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Development of a Water-Retentive Hydroponic Green Roof Using Gel Beads for Sustainable Urban Cooling

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Abstract: *Currently, due to increasing urbanization, surrounding temperatures have risen significantly. Thereby leading to decrease in natural cooling and reduced thermal comfort. To tackle this problem, this study is introduced as a modified form of conventional Green Roof, as to address various issues occurring with the conventional one like; High structural weight that the normal existing building cannot sustain without external fixing, Higher Maintenance, etc. This Study tends to Develop a new Lightweight Substrate and improves the thermal comfort. Small Scale prototype had been built and tested by sensor setup to know the temperature and humidity difference in exposure conditions. The Result showcase that temperature reduction happened of approximately 1.6-1.7 degree along with 6.5 percent increase in relative humidity, indicating consistent passive cooling performance over various monitored sessions conducted during testing.*

Keywords: Green Roof, Lightweight Substrate, Hydroponic System, Thermal Regulation, Sustainable Urban Cooling

I. INTRODUCTION

As there is significant growth in population, we can see the spread of urbanization and an increase in density of construction of residential buildings using the materials that absorb heat that causes Urban Heat Island (UHI) Effect, which has led to high energy demand and less comfort [1]. Conventional Green Roof system are the good solutions but as overtime various issues occurred. The hydroponic method helps us to tackle the problem of weight but they are certain to check often and don't hold moisture well as well as there are few options of plants available for the full hydroponic method. This study proposes a water - retentive hydroponic green roof prototype by hydrogel beads as they hold water in them and maintain the moisture content, the substrate consist of various material under substrate composition. The system is created and tested by making two identical miniature models one with green roof using hydrogel beads and other as a bare roof, this experimental setup is done to observe the temperature difference in both roofs at similar exposure condition and also to evaluate on its scalability and modularity for implementation in various Indian residential building terraces [4].

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II. METHODOLOGY



III. RESEARCH OBJECTIVES

Development of a multi-layered hydroponic substrate configuration that eliminates soil and replaces it with LECA, hydrogel, rockwool and each is selected for its specific function to achieve structural and passive cooling.

Another objective is to design the system modular and scalable according to the rooftop design pattern that can be found in Indian cities by standardizing a tray unit of fixed dimensions, which can be easily customized according to the occupants, and it can be partially or implemented in phases. It ensures that the new green roof can be catered to smaller residential as well as large commercial applications [2].

Measure and evaluate the comparative difference between the proposed hydroponic green roof against conventional bare roof for temperature and humidity behaviour under identical exposure, quantifying the extent of daytime temperature reduction and nighttime heat retention.

Conducting a side-by-side comparison of two identical models under identical exposure can identify the precise difference between the thermal behaviour and humidity levels. And overall, the system response can be attributed specifically to the presence of hydroponic substrate, and it's working [3].

IV. SUBSTRATE COMPOSITION

Layer	Role
Vegetation	Provides shading and evaporative cooling
Rockwool	Reduces heat transfer and supports roots
Hydrogel	Stores water and release it gradually
Fiber Mesh	Prevents mixing of layers
LECA	Provides drainage and lightweight base support



Fig. 1. Experimental Setup

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V. RESULT AND ANALYSIS

Green Roof vs. Bare Roof — Experimental Performance Summary				
Parameter	**Green Roof (Morning)**	**Bare Roof (Morning)**	**Green Roof (Night)**	**Bare Roof (Night)**
Avg. Temp. (°C)	28.32	29.98	24.78	24.30
Temp. Difference (°C)	+1.68°C cooler (Green)		+0.15°C (thermal retention)	
Avg. Humidity (% RH)	49.89	43.78	66.47	64.49
Humidity Difference (% RH)	+6.54% RH higher (Green)		+1.49% RH higher (Green)	
Peak Temp. Diff. (°C)	Up to +2.58°C (26 Mar)		Max +0.27°C (inversion)	
Sessions (n)	11 mornings + 11-night sessions | 26 Mar – 13 Apr | Simultaneous DHT22 sensors			

IV. CONCLUSION

The Proposed Study showcased effective passive cooling by reducing temperature by approximately 1.6-1.7°C and increasing humidity, while also maintaining low structural load and practical feasibility for urban applications.

V. ACKNOWLEDGMENT

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