



Sustainable Roofing Solutions: A Review of Energy-Efficient Technologies

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Abstract : This systematic review examines the existing literature on energy-efficient roofing systems and their construction. The study focuses on seven distinct types of roofs, including insulated, double-skin, cool, green, photovoltaic, bio solar, and roof pond systems. The review provides an in-depth analysis of each roof type, highlighting their key characteristics, heat flux reduction capabilities, and suitability for various climates. These energy-efficient roofing systems can significantly reduce energy consumption associated with heating and cooling systems. In cold climates, the most effective roof type was found to be the insulated roof, which minimized heat losses by up to 70%. In contrast, cool roofs were identified as the simplest and most effective solution for hot climates, reducing solar radiation influx by up to 30%. The installation of double-skin roofs or roof ponds was found to stabilize indoor temperatures during hot weather. Green roofs, in particular, were shown to reduce solar radiation heat gain by up to 35% in hot climates. Moreover, integrating photovoltaic panels into green roofs can enhance their efficiency by up to 8.3%. To maximize energy efficiency, it is recommended to combine multiple roof types. This hybrid approach can lead to significant reductions in energy consumption and improved overall building performance.

KEYWORDS: Photovoltaic, Heat Flux, Solar Radiation, Double Skin Roofs, Energy Efficiency

1. INTRODUCTION

The majority of a person's life, approximately 4/5, is spent indoors. To maintain a comfortable indoor environment and support daily activities, a significant amount of energy is consumed, accounting for up to 45% of total energy consumption in various countries. This energy usage by residential buildings contributes to up to 50% of carbon dioxide emissions, thereby impacting climate change.

To mitigate this issue, the construction sector is implementing energy efficiency and conservation measures. The primary strategies for enhancing building energy efficiency include the use of low-energy building materials, energy-efficient equipment, and the integration of renewable energy technologies into building systems.

The roof plays a crucial role in determining a building's energy efficiency. During warm periods, the roof allows significant solar radiation to enter the building, while during cold periods, it loses heat. Recent studies have focused on innovative roof designs to improve thermal comfort, increase energy efficiency, and reduce environmental impact. Energy-efficient roof constructions can minimize energy consumption for heating and cooling systems, ultimately enhancing the overall energy efficiency of a building.

2. EVALUATION OF PRIOR INVESTIGATIONS

Several energy-efficient roof structures have been developed to reduce energy consumption. Each of these roofs has its advantages and disadvantages, competing in aspects such as installation features, heat flux reduction, construction cost, maintenance complexity, and climatic suitability.

In temperate and cold climates, insulated roofs are the most common type of energy-efficient roof. Roof insulation is mandatory in many areas where regulations govern thermal characteristics. The efficiency of insulation depends on the thermal conductivity of the material and the thickness of the insulation layer.

Insulators such as mineral wool, glass wool, and polyurethane foam are used, with thickness determined by thermal calculation. Insulation can reduce heat loss through the roof by up to 70%. A layer of insulation can be applied directly to the roof or attic floor.

In foreign countries like Ukraine, attic floor insulation is common, known as a "cold roof." However, this design can lead to moisture condensation on attic structures. Insulation directly on the roof is more energy-efficient and avoids these disadvantages.

Passive energy-saving technologies include green roofs, which provide thermal insulation, passive cooling, and environmental benefits. Green roofs can reduce thermal energy loss by up to 37% and provide energy savings for heating and cooling systems.

In hot climates, green roofs can reduce heat flow by up to 35%. However, their effectiveness decreases with increasing outdoor temperature. Cool roofs with reflective coatings can reduce heat flux by up to 35%.

Double-skin roofs consist of two parallel layers separated by an air layer, reducing heat transfer by up to 50%. These roofs are effective in hot climates and can be combined with cool and insulated roofs for increased energy efficiency.

Roof photovoltaic panels provide electricity and reduce dependence on fossil fuels. They also offer shading, reducing heat flow to the roof. The temperature under solar panels can be up to 2.5 degrees lower than on open roofs.

Overall, various energy-efficient roof structures can reduce energy consumption and provide environmental benefits. The choice of roof design depends on the climate, building type, and desired level of energy efficiency.

Green roofs and photovoltaic panels are popular sustainable options for environmentally friendly roofs, each offering unique benefits. By integrating green roofs and solar photovoltaic systems, the advantages of both options can be combined, enhancing their functionality and efficiency through simultaneous use.

The concept of a bio solar roof combines a green roof with solar panels installed above the plantings. It has been established that high ambient temperatures negatively impact the electricity generated by photovoltaic panels. Specifically, when temperatures exceed 25°C, power output decreases. However, studies have shown that the temperature of the green roof surface and surrounding area is reduced due to shading by solar panels, resulting in increased power output.

The presence of plants beneath the solar panels also contributes to lower temperatures, leading to enhanced electricity generation. Research has demonstrated that bio solar roofs can increase photovoltaic system efficiency by up to 8.3% compared to traditional roofs.

Among various passive cooling methods, evaporation has been identified as a highly effective means of reducing roof temperatures. Water evaporates, absorbing heat from the environment and lowering its temperature. This principle is applied in roof ponds, which reduce roof temperatures through evaporation. A simple and efficient way to install a water layer on a roof is to use an uncovered pond.

Studies have shown that a 30 cm deep water layer on a roof can reduce the roof surface temperature by an average of 6.8°C compared to an open roof surface.

One of the drawbacks of this type of roof is the high thermal inertia of water, which can hinder the evaporation process. To mitigate this issue, alternative pond installation designs have been developed. For instance, covered ponds feature a movable cover that shields the pond from sunlight during the day and is removed at night, allowing the water temperature to drop to ambient levels.

Shaded ponds operate on a similar principle, employing a shading device to partially or completely block solar radiation from reaching the water surface. This design enables the roof to maintain an internal water temperature below 30°C, even when ambient temperatures exceed 40°C.

To further enhance the evaporation process, sprayers can be added to the ponds. Additionally, installing a pond in a ventilated roof can improve convective flows over the water layer, thereby intensifying evaporation.

To maximize energy efficiency, it is advisable to combine multiple roof options. Potential combinations include insulated and double roofs, insulated and reflective roofs, insulated roofs and green roofs, and double roofs and roof ponds.

The use of various energy-saving structures can reduce the load on cooling systems in summer and heating systems in winter, leading to decreased electricity demand, lower roofing costs, and potentially reduced global CO₂ emissions. The selection of an energy-saving roof construction is guided by project specifications, construction and sanitary standards, environmental and economic requirements, and the specific needs of the building.

3. CONCLUSION

This study examined seven energy-efficient roof structures, including insulated, double-skin, cool, green, solar, bio solar, and roof pond designs. In cold climates, the insulated roof proved to be the most effective, reducing heat loss by up to 70% through the presence of thermal insulation.

To further enhance the energy performance of insulated roofs, incorporating green or bio solar roof structures is recommended. In hot climates, the simplest and most effective solution is the cool roof, which can reduce solar radiation influx by up to 30%.

The installation of double roofs or roof ponds can stabilize indoor temperatures on hot days, reducing the load on cooling systems. Green roofs have the most significant positive environmental impact, capable of reducing solar radiation flow through the roof by up to 35% in hot climates.

Additionally, green roofs can increase the efficiency of photovoltaic panels by up to 8.3% when installed underneath. To maximize energy efficiency, combining multiple roof types is advisable.

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