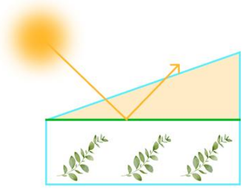
Enhancing Greenhouse Productivity in India using Optimized Heat Transfer techniques

Sujal , Shobhit Kumar , Deepanshu, Rishabh Dewangan , Piyush Kanwat
Department of Chemical Engineering, Indian Institute of Technology, New Delhi(110016)

"Optimizing Heat Transfer Techniques to Enhance Greenhouse Productivity in India"

Thermal screen effectiveness



crop temperature fluctuations by 69%.

1.91 → 0.58
(Standard Deviation)

TES (Thermal Energy Storage) Efficiency

external energy reliance by stabilizing heating and cooling

(Heating Demand Peak) - **59**
(Cooling Demand Peak) - **113**

Productivity and Sustainability Gains

Energy cost Crop quality

18 - 25
(Favourable temp range)

Discussion

Crop temperature fluctuations decreased by over **70%**, improving plant health and minimizing stress.

Thermal screens effectively reduced nighttime heat loss and stabilized internal greenhouse temperatures.

Thermal Energy Storage (TES) systems balanced heating and cooling demands by storing surplus energy for night use.

Combined use of thermal screens and TES led to **higher crop yields**, **lower energy costs**, and **greater sustainability**.

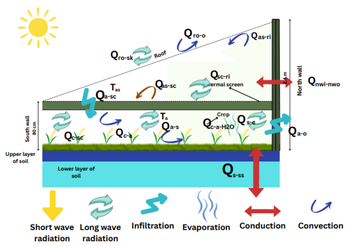
The strategies demonstrated are scalable and adaptable for diverse **Indian climatic conditions**.

Initial installation costs for thermal screens and TES systems can be high for small-scale farmers. The model assumes ideal material properties and may not account for long-term material degradation or extreme weather events.

Integration with **renewable energy systems** (e.g., solar panels, wind turbines) for complete energy self-sufficiency. Development of **dynamic climate control algorithms** to adjust thermal screens and TES usage in real-time based on external weather forecasts.

Methods and Materials

Semi-solar greenhouse with glass cover and concrete north wall → Movable thermal screen inside for insulation and heat control → Underground thermal energy storage (TES) with buffer tank and heat pump → Excess energy stored in TES and utilised in winter or in night → Used MATLAB to solve system and analyze temperature changes at different points → COMSOL simulation of Semi-Solar Greenhouse in ambient conditions to obtain the heat map → Leads to greener, more resilient, cost effective methods with enhanced productivity and sustainability



- During daytime shortwave radiation heats plants, soil, air and structural components.
- **Heat transfer modes** include conduction, convection, and longwave radiation exchange.
- **Nighttime heat loss** mainly occurs through longwave radiation, especially under clear skies.
- **Evapotranspiration** from plants adds moisture to indoor air.

The **thermal screen**, made of cloth-type material, is installed inside the greenhouse.

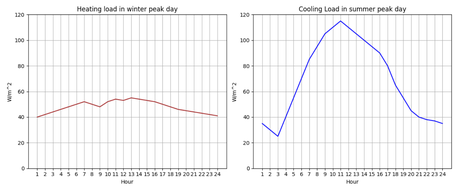
It is **used primarily during nighttime** to reduce heat loss.

It **limits longwave radiation** and **convective heat transfer**, helping retain warmth.

It **maintains stable temperatures** around crops, reducing energy consumption and dew risk.

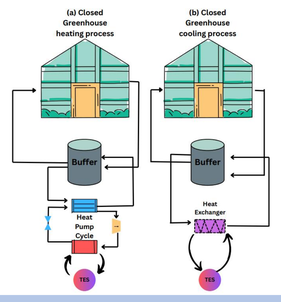
Winter: Extra heating needed to protect crops ~1.2 kWh/m² peak.

Summer: Cooling required to prevent overheating ~1.7 kWh/m² peak.



Heating Process: Heat from solar/renewables → stored in buffer tank via heat pump. → Buffer tank + TES store energy for later use. → Stored heat released to warm greenhouse. → Saves energy and reduces fossil fuel use.

Cooling Process: Excess heat → removed by heat exchanger to buffer/TES. → Heat stored or dissipated later. → Prevents overheating and protects crops. → Maintains stable greenhouse climate.

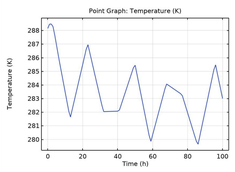


Results

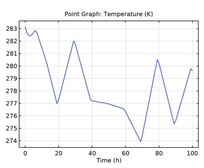
With thermal screen

Without thermal screen

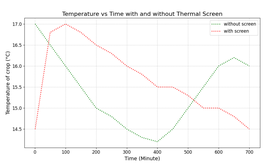
By visualizing both heat maps, we can observe that the thermal screen helps to maintain a higher temperature inside the greenhouse compared to the case without the thermal screen.



With thermal screen



Without thermal screen



Comparison Plot of crop of temperature with and without thermal screen obtained by solving system on MATLAB

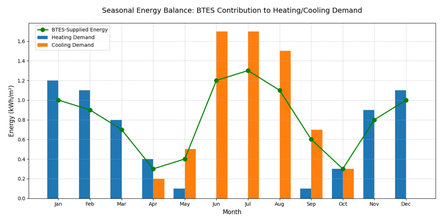
Fluctuations in temperature at night get reduced by the use of thermal screen.
Thermal screens proven effective in reducing long wave radiation at night.

Heating demand (winter months): ~1.2 kWh/m² peak (Jan–Mar, Nov–Dec)

Cooling demand (summer months): ~1.7 kWh/m² peak (Jun–Aug)

58% of annual fossil fuel offset by BTES (Vadiee & Martin, 2013)

BTES covers 80–95% of heating demand in winter and 60–75% of cooling demand in summer



Conclusions

- Integrated thermal screens and TES to improve temperature stability, energy efficiency, and crop yield.
- Reduced environmental impact and operational costs.
- Future work should combine these methods with renewable energy and automated climate control.
- Provided a sustainable and scalable solution for greenhouse farming in India.

Figure Greenhouse

Contact

Sujal, Shobhit Kumar, Rishabh Dewangan, Deepanshu, Piyush Kanwat
Indian Institute of Technology, New Delhi (110016)
ch1230170@iitd.ac.in, ch7230769@iitd.ac.in
+91-9518464645,+ 91-9319894169

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