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ORIGINAL ARTICLE

Simulation and optimization of energy consumption systems in buildings in varying climatic conditions

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Abstract

Green roof research has grown rapidly over the past decade. The green roof has been proposed as a lasting move to reduce urban-related complications. The installation of green roof systems has been made as a specific measure to achieve a wider objective to enhance environmental sustainability. As one of the effective parameters on energy consumption, buildings have always been considered the attention of engineers to reduce the amount of energy consumption. In this study, the effect of different factors including effect of different facades on energy consumption has been investigated, for this purpose, the Energy Plus software has been used to model and perform sample building calculations at three parts of Tehran, Tabriz and Bandar-e-Abbas. The results of this study show that the city of Tehran will have the best performance in reducing energy consumption and it will be suitable for Tabriz city of color concrete, as well as in Bandar-e-Abbas, a warm climate representative, the use of travertine 1 is suitable.

Keywords Energy · Plus · Facade · Climate · Green roof · Reducing energy

List of symbols

- $\dot{Q}_i$ Heat transfer (W)
- h_i Convection heat transfer coefficient (W/m^2.K)
- A_i Interior surface (m^2)
- T_{si} Internal surface temperature (K)
- C_p Heat capacity (J/Kg.K)
- T_∞ Outdoor temperature (K)
- $\dot{m}$ Mass flow rate (kg/s)
- T_z Zone temperature (K)

Introduction

Today, with the reduction of renewable resources and closing them off, saving and taking advantage of energy is considered important, and all scholars and pundits are looking for ways to reduce energy consumption and to use renewable energy (Bashirpour-Bonab and Javani 2019). Meanwhile, one of the sectors in developing countries has a significant contribution to the total energy consumption of the whole country. Therefore, it is necessary to find solutions to reduce energy consumption in buildings. The proper selection of building materials tailored to the climatic conditions of each region can save energy consumption (Coma et al. 2016). One of the factors that can have a great impact on solar energy intake by the building is the material used in the exterior facade of the building (Korol and Shushunova 2016). When sunlight hits the surface of the non-transparent region of the building, part of its thermal energy is reflected and the remainder is absorbed by the facade. The amount of solar energy absorption is dependent on the material, the color, and the surface (rough or glossy) of the outer facade (De-Ville et al. 2017).

So far, a lot of research has been done to investigate the impact of foreign surface on building energy consumption. Lindberg et al. (2004) studied solar energy intake on walls with brick and wooden facades. Their results were related to the significant effect of building facade on building energy consumption. Badescu et al. (2006) discussed the effects of solar energy storage on the outside of the building on a reduction in energy consumption in the cold climate. In the same year, Prager et al. (2006) investigated experimentally the effect of the solar reflection coefficient on the building load on the building load. Their research results showed that, if the exterior facade of the building was covered with gray, the heating load of the building was reduced to the white-painted facade and its cooling load increased.

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Lobaccaro et al. (2012) used a numerical simulation to analyze the effects of the external appearance of the building on the annual energy consumption of buildings in the Milan region of Italy, and in his studies, concrete facades, aluminum facades, glass facades and vegetation facades were studied. Also, Susorova et al. (2013) examined the effect of using vegetation coverings on the outer wall of the building numerically and experimentally. The results of this study showed that the use of plant coverings reduced the absorption of solar energy and reduced summer load, while it could increase the winter load of the building.

Green roof for the building and its surroundings has many advantages and disadvantages. Some of these benefits include reducing drainage systems, improving run-off quality, reducing air pollution and reducing carbon dioxide, protecting roofing shells and increasing the life span of the roof, reducing the effects of thermal islands and many other benefits, including improving the architectural quality of the building and environmental diversity (Chen et al. 2019; Sangkakool et al. 2018). In 2003, Herman (2003) reported that Germany is the largest absorbent of green roofing technology in the world. 13.5 km^2 of roofs in Germany, which is 14% of all flat roofs in Germany. According to the official site of the livingroofs website (The UK's Leading Independent Green Roof 2010), London's green roofs have been calculated and 0.93 km^2 from London is covered with green roofs. Wong et al. (2003) found that in hot weather, they would accumulate throughout the day in normal roofs to reach the building by night. The green roof during the day increases the heat, so the heat is less effective. Also, by measuring the air temperature at different heights in the green roof, it was found that after the sunset, the temperature of the environment was significantly reduced. This reduction continues to cool down the ambient air over the course of 24 h. That is why using the green roof can control the heat inside the building. Lui et al. (2005) in Toronto, two different green roof systems were each planted between 100 and 75 mm in average and growing weight, and heat exchangers were placed under a green roof membrane. For comparison, a roof of the same type was used. They found that through the green roof, the heat increased between 70 and 90% in the summer and decreased by 10–13% in the winter. Alcazar et al. (2005) concluded that the shadow caused by solar radiation, evaporation and sweating and plant physiological processes affects the performance of the roof over increasing thermal resistance. Their results showed that the green roof could lead to a dramatic decrease in the heat flux of the incoming heat to the building under the roof.

In Iran, some research has been done to evaluate the effects of the exterior facade of the building. In the research, Marefat et al. (2006) in a study showed that by choosing the appropriate materials for the facade of the building, it would be possible to prevent condensation in the cooling systems in the Tehran climate. Ebrahimpour et al. (2012) studied Energy Consumption in Tabriz University Building using Energy Plus software. It also examined the effects of its appearance and its color on energy consumption. The results of their research showed that the use of white instead of dark colors can reduce annual energy consumption by about 9%; though a number of studies have been conducted on the effect of the external appearance of the building on energy consumption. But so far there has not been a comprehensive study on the comparison of the effects of the use of common materials for the facade in different climates in Iran. Also, the suitability of materials used in the facade is strongly dependent on the climatic conditions of the area. In other words, if a material reduces the absorption of solar heat, it will naturally reduce the summer load and increase the winter load. Accordingly, only by specifying the annual load for a given climate, one can comment on the suitability or lack of external building materials (Zhang et al. 2019).

In this research, the modeling of a typical building in three climates, Tehran (as a representative of the average climate), Bandar-e-Abbas (as a warm climate), and Tabriz (as the representative of the cold climate) has been explored through the Energy Plus software, and the magnitude of the impact of common types of facades on energy efficiency is studied.

Energy Plus software

Energy Plus is one of the most powerful energy simulation softwares in the world. The software, the first version of which was presented in April 2001, provides a comprehensive energy simulation of the building to engineers, architects and researchers for use in energy and water models (Hashemi et al. 2015). Energy Plus has innovative and useful capabilities in simulation, analysis with less than an hour, modular system, multi-regional airflow, comfort conditions, natural ventilation and photovoltaic systems. A new energy simulation program based on a combination of BLAST and DOE2 programs.

As shown in Fig. 1, this program is divided into two parts of the heat and mass balance simulator and system simulator used in the building. Of course, this program performs analyzes in less than an hour and is based on a thermal equilibrium of the entire simulation zone and optimal scenarios are provided by the software. The software is provided with insulation between the walls of the roof and wall (with the default insulations defined in the software) and the examination of the windows in single-, double- and triple-glazed (with different glasses) and time. The function of the ventilation system (according to the time of the people's presence) is to automatically provide an improvement percentage for

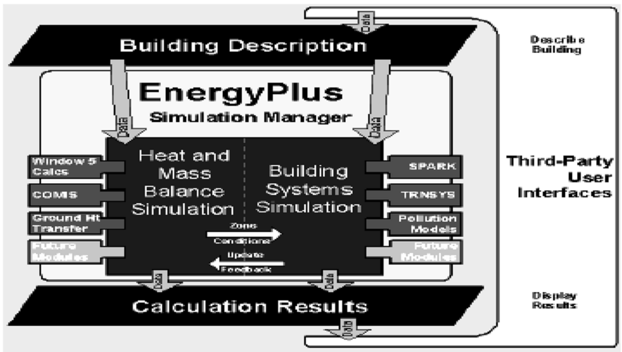

Fig. 1 Overall Energy Plus structure

all modes and provide the best results for each part. The basis of the software work is the following equation:

$$C\frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p (T_{zi} - T_z) + \dot{m}_{inf} C_p (T_\infty - T_z) + \dot{Q}_{sys} \quad (1)$$

where $C\frac{dT_z}{dt}$ is equation of energy stored inside the building, $\sum_{i=1}^{N_{sl}} \dot{Q}_i$. is total heat transfer internal displacement, $\sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si} - T_z)$ is convection heat transfer from the surface of the examined area, $\sum_{i=1}^{N_{zones}} \dot{m}_i C_p (T_{zi} - T_z)$ is heat transfer caused by mixing air inlet, $\dot{m}_{inf} C_p (T_\infty - T_z)$ is heat transfer due to temperature change of the air temperature to the internal temperature, $\dot{Q}_{sys}$ indicates heat transfer and refrigeration.

In this thermal application, the thermal simulation is accompanied by a test and error, and thus, the above equation is the amount of energy necessary to balance the environment, and then, based on the estimated amount of energy, the simulation system equipment is also simulated if necessary. Then the calculations are done according to the real power of the environment.

Materials and methods

In this research, a building sample of 10 × 20 m has been selected. Also, internal space separation is avoided to prevent the effects of internal partitioning. There are windows in the south and north walls of this building. The windows are double-sided, each glass having a thickness of 3 mm and a gas between the glasses, the air is 13 mm thick. Also, considering the effect of the type of the facade and the exact specified, this study examines all the building's walls with outside air, or, in other words, the facade is used for all the walls. The modeling building has two floors, and the conditions of each floor are similar to each other. The building has no angles over the north axis and is simulated in the urban area. In Fig. 2, you can see a view of the building.

For a simulated building, the standard is suitable for office locations. The temperature inside the rooms is 22 °C in the summer and 24 °C in the winter. The building is connected to the outside with air, and the intrusive air is replaced by a room temperature equivalent to the outside air temperature, 1 time per hour. Also, the heat transfer algorithm for internal and external surfaces is considered by default as TARP and DOE-2, respectively. The hours of presence of individuals according to the UK NCM (2018) standard for office buildings are as follows: it should be noted that the heating and cooling systems are used when people are present and maintain indoor temperature in the presence of people in the mentioned conditions. Other systems, such as the supply hot water production system, also match the hours of presence of people in the building.

The type and structure of materials used in the walls of the building and their physical properties are given in Tables (1 and 2). As shown in Table 2, the walls are

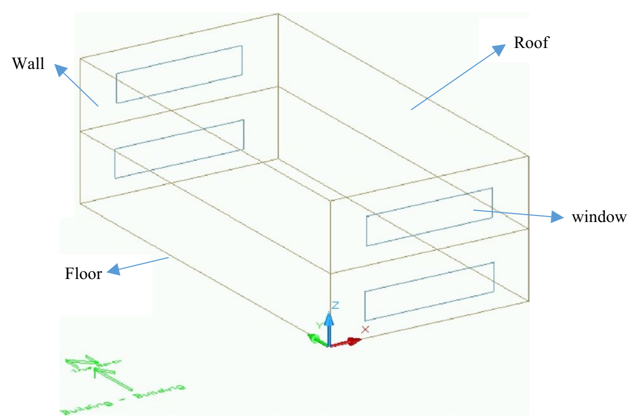

Fig. 2 View of the building under review

Table 1 Material and physical properties of the materials used in the building

Material	Thickness (mm)	Thermal conduction (W/m K)	Density (kg/m^3)	Special heat (J/kg K)
Concrete	50	1/4	2300	880
Cement	–	0/72	1860	780
Soil plaster	2	0/14	530	900
Bricks	11	0/84	1700	800
Plaster 1	1.5	0/16	950	840
Plaster 2	2	0/16	1200	2000

Table 2 Materials used in the walls of the building

Crust	Outer layer	Inner layer 1	Inner layer 2	Inner layer 3
Wall	Facade	Bricks	Plaster 2	Plaster 1
Roof	Cement (thickness 20 mm)	Bricks	Soil plaster	Plaster 1
Floor	Concrete	Cement (thickness 60 mm)	–	–

composed of four layers, as well as the roof of four layers and the floor of two layers.

To calculate the energy consumption, the city temperature is considered over a period of 1 year. As shown in Table 3 in this research, the temperature of the city of Tabriz, − 2 to 26 °C, Tehran's air temperature, 1–31 °C, and the temperature of the city of Bandar-e-Abbas, 17–34 °C, are considered (Canty and Frischling 2019).

Software validation

Various tests are conducted every year on the Energy Plus program to upgrade the software, a few of which are listed here. These tests will improve the software. ASHRAE (2017) is an application that has simple tests to test software outcomes (Vijayaraghavan 2016). The calculations of this software are completely theoretical and mathematical formulas. In the following figures, several cases of different analyzes are identified between this software and the Energy Plus software.

In Fig. 3, the comparison of the simulated and measured solar radiation measured in the south side glasses of the test room is in shaded and without shaded modes. The results indicate the accuracy of the software.

Figure 4 shows the different temperatures (dry temperature outside, temperature on the outer surface, and temperature on the inner surface), and the volume of space cooling is simulated and measured. The results show the acceptable software precision (Li and Yeung 2014). In this test the temperature inside the room is maintained at 20 °C with a wall of 10 cm thick and made of wood where heat transfer is

Table 3 City monthly weather summary (°C)

City	January	February	March	April	May	June	July	August	September	October	November	December
Tabriz	− 2	0	5	11	16	22	26	26	21	15	7	1
Tehran	1	5	10	17	21	27	31	29	26	18	11	5
Banadr-e-Abbas	17	19	22	26	31	33	34	33	32	29	25	20

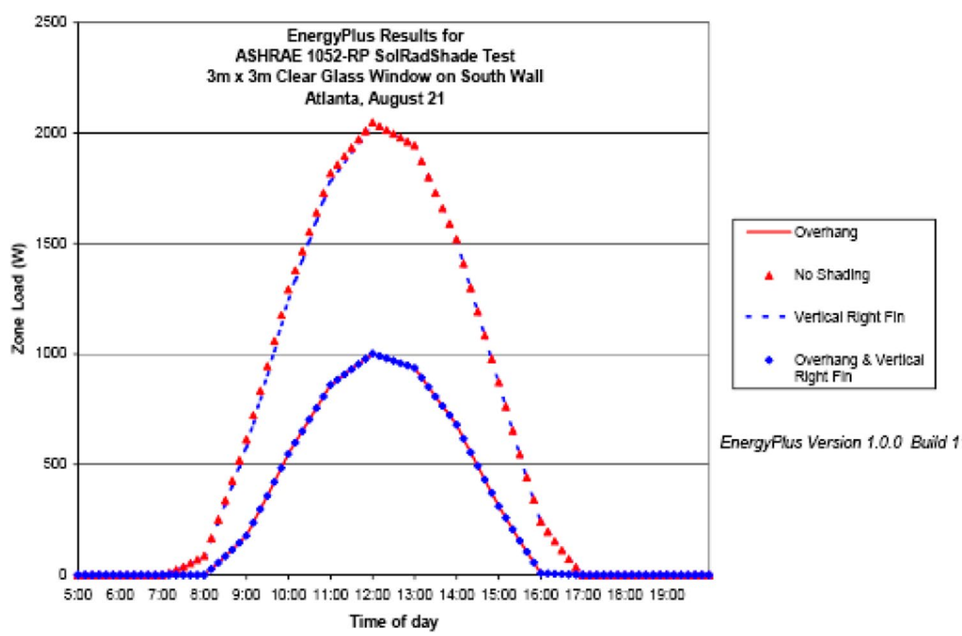

Fig. 3 Comparison of solar radiation extracted from the software and experimental data

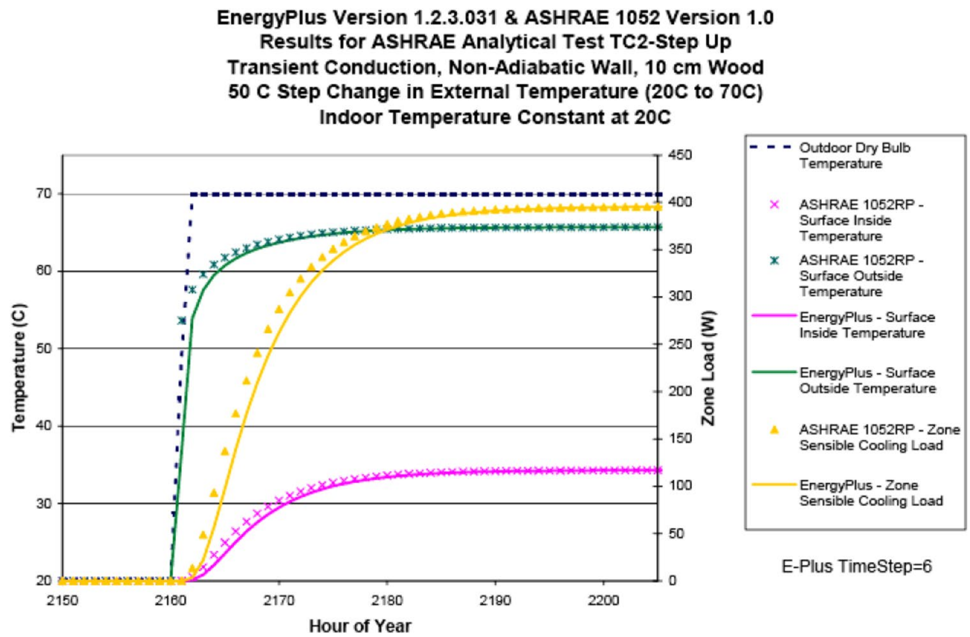

Fig. 4 Comparison of different temperatures calculated by software and measured data

Table 4 Building materials with properties (Zolfaghari and Jajaram 2015; Cascone et al. 2019)

Facade type	Thermal conduction (W/m K)	Special heat (J/kg K)	Density (kg/m^3)	Solar absorption coefficient
Colored concrete	0.51	1000	1400	0.9
Refractory bricks	0.84	800	1700	0.35
Bricks (3 cm)	0.72	835	1920	0.55
Red brick	0.84	800	1700	0.75
Purdue brick	0.62	800	1700	0.63
White marble	1.5	910	2180	0.46
Travertine 1	1.4	950	2000	0.4
Travertine 2	1.4	950	2000	0.6

possible, for the embedded room, simulation, and measurement on this wall and room (Huang et al. 2018).

Results and discussion

Analysis of the results of the facade

Now that the modeling method is somewhat assured, we will examine the effect of different facades on the annual energy consumption in the building. To investigate the effect of the facade for the external walls of the building, different facades have been used, the characteristics of each of these facades are specified in Table 4. For the same purpose, we simulate the different climates of the modelled building with different facades to determine the most appropriate type of facade for each climate. During the simulation process, all parameters ranging from the specification of other thin walls and roof and roof layers

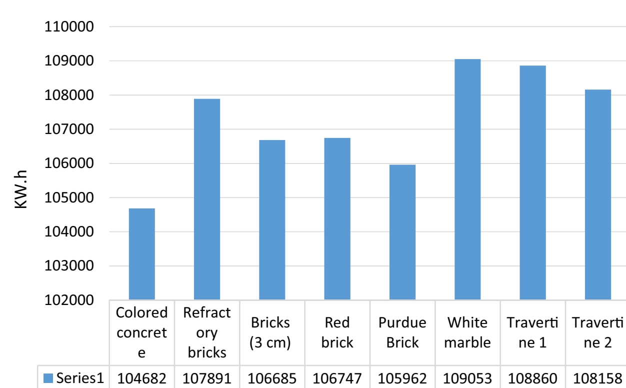

Fig. 5 Annual energy consumption for the Tabriz climate

and remain static and only change the type and aspect of the outer wall, or the outermost layer of the outer wall, and extract the results of the annual energy content.

The results of Fig. 5 show that in general, the use of high absorption coefficients such as colored concrete has a better performance in Tabriz's cold climate. Considering that the use of high absorption high-visibility absorbs more solar energy during the day and is more effective for climates with more cold seasons.

Figure 5 also shows the annual performance of facade in the Tabriz region. Accordingly, the white marble facade exhibits the weakest thermal performance among the faces. Also, colored concrete with a 7.31% reduction in annual energy consumption than white marble shows the best performance. After colored concrete, Purdue bricks with 5.64%, bricks (3 cm) with 5.5%, red bricks with 5.24%, refractory bricks with 4.78%, travertine 2 with about 4.12% and travertine 1 with about 1.68 reduction in annual energy consumption in the next rank.

As can be seen from the results of the above diagram, the use of low-absorption coefficients such as travertine 1, white marble and refractory bricks in the climate of the city of Bandar-e-Abbas, where the climate is quite warm, is more appropriate. The use of low-absorption coefficients reflects more on the energy of the sun compared with its absorption, and these species are more suitable for climates with very high seasons. According to the results of Fig. 6, the most suitable type for the climate is Bandar-e-Abbas, in terms of reducing energy consumption travertine 1.

According to Fig. 6, which shows annual performance of species in the Bandar-e-Abbas climate, it is clear that travertine 1 has the most appropriate performance with a decrease of about 23.82% compared to the worst (colored concrete) performance. After Travertine 1, refractory bricks with a 22.8% reduction in energy consumption, white marble with about 21.1%, bricks (3 cm) with 18.26%, Purdue brick with 15.1%, travertine 2 with 13.21% and red brick with about 8% reduction in annual energy consumption is in the next order, respectively.

Considering that in a city like Tehran that has a temperate climate and the rate of cold and warm seasons is relatively

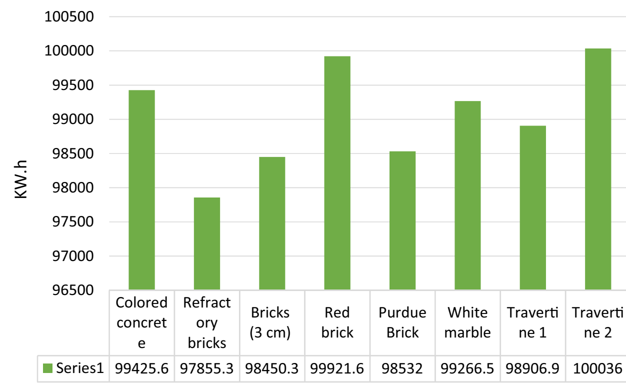

Fig. 7 Annual energy consumption for the Tehran climate

identical, the results cannot be decisively recommended to this climate. According to Fig. 7, it can be summarized that in this climate, in the whole of the scales with a relatively low absorption coefficient, the fire performance is the most suitable.

In Fig. 5, the annual performance of the views is shown. Clearly, travertine 2 has shown the worst thermal performance among the eight specimens surveyed for the Tehran climate. On the other hand, the refractory brick facade had a 6.9% reduction in energy consumption compared to Travertine 2. Thereafter, bricks (3 cm) with about 5.04%, Purdue bricks with 4.75%, Travertine 1 with 4.57%, white marble with 4.16%, color concrete with 3.91% and red brick with 2.97% reduce energy consumption compared to travertine 2.

In Fig. 8, the effect of the solar absorption coefficient parameter on the annual energy consumption for a construction in the Bandar-e-Abbas climate with an exponential facade of the thermophysical properties in the conventional interval is shown. As the process of energy change shows, due to the fact that the weather in Bandar-e-Abbas is very warm and the intensity of the solar radiation is relatively high, the energy consumption in this city is strongly

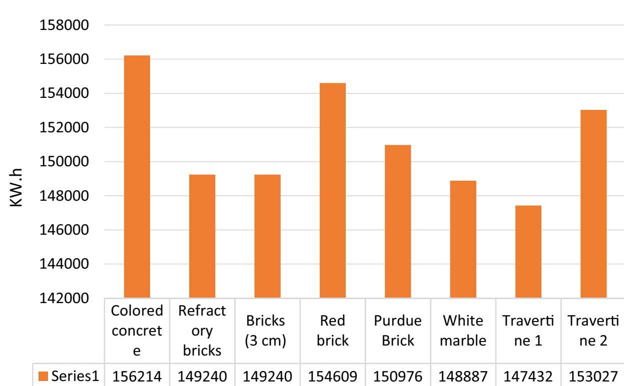

Fig. 6 Annual energy consumption for the Bandar-e-Abbas climate

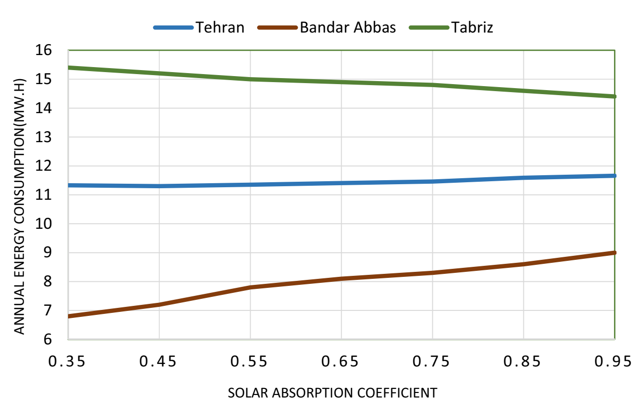

Fig. 8 Annual energy consumption graph for different absorption coefficients for facade

dependent on the external absorption coefficient of the building. It can be seen that with increasing the solar absorption coefficient from 0.35 to 0.95, the energy consumption is linear and with a relatively high slope. Accordingly, given the fact that the Bandar-e-Abbas climate has almost 9 months of hot air and the need for cooling equipment, it is better to use specimens with a minimum absorption coefficient for building buildings in the city. Usually, low absorption scales have smooth, polished and brightly colored surfaces that are suitable for building exposure in hot climates. Also, to determine the effect of the solar absorption coefficient parameter, the annual energy consumption for an exponential building with thermophysical properties in the conventional range is shown in Fig. 8 for the changes in the absorption coefficient. The results show that in Tehran, with an increase in the absorption coefficient of 0.35, the energy consumption decreased first, reaching its minimum in the absorption coefficient of 0.45, and after that, the energy consumption increases with steep gradients. Therefore, for the city of Tehran and cities with climatic conditions such as Tehran, a facade with an absorption coefficient of 0.45 is considered to be the most appropriate energy consumption and imposes the least amount of annual energy consumption on the building.

Also, in Fig. 8, the effect of the solar absorption coefficient parameter on the annual energy consumption for construction in the Tabriz climate and the exponential with thermophysical properties in the conventional range is shown. As the process of energy change suggests, the weather is very cold in Tabriz. It can be seen that with increasing solar absorption coefficient from 0.35 to 0.95, energy consumption decreases linearly and with a slight slope. Accordingly, considering that in the Tabriz, the climate for almost 9 months is cold and there is a need for heating equipment, it is better to use scenes with a maximum absorption coefficient for building buildings in the city.

Investigation of the effect of green roof effect

In addition to investigating the effect of the type of facade, the effect of the use of green roofing has been studied in this research. So, according to the studies carried out in the previous stage, we select the best type of facade for the building in each climate and embed it in the green roof. Obviously, considering the importance of heat transfer from the ceiling, adding a green roof can be a way to prevent this heat transfer. In this research, the roof of the second floor is a global green roof system.

In the green roof system, many items and parameters are effective in improving this method and system. Therefore, it is important to note the exact specifications of the embedded green roof system for the modeling building in this research. The green roof specifications embedded for the building are shown in Table 5.

Figure 9 shows the annual energy consumption of buildings in both non-green and green roof systems in Tabriz. The figure shows that if the green roof system is added to the roof of the building, about 3.74% of the building energy will decrease. It should be noted that the color concrete facade is used for external surfaces of the modeling building.

Figure 10 shows the annual energy consumption of buildings in both non-green and green roof systems in

Table 5 Green roof embedded for building

Leaf index rate	1
Depth of soil (m)	0.1
Soil density (Kg/m^3)	1100
Soil thermal conduction (W/m k)	0.35
Solar absorption coefficient	0.7
Soil special heat (J/kg-k)	1200
Plant height (m)	0.2

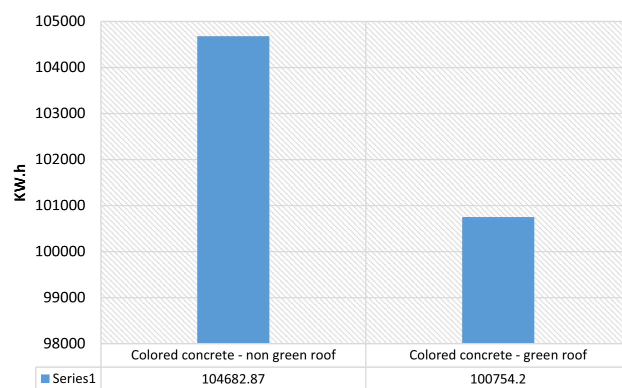

Fig. 9 Annual energy consumption when using the green roof system and normal mode in the Tabriz climate

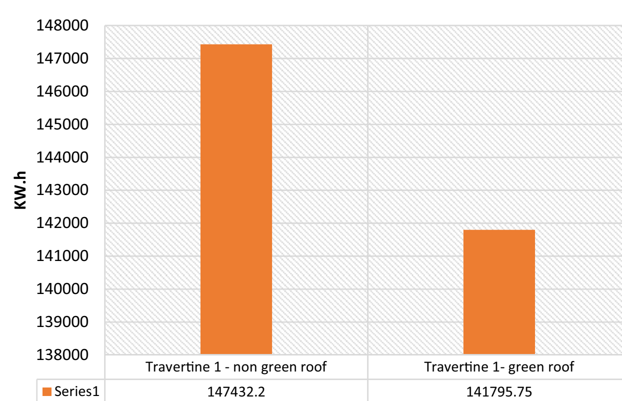

Fig. 10 Annual energy consumption when using the green roof system and normal mode in the Bandar-e-Abbas climate

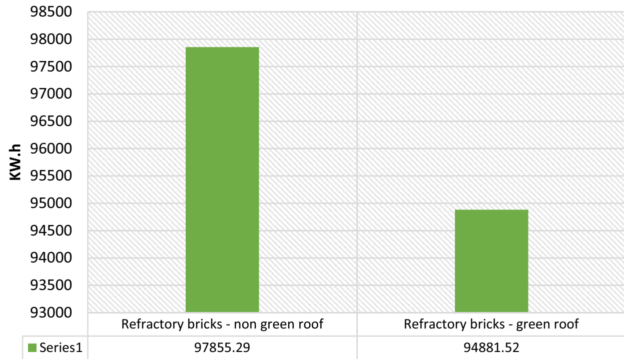

Fig. 11 Annual energy consumption when using the green roof system and normal mode in the Tehran climate

Bandar-e-Abbas. The figure shows that if the green roof system is added to the roof of the building, about 3.82% of the building energy will decrease. It should be noted that the travertine 1 facade is used for external surfaces of the modeling building.

Figure 11 shows the annual energy consumption of buildings in both non-green and green roof systems in Tehran. The figure shows that if the green roof system is added to the roof of the building, about 3.06% of the building energy will decrease (Zolfaghari and Jajaram 2015). It should be noted that the refractory bricks facade is used for external surfaces of the modeling building.

Conclusion

The facade of the building is one of the most important items that affects the energy consumption of buildings. Also, given that the country has a different climate and weather, this effect is becoming increasingly apparent. With reviews by Energy Plus software in each climate, there are weather patterns for each climate that their use will save energy, the results are as follows. The most suitable facade type for a climate like the Tabriz city [climate the most suitable facade for a climate like Bandar-e-Abbas (a climate representative of the warm and humid climate) is in terms of reducing energy consumption travertine i.e., representative with cold weather] is the color concrete viewpoint in terms of energy consumption. The most appropriate type of facade for a climate like the city of Tehran (climate representative with average temperate) in terms of reducing the energy consumption of the refractories. For the climate of the city of Tabriz, Bandar-e-Abbas and Tehran, adding green roof system to the ceiling of the building will decrease building energy by about 3.72, 3.82, and 3.06%.

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References

Alcazar, S., & Bass, B. (2005). Energy performance of green roofs in a multi-story residential building in Madrid. In Greening Rooftops for Sustainable Communities, Washington, DC.

ASHRAE. (2017). *Standard method of test for the evaluation of building energy analysis computer programs*. New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Badescu, V., & Staicovici, M. D. (2006). Renewable energy for passive house heating: model of the active solar heating system. *Energy Build, 38*(2), 129–141.

Bashirpour-Bonab, H., & Javani, N. (2019). Investigation and optimization of solar volumetric absorption systems using nanoparticles. *Solar Energy Mater Solar Cells, 194,* 229–234.

Canty, J. L., & Frischling, D. (2019). Weatherbase. Find travel weather, climate averages, forecasts, current conditions and normals for 41,997 cities worldwide 2019; http://www.weatherbase.com/. Cited 2 Jan 2019.

Cascone, S., Coma, J., Gagliano, A., & Pérez, G. (2019). The evapotranspiration process in green roofs: a review. *Build Environ, 147,* 337–355.

Chen, X., Shuai, C., Chen, Z., & Zhang, Y. (2019). What are the root causes hindering the implementation of green roofs in urban China? *Sci Total Environ, 654,* 742–750.

Coma, J., Pérez, G., Solé, C., Castell, A., & Cabeza, L. F. (2016). Thermal assessment of extensive green roofs as passive tool for energy savings in buildings. *Renew Energy, 5,* 1106–1115.

De-Ville, S., Menon, M., Jia, X., Reed, G., & Stovin, V. (2017). The impact of green roof ageing on substrate characteristics and hydrological performance. *J Hydrol, 547,* 332–344.

Ebrahimpour, A., & Karimi, V. Y. (2012). The best methods to optimize energy consumption for an educational building in Tabriz. *Modares Mech Eng, 12*(4), 91–104.

Hashemi, S. S. G., Mahmud, H. B., & Ashraf, M. A. (2015). Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: a review. *Renew Sustain Energy Rev, 52,* 669–679.

Herman, R. (2003). Green roofs in Germany: yesterday, today and tomorrow. In Greening Rooftops for Sustainable Communities (pp. 41–45). Chicago, 29–30 May 2003.

Huang, Y. Y., Chen, C. T., & Liu, W. T. (2018). Thermal performance of extensive green roofs in a subtropical metropolitan area. *Energy Build, 159*(15), 39–53.

Korol, E., & Shushunova, N. (2016). Benefits of a modular green roof technology. *Procedia Eng, 161,* 1820–1826.

Li, W. C., & Yeung, K. K. A. (2014). A comprehensive study of green roof performance from environmental perspective. *Int J Sustain Built Environ, 3*(1), 127–134.

Lindberg, R., Binamu, A., & Teikari, M. (2004). Five-year data of measured weather, energy consumption, and time-dependent temperature variations within different exterior wall structures. *Energy Build, 36*(6), 495–501.

Lobaccaro, G., Fiorito, F., Masera, G., & Poli, T. (2012). District geometry simulation: a study for the optimization of solar façades in urban canopy layers. *Energy Procedia, 30,* 1163–1172.

Lui, K., & Minor, J. (2005). Performance evaluation of an extensive green roof. Presentation at Greening Rooftops for Sustainable Communities, Washington DC.

Marefat, M., & Omidvar, A. (2006). Suitable exterior and outer shell design, effective way to prevent condensation occurrence in ceiling radiant cooling systems. *Iran J Energy, 10*(1), 3–18.

Prager, C., Köhl, M., Heck, M., & Herkel, S. (2006). The influence of the IR reflection of painted facades on the energy balance of a building. *Energy Build, 38*(12), 1369–1379.

Sangkakool, T., Techato, K., Zaman, R., & Brudermann, T. (2018). Prospects of green roofs in urban Thailand—a multi-criteria decision analysis. *J Clean Prod, 196,* 400–410.

Susorova, I., Angulo, M., Bahrami, P., & Stephens, B. (2013). A model of vegetated exterior facades for evaluation of wall thermal performance. *Build Environ, 67,* 1–13.

The UK's Leading Independent Green Roof (2010). https://livingroofs.org/. Accessed 13 Jan 2019.

UK NCM (2018). The National Calculation Method for the EPBD (Energy Performance of Buildings Directive). http://www.uk-ncm.org.uk/index.jsp. Accessed 18 Dec 2018.

Vijayaraghavan, K. (2016). Green roofs: a critical review on the role of components, benefits, limitations and trends. *Renew Sustain Energy Rev, 57,* 740–752.

Wong, N. H., Chen, Y., Ong, C. L., & Sia, A. (2003). Investigation of thermal benefits of rooftop garden in the tropical. *Build Environ, 38*(2), 261–270.

Zhang, Z., Szota, C., Fletcher, T. D., Williams, N. S. G., & Farrell, C. (2019). Green roof storage capacity can be more important than evapotranspiration for retention performance. *J Environ Manag, 232,* 404–412.

Zolfaghari, S. A., & Jajaram, E. N. (2015). Evaluation of the influence of exterior façade on the annual energy consumption of building in different climates of Iran. *Iran J Energy, 17*(4), 69–80.