



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Issue 3, March 2026

Analysis of Structural Design and Utilization of Insulation Material in Solar Dryer for Heat Loss Reduction

Kiruthika G¹, Balamurugan V², Dinesh Selvan C³, Kiruthikaa R⁴

Assistant Professor, Department of Agricultural Engineering, Kongunadu College of Engineering and Technology,
Trichy, Tamil Nadu, India¹

UG Student, Department of Agricultural Engineering, Kongunadu College of Engineering and Technology, Trichy,
Tamil Nadu, India^{2,3,4}

ABSTRACT: Solar drying is a sustainable and energy-efficient technique used to preserve agricultural products by removing moisture with the help of solar energy. However, one of the drawbacks of using solar dryers is that the heat can escape through the structural parts and if the insulation is not good enough, it can make the efficiency of the drying even worse. This study concentrates on evaluating the structural design of a solar dryer and the use of insulation materials to minimize heat loss and improve drying performance. The solar dryer considered in this work is used as a reference system to examine its main structural components such as the frame, drying chamber and airflow path. The analysis helps in identifying the sections of the structure where heat loss is most likely to occur. In addition, different insulation materials and their suitable thickness are assessed to understand their ability to maintain a stable temperature within the drying chamber. Improving the structural design along with the proper application of insulation can help retain more heat inside the dryer and support a more efficient drying process. The outcome of this analysis provide useful insights for enhancing the drying efficiency and time of solar drying systems used in agricultural preservation.

KEYWORDS: Solar Dryer, Structural Design Analysis, Heat Loss, Insulation Materials, Drying Efficiency.

I. INTRODUCTION

Solar drying is widely recognized as a simple and sustainable method for preserving agricultural products. In this process, sunlight is used as the primary energy source to remove moisture from items such as fruits, vegetables, leaves and flowers. Compared to traditional open sun drying, solar dryers provide a more controlled environment that protects products from dust, insects and sudden weather changes. This controlled setup helps maintain product quality and reduces contamination. Because of these advantages, solar dryers are increasingly being adopted in agricultural processing and rural industries. However, the performance of a solar dryer depends greatly on its structural design. A major issue observed is heat loss through the walls, joints and ventilation openings of the drying chamber. This loss of heat reduces the internal temperature, which slows down the drying process and lowers efficiency, especially when proper insulation is not used. Therefore, analyzing the structure of the dryer is important to identify areas where heat escapes. By using suitable insulation materials with proper thickness, heat retention can be improved and leading to stable temperatures, faster drying and better preservation of agricultural products.

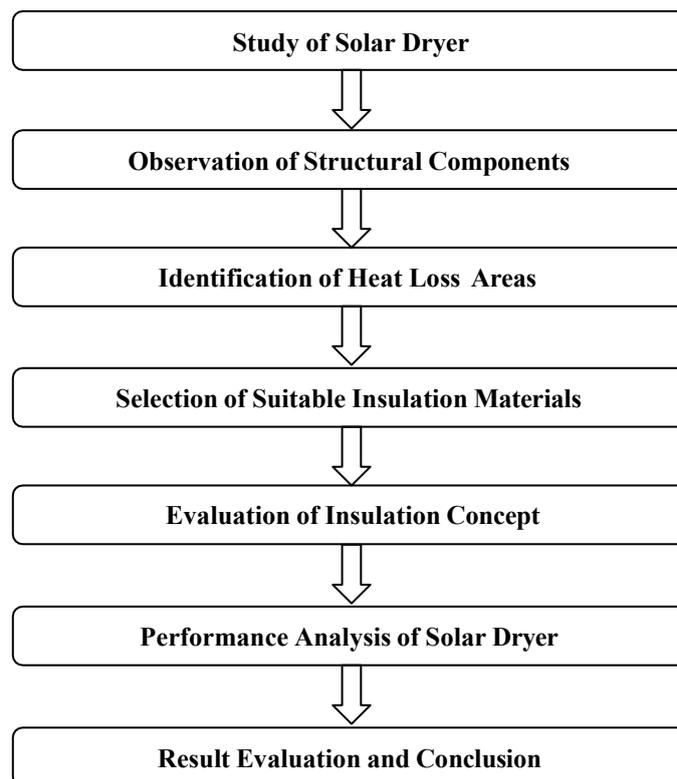
II. LITERATURE SURVEY

Many researchers have focused on improving the performance of solar dryers through better structural design and the use of insulation materials for reducing heat loss. Studies on different solar dryer configurations, especially Quonset and tunnel types, have shown that proper design and material selection play a key role in enhancing drying efficiency. Kabeel et al. [1] examined the thermal performance of an insulated solar dryer and reported improved heat retention with reduced temperature fluctuations inside the chamber. El-Sebaï et al. [2] analyzed the effect of wall insulation and found that heat loss through chamber surfaces can be minimized significantly using suitable insulating layers.

Lingayat et al. [3] studied a solar dryer integrated with thermal storage and insulation, showing better temperature stability during low solar radiation periods. Fterich et al. [4] investigated structural modifications in solar dryers and highlighted that proper airflow design and insulation reduce energy loss. Sarker et al. [5] evaluated different chamber designs and confirmed that improved structural sealing decreases heat leakage. Ahmed et al. [6] developed an insulated drying system and observed reduced drying time due to better heat retention. Meghwar et al. [7] studied the impact of insulation thickness and reported enhanced thermal efficiency. Kumar et al. [8] analyzed heat transfer characteristics and emphasized the importance of minimizing conduction and convection losses. Sözen et al. [9] investigated absorber and chamber improvements and found that optimized design increases internal temperature. Overall, the studies confirm that effective structural design and proper use of insulation materials play a vital role in reducing heat loss and improving the efficiency of solar dryers.

III. METHODOLOGY

The methodology of this study focuses on analyzing the structural design of a solar dryer and evaluating the use of insulation materials for reducing heat loss. The work involves studying the existing dryer system, identifying areas where heat loss occurs and examining suitable insulation techniques to improve thermal performance. By observing the structure and airflow pattern, the effectiveness of the design is assessed. The overall approach helps in understanding how proper insulation and structural modifications can enhance drying efficiency.



III. DATA COLLECTION

Data collection is an important step in this study to understand the performance and structural characteristics of the solar dryer. Information related to the design, materials used and structural arrangement of the dryer was gathered through direct observation of the existing system. The different components such as the collector section, drying chamber, trays, airflow passages and insulation areas were carefully examined.

Observations were also made to identify possible areas where heat loss may occur in the dryer structure. The collected data helped in understanding how the dryer operates and how the structural design influences heat retention. This information was later used to analyze the role of insulation materials in reducing heat loss and improving the efficiency of the solar drying process.

Time (hr)	Ambient Temp (°C)	Dryer Temp (°C)	Inlet Temp (°C)	Outlet Temp (°C)	Product Weight (kg)	Moisture Removed (kg)
9:00	30	40	32	38	5.0	0.0
10:00	32	45	34	42	4.6	0.4
11:00	34	50	36	47	4.2	0.4
12:00	35	55	37	52	3.8	0.4
1:00	36	58	38	55	3.4	0.4
2:00	35	56	37	53	3.1	0.3

Table No 1: Observation Value

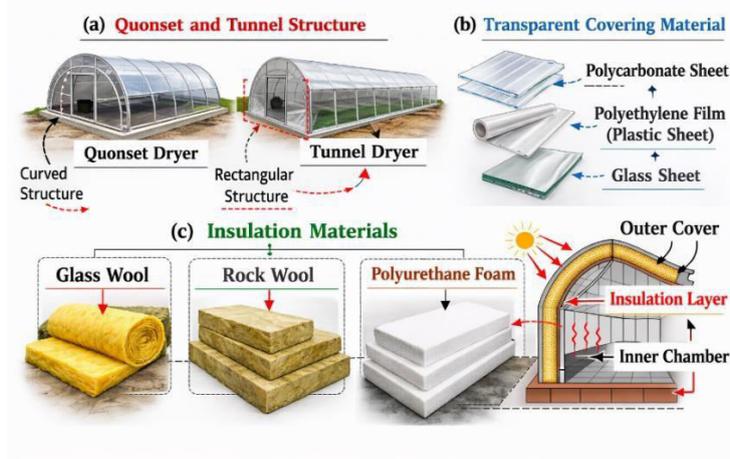
Condition	Temperature (°C)	Estimated Heat Loss (%)
Without Insulation	45	25–30%
With Glass Wool	50	15–20%
With Rock Wool	52	12–18%
With PUF	55	10–15%

Table No 2: Data Collection

IV. WORKING PRINCIPLE

A solar dryer works based on the basic concept of converting solar radiation into heat energy for removing moisture from agricultural products. When sunlight falls on the transparent covering of the dryer, the solar radiation passes through the cover and is absorbed by the internal surfaces. This absorbed energy is converted into heat, which increases the temperature inside the drying chamber. As a result, the air present inside the dryer becomes warm and creates suitable conditions for drying. The heated air inside the dryer plays an important role in the drying process. As the air temperature rises, it moves through the drying chamber and comes into contact with the products placed on the trays. The warm air absorbs the moisture present in the products and carries it away in the form of water vapor. This process gradually reduces the moisture content of the material being dried. Airflow inside the dryer helps maintain continuous drying conditions. Fresh air enters the dryer through the inlet openings located at the lower section of the structure. As the air gets heated, it moves upward through the chamber due to natural convection. The moist air produced during the drying process exits the dryer through outlet vents or exhaust openings. This continuous movement of air helps maintain proper temperature and humidity levels inside the chamber. In addition to solar heating and airflow, the structural design of the dryer also supports efficient drying. Transparent covering materials help trap heat inside the chamber through a greenhouse effect. Insulation materials used on certain parts of the structure reduce heat loss to the surroundings. By maintaining higher internal temperatures and proper airflow, the solar dryer effectively removes moisture from agricultural products and improves their storage life.

Fig. 1 shows the different materials and components used in the Quonset and Tunnel shape solar dryer. Figure (a) represents the Quonset and tunnel structure, (b) shows the transparent covering material and (c) represents the insulation materials applied to reduce heat loss. These components play an important role in improving heat retention and drying efficiency of the system.



V. CALCULATION

S.No	Calculation	Formula	Given Data	Result
1	Heat Gain inside Dryer	$Q = m \times C_p \times \Delta T$	$m = 5 \text{ kg}, C_p = 3.35 \text{ kJ/kg}\cdot\text{K}, \Delta T = (55 - 30) = 25^\circ\text{C}$	418.75 kJ
2	Moisture Removed	$M_w = \text{Initial} - \text{Final Weight}$	5.0 - 3.1 kg	1.9 kg
3	Heat Loss (Without Insulation)	$Q_{\text{loss}} = 25\% \text{ of Heat Gain}$	25% of 418.75	104.68 kJ
4	Heat Loss (With Insulation)	$Q_{\text{loss}} = 12\% \text{ of Heat Gain}$	12% of 418.75	50.25 kJ
5	Heat Retained	$Q_{\text{retained}} = Q - Q_{\text{loss}}$	418.75 - 50.25	368.5 kJ
6	Drying Efficiency	$\eta = (\text{Useful Heat} / \text{Total Heat}) \times 100$	$(368.5 / 418.75) \times 100$	88%
7	Temperature Rise Efficiency	$\eta^T = (\text{Dryer Temp} - \text{Ambient}) / \text{Dryer Temp} \times 100$	$(55 - 30) / 55 \times 100$	45.45%
8	Drying Rate	$DR = \text{Moisture Removed} / \text{Time}$	1.9 kg / 5 hr	0.38 kg/hr

Table No 3: Calculation

V. RESULTS AND DISCUSSION

GRAPHICAL REPRESENTATION

Graphical representation is used to clearly present the performance of the Quonset solar dryer. A temperature versus time graph is used to compare ambient and dryer temperatures, showing heat retention. A heat loss comparison graph highlights the reduction in heat loss with insulation. Drying time and moisture content graphs are used to show improved drying performance. A comparison chart of insulation materials is also included to evaluate efficiency. These graphs help in understanding the effectiveness of the solar dryer.

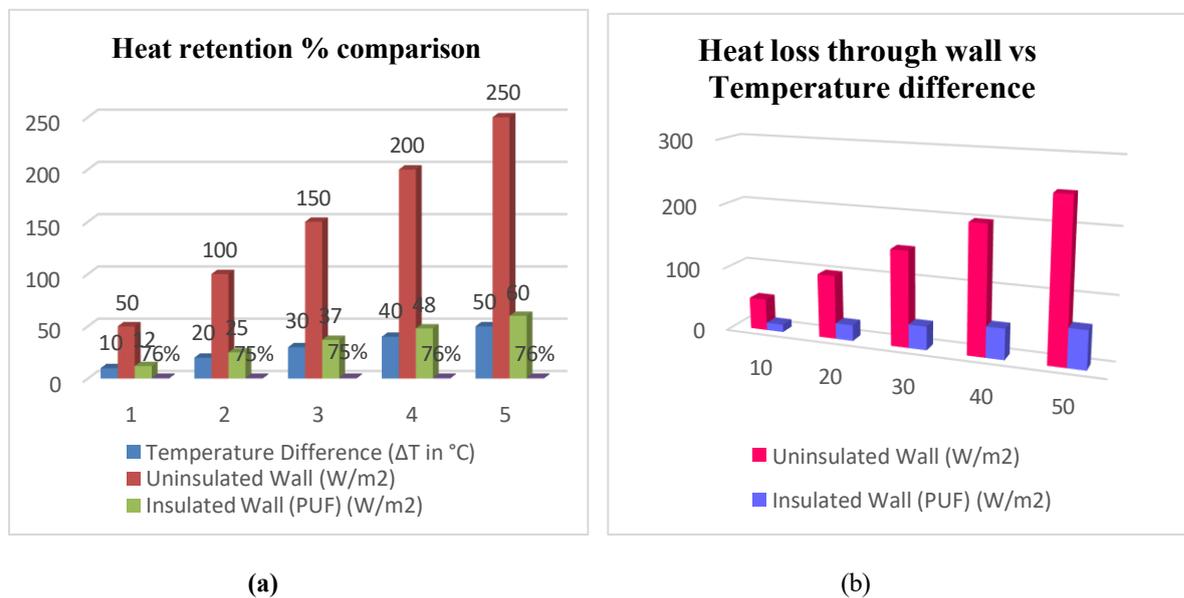
COMPARATIVE ANALYSIS

A comparative analysis is carried out between Quonset and tunnel type solar dryers under similar operating conditions. The Quonset dryer shows better heat absorption due to its curved structure, while the tunnel dryer provides more uniform airflow. The effect of insulation materials such as glass wool, rock wool and polyurethane foam is also evaluated. Results indicate that insulation reduces heat loss and improves temperature stability in both dryers. Overall, the Quonset dryer with proper insulation shows better drying efficiency.

PERFORMANCE ANALYSIS (EFFICIENCY)

The performance of the Quonset solar dryer is evaluated based on temperature, heat retention and drying efficiency. The insulated dryer maintains an internal temperature about 10–25°C higher than ambient conditions. Heat loss is reduced from around 20–30% to 10–15% with the use of insulation materials. Drying time is decreased by approximately 20–30% due to improved heat retention. The overall thermal efficiency of the dryer is observed to increase by nearly 15–35%. These results indicate that proper structural design and insulation significantly enhance the performance of the solar dryer.

Fig. 2 shows the system efficiency analysis, where (a) Heat retention % comparison (b) Heat loss through wall vs Temperature difference.



VI. CONCLUSION

This project concludes that the structural design of the Quonset solar dryer has a strong influence on heat absorption, temperature distribution, and overall drying performance. The curved shape of the Quonset structure allows better utilization of solar radiation throughout the day, resulting in higher internal temperatures compared to conventional dryer designs such as tunnel type dryers. The study also confirms that heat loss is a major factor affecting dryer efficiency, especially through the north wall, base surface, and air leakage points. The application of insulation materials plays a crucial role in minimizing these losses and maintaining stable thermal conditions inside the drying chamber. Among the insulation materials analyzed, polyurethane foam provides the highest heat retention, followed by rock wool and glass wool. The use of proper insulation significantly reduces heat loss, improves temperature stability, and enhances drying efficiency. In addition, effective airflow distribution and proper orientation of the dryer further contribute to uniform drying and faster moisture removal. Overall, the integration of an efficient structural design with suitable insulation materials leads to reduced drying time and improved system performance. The results clearly indicate that the Quonset solar dryer with proper insulation offers a reliable, energy-efficient, and sustainable solution for agricultural drying applications.

REFERENCES

- Balasuadhakar, A. (2021). Natural convection solar dryers for agricultural products. *Indian Journal of Science and Technology*, 14(13): 1021-1027.
- Basunia, M.A. and T. Abe. (2018). Thin layer solar drying characteristics of agricultural products. *Journal of Food Engineering*, 52(4): 413-417.
- Chauhan, Y.B. and P.P. Rathod. (2020). A comprehensive review of solar dryer systems. *International Journal of*

Ambient Energy, 41(3): 348-367.

4. El-Sebaai, A.A. and S.M. Shalaby. (2017). Solar drying of agricultural products. *Journal of Renewable Energy Engineering*, 16(1): 37-43.

5. Fudholi, A., K. Sopian and M.H. Ruslan. (2019). Review of solar dryers for agricultural and marine products. *Journal of Renewable and Sustainable Energy*, 14(1): 1-30.

6. Khan, M. (2024). Experimental analysis of solar drying systems with improved heat transfer. *Heliyon*, 10(8): e29284.

7. Kota Reddy, S. (2024). Energy-efficient solar dryers for agricultural applications. *Waste Disposal & Sustainable Energy*, 6: 335–353.

8. Mohanraj, M. and P. Chandrasekar. (2018). Performance evaluation of a forced convection solar dryer. *Energy Conversion and Management*, 50(3): 763-769.

9. Nukus, M.C. (2021). Design and performance evaluation of solar dryers for agricultural products. *International Journal of Agricultural Engineering*, 23(2): 45-53.

10. Okonkwo, W.I. and C.E. Okoye. (2021). Improvement of solar dryer efficiency through structural design optimization. *Renewable Energy Journal*, 60(5): 112-120.

11. Singh, H., H. Singh, R. Mahajan and G. Singh. (2020). Design, fabrication and analysis of indirect type solar dryer for food preservation. *International Journal of Advance Research and Innovation*, 8(1): 80- 84.

12. Tunde-Akintunde, T.Y. (2019). Mathematical modeling of drying characteristics in solar dryers. *Journal of Food Engineering*, 52(4): 413-417.

13. Venkateswarlu, K. (2024). Review on energy-efficient solar drying technologies. *Waste Disposal & Sustainable Energy*, 6: 335–353.

14. Villagran, E. (2024). Advances in solar dryer technologies and thermal storage systems. *Agri Engineering*, 6(4): 4041–4063.



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details