Journal of Petroleum Science and Technology 14(3): 43, 2024, Pages 30-40
DOI:10.22078/jpst.2025.5598.1965

Journal of Petroleum Science and Technology

Research Paper

https://jpst.ripi.ir/

Reducing Energy Consumption in Organizational Buildings of National Iranian Oil by Accurately Adapting Consumption Patterns, Cold Storage Tanks and Solar Panels

Rawand Abdollah, Ali Ali Nia Ziazi*, and Mohammad Najafi

Department of Mechanics, Islamic Azad University, Tehran Branch of Science and Research, Technical and Engineering Faculty, Iran

Abstract

Nowadays, with the increase in energy consumption, governments are forced to apply various tariffs to optimally control energy consumption in society. For this reason, electricity consumption meters have been designed and implemented in three modes: low, medium, and peak load. One of the methods that can be used in the summer season to reduce energy consumption is to store cooling load in low-load hours and use it during high-load hours. In this design, an ice chiller is used to prepare ice in a tank. In this thesis, first, a 5-story, two-unit building in the east of Tehran was dynamically simulated with Design Builder software, and accurate heating and cooling loads were obtained. Then, the ice tank was designed in such a way that it can cool all the units from 1:00 p.m. to 11:00 p.m. The amount of savings in the simulation with this year's electricity tariff was about 965$ in one year, which will result in a return on investment of about 5 years for this building. Also, to reduce energy consumption during the day and based on accurate simulation results, 20 high-efficiency 500-watt panels were used to provide electricity for lighting and equipment, which economic calculations showed that this amount will be returned in less than two years.

Keywords: Ice Storage, Builder Design, Dynamic Simulation, Energy Consumption Optimization, Solar Panels.

Introduction

Buildings account for 30% of global energy consumption and 26% of energy-related emissions. Of these emissions, 8% come directly from the buildings themselves, while 18% come from energy used for heating and cooling produced by power plants. In 2022, energy consumption for cooling increased by more than 5% compared to 2021. This increase affects peak electricity demand, especially on hot days, which may lead to power outages [1].

These days, the issue of global warming and trying to find clean sources for air conditioning in homes and factories is one of the global concerns. About 25 years ago, advanced countries such as France, Italy, Germany, Belgium, the Netherlands, etc., used the ice storage system as an air conditioner for residential and commercial complexes, office buildings, and hospitals in the year's hot seasons. And every year, governments consider benefits and incentives (or motivations) for the widespread use of this process in construction infrastructure [2].

Chillers impose high costs on households by consuming large amounts of electrical energy to convert hot summer air into pleasant spring air. Also, providing this energy during the peak consumption hours in this year's season requires a lot of government power to increase the power plant load.

An ice thermal storage system refers to using the power of chillers to make ice in tanks during low-load hours of electric energy and using the latent heat of these tanks for air conditioning of buildings during high-load hours. In the middle and hot hours of summer days, due to the highest use of electrical energy in cooling buildings, the energy consumption peak occurs. Sometimes, we may witness outages and disruptions in the electricity distribution network due to an excessive increase beyond the power plant's capacity. In addition to achieving an air conditioning system, even during power outages, and reducing the consumption during these hours of the day, we should have ideal ventilation by using ice storage technology.

In this method, the water in the tanks turns into ice at night, and due to the lower temperature at night, the

**Corresponding author:* Ali Ali Nia Ziazi, Department of Mechanics, Islamic Azad University, Tehran Branch of Science and Research, Technical and Engineering Faculty, Iran

E-mail addresses: Ali_alinia@srbiau.ac.ir

Received 2024-12-29, Received in revised form 2025-02-26, Accepted 2025-03-11, Available online 2025-08-16

double pressure to the condenser and compressor of the chiller is reduced, and their efficiency is increased. Also, these ice tanks are cooled with the help of chillers during the hot hours of the day. They reduce the pressure on the cooling device and chillers by providing the highest cold temperature during peak consumption hours. It is worth mentioning that using the ice storage system in places that calculate the cost of electricity consumption according to the time of consumption will be much lower. Steel, concrete, and even plastic can be used to make ice tanks in the ice storage system. Depending on the type of covered and military tanks, they can be installed on the ground, roof, or basement.

Many studies have been conducted in energy storage and optimization; some are experimental, and some are numerical. Certainly, in projects that need to attract investors, it is better to carefully examine all refrigeration needs and simulate according to exact hourly tariffs, i.e. the investor can be sure of the return on their investment. In 2024, Toffoletti et al conducted an experimental study on the use of ice storage systems and optimal consumption control. Moreover, they reported that the use of storage systems could save €58,699 over 10 years. Also, this system dramatically reduces the required capacity of heat pumps for the whole system [3].

In the optimization and application of consumption reduction algorithms, the need for accurate data is extremely critical, and the more information we have, the better and more accurate technical and economic calculations we can provide. Furthermore, in 2024, Yu M and colleagues conducted detailed studies using imaginary functions to optimize energy consumption and the optimal design of ice tanks and batteries. Moreover, they reported valuable data on the simultaneous reduction of energy consumption and environmental impact [4].

Simultaneous control of cold production and storage can also help greatly in reducing energy costs. In this regard, Zhao et al. experimentally investigated the coupled control system between the cold storage and consumption sections. Using this method, they reported a reduction of about 21% in energy costs [5].

Many studies have been done on the types of converters used in the ice storage sector. The effect of using corrugated tubes compared to smooth tubes in ice storage exchangers was investigated in 2024 by Wang Y et al. They reported that, contrary to the idea, reducing the height of the fins on the tubes increases the heat transfer efficiency, and this is due to the better formation of the boundary layer on the tube surface [6].

The use of renewable energy sources to convert water into ice will greatly help in reducing energy consumption. In this regard, Xia et al presented a comprehensive review on a new photovoltaic ice storage air conditioning system. They studied the system's performance through experiments and built a mathematical model for comparative verification. In addition, the experimental results showed that the daytime cooling COP of the system is 1.18, the photovoltaic conversion efficiency is 6.29%, and the nighttime cooling time is 9 hours, which meets the cooling requirements. They also optimized the performance of the system through simulation [7].

The use of horizontal and vertical heat exchangers in storage systems was reviewed in 2024 by Chang et al. Furthermore, they reported that vertical heat exchangers perform 13.3% better than horizontal ones, and the main reason for this is better natural displacement in vertical heat exchangers and boundary layer mixing [8].

The use of regional cooling systems due to their high flexibility in planning will significantly help reduce summer electricity consumption. Moreover, in 2024, Mr. Zhu P and colleagues conducted an experimental study on large-scale distributed ice storage systems. In addition, their study develops models based on per-unit value for DCS with ice storage units, and employs several objective functions to validate the choice of base values, demonstrating the superiority of the calculation process for the per-unit value model. The simulation results show that the adoption of DCS unit value models significantly reduces the calculation time, especially for large systems, where it is possible to reduce the time consumption by more than 68% [9].

Solar ice slurry systems are a good alternative to thermal systems (such as heat pumps). A relatively complete study in continental Europe in 2024 by Arenas-Larrañaga et al. to investigate the energy performance of two solar ice slurry systems (one using carbon dioxide as refrigerant for an electric heat pump and the other using propane) under boundary conditions was conducted in a variety of ways. In this study, they investigated the effect of the main parameters on the system's overall performance. The simulation of the Hass building section was done using Transys software. Their results showed that the system based on carbon dioxide has a better performance [10].

To optimize energy in the building sector, heating and cooling loads must be accurately calculated, and devices with high efficiency and accurate management must be designed to supply this energy. Moreover, total site integration can be used to manage energy production and consumption [11]. If accurate building energy consumption data (for example, hour by hour) is available, we can use programming and match the experimental diagrams of energy production devices with the amount of consumption instead of using statistical methods (which are not very accurate) [12]. Another important factor in providing thermal and cooling loads is to consider the performance of devices in conditions outside of design. This parameter strongly affects the final energy consumption of the entire building, because in conditions outside the design, the device's efficiency will decrease drastically, and its energy consumption will increase. Furthermore, this increase in consumption will have a significant effect on the economic sector of computing in the long run [13]. Another factor affecting office buildings' energy costs is the use of variable tariffs during the day and according to peak hours. The more you can use less energy during these hours or save the required amount of energy during off-peak hours (from 12:00 PM to 6:00 AM), the more attractive you can be in implementing energy consumption optimization plans from a financial point of view [14]. Unfortunately, most of the existing buildings in Iran are interested in energy independence, so the use of central HVAC is limited.

Despite the significant increase in electricity tariffs, especially in the administrative and commercial sectors, energy costs in Iran are still very low. For this reason, the initial price of many energy optimization equipment is not justified for building owners. The relatively reasonable initial price is what causes the penetration of this equipment in the consumer market.

It is not economical for governments to create new electricity production facilities based on maximum demand, and this has caused power cuts in administrative departments and factories in recent years. So, one of the best solutions is financial assistance to the owners of commercial and office buildings to use high-efficiency HVAC systems that help reduce power consumption, especially in summer. One of the best solutions for reducing power consumption by chiller is using ice storage for peak shaving. Today, the desire to use software whose part of its libraries relies on accurate experimental results has increased. In fact, this database greatly helps the accuracy of the software in predicting the main parameters. One of these software programs that is used in the construction sector is Design Builder software. The main engine of this software is Energy Plus, which is taken from the US Energy Department, and many simulations have been done with it so far [15-17].

Government policies and regulations are pivotal in driving energy efficiency initiatives in buildings. Mandates for energy performance standards, green building certifications, and incentives for renewable energy adoption can incentivize compliance and spur innovation. Moreover, public-private partnerships and collaboration with industry stakeholders can facilitate knowledge sharing and resource mobilization for energy management projects.

So far, many studies have been conducted on the use of ice tanks in different climates, but the required cold load has been calculated from static results. In this study, an attempt has been made to accurately calculate the required amount of ice by accurate and hourly (dynamic) simulation of the cold loads and obtain the best performance for the chiller by having the experimental diagrams of the efficiency of the ice-making chiller. Also, to reduce electricity consumption during the day, solar panels were used according to the exact requirements calculated in the software. To reduce investment costs in these systems, batteries are not used.

Problem Description

First, for the accurate simulation of energy consumption (gas and electricity), a 5-story, two-unit building with two parking floors, each floor about 156 square meters, was modeled using the Design Builder software. This modeling includes entering detailed architectural details and construction materials used in the building. The software enters the total number of equipment and other electrical devices used in this building, along with the amount of electricity consumption. The number of times doors and windows are opened should also be included to calculate heat loads. This building is located in the eastern part of Tehran. After modeling all the details and specifying the height of the nearby buildings (to discuss radiation reflection or creating shadows in cold load calculations) and their dominant color, a simulation was done hourly for one year. The software output includes all thermal loads, cooling loads, electricity, received radiation, wind speed, air exchange rate, and other detailed information.

In the next step, based on the cooling load, we should select a high-efficiency ice maker chiller with the exact capacity for these buildings. Furthermore, these devices have characteristic diagrams that must be considered when operating in off-design mode. In fact, the thermal or cooling requirement of the exact efficiency of all the devices is considered in the coding against each hour. With hourly information on electricity and gas consumption, you can make an accurate choice for solar panels, which will significantly reduce energy consumption during the day.

In Fig. 1, the building is drawn in three dimensions. Nearby buildings are also drawn in this figure. If you zone any floor, you can see the details related to that floor. After the complete shape of the building is accurately drawn, the activity in each area of the building should be determined. This division is related to the comfort temperatures of each region. For example, the comfort temperature of washrooms is different from that of dining rooms. This division is shown in Fig. 2.

Fig. 1 The three-dimensional shape of the building and the height of the adjacent buildings.

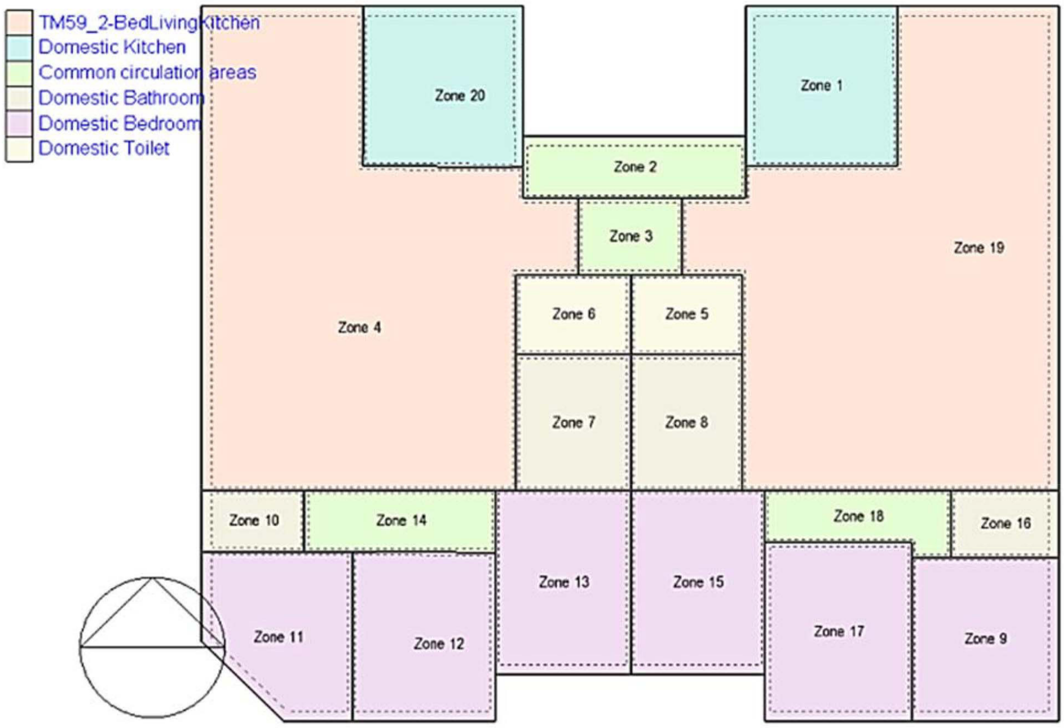

Fig. 2 Zoning of the first to fifth floors.

In the next step, we have to specify the material of the software's internal and external walls and ceilings. Also, all the thicknesses should be specified to calculate the heat transfer coefficient. these specifications are presented in Tables 1 to 3.

Table 1 Materials of external wall layers in the software

Layer	Thickness (cm)
Color	0.1
soft plaster	1
Plaster and plaster and soil	1
earthenware	10
Gypsum plaster and soil	1
soft plaster	1
Color	0.1

Table 2 Materials of internal wall layers in the software

Layer	Thickness (cm)
Color	0.1
soft plaster	1
Plaster and plaster and soil	1
earthenware	10
Gypsum plaster and soil	1
soft plaster	1
Color	0.1

Table 3 Materials of external roof layers in the software

Layer	Thickness (cm)
Asphalt	10
Cement plaster	10
Concrete Roofing Slab	20
plasterbord	1/3
Color	0.1

In the discussion of energy consumption simulation, you must accurately specify the amount of cold air penetration and lighting of the building. Also, all the electronic equipment and the duration of their usage have also been determined. After inputting all necessary data into the software, we run hourly simulations to generate detailed reports on thermal and cooling loads and electricity consumption. The algorithm governing the problem is drawn in Fig. 3. In fact, every hour, these calculations are completed through coding in the output of the software and are considered for one year.

Materials and Methods

Technical Specifications of the Equipment

Table 4 specifies the technical specifications of the ice maker chiller, along with its power consumption and efficiency. As the table clearly shows, the refrigerant gas output pressure at the compressor's output is equal to 10 bar, and its power is about 10 horsepower. Table 5 shows the technical specifications and costs associated with various storage methods for cooling.

Results and Discussion

Fig. 4 shows the building's daily heating loads. The maximum daily load is about 1600 Kw-h. As can be seen in the figure, the thermal demand for hot water is almost constant and equal to 200 kilowatt hours per day. Moreover, the amount of heat needed per square meter in the building is 50 watts per square meter, as shown in Fig 5. The amount of filtration in different seasons is shown in the figure below. As Fig. 6 shows, this ventilation is more intense in the winter season.
The cooling load for the building (all units) is drawn in Fig. 7.

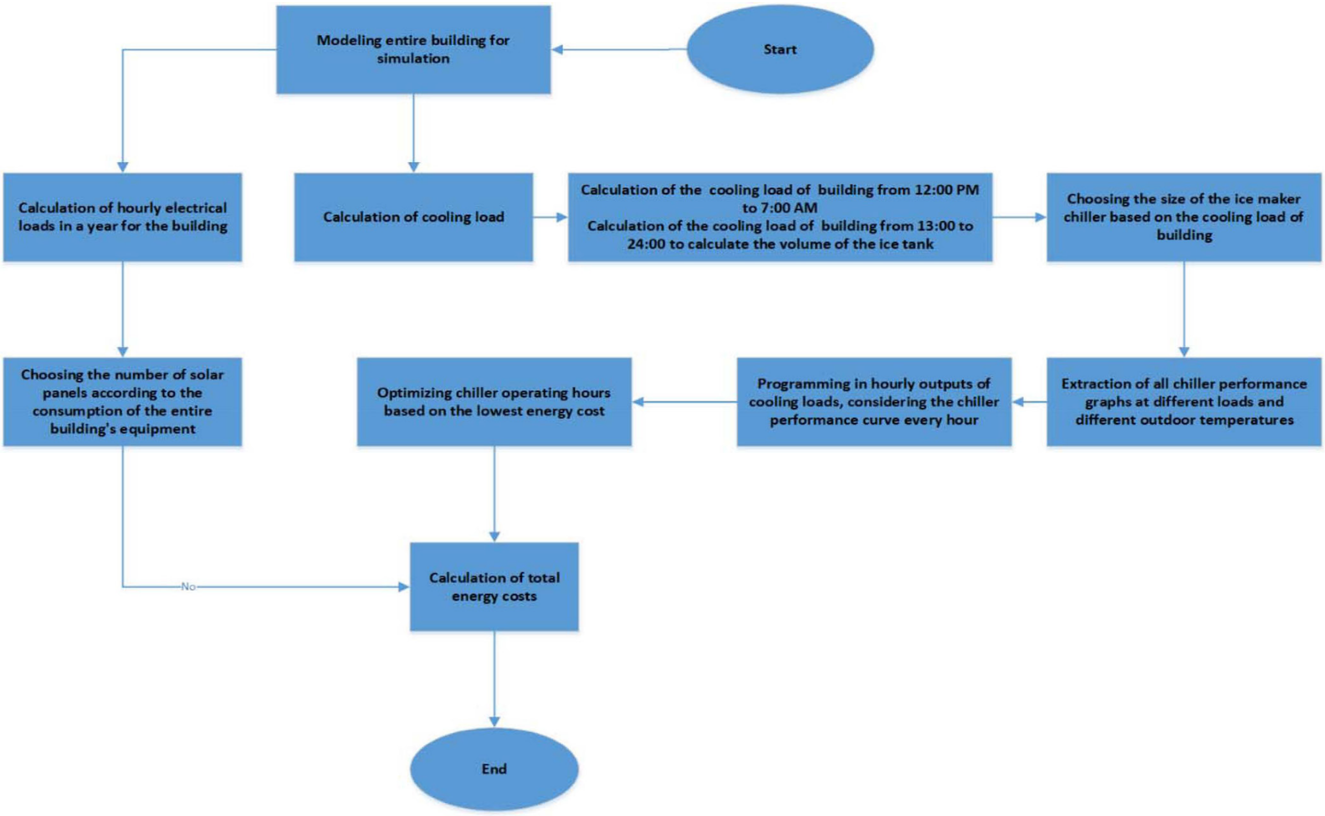

Fig. 3 Algorithm governing the problem.

Table 4 Technical specifications for Ice maker chiller [18].

Technical specification				
Power	3 Phase	Rated Input	10	hp
		Voltage IFrequency	400, 50	V, Hz
		Phases	3	Phases
		Modulation	5-10	hp
Cooling Characteristic	Refrigrant	R415	5kg	
	Pressure	10	bar	
	Power of the Glycol circulation pump	1.5	hp	
Cooling output	Rated Ice production	10 Ton	Within 24 h	
	Operating Capacity	7 Ton	At night, for a maximum of 50 F	
Dimention	60-36.5-48	inch		

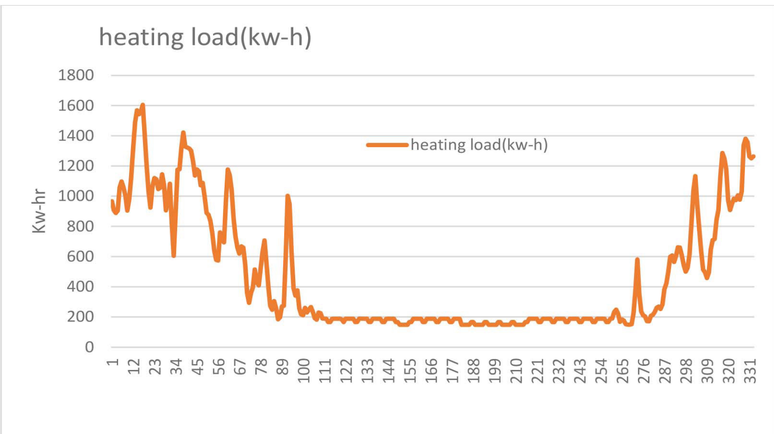

Fig. 4 Daily heating load.

Table 5 Summary of Cool Thermal Storage Technologies [19].

Parameter	Units	Chilled water		Ice Harvester		External melt ice		Internal melt ice		Encapsulated ice		Phase-change Material	
	Range	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Chiller Cost	$/Ton	200	300	1100	1500	200	500	200	500	200	500	200	300
	$/kwh	57	85	313	427	57	142	57	142	57	142	57	85
Tank Volume	Ft3/ton-h	11	21	3	3.3	2.8	2.8	2.4	2.8	2.4	2.8	6	6
	M3/kWhr	0.089	0.169	0.024	0.027	0.023	0.023	0.019	0.023	0.019	0.023	0.048	0.048
Storage Installed Cost	$/ton-hr	30	100	20	30	50	70	50	70	50	70	100	150
	$/kwh	8.53	28.4	5.7	8.5	14.2	19.9	14.2	19.9	14.2	19.9	28.4	42.7
Charging temperature	F	39	42	15	24	15	25	22	26	22	26	40	42
	C	3.9	5.6	-9.4	-4.4	-9.4	-3.9	-5.6	-3.3	-5.6	-3.3	4.4	5.6
Chiller Charging Efficiemcy Indicators	COP	5	5.9	2.7	3.7	2.5	4.1	2.9	4.1	2.9	4.1	5	5.9
	Kw/Ton	0.6	0.7	0.95	1.3	0.85	1.4	0.85	1.2	0.85	1.2	0.6	0.7
	Kw/Kw	0.171	0.199	0.27	0.37	0.242	0.398	0.242	0.341	0.242	0.341	0.171	0.199
Discharge Temperature	F	40	46	34	36	34	36	34	36	34	38	48	50
	C	4.4	7.8	1.1	2.2	1.1	2.2	1.1	2.2	1.1	3.3	8.9	10

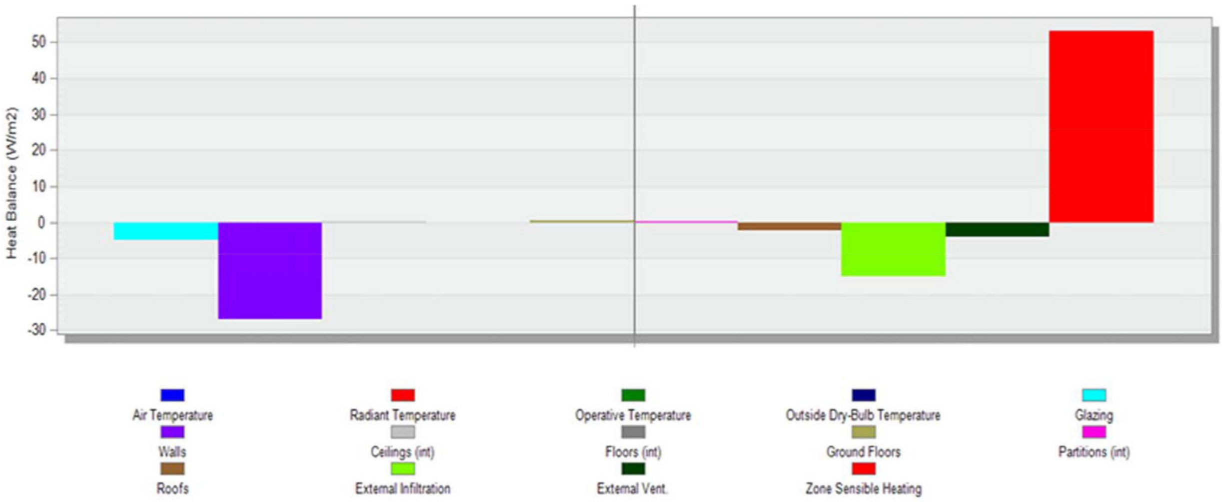

Fig. 5 Heat Balance (w/m^2).

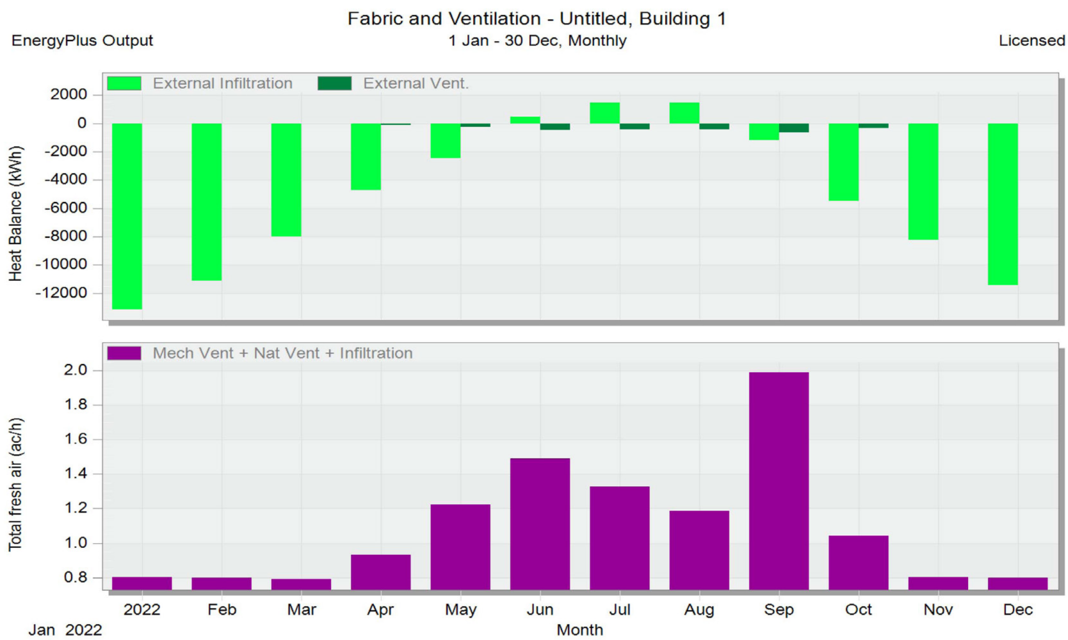

Fig. 6 External Infiltration and Total Fresh Air.

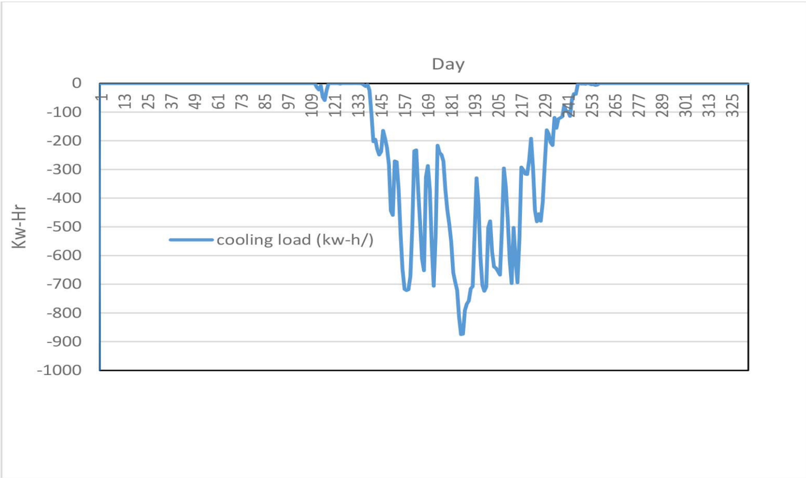

Fig. 7 Daily cooling load.

According to these results, the maximum cooling load is about 900 kWh. Note that the numbers presented in the graph below are the result of the chiller operating for a full day, and the amount of refrigeration load during peak hours will undoubtedly be a very large number.

If we want to calculate the average power based on 900 kWh, the chiller capacity is equal to the following value:

Capacity=900/24=37.5kw

Ton Ref=37.5/3.52=10.65 Tons

Based on the above calculations, the capacity is equal to 11 tons, but if we act based on the hourly data output from Design Builder software, the maximum cooling load requirement is as follows:

Ton Ref=85/3.52=24.14 Ton

Note that the number 85 is the highest hourly cooling load of the year. According to the calculations, the cooling load is between 20 and 25 tons of refrigeration. Fig. 8 shows the total energy consumption in different months of the year. This energy includes both electricity and gas.

To calculate the capacity of the ice storage tanks, the cooling load has been calculated from 13:00 to 23:00 for each day. Moreover, the maximum cooling load for these hours reaches about 600 kilowatt hours, which, after unit conversion, is equal to 2131200 kilojoules. This amount of cooling is equal to the cooling created by 6000 kg of ice, which we need to consider a tank with a height of 1 meter, length of 3 meters, and width of 2 meters for this building. In addition to producing 6000 kg of ice, the chiller must supply the building's required refrigeration load during night operation. According to the Fig. 9, the maximum cooling rate from midnight to 7 am equals 160 kilowatt hours.

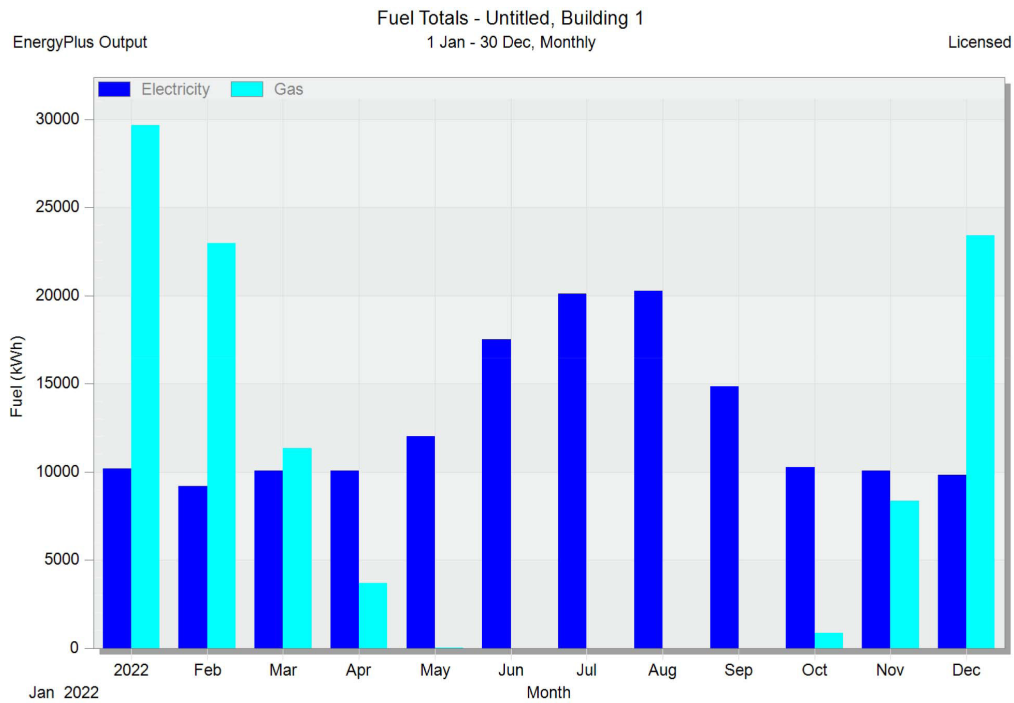

Fig. 8 Total energy consumption in different months.

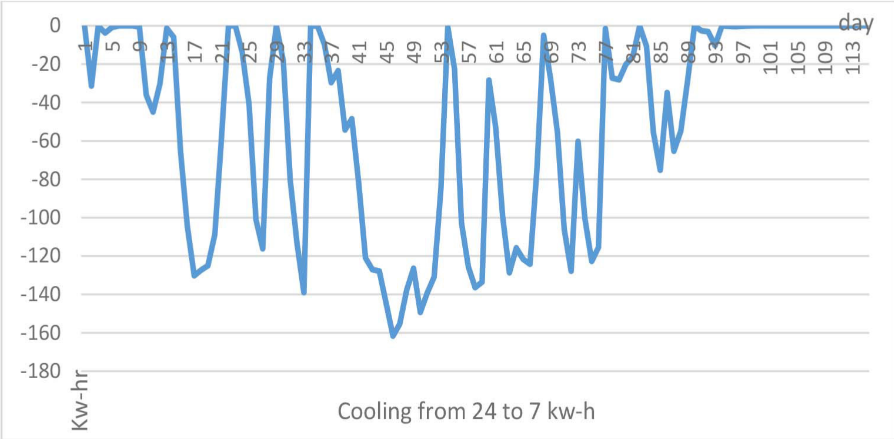

Fig. 9 Cooling load from 24:00 to 7.

Considering that the cooling loads are calculated separately, the solar panels in this building will only be used for electrical equipment and lighting during the day. The maximum lighting load required in our field is about 8 kilowatts. On the same day, the maximum load of the equipment in the building is about 5 kW.
We consider the usage charts to calculate the required number of solar panels. In fact, according to the previous calculations, we need about 10 kilowatts (5 kilowatts of lighting and 5 kilowatts of equipment) of electricity from the solar panel to cover the consumption of lighting per day and electrical equipment per day. The price of each 550-watt monocrystalline panel from the reliable company AE costs about 100 dollars. According to the calculation of the required electricity, 20 panels should be purchased, the total cost of which is 2000 dollars. In addition, this cost should be done only for the purchase of the panel, and if it is necessary to store the price of the batteries, which becomes a large number, it will be added to the total costs. The battery package has been removed due to economic discussions and a lack of acceptance by buyers.

Effect of Adding Polystyrene Insulation to Exterior Walls
To investigate the insulation in exterior walls, the composition of the layers in the exterior walls was changed as shown in Fig. 9. In this case, the overall heat transfer coefficient will be 0.351, which has resulted in a reduction of about 80%. In this case, the heat loads over a year will be as follows. As Fig. 10 shows, the maximum heat loads have decreased from 1600 kWh to 900 kWh, i.e. a 50% reduction in the maximum heat load.

The results for cooling loads are as follows. In this case, the maximum cooling load is greatly reduced (Fig. 11), but at times when the cooling load is low, its effect is not great. It causes the storage of heat loads inside the walls during the day and slightly increases the required cooling load. According to Fig. 12, external wall insulation is more beneficial for the heat load.

Fig. 10 Different layers of exterior walls (3 inches of added polystyrene insulation).

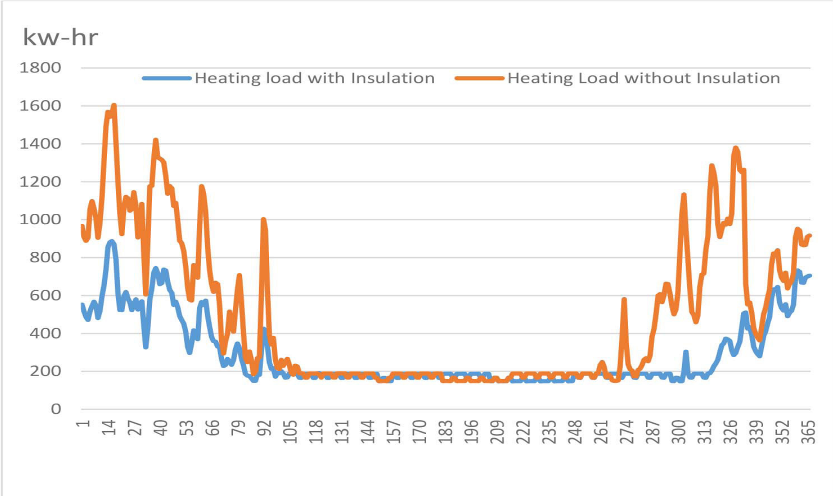

Fig. 11 Daily heat loads for two different modes.

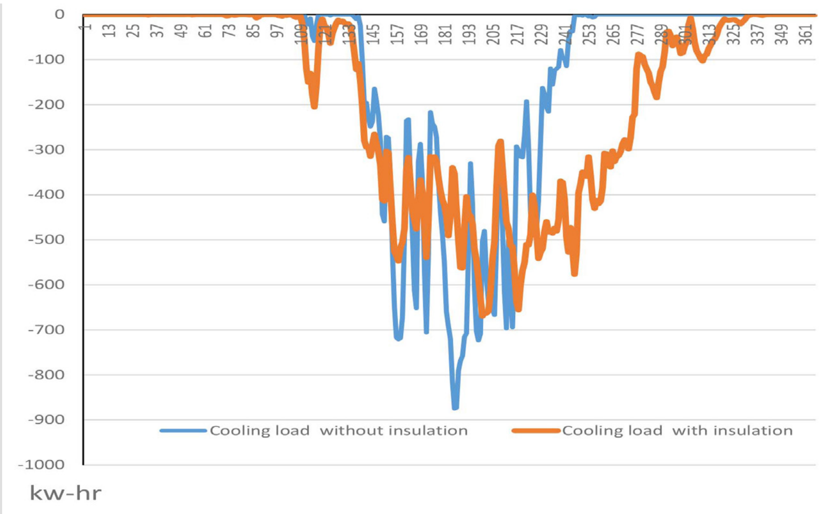

Fig. 12 Daily cooling loads for two different modes.

Economical Consideration

Before economic calculations, it is necessary to determine the difference between low and peak load tariffs for office and residential buildings in Tehran. According to Table 6, this amount is staggered for different uses and reaches 3.5 cents per kilowatt hour at the maximum. The division of different hours in the electricity tariff is explaine in Table 7.

By applying the above assumptions in the hourly schedule of the entire building, the cost of electricity will be calculated hour by hour and multiplied by the specified tariff. After the calculation, we will reach 1543 $ in 1402. Of course, if we reduce the chiller's efficiency during peak hours and do not work at full load during low load, about 20% will be added to the mentioned amount, which will reach 1852$. Moreover, each unit's share in 1402 is about 186$ per year (residential electricity with penalty).

In the second case, the peak cooling load is transferred to the low load mode. In this case, the cost of electricity will be 877. Note that we have access to the building's cooling load hour by hour in the Design Builder software. We calculate the exact amount for each day and calculate the electricity cost accordingly.

Table 6 Residential electricity tariff (including penalty).

Residential electricity cost in cents per kilowatt hour		
low load	medium load	peak load
0.5	1.31	3.5

Table 7 Separation of different hours of electricity consumption in tariff application.

Low load hours	middle hour	Peak hour
24 to 7	7 to 13	13 to 24

The difference between the two scenarios is $ 965$ per year, which will be considered income in cash flow. The additional equipment needed in the second scenario is as follows:

1- Ice storage tank

2- A separate control system to control the whole system

3- Separate pumping system for cold water circulation in the alternative system

According to the inquiry made from domestic companies, this equipment, along with a 6 cubic meter insulated tank, will add a price of around 5000$ to the costs. The return on investment in this case will reach 5 and a half years, which is not very suitable. Considering that the implementation of these projects will greatly help the electricity supply by the government, it is better to provide an amount of the required investment by the Ministry of Energy so that the return on investment reaches about 2 years, or whatever the electricity tariff is, there is a greater difference between low load and peak load. find that the implementation of such plans will be more justified.

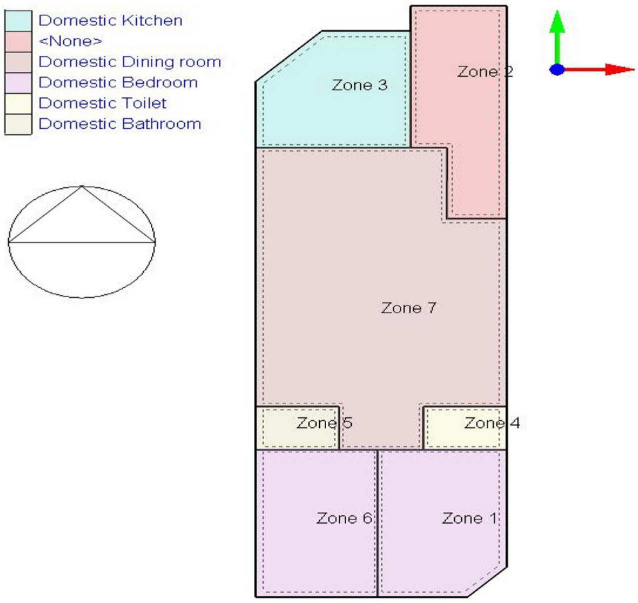

Fig. 13 First floor plan and building zoning.

The average gas consumption in this building in different months is extracted in the following table. Now, considering the package system's efficiency of 75% (according to the device catalog) and the simulation results from the Design-Builder software, the simulated heat load with the actual amount of gas consumed for heating is compared. As can be seen in Fig. 14, the simulation results and the actual consumption are accurate, i.e. in the worst case, the error rate is below 5%.

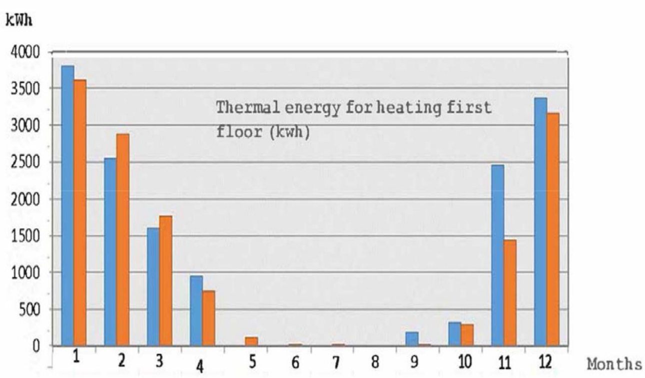

Fig. 14 Comparison of simulation (orange color) of Design Builder with actual gas consumption (blue color).

Validation

Considering that the building under study is under construction and its actual use has not yet been determined, we use an existing building to validate the simulation results. The plan of the first floor of this building is as shown in Fig.13. Average gas consumption for every month from the bill of the studied building is presente in Table 8.

Table 8 Average gas consumption from the bill of the studied building

Year	Month	HDD	consumption (cubic meters)
2022	December	416.4	74.7
2023	January	358	258.7
2023	February	254.6	437.3
2023	March	158	291.6
2023	April	84.4	185.8
2023	may	7.5	20.9
2023	June	6	33.8
2023	July	0	24.8
2023	August	0	25.1
2023	September	2.2	55
2023	October	38	81.6
2023	November	268	420.4
2023	December	378	561.9
2024	January	406	629.6

Conclusions

In this article, a 5-story, two-unit building in Tehran was accurately simulated, and the cooling and heating requirements were calculated hourly. In the following, photovoltaic panels (about 10 kilowatts) were used to meet the electrical needs (except for cooling), and an ice-making compression chiller with an ice storage tank with a capacity of 6000 kg and a corresponding control system was used to meet the cooling needs during non-peak hours. The costs of this combined system with high efficiency were compared with a normal system (without ice storage tank and related control systems), and the amount of investment as well as return on investment was calculated according to water, electricity, and gas tariffs. Then we checked the effect of using insulation in external walls. Below is a summary of the thesis:

1. The maximum daily heating load of the entire building is 1600 kilowatt hours, and the thermal load of hot water consumption is 200 kilowatt hours.
2. The maximum daily cooling load of the entire building is 900 kilowatt hours.
3. Based on this load and considering the performance factor of 3, a chiller with a capacity of 20 to 25 tons of refrigeration is suitable for a compression chiller.
4. The daily electrical load of the entire building for equipment and lighting is equal to 10 kilowatts.
5. To meet the electrical needs of the entire building, at

least 20 solar panels (500-watt) should be used to provide electricity for lighting and equipment, which costs $2,000.
6. If the ice storage tank is not used, the electricity cost of the chiller will be about 1852 per year, and if the storage tanks are used, this number will decrease to 877. In fact, by using this tank, we see savings of 965 per year.
7. Considering the cost of 5000$ storage tanks, thermal insulation, pump and control system, it will take about 5.5 years to return the initial investment.
8. Also, the investment return time for purchasing panels is about 2 years, which is more attractive than storage tanks.
9. Note that storage tanks help a lot during the summer peak of electricity consumption, and it is better in these scenarios for large government companies like Tawanir to pay applicants for free or good loans.

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