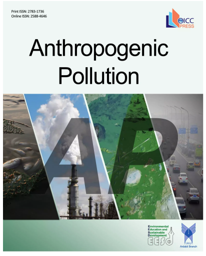


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# Modeling the pattern of energy consumption in residential buildings based on optimal energy management approach (Case study: conventional apartments in Lahijan, Iran)

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**Original Research**

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**Abstract:**

Nowadays, buildings are one of the most consuming sectors that cause excessive energy loss. The present applied research aimed to model the energy consumption pattern in conventional residential apartments in Lahijan city (Gilan province, Iran). Design Builder software was used to model four scenarios, including the current state, the use of a movable canopy, the use of photovoltaic panels, and the combined state. According to the results, the infiltration load coefficient was obtained to be 1778 W/K. The highest heat dissipation in cold seasons was related to the roof and glazing parts. The lighting state was within the standard range in 12%, more than the standard in 52% and less than the standard in 36% of the points. The shortcomings of the study buildings were significant from the energy point of view, so that the average heat transfer coefficients of the walls, windows and ceilings were 2.5, 1.7 and 2.2 times the standard value of Standard Topic 19 of the National Building Regulations, respectively. The total electricity consumption was 776,543 kilowatt-hours per year (kWh/year), and the panels were able to generate 14.87% of the required electricity (115,544 kWh/year). The use of smart movable canopy and photovoltaic panel led to energy savings of 18% and 17%, respectively. The simultaneous use of both would bring the amount of energy saving by 24%. To conclude, adopting purposeful and effective measures and training can lead to saving energy consumption and benefiting from clean energy in such buildings.

**Keywords:** Energy consumption modeling; Residential buildings; Conventional apartments; Optimal energy management; Lahijan

## 1. Introduction

The ever-increasing elevation in energy consumption in all aspects of human life and the limitation of energy resources on the one hand and its overconsumption in different societies on the other hand, not only cause environmental pollution and waste national capital, but also endanger the future life of mankind (Khadivi et al., 2016). These days, energy is known as one of the main factors for the formation and progress of societies, and the degree of access of countries to various energy sources indicates their development potentials as well as their political and economic power (Behboudi et al., 2010). According to forecasts, global energy consumption will increase by nearly 48 % in 2040 compared to the same amount in 2012, and Asia will still be the largest energy consumer in 2040. Meanwhile, over 50 % of global energy will be consumed in the industry sector (Mariano-Hernandez et al., 2020). Energy consumption in Iran has been estimated to be over 2.5 times the average annual global energy consumption. The energy intensity index in Iran has been determined to be 0.63 %, and subsequently, Russia (0.53 %) and Saudi Arabia (0.51 %) have occupied the next places, respectively. In accordance with the latest statistics, Iran is known as the ninth energy consumer in the world, and such energy consumption means 3.4 million barrels of crude oil (Hesami, 2020).

Improving urban energy efficiency not only helps save energy, but also leads to the development of cities' budgets, improved services and increased competition in this field (Environment, 2019). Because a large amount of electricity in Iran is generated by thermal power plants, high consumption of electrical energy indicates the high consumption of non-renewable fossil fuels. Electricity consumption of buildings in Iran has doubled during the past decade. According to the statistical data of the Ministry of Energy, per capita energy consumption in Iran is about three times that of industrialized countries, and a large segment of this difference can be attributed to energy losses in the construction sector (Bahrami and Davoudi, 2004). The per capita energy consumption in Iran is estimated to be more than 5 times that of Indonesia (with a population of 225 million), 2 times that of China (with a population of 1.3 billion), and 4 times that of India (with a population of 1.122 billion. The estimation of per capita energy consumption in Iran between 2004 and 2011 shows a 25% increase in these years (Bahmanpour et al., 2021).

Due to the limited energy resources in Iran and considering the national plan to diminish dependence on oil resources, the need to decrease energy consumption in different sectors of industry and construction is regarded as the first option in the field of attention to energy saving solutions (GhafariJabari et al., 2013). Among the environmental bottlenecks in urban management that must be considered in a systematic and integrated manner, decreasing the high costs of energy consumption in buildings and especially office ones, paying attention to preserving the environment and reducing environmental problems are increasingly being considered. Environmental management of energy in buildings is a creative solution to reach green buildings (Pallante et al., 2020). The building sector accounts for over a third of energy consumption, and its annual value is more than six billion dollars. Most of buildings in Iran are free of technical standards predetermined to prevent the waste of cooling or heating energy (Tatar and Marafet, 2013). Energy consumption in the country's buildings is about 2.5 to 4 times the average energy consumption in other countries of the world. Public buildings account for 70 % of energy consumption in this sector, and old buildings show between 40 and 60 % of energy loss. Following the implementation of comprehensive plans related to the optimization of resource consumption (water, electricity and gas) in residential buildings, energy consumption includes the formulation of executive guidelines and effective solutions, which, in addition to avoiding energy waste, have also saved the economic costs of the household (VerijKazemi and Kazemi, 2017).

Almost more than half of the country's energy is consumed by the building sector, whether in the domestic sector, in the office sector, in the commercial sector or in the industrial sector. It should be noted that more than 40% of Iran's buildings have energy loss compared to international standards. Article 19 (Energy Saving) of the National Building Regulations of Iran, which is the most basic issue of energy efficiency in the building sector, has been announced for more than five years, but has not yet been fully implemented and is not a major concern for the Ministry of Roads and Urban Development. Actually, economic factors are influential to some extent in the housing sector where energy efficiency is lost (Fazli and Heydari, 2013).

Energy management means the regulation and optimization of the use of energy systems, including engineering, control and managerial techniques (Samavati, 2016). The energy management must be connected to the organization's operational goals, not moving in an independent direction (Shabanzadeh and Javan, 2003). In this line, building energy index (BEI) refers to total energy of electricity consumed by the building (kWh/m$^2$/yr). Energy Consumption Optimization is defined as adopting patterns and implementing energy consumption policies, which are desirable for the national economy, guarantee the continuity and durability of energy, improve life indicators, decrease costs, and cause the spread of justice in the society. In such a framework, it is regarded to apply the most efficient manner of using resources, which implies decreasing the destruction of energy resources and also reducing the adverse impacts on the environment due to incorrect use of energy (Tatar and Marafet, 2013).

Recently, there have been various studies on the optimization of energy consumption in Iran. For example, Hesami (2020) investigated the effectiveness of the implementation of the resolution to reform the energy and resource consumption pattern in Tehran municipality buildings. The findings indicated that the implementation of this plan decreased the consumption of energy and resources within two years (2018-2019), which resulted in a reduction in water (3%), electricity (9%) and gas (5%) consumption per capita. Moharami et al. (2016) applied selected indices to manage energy and environmental safety to offer some projects. Their purposes were aimed at preventing the harms that humans were unable to deal with due to mental preoccupations, lack of opportunity or human errors, thus leading to unwanted events. Khadivi et al. (2016) determined seven parameters affecting energy consumption in a 15-story high-rise office building in Tehran equipped with an energy management system and used Design Builder software to model the available data, and found that saving the energy of cooling and heating devices could reduce the annual energy consumption by 35-40%. In a work on smart buildings as an effective choice in energy efficiency through library studies, Nikghadam NikghadamHojjati et al. (2012) reported that Iran accounts for the highest intensity of energy consumption in the world, with the maximum amount (about 40%) in the non-productive segments. Verij VerijKazemi and Kazemi (2017) studied the social inhibiting factors of energy consumption efficiency in office buildings in Iran. Samavati (2016) evaluated the energy management of smart buildings with renewable energy sources and found that their proposed energy management algorithm saved about 28% of the electricity cost of buildings.

Salvia et al. (2021) investigated ways to promote policy making to improve energy efficiency in municipal public buildings, focused on public policy making related to energy management, and found that technical, engineering and managerial aspects should be used in an integrated manner. Mariano-Hernandez et al. (2020) developed a model for energy management in office buildings, so that they presupposed that building energy consumption was expected to elevate by 40% in the next 20 years. They reported that electricity had the maximum energy consumption in buildings, and found different strategies used for energy management in buildings based on the type of building and basically two strategy models of residential and non-residential buildings. In a review article by Chen et al. (2020) on the factors affecting energy efficiency in buildings, the results showed three main internal and external classes of building features, equipment and technology, and occupant's behaviors. They also reported that the use of only one of the above three categories would not provide the possibility of achieving effectiveness in energy management. According to some review studies, the energy consumption reduction rate in smart buildings would be almost 10-28% and 43-71% in heating, ventilation and air conditioning (HVAC) and lighting systems, respectively. Pallante et al. (2020) concluded that the control of some factors would save an average of 10-28% of energy costs. Economidou et al. (2020) reviewed 50 years of European Union (EU) energy efficiency policies for buildings. The analysis of economic and environmental aspects revealed that the EU has been promoting public energy efficiency since the 1970s by focusing on buildings, policies and special programs. These strategies have been gradually strengthened to fulfill the commitments of energy and climate policies and priorities.

The purpose of this research was to model the energy consumption pattern in conventional residential apartments in Lahijan city. Basically, the researchers sought to find out how the amount of energy consumption would change under various scenarios. The main question of the research was that what change will be caused in the amount of energy consumption in the studied building by using different solutions such as the use of smart canopy and photovoltaic panel? In other words, the hypothesis of the research was that the use of a combined solution would result in the greatest amount of energy savings.

## 2. Material and methods

Lahijan city (Lahijan province, northern Iran) is located at the geographical coordinates of 37° 4′ to 37° 23′ north latitude and 49° 45′ to 50° 13′ east longitude, with an area of over 407 square kilometers, an average altitude of 42 meters and an average slope of 7%. Figure 1 shows the location of Lahijan city in the province and country (BahmanPour et al., 2020).

This research was confirmatory in terms of approach, applied in terms of outputs, and practical in nature. In the first step, a 5-story residential building with an age of about 10 years was selected as the basis of modeling. It had general engineering features and followed the common pattern in the city in terms of the use of materials and building form. It was built in 2012 and had a built-up area of 2248 square meters, with residential use, which included a basement, ground floor and four floors. The number of units in this building was 20 and the number of people living in the building was 96. The different percentages of building use were 70% residential, 5% warehouse, 15% corridor, 10% parking place. The dominant type of energy used for both

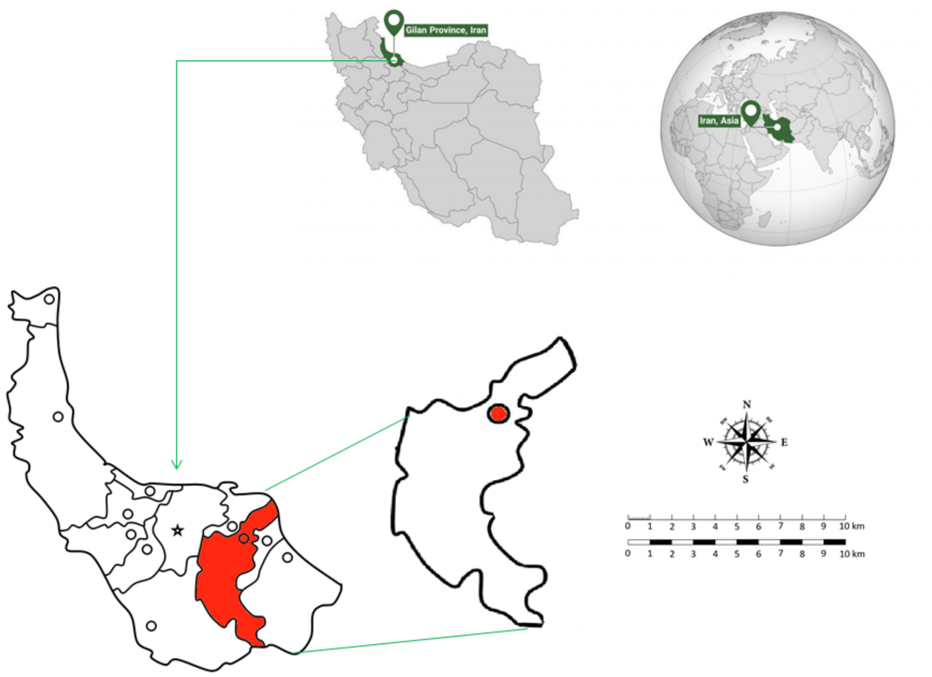


**Figure 1.** The location of the study area in the country and Gilan province (scale: 1/100000).

heating and cooling was natural gas. The plan of the building was rectangular and its roof was flat and sloping. The main extension of the building was in the east-west direction, and the main entrance of the building was facing west. Then, climatic and meteorological data were obtained from the General Directorate of Meteorology of the province and Lahijan municipality.
In the second step, based on field observations and preparation of a checklist, the reviewed structural engineering items included Body and structure; Facilities and equipment; Thermal comfort and energy consumption rate. Next, the amount and type of energy consumption in the building were compared and analyzed with three separate standards, including Topic 19 Standard, International Energy Conservation Code (IECC) and ISO 7730 (Thermal Comfort Standard).
In the third step, the energy consumption pattern in the study site was modeled based on the optimal state. Since the studied building was ten years old and all its physical components were completed and had been used, the relevant modeling in this section only included components and elements that could be changed or modified in the current conditions.
The research variables included independent (optimization of energy consumption), dependent (energy consumption) and intervening (type of energy, movable canopy, photovoltaic panel) ones. The meaning of optimal state was to take into account the following assumptions:
• Using a smart canopy (movable) on the outer wall of the building to prevent energy loss
• Installing photovoltaic panels on the roof of the building to supply the required electricity
Design Builder version 4.2.0.0.054 software was used for modeling. Based on the physical characteristics of the building, its occupants, equipment, mechanical and electrical systems, as well as the annual hourly weather data of the location of the building, this software can calculate and, in a more precise sense, predict several variables related to the energy consumption of the building at any time of the year. Examples of these variables are the air temperature of spaces, the temperature of surfaces, heat transfer from cloudy and transparent surfaces, as well as the heating and cooling loads necessary to maintain the desired temperature or thermal comfort conditions in the building; the results can be presented both numerically and graphically (Mariano-Hernandez et al., 2020). The required climatic data was imported into the software based on regional periodic meteorological reports.

# 3. Results

## 3.1 Determining energy consumption rate in the study area

In the first step, the body of the building was examined. In this part, the types of walls, the position of and the materials used in the wall, by which the heat transfer coefficient of a type of wall is obtained, were given. A type of wall includes walls that have a similar situation in terms of position and heat transfer coefficient. For example, if two walls have the same heat transfer coefficient and both have a controlled position, they are placed in the same type. In this part, the main materials used in the wall and the thermal resistivity or thermal conductivity coefficient of the materials, their density and approximate thickness according to the thickness of the whole wall were given, by which the overall heat transfer coefficient, or U-value, was calculated. Then, the area of all the walls that were in a same type were added together and included in the wall area. According to topic 19, the studied building had the following characteristics:
1- Type of the building use: A
2- Heating-cooling energy requirement: Moderate
3- City condition: Moderate
4- Built-up area of the building: More than 1000 square meters
5- Type of energy consumption: Non-electrical
Accordingly, the building was placed in group 2. According to the approved guide, the theoretical wall load coefficient of the building (building load coefficient: BLC) was: $BLC_1$ = 8282.4 W/K. The wall load coefficient to comply with the topic 19 of the National Building Regulations was: $BLC_1$ = 3732.2 W/K.
In order to determine the infiltration load coefficient, it is necessary to determine the amount of fresh air infiltration for each space. Topic 14 of the National Building Regulations (heating, ventilation and air-conditioning, or HVAC) has provided the minimum fresh air required for different spaces based on people, surface unit and each room. This amount is 10 liters per second for each person (BLCS = $\rho$.Q.CP; $\rho$ = 1.200 Kg/m$^3$; CP = 1.004 Kj/kg°K). Consid-

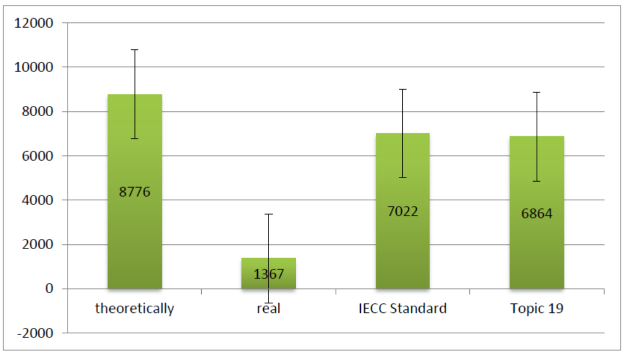


**Figure 2.** Comparison of building load coefficients.

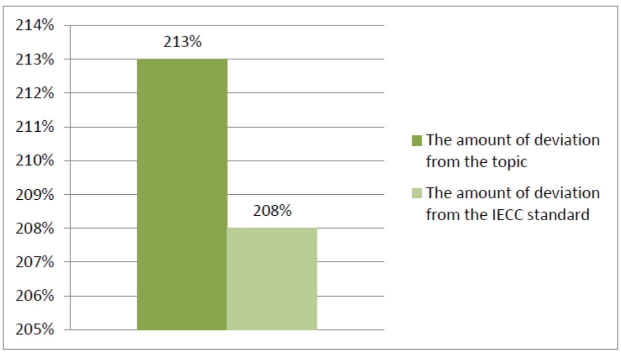


**Figure 3.** Comparison of the deviation of energy consumption from the current state standard (percentage).

ering that the number of people living in the building was announced as 96, assuming a simultaneity coefficient of 1.00, the infiltration load coefficient was calculated to be 1788 W/K. Figures 2 and 3 compare the building load coefficient in the current state with the selected standards.
Due to the high number and variety of lights and also to prove the mentioned number, the type of lighting was taken separately for each room. Figure 4 presents the analysis of the building lighting measurement results.

The amount of energy consumption in different sectors was calculated, the results of which are given in Table 1. As indicated in the table, the highest amount of current energy consumption in the studied building was in the heating sector (25%) and then the cooling sector (20%). The lowest amount of energy consumption belonged jointly to the lighting and gas equipment sectors (11%).
In this building, in general, it can be said that natural gas was often used for heating, cooling and hot water supply, and electricity was used for cooling, lighting and electrical equipment.

### 3.2 Modeling energy consumption in current state

In the studied building, the number of occupants, number of equipment and lighting system were considered in the modeling of energy consumption. Other items were selected based on the standard templates of Design Builder software. The heat transfer coefficient was 0.573 $W/m^2K$ for the external wall and 0.542 $W/m^2K$ for the ceiling. The materials considered for the external wall and ceiling were in accordance with the actual conditions. Based on the standard software template, the windows were chosen to be double-glazed with transparent glass and UPVC bi-fold sales, which coincidentally matched the current state of the building. The double-glazed windows were made of "3 mm clear -13 mm air -3 mm clear". The thermal comfort temperature was considered to be 23°C in the cold season and 25°C in the hot season (Figures 5-8).
After modeling and extracting the results, the heat received through different parts of the building, as shown in Figure 9. The received heat would increase the building cooling load in hot months and decrease the building heating load in cold months. The heat would be provided by the lighting system, electrical equipment, the presence of occupants and solar radiation through interior and exterior windows. The most received heat was related to the solar heat. The red and blue colors are related to the zone sensible heating and cooling

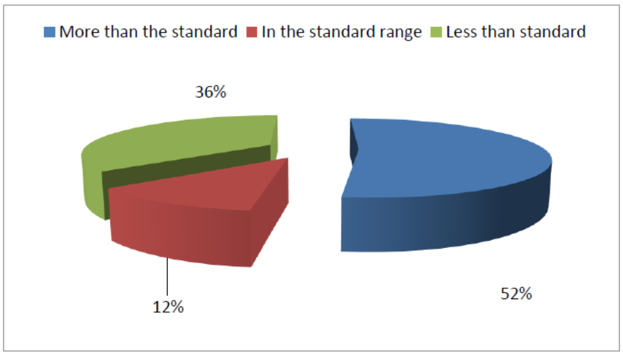


**Figure 4.** Comparison of the percentage of matching the building lighting with the standard limit based on the number of points.

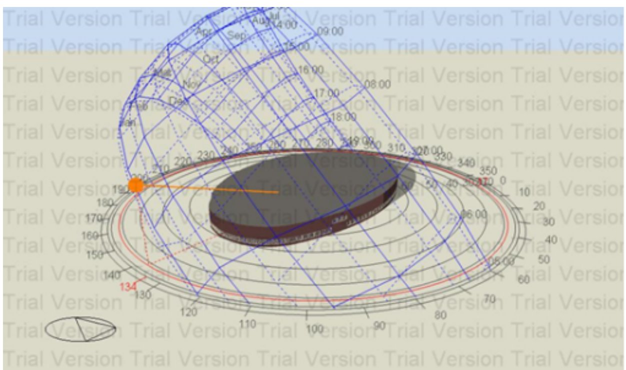

**Figure 5.** Sun path towards the studied building.

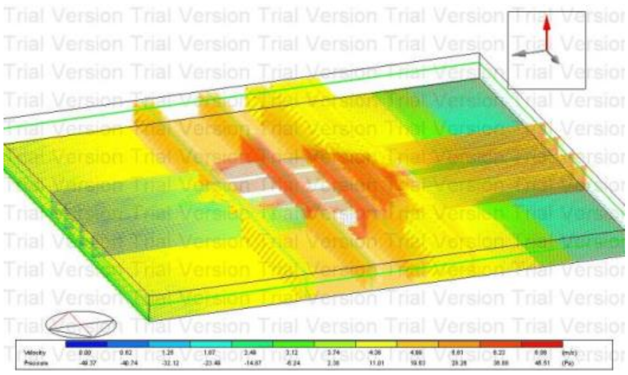

**Figure 6.** Wind movement and pressure to volume.

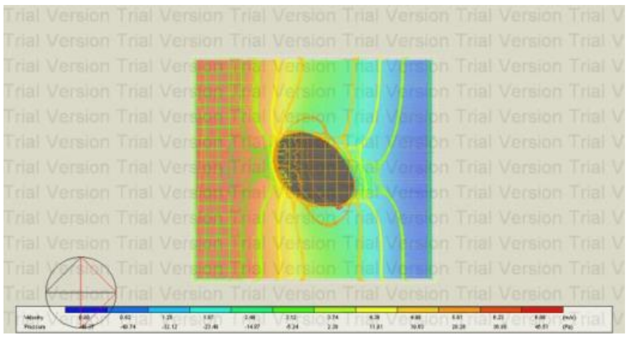

**Figure 7.** Wind movement in the main volume direction.

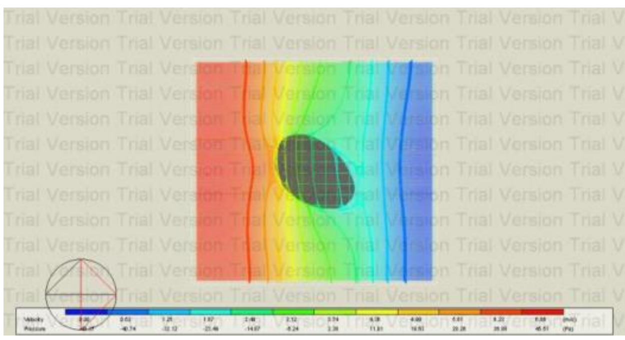

**Figure 8.** Pressure path to the main volume.

**Table 1.** The amount of energy consumption in different parts of the building.

| | **Heating** | **Hot water supply** | **Cooling** | **Lighting** | **Electrical equipment** | **Gas equipment** |
|---|---|---|---|---|---|---|
| **Amount of energy consumed (kWh/year)** | 567331 | 243671 | 328876 | 155762 | 225954 | 155762 |
| **Percent of total** | 25 | 17 | 20 | 11 | 16 | 11 |

load.
Figure 10 shows how heat is transferred from different parts of the building, including glazing, walls, floors, partitions and roofs. Positive numbers mean heat gain by that part and negative numbers mean heat loss. For example, in hot seasons, major heat enters the building space through glazing. The breakdown of electricity consumption according to the type of use is as per Figure 11. This consumption was related to electrical equipment, cooling system, heating system, hot water supply and lighting. The most consumed electricity was related to the cooling system of the building throughout the year.

### 3.3 Modeling energy consumption in optimal state

Since the studied building was ten years old and all its physical components were completed and had been used, the relevant modeling in this section only included components and elements that could be changed or modified in the current conditions. The meaning of the optimal state was to consider the following assumptions:
• Using a smart canopy (movable) on the exterior wall of the building to prevent energy loss
• Installing photovoltaic panels on the roof of the building to supply the required electricity.

### 3.4 Modeling based on the use of a smart (movable) canopy

In this state, to prevent excessive radiation to indoor in hot seasons and thus prevent overheating, as well as help to heat the building in cold seasons, movable shutter curtains were used as a hypothetical scenario. This canopy operated based on the intensity of the inside radiation as well as the thermal comfort temperature set in the inside space; that is, if the radiation entering the building exceeded a certain limit, the shutter curtain would be activated. In addition, this canopy controlled the radiation to some extent so as not to increase the temperature inside. According to Table 2,

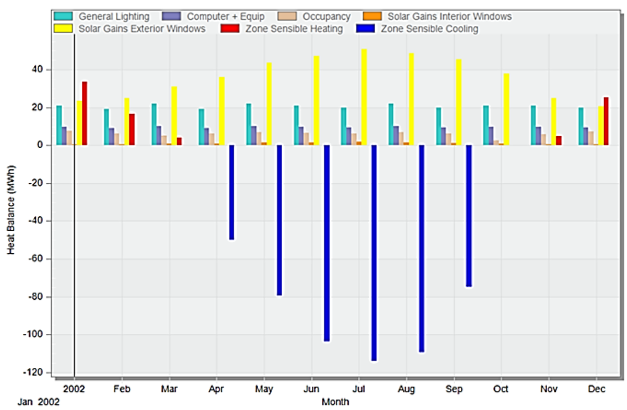


**Figure 9.** Internal loads (source: the authors).

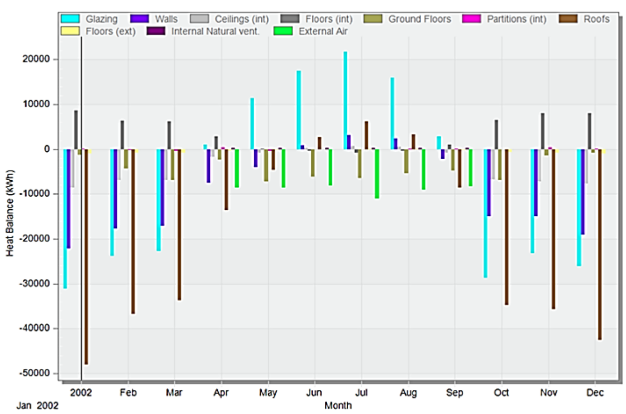


**Figure 10.** Heat transfer status in current state.

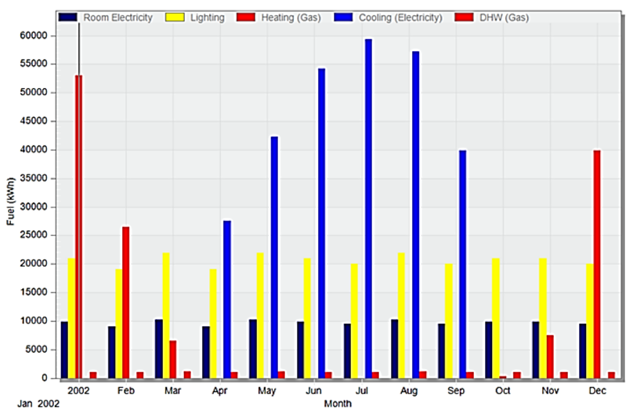


**Figure 11.** Breakdown of electricity consumption on a monthly basis (source: the authors).

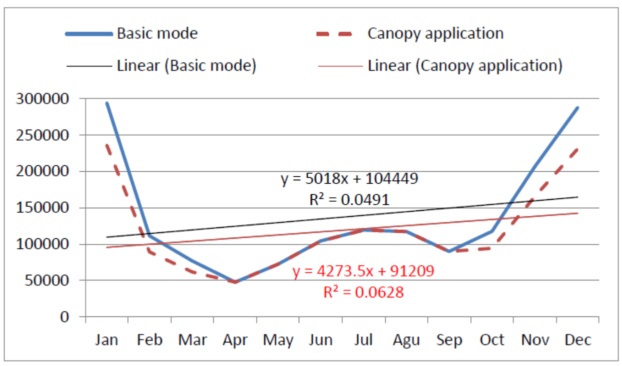


**Figure 12.** Energy consumption of heating and cooling systems of the studied building.

the use of smart canopy caused an 18% reduction in cooling and heating energy consumption compared to the current state.
According to the results, the heat received in the hot seasons was reduced due to the high intensity of radiation and also due to the prevention of the increase of the temperature inside by the smart canopy system. According to the total energy used for cooling and heating in both states (Figure 12), the required cooling load of the building decreased during the hot seasons.

### 3.5 Modeling based on the use of photovoltaic panels

In order to supply a part of the building's electricity consumption, the use of 80 panels of 2 square meters on the roof of the building was considered as a default. The total surface area of these panels was 160 square meters, with an efficiency of 17%. These panels were designed facing south and with a 28-degree slope. This number of panels could generate 115,544 kilowatt-hours of electricity throughout the year. The electricity profile of the building during the year was according to Figure 13.

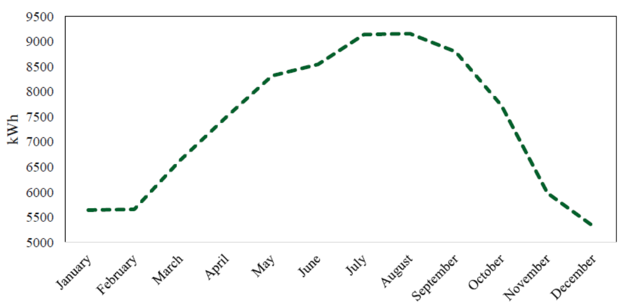


**Figure 13.** Efficiency of electricity produced by hypothetical photovoltaic panels for the building under study.

### 3.6 Modeling based on optimal state (simultaneous use of panels and smart canopy)

In this case, all solutions reviewed in the building were implemented simultaneously. These solutions included the use of smart canopy and photovoltaic panels. Figure 14 compares the total energy consumption of cooling and heating systems between the current state and the optimal state.
In the following, Table 3 summarizes the results of this modeling.
As mentioned, the use of a movable smart canopy could save energy consumption by 18%. In addition, the use of photovoltaic panels could reduce energy consumption by 17%. However, if both solutions were used in a combined form, the amount of energy saving would reach 24% (Table 4).

## 4. Discussion

The results of this research indicated that the heating of the building was provided by 26 heating packages. The cooling

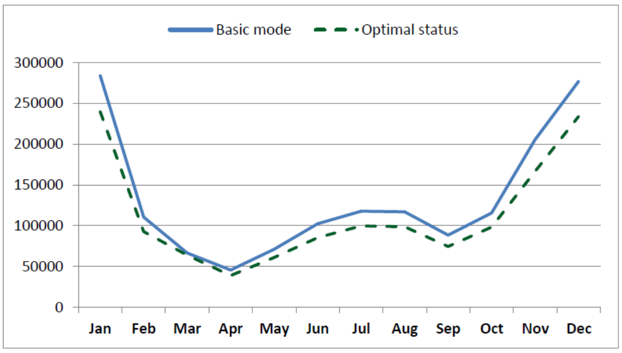


**Figure 14.** Comparison of the total cooling and heating energy required in both current and optimal state for the studied building

**Table 2.** Results of modeling based on the use of smart canopy

| | Heating system energy (kWh) | Cooling system energy (kWh) | Total energy (kWh) | Savings on heating (%) | Savings on cooling (%) | Total savings (%) |
|---|---|---|---|---|---|---|
| **Current state** | 1094302 | 550486 | 1644788 | - | - | - |
| **Use of canopy** | 1093865 | 441490 | 1447414 | -0.04 | 8.19 | 0.18 |

**Table 3.** Results of modeling based on the use of smart canopy.

| | Solar energy (kWh) | Heating system energy (kWh) | Cooling system energy (kWh) | Total energy (kWh) |
|---|---|---|---|---|
| **January** | 38582 | 249301 | 0 | 249301 |
| **February** | 37719 | 94307 | 0 | 94307 |
| **March** | 44717 | 64851 | 0 | 64851 |
| **April** | 30518 | 0 | 40296 | 40296 |
| **may** | 35630 | 0 | 61235 | 61235 |
| **June** | 38022 | 0 | 88290 | 88290 |
| **July** | 40623 | 0 | 101056 | 101056 |
| **August** | 39519 | 0 | 99315 | 99315 |
| **September** | 38690 | 0 | 76070 | 76070 |
| **October** | 56006 | 99484 | 0 | 99484 |
| **November** | 41909 | 174951 | 0 | 174951 |
| **December** | 35142 | 243980 | 0 | 243980 |

**Table 4.** Results of modeling based on the optimal state compared to the current state.

| | Heating system energy (kWh) | Cooling system energy (kWh) | Total energy (kWh) | Savings on heating (%) | Savings on cooling (%) | Total savings (%) |
|---|---|---|---|---|---|---|
| **Current state** | 1094302 | 550486 | 1644788 | - | - | - |
| **Optimal state (simultaneous use of canopy and panel)** | 887065 | 419379 | 1183135 | 13 | 11 | 24 |

of the building was provided by 15 gas coolers and 17 split air conditioners. The hot water of the building was supplied by 26 heating packages. Moreover, the lighting was within the standard range in 12% of the points, more than the standard in 52% of the points and less than the standard in 36% of the points. A total of 44 types of electrical devices were used in this building. As it can be deduced from the available results, the lighting condition (based on the installed capacity per unit surface area) of the studied building was more than the international standards, which could be reduced to some extent without affecting the indoor comfort conditions.
According to the analysis done, the shortcomings of the study buildings were significant from the energy point of view, so that the mean heat transfer coefficients of the walls, windows and ceiling were 2.5, 1.7 and 2.2 times the standard value of topic 19, respectively.
On the other hand, based on the modeling done, it was clear that the total electricity consumption was 776,543 kilowatt-hours per year, and the panels were able to produce 14.87% of the electricity required by the building, that is 115,544 kilowatt-hours per year. The highest heat dissipation in cold seasons was related to the roof and glazing parts. The use of smart movable canopy and photovoltaic panel led to energy savings of 18% and 17%, respectively. The simultaneous use of both would bring the amount of energy saving to 24%. The results and outputs of this research were completely consistent with many previous researches such as Moharami et al. (2016), Hesami (2020) and Khayatnezhad et al. (2023).

## 5. Conclusion

The amount of energy consumption in the studied residential buildings of Lahijan city (Iran) in the current state showed a relatively large difference with national and international standards. On the other hand, adopting targeted measures and observing special considerations, especially the use of movable canopy for windows and also the use of photovoltaic panels, to a relatively large extent can result in saving energy consumption and benefiting from clean energy in such buildings. Meanwhile, education and promotion of environmental awareness is one of the most important principles of energy management.

**Authors Contributions**
Authors have equal contribution role in preparing the paper.

**Availability of Data and Materials**
The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Conflict of Interests**
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



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