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Toward Nearly Zero Energy Building Designs: A Comparative Study of Various Techniques

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ABSTRACT: Global warming is a very serious issue that most countries in the world are facing its consequences; the construction industry has a significant impact on global warming by emitting greenhouse gases (GHG). The construction industry began to recognize the impact of its activities on the environment during the 1990s and has faced some challenges towards more sustainable buildings with minimal environmental damage. One of the practical ways to reduce energy and GHG emissions is to use a relatively new approach called Zero/Near zero buildings. To achieve zero energy buildings (ZEB), building energy demand should be initially minimized, and then met by renewable energy resources. Heating, ventilation, and air-conditioning (HVAC) systems represent a large share of buildings' energy consumption. Construction materials can also attenuate consumption if appropriately selected. In this paper, the assessment of the energy performance of a building located in Tabriz is studied, considering two case studies where different HVAC systems and construction materials are used. Moreover, the efficiency of AAC and BioPCMs in energy consumption and sustainable development was also assessed. It was found that case No.2, where PCM and AAC are incorporated into the building simultaneously, can reduce natural gas and electricity consumption by 139 MWh and 8.4 MWh, respectively, compared to the conventional construction. The availability of this system and materials allows building designers and project teams to manage the sustainable design and construction, and energy performance of their building in the early stages of project operation.

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Bio PCM, Design builder.

1- Introduction

On account of overpopulation which has caused a rising request for heating energy in diverse settlements, buildings and construction are being turned into the most energy-intensive parts, which universally causes to increase the tensions. Although the existence of high-performance settlements makes it possible to decrease energy usage, it supplies comfortability [2]. By attending to this issue that buildings are at the first level of using the initial energy with 40%, they are assigned as the highest sectors for wasting energy, and because of it, the greenhouse gases (GHG) have been emitted throughout the world [3-5]; that is, about 7.9% of whole CO_2 emission through the 34 years from 1970 to 2004 were considered by residential and commercial constructions. By keeping on the GHG emissions above the present amount, the present century has experienced many alters and more weather warming at the global level, which can be more than the former one [6]. Consequently, the concept of nearly zero-energy buildings (nZEB) has been stated. The concept of Zero Energy Building (ZEB) is no longer considered as a concept of a remote future, but as a realistic solution for the mitigation of CO2 emissions and/or the reduction of energy usage through the building point of view. Absorbing the attention toward the ZEBs can be accessed by improving the number of ZEB demonstration projects and research interest in the international perspectives [7]; that is, renewable energies can play an important role in buildings' energy requesting [8]. Since 2020, THE EUROPEAN PARLIAMENT AND OF THE COUNCIL has verified that almost all modern constructions have to consume zero energy (nearly ZEBs) [9]. There have been many rules and regulations in Iran to develop the energy use intensity, but it is 1.8 and 1.2 times more than that in the EU and MENA (the Middle East and Northern Africa). It can be understood from the figure that a powerful potential to save energy in the Iranian building part can be existed [10]. Iran has suffered from a rapid increase in energy consumption and environmental challenges through the last decades, which is not a result of economic development, but it reflects the dramatic rise of the energy usage intensity [11]. To do this, the reasonable affair is to minimize the building energy demand initially and then supply them. Generally, three phases can be accessed from the global movement towards the energy-efficient and Zero Energy Buildings which are as follow:

- Buildings' heating energy efficiency can be grown up and the optional codes can be introduced in the building construction;

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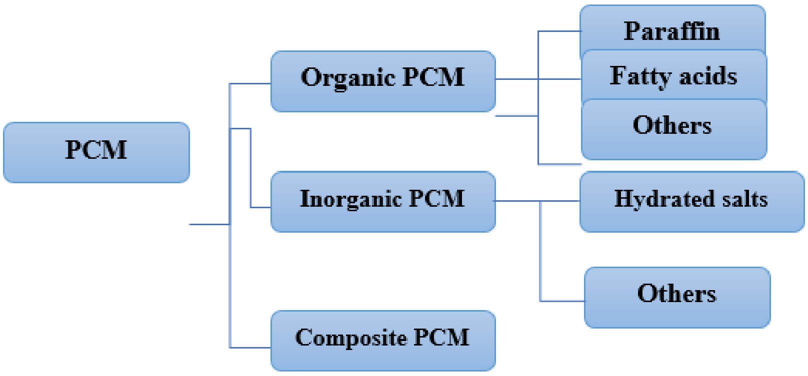


Fig. 1. Categorization of PCMs [1].

- The required energy can be generated from the on-site renewable energy resources and the accurate date can be determined to get the ZEB target;
- Not only the compulsory codes but also the specific standard and certificates can be applied for the Green buildings [12].

More than half of the buildings' energy is consumed because of heating, ventilation, and air conditioning (HVAC) systems [13]. One of the approved methods for reducing energy usage is to utilize thermal energy storage (TES) [14]. The most significant energy system to exploit the RES, which is considered tough for being used in building-specific applications, is the European Technology Platform on Renewable, Heating, and Cooling identified that Thermal Energy Storage (TES) [15], which can be accessed by utilizing three methods, i.e., sensible heat, latent heat, and thermochemical [16]. Sensible energy storage needs a massive material which can be considered as a disadvantage, but it has been commonly used. Energy is stored through the sensible TES by changing the temperature of a storage medium such as water, air, oil, rock beds, bricks, sand, or soil, which the Sensible TES materials undergo no change in phase over the temperature range encountered in the storage process [17]. Water, by including several residential and industrial applications, is the most popular and commercial heat storage [18]. Latent thermal energy storage has received a lot of attention in recent years due to its high energy storage capacity with a slight temperature change. Liquid solid phase change materials, which are efficient for heat or cold storage, are commonly known as latent heat storage materials (LHS) or simply phase change materials (PCMs) [19]. The use of an LHS system utilizing the PCMs is an effective way to store the thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process [18]. Over 200 compositions, including organic and inorganic combinations, eutectics, and other admixtures, have been deemed as promising PCMs. Based on the chemical composition, the primary three groups of PCMs utilized in building wall application are categorized in Fig. 1 [1]. When PCM undergoes a liquid/solid phase change at a specific temperature, it absorbs or releases heat [20]. PCMs store is 5-14 times more than the conventional building materials [21]. These materials can decrease the heating and cooling loads and curb indoor air temperature fluctuations. However, the quality of the PCMs depends completely on the climatic conditions, placement, and PCM properties such as melting temperature and storage capacity. In terms of thermochemical, a significant improvement can be accessed by thermochemical energy storage. In other words, through decreasing the disparity between supply and demand, thermochemical storage devices can improve building's sustainability and energy performance of the system. There are two types of thermochemical storage systems namely open and closed systems, in which the open storage system is based on the adsorption process which uses desiccant and heat storage systems to complete the adsorption process. However, Closed devices use a closed operating fluid cycle that is sealed off from the outside world [22].

A lot of investigations have been done by different researchers in integrating the PCM in buildings. Since seasonal changes cause a change in the performance of the PCM, three PCM walls were studied by Sun et al. in summer and winter to be used in lightweight buildings [23]. Their findings determined that by using the proposed walls, an energy saving of 20% on average can be achieved annually. The EnergyPlus was used for studying the thermal performance of a high-rise lightweight building with PCM wallboards located in Shanghai, China [24], and for the building under the study, the optimal melting temperature was found to be between 22-26°C. TRNSYS software was utilized by Stritih et al. to study the energy performance of a building with PCM integrated walls in summer, and it illustrated that the PCM can efficiently lower energy demand and be used in NZEB [25], and scrutinizing the energy and economic performance of a super-insulated wall, which was to be economically feasible in subarctic and polar climates with the transparent insulation material and PCM through the various climatic conditions [26]. A study which was done in Delhi, India, by Saxena et al. for investigating the thermal behavior of a PCM-enhanced brick considering two types of PCM showed the temperature of the PCM-enhanced brick is 5-6°C lower than that of the conventional bricks [27]. Using Enerciel 22 PCM, the impact of PCM position, thickness, and thermo-physical prop-

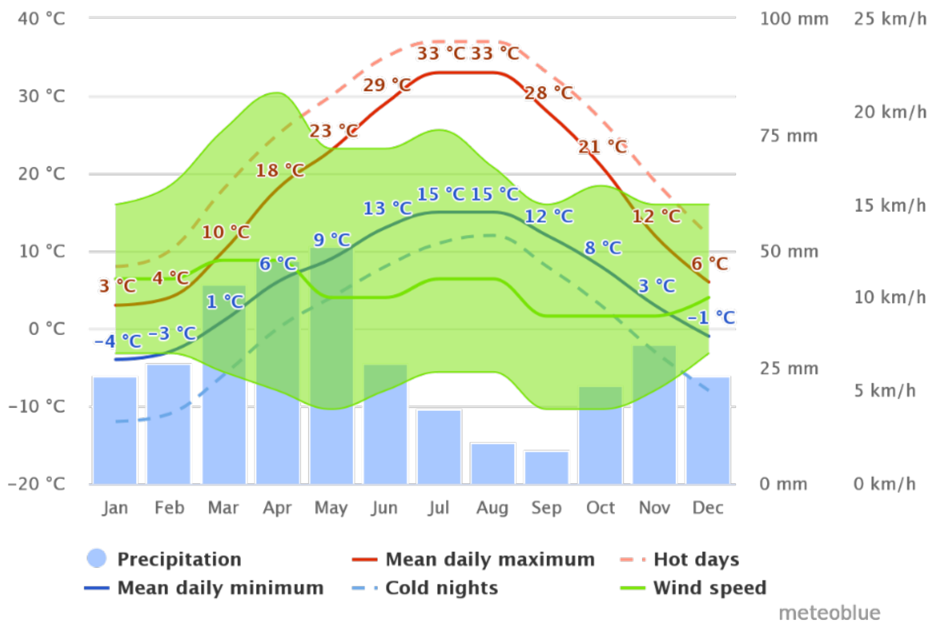


Fig. 2. Climatic information of Tabriz.

erties on the heat transfer were examined, and a reduction of 15-48% in heat transfer was observed [28]. Wang et al. also conducted a parametric study to evaluate the impact of several factors on the energy performance, showing that the optimized PCM could reduce the heat flow by nearly 35% compared to the wall without PCM [29]. A single-story building located in Melbourne was retrofitted by installing the macro-encapsulated BioPCM in ceiling and walls to minimize the heat stress caused by heatwaves [30], the results declared that the thermal comfort and occupants' health could be significantly enhanced through the use of PCMs. Through the use of TRNSYS software, the application of micro-encapsulated PCM in Cyprus was assessed, and it was identified that an energy saving of 66% could be attained when PCM was combined with the insulation layer [31]. Baniassadi et al. performed an optimization to unearth the optimal PCM and insulation layer thickness in terms of the minimum total cost in Iran and specified that the optimal PCM thickness in Iran was zero because of the existence of the economic situation [32]. By using two test structures, the thermal behavior of walls with PCM-impregnated cellulose insulation was experimentally studied, and the experiments showed that the PCM-cellulose wall could reduce daily peak heat flux by 25% [33]. To boost the energy performance of the building, Saffari et al. conducted an optimization of PCM melting temperature under various climatic conditions. While the optimal melting temperature for the warmer climates is 26 °C, it has been 20°C for the cooler climates [34]. The performance of an under-floor-heating system with PCM was studied by using the EnergyPlus tool, and it was observed that the utilization of the PCM with lower melting temperature could provide thermal comfort for occupants [21].

This study aimed to design an energy-efficient building. Furthermore, the role of AAC and PCMs in residential buildings was studied in terms of reducing monthly and annual energy, natural gas consumption, and also their role in sustainable development. In this regard, a residential building located in Tabriz, Iran, is examined in two cases and compared to the conventional construction (base case). In these cases, different HVAC systems and construction materials such as Autoclaved Aerated Concrete (AAC) blocks and PCMs were used.

2- Methodology

The present research is to decline the energy consumption of a building situated in Tabriz, Iran. Because of that, two scenarios are considered and compared to the base case. The followings are a detailed account of the procedure.

2- 1- Climatic conditions

The building was located in Tabriz, East Azerbaijan province in the northwest of Iran. Tabriz (38°04′N 46°18′E) has a cold semi-arid climate and falls under BSk Köppen climate classification. Fig. 2 presents the climatic information of Tabriz.

2- 2- Building description

A residential five-story building, as modeled in Fig. 3 with a total area of 900 m^2, was selected for the study. The ground floor of the building is parking, while the others are typical residential apartments, including a kitchen, bathroom, toilet, living room, and two bedrooms, as shown in Fig. 4. Besides that, the construction materials and their specifications are shown in Table 1. Table 2 has summarized the gains of the building. 3-mm clear single glazed windows with aluminum frames are used in the building. The thermal conductivity of the windows is 0.0176 W/m.K.

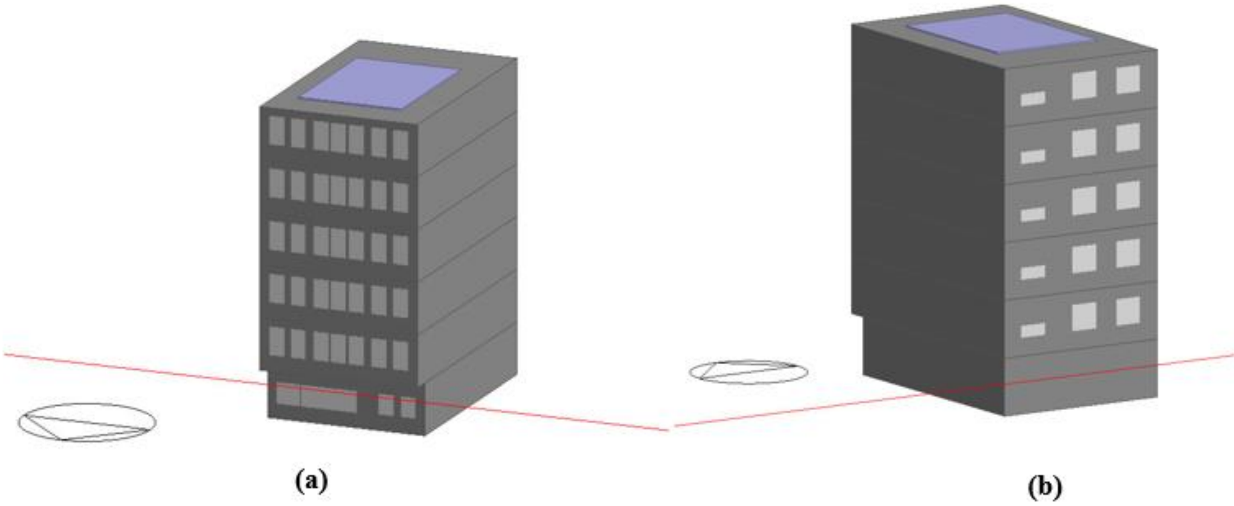


Fig. 3. 3D building model of case study: a) North view of the building b) South view of the building.

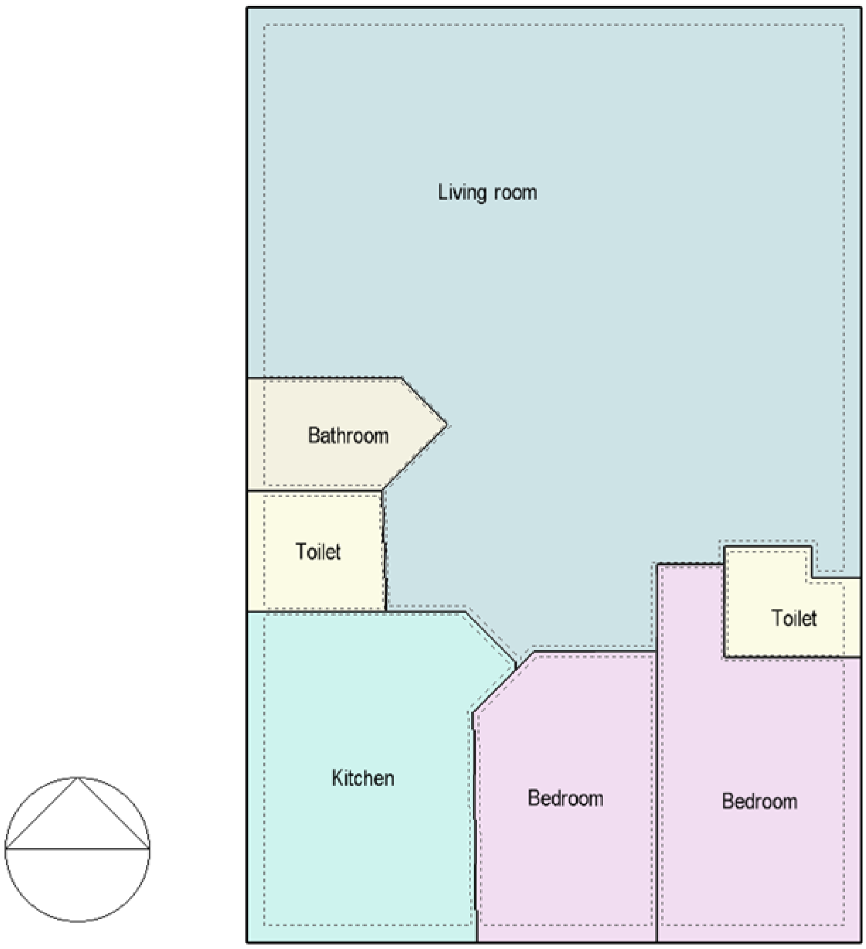


Fig. 4. The 2D plan of the building.

Table 1. The construction material used in the base case.

	Material	Thickness (cm)	Conductivity (W/mK)	Specific heat (J/kg.K)	Density (kg/m^3)
External walls	marble	2	3.5	1000	2800
	sand and cement mortar	3	1	920	1600
	concrete block	20	1.05	1000	900
	browning plaster	3	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal walls	white gypsum	1	0.57	1090	1300
	browning plaster	3	1.1	960	1500
	clay block	10	0.5	840	1850
	browning plaster	3	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal walls (between rooms and toilets)	ceramic	1	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	clay block	10	0.5	840	1850
	browning plaster	3	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal wall (between kitchen and toilet)	ceramic	1	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	clay block	10	0.5	840	1850
	sand and cement mortar	3	1	920	1600
	ceramic	1	0.85	1090	2000
Internal floors	ceramic	1	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	4	0.52	1000	1200
	concrete	20	1.5	1000	2200
	browning plaster	3	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Flat roof	asphalt	2	0.017	1000	2250
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	4	0.52	1000	1200
	concrete	20	1.5	1000	2200
	browning plaster	3	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Ground floor	marble	3	3.5	1000	2800
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	10	0.52	1000	1200
	concrete	75	1.5	1000	2200

Table 2. Gains of the base case building.

General Lighting (kWh)	Electrical appliances (kWh)	Occupancy (kWh)	Solar Gains (kWh)	Zone Sensible Heating (kWh)	Zone Sensible Cooling (kWh)
10622	7303	2126	36740	116467	17562

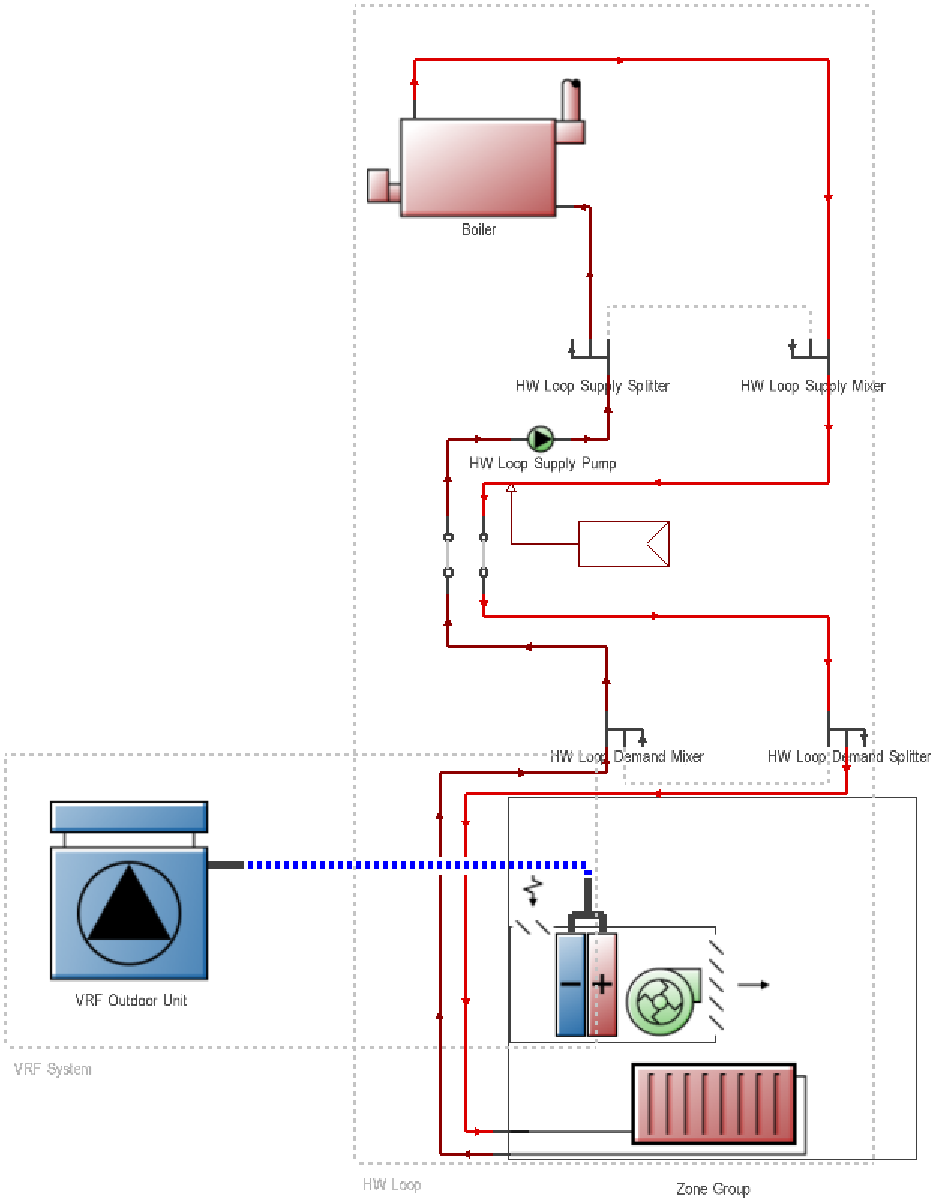


Fig. 5. Schematic of VRF system.

A central heating system for heating purposes and a VRF unit for cooling as illustrated in Fig. 5 was installed in the conventional building. The heating and cooling setpoints are taken to be 25°C. The heating and cooling setback temperatures are set at 22°C and 28°C, respectively.

2- 3- Case Studies

2- 3- 1- Case Study No. 1

In this case, Autoclaved Aerated Concrete (AAC) blocks, including the lightweight concrete with a low environmental footprint, were utilized in the building. Table 3 shows the

Table 3. The construction materials used in case No. 1.

	material	Thickness (cm)	Conductivity (W/mK)	Specific heat (J/kg.K)	Density (kg/m^3)
External walls	marble	2	3.5	1000	2800
	sand and cement mortar	3	1	920	1600
	AAC block	15	0.11	896	2800
	browning plaster	2.5	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal walls	white gypsum	1	0.57	1090	1300
	browning plaster	2.5	1.1	960	1500
	AAC block	15	0.11	896	2800
	browning plaster	2.5	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal walls (between rooms and toilets)	ceramic	1.2	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	AAC block	15	0.11	896	2800
	browning plaster	2.5	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal wall (between kitchen and toilet)	ceramic	1.2	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	clay block	10	0.5	840	1850
	sand and cement mortar	3	1	920	1600
	ceramic	1.2	0.85	1090	2000
Internal floors	parquet	0.8	0.14	1350	550
	elastomer insulation	0.5	0.32	1400	50
	sheet foam	0.2	0.1	1470	38
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	4	0.52	1000	1200
	floor concrete	20	1.5	1000	2200
	browning plaster	2.5	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Flat roof	asphalt	2	0.017	1000	2250
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	4	0.52	1000	1200
	elastomer insulation	0.5	0.32	1400	50
	concrete	20	1.5	1000	2200
	browning plaster	2.5	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Ground floor	marble	3	3.5	1000	2800
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	10	0.52	1000	1200
	concrete	75	1.5	1000	2200

Table 4. Specifications of the PV system.

Manufacturer	Universal Energy
Type	Monocrystalline
Power	200 W
Open Circuit Voltage	32V
Short Circuit Current	6.4 A
Number of modules	50

construction materials for case no.1. Triple-glazing windows with three 3-mm clear glass panes and a 13mm-air gap in between are considered in this case. The windows are made from thermally broken aluminum frames. Moreover, the building is equipped with a central heating system and an air-cooled compression chiller with a fan coil exchanger. Fig. 6 states the schematic of the HVAC system. To meet the electricity demand of the building, photovoltaic (PV) modules with a total area of 58.5m^2 are mounted on the roof with a tilt angle of 33° towards the south. Table 4 specifics the PV system.

2- 3- 2- Case Study No. 2

In addition to AAC blocks, phase change materials (PCM) are incorporated into the external and internal walls, as presented in Table 5. PCMs can reduce the building energy demand by stabilizing the indoor air temperature. Through the current study, bio-based organic PCMs known as BioPCM were utilized because they had been made of sustainably grown plant-based by-products with minimized environmental footprint. Considering the climatic condition of Tabriz, M51/Q25 BioPCM with a thermal storage capacity of 51Btu/ft^2 and melting temperature of 25°C is selected. The HVAC and PV systems are the same as case No. 1.

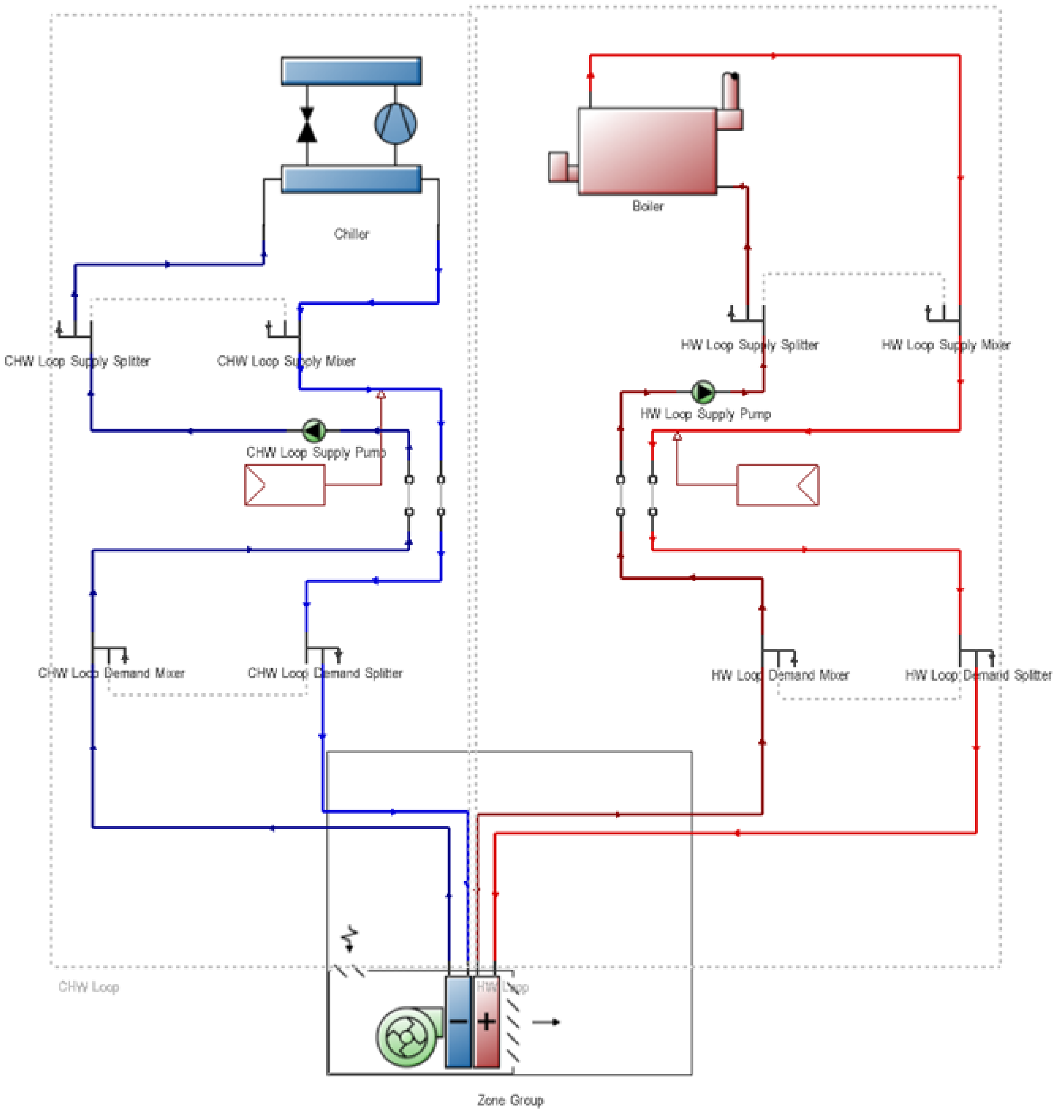


Fig. 6. schematic of FCU system.

Table 5. The construction materials used in case No. 2.

	material	Thickness (cm)	Conductivity (W/mK)	Specific heat (J/kg.K)	Density (kg/m^3)
External walls	marble	2	3.5	1000	2800
	sand and cement mortar	3	1	920	1600
	AAC block	15	0.11	896	2800
	browning plaster	2.5	1.1	960	1500
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	white gypsum	1	0.57	1090	1300
Internal walls	white gypsum	1	0.57	1090	1300
	browning plaster	2.5	1.1	960	1500
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	AAC block	15	0.11	896	2800
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	browning plaster	2.5	1.1	960	1500
	white gypsum	1	0.57	1090	1300
Internal walls (between rooms and toilets)	ceramic	1.2	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	AAC block	15	0.11	896	2800
	browning plaster	2.5	1.1	960	1500
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	white gypsum	1	0.57	1090	1300
Internal wall (between kitchen and toilet)	ceramic	1.2	0.85	1090	2000
	sand and cement mortar	3	1	920	1600
	clay block	10	0.5	840	1850
	sand and cement mortar	3	1	920	1600
	ceramic	1.2	0.85	1090	2000
Internal floors	parquet	0.8	0.14	1350	550
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	elastomer insulation	0.5	0.32	1400	50
	sheet foam	0.2	0.1	1470	38
	sand and cement mortar	3	1	920	1600
	clinker (lightweight concrete)	4	0.52	1000	1200
	floor concrete	20	1.5	1000	2200
	browning plaster	2.5	1.1	960	1500
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	white gypsum	1	0.57	1090	1300
Flat roof	asphalt	2	0.017	1000	2250
	sand and cement mortar	3	1	920	1600

	material	Thickness (cm)	Conductivity (W/mK)	Specific heat (J/kg.K)	Density (kg/m³)
Ground floor	clinker (lightweight concrete)	4	0.52	1000	1200
	elastomer insulation	0.5	0.32	1400	50
	concrete	20	1.5	1000	2200
	browning plaster	2.5	1.1	960	1500
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	white gypsum	1	0.57	1090	1300
	marble	3	3.5	1000	2800
	sand and cement mortar	3	1	920	1600
	BioPCM® M51/Q25	0.0208	0.2	1970	235
	clinker (lightweight concrete)	10	0.52	1000	1200
	concrete	75	1.5	1000	2200

2- 4- Simulation tool

Design-Builder v.5.0.3 was employed to assess the energy performance of the building. The mentioned software uses the Energy Plus engine for its simulations and can simulate advanced building materials like PCM with the variable thermo-physical properties [30]. A conduction finite difference (CondFD) algorithm is applied to discretize the building envelope into nodes and solve the heat transfer equation by a finite difference scheme. The temperature of the internal nodes can be obtained from Eq. (1):

$$\rho C_p \Delta x \frac{(T_i^{j+1} - T_i^j)}{\Delta t} = k_E \frac{(T_{i-1}^{j+1} - T_i^{j+1})}{\Delta x} + k_W \frac{(T_{i+1}^{j+1} - T_i^{j+1})}{\Delta x} \quad (1)$$

In which ρ is density (kg/m³), C_p is specific heat capacity (kJ/kg K), T is node temperature (°C), and Δx and Δt are finite difference layer thickness (m), and time step (s), respectively. i is the node being simulated, while $i-1$ and $i+1$ are the adjacent nodes. $j+1$ and j are the present and previous time steps, respectively. K_E (W/m °C) and K_W (W/m °C) denote the thermal conductivities between i and $i-1$ and between i and $i+1$, respectively.

C_p is updated at each iteration by Eq. (2) [35]. The iterations ensure that precise values of enthalpy and in turn precise values of C_p are calculated at each time step.

$$C_p = \frac{h_i^j - h_i^{j-1}}{T_i^j - T_i^{j-1}} \quad (2)$$

h is enthalpy which is defined as a function of temperature.

2- 4- 1- Validation

To evaluate the accuracy of the Energy Plus in building energy simulation, various investigations have been conducted, like the studies which were reported by Ascione et al. [35], Alam et al. [36], Kuznik et al. [37], and Auzeby et al. [38]. However, to further ensure the reliability of the findings, a single-zone building integrated with PCM as reported by Alam et al. [36] is simulated by DesignBuilder on an hourly basis from April 1 to April 2. Further information about the building can be found in Alam et al. The indoor temperature of the building compared to that reported by Alam et al., as shown in Fig. 7. It can be seen that the findings of the present study reasonably agree with those of Alam et al.

3- Results and Discussion

Having simulated the building in DesignBuilder, the present researchers introduce the monthly and annual results in this section. An economic assessment is also performed to ascertain whether the proposed cases are economically justifiable or not?

3- 1- Monthly energy performance

Both Figs. 8 and 9 illustrate the consumption of electricity and natural gas (NG) monthly for the three cases, respectively. It can be seen that the electricity and (NG) consumption can be reduced significantly through the proposed cases (cases 1 and 2). The electricity consumption comes down from May to June in the inclusion of PCMs, but the consumption slightly increases in the other months compared to case 1. As Fig. 8 shows, both cases 1 and 2 can considerably reduce NG consumption. However, the difference between cases 1 and 2 is negligible. The monthly electricity generation for cases 1 and 2 is also depicted in Fig. 10. It can be observed that the electricity generation peaks in summer, coinciding with the peak electricity consumption.

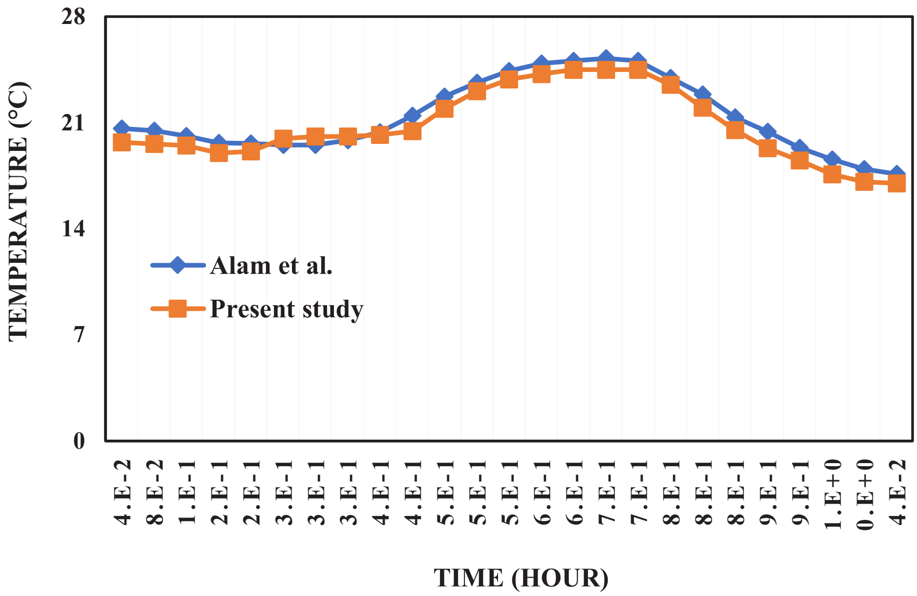


Fig. 7. Indoor air temperature of the single zone building.

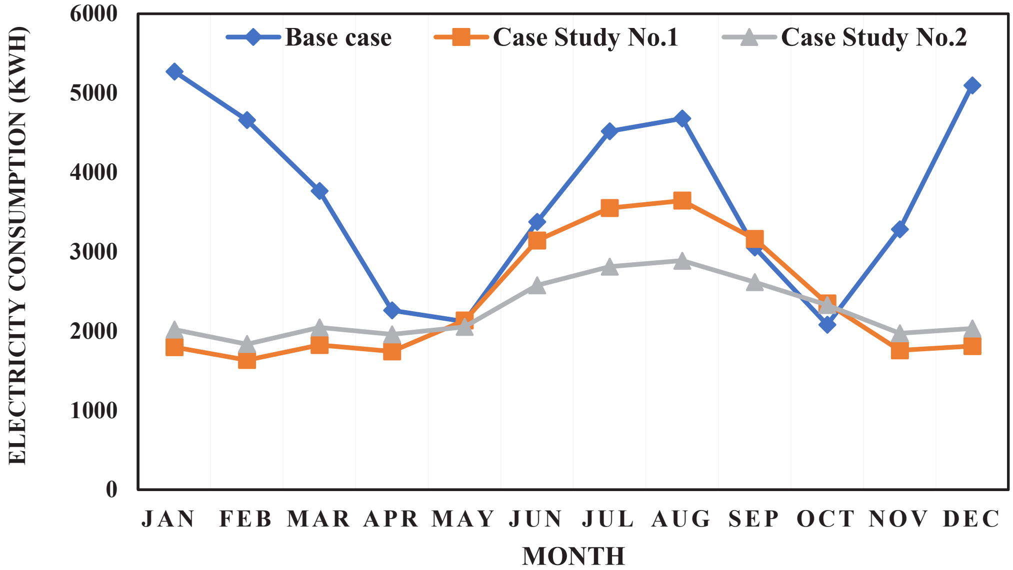


Fig. 8. Monthly electricity consumption.

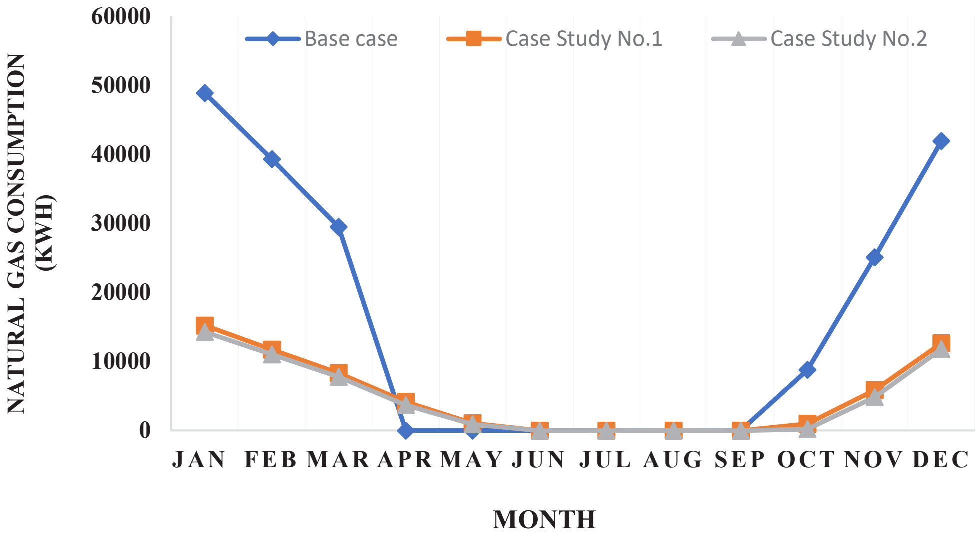
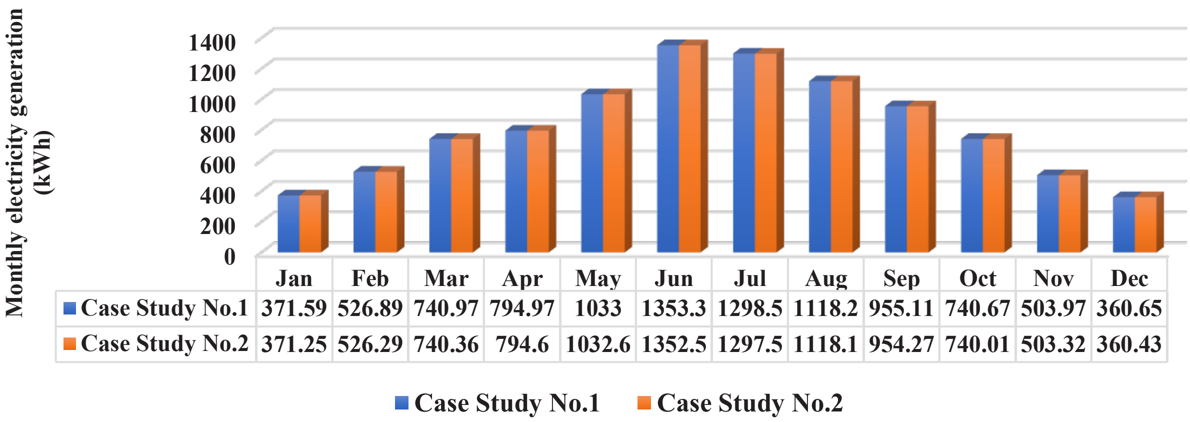


Fig. 9. Monthly NG consumption.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Case Study No.1	371.59	526.89	740.97	794.97	1033	1353.3	1298.5	1118.2	955.11	740.67	503.97	360.65
Case Study No.2	371.25	526.29	740.36	794.6	1032.6	1352.5	1297.5	1118.1	954.27	740.01	503.32	360.43

Fig. 10. Monthly electricity generation in both case studies.

Fossil fuel-based electricity generation in developed countries is one of the most important factors in the production and emission of greenhouse gases, and consequently climate change and global warming; whether diesel is used in electricity generation or the best-case electricity is produced with natural gas. Generating electricity with sources other than renewable sources is to blame for changing the future of the earth. However, based on the results obtained by Fig. 8, it can be concluded that using novel materials such as AAC and PCMs has a key role in reducing the monthly consumption of electricity. Regarding sustainable development and reducing the amount of electricity consumption in construction projects, especially in the coldest months such as January and February due to cumulative cooling and a relatively low sun angle, the use of the mentioned materials can be beneficial. According to the data obtained in this study, the use of AAC and PCMs has caused a decrease of approximately 4000 and 3000 (KWH) in the consumption of electricity in January and February, respectively. Also, the simultaneous use of materials AAC and PCMs instead of single-use of AAC in the case study project has reduced the consumption of electricity by about 500 (KWH) in the hottest months. Meanwhile, the amount of electricity consumption in all three cases was almost the same in October. In general, the use of new materials such as AAC and PCMs in cities with a cold semi-arid climate such as Tabriz has a significant role in reducing household electricity consumption. As electricity generation in developed countries has become one of the most important and challenging issues, contractors can use a variety of new and emerging materials to reduce energy consumption as well as sustainable development.

In the following years, along with population growth and economic growth, natural gas consumption will increase which environmental policies, energy efficiency, technological changes, and natural gas prices and alternative energy sources also will affect gas consumption. Therefore, most countries in the world try to reduce and manage natural gas consumption as much as possible. In te-rms of natural gas consumption in residential buildings, the use of smart and new materials plays an essential role in reducing the amount of natural gas consumption. Based on the data obtained from Fig. 9, the use of materials such as AAC and PCMs has reduced the consumption of natural gas in the months with low average temperatures such as January and February, so the consumption of natural gas in these months has decreased to at least one-third of the amount consumed in case study constructed by traditional and common materials.

3- 2- Annual energy performance

Figs. 11 to 13 compare the net energy consumption, the annual electricity, and NG consumption for the three cases, respectively. The net energy consumption, annual electricity consumption, and NG consumption are found to be 244 MWh, 19.56 MWh, and 193MWh for the base case, 78.7 MWh, 12.3 MWh, and 59.9 MWh for cases 1 and 71.7 MWh, 11.2 MWh, and 54.3 MWh for case No.2, respectively. The electricity consumption is reduced by 7.2 MWh for case 1 and by 8.4MWh for case No.2, while the NG consumption is dropped by 133MWh for case No.1 and by 139MWh for case No.2 compared to the conventional building. A reduction of 165MWh for case No.1 and 172 MWh for case No.2 is also observed in net electricity use.

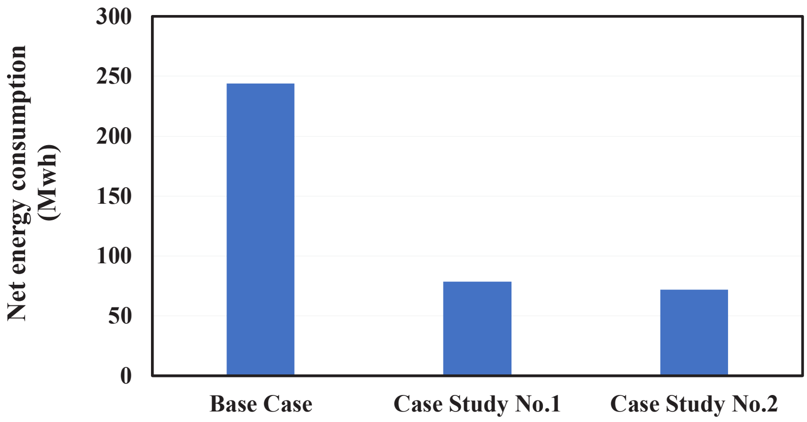


Fig. 11. Net energy consumption.

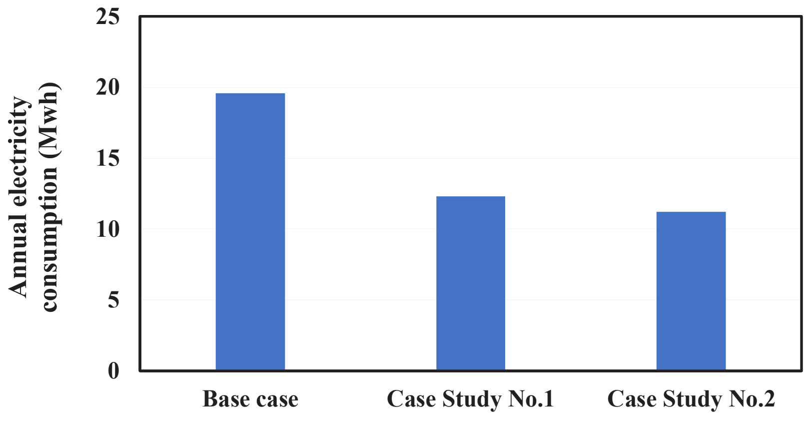


Fig. 12. Annual electricity consumption.

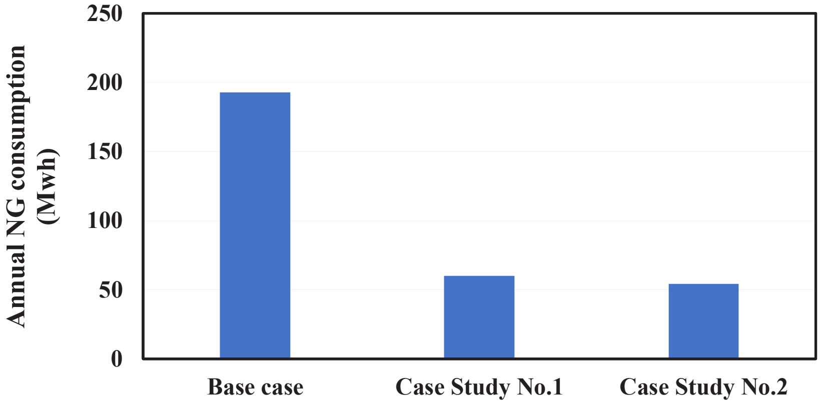


Fig. 13. Annual NG consumption.

Designing buildings that save energy consumption is now one of the main responsibilities of architects and other professionals. One of the great sources of thermal energy is the radiant energy of the sun. One way to store energy in a building is to store it in the form of latent heat. The use of phase change materials (PCMs) in buildings has a significant effect on improving thermal comfort and reducing energy consumption. According to Fig. 11, the use of common and traditional materials in residential buildings increases the amount of net energy consumption, annually. Regarding the data, the energy consumption of a 5-storey building located in a city with a cold climate is 250 (Mwh) per year, while the use of new smart materials can significantly reduce energy consumption in the buildings. In this study, the use of AAC in a residential building reduced the net energy consumption by 166 (Mwh) per year; in other words, each residential unit can have 33.2 (Mwh) energy savings. In case No.2, using a combination of materials AAC and PCMs in the residential dwelling can save nearly 172 (Mwh) net energy consumption compared to the construction of the building with traditional materials, which is an average of 34.3 (Mwh) per residential unit. In general, since the amount of energy consumption in cases No.1 and No.2 is slightly different, so the contractors and the project team can use AAC individually to reduce energy consumption if PCMs are not available.

In terms of electricity consumption, Fig. 12 shows that the annual consumption of electricity in a building executed by traditional materials is about 1.5 times the electricity consumption in a building executed by new and smart materials. Based on the results, using AAC in the residential building has been able to save 7 (Mwh) in electricity consumption. However, simultaneous use of AAC and PCMs in the residential building has been able to save approximately 8 (Mwh) in electricity consumption.

Consumption of natural gas in residential homes is one of the important issues that should be considered. According to Fig. 13, the annual consumption of natural gas in a 5-storey residential house located in an area with a cold climate is about 195 (Mwh). However, using AAC in the building has been able to reduce the annual consumption of natural gas to one-third of the amount consumed in the building constructed with traditional materials, accounting for 60 (Mwh); however, this value is reduced to 54.3 (Mwh) if AAC and PCMs are used simultaneously.

3- 3- Economic assessment

An economic assessment is conducted to ensure that the proposed cases are economically viable. According to the statistics, the cost of electricity and natural gas for the residential buildings located in cold climates such as Tabriz are obtained at 5$ and 1$ per Mwh, respectively [39, 40]. To consider the environmental effects, a carbon penalty cost of 20$/ton is also considered by the U.S. government [41]. Table 6 illustrates the area of the materials incorporated into cases 1 and 2 and their total cost. The energy and cost savings are also presented in Table 7. Although the price of natural gas and electricity in Iran is much lower than in other countries, the price of natural gas and electricity in developed countries such as Canada, according to statistics, are 33 and 112 $ per Mwh, respectively. According to the data, it can be seen that the amount of Electricity and NG cost savings in Tabriz are 41.8 and 138.7$ per year, in case No.2. Meanwhile, all prices are calculated based on 2020 data.

Table 6. The cost of materials used in cases 1 and 2.

Material	Area (m^2)	Cost ($/$m^2$)	Total cost ($)
AAC	870	4.52	3936
Insulation	150	4.76	714
PCM	870	22.53	19601
PV	58	4.59	260
Glass	82	9.52	781

Table 7. NG and electricity consumption, energy, and cost-saving.

Case	NG consumption (Mwh)	Electricity consumption (Mwh)	CO_2 generation (ton)	NG saving (Mwh)	Electricity saving (Mwh)	CO_2 saving (ton)	NG cost saving ($)	Electricity cost saving ($)	CO_2 cost saving ($)
Base case	193	19.56	92.08	-	-	-	-	-	-
Case 1	59.9	12.3	87.569	133.1	7.26	4.5	133.1	36.3	90.2
Case 2	54.3	11.2	50.60	138.7	8.36	41.5	138.7	41.8	830

Regarding comparing with other studies, results show that in the research conducted by Khakian et al. (2020), using the double Low-E glazing in the residential dwelling can reduce annual electricity consumption by 4%, while the current paper indicates that utilizing AAC and also the combination of AAC and PCMs could dwindle annual electricity consumption by 37.11 and 42.74%, respectively. Furthermore, Khakian et al. (2020) concluded annual NG consumption could be declined by 1.9% providing that the double Low-E glazing is used; in stark contrast, using AAC and also the combination of AAC and PCMs could decrease annual NG consumption in residential buildings by 68.96 and 71.86%, respectively. However, comparisons elucidate that using AAC and PCMs in residential buildings shows better performance rather than double Low-E glazing in terms of saving in energy consumption. Moreover, Khakian et al. (2020) suggested that Polyurethane could be an appropriate insulation material that can reduce the total building energy by 27.8% while using AAC and PCMs simultaneously can decrease the total building energy by 70.6%. additionally, Thiele et al. (2015) proposed that adding microencapsulated PCM to the exterior concrete walls could save the annual electricity cost ranging from 94$ to 143$ in Los Angeles; on the other hand, the amount of electricity cost saving in Tabriz is 41.8% if PCMs are incorporated with AAC in residential building. So, we can use microencapsulated PCM instead of PCMs and AAC when the electricity cost saving is deemed as the main purpose.

4- Conclusion

The main aim of the present investigation was to reduce the energy consumption of the buildings. To respect this, a four-story residential building situated in Tabriz, Iran, was selected as the case study and investigated in three cases. Thus, DesignBuilder primarily simulated the conventional building as the base case to evaluate the performance of its energy. Then, in cases 1 and 2, the researcher utilized various building materials like AAC blocks and PCMs. The considered building was equipped with VRF HVAC, yet for improving the efficiency of the energy, the FCU system was spotted in cases 1 and 2. The findings of the research are as follow:

- For case No.1, the net energy consumption of the building would be declined by 165 MWh/yr. in contrast, it was 172 MWh/yr. for case No.2.
- For case No.1, the annual electricity consumption would be decreased by 7.2 MWh, but it was 8.4 MWh for case No.2 compared to the base case.
- For case No.1, the annual NG use would be reduced by 133 MWh, while it was 139 MWh for case No.2.

To sum up, case No.2 were incorporated the PCM and AAC blocks into the construction and considered an FCU HVAC system that included optimum energy efficiency. In addition, using PCMs and AAC blocks can significantly save energy costs in countries with high energy costs. To apply modern construction methods for the processing of reducing energy consumption and costs, it is necessary to have a coherent and integrated environment. In this case, the efficiency of this research will be more guaranteed than before. Due to the differences in the executive structure in the methods of construction or execution of construction activities, depending on the needs and goals of the projects, and climatic conditions of the project, researchers can assess the efficiency of various novel materials and methods such as photochromic materials, halochromic smart materials, and Thermal expansion smart materials for sustainable development and reducing energy consumption.

In the future, we will try to analyze energy data by using various smart and emerging materials and parameters and energy consumption in construction projects, which will include more comprehensive information in all construction activities to achieve sustainable development.

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