Zeszyty Naukowe Politechniki Częstochowskiej
Budownictwo
ISSN 0526-5916

Zeszyty Naukowe Politechniki Częstochowskiej nr 27 (2021), 219-224
DOI: 10.17512/znb.2021.1.32

A review of energy saving and energy effective roofings

Olena Savchenko[1]

ABSTRACT:
This article is a systematic review of the literature on the energy efficiency and energy efficient construction of roofs. This paper considers seven types of roof, including insulated, double-skin, cool roofs, green roofs, roofs with photovoltaic panels, biosolar roof and roof ponds. The review covers the main characteristics of each roof, the reduction of heat flux and the appropriate climate for its implementation. These roofs can reduce energy consumption for cooling or heating systems. For the cold period of the year the warmed roof which reduced heat losses of the room to 70% proved to be the most effective. In hot climates the cool roof is the simplest covering, which reduces the flow of solar radiation into the room by 30%. The installation of a double-skin roof or a pond on the roof stabilizes the temperature in the room on hot days. Green roofs in hot climates can reduce the heat of solar radiation through the roof to 35%, and the presence of photovoltaic panels on the green roof can increase their efficiency by 8.3%. To increase the energy efficiency of the roof, it is advisable to combine several types of roofs.

KEYWORDS:
insulated roof; double-skin roof; cool roof; green roof; biosolar roof; roof ponds

1. Introduction

A person spends 4/5 of his life indoors. To maintain the parameters of the microclimate in the premises and to ensure daily activities, energy is consumed, the amount of which for different countries can be up to 45% of total energy consumption. Such energy consumption by homes causes up to 50% of carbon dioxide emissions into the atmosphere [1], and, accordingly, affects climate change. Energy efficiency and energy saving measures are being implemented in the construction sector to reduce energy consumption. Thus, the main ways for increasing the energy efficiency of buildings are the use of low-energy building materials, the use of energy-efficient equipment and the integration of renewable energy technologies into life support systems.

The roof has an important role in determining the energy efficiency of a building. It is through the roof of the building in the warm period of the year that a significant amount of solar radiation enters the room, and in the cold period of the year, heat is lost. In recent years, many studies have been conducted on various roof designs to improve thermal comfort, increase the energy efficiency of buildings and reduce the negative impact on the environment. Energy-saving roof constructions reduce the amount of energy consumed for the needs of the cooling or heating systems. Increasing the energy efficiency of the roof increases the overall energy efficiency of the house.

2. Aim of the article

The aim of this article is a review of the literature on energy saving and energy efficient structures of roofs, in order to systematize the knowledge available about roofing.

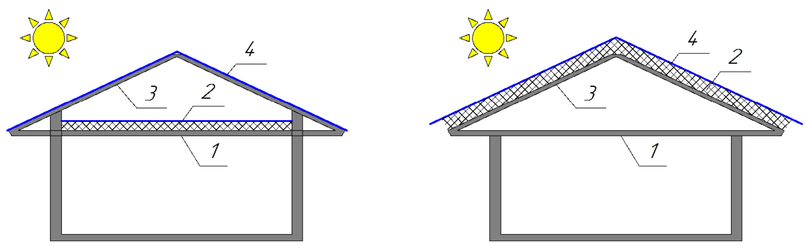
[1] Lviv Polytechnic National University, Bandery 12, 79013, Lviv, Ukraine, e-mail: o.savchenko@i.ua, orcid id: 0000-0003--3767-380X

3. Analysis of existing research

Currently, several energy saving and energy efficient structures of roofs are known. Each of these roofs has both advantages and disadvantages. They compete with each other in many aspects, including the features of installation, reduction of heat flux and/or heat loss through the roof, the cost of construction, complexity of maintenance, suitability for climate.

The most common type of energy efficient roof in regions with temperate and cold climates is an insulated roof. In many countries, in particular in Ukraine and Poland, roof insulation is mandatory, and the regulations of these countries regulate the requirements for thermal characteristics of the roof. Depending on the climatic zone of the city of construction and the type of roof, the requirements for the heat transfer coefficient of the roof of the house also differ [2]. The insulation efficiency depends on the thermal conductivity of the material and the thickness of the insulation layer. For roof insulation, such insulators such as mineral wool, glass wool, expanded polystyrene, polyfoam, polyurethane foam are used, the thickness of which is determined in the thermal calculation of the roof structure. The presence of thermal insulation reduces heat loss through the roof to 70%.

A layer of insulation can be applied directly to the roof or attic floor (Fig. 1). In Ukraine, the most commonly used insulation of the attic floor (Fig. 1a), the so-called cold roof. The space between the ceiling and the roof in residential buildings is called the attic and is used to store various things. With a cold roof, the air temperature in the attic approaches the outside air temperature. Therefore, to prevent moisture condensation on the internal structures of the attic, it must be well ventilated.



a *b*

Fig. 1. Insulated roof: a) cold roof, b) warm roof, 1 – attic floor, 2 – insulation, 3 – timber sub deck, 4 – roof covering

Thermal insulation directly on the roof is more energy efficient and avoids the disadvantages of a cold roof, in particular the condensation of moisture on the attic structures (Fig. 1b). The presence of a warm roof allows you to use the mansard in the house as a residential or non-residential premises. When installing additional translucent openings in the roof over the mansard, it is necessary to use special window designs that will not increase the overall energy consumption.

Passive energy-saving technologies include green roofs, which are a complex multilayer structure, the upper layer of which is formed by greenery (Fig. 2). In this case, the roof, in addition to protective functions, performs environmental and aesthetic functions [3]. The presence of plants on the roofs gives the building a number of advantages, such as thermal insulation of the roof, passive cooling in summer and passive heating in winter under the roof, absorption of CO_2 from the environment, and rainwater management.

Most studies evaluating the performance of green roofs have been conducted in warm climates, they indicate the feasibility of using a green roof in winter for passive heating of houses. Thus, in [4] it is stated that the presence of a green roof reduces the amount of thermal energy lost from the room by up to 37%. There are very limited studies of green roofs in cold climates. The results presented in [5] indicate that a green roof can provide energy savings for the needs of heating and cooling systems compared to a traditional roof. Study [6] assesses the heat flux and heat impact on a green roof located on a passive house in Sweden. Temperature and heat flux studies were performed on the green roof and a roof covered with a layer of roofing material. Since the roofs were covered with snow, the surface temperature of both roofs was approximately the same. However, heat loss from the house with the green roof was sometimes higher than from the building with a black roof. Consequently, in cold climates, an additional layer of thermal insulation must be introduced into the green roof structure.

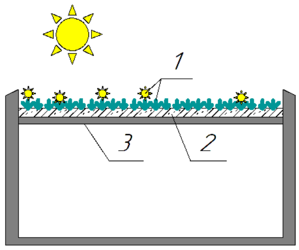


Fig. 2. Green roof: 1 – plants, 2 – substrate, 3 – ceiling

In hot climates, green roofs can reduce the heat flow that enters the room through the roof to 35% [7]. Although, the effect of passive cooling decreases with increasing outdoor temperature, especially in arid areas.

The easiest way to reduce heat flux from solar radiation through the roof is to use a reflective, mostly white, roof covering. Such a cool roof is used in areas with hot climates for passive cooling of the house [8]. However, on cold days or in winter, the cool roof blocks the passive heating of the upper floor of the house and does not reduce heat loss by the house.

Heat reduction by thermal conductivity and convection from the roof to the ceiling of the house also occurs when using a double-skin roof. The double-skin roof also effectively blocks the radiative heat exchange between the roof and the ceiling [9]. The double-skin roof consists of two parallel layers of a roof separated by an air layer (Fig. 3). The first layer acts as a reflector/absorber of heat , and the second layer serves as the upper enclosure of the premises. The air layer acts as an insulating layer to prevent heat transfer between the roof layers. The presence of an air layer allows up to 50% reduction in the flow of heat flux through the roof into the house [10].

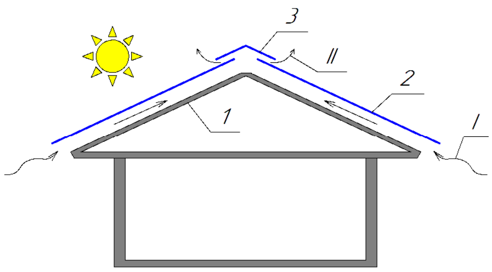


Fig. 3. Double-skin roof: 1 – primary roof, 2 – secondary roof, 3 – outlet cover, I – inlet air, II – outlet air

The heat transfer resistance of a double-skin roof is variable and depends on the parameters of the air in the air layer. The double-skin roof should be used in areas with hot climates as a method of passive cooling. To increase the energy efficiency of a double-skin roof, it can be combined with a cool roof and an insulated roof. Applying reflective material on the upper layer of the double-skin roof and heat-insulating material on the lower layer allows to further reduce the inflow of solar radiation through the roof into the house by up to 25% [10].

Roof photovoltaic panels are used because of their ability to supply electricity to homes and reduce dependence on fossil fuel energy consumption (Fig. 4). They also have an indirect effect on the energy performance of the building, providing shading of the roof with panels that absorb solar radiation, which reduces heat flow to the roofs. Thus, in [11] it was found that the temperature of the roof surface under the solar panel was 2.5 degrees lower than the temperature on the open part of the roof. However, the reduction of the load on the cooling system due to shading by photovoltaic panels differs depending on the type of roof insulation. Installation of solar panels on the roof allows reduced electricity consumption for the needs of cooling systems by 6-7% compared to open roofs [12].

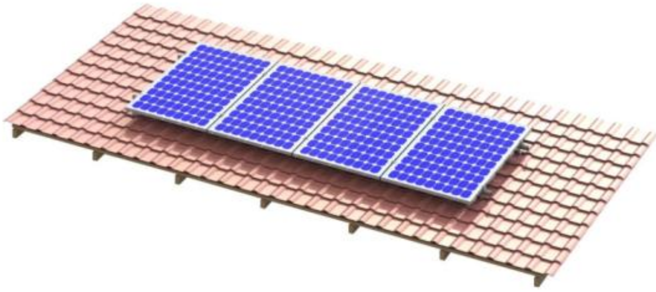


Fig. 4. Photovoltaic panels on the roof

Green roofs and photovoltaic panels on the roof are common sustainable versions of environmentally friendly roofs, each of which has its advantages. Integration of green roofs and solar photovoltaic systems gives the individual advantages from both options and improves their functionality and efficiency through simultaneous use [13]. The concept of a biosolar roof is a combination of a green roof and solar panels that are fixed over the plantings (Fig. 5).

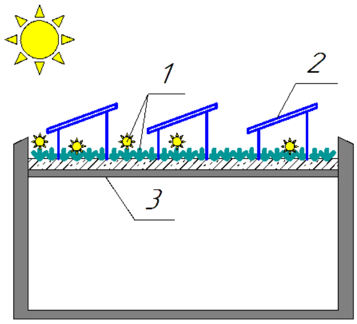


Fig. 5. Biosolar roof: 1 – plants, 2 – photovoltaic panels, 3 – ceiling

It is established that high ambient temperatures negatively affect the amount of electricity that can be produced by photovoltaic panels. In particular, under standard test conditions for photovoltaic panels, it has been determined that when the ambient temperature rises above 25°C, the power output decreases. Studies show that the temperature of the green surface of the roof and ground is reduced due to shading by solar panels, and greater output power of the panel is achieved by lowering the temperature under the solar panels due to the presence of plants. Thus, in [14] it was found that when using a biosolar roof, the photovoltaic system generates 8.3% more electricity than in the absence of a green roof.

Of the various passive cooling methods, evaporation has been attributed to the most effective way to reduce the temperature of the top floor. Water, in the process of evaporation, absorbs heat from the environment, and, accordingly, reduces its temperature. This principle is seen in the use of ponds on the roof, which, by evaporating, reduces the temperature of the roof. An uncovered ponds is the easiest way to install a layer of water on the roof (Fig. 6). At the same time on the roof is a layer of water, 30 cm deep, whose evaporation reduces the temperature of the roof. Thus, the temperature of the roof surface with a layer of water on average was 6.8°C lower than with an open roof surface [15].

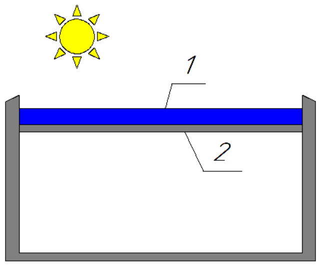


Fig. 6. Uncovered pond on the roof: 1 – water, 2 – ceiling

The disadvantage of this type of roof is the high thermal inertia of water. To reduce the impact of the thermal energy of water on the evaporation process, other types of pond installation on the roof have been developed. Thus, in covered ponds above the roof slab there is a pond with a movable cover, which closes the pond during the day from the sun's rays. At night, the cover is removed, which allows the water temperature to drop to ambient temperatures. Shaded ponds work on a similar principle, in which a shading device is arranged above the water surface, which allows the complete or partial avoidance of solar radiation on the water surface. Such a roof can maintain an internal water temperature below 30°C when the ambient temperature exceeds 40°C [16]. Sprayers are added to the ponds to intensify the evaporation process. When installing a pond in a ventilated roof, the surface of the pond is closed from the inflow of solar radiation, and convective flows over the water layer can improve the evaporation process.

To increase the energy efficiency of the roof, it is advisable to combine several roof options. Thus, such combinations as insulated and double roof, insulated and reflective roof, insulated roof and green roof, double roof and roof pond can be used. The use of different types of energy-saving structures can reduce the load on cooling systems in summer and heating systems in winter, and, accordingly, reduce the demand for electricity, reduce roofing costs and potentially reduce global CO_2 emissions.

The choice of energy-saving roof construction is made in accordance with the terms of reference for the project, construction and sanitary standards, environmental and economic requirements for a particular object.

4. Conclutions

Seven types of energy saving and energy efficient structures of roofs were considered, in particular insulated, double-skin, cool, green, solar and biosolar roofs, as well as roof ponds. In the cold period of the year the warmed roof proved to be the most effective. The presence of thermal insulation in the roof structure reduces heat loss to 70%. To increase the energy performance of the insulated roof, it is advisable to additionally use green or bio-solar roof structures. In hot climates, the simplest type of coating is a cool coating, which allows you to reduce the flow of solar radiation into the room by 30%. The installation of a double roof or a pond on the roof allows you to stabilize the temperature in the room on hot days, and, accordingly, reduce the load on the cooling system. Green roofs have the greatest positive impact on the environment, in hot climates, the can reduce the flow of solar radiation through the roof to 35%. The presence of a green roof under the photovoltaic panels increases their efficiency by 8.3%. To increase the energy efficiency of the roof, it is advisable to combine several types of roofs.

References

[1] Chel A., Kaushik G., Renewable energy technologies for sustainable development of energy efficient building, Alexandria Engineering Journal 2017, 1-15.

[2] Savchenko O., Lis A., Economic indicators of the heating system of a cottage in Ukraine and Poland, BoZPE 2020, 9, 2/2020, 89-94.

[3] Ezema I.C., Ediae O.J., Ekhaese E.N., Prospects, barriers and development control implications in the use of green roofs in Lagos State, Nigeria, CJRBE 2016, 4(2), 54-70.

[4] Bevilacqua P., Mazzeo D., Bruno R., Arcuri N., Experimental investigation of the thermal performances of an extensive green roof in the Mediterranean area, Energy Build 2016, 122, 6379.

[5] Moody S.S., Sailor D.J., Development and application of a building energy performance metric for green roof systems, Energy Build. 2013, 60, 262-269.

[6] Schade J., Shadram F., The energy performance of green roof in sub-arctic climate, Cold Climate HVAC Conference CCC 2018, 135-143.

[7] Mahmoud A.S., Asif M., Hassanain M.A., Babsail M.O., Sanni-Anibire M.O., Energy and economic evaluation of green roofs for residential buildings in hot-humid climates, Buildings 2017, 7, 30.

[8] Tartibu L.K., Bakaya-Kyahurwa E., Potential energy savings from cool roofs in South Africa, Conference proceedings, 2017.

[9] Wu H.-H., Lai C.-M., Energy saving analysis of double roofs incorporating a radiant barrier system, Energy and Sustainability 2007, 105, 259-266.

[10] Omar A.I., Virgonea J., Vergnaulta E., Davida D., Idriss A.I., Energy saving potential with a double-skin roof ventilated by natural convection in Djibouti, Energy Procedia 2017, 140, 361-373.

[11] Domingueza A., Kleissla J., Luvall J.C., Effects of solar photovoltaic panels on roof heat transfer, Solar Energy 2011, 1-32.

[12] Chenvidhya T., Seapan M., Parinya P., Wiengmoon B., Chenvidhya D., Songprakorp R., Limsakul C., Sangpongsanont Y., Tannil N., Investigation of power values of PV rooftop systems based on heat gain reduction, Paper of Conference SPIE 9563, 2015, 95630E, 7 p.

[13] Catalano C., Baumann N., Biosolar roofs: a symbiosis between biodiverse green roofs and renewable energy, CityGreen 2017, 15, 41-48.

[14] Hui S.C.M., Chan S.C., Integration of green roof and solar photovoltaic systems, Proceedings of Joint Symposium 2011: Integrated Building Design in the New Era of Sustainability, Kowloon, Hong Kong 2011, p. 1.1-1.10.

[15] Yang W.S., Wang Z.Y., Zhao X.D., Experimental investigation of the thermal isolation and evaporative cooling effects of an exposed shallow-water-reserved roof under the sub-tropical climatic condition, Sustain. Cities Soc. 2015, 14, 293-304.

[16] Spanaki A., Tsoutsos T., Kolokotsa D., On the selection and design of the proper roof pond variant for passive cooling purposes, Renew. Sustain. Energy Rev. 2011, 15, 3523-3533.

Przegląd energooszczędnych rozwiązań pokryć dachowych

STRESZCZENIE:
Artykuł stanowi przegląd literatury dotyczącej energooszczędnych rozwiązań konstrukcji dachów. W artykule omówiono siedem rozwiązań dachów, w tym dach izolowany, dach o podwójnej konstrukcji, dach chłodzony, dach zielony, dach z panelami fotowoltaicznymi, dach biosolarny i taras. Przegląd zawiera charakterystykę każdego dachu, redukcję strumienia ciepła oraz wskazuje warunki klimatyczne odpowiednie do zastosowania takiego rozwiązania. Zastosowanie odpowiednich rozwiązań może zmniejszy zużycie energii na chłodzenie lub ogrzewanie. W okresie zimowym najkorzystniejszy okazał się dach ocieplony, który pozwala na zmniejszenie strat ciepła do 70%. W klimacie gorącym najlepszym rozwiązaniem jest powłoka chłodząca, która ogranicza dopływ promieniowania słonecznego do pomieszczenia o 30%. Zastosowanie dachu podwójnego lub tarasu pozwala na stabilizację temperatury w pomieszczeniu w upalne dni. Zielone dachy w gorącym klimacie mogą zmniejszyć ciepło promieniowania słonecznego przez dach do 35%, a obecność paneli fotowoltaicznych może podnieść ich wydajność o 8,3%. Aby zwiększyć efektywność energetyczną dachu, zaleca się łączenie kilku rodzajów dachów.

SŁOWA KLUCZOWE:
dach izolowany; dach dwupłaszczowy; dach chłodzony; dach zielony; dach biosolarny; taras