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A CASE STUDY ON THE IMPACT OF BUILDING ENVELOPE ON ENERGY EFFICIENCY IN HIGH-RISE RESIDENTIAL BUILDINGS

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Abstract
The building envelope, the most important element in the energy consumption of a building, gains more importance due to the large amount of the surface area of building's façade in high-rise buildings. The energy consumption of these buildings is increasing depending on their high transparency ratio as a result of decrease in the thermal resistance of the façade. The aim of this study is to show the importance of building envelope design in energy efficiency of high-rise residential buildings and to analyze the effect of the building envelope design on energy consumption. Turkey's highest residential building from 2010 to 2017 was selected for the case building. DesignBuilder program with the EnergyPlus simulation engine was used for energy analysis of the building. The energy consumption results were compared with the other study data in the literature. As a consequence of the simulation conducted according to the existing façade of the building, 25% of the energy is used for heating and 14% for cooling in total energy consumption. It has been found that the building envelope designed with double-layered air corridor can offer the maximum level of residential comfort to the occupants. This study shows that the building façade with air corridor also reduces energy consumption by 30% compared to the same sized buildings.

Keywords: **BIM; Building envelope; DesignBuilder; Energy efficiency; High-rise residential buildings.**

1. INTRODUCTION

Energy consumption is gradually increasing due to the increase in user-oriented comfort requirements besides the continuously growth in population and building stock. According to the 2010 AR5 Report (Fifth Assessment Report) by IPCC (Intergovernmental Panel on Climate Change), globally 32% of the total energy consumption and 19% of the greenhouse gas emissions belong to the buildings [1]. The energy data of EU in 2016 shows that these rates increased to 40% and 36%, respectively [2]. The reduction in non-renewable energy resources, increased energy prices and environmental problems like global warming are essential to the efficient use of energy. In fact, it is not surprising that the construction sector started to produce buildings to meet the needs of energy efficiency policies. Recent studies in this issue mainly focus on energy consumption in residences and methods to reduce their consumption [3–6]. Thus, the share of the residential building sector in the total energy consumption is high but varies from one society to another. While this share is ranging between 17% and 50%, the worldwide average is approximately 31% that is the same as in Turkey [7] (Fig. 1).

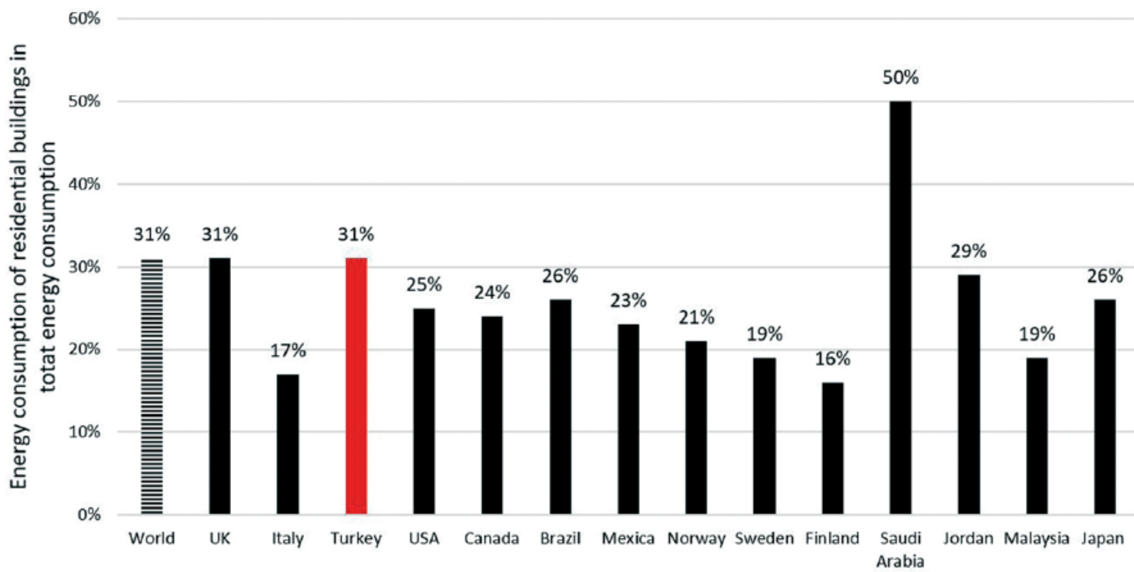

Figure 1.
Residential buildings energy consumptions [7]

The production of high-rise buildings, which are resulting from increasing population, limited new construction areas in city centers, user needs and technologies developed after the 19th century industrialization process, continues to grow rapidly and their share in building stock is also increasing. CTBUH (Council on Tall Buildings and Urban Habitat) data reveal that the use of high-rise buildings for only residential function and mix-use with including residential function has increased due to the fact that these buildings help to provide an effective shelter to the increasing population. As of 2018, only 42% of the high-rise buildings in the world are used as office buildings according to the building stock in the CTBUH database. In developing countries where population density is high like Turkey, use of these buildings for residential function is more common. In Turkey, more than 53% of high-rise buildings are used as residential buildings while additionally, 27% are used as mix-use living spaces [8].

Depending on the large scale of the high-rise buildings, the amount of material used and energy consumed in construction and also operation of these buildings are considerably higher than in other buildings. In addition, more than 75% of the energy consumption in high-rise buildings which is highly dependent on the building systems (HVAC, CCTV, elevator etc.) is used by HVAC [9]. This means that with the use of efficient systems, high-rise buildings have a great potential to save and recycle energy resources. Furthermore, for some reasons such as the complexity of high-rise building design and the need for more experience, the sustainable design of high-rise buildings is an important issue that needs to be addressed [10]. If high-rise buildings are not designed with energy-efficient and sustainable approaches, by considering the energy consumption values of these buildings renovation and/or retrofit applications should be done in order to increase the efficiency [11]. Otherwise, because of high operational energy needs, artificial lighting and air conditioning requirements, high embodied energy and increased maintenance costs, today high-rise buildings are considered as anti-environmental buildings [12].

In addition to being a modern symbol of this era, high-rise buildings have a share of 16% in energy consumption worldwide [13]. Furthermore, considering the long service life of these buildings, it is very important to design high-rise buildings energy-efficient. Due to the fact that a large part of people's time is spent in houses, when high-rise buildings are used for residential function, they should offer a standard residential comfort to their users [14]. The calculation of the amount of energy needed to provide the required comfort conditions and the determination of the effects of the building envelope design in this energy consumption constitute the research problem of the study. In this study, the main aim is to determine the energy consumption values in high-rise residential buildings with the help of simulation program (DesignBuilder) and to examine the importance of building envelope design for energy efficiency and to investigate its effect on energy consumption. Therefore, Sapphire Residence Tower, the tallest residential building in Turkey and Europe from 2010 until 2017, is examined in the study as a case. Determining the energy consumption values of the building, analyzing the effects of the building's air corridor façade on especially the heating energy load and comparing the values with the heating energy loads of other high-rise residential buildings in different geographies constitutes the scope of the study. Thus, the importance of building envelope design in increasing energy efficiency has been evaluated in the study. In Turkey, where high-rise buildings are mostly used for the residential function, examining the one of the country's tallest residential buildings is very important in this respect.

2. LITERATURE REVIEW

The high-rise buildings that emerged at the end of the 19th century, have managed to integrate every technological development into their design and construction processes. Moreover, these buildings are always open to innovation and have been the type of building that leads to innovation. For this reason, the changes in the design, material, technology and operation stages of the high-rise buildings from the first period they were constructed until today have affected their energy consumption. Due to these continuous change and development, it is seen that high-rise buildings are divided into 5 different energy generations depending on the differentiations in their energy consumption. Factors causing the determination of these energy generations are (1) the New York Zoning Law of 1916, (2) the post-war innovations in curtain wall, (3) the energy crises of the 1970s and (4) the environmental awareness towards the end of the 1990s [15]. Today, the first three-generation features of high-rise building construction are not in question, while the last two periods of high-rise buildings are still in production.

In the literature, although the limited number of studies investigates the energy consumption of the high-rise residential buildings, it is found that these studies focus on the different issues like structure and construction activities, environmental effects, indoor environmental quality (IEQ) and energy consumption, effects of thermophysical properties of building envelope on energy consumption, energy losses caused by windows and other façade openings, and effects of user preferences on energy consumption [7, 16–19]. One of the studies in the literature examines the evaluations of the users living in the high-rise residential buildings in Korea in terms of sustainability. The study shows that there are differences between the parameters that the users are satisfied and the parameters they care about when they live in a high-rise building. While living in a high-rise building satisfies the users in terms of transportation, security and location, it is observed that the energy consumption and the IEQ, which are important elements for sustainability, do not satisfy the users. However, in the study, it is stated that the most important element of the users after the safety is the energy consumption of the building [20].

Studies to increase the energy efficiency of the residences are focused on building envelope design. In addition, it is emphasized that the most effective element in the energy consumption of the building is the building envelope [5]. The façade design and the thermophysical properties of the materials used can be considered as the most important factors in determining the energy efficiency of the high-rise buildings, which have much more surface area than any conventional buildings. In fact, the average of 75% of the heat loss/gain occurs in the building envelope while the other losses and gains are caused by the orientation of the building and the ventilation openings on the façade [21, 22]. Furthermore, increasing transparency in today's high-rise residential buildings decrease the thermal resistance of the building envelope and increase the heat loss/gains, which increases the energy consumption required to provide the indoor thermal comfort conditions. This situation clearly states the importance of building envelope in terms of energy consumption in high-rise buildings.

Until 1970, the energy consumption value of the high-rise buildings, which were completely closed to the outdoor environment and which were designed as air-conditioned with the glass façade, was an average of 1,000 kWh/m^2 [23]. Today, when the average energy consumption of the buildings is between 150 and 300 kWh/m^2, it is seen that the current conditions of these buildings are not sustainable [24]. For this reason, with the effect of energy crises between 1980 and 1990, these buildings have been designed to have a naturally ventilated and semi-conditioned indoor environment, thus this consumption value could be reduced to an average of 400 kWh/m^2. However, depending on the location of the building 100–200 kWh/m^2 could be obtained applying the environmental friendly conscious, using high insulation materials and passive systems in the design of the buildings [23].

Depending on the high degree of transparency, especially in the high-rise buildings with a single-layered façade, increasing the thermal resistance of the façade requires the use of film-layer or layered glass [7]. For the high-rise buildings, especially in warm and cold climates, rising height increases the heating loads while reducing the cooling loads [25]. In addition, the design of the façade of the building with natural ventilation is more advantageous than the mechanical ventilation in order to ensure suitable IEQ for the user comfort and to save energy. However, it is not possible to have natural ventilation facilities for each high-rise building. The increased height in high-rise buildings is an important factor that affects both the natural ventilation conditions of the building and the heating and cooling loads. This also causes another problem in the buildings. When high-rise buildings are used for residential function, the lack of opportunity to open a window in these buildings becomes one of the most significant problems [26]. The solution to this is the use of double-skinned/layered façades in high-rise residential buildings. Because having an openable window to obtain fresh air is important for the building's users [26]. Therefore, in high-rise residential buildings, designing the building envelope as a double-skinned façade offers thermal comfort with layered structure, fresh indoor air quality with opportunities for natural ventilation, acoustic comfort with noise absorption, and illumination comfort with sun control elements and can easily and sustainably ensure IEQ and occupant safety [14].

The fact that high-rise buildings have an important role in energy consumption shows the necessity of their energy efficient production. Recently, with the help of developing technology, the energy needs of these buildings can be estimated before the building construction and the necessary improvement measures can be made in advance within the life cycle. In addition to new constructed buildings, it is possible to provide energy efficiency between 10% and 50% by analyzing existing high-rise buildings and by reducing their energy consumption [11]. In order to analyze the energy consumption values of both the new buildings and the existing buildings, the use of building information modeling (BIM), which is a 21st century product and is defined as the use of the computer as a multi-user archive/database, is becoming increasingly widespread. BIM offers the building as a composite database of coordinated information, allowing you to access and analyze all the data required for the building [27]. Thus, many examination can be conducted from the structural analysis of the building to the environmental analysis. Therefore, it can be said that due to the complexity of the construction projects and the difficult management of the projects, the projects can progress more easily and faster with BIM based programs.

Especially in UK, in many countries including Germany, France, Finland and Norway, BIM-based construction projects are rapidly developing [28]. The use of BIM in developing countries such as Turkey, where the construction sector is an important input in national economic growth, has been extremely slow. While countries such as UK are in Level-2 in the use of BIM, Turkey has recently completed the transition from Level-0 to Level-1. Today, Turkey is trying to reach Level-2. BIM usage in Turkey, in which mainly 2D and 3D CAD-based project production is common, has started to accelerate after 2007. It can be said that the increase in awareness of sustainability, green buildings and energy efficiency especially led to this. Also, regulations and laws related to energy efficiency (Energy Efficiency Law No. 5627, Regulation on Energy Performance in Buildings, etc.) have been strictly applied in Turkish construction sector since 2007. In this framework, BIM contributes the green design in the issues like energy performance simulations of projects, reduction of carbon footprint of projects, waste reduction, calculation of material quality and LEED documentation [29]. BIM, which evaluates the whole production with an integrated process, has many dimensions (Fig. 2). 6th dimension of BIM includes software for energy analysis based on sustainability [30]. In this context, "gbxml" extension models obtained from BIM-based programs provide to analyze the energy consumption of the building through the use of programs like EnergyPlus,

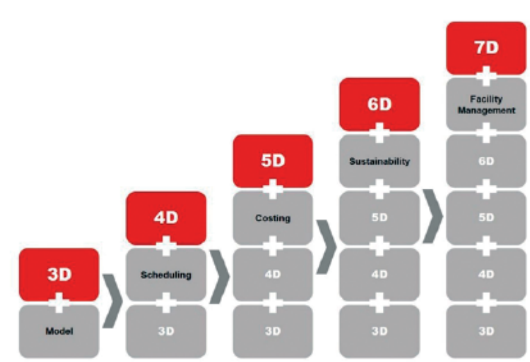

Figure 2.
BIM dimensions [30]

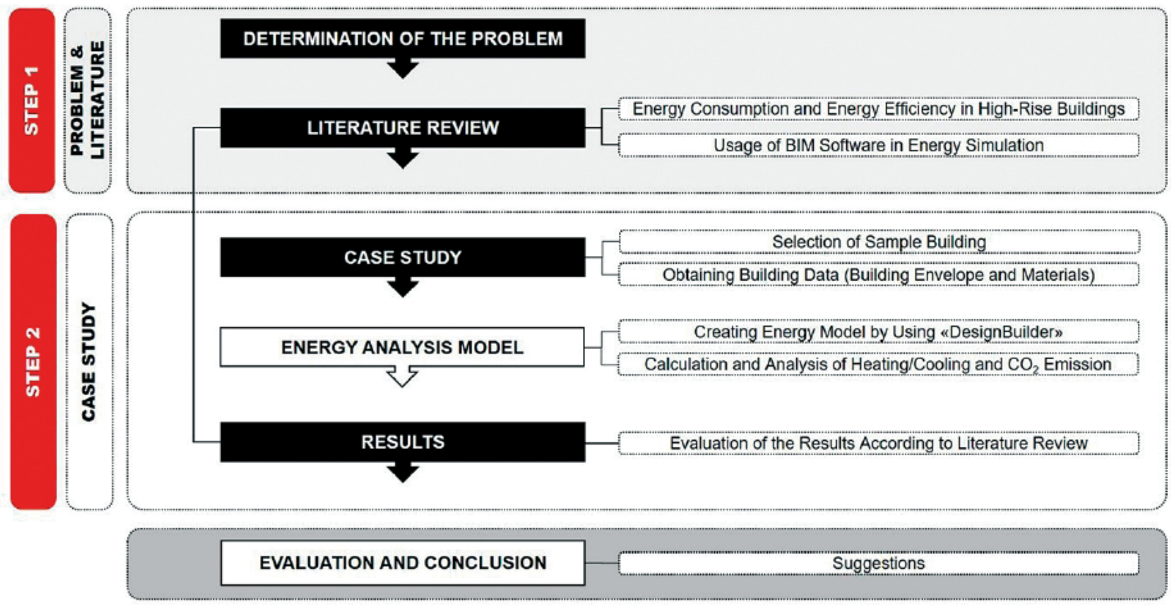

Figure 3.
Structure of the study. Source: Authors

e-Quest, DOE-2, ESP-R, BLAST, HVAC-SIM+, TRNSYS etc. [31].

High-rise buildings, which have begun their construction after 1950 in the construction sector of Turkey, are being constructed rapidly since 2000 and their numbers are constantly increasing. The use of BIM in the production of these high-tech buildings is almost nonexisting. The BIM model, which is also required for sustainable building certification systems like BREEAM, LEED, CASBEE etc., is used in large-scale and prestigious building projects. In high-rise buildings, certification systems are used to document the availability of energy efficiency, sustainability, user comfort and health. However, there are very few high-rise buildings in Turkey which are both internationally and nationally energy certified.

3. RESEARCH METHODOLOGY

The study is organized in two steps; literature review and case study. The structure of the study and the methods used in the study and the relations between each process are summarized in the flow diagram in Fig. 3. Accordingly, in the first step, a literature review was conducted to evaluate the energy consumption and energy efficiency in high-rise buildings and BIM programs as a tool in the calculation of energy consumption values.

In the second step, a case study was evaluated to obtain quantitative data. Therefore, total energy load, heating and cooling energy loads and CO_2 emission amounts depending on energy consumption of the sample building were calculated. That is why, DesignBuilder, one of the environmental analysis simulation program designed to measure and control the thermal and lighting comfort of a building, was used to determine the energy consumption of the building and the CO_2 emissions. According to the location of the building, calculations on the amount of heat gained and lost through the building enveloped were done with the help of the program, which analyzes the energy flow by using the hourly data of the typical year and keeping constant the indoor temperature. For those purposes, the EnergyPlus simulation engine developed by DOE (United States Department of Energy) has been used. Within the scope of the study, version 5.0.1.024 of DesignBuilder, which was introduced in the last quarter of 2016, was used.

The investigation using the DesignBuilder program was carried out in 5 separate stages (Fig. 4). In the first stage, all data (like occupants, building envelope, etc.) belonging to the case building was collected. Then, data entries were made by selecting the residential function. The activities of the building occupants were defined as “standing relax”, the value of which is 1.00. Furthermore, the occupancy density used in the program was 0.0215 people/m^2. Then, heating and cooling energy calculations were made according to EnergyPlus with 1-hour time intervals for one year period. Finally, the results obtained in DesignBuilder transferred to Excel in order to process and analyze the data.

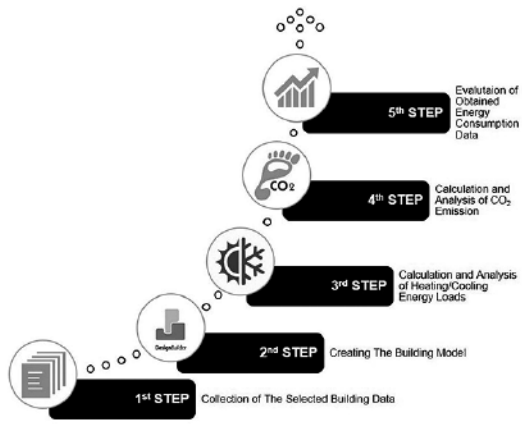

Figure 4.
Evaluation of energy analysis flow diagram. Source: Authors

In the evaluation step, the heating and cooling energy loads obtained as a result of the simulation and the total annual energy consumption of the building are compared with the values of the different high-rise residential buildings in different geographies in the literature. The positive or negative effects of the façade characteristics of the case on the energy efficiency of the building have been evaluated in line with the results obtained.

4. CASE STUDY

Sapphire Residence Tower, which was constructed between 2006 and 2010, is located on Büyükdere Avenue located on Levent-Maslak axis in Istanbul's Central Business District (CBS). The building is oriented in the east-west direction with its main façade not facing to the north directly (Fig. 5). The building is Turkey's first tallest residential building with its 261 meters height. At the time it was built, Sapphire Residence Tower was the highest building of Europe. In 2018, the building was Turkey's highest 4th, Europe's 12th and world's 313rd [32].

The façade of the building consists of two independent layers. Conventional double-skinned façades are usually not deeper than 1 meter. However, at Sapphire Residence Tower, this depth decreases from 6 meters to approximately 3 meters as the building rises, and this space is used as indoor gardens. Therefore, the façade of the building should be called as double-layered skin with air corridor. The height of the cavity divided horizontally on each 3 floors is 12 meters (Fig. 6). These spaces are also converted into areas where the whole space is used for a floor garden with a double height between each zone (Fig. 7).

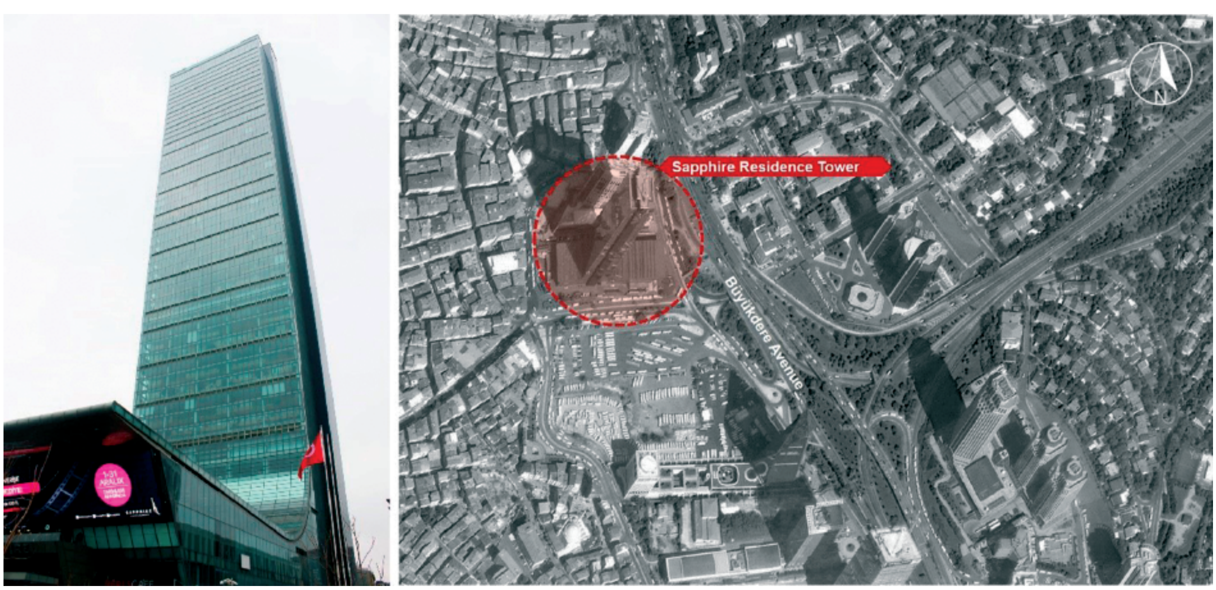

Figure 5.
Sapphire Residence Tower and location of the building. Photo: D. Aydin

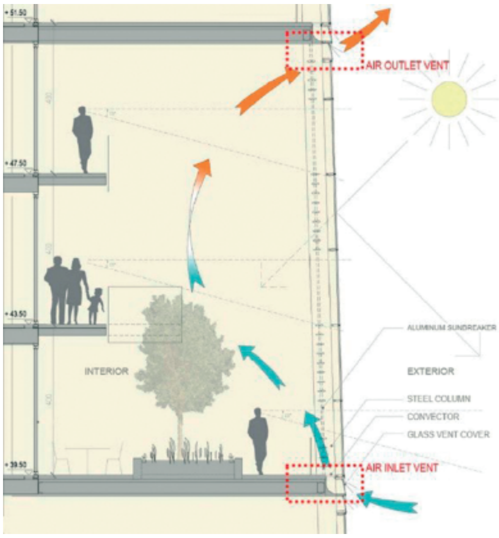

Figure 6.
Floor garden section detail and interior view. Photo: Tabanlıoğlu Architect

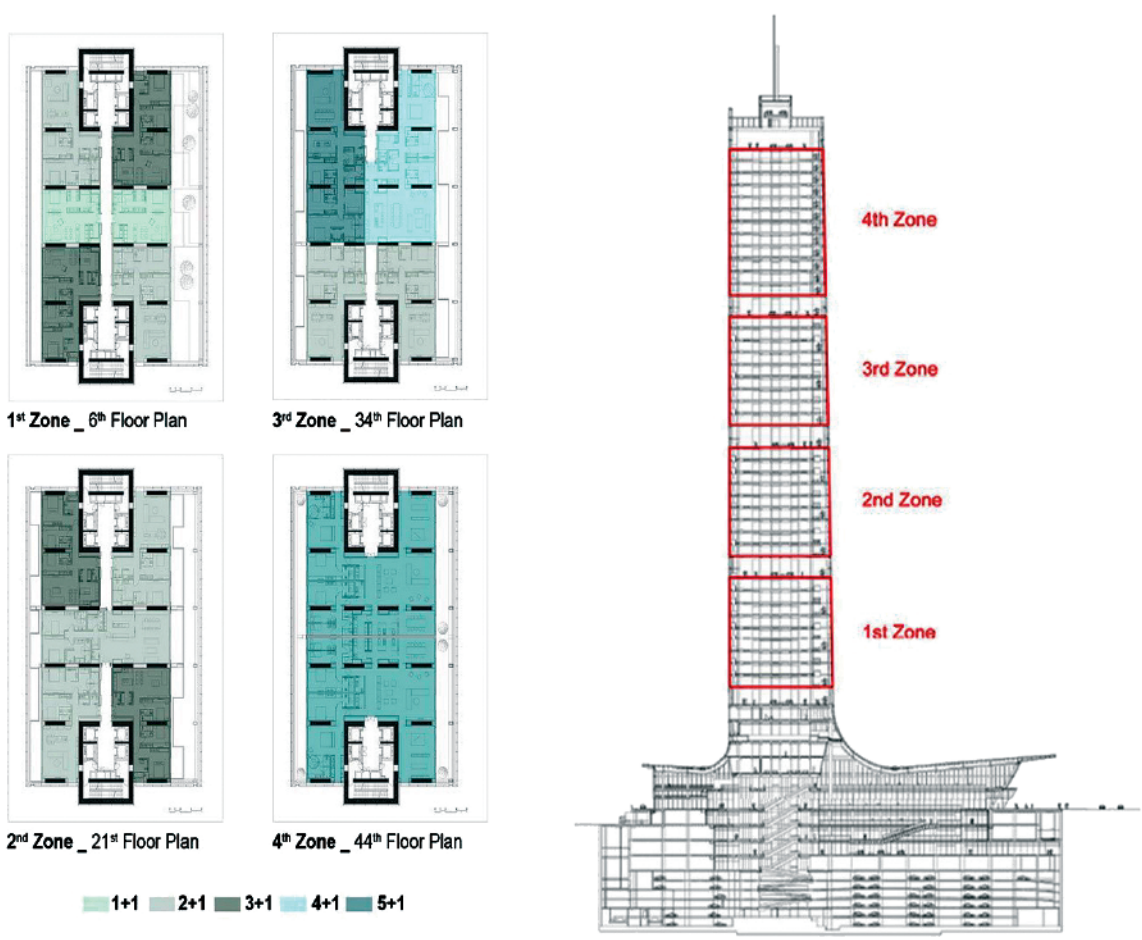

Figure 7.
Sapphire Residence Tower plans and section. Photo: Tabanlıoğlu Architect

Table 1.
General features of Sapphire Residence Tower. Source: Authors

Climate Data	Location	4.Levent, Istanbul – TURKEY			
	Coordinate	41° 5' 6.28" North		29° 0' 21.96" East	
	Altitude	124 m			
	Heating Degree-Days Zone	2nd HDD (internationally 2700 HDDs)			
Architectural Space Data	Total Building Floor Area	59.744 m^2			
	Total Building Volume	250.580 m^3			
	Area-Volume Ratio (A / V)	0,24			
	Heat-Loss Surface Area by Direction	North & South	7.260 m^2	East & West	11.880 m^2
	Total Facade Area	38.280 m^2			
	Facade Transparency Ratio	%71			
Mechanical System Data	Heating System	Floor Heating, Floor Type Fan Coil			
	Fuel of Heating System	Natural Gas			
	Cooling System	Fan Coil and Natural Ventilation			
	Fuel of Cooling System	Electricity			
	Conditioned Area	52.791 m^2			
	Unconditioned Area	6.953 m^2			

Table 2.
Transparency ratio of the building envelope. Source: Authors

Facade	Surface Area		Transparency Ratio
	Transparent	Opaque	
North – South	3.350 m^2	3.910 m^2	%46
East – West	10.295 m^2	1.585 m^2	%87
TOTAL	**27.290 m^2**	**10.990 m^2**	**%71**

Table 3.
Thermophysical properties of the envelope. Source: Dekoral; Façade Construction Company

Façade	Properties		
	Façade Component	Thickness	TOTAL U-Value
Opaque Curtain-wall	Gypsum Plaster	20 mm	0.20 W/m²K
	Reinforced Shear Wall	800 mm	
	Rock Wool Insulation	80 mm	
	Air Gap	100 mm	
	Enamel Painted Glass (6mm+1.5mm+10 mm)	175 mm	
Glass Curtain-wall	Glass (with 0.691 SHGC)	-	1.10 W/m²K
	Metal Facade System Profile	-	2.00 W/m²K

Table 1 shows general information about the building; climate data, architectural space data and mechanical system data are summarized under three groups. When the structural components of the building are evaluated, it is seen that the structural system consists of reinforced concrete shear wall frame and the structure of the envelope consists of two independent layers. While insulated glass curtain wall was used on the transparent surfaces of the external façade, enamel painted glass was used on the surface of opaque building cores in north and south direction. Depending on the symmetrical planning and the form of the building, the transparency of the east-west and north-south façades are the same (Table 2). Table 3 shows the layers of the building envelope components and their thermophysical properties. These data were obtained by the façade construction contractor firm after the meeting the director of the building envelope.

After obtaining the building envelope data, the energy model of the building was created in DesignBuilder. In this process, creating each zone of the building separately helps the building to give the closest result to actual energy consumption.

However, the fact that the zone is a conditioned space or not affects the heat conduction mechanism. Especially when the number of zones forming the building is too great, the zone separation of the building is applied by combining together the conditioned and unconditioned spaces in order to make the simulation faster and easier. Therefore, it can be said that for high-rise buildings, it is very important to reduce the number of zones by grouping the zones. In this study, zone separation for the case building was made in 3 groups as the conditioned and unconditioned spaces of the building and the space between the inner and outer façade surfaces due to the structure of the air corridor façade of the building. The zone separation in the DesignBuilder building model was made with this acceptance (Fig. 8) while the "ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality" standard was defined among the zones existing in the program. Accordingly, the conditioned spaces were calculated according to the "Residential-Dwelling Unit" values and the unconditioned spaces were calculated according to the "Residential-Corridor" values. "Residential-Dwelling Unit" values were used for the common ground areas (used for floor garden) between each three floors.

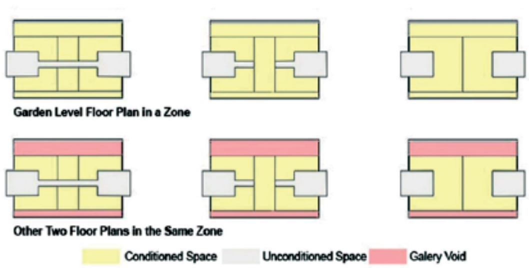

Figure 8.
Floor plan zoning of Sapphire Residence Tower. Source: Authors

Since the energy consumption calculations of the building were made only for the residential tower, the shopping mall area located at the entrance level was created as a solid model only. The 3-dimensional energy model of the building was completed by combining all the floors. The other high-rise buildings surrounding the building were also included in the model due to the fact that these buildings affect the physical external environment conditions, especially the sunbathing of the building and also the energy consumption of the building (Fig. 9).

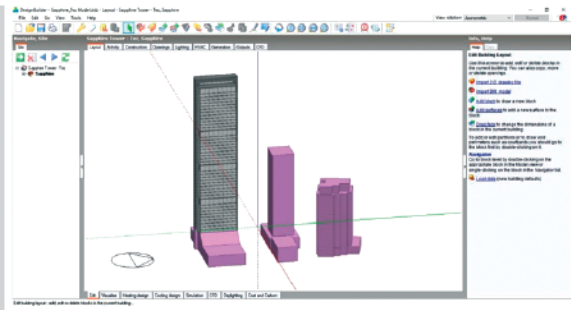

Figure 9.
Solid model of the building with shopping mall and the other surrounding high-rise buildings Source: Authors

After the building model was created, the building envelope properties in Table 3 of the case building were defined on the respective façade surfaces. At the last stage, the data of the temperature values, when the heating and cooling system will work, was entered. This was done according to the limit values for winter and summer comfort as in "ASHRAE-55 Thermal Environmental Conditions for Human Occupancy". Accordingly, the heating system will be activated by assuming that the indoor temperature falls below 20°C and the cooling system will be activated when it exceeds 27°C. It is foreseen that natural ventilation will be done when the ambient temperature rises above 22°C.

5. RESULTS AND DISCUSSION

The heating and cooling energy consumption of the Sapphire Residence Tower was calculated according to the annual meteorological data of Istanbul by considering the ASHRAE-55 limit values. As a result of the simulation, the annual heating energy requirement of the building is obtained as 2,964,246.24 kWh and 1,629,678.68 kWh per year is the amount of energy required to cool the building. In other words, the energy required for heating the building is 65.8 kWh/m^2 per square meter area while cooling energy load is only 17 kWh/m^2. It can be said that the natural ventilation of the building helped to reduce the required energy in order to cool the environment by using mechanical ventilation. According to the assessment made on all conditioned spaces of the building, the total annual energy consumption is 11,766,760.63 kWh and 226.4 kWh/m^2 per square meter area. Monthly heating and cooling energy change of the building is as in Fig. 10. It is found that the heating energy consumption of the building is the maximum in February, while the cooling energy consumption is the maximum in August.

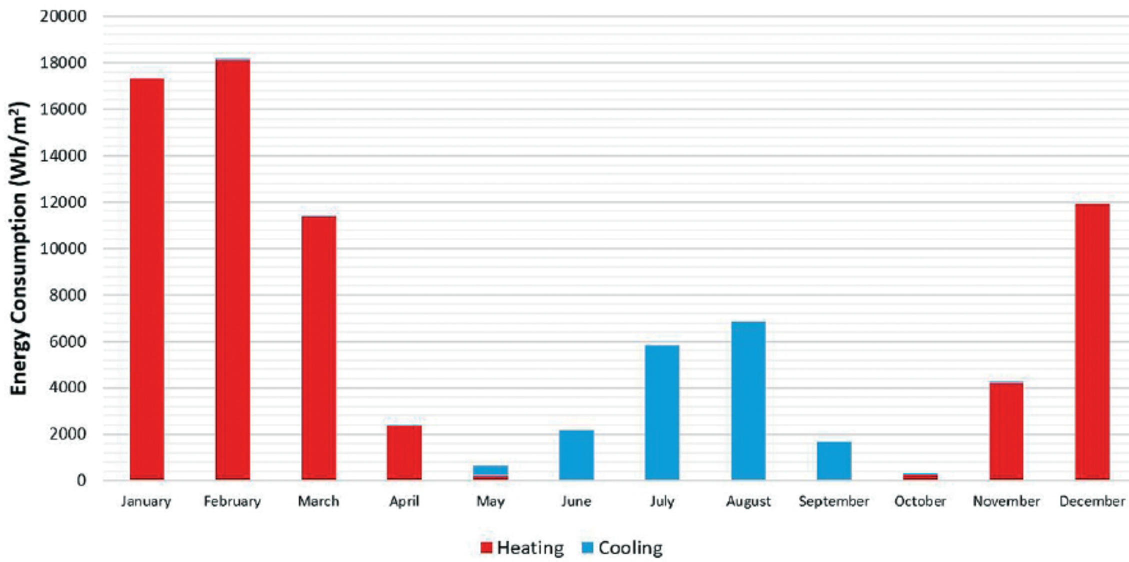

Figure 10.
Monthly heating and cooling energy consumption change in Sapphire Residence Tower. Source: Authors

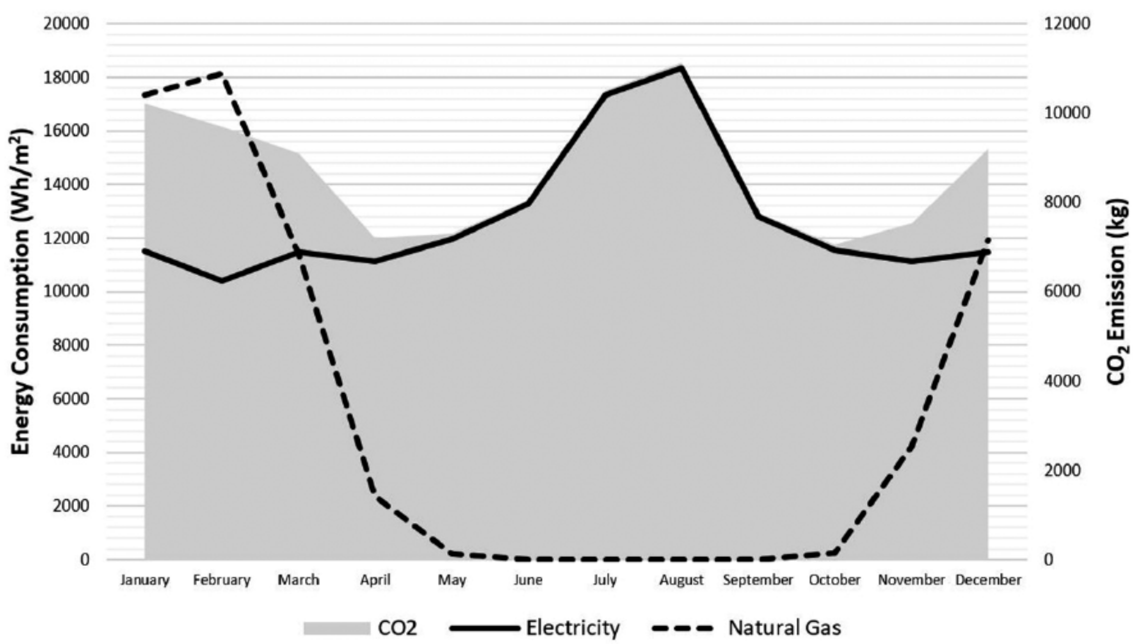

Figure 11.
Energy consumption by fuel type and the amount of CO_2 emission based on energy consumption in Sapphire Residence Tower. Source: Authors

While the heating system of the building works with natural gas, electricity is used for the cooling system, lighting and other electrical devices. The change in energy consumption of the building according to fuel type and the amount of CO_2 emission due to this energy consumption are given in Fig. 11. Natural gas consumption was realized during the October-April heating period. However, the CO_2 emission was mostly realized in August. It can be said that this is the result of high electricity consumption in that period. This is because CO_2 emissions during electricity consumption are higher than natural gas. Thus, the total annual CO_2 emission of the building was calculated as 104,714.55 kg.

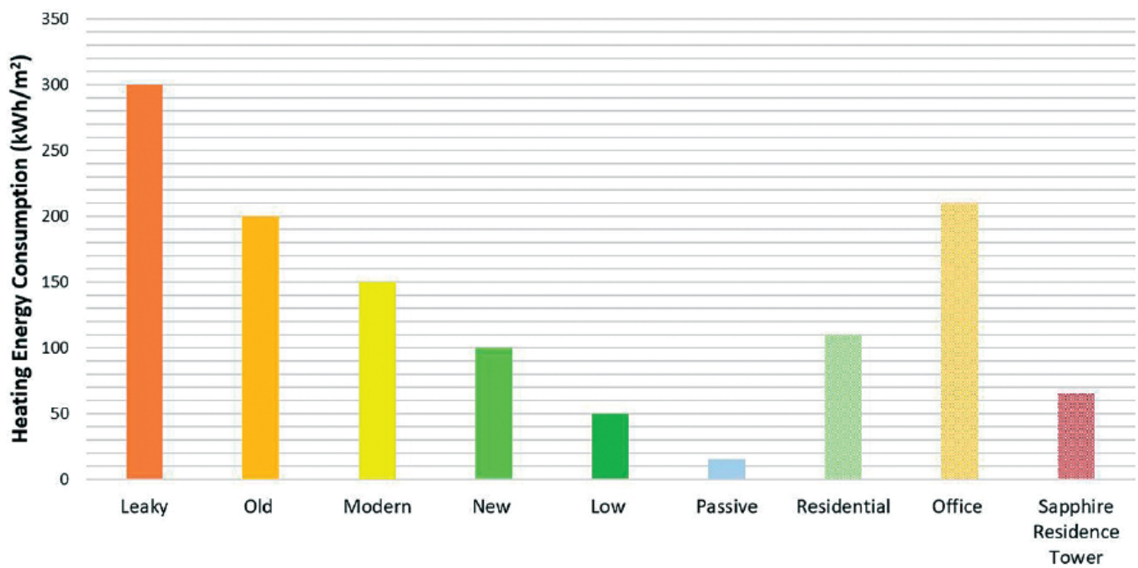

Figure 12.
Comparison of heating energy consumption of Sapphire Residence Tower. Source: Authors

Table 4.
Energy consumption comparison of the different high-rise residential buildings [34–38]

Country	TURKEY	CHINA	SOUTH KOREA		CANADA
Location	Istanbul	Shanghai	Seoul		British Colombia
Year	2006–2010	1995	2000	2008-2010	1974–2002
Façade Design	Double-Layered Skin With Air Corridor	Single-Skin	Single-Skin	Single-Skin	Single-Skin
Heating Energy Load (kWh/m^2)	65.8	101.7	105.6	123.2	111.0
Total Energy Load (kWh/m^2)	226.4	182.2	179.2	212.1	213.0

Generally in a high-rise building, a large part of energy consumption is used for space heating, followed by electricity consumption (lighting and devices) and hot water supply [33]. When the total energy consumption of the case is examined, it is seen that 25% of the energy is used for heating. However, 65% of the energy consumption can be used by the heating system especially in the buildings which do not have high insulation. Thanks to the very low U-value of the building envelope, it is obtained that the energy required for heating is saved. Fig. 12 shows comparative results, the average energy consumption of the high-rise buildings used for residential and office functions and the energy consumption of the Sapphire Residence Tower. According to the classification of the heating energy consumption of the buildings, the Sapphire Residence Tower energy demand is very close to the low energy building class.

Most of the high-rise buildings are located in Asia, and South Korea is one of these countries. The use of high-rise buildings for residential purpose function is quite common in this region, such as Turkey. In this context, it is seen that the studies on energy consumption of high-rise residential buildings are mainly conducted in South Korea [34]. Thus, the results of two different studies were followed. In addition, while evaluating the heating energy loads, the results of different climatic conditions should be taken into consideration in the study. Therefore, the results obtained in the case studies were compared with the results obtained from the studies conducted in China and Canada where high-rise residential buildings are also dense and common [35–38]. This comparison was based on the total energy consumption of the buildings and the heating energy loads (Table 4).

According to Table 4, the share of heating energy in the total energy requirement varies between 25% and 58%. Sapphire Residence Tower's energy consumption is higher than others with 226.4 kWh/m^2 energy consumption per year. However, in terms of heating energy load, it is observed that it is in the energy efficient class among the other buildings. In addition, the average energy consumption values of the buildings with 40,000 to 50,000 m^2 total construction area vary between 300–325 kWh/m^2. It can be said that the building consumes about 30% less energy to heat than other high-rise residential buildings on the same scale. This is a result of the effect of building envelope design on the energy consumption of the building. As seen in the case study, the façade design as double-layered or air corridor, energy can be saved from 20% up to 50% depending on the surface materials used, the system details and the distance between the two layers [21, 39, 40].

The building should also provide the adequate thermal comfort conditions to its users while consuming these heating energy loads. It is seen that the current heating energy consumption is sufficient to provide the thermal comfort of the building. The results of the interviews with three different users living on the 16^{th} floor of the building support this situation. When all three users were asked to evaluate the thermal comfort conditions of the building, they were satisfied with the indoor temperature. Only one of the users stated that the relative humidity was "dry" and the air flow rate was "slow". In addition to interview, the PMV value for thermal comfort was -0.46 and PPD index was 9.47% in the simulation result under the current indoor conditions where the indoor temperature is 22°C, the humidity rate is 45% and the air flow rate is 0.137 m/sec. Therefore, both the user perception and the calculation show that the building is comfortable in terms of thermal comfort.

6. CONCLUSION

As a result of the study, it has been seen that high-rise buildings, which are considered as anti-environmental buildings, are able to present a standard residential comfort to their users while at the same time they can provide energy efficiency. In addition, according to the literature, the most effective component in the energy consumption is the building envelope, which can lead to an increase in the cost of the façade compared to a low-rise building depending on the increased height and the building scale. Thus, the impact of the use of high-rise buildings with residential function on the cost of façade is 50% higher than the cost of the high-rise office buildings [41]. Therefore, it is thought that the data obtained from this study will be helpful especially in designing the building façade. The limited number of studies on direct energy consumption values in the case building scale examined increases the importance of the findings in terms of guiding further studies.

The results obtained from the case building show that the heating and cooling energy efficiency of the buildings designed with double-layered or air corridor façades is higher than the high-rise residential buildings designed as single-layered façades. As a consequence of the simulation conducted according to the existing façade of the case building, 25% of the energy is used for heating and 14% for cooling in total energy consumption. This shows that the case building has high energy efficiency. Apart from energy efficiency, such façades offer users a safe natural ventilation opportunity despite increasing height. Thus, the indoor comfort level of the building increases and the heating load of the building for the winter period and the cooling energy load required for the summer period decrease.

Designing the high-rise residential buildings with energy efficient approaches is very important for Turkey, which is dependent on outside energy sources, to obtain sustainable development. In this context, the effective use of BIM in the construction sector is also important in the design, construction and operation of the buildings throughout the whole life cycle. To sum up, the design, construction and operation of large and complex projects such as high-rise buildings can be carried out coordinately, quickly and easily.

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