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An experimental and numerical study to compare evacuated tube collectors and flat plate collectors for tent cooling in the Iraqi climate

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Abstract

This paper compares Flat Plate Collector and Evacuated Tube Collector: their thermal performance, cooling capacity, cost and applicability as a tent in a warm climate. Case studies of two field installations in Iraq. In August 2022, there was a field installation that used Flat Plate Collector with evaporative cooling in Anbar. In August 2025, a field installation of Evacuated Tube Collector was completed at Nasiriya with absorption cooling. In a site in Anbar, the Flat Plate Collector system was able to successfully lower the inner tent temperatures by 6–8 °C, Record outlet water temperatures of 40–65, and thermal efficiency of about 45%. Evacuated Tube Collector sys. in Nasiriya matched an average efficiency of 62% and generated greater outlet temperatures of 55-90 °C (average 71 °C), which facilitated. Due to the Evacuated Tube Collector having a higher output temperature and a stable efficiency under strong solar radiation, they are suitable for the cooling based on absorption in long lasting or semi-permanent camps. The Flat Plate Collector offer an easy and inexpensive solution that is more appropriate for faster deployment in humanitarian situations where evaporative cooling can.

Introduction

Thermal comfort in shelters is a big challenge. Tents are among the most readily available structures used in shelters and emergency or temporary accommodation due to their easy transport and speed of installation in any zone. Displacement of population is significant in case of some event like earthquake or flood or even war. The tent material is incapable of catering to the internal environment of occupants in a range of climatic conditions. For instance, during chilly weather when the outside temperature is below freezing, the fabric of the tent is not able to create an appropriate temperature inside. Likewise, in temperatures, the temperature surges to high levels causing discomfort to the occupants of the tent. In addition, tents are poorly insulated; the fabric with which their walls are made is not enough to maintain a comfortable temperature inside the tent.

The tents also remain poorly ventilated which further exacerbates the problem of the occupants. As a result, you must make efforts to provide a suitable internal environment during climate fluctuation periods.

The focus of research to date has been the use of solar for heating and cooling plus maximizing the possibility of getting electricity from solar power[3]. It is worth noting that Iraq is a country hot summer with the ambient temperature exceeding 45°C in most parts of the country. This has caused many solar energy experts to utilize this heat for cooling. There are two types of collectors that are used in solar thermal, namely flat panel collector (FPC) and evacuated tube collector (ETC). A flat plate collector consists of an insulator, translucent cover, and a flat absorber etc. Flat plate collectors are strong and economical. When the temperature increases, collectors lose significant amounts of heat. Even a little rise in temperature makes these collectors work efficiently [4]. In contrast, evacuated tube collectors use vacuum-sealed glass tubes, which greatly reduces heat loss and allows for consistent efficiency and higher temperatures in harsh environments [5]. This study presents an experimental comparison between flat panel collectors and evacuated tube collectors for tent cooling in Iraq's hot climate. To provide recommendations for system selection under different climatic and financial constraints, the research aims to highlight differences in thermal efficiency, the possibility of integrating cooling, cost, and practical feasibility.

Although the research on the topic of solar thermal collectors and the solar-assisted cooling technologies is vast, it seems that the number of the experimental studies on the use of solar-driven cooling systems as a specific one aimed at the humanitarian relief tents is rather scarce. The majority of the past studies have been made on permanent constructions or greenhouse use with little consideration on lightweight tents in the real field conditions. In addition, comparative evaluations that examine the appropriateness of various kinds of solar collectors in the cooling of tents, in the light of thermal efficiency as well as the feasibility of real-world application are limited, especially in the climatic environment of southern Iraq. Thus, the current research is supposed to fill this gap as it is going to experimentally assess the performance of a solar-assisted cooling system to a relief tent, including the enhancement of the indoor temperature, indicators of comfort, and practical applicability. The results add new information to the viability of implementing solar cooling technologies in the use of humanitarian shelters in hot climatic conditions.

Literature Review

Although solar thermal collectors have been extensively studied for heating applications, nothing is known about their potential for tent cooling. The most pertinent research on solar-assisted cooling systems, evacuated tube collectors (ETCs), and flat plate collectors (FPCs) is summarized below. In Baghdad, Iraq, Rashid and Aljubury (2022) conducted a combined experimental and numerical analysis on a PV-powered evaporative cooling system intended for relief tents. Photovoltaic panels provided solar electricity for the system, which used submersible pumps to move well water across wetted cooling pads. In August, field measurements showed that the inside temperature was consistently lower than the outdoor temperature by 6–8 °C. Numerical simulations confirmed the findings and showed improvements in thermal comfort indicators, with the Predicted Percentage of Dissatisfied (PPD) sharply declining and the Predicted Mean Vote (PMV) approaching neutral. These technologies, according to the scientists, offer a workable and affordable option for humanitarian relief efforts in hot regions [1]. The effectiveness of evacuated tube collectors (ETCs) in actual weather conditions in Greece was examined by Souliotis et al. (2017). Direct water heating was used in their experimental setup, and flow rate and inlet–outlet temperature were measured at various irradiance levels. According to the study, ETCs routinely produced outlet temperatures that were higher than those of flat plate collectors working in comparable circumstances—up to 90 °C. The vacuum insulation significantly decreased thermal losses, resulting in a collector efficiency of about 60% when operating at high temperatures. The study emphasized that ETCs are appropriate for uses like industrial drying or absorption cooling that call for steady, high-temperature output [7]. In an experimental comparison of FPCs and ETCs in Turkey, Yildiz et al. (2018) examined thermal performance in several seasons. According to their findings, FPCs performed well at modest to moderate temperature lifts, with efficiencies ranging from 45 to 55%. However, when the temperature differential between the absorber and ambient grew, performance drastically declined. On the other hand, at higher output temperatures (>70 °C), ETCs maintained efficiencies above 60%. The researchers came to the conclusion that while FPCs are still useful for low- to medium-temperature applications like household hot water or evaporative cooling, ETCs are better suited for applications requiring high and consistent thermal output, like driving absorption chillers [8]. A thorough analysis of solar cooling technologies was provided by Allouhi et al. (2015), with a focus on collector-driven absorption and adsorption systems. Their research demonstrated how the type of solar collector selected directly affects the system's reliability and Coefficient of Performance (COP). They pointed out that although though FPCs are inexpensive, their output is unstable when the weather changes, which lowers COP in absorption cooling. On the other hand, ETCs greatly enhance the stability and performance of solar cooling systems due to their lower thermal losses and higher outlet temperatures. According to the review, FPCs are suitable for hybrid evaporative systems, whereas ETCs are better suited for advanced cooling approaches [9]. The use of selective coatings, enhanced vacuum sealing, and heat-pipe integration were among the design innovations in evacuated tube collectors that Amrizal et al. (2021) concentrated on. They concluded that ETCs consistently provide superior thermal efficiency under both direct and diffuse radiation after summarizing results from more than 100 experimental and numerical research conducted worldwide. Additionally, the study emphasized how well they operate throughout the year, particularly in regions with variable weather. The authors concluded that ETCs are perfect for situations where high outlet temperatures and long-term stability are crucial after highlighting the trade-off between increased cost and greater thermal output [10]. Practical needs for shelter cooling systems in humanitarian operations were described by UNHCR (2019).

These include ease of installation, durability, portability, and little maintenance. The manual emphasized that technical superiority alone is insufficient if systems are unstable or logistically difficult, even though it is not a technical study of collectors. This recommendation is in line with the relative benefits of FPCs over ETCs, which include their greater mechanical strength, lower transportation costs, and simpler deployment. Therefore, despite their reduced efficiency, FPCs may occasionally be more suited from the standpoint of humanitarian logistics [11]. Aggarwal et al. (2023) examined current developments in ETCs, specifically the incorporation of improved coatings, phase-change materials, and nanofluids. When compared to traditional working fluids, their research revealed efficiency gains of up to 10–15%. The scientists pointed out that these developments might allow ETCs to be used in industrial and cooling processes in addition to household hot water. They did, however, caution that there are still unresolved issues with long-term dependability, the cost of sophisticated coatings, and nanofluid stability [12]. Rajamurugu et al. (2024) investigated how structural and material changes could enhance flat plate collector performance. In comparison to conventional water-based systems, their experiments showed that micro-channel absorber plates and nanofluid-based working fluids improved collector efficiency by 8–12%. They contended that these advancements make contemporary FPCs more competitive for moderate-temperature applications, such as solar-assisted evaporative cooling, by closing the efficiency gap between FPCs and ETCs [13]. The techno-economic and environmental features of ETC-based solar air collectors were evaluated by Dabra et al. (2024). Air temperature increases of 7.2–13.7 °C were found in field tests, allowing pre-cooling or pre-heating applications. Environmental assessment revealed considerable CO_2 emission savings over the system lifespan, while economic research revealed a payback period as low as 1.5 years. Their research confirmed that ETCs are economically and environmentally feasible to scale in big deployments in addition to being efficient [14].

Aljubury and Ridha (2017) conducted an experimental investigation into the impact of employing an indirect/direct evaporative cooling system on improving the greenhouse's thermal conditions. The cooling system was made up of three cellulose pads, each three centimeters thick, in the direct cooling stage and one heat exchanger in the indirect cooling stage. In the suggested cooling system, subterranean water was used as an operating fluid at a rate of 2 L/s in the indirect cooling stage's heat exchanger and 3 L/s in the direct cooling stage's cellulose pads. The studies were carried out in Baghdad City throughout the summer of 2015 (July to August). The results of the trial showed that, in comparison to the direct evaporative cooling system's efficiency of 77.5%, the indirect/direct evaporative cooling system increased system efficiency by up to 108%.

In conclusion, research shows that while FPCs continue to be useful for inexpensive, reliable, and quickly deployable evaporative cooling solutions, ETCs offer better thermal performance, stability, and suitability for absorption cooling. This dual viewpoint is especially crucial for applications involving humanitarian shelters, where logistical viability and technological performance must be taken into account.

Methodology

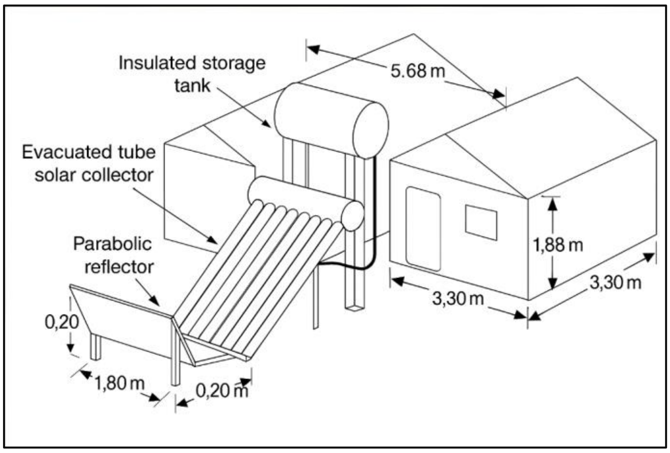
A pilot study was conducted in August 2025 in Nasiriyah, southern Iraq, to compare it with a study conducted by M. A. Rashid and I. M. A. Al-Jubouri [1] in August 2022 in Anbar, Iraq, to provide cooling for a humanitarian relief tent using a solar-powered cooling system. The difference is that the previous study used solar panels, while the current study used a solar system with evacuated tubes.

The same working hours and days were selected, with temperatures exceeding 40°C and solar irradiance ranging between 800 and 950 W/m².

Table 1: Specifications of photovoltaic panels[1]

Dimensions (Hight×Width× Thickness) (mm)	1480x680 x 35 mm
Peak power	130 W
Number of panels	6
Open circuit voltage	21.96 V
Short circuit current	8.46 A
Rated voltage	17.46 V
Rated current	7.45 A
Power output tolerance	5%
Maximum system voltage	600 V

An evacuated tube collector (ETC) system integrated with evaporative cooling as show in fig 2.



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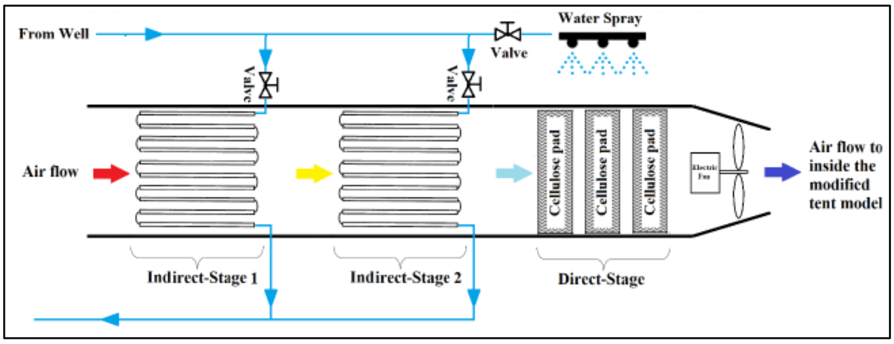


(b)

Figure 1: (a) Schematic diagram of evacuated tube system (b)Schematic diagram of the proposed evaporative cooling system[1].

Figure 2: evacuated tube with reflocter.

The practical study was conducted in both cases on an emergency relief tent (as shown in Figure 3) with approximate dimensions of 5.68 × 3.3 × 1.88 meters, made of lightweight PVC-coated fabric with very limited insulation. The assumption was that the tent would house four occupants, who would be engaged in light activity and wearing light summer clothing. [2].

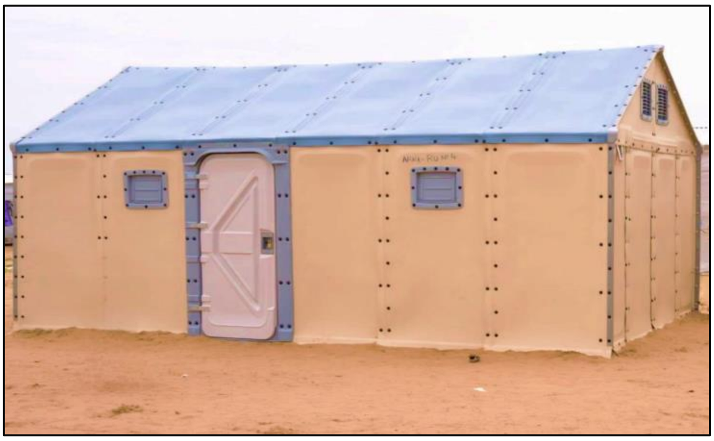


Figure 3: emergency relief tents used in both study[2].

Solar Collector Configurations

Two solar collector technologies were deployed as in table (2)

Table-2: The characteristics of two collector technologies.

Feature	Flat Plate Collector (FPC – Anbar, 2022)	Evacuated Tube Collector (ETC – Nasiriyah, 2025)
Design	Conventional glazed design	Vacuum-sealed tube array
Effective aperture area	≈ 6 m^2	≈ 3 m^2
Collector configuration	Single flat plate	10 tubes, 1.8 m length, 58 mm diameter
Outlet water temperature	40–65 °C (average ≈ 52 °C)	55–90 °C (average ≈ 71 °C)
Main application	Evaporative cooling pads	LiBr–water absorption chiller
Operating requirement	Moderate temperature enhances evaporation efficiency	High inlet temperature required for chiller operation

Cooling System Configurations

The collectors were coupled with different cooling technologies, reflecting their thermal characteristics:

Anbar (2022): FPC + Evaporative Cooling → requires water in the range of 35–45 °C.

Nasiriyah (2025): ETC + Absorption Cooling → requires water in the range of 70–90 °C.

This setup enables a direct comparison between low-cost evaporative cooling and high-performance absorption cooling in tent environments.

Climatic Measurements

Both Anbar (2022) and Nasiriyah (2025) used portable weather stations with sensors for air temperature, sun irradiance, and wind speed to measure the local climate. Throughout August, which is Iraq's hottest month of the year, measurements were taken continuously. The following representative values were employed in the analysis:

G (Solar irradiance): peak averages around 850 W/m².

Ta (Ambient temperature): between (39–45 °C), with an average of ~40 °C.

Wind speed: typically <2 m/s during daytime.

3.5 Thermal Performance Model

The thermal performance of both collectors was evaluated using the Hottel–Whillier–Bliss (HWB) model[17][18]:

$$Q_u = A_c F_r [S - U_L (T_i - T_a)] \quad (1)$$

Where: Q_u: useful heat gain (W),A_c= collector area (m²), F_r: heat removal factor,S: absorbed solar radiation (W/m²), U_L: overall heat loss coefficient (W/m²·K), T_i: inlet fluid temperature (°C), T_a: ambient air temperature (°C).

The instantaneous efficiency was calculated as:

$$\boldsymbol{\eta} = \frac{Q_u}{A_c\, G} \quad (2)$$

Where G is the incident solar irradiance (W/m²).

3.6 Performance Indicators

The comparison between the two systems was based on the following indicators:

Collector thermal efficiency (η).

Daily useful heat gain (kWh/day).

Average and peak outlet fluid temperature (°C).

Indoor tent temperature reduction (ΔT).

Cooling capacity (kW).

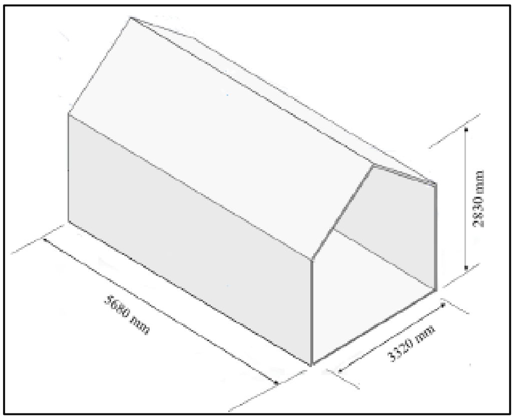
Economic feasibility (initial cost, robustness, ease of maintenance).

Simulation Tools

To validate and complement the field measurements, numerical simulations were carried out for both case studies using different approaches:

Anbar (2022): A customized Fortran program was developed to model the thermal performance of the flat plate collector and its integration with evaporative cooling pads. The program was based on energy balance equations and heat transfer correlations, enabling calculation of outlet water temperatures and collector efficiency under varying climatic inputs as in fig (4a).

Nasiriyah (2025): A SimScale CFD model was applied to simulate the ETC–absorption cooling system. The platform provided detailed insights into airflow patterns, heat transfer inside the tent, and temperature reduction achieved under field operating conditions, serving as validation for experimental measurement as in fig (4b).



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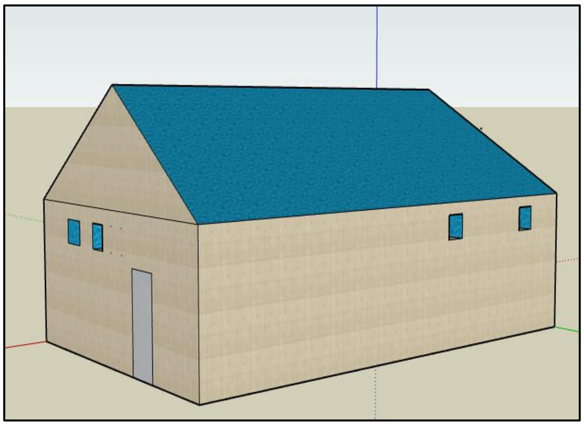

(b)

Figure 4: Schematic diagram of the studied case

Uncertainty Analysis

The uncertainty analysis was performed in order to determine the validity and correctness of the experimental measurements applied in the present research. A digital sensor with the accuracy of +-0.5 oC was used to measure temperature. A pyrometer was used to measure solar irradiance at an uncertainty of +-3% and measurement of airflow velocity in an uncertainty of +-5%. The general uncertainties of the calculated parameters, useful heat gain, and cooling effectiveness, were evaluated in the root sum square (RSS) technique. According to this method, the uncertainty of measurements of air temperature in indoor air was in the range of +-0.6 degC, and the uncertainty of the calculated collector efficiency was not more than +-6%. These are the uncertainty levels that can be accepted in outdoor experiment work with the use of solar thermal systems and do not influence the tendencies that should be observed considerably and the comparison of flat plates and evacuated tube collector systems.

Results and Discussion

The comparison between Anbar (2022) and Nasiriyah (2025) highlights the influence of collector type, cooling method, and simulation approach on the thermal performance of humanitarian tents.

In Anbar (2022) as in fig (5), the flat plate collector (FPC) system delivered outlet water temperatures between 40–65 °C, averaging 52 °C, with a thermal efficiency of about 45% and a daily useful heat gain of approximately 24.3 kWh. When coupled with evaporative cooling pads, this performance resulted in an indoor temperature reduction of 6–8 °C. To ensure reliability, the results were not only measured in the field but also validated using a Fortran-based numerical program. The program applied energy balance and heat transfer equations to predict collector outlet temperatures and efficiencies, and the outputs closely matched the experimental measurements. This dual approach confirmed the suitability of FPCs as a low-cost and robust solution for short-term deployments. In Nasiriyah (2025) as in fig (6), the evacuated tube collector (ETC) system achieved significantly higher outlet water temperatures, ranging from 55–90 °C (average 71 °C, peak 88 °C), with an efficiency of about 62% despite its smaller aperture area (~3 m² compared to 6 m² for FPCs), which reduced indoor tent temperatures by 8–11 °C. Here, validation was conducted using SimScale CFD, which provided detailed visualization of airflow, heat distribution, and indoor comfort levels. The simulation confirmed the experimental findings and demonstrated the advantages of ETCs for stable high-temperature applications. From an economic standpoint, the Anbar FPC system required lower installation costs and minimal maintenance, while the Nasiriyah ETC system, although technically superior, involved higher costs and greater operational complexity. This trade-off suggests that FPCs remain ideal for short-term emergency response, whereas ETCs are more suitable for long-term or semi-permanent camps where advanced absorption cooling can be justified.

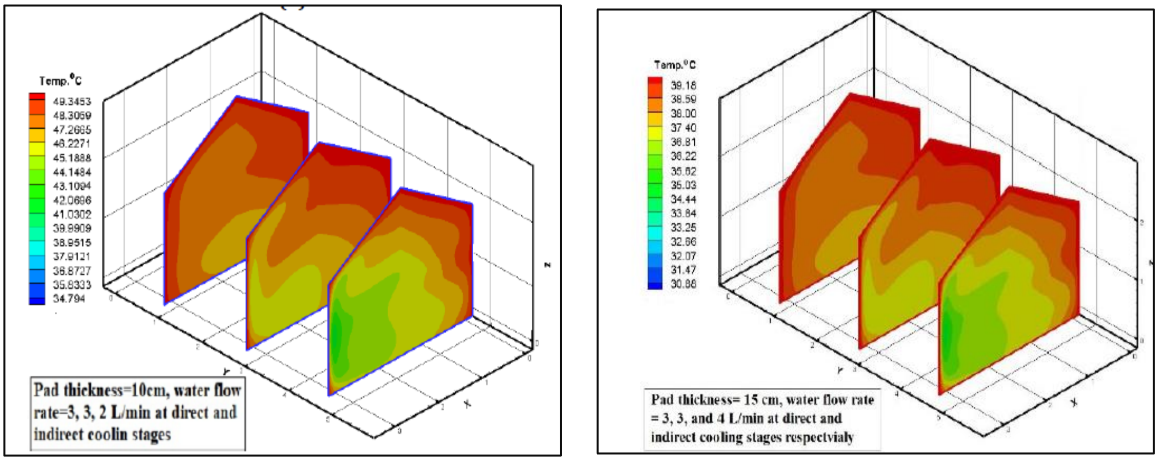

Figure 5: Temperature distribution inside the modified tent model along its axis at peak hour, one pad with 15 cm thickness, the water flow rate of (3, 3, and 4) lpm in the direct stage, first, and second coils of the indirect stage, respectively, Distribution a along the x-axis[1].

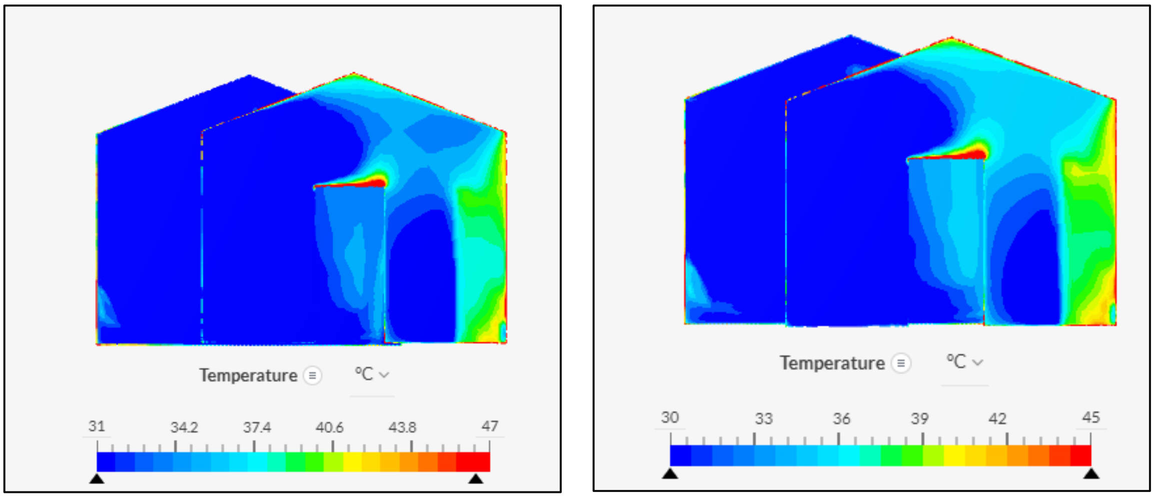

Figure 6: Temperature distribution inside the modified tent model along its axis at peak hour Distribution along the x-axis

Conclusion

In this paper, the authors have provided a two-way analysis of the solar cooling solutions, specifically flat plate collector-driven evaporative cooling systems in Anbar (2022) and evacuated tube collector-driven absorption cooling systems in Nasiriya (2025), and compared them to humanitarian relief tents in Iraq. The comparison brings a great understanding of the appropriateness of various solar technologies in different climatic conditions, economic conditions, and the conditions of operations. The experiment revealed apparent variations in thermal collector performance. The flat plate collectors used in Anbar attained an average outlet temperature of about 52 oC at an average daily useful heat gain of 24.3 kWh and an average thermal efficiency of about 45%. Only evacuated tube collectors in Nasiriya provided much more thermal output with an average outlet temperature of 71 oC and a top temperature of 88 oC and a higher efficiency of around 62 even though the aperture of the collectors is much smaller. These results support the high performance of ETCs as it can be utilized in applications with high and constant operating temperatures. When compared to other cooling methods, the FPC-based evaporation cooling system at Anbar decreased the indoor tent temperature by 6-8 oC, indicating the feasibility of the low-cost solar-powered evaporative cooling system in direct use by humanitarian organizations. In the meantime, the ETC-based system of absorption cooling in Nasiriya produced larger temperature decreases of 8-11 oC, which indicates that evacuated tube collectors can be used to sustain high-technology cooling systems like absorption chilling in hot climates. Economically and practically, the findings suggest the obvious trade-off between the performance and the deplorability. The FPC-evaporative cooling system has a good ratio of price, simplicity and efficiency in cooling, it is more applicable in emergency response operations that require quick responses and short term relief operations. The ETC-absorption cooling system on the other hand has greater thermal and cooling performance and is however more expensive to capitalize and more complex in terms of the system thereby making it more suitable to long-term or semi-permanent humanitarian camps where increased indoor comfort and system life are worth the investment. On the whole, the research proves that the use of solar-based cooling technologies can have a significant positive influence on the temperature conditions indoors of humanitarian relief tents, when properly balanced with the characteristics of the work and the available logistics. The next task that should be performed in the future is the extension of the analysis of the year-round operation, the implementation of thermal energy storage that will enhance the continuity of the system, and the analysis of hybrid cooling designs that should integrate evaporative and absorption-based cooling systems. Moreover, it is suggested to include life-cycle cost assessment and occupant-based comfort surveys to facilitate the large-scale application and make informed decisions in humanitarian shelter utilization.

Nomenclature

Symbol	Description	Unit
Ac	Collector aperture/absorber area	m^2
Fr	Heat removal factor	–
G	Incident solar irradiance	W/m^2
Qu	Useful heat gain	W
S	Absorbed solar radiation	W/m^2
Ta	Ambient air temperature	°C
Ti	Inlet fluid temperature	°C
To	Outlet fluid temperature	°C
UL	Overall heat loss coefficient	$W/m^2 \cdot K$
η	Collector thermal efficiency	%
ΔT	Indoor temperature reduction in tent	°C
ETCs	evacuated tube collectors	
FPCs	flat plate collectors	
COP	Coefficient of Performance	

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