Challenges in Improving Thermal Comfort in Tents

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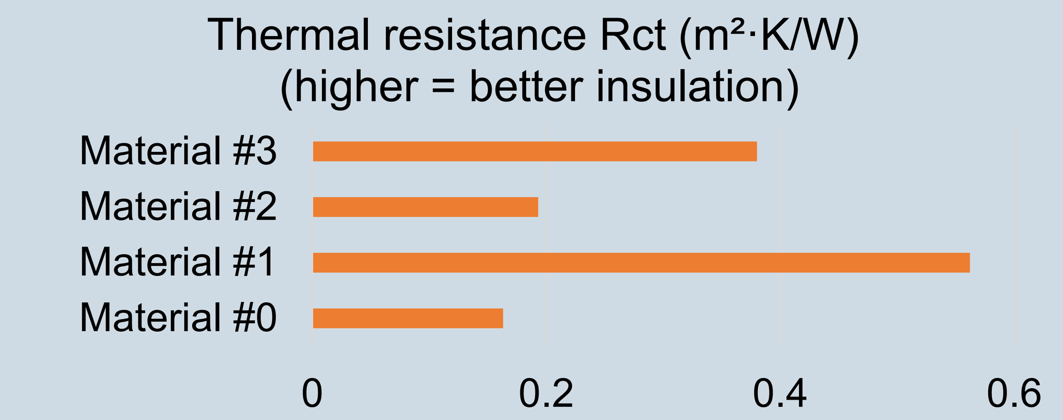
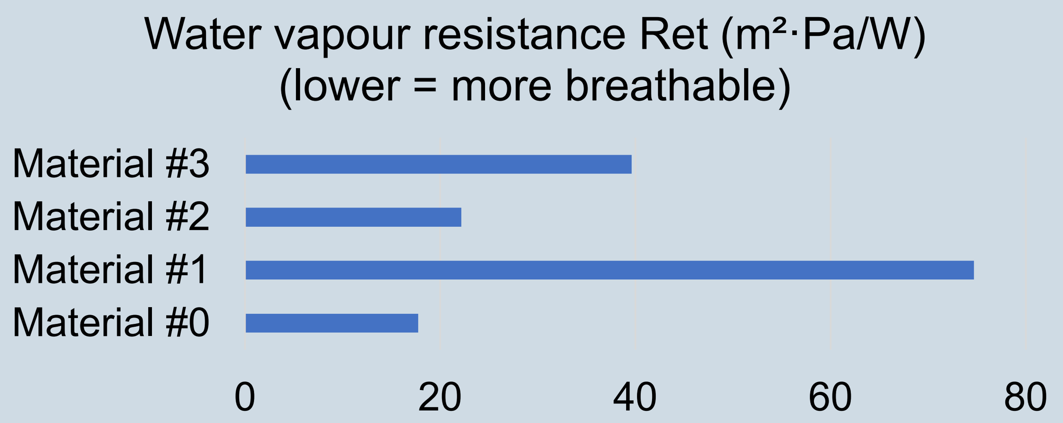
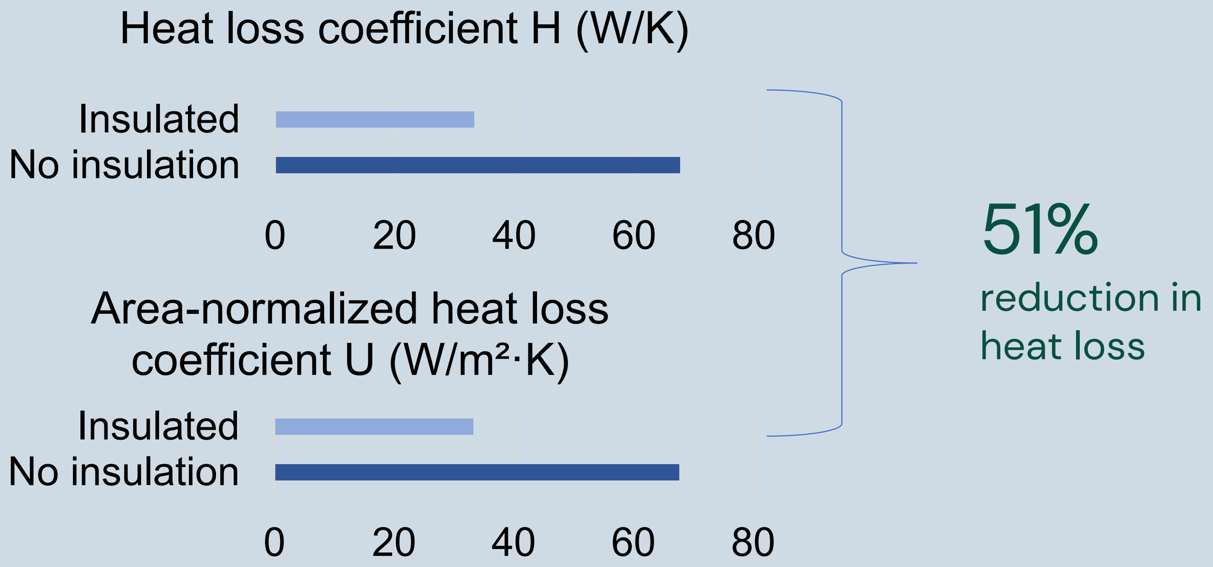
4
textile insulation materials tested using Guarded hotplate





Better insulation consistently came with lower breathability – material selection must balance both properties for the intended climate and ventilation strategy.

2
mockup tent configurations evaluated: insulated vs. non-insulated



−1.3°C
No insulation
±0.95 °C

→

+5.1°C
With insulation
±0.58 °C

Outdoor conditions nearly identical in both tests: −7.90 °C vs −7.93 °C. Same 441 W heat input applied. The insulated tent also showed lower temperature variability (σ = 0.58 vs σ = 0.95 °C), indicating more stable indoor conditions.

8kg
phase change material (PCM) tested as thermal mass

Daytime phase (6 h)
PCM absorbed heat and charged (T_{out} ~25–26 °C). Limited reduction in peak overheating – both with/without PCM reached ~29 °C due to control limit.

Nighttime phase (>12 h, chamber at −10 °C)
PCM released stored heat gradually. Indoor air temperature decreased more slowly and stayed notably higher compared to the reference case (no PCM).

- × PCM did not significantly reduce daytime peak temperature (Theoretically must; temperature limiter engaged at 30 °C in both cases)
- ✓ Slowed nighttime cooling – PCM acted as a thermal buffer, releasing latent heat during the cold phase
- ✓ Maintained higher indoor temperature for longer during the night, consistent with RT22HC's operating range (20–23 °C)

8 kg RT22HC in 56 spheres; forced air circulation at 1 ACH; PCM loading: 1.15 kg/m³ or 1.66 kg/m².

Introduction

Temporary shelters are widely used in emergency, military, and temporary housing applications, yet they exhibit poor thermal performance due to low insulation and minimal thermal mass. This results in high heat losses in cold conditions and significant indoor temperature fluctuations. Improving thermal comfort in such structures is therefore essential for occupant well-being and energy efficiency. This study investigates the effect of textile insulation and PCM on the thermal behavior of lightweight tents.

Methods

The study combines laboratory measurements and controlled experiments to address the key limitations of lightweight tents: high heat loss and lack of thermal mass.

Four textile insulation materials (Fig.1) were tested using a guarded hotplate to determine thermal resistance (Rct) and water vapour resistance (Ret), to evaluate the trade-off between insulation performance and breathability relevant for material selection.

A full-scale mockup tent (Fig. 2) was tested in a climate chamber (~-8 °C) with and without an internal insulation layer. This experiment was conducted to quantify the impact of insulation on heat loss and indoor air temperature under controlled and comparable conditions.

The effect of thermal mass was assessed by integrating 8kg of phase change material (PCM) and analysing the day-night temperature response (Fig. 3), to determine its ability to reduce temperature fluctuations and improve nighttime thermal stability.

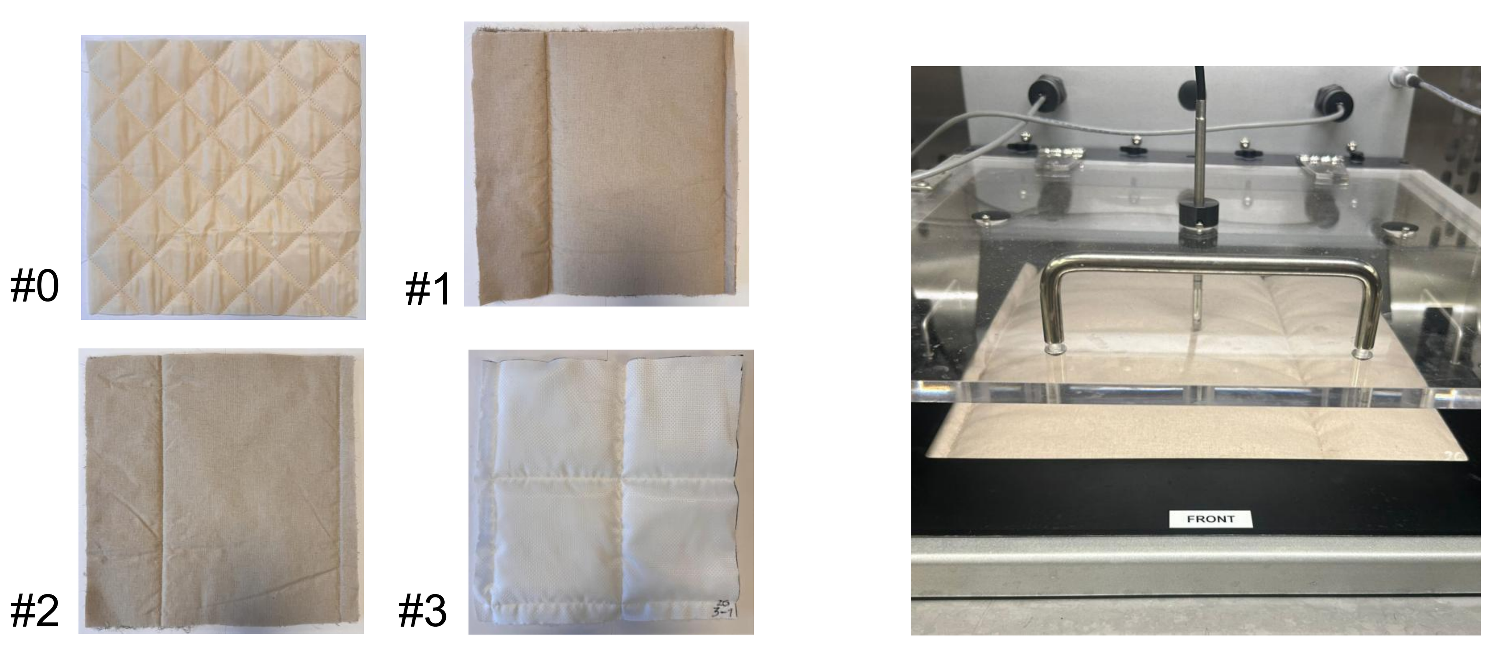


Fig. 1. Investigated textile insulation materials (#0-#3) and experimental guarded hotplate setup used for thermal resistance and water vapour resistance testing.

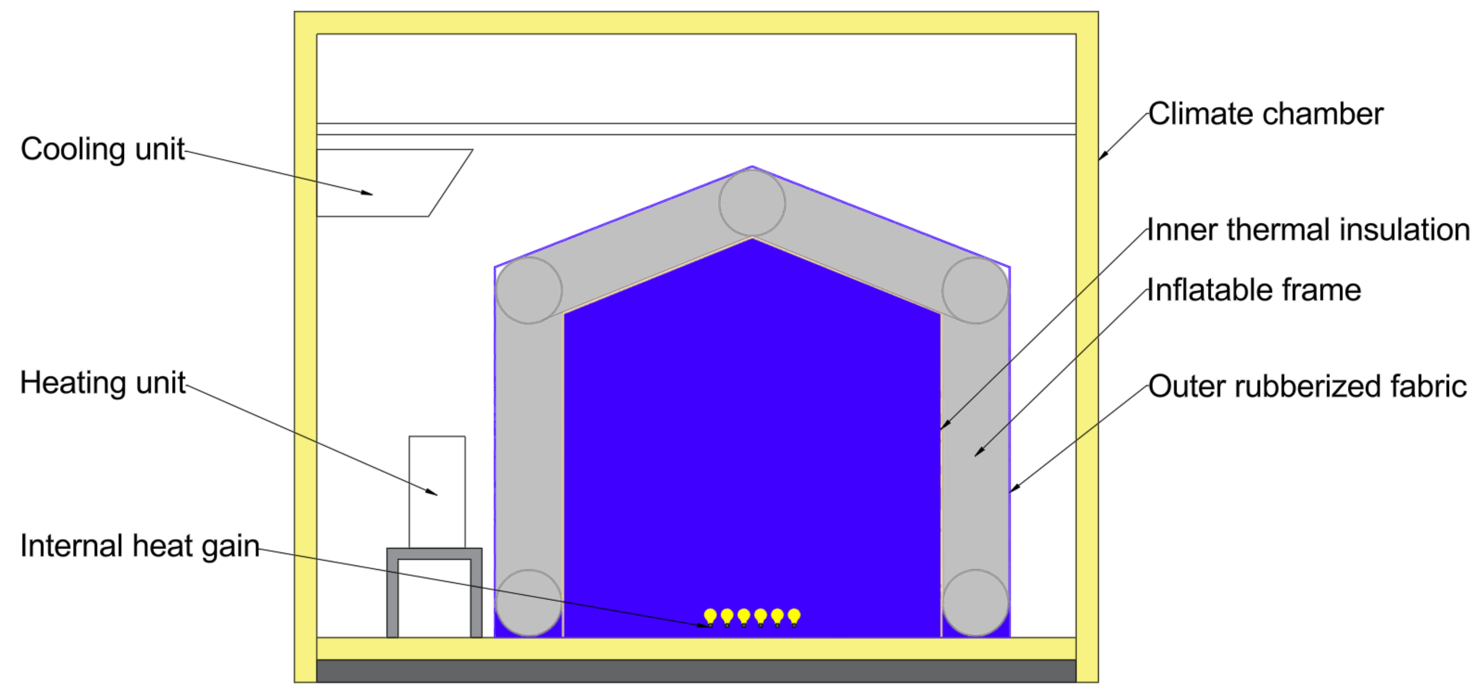


Fig. 2. Schematic of the mockup tent experimental setup inside the climate chamber, including cooling and heating units, internal heat source, and multilayer tent structure.

Fig. 3. PCM-based thermal storage unit with forced airflow: system configuration (left), packed PCM spheres within the cartridge (centre), and in-situ integration inside the mockup tent (right).

Main conclusions

1. All four fabrics showed a clear insulation–breathability trade-off: better thermal resistance came with lower vapour permeability.
2. Adding an internal insulation layer reduced the heat loss coefficient by ~51% and raised average indoor temperature from −1.3 °C to +5.1 °C under the same outdoor conditions.
3. PCM showed limited benefit for daytime overheating but meaningfully delayed nighttime cooling, demonstrating value as a thermal-mass strategy.
4. The most effective improvement strategy combines insulation (lower heat loss) with PCM (greater thermal inertia) to address both temperature extremes.

Acknowledgement

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