ANALYSIS OF THERMAL COMFORT IN PREFABRICATED BUILDINGS

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Abstract - *Prefabricated construction has become a pivotal strategy in addressing the global demand for affordable, sustainable, and rapidly deployable housing. Particularly in warm-humid climates, where thermal discomfort leads to increased energy demands, the selection of appropriate building envelope materials is crucial. This paper presents a comparative analysis of three prefabricated panel systems: Polyurethane Foam (PUF) Panels, Glass Fibre Reinforced Gypsum (GFRG) Panels, and Fibre Cement Boards (V-Panels). Using dynamic thermal simulation models and applying the ASHRAE 55 and NBC 2016 standards for thermal comfort, the study evaluates the Predicted Mean Vote (PMV) indices, energy consumption patterns, and the overall thermal performance over a continuous 72-hour monitoring period. Results underscore the superior insulation efficiency and comfort stability provided by V-Panels, primarily due to their low U-value (0.33 W/m²K) and consistent PMV scores within the comfort threshold. The findings aim to inform policy decisions and design frameworks for climate-resilient prefabricated housing.*

Key Words: **Prefabricated buildings, Thermal comfort, PUF panels, GFRG panels, V-Panels, U-value, PMV index, simulation, Building envelope materials**

1.INTRODUCTION

Prefabricated buildings are increasingly popular due to their fast assembly, cost-effectiveness, and environmental benefits. Unlike traditional construction, prefabrication involves manufacturing building components, such as wall panels and frames, off-site in a controlled environment. These parts are then quickly assembled on-site, reducing construction time, labour, and waste, making them ideal for residential and commercial projects seeking efficiency and sustainability. However, achieving thermal comfort in prefabricated structures, especially in warm and humid climates like India, poses challenges. Thermal comfort, how well indoor temperatures match occupant preferences, is critical for well-being and energy efficiency. In warm climates, materials with high thermal conductivity and low insulation allow excessive heat transfer, making indoor spaces uncomfortable and increasing reliance on cooling systems, which leads to higher energy costs.

This study focuses on assessing three prefabricated materials Polyurethane Foam (PUF) panels, Glass Fiber Reinforced Gypsum (GFRG) panels, and V-panels (Fiber cement boards) to determine which offers optimal thermal comfort in hot climates. PUF panels are lightweight and insulating but may allow some heat gain. GFRG panels provide moderate insulation, balancing thermal comfort and sustainability. V-panels, known for their low U-value, effectively reduce heat transfer, offering stable indoor temperatures with reduced cooling demands. By comparing these materials through thermal simulations, this research aims to identify the material that best supports comfortable, energy-efficient indoor climates in warm regions, helping guide sustainable material choices for prefabricated construction.

1.1 PROBLEM DEFINITION

Thermal comfort in prefabricated buildings is essential for occupant well-being, productivity, and energy efficiency. In warm and humid regions, achieving a comfortable indoor climate can be challenging due to high outdoor temperatures and humidity levels. Prefabricated materials have varying thermal properties, impacting how well they insulate against outdoor heat. Understanding the performance of PUF, GFRG, and V-panels is critical for developing effective solutions for energy-efficient prefabricated buildings. This study aims to provide insights into selecting appropriate materials that maximize thermal comfort and reduce energy demands, particularly in climates that are prone to high temperatures and humidity.

2.OBJECTIVES

- To conduct a critical review of thermal comfort metrics, with a focus on ASHRAE 55, NBC 2016, IMAC, and ENS 2018/2021 frameworks.
- To determine the thermo-physical properties (thermal conductivity, specific heat, thermal diffusivity, U-values) of PUF, GFRG, and V-Panels using both empirical data and published literature.
- To perform real-time thermal profiling in prefabricated units over a period of 72 hours using calibrated data loggers and sensors.
- To simulate thermal behaviour using sefaira evaluating PMV indices, energy consumption in kWh/year, for initial simulation readings.
- To identify the material offering optimal thermal performance under diurnal temperature fluctuations in warm-humid climates.

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3.METHODOLOGY

The study integrates mixed methods, comprising field instrumentation, computational simulations, and analytical derivations. Prefabricated test units constructed from PUF, GFRG, and V-Panels were selected across three locations in Tamil Nadu. Temperature sensors (with ±0.5°C accuracy), humidity sensors, and data loggers were deployed for continuous environmental monitoring. Simulation models were calibrated using climatic data from IMD Chennai for April.

U-values were calculated using: $U = 1 / \Sigma(R_n)$ where $R = d / \lambda$

Energy consumption estimates were derived from thermal loads applied to the modelled units under identical occupancy and activity schedules.

4.MATERIAL SPECIFICATION & THERMAL PERFORMANCE

PUF Panels

Composition: Polyurethane core, pre-coated steel skins

Characteristics: High initial insulation, poor long-term thermal stability under humid exposure

GFRG Panels

Composition: Calcined gypsum reinforced with glass fibre; concrete-filled core

Characteristics: Moderate thermal resistance, high load-bearing capacity

V-Panels (Fibre Cement Boards)

Composition: Cement-fibre sheets with rock wool core insulation

Characteristics: Superior thermal resistance, improved fire and acoustic performance

U-VALUE CALCULATION:

U-Value Calculation Formula:

$U= 1/ R_1 + R_2 + R_3 + \cdots + R_n$

Where:

U = Thermal transmittance (W/m^2K)

R_n = Thermal resistance (m^2K/W) of each layer in the building element

Thermal resistance R is calculated as:

$R=d/\lambda$

d = Thickness of the material (meters)

λ = Thermal conductivity of the material (W/mK)

• PUFF PANEL:

Thermal resistance= 0.33

U= 1/0.33

=3.03 W/m^2k

• GFRG PANEL:

Thermal resistance= 0.36

U= 1/0.36

=2.77 W/m^2k

• V- PANEL (Fiber cement board):

Thermal resistance= 60/0.21= 285.7

U= 1/285.7 =0.03 W/m^2k

THEREFORE:

Table -1: U-Value of the panels

Material	U-value
PUF Panel	3.03 W/m^2K
GFRG Panel	2.77 W/m^2K
V-Panel	0.03 W/m^2K

5.RESULT AND DISCUSSION

Case study analysis

- **PUF Panel Unit (Chepauk, Chennai)**
  Avg. Indoor Temp: 30.5°C
  Energy Consumption: 2163 kWh/year
  Peak PMV: +1.3 (slightly warm)
- **GFRG Panel Unit (SPSR Nellore District)**
  Avg. Indoor Temp: 29.5°C
  Energy Consumption: 2120 kWh/year
  PMV: +0.9
- **V-Panel Unit (Mangadu)**
  Avg. Indoor Temp: 27.5°C
  Energy Consumption: 1345 kWh/year
  PMV: +0.1 (neutral)
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Field data aligns with simulation predictions, indicating the superior performance of fibre cement panels.

Simulation analysis

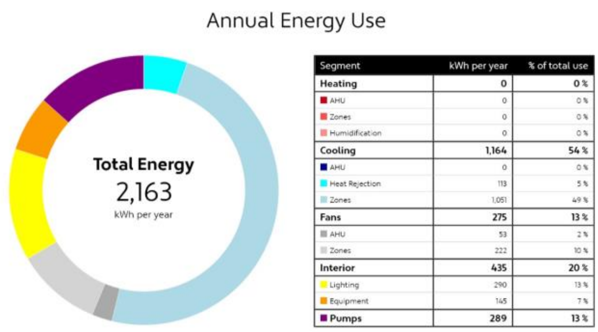

Fig -1: Total energy efficiency of puf panels is 2163kWh per year

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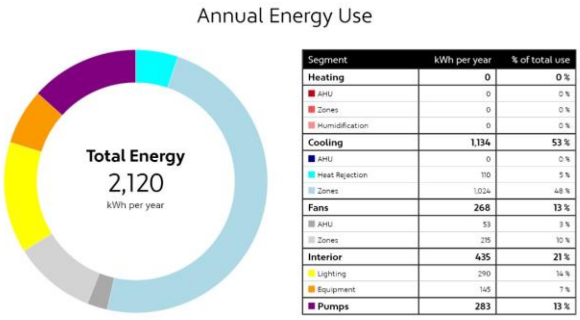

Fig -2: Total energy efficiency of gfrg panels is 2120kWh per year

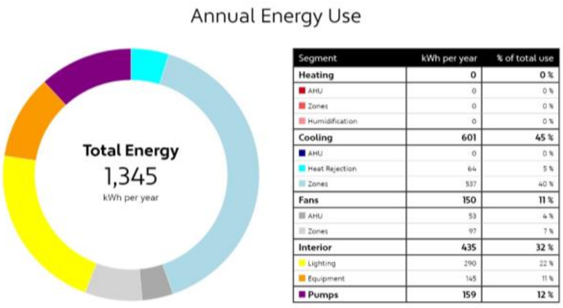

Fig -3: Total energy efficiency of v-panels is 1345kWh per year

Table -2: Analysis of annual energy consumption of each material

Material	Energy consumption
PUF Panel	2163 kWh/year
GFRG Panel	2120 kWh/year
V-Panel	1345 kWh/year

Dynamic simulations using sefaira revealed:

- PUF Panels required peak cooling load of ~4.2 kWh/day
- GFRG Panels required ~3.9 kWh/day
- V-Panels required ~2.4 kWh/day

PMV values fluctuated more in PUF and GFRG units due to higher thermal gain. V-Panels maintained steady-state PMV within -0.5 to +0.5.

The findings demonstrate that thermal comfort is strongly influenced by material U-value and thermal inertia. V-Panels, with their rock wool insulation and layered construction, mitigate diurnal heat ingress effectively. While PUF offers high initial resistance, degradation in tropical humidity reduces its long-term efficiency. GFRG offers moderate performance and is suitable where structural strength is a priority.

6. CONCLUSIONS

As the U- value reduces, thermal insulation will be high and energy consumption for cooling will be considerably reduced.

V-PANEL shows the best energy efficiency as it has low U-value which in turn results in best performance of thermal comfort when compared to other prefabricated PUFF PANELS and GFRG PANELS

Comparison of U-Values: V-panel (fiber cement board) buildings demonstrated the lowest U-value among the three materials, which indicates superior insulation properties and, consequently, better thermal comfort.

Thermal Comfort Performance: Based on the U-values, V-panels are the most effective in maintaining stable indoor temperatures, reducing the reliance on heating or cooling systems. This makes them potentially more energy-efficient and suitable for warmer climates

Material Suitability: Each material has unique characteristics, but for projects prioritizing thermal comfort, V-panels would be the preferable choice among prefabricated options.

For Sustainable Building Design: Recommend V-panels for prefabricated buildings aiming for energy efficiency and improved thermal comfort, especially in areas with high ambient temperatures or significant daily temperature swings. This research validates that V-Panels are the most effective among the materials studied for warm-humid regions due to their superior insulation properties and stable PMV values. These findings support the inclusion of V-Panels in national affordable housing policies and climate-resilient building codes.

7. LIMITATIONS

- This study exclusively examines puf panels, gfrg panels and v-panels, without considering other prefabricated materials that may offer different insulation properties. Consequently, the findings may not be applicable to other material types.

- The analysis focused on warm and humid climatic conditions. Therefore, the results may not be directly transferable to other climate zones such as cold or arid regions.

- Exclusion of building typology-The study does not differentiate between building typologies.

- Sefaira software was used for initial simulations, future research is encouraged to employ more detailed tools such as energy plus or IES-VE for comprehensive analysis.

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