BUILDING ENERGY OPTIMIZATION OF A RESIDENTIAL BUILDING IN ISFAHAN CITY OF IRAN

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ABSTRACT

Buildings are one of the most energy consuming parts in the world. It is essential to design optimized new buildings and also to try to modify and retrofit the exciting ones. In this research, an existing residential one-story house located in the city of Isfahan in the center part of Iran has been simulated and studied to find the best options for retrofitting. Some photovoltaic panels are proposed to be used in the roof of the building. The studied methods to modify the building and optimize the energy consumption include replacement of simple old windows with double glazed smart windows, and adding thermal insulators embedded in the walls and the ceiling. Results indicate that considering all of the methods except installing solar panels, about 40% of energy savings will be available. Also, it is indicated that solar power can support more than 35% of energy in Isfahan. Finally, the total energy saving of about 61% can be obtained after retrofitting and solar panel installation.

Keywords: *Building Energy Optimization, Solar Energy, Design Builder.*

1. INTRODUCTION

The biggest global challenges to sustainable development are the diminution of energy and water resources and increased environmental pollutions. Global statistics report the construction sector accounting for 40% of energy consumption and 30% of the world's greenhouse gas emissions [1]. The best strategy to reduce global energy consumption and emission of harmful gases to the environment is to improve energy efficiency in buildings.

According to studies, the 30-year period between 1983 and 2012 is likely to have been the warmest in the past 1,400 years [2]. Given the longevity of buildings and the initial construction cost, the impacts of construction on climate change and the importance of reducing energy consumption and pollution production should be considered [3].

The major contribution of the building energy consumption is related to the buildings constructed prior to the need for compliance with the sustainability criteria that need to be

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improved in order to reduce energy consumption in the construction sector [4]. Research also shows that renovating existing buildings has a significant impact on reducing the total global energy demand [5].

The construction of new buildings and the creation of different applications make up a large portion of the total final energy consumption in the world [6]. Statistics also suggest that in the construction sector, most of the energy consumption occurs in the existing buildings, with the energy consumption of new constructions rating about 1 to 3 percent of the existing buildings per year [7, 8]. Therefore, improving the energy efficiency of existing buildings is more important than constructing new ones to reduce global energy consumption and promote environmental sustainability [4].

Generally, two solutions are offered when designing urban renewal projects; one is to maintain and improve existing buildings with minor modifications and interventions, and another is to replace existing buildings with new ones. Making improvements to existing buildings may be acceptable if the current status of the building is good enough to meet current needs, but in general improving the current buildings is closer to the principles of sustainability [9].

Improving existing buildings for energy efficiency has also been recognized as an effective step towards reducing global energy consumption and greenhouse gas emissions [10].

Among studies conducted to investigate the significance, advantages and disadvantages of improvement, is a study by Letham in 2000, in which he discussed the importance of reusing existing buildings and even changing their use given their current status. Letham considers using existing buildings to be far more creative than constructing new ones. His paper provided the starting point for his book, in which he examines a case study and factors affecting the state of reusing old structures [11]

In 2006, Shipley et al. focused on commercializing and reconstructing existing buildings, especially historic ones in Ontario, Canada. In some cases, they examined, improving a building to be reused was more costly than constructing a new one; but in general, the existing building had more positive economic impacts along with other factors compared to new constructions [12].

In the same year, in his book, Douglas introduced how to adapt existing buildings by improving and renovating them. This book discusses the reasons for renovating buildings, feasibility conditions, advantages and disadvantages, maintenance, energy efficiency, compliance with sustainability principles, and how to apply changes to improve existing buildings [13].

In 2007, Itard et al. discussed the environmental impact of renovating existing buildings compared to constructing new ones. In this study, renovation, maintenance and redevelopment of Dutch urban textures were investigated and compared. The parameters investigated in this study were materials, energy, water consumption and environmental impacts calculated based on the building life cycle. Based on the results of this study, reconstruction of existing buildings imposes less environmental impact, and directs new construction such that the longevity of the buildings suffices for future reconstruction and improvement practices [9].

In 2011, Bolen et al. conducted interviews with owners and users of various buildings to inform them on the benefits and strategies to preserve buildings and reuse them. According to the analysis of these interviews, three factors influenced owners' decision to preserve buildings, including the amount of national capital, assets status and regulations. Eco-social sustainability principles were also considered important, but less prioritized by owners and users [14].

Given the extending construction process in recent years in Iran and consequently the growing need for reconstruction, as well as ecological and climatic problems in Iran, in a study conducted in 2016, Afzalian et al. presented the principles of passive architecture design based on green principles and sustainability by examining case studies objectively [15]

In 2015, Oliviera et al. introduced a new system aimed at adhering to the principles of sustainability by reviewing existing systems to reconstruct and improve historic buildings. The study was conducted on a historic building in Portugal and a questionnaire was filled by beneficiaries in order to investigate aspects of sustainability, as well as some economic information and parameters [16].

In 2016, Alam et al. reviewed and evaluated guidelines and research conducted in this area to develop guidelines for the reconstruction of existing buildings for energy efficiency purposes. In this study, guidelines developed in the United States, England, Singapore, Australia, and India were investigated and compared. According to the results of these studies, the common disadvantage of these guidelines were assessing their constraints and managing them. They also examined factors affecting the choice of building reconstruction such as economy, community, energy, and awareness[10]. In 2017, Littlewood et al. investigated the current status of buildings in Wales and the impact of their reconstruction on economy, carbon emissions, energy performance, thermal comfort and user health. Unlike other studies conducted in the UK, all of the above-mentioned parameters were investigated simultaneously while affecting one another [17].

Di Agostino et al. also examined the different levels of improvement including surface and deep level and approaching near-zero energy, and introduced the best policies and administrative strategies to improve existing non-residential buildings. The study also emphatically compared existing residential and non-residential buildings and returns on capital as an important parameter in Europe [18].

In some of the studies conducted on improvement of the current status, a specific construction sector was considered; for example, in 2016, Karimian examined the energy improvement process of buildings in warm and dry climate of Iran in his Master's thesis with an ecological attitude while considering climate change. The sample investigated in this study was a common office building in Isfahan in which energy audit was conducted with the aim of profound improvement. Open Studio and Energy Plus were employed in this study, and appropriate details were suggested after calibration and evaluation of optimization scenarios and adhering to minimum shell requirements. In this study, using fixed awnings, internal insulation, low emission film, and secondary windows and doors reduced energy consumption by 19% and solar cells were used for deep improvement [19].

In 2013, Arias investigated the process of improving building facades to increase energy efficiency in a master's thesis focusing on existing buildings from the mid-20th century, most of which were equipped with mechanical systems. In most samples, facade retrofitting was introduced as the first approach to reconstruction for rapid action. However, in this study, several solutions have been investigated using simulation process. The building in question was located in a temperate and climate, on which passive solutions were evaluated [20].

One of the functional studies on improvement of existing buildings is the study by Chadiac et al. conducted in 2011 who explored various methods and approaches to improve office buildings in Canada with the aim of achieving the most economically viable status, and finally obtained a methodology. To find this methodology, several other factors such as climate, user conditions, heating and cooling systems, shells and building shape were also considered [5].

In 2012, Ma et al. provided a planned system to select and identify the best process and strategy for reconstruction of existing buildings. They examined the most important and key issues in the reconstruction of existing buildings, and identified building energy audits, economic analysis, potential risks and constraints, and certification of energy storage as the most important measures in assessing the current status of existing buildings. They have also addressed the technologies and strategies of building reconstruction to raise awareness on the importance and impact of reconstruction on sustainability and energy consumption [4].

One of the case studies on improvement was conducted in 2015 by Shan et al. to reconstruct a floor of a house in Beijing with an energy storage approach using passive systems. A layer of polystyrene insulation was used in the reconstruction of this house as the heat insulation in the walls and ceiling. Results of this study indicated that energy consumption was reduced by 57% and the period of return on capital required for reconstruction was estimated as 5 to 6 years [21].

Since developing energy efficiency policies has been an important tool in resolving the energy, water and climate change crises, in recent years many governments have taken steps to reduce energy consumption of buildings, convert them into zero-energy buildings and, consequently, reduce carbon emissions. In 2018, in a research project sponsored by the Australian Department of Environment and Energy, with an emphasis on standardizing and developing economic and administrative plans for zero-energy buildings, Harrison obtained different definitions of zero-energy buildings and administrative policies in their construction [22].

In addition, in terms of zero-energy buildings, near to zero energy and other related definitions, Torcellini et al. critically examined different definitions of zero and pure zero-energy buildings and provided various definitions for each one with regard to influential parameters such as construction site [23].

In addition, in 2009, Marsal et al. studied different definitions of zero-energy buildings during a technical report at the University of Aalborg. Based on the results of their study on existing definitions of zero-energy building, they have found the exact definition to be very complex which demanded a wide range of terms. In general, given the differences and similarities of available definitions, zero-energy structures can be defined from different perspectives [24].

In 2014, in a study sponsored by Asia-Pacific Economic Cooperation [25], Wei at al. studied and evaluated policies, indicators and definitions of zero energy buildings, related codes and standards, required infrastructures, related organizations and some examples of such buildings have been addressed in leading countries such as Canada, Japan, USA, Korea and China to find out the latest advances in zero-energy building types and improve their performance in Asia [25].

In 2018, in a case study in Tabriz metropolis, Namdar Akbari et al. investigated the feasibility of creating and developing zero-energy buildings in Iranian metropolises. By evaluating statistics of peak electricity consumption in some months and the potential for using renewable energies such as solar radiation and wind in Iran, they studied design strategies for zero-energy buildings to find the most effective solutions [19].

In 2016, Cao et al. examined the state of energy consumption in existing buildings and the trend of change in the next century and its impacts on climate change, as well as zero-energy buildings as a strategy to reduce energy consumption in buildings. They also revised a design approach to zero-energy buildings as a combination of traditional green architecture and new energy production technologies [1].

In a study conducted in 2019, Liu et al. conducted a comprehensive analysis on the definitions, development and design rules for near-zero-energy buildings, with an emphasis on Chinese buildings. In their paper, they described the international definitions of zero-energy buildings, analyzed the latest definitions and determined the design boundaries of zero- and near-zero-energy buildings in China, and also provided suggestions to design building and develop its administrative policies [26].

In this study, an over 35-year-old real residential building in Isfahan was studied to optimize energy consumption. According to rich solar radiation in many parts of Iran, it is a good idea to use this renewable energy resource to support building energy needs. Here, several solutions were applied, such as photovoltaic panels, natural ventilation, installation of various insulators, built-in smart awnings and multiple glazing windows. The system was initially calibrated with existing water and utility bills. Assuming the same building in Bandar Abbas climate, the influence of climate on energy consumption was also investigated.

2. MATERIALS AND METHODS

The solar panels were used for energy optimization in this study in parallel with some other scenarios. Thermal insulations were also proposed for the ceiling and walls. Moreover, the benefits of replacing simple single windows with advanced double glazed windows integrating thermal sensors were investigated. The Design Builder software [27] was used to simulate the building and calculate thermal loads and energy consumption under different scenarios. The data from the electricity and gas bills were used to validate the software outputs. The effect of different climatic conditions on the energy consumption of the building was analyzed assuming that it is located in the hot and climate of Bandar Abbas, Iran.

This study investigates a residential villa building aged over 35 years old, located in the hot and dry climate of Isfahan city in Iran and also the similar one assumed to be located in hot and humid climate in Bandar Abbas to consider the effects of different climates. Figure 1 shows this single-story building with a basement used for storage purposes.

Figure 1. Real building in Isfahan city.

The thermophysical properties of the materials are presented in the different tables. First, without applying the optimization approaches, the heating and cooling energy consumptions were calculated in a one-year period and considered as the base state for both considered cities. The base state results were then compared to the simulated building after applying some modifications to the building, such as using photovoltaic solar panels, and using thermal insulation in the walls and ceiling, natural ventilation, smart shadings, and automatic double-glazed windows including thermal sensors.

Gas was used as the fuel for the heater packages and wall-mountable water heaters, and the evaporative coolers were used for cooling. Moreover, all spaces were exposed to sunlight through openings and glass doors.

Figures 2 and 3 show the simulated building from two different angles in the Design Builder.

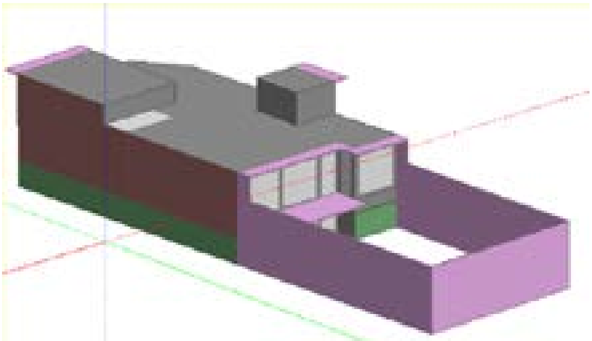

Figure 2. Schematic of the simulated building from angle 1.

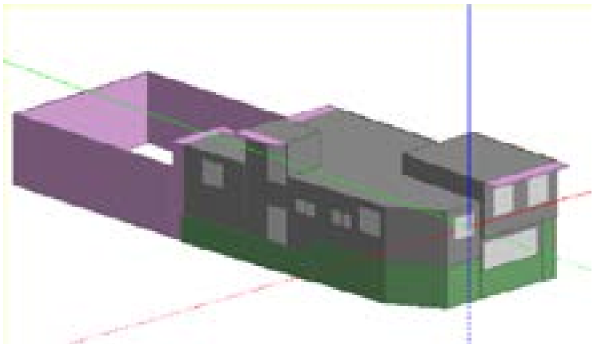

Figure 3. Schematic of the simulated building from angle 2.

Figures 4 and 5 show the overall geographical position of the sun in different months and different hours of the day for Isfahan and Bandar Abbas, respectively.

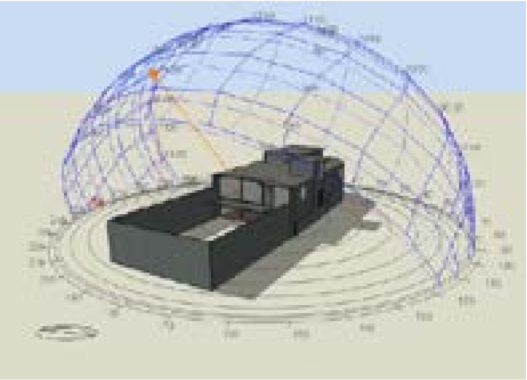

Figure 4. The overall geographical position of the sun in different months and different hours of the day for Isfahan.

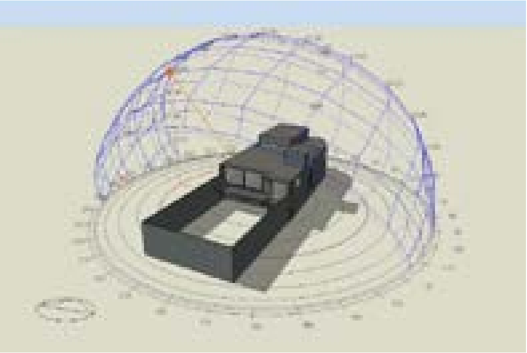

Figure 5. The overall geographical position of the sun in different months and different hours of the day for Bandar Abbas.

Table 1 presents the climatic data of Isfahan and Bandar Abbas.

Table1. Climate data for Isfahan and Bandar Abbas [27].

Reference	**IRN_Esfahan408000_ ITMYEPW**	**IRN_Bandar Abbas.408750_ ITMY**
Site:	Esfahan – IRN	Bandar Abbas - IRN
Location Time zone	{GMT + 3.0	{GMT + 3.0 Hours}
Elevation	Hours} 1550	10
above sealevel Standard	84038pa	101207pa
Pressure at ElevationData	ITMY	ITMY
Source WMO	408000	408750
Station Weather	Climate Design	Climate Design Data
File Design	Data 2013	2013 ASHRAE
Conditions	ASHRAE	Handbook
Maximum	Handbook 40.2	43.6
Dry BubbleTemp Maximum	04-Aug	30-May
Dry BubbleOccurs on Minimum	-7.5	5.7
Dry BubbleTemp Minimum	26-Jan	29-Dec
Dry Bubble Occurs onMaxi-mum	12.5	30.6

Dew PointTemp Maximum	18-Mar	20-Jul
Dew Point Occurs onMini-mum	-26.6	-17.1
Dew Point Temp		

Minimum Dew Point Occurs on	28-Aug	28-Nov
ASHRAE	Warm-Dry	Very Hot - Dry
Description		
ASHRAE	3B	1B
Climate		
Zone		

The properties of the materials used in the ceiling and walls are presented in Tables 2 and 3, respectively.

Table 2. The properties of the materials used in the ceiling [27].

Material	**Thickness**	**Density**	**Conductiv-ity**	**Specific**
	(m)	**(kg/m³)**	**(W/mK)**	**heat**
				(J/kgK)
Asphalt-roofing, mastic	0.1	2330	1.15	840
2010 NCM membrane	0.03	1100	1	1000

Concrete, high density	0.07	2400	2	1000
Concrete, reinforced (with 1% steel)	0.03	2300	2.3	1000
Gypsum Plastering	0.02	1000	0.4	1000

Table 3. The properties of the materials used in the walls [27].

Material	Thickness	Density	Conductivity	Specific heat
Brick sofall	0.2	1500	0.45	840
Plaster (lightweight)	0.005	600	0.16	1000
Brickwork outer	0.1	1700	0.84	800
XPS Extruded ply-styrene-CO2 blowing	0.0795	35	0.034	1400
Concrete block (medium)	0.1	1400	0.52	1000
Gypsum Plastering	0.013	1000	0.4	1000

Table 4 shows the soil temperature in different months of a year and at different depths in these two cities.

Table 4. The soil temperature in different months of a year and at different depths in Isfahan and Bandar Abbas [27].

Month	Surface monthly temperatures		Shallow monthly temperature (2m depth		C	
	Isfahan	Bandar Abbas	Isfah-an	Bandar Abbas	Isfa-han	Bandar Abbas
January	17.92	18.13	9.2	21.3	12.5	23.2
Febru-ary	17.65	17.87	7.3	21.6	10.5	23
March	17.67	17.87	7.7	23.1	10.1	23.7
April	19.26	19.45	9.3	24.9	10.7	24.6
May	19.61	19.78	14.5	28.6	13.6	27.1
June	19.72	19.85	19.2	31	16.8	29
July	21.32	21.42	23	32.1	19.8	30.1
August	21.62	21.70	25.1	31.9	21.8	30.4
Septem-ber	21.61	21.72	24.6	30.2	22.3	29.7
October	21.55	21.71	22	27.6	21.1	28.2
Novem-ber	19.92	20.10	17.6	24.7	18.6	26.2
Decem-ber	19.57	19.77	13.1	22.4	15.5	24.5

For the ceiling Polystyrene insulation with thickness of 5cm and heat transfer coefficient of 0.6 W/m2K was used and for the walls Polystyrene insulation with thickness of 5cm.

Since natural ventilation should be done automatically, it is necessary to apply thermal control conditions in the windows section when natural ventilation is activated in the Design Builder.

To this end, thermal sensors are placed on the windows to measure the indoor to outdoor temperature and prevent excess heat or cold from getting into the room. In this work, the windows-opening schedule was set 'off' in the winter and 'on' in the summer 24 hours a day. In the hot seasons, the sensors will send the required ventilation signal for automatic windows opening using the operators only if the outdoor temperature is lower than the indoor temperature. Regarding of hot and humid climate of Bandar Abbas, the natural ventilation was considered just for Isfahan cooling mode.

The solar panels with an area of 40 m2 were used for partial supply of the required energy. Figure 6 shows the images of the building and solar panels. The implemented panels are installed at geographical latitude in each city that means 35 in Isfahan and 57 in Bandar Abbas. They are also installed facing south direction.

Cooling loads(kWh)

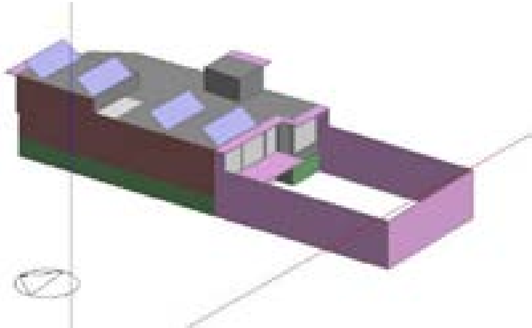

Figure 6. Schematic of the simulated building including photovoltaic panels.

By modeling natural ventilation in the software, the opening and closing schedule for the smart windows were obtained. Finally, the smart shading system installation was simulated for both cases to find its effects on energy consumption, especially in the cooling mode.

3. RESULTS AND DISCUSSION

In this part, the results of the study are presented and discussed. Figures 7 and 8 show the monthly cooling and heating loads for both studied cities in the base state where no retrofit scenario has been implemented.

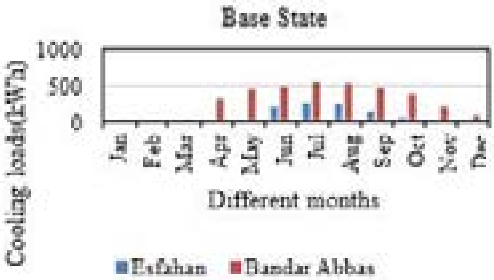

Figure 7. Monthly cooling loads for both studied cities in the base state.

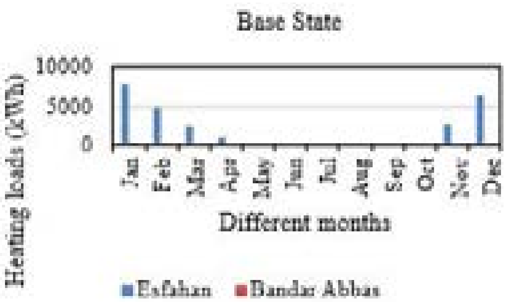

Figure 8. Monthly heating loads for both studied cities in the base state.

In coming graphs, the effect of each retrofit scenario is compared with the base state results of the city for both studied climates. Figures 17 and 18 report the cooling and heating loads of Isfahan when wall insulation is implemented, in compare with those of the base state.

As it is calculated, there is 4.6% decrease in the cooling loads in Bandar Abbas when installing smart shadings. The shading should not be used through cold seasons there.

It is obvious that natural ventilation in the method implemented here just helps the cooling loads of Isfahan by opening the windows in a smart manner. In hot and humid climate of Bandar Abbas there is no justification for natural ventilation with some window openings.

4. CONCLUSION

A climate-based study was conducted on a single-story residential villa building. The solar energy was used for partial supply of energy needs of the building. The effects of different factors on energy consumption were studied including: thermal insulators embedded in the ceiling and walls, and installation of double-wall windows equipped with temperature sensors and smart interior shades. According to the results, in hot and dry climate of Isfahan, implementing solar panels, wall and ceiling insulation, double glazed smart windows, internal smart shading and natural ventilation lead to optimal energy consumption with 38.43 and 50.94% reduction in the cooling and heating loads, respectively. In hot and humid climate of Bandar Abbas, all of mentioned scenarios except natural ventilations were used and showed 46% thermal loads reduction. Using natural ventilation had no justification in hot and humid climates. The solar photovoltaic panels could supply 67.3% of required electricity in Isfahan and 42.3% of it in Bandar Abbas. In the future works studying the effect of solar absorption coefficient of external walls on the energy saving may be considered.

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