Energy Reports 2 (2016) 107–116

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Performance analysis of greenhouse dryer by using insulated north-wall under natural convection mode

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ARTICLE INFO

Article history:
Received 22 January 2016
Received in revised form
15 March 2016
Accepted 16 May 2016
Available online 30 May 2016

Keywords:
Greenhouse dryer
Insulated north wall
Solar collector
Coefficient of performance
Heat utilisation factor

ABSTRACT

A prototype north wall insulated greenhouse dryer has been fabricated and tested in no-load conditions under natural convection mode. Experimentation has been conducted in two different cases. Case-I is when solar collector placed inside the dryer and Case-II is North wall insulated greenhouse dryer without solar collector. Coefficient of performance, heat utilisation factor, convective heat transfer coefficient and coefficient of diffusivity have been evaluated in thermal performance analysis. The difference of the highest convective heat transfer coefficient of both cases is 29.094 W/m^2 °C which is showing the effectiveness of insulated north wall and solar collector. The maximum coefficient of diffusivity (0.0827) was achieved during the third day of experiment in Case-II. The inside room temperature of wall insulated greenhouse dryer for Case-I is 4.11%, 5.08 % and 11.61 % higher than the Case-II during the day 1, day 2 and day 3 respectively. This result is also showing the effectiveness of solar collector and insulated north wall. The highest heat utilisation factor (0.616) is obtained during the second day for Case-I while for Case-II it is 0.769 during the third day of experimentation. Maximum coefficient of performance achieved is 0.892 during the third day of the experiment for Case-I whereas 0.953 is obtained on the first day of experimentation for Case-II.

1. Introduction

The production of fruits and vegetables in the world has been estimated around 392 million and 486 million tons, respectively in which 30%–40% is spoiled of total production due to lack of postharvest handling up to consumption in developed country (Sharma et al., 2013). India is a developing country and it is second the largest producer of fruits and vegetables (Sharma et al., 2013; Singh et al., 2014). Nearly 35% losses are estimated during postharvest period of fruits & vegetables (Sharma et al., 2013; Singh et al., 2014; Singh and Kumar, 2012b). Fruits and vegetables with higher water content help the easy attack of the micro-organism and the microbial effect plays a very important role in spoilage of fruits and vegetables (Singh et al., 2014; Singh and Kumar, 2012b). The financial value of those losses is approximately 104 million dollars annually and the reasons of these losses are poor preservation approaches, improper handling and improper storage facilities (Singh and Kumar, 2012b; Fudholi et al., 2015).

Food preservation is a process of moisture removal from agricultural produce up to a safe limit and this process is known as crop drying. Crop drying is a process of dehydration using the heat. That heat can be generated by burning of fossil fuels, through the electricity and by the solar radiation (Singh and Kumar, 2012b; Fudholi et al., 2015; Prakash et al., 2013). But consumption of fossil fuel again a problem like burden of foreign exchange on developing country and other problem is environmental concern (GHG emission). Other sources of heat energy can be electricity. But after a lot of practices and efforts, lot of villages of developing countries are still waiting for the continuous and sufficient supply of electricity. So avoid such problems, renewable energy can be best solution. Renewable energy is not available in the form of heat but sun can generate enormous amount of heat energy through various available technologies like solar collectors, solar concentrators and solar dryers which had been developed in past. Solar energy is a rising and smart option for the rural occupiers and farmers (Ekechukwu and Norton, 1999; Singh et al., 2006; Prakash and Kumar, 2014c,d).

The sun has great potential to fulfil our energy needs. Solar drying is one of the traditional and general methods of

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http://dx.doi.org/10.1016/j.egyr.2016.05.004

Nomenclature

A_c	Cross sectional area of the ventilator (m^2)
A_i	Cross sectional area of the inlet hole (m^2)
A_v	Cross sectional area of vent (m^2)
C	Constant
C_{df}	Coefficient of diffusivity
h_{cvt}	Convective heat transfer coefficient of the air ($W/m^2\,°C$)
I_{gr}	Global solar radiation (W/m^2)
I_{dr}	Diffuse solar radiation (W/m^2)
$I(t)$	Solar intensity inside the NWIGHD (W/m^2)
N'	Number of sets
N'_0	Number of observations in each set
n	Constant
$P(T)$	Vapour pressure of humid air at temperature T, N/m^2
ΔP	Partial pressure difference between room temperature and ambient air (N/m^2)
Q_{lf}	Heat loss factor (W)
Rh_a	Ambient relative humidity (%)
Rh_{gh}	Inside greenhouse relative humidity (%)
T_{rm}	Temperature inside the North wall insulated greenhouse dryer (°C)
T_a	Ambient temperature (°C)
T_{gd}	Ground temperature (°C)
v_s	Surface Velocity air (m/s)
U'	Internal uncertainty
$X_i - X'$	the deviation from the mean
σ'	Standard deviation,
ρ	Density of humid air (kg/m^3)
η_{ith}	The instantaneous thermal loss efficiency factor
COP	Coefficient of performance
HUF	Heat utilisation factor
WSC	with solar collector
WOSC	without solar collector

conservation of food crops. Solar drying is a combined process of heat and mass transfer. In this first heat is supplied to the product from the sun and then mass transfer form crop surface to the surrounding in terms of moisture content. According to heat utilisation technique, solar dryer can be classified as: direct, indirect and mixed mode (Prakash et al., 2013; Chauhan et al., 2015; Kumar et al., 2014).

Each dryer can be operated in either passive (natural convection) or active mode (forced convection). The passive mode of greenhouse dryer works on the principle of thermosyphic effect. The humid air gets ventilated through the ventilator provided at the roof or through the chimney of the dryer. Humid air is ventilated by the help of an exhaust fan provided at the ventilator. It is generally provided in the upper portion of the west wall (Kumar et al., 2006; Kumar and Tiwari, 2006b,a).

Greenhouse dryer is direct type solar dryer and crop can be dried in bulk. This is most suitable solar dryer for small farmer. A significant interest among researchers has been observed in the field of greenhouse drying for designing, development and testing of different kind of greenhouse dryers. The review revealed that the greenhouse effect can also be used for low and medium temperature drying application inside the greenhouse dryer accepting its other application, like plant soil solarisation cultivation, aquaculture and poultry (Prakash et al., 2013; Kumar et al., 2014; Prakash and Kumar, 2015). For small-scale greenhouse dryer, losses of incident solar radiation through the north wall is a major problem and so as to make the greenhouse more effective than previous designs, the losses through the north wall is to be eliminated. The researchers anticipated numerous ideas to minimise the losses through the north wall of the dryer.

A packed bed even shape greenhouse dryer introduced for onion drying. In this dryer to a solar energy collector was used to store the heat energy for crop drying. A brick made north wall was made to reduce the thermal losses from the greenhouse and the inside surface of the north wall was painted black (Jain, 2005). An inclined north wall reflection was applied under both modes of the greenhouse dryer to optimise the design of the system. This idea enhanced the drying performance of the system (Sethi and Arora, 2009). A phase change material based dryer was introduced. In this dryer, phase change material was applied in the north to store the heat energy during the sun shine hours. This was another approach for enhancing the efficiency of the greenhouse drying system and it increased the inside greenhouse room temperature (Berrouga et al., 2011). In another approach a mirror was placed in the north wall to improve the use of solar radiation. A black PVC sheet was also put on the ground to minimise the heat loss from the ground. The idea was found more effective, but there were again heat losses through the north wall (Prakash and Kumar, 2014d,b).

Coefficients of Performance (COP), Heat utilisation factor (HUF) and Convective heat transfer coefficient (h_{cvt}) are essential parameters to understand the greenhouse effectiveness and performance. Many researchers have studied on convective heat transfer coefficient under load and unload conditions. However, it is rare to see the study on coefficient of performance and heat utilisation factor for greenhouse drying systems under unload condition.

In this present experimental work, a North wall insulated greenhouse dryer (NWIGHD) with solar collector is introduced with novelty. The modification of NWIGHD is done by the use of the nickel polished aluminium sheet in the north side for maximum utilisation of solar radiation and this north wall is made insulated with the help of 10 mm thick Thermocol sheet. A solar collector made by the black PVC sheet is also placed inside the NWIGHD to enhance the performance of the dryer and eliminate the heat loss from the ground.

All the experiment has been carried out in two different cases, namely Case-I and Case-II. In Case-I solar collector is placed inside the NWIGHD and in Case-II dryer is tested without solar collector (i.e. simply keeping on the barren concrete floor). The objectives of this investigation were: (i) experimentations in no-load condition (ii) to study the thermal behaviour of designed greenhouse dryer in ambient conditions (iii) to compare the COP of the system in each case and (iv) to evaluate the HUF.

2. Material and methods

2.1. Experimental setup

The volumetric dimension of the roof type even span North wall insulated greenhouse dryer is $1.5 \times 1.0 \times 0.5\ m^3$ and the effective floor area of drying chamber is $1.35 \times 0.85\ m^2$. The structure of NWIGHD is made using box-type aluminium strip to provide the strength with less weight for the basic structure and it was covered with 3 mm thick UV treated polycarbonate sheet. The Polycarbonate sheet was fixed using screws and it was also tilted at 23.5° to allow the maximum solar radiation inside the NWIGHD according to the Bhopal latitude (23.5°). The central height of the east and west wall is 0.712 m while the height of north and south wall is 0.5 m. For the inlet air, two circular holes were provided just below the tray having the diameter of 0.15 m and for the exhaust air one rectangular air outlet vent is provided in the middle of the roof top with an area of $0.0255\ m^2$. The north wall of the dryer is made by $1.0 \times 1.5\ m^2$ nickel polished aluminium sheet which reflects the solar radiation over the tray during the crop drying A 10 mm thick Thermocol sheet was used to insulate the north wall, insulation will eliminate the chances of heat loss from the north wall.

A solar collector was also placed inside the NWIGHD. It is shown in Fig. 1(a). The objective of the designing the solar collector was to store the solar heat energy during the sunshine hours and further that stored heat energy was supplied to heat the inlet air. Now this heated inlet air can be utilised to remove moisture from the crop. Two black PVC sheet with dimension of 1.45 m × 0.950 m was used to fabricate the solar collector. The upper layer consist 10 × 7.0 equidistant circular holes of 70 mm diameter, which is made for better heat transfer from collector to inlet air. The distance between upper and lower layer is 80 mm and structure of the collector is made up of box type iron strip.

The tray is made of stainless steel wire meshed with the dimension of 1.4 × 0.9 m^2 and placed on runner at 0.25 m height so as to ensure a reasonable level of air circulation under and around the drying material. Fig. 1(a) shows the north wall insulated greenhouse dryer without solar collector and Fig. 1(b) shows the north wall insulated greenhouse dryer without collector.

2.2. Instrumentation

In both cases the solar radiation has measured on the inclined surface of the NWIGHD using TM 207 model solar power meter manufactured by Tenmars, Taiwan having experimented accuracy ±10 W/m^2 and measuring range of 0–2000 W/m^2. For measuring temperature and relative humidity, a well calibrated digital thermo-hygrometer (HT-305 manufactured by Lutron, Taiwan) is used for ambient conditions and NWIGHD. Accuracy and range of measurement of temperature and relative humidity was ±0.8 °C and 0–50 °C; ±3% and 10%–95% respectively. For the ground temperature measurement MT Raytek infrared gun type thermometer is used with the accuracy and precision ±2% and 0.2 °C respectively. The air speed was measured using of hot-wire anemometer Testo 490 having range 0.2–60 m/s.

2.3. Experimentation

The experiments were conducted in no-load conditions with and without solar collector dated on 10–12, 16–18 June 2014 respectively at the Energy Centre, Maulana Azad National Institute of Technology (Bhopal, India) situated at 23.5°N latitude, 77.25°E longitude. All the experiments were performed during 8 am to 6 pm only. The direction of NWIGHD in both cases was east to west during the experiment to maintain the maximum utilisation of incident solar radiation throughout the day.

2.4. Experimental uncertainty analysis

Experimental percentage uncertainty has been calculated for greenhouse room air temperature which is most sensitive parameter. It is the summation of internal and external percentage of uncertainty. The external percentage uncertainty is taken as least count of the measuring instruments while internal percentage uncertainty is determined as Kumar and Tiwari (2007) and Prakash and Kumar (2014a):

$$\%\ internal\ uncertainty\ U'_1 = \left(\frac{U'_1}{mean\ of\ total\ observation} \times 100\right). \quad (1)$$

Internal uncertainty (U_1') is found as follows

$$U'_1 = \frac{\sqrt{\sigma'^2_1 + \sigma'^2_2 + \ldots \sigma'^2_n}}{N} \quad (2)$$

where σ' is standard deviation, expressed as

$$\sigma' = \frac{\sqrt{\sum \left(X'_i - \bar{X}'\right)^2}}{N'_0} \quad (3)$$

where $X_i - X'$ is the deviation from the mean, N' is number of sets and N_0' is the number of observations in each set.

3. Performances analysis

Following thermal performance indicators have been computed and analysis for evaluating the thermal performance of insulated north wall greenhouse dryer under natural convection condition.

3.1. Convective heat transfer coefficient

The convective heat transfer coefficient is a measure of heat loss through the system to surrounding. The convective heat transfer coefficient (h_{cvt}) under natural convection mode can be calculated as Kumar and Tiwari (2006a), Prakash and Kumar (2014a), Singh and Kumar (2012a) and Jain (2006):

$$h_{cvt} = 0.884 \times \left[\left(T_{gd} - T_{rm}\right) + \frac{\left[P\left(T_{gd}\right) - \mathrm{Rh_a} P\left(T_{rm}\right)\right]\left(T_{rm} + 273\right)}{268\,900 - P\left(T_{gd}\right)}\right]^{1/3}. \quad (4)$$

3.2. Coefficient of diffusivity

The rate of moisture removal is the main factor and responsible for the drying inside the greenhouse under natural convection mode. As, rate of moisture removal is higher it reduces the drying time of the crops. This term is known as instantaneous thermal loss efficiency factor (η_{ith}) (Prakash and Kumar, 2014c, 2015, 2014b). This factor is defined as follows:

The rate of instantaneous thermal loss efficiency factor through canopy which is an indirect loss factor can be calculated as Prakash and Kumar (2014c), Prakash and Kumar (2015) and Prakash and Kumar (2014b):

$$\eta_{ith} = \frac{U \sum A_i (T_{rm} - T_a)}{I_{gr} A_c}. \quad (5)$$

The experiment of the natural convection mode of NWIGHD is conducted in no-load condition. The sum of loss factor through the canopy and vent is assumed as 1. With the help of this assumption, the coefficient of diffusion can be written as Prakash and Kumar (2015), Prakash and Kumar (2014b) and Barnwal and Tiwari (2008):

$$C_{df} = \frac{(1 - \eta_{ith}) I_{gr} A_c}{\left(C_{df} n A_v \sqrt{\frac{2\Delta P}{\rho}} \Delta P\right)}. \quad (6)$$

3.3. Heat loss factor

Sometimes due to excess air intake inside the NWIGHD, hot air moves towards the outlet of the roof due to lower density. So this kind of heat loss factor can be expressed as Tiwari (2003) and Gupta et al. (2012):

$$Q_{lf} = C_{df} A_v \sqrt{\frac{2\Delta P}{\rho}} \Delta P. \quad (7)$$

The value of the convective heat transfer coefficient was calculated by using Eqs. (4) of the experimental data.

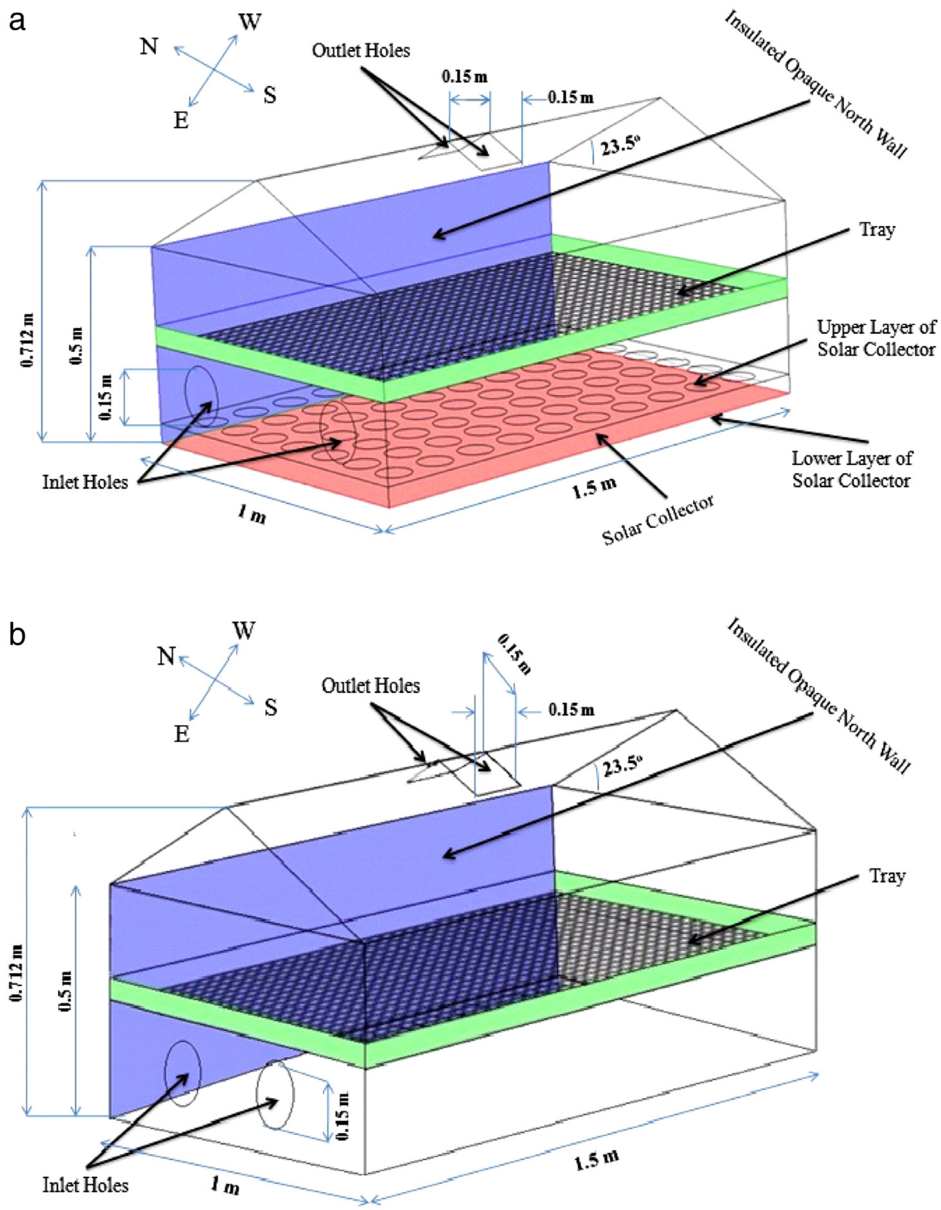

Fig. 1. (a) Schematic view of north wall insulated greenhouse dryer with solar collector. (b) Schematic view of north wall insulated greenhouse dryer without solar collector.

3.4. Heat utilisation factor (HUF)

Heat utilisation factor (HUF) is a ratio of temperature decrease due to cooling of air during drying and temperature increase due to heating of air (Tiwari, 2009)-

$$\text{HUF} = \frac{(T_{gd} - T_{rm})}{(T_{gd} - T_a)}. \quad (8)$$

3.5. Coefficient of performance (COP)

Coefficient of performance (COP) is ratio of temperature difference of NWIGHD room temperature and ambient temperature to a temperature difference of ground temperature and ambient temperature (Tiwari, 2009)-

$$\text{COP} = \frac{(T_{rm} - T_a)}{(T_{gd} - T_a)}. \quad (9)$$

4. Result and discussion

4.1. Ambient parameters during experimentation

The ambient parameters play very important role to understand the drying behaviour of any type of greenhouse drying. Figs. 2 and 3 represents the variation of ambient parameters such as global solar radiation (I_{gr}), diffuse solar radiation (I_{dr}), ambient temperature (T_a), relative humidity ($\mathrm{Rh_a}$) and surface wind velocity (V_s) with time of the day for three consecutive days of experiment. The global and diffuse radiations are mainly responsible for increase in temperature inside the NWIGHD. It is found that in both cases for first and second day having generally the same solar intensity, but on the third day, sometimes sudden variations were found due to clouds present in the atmosphere. Observations of solar radiation have been taken on the south roof of the NWIGHD which was inclined to 23.5° for both cases.

For Case I, the range of global and diffuse solar radiation varies from 78–958 W/m^2, 28–965 W/m^2 & 155–710 W/m^2

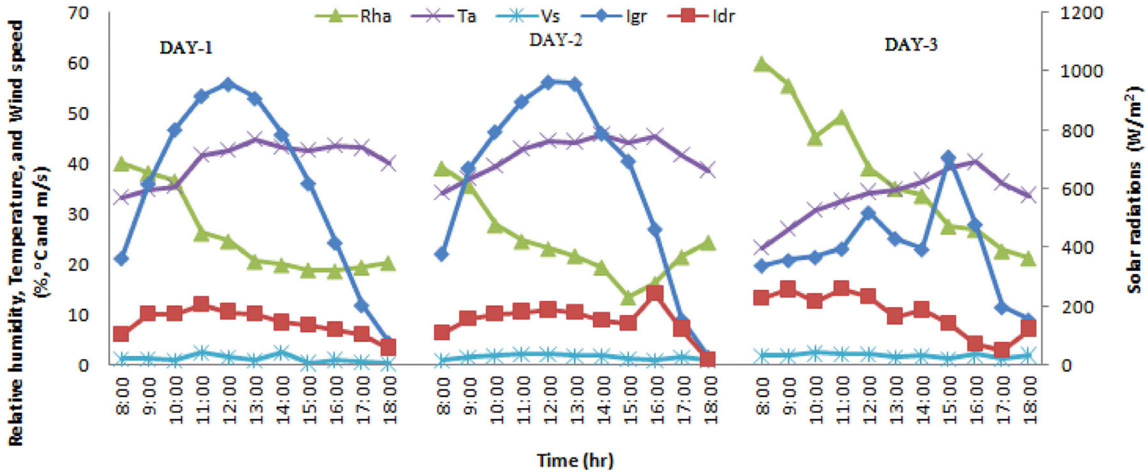

Fig. 2. Variation of ambient parameters with time of the day (10–12 June 2014) for Case-I.

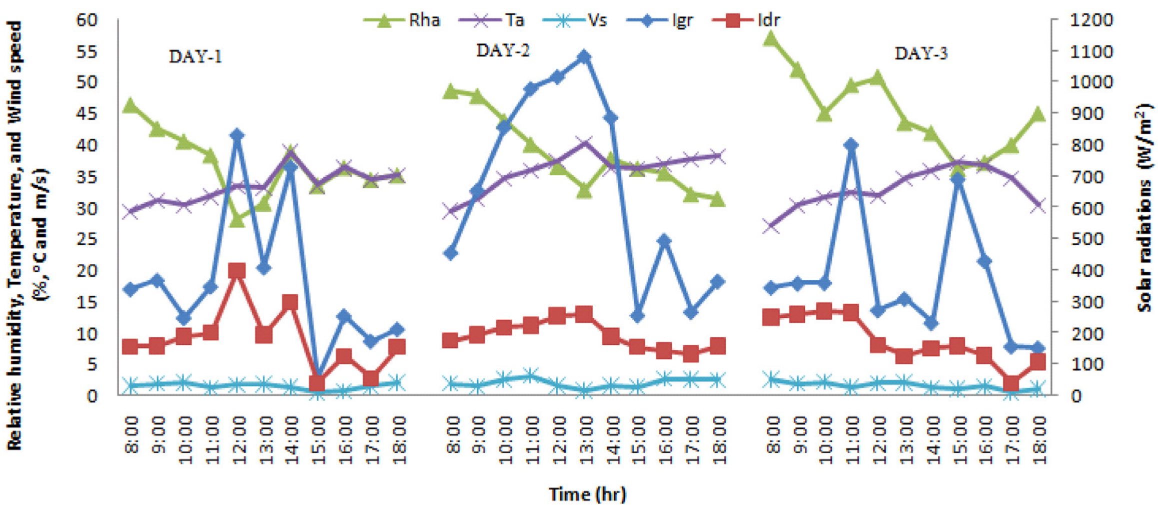

Fig. 3. Variation of ambient parameters with time of the day (16–18 June 2014) for Case-II.

and 61–209 W/m^2, 21–247 W/m^2 & 54–262 W/m^2 respectively, for day 1, day 2 and day 3 whereas for Case II it varies from 56–832 W/m^2, 256–1083 W/m^2 & 152–801 W/m^2 and 42–398 W/m^2, 135–260 W/m^2 & 42–270 W/m^2 respectively for day 1, day 2 and day 3. For Case I, day 1 & day 2 were almost clear sky condition, but in the day 3 some haziness found during the experimentation where as for Case II, only day 2 was clear sky condition and day 1 and day 3 were some clouds were found during the experimentation. For the Case I maximum global solar radiation of day 1 & day 2 were recorded 958 & 965 W/m^2 respectively at 12 h, but during the day 3, presence of cloud in the atmosphere it was 710 W/m^2 at 15 h. For the Case II maximum global solar radiation was recorded 832 W/m^2 at 12 h, 1083 W/m^2 at 13 h and 801 W/m^2 at 11 h for day 1, day 2 and day 3 respectively. The ambient temperature (T_a) varies from 33.3–45 °C, 34.2–45.8 °C and 23.4–40.4 °C for first, second and third day, respectively for Case I while for Case II, it varies from 29.4–38.9 °C, 29.5–40.3 °C and 27.1–37.3 °C for first, second and third day respectively. In Case I, the maximum ambient temperature of first, second and third day was 45 °C at 13 h, 45.8 °C at 14 h and 40.4 °C at 16 h respectively and for Case II it was 38.9 at 14 h, 40.3 at 13 h and 37.3 at 15 h respectively.

The ambient relative humidity (Rh_a) of day 1, day 2 and day 3 for Case I varies from 18.8%–40.2%, 13.6%–39.2% and 21.4%–60% respectively where as For Case II it was 28.2%–46.4%, 31.5%–48.6% and 36.2–57 respectively. Always at 8 h ambient relative humidity was found higher. Wind speed was turbulent in nature, sometimes it flows at very high speed and sometimes it flows at very low speed. High speed wind affects the dryer performance. For case I, wind speed (V_s) varies from 0.47–2.58 m/s, 1.12–2.2 m/s & 1.26–2.51 m/s for day 1, day 2 & day 3 respectively similarly for Case II, 0.53–2.15 m/s, 0.83–3.19 m/s & 0.54–2.58 m/s for day 1, day 2 & day 3 respectively.

4.2. Role of ambient temperature and solar radiation on greenhouse ground and room temperature

As global radiation increases, the ambient temperature, inside ground temperature and inside room temperature also increases and when global radiation decreases all the above parameters also decreases. Figs. 4 and 5 illustrates the variation of ambient temperature, inside ground temperature and inside room temperature of the North wall insulated greenhouse dryer in both conditions. For the Case-I inside ground and room temperature were found always higher than the Case-II. For Case-I, the maximum temperature difference between inside room and ambient were 17.7 °C at 14 h, 19.4 °C at 14 h & 15 °C at 15 h respectively for day 1, day 2 & day 3.

The inside room temperature of NWIGHD is 29.01%, 29.75% & 27.57% higher than the ambient temperature for day 1, day 2 & day 3 respectively for Case-I. For Case-II, the maximum temperature difference between inside room and ambient were 12.9 °C at 14 h, 13.2 °C at 13 h & 15.61 °C at 15 h respectively for day 1,

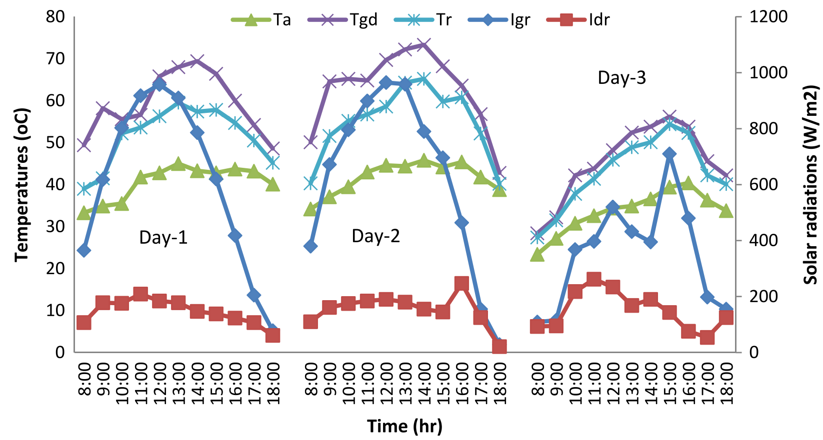

Fig. 4. Variation temperatures and solar radiation with time of the day (10–12 June 2014) for Case-I.

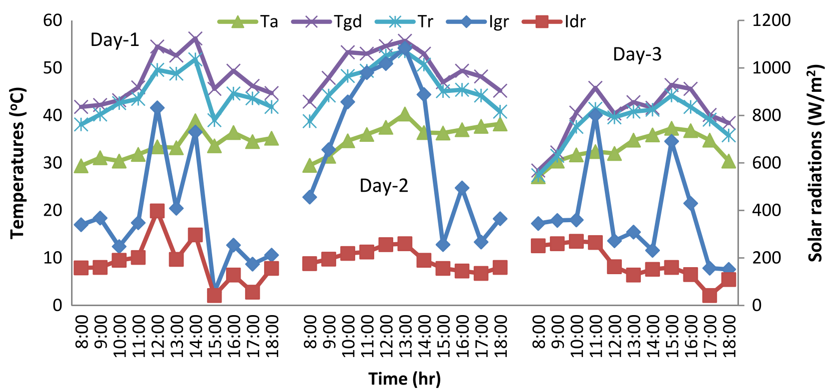

Fig. 5. Variation temperatures and solar radiation with time of the day (16–18 June 2014) for Case-II.

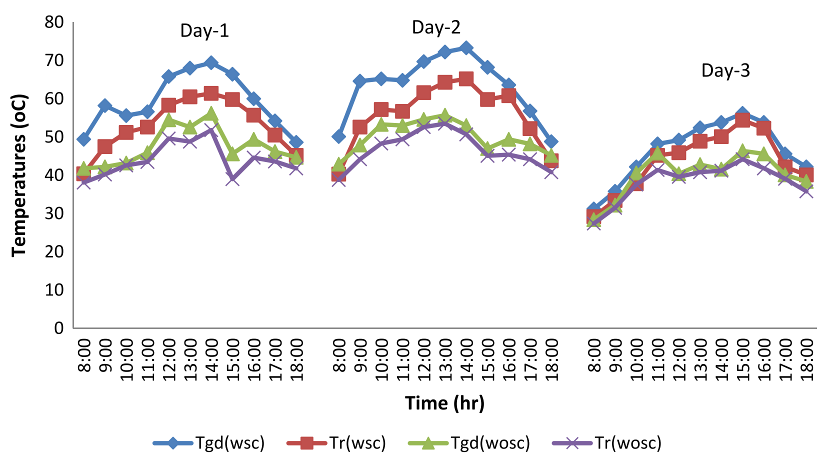

Fig. 6. Variation in greenhouse ground and room temperatures with ambient temperature, solar radiation and time of the day for Case-I & Case-II.

day 2 & day 3. It is 24.9%, 24.67% & 15.61% higher than the ambient temperature for day 1, day 2 & day 3 respectively. The inside room temperature of NWIGHD for Case-I is 4.11%, 5.08% and 11.61% higher than the Case-II during the experiment of day 1, day 2 & day 3 respectively. This result is showing the effectiveness of insulated north wall and solar collector. Table 1 is showing the value of ambient and greenhouse room temperature with respect to global solar radiation.

Due to influence of ground temperature the greenhouse room temperature increases and its relative humidity decreases. In the Fig. 6 it can be observed that the temperature of solar collector was always higher than ambient, inside room temperature for both cases. For Case-I maximum ground temperature was 69.4 °C, 73.3 °C & 56.2 °C where as the maximum ambient temperature was 45 °C, 45.8 °C & 40.4 °C. For Case-II maximum ground temperature was 56.2 °C, 55.7 °C & 46.4 °C while the maximum ambient temperature was 38.9 °C, 40.3 °C & 37.3 °C. In terms of percentage, rise in temperature of the solar collector was 19.91%, 21.1% and 13.38% for day 1, day 2 and day 3 respectively which is showing the effectiveness of solar collector placed inside the NWIGHD. The rise in temperature inside the greenhouse is a combined effect of solar collector and insulated north wall. It is justified that the use of solar collector inside the dryer can improve the dryer performance and minimise the heat loss. The increased temperature inside the NWIGHD will help the system for faster rate of moisture removal process. The difference of inside room air temperature of NWIGHD

Table 1
The global solar radiation, ambient temperature and greenhouse room temperature with time of the day.

NWIGHD without solar collector				NWIGHD without solar collector			
Time	I_{gr}	T_a	T_r	Time	I_{gr}	T_a	T_r
Day-1 (10/06/2014)				Day-1 (16/06/2014)			
8:00	340	29.4	38.1	8:00	365	33.3	40.4
9:00	368	31.1	40.2	9:00	618	34.9	47.5
10:00	248	30.4	42.6	10:00	803	35.5	51.2
11:00	348	31.8	43.5	11:00	918	41.8	52.6
12:00	832	33.4	49.6	12:00	958	42.8	58.3
13:00	409	33.2	48.8	13:00	910	45	60.5
14:00	730	38.9	51.8	14:00	786	43.3	61.4
15:00	56	33.6	39	15:00	620	42.8	59.8
16:00	254	36.4	44.6	16:00	418	43.7	55.7
17:00	174	34.5	43.6	17:00	205	43.2	50.5
18:00	212	35.2	41.8	18:00	78	40.1	45.2
Day-1 (11/06/2014)				Day-1 (17/06/2014)			
8:00	456	29.5	38.8	8:00	380	34.2	40.3
9:00	656	31.4	44.2	9:00	672	37.1	52.6
10:00	857	34.67	48.3	10:00	796	39.5	57.2
11:00	980	36	49.4	11:00	899	43	56.7
12:00	1018	37.5	52.6	12:00	965	44.6	61.6
13:00	1083	40.3	53.5	13:00	959	44.4	64.3
14:00	888	36.4	50.7	14:00	790	45.8	65.2
15:00	256	36.3	45.1	15:00	696	44.2	59.8
16:00	495	37	45.4	16:00	464	45.4	60.8
17:00	267	37.7	44.2	17:00	155	41.8	52.2
18:00	365	38.2	40.8	18:00	28	38.8	43.8
Day-1 (12/06/2014)				Day-1 (18/06/2014)			
8:00	345	27.1	27.4	8:00	340	23.4	29.2
9:00	358	30.4	31.5	9:00	358	27.2	33.4
10:00	360	31.7	37.6	10:00	368	30.8	37.8
11:00	801	32.4	41.4	11:00	397	32.6	45.2
12:00	272	32	39.6	12:00	520	34.4	45.9
13:00	309	34.8	40.8	13:00	432	34.9	48.9
14:00	232	35.9	41.2	14:00	395	36.6	50.1
15:00	691	37.3	44.2	15:00	710	39.4	54.4
16:00	430	36.8	41.8	16:00	480	40.4	52.3
17:00	157	34.8	39.1	17:00	198	36.3	42.2
18:00	152	30.4	35.8	18:00	155	33.8	40.1

and modified greenhouse dryer is 2.8 °C which is 14% higher than the modified greenhouse dryer (Prakash and Kumar, 2015).

4.3. Investigation on inside relative humidity with respect to ambient relative humidity and solar radiation

As the intensity of solar radiation increases the temperature inside of NWIGHD increases and as temperature inside the NWIGHD increases the relative humidity of NWIGHD decreases. Hence, relative humidity is inversely proportional to the temperature. Figs. 7 and 8 represents the variation of ambient and inside NWIGHD relative humidity with respect to global and diffuse solar radiation during the experiment. It was analysed that the relative humidity inside the north wall insulated greenhouse dryer is always higher than the ambient relative humidity and the relative humidity of Case-I was also higher than the Case-II. Relative humidity was found always higher at 8 h for both cases.

The range of ambient relative humidity for Case-I & Case-II for day 1, day 2 and day 3 are 18.8%–40.2%, 13.6%–39.2% & 21.4%–60% respectively and 28.2%–46.4%, 31.5%–48.6% & 36.2%–57% respectively. For Case-I and Case-II, inside the NWIGHD relative humidity varies from 6.9% to 30.2%, 4.4%–28.2% & 10.9%–56.2% respectively and 10.1%–39.4%, 15%–27.1% & 23.7%–40.1% for day 1, day 2 & day 3 respectively. Sometimes moisture present in the ground can also affect the dryer performance and this problem can be eliminated by placing the solar collector inside the NWIGHD.

4.4. Comparative analysis of heat transfer coefficient in NWIGHD with and without collector

The variation of the convective heat transfer coefficient for ground surface to greenhouse room air is shown in Fig. 9 for both conditions.

The heat transfer coefficient of Case-I is more than Case-II due to solar collector placed inside the NWIGHD. The maximum value of h_{cvt} for Case-I was 39.18 W/m^2 °C at 14 h during the first day, 46.622 W/m^2 °C at 14 h during the second day and 15.448 W/m^2 °C at 15 h during the third day, however, for Case-II it was 17.528 W/m^2 °C at 12 h during the first day, 14.670 W/m^2 °C as at 14 h during the second day and 10.583 W/m^2 °C at 15 h during the third day. The highest h_{cvt} 46.622 W/m^2 °C was recorded on second day at 14 h for Case-I whereas for Case-II it was 17.528 W/m^2 °C as at 12 h on first day. The difference between the highest values of h_{cvt} of both the case is 29.094 W/m^2 °C. On third day the value of convective heat transfer coefficient was found very low due to presence of cloud. The convective heat transfer coefficient of modified greenhouse dryer from the ground to the inside air was 40.29 W/m^2 °C (Prakash and Kumar, 2014b), where as for NWIGHD it was 46.622 W/m^2 °C, which is 13.65% higher than modified greenhouse dryer. This is showing the effectiveness of insulated north wall and solar collector of NWIGHD. The heat transfer coefficient of Case-I and case-II is shown in Table 2.

4.5. Comparative analysis of coefficient of diffusivity in NWIGHD with and without collector

Coefficient of diffusivity (C_d) can be calculated from Eq. (5). The dependent variables of C_d are solar radiation, ambient temperature and NWIGHD air temperature.

In the above Fig. 10, it can be seen that sometimes C_d is increasing with respect to time and it decreasing with respect to solar radiation. Generally the value of C_d was found more during noon and less in the evening. The effect of solar collector inside NWIGHD (Case-I) can be seen in Fig. 6, the curves are more standardised as compared (Case-II). The maximum C_d(0.0827) was achieved during the third day of experiment at 8 h in Case-II.

4.6. Evaluation of heat losses from NWIGHD with and without collector conditions

The hourly heat loss through the ventilation can be calculated with the help Eq. (7) using the value of C_d, in both cases. With the help of Fig. 11 it can be understand that the heat loss through the ventilation was higher in Case-II than Case-I that the heat loss should be as minimum as possible.

For Case-I, the maximum heat losses through the vent was 372.099 W at 11 h, 367.266 W at 12 h W and 260.784 W at 15 h during the first, second and third day respectively. However, for Case-II it was 310.649 W, 436.366 W and 326.718 W during the first, second and third day respectively. By using solar collector inside the NWIGHD the chances for heat recovery increases, which can be utilised for crop drying.

4.7. Investigation on heat utilisation factor and coefficient of performance of NWIGHD

Figs. 12 and 13 represents the variation of heat utilisation factor and coefficient of performance for three consecutive days of experiment under both the condition.

For Case-I HUF varies from 0.184 to 0.559 during first day, 0.153 to 0.616 during second day and 0.107 to 0.385 during third day of experimentation. For Case-II it fluctuates from 0.046 to 0.55, on first day, 0.116 to 0.628 on second day and 0.0701 to 0.769 on third

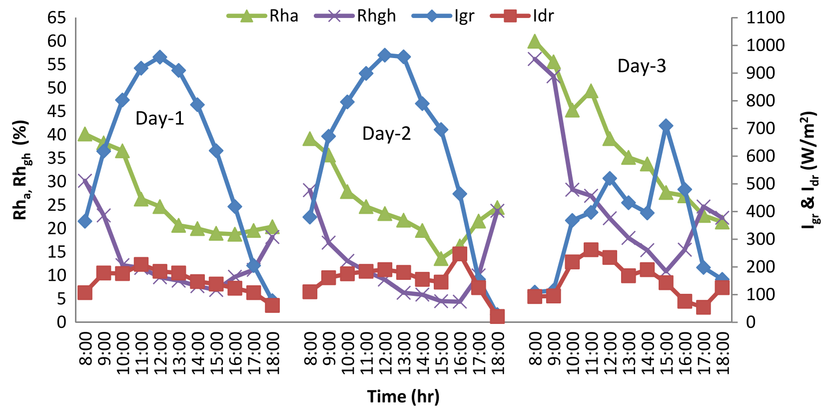

Fig. 7. Variation of relative humidity and solar radiation with time of the day (10–12 June 2014) for Case-I.

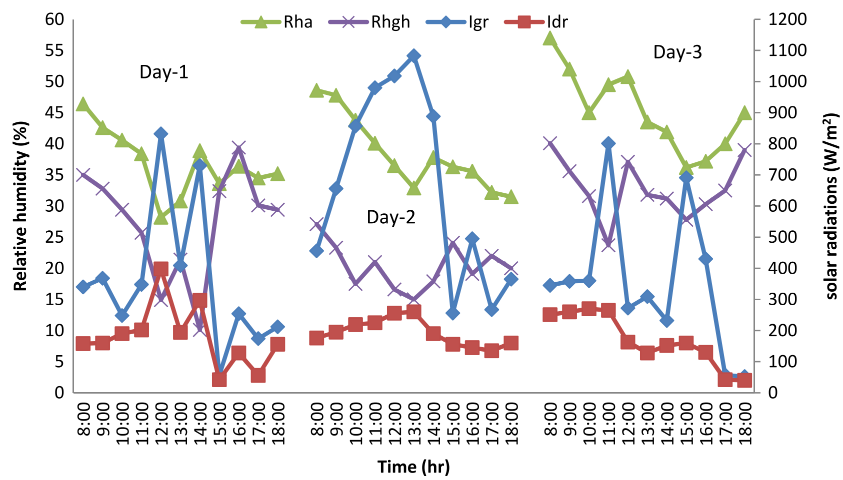

Fig. 8. Variation Relative humidity and solar radiation with time of the day (16–18 June 2014) for Case-II.

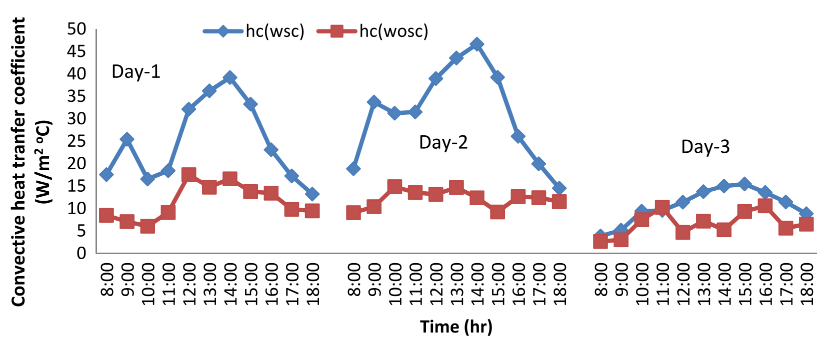

Fig. 9. Variation of convective heat transfer coefficient of NWIGHD with time of the day for both cases.

Table 2
The heat transfer coefficient of Case-I and Case-II with respect to time.

Time	h_{cvt} (Case-I) in W/m^2 °C	h_{cvt} (Case-II) in W/m^2 °C	h_{cvt} (Case-I) in W/m^2 °C	h_{cvt} (Case-II) in W/m^2 °C	h_{cvt} (Case-I) in W/m^2 °C	h_{cvt} (Case-II) in W/m^2 °C
8:00	17.54	8.46	18.83	9.053	3.85	2.64
9:00	25.42	7.06	33.70	10.39	5.15	3.01
10:00	16.54	6.04	31.23	14.85	9.39	7.48
11:00	18.40	9.10	31.50	13.55	9.55	10.24
12:00	32.12	17.5	38.94	13.15	11.3	4.67
13:00	36.19	14.7	43.52	14.67	13.7	7.16
14:00	39.18	16.6	46.62	12.37	14.9	5.24
15:00	33.24	13.7	39.23	9.219	15.4	9.30
16:00	23.07	13.4	26.06	12.64	13.5	10.58
17:00	17.24	9.81	19.94	12.40	11.4	5.61
18:00	13.20	9.46	14.49	11.52	8.81	6.50

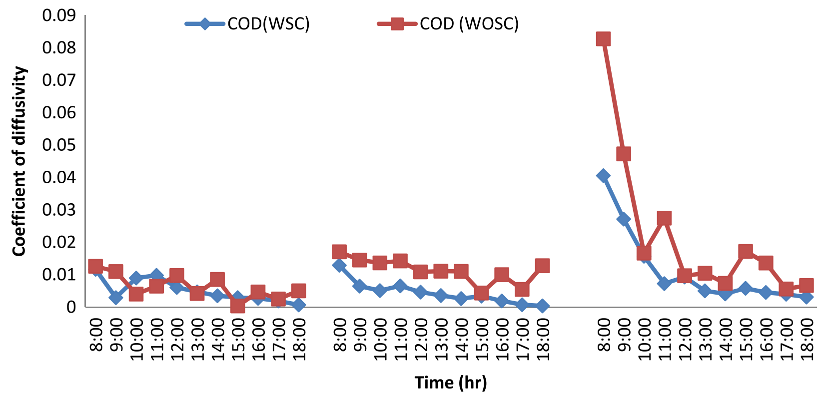

Fig. 10. Variation of coefficient of diffusivity with time of the day for both the cases.

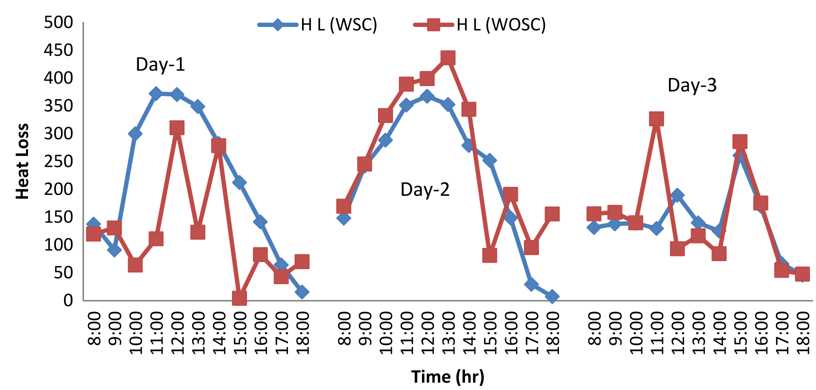

Fig. 11. Variation in heat losses from greenhouse dryers with time of the day for both the cases.

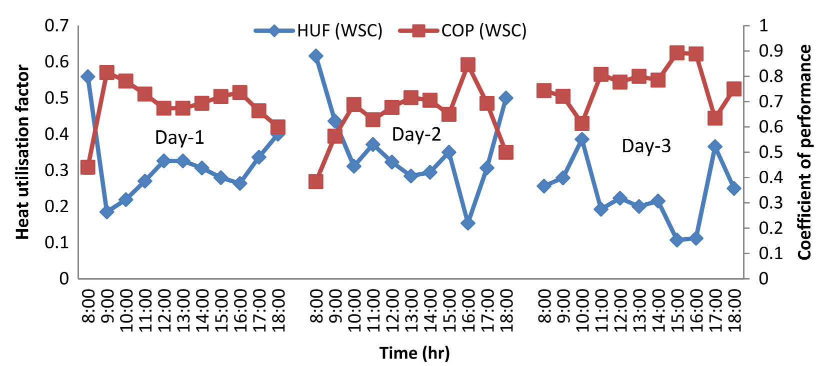

Fig. 12. Variation of heat utilisation factor and coefficient of performance with time of the day (10–12 June 2014) for Case-I.

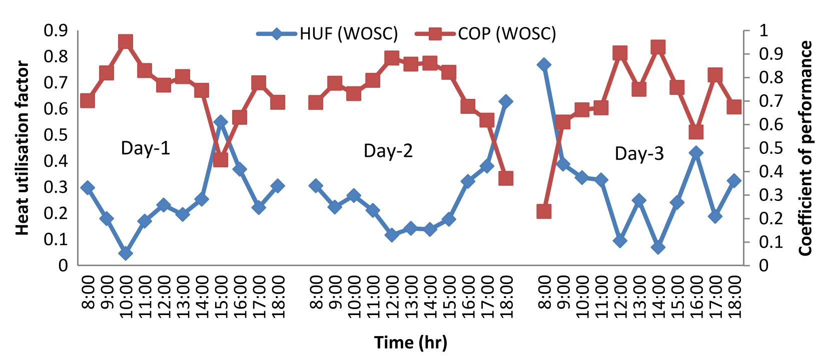

Fig. 13. Variation of heat utilisation factor and coefficient of performance with time of the day (16–18 June 2014) for Case-II.

day of the experimentation. COP variations of Case-I and Case-II were 0.440–0.815, 0.383–0.846 & 0.614–0.892 and 0.45–0.953, 0.371–0.883 & 0.230–0.929 during the experimentation for day 1, day 2 & day 3 respectively. The highest HUF i.e. 0.616 is obtained during the second day of the experiment for Case-I while for Case-II it is 0.769 in the third day of experimentation. Maximum COP achieved is 0.892 (for Case-I) during the third day of the experiment whereas 0.953 (for case-II) is obtained on the first day of the experiment.

5. Conclusion

In this experimental work, the performance evaluation of North wall insulated greenhouse dryer under natural convection mode in no-load conditions has been done in two different cases. The experimental percentage of uncertainty was found 18.91; in which 18.5 was internal and 0.4 was external uncertainty. The uncertainty analysis signifies that the observed data was precise adequate to determine the performance of NWIGHD. Result indicates that NWIGHD with solar collector was found to be most effective for drying as compared to earlier developed greenhouse dryers. It gives 65.2 °C as higher inside room temperature for greenhouse and 4.4% as lower inside room relative humidity for greenhouse during the experiment which is desirable drying condition for most of the fruit and vegetable. The selection of suitable crop for drying can be done by analysing this article's result. The radiation losses through the north wall were reduced with the help of reflector and the maximum utilisation of solar radiation was achieved. The thermal losses were also reduced by making the north wall insulated with the help of Thermocol sheet. Hence, the NWIGHD have potential to enhance the drying rate and reduce the payback period.

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