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Analyzing the Effect of Materials' Selection on Energy Saving and Carbon Footprint: A Case Study Simulation of Concrete Structure Building

M. Kouhirostamkolaei, M. Kouhirostami, M. Sam, J. Woo, A. T. Asutosh, J. Li, C. Kibert

***Abstract*—**Construction is one of the most energy consumed activities in the urban environment that results in a significant amount of greenhouse gas emissions around the world. Thus, the impact of the construction industry on global warming is undeniable. Thus, reducing building energy consumption and mitigating carbon production can slow the rate of global warming. The purpose of this study is to determine the amount of energy consumption and carbon dioxide production during the operation phase and the impact of using new shells on energy saving and carbon footprint. Therefore, a residential building with a re-enforced concrete structure is selected in Babolsar, Iran. DesignBuilder software has been used for one year of building operation to calculate the amount of carbon dioxide production and energy consumption in the operation phase of the building. The primary results show the building use 61750 kWh of energy each year. Computer simulation analyzes the effect of changing building shells -using XPS polystyrene and new electrochromic windows- as well as changing the type of lighting on energy consumption reduction and subsequent carbon dioxide production. The results show that the amount of energy and carbon production during building operation has been reduced by approximately 70% by applying the proposed changes. The changes reduce CO_2e to 11345 kg CO_2/yr. The result of this study helps designers and engineers to consider material selection's process as one of the most important stages of design for improving energy performance of buildings.

***Keywords*—**Construction materials, green construction, energy simulation, carbon footprint, energy saving, concrete structure, DesignBuilder.

I. Introduction

THE humankind depends on the earth as a source for natural, raw materials needed for erecting buildings on the land. Today, greenhouse gases are increasingly disseminated into the earth's atmosphere by human activities. For long, we have had access to reliable natural resources to tap into, but now our demand vastly exceeds what is within nature's capacity to supply. In this light, the concept of "sustainable development" was introduced in 1970. Sustainable development implies providing present needs without trampling on future generations' right to natural resources.

Emissions caused by buildings' heating and cooling systems far surpass the pollution generated by fossil-fueled vehicles, since construction materials are produced by energy-intensive processes that use up natural resources. In the building industry, emission of hazardous environmental pollutants can be discussed for any structure, regardless of its function, before or after construction, during operation, or even upon demolition. Accordingly, the design and use of buildings must accommodate reducing environmental pollutants to achieve sustainable development.

In view of the population growth and the depletion of fossil fuel resources looming on the horizon, the world faces an energy crisis, calling for more attention to optimizing energy consumption in all spheres. The perpetuation of the present situation leads to ever-increasing energy consumption. Accordingly, the construction industry in developed countries is experiencing a shift toward residential or non-residential buildings that operate independently of fossil fuel. In this regard, designers and engineers focus on making the most of local climatic conditions to retain as much energy as possible. Overall, energy consumption has grown in Iran, much in the same way as the rest of the world.

In line with sustainable development, green building implies adapting human activities with the environment aiming to save as much energy as possible. The phrase "green building" was coined in the construction industry in 1980. Sustainable buildings and zero-energy homes are also equivalent concepts [1]–[3].

The building envelope is one of the most complex elements of the structure in terms of design and implementation, for it is in close interaction with all other elements. The envelope is also the most critical factor for controlling energy loss and selecting mechanical systems for the building. Further, the envelope plays a significant role in providing thermal comfort in all parts of the structure. The envelope is composed of all planes that establish the building's boundaries with the exterior, including the roof and foundation. As recently as a decade ago, only in special projects such as hospitals, the design team would hire a building envelope consultant. Today, however, the U.S. Department of Energy requires inspection and testing of the building envelope and the U.S. Green Building Council accounts for the building envelope inspector separately in the fourth edition of its guidelines [1], [4], [5]. Further, envelope criteria are rapidly improving in different standards—e.g., ASHRAE [6]–[9] increased its standard thermal resistance factor from 13 to 21.

Considering the current mindset of green construction, the present study investigates the energy consumption and the carbon footprint of residential buildings in Mazandaran, Iran, through a case study. The goal is to determine the energy

Maryam Kouhirostami is with the Powell Center for Construction & Environment, 573 Newell Drive, University of Florida, Gainesville, Florida 32603 (corresponding author, e-mail: m.kouhirostami@ufl.edu).

consumption and carbon dioxide emission of a residential building in the region and the effectiveness of using novel envelopes to reduce energy consumption and minimize the ecological impact of using the building in this climate setting [10], [11].

II. Background

In an empirical analysis, Prager et al. studied the effect of Solar Reflectance (SR) of painted façades on the building's thermal load. The study showed that painting the exterior walls with gray reduces the heating load compared to the case of a white exterior while increasing the cooling load [12].

Ozel and Pihtili investigated the optimal insulation material location and distribution over exterior walls, showing its effects on energy-saving and delay and reduction factors through several diagrams. Orientation was another study factor, and the results suggested uniformly-distributed insulation offers better performance than non-uniform insulation, and the single-layer insulation is best placed on the exterior side. Further, the results did not significantly change in different climate settings [13].

Ucara and Balo studied the role of the fuel type in optimizing insulation material thickness for different climates, reaching the following conclusions:

1. Optimal insulation thickness is between 1 and 7.6 cm;
2. Savings of between 19 and 47 $.m-2 are possible;
3. Payback period between 1.8 and 3.7 years.

The above results depend on fuel type and climate [14]. Ozel addressed the thermal performance and optimization of thermal insulation thickness for exterior walls, reporting the following results [15]:

1. At 2 cm, the smallest thickness corresponded to the Extruded Polystyrene (XPS) insulation coupled with Autoclaved Aerated Concrete (AAC). Polystyrene (PS)—aka. Styrofoam—insulation is a rigid closed-cell insulation material made up of styrol or styrene monomers;
2. At 8 cm, the largest insulation thickness corresponded to the Expanded Polystyrene (EPS) insulation coupled with concrete;
3. The XPS insulation was found to be more effective than EPS in energy saving [15].

Focusing on an existing building in İzmir, Turkey, Yıldız relied on sensitivity analysis to identify the effective construction parameters in a hot and humid climate. It was found that the sensitivity of parameters in apartment buildings can be tuned based on the use of energy and structure's height. Further, the heat-transfer and energy-absorption coefficients of glass, depending on the building orientation, were shown to have the highest impact on the energy consumption in apartment buildings in the area [16].

Lobaccaro et al. used numerical simulation to analyze the effects of façade material on the annual energy consumption of buildings in Milan, Italy. Their study covered aluminum and glass façades, as well as green façades [17].

Susorova et al. investigated covering the façade with greenery both numerically and experimentally. Their study showed that using greenery helps reduce solar energy absorption and summer load. Simultaneously, this provision can increase the winter load [18].

Wu et al. investigated energy saving realized by insulated walls in both summer and winter, concluding that, depending on where the insulation material is placed, the wall's temperature variations will be much smaller than those of the outside. Further, interior walls must also be insulated if their adjacent rooms are not air-conditioned to improve the performance [19].

Moslehi used Phase Change Materials (PCM) to store energy and prevent thermal dissipation. PCMs are useful instruments for thermal energy storage and transition between phases as the temperature increases or drops [20].

This study attempted to find the best configuration of coupling thermal insulation with PCM in the wall structure and identify the best PCM through EnergyPlus simulation. For this purpose, a model was developed based on ASHRAE standards [7], [9], [21]–[23], considering three material configurations:

- Configuration 1: Brick–PCM–brick;
- Configuration 2: Thermal insulation–PCM–brick;
- Configuration 3: PCM–thermal insulation.

Based on simulation results, the best configuration was found to be the one that was composed of thermal insulation on the exterior side, followed by PCM and brick.

Further, the model was simulated using four different PCMs with 22, 30, 32, and 34 °C melting points, finding the last one to offer the best performance by cutting the annual energy consumption by 28% in the Tehran climate. In the best configuration integrating two types of PCMs, the annual energy consumption was reduced by 49.2%. Using PCMs of similar thermophysical properties to approximately determine the best PCM thermophysical properties for each climate resulted in a 27.9% reduction of annual energy consumption in the best case, and a 43.1% reduction by combining two types of PCMs [24], [25].

In a study focusing on an existing building in Anshan, Tian and Yu discussed the effects of exterior walls on energy saving, deciding that EPS offers the best performance among four insulation materials examined in terms of both energy consumption and economics [26].

Axaopoulos et al. addressed the economic thickness for different insulation materials based on orientation, deciding that north-facing walls are the most economical to insulate. They also calculated the optimal thickness for different insulation materials at various orientations, as well as the payback period in each case [27].

In their study, Sobhan and Yazdanfar addressed the effects of different optimization solutions, including insulating walls and the ceiling and employing electrochromic and Low-E glasses. For this purpose, a building was modeled in the Tehran climate using DesignBuilder to be studied under 11 configurations. The study results showed that, given the roof's small surface area relative to exterior walls and windows, insulating it does not considerably affect energy consumption in the building. However, insulating the walls enables an

11.7% reduction and smart electrochromic glass a 27.3% reduction in the building's energy consumption. Further, insulating the walls and using electrochromic glass cut the energy consumption by an impressive 46.3% from 287 to around 154 MWh [28], [29].

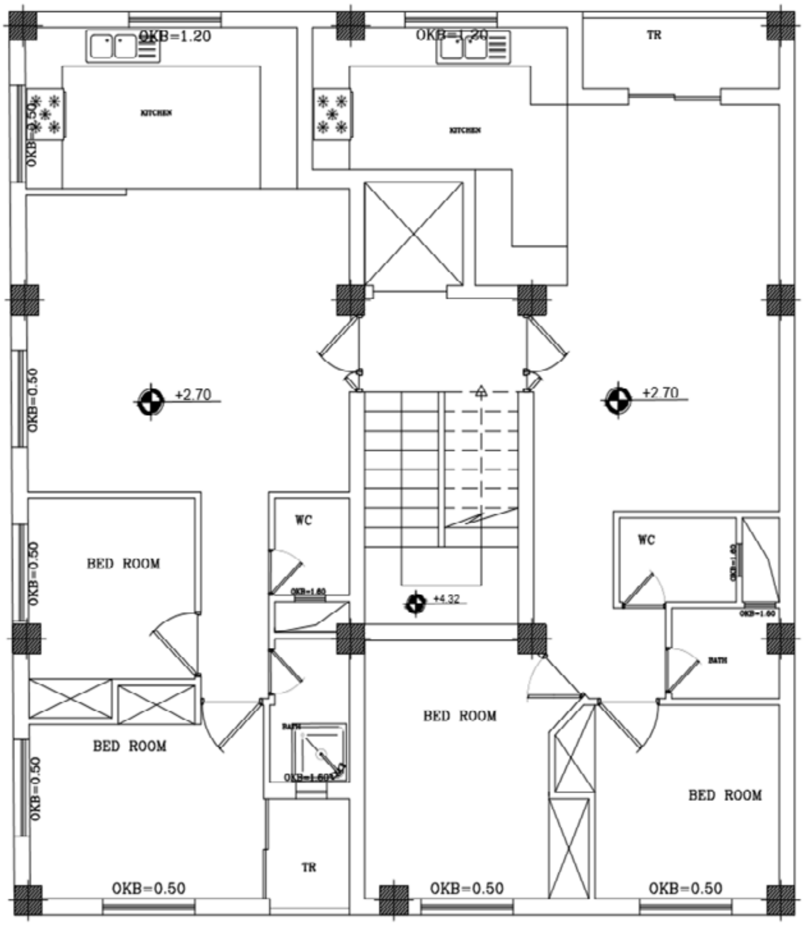

Fig. 1 First floor plan

Shabunko et al. relied on an EnergyPlus simulation to benchmark the performance of three groups of residential buildings, 400 in total, located in Brunei Darussalam, a region with tropical climate. The study involved the following steps:

1. Gathering the required fine-grade data on building geometry from constructors, property owners, and equipment installers;
2. Classifying different buildings;
3. EnergyPlus modeling to specify the annual consumption;
4. Comparing the EnergyPlus output with consumption data;
5. Recommending design changes to improve energy efficiency.

The study covered three types of buildings, including detached buildings, semidetached buildings with one retaining wall, and terrace houses. The results revealed a 64.2 kWh.m-2 power consumption for the first type of house, 55.7 kw.m-2 for the second type, and 47.8 kw.m-2 for the third. Further, considerable energy savings were achieved by modifying the building envelope and windows that, according to EnergyPlus simulations, can reach between 15 and 19.2% in different structures [30], [31].

In their study, Rocchi et al. investigated the effects of thermal insulation of a traditional rural building's roof. The study used the ELECTRE-TRI model as one of the most reliable multiple-criteria decision-making methods for energy, heat, and life-cycle optimization [32]. The results showed that polyurethane (PU), PS, and kenaf fibers are the best insulation options. The differences between insulation materials were well reflected in the performance. The study recommends using materials that expend minimum energy during production and offer the highest energy-saving for energy consumption optimization. Accordingly, sustainable materials, including kenaf fibers, can be proposed as excellent solutions [10], [32]. There are many studies which consider the effect of materials on building carbon footprint, energy saving, and performance with various methods and strategies [33]–[38].

III. Methodology

In this study, a combination of software methods, modeling analysis, and case study was used, with each one solving part of the problem investigated in the research [10], [11], [22], [39]–[42]. To investigate the carbon in the operation phase, the building energy modeling was used for the climatic conditions in Mazandaran [22], [42], [43]. For this purpose, a concrete building was selected as the study sample in Babolsar County, located in Mazandaran Province. Based on the literature those specifications have a significant effect on results [44]. This was a two-story residential building with a stilt car parking on the ground floor with an area of 537.57 m2. This type of building was selected due to the frequency of similar buildings across the county and the province.

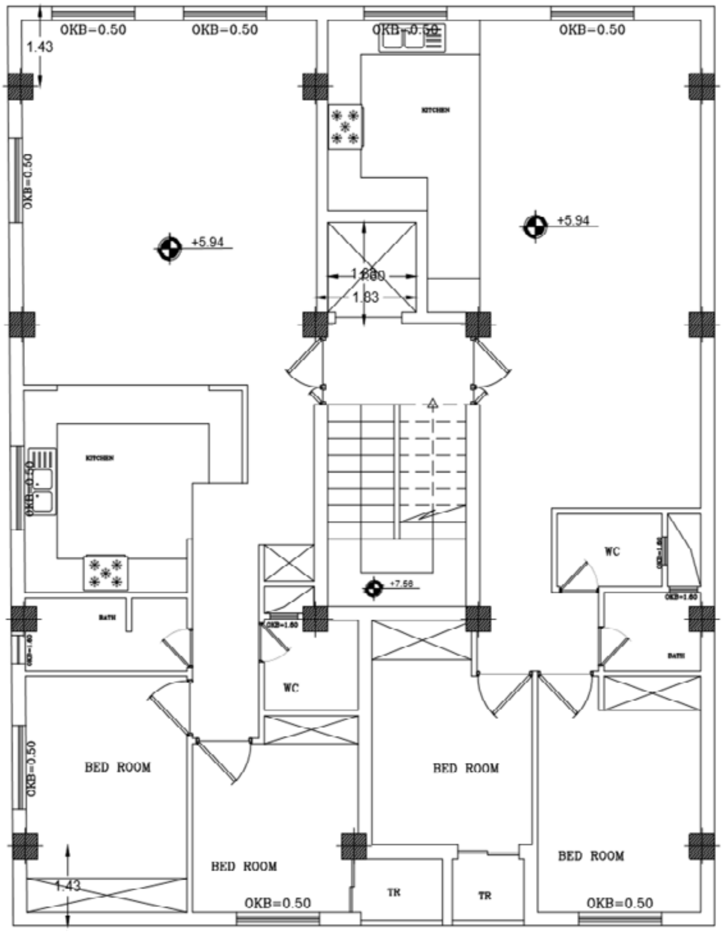

Fig. 1 Second floor plan

A. Features of the Building under Study

There is a stilt car parking on the ground floor that overlooks the alley on the east. It is a 500 m^2 two-story building with two apartment units on each floor. Each unit has two bedrooms, one bathroom, a kitchen, a living room, and a balcony. There are nine windows on each floor. Figs. 1 and 2 show the plan of the stories. Entering the two-dimensional plan obtained from AutoCAD with the dfx format into the DesignBuilder, the 3D plan of the building was created (Fig. 3) [7], [45], [46]. In this modeling, by drawing distinct areas in the interior of the building, all of its parts, including rooms, kitchen, bathroom, etc., were specified separately with their uses. Building use and information of the people are the important components of the modeling. Building function [27], whether it is a residential, office, educational, or medical building, affects the number of people residing there, their coming and going, heating and cooling requirements, and the amount of light and fuel required as well as many other factors. In the residential building under study, the information on people's presence in the building was recorded as follows:

- Occupancy: 0.02 people per m^2
- Metabolic factor: 0.9[1] [30], [47], [48]
- Clothing: 1 Clo-Value (winter), 0.5 Clo-Value[2] (summer)
- Minimum fresh air: 1 L/S per person [30], [31].

Also, different parts require different equipment that is defined separately. For instance, there are cooking facilities in the kitchen, a computer and light bulbs in the rooms, and a mechanical air conditioning system in the bathroom. Furthermore, the lighting demand for each section (in lux) is defined separately. The type of heating and cooling systems and the type of fuel required for the building are also determined. In the building studied, radiator, and evaporative

[1] Metabolic rate is the heat gain per person in the design condition domain. The number is based the activity level at home which can be considered as a light activity.

[2] Clo-Value was selected based on a DesignBuilder software recommendation. Referred to: https://designbuilder.co.uk/helpv2/Content/_Metabolic.htm

cooler fueled by natural gas and electricity were used [49]. Furthermore, meteorological data for one year were provided using Meteonorm software in epw file format. Those software applications that use the EnergyPlus engine are compatible with this input file format. The structure of building walls is defined in the construction section (Table I). The structure of windows, defined in the opening section, is single glazed windows with an aluminum frame.

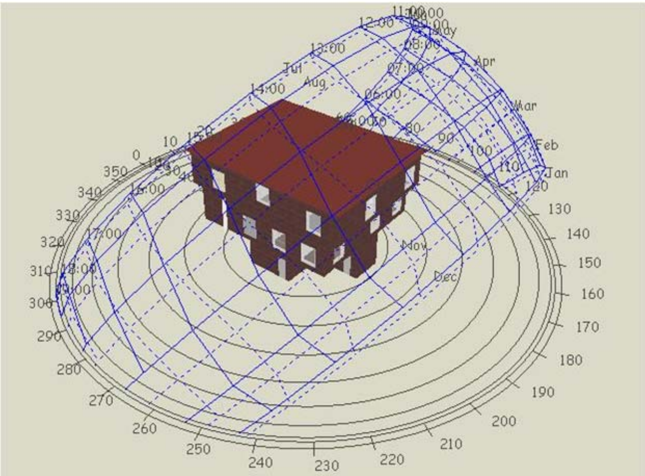

Fig. 3 Building 3D model in DesignBuilder software

TABLE I
PHYSICAL AND THERMAL PROPERTIES OF MATERIALS IN WALLS

Construction section	Detail	Heat Transfer Coefficient (W/(m^2 k))	Density (kg/m^3)
Exterior wall	Marble	3.5	2800
	Cement sand mortar	1	1800
	Cement block	0.153	2200
	Chalkdust	1.1	1500
	White plaster	0.57	1100
Interior wall	White plaster	0.57	1100
	Chalkdust	1.1	1500
	Cement block	0.153	2200
	Brick	0.72	1850

EnergyPlus simulates energy and performance of the environment by considering the interaction between all parts of the building and systems, including walls, windows, structure, heating and air conditioning systems, lighting, internal heat gain, etc. Using a prediction technique, the software examines the relationship between systems of the building and its different domains and predicts the system's load to maintain air temperature in different zones. The system software then simulates the building to determine the size of equipment, thermal restoration, and air balancing in the region. The following relation is used in EnergyPlus to calculate heating and cooling energy [31]:

- Heating energy = EnergyPlus load/COP of heating system
- Cooling energy = EnergyPlus load/COP of cooling system.

The coefficient of performance (COP) is used to calculate fuel consumption to supply thermal demand, which includes the impact of total energy consumed for heating and other issues related to the heating and cooling of the building, including fans and pumps, control equipment, etc. According to EnergyPlus Engineering Reference [4], the thermal load is calculated as follows:

$$C_z\frac{dT_z}{dt}=\sum_{i=1}^{N_{sl}}Q_i+\sum_{i=1}^{N_{surfiaces}}h_iA_i\left(T_{s_i}-T_z\right)+\sum_{i=1}^{N_{zones}}m_iC_p(T_{zi}-T_z)+\dot{m}p(T_\infty\dot{-}T_z)_{sys_{inf}} \quad (1)$$

$\sum_{i=1}^{N_{al}}\dot{Q}_i = sum\ of\ the\ convective\ heat\ transfer\ from\ the\ zone\ surfaces$
$\sum_{i=1}^{N_{aurfacca}}h_iA_i(T_{si}-T_z) =$
$convective\ heat\ transfer\ from\ the\ zone\ surfaces$

where:

$$\dot{m}_{inf}C_p(T_\infty-T_z)_{=\ heat\ transfer\ due\ to\ infiltration\ of\ outside\ air,}$$
$$\sum_{i=1}^{N_{zones}}\dot{m}_{inf}C_p(T_\infty-T_z)_{=\ heat\ transfer\ due\ to\ inter\ zone\ air\ mixing} \quad (2)$$

$\dot{Q}_{sys}=airsystemsstoredoutput$, $C_z\frac{dT_z}{dt}=energystoredinzoneair$, $C_z=pairC_pC_T$, $pair=zoneairdensity$, $C_p=zoneairspecificheat$, $C_T=sensibleheatcapacitymultiplier$ $(Detaileddescriptionisprovidedbelow)$.

If the air capacity is negligible, the output of the steady-state system is calculated as:

$$-\dot{Q}_{sys}=\sum_{i=1}^{N_{sl}}Q_i+\sum_{i=1}^{N_{surfiaces}}h_iA_i\left(T_{s_i}-T_z\right)+\sum_{i=1}^{N_{zones}}m_iC_p(T_{zi}-T_z)+\dot{m}p(T_\infty-T_z)_{inf} \quad (3)$$

The following equation calculates thermal and cooling load without the air system term:

$$\dot{Q}_{load}=\sum_{i=1}^{N_{sl}}Q_i+\sum_{i=1}^{N_{surfiaces}}h_iA_i\left(T_{s_i}-T_z\right)+\sum_{i=1}^{N_{zones}}\dot{m}_iC_p(T_{zi}-T_z)+\dot{m}p(T_\infty-T_z)_{inf} \quad (4)$$

The following relation is used to calculate the energy consumption of a hot water system:

DHW energy (kwh) = DHW cop * 1000 (kg/m^3) * 4.187 (kJ/Kg) * (Energyplus loads) * (Delivery water temperature-Mains water temperature) (5)

Carbon dioxide is a major GHG emission as a result of energy consumption in buildings. It is calculated by using the emission factor in DesignBuilder for various fuels set as default in the software [16]. Table II presents the emission factor for gas and electricity used in the building under study for Iran [17].

TABLE II
CO_2-EQ EMISSION FACTOR

Type of Energy	Emission Factor (kg CO_2/KWh)
Gas	0.195
Electricity	0.685

The present study determines insulation effectiveness in reducing buildings' energy consumption and ecological footprint during usage under different insulation conditions for the Mazandaran climate. Different insulation materials available in the region were investigated, and the one with the highest effect regarding fuel consumption was selected in the end. The building was insulated from the outside using three materials. Since the building's heating system was fueled by natural gas, the effect of insulation on the annual gas consumption is presented using the results in Table III.

TABLE III
COMPARING INSULATIONS

Energy/Insulation	XPS, 100mm	PU, 100mm	EPS, 100mm
GAS (Kwh)	4360	4371	4392

Considering the modeling results of Table III and by comparing the insulation materials, it is safe to conclude that:

- The comparison of the insulation materials showed that these materials have similar effects on annual energy consumption.
- The best results in reducing energy consumption were achieved with XPS, followed by PU and EPS.
- According to the results in Table III, and in comparison, with the natural gas consumption for heating the rooms, insulating the building walls using a 100-mm layer of XPS material offered a 17.3% reduction of natural gas consumption. Further, PU and EPS insulations offered 17.1 and 16.7% reductions; accordingly, the XPS was selected to insulate the building. PU was also found to have excellent performance but is rarely used in residential construction due to being an industrial insulator.

Previous studies have shown how little roof insulation contributes to reducing energy consumption, compared to wall insulation [50], [51]. In other words, when it comes to insulation, the walls are the top priority, and it is more cost-effective to put a thinner layer of insulation thickness on the roof than the walls [50], [51]. Electrochromic windows were used in this study to reduce energy consumption. The technology has found several applications, including glasses that can switch between transparent and translucent by the push of a button, preventing light and heat from entering the building. What is notable regarding this type of glass is that it preserves the residents' visual link with the outside and eliminating the need for curtains [52], [53]. Although the technology is not yet widespread in Iran, it has been used worldwide, especially in developed countries, to reduce energy consumption.

As mentioned earlier, the final model of the studied building incorporated a 100-mm XPS insulation layer for the exterior walls and a 50-mm layer on the roof. The insulation was found to be highly-effective, affordable, and widely available. Smart electrochromic double-pane windows were used in the building, and LED light bulbs were used to reduce illumination power consumption. Figs. 4 and 5 show wall and roof details after installing the PS insulation. Further, Fig. 6 presents the properties of the modeled electrochromic glass.

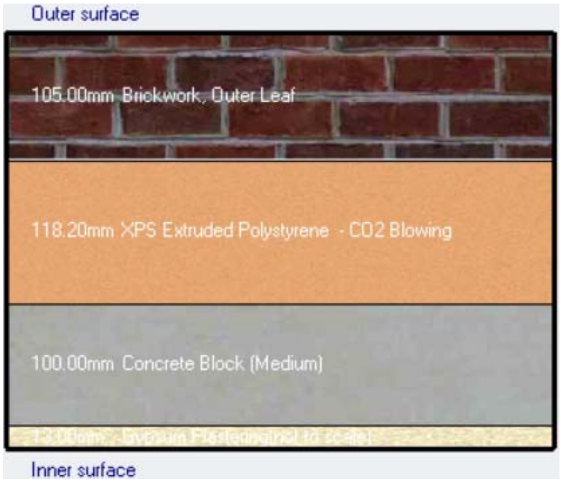

Fig. 4 Wall with xps polystyrene insulation

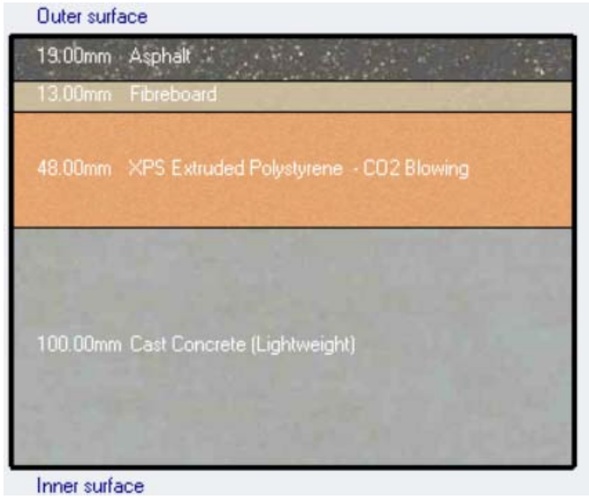

Fig. 5 Roof with xps polystyrene insulation

Calculated Values	
Total solar transmission (SHGC)	0.641
Direct solar transmission	0.545
Light transmission	0.727
U-value (ISO 10292/ EN 673) (W/m2-K)	1.679
U-Value (ISO 15099 / NFRC) (W/m2-K)	**1.761**

Fig. 6 Electrochromic glass modeled in DesignBuilder

IV. Analysis and Discussion

Following the modeling and software analysis, the results of annual carbon dioxide production through fuel consumption in the building studied are shown in Table IV.

As can be seen, given the information in Table I and the metabolic factor of 0.9, the amount of carbon produced through gas and electricity consumption and lighting of a residential building was 37,160.22 kgs per year and 69.12 kg/m^2 for the normal number of three people per unit and 12 people residing in the building given the climatic data, including temperature, relative humidity, direction of solar radiation, wind direction, and speed extracted from Meteonorm software. This value indicates that carbon produced by this building for one year is about 15% of the carbon produced during construction, showing that the amount of carbon produced during construction is high and significant. Therefore, during six years of operation, the building will have a carbon footprint equal to what was produced during construction. This suggests that the amount of carbon produced during the operation of a building is as important and significant as the amount of carbon produced during material production.

Table IV shows energy consumption in different parts of the building.

TABLE IV
ANNUAL AVERAGE ENERGY CONSUMPTION IN DIFFERENT PARTS OF THE BUILDING

Room Electricity	Room Gas	Lighting	Heating (Gas)	Cooling (Electricity)	DHW (Gas)	Exterior lighting
kWh	kWh	kWh	kWh	kWh	kWh	kWh
988.2	858.6	41562.9	4419.2	8275.1	5209.9	436.6

The results suggest energy consumption in each part of the building. As can be seen, the major energy-consuming utilities are heating, cooling, and lighting. Cooling energy consumption was about 8,275.13 kWh, and heating energy consumption was 5277.85 kWh. Gas consumption was much higher due to hot water demand, as well as cooking purposes. Electricity consumption was higher because of equipment such as computer. Lighting energy consumption for one year was 4,593.53 kWh for this building. This was due to using tungsten incandescent lamps and not controlling the lighting. In addition, the lack of appropriate thermal insulation in the walls caused higher gas and electricity consumption, which produced more carbon dioxide in the building. Table VI demonstrates carbon dioxide emissions of the building over the course of one year after modifications. Table V shows total CO_2 production in one year for new envelope.

TABLE V
TOTAL CO_2 PRODUCTION IN ONE YEAR

CO_2 Production (Time frame: 1 Jan- 31 Dec)		
Envelope type	New	Conventional
Production (kg)	11345.61	37,160.22

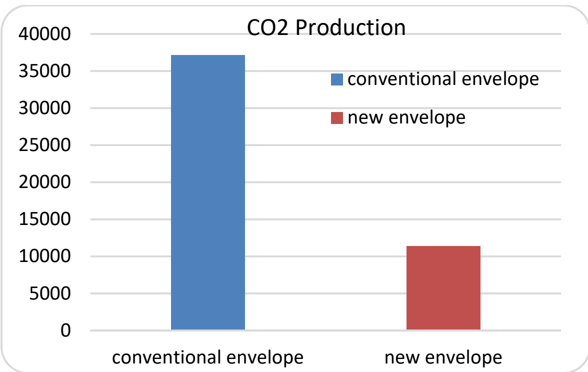

Fig. 7 Comparison the amount of carbon dioxide produced in the building due to operation during one year with traditional and modern insulation

Based on the program outputs, the modifications resulted in a considerable 69% cut in carbon dioxide emission compared to before insulation, bringing the annual sum to 11345.61. Fig. 7 illustrates the results.

The reduced carbon generation is due to the building's lower energy consumption over the one-year period after modifications.

TABLE VI
ANNUAL ENERGY CONSUMPTION OF DIFFERENT SECTORS AFTER CHANGES

Room Electricity	Room Gas	Lighting	Heating (Gas)	Cooling (Electricity)	DHW (Gas)	Exterior lighting
kWh	kWh	kWh	kWh	kWh	kWh	kWh
986.3	854.2	5642.5	3441.4	3840.5	5264.8	427

As evident from Table VI, insulating the walls and replacing the windows with electrochromic ones helped considerably reduce energy consumption for cooling and heating. Further, power consumption for illumination was drastically reduced after replacing the light bulbs. These changes directly affected the carbon dioxide generation and reduced it for the building over the one-year period. Fig. 8 compares the results.

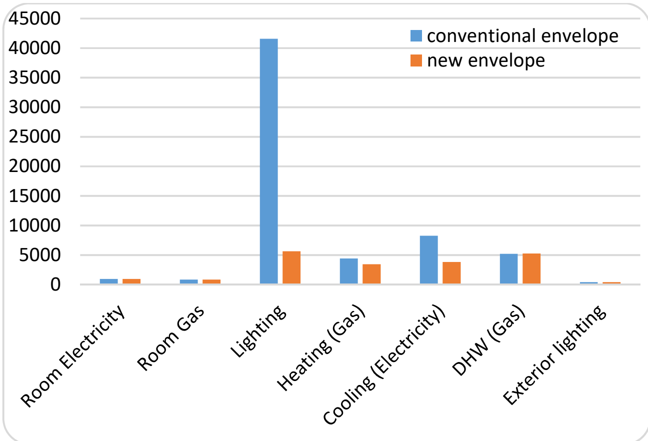

Fig. 8 Comparison of energy consumption between two buildings

Power consumption, which now stands at 3840.55 according to Table VII, shows a 54% reduction from 8275.13 in the previous model. Fig. 8 also demonstrates the substantial role of light bulbs in power consumption. In the first model, power consumption for illumination reached 41,562.91 kWh, which was reduced by 87% to 5642.56 kWh in the final model. Natural gas consumption was also reduced by 25%. The remarkably lower power consumption translates to much less carbon dioxide emission, since, according to Table II, the emission factor of electric power is 0.685 kg CO_2/KWH, which is three times that of natural gas. Considering the surge in energy costs, global issues arising from greenhouse gas emission, and the international push for reducing these emissions, the construction industry, as a major emitter in Iran, can serve an ever-more significant part in this regard, granted the government and the public recognize its role.

V. Conclusion

Population growth and increasing construction account for a substantial part of global energy consumption. Being informed about energy consumption can help reduce it by managing the construction adequately. Changes in this regard cover material types and the construction process. That can be achieved by adopting new materials with sufficient strength and improved effectiveness from an environmental perspective.

The energy consumption of a building and the resulting carbon dioxide emission was investigated over one year using DesignBuilder. The building was modeled in detail, and the results estimated energy consumption at 61,750.69 kWh and carbon emission at 37,160.22 kg, which is considerable. Solutions were proposed to reduce energy consumption, including: Insulating the walls using XPS, which was selected from three candidates based on natural gas consumption modeling results, using smart electrochromic glass, which can switch colors at the push of a button, and LED light bulbs to reduce illumination power consumption.

The model results are suggestive of the significant reduction of energy consumption for cooling, heating, and illumination after these modifications. The final energy consumption stood at 20,456.96 kWh, indicating a substantial reduction of carbon dioxide emission. A 11,345.61 kg carbon dioxide emission was estimated for the modified model, which shows a 70% improvement. Overall, bearing in mind that any activity or product wields some impact on the environment, referred to as its ecological footprint, employing practices such as insulation or the window material can help reduce these adverse impacts to a large extent.

VI. Limitation

The paper mainly focuses on energy of gas and electricity and but not on other technologies such as hydrogen, biomass, wind and others. In addition, this paper considers the CO_2 production in construction and does not include other greenhouse gases production in calculation process.

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