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Research Article

Comparative thermal analysis of applications using novel solar air heater with u-shaped longitudinal fins: suitable for coastal regions

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ABSTRACT

The aim of the present work is to analyse a novel solar air heater configured with U-shaped longitudinal fins. The application of the proposed air heater for freshwater production and agriculture drying has also been analysed for the coastal area of India. The results are motivating for use of the proposed air heater for household requirements and smallscale industrial purposes to improve the earning in coastal regions. The mathematical model for time-dependent behaviour of the proposed air heater has been prepared by considering the energy balance of air heater components and solved to get the outlet temperature of the air from air heater. The results proved that the heater is suitable for the desalination and drying of many agricultural products. The effect of operating parameters has also been analysed to find suitable values for freshwater production. Optimum air mass flow rate of 160 kg/hr in air heater has been found whereas higher water temperature in the storage tank and lower temperature of cooling water in dehumidifier found suitable for higher yield of freshwater. In the drying process, significant improvement has been observed compared to direct solar drying and conventional air heater with 12 hours drying time for banana slices and 10 hours for garlic was found.

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INTRODUCTION

Solar energy is nature's gift to mankind that has been helped to face the energy and water crisis due to growth in population and industrialisation. The solar air heater is a simple yet effective techniques to utilise solar energy in many applications like space heating, desalination, and industrial or agricultural drying. These applications always motivate for improvement in the performance of air heaters. The present work deals with the analysis of novel flat plate air heaters with U–shaped longitudinal fins for effective

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utilisation of solar energy. These air heaters can play a very important role in potable water production and crop drying in the coastal line of India which extended over more than 7500 kilometers [1]. This coastal area is gifted with the high solar insolation, more sunshine days, saline water, and a climate suitable for a variety of agriculture products. Like other regions of India, it is also heavily populated and facing problems to fulfill the daily need for freshwater. This air heater in combination with a desalination system can fulfill the household requirement of freshwater and a variety of grains, vegetables, fruits, and herbs can be dried for daily requirements and small scale commercial purposes in lower investment compared to other drying techniques

Many research works have been carried out to enhance the performance of solar air heaters by providing different configurations of fins. Yeh et al. [2] analysed a double pass solar air heater with fins attached over and under the absorber plate. Both experimental and analytical approaches are used for the study of the suggested air heaters. The proposed design proved to be beneficial by compensating the heat loss by larger heat transfer area between absorbing plate and heated air. Considerable improvement in thermal efficiency has been observed by using the suggested configuration. The flow rate ratio of air in two passes has been varied between 0 and 1 and the corresponding variation in efficiency was from 60 % to 71 %.

Bhattacharyya et al. [3] theoretically studied the application of solar air heater with extruded finned absorber plate in paddy drying for the climatic conditions of the Guwahati region. An optimum number of fins, fin height, and fin thickness were identified by using outlet temperature and pressure drop as deciding parameters. The study revealed that showed that 80 fins, 0.6 height to duct length ratio, and 2 mm fin thickness gives the best results for considered working conditions.

Chabane et al. [4] experimentally investigated the thermal performance of a solar air heater with five longitudinal fins attached with an absorber plate. Investigation revealed the effect of a mass flow rate of air on the outlet temperature and the thermal efficiency. The maximum efficiency obtained for air mass flow rate of 0.012 kg/sec and 0.016 kg /sec with and without fins was 40.02%, 51.50% and 34.92%, 43.94%, respectively, which shows significant improvement in the performance of air heater by using suggested fin arrangement.

Many works have been done with different configurations of humidification dehumidification desalination system to improve the productivity by heating water air or both. Li et al. [5] performed the experiments to analyse humidification dehumidification desalination system with evacuated tube solar air heater. Both air heater and desalination system were designed and optimised mathematically and then a pilot plant was built for experiments. The test results revealed that water temperature from 9 °C to 27°C can improve the relative humidity from 89% to 97% in a pad humidifier used in the designed system. Results are very valuable for designing a desalination system with productivity up to 1000 L/day. Huanga et al. [6] presented an innovative method to determine optimum operating parameters according to the required performance and specific energy consumption of HDH desalination system. They used regression equations to predict the optimum value of mass flow rate ratio for different operating conditions, then evapouration rate is used to find optimum operating parameters. The higher prices and shortage of fossil fuels always motivated to use solar energy for agriculture drying. Different arrangements have been suggested to improve the solar drying process. Lingayat et al. [7] designed an indirect type solar dryer configured with v-corrugated absorber plates for banana drying. An experimental study revealed air temperature as the most important parameter during the process. The moisture content was found to drop from 356% dry basis to 16% with an efficiency of 22.38%

Although many works have been done on different fin configurations in flat plate air heaters the scope of lots of work is there for better utilisation of solar energy. Present work deals with novel U-shaped longitudinal fin that can play important role in the performance enhancement of air heater. The application of proposed air heater for desalination and drying has also been analysed with the help of time-dependent mathematical model.

DESCRIPTION OF PROPOSED AIR HEATER

The schematic view of conventional air heater and proposed air heater with U-shaped longitudinal fins is shown in Figure 1. It is configured with a single flow of air through and over the longitudinal fins attached at bottom of an absorber plate. The absorber plate is 0.5 mm thick galvanised iron sheet with black chrome selective coating. A single transparent glass cover is provided at the top of the air heater. Due to a 4 cm thick insulation provided at the bottom of air heater convective and radiative thermal losses can be assumed negligible, thus conduction through insulation is mainly responsible for thermal losses from the back of the air heater. In particular, hollow U-shaped longitudinal fins are provided to the absorber plate to increase the heat transfer between air and plate and thus to achieve a higher outlet temperature compared to conventional air heaters. The outlet air temperature depends on the transfer of thermal energy from sun to air through various components of the air heater, thus the mathematical model of the proposed system is based on the energy balance of components of the air heater. The following equations 1–17 involve various heat transfer terms to and from the components of the proposed air heater in time-dependent behaviour. The description of each heat transfer term is listed in Table 1.

Energy balance equation for glass cover

$$m_{glass}.C_{glass}\frac{dT_{glass}}{d\tau} = I.\alpha_{glass}.A_{sur} - Q_{glass/air(C)} - Q_{glass/surr(C)} - Q_{glass/sky(R)} + Q_{plate/glass(R)} \quad (1)$$

Energy balance equation for air

$$m_{air}.C_{air}\frac{dT_{air}}{d\tau} = Q_{plate/air(C)} + Q_{glass/air(c)} \quad (2)$$

Energy balance equation for absorber plate

$$m_{plate}C_p\frac{dT_{plate}}{d\tau} = I.\alpha_g.\tau_g.A_{sur} - Q_{plate/air(C)} - Q_{plate/a2(C)} - Q_{plate/glass(R)} - Q_{plate/base(R)} \quad (3)$$

Energy balance equation for air flowing between absorber plate and base plate

$$m_a.C_{air}\frac{dT_{a2}}{d\tau} = Q_{plate/a2(C)} + Q_{base/a2(c)} - m_a.C_{air}.(T_{a2ex} - T_{a2in}) \quad (4)$$

Energy balance equation for base plate

$$m_{base}.C_{base}\frac{dT_b}{d\tau} = Q_{plate/base(R)} - Q_{base/a2(C)} - Q_{base/surr} \quad (5)$$

Figure 1 shows the comparison of conventional and proposed air heaters with U-shaped longitudinal fins. It is clear from the Figure 1 that the construction of both the air heaters is similar above the absorber plate therefore related heat transfer terms and input values in heat transfer terms will also be the same for both. However, below the absorber plate proposed air heater provides a larger area participating in heat transfer (which includes the inner surface area of fins, the outer surface area of fins, and area of absorber plate without fins) compared to a conventional air heater. In a conventional air heater, only the absorber plate area participates in heat transfer.

Various heat transfers involved in energy balance equations and listed in Table 1 can be calculated as follows

$$Q_{glass/surr(C)} = A_{sur}(2.8 + 3V_i)(T_{glass} - T_{surr}) \quad (6)$$

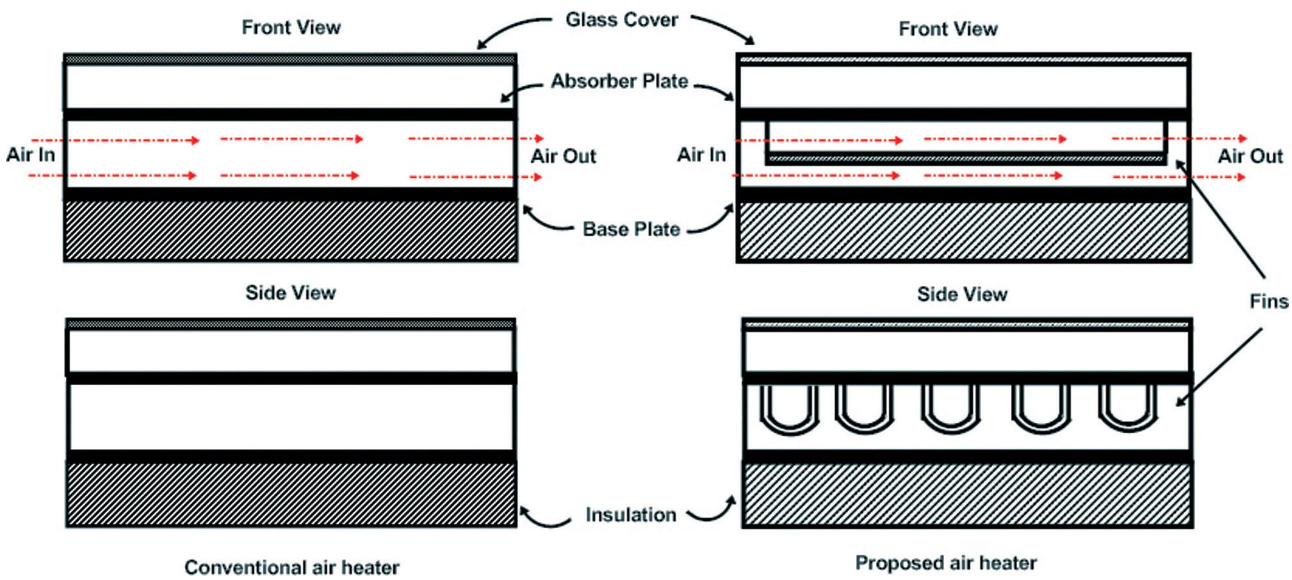

Figure 1. Conventional and proposed solar air heater with U - shaped longitudinal fins.

Table 1. Description of heat transfer terms of energy balance equations

$I.\alpha_{glass}.A_{sur}$ – Solar energy absorbed by glass cover	$Q_{glass/air(C)}$ – Convective heat transfer between glass cover and air
$Q_{glass/surr(C)}$ – Convective heat transfer between glass cover and surrounding	$Q_{glass/sky(R)}$ – Radiative heat transfer between glass cover and surrounding
$Q_{plate/glass(R)}$ – Radiative heat transfer between glass cover and absorber plate	$Q_{plate/air(C)}$ – Convective heat transfer between absorber plate and air above absorber plate
$I.\alpha_g.\tau_g A_{sur}$ – Solar energy available at absorber plate	$Q_{plate/a2(C)}$ – Convective heat transfer between absorber plate and air below absorber plate
$Q_{plate/base(R)}$ – Radiative heat transfer between absorber plate and base plate	$Q_{base/a2(C)}$ – Convective heat transfer between base plate and air below absorber plate
$Q_{base/surr}$ – Heat loss from the base plate to the surrounding	

$$Q_{glass/sky(R)} = A_{sur}\varepsilon_{glass}\sigma\left(T_{glass}^2 + T_{sky}^2\right)\left(T_{glass} + T_{sky}\right)\left(T_{glass} - T_{sky}\right) \quad (7)$$

$$Q_{glass/air(C)} = A_{sur}Nu_{glass/air}\frac{K_a}{D_h}\left(T_{glass} - T_{air}\right) \quad (8)$$

Where, D_h = 4 Area/wetted perimeter.

Thermal properties of the moist air are evaluated by relations [8–10]

Thermal conductivity:

$$K = 0.0244 + 0.6773.10^{-4}T \quad (9)$$

Thermal diffusivity:

$$\alpha = 7.7255 \times 10^{-10} + T^{1.8} \quad (10)$$

Kinematic viscosity:

$$v = 0.1284 \times 10^{-4} + 0.00105 \text{ x } 10^{-4}\ T \quad (11)$$

$$Q_{plate/glass(R)} = \left(A_{sur}\right)\frac{\sigma\left(T_{glass}^2 + T_{plate}^2\right)\left(T_{glass} + T_{plate}\right)}{\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_{plate}} - 1} \times \left(T_{glass} - T_{plate}\right) \quad (12)$$

$$Q_{plate/air(C)} = A_{sur}h_{plate/air(C)}\left(T_{plate} - T_{air}\right) \quad (13)$$

Here, convective heat transfer coefficient

$$h_{plate/air(C)} = h_{glass/air(C)}\ [8] \quad (14)$$

For proposed air heater:

$$Q_{plate/a2(C)} = A_{fin}h_{f\_p/a2(C)}\left(T_{plate} - T_{f\_a2}\right) \quad (15)$$

For conventional air heater:

$$Q_{plate/a2(C)} = A_{sur}Nu_{glass/air}\frac{K_a}{D_h}\left(T_{plate} - T_{c\_a2}\right) \quad (16)$$

For proposed air heater :

$$Q_{plate/base(R)} = A_{fin}\frac{\sigma\left(T_{plate}^2 + T_{base}^2\right)\left(T_{plate} + T_{base}\right)}{\frac{1}{\varepsilon_{plate}} + \frac{1}{\varepsilon_{base}} - 1}\left(T_{plate} - T_{base}\right) \quad (17)$$

For conventional air heater :

$$Q_{plate/base(R)} = A_{conv}\frac{\sigma\left(T_{plate}^2 + T_{base}^2\right)\left(T_{plate} + T_{base}\right)}{\frac{1}{\varepsilon_{plate}} + \frac{1}{\varepsilon_{base}} - 1} \times \left(T_{plate} - T_{base}\right) \quad (18)$$

For proposed air heater :

$$Q_{base/a2(c)} = A_{sur}h_{f\_base/a2}\left(T_{base} - T_{f\_a2}\right) \quad (19)$$

For conventional air heater :

$$Q_{base/a2(c)} = A_{sur}h_{c\_base/a2}\left(T_{base} - T_{c\_a2}\right) \quad (20)$$

$$Q_{base/surr} = A_{sur}U_{loss}\left(T_{base} - T_{amb}\right) \quad (21)$$

APPLICATION FOR DESALINATION

Figure 2 shows the schematic arrangement of the proposed solar desalination system working on humidification and dehumidification principle and using a novel solar air

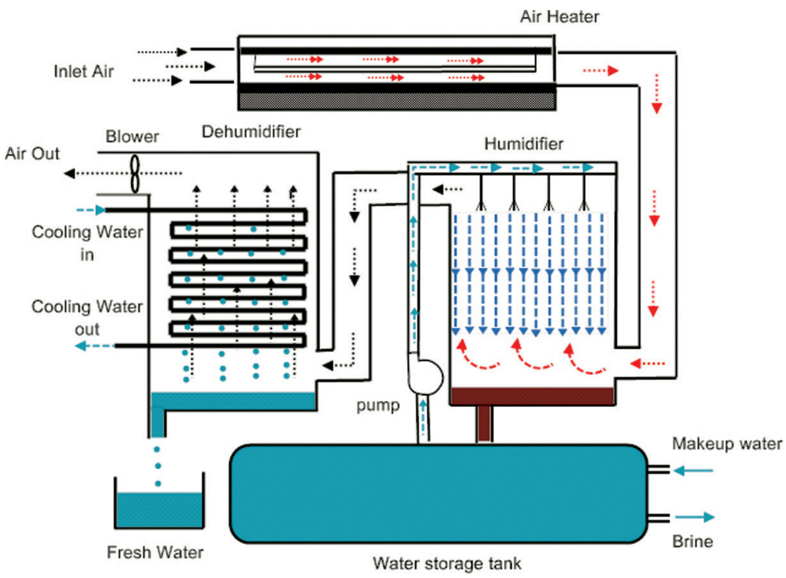

Figure 2. Proposed humidification – dehumidification desalination system.

heater with U-shaped fins. The process air moves through the main components of the proposed system that are solar air heater, humidifier, and dehumidifier during its journey in the desalination system for the production of fresh water.

During operational hours of the proposed system which are the sunshine hours, ambient air passes through the solar air heater and gets heated by absorbing the heat. Significant improvement in air outlet temperature from air heater because of novel finned arrangement used and thus considerable improvement in productivity can be expected here due to fact that moisture absorbing capacity of air increases as its temperature increases. The heated air now moves towards the humidifier to get humidified by saline water. A counter flow arrangement has been utilised here for better evapouration of saline water, therefore heated air from the air heater enters from the bottom of the humidifier and saline water is sprayed from the top. Storage tank acts as a reservoir of saline water and arrangement of brine removal and addition of make-up are provided to keep the salinity level in limits that will not interrupt the working of proposed system. In a humidifier, after getting enriched with moisture process air is supplied to dehumidifier for condensation of water vapour, and the remaining water is supplied to a storage tank for recirculation. At the outlet of dehumidifier, a blower has been provided to maintain the required airflow rate throughout the system.

The amount of water produced can be calculated by energy and mass conservation equations given below-

Energy balance equation for humidifier

$$m_a.(h_{a3} - h_{a2}) = M_{w,in} C_w T_{w1} - M_{w,out} C_w T_{w2} \quad (22)$$

Energy balance equation for De-humidifier

$$m_a.(h_{a3} - h_{a4}) = M_{w3} C_w (T_{w4} - T_{w3}) + M_{cw} C_w T_{w5} \quad (23)$$

Mass balance equation for humidifier

$$M_{w,out} + M_a W_3 = M_{w,in} + M_a W_1 \quad (24)$$

Productivity of the desalination system can be calculated by rate of condensation of water vapor in dehumidifier

$$M_{cw} = M_a (W_3 - W_4) \quad (25)$$

The parameters of air heater and desalination system used for simulation are listed in Table 2.

Table 2. Parameters related to proposed air heater

Parameter	Value
Location of collector	Chennai, India
Area of collector	1.5 m^2 (1.5 × 1)
Emissivity of glass	0.9[9]
Mass of absorber plate	4.5 kg
Mass of base plate	4.5 kg
Mass of glass	3.5 kg[10]
Number of fins	5
Length of fin	1.38 m
Thickness of fin	5 mm
Mass flow rate of air	110 kg/hr[11]

APPLICATION FOR DRYING

Crop drying is commonly used for storage and off-season consumption of food and vegetables. The most commonly used method of open sun drying simply exposed crops to the sun thus it is prone to high crop losses [12]. On the other hand, the fossil fuel dryers have shown their usability due to the characteristics of working in any season and controlled operation, but they are expensive and harmful to the environment. In contrast, solar drying is an environmentally friendly and cost-effective technique that can be used in remote areas also. In this work, an indirect solar drying system has been presented which uses a flat plate solar heater having U-shaped longitudinal fins for effective utilisation of solar energy.

Figure 3 shows the schematic arrangement of the proposed solar drying unit with the main components solar air heater and drying chamber. The crop is placed on trays provided inside the drying chamber and heated by incoming air from the air heater. Initially, the atmospheric air is forced to the air heater which is adjusted at the inclination equal to the latitude of Chennai. This air is heated by solar thermal energy due to energy exchange with components of the air heater. The proposed system offers the benefit of controlled air temperature that can be maintained by controlling the mass flow rate of air through the air heater with the help of a variable speed blower located at the inlet of air heater. Vents are provided at the top of the drying chamber to escape the air after absorbing moisture while flowing over the crop. The commonly produced crops in coastal areas of India and their safe moisture content for long-term storage

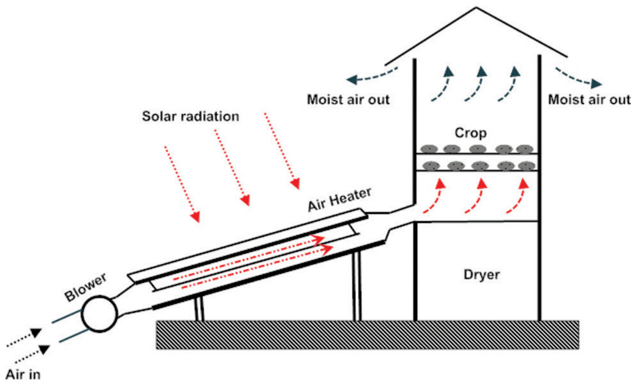

Figure 3. Proposed indirect solar drying system.

are listed in Table 3. The moisture content (wet basis)can be calculated by relation[13]-

$$\text{Moisture content} = \frac{m(iw) - m(fd)}{m(iw)} \tag{26}$$

The aim of solar drying devices is to bring the moisture content up to the required level for storage (Table 3) in a specific duration so that drying will not affect the nutrition level of the crop. Wet-basis moisture content is defined as the relative weights of moisture present per unit of un-dried material is used generally for commercial purposes [16]. The results of air temperature at the outlet of proposed air heater are shown in figure 6 and it is very clear that proposed air heater can be used in drying for most of the crops produced in the coastal area. However, in the present work focus is on the drying time estimation of banana fruit and garlic in climatic conditions of Chennai. India is the largest producer of banana and the second-largest producer of garlic whereas Indian coastal areas are the most potential producers and markets for both bananas and garlic. Parameter used for the analysis of drying time and thermal properties of garlic and banana is listed in Table 4.

Table 3. Commonly produced crops in coastal area and their drying characteristics [14, 15, 17]

Crop		Safe moisture content (% Wet Basis)	Maximum allowable temperature (^{0}C)
Grains	Paddy	13	50
	Rice	10	40–60
	Pulses	7–9	40–60
	Oil seeds	5	65
Vegetables	Green peas	6	65
	cauliflower	5	65
	onion	4	55
	Garlic	4	55
	Cabbage	7	55
	Potato	5	75
	chilies	24	65
Fruits	Apple	18	65
	Apricot	15–20	70
	Banana	7	65
	Guava	20	65
	Pineapple	10	60
	Tomatoes	6	60
	Coconut	5	65
	Mango	4	55

Table 4. Parameters used in drying time calculation of banana and garlic [18, 19, 20]

Parameter	Banana	Garlic
Scientific name	Musa acuminata/ Musa balbisiana	Allium sativum
Initial Moisture Content (% Wet basis)	80	80
Safe moisture content	7	4
Specific heat	3.35 kJ/kg-K	3.77 kJ/kg-K
Thermal conductivity	0.42 W/m-K	0.54 W/mK
Density	1320 kg/m^3	1000 kg/m^3
Appearance	Slices	Cloves
Weight	4 kg	2 kg
Heater area	1.5 m^2	1.5 m^2
Ambient conditions	Chennai (India)	Chennai (India)
Drying chamber size	600mm (height) × 600mm × 200mm	600mm (height) × 600mm × 200mm

RESULTS AND DISCUSSION

Figure 4 shows the monthly variation of solar intensity in Chennai and Figure 5 shows the variation in temperature and humidity for the same [21]. These figures help to understand the climatic condition of Chennai and its variation throughout the year so that the performance of the proposed system can be evaluated in this climate. For simulation, the initial values of solar irradiance, temperature, and humidity have been taken as the ambient condition.

Figure 6 shows the variation of air temperature at the outlet of the proposed air heater over the considered air mass flow rate range the 40 kg/hr to 180 kg/hr. It is clear that temperature drops as the mass flow rate of air increases which is evident by the fact that higher mass flow rate results in less retention time thus leads to a drop in temperature. Figures 7 –10 shows the effect of important operating parameters on the fresh water productivity by the proposed desalination system and compares the results for air heaters with and without fins. Figure 7 reveals that increase in mass flow rate of air through air heater is beneficial but only up to 160 kg/hr thereafter a slight drop in productivity has been observed. Initially, more water vapour has been carried out by air therefore fresh water yield has shown increasing nature but at a higher air mass flow rate significant drop in outlet temperature of air (due to less retention time) has been observed. Due to this fact at higher mass flow rate productivity ceases to increase. However, the use of the proposed air heater is found beneficial as the system resulted in 33 % more productivity compared to the desalination system configured with a conventional flat plate heater.

Figure 8 reveals the effect of storage tank water temperature on productivity. It is clear that the higher temperature of water in the storage tank is beneficial for fresh water production. For temperature gain of 12°C, the increase in productivity can be observed as 26.8% and 24.5% for finned and conventional air heaters respectively.The supremacy of the proposed novel air heater is evident here as it resulted the about 38 % higher fresh water yield compared to conventional air heater in the considered temperature range. The proposed system follows the closed cycle for water thus recirculation of water takes place in a humidifier and storage tank. This recirculation leads to a gradual increase in the water temperature of a storage tank and thus higher evapouration when this water is sprayed over the air in a humidifier. Finned air heater in resulted in higher temperature of the air entering the humidifier which promotes more evapouration and finally produces a higher yield of freshwater.

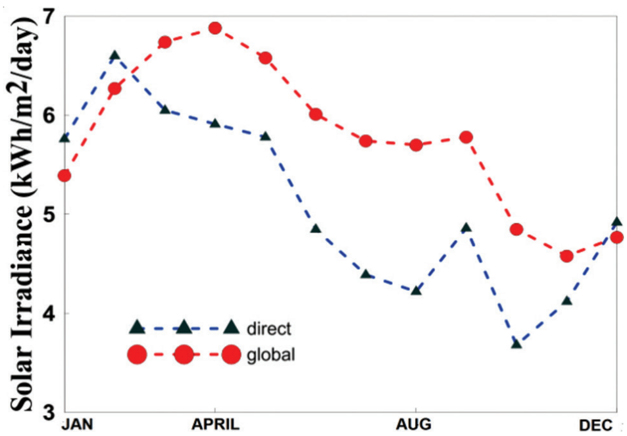

Figure 4. Variation of solar irradiance.

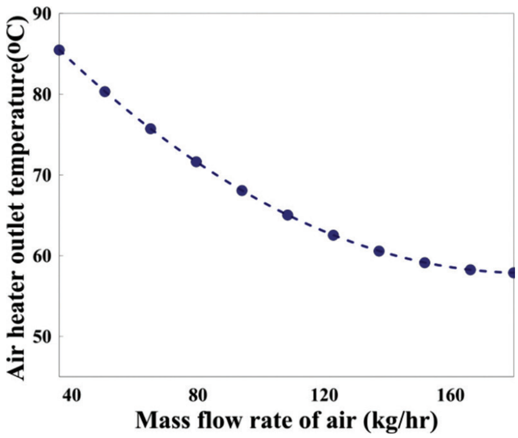

Figure 6. Effect of air mass flow rate on outlet temperature of air.

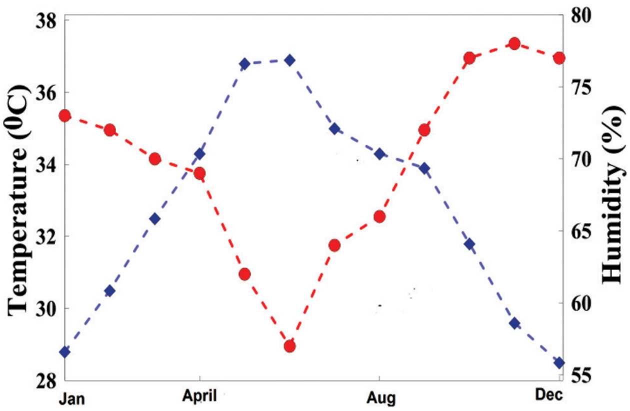

Figure 5. Variation of temperature and humidity.

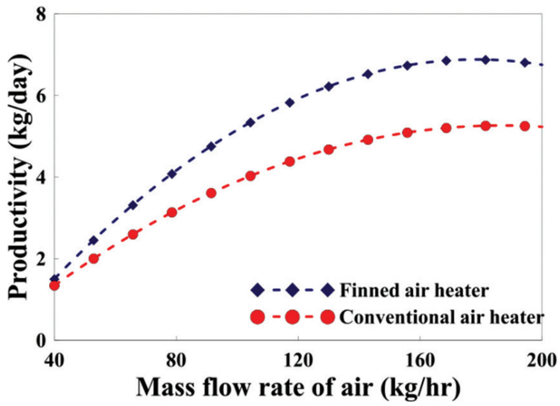

Figure 7. Mass flow rate of air vs Productivity.

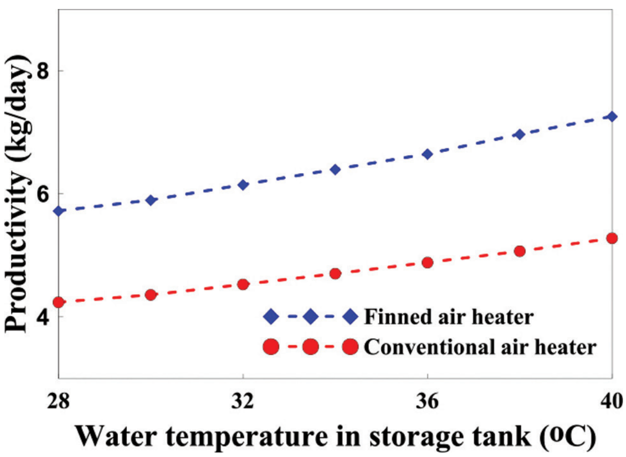

Figure 8. Storage tank water temperature vs productivity.

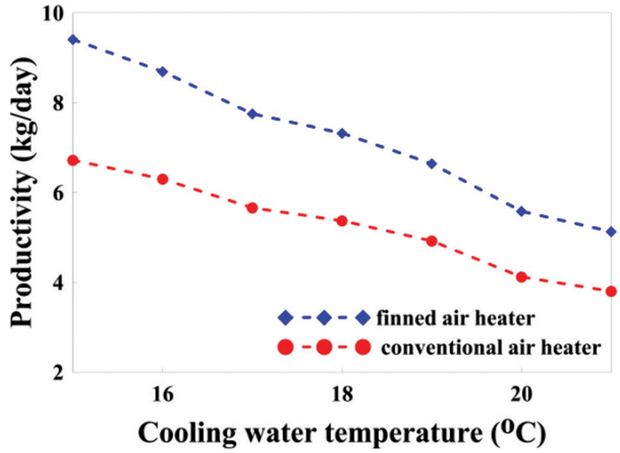

Figure 9. Cooling water temperature vs productivity.

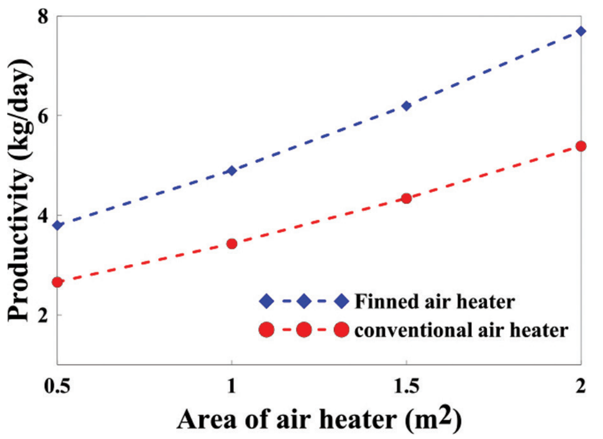

Figure 10. Heater area vs productivity.

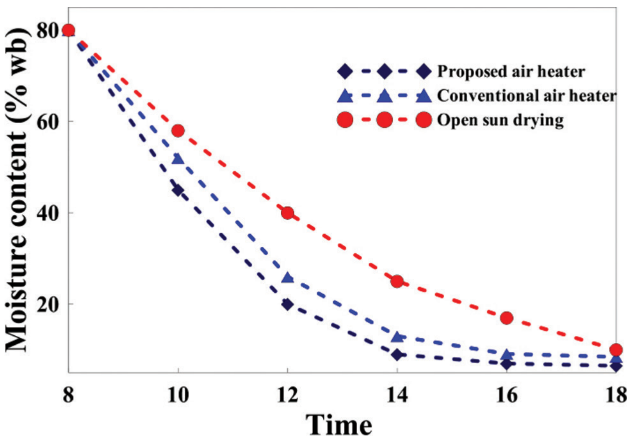

Figure 11. Drying time for banana.

Figure 9 shows the effect of cooling water temperature on productivity and lower temperature of the water is found suitable for higher productivity of freshwater. Lower cooling water temperature leads to an increase in the condensation of moisture thus productivity increases. Figure 10 shows the variation of productivity with an area of the air heater for constant mass flow rate. It is clear that the productivity increases significantly by increasing the heater area which contributes to raising the temperature of air coming out from the air heater and ultimately higher yield in a dehumidifier is found due to higher moisture content. As the heater area increases 4 times the yield increases 2.7 times for both arrangements, however, here also productivity remains higher by 40% for system with a finned air heater with a variation in productivity in the range of 4–10.2 kg/day.

Figure 11 shows the comparison of drying time that is the time required to bring the initial moisture content of 80% to a desired value of 4% in banana slices by proposed air heater, conventional flat plate air heater, and open sun drying. Significant improvement in drying time can be observed with the use of the proposed air heater which is

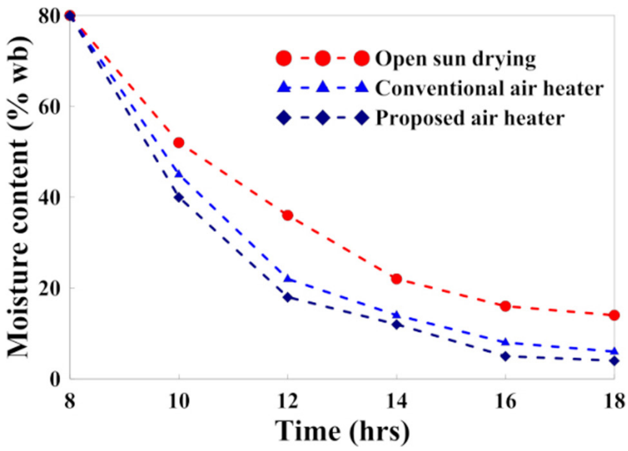

Figure 12. Drying time for garlic.

10 hours by the proposed system compared to 12 hours of the conventional air heater. On the other hand, open sun drying takes too much time that can extend up to 3–4 days to bring the moisture level up to 4%. The drying time comparison under three assumed drying conditions is shown in

Figure 12. Drying time of 8 hrs found sufficient by proposed air heater which is 10 hrs with conventional air heater. It is clear from the figure that initially drying rate is high due to surface moisture and moisture content drops from an initial 80% to 20% in 4 hrs. However, the remaining drop in moisture up to safe moisture content (7 % for banana and 4% for garlic) has taken a much longer time and the drying rate is much lower.

CONCLUSIONS

Novel solar air heater with longitudinal fins is analysed for application in fresh water production and agricultural drying. The results of simulation for timedependent behaviour of proposed systems are summarised below –

- Effect of air mass flow rate (in the range 40 kg /hr to 180 kg/hr) on outlet temperature of air heater has been analysed and it found to decrease from 85°C to 60°C
- Increase in mass flow rate of air through air heater is found beneficial but only up to 160 kg/hr thereafter a slight drop in productivity has been observed
- For temperature gain of 12°C, the increase in productivity has been observed as 26.8% and 24.5% for finned and conventional air heater, respectively.
- The supremacy of the proposed novel air heater is evident here as it resulted in about 38 % higher freshwater yield compared to conventional air heater in the considered temperature range.
- As heater area increases 4 times the yield increases 2.7 times for both arrangements, however, here also productivity remains higher by 40% for s system with a finned air heater with variation in productivity in the range of 4–10.2 kg/day.
- In the drying process, significant improvement has been observed compared to direct solar drying and conventional air heater with 12 hours drying time for banana slices and 10 hours for garlic was found.

NOMENCLATURE

A_{sur}	Surface area of glass over (m^2)
A_{conv}	Heat transfer area of absorber plate without fin (m^2)
A_{fin}	Heat transfer area of absorber plate with fin (m^2)
C	Convection
C_{air}	Specific heat of air above absorber plate (kJ/kgk)
C_{base}	Specific heat of air above base plate (kJ/kgk)
C_{glass}	Specific heat of glass (kJ/kgk)
C_p	Specific heat of absorber plate (kJ/kgk)
C_w	Specific heat of water (kJ/kgk)
H	Convective heat transfer coefficient (W/m^2k)
$h_{f\_p/a2}$	Overall heat transfer coefficient for finned absorber plate (W/m^2k)
h_{a2}	Enthalpy of air at humidifier inlet (kJ/kg)
h_{a3}	Enthalpy of air at humidifier outlet (kJ/kg)
h_{a4}	Enthalpy of air at Dehumidifier outlet (kJ/kg)
I	Solar irradiance (watt)
K	Thermal conductivity (w/mk)
L	Length of absorber plate (m)
m_a	Mass flow rate of air (kg/sec)
m_{air}	Mass of air above absorber plate (kg)
m_{base}	Mass of base plate (kg)
m(iw)	Initial mass of fresh crop (kg)
m(fd)	Final mass of dried crop (kg)
m_{plate}	Mass of absorber plate (kg)
m_{glass}	Mass of glass (kg)
M_w	Mass flow rate of water in humidifier (kg/sec)
M_{cw}	Mass flow rate of condensate water (kg/sec)
Q	Rate of heat transfer
R	Radiation
T	Temperature (°C)
T_{air}	Temperature of air between cover and absorber plate (°C)
$T_{a2\ in}$	Temperature of air at heater inlet
$T_{a2\ ex}$	Temperature of air at heater exit
$T_{f\_a2\ ex}$	Mean temperature of air in finned air heater
$T_{c\_a2\ ex}$	Mean temperature of air in conventional air heater
T_b	Temperature of base plate (°C)
T_{glass}	Temperature of glass cover (°C)
T_{plate}	Temperature of absorber plate (°C)
T_{w1}	Temperature of water at humidifier inlet (°C)
T_{w2}	Temperature of water at humidifier outlet (°C)
T_{w3}	Temperature of water at Dehumidifier inlet (°C)
T_{w4}	Temperature of water at Dehumidifier outlet (°C)
T_{w5}	Temperature of condensate water (°C)
V	Kinematic viscosity
Vi	Wind speed (m/sec)
W	Width of absorber plate (m)
W	Moisture content of air
W_1	Moisture content of air at humidifier outlet
W_3	Moisture content of air at humidifier inlet
α_g	Absorptivity of glass
E	Emissivity
T	Time (sec)
τ_g	Transmissivity of glass

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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