single Family Front Court	The Attached Rural Areas-Informal Settlements.	• Organic Structure and Configuration • Compact Blocks	
Tissue Type 5	• Multi-Story Front Court • Isolated Apartment	The Isolated Apartment Blocks and Grid Multi-Story Front Court	• Grid Structure • Isolated Block Apartments	

(Kropf & Changalvaiee, 2014)

MORPHOLOGICAL ASPECTS FOCUSING ON URBAN OPENNESS AND ENERGY PERFORMANCES

Quoted from Ratti et al., (2003) "Leslie Martin and others at Cambridge University selected six simplified urban arrays based on archetypal building forms. Then they analyzed and compared the archetypes in terms of built potential and day lighting criteria" (Ratti et al., 2003, p. 49). They introduced theoretical estimation of environmental performances of built form according to the geometry of urban form for the first time. The shapes of the urban blocks studied by Martin and March (1972) were considered by the researchers who were interested in thermal impacts of urban form (Salat, 2009y; Ratti et al., 2003; Ratti et al., 2005). So, at the present research, this methodology has been considered as the main concept for investigating the relations between urban morphology focusing on urban openness factor and environmental performances.

URBAN OPENNESS FACTOR

Spatial Openness as a general factor in urban morphological analysis was introduced by Gewirtzman (2003) and could be described as, natural lighting, natural ventilation and spaciousness influence perception and the ambience aspects of urban form in relation with human perception and comfort (Osmond, 2008), which is one of the main parameters determining the quality of life in built environment (Gewirtzman, 2003). Present research hasemphasized on environmental comfort according to the ambience ranges of heating and cooling demands (a form of human needs) resulting from urban form production, formation and transformation processes. Openness factor as one of the general aspects of urban form resulting from these processes embodied in geometrical context of general morphological characteristics has been investigated in several studies and researches in relation with energy performances. Reviewing the most important studies indicates that there are two different ranges of considered measures in terms of complexity levels, From simple to complicated levels. The partial assumption of the research is that complicated measures have strong correlation with energy demands in both cooling and heating than simple openness measures.

Ratii et al. demonstrated that the courtyard configuration showed better response through the calculated environmental variables (surface to volume ratio, shadow density, daylight distribution, sky view factor) than the pavilion types in a hot and arid climate (Ratti et al., 2003).

Baker and steemers indicated that in most cases the view of the horizon will not be free of obstructions in all directions (Baker and steemers, 2000); this is particularly true of urban tissue where other buildings often block out large areas of the sky. This will affect energy use in three ways by reducing the availability of daylight, the useful heating in winter due to solar gain, and the cooling load due to solar gain in summer. On this basis and according to the LT method (Baker & Steemers, 1996) they defined the Urban Horizon Angle (UHA) as the average elevation of the skyline from the center of the façade being considered (Baker & Steemers, 2000; Montavon, 2010).

The morphological model developed by Luc Adolphe (2001) addresses a more restricted category of metabolic flows, through description and explanation of the interactions between the micro-scale configuration of urban form, urban climate, building energy balances and the diffusion of airborne pollutants. Six classes of objects are included in the model: plots, buildings, outdoor spaces, routes, vegetation and water bodies. The details of Adolphe's indicator set – comprising the properties of rugosity, porosity, sinuosity, occlusivity, compacity, contiguity, solar admittance and mineralization (Osmond, 2008; Adolphe, 2001).

Regarding to these, Salat demonstrated that the morphological indicators which have a high influences on energy efficiency are these factors: average height of the canopy, occlusivity (indicating openness to the sky), density, shape factor and passive volume (Salat, 2009).

According to the other aspects of urban form, Robinson, Comapgnon and others indicated that three vertical surfaces (Mean sky view factor, Mean urban horizon angle and Mean height to width ratio) have significant influences on solar thermal viability in relation with solar gains which seems that these parameter could be considered as analytical factors to heating and cooling demands (Robinson et al., 2005).

Accordingly, based on complexity levels of analytical measures the final classification from simple measures to complicate measure is as follows: **Urban Horizon Angle** (UHA) and **Height to width ratio** (H/W), **Sky View Factor** (SVF), **Occlusivity** and **Total permeability.**

Sky View Factor (SVF), **Urban Horizon Angle** (UHA) **And Height To Width Ratio (**H/W):

Sky View Factor (SVF) is the common indicator used to examine the potential for utilizing natural radiation of urban forms along with the height to width ratio and the urban horizon angle. These indicators are conveniently related to one another (Robinson & Stone, 2004).

On this basis, Darren Robinson is the prolific author in this relation. He has demonstrated that the irradiance on a plane of slope β (where 0 corresponds to horizontal facing up,π/2 to vertical and π is facing down) viewing an isotropic sky obstructed by buildings of mean urban horizon angle μ is:

$$I_{d\beta} = I_{dh}[1 + \cos(\mu + \beta)] \,/\, 2$$

This is equivalent to the product of horizontal irradiance and view factor; so that we may write:

As illustrated in Fig. 2:

$$V_s = [1 + \cos(\mu + \beta)] \,/\, 2$$

$$\text{And then } \mu = \cos^{-1}(2V_s - 1) - \beta$$

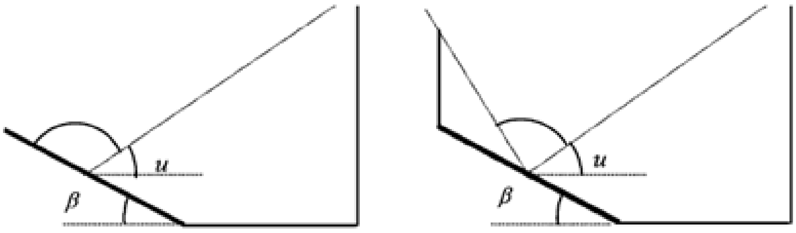


Fig. 2. Isotropic canyon model, (Robinson and Stone, 2004).

In this respect, h/w is then tangent μ (Robinson, 2006), as illustrated in figure 3.

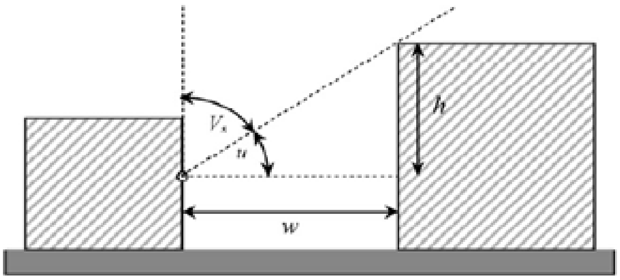


Fig. 3. Geometric Definitions of h, w, μ and Vs for a Point on a Vertical Surface (Robinson, 2006)

Occlusivity – mean openness of urban spaces to the sky, reflecting the height distribution of built elements; Vertical movement of air from the lower different types of open spaces may have impact on the rate of dispersion. Distribution of built area and void area with height could be a good indicator to consider the impact of rate of dispersion. According to Adolphe (2001), distribution of built elements in vertical plane has an impact on air pollutant dispersion, and solar heat/radiation. He suggested Occlusivity (Oc) for capturing these effects. Effects of perimeter is justifiable for the rate of dispersion; encompassing perimeter variations against building height within an urban building canopy.

This was also adopted from Adolphe (2001) as:

$$\frac{1}{Nhorz.Cuts \times \sum Pbuilt/Punbuilt}$$

Adolphe (2001) used a number of horizontal cuts on urban tissue at 3.5m intervals or floor by floor (Adolph, 2001).

Permeability: ratio of the "useful" volume to the total volume of the urban tissue, based on the hydraulic equivalent radius, which distinguishes between street profiles; Adolphe (2001) presents 'porosity factor' as the total of useful open spaces within an urban canopy that are effective for dispersion of air flows.

$$\mathrm{Po} = \frac{\sum \pi \times r^2 \times \mathrm{Li}}{\sum \mathrm{Vi} + \sum \mathrm{Vj}}$$

r= The hydraulic equivalent radius= HD/2

Li= Length of the open space i.

Vi= Mean canopy volume above open space i.

Vj= Mean volume of the built volume j.

H= Height of the canopy for the street (mean height of the adjacent built and non-built spaces).

W= Mean street width.

According to the Adolphe, (2001), Xuan and Quin proposed Permeability (PERM) index as follows:

$$PERM = \frac{\sum[(\cos\theta i)^2 \times \frac{\pi}{4} \times HD^2 \times Li]}{\sum Vi}$$

$(\cos\theta i)^2$ Is the Sinuosity (Si) factor, related to the acceleration of the enclosed air within the void (Adolphe, 2001; 2014), which in turn has a component in the direction of the pressure gradient caused by oncoming wind flow (Xuan and Quin, 2013).

In this research the Permeability equation has been modified in terms of Adolphe (2001) and Xuan and Quin (2013) works. The Permeability equation of this research includes two main parts. Wind Permeability and Solar Permeability coefficient. The main parts of the equation considering Adolphe, Xuan and Quin are as follows:

$$Fr = \frac{Openinig\ area}{Total\ built\ floor\ area}$$

1. Adding solar permeability coefficient to the Xuan and Quin equation as Total Permeability factor.

$$Total\ PERM = \frac{\sum[(\cos\theta i)^2 \times \frac{\pi}{4} \times (HD)^2 \times Li]}{\sum Vi} \times Sp$$

2. Solar permeability coefficient (Sp) includes the multiplication of two interrelated factors of Sky View Factor (SVF) and Frontal ratio (Fr). This coefficient is dimensionless.

3. Adopted and modified form MacDonald et al., 1998; Raupach, 1992 and Zhang et al., 2005, Frontal ratio defined as the ratio of frontal vertical wall surface area with solar admittance ability (opening areas) that faces the solar radiations, over the total built floor area.

So we have: Sp= SVF ×Fr   and;

and finally:

Hence, Total PERM index is defined as the summation of continuous pore space perpendicular to or an angle to wind direction, describing the corridor for wind flow within the building and open spaces. Li is the length (meters) of the linear segment i (within the buildings and open spaces), and θi is the angle (degrees) between the given azimuth (of wind flow) and the azimuth of linear segment i. Vi is the total volume of morphological unit.

Accordingly, two types of Permeability have been identified in this equation: Wind permeability (wind flows and direction in urban voids) and solar permeability (in terms of Sky View Factor and Urban Horizon Angel and its related useful exposure are, illustrated in Fig.3.

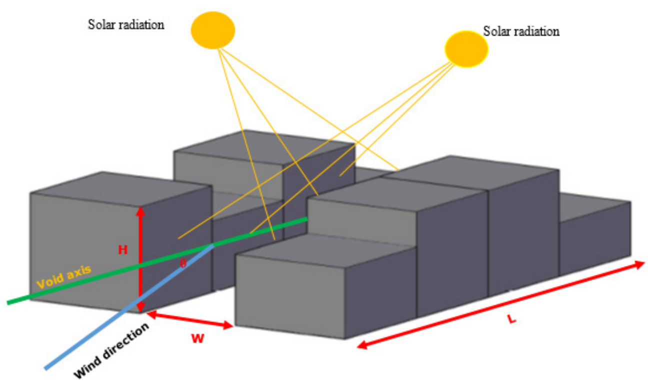


Fig. 4. Geometric Definition of Total Permeability According to the Wind Flows and Solar Radiations

ENERGY DEMAND SIMULATION METHODOLOGY

The urban energy simulation program CitySim is designed to compute the thermal loads of aggregations of buildings and the energy conversion systems (Robinson et al., 2011). The simulation program and software was developed at EPFL based on multiple physical models coupled together (Perez, 2014). The model is form-based calculation set according to the urban surfaces in a single or simple level or aggregation levels according to the electrical analogy models (Kampf, 2009; Kampf & Robinson, 2009a). A radiation model first computes the irradiation incident on each surface of the scene, direct from the sun, diffuse from the sky and reflected by other surfaces. On the other hand, the climate data as CLI formats resulting from Meteonorm software including sun diffusions, wind speed and direction, air temperature, humidity and etc. is the important part for the model calculations (Perez, 2014).

This model determines the thermal exchange through buildings' envelopes and computes the heating and cooling energy needs to maintain predefined temperature conditions (thermal comfort conditions) inside (Perez, 2014; Kampf, 2009).

RESULTS AND FINDINGS

Based on what has been mentioned, the calculation and simulation methodology has been formulated based on Climate information from Meteonorm software according to the hot and arid climate in the case of Isfahan, morphological calculation from CitySim software and their related energy consumption and demands. The heating and cooling energy demand of all the tissues was modelled so that the average annual heating and cooling energy demand per Cubic meters could be determined. Modelling can be used a reduced set of parameters, where all non-morphological factors impacting on heating and cooling energy demand such as the insulation factor (u-value), façade details, building age and materials were kept constant. The following table depicts the summary of results from morphological measure to theoretical energy demands calculations.

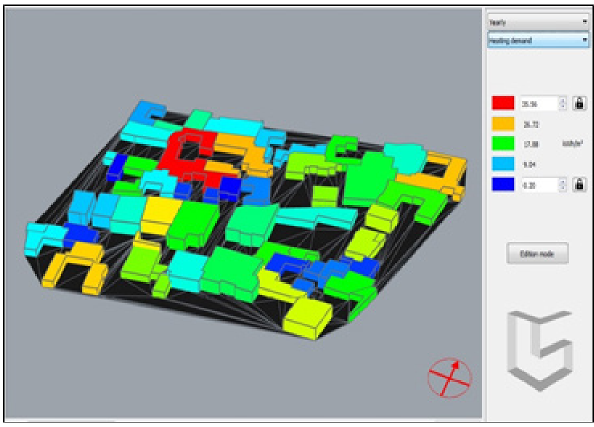
Table 2. Morphological and Energy Demands Calculation Results

Tissue Types	Heating Kwh/m3/ Year	Cooling Kwh/m3/ Year	SVF	UHA	H/W-tan(u)	Occlusivity	Solar PERM	Total PERM
T1	14.08	61	0.49	21.46	0.393	0.88	0.251	0.0041
T2	21.73	50	0.37	29.47	0.565	0.54	0.178	0.0085
T3	23.38	18	0.43	25.72	0.481	0.16	0.093	0.0168
T4	10.16	56	0.59	19.15	0.374	0.81	0.202	0.0031
T5	24.14	24	0.4	33.09	0.651	0.184	0.132	0.0149

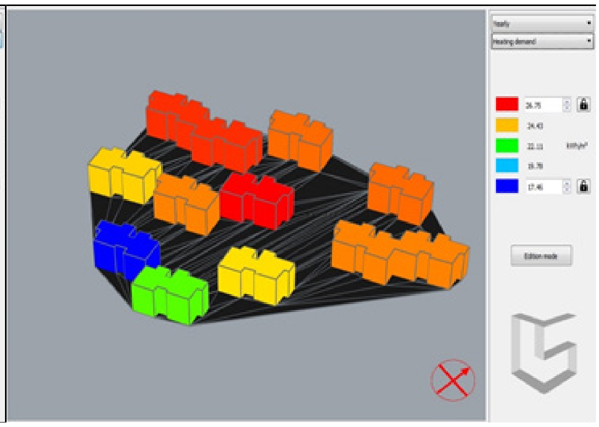
Regarding the research methodology and objectives, the results were classified into two levels base on the correlations between theoretical energy demand for heating and cooling and two levels of urban openness measure, simple and complicated levels.

Accordingly, results demonstrated that there is a significant negative correlation between theoretical heating energy demand and SVF with strong spearman value. So, heating energy demand significantly affected by SVF. The high value of SVF in old and organic morphological structure (tissue types 1 and 4) has significant influence on heating energy demand in cold seasons. Solar accessibility due to high value of SVF leads to benefit from natural solar gains to reach environmental comfort temperature during cold seasons. The results also indicate that there is no significant correlation between cooling energy demand and SVF (using null hypothesis).

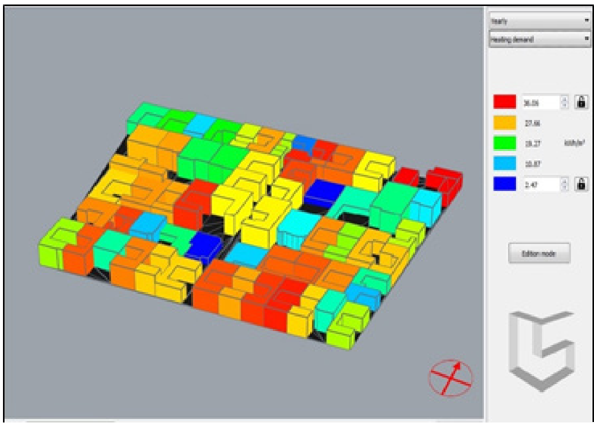
Following the table (3), for UHA measure, there is a significant positive correlation with heating energy demand this significant correlation cannot be found for cooling energy demand. In addition, both cooling and heating energy demand don't have significant correlation with H/W factor despite their strong positive correlation coefficient. Another important result for this part is strong negative correlation between UHA and SVF which indicates that the tissues (5 and 3) with grid and fragmented morphological structure with low value of SVF and high value of H/W represent the lowest value of solar accessibility during the cold seasons for benefit natural solar gains and this leads to increase in heating energy demands during this seasons.



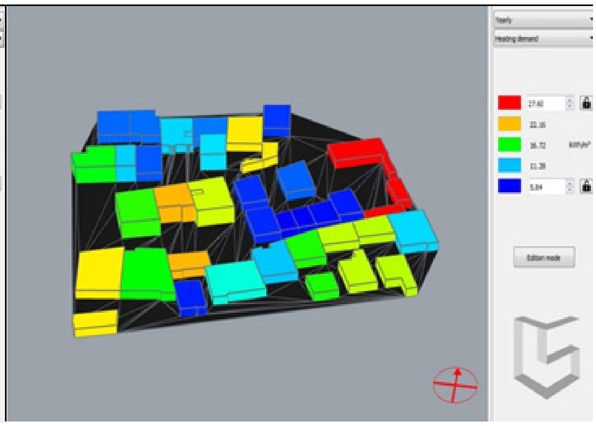
Tissue Type 1



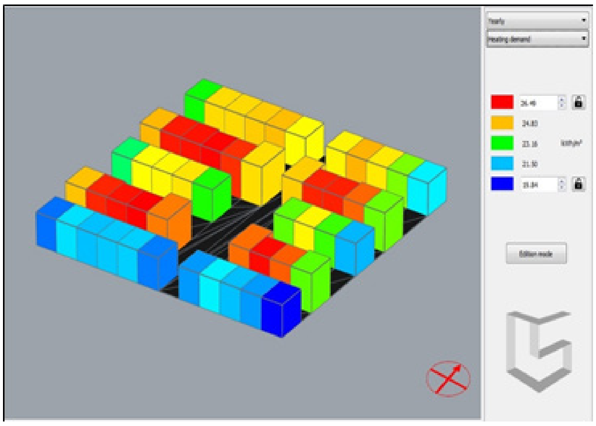
Tissue Type 3



Tissue Type 2

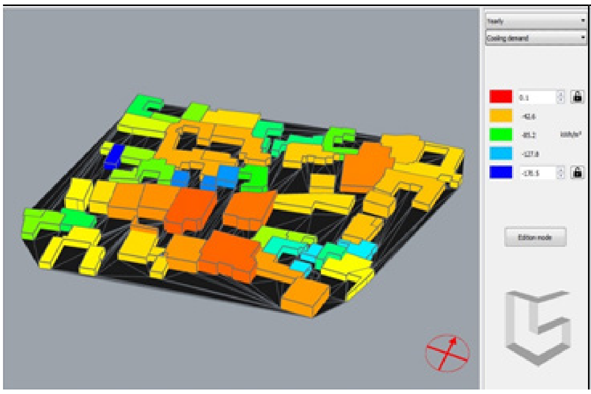


Tissue Type 4

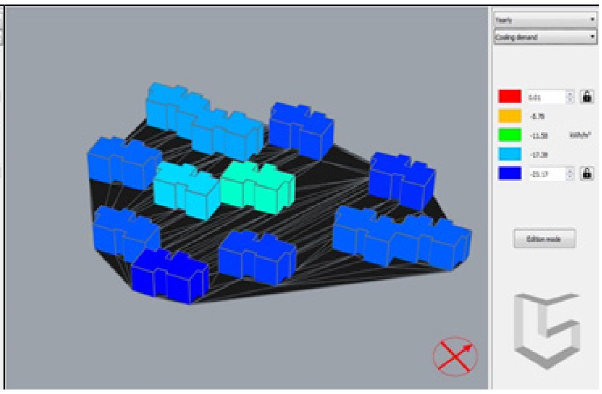


Tissue Type 5

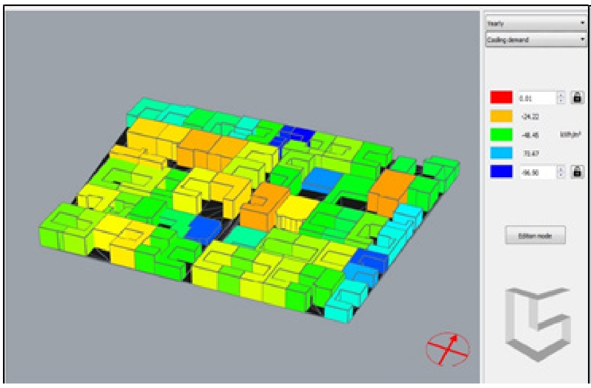
Fig. 5. Theoretical Heating Energy Demand, Graphical Results from CitySim Pro



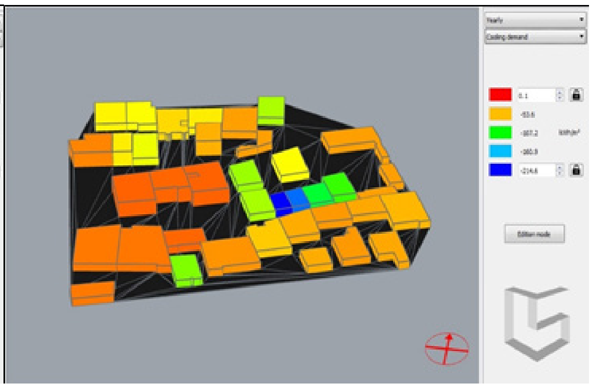
Tissue Type 1



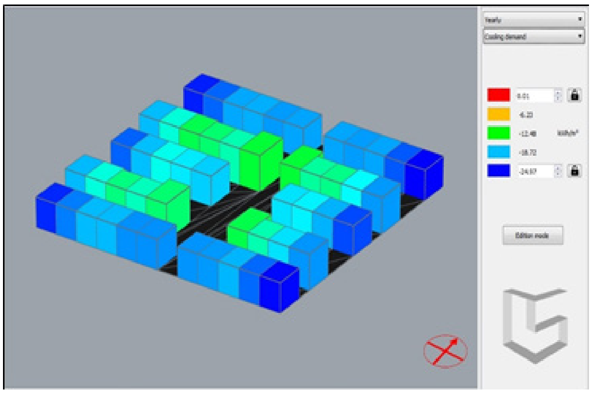
Tissue Type 3



Tissue Type 2



Tissue Type 4



Tissue Type 5

Fig. 6. Theoretical Cooling Energy Demand, Graphical Results from CitySim Pro

Table 3. Correlations between Energy Demands and Simple Level Measures of Urban Openness

		SVF	UHA	H/W
Heating Demand	Pearson Correlation	-.917*	.898*	.861
	Sig. (2-tailed)	.028	.039	.061
	N	5	5	5
Cooling Demand	Pearson Correlation	.510	-.620	-.609
	Sig. (2-tailed)	.380	.264	.275
	N	5	5	5
SVF	Pearson Correlation	1	-.888*	-.839
	Sig. (2-tailed)		.044	.076
	N	5	5	5
UHA	Pearson Correlation	-.888*	1	.994**
	Sig. (2-tailed)	.044		.001
	N	5	5	5
H/W	Pearson Correlation	-.839	.994**	1
	Sig. (2-tailed)	.076	.001	
	N	5	5	5

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

General conclusion for the correlations of simple level of measures with cooling and heating energy demands demonstrate that correlation results of these measures just signifies heating energy demands. For indicating reliable results based on integrated consideration of heating and cooling demands considering a holistic phenomenon in human needs in relation with built form specially in the case of urban openness factor is needed. For this purpose, combination of morphological aspects in a complicated level is necessary to investigating the environmental performances of built form. Two measures of total permeability and occlusivity then, have been considered as complicated level measures of the research arisen from integrated interaction of environmental performances (focusing on wind flow and solar admittance) which are affected by interactive and generative aspects of urban form especially in the case of urban openness factor.

1- For Total Permeability

This measure has significant and strong negative correlation with cooling energy demand and has significant and strong positive correlation with heating energy demand. Hence, the high value of permeability in grid and fragmented and isolated block apartments tissues (type 5, 2 and 3) lead to increase in heating energy demand due to the highest area exposed to shadow and obstacle surfaces and the lower ratio of solar permeability in comparing with old tissues and organic configuration (1 and 4), wind flows in cold seasons and etc. On the other hand, the highest value of permeability in fragmented and Isolated block apartments indicates the decreasing in cooling energy demand in comparing with organic and old tissue patterns (type 1 and 4) because of natural ventilation in hot seasons, the lower ratio of solar permeability, the higher areas exposed to shadow and obstacle surfaces (the lower ratio of SVF than old pattern tissue) and etc.

2- For Occlusivity

Results indicate that, there is a significant and strong negative correlation with cooling energy demand and significant and strong positive correlation with heating energy. Secondly, old and organic structure pattern tissue types (types 1 and 4 and type 2 due to compact blocks and plot types) have the higher value of occlusivity index in comparing with fragmented and grid-isolated apartment blocks (types 5 and 3). The measure is an indicative for horizontal and vertical built form interconnections. The higher ratio of occlusivity leads to the lower energy demand for heating (tissue types 1, 2 and 4) due to compactness and horizontal surface density, the lower height ratio and accordingly the higher solar permeability and lower wind flows in cold seasons (high areas of occlusive vertical and horizontal surfaces). The measure then has significant correlation with solar permeability which is important role in solar gains in cold seasons.

Table 4. Correlations Between Energy Demands and Complicated Level Measures of Urban Openness

		Total PERM	Solar PERM	Occlusivity
Heating Demand	Pearson Correlation	.9 07*	-.780	-.903*
	Sig. (2-tailed)	.034	.119	.036
	N	5	5	5
Cooling Demand	Pearson Correlation	-.979**	.959**	.977**
	Sig. (2-tailed)	.004	.010	.004
	N	5	5	5
Total PERM	Pearson Correlation	1	-.934*	-.987**
	Sig. (2-tailed)		.020	.002
	N	5	5	5
Solar PERM	Pearson Correlation	-.934*	1	.956*
	Sig. (2-tailed)	.020		.011
	N	5	5	5
Occlusivity	Pearson Correlation	-.987**	.956*	1
	Sig. (2-tailed)	.002	.011	
	N	5	5	5

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION AND CONCLUSION

As demonstrated in the case study analysis, the specification of the climatic zone within which any environmental research on urban form is taking place is fundamental in the analysis of results. The latter remains as givens and can only be interpreted within the climatic context. The case study demonstrated that the tissue type 1, 2 and 4 with courtyard configuration and compact blocks showed better response through the calculated environmental variables (sky view factor, total permeability and occlusivity) than the modern and fragmented patterns of tissues 3 and 5 in the specific context of hot-arid climates.

according to the results, it has been revealed that the simple level of urban openness measures (UHA, H/W and SVF) only have significant correlation with heating energy demands and this is while the complicated measure levels (occlusivity and total permeability) has significant and strong correlation with both cooling and heating energy demands.

Scrutiny on the relations and correlations between cocclusivity and total permeability indexes prove that the general impacts of urban form characteristics such as geometry and configuration on energy performances especially, for heating and cooling demand does not have an absolute impact but it is relative. Isfahan morphological tissue types with organic patterns and higher value of occlusivity and lower value of total permeability indexes has the lower heating energy demand (in cold seasons) and higher cooling energy demands (in hot seasons) than grid and fragmented tissue patterns.

Therefore, from what mentioned above, finding the paradoxical behaviors of heating energy demands in cold seasons and cooling energy demands in hot seasons especially in the case of hot and arid climate conditions in relation with urban morphological characteristics (focusing on urban openness factor) has been considered as the most important achievement of this research. The fact is that types of design strategies could be adopted in the context of urban design deeply depends on preferences of the controlling environmental conditions based on the given climate.

In the hot and arid climate of Isfahan due to the cold and dry weather conditions in the mid-autumn and winter and also the warm and dry weather conditions in the last month of spring and summer, the large amount of external resources to supply heating and cooling energy demands are fossil fuels in consuming domestic gas generally for heating energy and water resources directly and in producing electricity generally for cooling energy demands. Therefore the two important challenges of water crisis and climate change are required mitigation-led urban design strategies and energy efficient guidelines to sustainable design of built form.

Finally, as everywhere else throughout this study, the primary interest was in urban geometry and configuration. Many parameters have not been taken into account directly in the analysis, such as vegetation structures, land use, technical details, material and etc. Moreover, the operational domain of urban design focuses on proposing the patterns, guidelines and development briefs, the main mission of urban design relating the present study is guiding and controlling urban form in the context of urban development processes. On this basis, the main aspect of urban form and morphology which has direct interconnection with urban design is urban geometry and configuration. Hereupon, related to the research objectives following strategies would be derived from the findings and results of the relations between urban openness factors and environmental performances:

• Considering compact plot and block forms with a medium density according to the real values of occlisivity and total permeability.

• Considering courtyard plot types with high ratio of porosity.

• A critical look at the urban envelope aspect as an interface between open spaces and urban masses. The area with the high ratio of heat transfers regarding the geometrical and configurational context in a specific climate. For the envelope with the opening area these aspects are important to achieving better environmental performances: façade orientation according to the solar gains and shadow density, the ratio of exposure surfaces to mass volumes and passive zones.

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ENDNOTES

1. École polytechnique fédérale de Lausanne.

2. Meteonorm is a climatological database for solar energy applications.

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