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Construction Project Manager

Energy efficiency of residential complexes using BIM-integrated analysis of building design, climatic conditions and facilities optimization

Facilities (F)

Energy Efficiency Management

ABSTRACT

This study investigated the cost benefits of BIM-integrated energy optimization for a residential complex. The aim of this research is to optimally design residential buildings for energy efficiency by observing climatic conditions and the proportion between energy-consuming facilities using a building information modeling system in a temperate and humid environment. Revit software was used for modeling and simulation and Green Building Studio for scenario comparisons. Both are web-based and resource-efficient. The project aimed to assess energy cost variations due to BIM optimization, considering the building's size and seaside location. Building Information Modeling (BIM) was also used to examine building form and orientation. The building is a four-block residential complex exceeding 18,000 sqm with a central corridor. Located near the Caspian Sea, it experiences hot summers and mild winters with high humidity and frequent fog. The research steps include: (1) Initial building modeling using parameters common in the Iranian construction industry; (2) Initial energy analysis ...

ABDULAMIR REZASOROUSH

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Article

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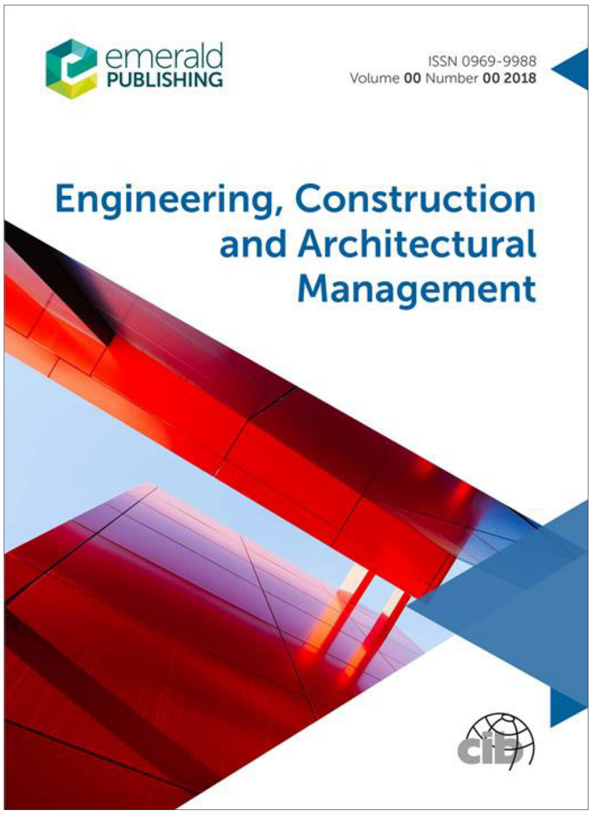
BIM-based approach to optimizing energy consumption in tower buildings: investigation of parameters and factors affecting energy efficiency



Engineering, Construction and Architectural Management (ECAM)

Building and Construction

ABSTRACT

This research aims to develop a multi-criteria framework for optimizing energy consumption in tower buildings by evaluating parameters and factors affecting energy efficiency over 30 years. Building information modeling (BIM) is employed to model and analyze the results. This study employed a building information modeling (BIM) approach using Autodesk Revit software to model a residential complex in northern Iran. The study considered various building parameters, including form, orientation, materials, HVAC systems and occupancy patterns, to assess their impact on energy consumption. Climatic data for Astara, Iran, with its humid subtropical climate, was automatically integrated into the energy models. The research focused on optimizing energy consumption by analyzing different building configurations and identifying design strategies that minimize energy use and costs. The results of the modeled building analysis indicate that the average annual energy cost will be $19.2 per square meter …

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Analysis of the amount of latent carbon in the reconstruction of residential buildings with a multi-objective optimization approach

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Abstract

Purpose – Due to the increase in energy demand and the effects of global warming, energy-efficient buildings have gained significant importance in the modern construction industry. To create a suitable framework with the aim of reducing energy consumption in the building sector, the external walls of a residential building were considered with two criteria of global warming potential and energy consumption.

Design/methodology/approach – In the first stage, to achieve a nearly zero-energy building, energy analysis was performed for 37 different states of thermal insulation. Then, the insulation materials' life cycle assessment was performed. These results were used to find a set of optimal modes in the Pareto front by using non-dominated sorting genetic algorithm II multi-objective genetic algorithm. Thus, based on the data obtained from this method, it was possible to compare and choose different thermal insulation materials based on the distance from the Pareto front, reducing the environmental effects.

Findings – The results showed that replacing the windows was possible to save 3.24% in energy consumption. Also, selecting the proper insulation reduced energy consumption value by 63.13%. Finally, this building can save 69.31% of energy consumption compared to the base building by following the zero-energy building standard. As a result, the Pareto curve was introduced as a guide for the optimal design of the building's wall insulation.

Originality/value – The proposed method provides designers with a framework for latent carbon analysis to access quickly and select optimal scenarios. It can also be used without restrictions for other decisions with different goals and criteria.

Keywords Life cycle assessment (LCA), Multi-objective optimization, Building energy analysis (BEA), Latent carbon, Nearly zero-energy building (nZEB), NSGA-II evolutionary algorithm

Paper type Research paper

Abbr

AN ...ards Institute;
A
...g, Refrigeration and Air-Conditioning Engineers;

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Handbook of Energy Analysis Using Building Information Modeling (BIM)

Book

Keywords:

- *Energy Consumption*
- *Energy Performance Assessment (EPA)*
- *Energy Simulation*
- *Optimize Energy Consumption*
- *Building Energy Efficiency*
- *Building Information Modeling (BIM)*

ABSTRACT

According to the United Nations Environment Programme (UNEP), buildings are the largest worldwide consumers of energy. Most of the energy used by any building is consumed during the usage (or operational) stage of the building's life-cycle. Achieving sustainable development at the national level will require minimizing the effects of buildings on the environment with the low energy consumed by buildings. The energy performance of a given building is predicted and assessed by conducting an energy simulation. Using BIM in EPAs greatly reduces time and costs. The purpose of this study was to optimize energy consumption in buildings, using Building Information Modeling Technology (BIM), which can assess energy performance in the building. In this research, the general form of the building was modeled in the Autodesk Revit Software. After reviewing the proposed designs, the main form of the building was selected for modeling. Then, according to the type of materials consumed, the equipment and location of the project, the calculation of the energy consumption of the building was carried out using relevant tools in this scope. Finally, the best possible mode was chosen by examining different energy consumption modes. The results of energy simulation showed that 61.48% of the difference between the best mode of energy consumption optimization and the current state of the building, as well as 79.35%, is compared to the initial state. Finally, parametric studies of alternative cost optimization schemes showed that saving 58.23% of the building's current status for a 30-year horizon.

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Energy analysis for construction of a zero-energy residential building using thermal simulation in Iran

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Abstract

Purpose – The purpose of this paper is to examine the feasibility and design of zero-energy buildings (ZEBs) in cold and semi-arid climates. In this study, to maximize the use of renewable energy, energy consumption is diminished using passive solar architecture systems and techniques.

Design/methodology/approach – The case study is a residential building with a floor area of 100 m^2 and four inhabitants in the cold and semi-arid climate, northeast of Iran. For thermal simulation, the climate data such as air temperature, sunshine hours, wind, precipitation and hourly sunlight, are provided from the meteorological station and weather databases of the region. DesignBuilder software is applied for simulation and dynamic analysis of the building, as well as PVsyst software to design and evaluate renewable energy performance.

Findings – The simulation results show a 30% decrease in annual energy consumption of the building by complying with the principles of passive design (optimal selection of direction, Trombe wall, shade, proper insulation selection) from 25,443 kWh to 17,767 kWh. Then, the solar energy photovoltaic (PV) system is designed using PVsyst software, taking into account the annual energy requirement and the system's annual energy yield is estimated to be 26,291 kWh.

Originality/value – The adaptive comparison of the values obtained from the energy analysis indicated that constructing a ZEB is feasible in cold and semi-arid conditions and is considered an effective step to achieve sustainable and environmentally friendly construction.

Keywords Energy sector, Renewable energies, Solar, Energy conversion, Construction, Simulation, Optimization, Zero-energy building, Energy management, Sustainable development, Renewable energy, Photovoltaic, Residential building

Paper type Research paper

Introduction

Studies accomplished by the International Organization for Economic Co-operation and Development (OECD) show that energy consumption in the construction sector has continuously increased since 1960 and will continue to increase in the coming years, mainly because of the high construction intensity in Asia, the Middle East and Latin America. In total, 50% of the

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world's raw materials are used in buildings, while most of them are non-renewable. In fact, buildings are responsible for releasing more than 46% of the total greenhouse gas produced worldwide (Osman, 2014). According to the United Nations Intergovernmental Panel on Climate Change (IPCC) report, from the industrial revolution until the end of the 20th century, the Earth's temperature has increased by 0.5°C and on average, the ozone layer thickness has decreased by 20% in different parts of the world (IPCC, 2016). In Iran, as a developing country, residential buildings include 25% of total greenhouse gas emissions (Eshraghi *et al.*, 2014). With rapid construction development in Iran and electrical energy shortage, energy-efficient buildings and sustainable development of buildings have become the focus of the society (Amani, 2017; Amani, 2018). In the report published by the Public Relations of the Center for the Islamic Consultative Assembly studies, the Energy Studies Bureau, the construction sector with an average consumption of 41.42%, had a high share of energy consumption in the country. Meanwhile, given the figures published, Iran has ranked 11th of the countries with the highest energy consumption (Center for the Islamic Consultative Assembly studies, 2017; GES, 2020). Based on this information, efforts to lower fossil fuel consumption, construction of buildings with optimal energy consumption, the use of devices with high energy rank and the use of renewable energy resources are essential. The measures taken in this regard in the macro-scale programs in the developed countries account for the construction of zero-energy buildings (ZEBs). Advantages of net-zero energy buildings included a reduction in thermal fluctuations in these buildings, which results from adequate isolation and well provides the comfort conditions; energy supply, even in the event of shutting down in the global energy distribution network; protection against the ever-increasing rise in energy prices; reduction in greenhouse gases and saving in energy consumption (Mahdavi Adeli *et al.*, 2020). The basic scheme of a Net-zero building design is to provide thermal comfort with less energy consumption. Sudhakar *et al.* (2019) examined the various building designs in hot and humid climates. It was found that it is most important to concentrate on all possible passive energy-saving actions before adopting active measures. These measures included using the natural ventilation systems in places with high wind speeds; using different design strategies to achieve comfort performance in different seasons; as well as wind tower dehumidification design and ventilated attic building design for the hot and humid regions. To achieve an integrated nZEB standard, during designing and constructing based on the relevant geographic location, factors such as building envelope, window type, optimum air infiltration and tilt angle of PV panels and their proper orientation must be considered (Al-Saeed *et al.*, 2020).

These programs practically apply the standards in the investigation of sustainable architecture such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) with high quality in terms of reducing energy consumption and environmental compatibility and using efficient and modern technologies, provide the ground for the development of technology and technical knowledge in this field (Wang *et al.*, 2009). The Energy Performance of Buildings Directive (EPBD), approved by the European Parliament and Council in relation to the energy efficiency of buildings, pledges the European Union, including 28 European countries, to lower the energy consumption of residential and commercial buildings to near-zero in all new public buildings by 2019 and all new buildings by 2021 (Arbabiyan, 2001; Osmani and O'Reilly, 2009). In the USA, based on a law passed in 2007 to support the construction of ZEB, the net energy consumption must reach zero in half of the commercial buildings by 2040 and all commercial buildings by 2050 (Crawley *et al.*, 2009). The best way to improve the performance of existing buildings toward zero energy performance is an integrated approach of different energy strategies, running in parallel, that tackle behavior, the efficiency of equipment, on-site renewable energy generation and energy storage.

Fonseca *et al.* (2018) achieved nearly zero-energy building goals in the renovation of the university campus building by adopting an integrated approach such as the right combination of different strategies, including energy-efficient technologies and renewable energy. However, further investigations based on software analysis seem to be necessary for energy efficiency and the construction of efficient buildings with near-zero energy consumption. Amani and Reza Soroush (2020) investigated the simultaneous effect of parameters affecting energy consumption in the building. These parameters included Building orientation, window-to-wall ratio (WWR), Window shades, Window glass, Wall and Roof construction, Infiltration, Lighting efficiency, Daylighting and occupancy controls, Plug load efficiency, HVAC system, Operating schedule and photovoltaic system. Their findings showed that the simultaneous investigation of parameters affecting energy consumption in the case study building could save energy costs up to 58.23%. Hence, it can be concluded that each of the building components has a significant role in evaluating the energy performance of the building, which should be considered in the energy analysis.

The use of a photovoltaic (PV) system for zero-energy buildings is crucial to balance energy consumption. The potential of using PV systems for residential buildings in different climatic zones of China was investigated by Liu *et al.* (2019), taking into account parameters such as tilt angle, orientation, plot ratio, PV conversion efficiency and location. The results indicate that southwest China is the best place to develop zero energy buildings. Low-rise residential buildings can realize zero energy in China when the PV conversion efficiency is higher than 20%. The potential of using nearly zero-energy buildings (nZEB) was investigated by Al-Saeed *et al.* (2020) to improve the performance of residential buildings in the hot and dry climate of Iraq. Their findings showed that both significant annual energy reductions and nZEB standards have been achieved, which could range from 41% to 87% for current climatic conditions. Walter Costa *et al.* (2020) conducted a study on pure energy office buildings in the hot climate of Brasilia. Their studies showed that the nZEB goal could be achieved in office buildings up to four floors in the Brazilian climate zone by following the nearly zero-energy building improvement guidelines. These guidelines included measurement of available building shell for collecting solar irradiation, the reduction of the WWR, using glasses with a Solar Heat Gain Coefficient of 43% or lower, the addition of solar shading devices, the reduction of the installed power density of the lighting system by 25% and the use of natural ventilation. The potential impacts of energy-efficient measures for retrofitting existing UK hotels to reach the nearly zero-energy building (nZEB) standard were investigated by Salem *et al.* (2019). The findings show that it is possible to achieve the nZEB standard for older UK hotel buildings. Thus, attention must first be paid to improving the building fabric or building envelope elements, then if necessary, to achieve the nZEB goal in the historical buildings can be used the renewable energy systems. Al-Saadi and Shaaban (2019) conducted a study based on the design of sustainable architectural and engineering systems for a zero-energy building (ZEB) in the hot climate of Oman. Sustainable passive and active energy systems have been successfully integrated into this building typology. Passive strategies have resulted in a small equipment capacity of air conditioning systems. However, a PV system was installed on the rooftop providing electrical energy for immediate house demand. A solar water heater was also installed to provide free hot water. The results showed that when grid interaction was considered, 40% of the building load was supplied by site generation, which meets zero energy targets. Albadry *et al.* (2017) proposed increasing insulation surfaces to reduce energy consumption and design a photovoltaic system for renewable energy to reach the nZEB targets for a 5-story residential building in Egypt. Charisi (2017) stated that the appropriate combination of the building shell and increasing the insulation layer thickness in achieving the nearly zero-energy building of a residential building in Greece could save up to 30% in energy consumption. The heating and cooling loads between a ZEB and a similar building in a very cold area in China were simulated and compared by Li *et al.* (2015). The findings indicated that the overall energy savings were more than 55%, among which the air conditioning system played a significant role in saving energy. Ferrari and Beccali (2017) were able to reduce the primary energy demand and CO2 emissions by up to 40% by adopting accessible technological solutions in a building at the Polytechnic School of the University of Milan, Italy. The use of semi-transparent photovoltaics (STPV), which transmits visible light yet, at the same time, produces electricity has most likely the highest potential to achieve the nZEB goal. Refat and Sajjad (2020) showed that for 50% visible transmittance, STPV on clear glass saves about 50% and 30% of the energy demand in tropical and hot desert regions, respectively, and around 20%–25% in Scandinavian and cold continental regions. Moreover, when combined with low-emissivity glass, the net saving reaches as high as 90% in tropical regions, 60% in hot desert regions and 45%–70% in the rest of the regions. Renewable energy systems (RES) in buildings are designed to operate over their lifetime. Sobhani *et al.* (2020) stated that without considering the potential future changes in influential parameters such as climate and energy price data may lead to inappropriate solutions for long-term operation. Findings showed a decrease in heating and electricity demand by 14.6% and 2.29% and an increase in cooling demand by 19.9% after 20 years. The consideration of uncertainties in the design would further increase the computing cost significantly. It may also lead to low energy efficiency and even failure of achieving zero/low energy goal in operation, as each design option needs to be evaluated under a large number of uncertain scenarios. Li and Wang (2020) reviewed a coordinated robust optimal design method to efficiently identify the global optimal design solutions for the entire zero/low energy buildings under uncertainties. Their studies showed that taking into account uncertainties in design optimizations of building envelope and energy systems would save more than 90% of computational time. Also, the durability of materials and technologies is an important aspect that warrants further analysis to assess the proper efficiencies and the expected lifetime of a ZEB. Past studies have shown that ZEB performance in the building life cycle has decreased due to the instability of building materials (Danza *et al.*, 2018). Mahdavi Adeli *et al.* (2020) conducted a study on an office building in the hot and dry climate of Iran with the aim of thermal comfort as well as optimizing energy consumption. Their findings showed that using photovoltaic panels alone is not able to create a net-zero energy building. They found that using wind turbines for electricity generation in cold seasons would be an appropriate substitute for the reduction in the electricity generated by photovoltaic panels.

Table 1 shows the review of previous studies in the field of ZEBs. These studies have been derived from prestigious scientific bases such as ScienceDirect, Taylor and Francis, Wiley, ASCE, Springer and Emerald. The investigation of ZEB, feasibility studies and research on its components have been conducted in studies by Albadry *et al.* (2017) Al-Saadi and Shaaban (2019), Al-Saeed *et al.* (2020), Cellura *et al.* (2015), Charisi (2017), Danza *et al.* (2018), Ferrari and Beccali (2017), Fonseca *et al.* (2018), Heravi and Qaemi (2014), Li and Wang (2020), Li *et al.* (2015), Liu *et al.* (2019), Lizana *et al.* (2017), Mahdavi Adeli *et al.* (2020), Salem *et al.* (2019), Sudhakar *et al.* (2019), Walter Costa *et al.* (2020) and Zhou *et al.* (2016). Based on Table 1, it can be concluded that no study has been performed worldwide regarding the examination, feasibility and simulation of ZEB in cold and semi-arid climates using the Meteonorm, PVsyst, Ecotect Analysis and DesignBuilder software packages. The study of the feasibility of using solar panels system in the cold and semi-arid climate of Iran and achieving a building with zero energy by considering the principles of passive design including optimal selection of direction, Trombe wall, shade and proper insulation has been the main focus of this research. For this purpose, a case study building has been adopted in the design phase to select the best case for construction and computer simulation in the cold and semi-arid region of Mashhad using Ecotect and DesignBuilder software,

Table 1. Previous studies on zero-energy buildings (ZEB)

Author(s)	Objective	Research methodology	Achievements	Year
Al-Saeed *et al.*	Investigating the potential of using nearly nZEB	Validating the simulation by comparing the simulated primary energy consumption of the case-study building	Significant annual energy reduction; 41% to 87% for current climatic conditions and 40% to 84% by 2080 Achieving nZEB standards	2020
Li and Wang	Coordinated robust optimal design of building envelope	Coordination of design optimization method of building envelope and energy system	Provide better services compared to current design methods at a lower cost	2020
Mahdavi Adeli *et al.*	Increasing thermal comfort of an nZEB	Using of computational fluid dynamics model to determine the temperature for thermal comfort	Using wind turbines for electricity generation in cold seasons as an appropriate substitute for the reduction in the electricity generated by photovoltaic panels	2020
Walter Costa *et al.*	Retrofit guidelines toward the achievement of nZEB	Investigation of the effect of an outer shell on energy consumption	Achieving the nZEB goal in the up to four-story office buildings	2020
Amani and Kiaee	Developing a two-criteria framework to rank thermal insulation materials	Using 12 typical insulation materials with different thicknesses, a four-layer insulation system was developed and applied to a Case study	more than 70% reduction in the energy demand and a global warming potential range of 192e1500 kgCo2 eq.	2020
Al-Saadi and Shaaban	ZEB in an extremely hot climate	Investigation of the data acquisition system for energy and thermal performance	ZEB is feasible in the extremely hot climate of Oman	2019
Salem *et al.*	Investigating the potential impact of energy-efficient measures for retrofitting existing UK hotels	Investigation of the effect of the building fabric and/or building envelope elements on energy consumption	Achieving the nZEB standard for older UK hotel buildings based on prioritizing improving the building fabric	2019
Sudhakar *et al.*	Net-zero building designs in hot and humid climates	Investigation of basic guidelines, natural ventilation systems, cooling and dehumidification, insulation and construction materials	Using the natural ventilation systems in places with high wind speeds Using different design strategies to achieve comfort performance in different seasons	2019
Liu *et al.*	Energy balance evaluation and optimization of photovoltaic systems for ZEB in different climate zones of China	Investigating the potential of PV systems for zero energy buildings in different areas of China Investigation of tilt angle, orientation, plot ratio, PV conversion efficiency and location Building simulation by RETScreen in combination with TRNSYS software	Southwest China was identified as the best place to develop zero energy buildings Low-rise and mid-rise residential buildings can realize zero energy in China when the PV conversion efficiency is higher than 20%	2019

(*continued*)

Table 1.

Author(s)	Objective	Research methodology	Achievements	Year
Danza *et al.*	The durability of technologies in the keeping of ZEB's performances	Definition of the reference building Definition of the refurbishment scenario The durability of the adopted technical solutions Analysis of the degradation of energy performance	ZEB performance in the building life cycle has decreased due to the instability of building materials	2018
Fonseca *et al.*	Achieving nZEB goals on the university campus	Using a wide range of technologies, systems and solutions	Achieving almost zero energy goals by the renovation with two main measures	2018
Albadry *et al.*	Achieving nZEBs through retrofitting existing residential buildings using PV panels	The use of polycrystalline solar cells in the optimization process	Increasing insulation surfaces to reduce energy consumption	2017
Charisi	The role of the building envelope in achieving nZEBs	Investigation of the effect of an outer shell, openings and shadows on energy consumption	Save up to 30% of energy and bring total annual energy demand to 50 kWh/m^2	2017
Ferrari and Beccali	Passive design strategies to complete a building aiming to approach a ZEB	Definition of frameworks for the formulation of statutory requirements	Primary energy demand and related CO_2 emissions can be reduced by up to 40%	2017
Lizana *et al.*	Advances in maintaining the thermal energy of materials	Review of recent advancements in the development of thermal energy storage materials for creating ZEB applications	Chemical and thermodynamic properties of materials for increasing the efficiency of maintaining the thermal energy were the most important factors	2017
Zhou *et al.*	Operational implementation of solar nZEB	Dynamic thermal simulation (DTS) with e-QUEST software	Development of new technologies (such as PV) and their generalization to diminish the initial cost of nZEBs	2016
Cellura *et al.*	Balancing various types of energy for redesigning nZEBs	Simulation of the study building called "Leaf Home" as the first nZEB	Proposing a framework to analyze different definitions and conventions for reaching the ZEB	2015
Li *et al.*	Simulation and comparison of the heating and cooling load	Developing the physical model of the building using the DeST software	Energy recovery can reduce over 72% of new loads	2015
Heravi and Qaemi	Building energy performance	Use of the mean score (MS) method to rank the design scales	Passive solar energy is the most applicable renewable energy system	2014

considering all the required frameworks. Most of the existing studies have used only one software tool to analyze energy efficiency in all stages of drawing, analysis and thermal simulation, which increases the probability of error. In the current study, one of the most powerful software tools has been used in each stage by examining the strengths and weaknesses of software. AutoCAD software has been used at the drawing stage to reduce the drawing and volumizing error. The *weather* tool was used in Ecotect software to analyze climatic data. Moreover, DesignBuilder software was used for dynamic thermal simulation (DTS) and analysis of the building, as well as was used the PVsyst software to design and evaluate the renewable energy yield. In general, the building was first designed and evaluated in Ecotect software in terms of optimum building orientation by considering parameters such as daylight, shade and wind. Then, the building energy consumption was evaluated in DesignBuilder software in two modes, with and without complying with the principles of sustainable design. Finally, based on the optimum annual tilt angle of Mashhad, the energy produced by the solar panels in PVsyst software was estimated and compared with the energy consumption of the building. The findings showed that complying with the principles of passive design in the building will significantly reduce energy consumption and achieving zero energy in the building at a lower cost will be more practical.

Problem statement

Given the rapid economic development of metropolitan cities in Iran, the construction industry has entered its critical phase. According to the latest information, about 260 million m^2 of buildings are constructed annually (Sheykhansari, 2016). The residential, commercial and office buildings have accounted for the highest energy consumption, about 40% of the total energy produced in the country (Amani and Reza Soroush, 2020). Therefore, supporting the use of environmental energy and the development of green and zero-energy buildings has become an important activity in Iran. The solution to the problem is to provide the energy needed by any energy-consuming system, including the building within the same set to overcome the energy crisis and reduce greenhouse gas emissions. A vision that changes the quality of life and prepares us for life in the new era. In this regard, to create the best conditions in the building is emphasized the study of the architecture of buildings with the minimum energy required and the maximum use of solar energy. This study was accomplished by focusing on the feasibility of constructing a ZEB using computer simulation and analysis, in the cold and semi-arid region of Iran. A case study was selected by choosing the best computer simulation in the cold and semi-arid region using Ecotect and DesignBuilder software, taking into account all the required frameworks. Table 2 shows the design of ZEB design.

Research methodology

The building energy consumption strategy in this study was conducted with the approach that the researchers were pursuing to develop a sustainable and environmentally friendly adaptive model. This study was performed in four stages. The first step involved collecting data and

ZEB design	Passive design methods	Choosing suitable orientation, choosing proper insulation, the position of windows, walls, porches, canopies and trees, using double-glazed windows with low emissivity coefficient, Trombe walls, green roof and canopy
	Active design methods and renewable technologies	Solar PVs, wind turbines, fuel cells, solar water heaters and heat pumps

Table 2. The design phases of the zero-energy building (ZEB)

analyzing the site during the hottest month of summer and the coldest month of winter in cold and semi-arid weather. The data collected were classified into two groups. The first category included a set of annual temperature data and the second one was a list of the building components, including the specification of materials and their implementation details. These data were used for computerized simulations to thermal analysis of the model, its energy performance and the design of an appropriate PV system in the software. The most important data analyzed were associated with the proper orientation of the structure for maximum use of the sun, the amount of annual energy required for building and the amount of energy derived from the solar system in cold and semi-arid climatic conditions. In the second stage, a computer model was simulated to validate the proposed design using the data calculated. DesignBuilder is a graphical software for simulation of energy consumption in the building, in which the problem solution is performed by the powerful "EnergyPlus" engine. The EnergyPlus simulation engine has been developed by the US Energy Department in 2011 and is recognized as one of the most prestigious energy modeling software. The reliability of the Energy Plus software has been confirmed, according to Building Energy Simulation Test (Bestest) and ASHRAE 14 standards (Zomorodian and Tahsildoost, 2015; Naghdalizadeh and Heybati, 2015). Energy simulation software such as eQuest, DesignBuilder and Ecotect are widely used to model the energy performance of buildings (Ham and Golparvar-Fard, 2013). PVsyst software is used to design a renewable energy system. This software is comprehensive and applied software in the field of solar systems, which includes a set of tools for examining, sizing, simulating and analyzing data of PV systems. This software, which is continually developed at the University of Geneva in Switzerland, is one of the most important and most widely used software tools in the design of solar systems. In the third stage, two buildings, one in accordance with the principles of sustainable design (Trombe wall, optimal orientation, canopy, proper insulation selection) and one without these principles, were designed and simulated under different conditions to compare their energy and environmental performance. Moreover, at this point, the solar photovoltaic system (PV) was designed to obtain as much renewable energy as possible. In the final stage, an adaptive comparison was made to specify the amount of energy reduction with respect to the principles of sustainable design, as well as the feasibility of building a ZEB in a cold and semi-arid climate. As the ZEB refers to its grid-connected type, if the energy obtained is less than the required amount of energy over a few consecutive cloudy days, the building will provide its energy from the power grid and in days when the system has surplus energy, this energy will be injected into the grid. Hence, the annual energy required for the building and energy yield of the renewable energy system can be compared with each other. Figure 1 shows the steps of the study method in the following flowchart format.

Weather data

Stage one: The 1-h climate data of Mashhad was used based on the climatic data of 1991–2010, using the Meteonorm software database. Mashhad is located at the latitude of 36.2605° N, the longitude of 59.6168° E and an altitude of 985 m. The city is topographically composed of two types of terrains of mountainous and plain. Based on the climatic classification, Mashhad is located in a cold and semi-arid climate (Kasmaei, 2006). The average annual temperature and precipitation in Mashhad are 15.3°C and 217.38 mm, respectively. In addition, the hottest and coldest months are July and January, with an average temperature of, respectively, 27.4°C and 3.3°C (Climate, 2016). The 12-year-old weather data of Mashhad (2002–2014) was collected from the regional weather station as an annual indicator according to the recommendations of the same station. This collection of climatic information was used in thermal modeling to predict annual energy consumption and building optimal orientation under various

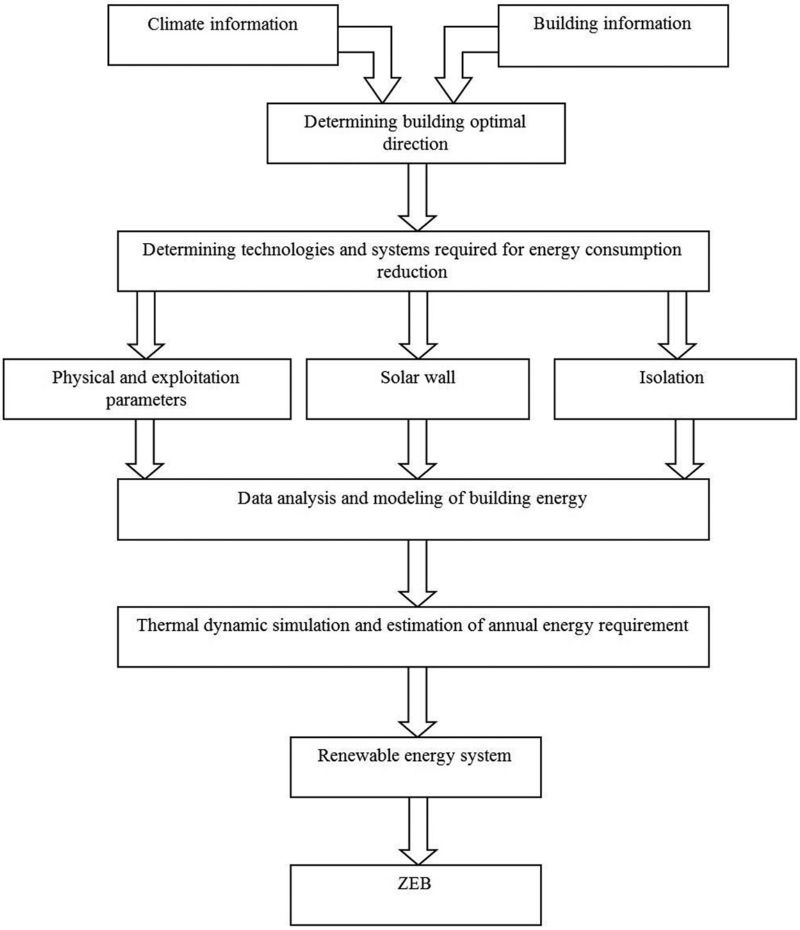

Figure 1.
Research method flowchart

atmospheric conditions. These data, while being compared with the output file from the Meteonorm software, were imported from the *Weather* tool of the Ecotect software and were displayed as the analytical results (Sabet Dizavandi, 2017). This tool is capable of calculating the amount of solar radiation received on a vertical plate with a surface area of 1 m^2 in warm and cold periods, as well as the whole year. It can also provide the most proper and the most improper orientations of the building in terms of obtaining radiation. The cold months of the year for the city of Mashhad included December, January and February, as well as the warm months, were June, July and August. Figure 2 displays the solar protractor to determine the radiation level in different directions.

In Figure 2, the yellow-red spectra represent the most appropriate and most inappropriate orientations of the building in terms of solar radiation. Figure 3 shows the direction and amount of wind. This figure shows that the dominant winds of Mashhad are from east to west, so the length of the building sides should be as low as possible in the east to the west direction. Hence, the building will be exposed to the least effect of the adverse wind in the winter.

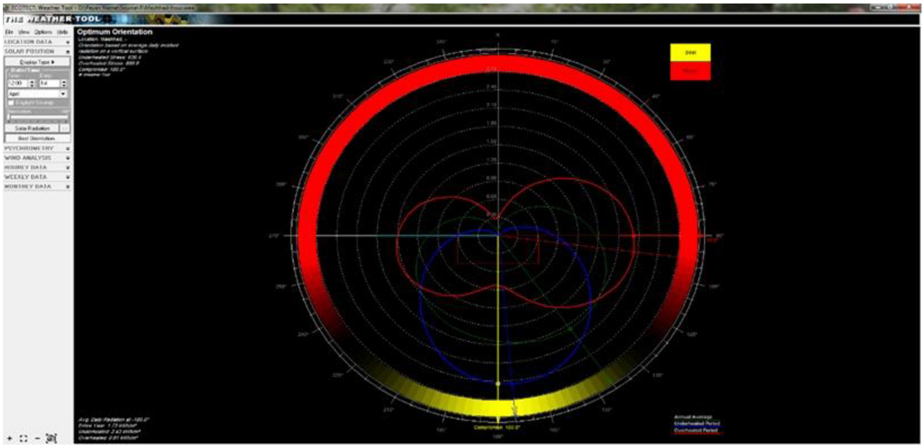

Figure 2.
Solar protractor, the most appropriate and most inappropriate orientations of the building

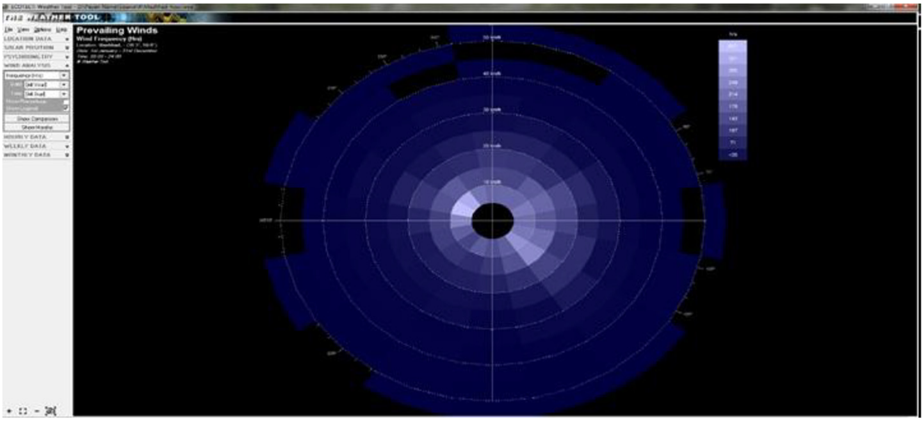

Figure 3.
Protractor of regional winds around the building

Given Figure 4, the building plan was designed in a direction that it was exposed to cool northern winds in the summer and is free from cold winds in the winter. Therefore, the building plan has an eastern-western extension for maximum use of solar heating and natural light, plus, the most commonly used and the unused spaces lay on the southern and northern sides, respectively.

Model specifications and software data

The second stage included the simulation of a residential building with an area of 100 m^2 and a height of 3 m. Table 3 indicates the specifications of the materials of the boundary elements.

Given the residential use, four individuals were considered to reside full-time on all days of the year. Also, natural light could be used in all directions of the building. Table 4 indicates the input data to the DesignBuilder software.

To examine and compare the annual energy consumption of the modeled building with a building in which the principles of sustainable design have not been met, the simulation

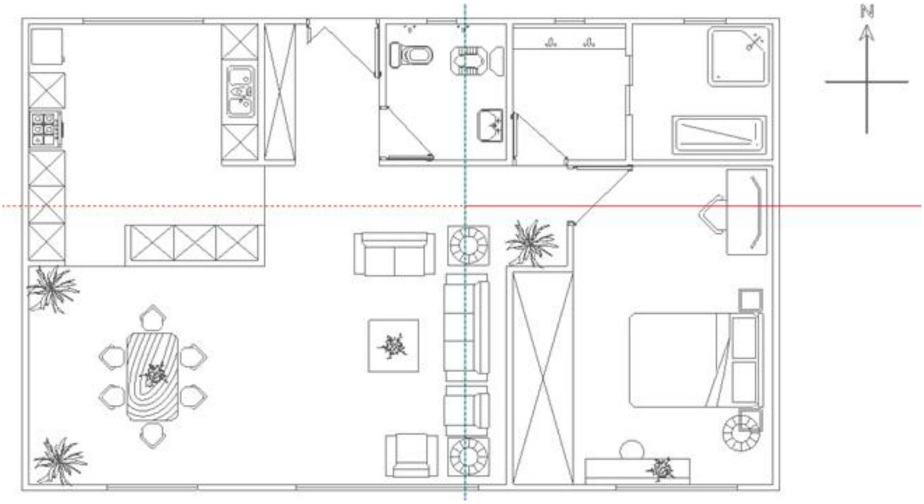

Figure 4.
Plan of the building modeled

Table 3.
Specifications of materials of elements in the DesignBuilder software

Elements	Specifications of materials	Heat transfer coefficient (W/m^{2}K)
Outer walls	100 mm Brickwork outer + 79 mm Extruded polystyrene + 100 mm Concrete block	0.35
Ceiling	19 mm Asphalt + 13 mm fiberboard + 122 mm Extruded polystyrene	0.25
Floor	30 mm Timber flooring + 70 mm Floor screed + 100 mm Cast concrete + 59.6 mm Formaldehyde foam	0.46
Windows	Triple layers + Argon 13 mm (Window gas type)	1.635
Entrance door	35 mm Wooden door	2.823

Table 4.
Input data to the DesignBuilder software

No. of residents	4 persons	Coefficient of performance (Cop) of the cooling system	0.45
Use	Residential	Cop of the heating system	0.85
Building dimensions (m)	8*12.5*3	External wall heat transfer coefficient	0.35 (W/m^{2}K)
Plan elongation	East-West	Ceiling heat transfer coefficient	0.25 (W/m^{2}K)
The building orientation, panels and collectors	South	Floor heat transfer coefficient	0.46 (W/m^{2}K)
WWR (window to wall ratio)	20%	Window heat transfer coefficient	1.635 (W/m^{2}K)
Lighting rate	300 Lux	Door heat transfer coefficient	2.823 (W/m^{2}K)
Heating set temperature	20°C	Air penetration rate	1.8 AC/H
Cooling set temperature	26°C	Heater set temperature	65 °C

process was performed again in a similar building in terms of the number of inhabitants and the area, as well as the thermal zones, without considering the appropriate angle and other passive design principles and systems. The input data of this conventional building were in accordance with Tables 5 and 6.

Table 7 shows the input data to the PVsyst software for the design of the PV solar system. The optimum tilt angle for panels in Mashhad is 30° (Taheri *et al.*, 2013).

Figure 5 shows the simulation steps in the DesignBuilder software. These steps include calling the two-dimensional (2D) output file from AutoCAD with the "dxf" extension, defining the thermal regions and boundary elements, assigning materials of elements (walls, floor, ceiling, door and windows), as well as calling the climate file with the "epw" extension, defining the geographic coordinates and designing cooling, heating and lighting systems.

To design a solar system in PVsyst software, a climate file with the "dat" extension was first called from the output of the Meteonorm software database. Figure 6 shows the input information for designing the PV system in PVsyst software. This information included the type of solar cells, the type of solar cell array, the type of solar module, the pitch for shadow overlap, the tilt angle of the panels, the width of the panels and the number and the nominal power of the panels.

Table 5.
Specifications of materials of elements in the DesignBuilder software for the conventional building

Elements	Specifications of materials	Heat transfer coefficient (W/m^{2}K)
Outer walls	100 mm Brickwork outer + 200 mm Concrete block	1.80
Ceiling	20 mm Asphalt + 80 mm Slab Concrete	2.25
Floor	200 mm Cast concrete	2.12
Windows	Double layers + Argon 7 mm (Window gas type)	2.412
Entrance door	35 mm Wooden door	2.823

Table 6.
Input data to the DesignBuilder software for the conventional building

Number of residents	4 persons	Cop of the cooling system	0.45
Use	Residential	Cop of the heating system	0.85
Building dimensions (m)	8*12.5*3	External wall heat transfer coefficient	1.80 (W/m^{2}K)
Plan extension	North-South	Ceiling heat transfer coefficient	2.25 (W/m^{2}K)
The building orientation, panels and collectors	North-East	Floor heat transfer coefficient	2.12 (W/m^{2}K)
WWR (window to wall ratio)	30%	Window heat transfer coefficient	2.412 (W/m^{2}K)
Lighting rate	300 Lux	Door heat transfer coefficient	2.823 (W/m^{2}K)
Heating set temperature	20°C	Air penetration rate	1.8 AC/H
Cooling set temperature	26°C	Heater set temperature	65 °C

Table 7.
Input data in PVsyst software

Panel type	Monocrystalline	Short circuit current	5.65 A
Width of the PV array	2 m	Open circuit voltage	52.3 V
Nominal power of panels	16 kW	Panel efficiency	17.45%
Number of panels	12	Pitch	6.6 m
Rated power	220 W	Tilt angle	30°

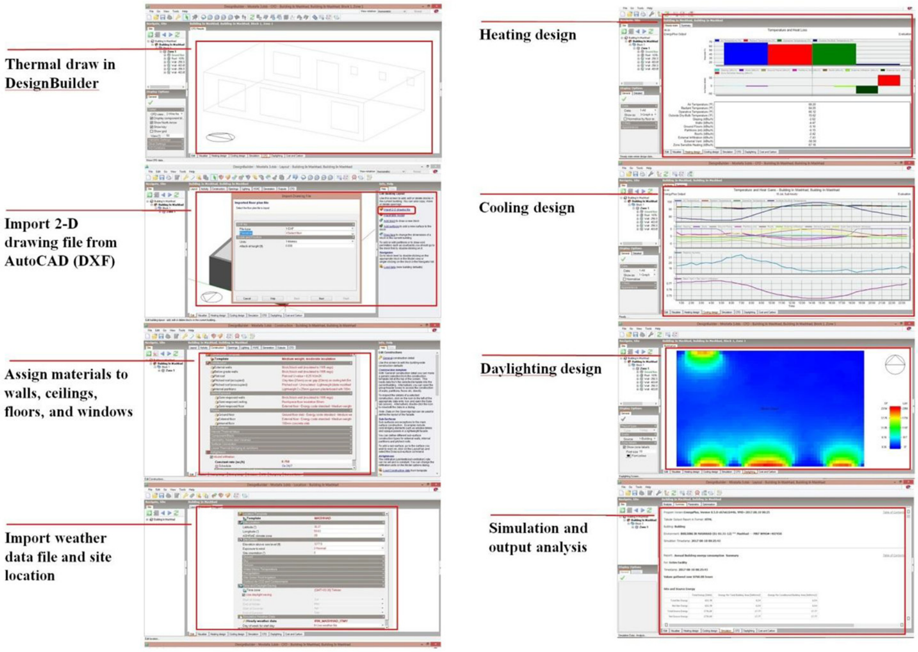

Figure 5.
Simulation steps in the DesignBuilder software

Software simulation

In this study, building energy simulation was performed in DesignBuilder software. This software is capable of calculating energy consumption in less than 1-h intervals and can simulate the space of a building that is composed of several thermal zones with different ventilation conditions, and hence is suitable to calculate the amount of energy consumed in the building (Zomorodian and Tahsildoost, 2015). Accordingly, DesignBuilder was chosen as the simulation software in the present study and the PVsyst software was used to design the renewable energy system.

Third stage: the simulation results using the DesignBuilder Results View tool were provided in a table including the amount of annual energy required for the structure, the energy required by the structure per square meter, the structure carbon use during the structure life cycle, the rate of the annual production of greenhouse gases, estimation of recycling rate and structural waste in the useful life of the structure in the form of an HTML file. Table 8 shows the amount of energy required for a model simulated, taking into account the principles of sustainable design and passive architecture (optimal selection of direction, Trombe wall, canopy, selection of proper insulation).

Based on Table 8, the amount of energy required of the building was 65.38 kWh/m^2 and the total annual energy required of the building was equal to 17,767 kWh; considering the electrical devices including an LED lighting system, a computer, a pump, a chiller and common types of kitchen and administrative equipment for the four residents of the building.

Table 9 shows the amount of energy required for a model simulated without respecting the principles of sustainable design and passive architecture (optimal selection of direction, Trombe wall, canopy, proper insulation selection). As shown in Table 9, the annual energy required by a conventional building without respect to the principles of the passive architecture, taking into

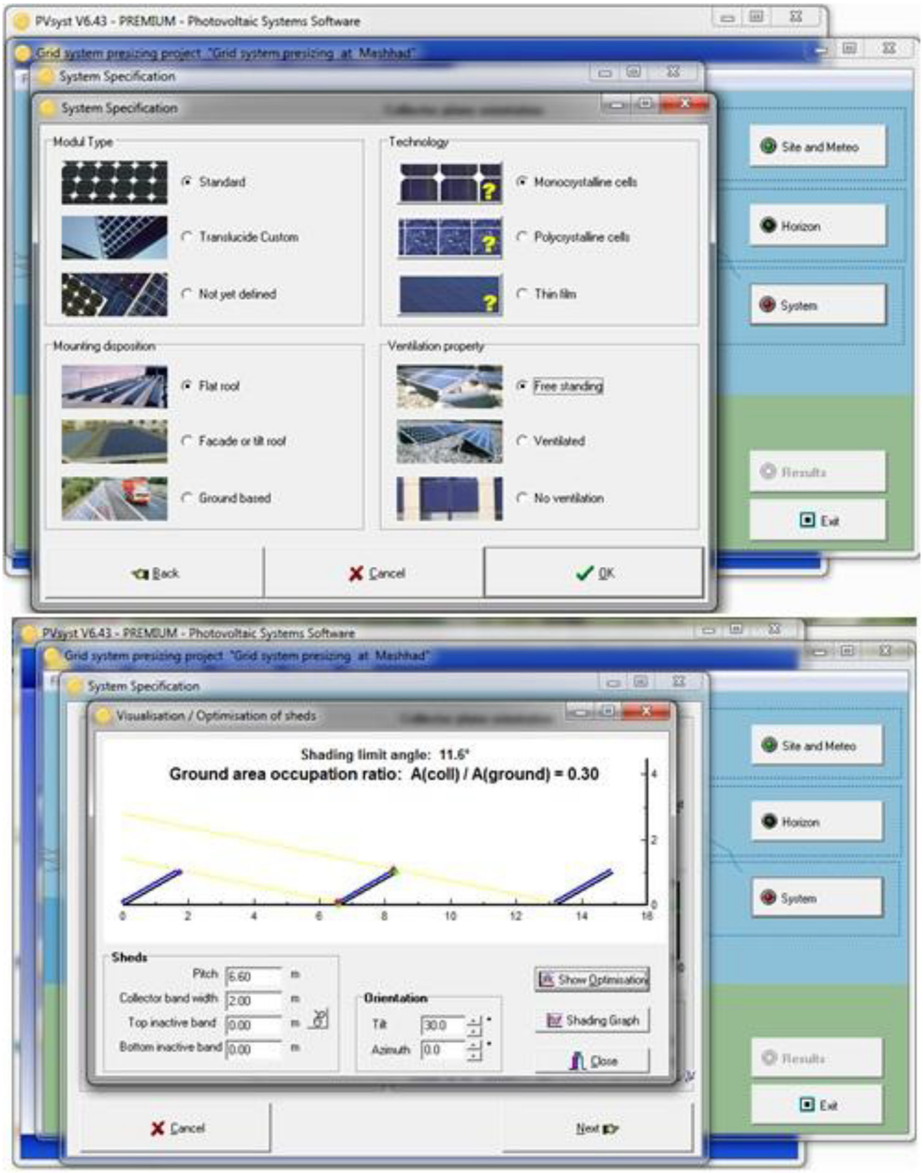

Figure 6.
Input data for the photovoltaic system design in PVsyst software

account electrical equipment including a lighting system, a computer, a pump, a chiller and various common kitchen and administrative equipment for four residents of the building is equal to 25,443 kWh, and hence the amount of energy needed of the building is 98.5 kWh/m^2.

In Figure 7, the horizontal and vertical axes represent, respectively, the year and the average amount of energy obtained per month in kWh/day. Given this figure, the highest rate of energy has been produced in June, July, August and September and its lowest levels have been produced in November, December, January and February. A comparison of this amount of energy with the average monthly energy demand indicated that there was an energy surplus in July and August that was injected into the electricity distribution grid. However, there was an energy shortage in December and January, which had to be provided from the grid. The results have shown that the annual energy yield of the PV solar system is equal to 26,291 kWh/year.

Comparative analysis

Final stage: One of the causes of heat dissipation in buildings is the incorrect behavior and habits of some users. Opening the window to regain thermal comfort due to overheating in

	Total energy (kWh)	Energy per total building area (kWh/m^2)	Energy per conditioned building area (kWh/m^2)
Total site energy	6,537.9	65.38	65.38
Net site energy	6,537.9	65.38	65.38
Total source energy	17,767	177.7	177.7
Net source energy	17,767	177.7	177.7

Table 8. Annual building energy consumption in DesignBuilder software

	Total energy (kWh)	Energy per total building area (kWh/m^2)	Energy per conditioned building area (kWh/m^2)
Total site energy	9,854	98.5	98.5
Net site energy	9,854	98.5	98.5
Total source energy	25,442.7	254.4	254.4
Net source energy	25,442.7	254.4	254.4

Table 9. Annual energy consumption of the building in DesignBuilder software without passive architecture

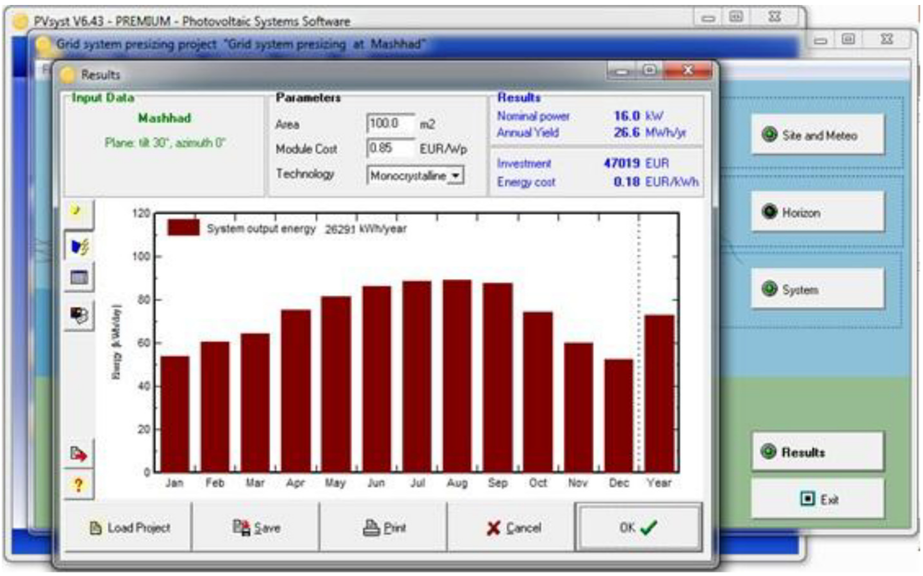

Figure 7. PV system energy production graph by month in PVsyst software

the cold season and rising humidity in the hot season, as well as the use of artificial lighting, despite the presence of sufficient natural light, due to improper design of space are among these habits. Due to the lack of sufficient information to achieve a comfort level such as consumer exploitation pattern, modeling and operational errors, material quality, accurate determination of cloudy days and building occupancy conditions (comfort temperature and type of occupant coverage), was considered a safety factor with a coefficient of 1.4. Table 10 shows the results of the thermal analysis of the building with and without observing the principles of sustainability and the annual energy yield of the photovoltaic system.

As previously mentioned, the Ecotect analysis specified the appropriate orientation of the structure as the north-south direction to the south in the area. Observing the principles of sustainable and passive architecture, including the use of Trombe wall, canopy and needle-leaved trees in the wind-catching side of the plan and selection of the optimal design orientation for maximum use of the sun with respect to the surrounding winds, decreased the amount of energy by 30% in the building studied, reducing this amount from 25,443 kWh/year to 17,767 kWh/year. The capacity of the photovoltaic system was determined based on default items in PVsyst software (as shown in Table 7 and Figure 6). As a ZEB is of the grid-connected type, the energy storage system was not considered in this study. Hence, if the energy obtained is less than the required amount of energy over a few consecutive cloudy days, the building will provide its energy from the power grid and in days when the system has surplus energy, this energy will be injected into the grid. Thus, the annual energy required of the building and energy yield of the renewable energy system can be compared with each other. As explained, the energy required for the building by complying with the principles of sustainable design is 17,767 kWh/year. Also, the energy produced by the photovoltaic system will be equal to 26,291 kWh per year, which is about 48% more than the energy required by the building. Hence, considering the 30% reduction in energy requirements of the building and the monthly energy produced by the photovoltaic system, as shown in Figure 7, it can be met that achieving the zero-energy building goals is possible, albeit the need for economic analysis.

Conclusion

A review of past studies shows that 50% of the world's raw materials are used in buildings. In Iran, the construction sector, with an average consumption of 41.42%, has a high share of energy consumption in the country. Meanwhile, according to published statistics, Iran is ranked 11th among the countries with the highest rates of energy consumption. As many Iranian cities have a cold and semi-arid climate, the energy consumption rate is significant in these areas. In this study, aiming to examine the feasibility and simulate the ZEB in the cold and semi-arid climate of Mashhad, Meteonorm software was used to obtain meteorological data of the study area. AutoCAD and Ecotect software were used to create, volumizing and analyze climatic data in the case study building. Also, DesignBuilder and PVsyst software were used for thermal simulation and renewable energy system design,

Table 10. Comparison of software results

Energy	Total annual energy (kWh)
Amount of energy required for building without observing the principles of sustainability	25,443
Amount of energy required for building with observing the principles of sustainability	17,767
Amount of energy required for building taking into account a safety factor of 1.4	24,874
The energy yield of the PV system	26,291

respectively. The simulation results show that the annual energy requirement of the case study building based on the principles of sustainable design and passive architecture (Trombe wall, optimum direction, shading and proper insulation) was equal to 17,767 kWh/year. As mentioned, taking into account the safety factor of 1.4, energy consumption was estimated to be 24,874 kWh/year and proportionally, a renewable energy system using solar panels was designed for the building with a production capacity of 26,291 kWh/year. By adaptive comparison of these values, it can be concluded that constructing a ZEB in the cold and semi-arid climate of Mashhad is feasible. Observing the principles of sustained and passive architecture reduced energy consumption by 30% in the building under study. Decreasing this rate was from 25,443 kWh/year to 17,767 kWh/year, which is considered an effective step to achieve sustainable and environmentally-friendly construction. A summary of the key findings of this study is provided below:

- Optimization of building orientation.
- Significant reduction of building energy consumption by complying with the principles of sustainable design.
- Achieving ZEB at a minimum cost by considering the principles of passive design.
- Possibility of using the ZEB in the cold and semi-arid climate.

In designing buildings with zero energy, in addition to environmental aspects such as reducing energy consumption, economic and socio-cultural aspects should also be considered. The high potential of solar energy in Iran to diversify the energy basket and create a platform for the development and promotion of renewable energy provides the possibility of exploiting this endless resource.

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Further reading

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Energy Consumption Management of Commercial Buildings by Optimizing the Angle of Solar Panels

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ABSTRACT

One of the main reasons of environmental pollution is energy consumption in buildings. Today, the use of renewable energy sources is increasing dramatically. Among these sources, solar energy has favorable costs for various applications. This study examined a commercial building in a hot and humid climate. The findings showed that choosing the optimal angle of solar panels with the goal of optimized energy consumption would yield reduced costs and less environmental pollutants with the least cost and maximum energy absorption. In this study, to calculate the energy requirements of the building, DesignBuilder software was used. To study the solar angles and estimate the energy produced by the solar panels, Polysun software was used after simulating the building energy. Energy simulation results showed that the whole building energy consumption was 26604 kWh/year. Finally, the evaluation results of solar panels showed that the energy produced by photovoltaic modules at an optimal angle of 31° would be equal to 26978 kWh/year, which is more than the energy required by the building. This system can prevent 14471 kg of carbon dioxide emissions annually. Sustainable energy criteria showed that for the studied building, photovoltaic modules could be used in energy production to reach a zero-energy system connected to the grid with an annual energy balance.

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1. INTRODUCTION

Today, environmental threats have created a negative impact on construction fields due to urbanization and lack of energy in the public sector and professional organizations. Commercial buildings play an important role in saving energy. According to the Iran Department of Energy (2015), residential, commercial, and office buildings consume about 40 % of the total energy in the country [1, 2]. Due to the large share of final energy consumption in this sector, accurate analysis of the thermal and cooling loads of a building and the efforts to reduce energy losses in it are effective ways to reduce energy consumption [2]. Important decisions must be made by architects and engineers in the early stages of building design, regarding the final effects of building physics on the overall performance of the building [3]. As mentioned, one of the main reasons of environmental pollution is fuel consumption in commercial and residential buildings. This issue has captured the attention of many researchers and experts in recent years due to the need to optimize energy consumption in cities, especially the construction sector [4]. Amani and Reza Soroush (2020) examined effective parameters of energy consumption in the building. Their findings showed that each of the building components had a significant role in evaluating the energy performance of the building [2]. Today, the use of solar panels is increasing worldwide due to the importance of solar energy production [5]. Solar panels are one of the best renewable technologies for energizing buildings. For this purpose, knowledge of the optimum tilt angle is necessary for obtaining the highest possible annual or seasonal energy yield. The optimum tilt angle is dependent on many factors such as the latitude, weather conditions, and surroundings [6, 7]. To increase the efficiency of solar systems, it is suggested that necessary measures be considered from the initial phases of design to combine solar panels with the building facade [8]. For active solar systems such as solar collectors and PV panels, it is important to estimate the possible thermal or electrical energy production [9]. The availability of global irradiation data measurements is one of the most important factors in the assessment of the solar potential for the installation of photovoltaic panels [10]. For this purpose, the use of daily data for modeling is very important. Also, input data for the models and the data for validation should be assessed at the same station [9]. In some countries where it is not possible the use of numerical models has been proposed to estimate the monthly, seasonal, and annual solar radiation (global diffuse and direct solar radiation), especially on tilted surfaces [10]. Many solar panels are connected serially. As a result, the panels are often exposed to relatively high potential relative to the ground, resulting in High Voltage Pressure (HVS). The effect of this pressure was considered on the long-term stability of solar panels by NREL in 2005 [5]. One of the effective measures in the field of optimizing fuel consumption in commercial and residential buildings is the use of natural

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energy in the climatic design of buildings based on the principles of architecture compatible with the climate of each region. Therefore, one of the main tasks of planning and design in Iran can be the revision of the construction laws due to the energy crisis and the necessity to save on energy consumption [11]. Ifaei et al. (2017) conducted a study on sustainable development in Iran using Technical-Economic-Socio-Environmental Multivariate Analysis (TESEMA) using renewable energy. The results showed that the current centralistic policies in Iran should be revised to achieve sustainable development [12]. Also, Karbasi et al. (2007) showed that increasing energy efficiency, including combined cycle power generation, was the most economical option for reducing greenhouse gas emissions in Iran. Therefore, price reform is the key policy in promoting energy savings and replacing fuel with renewable energy [13]. The most important factors that have challenged human beings in the past are climatic elements. Therefore, one of the issues that leads to the incompatibility of architecture with the regional climate is the lack of sufficient knowledge on recognizing the climatic conditions and their impact on architecture [11]. Since a large part of the country is located in a hot climate, the implementation of appropriate methods to reduce the cost of cooling the building is very important. Due to the climate of Ahvaz city, characterized by long and hot summers, it is necessary to apply the principles of energy optimization in the building [14]. On combined wind and solar systems, Ifaei et al. (2017) stated that Iran was mainly a solar country and had approximately 74 % solar energy fraction under optimum conditions [15]. Also, Karbassi et al. (2008) showed that solar water heating systems as a means of conventional energy substitution could reduce the use of electricity or fossil fuels by up to 80 % [16]. Due to the importance of reducing energy consumption to achieve sustainable development and reduce operating costs [17], the ways should be sought to reduce fossil fuel consumption. One of the building's energy management solutions is the use of new technologies to optimize and sustain energy. In other words, the use of new technologies in energy management is felt based on the cooling-heating needs of buildings in Iran. A comprehensive review of previous research has been done on the energy consumption of buildings using solar panels. These studies were adopted from such famous databases as Science Direct, Wiley, and Taylor & Francis. The issues relating to the building energy conservation and efficiency with solar panels through modeling and simulation have been discussed [18-29]. To perform energy analysis, DesignBuilder software was used. This software is one of the best building energy simulation and analysis software packages. The main reasons for choosing this software are its high accuracy in calculations as well as forecasting air temperature at any time of the year. Also, the application of advanced EnergyPlus engine may yield the results of energy analysis graphically and numerically. In this study, a 5-story commercial building in Ahvaz was simulated and it was finally showed that the use of solar panels to optimize energy consumption could reduce costs and environmental pollutants. It should be noted that the optimal angle of panels plays an important role in achieving this goal. It is a conceptual framework for implementing the principles of energy management and its application strategies in buildings with the perspective of the construction life cycle to contribute to sustainable development. This study intends to minimize the costs of using a solar panel system to optimally convert solar energy into electrical energy by selecting the suitable angle of solar panels using Polysun software.

2. METHODOLOGY

2.1. Software selection

In this study, DesignBuilder software was used to create the energy model. This software can be used to calculate cooling and heating loads based on such parameters as material structure, occupants, mechanical and electrical systems, and annual or hourly climate data to keep the temperature in the comfort range. Another feature of this software is predicting air temperature at different spaces of the building based on the mentioned parameters at any time of the year. After creating the energy model in DesignBuilder software, the annual energy requirement of the building was calculated. Then, to supply the required energy of the building using solar panels, Polysun software was used. According to the geographical location of the project, the angles of solar radiation were examined by Polysun software to select the most optimal annual angle. Fig. 1 shows the details of the composite roof layers in the DesignBuilder software.

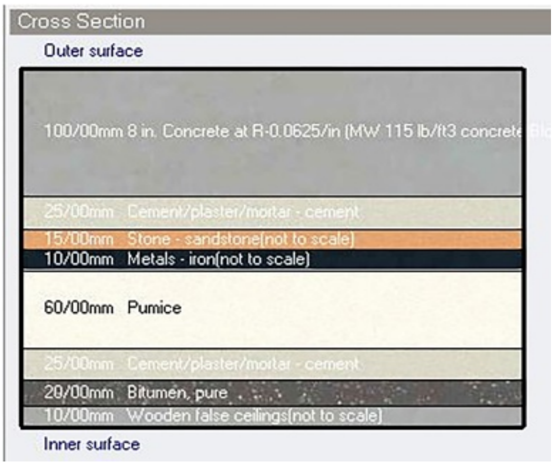

Figure 1. Details of the composite roof layers in DesignBuilder software

2.2. Case study

The case study building is a 5-story commercial building in Ahvaz with an area of 2200 m^2, which is located on an integrated concrete surface with a height of 30 cm. To calculate the amount of energy required to reach the comfort level, which is the supply of temperature and humidity in the standard range, the conditions of the spaces must be transient. For this purpose, the studied building was simulated using DesignBuilder software. This software provides the ability to energy simulation on an hourly basis throughout the year. Fig. 2 shows a three-dimensional view of the building in DesignBuilder software. The height of each floor is 3.5 m and the total height up to the rooftop is 17.5 m above the ground. The thickness of the exterior walls of the building was 20 cm and the roof material was the type of composite. All windows are double glazed with a 6 mm thickness middle air layer and have no shades. The window-to-wall ratio on the southern side of the building was 8 % and the eastern side of the building was 9 % on the floors. Also, the doors were made of unbreakable glass. The building lighting was supplied by fluorescent lamps with a light intensity of 600 Lux and a brightness coefficient of 0.74. The average number of customers was considered 60 people per day.

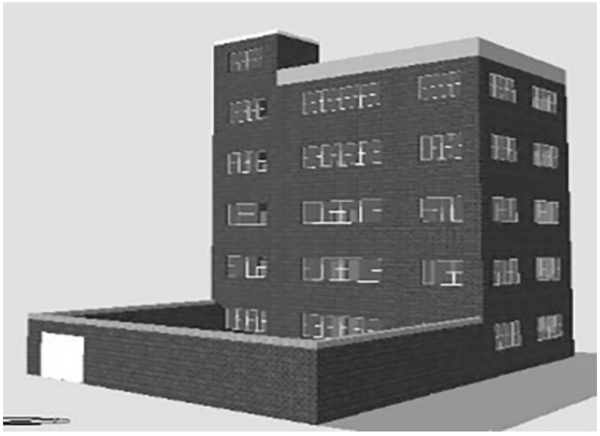

Figure 2. Three-dimensional view of the building in DesignBuilder software

2.3. Climate conditions

Ahvaz is characterized by particular climatic conditions due to its location in a special geographical location (topographic and climatic conditions of the region). One of the features of this climate is the high intensity of sunlight, which according to Article 19 of the National Building Regulations of Iran [30], is in the group of buildings with high energy consumption. Extreme heat causes many problems for people. Hence, the study of climatic conditions is an attempt to reduce relevant problems. For this purpose, synoptic meteorological data were employed to examine the climatic situation of Ahvaz. As shown in Table 1 [31], Ahvaz has hot and long summers and short and mild winters. The maximum temperature in July and August is higher than 50 °C and the maximum relative humidity in January is 60 %. The maximum rainfall in April is 40.8 mm. Also, the highest hours of sunshine in June are equal to 353 hours and the lowest hours of sunshine in January are equal to 167.5 hours.

2.4. Solar radiation analysis

Solar radiation modeling is a complex process that examines factors such as latitude, solar radiation interval, model height, surface orientation, surface reflectivity, and atmospheric phenomena. The results show that the lowest average monthly sunshine is in December, and its value varies from 2.83 to 3.46 kWh. Then, January and November have the least amount of sunshine. The maximum value of sunshine is in June with an average daily of 8.29 kWh/m^2. The average daily sunshine from April to September is higher than 5.78 kWh/m^2 (more than the average annual radiation). The average annual intensity of solar radiation is equal to 5.18 kWh/m^2/day, which is in a very suitable category according to the division of solar radiation by the US National Renewable Energy Laboratory. The highest amount of solar energy is in the hot months of the year, which coincides with the highest electricity consumption in Ahvaz. The high energy received during these months makes it possible to use it to supply part of the region's electricity and reduce the pressure on power transmission lines and, consequently, reduce the power outage. However, despite this massive potential, there is no photovoltaic power plant in Khuzestan province and solar energy production is negligible in the experimental and research stages. Fig. 3 shows the intensity of solar radiation based on the annual average [32].

Table 1. Meteorological information of Ahwaz station per month

Month	Temperature (°C)				
	Maximum average	Minimum average	Average	Highest maximum	lowest minimum
January	20.5	9.2	14.9	25.9	9.2
February	19.2	7.1	13.2	25.2	7.1
March	25.4	11.3	18.3	30.5	11.3
April	29.5	16.0	22.7	35.6	16.0
May	39.7	23.8	31.8	45.8	23.8
June	42.3	26.4	34.4	47.8	26.4
July	47.3	30.7	39.0	50.4	30.7
August	47.4	29.9	38.6	50.4	29.9
September	45.0	27.4	36.2	49.1	27.4
October	38.2	20.0	29.1	43.5	20.0
November	31.6	15.5	23.6	36.6	15.5
December	20.8	9.0	14.9	25.6	9.0

Month	Rainfall (mm)	Maximum rainfall in one day (mm)	Relative humidity (%)	Frosty day (s)	Dusty day (s)	Sunshine duration (h)	Wind speed (m/s)
January	16.5	16.5	60.0	0.0	3.0	167.5	15.0
February	6.0	2.8	54.0	1.0	8.0	179.1	18.0
March	24.9	15.2	47.0	0.0	3.0	215.8	19.0
April	40.8	23.0	48.0	0.0	3.0	269.4	20.0
May	0.3	0.2	36.0	0.0	5.0	308.9	17.0
June	0.0	0.0	23.0	0.0	8.0	353.0	16.0
July	0.0	0.0	25.0	0.0	6.0	348.0	13.0
August	0.0	0.0	30.0	0.0	1.0	351.7	12.0
September	0.0	0.0	27.0	0.0	3.0	319.3	16.0
October	0.0	0.0	29.0	0.0	5.0	275.5	14.0
November	0.0	0.0	44.0	0.0	3.0	236.4	15.0
December	21.3	11.0	49.0	0.0	2.0	193.3	17.0

Solar radiation depends on the climate of the region and the different seasons of the year. The building orientation should be such that it receives the most solar radiation in cold months for maximum use of solar energy. Conversely, during hot months, the intensity of sunlight should be reduced on the surface of the building. However, according to the criteria of the region, the building location was considered to the south. The amount of solar energy received in different places varies based on latitude, altitude, atmospheric phenomena, and so on. Therefore, to receive information about solar radiation, the latitude and altitude of the region must be determined. In this case, the monthly and annual averages of solar radiation can be calculated for the desired location at all levels with different directions and slopes. In this study, the latitude is 31.3° and the altitude is 16 m. Fig. 4 shows the values of solar radiation in the building on an annual basis. These values have been extracted up to an acceptable level of 400 Lux, depending on the amount of energy received from the translucent walls. Also, all the spaces had enough light.

2.5. Surface coverage and location for solar panels

The use of solar panels reduces the cost of electricity in the building. These panels must be installed in the right place and at the right angle to achieve greater efficiency. The building roof has a high potential for using solar energy. Also, it is very important to determine the sunray angle to the desired surface. To install solar panels, much research has been done on the amount of usable roof area of buildings. One study in the United States shows that 32 % of the total roof area of houses can be used to install solar panels. This value will be 18 % for houses with sloping roofs and 65 % for flat roofs [33]. Another study shows that 60 % of flat roofs can be used in the tropical regions of the United States to install solar panels [34]. Another study showed that in places where there is no accurate information about its characteristics for the installation of solar panels, 50 % of the roof area can be considered [35]. Moreover, one study in Taiwan showed that 25 % of buildings' roofs for the installation of solar panels were considered [36]. In this study, the panel surfaces were determined by about 25 %. In order to increase the efficiency of solar panels, the angle of the panels should change according to the position of the sun in the sky. For this purpose, the angle of the sun must always be perpendicular to the surface of the panels. The angular altitude of the sun is indicated by SA and the latitude by L. Thus, the maximum and minimum values of the angle of radiation on the first days of summer and winter are calculated through Eqs. 1 and 2, respectively. On the first days of spring and autumn, the earth is in the middle of its orbital path between the two maximum and minimum values and the angle of deviation remains unaffected. Therefore, the average of the solar altitude angles is calculated through Eq. 3.

$$SA_{(Max)}=90-L+23.5=90-31.3+23.5=82.2 \quad (1)$$

$$SA_{(Min)}=90-L-23.5=90-31.3-23.5=35.2 \quad (2)$$

$$SA_{(Mid)}=90-L=90-31.3=58.7 \quad (3)$$

According to the above Equations, different approaches can be used to adjust the angle of the panels. Based on Rule no. 667 of the Ministry of Energy, the energy absorption efficiency rates in different modes of panels installation as the fixed panel, two-season constant, four-season constant, and two-axis tracker relative to the optimal annual angle of 23.7° for Ahvaz are equal to 71.1 %, 75.2 %, 75.7 %, and 100 %, respectively [37]. Energy simulation results show that the whole building energy consumption is 26604 kWh/year. Accordingly, the value of building energy consumption is 69.10 kWh/m^2/year. Due to the investment cost and the need for minimum energy in the building, which is the result of its architectural energy, it can be converted into a zero-energy building that is also economical. For this purpose, new energy production systems should be used. To achieve zero-energy standard, different ideas and methods are used. The use of active solar systems such as photovoltaic modules and solar water heater system is one of the most important solutions to produce the energy required by the building.

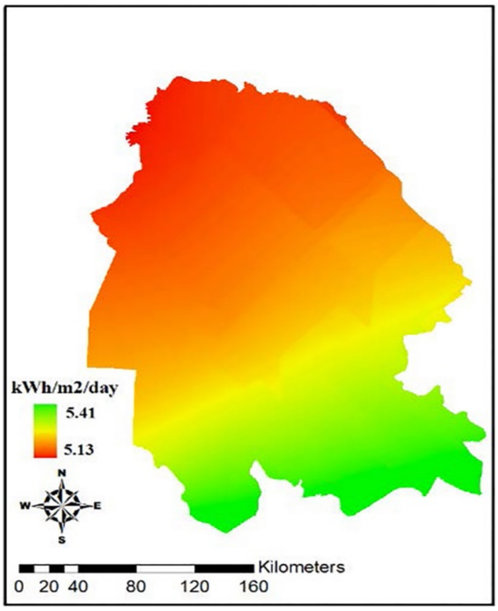

Figure 3. Average annual of daily solar radiation in Khuzestan province

Temperatures, Heat Gains and Energy Consumption - test, Building 1

EnergyPlus Output — 1 Jan - 31 Dec, Daily — Evaluation

Day										
Air Temperature	26/00	30/81	34/73	37/70	46/04	47/44	47/07	41/87	39/17	31/93
Radiant Temperature	27/61	31/82	35/47	39/00	46/87	48/10	47/73	43/24	40/48	33/67
Operative Temperature	26/81	31/31	35/10	38/35	46/46	47/77	47/40	42/55	39/82	32/80
Outside Dry-Bulb Temperature	14/46	20/51	26/55	29/42	36/48	39/23	38/79	31/28	26/53	16/31
External Infiltration	-94/33	-81/64	-63/36	-63/55	-71/50	-60/97	-61/28	-81/06	-98/31	-125/57
General Lighting	48/51	64/68	64/68	0/00	64/68	64/68	64/68	48/51	64/68	64/68
Miscellaneous	5/78	27/86	27/86	1/73	27/86	27/86	27/86	5/78	27/86	27/86
Occupancy	2/24	4/14	0/56	0/00	0/00	0/00	0/00	0/00	0/00	3/05
Solar Gains Exterior Windows	67/21	122/57	111/77	97/56	71/52	90/67	77/37	100/13	123/79	136/71
Mech Vent + Nat Vent + Infiltration	0/73	0/72	0/72	0/72	0/72	0/72	0/72	0/72	0/73	0/74

Figure 4. The values of solar radiation in the building using DesignBuilder software

2.6. Evaluation of photovoltaic modules in polysun software

In Polysun software, it is possible to simulate solar systems as well as facilities including heat pumps, geothermal energy, etc. to cover all or part of the building's energy needs. In this research, by specifying the project location in Polysun software, the required data were collected by the software. Table 2 shows the value of the energy generated by photovoltaic modules on an annual average. Also, for example, the value of energy production was calculated in August and February. The results showed that the average annual value of energy generated by 61 photovoltaic modules with a power of 350 watts and an angle of 31° was equal to 26978 kWh/year. This value will be higher than the whole building energy consumption. Also, the value of energy generated in August by 41 photovoltaic modules with a power of 350 watts and an angle of 5.3° is equal to 27572 kWh/year. This value of energy for February by 80 photovoltaic modules with a power of 350 watts and an angle of 42.3° will be equal to 26463 kWh/year. The surface coverage of panels in all cases was 99.5 m^2. Energy storage can be used based on the review in August and February to balance energy throughout the year. The angles provided based on the software analysis follow the minimum costs for installing solar panels to convert solar energy into electrical energy. Fig. 5 shows the value of energy generated by photovoltaic modules in general mode (annual average) in Polysun software. The results show that this system can prevent the emission of 14471 kg of carbon dioxide annually. Also, by using the solar water heater system, the release of environmental pollutants can be prevented as much as possible. At the national level, this amount can help preserve and sustain the environment and lead the country towards sustainable development.

Table 2. Energy generated by photovoltaic modules in Polysun software

Component overview (annual values)				
Photovoltaics roof plan	PV-Modul-350W			
	Unit	Annually	August	February
Number of modules		61	41	80
Total nominal power generator field	kW	21.35	21.35	21.35
Total gross area	M^2	99.47	99.47	99.47
Tilt angle (hor.=0°, vert.=90°)	°	31	5.3	42.3
Orientation (E=+90°, S=0°, W=-90°)	°	0	0	0
Inverter 1: Name		Inverter 10500T		
Manufacturer		Anonymous		
Inverter 2: Name		Inverter 4000		
Manufacturer		Anonymous		
Manufacturer		Anonymous		
Energy production AC [Qinv]	kWh	26978	27572	26463

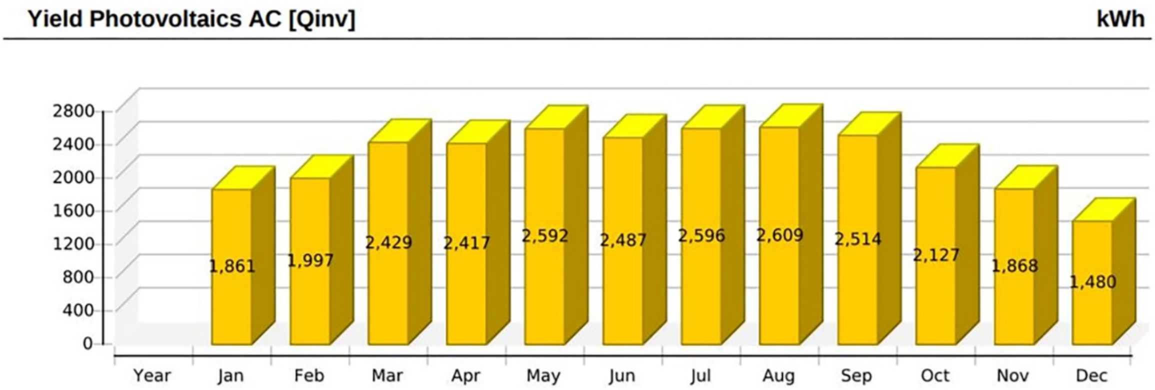

Figure 5. The energy produced by photovoltaic modules monthly

3. DISCUSSION

Increasing global warming and environmental pollutants has been on the minds of researchers for years to make a useful contribution to the future with the development of new energies. Solar energy is one of the clean and available energies. The solar panels are of great importance in this field due to the direct conversion of solar energy into electrical energy. The tilt angle of a solar energy system is one of the important parameters for achieving maximum solar radiation falling on the solar panels. This angle is site-specific which is dependent on the daily, monthly, and yearly path of the sun. The accurate determination of the optimum tilt angle is essential for maximum energy production by the system. Yadav and Chandel (2013) conducted a study on the relevance of the optimum tilt angle in energy production and reducing the cost of solar energy systems. Their findings showed that for maximum energy gain, the optimum tilt angle for solar systems must be determined accurately for each location. For this purpose, different anisotropic models and optimization techniques could be used. Also, for urban areas, the obstacles affecting solar radiation should be considered for computing optimum tilt angles [38]. In addition, Yadav and Chandel (2014) studied different isotropic and anisotropic diffused solar radiation models for determining optimum tilt angle in India. They found that the Liu and Jordan models showed the lowest error among other models. Accordingly, the annual optimum tilt angle was determined to equal to 27.1° [39]. The thermal performance of a passive solar commercial building was evaluating by Chandel and Aggarwal (2008) in the Indian state of Himachal Pradesh. The results showed that the solar passive system features saved on the electricity required for space heating and the heat losses in the building are reduced by about 35 % [40]. Ben Othman et al. (2018) evaluated global solar radiation on tilted surfaces in Tunisia and found that the optimal annual angle in the north was equal to 37.5°and the northeast and south were equal to 36.6° [10]. This research simulated a commercial building in Ahvaz. Due to the high intensity of sunlight, Ahvaz is in a group of buildings with high energy consumption. This climate has a high potential for the optimal use of sunlight to produce energy. Solar radiation studies showed that the lowest average monthly solar radiation was in December and its value varied from 2.83 to 3.46 kWh. Also, the maximum value of sunshine was in June with an average daily rate of 8.29 kWh/m^2. The average daily sunshine from April to September is more than 5.78 kWh/m^2, which will be more than the average annual radiation. The optimum tilt angle of solar photovoltaic panels plays an important role in the optimum sizing of solar photovoltaic systems for a location. Hence, the capability of a solar module to maximize the incident radiation depends on monthly, seasonal, and yearly optimum tilt angles, which should be determined for the considered site to enhance the power generation of solar photovoltaic systems. In this study, the optimal tilt angle of the photovoltaic panels was determined to be 31°. Evaluation of photovoltaic modules showed that the angle of placement of panels affected the amount of energy produced and the number of modules. As a result, choosing the optimal angle of placement of panels will have a significant impact on cost optimization in the building life cycle. Sustainable energy criteria showed that the studied building could use photovoltaic modules in energy production to reach a zero-energy system connected to the grid with an annual energy balance. In designing zero-energy buildings, in addition to environmental aspects such as reducing energy consumption, economic and socio-cultural aspects should also be considered. The high potential of solar energy in Iran to diversify the energy basket and create a platform for the development and promotion of renewable energy provides the possibility of exploiting this endless resource.

4. CONCLUSIONS

The optimal annual angle for Ahvaz at 23.7° was set by Rule no. 667 of the Ministry of Energy. However, this study showed that determining the optimal angle of solar panels, based on the energy required by the building, would be the most important factor in reducing costs for optimal energy management. These results would minimize the cost of using solar panels to convert solar energy into electrical energy. Energy simulation results showed that the whole building energy consumption was 26604 kWh/year. Accordingly, the value of building energy consumption was equal to 69.10 kWh/m^2/year and to bring it to zero, the solar panels were used. Also, the results of photovoltaic modules evaluation in Polysun software showed that the energy generated by 61 photovoltaic modules with a power of 350 watts and surface coverage of 99.5 m^2 was 26978 kWh/year. This value was higher than the whole building energy consumption. By using this system, the emission of 14471 kg of carbon dioxide can be prevented annually. Finally, the comparison of different modes of energy consumption showed that the best method to achieve zero energy system was 61 photovoltaic modules with a power of 350 watts and an angle of 31° with a surface coverage of 99.5 m^2.

5. ACKNOWLEDGEMENT

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Building Energy Management Using Building Information Modeling: Evaluation of Building Components and Construction Materials

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ABSTRACT

Traditionally, building energy model is created in isolation from the architectural building information model and energy analyses have relied on a single analysis tool. The building energy model can be generated more quickly by leveraging existing data from the BIM. The impacts of energy consumption are significant in the building usage phase, which can last several decades. Due to the large share of the final energy consumption in the building sector, accurate analysis of thermal and cooling loads of a building and the efforts to reduce energy losses represent an effective way to reduce energy consumption. Therefore, it is essential to analyze the building energy performance in the design phase, which is when critical decisions are made. This study aims to investigate the impact of the building components and construction materials on building energy efficiency using Building Information Modeling (BIM) technology in a mild climate zone. After reviewing the proposed designs, the main building form was chosen for energy modeling and analysis. Then, building energy consumption analysis was performed based on the basic parameters of the building energy model. Eventually, the most optimal mode was selected by examining different energy consumption forms. This study showed that the building HVAC system always had the largest share of energy consumption. Finally, the results of parametric studies on alternative schemes of energy use intensity optimization showed that 22.59 % savings could be achieved as compared to the base building model in a 30-year time horizon.

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1. INTRODUCTION

Buildings are the world's largest energy consumer, according to the United Nations Environment Program [1]. Residential energy consumption has allocated a large percentage of national energy consumption to itself in most countries [2]. Recently, global efforts have been directed at reducing carbon emissions from buildings [3]. Operational energy reduction has been the main focus of the industry because it accounts for a greater proportion of carbon emission throughout the building lifecycle and it is easier to predict than embodied energy [4]. Usually, following the architectural plans and considering construction documents, the building performance analysis should be done [5]. Analyzing the energy performance of a building in its early design stage requires access to specific information such as properties of materials, U-value, and technical systems. Such information is one of the determinants of building energy performance [6]. The geometric information of buildings is usually extracted from architectural drawings. Then, an energy analyst can benefit from this information to define the building's thermal view, which depends on its knowledge, skills, and experience. Therefore, various building energy analysts will generate differing thermal views [5]. BIM is a technology used for improving productivity and efficiency in the construction industry [7]. A data model created by integrating 3D digital techniques and specific information related to an engineering project is the best description for building information modeling [1]. One of the most significant benefits of BIM lies both in early-stage design and later stages of building energy simulation analysis [8]. Application of BIM in Energy Performance Assessment (EPAs) considerably reduces time and costs [7]. The limitation of energy resources and the significant growth of using them in Iran compared with the worldwide average have doubled the necessity of optimizing energy consumption in this country [9]. According to the information provided in 2016, the share of building fuel consumption is about 41.4 % of the total energy consumption in the country, which is considered the largest energy consumer sector [10]. Due to the high share of energy consumption in this sector, accurate analysis of thermal and cooling loads of a building and the efforts to reduce energy losses represent an effective way of reducing energy consumption. Building Information Modeling enables information sharing and reuses for interoperability between popular software packages in Architecture, Engineering, and Construction industry. BIM-based energy simulation can significantly reduce the costs and time required to create a geometric model [11]. Many different studies have employed BIM technology in the field of building energy management.

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Based on previous studies from the famous database [12-28], it can be concluded that there is a limited body of research on energy efficiency using the simultaneous evaluation of building components and construction materials using Building Information Modeling (BIM) technology. In other words, all related studies were focused on a specific component and there was not any research that had simultaneously investigated the impact of all involved components on energy consumption. This paper carries out energy performance assessment based on BIM technology. The results indicate that the use of BIM technology will lead to design identification, comparison, and reduction of energy consumption in the early stages of design.

2. METHOD

2.1. Methodology

In this study, to examine different design ideas, several conceptual masses were created using Autodesk Revit software with a top-down design approach. The main form of the building for energy modeling and analysis was selected only after reviewing the proposed designs. Then, an exact model of building elements was fabricated. After generating the energy model, the building energy consumption analysis was carried out based on basic parameters. Finally, the most optimal mode was selected by examining different energy consumption forms.

2.2. Case study

The case study is a residential building that is located in a mild climate in Rasht, Iran. The total area of the building is about 101000 m^2 and the project location is in Rasht, Gilan province, Iran (37°18'34.8"N, 49°36'49.0"E). At first, several conceptual masses were created to study different design ideas. The closest form to the real model of the building and items such as the number of units and the area of the building were considered in the construction of conceptual models. Input parameters of the energy model were selected according to the software defaults (as shown in Table 2). Table 1 shows the comparison of different building forms based on the simulation of energy consumption in conceptual masses. After reviewing the proposed designs and creating a real model of the building, an energy analysis was performed. Carrying out the whole building energy analysis is not possible in the cloud due to the software limitation in sending the shade surfaces (max. 10000 surfaces) as well as the number of doors (max. 4096 doors). For this reason, as shown in Figure 1, each block of this residential tower is analyzed separately. Finally, due to increased shade surfaces, the ceiling elements were removed from the building model. The samples of the second-floor plan and penthouse plan are separated by unit type, as shown in Figure 2.

The results of the analysis show that the first form of the building has the lowest energy consumption among others. The cost of energy consumption based on Table 2 parameters is 13.5 USD/m^2/year. Accordingly, the energy use intensity is equal to 110 kWh/m^2/year, as shown in Table 1. In this form, the building orientation is based on the geographical north. Thus, the angle of the building is automatically determined by the software based on the building form and the geographic coordinates of the project. The window-to-wall ratio in all directions is 40 % by default. All windows have shades with a depth of 45.72 cm. Also, the type of windows in the conceptual model is double-glazed windows without any external coating. The structure of walls in the conceptual model in the form of lightweight walls with typical mild climate insulation and the roof structure is lightweight without insulation. The values of the building infiltration rate, the lighting efficiency, the plug load efficiency, and the operating schedule are adjusted according to the BIM parameter (as shown in Table 2). The building's HVAC system is assumed to have a BIM parameter (Residential 14 SEER/0.9 AFUE Split/Packaged Gas <5.5 ton). This building has no daylighting and occupancy controls system and photovoltaic solar panels. After adjusting the effective parameters for energy consumption, according to Table 3, the energy cost would be 5.71 USD/m^2/year. Accordingly, the energy use intensity would be equal to 75.3 kWh/m^2/year. The building orientation remains unchanged relative to the previous model (base model) and is based on the geographical north. The window's ratio to the northern and southern walls is 40 % by default. These windows have shades as high as 2/3 of the window height. Also, the type of these windows in the conceptual model is triple-glazed windows with low emission. Due to the lack of significant efficiency, the eastern and western windows have been removed from the conceptual model. The structure of walls in the conceptual model is according to Table 2 and the roof structure is lightweight without insulation. The value of the building infiltration rate is 0.17 ACH. The value of the lighting efficiency parameter is assumed to be 3.23 W/m^2. The values of the plug load efficiency and the operating schedule were adjusted according to the BIM parameter. The building's HVAC system is assumed to be a high-efficiency variable air volume system. Also, the building has a daylighting and occupancy control system. Finally, to achieve the highest level of energy efficiency, photovoltaic solar panels were used. To this end, the photovoltaic solar panels were used with a yield of 20.4 % and surface coverage of 90 %. The payback limit of these panels was selected for 30 years. The results of this analysis show that the use of building information modeling technology for adjusting the parameters affecting energy consumption in the conceptual designs can save up to 57.7 % in energy cost. Based on the energy use intensity, this value would be 31.54 %.

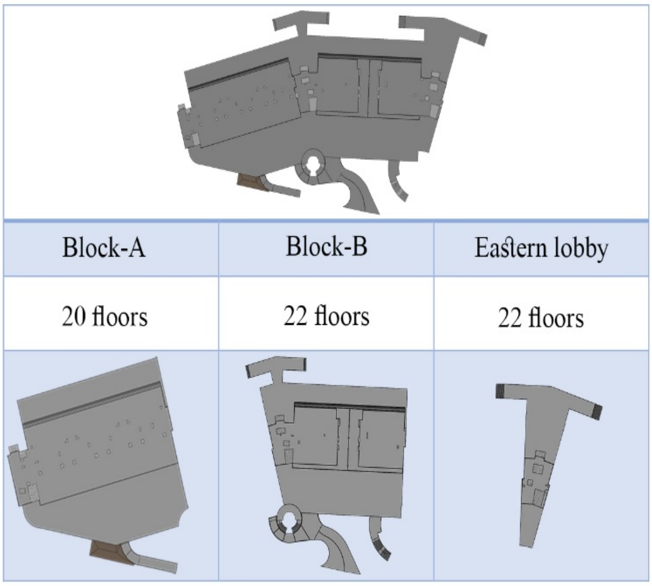

Figure 1. Separation of building blocks for energy analysis

Figure 2. Top left) A sample of the second-floor plan (Block A); Top right) A sample of the penthouse first-floor plan (Block B); Bottom left) A sample of the second-floor plan (Block B); Bottom right) A sample of the penthouse second-floor plan (Block B)

Table 1. Comparison of different building forms in conceptual masses

		Module-1	**Module-2**	**Module-3**
	Floors	22	43	43
	Units	548	560	561
	Height (m)	81.70	159.40	159.40

Building form		**Energy cost** (USD/m^2/year)	**Saving** (%)	**Energy use intensity** (kWh/m^2/year)	**Saving** (%)
Module-1	BIM parameters	13.50	0	110	0
	Optimized parameters	5.71	57.70	75.30	31.54
Module-2	BIM parameters	14.10	0	115	0
	Optimized parameters	7.45	47.16	92.10	19.91
Module-3	BIM parameters	13.90	0	114	0
	Optimized parameters	7.24	47.91	88.10	22.72

Table 2. Basic and optimized parameters based on energy consumption simulation in conceptual masses

Building form	**Module-1**		**Module-2**		**Module-3**	
Energy cost (USD/m^2/year)	13.5*	5.71**	14.1*	7.45**	13.9*	7.24**
Effective factor	Input parameter					
Building orientation	BIM°					
WWR (South)	BIM (40 %)°					
Window shades	BIM (0.4572 m)*					
	2/3 Win height**					
Window glass	BIM (Double pane clear-No coating)*					
	Trp LoE**					
WWR (North)	BIM (40 %)°					
Window shades	BIM (0.4572 m)*					
	2/3 Win height**					
Window glass	BIM (Double pane clear-No coating)*					
	Trp LoE**					
WWR (West)	BIM (40 %)*					
	(0 %)**					
Window shades	BIM (0.4572 m)*					
	BIM (No shade)**					
Window glass	BIM (Double pane clear-No coating)*					
	BIM (No window)**					
WWR (East)	BIM (40 %)*					
	(0 %)**					
Window shades	BIM (0.4572 m)*					
	BIM (No shade)**					

Window glass	BIM (Double pane clear-No coating)*
	BIM (No window)**
Wall construction	BIM (Lightweight construction-Typical mild climate insulation)*
	R13+R10 Metal**
Roof construction	BIM (Lightweight construction-No insulation)°
Infiltration	BIM (None)*
	0.17 ACH**
Lighting efficiency	BIM (10.76 W/m^2)*
	3.23 W/m^2**
Daylighting and occupancy controls	None*
	Daylighting & occupancy controls**
Plug load efficiency	BIM (10.76 W/m^2)°
HVAC	BIM*
	High Eff. VAV**
Operating schedule	BIM (24 Hours)°
Panel efficiency (PV)	None*
	20.4 %**
Payback limit (PV)	None*
	30 years**
Surface coverage (PV)	0 %*
	90 %**
*Base Model, **Optimized, °Unchanged	

The building energy model requires a group of parameters depending on the analysis tools and specific studies. Table 3 shows the basic parameters of the building energy model as the basis of design. These parameters include HVAC, materials with thermal properties, plug loads, building occupancy, building natural infiltration rate, lighting density and efficiency, natural ventilation, internal heat gains (plug loads and occupancy), thermostat set-point temperatures, and operating schedules. These parameters are specified by the BIM title in the provided data.

Table 3. Basic parameters of the building energy model

Input parameter	**Value**
HVAC system	Residential 14 SEER/0.9 AFUE Split/Packaged Gaz < 5.5 ton
Area per person	105.82 m^2
Sensible heat gain (per person)	73.27 W
Latent heat gain (per person)	58.61 W
Power load density	10.76 W/m^2
Lighting load density	10.76 W/m^2
Plenum lighting contribution	20 %
Occupancy schedule	24 Hours
Lighting schedule	All day
Power schedule	All day
Outdoor air (per person)	2.36 L/s
Outdoor air (per area)	0.30 L/ (s.m^2)
Unoccupied cooling set point	27.78 °C
Infiltration (ac/h)	None
Fabric *U*-values	
External walls	20 cm concrete block (*U*-value 6.5 W/m^{2}K)
Internal walls	10 cm concrete block (*U*-value 13 W/m^{2}K)
Shear walls	45 cm reinforced concrete (*U*-value 2.3244 W/m^{2}K)
Floor	22.5 cm concrete slab (*U*-value 4.6489 W/m^{2}K)
External doors	Wooden, Single-Flush (*U*-value 2.1944 W/m^{2}K)
Terrace doors	Wood frame with single clear glass (*U*-value 5.6212 W/m^{2}K)
Lobby doors	Metal frame with single clear glass (*U*-value 6.5580 W/m^{2}K)
Elevator doors	Metal (*U*-value 3.7021 W/m^{2}K)
Windows	1/8 in Pilkington single glazing (*U*-value 3.6886 W/m^{2}K)

2.3. Climate data

Climate data are automatically taken from the nearest meteorological station database after the energy model sending as the first element of the environment in which the building is located (Table 4). This information is related to the project location, which is available in the Autodesk Green Building Studio (GBS) software database, and the distance specified in Table 4 is only the storage of data at the desired station. Data on design conditions based on dry-bulb temperature and Mean Coincident Wet Bulb (MCWB) temperature are shown annually in Table 5. Also, Figure 3 shows the average daily minimum and maximum temperature basis on monthly data.

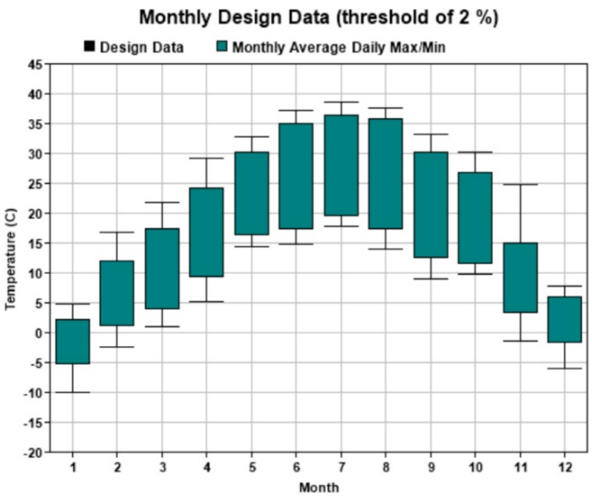

Figure 3. Average of Max. and Min. daily temperatures on a monthly basis [29]

Table 4. Receiving the temperature data from the nearest weather station database by Autodesk Green Building Studio software

Weather station: GBS_06M12_12_002300 Distance to project 474.2 mi (763.2 km) Latitude=36.4167, Longitude=58.1500			Unit: SI
Cooling degree day		**Heating degree day**	
Threshold	Value	Threshold	Value
18.3 °C	1110	18.3 °C	2047
21.1 °C	657	15.6 °C	1577
23.9 °C	316	12.8 °C	1172
26.7 °C	104	10 °C	807

Table 5. The dry-bulb and Mean Coincident Wet Bulb temperature based on annual data

Annual design conditions				Unit: SI
Threshold	**Cooling**		**Heating**	
	Dry bulb (°C)	MCWB (°C)	Dry bulb (°C)	MCWB (°C)
0.1 %	39.2	18.1	-10.4	-11.3
0.2 %	38.8	17.9	-9.8	-11.0
0.4 %	38.4	17.9	-9.2	-10.4
0.5 %	38.2	18.0	-8.8	-9.8
1 %	37.3	17.3	-7.6	-8.9
2 %	36.4	16.9	-4.8	-6.5
2.5 %	36.0	16.7	-3.9	-5.7
5 %	34.1	15.8	-1.9	-3.7

2.4. Solar orientation study

This study investigates solar radiation on building surfaces. After setting parameters such as project location, date, time, and time interval, a graphical illustration of solar radiation is given (Figure 4). This study shows that block A (located on the western side of the site) with much sunlight received during a day has a better position than block B.

3. DATA ANALYSIS

After modeling and adjusting the parameters required in Autodesk Revit software (Table 3), an energy model was made using the analysis tab. Then, to send the energy model and receive the data analysis results, an Autodesk account was used. It should be noted that by sending the energy model through the Autodesk Revit software to the Autodesk Insight software, an energy model will be sent to the Autodesk Green Building Studio software. Also, this software could be used to validate the results of energy analysis.

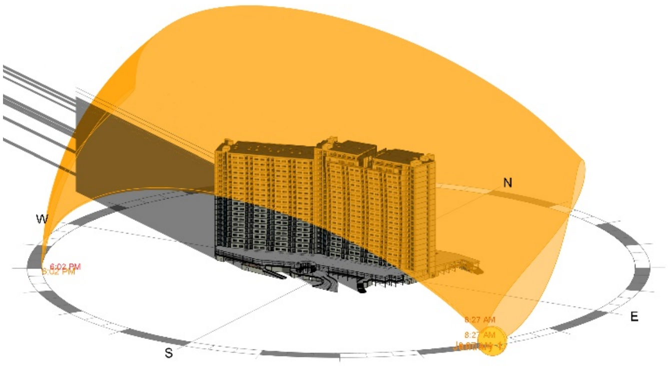

Figure 4. Sunlight radiation on building surfaces

Investigation of the charts of Figure 5 for block A shows that the highest energy cost is in July. According to this analysis, ventilation fans and space cooling have the highest share among all other affecting parameters for energy consumption. Also, the maximum energy use intensity of block A is in January, as shown in Figure 6. The space heat and ventilation fans have had the largest share among other parameters. Accordingly, the highest level of energy consumption based on energy cost is in July and August and energy use intensity is in January and December. The schematic diagrams of energy consumption for block B and the eastern lobby are similar.

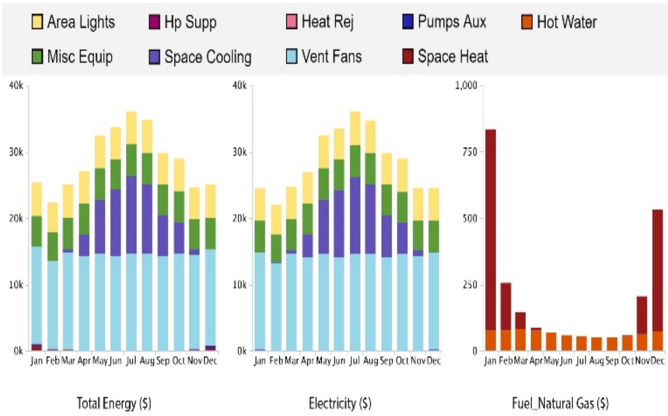

Figure 5. Energy consumption index based on energy cost, Block A

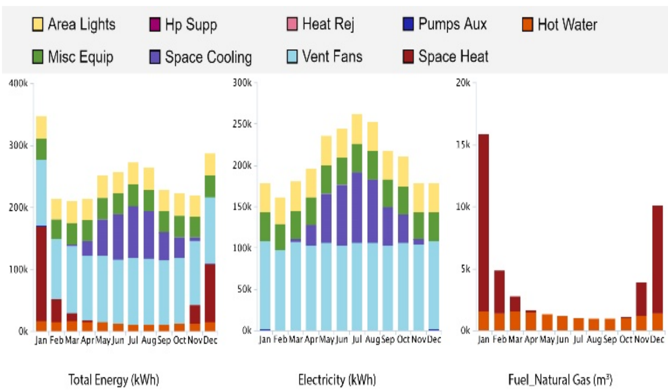

Figure 6. Energy consumption index based on energy use intensity, Block A

4. DISCUSSION

The results of the analysis show that block A has the lowest energy consumption. The cost of energy consumption based on the parameters in Table 7 is 13 USD/m^2/year, as shown in Table 6. This value for block B and the eastern lobby is 13 and 14.1, respectively. Accordingly, the energy use intensity for blocks A, B, and the eastern lobby will be equal to 112, 119, and 191 kWh/m^2/year, respectively. The building orientation, in this case, is based on the geographical north. Thus, the angle of the building is automatically determined by software based on the building form and the project geographic coordinates. The ratios of the window to the northern, southern, eastern and western walls are 16 %, 20 %, 7 %, and 5 %, respectively. The ratio values for blocks B are: 18 %, 22 %, 9 %, and 7 % and for the eastern lobby 15 %, 25 %, 13 %, and 14 %. The shades of all windows are considered by default. Therefore, the windows installed on the terraces use their overhead ceiling as shade. Other windows installed on the surfaces of external walls lacked a shading system. Also, the type of windows was based on the element defined in Autodesk Revit software (as shown in Table 7). The walls and roof structures are shown in Tables 3 and 7. The values of building infiltration rate, lighting efficiency, plug load efficiency, operating schedule, and building's HVAC system were adjusted according to the BIM parameter (as shown in Table 7). This building has no daylighting and occupancy controls system and photovoltaic solar panels. According to Table 7, after adjusting the effective parameters for energy consumption, the energy cost of block A is determined at 5.4 USD/m^2/year. This value for block B and the eastern lobby is 6.47 and 8.03, respectively. Accordingly, the energy use intensity for blocks A, B, and the eastern lobby will be equal to 86.7, 99, and 170 kWh/m^2/year, respectively. The building orientation in comparison to the previous base model remains unchanged based on the geographical north. The window's ratio to the northern and southern walls is unchanged and equal to 16 % and 20 % for block A; 18 % and 22 % for block B; 15 % and 25 % for the eastern lobby, respectively. The northern window shades were considered by default, for all blocks. Also, the southern window shades are selected as high as 2/3 of the window height. As shown in Table 7, the type of northern windows was unchanged for all blocks. The type of southern window is of triple-glazed one with low emission. Due to insignificant efficiency, the eastern and western windows were removed from the building model. The walls and roof structure are shown in Table 7. The value of the building infiltration rate is 0.17 ACH. The value of the lighting efficiency parameter is assumed to be 3.23 W/m^2. The values of plug load efficiency and operating schedules were adjusted according to the BIM parameter. The building's HVAC system was assumed to be a high-efficiency variable air volume system. Also, the building has a daylighting and occupancy control system. Finally, to achieve the highest level of energy efficiency, photovoltaic solar panels were used. For this purpose, the photovoltaic solar panels were used with a yield of 20.4 % and surface coverage of 90 %. The payback limit of photovoltaic panels in Autodesk Insight software is in 10-year, 20-year, and 30-year periods. Considering the arrangement of other parameters affecting energy consumption and related analysis showed that the time period between 20 and 30 years would not affect the output results. Therefore, the payback limit of these panels was considered for 30 years. The results of this analysis showed that the use of building information modeling technology in the adjustment of effective energy consumption parameters could save up to 58.46 % in energy cost for block A. This value for block B and the eastern lobby is 50.23 % and 43.05 %, respectively. Based on this result, this value based on the energy use intensity for blocks A, B, and the eastern lobby is 22.59 %, 16.81 %, and 11 %, respectively.

Table 6. Investigation and comparison of different energy consumption scenarios in building blocks

Building block		**Energy cost** (USD/m^2/year)	**Saving** (%)	**Energy use intensity** (kWh/m^2/year)	**Saving** (%)
A	BIM parameters	13	0	112	0
	Optimized parameters	5.40	58.46	86.70	22.59
B	BIM parameters	13	0	119	0
	Optimized parameters	6.47	50.23	99	16.81
Eastern lobby	BIM parameters	14.10	0	191	0
	Optimized parameters	8.03	43.05	170	11

Table 7. Basic and optimized parameters for building energy consumption

Building block	**Block A**		**Block B**		**Eastern lobby**	
Energy cost (USD/m^2/year)	13^{*}	5.40^{**}	13^{*}	6.47^{**}	14.1^{*}	8.03^{**}
Effective factor	Input parameter					
Building orientation	BIM$^{\circ}$					
WWR (South)	BIM (20 %)$^{\circ}$		BIM (22 %)$^{\circ}$		BIM (25 %)$^{\circ}$	
Window shades	BIM*					
	2/3 Win height**					
Window glass	BIM (Sgl Clr)*					
	Trp LoE**					
WWR (North)	BIM (16 %)$^{\circ}$		BIM (18 %)$^{\circ}$		BIM (15 %)$^{\circ}$	
Window shades	BIM$^{\circ}$					
Window glass	BIM (Sgl Clr)$^{\circ}$					
WWR (West)	BIM (5 %)*	(0 %)**	BIM (7 %)*	(0 %)**	BIM (14 %)*	(0 %)**

Window shades	BIM*					
	BIM (No Shade)**					
Window glass	BIM (Sgl Clr)*					
	BIM (No Window)**					
WWR (East)	BIM (7 %)*	(0 %)**	BIM (9 %)*	(0 %)**	BIM (13 %)*	(0 %)**
Window shades	BIM*					
	BIM (No shade)**					
Window glass	BIM (Sgl Clr)*					
	BIM (No window)**					
Wall construction	BIM (Concrete masonry units)*					
	R13+R10 Metal**					
Roof construction	BIM (Concrete, Cast in situ)°					
Infiltration	BIM (None)*					
	0.17 ACH**					
Lighting efficiency	BIM (10.76 W/m^2)*					
	3.23 W/m^2**					
Daylighting and occupancy controls	None*					
	Daylighting & occupancy controls**					
Plug load efficiency	BIM (10.76 W/m^2)°					
HVAC	BIM*					
	High Eff. VAV**					
Operating schedule	BIM (24 Hours)°					
Panel efficiency (PV)	None*					
	20.4 %**					
Payback limit (PV)	None*					
	30 years**					
Surface coverage (PV)	0 %*					
	90 %**					
*Base Model, **Optimized, °Unchanged						

It should be noted that this study was performed to convince the employer of the worth and benefit of BIM technology in optimizing energy consumption in a real project. As mentioned, due to the software limitations in sending the energy model, the building blocks were divided and also the ceiling elements were removed from the building model. Thus, the thermal height on the first and other floors was 4 m and 3.7 m, respectively. This building could have lower energy consumption than the values obtained in this analysis due to the implementation of the ceiling elements during the construction phase and reduced computational height of the spaces as a result. However, the results of this analysis show that block A has the lowest energy consumption. Considering the similar materials and equipment, this is due to the building orientation with the actual north of the region (geographic north). Accordingly, with the implementation of block B along the block A, the lowest energy consumption resulting from the maximum solar radiation during a day can be achieved. Also, this study shows that the results of the conceptual model analysis are more acceptable than the results of the actual building model. It can be useful in the early stages of decision-making for the project.

5. CONCLUSIONS

To investigate different design ideas, several conceptual masses were created in Autodesk Revit software. Next, the main form of the building was chosen only after reviewing the proposed designs in terms of energy cost as well as considerations such as project location, site scope, building height, facilities, and project cost. Then, an exact model of the building elements was created in Autodesk Revit software. Finally, after generating and analyzing the energy model, the most optimal mode was selected by examining different forms of energy consumption. The results of this analysis showed that the use of building information modeling technology in adjusting the affected energy consumption parameters would save up to 58.46 % in energy cost for block A, compared to the base building model in a 30-year time horizon. This value was 50.23 % for block B and 43.05 % for the eastern lobby. As a result, this value would be 22.59 %, 16.81 %, and 11 % for blocks A, B, and the eastern lobby, respectively, based on the energy use intensity. The results of this study showed that the use of Building Information Modeling (BIM) technology in optimizing the building energy consumption could significantly save energy costs. Also, the results of this study showed that the building HVAC system always had the highest share of energy consumption. Therefore, choosing the right type of HVAC system could achieve the lowest level of energy consumption in the building.

6. ACKNOWLEDGEMENT

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NOMENCLATURE

ACH	Air Changes per Hour
AFUE	Annual Fuel Utilization Efficiency
BIM	Building Information Modeling
Clr	Clear

Eff	Efficiency
HVAC	Heating, Ventilation, and Air Conditioning
LoE	Low Emissivity
PV	Photovoltaics
R13+R10	Construction material
SEER	Seasonal Energy Efficiency Ratio
Sgl	Single
Trp	Triple
VAV	Variable Air Volume
WWR	Window-to-Wall Ratio

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BIM-based optimum design and energy performance assessment of residential buildings

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Buildings are the largest energy consumer in the world, according to the United Nations Environment Program. Most of the energy will be used during the building life-cycle stage. Thus, achieving sustainable development at the national level requires minimizing the impact of buildings on the environment by reducing energy consumption. Using Building Information Modeling technology in energy performance assessment could be significantly reduced time and cost. This study aimed to optimize energy consumption in a residential building using BIM technology. The main focus of this study was to evaluate energy performance through the simultaneous evaluation of building components using BIM technology with a conceptual design approach, comparison, and reduction of energy consumption. To investigate different design ideas were created several conceptual masses in Autodesk Revit software with a top-down design approach. After reviewing the conceptual masses, the main building form was chosen for modeling. Then, building energy consumption was computed using related tools in this field, based on the type of materials, equipment, and project location. Finally, the most optimal mode was selected by examining different energy consumption forms. The results of parametric studies on alternative schemes of energy optimization showed that 58.46% of energy cost savings could be achieved compared to the initial model of the building on a 30-year time horizon.

keywords: *Energy consumption, Energy performance assessment (EPA), Energy simulation, Building energy efficiency, Building Information Modeling (BIM).*

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NOMENCLATURE

Abbreviations

ACH Air Changes per Hour
AFUE Annual Fuel Utilization Efficiency
BIM Building Information Modeling
Clr Clear
Eff Efficiency
HVAC Heating, Ventilation, and Air Conditioning
LoE Low emissivity
PV Photovoltaics
R13+R10 Construction material
SEER Seasonal Energy Efficiency Ratio
Sgl Single
Trp Triple
VAV Variable Air Volume
WWR Window-to-Wall Ratio

1. INTRODUCTION

In 2019, U.S. residential and commercial buildings used more than 39.2% of the nation's total energy and more than 71.1% of the electrical energy [1]. Emerging technologies are helping to reduce the energy use intensity by enabling cost-effective and energy-efficient technologies to be developed and introduced into the marketplace. Some of these technologies include HVAC, water heating, and appliances, windows and building envelope, solid-state lighting, grid-interactive efficient buildings, sensors and controls, and building energy modeling [2, 3]. Building energy models are usually created separately from building information models, and energy analysis is done with a separate analysis tool [4, 5]. In the traditional way of evaluating energy performance, which designers manually simulate an energy model, there are serious problems such as error-prone data duplication, data leaks, and redundant data processing and storage [6]. The building energy model can be generated more quickly by leveraging existing data from BIM, and the use of multiple analysis tools is more practical [4]. Buildings cause environmental pollution due to energy and resource consumption, emission of pollutants, and waste disposal throughout construction, maintenance, and demolition [7, 8]. Furthermore, the impact of energy consumption is significant in the building usage phases, which can last multiple decades [9]. Therefore, it's essential to analyze building energy performance when the most critical decisions are made (especially the design phase) [6]. The building energy performance analysis requires access to specific information such as properties of materials, U-value, and technical systems during the initial phase of design. This information is one of the factors determining the energy performance of the building [10]. Building Information Modeling is a technology for improving productivity and efficiency in the construction industry by taking advantage of the information generated throughout the facility life-cycle using a consistent system [6]. The best description for building information modeling is a data model, which is made by integrating 3D digital techniques with different methods of information related to a specific engineering project [9]. One of the main benefits of BIM in both the initial phase of design and subsequent stages of analysis is building energy simulation [4]. This technology makes it possible to continuously measure energy performance for the whole life cycle of a building [11]. Building energy simulation programs can be used effectively in the initial phases of design to evaluate "what-if" scenarios in the search for optimal solutions [12]. These programs can provide useful insights into changes that can improve energy performance. The parametric nature of BIM programs allows the suggested changes to the building energy model to be quickly updated [4]. In Iran, a considerable amount of energy annually is consumed in the household, public, and commercial sectors. According to the latest existing data, the share of buildings' fuel consumption in 2016 was 34% of the total energy consumption [13]. The limitation of energy resources and the significant growth of using them compared with the worldwide average have doubled the necessity of optimizing energy consumption in Iran. Due to the high share of energy consumption in the building sector, accurate analysis of thermal and cooling loads of the building and efforts to reduce energy losses is an effective way to reduce energy consumption. Building information modeling provides the capacity to generate and manage all the information about a building during its life cycle, which will be used in energy performance assessment [6]. Many types of research have been done on the main potential and value-added as a result of BIM adoption to achieve energy efficiency in the energy sector [9, 14–28]. However, in the optimum design and energy performance assessment based on BIM, there has not been much-focused research using simulation and analysis. Looking at the previous studies can be found that there are not any researches to study energy performance assessment through the simultaneous evaluation of building components using BIM technology with a conceptual design approach, comparison, and reduction of energy consumption. These components include building orientation, window-to-wall ratio (WWR), window shades, window glass, wall construction, roof construction, infiltration, lighting efficiency, daylighting and occupancy controls, plug load efficiency, HVAC, operating schedule, photovoltaic panels efficiency, payback limit of photovoltaic modules, and surface coverage of photovoltaic modules. This research achieved the lowest level of energy consumption in the studied building by examining the simultaneous combination of building components and showed that the use of building information modeling technology in evaluating energy performance could significantly reduce energy consumption in the life cycle of the building.

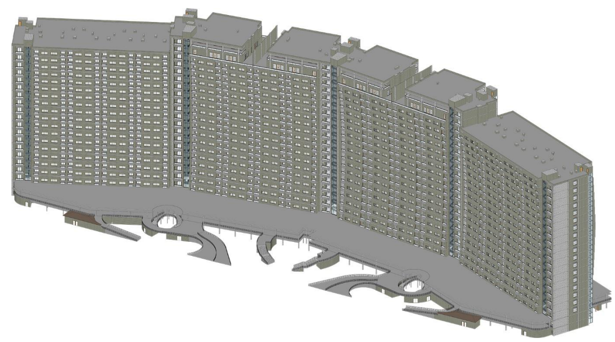


Fig. 1. The 3D view of the simulated building in Autodesk Revit software.

2. METHODOLOGY

A. Software Selection

Autodesk Revit 2020 was chosen to create a building information model for several reasons. One, Autodesk Revit provides various strategies for model creation using either a bottom-up or top-down design approach. Two, using the Autodesk Insight plugin, it's also possible to perform energy analysis in Autodesk Revit software. Three, support of building data output in standard formats such as IFC and gbXML, which makes it possible to perform energy analysis by other energy analyzer software. To perform energy analysis in this study was used related tools in the energy field. This tool was chosen because of its ability to quickly create an energy model and visualization in the initial phase of design. Moreover, Autodesk Green Building Studio (GBS) software was used to obtain the results of climate data analysis and building energy consumption index. Also, this software was used to validate the results of energy analysis. Thus, by sending the energy model to the Autodesk Insight software, a file will be sent to the Autodesk Green Building Studio software simultaneously. Using an Autodesk account provides the ability to review energy analysis. It should be noted that both Autodesk Green Building Studio software and Autodesk Insight software are flexible cloud-based services that allow for simulation of building performance to optimize energy efficiency. In addition to the reasons mentioned for choosing the software, it can use the minimum hardware resources of the system and provide a very high speed of energy analysis in cloud computing. Fig.1 shows the 3D view of the building case study in Autodesk Revit software.

B. Case Study

This case study is a residential building located in a region with a mild climate. The building area is about 191000 m2, located in Anzali trade-industrial free zone, Gilan province, Iran (37°27'14.7"N, 49°40'03.4"E). The main reasons for choosing this building were to study the form and orientation of the building and the cost changes caused by changing the effective parameters to optimize energy consumption using Building Information Modeling technology. To examine different design ideas were created several conceptual masses in Autodesk Revit software with a top-down design approach. Then, the floors and types of materials and energy settings were defined for each mass. Finally, after generating the energy model and sending the related file to the Autodesk cloud services were received the results of energy analysis. After reviewing the proposed designs in terms of energy cost as well as considering the items such as project location, site scope, building height, facilities, and project cost, the main form of the building was chosen for accurate modeling and energy analysis. Table 1 shows the comparison of different building forms.

The results of this analysis show that module-1 has the lowest energy consumption, among other modules. The cost of energy consumption based on Table 2 parameters is 13.4 USD/m2/year. Accordingly, the energy use intensity is equal to 110 kWh/m2/year, as shown in Table 1. The building orientation, in this case, is based on the geographical north. Thus, the angle of the building is automatically determined by the software, based on the building form and the project geographic coordinates. The window to wall ratio in all directions is 40% by default. All windows have shades with a depth of 45.72 cm. Also, the type of windows in the conceptual model was double-glazed windows without any external coating. The walls structure used in the conceptual model is lightweight walls with typical mild climate insulation, and the roof structure is lightweight and without insulation. As shown in Table 2, according to the BIM parameter were adjusted the values of building infiltration rate, lighting efficiency, plug load efficiency, operating schedule, and building's HVAC system. This building has no daylighting and occupancy controls system and photovoltaic solar panels. After adjusting the parameters affecting energy consumption, according to Table 2, the energy cost would be 6.56 USD/m2/year. Accordingly, the energy use intensity would be equal to 81.6 kWh/m2/year. The building orientation relative to the previous model (initial model) isn't changed and based on the geographical north. The windows ratio to the northern and southern walls is 40% by default. These windows have shades as high as 2/3 of the window height. Also, the type of these windows in the conceptual model was triple-glazed windows with low emission. Due to the lack of significant efficiency have been removed the eastern and western windows from the conceptual model. The walls structure in the conceptual model is according to Table 2, and the roof structure is lightweight and without insulation. The building infiltration rate was considered 0.17 ACH. The value of the lighting efficiency is assumed to be 3.23 W/m2. The values of the plug load efficiency and the operating schedule were adjusted according to the BIM parameter. The building's HVAC system was assumed to be a high-efficiency variable air volume system. Also, the building has a daylighting and occupancy control system. Finally, to achieve the highest level of energy efficiency were used the photovoltaic solar panels. For this purpose, the photovoltaic solar panels were used with a yield of 18.6% and surface coverage of 90%. The payback limit of these panels was assigned for 30 years. The results of this analysis show that the use of building information modeling technology for adjusting the parameters affecting energy consumption in conceptual designs can save up to 51.04% in energy cost. Based on the energy use intensity, this value would be 25.82%.

C. Baseline Energy Model Specifications

The building energy model requires a set of parameters depending on analysis tools and specific studies. Table 3 shows the basic parameters of the building energy model as the basis of design. These parameters include materials with thermal properties, building occupancy, plug loads, HVAC, building natural infiltration rate, lighting density and efficiency, internal heat gains (plug loads and occupancy), operating schedules, thermostat set-point temperatures, and natural ventilation. These parameters are specified by the BIM title in the provided data.

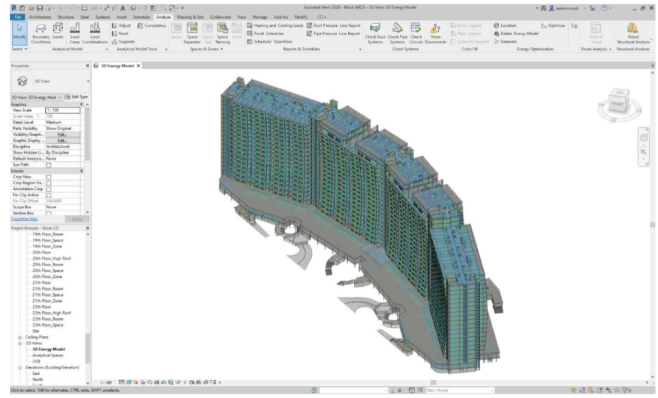


Fig. 2. Creating the energy model using building elements in Autodesk Revit software.

Table 3. Basic parameters of building energy model

Input parameter	Value
HVAC System	Residential 14 SEER/0.9 AFUE Split/Packaged Gaz <5.5 ton
Area per Person	105.82 m2
Sensible Heat Gain (per person)	73.27 W
Latent Heat Gain (per person)	58.61 W
Power Load Density	10.76 W/m2
Lighting Load Density	10.76 W/m2
Plenum Lighting Contribution	20%
Occupancy Schedule	24 Hours
Lighting Schedule	All Day
Power Schedule	All Day
Outdoor Air (per person)	2.36 L/s
Outdoor Air (per area)	0.30 L/ (s.m2)
Unoccupied Cooling Set Point	27.78 °C
Infiltration (ac/h)	None
Fabric U-values	
External walls	20cm concrete block (U-value 6.5 W/m2K)
Internal walls	10cm concrete block (U-value 13 W/m2K)
Shear walls	45cm reinforced concrete (U-value 2.3244 W/m2K)
Floor	22.5cm concrete slab (U-value 4.6489 W/m2K)
External doors	Wooden, Single-Flush (U-value 2.1944 W/m2K)
Terrace doors	Wood frame with single clear glass (U-value 5.6212 W/m2K)
Lobby doors	Metal frame with single clear glass (U-value 6.5580 W/m2K)
Elevator doors	Metal (U-value 3.7021 W/m2K)
Windows	1/8 in Pilkington single glazing (U-value 3.6886 W/m2K)

3. BUILDING ENERGY SIMULATION AND DATA ANALYSIS

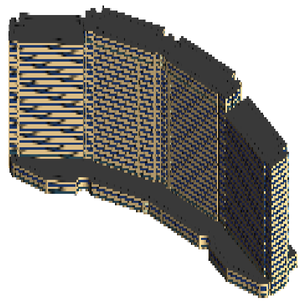
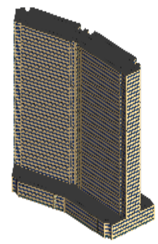
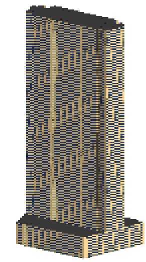
A. BIM Data Export Process

After modeling and adjusting the parameters required in Autodesk Revit software (Table 3), was created an energy model using the analyze tab (Fig.2). Then, an Autodesk account was used to send the energy model and receive the data analysis results. It should be noted that by sending the energy model through Autodesk Revit software to Autodesk Insight software, simultaneously, an energy model will be sent to Autodesk Green Building Studio software.

B. Climate Analysis

After sending the energy model, the climate data, as the first element of the environment in which the building is located, were automatically taken from the nearest weather station database.

Table 1. Comparison of different building forms based on the simulation of energy consumption in conceptual masses

	Module-1	Module-2	Module-3
			
Floors	22	43	84
Units	1070	1073	1084
Height (m)	81.7	159.4	311.1

Building Form		Energy Cost	Saving	Energy Use Intensity	Saving
		USD/m2/year	Percent	kWh/m2/year	Percent
Module-1	BIM Parameters	13.4	0	110	0
	Optimized Parameters	6.56	51.04	81.6	25.82
Module-2	BIM Parameters	13.5	0	108	0
	Optimized Parameters	7.33	45.7	89	17.59
Module-3	BIM Parameters	14	0	111	0
	Optimized Parameters	8	42.86	96.3	13.24

The data related to design conditions based on dry-bulb temperature and Mean Coincident Wet Bulb temperature (MCWB) are shown in Table 4. Fig. 3 shows the average of the minimum and maximum daily temperatures every month. Fig. 4 shows the wind speed frequency distribution based on annual data. The wind rose diagram is also shown based on annual data. This graph represents the relative frequency of direction and wind speed over a period of time at a specific location. Fig. 5 shows the relative frequency of direction and wind speed in the summer and winter seasons.

Table 4. Basic parameters of building energy model

Annual Design Conditions				Unit: SI
Threshold	Cooling		Heating	
	Dry Bulb (°C)	MCWB (°C)	Dry Bulb (°C)	MCWB (°C)
0/10%	39/2	18/1	-10/4	-11/3
0/20%	38/8	17/9	-9/8	-11
0/40%	38/4	17/9	-9/2	-10/4
0/50%	38/2	18	-8/8	-9/8
1%	37/3	17/3	-7/6	-8/9
2%	36/4	16/9	-4/8	-6/5
2/50%	36	16/7	-3/9	-5/7
5%	34/1	15/8	-1/9	-3/7

C. Solar Orientation Study

This study investigates how solar radiation on building surfaces. After setting parameters such as project location, date, time, and time interval, will be obtained a graphical presentation of solar radiation (Fig. 6). The results indicated that block A (located on the western side of the site) with the most sunlight received during a day, had a better position compared to other blocks.

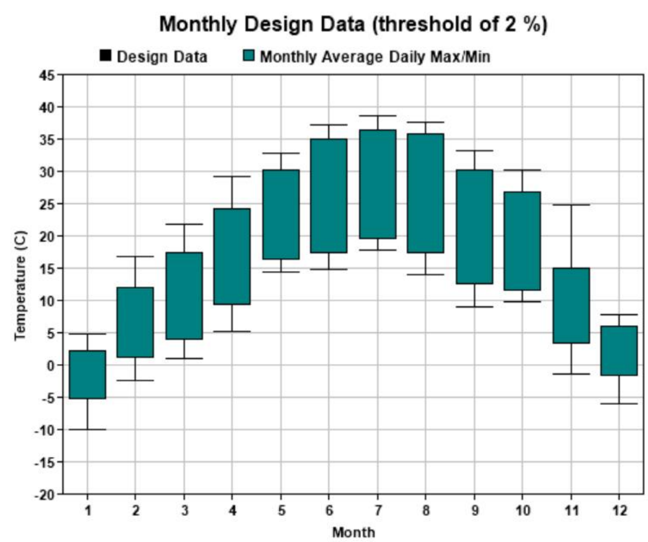


Fig. 3. Average maximum and minimum daily temperatures on a monthly basis.

D. Energy Effective Parameters Analysis

Fig. 7 for block A shows the highest energy cost in July. According to this analysis, ventilation fans and space cooling have the largest share compared to other parameters affecting energy consumption. The maximum energy use intensity in block A is observed in January (Fig. 8). Obviously, space heat and ventilation fans have the highest share among other parameters. Accordingly, the highest level of energy consumption based on energy cost is seen in July and August, and based on energy use intensity is seen in January and December. The schematic diagrams of energy consumption for blocks B, C, D, and the

Table 2. Basic and optimized parameters of energy consumption in conceptual masses

Building Form	Module-1	Module-2	Module-3
Energy Cost (USD/m2/year)	13.4*, 6.56**	13.5*, 7.33**	14*, 8.00**
Effective Factor		Input parameter	
Building Orientation		BIM	
WWR (S)		BIM (40%)°	
Window Shades		BIM (0.4572 m) *	
		2/3 Win Height**	
Window Glass		BIM (Double Pane Clear – No Coating) *	
		Trp LoE**	
WWR (N)		BIM (40%)°	
Window Shades		BIM (0.4572 m) *	
		2/3 Win Height**	
Window Glass		BIM (Double Pane Clear – No Coating) *	
		Trp LoE**	
WWR (W)		BIM (40%) *	
		(0%) **	
Window Shades		BIM (0.4572 m) *	
		BIM (No Shade) **	
Window Glass		BIM (Double Pane Clear – No Coating) *	
		BIM (No Window) **	
WWR (E)		BIM (40%) *	
		(0%) **	
Window Shades		BIM (0.4572 m) *	
		BIM (No Shade) **	
Window Glass		BIM (Double Pane Clear – No Coating) *	
		BIM (No Window) **	
Wall Construction		BIM (Lightweight Construction – Typical Mild Climate Insulation) *	
		R13+R10 Metal**	
Roof Construction		BIM (Lightweight Construction – No Insulation)°	
Infiltration		BIM (None)*	
		0.17 ACH**	
Lighting Efficiency		BIM (10.76 W/m2) *	
		3.23 W/m2**	
Daylighting and Occupancy Controls		None *	
		Daylighting & Occupancy Controls**	
Plug Load Efficiency		BIM (10.76 W/m2)°	
HVAC		BIM*	
		High Eff. VAV**	
Operating Schedule		BIM (24 Hours)°	
Panel Efficiency (PV)		None*	
		18.6%**	
Payback Limit (PV)		None*	
		30 years**	
Surface Coverage (PV)		0%*	
		90%**	

*Base Model, **Optimized, °Unchanged

middle-lobby are similar.

4. BUILDING SIMULATION RESULTS

The results of this analysis show that block A has the lowest energy consumption, among other blocks. The cost of energy consumption based on Table 6 parameters is 13 USD/m2/year, as shown in Table 5. This value for blocks B, C, D, and the middle-lobby is equal to 13, 13.6, 14.1, and 14.1, respectively. Accordingly, the energy use intensity for blocks A-D and the middle-lobby would be equal to 112, 119, 126, 119, and 191 kWh/m2/year, respectively. The building orientation, in this case, is based on the geographical north. Thus, the angle of the building is automatically determined by the software, based on the building form and the project geographic coordinates. The windows ratios to the northern, southern, eastern, and western walls are 16%, 20%, 7%, and 5%, respectively. These values are 18%, 22%, 9% and 7% for block B, and 21%, 23%, 7% and 8% for block C, and 21%, 21%, 5% and 10% for block D, and 15%, 25%, 13% and 14% for the middle-lobby, respectively. The shades of all windows were considered by default. Therefore, the windows installed on the terraces would use their overhead ceiling as a shade. Other windows installed on the surfaces of the external walls lacked a shading system. As shown in Table 6, the type of windows is based on the software-defined element. The walls and roofs materials are shown in Tables 3 and 6. The values of the building infiltration rate, lighting efficiency, plug

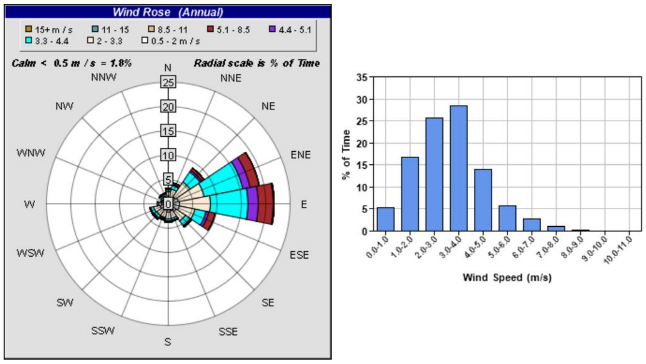


Fig. 4. Wind speed frequency distribution (Right) and Relative frequency of direction and wind speed (left).

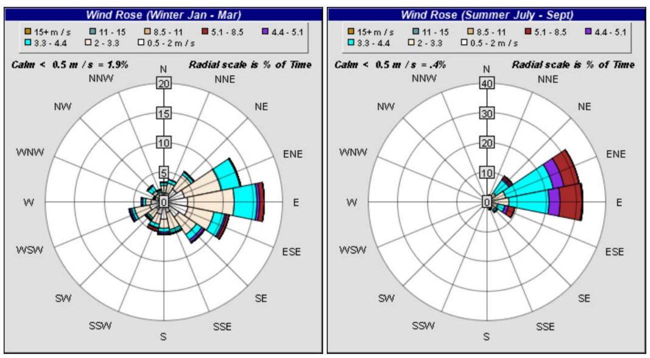


Fig. 5. Relative frequency of direction and wind speed in summer (Right), and in winter (left).

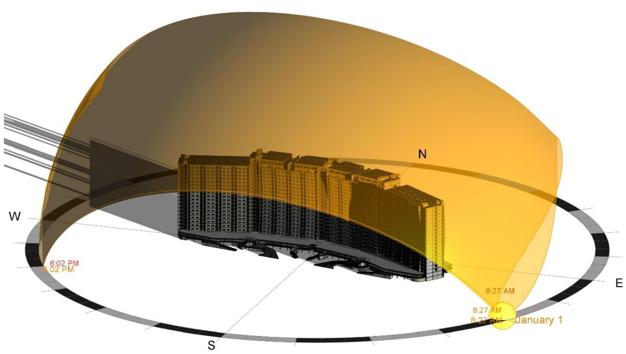


Fig. 6. Solar radiation on building surfaces.

load efficiency, operating schedule, and building's HVAC system were adjusted according to the BIM parameter (as shown in Table 6). This building has no daylighting and occupancy controls system and photovoltaic solar panels. After adjusting the parameters affecting energy consumption, according to Table 6, the energy cost of block A would be 5.4 USD/m2/year. This value for blocks B, C, D, and the middle-lobby is equal to 6.47, 6.66, 5.89, and 8.03, respectively. Accordingly, the values of energy use intensity for blocks A-D and the middle-lobby would be equal to 86.7, 99, 105, 99.6, and 170 kWh/m2/year, respectively. The building orientation relative to the previous model (initial model) isn't changed and based on the geographical north. The windows ratios to the northern and southern

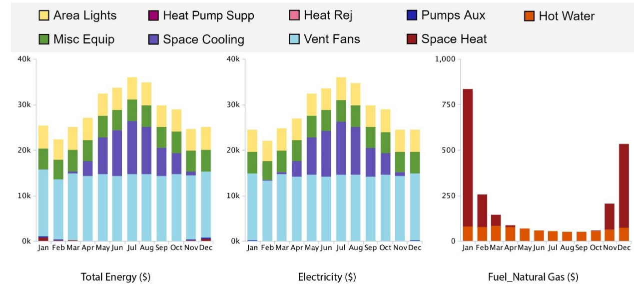


Fig. 7. Energy consumption index based on energy cost, Block A.

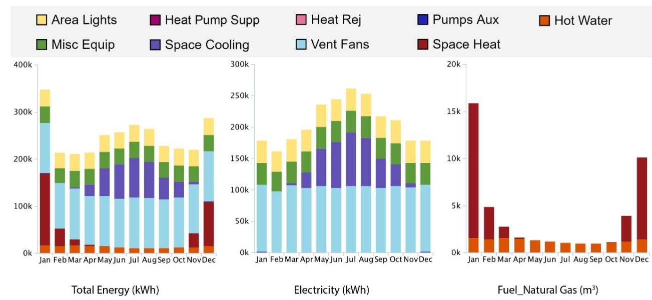


Fig. 8. Energy consumption index based on energy use intensity, Block A.

walls are unchanged and equal to 16% and 20% for block A, 18% and 22% for block B, 21% and 23% for block C, 21% for block D, 15% and 25% for the middle-lobby, respectively. For all blocks, the northern window shades are considered by default. Moreover, the southern window shades were selected as high as 2/3 of the window height. As shown in Table 6, the type of northern windows was determined based on the software-defined element for all blocks. The triple-glazed type with low emission was chosen to be used in southern windows. Due to the lack of significant efficiency, have been removed the eastern and western windows from the building model. The walls and roof structure are shown in Table 6. The building infiltration rate was considered 0.17 ACH. The value of the lighting efficiency is assumed to be 3.23 W/m2. The values of the plug load efficiency and the operating schedule were adjusted according to the BIM parameter. The building's HVAC system was assumed to be a high-efficiency variable air volume system. Also, the building has a daylighting and occupancy control system. Finally, to achieve the highest level of energy efficiency were used the photovoltaic solar panels. For this purpose, the photovoltaic solar panels were used with a yield of 20.4% and surface coverage of 90%. The payback limit of these panels was assigned for 30 years.

The results show that the use of building information modeling technology for adjusting the parameters affecting energy consumption can save up to 58.46% in energy cost for Block A. This value for block B, C, D, and the middle-lobby are 50.23%, 51.03%, 58.23%, and 43.05%, respectively. However, based on the energy use intensity, this value would be 22.59%, 16.81%, 16.67%, 16.30%, and 11% for blocks A, B, C, D, and the middle-lobby, respectively. The saving based on energy cost can be calculated by Eq. (1), and saving based on energy use intensity can be estimated using Eq. (2).

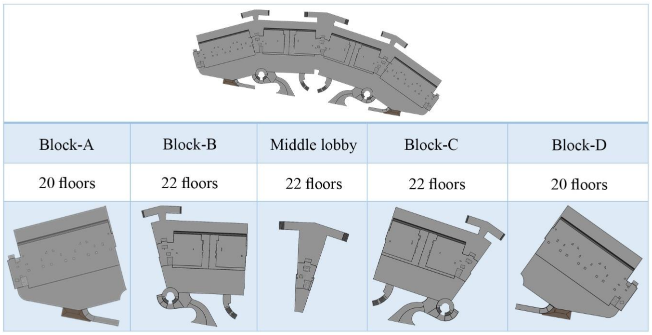


Fig. 9. Separation of building blocks for energy analysis.

$$Block\ A \rightarrow \left(\frac{5.4-13}{13}\right) * 100 = -58.46\% \quad (1)$$

$$Block\ A \rightarrow \left(\frac{86.7-112}{112}\right) * 100 = -22.59\% \quad (2)$$

Table 5. Comparison of different energy consumption scenarios in the building blocks

Building Block		Energy Cost	Saving	Energy Use Intensity	Saving
		USD/m2/year	Percent	kWh/m2/year	Percent
A	BIM Parameters	13	0	112	0
	Optimized Parameters	5.4	58.46	86.7	22.59
B	BIM Parameters	13	0	119	0
	Optimized Parameters	6.47	50.23	99	16.81
C	BIM Parameters	13.6	0	126	0
	Optimized Parameters	6.66	51.03	105	16.67
D	BIM Parameters	14.1	0	119	0
	Optimized Parameters	5.89	58.23	99.6	16.3
Middle lobby	BIM Parameters	14.1	0	191	0
	Optimized Parameters	8.03	43.05	170	11

5. RESEARCH LIMITATIONS

Due to the software limitation in sending the shade surfaces (max. 10000 surfaces) as well as the number of doors (max. 4096 doors), the whole building energy analysis was not possible in the cloud. For this reason, as shown in Fig. 9, each block of this residential building is analyzed separately. Finally, due to increased shade surfaces, the ceiling elements were removed from the building model.

6. DISCUSSION

As mentioned, due to the software limitations in sending the energy model, the building blocks were separated from each other and were removed the ceiling elements from the building model. Therefore, the thermal height was 4 m on the first floor and 3.7 m on the other floors. This building could have lower energy consumption than the obtained values, due to the implementation of ceiling elements during the construction phase and reduced computational height of the spaces as a result. However, the results show that block A has the lowest energy consumption. Considering the similar materials and equipment used, this can be due to the building orientation towards the geographical north of the region. Accordingly, by the implementation of other blocks in the direction of block A, the lowest energy consumption can be achieved as a result of the maximum solar radiation during a day. This study shows that the results from the conceptual model analysis are acceptable compared to the results from the actual building model. It can be useful in the early stages of decision-making for the project.

7. CONCLUSION

Today, most of the environmental problems in the world are related to the use of fossil fuels, especially in the construction sector. In Iran, considerable amounts of energy are consumed annually in the building and housing sectors. In this study, after reviewing the conceptual masses and choosing a building form, an exact model of building elements was created in the Autodesk Revit software. Then, the energy model was generated based on the BIM parameters. Finally, adjusting the parameters affecting energy consumption led to the reduction of energy costs in the building. Finally, the results of parametric studies on alternative schemes of cost optimization showed that 58.46% of energy cost savings would be achieved compared to the initial model of the building on a 30-year time horizon. The results showed that optimizing the energy consumption of the building using building information modeling technology could significantly save energy costs. In this regard, the optimization of energy consumption would reduce environmental pollutants emissions and contribute to the preservation and sustainability of the environment. It should be noted that the general method and findings of this study can be used in all regions of the world.

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Table 6. Basic and optimized parameters in building energy consumption

Building Block	Block A	Block B	Block C	Block D	Middle lobby
Energy Cost (USD/m2/year)	13*, 5.40**	13*,6.47**	13.6*, 6.66**	14.1*, 5.89**	14.1*, 8.03**
Effective Factor			Input parameter		
Building Orientation			BIM		
WWR (S)	BIM (20%)°	BIM (22%)°	BIM (23%)°	BIM (21%)°	BIM (25%)°
Window Shades			BIM*		
			2/3 Win Height**		
Window Glass			BIM (Sgl Clr) *		
			Trp LoE**		
WWR (N)	BIM (16%)°	BIM (18%)°	BIM (21%)°	BIM (21%)°	BIM (15%)°
Window Shades			BIM°		
Window Glass			BIM (Sgl Clr)°		
WWR (W)	BIM (5%) *	BIM (7%) *	BIM (8%) *	BIM (10%) *	BIM (14%) *
			(0%) **		
Window Shades			BIM*		
			BIM (No Shade) **		
Window Glass			BIM (Sgl Clr) *		
			BIM (No Window) **		
WWR (E)	BIM (7%) *	BIM (9%) *	BIM (7%) *	BIM (5%) *	BIM (13%) *
			(0%) **		
Window Shades			BIM*		
			BIM (No Shade) **		
Window Glass			BIM (Sgl Clr) *		
			BIM (No Window) **		
Wall Construction			BIM (Concrete Masonry Units) *		
			R13+R10 Metal**		
Roof Construction			BIM (Concrete, Cast In Situ)°		
Infiltration			BIM (None)*		
			0.17 ACH**		
Lighting Efficiency			BIM (10.76 W/m2) *		
			3.23 W/m2**		
Daylighting and Occupancy Controls			None*		
			Daylighting & Occupancy Controls**		
Plug Load Efficiency			BIM (10.76 W/m2)°		
HVAC			BIM*		
			High Eff. VAV**		
Operating Schedule			BIM (24 Hours)°		
Panel Efficiency (PV)			None*		
			20.4%**		
Payback Limit (PV)			None*		
			30 years**		
Surface Coverage (PV)			0%*		
			90%**		

*Base Model, **Optimized, °Unchanged

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ORIGINAL RESEARCH PAPER

Effective energy consumption parameters in residential buildings using Building Information Modeling

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ABSTRACT

Building information modeling can help in predicting the energy efficiency in future based on dynamic patterns obtained by visualization of data. The aim of this study was to investigate the effective parameters of energy consumption using BIM technology which can evaluate the buildings energy performance. First, three forms of general states in the building were modeled to evaluate the proposed designs in Autodesk Revit Software. Then, the main building form for energy modeling and analysis was selected. Autodesk Revit 2020 software was also used to obtain the results of climate data analysis and building energy consumption index. Finally, the most optimal mode was selected by examining different energy consumption modes. The results showed that the use of building information modeling technology in adjusting the parameters affecting energy consumption can save energy cost up to 58.23% in block D. Energy cost savings for block C and the western lobby were obtained as 51.03% and 43.05%, respectively. Based on energy use intensity, energy cost savings for blocks C, D, and the western lobby were estimated as 16.67%, 16.30%, and 11%, respectively. The results of parametric studies on alternative schemes of energy use intensity optimization showed that 16.30% savings could be achieved by the base building model in a 30-year time horizon. Therefore, it was concluded that optimization of energy consumption would reduce the environmental pollutants emission and contribute to preservation and sustainability of the environment.

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INTRODUCTION

Along with rapid increase of energy consumption the concerns about production problems, degradation of energy resources and severe environmental impacts (loss of ozone layer, global warming, climate change, etc.) have been increased in the world (Jung *et al.,* 2013). Nowadays, energy efficiency in the building is the main objective in energy policy at regional, national, and international levels (Pérez-Lombard *et al.,* 2008). Achieving sustainable development at the national level requires minimizing the impact of building on the environment by reducing energy consumption (Choi *et al.,* 2016). The current methods and techniques for energy simulation of buildings are time-consuming and difficult. Moreover, they suffer from lack of high interaction capability between the theoretical and real energy data.)Venkataraman and Kannan, 2013). Early phases of building design play a crucial role in the performance of a building's life cycle in terms of resources, energy consumption and life cycle costs (Kovacic and Zoller, 2015). Analyzing the energy performance of a building during the early design stage requires access to specific information such as properties of materials, U-value, and technical systems. Such information is one of the determinants of building energy performance (Schlueter and Thesseling, 2009). Insufficient adaptation due to the complexity of data exchange between architectural design and building energy simulation prevents the effective use of energy performance analyses in the initial design stage (Kim *et al.,* 2015). Efficiency of energy resources in new buildings can affect the design of a building by adopting an integrated approach (Venkataraman and Kannan, 2013). Building information modeling (BIM) is a good candidate to be used for extracting the data such as daylighting or energy in different areas. (Cemesova *et al.,* 2015). BIM consists of digital representation of physical and functional characteristics of a building. It is used as a common source of information about a building's reliable facilities for decision making during its lifecycle from the beginning to the end (Shivsharan *et al.,* 2017). Based on literature review, the main potentials and value-added for accepting BIM technology in the energy sector have been summarized in Table 1. Famous database (sciencedirect, emerald, ASCE, tandfonline) has been searched using the keywords including energy conservation, BIM, effective parameters, and cost saving. All the authors whose fields of study were close to the theme of this study were extracted. The findings show that no studies have addressed the effective parameters of building energy using BIM.

Today, most of the environmental problems in the world are related to the use of fossil fuels, especially in the construction sector. In Iran, a considerable amount of energy is annually consumed in the building and housing sectors. The share of buildings' fuel consumption in 2016 was about 41.4% of the total energy consumption in the country, which was the highest amount of energy consumption (Ministry of Energy, 2016). Due to the large share of final energy consumption in this sector, accurate analysis of the thermal and cooling loads of a building and efforts to reduce energy losses in it are effective ways to reduce energy consumption. Energy performance assessment using BIM would save a lot of time and money (Choi *et al.,* 2016). This study attempts to render energy performance assessment based on Building Information Modeling technology (BIM-EPAs) and indicates that it can help in design identification, comparison, and reduction of energy consumption in the initial phase of design. The aim of this study is to investigate the effective parameters envolved in energy consumption and uses Building Information Modeling (BIM) technology to evaluate the buildings energy performance. This study has been carried out in Bandar Anzali, Iran during 2019-2020.

MATERIALS AND METHODS

Software selection

Autodesk Revit 2020 was selected to create a building information model. One of the reasons for choosing this software as a reference software is its tools for different design strategies with a modeling approach from bottom to top and top to bottom. Using the Autodesk internal plugin of the site, it is also possible to perform energy analysis in this software. Another application of this software is support of building data output in standard formats (such as IFC and gbXML), which makes it possible to perform energy analysis by other energy analyzer software. To perform energy analysis in this study, an energy-related tool was used. This tool was chosen due to its good ability to create an energy model and visualize it in early design studies. Moreover, Autodesk Green Building Studio (GBS) software is used to obtain the results of climate data analysis and building energy

Table 1: Previous studies on main potentials and value-added for accepting BIM technology in the energy sector

Author(s)	Title	Potentials of BIM	Value-added	Y
Singh and Sadhu	Multicomponent Energy Assessment of Buildings using BIM	Building performance analysis	Improving design quality and energy efficiency	2019
Farzaneh *et al.*	Review of using BIM for building energy modeling	Integrated design and building performance analysis	Improving design quality and energy efficiency	2019
Gao *et al.*	Building information modeling-based building energy modeling	Integrated design and energy analysis	Improving design quality and energy efficiency	2019
Najjar *et al.*	Integrated energy optimization and life cycle assessment with building information modeling	Help to perform buildings performance analysis	Reducing energy consumption and resources	2019
Nizam *et al.*	A BIM-based tool for assessing embodied energy for buildings	Integrated design and building performance analysis	Improving design quality and reduced the environmental impacts of the building	2018
Banteli and Stevenson	Analysis of energy and carbon in early-stage design using BIM	Help to perform buildings performance analysis in early-stage design	Energy efficiency and reduction of greenhouse gas emissions	2017
Beazley *et al.*	Enhancing energy efficiency in residential buildings using BIM	Integrated design and energy analysis	Increasing energy efficiency	2017
Egwunatum *et al.*	Assessment of energy consumption and leakage in buildings with building information model energy	Integrated design and energy analysis	Improving design quality and energy efficiency	2017
Gerrish *et al.*	BIM application to building energy performance visualization and management	Visualization and management of building performance	Improving interoperability and building performance management	2017
Habibi	BIM for improving building performance	Integrated design and energy analysis	Improving design quality and energy efficiency	2017
Maltese *et al.*	Sustainability assessment through green BIM	Using BIM in the building lifecycle	Improving design quality	2017
Abanda and Byers	An investigation of the impact of building orientation on energy consumption using BIM	Building performance analysis	Reducing energy consumption	2016
Guo and Wei	Evaluation of cost-effective energy saving	Integrated design and economic analysis	Improving design quality and cost efficiency	2016
Kurian *et al.*	Sustainable Building Design based on BIM	The share of building components in energy consumption	Reducing energy consumption	2016
Peng	Calculation of a building's life cycle carbon emissions based on BIM	Integrated design and building performance analysis	Improving design quality and Reducing resources consumption	2016
Eguaras-Martínez *et al.*	Simulation and evaluation of Building Information Modeling in a real pilot site	Investigation of real people's behavior in building energy simulation	Energy efficiency	2014
Li *et al.*	Analysis of BIM technology in the Design of Green Village buildings	Building performance analysis	Improving design quality and energy efficiency	2014
Motawa and Carter	Sustainable BIM-based evaluation of buildings	BIM capability to homogenize sustainable buildings	Improving design quality and energy efficiency	2013

consumption index. It should be noted that both Autodesk Green Building Studio and Autodesk Insight software are flexible cloud-based services that allow for simulation of building performance in order to optimize energy efficiency. In addition to the reasons mentioned for choosing the software, it can use the

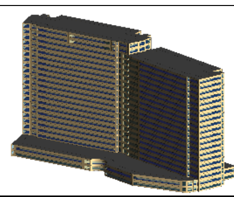
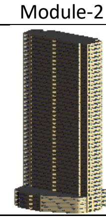
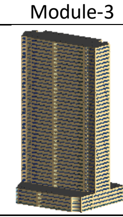
Fig. 1: The 3D view of the simulated building in Autodesk Revit software

minimum hardware resources of the system and provide a very high speed of energy analysis in cloud computing. Fig. 1 shows the 3D view of the building case study in Autodesk Revit software.

RESULTS AND DISSCUSSION

The building case study is a residential complex located in a mild climate zone. The building area is about 101,000 m^2 located in Bandar Anzali, Gilan Province, Iran (37°28'39.5"N, 49°25'11.8"E). The main reason for choosing this building is to study of the form and orientation of the building and the cost changes caused by changing the effective parameters with the aim of optimizing energy consumption using BIM technology. First, three conceptual masses were created to examine various design ideas in the Autodesk Revit software (a top-down design approach). Then, floors, type of materials

Table 2: Comparison of different building forms based on simulation of energy consumption in conceptual masses

		Module-1		Module-2	Module-3
					
Floors		22		43	43
Units		548		560	561
Height (m)		81.70		159.40	159.40
Building Form		Energy cost	Saving	Energy use intensity	Saving
		USD/m^2/y	Percent	kWh/m^2/y	Percent
Module-1	BIM parameters	14	0	113	0
	Optimize parameters	5.96	57.43	80.40	28.85
Module-2	BIM parameters	14.80	0	121	0
	Optimize parameters	7.69	48.04	97.60	19.34
Module-3	BIM parameters	14.30	0	117	0
	Optimize parameters	7.18	49.79	88.80	24.10

and energy settings were defined for each mass. Finally, the results of energy analysis were received after generating the energy model and sending the related file to the Autodesk cloud services. After considering the proposed building design in terms of cost of energy consumption and considering the items such as project location, site scope, building height, facilities and project cost, the first mode of the building form was selected for accurate modeling and energy analysis. Table 2 shows the comparison of different building forms.

Several conceptual masses were first developed to study different design ideas. The closest modes to the actual model of the building and the items such as number of units and area of the building were considered in construction of concept models. Input parameters of the energy model were selected according to the default software (Table 3). The results of the analysis show that the first form of the building has the lowest energy consumption among others. The cost of energy consumption based on the parameters listed in Table 3 is 14 USD/m2/y. Accordingly, the energy consumption is equal to 113 kWh/m2/y (Table 2). In this form, the building orientation is based on the geographical north. Thus, the angle of the building is automatically determined by the software, based on the building form and geographic coordinates of the project. The ratio of windows to north, south, east and west walls is 40% by default. All windows have shades with a depth of 45.72 cm. Also, the type of windows in the conceptual model is double-glazed windows without any external cover. Structure of the walls used in the conceptual model is light with insulation coverage in a mild climate, and the roof structure is light and without insulation. Values of the building infiltration rate, lighting efficiency, plug load efficiency, and operating schedule are adjusted according to the BIM parameter (Table 3). The building's HVAC system is assumed to have a BIM parameter (Residential 14 SEER/0.9 AFUE Split/Packaged Gas <5.5 ton). This building has no day lighting and occupancy control system and photovoltaic solar panels. By adjusting the effective parameters on energy consumption according to Table 4 and Appendix B, the energy cost would be 5.96 USD/m2/y. Accordingly, the energy

Table 3: Basic parameters of the energy model in the conceptual masses

Building form	Module-1	Module-2	Module-3
Energy cost (USD/m^2/y)	14	14.8	14.3
Effective factor	Input parameter		
Building orientation	BIM		
Window-to-Wall ratio (Southern walls)	BIM (40%)		
Window shades (south)	BIM (0.4572 m)		
Window glass (south)	BIM (Double Pane Clear – No Coating)		
Window-to-Wall ratio (Northern walls)	BIM (40%)		
Window shades (north)	BIM (0.4572 m)		
Window glass (north)	BIM (Double Pane Clear – No Coating)		
Window-to-Wall Ratio (Western walls)	BIM (40%)		
Window shades (west)	BIM (0.4572 m)		
Window glass (west)	BIM (Double Pane Clear – No Coating)		
Window-to-Wall ratio (Eastern walls)	BIM (40%)		
Window shades (East)	BIM (0.4572 m)		
Window glass (East)	BIM (Double Pane Clear – No Coating)		
Wall construction	BIM (Lightweight Construction – Typical Mild Climate Insulation)		
Roof construction	BIM (Lightweight Construction – No Insulation)		
Infiltration	BIM (None)		
Lighting efficiency	BIM (10.76 W/m^2)		
Day lighting and occupancy controls	None		
Plug load efficiency	BIM (10.76 W/m^2)		
HVAC	BIM (Residential 14 SEER/0.9 AFUE Split/Packaged Gas <5.5 ton)		
Operating schedule	BIM (24 Hours)		
PV - panel efficiency	None		
PV - payback limit	None		
PV - surface coverage	0%		

use intensity would be equal to 80.4 kWh/m2/y. The building orientation does not change relative to the previous model (base model) and is based on the geographical north. The ratio of windows to the northern and southern walls is 40% by default. These windows have shades as high as 2/3 of the window height. Also, the type of these windows in the conceptual model is triple-glazed windows with low emission. The eastern and western windows have been removed from the conceptual model due to the lack of efficiency.

The walls structure in the conceptual model is according to Table 4, and the roof structure is lightweight and without insulation. The value of the building infiltration rate is 0.17 ACH. The value of the lighting efficiency parameter is assumed to be 3.23 W/m2. The values of the plug load efficiency and the operating schedule are adjusted according to the BIM parameter. The building's HVAC system is assumed to be a high-efficiency variable air volume system. Also, the building has a daylighting and occupancy control system. To achieve the highest level of energy efficiency, the photovoltaic solar panels were used with a yield of 20.4% and surface coverage of 90%. The payback limit of these panels are set at 30 years. Results of this analysis show that the use of BIM technology for adjusting the parameters affecting energy consumption in the conceptual designs can save up to 57.43% energy cost. Based on the energy use intensity, this value would be 28.85%.

Baseline energy model specifications

Depending on analysis tools and specific studies, the building energy model requires a set of parameters. Table 5 shows the basic parameters of the building's energy model as the basis of design. These parameters include: material constructions of building elements and associated thermal properties, HVAC and hot water system types and efficiencies, lighting density and efficiency, building occupancy, plug loads (appliances and electronic devices), internal heat gains from plug loads and occupancy, building natural infiltration rate (air leakage), natural ventilation (the opening and closing of doors and windows), thermostat set-point temperatures, and operating schedules. These parameters are specified

Table 4: Optimization of the parameters effecting energy in the conceptual masses

Building form	Module-1	Module-2	Module-3
Energy cost (USD/m^2/y)	5.96	7.69	7.18
Effective factor		Input parameter	
Building orientation		BIM	
Window-to-Wall ratio (Southern walls)		BIM (40%)	
Window shades (south)		2/3 Win Height	
Window glass (south)		Trp LoE	
Window-to-Wall ratio (Northern walls)		BIM (40%)	
Window shades (north)		2/3 Win Height	
Window glass (north)		Trp LoE	
Window-to-Wall Ratio (Western walls)		(0%)	
Window shades (west)		BIM (No Shade)	
Window glass (west)		BIM (No Window)	
Window-to-Wall ratio (Eastern walls)		(0%)	
Window shades (East)		BIM (No Shade)	
Window glass (East)		BIM (No Window)	
Wall construction		R13+R10 Metal	
Roof construction		BIM (Lightweight Construction – No Insulation)	
Infiltration		0.17 ACH	
Lighting efficiency		3.23 W/m^2	
Daylighting and occupancy controls		Daylighting and Occupancy Controls	
Plug load efficiency		BIM (10.76 W/m^2)	
HVAC		High Eff. VAV	
Operating schedule		BIM (24 Hours)	
PV - panel efficiency		20.4%	
PV - payback limit		30	
PV - surface coverage		90%	

by the BIM title in the provided data.

According to Table 2, the parameters presented in Table 3 were used to examine the various ideas of multi-mass concept design. Then, based on the parameters in Table 4, the main form of the building was selected after reviewing the proposed designs. After creating the building model (current condition of the building), energy analysis was performed based on the parameters presented in Table 5. Finally, the lowest energy consumption in the building was achieved by setting the parameters effecting energy consumption.

Building energy simulation and data analysis

BIM data export process

After modeling and adjusting the parameters required in the Autodesk Revit software (Table 5), the energy model was created using the analyze tab (Fig. 2). Then, an Autodesk account was used to send the energy model and receive the data analysis results. It should be noted that by sending the energy model through the Autodesk Revit software to the Autodesk Insight software, the energy model is simultaneously sent to the Autodesk Green Building Studio software.

Climate data

After sending the energy model, the climate data, as the first element of the environment in which the building is located, were automatically taken from the nearest weather station database (Table. 6).

The data related to design conditions based on the dry-bulb temperature and the Mean Coincident Wet Bulb (MCWB) temperature are shown in Table 7. Fig. 3 shows the average daily minimum and maximum temperatures on a monthly basis.

Solar orientation study

Solar radiation on building surfaces were investigated. The results indicated that block D (located on the eastern side of the site), with the most sunlight received during the day, had a better position compared to block C. The frequency distribution diagrams of total sky cover, direct normal radiation, diffuse horizontal radiation, and global horizontal radiation are shown in Fig. 4 based on annual data.

Analysis the parameters affecting energy

Fig. 5 for block D shows the highest energy cost in July. It is obvious that ventilation fans and space cooling have the highest share compared to other

Table 5: Basic parameters of the building's energy model

Input parameter	Value
HVAC system	Residential 14 SEER/0.9 AFUE Split/Packaged Gaz < 5.5 ton
Area per person	105.82 m^2
Sensible heat gain (per person)	73.27 W
Latent heat gain (per person)	58.61 W
Power load density	10.76 W/m^2
Lighting load density	10.76 W/m^2
Plenum lighting contribution	20%
Occupancy schedule	24 Hours
Lighting schedule	All Day
Power schedule	All Day
Outdoor air (per person)	2.36 L/s
Outdoor air (per area)	0.30 $L/(s.m^2)$
Unoccupied cooling set point	27.78 °C
Infiltration (ac/h)	None
Fabric *U*-values	
External walls	20cm concrete block (*U*-value 6.5 W/m^2K)
Internal walls	10cm concrete block (*U*-value 13 W/m^2K)
Shear walls	45cm reinforced concrete (*U*-value 2.3244 W/m^2K)
Floor	22.5cm concrete slab (*U*-value 4.6489 W/m^2K)
External doors	Wooden, Single-Flush (*U*-value 2.1944 W/m^2K)
Terrace doors	Wood frame with single clear glass (*U*-value 5.6212 W/m^2K)
Lobby doors	Metal frame with single clear glass (*U*-value 6.5580 W/m^2K)
Elevator doors	Metal (*U*-value 3.7021 W/m^2K)
Windows	1/8 in Pilkington single glazing (*U*-value 3.6886 W/m^2K)

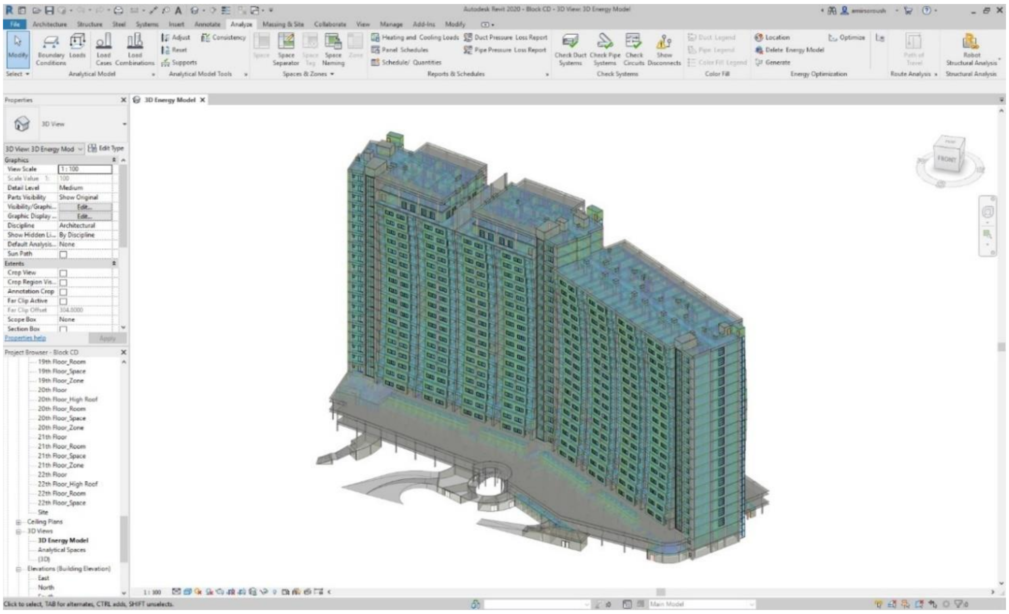


Fig. 2: Creating the energy model using building elements in Autodesk Revit software

Table 6: Temperature data from the nearest weather station database

Weather Station: GBS_06M12_12_002300
Distance to your project 474.2 mi (763.2 km)
Latitude = 36.4167 , Longitude = 58.1500

IP SI

Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
18.3 °C	1110	18.3 °C	2047
21.1 °C	657	15.6 °C	1577
23.9 °C	316	12.8 °C	1172
26.7 °C	104	10 °C	807

Table 7: The dry-bulb and the mean coincident wet bulb (MCWB) temperature based on annual data

IP SI

Annual Design Conditions				
Threshold	Cooling		Heating	
	Dry Bulb(°C)	MCWB(°C)	Dry Bulb(°C)	MCWB(°C)
0.1 %	39.2	18.1	-10.4	-11.3
0.2 %	38.8	17.9	-9.8	-11.0
0.4 %	38.4	17.9	-9.2	-10.4
0.5 %	38.2	18.0	-8.8	-9.8
1 %	37.3	17.3	-7.6	-8.9
2 %	36.4	16.9	-4.8	-6.5
2.5 %	36.0	16.7	-3.9	-5.7
5 %	34.1	15.8	-1.9	-3.7

parameters affecting energy consumption.

The maximum energy use intensity in block D is observed in January (Fig. 6). Obviously, space heat and ventilation fans have the highest share among other parameters. Accordingly, the highest level of energy consumption based on energy cost is seen in July and August and based on energy use intensity is seen in January and December. The schematic diagrams of energy consumption for block C and the western lobby are similar.

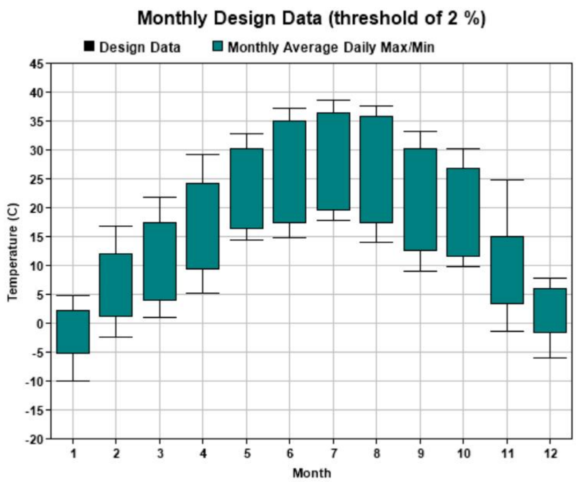


Fig. 3: Average maximum and minimum daily temperatures on a monthly basis

The results show that block D has the lowest energy consumption after optimization. Based on the parameters presented in Table 8, the cost of energy consumption for block C is 13.6 USD/m2/y. This value for both block D and the western lobby is 14.1. Accordingly, the energy use intensity for blocks C, D, and the western lobby would be 126, 119, and 191 kWh/m2/y, respectively (Table 10). The building orientation, in this case, is based on the geographical north. Thus, angle of the building is automatically determined by the software, based on the building form and the project geographic coordinates. The windows ratios to the northern, southern, eastern and western walls are 21%, 23%, 7%, and 8%, respectively. These values are 21%, 21%, 5%, and 10% for block D, and 15, 25, 13, and 14% for the western lobby, respectively. The shades of all windows are considered by default. Therefore, the windows installed on the terraces would use their overhead ceiling as a shade. Other windows installed

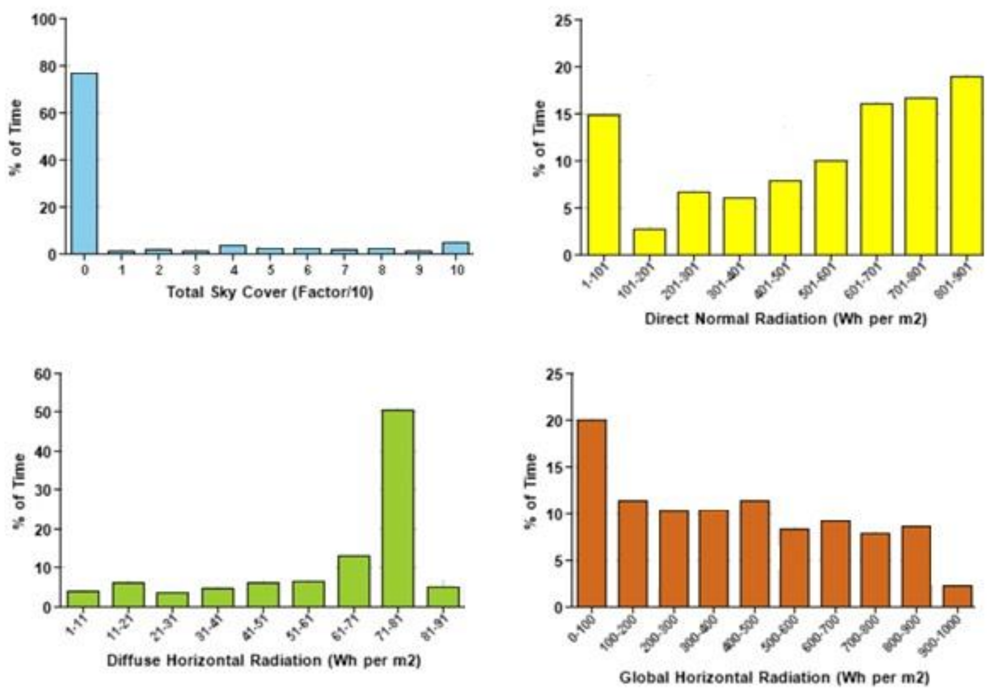


Fig. 4: Top left) Total sky cover frequency distribution; Top right) Direct normal radiation frequency distribution; Bottom left) Diffuse horizontal radiation frequency distribution; Bottom right) Global horizontal radiation frequency distribution

on the external walls surfaces lack a shading system. Also, the type of windows is based on the software-defined element (single clear glass). The walls and roof structure are shown in Tables 5 and 6. The values of the building infiltration rate, lighting efficiency, plug load efficiency, and operating schedule are adjusted according to the BIM parameter (Table 6). The building's HVAC system is assumed to have a BIM parameter (Residential 14 SEER/0.9 AFUE Split/Packaged Gas <5.5 ton). This building has no daylighting and occupancy control system and photovoltaic solar panels.

Energy analysis was performed after creating the building model based on the parameters in Table 5. The results presented in Table 8 are based on the software output. The lowest energy consumption in the building can be obtained by setting the parameters affecting energy consumption (Table 9). After adjusting the parameters affecting energy consumption, the energy cost of block D was found to be 5.89 USD/m2/y. This value for block C is 6.66 and for the western lobby is 8.03. Accordingly, the values of energy use intensity for blocks C, D, and the western lobby would be equal to 105, 99.6, and 170 kWh/m2/y, respectively. The building orientation relative to the previous model (base model) is unchanged and is based on the geographical north. The windows ratios to the northern and southern walls are unchanged and equal to 21% and 23% for block C, 21% for block D, and 15% and 25% for the western lobby, respectively. For all blocks, the northern window shades are considered by default. Moreover, the southern window shades are selected as high as 2/3 of the window height. The type of northern windows is determined based on the software-defined element (single clear glass) for all blocks. The triple-glazed type with low emission was

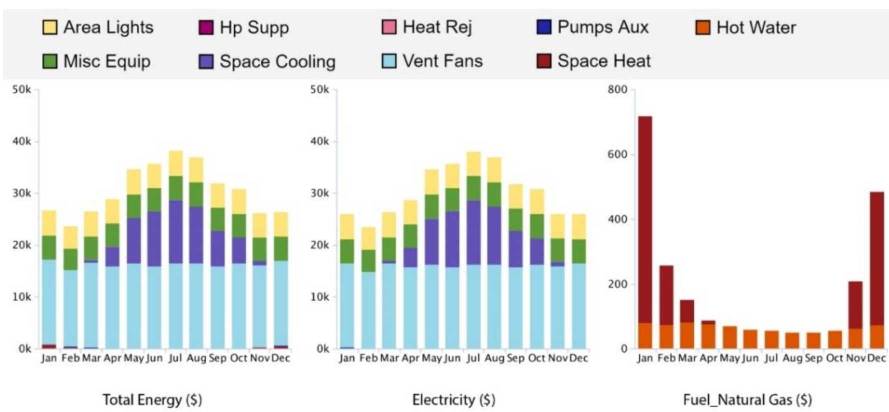


Fig. 5: Energy consumption index based on energy cost, Block D

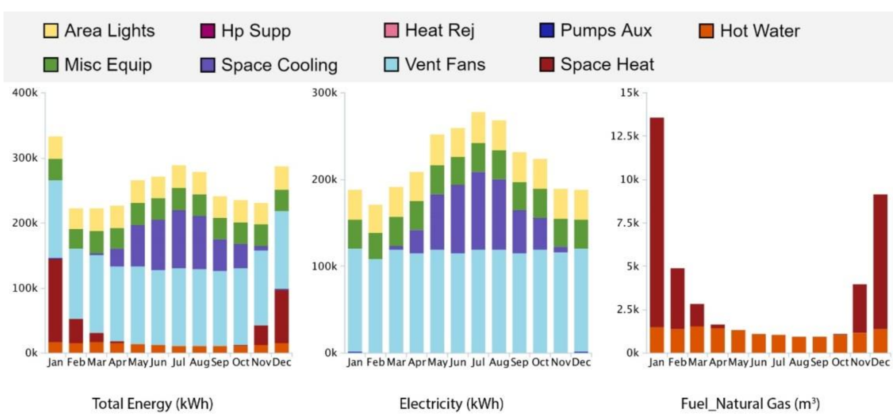


Fig. 6: Energy consumption index based on energy use intensity, Block D

Table 8: Basic parameters of building energy consumption

Building form	Block C	Block D	Western lobby
Energy cost (USD/m²/y)	13.6	14.1	14.1
Effective factor		Input parameter	
Building orientation		BIM	
Window-to-Wall ratio (Southern walls)	BIM (23%)	BIM (21%)	BIM (25%)
Window shades (south)		BIM	
Window glass (south)		BIM (Sgl Clr)	
Window-to-Wall ratio (Northern walls)	BIM (21%)	BIM (21%)	BIM (15%)
Window shades (north)		BIM	
Window glass (north)		BIM (Sgl Clr)	
Window-to-Wall Ratio (Western walls)	BIM (8%)	BIM (10%)	BIM (14%)
Window shades (west)		BIM	
Window glass (west)		BIM (Sgl Clr)	
Window-to-Wall ratio (Eastern walls)	BIM (7%)	BIM (5%)	BIM (13%)
Window shades (East)		BIM	
Window glass (East)		BIM (Sgl Clr)	
Wall construction		BIM (Concrete Masonry Units)	
Roof construction		BIM (Concrete, Cast In Situ)	
Infiltration		BIM (None)	
Lighting efficiency		BIM (10.76 W/m²)	
Daylighting and occupancy controls		None	
Plug load efficiency		BIM (10.76 W/m²)	
HVAC		BIM (Residential 14 SEER/0.9 AFUE Split/Packaged Gas <5.5 ton)	
Operating schedule		BIM (24 Hours)	
PV - panel efficiency		None	
PV - payback limit		None	
PV - surface coverage		0%	

chosen to be used in southern windows. The eastern and western windows have been removed from the building model due to lack of efficiency. The walls and roof structure are shown in Table 9. The value of the building infiltration is 0.17 ACH. The value of the lighting efficiency is assumed to be 3.23 W/m2. The values of plug load efficiency and operating schedule are adjusted according to the BIM parameter. The building's HVAC system is assumed to be a high-efficiency variable air volume system. Moreover, the building has a daylighting and occupancy control system. To achieve the highest energy efficiency, the photovoltaic solar panels, with a yield of 20.4% and surface coverage of 90%, were used. The payback limit of these panels was assigned as 30 years. Depending on the analysis tool, the building energy model may need a set of parameters. According to Table 5, the input parameters entered the software by default. Thus, variables of the proposed model were also received as output from the software (Table 9).

Table 10 shows that employing the BIM technology for adjusting the parameters affecting energy consumption can save up to 58.23% energy cost for block D. This value is 51.03% for block C and 43.05% for the western lobby. However, based on energy use intensity, this value would be 16.67%, 16.30%, and 11% for blocks C, D, and the western lobby. The saving based on energy cost can be calculated by Eq. 1 and the saving based on energy use intensity can be estimated using Eq. 2.

$$\left(\frac{5.89}{14.10}-1\right)*100=-58.23\% \quad (1)$$

$$\left(\frac{99.60}{119}-1\right)*100=-16.30\% \quad (2)$$

As previously mentioned, the building blocks are separated from each other and the ceiling element has been removed from the building model, due to the software limitations in sending the energy model. Therefore, the computational height is 4 m on the first floor and 3.70 m in other floors. This building could have lower energy consumption values than the obtained values, due to the implementation of ceiling element during the construction phase and reduced

Table 9: Optimization of the parameters effecting building energy consumption

Building form	Block C	Block D	Western lobby
Energy cost (USD/m²/y)	6.66	5.89	8.03
Effective factor		Input parameter	
Building orientation		BIM	
Window-to-Wall ratio (Southern walls)	BIM (23%)	BIM (21%)	BIM (25%)
Window shades (south)		2/3 Win Height	
Window glass (south)		Trp LoE	
Window-to-Wall ratio (Northern walls)	BIM (21%)	BIM (21%)	BIM (15%)
Window shades (north)		BIM	
Window glass (north)		BIM (Sgl Clr)	
Window-to-Wall Ratio (Western walls)		(0%)	
Window shades (west)		BIM (No Shade)	
Window glass (west)		BIM (No Window)	
Window-to-Wall ratio (Eastern walls)		(0%)	
Window shades (East)		BIM (No Shade)	
Window glass (East)		BIM (No Window)	
Wall construction		R13+R10 Metal	
Roof construction		BIM (Concrete, Cast In Situ)	
Infiltration		0.17 ACH	
Lighting efficiency		3.23 W/m²	
Daylighting and occupancy controls		Daylighting and Occupancy Controls	
Plug load efficiency		BIM (10.76 W/m²)	
HVAC		High Eff. VAV	
Operating schedule		BIM (24 Hours)	
PV - panel efficiency		20.4%	
PV - payback limit		30	
PV - surface coverage		90%	

Table 10: Comparison of different energy consumption scenarios in the building blocks

Building bock		Energy cost	Saving	Energy use intensity	Saving
		USD/m²/y	Percent	kWh/m²/y	Percent
C	BIM parameters	13.60	0	126	0
	Optimize parameters	6.66	51.03	105	16.67
D	BIM parameters	14.10	0	119	0
	Optimized parameters	5.89	58.23	99.60	16.30
Western lobby	BIM parameters	14.10	0	191	0
	Optimized parameters	8.03	43.05	170	11

computational height of the spaces as a result. However, the results show that block D has the lowest energy consumption. Considering the similar materials and equipment used, this can be due to the building orientation towards the actual north of the region (geographic north). Accordingly, by implementation of block C along block D, the lowest energy consumption can be achieved as a result of the maximum solar radiation during the day. This study shows that the results from the conceptual model analysis are more acceptable compared to the results from the actual building model. This can be useful in the early stages of decision-making for the project.

CONCLUSION

Most of the current environmental problems are related to the use of fossil fuels, especially in the construction sector. In Iran, a large amount of energy is annually consumed in the building and housing sectors. In this study, energy performance assessment was carried out based on the Building Information Modeling technology (BIM-EPAs) and it was found that application of this technology can lead to design identification, comparison, and reduction of energy consumption in the early stages of design. The aim of this study was to investigate the parameters affecting energy consumption using the Building Information Modeling (BIM) technology. After reviewing the proposed designs and choosing the building form, an exact model of building elements was created in the Autodesk Revit software. Then, the energy model was generated based on the basic parameters. The results showed that application of the building information modeling technology for adjusting the parameters affecting energy consumption would save up to 58.23% energy cost for block D. This value was 51.03% for block C and 43.05% for the western lobby. As a result, this value would be 16.67%, 16.30% and 11% for blocks C, D, and the western lobby, respectively, based on the energy use intensity. Finally, adjusting the energy-efficient parameters led to reduction of energy cost in the building. The energy simulation results showed that 16.30% saving would be achieved based on energy use intensity for the base building model in a 30-year time horizon.

AUTHOR CONTRIBUTIONS

N. Amani performed the methodology, investigation, validation, conceptualization, and supervision. A.A. Reza Soroush performed the literature review, data collection, software, and writing the original draft.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

ACH	Air Changes per Hour
AFUE	Annual Fuel Utilization Efficiency
BIM	Building Information Modeling
CM	Centimeters
E	East
EFF	Efficiency
HVAC	Heating, ventilation, and air conditioning
K	Thermal conductivity of the material
kWh	kilowatt-hour
$kWh/m^2/y$	kilowatt-hour per square meter per year
L	Liter
L/s	Liter per second
$L/(s.m^2)$	Liter per second to square meter
M	Meter
M^2	Square meter
N	North
R13+R10	American energy codes
S	Second
SEER	Seasonal Energy Efficiency Ratio
SGL	Standard General Ledger
USD	United State Dollar
USD/m2/y	United State Dollar per square meter per year
VAV	Variable Air Volume
W	Watt
W/m^2	Watt per square meter
W/m^2K	Watt per square meter per thermal conductivity of the material
y	Year
%	Percent
$	Dollar
°C	degree Celsius

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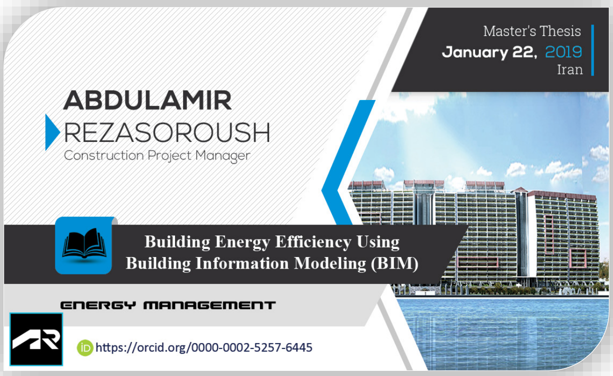

ABSTRACT

Buildings are the largest energy consumer worldwide, according to the United Nations Environment Programme (UNEP). Most of the building's energy consumption is in the building's life cycle stage. Therefore, achieving sustainable development at the national level requires minimizing the building's effects on the environment via reducing energy consumption by buildings. The building's energy performance will be predicted and evaluated by the energy simulation. Using BIM in EPAs significantly reduces time and costs. This study aimed to optimize energy consumption in buildings using Building Information Modeling (BIM) Technology, which can assess energy performance in the building. In this research, the general form of the building was modeled on the Autodesk Revit Software. The main shape of the building was chosen for modeling after reviewing the proposed designs. Then, the building energy consumption was calculated using the relevant tools in this scope, according to the materials, equipment, and project location. Finally, the best possible mode was selected by examining different modes of energy consumption. The results showed that 61.48% difference between the best mode of energy consumption optimization and the current mode of the building and 79.35% compared to the initial mode. Finally, parametric studies of alternative cost optimization schemes showed that saving 58.23% of the building's current status for a 30-year horizon.

Thesis

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