Energy Efficiency in The Settlement Texture Through the Use of BIM

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Abstract. In the emerging new and densely settled areas in Turkey, rapid construction and unplanned urbanization where energy efficiency approach is ignored, cause rapid destruction of natural environment and depletion of energy resources. In terms of economic and environmental aspects, the reduction of energy consumption is a matter of priority in the settlement texture design. The settlement texture is a significant design variable to control energy consumption. The dimensions of the buildings, their spacing (distance between buildings) and the arrangement of buildings with respect to one another are the design parameters which define the settlement texture. This study aims to determine the energy efficient settlement texture design parameters by the using Revit that software of BIM. In this context, the first step of the method of the study is to develop different settlement texture alternatives which benefit from the solar energy. In the second step, annual energy consumption for a selected residential building in the developed alternatives is calculated. Finally, calculated annual energy consumptions are analysed and the appropriate of the settlement texture design parameters in terms of energy efficiency are determined. As a result, this study is focused on determining the appropriate settlement texture in terms of energy efficiency by using BIM in order to take the right decisions in the design stage. According to the results of this limited studies with 48 different settlement textures, SF3-10-EW-0.5 achieved the lowest total energy consumption. However, in order to reach an acceptable general conclusion, similar studies should be analyzed for many alternatives.

1. Introduction

Due to the development of technology, as a result of the desire of people to live in comfortable and qualified settlements, construction is gradually increasing. In Turkey, especially the rapid construction, unplanned urbanization, which ignores the energy efficiency approach, leads to the destruction of the natural environment and the depletion of energy resources. In this context, while creating new settlements that use energy sources effectively and minimizing the effects on the environment, energy efficient design approach is adopted in architecture to enable future generations to meet their needs. The aim of the energy efficient design approach is to ensure that the energy requirement is achieved through effective use of natural energy resources without damaging the natural cycle. When the energy statistics in Turkey examined, according to final energy consumption rates, the housing sector has a share of 20% in other sectors. However, with the effective use of energy efficient design approach in buildings, high saving potential can be evaluated and energy consumptions can be greatly reduced [1].

Since settlement design represents the upper scale in the energy efficient design approach, design decisions taken at the settlement scale play a decisive role in the energy consumption of buildings. Therefore, energy efficient design parameters need to be handled in a holistic approach. In addition, the
design decisions taken at the settlement scale, will remain unchanged for long years, very difficult to reconstruct and has negative consequences both the user and the country's economy [2]. Providing energy efficiency in buildings is possible by determining the optimum values of design parameters on the settlement scale. The design parameters that are effective on the settlement scale are site, location of buildings relative to each other and distances between buildings [3]. On the building scale building form, building orientation and optical, thermophysical properties of building envelope. The buildings in the settlements act as obstacles to each other in terms of solar radiation and daylight, depending on the distance between them, their height and their position relative to each other. Therefore, the heating effect of the solar radiation and the shade areas vary depending on the open space between buildings. However, the orientation of buildings has an important factor in making the buildings benefit from solar radiation according to the different positions of the sun during the year. On the building scale, one of the most important parameters is the form of the building. Because it defines all the geometric features of the building and determines the surfaces exposed to environmental factors such as the sun. All of these parameters should have optimum values in order to ensure energy efficiency in the settlement texture at the design stage.

In various studies, design parameters that are effective in reducing energy consumptions on settlement scale were examined. In the studies, among the parameters examined, the most important parameters that determine the dimensional properties of the settlement texture and which are effective in energy consumptions are distance between buildings and building heights. In order to create the ideal settlement texture, Oke [4] evaluated different street canyons depending on the ratio of building height to street width and building density parameters. Rattia and Baker [5], examined the effects of settlement texture on energy consumption for three different cities in Europe. As a result, it has been observed that the settlement texture has an effect of approximately 10% in energy consumptions. Strømann-Andersen and Sattrup [2] analyzed settlement textures developed depending on the different building height-street width ratios in North Europe. As a result, it was observed that the height/width ratio had an effect up to 30% in total energy consumptions. Van Esch and others [6] investigated the effects of settlement texture and building design parameters in terms of solar radiation gains. It is concluded that street widths affect the solar radiation gain between 17-20%. Mohajeri and others [7] conducted an urban-scale study. They evaluated their solar radiation gains depending on the direction and dimensional characteristics of the streets.

It is increasingly important to ensure that the optimum values of these design parameters can be used by all designers in the design process through BIM systems which have significant advantages in terms of parametric components, automation and simulation features and adaptability [8]. Combining energy efficient design approach with BIM methods creates great potential in the evaluation of the design process [9]. The results of the settlement texture alternatives developed for energy consumptions, together with the model image, provide real-time viewing in the same software. It will enable the design process to reduce energy consumptions by providing easier and faster intervention to design.

In this study, it is aimed to determine the settlement texture design parameters which are aimed to provide energy efficiency in buildings by means of BIM and to determine the proper settlement texture at the design stage. Since making the right decisions in the design phase will enable the right results to be reached during the construction and usage phase, minimizing the errors that may occur in the settlements that affect a lot of users is of great importance in terms of the construction economy and the national economy. For this purpose, energy consumption of a reference building modelled in different settlement texture alternatives were evaluated. The evaluations were performed for Istanbul representing temperate-humid climatic zone where the heating period is longer than the cooling period.

2. Methodology
The objective of the study is to evaluate the effect of settlement texture design parameters developed with the defined design parameters on energy efficiency within those settlement textures through the use of BIM. In order to evaluate the effect of settlement texture design parameters on energy efficiency,
a reference building is defined for each settlement texture and energy consumption is calculated for this reference buildings.

2.1. Defining design parameters for settlement textures
Dimensional parameters that define the settlement texture in a planned settlement are building height, building form and street width. Energy-efficient design in the settlement texture is possible by determining the optimum values of these design parameters that affect the energy consumptions. In this study, settlements were created by using the H/W ratio, which is defined as the ratio of the building height to the width of the street. In order to develop settlement textures with different street widths, the H/W ratio was accepted as three different values as 0.5, 1.00 and 1.5. In addition, number of storeys in the settlement textures were determined based on the commonly used 5 and 10 storey buildings in Istanbul and the floor heights were accepted as 3 meters.

![Figure 1. Dimensional parameters that define the settlement texture in a planned settlement](image1.png)

Another parameter in the settlement textures is orientation. In this study, in order to see the effect of orientation on energy efficiency, the settlement textures with different number of storeys and H/W ratios were oriented in north-south, east-west and northwest-southeast directions.

![Figure 2. Orientation options in settlement textures](image2.png)

2.2. Defining design parameters for reference buildings
The parameters that define the reference buildings where energy analyses will be performed in the settlement texture consist of the building form, the optical and thermophysical properties of the building envelope and the active subsystems used in the building. In this study, the building forms were
developed based on the common plan types seen in regular settlement textures in Istanbul. Plan types are defined by the ratio of the shape factor defined as the ratio of building width to building depth. Three different plan types were determined with the shape factor being 1.00, 2.00 and 3.00.

Plan types including different number of modules (housing units) with area of 100 m² were chosen and each housing unit was accepted as a single conditioned zone. Residential buildings in Turkey, generally used radiator system using natural gas as the heating system and split air conditioners using electricity from the grid for the cooling system. However, these system options are not available in the Revit software, 4-pipe fan coil system that is capable of both heating and cooling was defined. The indoor comfort temperature was accepted as 20 °C for the heating, 26 °C for the cooling period.

![Figure 3. Plan types based on the shape factors (SF)](image)

Building envelope layers of alternatives was determined in accordance with the upper limit values of overall heat transfer coefficient values (maximum permissible U values) specified in TS-825 Thermal Insulation Requirements for Buildings (2013). Determined U values of building envelope are given in Table 1. The transparency ratio (total transparent area/ total facade area) was assumed as %30 for all facades.

| Component Name | External Wall | Internal Wall | Internal Floor | Ground Floor | Roof | Window |
|----------------|---------------|---------------|----------------|--------------|------|--------|
| U Value (w/m²K)| 0.568         | 1.265         | 1.674          | 0.527        | 0.384| 1.8    |
| Maximum Permissible U Values for Istanbul - Ts 825 (w/m²K) | 0.57 | 0.57 | 0.38 | 1.4 |

### Table 1. Determined U values of building envelope layers according to TS 825 [10]

2.3. Development of Alternatives based on the defined design parameters

Settlement textures to be analysed in the study were formed by combinations of different values of defined energy efficient design parameters. In the settlement textures, the reference building to be analysed is the building located in the middle of the settlement texture, all other buildings in the settlement have the same parameter values as the reference building. Settlement textures consist of shape factor 1.00, 2.00 and 3.00, building floor numbers 5 and 10, orientation N-S, E-W, NW-SE and H / W ratios 0.5, 1, 1.5. By combining these values, 48 different settlement texture alternatives were created.
The developed settlement textures were named by writing Shape factor – Number of storey - orientation - H/W values respectively. For example, the alternative which named SF1-5-NS-0.5, indicates that shape factor is 1, number of storey is 5, orientation is the North-South and H / W value is 0.5.

![Figure 4. Developed settlement texture parameters values](image)

The Revit, a BIM-based software, was used to model the settlement textures and perform energy simulations. Revit software uses Green Building Studio and Insight systems for energy calculations. All the data prepared in Revit is uploaded to these integrated systems and energy calculations are performed and the results are presented to the users. In this study, energy simulations were performed for reference buildings in 48 different settlement textures and the results were given in Figure 5-6. The effect of energy efficient design parameters on energy consumption rates was evaluated by comparing annual heating, cooling and total energy consumptions.

3. Results

When the results were evaluated in terms of shape factor, among the three different shape factors, minimum heating energy and total energy consumptions were obtained in alternatives with the shape factor 1.00 value. Alternatives with shape factor 1.00 are more advantageous than other alternatives in terms of heat losses since they consist of 4 modules on the plan and have a compact form. The highest energy consumptions were obtained in alternatives with a shape factor of 2.00. Although the results of the cooling energy consumptions are very close to each other, alternatives with 3.00 shape factor have resulted in minimum cooling energy consumptions. When examining the best performing alternatives with H/W “0.5” among 5-storey settlement textures, the "SF1-5-NS-0.5" alternative have 23% less heating energy consumptions and %17 less total energy consumptions compared to the "SF2-5-DB-0.5" alternative and 12% less in terms of heating energy consumptions and 6% less in terms of total energy consumptions, compared to "SF3-5-DB-0.5" alternative.

The main parameter that determines the benefit rate of housing units from solar radiation in the settlement is the H/W ratio, which is the ratio of building height to street width. In this study, the main determinant of total energy consumption is the heating energy consumption, since analyses were conducted for Istanbul, which is located in a heating priority zone. As street width increases, the benefit of buildings from solar radiation increases, As H / W ratio increases, there is a significant increase in heating energy consumption and total energy consumption. Unlike heating energy consumption, cooling energy consumption decreases as the H/W ratio increases. Alternatives with H / W ratio of 0.5 achieve lower heating and total energy consumption with a wider street width. For example, the “SF1-10-NS-0.5”, which shows the best performance from the alternatives with shape factor 1.00, 19% better in heating energy consumptions and 8% in total energy consumptions compared to the “SF1-10-NS-1.5” alternative that shows the most negative performance. In cooling energy consumptions, the “SF1-10-NS-1.5” alternative performed 11% better than the “SF1-10-NS-0.5” alternative.
Figure 5. Heating and cooling energy consumptions of reference buildings in settlement textures with shape factor 1.00 (a), shape factor 2.00 (b) and shape factor 3.00 (c).

When the heating energy and total energy consumption are compared depending on the number of floors, the energy consumption per module decreases significantly as the number of floors increases. Settlement textures consisting of 10-storey buildings have lower energy consumption than 5-storey settlement textures. In terms of cooling energy consumption, although the changes are small, unlike heating energy, 5-storey settlement texture alternatives have lower energy consumption.

Figure 6. Total energy consumptions of reference buildings located at 48 different settlement textures
According to the results, when the effect of orientation in settlement textures are evaluated, effect of orientation on energy consumption according to shape factor values, settlement textures with 1.00 shape factor which oriented to the N-S direction resulted in lower energy consumptions in terms of heating and cooling consumptions than settlements which oriented to the NW-SE direction.

In the settlement textures having 2.00 and 3.00 shape factor values, settlements oriented to the N-S direction yielded the highest energy consumptions, while settlements oriented to the E-W direction yielded the lowest energy consumptions. In all alternatives, the changes in cooling energy consumptions depending on the orientation is very low. In addition, when the relationship between the number of floors and orientation is examined. The effect of orientation on energy consumption is higher for the 10-storey settlement textures than for the 5-storey settlement textures. According to the results obtained in developed 48 different settlement textures, SF3-10-EW-0.5 achieved the lowest total energy consumption per module.

4. Conclusion

In this study, design parameters which play an important role in providing energy efficiency in settlement textures, were evaluated by simulations using Revit, a BIM based software. The use of BIM at the design stage has advantages such as easy alternative generation and fast results in terms of energy efficient design approach. However, there are many shortcomings in conducting detailed energy analyses. With the further development in the coming years, it is clear that it will benefit the designers in energy efficient design issues. As can be seen from the results, values of the reference building energy consumptions can vary significantly according to design parameters in the settlement scale and building scale as a great deal. In 5-storey settlement textures, 17% less energy consumption was observed in total energy consumption due to shape factor, and 12% less total energy consumptions in 10-storey settlement textures. According to the results obtained depending on different H/W values, the alternatives with the value of "0.5" which have the wider building distances, have 10-15% fewer energy consumptions compared to the value of "1.5". Therefore, determination of the proper values for the design parameters in the design stage, effect the building energy performance and design sustainable, energy efficient environments. For this purpose, in this study, for Istanbul representing a temperate-humid climatic region, the effect of design parameters of settlement textures was analysed and the findings were compared and presented. However, in order to have an acceptable general conclusion, similar analysis using a high number of alternatives should be carried out. This analysis becomes crucial to provide sustainable and energy efficient built environment especially for Istanbul because of ongoing mass urban renewal studies in Istanbul.

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