# CFD ANALYSIS AND PERFORMANCE EVALUATION OF A GREENHOUSE CONVECTION SOLAR DRYER

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**Abstract:** *This research presents a comprehensive computational fluid dynamics (CFD) analysis coupled with experimental performance evaluation of a novel greenhouse convection solar dryer designed for agricultural applications. The study aims to optimize the drying process by leveraging the principles of solar energy utilization within a controlled environment. The CFD simulations focus on the fluid dynamics and heat transfer mechanisms involved in the greenhouse convection, providing insights into the temperature distribution, air velocity, and thermal gradients. Concurrently, experimental trials are conducted to validate the CFD results and assess the practical performance of the solar dryer under varying environmental conditions.*

**Keywords:** *Solar drying, Greenhouse convection, Computational Fluid Dynamics (CFD), Heat transfer analysis Drying chamber design, Solar collector optimization*

## 1. INTRODUCTION

Industrial The increasing demand for sustainable and energy-efficient agricultural practices has spurred innovation in the field of solar drying technologies. Among these, greenhouse convection solar dryers have emerged as promising solutions for preserving agricultural produce while minimizing energy consumption. This study focuses on a comprehensive investigation through Computational Fluid Dynamics (CFD) analysis and experimental performance evaluation of a greenhouse convection solar dryer, aiming to enhance its design and operational efficiency[1]–[6].

Traditional sun drying methods are often limited by uncontrollable environmental factors, leading to inconsistent drying rates and potential spoilage of crops. Greenhouse convection solar dryers address these challenges by providing a controlled environment that harnesses solar energy for efficient drying. The integration of CFD analysis in this research enables a detailed exploration of fluid dynamics and heat transfer phenomena within the greenhouse structure. This computational approach allows for a thorough examination of temperature distribution, airflow patterns, and thermal gradients, providing valuable insights into the system's performance[7]–[10].

The experimental component of the study complements the CFD analysis by validating the simulation results in real-world conditions. Performance evaluations are conducted under varying environmental parameters to assess the solar dryer's efficiency in terms of moisture removal, drying rates, and overall energy utilization. Additionally, the influence of key design parameters, including collector area, airflow rate, and drying chamber geometry, is systematically examined to identify optimal configurations for enhanced performance[11]–[13].

The outcomes of this research are expected to contribute significantly to the advancement of greenhouse convection solar drying technology. By combining theoretical insights from CFD analysis with practical performance evaluations, the study aims to provide a holistic understanding of the system's capabilities. The ultimate goal is to optimize the solar drying process, reduce post-harvest losses, and promote sustainable agricultural practices, aligning with the broader objectives of renewable energy integration and environmental conservation[14], [15]. Therefore, meticulous attention must be devoted to sustaining these processes at their ideal operating temperatures. Within industrial facilities, the indispensability of heat exchangers becomes apparent, as they are instrumental in regulating the temperature of machinery, chemicals, water, gases, and other substances, ensuring safe and efficient operation. Furthermore, heat exchangers also contribute to energy efficiency by capturing excess heat or steam generated as byproducts during operations. This surplus thermal energy can then be repurposed elsewhere, enhancing overall operational efficiency[16].
he numerical simulations reveal the intricate flow patterns and temperature profiles within the greenhouse, facilitating the identification of potential areas for improvement in terms of uniformity and efficiency. The experimental results complement the CFD findings, offering real-world validation and showcasing the system's performance in terms of drying efficiency, moisture removal, and overall energy utilization. Furthermore, the impact of key design parameters

such as collector area, airflow rate, and drying chamber geometry on the system's effectiveness is systematically investigated[11], [17].

The synergy between CFD analysis and experimental validation provides a holistic understanding of the greenhouse convection solar dryer's functionality and performance. The findings contribute valuable insights for optimizing the design and operational parameters of such solar drying systems, thereby promoting sustainable and energy-efficient agricultural practices. This research serves as a foundation for future advancements in solar drying technology, with implications for enhancing food preservation, reducing post-harvest losses, and promoting renewable energy integration in agricultural processes[18], [19].

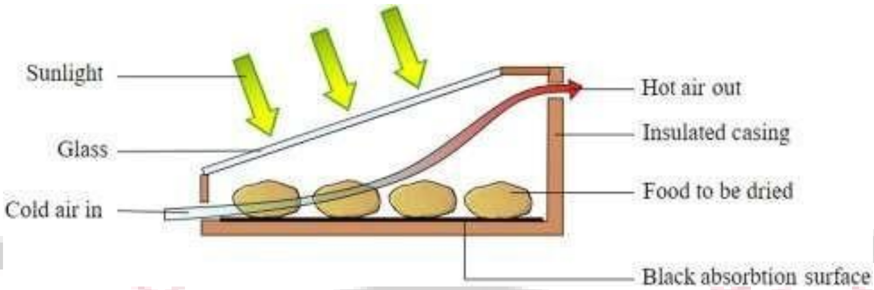


**Figure 1 Basic schematic of Solar dryer**

## 2. LITERATURE REVIEW

Richard et al. [20] (Lamrani et al., 2019) [1] The goal of this project is to use TRNSYS software to create a numerical model for trying to investigate the effectiveness of an implicit photovoltaic energy dryer for wood. To generate thermal energy, a solar compound parabolic concentrator (CPC) is used, and employee 's regular vibrant simulation results are run using Moroccan weather information. The Mean Relative Error (MRE) and the Root Mean Squared Error (RMSE) are 3.9 percent and 0.024 kg/kg, respectively, in a comparison study among both our mathematical experimental outcomes results. The effect of some operating and design specifications on drying kinetics is presented, as well as the energising achievement of the industrial drying elements.The amount of carbon dioxide (CO2) carbon output due to incomplete combustion at the supplementary heating unit is the focus of an environmental assessment. The results show that incorporating a solar panel into the dryer system reduces the auxiliary heating element system's power consumption and reduces CO2 emissions by about 34% annually.

(Kuan et al., 2019) [2] In this paper, a measurement simulation for trying to predict the electricity thermal performance compressor supported solar dryer in european environments is proposed. The model is determined by the balance of energy and mass. The energy efficiency of heat pump drying systems, photovoltaic dryers, and heating system assisted solar dryers is compared. The model was conducted in Almaty, Kazakhstan, under four different climatic conditions. When opposed to ordinary solar dryers, the heating system supported photovoltaic dryer seems to be more energy efficient, according to the simulated data. It has also been confirmed that traditional solar dryers are ineffective in continental climates with intermediate temperatures.

(Lingayat et al., 2020) [3] An indirect type solar dryer (ITSD) for drying apples and melon has been developed in this paper. The ITSD's performance as well as Watermelon and apple slices were dried in a drying chamber. Using the experimental results, the degradation rate, surface transfer coefficients, and reaction temperature of apple and cantaloupe were calculated. Since of the frequent changes in solar radiation, the average temperature inside the drying cabinet fluctuated over time. activity, according to the results of the experiments.

(Atalay, 2019) [4] The energy and and perhaps appearances of a sun drying able to integrate with a packed bed (TES) as a heat storage medium are presented in this study. The drying chamber of orange slices were studied as a case study. The goal of this research is to assess the packed bed's heat transfer possibilities by choosing to focus on electricity usage and entropy generation indicators. Experiments were conducted out twice daily. The results showed that using a solar thermal collector with a packed bed whittled down the moisture levels of orange slices from 93.5 percent to 10.28 percent (in the first experiment) and 10.76 percent (in the second).

(Bhardwaj et al., 2019)[5]The laboratory experiment of an implicit forced convection dryer with sensible heat storage material (SHSM) and phase change material (PCM) in the Himalayan meteorological environment (latitude 30.91 °N) is presented in this paper. In the solar collector, iron scrap mixed with gravel is positioned on the solar collector, and copper tubes containing engine oil are used as SHSM. In the drying chamber, the Paraffin RT-42 was used as a PCM. Experiments with drying Valeriana Jatamansi (a medicinal herb) were conducted, and the moisture content was reduced from 89 percent to 9 percent..

(Vijayan et al., 2020)[6]In this study, a reduced ambiguously defined forced convective heat transfer solar dryer with a highly permeable bed heat storage material was developed and tested for drying fenugreek slices throughout Coimbatore's environmental conditions. A solar panel with a surface area of 2 m2, a drying chamber, and a centrifugal blower make up the development setup. The exploratory study of an indirect forced convection dryer with sensible heat storage material (SHSM) and phase change material (PCM) in the Himalayan weather forecasting surroundings (latitude 30.91 °N) is presented in this paper. In the solar panel, iron scrap mixture with granular material is placed on the absorber tube, and brass tubes containing engine oil are used as SHSM.In the drying medium, the Paraffin RT-42 was used as a

PCM. Experiments with drying AzadirachtaindicaJatamansi (a medicinal herb) were undertaken, and the moisture content was reduced from 89 percent to 9 percent. When SHSM and PCM were used instantaneously, the overarching rate of evaporation was 0.051 kg/hr, almost double that of 0.028 kg/hr and 0.018 kg/hr, respectively, when no thermal storage medium was used and classical shade evaporation was used.

(Sözen et al., 2020) [7] For the developing world, clean renewable energy production is a must. Solar energy is a widely used renewable fuel that can be used to generate both electric and thermal heat. Rooftop solar approaches have the potential to be used in a variety of processes, including space process heat. Three easy and price solar air heating systems were developed and made in this study. A hollow tube heating element is the first type of heater. The 2nd heating element will have the same basic properties as the first, but in the fluid flow, iron blended seamlessly were added to improve thermal contact area.Using Computational Fluid dynamics software, a honeycomb tube-type heater was created based on simulated results. Both heaters had a drying chamber built in, and drying tests were done at three different air mass flow rates (0.014, 0.011, and 0.009 kg/s). In an iron matrix system has different heater, the peak power thermal efficiency was found to be 74.71 percent.

(Ndukwu et al., 2020) [8]With pre-treated potato slices, the paper compares an active mix-mode wind-powered fan solar dryer (AWPFS) to a detached combination non-wind-powered solar dryer (PNWPS). The two dryers were put through their paces with and without the use of glycerol as an energy storage medium. The goal was to demonstrate a non-electric sun ’s energy dryer that relied solely on clean energy sources. The dryer was tested at a room temperature of 24–50 °C and a humidity of 10–52 percent. The findings demonstrate that drying with AWPFS combined with glycerol takes less time than drying with AWPFS alone or with PNWPS. When especially in comparison to other treatments, dunking the beetroot in a saline solution and blanching for 30 seconds before drying accelerated the drying time.The energy conversion efficiency for drying ranged from 2.846 to 3.686 kWh/kg, while the total energy consumption.

(Güler et al., 2020)[9]The present study designed, analysed, assembled, and checked the double indirect solar dryer (DPISD) or a double solar thermal DPISDMA dryer with mesh absorber modification. The primary goal of this study is to use iron meshes to improve thermal efficiency of the double photovoltaic panel. The experimental investigation used specimen of de pescado fruit (Solanummuricatum L.) in two thicknesses. In addition, CFD analysis of both the solar air collection and the drying chamber was performed, as well as Quality indicators include phenolic content, flavonoids content, and antioxidant properties. Numerical simulation and experimental results revealed that mesh modification improves collector performance. DPISDMA yielded the highest average dryer efficiency of 23.08% for thin sample thickness. According to the quality analyses, the experiments performed in DPISDMA produced the best results, with the highest values of TPC, TFC, and antioxidant activity (p 0.05). Drying data from pepino fruit were modelled using eight of the most commonly used mathematical models. As a result, the best-fitting kinetics framework for all experimental tests was determined to be the Logarithmic model, which provided the most statistically reliable value systems.

(Vigneshkumar et al., 2021)[10] Solar dryers are essential in the food industry for keeping granules, vegetables, fish, and other foods safe to eat by removing moisture levels. They are superior to outdoor public drying in that they protect the food from soot, invertebrates, and other potentially harmful elements. They are also said to save more. environment for future generations from deterioration. Solar dryers of the indirect type consist mainly of a solar concentrator and a space to place grated zucchini. Their water evaporation rate is high, and the end product performance would be enhanced as well. An implicit based classification natural convection solar evaporator was fabricated in this study, and petroleum distillates was used as a phase different set (PCM) in the solar concentrator to continue improving.

(Malakar et al., 2021)[11]The current study focused on the design and advancement of a heat exchanger gadget freak drying system with a heat exchanger for drying garlic cloves. Garlic cloves (10 kg) were dried from 69 percent to 8% moisture content for the experimental performance evaluation (wb). At distinct air flow flow velocity (1, 2, and 3 m/s), the heat transfer performance of the evacuated tube dryer (ETSD) was tested in no-load and comprehensive circumstances. In the drying medium, the hottest temperature of 86.7 °C was achieved at no load with a 2 m/s air flow velocity and optimum radiation from the sun of 1204 W/m2 while the maximum height sun evening was 6.27.At a 2 m/s air flow velocity, the optimum rate of evaporation, Collector productivity, 45.86 percent, and 56 percent, accordingly, were discovered to be 1.56 kg H2O/kg dry solid/h, 45.86 percent, and 56 percent. The average energy conversion efficiency was 56.59 percent at 2 m/s, while the average exergy loss was 4.74 W at 1 m/s. ETSD was able to dry the garlic clove in less than 8 hours using a 2 m/s air velocity. The developed ESTD was discovered to have a payback period of 1.3 years.

(Sözen et al., 2021)[12]The use of renewable and clean energy sources has increased in recent years to rising energy demand and depletion of fossil fuel mineral wealth. Solar thermal systems are used to generate electricity and heat that is both clean and environmentally friendly. A single process heating element with hose absorber was built and assimilated with a drying medium in this survey. Simulation results have been used to measure the influence of the insulating plate's shape and layout in this frame of reference. Then, based on the results of the computer model, tubular solar heaters were built.In addition, aluminium wool has been inserted into the tubes to improve the system's thermal performance. Studies on drying were carried out at two different air flow rates of 0.010 and 0.013 kg/s. The accomplishment of the tubular absorbing material for solar heater was demonstrated by the numerical modelling results of this study. Moreover, the According to the findings, using aluminium wool inside the tubes improved thermal performance and reduced drying time. by 30%. For the modified dryer, average SEC values at maximum and minimum mas flow rates were 1.39 and 1.82 kWh/kg, respectively.

(Mathew & Thangavel, 2021) [13]The configuration, advancement, and effectiveness of a novel thermal energy storage interconnected ordered to evacuate tube direct absorption solar dryer were examined in this work. In the dryer's solar concentrator, a good common heat exchanger heat transfer system with thermal storage was installed. The thermal storage medium used was Therminol 55. Air mass flow rates ranging from 0.003 kg/s to 0.02 kg/s, as well as a mixture of different mass flow rates of 0.015 kg/s and 0.0065 kg/s, were used in the performance assessment. During the study, the optimum outlet temperature conveyed by the solar concentrator was 118 °C.The solar collector's ordinary energetic and exergetic efficiency ranged from 10% to 30% and 1.9 percent to 5.6 percent, respectively. Vegetables and vegetables were among the agricultural goods that were hardened in the drying chamber. This study looked at the effect of moisture diffusion coefficient variability on tomatoes and carrots, as well as the mass flow of air and commodity thickness. The Newton model accurately depicted the drying behavior of tomatoes in the sun. The consolidated flowrates method raised the average concentrator outlet temperature to 67°C, compared to 56°C with a single flow rate, and reduced drying time by 2 hours. The dryer had a 2.6-year payback period.

(Vijayan et al., 2020)[14]In this study, a low-cost ambiguously defined compelled convective heat solar dryer with a porous bed thermal energy storage medium was developed and tested for drying fenugreek slices in Coimbatore's weather conditions. A solar collector with a surface area of 2 m2, a drying chamber, and a rotational blower make up the experimental setup. The exploratory program of an informal natural convection solar dryer with thermal energy storage material (SHSM) and phase change material (PCM) in the Himalayan weather forecasting surroundings (latitude 30.91 °N) is discussed in this work. In the solar collector, iron scrap mixed with granular material is placed on the absorber surface, and metal tubes containing engine oil are used as SHSM.In the drying chamber, the Paraffin RT-42 was used as a PCM. Experiments with drying ValerianaJatamansi (a medicinal herb) were conducted, and the moisture content was reduced from 89 percent to 9 percent.

(Mathew & Thangavel, 2021)[15]The configuration, advancement, and achievement of a novel thermal storage incorporated evacuated tube heat pipe solar dryer were investigated in the present study. In the dryer's solar concentrator, a common european compressor heat pipe system with energy storage was installed. The thermal storage medium used was Therminol 55. Air mass flow rates ranging from 0.003 kg/s to 0.02 kg/s, as well as a mixture of different mass flow rates of 0.015 kg/s and 0.0065 kg/s, were used in the performance assessment. During the study, the maximum outlet surrounding temperature supplied by the solar concentrator was 118 °C.The solar collector's ordinary energetic and exergetic efficiency ranged from 10% to 30% and 1.9 percent to 5.6 percent, to between. Vegetables and vegetables were among the agricultural goods that were dried in the dryer. This study looked at the effect of condensation diffusion coefficient variability on vegetables and carrots, as well as the mass flux of air and commodity penetration depth. The Newton model accurately depicted the drying behavior of tomatoes in the sun. The consolidated flowrates method raised the ordinary recycler temperature to 67°C, compared to 56°C with a single flow rate, and reduced drying time by 2 hours. The dryer had a 2.6-year payback time.

## PROPOSED METHODOLOGY

Solar Dying is a more inventive alternative to the classic sun convective drying, in which the product is kept in a translucent tank exposed to sun. Solar Dryer differs from solar dryer in that it needs the use of a solar concentrator, the dehydration product is not exposed to bright sun, as well as the solar panel can be connected with such a control scheme.

The dimensions of the green-house solar dryer are 1.2 x 1.2 x 1.5 m, with 0.64 m for the height of the side panels from of the base, 0.01 m for the intake manifold gap on 4 corners, and 0.15 m for the masses circulating speed of the blade need radius. A transparent covering is used to encase the ceiling, allowing thermal light to penetrate the drier. The irradiation model is used to calculate the temperature of Bhopal, which is situated at 23.20°N and 77.22°E.

### Computational Fluid Dynamics Analysis of Greenhouse Solar Dryer

Mathematical modeling is the use of laptop simulations to analyse systems involving fluid movement and heat transport. The approach is extremely versatile and can be used in both commercial and quasi settings. The current study uses Finite element software fluent to do a computer simulation simulation for a greenhouses sun drying at various mass flow rates. This computational study is carried out using numerical solution such as the conservation equations, constant acceleration, and dissipation rate.

Numerical approaches for The study of flow problems is central to continuum mechanics. All Computational Fluid software includes sophisticated user interfaces for entering problem parameters and viewing results. in order to just provide quick access to their solution capabilities. To address computer simulation issues, three main aspects are used.

1) Pre-procesor,
2) Solver and
3) Post-processor.

#### Pre-procesor

Pre-processing stage involve:

- The computational domain is defined by the geometry of the area of interest.
- Grid generation — the partition of a domain into smaller units, such as a grid (or mesh) of cells (or control volumes or elements).
- Choosing which mechanical / chemical phenomena should be modelled.

- Fluid characteristics are defined.
- Determination of suitable boundary layer.

At nodes inside each cell, The channel flow resolution (velocity, pressure, temperature, etc.) is specified. The accuracy of a CFD solution is determined by the percentage of layers in the grid. In general, the greater the number of cells, the more accurate the solution. In the end, such systems will refine the grid autonomously in places with quick fluctuations. Before these approaches are strong enough to be included into commercial CFD programmers, a substantial portion of basic development and testing must be completed.

**Solver**

In Computational fluid dynamics problems a special finite difference formulation such as CFX/ANSYS, FLUENT, PHOENICS and STAR-CD.

The quantifiable information in this stage involves the following steps:

- Integration of the fluid flow regulating formulae over all of the domain's (finite) physical quantities.
- Discretization entails converting the resultant sets of equations into an analytical system.
- An incremental approach for solving mathematical equation.

**Post-processor**

The findings will be further processed and seen. We may want to observe the following at this point:

- Geometry domain
- Line and shaded contour plots
- Plots with vectors
- diagrams of contours

**Algorithm used for Computational fluid dynamics analysis:**

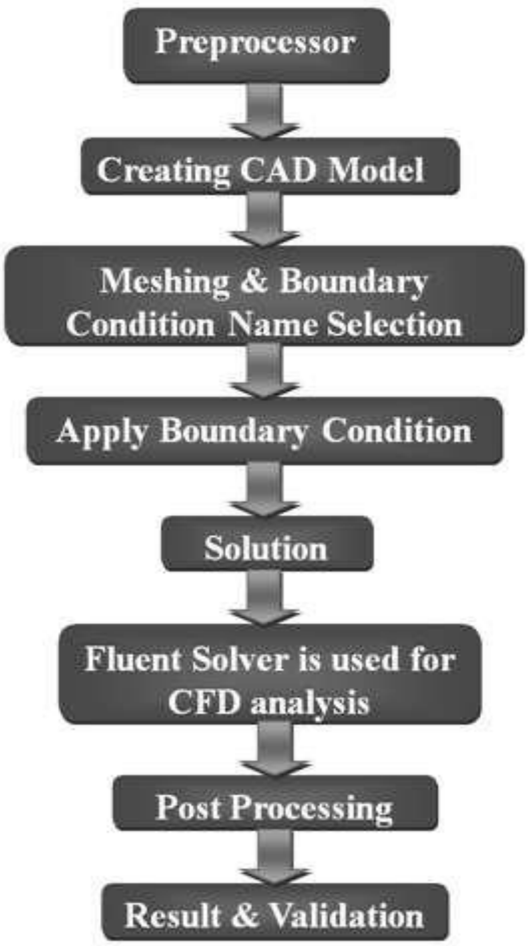


**Figure 2 Computational fluid dynamics analysis**

**Governing Equations:**

The primary goal is to investigate the thermal behaviour and velocity distribution caused by a difference in temperature in a conservatory solar drier.

**Solar load calculation:**
The solar load concept in ANSYS language can be used to estimate the effect of the sun's rays entering a computational area. For the model, there are two alternatives. The beam propagation technique is a very effective and appropriate way of using solar loading as heating systems in the new sources of energy.

**RESULTS**
The major goal of this research is to increase the warming effectiveness of a greenhouses sun drying by applying numerical simulations. For the changes in temperature inside the dryer, a commercial cfd assessment was conducted on four distinct designs of greenhouse solar dryers. To acquire the best findings, this analysis is done on the warmest day of the year (May 21st). For a better knowledge of temperature profile, three separate planes were considered: horizontal, middle, & bottom. The greenhouse solar dryer's geometrical dimensions are 1.2 x 1.2 x 1.5 m, 0.65 m for the elevation of the dividers from the ground, 0.01 m for the inlet gap on four sides of the dryer, and 0.15 m for the mass flow rate of the fan providing width. The building is covered with a polycarbonate sheet, which allows infrared radiation to enter the machine. The irradiation model is applied to the location of Bhopal, which is located at 23.25°N and 77.33°E, correspondingly. Various CFD study results are explained in this chapter utilising contours diagrams, quantitative questions, and line graph. The greenhouse solar dryer's geometrical characteristics are 1200 x 1200 x 1500mm, 0.65 m for the thickness of the side panels from the ground, 0.01 m for the inlet gap on four sides of the drier, and a negative masses fluid velocity of 0.15 m for the fan providing width. The roof of the natural greenhouse dryer was coated with a 100 m thick polycarbonate sheet, allowing radiation from the sun to enter the laundry. The with identical boundary conditions, the results of the basis study and the current work were compared. The temperature increase at mid plane for flowrate at 0.025 kg/sec is clearly noticed for both the background and the current work, with an 8.34 percentage change due to the chosen site as shown in figure no. 5.1 (a) & (b) (b). Following the verification of the baseline model, a new greenhouse solar dryer design was created and tested using numerical simulations to improve temperature difference. Because it was discovered in the base article that a 100m thick of polycarbonate sheet produces superior results in getting the highest temperatures in the Greenhouses solar dryer, the width of polycarbonate sheet in the current work was set at 100m for all configurations.

**Temperature distribution at different planes for base paper and present work**

**Tabel 1 Temperature distribution at 1.00 PM at different planes**

| **Planes considered** | **M. Purusothaman& T. N. Valarmathi** | **Present work** |
|---|---|---|
| Mid plane | 51 | 55.44 |
| Vertical plane | 48 | 55.47 |
| Bottom plane | 65 | 47.65 |

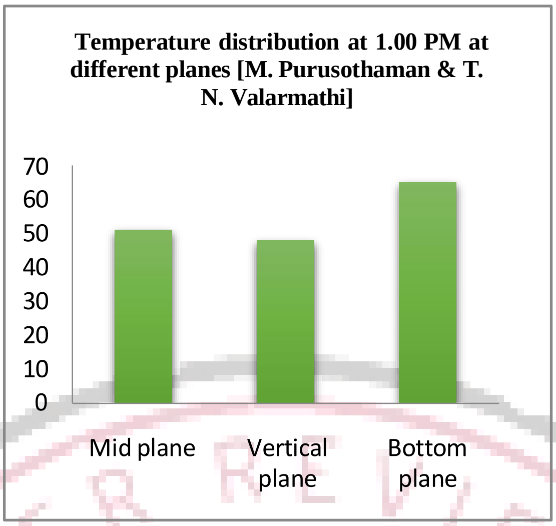


**Figure 3 Temperature distribution at 1.00 PM at different planes [M. Purusothaman & T. N. Valarmathi]**

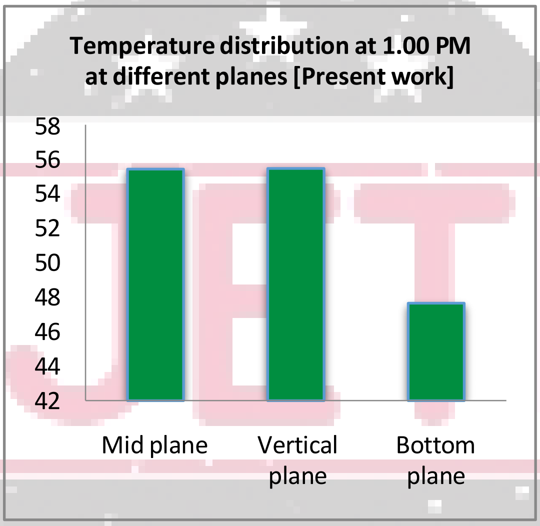


**Figure 4 Temperature distribution at 1.00 PM at different planes [Present work]**

## CONCLUSION

The For the temperature change within the dryer, a commercial cfd analysis was performed on four distinct designs of greenhouses solar dryers. To acquire the best findings, this analysis is done on the warmest day of the year (May 21st). For a better knowledge of temperature field, three separate planes were regarded: horizontal, middle, and bottom. The greenhouses solar dryer's geometric dimensions are 1.2 x 1.2 x 1.5 m, 0.65 m for the elevation of the side panels from the ground, 0.01 m for the inlet gap on four sides of the dryer, and 0.15 m for the flowrate of the fan supply width. The building is covered with a polycarbonate sheet, which allows thermal light to enter the dryer. The irradiation model is applied to the site of Bhopal, which is located at 23.25°N and 77.33°E, correspondingly. After performing a CFD analysis on a sustainable home sun drying, the following conclusions were discovered.

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