Scientific Research Publishing

Journal of Power and Energy Engineering, 2023, 11, 44-63
https://www.scirp.org/journal/jpee
ISSN Online: 2327-5901
ISSN Print: 2327-588X

Optimizing Solar Drying: A Critical Review of Shapes, Orientation, and Future Prospects for Hybrid Solar Dryers

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How to cite this paper: Zziwa, A., Okello, A.W., Kabenge, I., Matsapwe, D., Kizito, S.S., Paul, S. and Kambugu, R.K. (2023) Optimizing Solar Drying: A Critical Review of Shapes, Orientation, and Future Prospects for Hybrid Solar Dryers. *Journal of Power and Energy Engineering*, **11**, 44-63.
https://doi.org/10.4236/jpee.2023.1112004

Received: November 23, 2023
Accepted: December 25, 2023
Published: December 28, 2023

Abstract

This comprehensive review focuses on the performance of solar dryers, with a specific emphasis on their structural shape and orientation. Researchers have extensively examined these design parameters, often employing Computational Fluid Dynamics (CFD) to assess thermal attributes and predict temperature distribution, airflow patterns, and temperature profiles within the structures. Geographical location significantly influences solar dryer shape preferences, with the parabolic shape finding favor in tropical regions for its superior solar radiation capture and storm resistance, while even-span and Quonset shapes are popular elsewhere. Solar dryer orientation is another crucial factor, with east-west alignment consistently proving optimal due to its ability to maximize year-round solar radiation absorption and, consequently, enhance drying efficiency. Economic considerations, however, fall beyond the scope of this review, which predominantly focuses on thermal aspects. This investigation reveals diverse global preferences for solar dryer shapes and orientation, highlighting the necessity of considering geographical factors in design choices. While CFD and shape/orientation dynamics have provided valuable insights, there remains room for future research to expand into transient state simulations under various conditions, contributing to a more comprehensive understanding of solar dryer performance. Such insights promise to promote sustainable and efficient drying processes, benefitting agricultural and drying applications across the globe.

Keywords

Solar Dryers, Computational Fluid Dynamics, Shape Orientation, Thermal Performance

1. Introduction

According to the International Energy Agency's 2021 report, fossil fuels accounted for 80% of global energy consumption. This statistic underscores the urgency of transitioning to sustainable alternatives like solar energy for food preservation, driven by the need to mitigate climate change's adverse impacts. One such area that is receiving more attention is food preservation using solar energy. Solar energy is a clean and renewable source of energy that is abundant in many parts of the world. Food preservation or conditioning using energy from the sun is one of the oldest methods available to man [1] [2]. This method of using solar energy for drying foods and fruits is mostly found in countries with tropical climatic conditions, which typically receive a good amount of sunshine throughout the year. As noted by [3] solar drying methods are divided into two; open space drying and enclosed space drying. Open space drying, despite its shortfalls, is the most prevalent method used in developing countries for drying agricultural produce because it is simple and cheap to use [4]. On a clear sunny day, spreading agricultural products like seeds, grain or fruits on a flat surface exposes them both to direct sunshine to heat up the food and to the moving air to carry away the moisture from that drying food product. This open exposure enables almost even distribution of drying agents to enable uniform texture and taste. This openness, however, exposes them to dust, microorganisms and moisture when it begins to rain which increases contamination and toxins like aflatoxin. Therefore, farmers are denied incomes that result from value addition due to loss of product quality. For this, different types of closed solar dryers have been promoted to overcome the disadvantages of open-sun drying, and they are now popular in many countries as a better option [2]. One such type is the greenhouse solar dryer. Greenhouse solar dryers are also known as tent dryers [5].

Research into greenhouse solar dryers has gained traction in the last decade. A greenhouse solar dryer is seen as an energy-saving technology that helps to reduce the use of fossil energy such as oil, coal, and natural gas [6] [7]. The greenhouse solar dryer is one of the best among other types of dryers and is two to five times more effective for drying purposes [8], and can be used on an industrial scale due to its capacity [9]. These dryers reduce the consumption of fossil fuels for drying purposes and provide the best quality, color, and taste of the dried products which are free from dirt and insects [5] [10] [11]. The working of greenhouse solar dryers is based on the principle of the greenhouse effect [8] [11]. In the greenhouse solar drying concept, radiation from the sun enters the dryer's roof structure in form of short wavelengths, and upon reflection, the long wavelengths radiations are captured and retained inside the dryer [12]. The process of retaining the long wavelength radiations leads to an increase in the temperatures inside the dryer, which facilitates the drying of the food product. The structures have a transparent medium that allows incoming short-wavelength solar radiation and traps the long-wavelength radiation to create a favorable microclimate. In the drying process, the product's moisture content is reduced by evaporation when the temperatures on the surface and inside the product increase [13]. These solar dryers can function using either natural convection or forced convection, as explained by [11]. When operating based on natural convection, the dryer is referred to as a passive dryer, whereas under forced convection, it is termed an active dryer. In the case of natural convection, a solar dryer operates by utilizing the buoyancy principle, which occurs when the air density changes due to heat. In this process, warm air exits the solar dryer through ventilation openings located around the top of the structure, while colder and less humid air enters from the opposite side through lower-level ventilation, as described by [14]. In contrast, forced convection dryers require air blowers to assist in removing humid and warm air from the inside of the drying chamber [12] [15] [16]. Microclimate control and regulation within the solar dryer are greatly enhanced by the operation of the blowers, and this optimizes the drying process and the drying time [4] [11]. Further enhancement of such solar dryers can also be achieved by the addition of auxiliary heat sources such as renewable energy, and heat storage to increase the inside temperature as well as enable continuation of drying during non-sunshine hours [12] [17]. In this case, the dryer then becomes a hybrid type.

Shape and orientation, in addition to cladding material characteristics and air change rate, are important design parameters that determine the total solar radiation received by a solar dryer structure at a particular time and location [12] [18] [19]. The parameters ultimately determine the dryer's internal temperature distribution and airflow velocity pattern. As noted by some authors [1] [20] [21] [22] selection of a suitable orientation and shape is crucial for the proper functioning of a solar dryer, as these eventually determine the drying chamber air temperature. The quantity of solar energy that gets diffused into the solar depends on the incident angle of the incoming rays. The incident angle of the incoming radiation depends on the geometry of the solar dryer. This emphasizes the crucial role of roof structure and orientation in maximizing solar energy capture during the drying process [21]. This paper examines various studies conducted worldwide on different roof shapes and orientations for solar dryer structures. It provides guidance for selecting suitable solar structures for drying purposes in tropical regions, as highlighted by [23], with consideration for available materials and capital investment requirements. The review also investigates the methods employed to determine roof shapes conducive to produce drying, addressing both the strengths and limitations of these methods. It concludes by suggesting potential areas for further research concerning greenhouse structure roof shapes for crop and fruit drying.

2. Methodology

This review was conducted by thoroughly examining peer-reviewed journals accessible through online library resources like Research4Life, Z-Library, and Elsevier. These three online platforms were selected due to their inclusion of peer-reviewed journals. Additionally, Research4Life and Z-Library offer free online access to academic and professional peer-reviewed content for institutions in low- and middle-income countries. During the search process on these platforms, the primary search terms employed were "solar dryers". This process generated over 200 journals, from which the keywords; shapes, orientation, and performance were used to obtain 96 journal articles. The 96 journal articles were then analyzed for the relevancy of the content necessary for this review. The analysis involved reading the abstract section to see if it contained the words of interest. The words of interest included; performance, shape, classification, orientation, and structure. Based on the above search method, journal articles found relevant for the review were imported to the reference software Mendeley. The literature reviewed revealed that the use of greenhouse solar structures for larger drying of agricultural produce and fruits is a recent innovation that has gained research traction in the last 10 years. Ultimately, this review incorporated information from 56 journal articles.

3. Evaluation of Solar Dryer Performance

When assessing the performance of various solar dryer shapes, two approaches have been employed: the experimental and the mathematical modeling approaches. In recent times, the latter has been favored due to its ability to provide superior and more expeditious results [24] [25] [26], in contrast to experimentation, which is both costly and time-consuming. Several simulation software options have gained prominence in the examination of solar dryer performance. The main ones include; Computational Fluid Dynamics (CFD), FORTRAN, MATLAB, artificial neural network modeling, SPSS, and TRNSYN [12] [27]. CFD is the preferred choice of many researchers [28]-[36], and is mainly used for analysis and investigation of airflow and temperature distribution with the aid of ANSYS and FLUENT [3] [11] [37]. FORTRAN and MATLAB have been mainly used to predict air temperature in solar dryer chambers.

The literature review also reveals that performance studies have been conducted under either no-load, full load, or both conditions. [38] analyzed the performance of passive and active greenhouse dryers under no-load conditions, while [26] modeled and simulated drying with a backup biomass heat source under full-load conditions. [39] employed both Computational Fluid Dynamics (CFD) and experimental methods under full load to analyze the performance of greenhouse solar structures in Senegal's weather conditions.

3.1. Classification of Solar Dryers

There have been limited efforts to establish a universally applicable classification system for solar dryers. Several authors have attempted to categorize them in diverse manners. [10] notably provided a broad classification of greenhouse solar dryers, differentiating them into two main groups based solely on the roof shape, which were: 1) dome type, and 2) roof even types. This classification is rather limited given that greenhouse solar structures have other components that distinguish one from another. A wider classification was used by [14]. They classified greenhouse solar dryers into two categories; based on the material used and the shape of the cover/roof. [13] stated that solar dryers have also been broadly classified into three categories of heat application mechanism, which included; direct, indirect, and mixed-mode. Singh *et al.* [11] conducted a review in which they categorized solar dryers based on five principles: the airflow method, the structure type, the floor type, the covering material type, and the principle of the north wall (**Figure 1**).

[4] [7] classified solar dryers according to; 1) working principles, Shapes, cost of factor, material, and utility. [40] proposed a systematic and comprehensive classification based on their mode of heating, how solar heat is utilized, and the type of external energy supplemented to the dryer as shown in **Figure 2**. This classification is much broader encompassing the three main ways of classifying solar dryers. In terms of external energy, [40] classified solar dryers into renewable and non-renewable energy types.

[41] classified greenhouse dryers into four categories, which included; 1) solar tunnel dryer, 2) solar tent dryer, 3) improved solar tunnel dryer, and 4) roof type

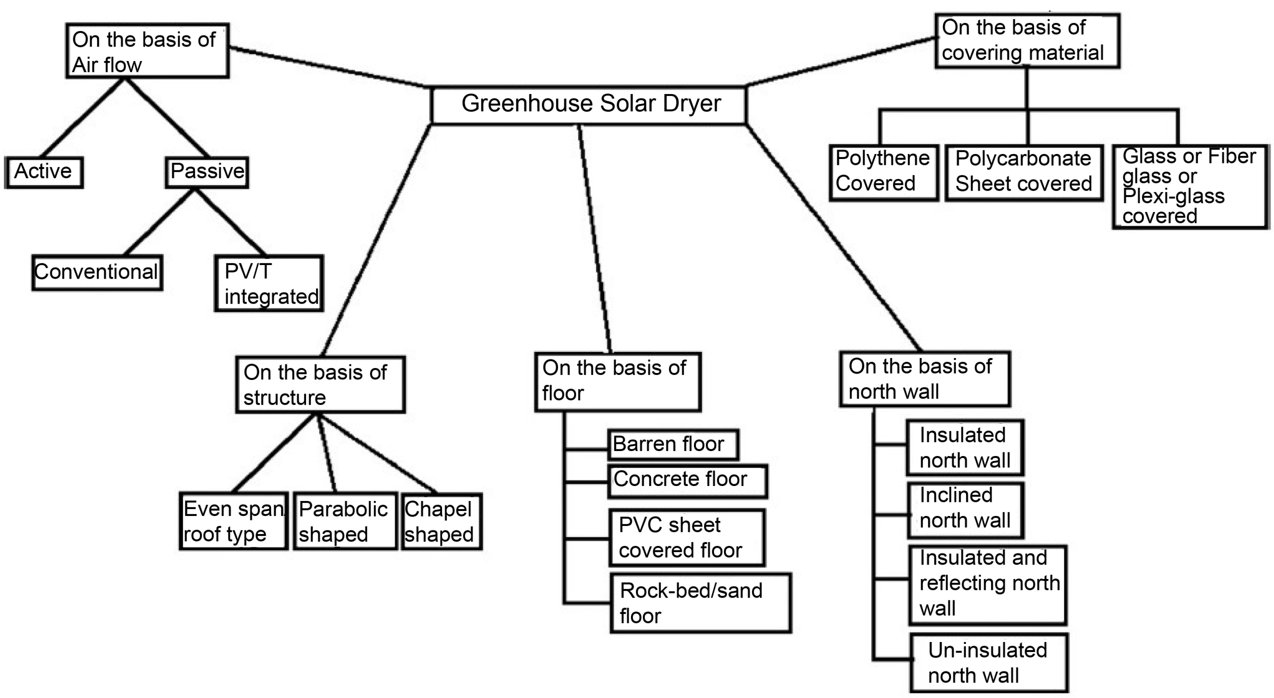

Figure 1. Classification of greenhouse solar dryer [11].

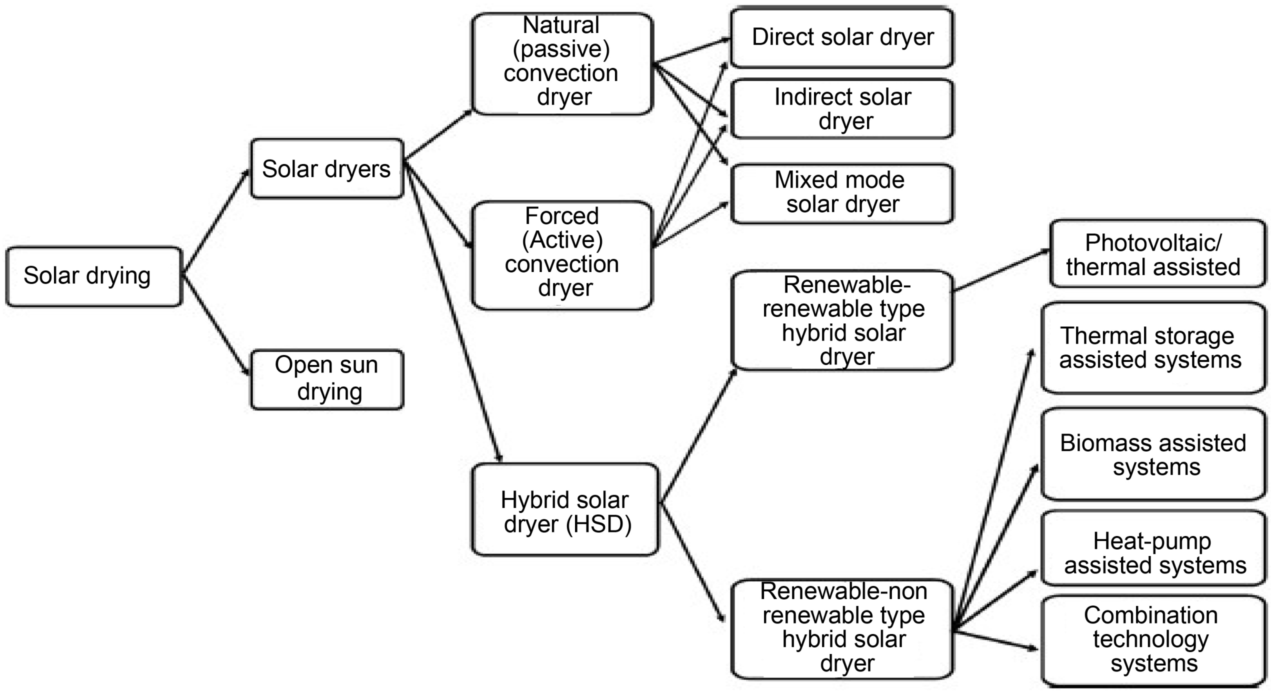

Figure 2. Classification of solar dryer systems [40].

solar dryers.

3.2. Classification of Solar Dryer Roof Shapes

The design of solar dryers varies in shape, with the choice of roof structure being significant and dependent on the intended drying purpose. [4] [13] categorized solar dryer roof structures into two; spherical dome, and flat roof. This research also observed that dome-shaped structures aim to maximize overall solar energy capture, whereas flat roofs are favored for effectively blending air temperatures within the dryer. The primary shapes encompass parabolic, trapezium, triangle, and parabolic designs. [7] noted that commonly researched greenhouse solar shapes include; even-span, even-span, single slope, dome, Quonset, modified Quonset, mansard roof, gothic arch, modified arch, and modified IARA (**Figure 3**).

3.3. Effect on the Shape of Solar Dryer Performance

The effect of roof shapes on the performance of solar dryers for drying agricultural products or cropping farming has been reviewed or studied by many researchers. [7] reviewed several pieces of literature on greenhouse solar shapes and their application and concluded that even-span and Quonset shapes are the most widely used greenhouse solar shapes worldwide [42] carried out dryer analysis with free and forced convection for triangle, hemispherical, and trapezium shapes using CFD. The study concluded that the trapezoidal roof-shaped solar dryer recorded the highest average temperature inside the dryer than the other two shapes. For natural convection state, the study found out that the

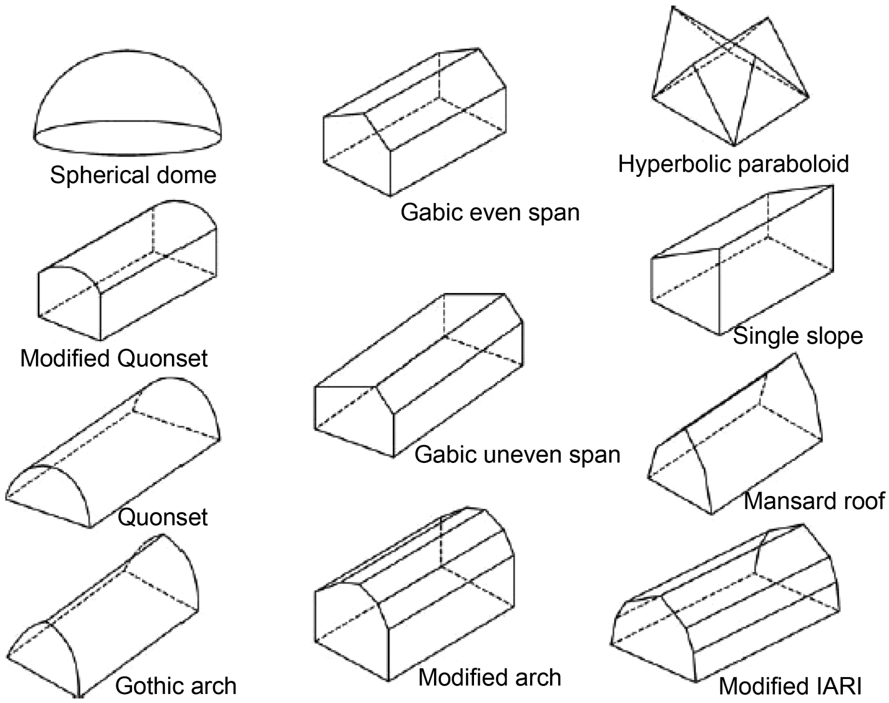

Figure 3. Single-Span greenhouse shapes [7].

highest temperature of 58˚C was attained in trapezium while the highest of 64˚C was attained for forced convection still under the same shape, with hemispherical being second best and triangle third. [43] used CFD to study the pattern of humidity, airflow, and temperatures within four selected solar-type dryers (**Figure 4**) under natural/free convection and no-load conditions. The four shapes included; M1-dual-roof tunnel type structure which had heights of 1.5 m and 2.6 m (minimum and maximum), M2-a tunnel-type structure attached to spans of heights 1.7 m and 2.7 m (minimum and maximum), M3-a chapel-type structure with a flat roof on two sides, and M-4 a tunnel-type roof structure with heights of 1 m and 2.7 m (minimum and maximum).

In developing the numerical model for the CFD analysis, the authors considered the turbulent flow of air for steady-state within the drying chamber under the working of free convection. This enabled the generation of three non-linear part equations representing the conservation of momentum, mass, and energy represented by Equations (1), (2), and (3) respectively.

$$\nabla\left(\rho U\right)=0 \tag{1}$$

$$\nabla\left(\rho UU\right)=\nabla p+\mu T\nabla U^{2}+\rho g+S_{h} \tag{2}$$

$$\nabla\left(-k\nabla T+\rho C_{p}TU\right)=0 \tag{3}$$

In the prototype evaluation of four greenhouse solar shapes, [43] found that dual-roof tunnel type structure and tunnel-type roof structure generated the highest temperature values ranging between 43˚C and 49˚C, compared to tunnel-type structure and chapel type. The study concluded that the dual-roof

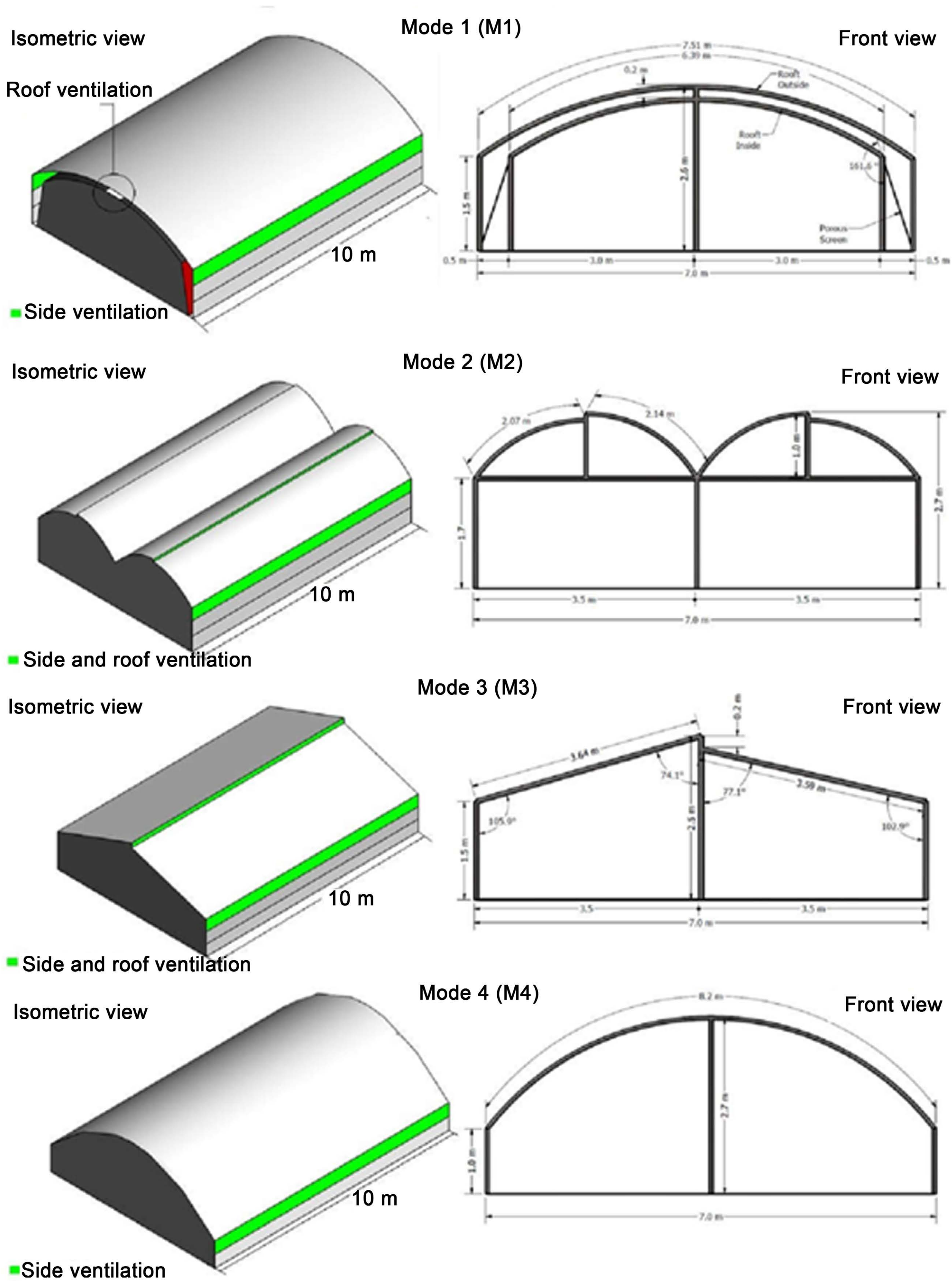

Figure 4. Other greenhouse dome shapes [43].

tunnel type was the best for the region of Columbia but recommended future evaluation under loading conditions. [44] studied the performance of the five frequently used single-span greenhouse solar dryer roof shapes which included; vinery, Quonset, even-span, uneven-span, and modified arch under different climatic environments. The dimensions (length, width, and height at the center) were all kept the same for all five shapes. The authors created a mathematical model and utilized C^{++} to solve Equations (4) and (5) in order to forecast hourly temperatures.

$$S_t = \sum_0^i A_i I_i \quad (4)$$

A_i and I_i in Equation (5) are the area of i^{th} section and total solar radiation available on the i^{th} section of the dryer structure. Equation (5) represents the energy balance equations for the different components of the greenhouse structure.

$$\alpha_p (1-\rho)\tau S_t (1-F_n) = M_p C_p \frac{dT_p}{dt} + h_{pr} A_p (T_p - T_R) + h_r A_p (T_p - T_R) \quad (5)$$

The research concluded that an uneven-span greenhouse solar dryer captured the maximum solar energy at 31˚N. In New Delhi, [45] conducted a comparison of the thermal performance of five different shapes, which included the modified arch, vinery, modified IARI, even span, and uneven span designs. The performance tests relied on the dryer air temperature and thermal load leveling. The study concluded that under hot and cold temperature conditions, the modified arch and vinery-shaped greenhouse solar dryers exhibited the best performance, respectively. [8], who investigated six distinct geometries under no-load conditions, conducted the most comprehensive study aiming to identify the optimal dryer shape. These six shapes included parabola, Quonset, modified Quonset, Pyramid, Igloo, and tropical designs (**Figure 5**). Refer to the supplementary ESD_1.

As seen from **Table 1**, this study recommended the Quonset shape as the most ideal with a generated temperature of 72˚C. The study by [46] noted that the dryer temperature of six selected greenhouse solar dryers was in order (maximum to minimum) of Quonset, Tropical, Pyramid, Parabola, Modified Quonset, and Igloo during the summer period. The study compared the temperatures

Table 1. The temperature inside selected greenhouse dryers. Vivekanandan *et al.* (2021).

Shapes	Max. Temp.	Min. Temp
	˚C	˚C
Modified Quonset	66.822	50.932
Quonset	72.151	52.602
Pyramid	68.438	51.125
Igloo	68.252	49.261
Tropical	70.933	50.548
Parabola	68.824	50.043
Atmosphere	43.711	35.255

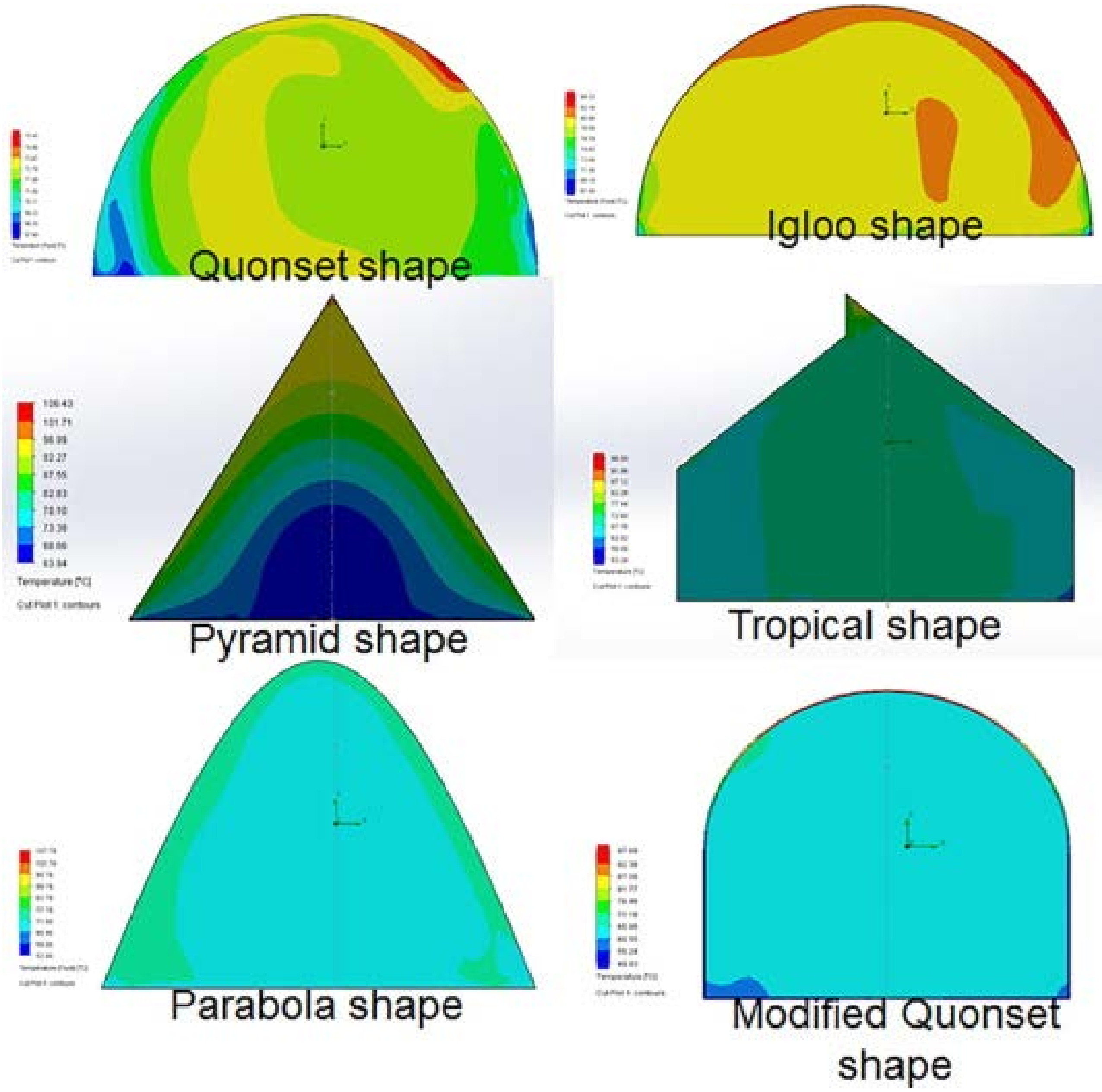

Figure 5. Temperature color plot for the six different shapes [8].

generated inside the different dryers against the atmospheric temperature. It found that Quonset generated the highest temperature of 64% in contrast to the atmosphere than any of the other shapes in the study. Igloo shape had the lowest performance with a 54% more temperature generation in contrast to the outside temperature.

[47] conducted a review study on the impact of solar dryer shape and orientation in crop farming. This study underscored the significance of considering technical factors when choosing both the shape and orientation, in addition to taking into account the specific region and elevation. It noted that the amount of solar energy available at various latitudes is different for the same solar dryer

shape. This review showed that uneven-span shape greenhouse solar dryer captured the highest amount of solar energy available and Quonset captured the least amount of solar energy all year round at all the selected latitudes. [48] conducted a study on six shapes of solar dryers including uneven span, even span, single span, vinery, Quonset, and arch type. In this study, the amount of solar captured by the different solar dryer roof structures at the selected location was the focus of the study. The study predicted the inside greenhouse solar dryer temperatures and the north wall insulation on temperatures using a dynamic model. East-west orientation was recommended by the results of [49] study which showed that 8% more solar energy was received by the single-span shape greenhouse solar dryer structure throughout the year. [50] carried out a study comparing the total energy gained inside five different greenhouse solar shapes under similar conditions. These shapes were; semicircular, even span, elliptic, uneven span, and vinery types of greenhouse solar dryers. The study revealed that the elliptic type captured the highest amount of solar energy and had good uniform temperature distribution among the analyzed types of greenhouse solar dryers for all floor areas. The uneven span and the even span also showed good temperature distribution inside the dryers. Vinery shape roof structures had the least performance among the selected shapes. This study agreed with other previous studies, which underscored the importance of solar dry roof shapes and orientation as design parameters for good thermal performance.

[51] simulated the thermal performance of three shapes of Arc, Quonset, and Even-span using TRYSYS software. The simulation was solved using the energy balance Equation (6) for the different geometries.

$$C\frac{\mathrm{d}T_{ai}}{\mathrm{d}t} = \dot{Q}_{surf} + \dot{Q}_{inf} + \dot{Q}_{vent} - \dot{Q}_{ET} + \dot{Q}_{solair} \quad (6)$$

The study looked at the annual energy demand for the 3 shapes, which were found to be 162.7, 153.8, and 154.6 MJ/m^2 respectively for Arc, Even-span, and Quonset. In conclusion [51] showed that the Arc shape had the lowest consumption from a heating point of view. [52] while using CFD studied the thermal efficiency of two shapes; parabola and sinusoidal. The study used both shapes of length 8.2 m and wide 6.0 m, with the surface area being the only variation. In the analysis, the authors used equations (7 - 10) for the transient state to generate mass conservation, momentum conservation, and energy conservation equation representing the Navier-Stokes equation

$$\frac{\partial \rho}{\partial t} + div(\rho u) = 0 \quad (7)$$

$$\frac{\partial(\rho u)}{\mathrm{d}t} + div(\rho uu) = -\frac{\rho p}{\partial x} + div(\mu gradu) + S_{Mx} \quad (8)$$

$$\frac{\partial(\rho v)}{\mathrm{d}t} + div(\rho vu) = -\frac{\rho p}{\partial y} + div(\mu gradv) + S_{My} \quad (9)$$

$$\frac{\partial(\rho w)}{\mathrm{d}t} + div(\rho wu) = -\frac{\rho p}{\partial z} + div(\mu gradw) + S_{Mz} \quad (10)$$

This research revealed that the average time to be 48.05˚C and 49.11˚C for a parabola solar dryer and sinusoidal solar dryer respectively. It concluded that the sinusoidal solar dryer had a shorter drying time than parabola greenhouse for the same amount of fruits to be dried [53] conducted a study on the thermal performance of Quonset shape, gable-even-span, and pyramid shape. The study used the thermal balance equations to conduct the analysis of the dryers. Equation (11) was used to describe the relationship between total energy incident on the dryer (Q) which equates to useful energy gained (Q_u) and thermal losses (Q_{loss})

$$Q = Q_u + Q_{loss} \tag{11}$$

where

$$Q = RA_d \tag{12}$$

$$Q_u = m_a C_p \left(T_{ai} - T_{ao}\right) \tag{13}$$

The thermal efficiency (η_0) of the dryers was calculated using Equation (14);

$$\eta_0 = \frac{Q_u}{RA_d} \times 100 \tag{14}$$

The study recommended the Quonset shape as the best shape solar dryer because its large surface area exposure enables it to receive the highest amount of radiation.

From literature (summarized in **Table 1**), it can be seen that the study of solar dryer shapes features the Even-span, Quonset and parabolic shapes as the most optimal depending on the location. [16] [44] recommended Uneven-span. [8] recommend Quonset. [7] review study remarked that Even-span and Quonset are the most widely used shapes. Some studies [10] [54] [55] [56] [57] suggest the use of parabolic cross-sectional shape to help reduce wind load in case of a tropical rainstorm. Dome-shaped greenhouse solar dryers such as Quonset and parabola are recommended because of their ability to maximize the capture and retention of solar energy while roof-even structures are preferred because of their ability to enhance airflow inside the drying chamber [10] [58] note that parabolic cross-sectional shapes are preferred in countries within the tropics because they can resist strong winds and wind. While even-span has been commonly recommended in literature it has been noted during this review that most of the studies took into consideration the summer–winter climatic conditions as shown in **Table 2**. There seems to be little attention paid to the use of greenhouse solar dryers in the Equator where the sun's orientation is almost constant through the year.

Regarding the research methodology, the review highlights that the majority of CFD simulations were conducted under no-load conditions and in a steady-state environment. These simulations were typically performed at specific times or hours, often in a 2-D format, focusing on temperature and humidity profiles. Consequently, there is a clear need for future studies to enhance their

Table 2. Summary of different studies on greenhouse roof shapes.

No	Shape	Orientation	Location details and mode of study	Conclusion	References
1	Even-span, uneven-span, vinery, modified arch & Quonset	East-West & North-South orientation	All ranges of latitude/Thermal modeling (energy balance equations)	The maximum solar radiation was reported in un-even span shape, and the Quonset shape reported the lowest value at east–west orientation. The rise of air temperature depends on the geometry of the greenhouse dryer.	Sethi (2009)
2	Uneven span, even span, single span, vinery, Quonset and arch	East-West and North-South orientation	Iran (38˚10' north latitude and 46˚18' east longitude)/ Thermal modeling (energy balance equations)	Single span shape received 8% more radiation than any of the other shapes at the east-west orientation. Brick (sun-facing direction) minimises radiation loss.	Mobtaker *et al.* (2019)
3	Even-span, uneven-span, vinery, semi-circular & elliptic	East-West orientation	Bayburt-Turkey (39˚52' to 40˚37' latitudes and 39˚37' to 40˚45' longitudes)/Mathematical modeling (Matlab)	The elliptical-shaped greenhouse received the highest amount of radiation compared to other shapes in the study.	Cakır and Sahin (2015)
4	Even span, standard peak uneven span, vinery, arch & Quonset	East-West orientation	Delhi, India/Numerical computation using empirical formulas	The peak uneven span shape reported higher solar energy transmission than other shapes.	Singh and Tiwari (2010)
5	Triangle, hemispherical & trapezium	Not indicated	Chennai, India. CFD modeling under free and forced convection	The trapezoidal greenhouse solar dryer achieved a maximum temperature than other hemispherical and triangular dryers.	Purusothaman, Valarmathi & Santhosh (2019)
6	Vinery, uneven-span, even span, modified arch & modified IARI shape	East-West orientation	New Delhi, India. Experimental comparison study	Vinery shape performed best during winter while the even span was best in summer	Tiwari & Gupta (2002)
7	Parabola, Quonset, Modified Quonset, Pyramid, Igloo and tropical	Not indicated	Nadu, India. Experimental and CFD investigation	The ideal shape is Quonset Shape, it generates a maximum of 72˚C in summer and 66˚C in winter.	Jagadeesh, Vivekanandan, Natarajan, & Chandrasekar (2020)

Continued

8	Different shapes	East-West and North-South orientation	Review study	Even-span roof and Quonset shape greenhouses are the most commonly used for crop cultivation and drying	Sahdev, Dhingra & Kumar (2017)
9	Different shapes	East-West and North-South orientation	Review study	Uneven span shape maintains the high temperature all year round. East-west orientation is gives best performance.	Odesola & Ezekwan (2012)
10	Parabola and sinusoidal	Not considered	CFD investigation	The sinusoidal shape captured more radiation had shorter drying time than parabola	Srichat, Veng-sungnle, Hongtong, & Jongpluempiti (2019)
11	Even-span, arc and Quonset	East-West and North-South orientation	CFD investigation using TRNSYS software	Quonset shape is the optimum greenhouse shape in Morocco, with east-west orientation	Choab *et al.* (2021)
12	Quonset, gable, even-span & Pyramid	Not considered	Experimental study, Cairo. latitude angle of 30.62˚, longitude angle 32.27˚	Quonset is the ideal shape. It has absorbs the largest amount of radiation	Radwan, El-Kholy, El-Sheikh and Mousa (2016)

robustness by conducting simulations in transient states under full-load conditions. Such simulations should encompass the entire drying process, beginning to end, with boundary conditions that accurately mirror the dynamic nature of the drying process. It is advisable to conduct additional research focusing on the optimal shapes for various locations. This research should encompass the evaluation of various conditions, including temperature, humidity, solar radiation, wind speed, wind direction, and the specific characteristics of the materials being dried. Analyzing the results in a three-dimensional format would provide a more comprehensive understanding of the conditions within different parts of the solar dryer during various times.

3.4. Effects of Orientation on the Performance of Solar Dryer

Many researchers have conducted studies on the orientation of greenhouse solar dryers. [22] studied the orientation of the uneven shaped gree-uneven-shaped house in the east-west and north-south orientation using structures of similar dimensions. The study concluded that an east-west orientation captured most solar energy throughout the year at latitude of 44˚N and 54˚N. [51] found that the solar dryer structure in the east-west orientation captured and retained more solar radiation compared to the similar structure placed in the north-south. The study also found out that east-west orientation is an optimum orientation for sites in Morocco because it saves 9.28% of the annual cost of air conditioning of the greenhouse solar dryer. [44] using a mathematically derived model analyzed five commonly available greenhouse solar dryer shapes and recommended the use of east-west orientation for all installations in northern hemisphere. [21] study of radiation received by different greenhouse solar dryer structures at different locations and orientation recommended east-west orientation for northern hemisphere installations. [59] used a CFD model to determine the best orientation for greenhouses solar dryers in different latitudes in china, and concluded that south by western orientation should be adopted for northern China. [60] use mathematical model to study the orientation of three dryer shapes (Gothic arch, gable and Quonset), and concluded that east–west oriented for all the three shapes required less heating as compared to a solar dryer of the same size oriented north–south. [61] studied the even-span and uneven-shapes for optimal drying of crops during winter in Morocco. The [61] study recommended the uneven-span with a roof tilt angle of 45˚ and east-west orientation for agricultural purpose in Morocco, based on the ability of the structure at that tilt angle to capture maximum radiation. In their review of solar dryer shapes and orientation, [60] recommended east-west orientation for year-round greenhouse solar dryer use for both farming and drying at all latitudes. They further noted that this orientation recorded greater total energy captured and retained in winter period and less in summer except near the equator.

4. Conclusions

This paper has offered a comprehensive and contemporary overview of solar dryer performance, with a particular focus on shape and orientation. The evaluation primarily centered on the thermal aspects of these dryers, while economic assessments were not within the scope of this review. Several key findings have emerged:

1) Computational Fluid Dynamics (CFD) stands out as the predominant tool for assessing the thermal properties of solar dryer structures. It has proven invaluable in predicting temperature distribution, profiles, and airflow patterns within these structures.

2) The performance of solar dryers exhibits notable variations depending on their shape and orientation, often in relation to their geographical location. In tropical regions, the parabolic shape emerges as the preferred choice due to its efficient solar radiation capture and resistance to tropical storms. Conversely, even span and Quonset shapes find widespread use in other parts of the world.

3) Among different orientations, the east-west alignment stands out as the optimal choice. Its capacity to maximize solar radiation absorption throughout the year makes it particularly advantageous.

4) Future studies should encompass transient state simulations across a broader spectrum of conditions, extending beyond temperature, humidity, and velocity considerations for full load conditions. This approach will provide a more comprehensive understanding of solar dryer performance.

In conclusion, this review not only underscores the importance of shape and orientation in solar dryer design but also highlights the need for further research to enhance our knowledge in this field. By delving into transient state simulations and embracing a wider range of conditions, future studies can contribute significantly to advancing the efficiency and effectiveness of solar drying technology.

Acknowledgements

The Ministry of Science, Technology, and Innovation, Government of Uganda, is acknowledged for funding this study. The Department of Agricultural and Biosystems Engineering at Makerere University is gratefully acknowledged for facilitating review meetings that contributed to the production of this paper.

Funding

This study was funded by The Ministry of Science, Technology through the National Research Innovation Program (NRIP) grant (MoSTI/NRIP/2020-2021/52).

Conflicts of Interest

The authors declare that they have no conflict of interest.

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