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Building Energy Optimization: Implementing Green Roof and Rainwater Harvester System for a Residential Building

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ABSTRACT

Both energy and environmental criticisms push a society toward energy-efficient buildings with green technologies. Green roofs are of significant importance due to their remarkable role in decreasing the thermal loads ofbuildings, especially in summer, and also in sound insulation. Here in, the thermal loads of a residential building were calculated, and then, an optimized green roof was designed for it in three different cities of Tehran, Rasht, and Tabriz. The energy saving was analyzed in each case, and proper plants and roof thickness were selected to achieve both comfortable air conditioning and energy optimization. It is also important to use water resources in an optimized manner. Considering the annual mean rain magnitude, here, a suitable system is designed to harvest rainwater for watering the plants. Results indicate that a sedum grass-based green roof with the thickness of 10 cm leads to a 21.3 % reduction in the annual total thermal loads in Tehran; one with thickness of 8 cm in Tabriz will result in a 11.7 % thermal load reduction per year; a green roof with 9 cm thickness in Rasht, Iran shows 13.2 % energy saving per year. Therefore, Tehran is the best option here to integrate the green roof into the structure of the building. The patterns of the obtained data indicate that the reduction of cooling loads is more noticeable when implementing a green roof in comparison with heating loads. Moreover, it has been revealed that harvested rainwater is sufficient to support about 72 % of required water in Tehran, 81 % of it in Tabriz, and 93 % in Rasht.

1. INTRODUCTION

Energy is necessary for conducting any kind of activity. More than 30 % of energy is used in buildings to ensure comfort and convenience. Regarding the reductive nature of classic energy and water resources, there is a significant tendency to optimize the energy and water consumptions in the buildings. Green roofs have obtained significant curiosity in new research due to various challenges such as climate change, environmental collapse, and energy criticism. The installation of green roofs is a helpful idea solving these problems. The implementation of green roof technology has been encouraged by many governments [1-3]. These roofs are able to overcome the problem of heat island effect [4-6], reduce overflow of water [7], and decrease carbon footprints [8,9]. In addition, the green roof is an important technology in order to move toward energy-efficient buildings. Past studies have demonstrated that due to shading, evapotranspiration, photosynthesis, and thermal insulation, green roofs significantly decrease the amount of required energy [10,12]. There are some mathematical models [13-16] that are designed to analyze the related thermal effects. Some of these mathematical models are added to building simulation software [17]. Green roof usually consists of general materials, except for the plant and the water content. Some research works have assumed these roofs as some layers of substrate and other materials with no plant by using approximate thermal resistance (R-value) [11] or thermal transmittance (U-value) [18-21]. The thermal performance of green roofs has been compared with common roofs in some research. For instance, the dynamic benefit of this roof index implementing the ratio of the annual heating, ventilation, and air conditioning (HVAC) energy consumption for a building with a traditional roof to that of a green roof was investigated by Moody et al. [22]. Another research suggested a collection of modified parameters for the total heat transfer of a building with a green roof in comparison with that for a traditional one [23]. The above studies have calculated the effects of green roofs for the whole year. Usually, when designing a building in terms of energy, the maximum thermal loads are considered. Therefore, the efficiency of green roofs in hot season is of great significance. The role of this roof for air-conditioned buildings in summer resembles that of envelope insulation. The mechanism of green roofs is somehow difficult to exactly be modeled; however, the main result is decreasing the heat flow into the building. Takakura et al. [24] conducted a study under a non-air-conditioned situation, and reported that a concrete roof with a green cover layer had heat transfer from the inside toward the outside. This negative heat transfer through the green roof was also reported in a non-air-conditioned room by Yang et al. [25], Jiang and Tang [26], and Tian et al. [27]. It is interesting that when the indoor air is relatively cold under the air-conditioned situation, the heat transfer through the roof appears positive [14, 28]. It is very important to design a proper green roof for each climate.

Del Barrio proposed a simple mathematical model to assess green roofs as a cooling system and thermal insulation to reduce the heat flux through the roof. He introduced important parameters in the vegetation design and selection, including leaf area index, and soil properties, thickness, and moisture [29]. Feng et al. experimentally analyzed energy balance for an extensive green roof system, and showed that in a summer

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day when the soil is fully moist, only 1.2 % of the total heat is conserved in the plant or soil or enters the building and the remaining heat is dissipated through evaporation, radiation exchange, and photosynthesis [30].

Another research investigates the thermal performance of green roofs and their biophysical properties such as the soil surface temperature, soil moisture, ground surface temperature, and tree cover. The results show that the perspiration rate depends highly on seasonal and climatic conditions. Moreover, the vegetation layer is effective in the amount of radiant energy absorbed by the soil. The green roof's bed soil can be considered a huge thermal well that reduces temperature fluctuations. In fact, soil absorbs solar radiation on sunny days. Then, the dissipation of, or conversion into, thermal heat takes place at night [31].

Lin compared thermal conditions of extensive green roofs in different climates, and indicated that the cooling effect of the green roof was greater when the ambient temperature was higher [32]. Zhao et al. studied the effect of plants and bed selection on the thermal performance of green roofs in summer, and reported that they were two important factors in the design of green roofs [33]. There are significant studies about the combination of the soil in green roof structures. Rumble et al. showed that the succession of soil organisms was influenced by the communities present in construction materials that had implications for the substrate design, showing that soil organisms might be inoculated by green roofs to provide functioning techno sols [34]. The effect of the existence of different climates on designing green roofs should be also considered. Many studies have focused on a special climate, e.g., Mediterranean climate [35,36]. Therefore, it is a good idea to compare the effects of integrating green roof in various climates in a country.

As mentioned before, another important issue when designing a building is to optimize water consumption. Nowadays, the water criticism is more sensible, because water demand is increasing due to the growth of global population, rapid industrialization and urbanization, and water resources that are in danger because of environmental pollution and climate changes. The population of the world has grown about three times in the 20^{th} century; however, water consumption has increased about six times. Moreover, water seems to be one of the most considerable natural wealth sources in the 21^{st} century [37].

Domestic water in buildings is used for usual household applications and also daily water consumption. Decreasing requested water for domestic consumptions has become an important requirement. There are various water conservation scenarios applicable. Harvesting rainwater is one of the common methods for water conservation in buildings.

In classic architecture, one of the common solutions is to collect rainwater in water cisterns or wells in rainy seasons and, then, to use it in suitable times and places. Collecting rainwater, which has been used for approximately a thousand years, in combination with new technology has become a common method all over the world. Using rainwater in dry areas where water is not sufficient may support water safety up to 80 % [38]. Rainwater is a natural water resource that may be harvested in many regions. By going through a short process, rainwater is suitable for use in almost all domestic applications in a residential building.

In recent decades, overbuilding in Iran has obscured urban landscapes. This has negatively affected the quality of air, increased the mean temperature of cities, and led to the formation of heat islands within the cities. The undesired effects of urban life can be reduced by increasing green areas across the cities, specifically on the roofs.

In this research, a residential building has been studied in three different cities and, consequently, climates in Iran including Rasht, north part of Tehran, and Tabriz. The thermal loads of the buildings are calculated and an optimized green roof is designed in these climates. The energy saving is analyzed, and the suitable plants and optimized thickness of the green roof are proposed to obtain both comfort condition and energy optimization, simultaneously. Moreover, considering the annual mean rain magnitude in each related region, here, a suitable system is designed to harvest rainwater to support plants' water requirements. This helps to use water resources in an optimized manner. The outcomes are finally compared for the three mentioned regions.

2. METHODOLOGY

This study focuses on the analysis of the effects of implementing an optimized green roof in a residential building on reducing energy consumption in Tehran, Tabriz, and Rasht climates. Design Builder software is used to calculate the thermal loads in various cases. Moreover, an optimized irrigation system is designed to decrease the water consumption of the building.

2.1. Case illustration

The studied building has five floors including an office in the ground floor. There is also an additional parking floor. Its total area is about 950 m^2. All windows of the building have a UPVC frame with thickness of 4 mm and have a double-glazed bronze glass filled with Argon gas (thickness of 6 mm and gas layer of 13 mm), and there is no external shading. Moreover, all of the walls have thickness of 20 cm [39]. The sample space is residential and there is one unit on each floor with the occupancy of four people. Table 1 shows energy consumption of the official equipment including a personal computer, fax, printer, etc. Other spaces as staircase, kitchen, facilities, etc. are assumed according to the standard conditions of each case. The comfort temperature is assumed to be 22 and 24 degrees of centigrade in the winter and in the summer, respectively. Different thicknesses are considered in the case of green roof for various designs to consider a sensitivity analysis issue. Cooling and heating loads of the building have been calculated in both cases of normal roof and green roof in each climate. Figure 1 represents the 3D model of the current building.

External walls include a polyethylene foam layer of 5 cm thickness. Moreover, roofs include polyethylene foams with 10 cm thickness as acoustic and thermal insulation. Properties of the ingredient materials are represented in Table 2 [39].

Table 1. Power of different equipment used in the office [40].

Equipment type	Power(W)
Computer	400
Fax machine	150
Copy machine	350
Printer	450

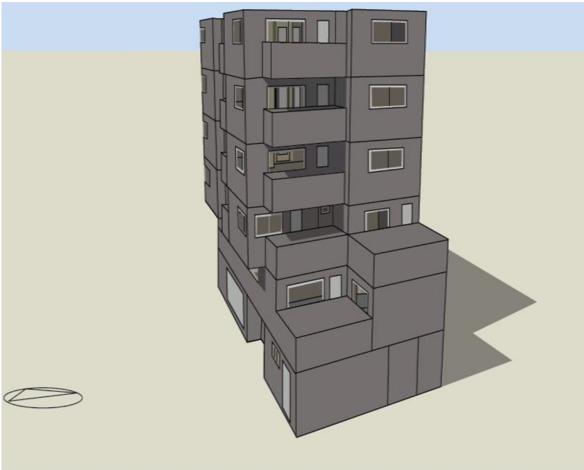

Figure 1. 3D model of the building.

Table 2. Properties of ingridient materials.

Material	Specified heat value J/KgK	Conductivity W/mK	Density g/km^3	Thickness m
Conc1	880	1.4	2300	**0.15**
Conc	950	1.35	1800	**0.35**
Stone	1470	1.44	1600	**0.1**
Mortar	920	0.72	1650	**0.03**
Gypsum & sand	900	0.14	530	**0.02**
Gypsum1	840	0.16	950	**0.015**
Gypsum2	2000	0.16	1200	**0.02**
Granit	1000	1.3	1750	**0.025**
Ceramic	1900	0.84	800	**0.02**
Brick	800	0.84	1700	**0.1**
Poly ethylene foam	2037	0.042	20	**0.02**

2.2. Green roof

There are different techniques to simulate green roofs. The U-value model is one of the most applicable models. Some other models include shading with leave and branches and, also, surface vaporization. The selection of suitable soil is among the most important steps of a green roof design. Different compounds have been proposed for this purpose, and studies have revealed that the best soil combination for sedum and grass consists of humus, clay, sand, coir, Lea capon, and pearlite [41]. This combination has the lowest weight in its dry and saturated form. The volumetric percent of these soil components is presented in Table 3. This composition is proposed for sedum-grass plants in green roofs [41].

Table 3. The volumetric percent of the soil components [41].

Soil components	Volumetric percent
Cockpit	**45**
Vermi compost	**13**
Humus	**15**
Leca	**13**
Pearlite	**10**
Rice slack	**4**

Typically, taking into account a green roof in the design process results in no considerable additional costs. In both cases of the implementation of a green roof on a constructed building or during the construction, the desired green roof type and its plants should be exactly determined according to the climate and other situations.

The first priority in the selection of suitable plants for a green roof is attention to the roof type. To achieve a sustainable green roof, it is of great importance to accurately and correctly select the plants to be in harmony with native conditions. In addition, the building conditions and its load-bearing capacity are other important factors in this regard.

The green roof type, considered in the current study, is an extensive green roof with a weighted arithmetic mean of 150 kg/m^2 and a height of 5-20 cm. This system is mainly focused on economic and ecological functions [42]. In this model, all surface areas require a drainage system. The thickness and weight of the roof are slightly low, making it a suitable option for buildings with load-bearing constraints.

The research assumptions regarding the green roof type, as plant type, height, emissivity, leaves reflectivity, etc. are presented in Table 4. This information is used in the design step of the integrated green roof. LAI is the leaf area index that is a dimensionless quantity, which characterizes plant canopies. It is defined as a one-sided green leaf area per unit ground surface area in broadleaf canopies. The following equation shows this parameter:

$$\text{LAI} = \text{leaf area/ground area, m}^2/\text{m}^2 \qquad (1)$$

Table 4. The green roof properties [42-43].

Type of the green roof	**Extensive**
Plant type	**Grass-sedum**
Average LAI*	**0.5-5**
Height of the plant (cm)*	**6-15**
Reflectivity of leaves	**0.25**
Emissivity of plant	**1**
Minimum stomata resistance(s/m)	**150**
Max volumetric moisture content at saturation	**0.5**
Min residual volumetric moisture content	**0.01**
Initial volumetric moisture content	**0.15**
Soil conductivity(W/mK)	**1**
Specific heat value(J/kgK)	**1550**
* The minimum belongs to the winter and the maximum belongs to the summer.	

Because of various weather conditions and growth rates of plants, the average of LAI is different in winter and summer. It is assumed 0.5 cm and 5 cm in winter and summer, respectively. During winter, plants are in the sleep mode; therefore, the average LIA is obviously lower [43].

In the following session, the making of the model of a building and, also, the simulation and solution steps are shown and determined, respectively.

2.3. Modeling the building

Buildings are very complex environments in which the external walls and facades, facilities, and lighting systems are the most important components of energy consumption, and the energy consumption behavior is characterized as an integrated system. These factors make it difficult to precisely predict energy consumption and necessitate the use of accurate software applications to reduce the estimation error. The most efficient energy consumption estimation tools available in this field are the energy simulators, which virtually provide almost a real prediction of building performance. Moreover, designers should introduce new energy-saving technologies through optimization and improvement.

In the present study, Design Builder software is used to model and simulate the system and analyze it. In the first step, AutoCAD is used to draw the 2D plan of the building floors. Then, the .dxf file is inputted into Design Builder. In the next step, all thermal zones of the building are determined. Based on their usage, each zone could be equipped with an air conditioning system, which affects the heat and cooling load of the building. Moreover, depending on the application, each zone has a specific schedule, which is developed for a more accurate calculation of the cooling load of the building in this study based on the Iranian lifestyle. The schedule in each zone includes lighting, certain lights, electrical equipment, and individuals. This information is used to calculate the heat transfer through walls, doors, and windows.

It is worth noting that the building design and the used materials are fully modeled from a real sample according to the standards of the Iran Construction Engineering Organization [39]. Another important factor affecting the heat transfer through the floor is the mean soil temperature. In this study, in different months of the year, the mean soil temperatures at a depth of 0.5 m as the ground surface and at a depth of 2 m are presented in Table 5. This data is accessible through climate. stat files [42]. Table 5 presents these data for Tehran.

Table 5. Soil depth temperature per year for Tehran [42].

Month	Soil depth Temperature	
	2 m	**0.5 m**
Jan.	6.4 °C	**10.4 °C**
Feb.	5.4 °C	**8.5 °C**
Mar.	7.3 °C	**8.9 °C**
Apr.	10.2 °C	**10.4 °C**
May	17.9 °C	**15.6 °C**
Jun.	23.8 °C	**20.2 °C**
Jul.	27.8 °C	**23.9 °C**
Aug.	29 °C	**25.9 °C**
Sep.	27 °C	**25.5 °C**
Oct.	22.4 °C	**22.9 °C**
Nov.	16.2 °C	**18.6°C**
Dec.	10.5 °C	**14.1 °C**

Another important parameter of the cooling and heating calculations and energy analysis in a building is infiltration. It refers to the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through the use of doors for passage. There are two methods for the calculation of air infiltration and exfiltration the seamless method and the volumetric method. In this study, the seamless method is used due to its high accuracy.

In the next step, an air conditioning system is designed for the building. In the arid climate of Iran, the conventional air conditioning systems, such as water-based air coolers, are unfortunately more common and popular than new air conditioning systems. One of the air conditioning objectives is to provide appropriate air temperature, humidity, quality, and distribution.

In direct evaporative cooling systems, water droplets are directly combined with the airflow. The water temperature balance, which constantly circulates, is equal to the wet-bulb temperature of the inlet air. The dry-bulb temperature reduces and its relative moisture increases due to the mass and heat exchange between air and water at the same time with a constant wet-bulb temperature.

One of the greatest weaknesses of direct evaporative cooling systems is the huge water consumption. Depending on water capacity, the direct evaporative cooling system can consume 30-45 liters of water per hour on average, which is approximately 700 liters every day. Under the current water crisis in Iran, it is very important to select an optimal air conditioning system. Among other weaknesses of direct evaporative cooling systems is the inability to supply high-quality air inside the building. Direct evaporative cooling systems carry pollutants and particulate matters from outside to the inside of the building. Moreover, since the wood wool cooling pads should be kept wet, they are a suitable place for the growth and proliferation of fungi. Due to the lack of a thermostat system, the operation of such coolers cannot be set based on internal temperature.

Therefore, the desired air conditioning system for this building is split air conditioners at the right capacity for each space in summer and a floor heating system in winter. Moreover, the required hot water is supplied by the central heating system.

In this stage, climatic data are inputted into the software. There are two ways to collect climatic data: the software default settings and data and the use of Metronome, a software application that creates .ewp files containing geographical and climatic data of the given region for a specific year [44]. When the climatic data are inputted into the software, the temperature of solar radiation at each hour of every day of the year is automatically included in calculations.

In this study, one side of the building is completely attached to another building by an adiabatic wall. On the other side, the building has three floors attached to its neighboring building by adiabatic walls.

2.4. Designing a proper irrigation system

In many parts of Iran, the construction of a green roof depends on the possibility of irrigation considering the climatic conditions. Although the amount of irrigation depends on the green roof type and its vegetation as well as the climate of different regions, it is essential to predict an appropriate irrigation system. The green roof irrigation with conventional methods using the tap water is not proper according to the sustainable development objectives and imposes huge costs on the system and residents. Therefore, suitable measures should be predicted concerning water resources for irrigation and optimal irrigation methods to avoid water loss.

There are different methods for supplying the water from additional water resources such as recycled greywater, condensation leak, and drained water.

One of the steps in the green roof design is to design an optimal irrigation system proportional to the plants. In general, stonecrops are perennial plant species that need less irrigation and care than other plants. They also perform better in dry soils. Although there are both conventional and automatic systems of green roof irrigation, the latter is very costly and inapplicable to all buildings. The conventional system, which depends on the tap water, is not a good choice regarding the current water crisis. The other water supply method for green roof irrigation is the rainwater harvesting and mechanical treatment. In this study, the required irrigation water is supplied through rainwater harvesting and treatment.

The following factors should be taken into account in rainwater harvesting for irrigation: rainfall volume, rainfall intensity, evaporation and transpiration, soil infiltration, soil water-holding capacity, soil depth, and product properties such as water requirement and growth period.

Generally, the rainwater harvesting includes four major elements including rainwater harvesting area, distribution system including pipes and downspouts, reservation area, and a delivery system like a tap or a pump.

Figure 2 shows a schematic view of a rainwater harvesting system in a green roof. This system generally includes a simple structure, such as a roof and a downspout, which directs the rainwater towards the storage tank. The rainwater delivery system, including fittings, roof drainage pipes, and piping from the roof to one or more water ducts, aims to collect rainwater through a filtering system. The best piping materials are made of polyethylene (PE), polypropylene (PP), or stainless steel.

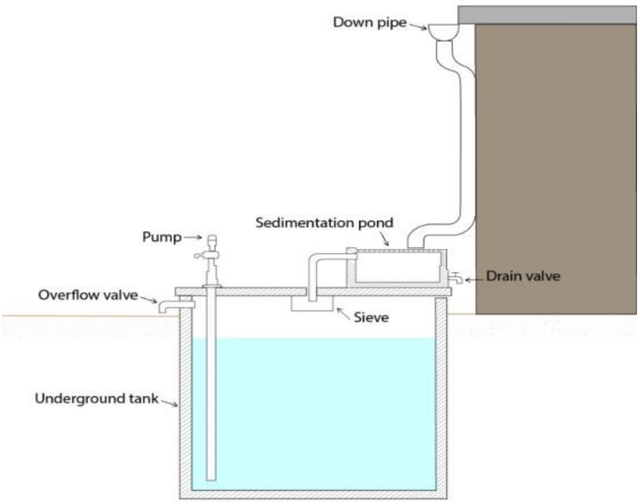

Figure 2. The schematic view of a rainwater harvesting system.

Before storing and using the water, it should be treated. The selection of the filtering system depends on the building conditions. This system should be designed such that rainwater pollutants can be surely eliminated, which are at the maximum level in the early heavy rainfalls.

Depending on the available area, the storage tank can be placed above or under the ground. This system can be installed as part of the building or a separate unit away from the building. The storage tank should have a dark color to prevent algae growth and also should be near the consumption site to reduce water supply cost. The storage tank is typically the most expensive part of a rainwater harvesting system, which requires a precise design and structure. It should be also durable and resist the infiltration of water and pollution. A good design should include a strong solid cover, an appropriate input filter, an overflow pipe, large valves, basin, a drainage system to facilitate cleaning, and a suitable discharge system including a pump or a tap. The meteorological data should be used for designing a rainwater harvesting system. These data should minimally include a 10-year period. The monthly and annual precipitation data are used to design a rainwater harvesting system in these cities [45].

The common equation is as follows:

$$G = \alpha RA \tag{2}$$

where G is collected water in gallons, α is the rainwater harvesting factor for residential building, R is the magnitude of rain in inches and A is the effective area in square feet [46].

In theory, approximately, 0.6 gallons of rainwater can be harvested from 1 inch of rainwater on a roof area of 1 ft². Approximately, 35 % of rainfalls in the region cannot be harvested because of evaporation or infiltration. Accordingly, the following equation shows the harvestable water from a certain amount of rainfall on a roof. Since the green floor does not need irrigation during the rainy seasons, the required amount of water during dry seasons should be considered in designing a rainwater harvesting system.

3. RESULTS AND DISCUSSION

Design Builder software was used in this study to calculate cooling and heating loads of the building in three different climates. At first, the calculation of thermal loads was done without considering the green roof. Split was chosen as a cooling system in summer and floor heating system was used for heating in winter.

Firstly, the effect of the green roof on the heating load of the building has been studied. Figures 3-5 report the results of the heating and cooling loads of the building for the base form without a green roof for Tehran, Rasht and Tabriz. It is observable that for all of the three cities the maximum cooling and heating loads appear in August and December, respectively.

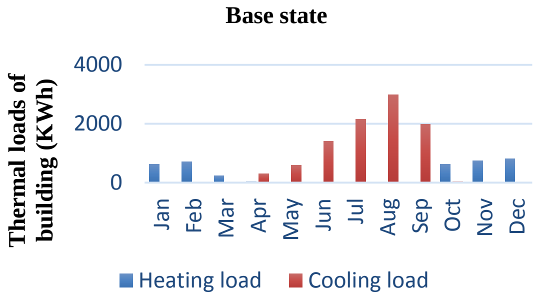

Figure 3. Heating and cooling loads of the building per year for the base state in Tehran.

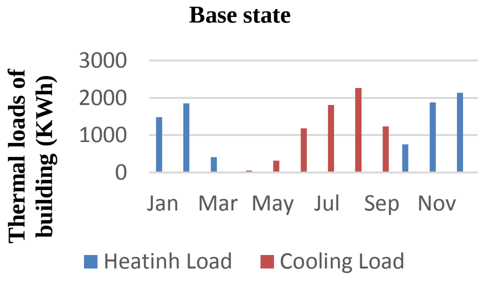

Figure 4. Heating and cooling loads of the building per year for the base state in Rasht.

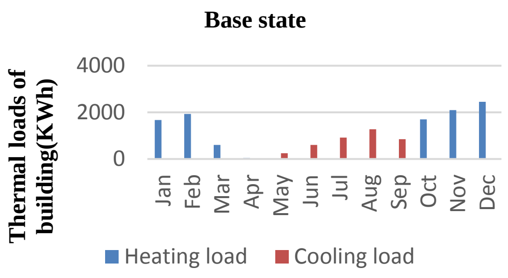

Figure 5. Heating and cooling loads of the building per year for the base state in Tabriz.

In Tehran, being included in hot and arid climate, more cooling loads are needed as reported in Figure 3. In Rasht as a mild climate region, there is no significant difference in the cooling and heating loads finally in Tabriz as a cold and dry climate, there are more required heating loads in comparison with cooling ones.

Figure 6 indicates the results for the heating loads of the building considering various thicknesses of a green roof for Tehran.

It is obvious that increasing the thickness of the green roof continuously leads to the reduction of the heating loads, and the least load has been reported in the case of 10 cm thickness.

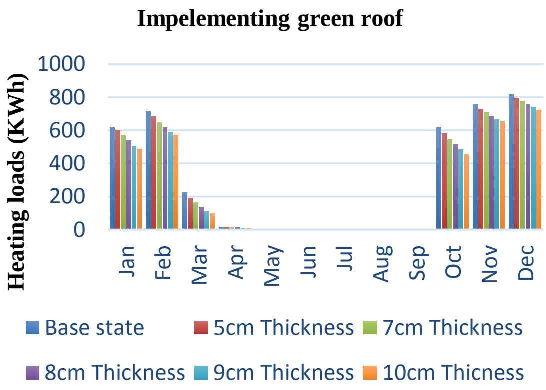

Figure 6. Heating loads of the building per year for various thicknesses of green roof in Tehran.

Figure 7 shows the cooling loads of the building around the year for different thicknesses of green roofs in Tehran. It is observable that the increase of thickness results in a load reduction at a steeper rate in comparison with the decrease of heating load in the same situation. According to the archived results, the percentage of the energy saving due to different thicknesses of the green roof is reported in Table 6 for city of Tehran.

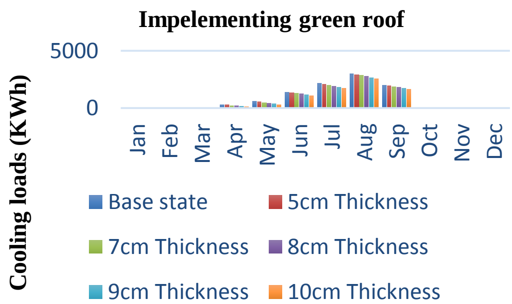

Figure 7. Cooling loads of the building per year for various thicknesses of green roof in Tehran.

Table 6. Annual energy saving of the building in Tehran.

Thickness (cm)	Total load (KWh)	Energy-saving percentage
0	13188.4	**0**
5	12652.8	**4.06**
7	12109.8	**8.16**
8	11536.5	**12.54**
9	10931.2	**17.11**
10	10379.6	**21.3**
11	10380.1	**21.31**

Since increasing the thickness of the implemented green roof to more than 10 cm does not lead to any significant energy saving in the building and also considering maintenance cost and building weight loads and green roof type as an extensive one, 10 cm thickness is proposed as the optimum magnitude in Tehran.

Figures 8 and 9 report a comparative graph for all studied cases' heating and cooling loads of the building.

Figure 8 reports that a decrease in the heating loads of all of the studied cases when adding thickness of the green roof.

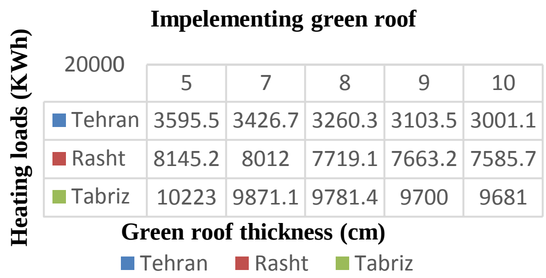

Figure 8. Comparative graph for all studied cases' heating loads.

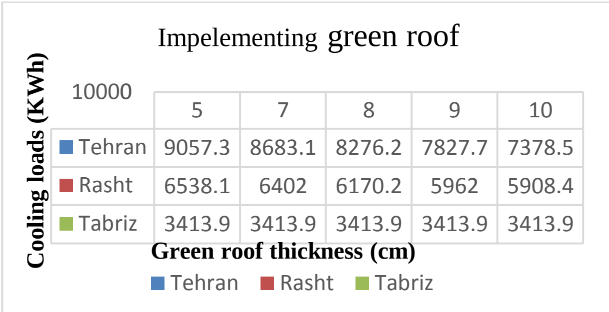

Figure 9. Comparative graph for cooling loads of all studied cases.

As obvious from Figure 9, cooling loads also have a decreasing trend while increasing thickness of the green roof. This reduction is more sensible in comparison with that of heating loads, because of less LAI of plants and the winter sleeping mode of plants on cold days, resulting in the lower performance of the green roof in cold seasons. For Tabriz in the thickness of 8 cm 11.7 % of energy saving has been reported and an increase from 8 cm to 9 cm leads to less than 1 % load reduction; therefore, the optimized selected thickness is 8 cm. For the same reason, in Rasht a green roof with thickness of 9 cm that results in 13.2 % of annual load reduction is the optimized design. As is observable, Tehran owns the best results. In Tabriz because of less sun radiation and consequently less opportunity to have an active green roof, the least load reduction has been reported.

Concerning the water harvesting system, considering Meteoroidal Organization of Iran statistics and Equation 1, with a roof effective area of 190 m^2 for the building, 6544 L rainwater will be harvested in the tank during a year in Tehran, 5436 L in Tabriz and 8324 L in Rasht [45]. Because of the low-volume activity of plants during cold seasons little water is required. The calculation of harvested water reveals that the designed system can supply water for about 130 days in a year in Tehran and 150 days in Tabriz. Therefore, approximately 72 % of the total required amount in Tehran, 93 % in Rasht and 81 % in Tabriz are supplied.

It should be mentioned that to validate the software results, the heating and cooling loads of the first floor of the building have been computed manually. Consequently, the cooling loads resulting from manual calculations approximately represent 5 % relative error compared with the simulation results. This error is about 5.5 % for the heating loads. In addition, the behavior of thermal loads in summer and winter regarding various thicknesses of the green roof is in good similarity with those in previous research indicating that green roofs obviously decrease the cooling load of the buildings in the hot season more than heating load during the cold season [47, 48].

4. CONCLUSIONS

In this research a green roof and a rainwater harvester system were designed for a residential building in three different cities including Tehran, Rasht and Tabriz. To get optimized results and improvements, an extended grass-sedum type of green roof was selected. The effect of various thicknesses of the green roof on the thermal loads and energy consumption of the building was studied. Results revealed that, in Tehran, the integration of an extensive green roof with thickness of 10 cm led to 21.3 % annual energy-saving in Tabriz implementation of a green roof with thickness of 8 cm resulted in 11.7 % of energy saving during a year in Rasht, that with thickness of 9 cm led to 13.2 % of saving in the annual energy consumption. The best performance of green roof was reported for Tehran and the worst one belonged to Tabriz because of its low solar radiation and consequently the weaker situation for plants growth. The designed rainwater harvester was able to support 72 % of the required water for water plant of the building in Tehran, 93 % in Rasht and 81 % in Tabriz. In the future works the effect of relative area of the green roof to the total area on the efficiency of this system, the integration of greenhouse space for the purpose of a stronger green roof during cold seasons may be considered.

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NOMENCLUTURE

A	Area (f^2)
G	Collected water (gallons)
A	Rain water harvesting factor
R	Magnitude of rain (inch)
LAI	Leaf area index (m^2/m^2)

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