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Effectiveness of Hot Water Collectors and Photovoltaic Cells in Heating and Reducing Energy Consumption in Elementary Schools located in Urmia; Case Study: Female Elementary School in Urmia City*

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ABSTRACT

After the rising environmental crisis, solar energy use became a significant, effective measure in reducing the pollution caused by fuels and energy consumption. Hence, it is necessary to adopt modern technologies in the architecture of educational spaces. Solar cell systems (photovoltaic (PV) systems) and hot water collectors have a considerable impact on heating providing usefulness in this case. This study aims to examine the effectiveness of these two components in heating and reducing energy consumption in educational buildings located in cold and mountainous climates. In this study, the first step is to extract effective components using library and documentary studies. In the second step, the solar water heater is first simulated using TSOL software through the dynamic method in the Urmia climate, and then one of the schools located in Urmia is assessed and analyzed. By simulating the proposed educational building designed in Design Builder and modeling the solar water heaters and PV cells on the building, their effectiveness and function are examined in heating, output energy, and hot water supply (%). According to the results, in the solar water heater, the hot water supply equals 81.3%, the efficiency of this system equals 49.9% and saved gas equals 2670m3. The energy produced by the PV system supplies 47% of the electricity consumption in the rooftop power plant, while supplies 22.3% in the power plant of south side walls. According to the comparison between the current mode and the proposed designed mode, total savings equaled 80.3%. Therefore, hot water collectors and PV cells have a significant effect on the minimization of energy in educational buildings.

Keywords: Active Solar System, Hot Water Collectors, Photovoltaic Cells, Energy Consumption Reduction, Educational Spaces.

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1. INTRODUCTION

Energy supply resources in the world are divided into three main categories, nuclear, fossil, and renewable energies. Rising energy consumption made it possible to use renewables, especially solar energy which is the best energy exploitation source for any natural or artificial activity and various technologies. Environmental crises such as air and water pollution, global warming, and so on have occurred in the current era due to excessive use of fossil fuels. Hence, the best solution is to use natural energies like solar energy. Simple technology, lack of air and environmental pollution, and most importantly, saving fossil fuels for the next generation are the reasons that reveal the importance of solar energy use in our country, Iran (Khan Mohammadi and Sobhan 2015). This renewable energy can be exploited and used in most areas in Iran so that this energy is absorbed and converted to electric energy using modern technologies. There are various methods for using this endless energy, Heating water through solar water heaters is the easiest and most inexpensive method, while the PV system is another technique in the active solar system that improves the quality of educational buildings and preserves the resources for the next generation. In the case of using different types of solar systems, various active and passive systems with different capabilities exist that mitigate the thermal load based on the standard design in architectural spaces and elements. Many studies must be done for the optimal use of these systems in the architecture to determine the most suitable option (Gilani and Mohammad Kari 2011). Now, the energy consumption rate in Iran is greater than the global standards. This study considers active solar systems as the independent variable while analyzing energy consumption reduction is affected by many factors- as the dependent variable. These principles can be useful for the design of educational spaces in cold and mountainous climates. Therefore, a clear concept of active solar systems and their types must be examined. This research looks at the answer to this question: How many active solar systems can reduce energy consumption in educational spaces and what are the most effective ones? This is a question-based study that investigates the effect of hot water collectors and PV cells to find the best factor for reducing energy consumption in educational spaces. This study aims to examine the effectiveness of hot water collectors and PV cells in heating and reducing energy consumption in educational spaces in Urmia City.

Research process: In the first step of the literature review, active solar systems and their design techniques, as well as the performance of indicators were examined and evaluated then the theoretical framework was extracted. In the second step, simulation and modeling were done through TSOL and Design Builder software, in which effectiveness and efficiency rates of solar water heaters and PV cells in heating were measured then the output energy and hot water supply (%) were calculated and energy consumption reduction rate was obtained.

2. Background

Regarding the significance of education and the severe energy crisis in current societies, many studies have been conducted on the substitution of renewable energies, sustainable architecture, and energy-optimized architecture (Abolhasani 2013). According to studies conducted on PV systems from 2011 to 2021, some studies have been done on the techniques for designing building-integrated PV systems and coordination between PV systems' details and other elements of the building carried out by Saeedzadeh Khanghah. Also, Poorsistani investigates the application of PV systems and factors affecting the performance of PV systems and the use of PV plates in the atrium. At the same time, Naderi and Ahmadi examined the role of PV systems in the active use of solar energy and shading with photovoltaics, etc. In terms of solar water heaters, Torabi studied the use of solar water heaters in the building and analysis of collectors; Farhangi reviewed different kinds of systems and their functioning; Bakhshi and Moosavi studied the criteria for designing solar water heaters, and so forth.

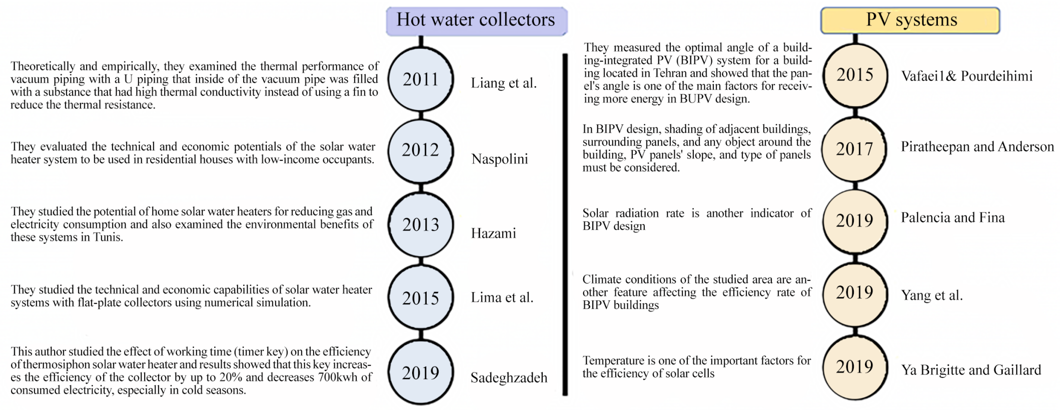

Fig. 1. Research Background in PV Systems and Hot Water Collectors

The results of examined effective factors indicate that PV systems and hot water collectors in the building are suitable patterns for better performance and reduction in costs and energy consumption. The important point of this research is an assessment of the efficiency rate of hot water collectors and PV systems and their comparison in educational spaces of cold and mountainous climates, which has not been mentioned in previous studies.

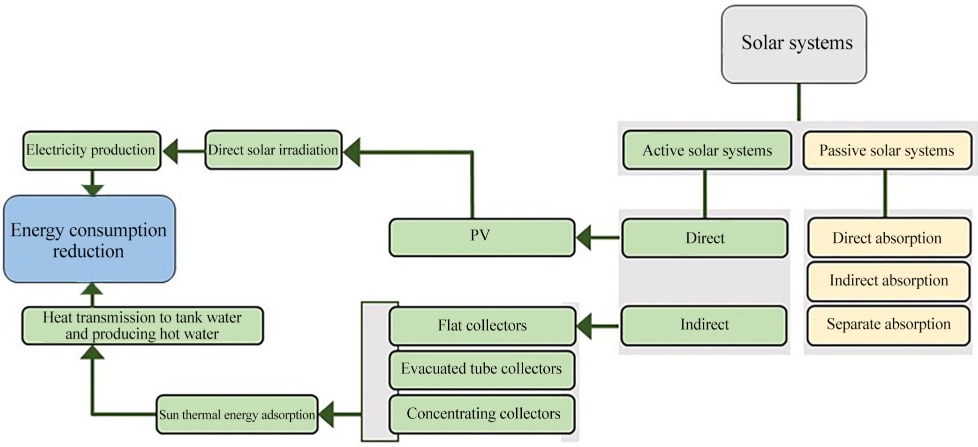

Fig. 2. Conceptual Model of the Relationships between Components Extracted from Studies

3. THEORETICAL FOUNDATIONS

In the design of the schools located in cold and mountainous climates where most of the teaching hours during the academic year are spent in winter and cold seasons, heating buildings is the most critical need. Hence, some systems can be used to maximize solar energy absorption (Fakhrjoo 2015). Educational spaces have various uses with different lighting rates; therefore, we can achieve maximum natural light by deploying functions in architectural design to supply suitable light but also save energy. In the design of educational spaces, energy saving and improvement of environmental quality are two main significant objectives (Iranmanesh 2015).

3.1. Solar Energy

Solar energy is used because it is eco-friendly and does not emit greenhouse gases. Solar energy is the most clean and safe energy that can be achieved. Moreover, solar energy use has a fixed cost (Sarookhani 2003). Different types of solar systems include:

A- Active (dynamic) solar systems: In this method, the solar collectors and another energy source must be used to prepare and transfer the heated fluid into the building (Asadi and Bamdad 2016). Different types of dynamic systems are classified into two categories based on their performance:

1. Direct: Photovoltaic phenomenon generates electricity under light radiation without using mechanical propulsion mechanisms. PV system converts the optical energy to electrical energy directly.

2. Indirect: In this method, flat collectors are used for ventilation and heating the space or water required for industrial processes (Izadi 2014).

B- Passive (static) solar systems: This system collects, stores, and diffuses solar energy without using fans, pumps, or complex controllers (Nerbert 2006).

3.1.1. PV System and Its Use in the Building

In this technique, solar cells produce electricity without using propulsion and chemical mechanisms of sunlight radiation. Solar cells are semiconductors that are made of silicon, which is the second most abundant element in the earth's crust. When sunlight is irradiated to a PV cell, a potential difference occurs between two positive and negative electrodes, and the current flows between them (Poor Sistani et al. 2013). Sunlight is the source for feeding PV cells; hence, the cells are placed in some walls of the building that have a suitable environment for direct irradiation. Therefore, the external façades and external surfaces of the building roof are mainly the best places for installing PV plates (Poor Sistani et al. 2013). These cells are capable of transmitting 90% of sunlight colling the air of indoor space during summer through the windows equipped with solar cells making the façade of the building beautiful while supplying the required electricity energy (Vafaei 2009).

3.1.2. Direction of PV Panels

The maximum solar radiation is collected when the collector is perpendicular to the direct radiation rays. The best angle is a function of the year's duration when the highest electricity rate is required. In cold areas, the maximum electricity amount is needed during winter while hot climates need the maximum electricity during summer for desired ventilation, lighting systems, pumps and fans, and heating. southward direction is mainly optimal but a minor loss occurs in the system up to 20 degrees toward the west or east from the south (Vafaei 2009).

3.1.3. Techniques for the Design of Building-Integrated PV (BIPV) Systems

A- Determining optimum slope and direction of PV panels: The use of radiation conducts is the most common technique in which, solar radiation on all vertical and horizontal surfaces is illustrated within different slopes and directions monthly and annually based on the meteorological data through computer programs. Panels have different efficiency rates based on their angles with each slope and the energy gained from the sun (Saeed Zadeh Khanghah 2015).

B- Effect of shadings on PV panels: Shadow affects solar access. The shadow of surrounding buildings, the shadow of the building, and the shadow of panels on each other, as well as the earth's reflection, would affect the BIPV system (Saeed Zadeh Khanghah 2015).

C- Consistency between PV systems and passive solar systems in the building: The building coverage is designed in a way that radiation decline is low on the building surface (being reflective) to reduce cooling energy consumption; the proper integration of PV system in the building coverage, however, it produces the electricity required for cooling but avoids sunlight penetration. Designers integrate PV systems with the building to provide natural light (direct and indirect), a view of outdoor landscape, ventilation, etc. Therefore, higher efficiency is achieved when active and passive solar systems are adapted and matched in a building (Saeed Zadeh Khanghah 2015).

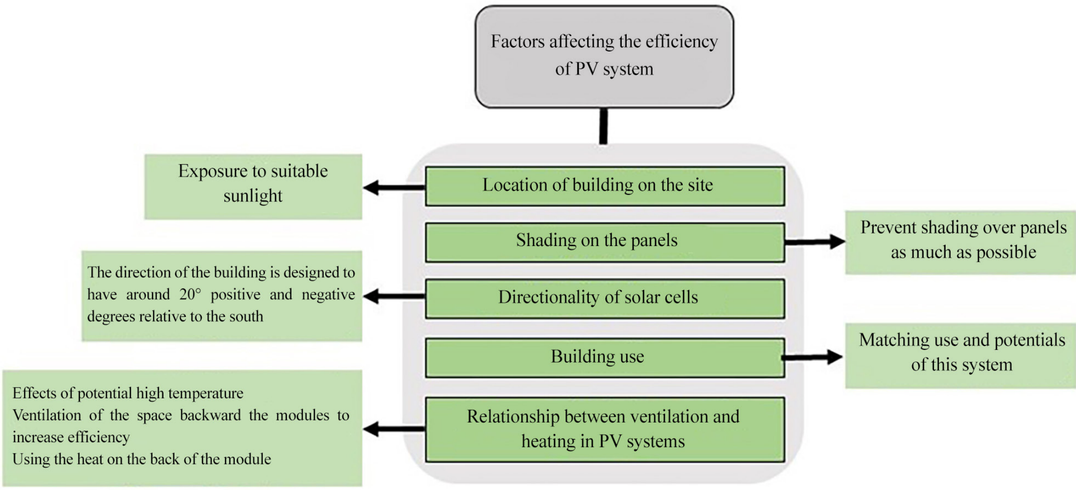

Fig. 3. Factors Affecting the Performance of PV System

(Quoting Poor Sistani 2013)

4. METHOD

The simulation method has been used in this research. Effective variables are derived after examining the components of active solar systems and data collection through documentary and library studies. In the next step, one of the schools located in Urmia (case study: Golshahr School) was examined and analyzed then the energy consumption and loss were obtained, and then the proposed designed educational building was simulated and modeled in the base mode. In the next step, the performance of solar water heaters and PV cells and their effects on the heating were assessed and compared in different modes through Design Builder 7 software. All modes were examined within two periods of the first and second six months of the year (winter and summer), day and night temperatures in Urmia regarding the solar energy gain, and the results were proposed in separate diagrams. Research findings were simulated and analyzed as the principles used to reduce energy consumption in educational buildings located in cold and mountainous climates using active solar systems.

4.1. Validation

For validation of simulation examining records based on the electricity and gas bills, the annual consumption of the building is prepared then modeling and simulation are started, the results are compared with real-world values of the school then different strategies are presented to reduce the energy consumption of the building. The coefficient 10.5 has been used to convert each m3 natural gas to kWh.

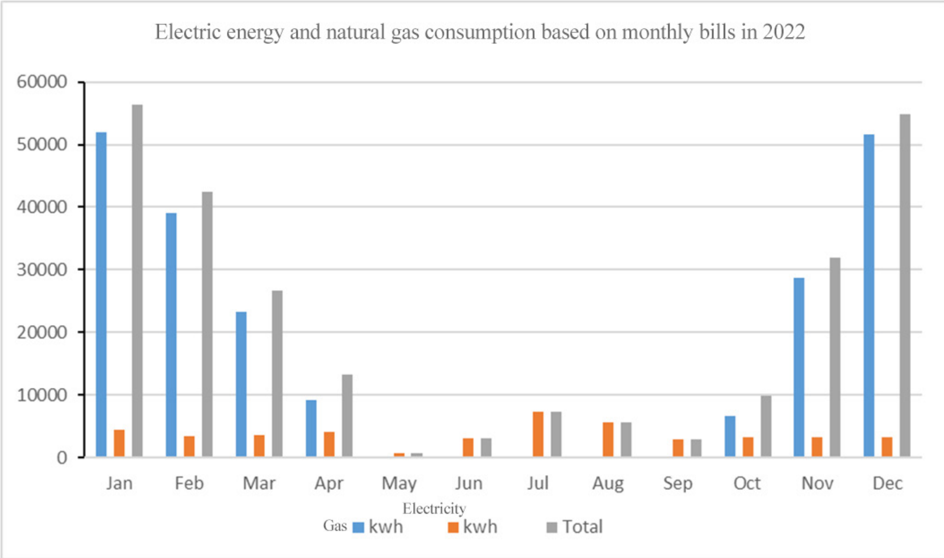

Fig. 4. Electric Energy and Natural Gas Consumption based on Monthly Bills in 2022

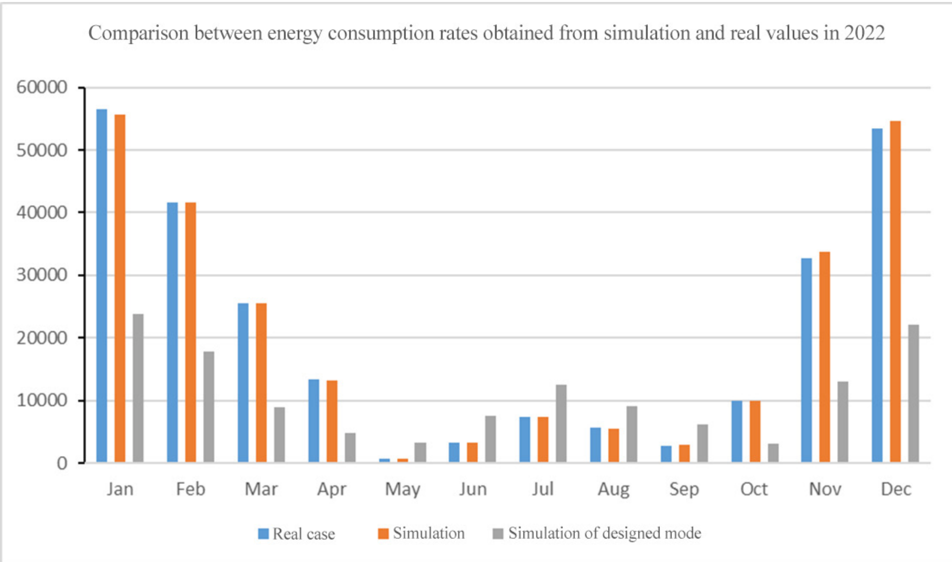

Fig. 5. Comparison between Energy Consumption Rates Obtained from Simulation and Real Values in 2022

The sum of monthly values of consumed gas and electricity bills based on the kWh unit makes up the total real energy consumption of the building (Fig. 4). The values obtained from simulation through different months have minor differences with real values due to the effect of some unknown parameters. However, the simulated energy consumption trend over the year is similar to the real values. The real value of total energy consumption over a year equals 309191Kwh, and the simulated rate equals 308563Kwh, which has a difference of less than 7% that is acceptable.

5. FINDINGS (RESEARCH ANALYSIS AND SIMULATION)

DesignBuilder software is an appropriate instrument for doing research projects in the field of building and energy evaluation of buildings and their installation systems in terms of energy optimization of architecture, materials, and installation systems of buildings. Also, the considered building model can be simulated with a very high modeling accuracy consistent with real climatic conditions to find how the considered building is in the real world (Saebi Safa 2020).

5.1. Thermal Modeling of Building-Simulation Assumptions

In this research, the educational buildings in Urmia Climate have been simulated and compared in terms of energy through DesignBuilder Software. In the base mode, the assumed data are used in the model for the simulation process. Lighting, occupancy, equipment data, materials, and ventilation systems have been imported into the software and simulated based on the educational use of the building. The schematic of the building plotted through software has been shown in Figure 7. The building has around 1300m2 of infrastructure in current mode. The plan of floors is depicted in Figure 6, in which the first and second floors are types of floors, and the area of floors is mentioned in the plans.

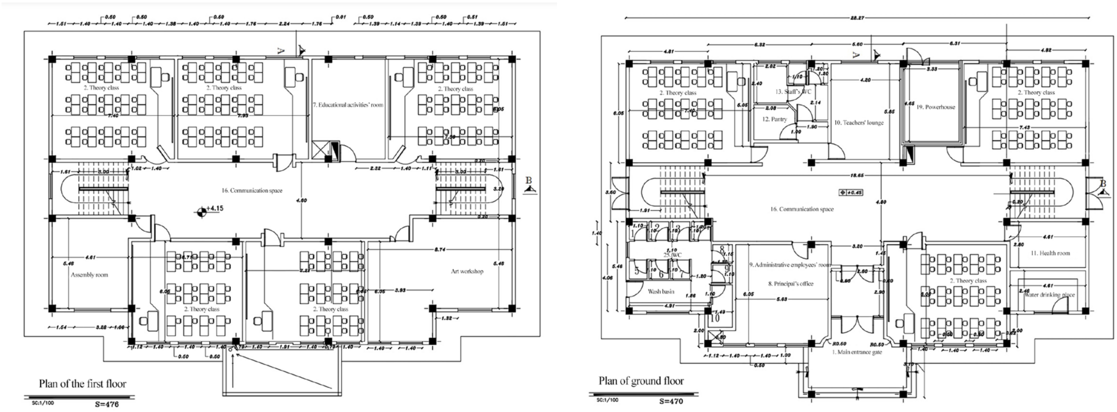

Fig. 6. Plan of Floors in Existing School (Golshahr)

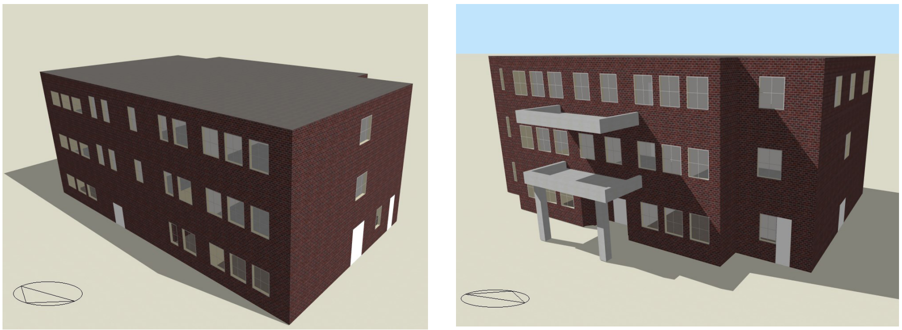

Fig. 7. Plotted Schematic of Existing School (Golshahr), Simulation through Design Builder Software

According to standard templates of DesignBuilder and considering the use, the number of individuals (occupancy) and equipment, lighting system, and schedule of their performance have been chosen in the simulation of this building. The materials considered for the external walls and ceiling are shown in the Figure below. The heat transmission rate for the external wall with the brick core of 20cmequalss 2.27 $\frac{W}{m^2.K}$ while equaled 2.6 $\frac{W}{m^2.K}$ for the ceiling with ca oconcretecore. The material details of the single-glazed 3mm window of the transparent wall are in the next rank indicating a thermal resistance of 5.89 W/ $\frac{W}{m^2.K}$ and a heat transmission rate of 0.86 (SHGC).

Calculated Values	
Total solar transmission (SHGC)	0.861
Direct solar transmission	0.837
Light transmission	0.898
U-value (ISO 10292/ EN 673) (W/m2-K)	5.829
U-Value (W/m2-K)	**5.894**

Fig. 8. Thermal Features of Glass

The lighting system of this building is LED type. The consumption power of the lighting system equals 7.5 w/m^2. Thermal comfort temperature equals 24°C and 22°C during hot and cold seasons, respectively. Table 1 reports the other assumptions.

Fig. 9. Thermal Comfort Temperature

Table 1. Software Settings in Existing School (Golshahr)

Row	Title	Details
1	Number of Individuals	0.1 Member per m^2
2	Power of Equipment	3w per m^2
3	Working Hours	18:00-19:00 Except for Thursdays and Fridays
4	Meteorological File Sources	climate.onebuilding.org
5	Type of Cooling and Heating System	Heating (Gas Fuel) and Air Conditioner (Electric Fuel)
6	Unexpected Air Penetration	0.7 SHGC

5.1.1. Simulating the Current Mode

The heat gain in different parts of the building is shown in Figure 10 based on the model simulation and extraction of results. This heat is produced through electrical equipment, a lighting system, the presence of people, and input radiation throughout the window that reduces the heating load of the building in cold seasons while increasing the cooling load in hot seasons. The highest heat gain occurs through the lighting system and irradiation throughout the windows.

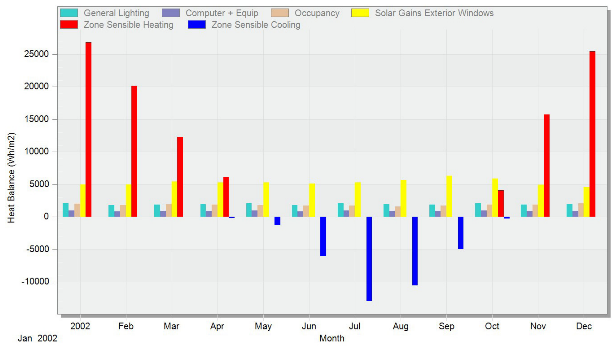

Fig. 10. Heat Gain by Building (Available School (Golshahr))

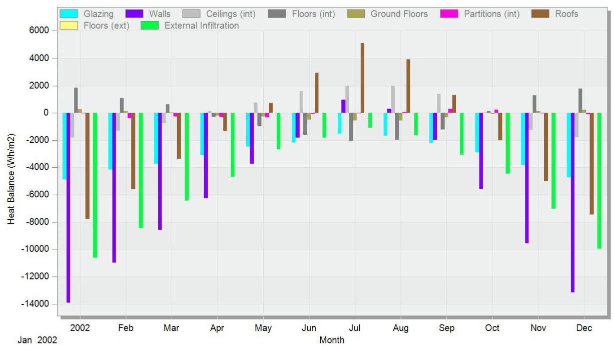

Fig. 11. Heat Transmission of Different Walls of the Building (Available School (Golshahr))

Figure 11 depicts the heat transmission through different walls of the building. In this figure, heat transmission has occurred through exterior walls, glazing, floor, ground floor, interior walls, and ceiling. The major heat entering the interior space through the roof in the hot season is lost through penetration and walls in the cold season. Negative values represent heat loss and positive values mean heat gain at that part.

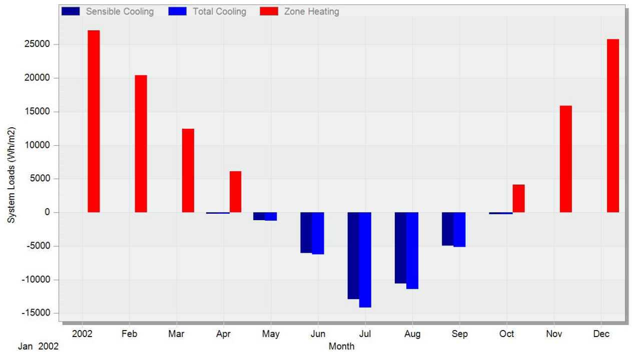

Fig. 12. Heating and Cooling Load Profile of Building (Available School (Golshahr))

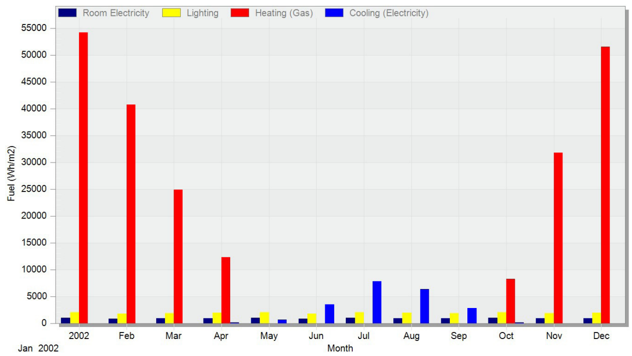

Fig. 13. Separated Consumptions of Building (Available School (Golshahr))

Finally, Figure 12 indicates that 24°C and 22°C temperatures have been set for cooling and heating systems that are heating and cooling requirements of the building, respectively. Negative values indicate the direction of heat transmission. It means that this amount of heat must be lost in interior space to reduce the temperature of the building until it reaches the thermal comfort temperature in hot seasons. According to the large area of glazing in the building, the cooling load is the dominant load of the building.

Figure 13 depicts the separated monthly gas and electricity consumption in different parts. The highest electricity consumption occurs in the cooling system, while the heating system consumes the highest amount of gas. The gas consumption unit is kwh in this software. The kwh can be converted to m^3 based on the average thermal value of gas. Each $1m^3$ gas brings around 10.4kWh thermal value. According to simulation results, total monthly gas and electricity consumption equals the values indicated in Figure 14.

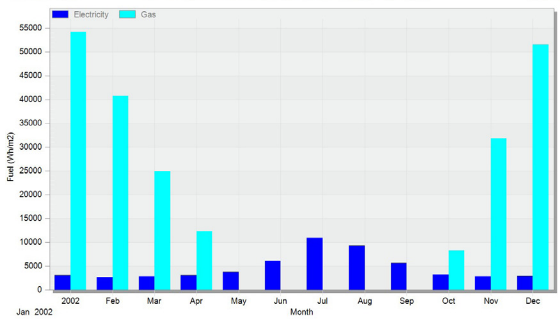

Fig. 14. Total Gas and Electricity Consumption of the Building over the Year (Available School (Golshahr))

In this mode, the cooling and heating systems' energy of the building equals values reported in Table 2.

Table 2. Summarized Simulation Results

Time (Month)	The Heating System's Energy kWh	Colling System Energy	Total Energy of Cooling and Heating Systems kWh
January	68273	0	68273
February	51368	0	51368
March	31285	0	31285
April	15484	140	15624
May	0	845	845
June	0	4347	4347
July	0	9873	9873
August	0	7970	7970
September	0	3580	3580
October	10361	176	10536
November	39986	0	39986
December	64875	0	64875
Annual	281632	26931	308563

5.2. Thermal Modeling of Design Building in Base Mode

In this research, the designed education building has been simulated and compared without applying systems in the Urmia climate using DesignBuilder software. In base mode, the simulation process has been done based on the data assumed in the model. Lighting, equipment information, materials, ventilation system, and occupants have been imported into the software and simulated regarding the educational use of the building. Figure 15 depicts the schematic of the building plotted in the software. The building has around 2611m² of infrastructure in the existing mode.

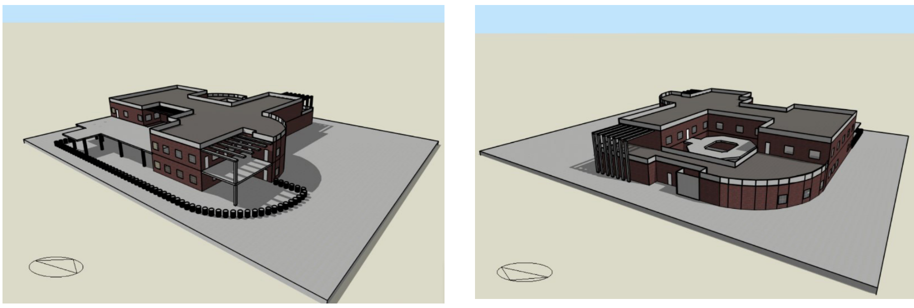

Fig. 15. Schematic of Building

According to standard templates of DesignBuilder and considering the building use, number of equipment and individuals, lighting system and performance schedule were chosen for the simulation process of this building. The materials used for the exterior wall and ceiling are reported in the figure below. The heat transmission rates of the exterior wall and ceiling equal 0.704 and 0.918 $\frac{W}{m^2.K}$, respectively.

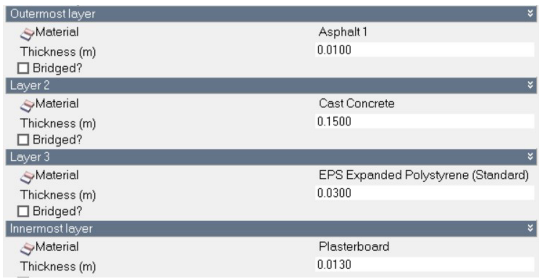

Fig. 16. Ceiling Wall Properties

Outermost layer	
Material	Brickwork Outer
Thickness (m)	0.1000
Bridged?	
Layer 2	
Material	XPS Extruded Polystyrene - CO2 Blowin
Thickness (m)	0.0300
Bridged?	
Layer 3	
Material	Concrete Block (Medium)
Thickness (m)	0.1000
Bridged?	
Innermost layer	
Material	Gypsum Plastering
Thickness (m)	0.0130

Fig. 17. Exterior Wall Properties

According to the reported details of the double-glazed window, thermal resistance, and heat transmission rate equals 1.96 $\frac{W}{m^2.K}$ and 0.691 (SHGC) (Fig. 18). The lighting system of this building is LED type. The consumption power of the lighting system equals 7.5w/m^2. Thermal comfort temperature equals 24°C and 22°C for hot and cold seasons, respectively (Fig. 19).

Calculated Values	
Total solar transmission (SHGC)	0.691
Direct solar transmission	0.624
Light transmission	0.744
U-value (ISO 10292/ EN 673) (W/m2-K)	1.924
U-Value (W/m2-K)	**1.960**

Fig. 18. Thermal Profile of Glazing

Environmental Control	
Heating Setpoint Temperatures	
Heating (°C)	**22.0**
Heating set back (°C)	13.0
Cooling Setpoint Temperatures	
Cooling (°C)	**24.0**
Cooling set back (°C)	32.0

Fig. 19. Thermal Comfort Temperature

5.2.1. Simulation of Basic Designed Mode

After model simulation and extraction of results, the heat gain in different parts of the building is measured as shown in Figure 20. This heat is produced by electrical equipment, lighting systems, occupancy, and irradiation through the windows, which reduces the heating load of the buildings in cold seasons while increasing the cooling load during hot seasons. The highest heat gain occurs through the lighting system and irradiation through windows. Figure 21 indicates heat transmission through all walls of the building. In this Figure, heat transmission is done through exterior walls, glazing, roof, ground floor, internal walls, and ceiling. A high heat rate enters the building space in the hot season, while a high heat is lost through the ceiling and wall during the cold season. Negative values indicate heat loss and positive values represent heat gain in that part of the building.

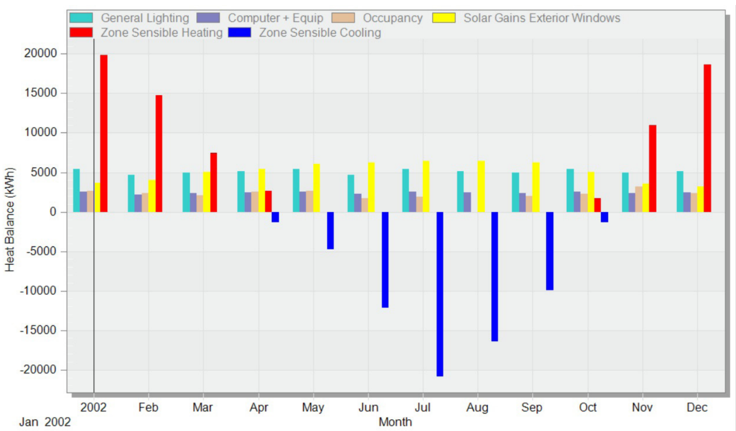

Fig. 20. Heat Gain by Building

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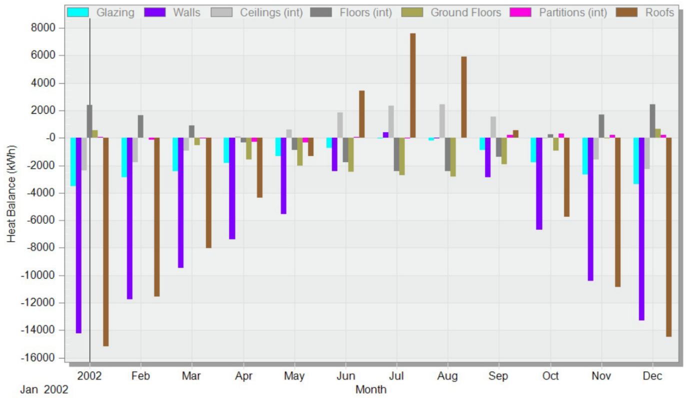


Fig. 21. Heat Transmission through Different Walls of the Building

Finally, Figure 22 indicates that 24°c and 22°c temperatures are set for cooling and heating systems, respectively that are heating and cooling requirements of the building. Negative values of the cooling load depict the heat transmission direction; it means that this amount of heat must be lost in interior space to reduce building temperature achieving thermal comfort in hot seasons. Regarding the wide area of glazed surfaces in the building, the cooling load is the dominant load of the building. Figure 23 indicates separated monthly gas and electricity consumption in different partitions of the building. The highest electricity consumption occurs in the cooling system while the heist gas is consumed in the heating system. Gas consumption unit in kWh in this software. The kWh can be converted to m3 based on the average thermal value of gas. Each 1m3 gas has around 10.4kWh thermal value.

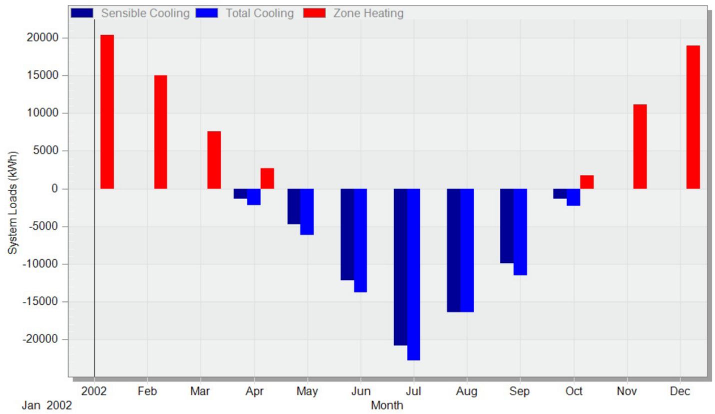


Fig. 22. Cooling and Heating Load Profile

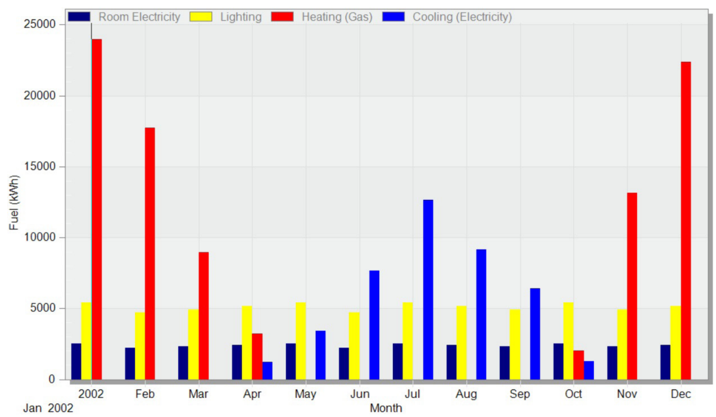


Fig. 23. Separation of Consumptions in the Building

Table 24 reports the total monthly gas and electricity consumption over the years based on the simulation results.

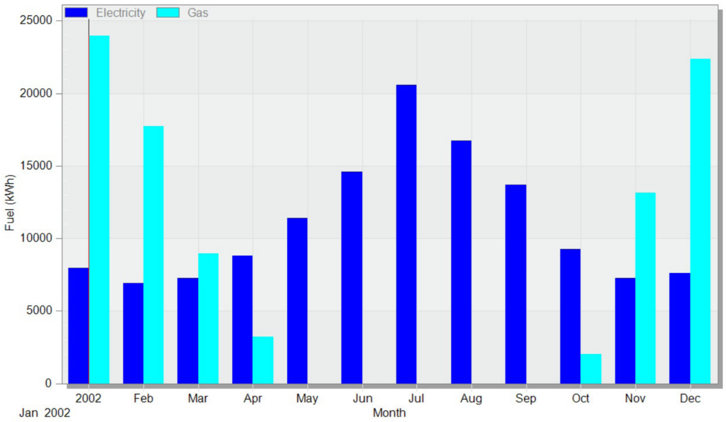


Fig. 24. Total Gas and Electricity Energy Consumption over the Year

In this mode, Table 3 reports the energy of the cooling and heating system of the building.

Table 3. Summarized Simulation Results of Base-Designed Mode

Time (Month)	The Heating System's Energy (kWh)	The Heating System's Energy (kWh)	Total Energy of Cooling and Heating System (kWh)
January	23944	0	23944
February	17725	0	17725
March	8946	0	8946
April	3201	1219	4420
May	0	3439	3439
June	0	7672	7672
July	0	12661	12661
August	0	9140	9140
September	0	6410	6410
October	2036	1295	3331
November	13141	0	13141
December	22381	0	22381
Annual	91347	41837	133211

Table 4 reports the annual energy consumption of the building regarding its use.

Table 4. Annual Energy Consumption of Buildings in Different Scopes

Month	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Gas) (kWh)
January	2531	5406	43964	0	2158
February	2211	4701	32405	0	1962
March	2338	4936	18447	0	2158
April	2424	5171	7592	267	2158

Month	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Gas) (kWh)
May	2531	5406	0	1928	2060
June	2231	4701	0	7001	2158
July	2531	5406	0	13729	2256
August	2434	5171	0	10034	2060
September	2328	4936	0	5505	2158
October	2531	5406	4794	350	2158
November	2328	4936	24774	0	2060
December	2434	5171	41349	0	2256
Sum	28851	61346	173325	38815	24698

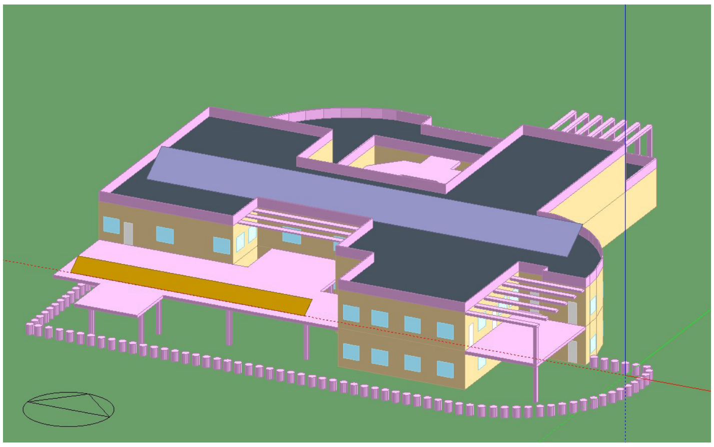


Fig. 25. Building Schematic with PV and Water Heater Simulated through DesignBuilder Software

In this research, TSOL software has been used to simulate solar water heaters, while DesignBuilder software has been used to simulate PV and hot water consumption. To supply hot water consumed in the building, the volume of hot water consumed equals an average amount of 1700l per day based on the standards and the volume of storage source equals 3000l. Sollar collectors are evacuated tube collectors in this mode.

5.3. Evacuated Tube Collector

There are some parallel transparent double-walled tubes in which, a tube covered with adsorbent exists and air exits the space between two walls, so the vacuum prevents the heat loss. Moreover, it resists icing up to -15°C. The efficiency of this collector is greater than the plate collector, and its maximum heat equals 110° under excellent conditions It is inexpensive rather to other collectors bringing many advantages.

5.3.1. Advantages of Evacuated Tube Collectors

The absorbed thermal energy loss is minimized in cold climates due to double-walled tubes and a vacuum between two glazed walls. If the flat collector is damaged, the whole collector must be replaced while in the tube system, The system can continue working if the tube system stops working due to one broken or damaged tube that can be easily replaced. Evacuated tube systems are suggested for Iran's climate that have cold winters and hot summers. The proposed system for solar water heater is designed using one source.
In this system, an 8m^2 evacuated tube solar collector is used. This system is coupled with the building's heating system boiler.
In the Urmia climate, the solar water heater has been simulated using TSOL software. The area of the evacuated tube solar collector of this system equals 20m^2. The heat required for heating the hot water consumed in the boiler almost equals 22.3mWh over the year of which, 22.3mWh is supplied by a

thermosiphon evacuated tube solar collector during the year.

Table 5. Required and Supplied Heat

DHW Heating Energy Supply	24.689.42 kWh
Solar Energy Contribution to DHW	22.296.76 kWh
Energy from Auxiliary Heating	5.143.1 kWh

Figure 26 depicts the heat loss and energy flow in the thermosiphon system. According to the results, the highest heat loss occurs in heat transmission through solar collectors, piping, and storage sources. The values introduced on the energy flow diagram are matched with the guide (Table 6).

Table 6. Map Guide of Energy Flow

Legend		
1	Irradiation on Collector Surface (Active)	44.668 kWh
1.1	Optical Collector Losses	11.966 kWh
1.2	Thermal Collector Losses	8.623 kWh
2	Energy from the Collector Array	24.079 kWh
2.1	Solar Energy to Storage Tank	23.211 kWh
2.5	Internal Piping Losses	573 kWh
2.6	External Piping Losses	296 kWh
3.1	Tank Losses	3.002 kWh
3.2	Circulation Losses	650 kWh
6	Final Energy	5.778 kWh
6.1	Supplementary Energy to the Tank	5.143 kWh
9	DHW Energy from the Tank	24.698 kWh

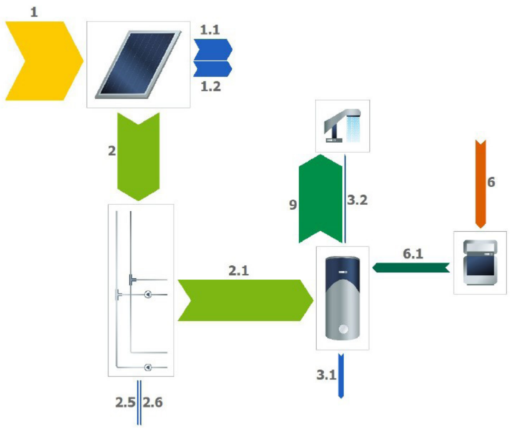


Fig. 26. Energy Flow Diagram

According to the results, the hot water supply through the solar fraction of the system equals 81.3% indicating the maximum supply of hot water by solar collector. The efficiency of this system equals 49.9% and the saved gas equals 2670m^3.

Table 7. Obtained Saving

Natural Gas (H) Savings	2.670.6 m^3
CO2 Emissions Avoided	5.647.44 kg
DHW Solar Fraction	81.3%
Relative Savings of Supplementary Energy (DIN EN 12977)	80.8%
System Efficiency	49.9%

According to Figure 27, solar hot water supply and use of boiler heat and energy required for the consumed hot water supply of the building have been determined by simulating the profile. The orange-colored diagram indicates the total heat required for hot water over the year, while the yellow-colored area indicates the heat supply by the solar water heater. Figure 28 indicates the temperature of the collector's water output at different hours of the year.

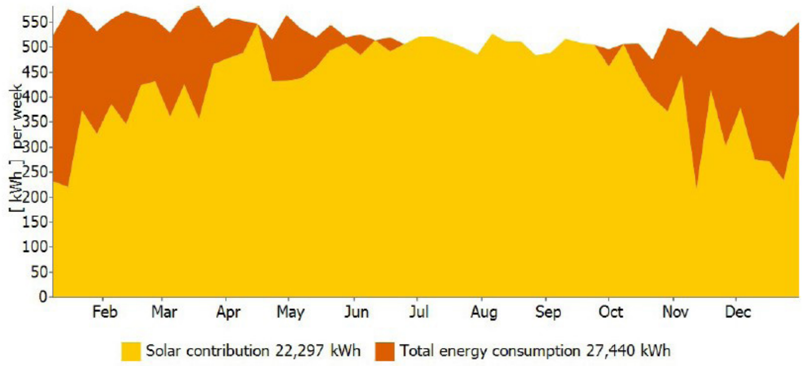


Fig. 27. Profile of Energy Required for Consumed Hot Water

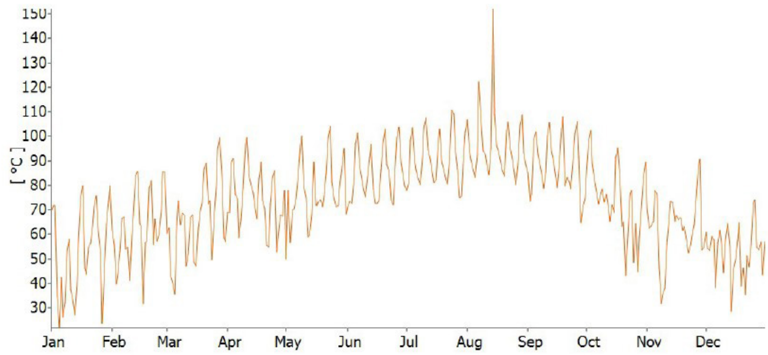


Fig. 28. Temperature of Collector's Water Outlet

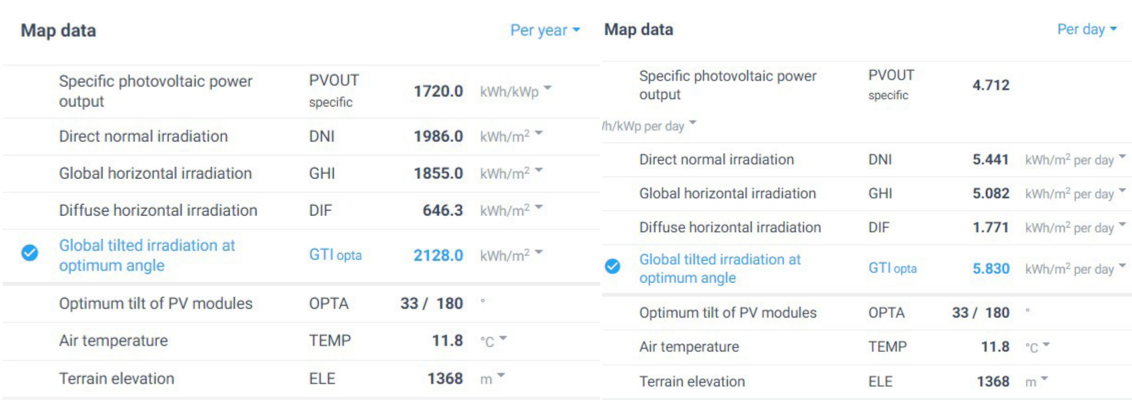
Table 8. Technical Profile of Collector and Panels based on the Manufacturing Companies and Their Adjustments

250w Monocrystalline Isola Solar Panel		Evacuated Tube Solar Collector	
Maximum Power (Nominal Power)	250w	Pressure Tolerance Capacity	6 kg/cm^2
Voltage of Open Circuit (Voc)	36.4v	Optimal Installation Angle	20-70 Vertical Degrees, -5 Degree to +5 Horizontal Degree
Open Circuit (No-Use) Ioc	8.93 amp	Insulation	Compressed Fiberglass-K=0.041 W/mK
Working Voltage (Vmp)	30.32v	Body Made of Manifolds Materials	Aluminum (3A21degree)

250w Monocrystalline Isola Solar Panel		Evacuated Tube Solar Collector	
Panel Workflow (Imp)	8.24amp	Frame's Materials	Aluminum Alloy 6063 (1.8mm)
Cell Type	Monocrystalline	Header Pipe Materials	Soldering 99.93% Pure Copper and 45% Lead-Free Silver
Efficiency	18.1% 15.67% cell	Thermal Tube Profile	Thickness: 0.6mm, Condenser 14mm, (24mm Condenser Optional)
Number of Cells	60 10*6 Cells	Valves Around the Thermal Tube	Circular 1.68m Double Aluminum
Grade Class of Cell Construction	A	Seal and Rubber Ring	Silicon-Made Rubber HTV Degree
Number of Load Bass (Energy Transmission Lines of Cells)	5 Bass Loads	Maximum Operating Pressure	8 Strip-16psi
Weight	22 kg	Optimal Flow Rate	0.1L/min/tube - 0.026G/min/tube
Dimensions	164 × 99.2 × 4 cm	Manufacturer Brand	Ensun Solar/Kesun New Energy OEM
Manufacturer Brand	Isola	-	-

5.4. Simulation of PV Powerplant

PV walls and roofs must be designed in a direction to collect sunlight, so its magnitude can cover the electrical load of the building. The highest efficiency is achieved in the south direction; therefore, solar energy gain surfaces must be towards the south. In winter, directions except for the south would considerably reduce the efficiency in higher latitudes, while in equatorial latitudes where the sun is on the highest point of the sky, solar plates' slopes have higher effectiveness than their directions. The energy produced by PV plates depends on the amount of light hitting these plates, exterior space temperature, and the efficiency of PV cells. Solar arrays are not alone and independently adequate for generating electrical power but other components must be incorporated into a single system: a structure for installation and placement of solar panels, different sensors for monitoring the general status of the PV system, electronic components of power for gaining DC power produced by cells and charging batteries and preparing electrical power for load feeding, automatic tracking system for minimization of solar energy gain, and adjusting optimal angle and location of panels. Figure 29 depicts the irradiation map of Urmia City and the estimation of irradiation gain and generated electricity in this city. It is possible to generate 4.712 kWh of electricity per m^2 daily and 1720 kWh annually in this city. According to the site below, the optimal angle in Urmia city is 33° towards the south, with the highest capacity for PV electricity generation equals 4.712 kWh per m^2.



Map data — Per year

Specific photovoltaic power output	PVOUT specific	1720.0	kWh/kWp
Direct normal irradiation	DNI	1986.0	kWh/m²
Global horizontal irradiation	GHI	1855.0	kWh/m²
Diffuse horizontal irradiation	DIF	646.3	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	2128.0	kWh/m²
Optimum tilt of PV modules	OPTA	33 / 180	°
Air temperature	TEMP	11.8	°C
Terrain elevation	ELE	1368	m

Map data — Per day

Specific photovoltaic power output	PVOUT specific	4.712	/h/kWp per day
Direct normal irradiation	DNI	5.441	kWh/m² per day
Global horizontal irradiation	GHI	5.082	kWh/m² per day
Diffuse horizontal irradiation	DIF	1.771	kWh/m² per day
Global tilted irradiation at optimum angle	GTI opta	5.830	kWh/m² per day
Optimum tilt of PV modules	OPTA	33 / 180	°
Air temperature	TEMP	11.8	°C
Terrain elevation	ELE	1368	m

Fig. 29. Irradiation Profile of Urmia[1]

The surface area of solar collectors or PV panels is determined based on the solar fraction or required hot water supply (%) and electricity consumption. Since hot water is consumed throughout the year, the number of solar collectors has been selected relative to the consumed hot water supply. Two powerplant models have been recommended to simulate energy produced by PV systems. One is a rooftop powerplant that has 180m² panels and a powerplant of the walls located on the south side that has 134m² panels.

5.4.1. Rooftop Powerplant

This powerplant has one string with 901 units, so we have 90 PV panels. The nominal efficiency of the panel equals 19%, and one solar 37kw inverter is used. The total electricity consumed in the building equals 129012 kWh, so 47% of the electricity required for the building can be supplied over the year by producing 60620 kwh by solar powerplant. The capacity of this powerplant almost equals 36kw.

Table 9. Electricity Generated in the Building

Month	kWh Produced PV Electricity
January	3327
February	3749
March	4741
April	5329
May	6101
June	6478
July	6741
August	6715
September	6209
October	4883
November	3407
December	2940
Total (in the Year)	60620

5.4.2. Powerplant on the Southern Wall

In this mode, we have a 134m² PV panel. The nominal efficiency of the panel equals 19%, and one 30kw solar inverter is used. The total amount of electricity consumed in the building equals 129012 kWh, so 22.3% of the electricity required for the building over a year can be supplied by generating 28779 kwh by the solar power plant. The capacity of this powerplant almost equals 27kw.

Table 10. Electricity Generated in the Building

Month	kWh Produced PV Electricity
January	2444
February	2475
March	2558
April	2328
May	2016
June	1818
July	2001
August	2483
September	3075
October	2965
November	2405
December	2211
Total (in the Year)	28779

5.5. Designed Mode

In the mode of designed school building, mixed PV systems and solar water heaters are used. In this mode, the energy of the cooling and heating system is reported in Table 11.

Table 11. Summarized Results of Cooling and Heating Simulation in Designed Mode

Month	The Energy of the Heating System kWh	The Energy of the Cooling System kWh	Total Energy of Cooling and Heating System kWh
January	43964	0	43964
February	32405	0	32405
March	18447	0	18447
April	7592	267	7859
May	0	1928	1928
June	0	7001	7001
July	0	13729	12729
August	0	10034	10034
September	0	5505	5505
October	4794	350	5144
November	24774	0	24774
December	41349	0	41349
Annual	173325	38814	212139

Table 12. Software Setting in Designed Mode

Row	Title	Details
1	Occupancy (Number of Individuals)	0.1 Members per m^2
2	Equipment Power	$3w/m^2$
3	Working Hours	18:00-19:00 Except for Thursday and Friday
4	Metrological file Source	climate.onebuilding.org
5	Cooling and Heating System	Hating (Gas Fuel) and Air Conditioner (Electricity Fuel)
6	Natural Ventilation	Active Controlled in PV Space and Water Heater
7	Cooling Setpoint	24°C
8	Heating Setpoint	22°C
9	Lighting Power	$7.5w/m^2$

The heat transmission rate for the external wall with a concrete core of 10cm and 3cm insulation equals 0.714 $\frac{W}{m^2.K}$ while equals 0.92 $\frac{W}{m^2.K}$ for the ceiling with a 15sm concrete core. The material details of the single-glazed 3mm window of the transparent wall are in the next rank indicating a thermal resistance of 1.96 $\frac{W}{m^2.K}$ and a heat transmission rate of 0.69 (SHGC).

5.6. Comparison of Modes

The figure below compares the total energy of cooling and heating systems in current and designed modes. According to the results of the designed mode, the energy of the cooling system is 28.3% less than the current mode, the energy of the heating system is 85.3% less, and the total energy of the cooling and heating system is 80.3% less than the current mode.

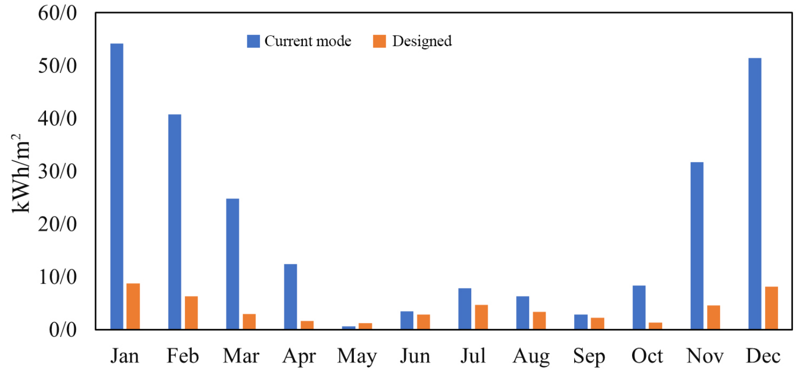


Fig. 30. Comparison between Total Energy Consumption in Cooling and Heating System

Table 13 reports the summarized results of these two strategies.

Table 13. Summarized Result

	The Heating System's Energy $\frac{W}{m^2.K}$	Cooling System's Energy $\frac{W}{m^2.K}$	Total Energy of Cooling and Heating System $\frac{W}{m^2.K}$	Heating System Saving (%)	Cooling System Saving (%)	Total Savings (%)
Current Mode	223.5	21.4	244.9	-	-	-
Designed	32.8	15.3	48.2	85.3%	28.3%	80.3%

6. DISCUSSION AND CONCLUSION

It is necessary to consider energy consumption management and reduction in educational spaces and provide strategies to minimize energy consumption during environmental crises. This study has evaluated the effectiveness rate of these strategies in different modes by assessing active solar systems and their components. According to the examination of the annual energy consumption of the building in different fields regarding its educational use simulated through DesignBuilder software that has 2611m^2 infrastructure in the cold and mountainous climate of Urmia, it is concluded that the use of modern technologies such as solar water heater and PV cells could significantly change the energy consumptions in the design of such spaces. According to the current status and simulation of PV cells that can adsorb solar energy and convert it to electrical energy directly- two modes of rooftop powerplant with 180m^2 panels and powerplant on the southern wall with 134m^2 panels were examined. According to irradiation gain in the optimal angle of the panel and estimated solar energy gain and produced electricity, it was found that 4.712 kWh of electricity is produced daily per m^2 and almost 1720 kWh of electricity is produced annually. According to the results of examinations, the energy generated by PV systems can supply 47% and 22.3% of electricity consumed in the building over the year using rooftop and southern side powerplants, respectively. Also, hot water consumption and supply were examined using hot water collectors and simulating them dynamically through TSOL software. In this mode, evacuated tubes with a 20m^2 area and 3000l-storage tanks were used. According to the obtained results, 81.3% of hot water is supplied through solar heat. The efficiency of this system equals 49.9% and the gas-saving amount equals 2670 m^3.

A comparison was made between the total energy amounts of cooling and heating systems in the current mode (Golshahr School) and the proposed designed mode (Table 13). According to the results of the designed mode, the cooling system energy is 28.3% less than the current mode in Urmia, the heating system energy is 85.3% less than the current mode, while the total energy amount of the cooling and heating system is 80.3% less than the current mode in this city.

According to the obtained values and statistics, hot water collectors and PV cells have effective potential for optimal energy consumption and supply in educational buildings. Finally, the examinations tried to combine these two systems in the considered educational building using technology to save energy consumption and provide a safe and affordable environment.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

ENDNOTE

1. https://globalsolaratlas.info

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