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Heat Transfer Reduction in Different Climatic Zones by Thermal Analysis and Energy Optimization of Structures with Eco-Green Roofs

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Abstract

Eco-green roofs have been examined as a passive architectural solution with numerous environmental benefits, notably energy savings. The present research evaluated the influence of eco-green roofs on thermal conductivity and heat loss reduction, comparing their efficacy with standard roofs across four distinct temperature zones. The modeling process was executed using Design Builder Version 4.5. The analyzed climates encompassed a humid climate exemplified by Rasht, a semi-arid climate exemplified by Tabriz, a tropical and temperate desert climate exemplified by Yazd, and temperate hot deserts exemplified by Bandar Abbas. The thermal data uploaded into the computer program for the roof garden comprised requirements of plant genera, thermal bulk qualities, and thermal factors like index of leaf size and surface features. The experiment was conducted on a residential building block over one year (including four months) to identify the periods during which the eco-green roof demonstrated the best thermal performance. The present research indicates that the vegetative roof in Rasht during May and August can mitigate temperature loss. The vegetated roofing in Rasht can enhance the reduction of transferred heat in May and August.

Keywords: Heat Transfer, Energy Optimization, Thermal Analysis, Climatic Zones.

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Introduction

Ninety-seven climate experts concur that the warming trends observed over the past century are probable to be attributable to human activity, and most prominent scientific associations globally have released public statements supporting this stance (Malla, et al., 2022). Researchers are confident that worldwide temperatures will persist in increasing for decades, primarily attributable to greenhouse gases generated by human activity (Jogdand, 2020). Mitigating or abolishing cooling and heating requirements in existing structures presents a considerable challenge, especially for those constructed before the establishment of building energy-efficient regulations, during which appliances were functional yet wasteful. In recent decades, academics have been advancing the Passive Design Strategy (PDS) (Ma et al., 2019) as a substitute for renewable energy sources like solar and wind to enhance indoor air quality. PDS is a design that leverages climatic conditions to sustain an appropriate temperature range in homes or buildings serving other purposes. Recent research indicates that flora and greenery have proliferated as integral components of the building environment (Al-Kayiem et al., 2020). The green covering initially safeguards the building exterior from diverse external factors.

The objective was to determine the environment in which the thermal impact of the vegetated roof is optimized. This study concentrated on PDS across four distinct climates, which included Rasht's humid environment, Tabriz's semi-arid environment, Yazd's tropical and desert environment, and Bandar Abbas's scorching desert environment. PDS is a design methodology that utilizes architectural elements to reduce energy consumption by projected climatic conditions.

Background

The instruments were affixed to the rooftop to measure heat flux, temperature unevenness, and thermal conductivity of the eco-green roof construction. This strategy primarily pertains to the heat effects of the roof's vegetation (Gilabert et al., 2021). The study focused on critical characteristics for developing eco-green roofs, including plant density, soil layer width, and precipitation rate. They determined that a rise in plant density factor enhances the reduction of the building's thermal stress rates.

The investigation utilized the Plus toolbox to construct sustainable energy options for Monachil to achieve 50% renewable energy sources (Parreño-Rodriguez et al., 2023). In a separate study, the HOMER program evaluated the economic and technical utilization of solar panels and hydrogen storage to satisfy a 2 MW energy requirement. The research examined residences with zero energy use in the northern region and assessed the possibilities of building such structures in this humid, hilly region. The research experiment simulated a multi-generational system powered by geothermal and sunlight integrated with a thermoelectric generator. An investigation was conducted in different countries with differing solar radiation levels and costs of electricity at temperatures of 0, 15, 30, 45, and 60°N, examining the impact of a Combined Parabolic Collector (CPC) on the annual auxiliary savings in energy of a solar hot water structure (Gilani & Hoseinzadeh, 2021). The energy efficiency of a conventional flat plate collector was computationally analyzed.

The research examined the possibility of vegetative roofs to reduce the electrical consumption of buildings. It analyzed the impact of various features of eco-green roofs on the thermal efficiency of the structures. The vegetated roof was created for a modest office establishment, followed by a thermal analysis using the Energy Plus program (Jamei et al., 2023). They assessed the efficacy of different eco-green roof variables (insulator width, Leaf Area Index, and development medium length) according to three distinct environments (wet, warm tropical, dry tropical, and coastline environments). They concluded that enhancing these variables significantly contributes to energy savings in structures, achieving a decrease in energy consumption of 62% in chilly and humid environments, a 71% decrease in tropical and coastal environments, and a decrease in energy consumption of 85% in tropical and dry environments during peak summer periods. A multitude of studies has been conducted in this domain across various countries.

Materials and Methods

3.1 Methodology for Study

The simulation investigation was conducted over one year to assess the impact of traditional and eco-green roofs on heat transmission and thermal efficiency across four climates within hypothetical residential building units. This study examined heat transfer between conventional and eco-green roofs during multiple phases. Initially, PDSs were offered for all four locations, each exemplifying distinct environments. This investigation included Rasht, characterized by humid weather; Bandar Abbas, exhibiting a hot desert temperature; Yazd, known for its hot and dry weather; and

Tabriz, which has a semi-arid climate. The Design Creator V.4.5 program was utilized to model the eco-green and conventional roofs in the examined climates and associated components. The period in the model was assessed across one year over four distinct seasons, represented by May and August for all four regions in 2016. Using the Design Builder software tool, the following part evaluated heat transfer generated through conventional and eco-green roofs. The weather information, formatted as an EPW file, was obtained from the Meteonorm program and subsequently imported into Design Builder as an address document. The research evaluated the setup of the software tools utilized to establish a digital workflow.

3.2 Research Areas

It encompasses many geographical locations with distinct climate conditions. Investigations encompassing four different environments are situated in four separate regions of Iran, specifically chosen from the eastern, north, south, and southeast areas, each exhibiting varying climatic features. The coordinates of these cities, including their latitude and height, are delineated by the World Meteorological Organization (WMO) database.

3.3 PDS

According to the findings, PDS utilizes existing energy sources rather than procuring energy such as electricity or gasoline. These solutions encompass sunlight, ventilation from nature, and solar energy utilization. Active design solutions utilize acquired energy to maintain the building's livability. Implementing these solutions yields beneficial outcomes, including diminished reliance on mechanical devices, decreased consumption of energy, decreased emissions of greenhouse gases, reduced prices, and further environmental advantages. To acquire these techniques in this research, the meteorological data for every town in layout, encompassing geographic coordinates such as longitude, standard stress, and height, was initially processed using the Climate Consultant software program. Using this data, the software produced the architectural concepts for each city and area.

A climate advisor from the Energy Planning Tools Unit created the study. Standards 55 and the current edition of the core model guidebook chose the thermal convenience model included in this software. Design concepts for each climate are significantly interrelated. Certain elements are utilized collectively across all four environments examined in this study. Strategies 12, 15, and 21 serve as examples. The research can collectively identify solutions applicable in two or three locations. It can be contended that certain methods pertain exclusively to specific climates, including methods 7, 10, 12, and 19, associated with the humid subtropical environment of Rasht; method 14 linked to the semi-arid climate of Tabriz; methods 25 and 32 relevant to the dry and hot environment of Yazd; and tactics 17 and 34 applicable solely to the subtropical warm deserts climate of Bandar Abbas. The vegetated roof was replicated and contrasted with the conventional roof to evaluate the study's hypothesis upon finding these tactics.

Results and Findings

Fig. 1 illustrates the impact of eco-green roofs on annual electrical consumption in three towns (Tabriz, Tehran, and Bandar Abbas) for meeting the cooling and warming demands of the dwellings under examination. The simulation findings for the structure under investigation, with a conventional roof in Tehran, indicate an energy usage rate of 74.2 MWh. In contrast, the analogous managed structure with an eco-green roof exhibits a consumption rate of 61.7 MWh, reflecting a 15.2% reduction. The modeling findings for a regulated structure with a standard roof in Tabriz indicate an energy use level of approximately 112.4 MWh. The energy values for a regulated building using an eco-green roof are 101.5 MWh, indicating a 13.7% reduction. The energy usage rate for Bandar Abbas decreased from 64.8 MWh to 27.2 MWh, indicating a 24% reduction. The findings suggest that the impact of eco-green roofs during winter is minimal in Tabriz due to a slight decrease in energy use.

The decline in cooling load for buildings in Bandar Abbas, which has a tropical and arid environment, is restricted. It experiences no winters with freezing temperatures. The reduction in refreshing load during August and the height of heat loss in Bandar Abbas underscore the critical function of eco-green roofs in this city and others in comparable circumstances.

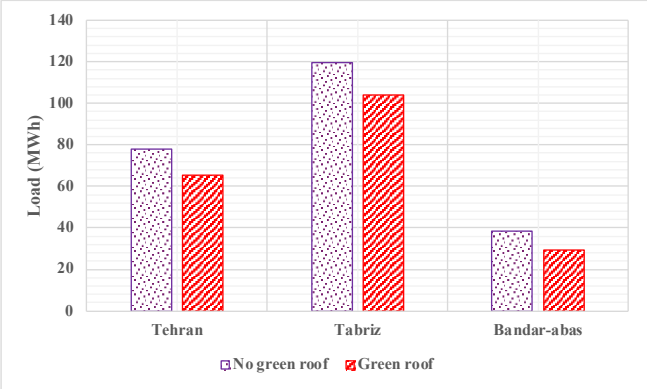


Fig. 1: Effect of Eco-Green Root Analysis

Conclusion

The present research aims to examine the thermal efficiency and mitigate heat transmission of eco-green roofs across four distinct climatic zones. Design ideas were offered for each of the four environments, as derived by the environment consultant. Eighteen methods of design were provided for Rasht, characterized by a humid climate; seventeen methods for Tabriz, which has a semi-arid environment; thirteen approaches for Yazd, known for its hot desert temperature; and seventeen techniques for Bandar Abbas, exhibiting a subtropical hot desert environment. The study exhibited minimal annual heat transmission via eco-green roofs. Implementing rooftop gardens in Tabriz, Yazd, and Bandar Abbas is advisable to enhance thermal efficiency by minimizing heat loss in these regions. The primary emphasis of this paper was the thermal effects of eco-green roofs as an effective passive strategy. Metrics are contrasted for conventional and eco-green roofs using models under different circumstances. An annual assessment of large eco-green roofs' thermal efficiency and heat exchange characteristics was conducted.

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