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Evaluation of Building Energy Performance Based on Settlement Scale Design Parameters Using BIM Tools

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Highlights

- The energy performance based on settlement scale design parameters handled comprehensively.
- The use, advantages and capabilities of BIM tools in the settlement design were tested.
- Energy efficient values for the settlement scale design parameters were specified.
- Effective use of BIM tools in energy efficient design is contributed for designers.

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Abstract

After the settlement textures were designed and constructed, they continue to exist without any change for years, and they have considerable effects on building energy consumption and the natural environment. With the changes in our lives following the COVID-19 global pandemic, employers have adopted working from home in many sectors, and energy expenditures in residences are increasing even more. The decrease of energy usage is a top objective in the design of the settlements from an economic and environmental standpoint. Also, while known energy modeling methods require extra expertise, labor and time in the integration of energy efficient design strategies into design processes, BIM systems have a significant potential in the evaluation of building energy efficiency. In this study, for the comprehensive evaluation of design parameters, different settlement texture alternatives, have been developed and building design parameters determined. These settlement textures were interpreted based on their annual energy consumption. By comparing the results, optimum values were sought for the settlement texture design parameters which are H/W, orientation, building height, and form factor. In addition, energy modelling and simulations were carried out with BIM software, and the use, advantages and capabilities of BIM systems were tested in the energy efficient design for reducing energy consumption. As a result, energy consumption in buildings get changes greatly in regard to combination of settlement scale design parameters. Alternative with form factor 3.00,10 storey, directed to east-west, and H/W 0.5 showed best performance and provided 7% to %17 energy reduction according to different parameter combinations.

1. INTRODUCTION

With the development of technology, people's lifestyle and understanding of comfort are changing rapidly. While the benefits of technology are easily integrated into human life, the most basic resource needed in the application of this development to human life is energy. In today's world, energy supply and consumption issues are one of the main problems of countries and create serious economic liabilities. Therefore, adopting and implementing the concept of sustainable energy in the energy sector is of great importance. In the energy sector, while buildings and building constructions constitute 36% of the total energy consumption in the world, they are responsible for approximately 39% of the world's CO2 emissions [1]. At the same time, the building energy sector has a great saving potential [2]. For this reason, buildings are an area that should be handled with priority in terms of energy efficiency and sustainable energy use [3].

When population growth rates are taken into consideration, it is predicted that by 2050, 68% of the world's population would reside in urban regions, up from 55% today. When rural-to-urban migration and increases

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in urban populations are taken together, it is predicted that 2.5 billion will be added to the city population in 2050 [4]. When these data are analyzed, meeting the housing needs of the large human population that will emerge and the amount of energy to be consumed in these urban areas will be an important problem in the future.

With increasing population and urbanization in Turkey, the energy need in the houses that form the settlement textures is growing rapidly. While this rate of increase was 2% between 2000 and 2016, it increased to 3.7% between 2015 and 2016. The housing sector’s share in total energy consumption in all sectors is 20% in [5]. Since the settlement areas contain lots of buildings in terms of the covering area, the wrong decisions taken while designing the settlement areas result in consequences that large-scale and difficult to return [6]. Therefore, it is of great importance to make the right design decisions in the settlement features that define the upper scale to ensure energy efficiency in buildings [7].

On the other hand, one of the biggest changes COVID-19 brought to the live is social distance. Social distance limited human to private areas such as houses and neighborhood. Traditionally, houses were the most special areas that made people feel safe, developed their relationships with family and friends, and reflected their personality. But suddenly houses became a center for popular digital applications and living rooms turned into expanded workplaces. In a scenario like the COVID-19 pandemic, remote working has proven to be an important way to ensure business continuity, which has certainly accelerated the adoption of remote working practices by employers [8]. Therefore, as working from home is an advantage for some sectors today and this situation is supported by employers, more people are working from home and therefore energy expenditures in residences are increasing even more. The Covid-19 epidemic, which has negatively affected all sectors on a global scale since 2020, has also caused significant effects in the energy sector, and it is estimated that these effects will continue for a long time [9]. In addition, Turkey, as an energy-dependent country, is one of the countries most affected by the global crisis created by the Covid-19 epidemic in the energy sector. Foreign dependency in a global epidemic such as the Pandemic, it has negatively affected the country's economy, from disruptions in supply to fluctuations in prices [10]. In this context, therefore, in order to eliminate the negative effects of the pandemic, Turkey's general energy policies aim to focus on local resources and reduce energy expenditures in order to reduce foreign dependency. Therefore, the high energy consumption in residences necessitate first of all to ensure energy efficiency in residences.

Reducing energy consumption in settlement textures is possible by first determining the optimum values for design parameters. Design parameters are design-related parameters that are under the control of the designer and are considered at different scales such as settlement, building, volume and element scale of the artificial environment. Architectural project outputs based on appropriate values of these parameters are settlement texture models with low energy consumption. Therefore, in energy efficient building design approaches, it is necessary to consider the processes comprehensively. Otherwise, it is not possible to evaluate the high energy saving potential in buildings. Especially in recent years, achieving the targets and conditions set for reducing energy consumption and carbon emissions depends on the implementation of these comprehensive strategies.

As a result of the studies conducted for years, it has been understood that the studies on single buildings are not sufficient in increasing the energy performance in buildings [11,12]. Since the thermal behaviors of the buildings, which are considered together with the settlement texture, vary [13], to obtain more accurate results, the energy performance of the buildings should be measured by considering the interaction with the environment [14]. When the interaction of the building with its environment is taken into account, factors affecting energy performance are listed as climate, urban geometry, building design, system efficiency and occupant behavior [15,16]. Among these parameters, building design is one of the factors that have the largest contribution on energy efficiency and includes the form of the building, its orientation, and the optical and thermophysical properties of the building envelope. In building energy performance studies, while system efficiency and building design are generally at the forefront, urban geometry can be ignored. However, as urban geometry is determinant in the interaction of buildings with external factors, it can provide conservation of 30% for commercial buildings and 19% for residences in total building energy consumption [6].

Urban geometry can be described as the measure of open spaces between buildings and buildings and basically affects the access of buildings to solar radiation and sunlight [17]. Urban geometry consists of dimensional variables such as distances between buildings, heights of buildings and their relative positions. In the literature, the concepts including these parameters are the urban canyon and aspect ratio. The urban canyon is a model that defines the urban space (usually a street), consisting of two adjacent buildings and the ground plane [18]. H/W, defined as the ratio of building height to street width, is a function that determines the amount of solar radiation access for buildings. Depending on their location relative to each other and the distance between them, buildings can create obstacles for solar radiation. Thus, solar gains and heating and cooling needs of buildings also vary. Since the distances between buildings are longer in settlement textures with low H/W ratio, the solar energy gains of the building increase. In settlement patterns with high H/W ratios, the distances between buildings become smaller and buildings cast shadows on each other, reducing solar gains. The characteristics of the urban canyon affect both indoor and outdoor microclimates and consequently play an important role in thermal comfort and building energy consumption [19,20]. A number of geometric ratios are used to define dimensional properties and facilitate calculations in settlement texture designs. Among these ratios, aspect ratio (H / W) is identified as the ratio of building height to street width and is one of the basic parameters that simply explain the geometric relationships between buildings [21]. In many studies, settlement textures were developed and analyzed using aspect ratio [6,19,22–26].

In the literature, it can be seen that many discussions were conducted on the variables that are effective in minimizing the energy consumption of settlement textures. Studies on single buildings generally show the effects of changes in building form and building envelope on energy consumption [27,28] it is not possible to design a settlement by considering the buildings separately from environmental interactions. However, in building energy performance studies to be carried out at settlement scale, modeling and analyzing complex settlement textures is a hard and time-consuming process. For this reason, it is necessary to develop conceptual, simple city and building forms that partially define the urban space in the studies to be carried out on settlement textures. In this context, settlement texture forms such as pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts have been developed [29]. These developed settlement texture forms have been used in many studies [23,30–33]. Apart from this, many studies have also developed settlement texture forms that reflect the characteristics of the urban space, where the energy performance of different settlement patterns can be analyzed [11,34,35].

On the other hand, the deficiencies in the use of traditional methods and other computer-aided design tools in the design process have caused the concept of Building Information Modeling (BIM) to come to the forefront. Although the concept of BIM is perceived by users as just a software at first glance, it is a method proposal for the building sector [36]. Although it has different definitions, BIM can be described as an architectural design process that creates consistent, workable and coordinated data in the building design process, is effective in the emergence of design decisions thanks to its parametric working features, where design can be tested in terms of cost, building performance and planning, and can achieve high quality application outputs [37].

Today, efforts to reduce building energy consumption are generally carried out through various simulation programs and methods [38]. However, the relationship with the architectural design tools used with energy simulation programs is not sufficient [39]. Therefore, in building design, energy issues are often overlooked and ignored. BIM is a process that promises the highest level of coordination among project teams, given its ideal functioning [40]. The ability to carry out all design studies on a single model makes a great contribution to energy efficient design as well as other fields. Although BIM does not perform energy calculations within its own structure, it has important advantages in terms of energy analysis thanks to its powerful data source. The advantages of BIM from the point of energy analysis are the automation of the energy model, the ability to keep the building data up-to-date, store and organize, also the material library can be continuously developed and the outputs can be presented more effectively through the BIM model [41]. Designers have the opportunity to conduct their studies in this direction by making energy analysis at every stage of the design without the need for an extra software [42].

The use of BIM in energy efficient building design has been a remarkable issue in recent years. When the studies are examined, it is seen that in this partly new and developing area, critical approaches are mostly presented on the integration of BIM and energy efficient design [42–44]. In addition, by using the simulation capabilities of BIM programs, optimizations on energy efficient design parameters [45,46], solar radiation [47], daylight [48] and thermal comfort studies were carried out to increase building energy performance [49].

Studies in the literature demonstrate that when designing energy efficient settlement textures, the design parameters have a significant impact on the building energy consumption. Within the scope of this study, it is aimed to find optimum values for settlement texture parameters. These parameters are the H/W ratio used to determine the distances between buildings, the form factor coefficient that determines the form of buildings and settlements, the orientation of the building and settlement, and the building height. The effects of combinations with different values of these parameters on building energy performance were examined. On the other hand, the BIM concept stands out as it offers serious convenience in energy efficient design. Therefore, in this study, starting from the upper scales in energy efficient design, determining the appropriate values for design parameters through BIM and the potential of BIM to lead energy efficient design at the settlement texture scale in the following years have been examined.

2. METHODOLOGY

Within the scope of the study, it is aimed to determine the proper values by using BIM for the design parameters that aim to reduce building energy consumption in settlement scale and building scale. Today, various BIM-based software is used in the architectural industry. However, the most widely used among these is the Autodesk Revit. In addition, Revit has various add-ons that will contribute to energy efficient design processes. Revit was preferred because it is widely used and is a pioneer in terms of innovations in the sector. Thus, the results of the study are intended to appeal to a wider user base. In addition, it is thought that this study will make a broader contribution to future studies, as it pioneers innovations in the field of energy efficient design. In addition, Green Building Studio and Insight, energy-efficient design add-ons, are easy-to-use software that can be easily integrated into design processes, and they offer effective solutions especially in the preliminary design stages. For this reason, energy modeling was carried out through Revit. Energy analysis results were obtained and evaluated through Green Building Studio and Insight, which are Autodesk's add-ons for energy efficient design. In this regard, the method of study contains the following steps (Figure 1).

• Different settlement texture alternatives development for achieving energy efficiency in the settlement scale.
• Annual energy simulation of a selected reference residential building for each settlement texture alternative
• Comparison of annual energy simulation results and determination of the optimum parameter values for energy efficient design by selecting proper settlement texture alternatives.

Statistics on Turkiye's current housing stock are insufficient to specify settlement textures as a reference. For this reason, the regular settlement patterns seen in Istanbul, and TOKI (Housing Development Administration of the Republic of Türkiye) projects, which have attracted attention with their housing investments throughout Türkiye in recent years, were examined and taken as a reference [50]. Different settlement texture alternatives have been developed in this direction. In addition, various design parameters should be determined while developing settlement texture alternatives. For this reason, climate and external environment, occupants, settlement scale and building scale design parameters were determined, respectively.

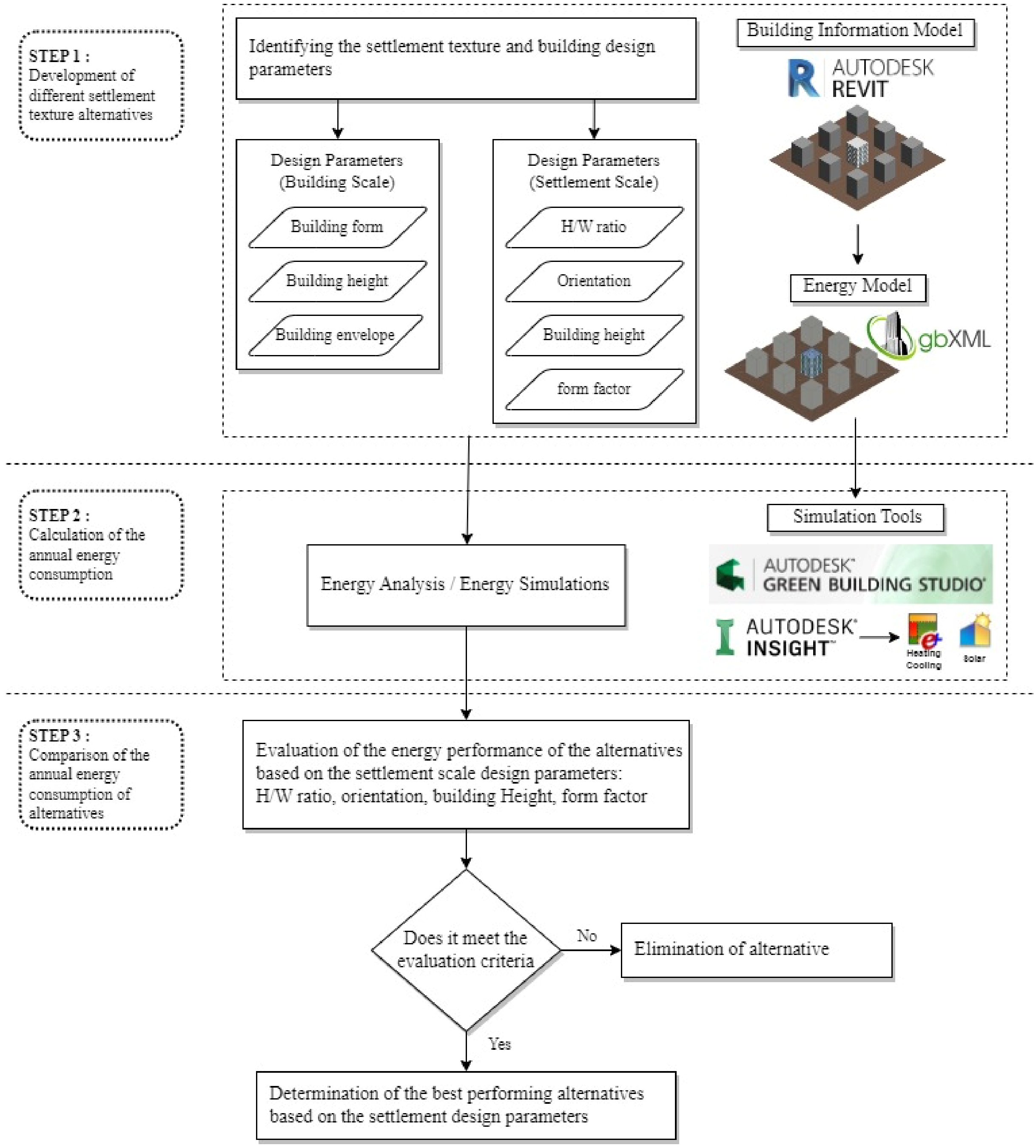

Figure 1. *The diagram of the approach used in the study*

The characteristics of the climate and the external environment are effective in energy consumption in the settlement texture and in the simulation method, these properties are defined by climate data. Within the scope of the study, it has been accepted that the developed settlement textures are located in the province of Istanbul, where settlement and building density are rapidly increasing. The climate data used in the study are the data that the Revit software received from the nearest weather station to the project location, through its own system, after determining the project location. In this study conducted in Istanbul, the data obtained from the weather station called ISTANBUL / ATATURK AB were used.

2.1. Identifying the Settlement Texture and Building Design Parameters

The settlements analyzed within the scope of the study were created by placing nine identical buildings at equal distances to each other and bringing them together to form a settlement texture. It was assumed that all settlement textures were on a flat surface. In the study, since Istanbul is taken as the basis, all alternatives is at latitude 40.97 and longitude 28.82 and its altitude from sea is 37m.

Building Form

While determining the building form in the study, the plan types that can be seen in the settlements in Istanbul were taken as basis. All the buildings that make up the settlement textures are accepted in the same form and uniform textures have been developed. Therefore, the building form is also the determinant parameter on the form of the settlement texture.

The reference buildings that were selected for energy analysis carried on in settlement textures are determined according to existing national regulations and standards on housing production. Thus, commonly agreed design standards and construction techniques in Turkey are taken into account. In this context, especially the mass housing investments in all part of the country directed by Housing Development Administration of Turkey (TOKI) were reviewed. Depending on this review, modules that including 100 m² building floor area were used in this study.

Based on the selected modules with 100 m² floor area, three different plan types created as square plan type and rectangular plan type. Square plan type has four modules and form factor (length/depth in plan) is 1.00, and rectangular plan types have two and three modules in each floor with 2.00 and 3.00 form factor, respectively. These three varied plan types and 5 and 10-storey building heights were taken into account to generate design alternatives. The used modules have 85 m^2 housing unit and 15 m^2 circulation area as 100 m² in total floor area. Building height determined as floor to floor 3.00m in each floor of building (Figure 2).

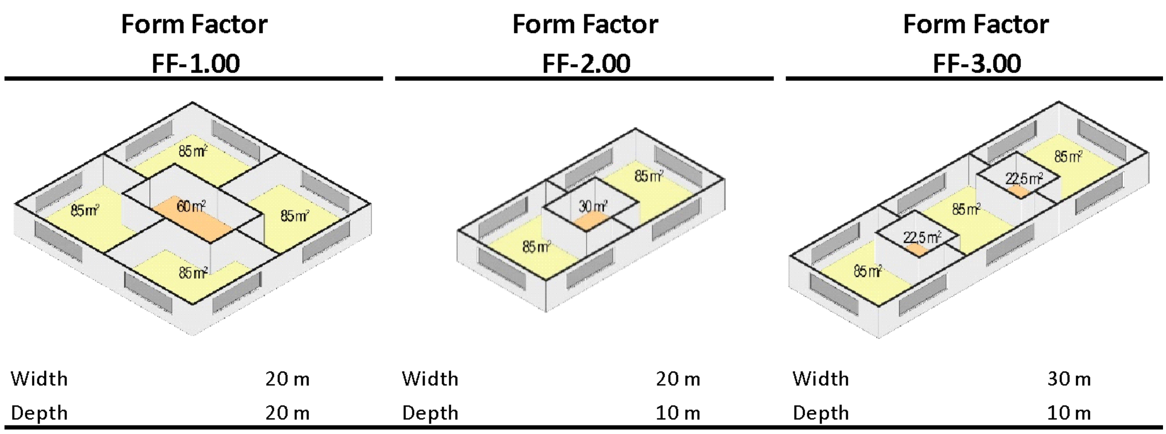

Figure 2. *Plan types developed depending on the form factor*

Distances Between Buildings

The most important parameter creating the settlement texture is the position of the buildings relative to each other and the distances between buildings. Since they are determinant on benefitting rate from solar radiation in buildings. For this reason, determining the optimum distances is quite significant in terms of reducing energy consumption in regions that have long heating periods.

In the study, since Istanbul, which is in a climate zone where the period for heating is long, is dealt with, it is desired that the solar radiation affect the facades at the highest intensity in the desired period of heating. For this reason, distances between buildings in settlement textures should be equal to or greater than the longest shadow depth created by neighboring buildings. In the study, the distance between buildings in the created alternative settlement textures was determined according to the H / W ratio which is the proportion of building heights to distances between them. When the distances between buildings are examined according to the Istanbul Development Regulation, it is seen that the H/W values vary between approximately 0.5 and 2.5 on different facades of the buildings [51]. Considering previous research on regular settlement textures, it has been declared that the appropriate H/W value is 1.86 [50]. Situations with higher than 1.86 H/W values are not compatible with energy efficient design strategies. In this context, five different H / W ratios as 0.5, 0.75, 1, 1.25 and 1.5 were taken into consideration while creating the settlement textures. Street widths in the developed settlements are given in Table 1.

Table 1. *Distances between buildings determined depending on H / W ratios in settlement textures*

Form Factor (FF)	**H/W**	**Street Width (m)**	
		5 Storey (15m)	**10 Storey (30m)**
1.00 – 2.00 – 3.00	0.50	30	60
	0.75	20	40
	1.00	15	30
	1.25	12	24
	1.50	10	20

Nine residential buildings (3 x 3) were included in the settlement textures that were created, and the building that was positioned in the settlement texture's center served as the reference building for all energy analyses. (Figure 3).

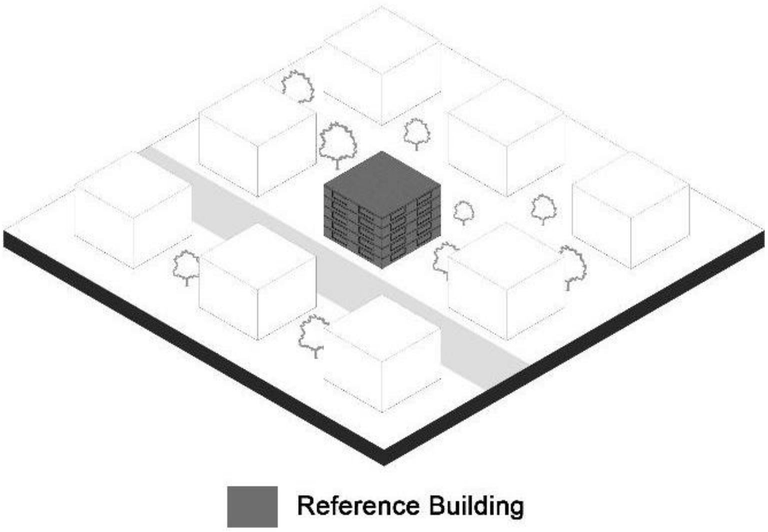

Figure 3. *A sample settlement texture model*

Depending on the orientation of the buildings and settlements, the effects of external environmental conditions on the building vary. For this reason, orientation becomes important in evaluating the effect level of external environmental conditions in reducing energy consumption. In the settlement textures, orientation was made based on the directions parallel to the streets indicating the facade of the reference buildings. By changing these directions with angles of 45º, settlement texture alternatives were produced. As seen in Figure 4, the red lines parallel to the road indicate the directions (N-S, NW-SE, W-E).

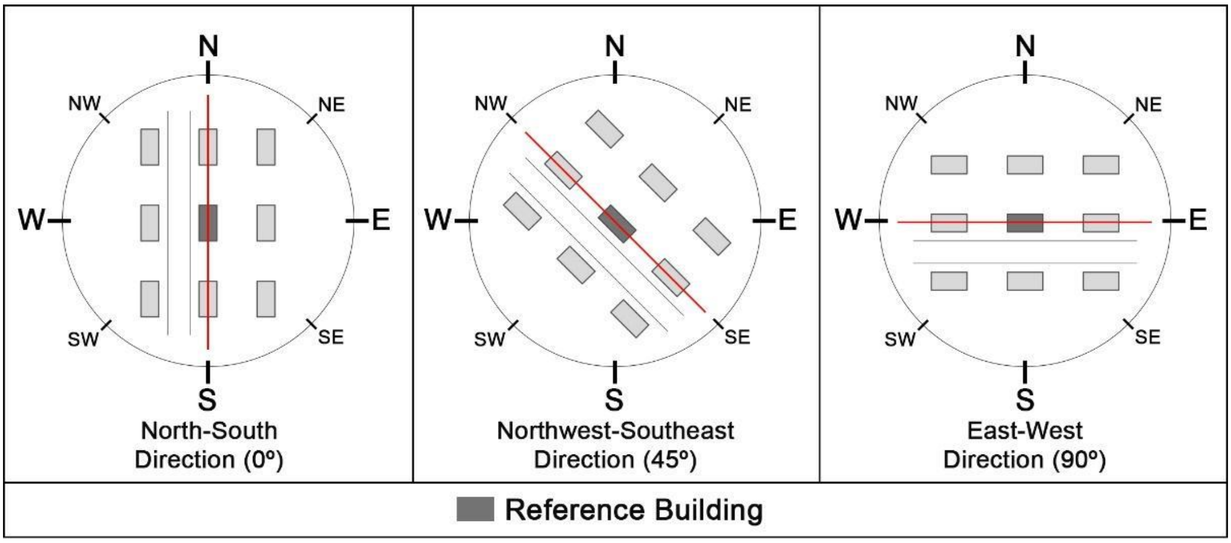

Figure 4. *Orientation of buildings and settlement textures*

2.2. Developing Settlement Texture Alternatives

In order to produce settlement texture options, it was assumed that every building in a settlement area would be the same. So, the design parameter values same with the reference residential building. Within the scope of the study, the explanation regarding the coding of settlement texture alternatives in the settlement texture is given in Figure 5.

The development process (Figure 5) generated 80 settlement texture alternatives, which differed in form factor (FF=1,2,3), number of storey (5 or 10), orientation (N-S, E-W, NW-SE), H/W ratio (0.50, 0,75, 1.00, 1.25 or 1.50) (Table 2).

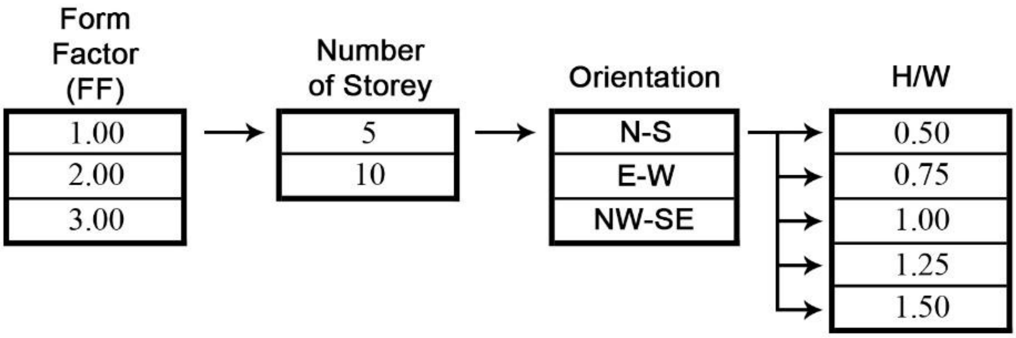

Figure 5. *Development process of settlement texture alternatives*

Table 2. *Features of developed settlement texture alternatives*

Form Factor	Plan Type	Number of Storey	Orientation	H/W Ratios	Code of Alternatives
1.00	Square	5	NS	0.5 / 0.75 / 1.00 1.25 / 1.50	FF1-5-NS-0.5 / FF1-5-NS-0.75 / FF1-5-NS-1.00 FF1-5-NS-1.25 / FF1-5-NS-1.50
1.00	Square	5	NW-SE	0.5 / 0.75 / 1.00 1.25 / 1.50	FF1-5-NWSE-0.5 / FF1-5-NWSE-0.75 / FF1-5-NWSE-1.00 FF1-5-NWSE-1.25 / FF1-5-NWSE-1.50
1.00	Square	10	NS	0.5 / 0.75 / 1.00 1.25 / 1.50	FF1-10-NS-0.5 / FF1-10-NS-0.75 / FF1-10-NS-1.00 FF1-10-NS-1.25 / FF1-10-NS-1.50
1.00	Square	10	NW-SE	0.5 / 0.75 / 1.00 1.25 / 1.50	FF1-10-NWSE-0.5 / FF1-10-NWSE-0.75 / FF1-10-NWSE-1.00 FF1-10-NWSE-1.25 / FF1-10-NWSE-1.50
2.00	Rectangle	5	NS	0.5 / 0.75 / 1.00 1.25 / 1.50	FF2-5-NS-0.5 / FF2-5-NS-0.75 / FF2-5-NS-1.00 FF2-5-NS-1.25 / FF2-5-NS-1.50
2.00	Rectangle	5	NW-SE	0.5 / 0.75 / 1.00 1.25 / 1.50	FF2-5-NWSE-0.5 / FF2-5-NWSE-0.75 / FF2-5-NWSE-1.00 FF2-5-NWSE-1.25 / FF2-5-NWSE-1.50
2.00	Rectangle	5	EW	0.5 / 0.75 / 1.00 1.25 / 1.50	FF2-5-EW-0.5 / FF2-5-EW-0.75 / FF2-5-EW-1.00 FF2-5-EW-1.25 / FF2-5-EW-1.50
2.00	Rectangle	10	NS	0.5 / 0.75 / 1.00 1.25 / 1.50	FF2-10-NS-0.5 / FF2-10-NS-0.75 / FF2-10-NS-1.00 FF2-10-NS-1.25 / FF2-10-NS-1.50
2.00	Rectangle	10	NW-SE	0.5 / 0.75 / 1.00 1.25 / 1.50	FF2-10-NWSE-0.5 / FF2-10-NWSE-0.75 / FF2-10-NWSE-1.00 FF2-10-NWSE-1.25 / FF2-10-NWSE-1.50
2.00	Rectangle	10	EW	0.5 / 0.75 / 1.00 1.25 / 1.50	FF2-10-EW-0.5 / FF2-10-EW-0.75 / FF2-10-EW-1.00 FF2-10-EW-1.25 / FF2-10-EW-1.50
3.00	Rectangle	5	NS	0.5 / 0.75 / 1.00 1.25 / 1.50	FF3-5-NS-0.5 / FF3-5-NS-0.75 / FF3-5-NS-1.00 FF3-5-NS-1.25 / FF3-5-NS-1.50
3.00	Rectangle	5	NW-SE	0.5 / 0.75 / 1.00 1.25 / 1.50	FF3-5-NWSE-0.5 / FF3-5-NWSE-0.75 / FF3-5-NWSE-1.00 FF3-5-NWSE-1.25 / FF3-5-NWSE-1.50
3.00	Rectangle	5	EW	0.5 / 0.75 / 1.00 1.25 / 1.50	FF3-5-EW-0.5 / FF3-5-EW-0.75 / FF3-5-EW-1.00 FF3-5-EW-1.25 / FF3-5-EW-1.50
3.00	Rectangle	10	NS	0.5 / 0.75 / 1.00 1.25 / 1.50	FF3-10-NS-0.5 / FF3-10-NS-0.75 / FF3-10-NS-1.00 FF3-10-NS-1.25 / FF3-10-NS-1.50
3.00	Rectangle	10	NW-SE	0.5 / 0.75 / 1.00 1.25 / 1.50	FF3-10-NWSE-0.5 / FF3-10-NWSE-0.75 / FF3-10-NWSE-1.00 FF3-10-NWSE-1.25 / FF3-10-NWSE-1.50
3.00	Rectangle	10	EW	0.5 / 0.75 / 1.00 1.25 / 1.50	FF3-10-EW-0.5 / FF3-10-EW-0.75 / FF3-10-EW-1.00 FF3-10-EW-1.25 / FF3-10-EW-1.50

2.3. Energy and Solar Analyses

Energy and solar analyses were conducted to determine the annual energy performance levels of the reference residential buildings and solar gains on building surfaces in each settlement texture alternatives.

Simulations were made in order to determine the alternative with the most convenient design parameter values in terms of building energy consumption among the settlement texture alternatives. The developed settlement texture alternatives were modeled through Revit, a widely used BIM software today. The parameters related to climate and external environment, user related parameters, HVAC systems used in buildings, parameters related to settlement texture and parameters related to the building were determined and processed into the energy model. Energy analyzes were performed and energy consumption were calculated in Green Building Studio and Insight working in coordination with the Revit program where the models were created. For reference buildings specified in the created settlement textures, energy simulations are run, and energy consumption are computed and evaluated.

In addition, annual solar radiation values were calculated for reference buildings in settlement texture alternatives. Solar, a Revit Insight plugin, was used for solar radiation analysis. When calculating solar radiation, only the surfaces that constitute the building envelope are taken as basis. Multi day and one-year solar study preset is selected. Annual average, maximum and total solar radiation values were calculated.

The final energy consumption of buildings including the heating, cooling, and total (heating + cooling) energy consumption (kWh/module), were simulated to determine the annual energy performance levels. To calculate the final energy consumption, parameter values identifying the reference residential building related to the climate, building, occupants, and the active building sub-system are determined.

For the design parameters related to the indoor climate, the indoor air temperature is 20ºC, set point temperature 13ºC, during the heating period, indoor air temperature 26ºC and set point temperature 32ºC during the cooling period. The minimum amount of fresh air per person in living areas is taken as 10 (L / s).

The parameters for the user, which are important in realizing the indoor climatic comfort, are determined according to the living space and climatic comfort conditions. In the reference building, the area per person is defined as 25m2, sensible heat gain 73.27 W, latent heat gain 45.43 W.

Within the scope of this study, "4 Pipes Fancoil, Chiller 5.96 COP, Boiler 84.5 eff" HVAC system was selected for reference buildings among the limited system options of Revit, as it is suitable for residences. Detailed features of the system can be listed as ;"water cooled centrifugal chiller (COP 5.96) , open, atmospheric pressure cooling tower with variable speed fan, forward curved constant volume fan and premium efficiency motor, 0.25 inch of water gauge (62.3 pascals) static pressure Constant Volume duct system, Gas-fired hot water boiler with draft fan, variable volume hot water pump, variable volume chilled water pump, variable volume condenser water pump, domestic hot water unit (0.575 Energy Factor)".

The construction details for the opaque and transparent components of buildings shown in Table 3. Details were determined according to limit U values (W/m^{2}K) for Istanbul. TS-825 Thermal Insulation Requirements for Buildings (Turkish Standards Institution, 2013) taken as reference [52].

Table 3. *U(W/m^{2}K) values for transparent and opaque components of reference buildings*

Component Name	External Wall	Internal Wall	Internal Floor	Ground Floor	Roof	Window	
U Value (W/m^{2}K)	0,568	1,265	1,674	0,527	0,384	1,4	1,042
Maximum U Values for Istanbul - Ts 825 (W/m^{2}K)	0,57			0,57	0,38	1,8	

3. RESULTS

Energy calculations were made for each reference building model in each settlement texture alternative, and the simulation results were shared and assessed (Figure 6). The findings are discussed based on H/W ratio, orientation, building height and form factor.

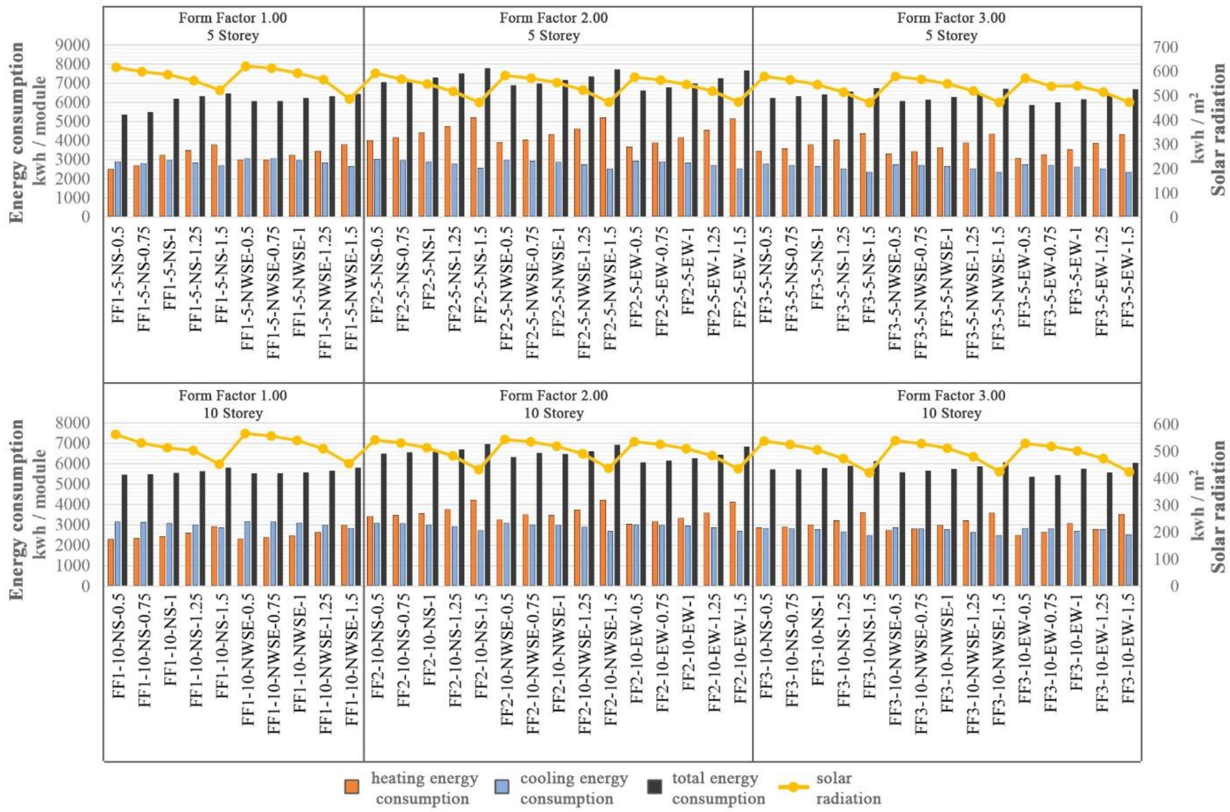

***Figure 6.** Annual energy consumption and solar radiations values of all alternatives*

H / W ratio: H / W, which is defined as the ratio of building height to street width, is one of the most important parameters in benefiting from solar radiation in settlement textures. Five different H/W ratios (0.50, 0.75, 1.00, 1.25 and 1.50) were defined from the developed settlement texture alternatives.

When the results of the analysis are examined, as the H / W ratio decreases, distances between buildings increase, the possibility of benefiting from the solar radiation of the reference buildings in the settlements has increased. Thus, a decrease was observed in energy consumption for heating purposes. On the other hand, energy consumption for cooling increased as the H / W ratio decreased, unlike heating. Since Istanbul, where simulations are carried out, is located in a region with priority heating, depending on the H/W ratio, the total energy consumption decreased or increased in similar with the heating consumption.

The energy simulation results of the reference building were compared, the alternatives with H/ W value of 0.50 revealed the lowest energy consumption. These settlement texture alternatives are "FF1-5-NS-0.5, FF1-10-NS-0.5, FF2-5-EW-0.5, FF2-10-EW-0.5, FF3-5-EW-0.5 and FF3-10-EW-0.5" respectively. When comparing with the alternatives with H / W values of 0.75, 1.00, 1.25 and 1.50, these settlement texture alternatives have lower heating energy ranging from 18% to 29%, lower total energy consumption ranging from 7% to 17% while revealed higher cooling energy ranging from 10% to 15%.

Orientation: The alternatives with form factor of 1.00, North-South oriented alternatives created lower energy consumption. In the alternatives with form factors of 2.00 and 3.00, greater changes occur in the benefit rate from solar radiation depending on the direction of the buildings long façade. In these alternatives, the lowest energy consumption occurred with the long façade facing south in the east-west direction. Because in a rectangular building, the surface area increases in the south direction, where solar radiation is at its highest intensity. The highest energy consumption was seen with the narrow façade facing south in the north-south direction. Because the surface areas facing the south side have decreased. Depending on the orientation, 5%-10% change in heating energy consumption, while a 2%-4% change in cooling energy consumption was observed. Total energy consumption varies between 4% and 7% depending on the orientation.

The Figure 7 is derived from Figure 6 and gives the comparison of the best performing alternatives among alternatives with the same form factor and the same building height, in terms of energy consumption.

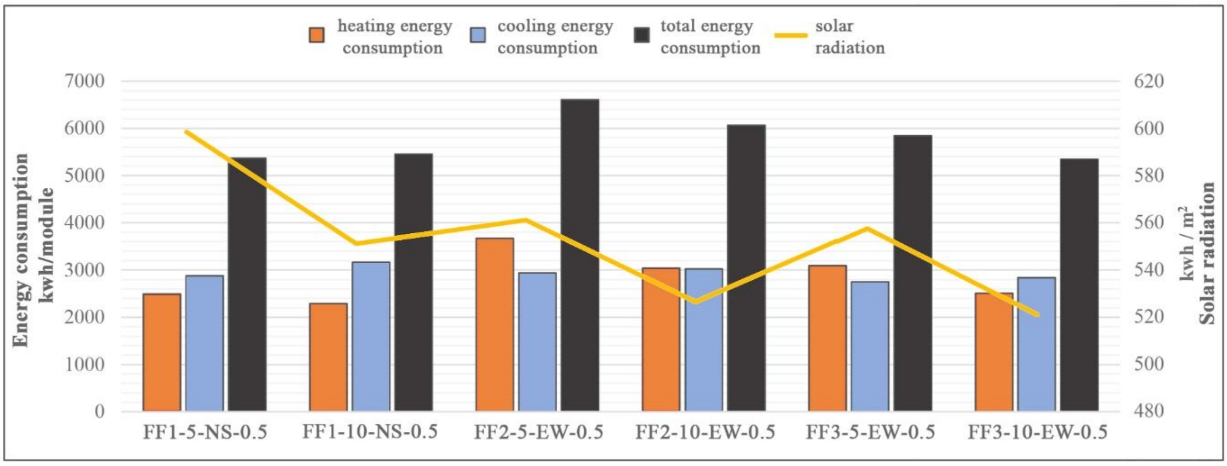

Figure 7. *Annual energy consumption and solar radiation values of best performing alternatives*

Compared with the best performing alternatives with the same H / W ratio (H/W=0.5), alternative FF3-10-EW-0.5 has the minimum total energy consumption and alternative FF2-5-EW-0.5 has the maximum total energy consumption. Alternative FF3-10-EW-0.5 consumed 27% less energy in terms of heating, 6% in terms of cooling and 20% in total compared to FF2-5-EW-0.5.

Number of floors (building height): According to energy simulation results of the reference buildings in settlement texture alternatives with 3 different form factor, the reference residential buildings had lower heating, higher cooling, and lower total (heating + cooling) energy consumption per module when building height increases. The alternatives with form factor of 1.00 and 5-storey building settlement alternatives have less total energy consumption than 10-storey settlements. The FF1-5-NS-0.5 alternative has 5% higher energy consumption, 9% lower energy consumption and 1% lower energy consumption in terms of cooling than the FF1-10-NS-0.5 alternative. In the alternatives with form factor (FF) of 2.00 and 3.00, 10-storey building settlement alternatives have less energy consumption than 5-storey settlements. FF2-10-EW-0.5 alternative has 14% lower energy consumption than the FF2-5-EW-0.5 alternative in terms of heating energy consumption, 3% in terms of cooling energy consumption and 8% in total energy consumption. The FF3-10-EW-0.5 alternative has 15% less energy usage with regard to heating and 9% in total compared to the FF3-5-EW-0.5 alternative. It has 3% higher energy consumption compared to cooling energy consumption.

Form Factor: When the reference residential building's energy analysis results handled in settlement texture alternatives with 5-storey buildings related to form factor, the alternative FF1-5-NS-0.5 has 24% less heating, 4% less cooling and 17% less total energy consumption compared to the alternative FF2-5-EW-0.5. The alternative FF1-5-NS-0.5 has 12% less heating, 6% more cooling and 6% less total energy consumption compared to the alternative FF3-5-EW-0.5.

When the reference residential building’s energy analysis results handled in settlement texture alternatives with 10-storey buildings related to form factor the alternative FF3-10-EW-0.5 has 15% less heating, 9% less cooling and 12% less total energy consumption compared to the alternative FF2-10-EW-0.5. The alternative FF3-10-EW-0.5 has 2% more heating, 4% less cooling and 11% less total energy consumption compared to the alternative FF1-10-NS-0.5.

Square plan alternatives with form factor of 1.00 gave the lowest energy consumption per module due to their compact form. In buildings with compact forms, heat losses are minimized due to the reduction in the external surface areas of the analyzed modules. These forms cause less energy consumption in heating priority regions such as Istanbul. Rectangular plan type alternatives with a form factor of 3.00 are advantageous in terms of benefiting from solar radiation, because they have a longer façade and surface area on south. Also, this form reducing heat losses as they consist of three modules on the floor compared to the alternatives with 2.00.

According to the results obtained, energy report cards showing the energy consumption and solar radiation values of best performing alternatives among alternatives with the same form factor and the same building height. These energy report cards are expected to guide designers (Figure 8).

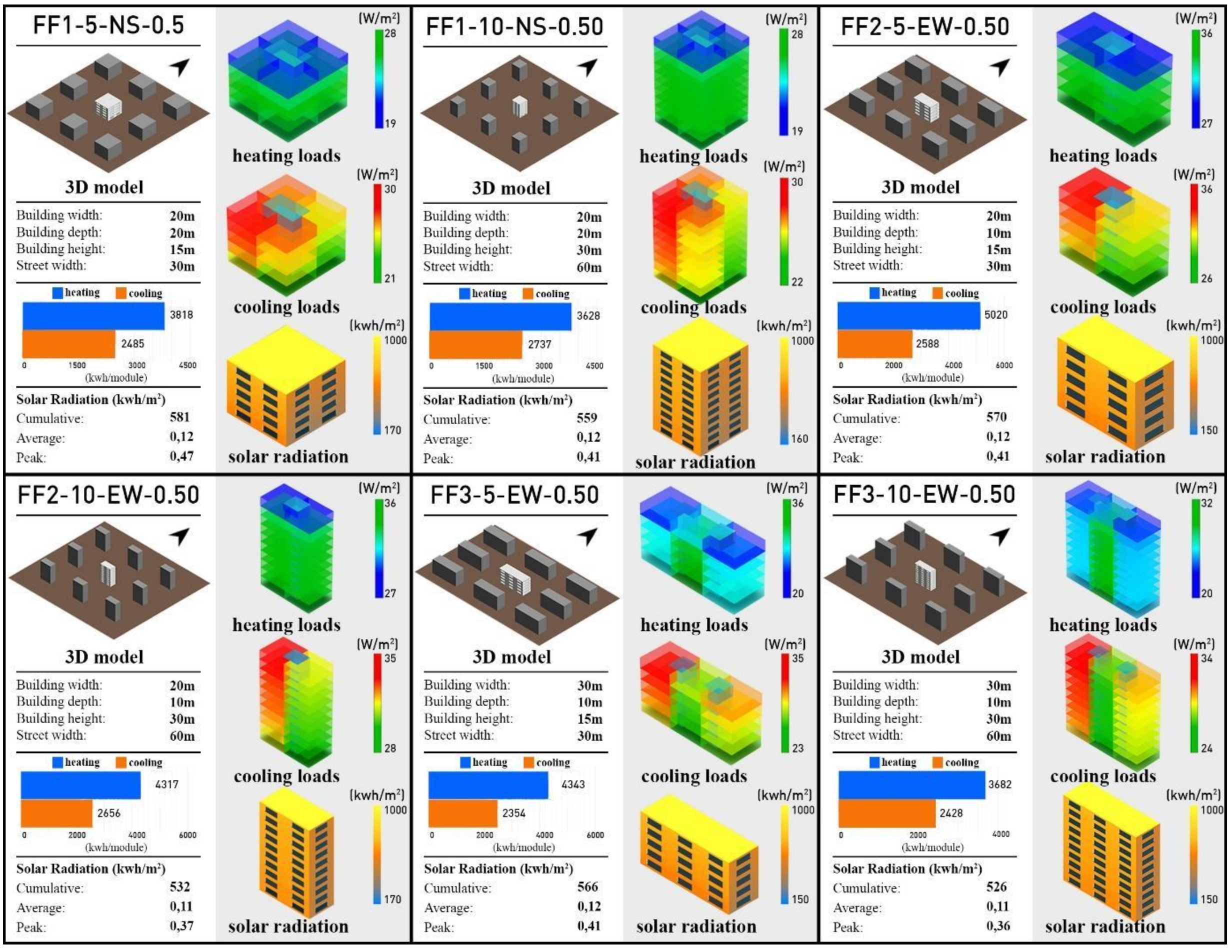

Figure 8. *Energy and solar radiation analysis results of best performing alternatives*

According to the energy simulation results, four different parameters that are effective at the settlement scale were analyzed for Istanbul. When the results are examined, choosing low values for the H/W ratio, which is one of the most effective parameters and determines the distances between buildings, in heating priority regions such as Istanbul, is effective with increasing the distances between buildings, allowing buildings to benefit from solar radiation at a higher rate and reducing total energy consumption. When the buildings are evaluated in terms of form factor values, it has been seen that forms with large surface areas in the south direction are effective in benefiting from high amounts of solar radiation and minimizing heat losses. Considering the orientation of the buildings, depending on the building form, surrounding buildings and building heights, first the southern facades, where solar radiation gains are highest, and then large surface areas on the eastern and western facades should be preferred. Although there is not enough information regarding building heights to make recommendations, according to energy simulations, lower consumption occur on higher building heights. However, it should not be forgotten that these recommendations were obtained from regular settlement textures within the scope of the research. It is clear that in real conditions, when many other parameters are taken into account, the analyzed parameters and the resulting values will vary. In order to reach a general conclusion, many alternatives in different climatic regions need to be analyzed and examined.

4. CONCLUSION

Buildings, which are responsible for most of the energy consumed in the world, are increasing in numbers day by day with the increasing human population and living standards. The newly formed settlements cause an increase in energy consumption and negative environmental impacts with high CO2 emissions in the building sector, which is currently highly dependent on fossil fuels. In addition, with the changes in our lives through the COVID-19 pandemic, the houses have turned into versatile spaces where we spend most of the time and the amount of energy used in the houses has increased even more. Because of the widespread adoption of working from home by companies in many industries as a result of the COVID-19 pandemic, residential energy costs are rising even faster. On the other hand, Turkey increases its energy demand every year due to newly developing residential settlements. For this reason, it has become inevitable to implement sustainable and energy efficient design approaches in today’s building and settlement areas.

On the other hand, with the development of technology in the building industry, the shortcomings of traditional methods have revealed the BIM concept known as "Building Information Modeling". BIM is defined as an architectural design process that creates consistent, workable and coordinated data in the building design process, is effective in the emergence of design decisions thanks to its parametric operating features, where the design can be tested in relation to cost, building performance and planning, and can achieve high quality application outputs. Thanks to the convenience and coordinated work it provides, BIM has easily integrated many approaches that are often ignored during the design phase. One of these is the energy efficient design approach.

One of the most important deficiencies in the execution of energy efficient design processes is the difficulties in integrating energy modeling software with other design processes. Due to limited integration, energy modeling processes can be carried out separately from other design processes and software, requiring additional expertise, labor and time. The BIM concept eliminates an important deficiency at this point. Integrated with the design process, it enables the implementation of energy efficient design strategies, energy modeling and simulations. Within the scope of the study, an example was created for the integration of energy efficient design processes into building processes by performing energy modeling and simulations through BIM in an integrated manner with this new process.

Revit, the BIM software where energy simulations are performed, and Green Building Studio and Insight, where calculations are made, offer the user the convenience of obtaining information about energy issues, generating alternatives and making analysis at every stage of the design process. In this respect, the analysis that the designer can make easily can allow the integration of energy efficient design issues into architectural design. However, the aforementioned BIM-based programs have data sets suitable for the conditions of the country where Revit-GBS was developed, and their options are still limited. Therefore, it can be said that it will be insufficient to calculate the final energy consumption rates and to obtain realistic results currently. On the other hand, it is clear that the Revit-GBS-Insight system is developing very rapidly and will make a significant contribution to the design development process at the preliminary design stage by making comparative analyzes.

The study's perspective includes the settlement texture design parameters' optimal values, which are effective at decreasing energy consumption for Istanbul. which is subject to unplanned and rapid construction by ignoring the energy efficient design approach, has been tried to be determined by BIM. In addition, the effectiveness of the BIM concept, which has become increasingly important with its recent facilities and innovations, in energy issues has been investigated. In this way, it is aimed to obtain technical information that can guide designers.

The alternatives with a square plan form factor of 1.00 performed better in heating, cooling, and total energy consumption per module compared to the alternatives with the rectangular plan form factors of 2.00 and 3.00, based on the reference residential building’s energy analysis results in settlement texture alternatives. When the alternatives with the rectangular plan form factor 2 and 3 are compared, the alternative with the form factor 3.00 has better performance than the alternatives with the form factor 2.00. As an instance, FF1-5-NS-0.5 provided energy reduction 23.9% in terms of heating, 9% in cooling, and 17% in total energy consumption than FF2-5-EW-0.5.

When the results are analyzed in terms of number of floors, 10-storey buildings have less heating and total energy consumption per module and higher cooling energy compared to 5-storey buildings. Considering the building height, FF3-10-EW-0.5 provide energy reduction 15% in heating, 9% in total energy consumption, but it provide 3% higher energy consumption in cooling than FF3-5-EW-0.5. When the results are examined according to the orientation, depending on the value of the form factor, the alternatives with a form factor of 1.00, the alternatives oriented in the north-south direction has lower energy consumption. As an example, the alternative FF1-5-NS-0.5, provide energy reduction 14% in terms of heating, 7% in terms of cooling and 11% in terms of total energy consumption with regard to FF1-5-NWSE-0.5. The alternatives with form factor of 2.00 and 3.00 caused lower energy consumption in the case of the long facade facing south. Depending on the H / W ratio, that is the most important dimensional parameter defining the settlement texture, the H/W of 0.50 value with the largest street width shows less heating and total energy consumption and higher cooling energy consumption compared to H/W ratios of 0.75, 1.00, 1.25 and 1.50. As an example, the settlement texture FF1-5-NS-0.5, provided energy reduction 29% in terms of heating and 17,8% in terms of total energy consumption than FF1-5-NS-1.5. However, FF1-5-NS-1.5 provided 10% energy reduction in terms of cooling energy consumption than FF1-5-NS-0.5.

As a result, when numerical comparisons are examined, energy consumption in reference buildings differ greatly according to the settlement scale and building scale design parameters. Therefore, determining the appropriate values for design parameters during the design phase affects the energy performance of the building, contributing to the creation of energy efficient and sustainable environments. This study's focus is on how settlement texture design parameters affect energy consumption for Istanbul, which is located in a temperate-humid climate zone, was analyzed, the findings were compared and presented. Thus, in cities such as Istanbul, where unplanned urbanization and energy efficient design are ignored, it has been seen that energy expenditures and carbon emissions resulting from buildings can be reduced at high rates by applying energy efficient design strategies. In addition, it is aimed to prepare the background for studies in this field and to contribute to the effective use of energy efficient design in building processes.

The presented study contributes to specify the effects of the settlement texture on the building energy performance and to determine the appropriate settlement alternative that provides the minimum energy consumption during the preliminary design phase. The analysis's scope should be expanded in order to examine design factors at various scales, economic performance analysis, and the microclimatic implications for various settlement texture parameters, such as green spaces and transportation. By addressing the many variables that shape the settlement texture and their relationships, the suggested strategy significantly contributes to the creation of sustainable built environments.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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