# Effect of displacing the separation plate on the heat exchange effectiveness of unglazed double skin transpired solar collector

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**Abstract.** Achieving zero-carbon or low-carbon buildings is possible by implementing innovative approaches and incorporating renewable energy sources into the building infrastructure. Thermal energy collection has become critical amid challenges such as climate change, global warming, and environmental pollution. One such thermal energy collection system is Transpired Solar Collector (TSC). TSCs are a well-proven and readily available technology and are a green energy alternative for large space heating. The utilization of Computational Fluid Dynamics (CFD) analysis for the optimization of TSC is a robust and cost-effective approach. A recent variant of TSC, the Double Skin Transpired Solar Collector (DTSC), has been studied for optimisation. The numerical simulations targeted one single parameter: distance of separation plate from the main absorber plate.

## 1. Introduction

Global energy demand is on a relentless upward trajectory, driven primarily by the rapid expansion of industrialization and urbanization. This surge in growth has led to a corresponding increase in the construction of both commercial and residential buildings, intensifying the demand for energy to power essential functions like lighting and HVAC (Heating, Ventilation & Air Conditioning) systems. The utilization of energy carries profound consequences, particularly in terms of greenhouse gas emissions. Notably, according to IEA, the building sector stands as a major contributor, responsible for a staggering 37% of global greenhouse gas emissions.

In the wide domain of building-integrated solar thermal systems, TSCs are among the most efficient. Initially designed to facilitate summer crop-drying, TSCs have undergone significant development and fine-tuning. Consequently, they can now be employed to augment indoor heating in temperate regions by supplying substantial quantities of warm air during the winter and spring seasons. Typically, TSCs can provide air that is 10–15 degrees Celsius warmer than the surrounding outdoor temperature [1]. This warm air can be directed into the building either through ducts or used to preheat HVAC systems [2]. In

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straightforward configurations, the warmer air is then delivered into the building's interior where heating is required. Heat transmission occurs continuously as air passes through the absorber plate and into the plenum, with most of the heat being localized at the air-steel interface and perforations. Heated air can be utilized to fulfil ventilation requirements [3].

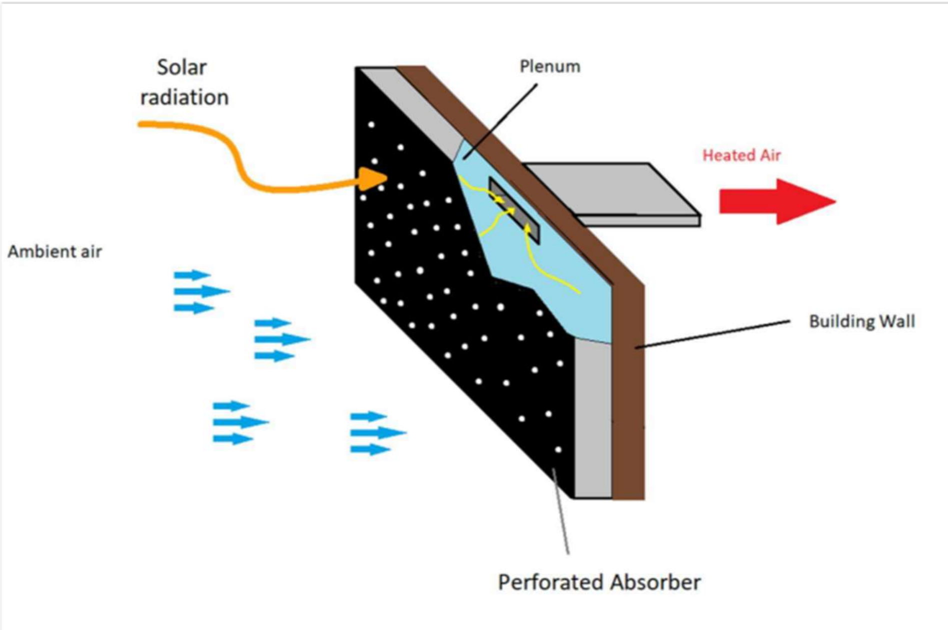


**Figure 1.** Layout of a Transpired Solar Collector

In addition to its applications in the construction industry, research has highlighted the extensive potential of TSCs in industrial operations, including drying and sterilization [4]. TSCs can effectively provide the necessary heat for these processes, diminishing the need for fossil fuels and leading to reduced operational expenses. Notably, industrial drying processes account for a significant portion, ranging from 12 to 20% of overall energy consumption [5]. In this study, a much more efficient variant of TSC, known as Double Skin TSC (DSTSC) is analysed. The ultimate objective is to establish design guidelines that optimize collector performance during the critical planning phase for engineers and architects.

This study investigates the combined effects of geometrical parameters on the performance of a double-plate solar collector. The primary focus is on the interplay between the distance between the absorber and separation plate.

## 2. Materials and Models

### 2.1 Energy Equations

Solar air collectors are often judged based on two parameters [6]; heat exchange effectiveness $\varepsilon_{HX}$ and solar collector efficiency $\eta$. These two coefficients of performance are based on energy balance equations and are used to quantify the thermal performance of TSCs in numerical results.Heat exchange effectiveness $\varepsilon_{HX}$ is defined by:

$$\varepsilon_{HX} = \frac{T_{outlet} - T_{ambient}}{T_{collector} - T_{ambient}} \tag{1}$$

where, $T_{outlet}$ is the temperature of air on the outlet (°C), $T_{ambient}$ is the temperature of ambient air (°C), and $T_{collector}$ is the temperature of the absorber plate (°C)

The solar efficiency of the collector (η) can be defined as:

$$\eta = \frac{c_{P,air}\dot{m}(T_{outlet} - T_{ambient})}{I_T A_S} \tag{2}$$

where, $c_{p,\ air}$ is specific heat capacity of air (J/kg K), $\dot{m}$ is the mass flow rate of air (kg/s), $T_{outlet}$ is the temperature of air on the outlet (°C), $T_{ambient}$ is the temperature of ambient air (°C), $I_T$ is the rate of solar radiation (W/m$^2$), and $A_S$ is the surface area of the absorber plate minus the area of perforations (m$^2$).

### 2.2 Numerical Model

A numerical model was realized in the commercial CFD software ANSYS. The governing equations were solved via ANSYS Fluent 19.0 based on the numerical finite volume method.

#### *2.2.1 Geometries*

Figure 2 shows the TSC being studied in this paper. It is an unglazed TSC that includes a separation plate. Inclusion of this separation plate makes it a Double Skin TSC (DTSC). The separation plate captures the solar radiations passing though the holes and prevents short-circuit on upper part of the absorber plate [7]. Both the absorber plate and the separation plate are made of Aluminum and are coated with black paint. The diameter of each perforation is 5mm and the pitch is 20mm.

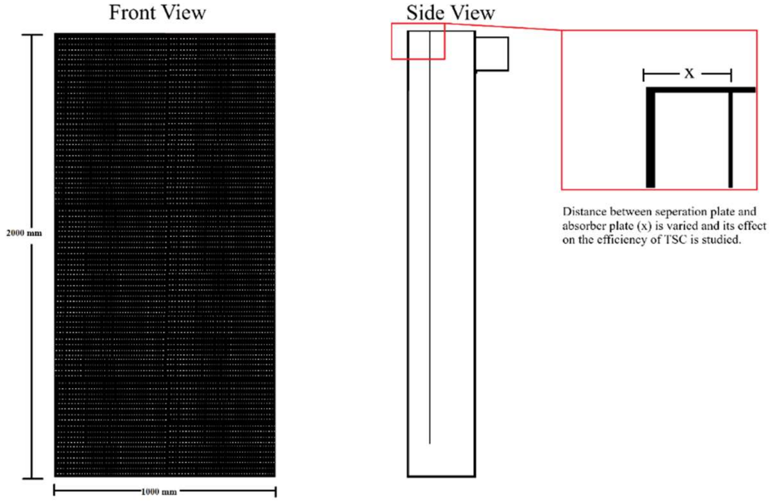


**Figure 2.** Simple schematic of UDS-TSC

Figure 2 depicts the separation distance between the absorber and separation plates, denoted by "x." To analyse the impact of varying this distance, three models with different x values (100mm, 150mm, and 200mm) were created.

The 3D geometries were created using ANSYS Design Modeler and Creo Parametric. Building a full-scale model of the TSC is impractical due to the immense computational resources required. Fortunately, research has demonstrated that a simplified model, focusing on a single longitudinal slice, can accurately predict the behavior of the entire system [8].

### *2.2.2 Model Configuration*

To achieve accurate results in our simulations, we employed ANSYS Fluent (with Fluent Meshing). A crucial role of mesh size was recognised through a mesh independence study [8]. This study revealed that a mesh comprised of 18 million tetrahedral elements offered the optimal balance between computational efficiency and capturing the crucial details of velocity and temperature gradients. In conducting CFD simulations, a steady-state condition was employed. The turbulence model selected for these simulations was the RNG k-ε turbulence model, which has been validated as suitable for TSC simulations [9]. The inlet air temperature was adjusted to 26.5°C, (standard room temperature and pressure), and approach air velocity has been set to 1.13 m/s. The absorber plate was maintained at a consistent temperature of 55°C. These specific values were determined through experimental measurements conducted on this absorber plate model [10].

## 3. Results

The analysis of numerical results was done by comparing different temperature profiles and determining the heat exchange effectiveness for each case. Three different simulations were performed.

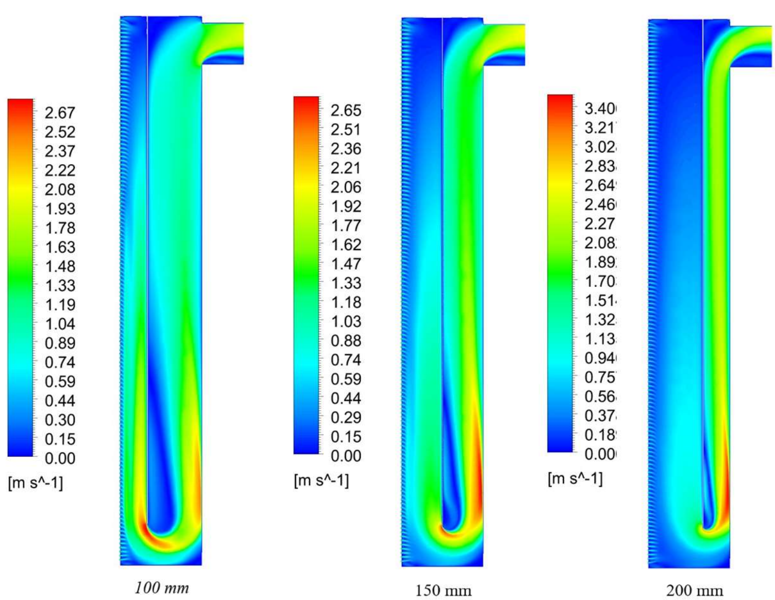


**Figure 3.** Velocity magnitude profile on median plane of UDS-TSC

Figure 3 shows the velocity magnitude profiles on median plane of UDS-TSC. It can be observed that the maximum velocity magnitude in the plenum significantly increases by just moving the separation plate 50 mm away from the absorber plate. It can also be observed that the there is a slight increase in maximum velocity magnitude if the plate is moved 50 mm towards the absorber plate.

Similarly, Figure 4 shows the temperature distribution on median plane of UDS-TSC.

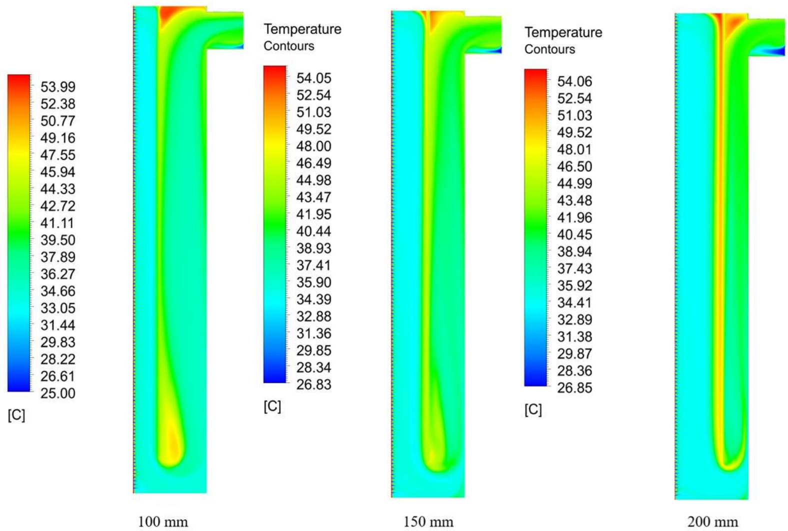


**Figure 4.** Temperature distribution on median plane of UDS-TSC

It can be observed that the UDS-TSC overheats in each case in upper part of aluminium separation plate. Though it overheats a little more in case 100 mm and case 200 mm when compared to case 150 mm.

The heat exchanger effectiveness was analysed to characterise the numerical results the performance of UDS-TSC in each case. The results are tabulated in Table 1

**Table 1.** Outlet Temperature and Heat Exchanger Effectiveness Data.

| **Distance between separation plate and absorber plate (mm)** | **Ambient air temperature (°C)** | **Absorber plate temperature (°C)** | **Outlet air temperature (°C)** | **Heat exchanger effectiveness, $\varepsilon_{HX}$** |
|---|---|---|---|---|
| 100 | 26.5 | 55 | 40.86 | 0.504 |
| 150 | 26.5 | 55 | 42.56 | 0.564 |
| 200 | 26.5 | 55 | 41.57 | 0.528 |

Table 1 shows the evolution of Heat exchanger effectiveness, and it can be noted that the UDS-TSC is most efficient if the separation plate is equidistant from absorber plate and the wall. The heat exchange effectiveness is higher when the plate is at 200 mm compared to when it is at 100 mm from the absorber plate.

## 4. Discussion

A prototype of UDS-TSC was analyzed in this study via CFD simulations. The mesh size of 18 million tetrahedral was deemed sufficient for a global analysis of UDS-TSC to accurately predict the temperature and velocity profiles. Furthermore, for validation purposes, the obtained results were compared with those presented in reference [7].

The aim of these simulations was to determine whether displacing the separation plate had any impact on the thermal performance of a UDS-TSC. Consequently, the results have shown that moving the separation plate towards or away from the absorber plate does negatively affects the performance of the UDS-TSC. This is because a UDS-TSC is susceptible to overheating when the plate is at any distance from the absorber plate. However, overheating is minimum when the plate is in the middle of the plenum. Additionally, the highest heat exchanger effectiveness was observed when the separation plate was at 150 mm.

Owing to limited computational capabilities, the numerical study was performed in steady-state conditions, as the time step is too small. In this study, the wind influence was also not considered due to high computational costs.

## 5. Conclusion

The CFD simulations performed in this study successfully analyzed the impact of separation plate displacement on the thermal performance of a UDS-TSC prototype. The results revealed that the optimal position for the separation plate is equidistant between the absorber plate and the enclosure wall, achieving the highest heat exchanger effectiveness (0.564) at 150 mm distance.

Moving the plate closer or further from the absorber plate in either direction resulted in decreased performance and overheating in the upper part of the aluminum separation plate. Improving airflow patterns and minimizing stagnation zones surrounding the separation plate by optimizing the plenum design will help combat this overheating. This could involve strategically shaping the plenum to promote more uniform airflow distribution and prevent pockets of stagnant air that contribute to overheating.

Future research can also focus on optimizing the plenum in such a way that this useful heat can be directed into the duct so to increase the heat exchanger effectiveness. While the simulations were limited to steady-state conditions due to computational constraints, they effectively demonstrated the importance of separation plate positioning for UDS-TSC performance. Future studies incorporating wind influence and transient simulations would provide a more comprehensive understanding of UDS-TSC behavior under real-world conditions.

## References

[1] S. Tajdaran, F. Bonatesta, R. Ogden, and C. Kendrick, “CFD modeling of transpired solar collectors and characterisation of multi-scale airflow and heat transfer

mechanisms," *Solar Energy*, vol. 131, pp. 149–164, Jun. 2016, doi: 10.1016/j.solener.2016.02.042.

[2] R. Hall, X. Wang, R. Ogden, and L. Elghali, "Transpired solar collectors for ventilation air heating," *Proceedings of the Institution of Civil Engineers - Energy*, vol. 164, no. 3, pp. 101–110, Aug. 2011, doi: 10.1680/ener.2011.164.3.101.

[3] S. Tajdaran, F. Bonatesta, R. Ogden, and C. Kendrick, "CFD modeling of transpired solar collectors and characterisation of multi-scale airflow and heat transfer mechanisms," *Solar Energy*, vol. 131, pp. 149–164, Jun. 2016, doi: 10.1016/j.solener.2016.02.042.

[4] W. Bandara, B. Amarasekara, and C. Rupasinghe, "Assessment of the possibility of unglazed transpired type solar collector to be used for drying purposes: a comparative assessment of efficiency of unglazed transpired type solar collector with glazed type solar collector," *Procedia Eng*, vol. 212, pp. 1295–1302, 2018, doi: 10.1016/j.proeng.2018.01.167.

[5] K. A. Jimoh, N. Hashim, R. Shamsudin, H. C. Man, M. Jahari, and D. I. Onwude, "Recent Advances in the Drying Process of Grains," *Food Engineering Reviews*, vol. 15, no. 3, pp. 548–576, Sep. 2023, doi: 10.1007/s12393-023-09333-7.

[6] X. Wang, B. Lei, H. Bi, and T. Yu, "A simplified method for evaluating thermal performance of unglazed transpired solar collectors under steady state," *Appl Therm Eng*, vol. 117, pp. 185–192, May 2017, doi: 10.1016/j.applthermaleng.2017.01.053.

[7] C. Berville, A. Tetang Fokone, C. I. Sima, and C. V Croitoru, "Mesh independency study for an unglazed transpired solar collector," *IOP Conf Ser Earth Environ Sci*, vol. 664, no. 1, p. 012059, May 2021, doi: 10.1088/1755-1315/664/1/012059.

[8] C. Berville, F. Bode, and C. Croitoru, "Numerical Simulation Investigation of a Double Skin Transpired Solar Air Collector," *Applied Sciences*, vol. 12, no. 1, p. 520, Jan. 2022, doi: 10.3390/app12010520.

[9] Y. Wang, A. Shukla, and S. Liu, "A state of art review on methodologies for heat transfer and energy flow characteristics of the active building envelopes," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 1102–1116, Oct. 2017, doi: 10.1016/j.rser.2017.05.015.

[10] S. Tajdaran, F. Bonatesta, R. Ogden, and C. Kendrick, "CFD modeling of transpired solar collectors and characterisation of multi-scale airflow and heat transfer mechanisms," *Solar Energy*, vol. 131, pp. 149–164, Jun. 2016, doi: 10.1016/j.solener.2016.02.042.