Sustainable Ventilation Solution for Thermal Comfort Using Bubble Sheet as A False Ceiling

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Abstract - Ventilation with human comfort is gaining prominence in the HVAC sector. Although renewable energy sources are in the limelight, there is still a lot to be discovered in this field. Ventilation with a sufficient air change rate (ACR) is necessary for healthy indoor air quality, particularly in buildings with poor ventilation. Conventional electromechanical systems work well but tend to be costly and energy-hungry. This phenomenon is more for sheet metal-roofed buildings, where the heat gain is much greater than in concrete slabs. The transfer of heat by conduction, convection, and radiation causes discomfort for people. A bubble sheet fixed as a false ceiling at a certain distance can function as a radiation barrier. The bubble sheet returns radiated heat to the roof, and a solar chimney or turbo ventilator removes the hot air between the sheet and roof. Adjustable ceiling openings permit controlled air change. In heavily populated areas, an ACR of up to 10 should be used. A green ventilating system with such attributes has been put in place in room B-341 of S.S.V.P.'s B.S. Deore College of Engineering, Dhule, Maharashtra. Sensors were installed to check efficacy. Findings indicate a temperature drop of 6–7°C without power, which is an important step in the direction of green energy solutions.

Keywords: ACR (Air Change Rate), HVAC (Heating, Ventilation, and Air Conditioning).

1. INTRODUCTION

Insulation is a vital element of building thermal comfort, with the main objective of minimising heat transfer. Traditional insulation materials like fiberglass and metal-based barriers are mainly effective against conductive and convective heat transfer. Nevertheless, they are mainly ineffective against radiant heat, which is one of the main contributors to indoor thermal discomfort and the greenhouse effect. Radiant heat is also one of the primary factors contributing to global warming. Thus, the choice of insulation materials should account for all heat transfer modes, especially radiation.

Alutix™ Noble 10mm thermal insulation, having a reflectivity ratio of 96%, presents a potential solution by reflecting radiant heat efficiently. In metal roof buildings, most heat gain is experienced through the metal roof. This research suggests an integrated method to reduce such heat gain by installing a false ceiling below the metal roof and a natural ventilation system.

The suggested ventilation system is based on the principle of buoyancy-driven air flow, where hot air of lower density rises and is vented out through strategically located chimneys. This passive ventilation method allows for the constant evacuation of hot air, thus lowering indoor temperatures in summer and keeping the indoors comfortable in winter.

The objective of this research is to present a low-cost, energy-saving substitute for traditional cooling systems like air conditioners, which are financially out of reach for most people. Unlike other traditional surface coatings such as white paint or lime slurry with adhesives (e.g., Fevicol), this process provides better performance, sustainability, and affordability..

2. LITERATURE REVIEW

Reflective insulation products, such as aluminum foil bubble sheets, are most commonly known for minimizing indoor heat gain, especially in metal and RCC roofed buildings. Raja et al. (2019) and Zalewski et al. (2002) illustrated their efficiency in reducing indoor temperature and enhancing thermal performance. Sadineni et al. (2011) emphasized their significance as passive saving schemes of energy in building enclosures. To improve ventilation, Yadav and behavior (2013) investigated solar chimneys for better air flow, while Bansal et al. (1994) stressed the joint application of natural ventilation and insulation for thermal comfort.

Additionally, Jadhav and Sawant (2020) investigated bubble insulation in Indian situations and registered a temperature reduction of up to 5°C in experimental arrangements. Kumar et al. (2017) evaluated aluminum foil-based thermal insulation and validated its potential to minimize radiant heat transfer. Tiwari et al. (2016) discussed low-cost cooling technologies for low-income housing, noting reflective insulation as cost-effective and effective. Finally, Ali and Ahmed (2021) researched passive strategies for thermal control and determined bubble sheets to be effective in hot and humid climates...

3. METHODOLOGY

3.1 Workflow Overview

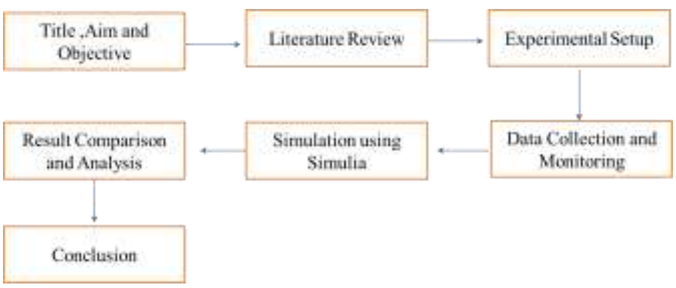

Chart 1: **Methodology Flow Chart**

This methodology combines both experimental and simulation approaches to evaluate thermal comfort improvements using a bubble sheet false ceiling. The experimental phase involves monitoring temperature variations in a real room setup, while the simulation phase uses CFD (SIMULIA) to model airflow and heat transfer under various configurations. Results from both methods are compared to assess the effectiveness of the bubble sheet and ventilator system.

4 Experimental Setup

The experimental setup was designed to evaluate the impact of using an aluminum foil bubble sheet as a false ceiling to enhance thermal comfort in a typical room setup. The experiment was conducted in a room measuring 5.5 meters by 9 meters located at SSVPS College of Engineering, Dhule, which provided a controlled environment to monitor the effect of roof insulation. The bubble sheet, composed of two reflective layers of aluminum foil with a layer of plastic air bubbles in between, was installed below the existing metal or RCC roof. This material is known for its high thermal resistance, durability, and lightweight structure, and can effectively control indoor temperature by reflecting radiant heat and reducing heat transfer. The choice of bubble sheet was driven by its cost-effectiveness and suitability for sustainable construction, especially in regions experiencing high solar heat gain through roofs.
As part of the instrumentation, temperature sensors were installed at multiple locations inside the room to capture temperature variations at different heights and zones. These sensors recorded temperature data continuously over 24 hours, both before and after the installation of the bubble sheet. The collected data was used to assess the temperature differential and understand the behavior of thermal insulation under real conditions. The setup aimed to replicate real-world usage, making the findings applicable for both residential and institutional buildings where energy-efficient and affordable cooling solutions are essential.

Figure 1 Installation of Bubble Sheet

Figure 2 Position of Sensors

5 Data Collection & Monitoring

5.1 Record room temperatures (with and without sheet).

To evaluate the effectiveness of the bubble sheet insulation, room temperatures were recorded in two scenarios—one with the aluminum foil bubble sheet installed as a false ceiling, and the other without it. Temperature sensors and thermocouples were installed at multiple points in both setups to monitor air temperatures across different heights and zones within the room. The data was logged over 24 hours, capturing variations throughout the day and night to account for changes in ambient temperature and solar heat acquire. This setup comprehensively compared the insulated and non-insulated conditions under real environmental influences.

TIME PERIOD OF 24 Hrs	Above Sheet Temp in °C	THERMOCOUPLE 1 °C	THERMOCOUPLE 2 °C	THERMOCOUPLE 2°C
9.15 AM	26.9	25.2	24.2	24.1
10.15 AM	30.2	26.6	25.7	25.4
11.15 AM	32.9	28.1	27.3	26.5
12.15 PM	34.1	28.7	28	26.7
13.15 PM	34.2	29.2	28.8	27.4
14.15 PM	34	28.6	28.3	28.5
15.15 PM	32.6	28.8	28.4	27.8
16.15 PM	30.5	28.4	27.7	27.1
17.15 PM	27.8	27.4	26.9	26.9
18.15 PM	27.1	26.4	26.8	26.8
19.15 PM	26.2	26.6	26.4	26.4
20.15 PM	25.6	25.9	26.4	26.2
21.15 PM	25.3	25.9	26.1	26
22.15 PM	25.6	26.5	25.9	26.3
23.15 PM	25.2	26.4	25.7	25.8
24.15 AM	24.7	26.1	25.6	25.9
1.15 AM	24	24.9	25.7	25.3
2.15 AM	23.5	24.7	25.2	25.4
3.15 AM	23.1	25.5	25	25.2
4.15 AM	22.7	25.3	24.8	25
5.15 AM	22.2	25.4	24.8	24.7
6.15 AM	22.1	24.8	24.5	24.6
7.15 AM	22.5	24.6	24.7	24.5
8.15 AM	24.4	25.4	24.6	24.9
9.15 AM	26	24.9	25.1	24.8

Figure 3 Temperature Reading

5.2 Temperature Analyze

The recorded data was then analyzed to determine the overall temperature difference between the two rooms. The analysis showed that the **room with the bubble sheet maintained significantly lower temperatures** compared to the control room. While the expected temperature reduction was around **3–4°C**, the actual results exceeded expectations, showing an **average drop of 7°C**, with peak temperatures reducing from **35°C to 28°C**. This confirmed that the **bubble sheet acted as an effective thermal barrier**, reducing heat transfer from the roof and significantly improving indoor comfort, especially in hot climates.

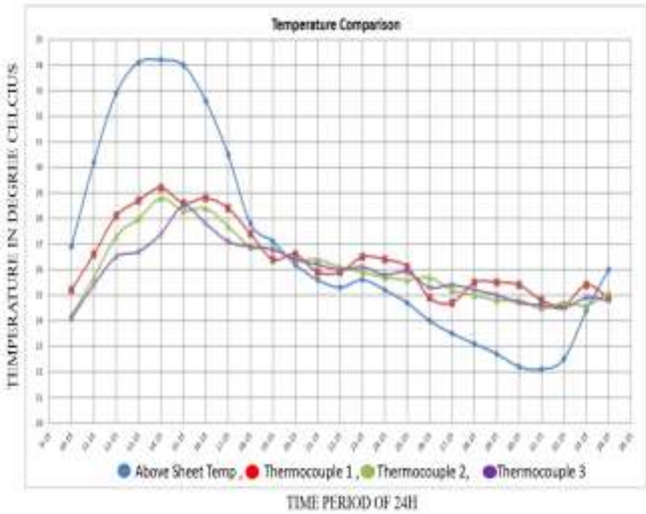

Figure 4 Temperature Comparison Graph

6 Simulation using SIMULIA

6.1 Create 3D Geometry (Room, Roof, Chimney

Initially, a precise 3D room model was designed using CATIA. The main enclosure (5.5 m x 9 m), a rooftop chimney, and a false ceiling with bubble sheet under the roof were included in the modeled room. The geometry also incorporated the turbo ventilator outlet and inlet openings (windows and doors). This realistic representation ensured that the boundary conditions and airflow dynamics mimicked actual experimental conditions.

Mesh Part	Element Size (mm)	Sag Size (mm)	No of Elements
Hex Mesh	365.829	0	4365845
Tetrahedron 1	15	2	8232726
Tetrahedron 2	15	2	96685

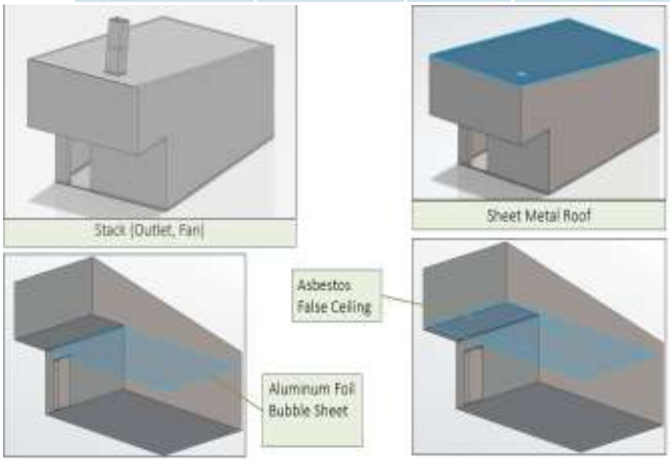

Figure 5 3d Model

6.2 Define Fluid Domain and Mesh

The fluid domain was defined by isolating the internal air volume in the room and chimney through which airflow would be simulated. This domain was extracted from the solid model and meshed using hex and tetrahedral mesh elements. Finer meshing was applied near boundaries and in areas of high gradient changes, such as near the turbo ventilator and openings, to ensure simulation accuracy and convergence.

Figure 6 Meshed Model

Fig -7: Meshed Details

6.3 Apply Boundary Conditions (Inlet, Outlet, Fan)

Appropriate boundary conditions were set to replicate real-world airflow behavior. Inlet velocities were applied at the window and door openings (typically 0.1–0.2 m/s), while outlet conditions were defined at the turbo ventilator or chimney exhaust. For the cases using a turbo ventilator, a fan outlet boundary was applied to simulate suction-induced flow. Additionally, no-slip conditions were imposed on walls and surfaces

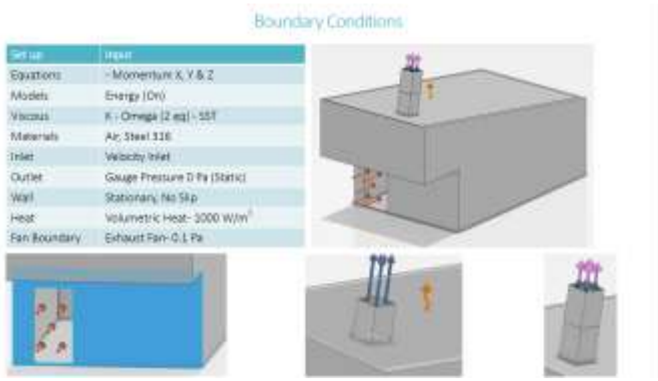

Figure 8 Boundary Conditions

6.4 Setup Material Properties

Material properties were assigned to all elements in the simulation. Air was set as the working fluid, with its standard properties (density, viscosity, specific heat). The roof and walls were assigned concrete or sheet metal properties depending on the configuration. The bubble sheet layer was given insulating properties with low thermal conductivity to simulate its real-world function. These settings were essential for capturing realistic heat transfer and fluid dynamics in the room.

- **Density**: Assumed constant for air (standard air density at 20°C = 1.2 kg/m³).
- **Viscosity**: Dynamic viscosity of air taken as 1.81 x 10^{-5} kg/(m·s) at room temperature.
- **Specific Heat**: Assumed constant, specific heat of air = 1005 J/(kg·K).
- **Thermal Conductivity**: Assumed constant for air = 0.026 W/(m·K).
- **Ideal Gas Assumption**: Considering air as an ideal gas.

7. Run CFD Simulation for Different

Thoroughly analyze the impact of various passive and active strategies on thermal comfort, multiple CFD simulation scenarios were executed. These scenarios helped compare airflow patterns, heat accumulation, and temperature distributions under different configurations involving ventilation and insulation methods. The simulations were performed using SIMULIA's CFD module with identical room dimensions and environmental conditions for consistency.

Case 1: Simulation of room ventilation using a turbo-ventilator and chimney.

In this simulation, the room was equipped with a **chimney and a turbo ventilator** installed at the top. The bubble sheet insulation was also included. This setup demonstrated significant improvement in airflow dynamics, as the **turbo ventilator created a strong suction effect**, drawing hot air from the gap between the roof and the bubble sheet. **Velocity vectors showed a smooth, upward airflow** from the lower regions of the room to the exhaust. **Recirculation zones were minimized**, and the temperature distribution was more uniform. The ceiling temperature dropped, improving thermal comfort significantly.

7.2. Case 2: Simulation of room ventilation with Chimney, without Turbo-ventilator

In Case 2, only a chimney was present, and the bubble sheet was installed. The room had micro-level geometry, and all windows were closed. The simulation revealed weak vertical airflow due to the lack of a mechanical ventilator. Air circulation relied solely on buoyancy, which was insufficient to drive proper ventilation. Velocity plots showed dead zones near corners and vent, while pressure contours reflected a minimal pressure gradient. Temperature contours indicated significant heat accumulation at the ceiling.

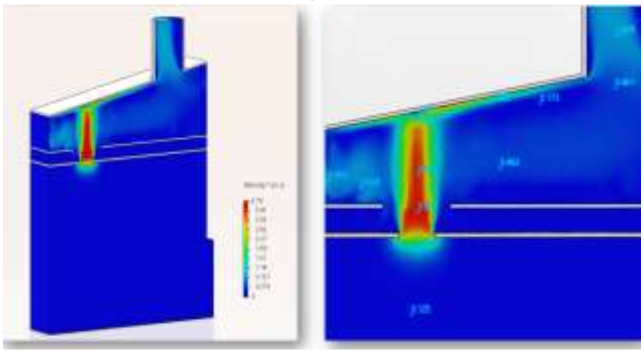

Figure 7 Case 2 - Velocity Counter

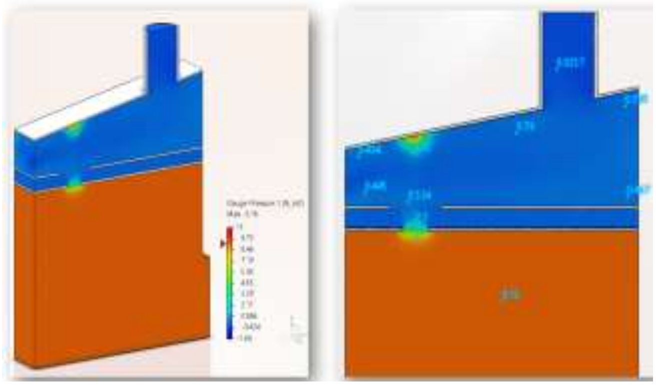

Figure 8 Case 2 – Pressure Counters

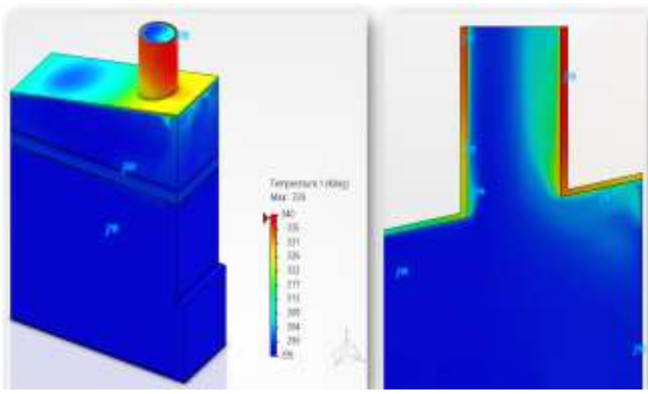

Figure 9 Case 2 – Temperature Contours

7.3. Case 3: Room ventilation simulation: chimney only (no turbo-ventilator).

Case 3 explored full room (original) geometry with only a chimney and no turbo ventilator. The bubble sheet was used, and the room was sealed. Velocity vector plots showed minimal air movement, with recirculation at ceiling level and stagnant corners. Pressure distribution was largely uniform, with a very low-pressure differential, limiting hot air escape. The temperature contours revealed strong stratification, with the gap temperature near the ceiling rising to 42°C, while occupant level temperatures remained around 36–38°C

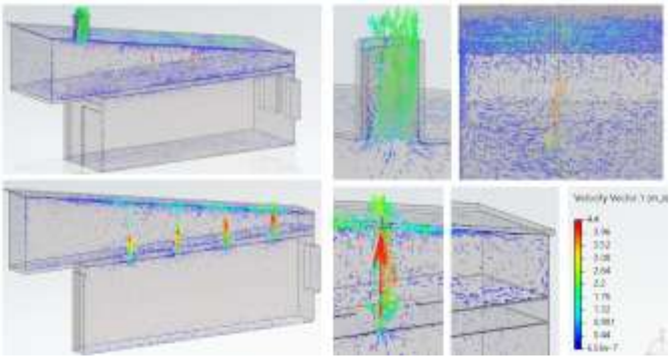

Figure 10 Case 3 – Velocity Vectors

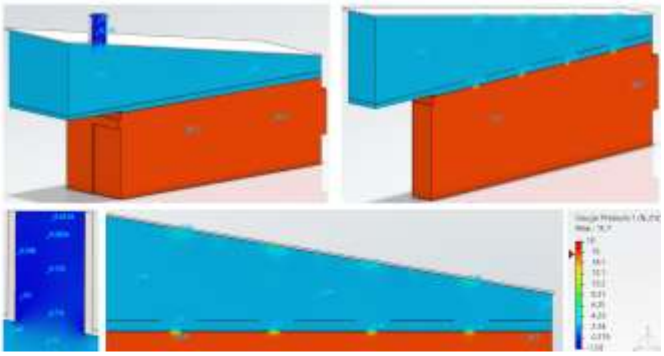

Figure 11 Case 3 – Pressure Counters

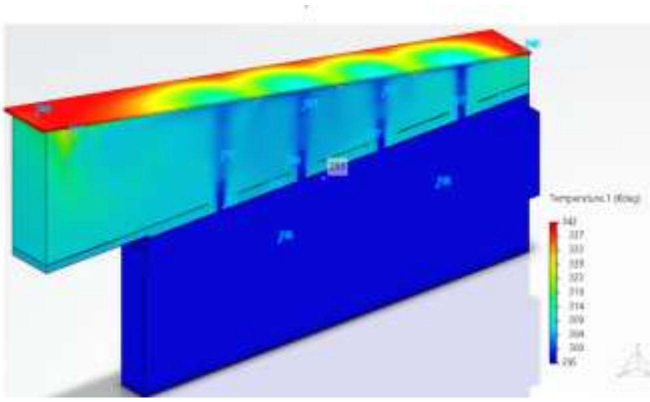

Figure 12 Case 3 – Temperature Contours

8 Results

Case 1: Simulation of room ventilation with Turbo-ventilator and chimney

- Airflow: Strong upward airflow due to suction from the turbo ventilator; velocity at the vent reaches 0.6 m/s.
- Temperature Distribution: Uniform cooling with ceiling temperature reduced to ~35°C; lower room level stays around 30–32°C.
- Recirculation Zones: Minimal; hot air exits efficiently through the vent.
- Pressure Difference: Sufficient pressure drop created by fan suction (ΔP noticeable in pressure plots).
- Thermal Comfort: ✅ Very Good – effective insulation + mechanical ventilation.

Case 2: Simulation of room ventilation with a Chimney, without a Turbo-ventilator

- Airflow: Very low airflow; weak natural convection through the chimney; no mechanical boost.
- Temperature Distribution: Strong vertical gradient; ceiling ~ 42°C, occupant level ~36–38°C.
- Recirculation Zones: Present near the ceiling and corners; poor heat removal.
- Pressure Difference: Minimal pressure difference; insufficient draft.
- Thermal Comfort: ❌ Poor – natural ventilation is ineffective in a closed room with micro-geometry.

Case 3: Simulation of room ventilation with a Chimney, without a Turbo-ventilator

- Airflow: Similar to Case 2, with slightly better draft due to full-scale geometry.
- Temperature Distribution: Stratified; gap air temperature ~ 42°C, lower room ~ 36–37°C.
- Recirculation Zones: Notably visible in ceiling and wall corners.

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- Pressure Difference: Low ΔP; heat builds up in the upper zone.
- Thermal Comfort: ❌ Poor – insulation helps, but airflow is too weak.

8.1 Summary Table:

Case	Chimney	Turbo Ventilator	Bubble Sheet	Windows	Thermal Comfort	Avg. Ceiling Temp	Recirculation Zones
1	✔	✔	✔	Closed	✅ Very Good	~35°C	Minimal
2	✔	X	✔	Closed	❌ Poor	~42°C	Present
3	✔	X	✔	Closed	❌ Poor	~42°C	Present

Figure 13 Thermal & Airflow Performance Across Cases

9. CONCLUSION

The simulation study of the ventilation configurations highlights the critical role of **active ventilation** and **roof insulation** in achieving indoor thermal comfort.

Case 1, which incorporated a **chimney, turbo ventilator, and bubble sheet insulation**, proved to be the most effective setup. The turbo ventilator created a strong upward airflow that efficiently extracted warm air accumulated near the ceiling. The combination of mechanical ventilation and insulation led to a **noticeable reduction in internal temperatures**, maintaining **ceiling temperatures around 35°C** and **lower room zones near 30–32°C**. The airflow was smooth, with minimal recirculation zones, resulting in significantly improved thermal comfort.

Case 2, featuring only a **chimney and bubble sheet** in a micro room geometry without a turbo ventilator, showed **poor ventilation performance**. The airflow relied solely on natural convection, which was insufficient in a sealed environment. **Hot air accumulated near the ceiling**, raising temperatures to **42°C**, and **recirculation zones were present**, especially near corners and the vent. While the bubble sheet provided thermal resistance, it could not effectively reduce room temperature without proper airflow.

Case 3, which used a **similar configuration to Case 2** but in a **full-scale room**, showed slightly better airflow due to the larger space, yet the absence of mechanical ventilation and open inlets still resulted in **inefficient air movement**. The **temperature distribution remained stratified**, with a significant **6–7°C difference between ceiling and occupant levels**, and airflow stagnation limited the effectiveness of the insulation layer.

efficiency and innovation in construction management.

The comparison of Cases demonstrates that while insulation like a **bubble sheet is essential for reducing heat transfer**, it is not sufficient alone. **Active airflow, provided by mechanical systems such as a turbo ventilator**, is critical to achieving optimal thermal performance. Thus, combining insulation with proper ventilation is key for improving indoor environmental quality in buildings with high solar heat gain through the roof.

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