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Design and construction of a solar air heater using recycled materials

A project submitted in partial fulfillment of the requirements for the degree of Bachelor in Mechanical Engineering

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بسم الله الرحمن الرحيم

قال تعالى:

{يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ}

صدق الله العلي العظيم

سورة المجادلة آية"11"

Acknowledgment

قال تعالى:

﴿قُلْ هُوَ الَّذِي أَنْشَأَكُمْ وَجَعَلَ لَكُمُ السَّمْعَ وَالْأَبْصَارَ وَالْأَفْئِدَةَ قَلِيلًا مَا تَشْكُرُونَ﴾. [الملك: 23] .

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Abstract

This project presents the design and construction of a solar air heater utilizing recycled materials, specifically soda cans and disposable aluminum bowls, as absorber elements. The primary objective is too cost-effective and an environmentally friendly solar air heater by repurposing waste materials, thereby reducing landfill burden and promoting sustainable engineering practices.

The experimental work involved constructing several configurations of solar air heaters, each employing different recycled components as the absorber. Performance was evaluated under both natural and forced convection conditions. Key parameters measured included temperature rise, heat transfer rate, and air velocity, using digital thermometers and anemometers.

Results demonstrated that solar air heaters made from recycled soda cans and aluminum bowls can effectively increase air temperature and provide useful heat, with forced convection generally enhancing performance compared to natural flow. The study highlights the potential of recycled materials in renewable energy applications, offering a practical solution for waste reduction and energy efficiency. The findings support the integration of recycling and renewable energy technologies to address environmental challenges and promote resource conservation.

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Chapter One: Introduction

1.1. Background

Reliable, affordable, and sustainable energy is the cornerstone of modern development and it remains unevenly distributed. Globally, roughly 675 million people still lack access to electricity, while many more face intermittent supply or tariffs that strain household budgets [1]. Iraq illustrates the depth of this challenge: national generating capacity lingers near 18 GW, whereas peak demand approaches 36 GW, forcing rolling blackouts and driving electricity prices to about 15 000 IQD per 1500 kWh. [2] This persistent shortfall reinforces dependence on diesel generators, inflates carbon emissions, and constrains socioeconomic growth. Accelerating the transition to renewable energy is therefore both an environmental imperative and a human-development priority.

Figure (1-1) solar air heater.

Among available renewables, solar energy is uniquely positioned to close the supply gap. In just ninety minutes, the sun bathes Earth in more energy than humanity consumed during the entire year 2001[3], and insolation levels across the Middle East are among the world’s highest. Solar technologies fall into two principal families: photovoltaics, which convert light directly into electricity, and solar-thermal systems, which capture heat. Solar air heaters (SAHs) is a subset of solar-thermal devices and offer an elegant, low-tech route to space heating, crop drying, and preheating of combustion air for industry, Figure (1-1). Because SAHs operate at moderate temperatures and use air rather than water as the working fluid, they can be fabricated locally with modest skills and maintenance requirements, making them attractive for off-grid and cash-constrained settings. In addition, the promise of solar energy intersects with a second, equally urgent global issue: waste management. Urbanization and consumerism have driven worldwide municipal solid-waste generation beyond 2 billion tonnes per year, with millions of tonnes of metals, plastics, and glass relegated to landfills or incinerators [4].

Recycling is widely promoted as a remedy—the energy saved by recycling aluminum, for instance, reaches ≈ 95 % relative to primary smelting [5] but current recycling practices often fall short of their environmental potential. In Iraq and many other developing economies, informal smelting yards rely on low-efficiency furnaces that emit particulates, heavy-metal fumes, and dioxins, compromising air quality and worker health (Fig. 1-2). Moreover, melting and casting still demand substantial fuel or electricity, eroding the very energy gains that make recycling attractive.

Combined the energy imperative to waste reduction unlocks a synergistic pathway: manufacture solar air heaters from discarded metal containers and sheets rather than virgin stock. Many post-consumer metals, especially aluminum beverage cans, exhibit high thermal conductivity, excellent formability, and corrosion resistance. By reshaping, perforating, or corrugating such scrap without remelting, one can produce high-surface-area absorber plates, fins, or flow-obstruction ribs that boost heat transfer while eliminating the combustion emissions associated with smelting [6].

Figure (1-2) Irregular furnaces for smelting aluminum in Iraq.

Furthermore, designs incorporating recycled materials can match or even exceed the thermal efficiency of commercial units when properly constructed [7]. Solar air heaters constructed from recycled materials represent a practical, economically viable solution to both energy access and waste management challenges. These systems can achieve impressive thermal efficiency while significantly reducing costs compared to commercial alternatives. From a lifecycle perspective, SAHs made with reclaimed metals represent a compelling example of circular design: they address energy poverty, reduce emissions, and extend the functional lifespan of materials that would otherwise degrade in dumpsites. As climate change accelerates and global energy demand climbs, such dual-purpose innovations merit wider dissemination and further optimization. They are not merely interim solutions but strategic tools in the effort to decarbonize heat, the largest end-use energy sector globally [8]. In short, recycling is not just about waste—it is about potential. And when paired with renewable energy, that potential becomes power.

1.2. Study aims and objectives

This study aims to investigate the performance of application solar air heater with different configurations from recycle metals in Iraq. The main goal of this study will be targeted by the following specific objectives:

I. Study on recycled materials that can be used in solar heating applications.
II. Selection of the best samples (in terms of thermal conductivity and availability) that can be used in the air heater.
III. study of the best air flow speed in the solar air heater.
IV. The examination of the optimum configurations of the solar heater collectors conducted.

Chapter Two: Literature review

The growing demand for sustainable and cost-effective energy solutions has led to increased research into renewable energy technologies. Among these, solar air heaters (SAHs) have gained significant attention due to their simplicity, efficiency, and potential for reducing reliance on conventional heating methods. SAHs utilize solar radiation to heat air, which can be used for residential, industrial, or agricultural applications. However, the high cost of materials and manufacturing remains a challenge, limiting widespread adoption, especially in low-income regions.

This literature review reviews the most important previous studies on solar air heater designs, the types of materials used, and their impact on thermal performance and overall efficiency. It also discusses the challenges associated with using recycled materials, such as availability, durability, thermal conductivity, and improved airflow, as well as the solutions proposed in recent research.

By analyzing previous research, this study aims to provide a comprehensive overview of the feasibility, benefits, and challenges of using recycled materials in solar air heater construction, thereby enhancing efforts to develop clean and sustainable energy technologies.

2.1. Design Requirements

Solar air heaters operate on a straightforward principle: they capture solar radiation, convert it to heat, and transfer that heat to air passing through the system. The fundamental components include an insulated frame, a heat-absorbing surface (typically painted black), a transparent cover to create a greenhouse effect, and a system for air circulation. When sunlight passes through the transparent cover, it strikes the dark absorber, which converts light energy to heat. This heat is then transferred to air flowing through or around the absorber, as illustrated in Figure (2-1). The efficiency of this process depends on maximizing three key factors: solar energy absorption, heat transfer to the air, and minimizing heat loss to the environment. Recycled materials can be effectively incorporated into each of these aspects. The basic design approach involves enclosing these components in a frame that allows for proper air flow while maintaining heat. Air enters the system at a lower temperature, passes through or around the heated absorber material, and exits at a higher temperature. This process creates natural convection in passive systems or can be enhanced with fans in active systems. Designing an effective solar air heater involves multiple considerations to ensure optimal performance, sustainability, and cost-efficiency.

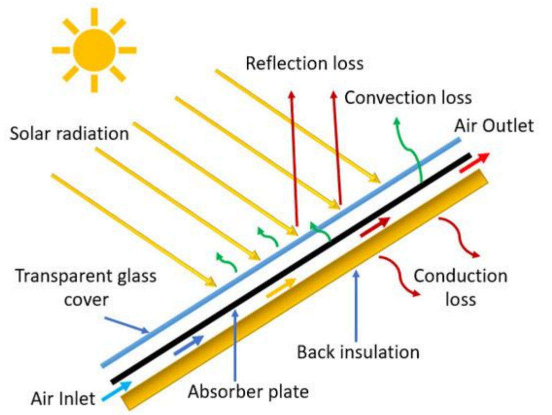


Figure (2-1) Basic illustration of a solar air heater (SAH) [9].

1-The heater must occupy an appropriate space while maximizing thermal conductivity, which is crucial for efficient heat transfer.

2-Materials with high thermal conductivity, such as aluminum or copper, are often used for absorbers because they enhance the system's ability to capture and transfer solar energy into usable heat.

3-the design must be weather-resistant and stable to endure varying environmental conditions like high winds, rain, or extreme temperatures. This ensures the heater remains functional over time without frequent repairs or replacements.

4-Simplicity in construction is another vital factor. A straightforward design minimizes manufacturing complexity and reduces costs. Simple designs also make installation easier and more accessible to a broader range of users, including those in remote areas. For example, using modular components that can be assembled on-site without specialized tools or expertise can lower barriers to adoption.

5-Maintenance-free operation is critical for long-term usability; this can be achieved by using durable materials and passive systems that do not rely on moving parts prone to wear and tear.

6-Sustainability is a cornerstone of modern solar air heater design. Incorporating recycled or recyclable materials aligns with environmental policies and reduces the carbon footprint of production. Sustainable design also emphasizes minimizing waste during manufacturing and ensuring end-of-life recyclability of components.

7-Cost-effectiveness is another key consideration. Solar air heaters should be affordable compared to other heating systems to encourage widespread adoption. This can be achieved by optimizing the design for mass production, reducing material costs through efficient use of resources, and leveraging economies of scale.

2.2. Solar air heater design

Solar air heater is a simple and convenient technology to utilize solar thermal energy, offering an eco-friendly and cost-effective alternative to conventional heating systems. They are designed to utilize the sun's radiation, converting it into thermal energy, which can then be used to warm indoor spaces. This technology is particularly beneficial for reducing reliance on fossil fuels, lowering energy costs, and minimizing environmental impact [10,11]. In general, the development of new-generation SAH focus on improving the thermal performance as well as minimizing the flow resistance. The design of the solar heater depends on several factors, which are: The collector cover, the absorbers materials, the shape of absorbers, type of absorbers flow pattern, Insulation, Flow type [12].

By controlling these factors, the best possible design can be achieved. Through these factors, the system can be classified into several classifications, through these classifications, we determine the optimal design to achieve the best results according to the requirements.

2.2.1. Absorber Shapes

A solar collector in a solar air heater is the component that absorbs sunlight and converts it into heat to warm air. Typically, it often made of metal or another heat-conductive material, coated with a dark, heat-absorbing surface to maximize solar energy absorption [13]. The collector is usually encased in a frame with a transparent cover to trap heat and reduce losses, while insulation on the back minimizes heat escape. In operation, air passes through or over the heated collector, either by natural convection or forced circulation, absorbing the heat. The warmed air is then directed into a building or space for heating.

Figure (2-2) a- Channel type collector b- flat plate collector

2.2.1.1. flat plate

Flat plate collectors consist of a shallow rectangular box with a glass cover, insulation, and a dark-colored absorber plate. The absorber plate is typically made of copper or aluminum, and it is coated with a special material that absorbs sunlight and converts it into heat. The heat is then transferred to an air that which can be used for space heating, or other applications, Figure (2-2) b. One of the advantages of flat plate collectors is their relatively low cost compared to other solar thermal technologies. They are also easy to install and maintain, and they have a long lifespan [14].

2.2.1.2. Channel type heaters

Instead of a flat plate, the absorber consists of tubes or channels. The channels are typically Made of high thermal conductivity materials like aluminum, or other to maximize heat absorption and retention, Figure (2-2) a. The confined air channels increase the contact surface area between the air and heated materials, enhancing heat transfer efficiency. Considerable improvement in collector efficiency is obtainable to enhance the effects of free and forced convections, to increase the transfer area and to create the turbulence inside the flow channel using fins ،baffles, multi-pass operation or corrugated surfaces. These heaters incorporate narrow channels within the collector to direct airflow [15,16].

2.2.1.3. Evacuated tube

An evacuated tube solar air collector is a solar thermal technology that captures solar energy to heat air for various applications, such as space heating, drying, and food processing. It consists of parallel rows of cylindrical glass tubes, each with a vacuum between an outer transparent tube and an inner absorber. This vacuum acts as an insulator, minimizing heat loss through conduction and convection. The inner tube features a selective coating that absorbs solar radiation while reducing heat escape. Inside the absorber, a heat transfer mechanism, often a copper heat pipe or U-pipe, facilitates the transfer of thermal energy to the circulating air [17].

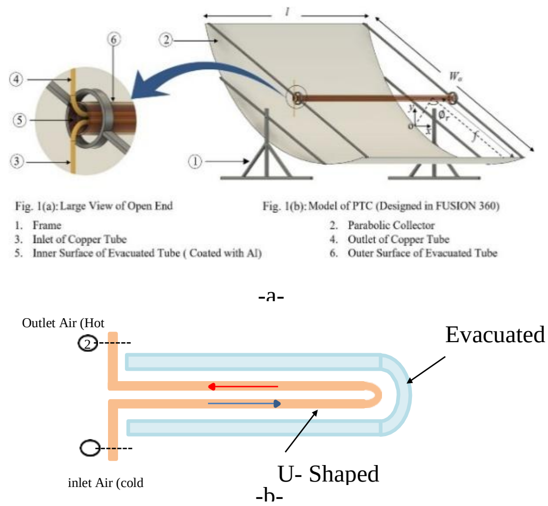


Figure (2-3) a- evacuated tube type solar air heater [38].
b- Schematic diagram of U-Shaped Copper Tube inser- tion in evacuated tube [19].

Solar radiation passes through the outer glass tube and heats the inner tube's working fluid or air. The vacuum ensures efficient energy transfer by preventing heat dissipation. The heated fluid or air circulates through the system, transferring thermal energy to its intended application, as indicated in Figure (2-3). This design allows the collector to achieve high temperatures, typically between 150°C and 200°C [18].

Evacuated tube collectors are highly efficient due to their ability to harness both direct and diffuse sunlight throughout the day. They perform well even in cold or cloudy conditions and are durable because the vacuum protects against corrosion and condensation. These collectors are modular and lightweight, making them easy to install on various surfaces.

However, they are more expensive than flat-plate collectors due to their advanced design and materials. Despite this, their efficiency and versatility make them suitable for industrial heating, cooling applications, food processing, and domestic space heating in regions with variable weather conditions [17].

2.2.2. The collector cover [20]

2.2.2.1. Glazed Solar Air Heaters

Glazing in solar air heaters refers to the use of a transparent or translucent cover, typically made of glass or plastic, placed over the absorber plate to enhance thermal performance (2-4). The glazing allows solar radiation to pass through and heat the absorber while reducing convective and radiative heat losses from the absorber to the environment. This creates a greenhouse effect, trapping heat within the collector to increase the temperature of the air passing through.

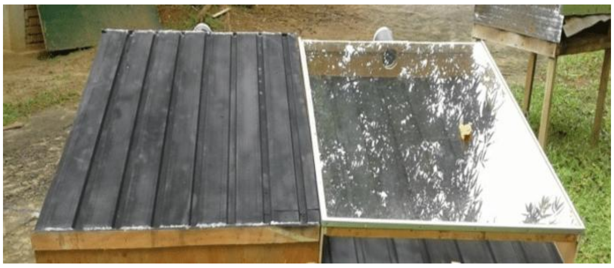


Figure (2-4) Unglazed Transpired type Solar Collector (left) and Glazed type solar collector (right) [21].

2.2.2.2. Unglazed Solar Air Heaters

unglazed Solar Air Heaters lack a glazing layer and rely on dark-colored absorber surface to directly heat air drawn, Figure (2-4). This simpler design results in lower costs but also higher heat losses.it is more cost-effective and simpler to construct, making them ideal for preheating ventilation air in industrial or commercial settings [21]. Their efficiency is often lower than glazed systems due to greater exposure to environmental heat losses. preferred for cost-sensitive projects with moderate heating requirements.

2.2.3. fluid flow

2.2.3.1. Natural flow

Natural flow operates based on passive mechanisms driven by buoyancy forces or pressure differences caused by temperature gradients. As air inside the solar heater warms up, it becomes less dense and rises, creating a natural circulation pattern. This method is energy-efficient since it does not require external power sources for air movement. However, natural flow systems generally have lower airflow rates compared to forced flow systems, which can limit their thermal efficiency and make them more susceptible to uneven heating or temperature variations within the collector [22].

2.2.3.2. forced flow

Forced flow in solar air heaters relies on external devices, such as fans or blowers, to actively propel air through the system. This approach ensures a consistent and controlled airflow rate, which enhances heat transfer efficiency by maintaining a higher velocity of air over the absorber surface. Forced flow systems are particularly effective in applications requiring higher thermal output or uniform heating, as they mitigate temperature stratification within the collector. However, they consume additional energy to operate the fans, which can slightly reduce overall system efficiency [23].

2.2.4. Final design

Despite the variety of designs, thermal insulation is a key requirement in the design of solar air heaters. It is a good investment in reducing heat loss. A review of the available options, designs, and requirements for solar air heaters revealed that using recycled materials in the form of channel type heaters is the optimal solution in terms of the absorbent surface These heaters maximize heat absorption and retention using channels made of materials with high thermal conductivity, like aluminum. The design increases the contact surface area between the air and heated materials, boosting heat transfer efficiency. They can also be enhanced with fins, baffles, multi-pass operation, or corrugated surfaces to improve collector efficiency by enhancing convection and creating turbulence inside the flow channel. Also, the glazing helps trap heat through the greenhouse effect, which makes them suitable for colder climates or applications needing higher air temperatures. Glazing reduces convective and radiative heat losses, increasing efficiency. As for the flow type, due to the differences in studies, it has been shown that it is better to use both types to cover all available options for the heater.

2.3. The constituent components of a solar air heater

When developing a final design, there are often multiple ways to achieve the desired outcome-using different structures, parts, and additional features. However, these alternatives can differ significantly in their types, properties, and suitability for the intended application. Therefore, it is essential to carefully select the parts that best meet the specific design requirements.

2.3.1. Insulation

Insulation plays a pivotal role in the performance and efficiency of solar air heaters, devices designed to harness solar energy for heating air in residential, commercial, and industrial applications. By minimizing heat loss, insulation enhances the system's ability to capture and retain solar energy, ensuring that the heated air maintains its temperature as it moves through the system. The choice of insulation materials, their placement, and their thermal properties directly influence the overall effectiveness of solar air heaters, impacting energy savings and environmental sustainability.

Solar air heaters operate by absorbing solar radiation, typically through a collector surface, which transfers heat to air passing through or over it. The heated air is then circulated for space heating or other uses. However, without proper insulation, much of the captured heat can escape to the surroundings through conduction, convection, or radiation. Insulation serves as a thermal barrier, reducing these losses and improving the system's efficiency. The effectiveness of insulation depends on its thermal conductivity, a measure of how easily heat flows through a material. Materials with low thermal conductivity, such as fiberglass, mineral wool, or polyurethane foam, are commonly used because they resist heat flow, keeping the warmth within the system.

Insulation is typically applied to the back and sides of the collector to prevent heat loss to the ambient environment. These materials trap air within their structure, leveraging the low thermal conductivity of still air to create an effective barrier. Research published in journals like Solar Energy highlights that a 5 cm layer of fiberglass insulation behind the collector can reduce heat loss by up to 30%, boosting the system's thermal efficiency The choice of insulation material is not solely about thermal conductivity. Density, thickness, and durability under varying environmental conditions are equally critical. The choice of insulation material and its application significantly influence the overall effectiveness of SAHs.

2.3.1.1. Glass wool

Insulation is a critical component in optimizing the performance of solar air heaters (SAHs), which harness solar energy for heating applications. Among various insulation materials, glass wool has emerged as a widely used option due to its thermal efficiency 0.033–0.044 W/m.K , cost-effectiveness, versatility, flexibility and ease of installation [24]. Its primary function is to minimize heat loss from the collector to the surrounding environment, ensuring that more of the absorbed solar energy is transferred to the working fluid (air). Composed of fine glass fibers, Figure (2-5), Glass wool is used as an insulating layer in solar air heaters, typically placed around or beneath the absorber plate. By reducing heat losses, glass wool helps maintain higher temperatures inside the collector, increasing the

Figure (2-5) Glass wool.

outlet air temperature and overall thermal efficiency, so it providing excellent thermal insulation properties. However, care must be taken to protect it from moisture, as its insulating properties can degrade when wet [25,26].

2.3.1.2. Rock wool

Rock wool, also known as mineral wool, is a fibrous insulation material made from molten volcanic rock (basalt) or recycled glass, spun into fibers and bound with additives, Figure (2-6). In solar air heaters (SAHs), rock wool is primarily used as an insulating material to minimize heat loss, enhancing the system's thermal efficiency. SAHs are devices that capture solar radiation to heat air for applications like space heating, crop drying, or industrial processes. The insulation is critical because it reduces heat loss through the collector's sides and bottom, ensuring more heat is transferred to the air.

Figure (2-6) Rock wool.

In SAH designs, rock wool is often placed around the collector box or beneath the absorber plate. Its low thermal conductivity, typically ranging from 0.030 to 0.040 W/m·K, makes it effective at retaining heat [24]. So, that rock wool's thermal conductivity is comparable to other conventional insulators like glass wool, ensuring minimal heat loss. This property is vital in SAHs, where maintaining high outlet air temperatures is key to performance. Additionally, rock wool's non-combustible nature and fire resistance enhance safety in SAH systems, which can reach high temperatures under direct sunlight.

However, rock wool has limitations in SAH applications. Its production involves energy-intensive processes, and handling requires protective gear due to potential skin irritation from mineral fibers. Environmental concerns also arise, as the manufacturing process can release pollutants, though rock wool is recyclable, reducing its lifecycle impact [27,28].

2.3.1.3. Polyurethane Foam

Polyurethane foam is utilized in solar air heaters primarily as an insulation material to enhance thermal efficiency by minimizing heat loss. Its low thermal conductivity, typically around 0.02–0.03 W/m·K, makes it effective for insulating the collector and ducting systems, ensuring that the absorbed solar energy is efficiently transferred to the air [24]. Beyond its insulating capabilities, polyurethane foam is lightweight and exhibits strong adhesion to various surfaces, facilitating easy application and structural stability. Its resistance to moisture and environmental degradation ensures long-term durability, making it suitable for diverse climatic conditions.The foam's adaptability allows for customization in density and thickness, catering to specific design requirements of solar air heaters, Figure (2-7). This versatility, combined with its insulating efficiency, contributes to the enhanced performance and longevity of solar thermal systems [29].

Figure (2-7) Spray polyurethane foam (SPF) is widely used to insulate.

2.3.1.4. Cellulose Insulation

Cellulose insulation is effective in this context due to its low thermal conductivity, approximately 0.040 W/m·K, which is comparable to glass wool or rock wool. This property allows it to resist conductive heat transfer, maintaining the temperature of heated air within the system. Its dense packing ability enables it to fill irregular spaces around pipes, wiring, or collector components, reducing air infiltration and convective heat losses,

Figure (2-8) Cellulose Insulation

Figure (2-8). Dense-pack cellulose, in particular, is installed under pressure to minimize settling (which can be 13–20% in loose-fill applications) and ensure long-term performance. Wet-spray cellulose, incorporating water and adhesives, further enhances air sealing by adhering to surfaces, which is beneficial for new solar air heater installations [24].

However, challenges exist. Cellulose is hygroscopic, meaning it can absorb moisture, potentially compromising thermal performance if expose to damp conditions. Proper sealing of the heater system and ventilation (e.g., rafter vents) are necessary to prevent moisture buildup. Fire resistance is achieved through treatments like boric acid, making cellulose safer than untreated paper but requiring careful installation to meet building codes. Settling in loose-fill applications can create voids, reducing insulation effectiveness over time, though dense-pack or wet-spray methods mitigate this [30].

2.3.2. Glazing

Glazing in solar air heaters plays a crucial role in enhancing their thermal performance by reducing heat losses and improving energy absorption. The choice of glazing material, the number of glazing layers, and the configuration of the air heater significantly impact the efficiency and effectiveness of solar air heaters.

The effectiveness of glazing depends on factors such as material properties, thickness, and the air gap between the glazing and absorber. The glazing material must have high solar transmittance (to maximize radiation absorption) and low thermal conductivity (to minimize heat loss). It improves collector efficiency by maintaining higher internal temperatures, especially in colder or windy conditions, but adds to the cost and complexity of the system [31,32].

2.3.2.1. Single glazing

The incorporation of single glazing in solar air heaters serves a critical role in enhancing their thermal performance by creating a greenhouse effect within the collector, as indicated in Figure (2-9). The glazing material, typically glass or a transparent polymer, allows a significant portion of the incoming solar radiation to pass through and be absorbed by the absorber plate. The performance of a single-glazed solar air heater is influenced by the material and transmissivity of the glazing. Materials with high solar transmissivity, such as tempered or low-iron glass, allow more sunlight to reach the absorber, thereby improving efficiency. For temperature increases ranging from 10°C to 35°C, single-glazed solar energy heaters demonstrate superior overall performance compared to double- or triple-glazed configurations. Consequently, single-glazed solar air heating collectors are more suitable for natural circulation solar energy drying applications. However, single glazing is less effective at retaining heat compared to double glazing, especially in colder climates or during winter. While single glazing offers better performance in terms of solar heat gain during sunny conditions and is cost-effective, it also allows more heat to escape, which can reduce efficiency when the temperature difference between the inside and outside is significant [33,34].

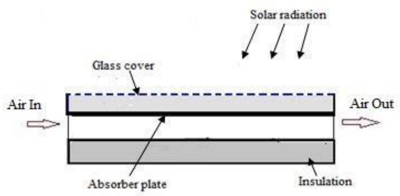


Figure (2-9) Single glazing

2.3.2.2. Multiple glazing

Multiple glazing in solar air heaters refers to the use of two or more transparent layers (typically glass or specialized plastics) as a cover over the absorber plate of the heater. The primary function of multiple glazing is to reduce thermal losses from the absorber to the environment, thereby improving the efficiency of the solar air heater.

When solar radiation passes through the glazing, it is absorbed by the dark surface of the absorber plate, which heats up and transfers this heat to the air flowing through the collector. However, heat can also escape from the absorber back to the outside, mainly through convection and radiation. Adding a second (or more) layer of glazing introduces an insulating air gap between the layers, which significantly reduces these losses, as indicated in Figure (2-10).

Multiple glazing is especially beneficial in systems operating at higher temperatures or in windy conditions, where heat loss through the cover would otherwise be significant. However, there is a trade-off: as more glazing layers are added, the amount of solar radiation reaching the absorber decreases due to reflection and absorption in the glazing itself, which can slightly reduce the solar gain In and increase in costs. Therefore, the design must balance the reduction in heat loss with the decrease in solar transmittance [34,35].

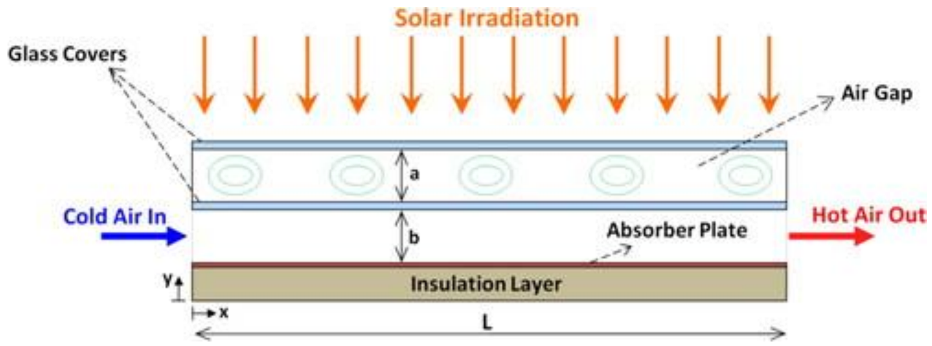


Figure (2-10) double glazing

2.3.3. Solar Absorber

A solar collector in a solar air heater is a component-usually made of metal or another heat-conductive material with a dark, heat-absorbing coating-that captures sunlight and converts it into heat. The collector is enclosed in a frame with a transparent cover to trap heat and reduce losses, while insulation on the back minimizes heat escape. Air flows over or through the heated collector, absorbing the heat, and is then circulated into a building for space heating, either by natural convection or with a fan. These DIY solutions offer cost-effective alternatives to commercial heating systems while promoting upcycling of waste materials [37]. In this case, using soda and food cans are the best and most available solution [38].

Figure (2-11) Soda can solar heater

most soda and food cans are Aluminum the primary material in it, has high thermal conductivity, which allows it to efficiently absorb and transfer solar heat to the air passing through or around it. When these cans are painted black, their solar absorptance increases significantly, enabling them to capture a greater portion of incoming solar radiation and convert it into heat [39]. This process is essential for the effective operation of a solar air heater, as the absorber's role is to maximize the conversion of solar energy into thermal energy and transfer it to the working fluid, typically air Figure (2-11). Also, availability is a key advantage, as these items are ubiquitous in household and industrial waste streams, reducing material costs and environmental impact through recycling. Their ease of use is evident in DIY solar air heater designs, where soda cans, for instance, are stacked into tubes to channel airflow, or food trays are arranged to maximize surface area exposed to sunlight.

Chapter Three: Experimental Work

3.1. Introduction

Solar air heaters (SAHs) constitute an innovative and sustainable technology for space heating, providing an environmentally benign and efficient approach to harnessing solar energy for thermal applications. The integration of recycled materials in their construction enhances their ecological benefits by minimizing environmental impact while simultaneously reducing production costs, thereby broadening their accessibility for diverse applications. The primary aim of this experimental study is to design, fabricate, and evaluate the performance of a full-scale solar air heater, constructed predominantly from recycled materials, optimized for the climatic conditions of Iraq for space heating and drying purposes. Additionally, the study investigates the influence of varying air velocities on the heater's thermal performance.

3.2. The structure of the solar air heater

A solar air heater is a simple device designed to capture solar energy and use it to heat air. Its structure mainly revolves around an absorber plate, a transparent cover, a frame or casing, insulation, and air ducts. The frame or casing holds all the parts together and protects them from external conditions. The structural frame is constructed from iron to ensure durability under outdoor environmental conditions and to provide stable support for all components of the device. The frame is encased in wood, which

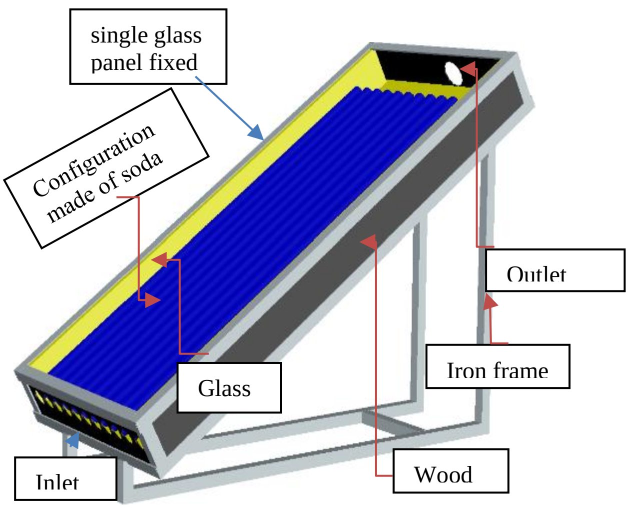


Figure (3-1) The structure of the solar air heater with configuration made of soda cans.

serves as a thermal insulating material due to its low thermal conductivity. Wood was selected for its widespread availability, ease of application, and cost-effectiveness. The structure incorporates multiple inlet openings and a single outlet opening to maximize air intake while regulating the airflow direction as it exits the duct through the outlet. The device is internally lined with glass wool, selected as the optimal material to satisfy the specified design requirements due to its superior thermal insulation properties, fire resistance, and cost-effectiveness. The device is encased in a single glass panel, optimizing efficiency under Iraq's climatic conditions. Internally, an absorbent surface is positioned, which undergoes heating from solar radiation, which made from recycle material. Surrounding insulation elevates the surface's temperature, facilitating heat transfer to the incoming air, which subsequently conveys the thermal energy to the designated space. The solar air heater structure is elevated 10 cm above the ground to promote effective ventilation. It is inclined at a 30-degree angle with its inlet-oriented southward to optimize solar energy capture, look at Figure (3-1). Three configurations are being tested:

1-Configuration made of soda cans.

2-Configuration is made of disposable aluminum plates.

3-Configuration is the same as the second configuration, but in reverse.

Temperature measurements of the inlet and outlet air are documented, along with the velocity of the outlet air, under both natural and forced flow conditions.

3.3. Construction the solar air heater

3.3.1. Collector enclosure

The solar air heater enclosure was constructed using square-section iron tubing with dimensions of 25 mm x 25 mm, selected for its structural rigidity. The required quantity of iron was procured, and the components were precisely cut to achieve the specified dimensions of 170 cm (length), 75 cm (width), and 17 cm (height) using high-precision cutting tools to ensure accuracy. The enclosure walls were clad with 12 mm thick plywood, chosen for its durability and thermal insulation properties. The plywood panels were meticulously fitted to the frame to prevent air leakage, with 22 inlet openings, each 3 cm in diameter, strategically positioned to optimize airflow distribution, and a single 8 cm diameter outlet to channel heated air efficiently. To maximize solar radiation capture, the enclosure was oriented at a 30-degree inclination angle, calculated based on the geographical latitude of the Iraqi climate to enhance solar exposure. Additionally, the structure was elevated to a height of 10 cm to facilitate sufficient air intake while maintaining stability. The fabrication process, including cutting, welding, and assembly, was conducted with precision to ensure structural integrity and thermal efficiency. The detailed construction and configuration are depicted in Figure (3-2).

Fabrication of the frame involves precision cutting of iron components, followed by welding to construct a structurally robust framework.

The wooden components are precisely cut to exact specifications and securely fitted to the frame, ensuring a tight seal to prevent air leakage. Subsequently, entry and exit apertures are drilled with precision to facilitate controlled airflow through the solar air heater.

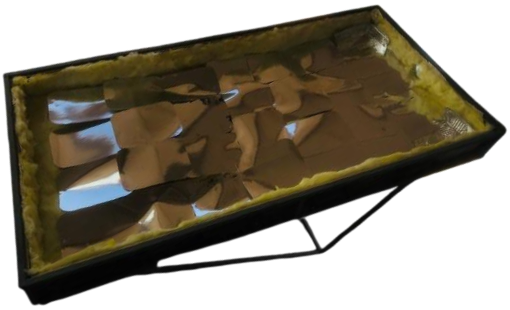
Figure (3-2) Solar air heater collector box manufacturing stages

3.3.2. Insulation

Glass wool is generally a better choice over rock wool, cellulose insulation, and polyurethane foam when you prioritize a combination of cost, weight, ease of installation, and good thermal. It’s lighter and more flexible than rock wool, making it easier to handle and install, especially in irregular spaces. Compared to cellulose, glass wool is non-combustible and does not settle over time, maintaining its insulation performance longer without risk of sagging or fire hazards. Against polyurethane foam, glass wool offers much better fire resistance because it doesn’t burn easily or release toxic fumes, while still providing solid thermal insulation at a lower cost. Glass wool insulation with 4 cm thick Covers the inner surface and sides of the box. To enhance thermal efficiency, the fiberglass surface of the solar air heater was covered with dish covers, securely fastened using paper clips to ensure a stable and uniform attachment, look at Figure (3-3). These covers were subsequently coated with a black paint to maximize solar absorptivity and optimize heat retention within the enclosure.



A wood stapler was employed to securely fasten the fiberglass to the wooden frame of the solar air heater, ensuring robust attachment and precise alignment.



A wood stapler was employed to securely fasten the bowl cover to the glass wool insulation within the solar air heater assembly. This method ensured a firm and uniform attachment, optimizing thermal insulation and contributing to the structural stability of the system.

Figure (3-3) Solar air heater insulation

3.3.3. Solar Absorber

In the development of solar absorbers, two types of metallic waste—discarded aluminum soda cans and single-use aluminum foil bowls —were repurposed to promote sustainability and reduce production costs while preserving the thermal efficacy of the solar air heater, Figure (3-4). These recycled materials were selected for their favorable thermal conductivity and availability, contributing to an environmentally conscious design. Furthermore, to optimize solar absorptivity, the impact of black paint on thermal performance was investigated. Specifically, an experimental study was conducted to determine the optimal mixing ratio of gasoline with opaque black paint. Various proportions were systematically tested to evaluate their effects on paint adhesion, solar absorption efficiency, and heat retention within the absorber. The results informed the selection of the most effective mixture, ensuring maximum thermal performance while maintaining cost-effectiveness and environmental benefits, Figure (3-5).

Figure (3-4) soda cans and disposable aluminum bowls

Figure (3-5) paint preparation

3.3.3.1. Configuration made of soda cans

Three different sizes of soda cans were evaluated for use in the solar absorber (3-6), and the 250 ml cans, measuring 13.5 cm in height and 5 cm in diameter, were selected. This decision was based on their widespread availability and optimal dimensions, which minimized the quantity required while ensuring effective thermal performance and structural suitability for the solar air heater system. For the construction of the solar absorber, 121 recycled aluminum soda cans were utilized, systematically arranged into 11 columns, with each column comprising 11 cans. Prior to assembly, the cans were thoroughly cleaned to remove residual contents, ensuring a contaminant-free surface. Subsequently,

A B C

Figure (3-6) Three different sizes of soda cans. A-250ml B-330ml C-185ml

As depicted, the top of each soda can was fully removed to create an unobstructed inlet, while the bottom was perforated with four precisely drilled holes to facilitate controlled airflow and enhance heat transfer within the solar absorber system.

A high-temperature-resistant thermal silicone, capable of withstanding up to 300°C, was applied to seal the ends of one section of the solar air heater enclosure. we fill one end of cans and then stick it to the other end of the other can, ensuring a robust, airtight connection that enhances thermal integrity and structural stability.

Figure (3-7) manufacturing stages of Configuration made from soda four holes were drilled into the base of each can to facilitate airflow. The top of each can was fully removed to create an open inlet, enabling air to enter and promoting efficient heat transfer from the heated back wall as air passed through the perforations. To ensure robust and thermally conductive connections, high-temperature-resistant silicone sealant was applied to the rim of one can, which was then adhered to the base of another, forming a continuous, airtight conduit within each column, as indicated in Figure (3-7). Following a 24-hour curing period to allow the thermal silicone adhesive to fully set, the assembled solar absorber was prepared for the application of a high-absorptivity black paint coating to enhance solar radiation absorption and thermal efficiency.

3.3.3.2. Configuration is made of disposable aluminum bowls

Disposable Food Bowl Aluminum Foil, with dimensions of 22 cm x 18 cm x 10 cm, were utilized in the construction of the solar absorber. These bowls were meticulously bonded using paper clips and high-temperature-resistant thermal silicone to ensure robust adhesion and effective thermal insulation. The bowls were systematically arranged into four groups, each comprising seven plates, to optimize heat transfer and structural integrity within the solar air heater system. Following a 24-hour curing period to allow the thermal silicone to fully set, five holes were precisely drilled in the center of the plate walls to facilitate airflow, as shown in the Figure (3-8). Additionally, at the inlet of each column, holes were aligned with corresponding apertures in the collector box to ensure seamless integration and efficient air circulation throughout the system. This methodical approach enhanced the thermal performance and durability of the solar absorber assembly. This configuration is used twice, the first time it is directed upwards and the second time it is directed downwards(In this case, it is preferable to staple it with a stapler along with the container to prevent leakage).

High-temperature-resistant thermal silicone adhesive was applied to the surfaces of the front and back aluminum foil bowls to facilitate bonding. These bowls were then meticulously connected to the adjacent bowls. To ensure secure attachment during the curing process, paper clips were used to hold the bowls together. The assembly was left undisturbed for 24 hours to allow the thermal silicone adhesive to fully cure, thereby achieving a robust, thermally efficient.

Following a 24-hour curing period to ensure the thermal silicone adhesive had fully set, five holes were precisely drilled into the walls of the aluminum foil bowls to facilitate airflow entry into the solar absorber. Similar holes were also made for the entry holes in the walls opposite the entry holes to ensure adequate air intake.

Figure (3-8) manufacturing stages of Configuration is made of disposable aluminum bowls

3.3.4. black paint

In the coating procedure, matte black paint was applied to the solar absorber to optimize solar radiation absorptivity and enhance thermal efficiency, tools used at Figure (3-9). To refine the paint's application characteristics and thermal performance, a systematic investigation of various mixing ratios with gasoline was conducted, ranging from undiluted paint to a maximum dilution ratio of 1 part paint to 1.5 parts gasoline. This experimental evaluation sought to identify the optimal mixture that ensured superior adhesion, uniform coating distribution, and maximized heat retention within the solar air heater system. The results indicated that undiluted paint exhibited lower gloss, higher viscosity, and increased cost, rendering it less practical. Conversely, the 1:2 paint-to-gasoline ratio demonstrated inadequate adhesion, particularly on the smooth surfaces of the aluminum cans, making it unsuitable. Consequently, intermediate ratios balancing paint and gasoline were determined to be the most effective, providing optimal adhesion, cost-effectiveness, and thermal performance for the solar absorber's coating application, Figure (3-10). The result of the painting can be seen in the Figure (3-11), Figure (3-12) and Figure (3-13).

brush gasoline matte black paint

Figure (3-9) Components of the painting process

Mixing ratio 1:1

Mixing ratio 1:0.5

Mixing ratio 1:0

Figure (3-10) Mixing ratios

Facing upwards the Configuration is made of disposable aluminum bowls

Facing downwards the Configuration is made of disposable aluminum bowls

Figure (3-11) Painting the Configuration is made of disposable aluminum bowls

Figure (3-13) Painting the cover of insulation

Figure (3-12) Painting Configuration made of soda cans

3.3.5. glazing

To encapsulate the solar air heater, a non-reflective glass panel, measuring 170 cm x 75 cm x 0.6 cm, was meticulously installed to optimize the transmission of solar radiation into the system, thereby enhancing thermal efficiency. A single glass panel was selected over a double-panel configuration for the solar air heater due to its cost-effectiveness and superior performance under the climatic conditions of Iraq, Figure (3-14). Specifically, the single panel demonstrates optimal thermal efficiency within the temperature range of 10°C to 35°C, which aligns with the prevalent environmental conditions in the region [34]. This choice balances economic considerations with functional efficacy, ensuring effective solar radiation transmission and heat retention while minimizing material and installation costs. The panel was deliberately supported by wooden ledges instead of the metal frame, leveraging the inherent pliability of wood to absorb mechanical shocks and vibrations. This design choice not only minimizes the risk of damage to the glass panel but also contributes to the longevity and structural resilience of the assembly. The non-reflective properties of the glass were selected to reduce glare and maximize the capture of diffuse and direct solar irradiance, ensuring efficient energy conversion within the heater. After placing it on the solar heater at Figure (3-15).

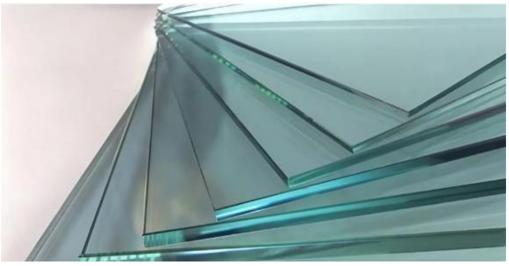


Figure (3-14) single glass panel

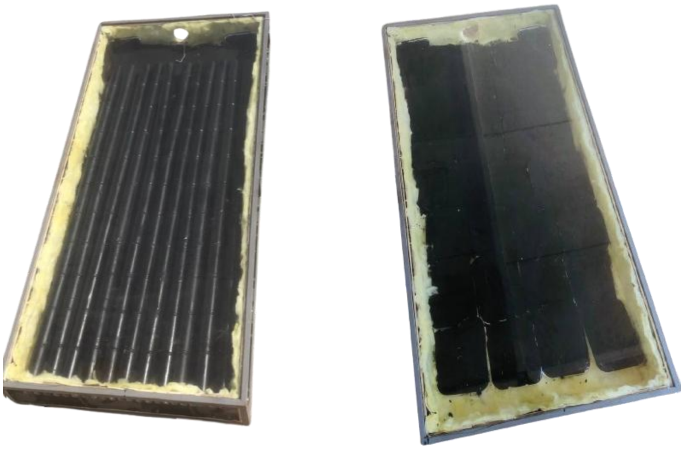


Figure (3-15) single glass panel used at solar air heater

3.3.6. The fan and the regulator of speed

The axial AC fan is a pivotal component of the solar air heater, responsible for extracting and circulating heated air from the absorber to the target space for effective heating. Operating within a voltage range of 220 V to 240 V, the fan achieves a maximum rotational speed of 2250 RPM and functions at a frequency of 50/60 Hz. This type was chosen to be compatible with Iraq's electricity supply (220V), and therefore we will not need a transformer to reduce the supplied voltage. It has a power consumption of 33 W, ensuring efficient airflow for optimal heat distribution. The fan's dimensions are 120 mm x 120 mm x 38 mm (length, width, and thickness, respectively), designed for compact integration within the system, Figure (3-16). A voltage regulator is incorporated to precisely modulate the fan's input voltage, allowing for tailored adjustments to the rotational speed and airflow rate to meet specific heating demands, Figure (3-17). This configuration enhances the system's thermal efficiency and operational flexibility, ensuring effective performance under varying environmental conditions.

Figure (3-16) the fan with five blades

Figure (3-17) the regulator of speed with five speeds

3.4. Measuring devices

3.4.1. Digital thermometer with small LCD screen

to measure the air temperature in the shade as well as the air temperature out the device.

Temperature Range: -10°C to 110°C, look at Figure (3-18).

Figure (3-18) Digital thermometer with small LCD screen

3.4.2. TP300 digital thermometer

It used in cases where the temperature exceeds 100 degrees Celsius. Temperature Range: -50°C to 300°C, look at Figure (3-19).

Figure (3-19) TP300 digital thermometer

3.4.3. Anemometer

It is used to measure the air velocity coming out of the solar heater. Cannot read air velocity less than 0.3 m/s, look at Figure (3-20).

Figure (3-20) Anemometer

3.4.4. Vape

It is used to generate smoke and by knowing the time it takes to reach the end of the device we can measure speeds less than 0.3 m/s, look at Figure (3-21).

Figure (3-21) Vape

3.4.5. Smoke production using charcoal and harmal

By burning it and then passing the smoke inside the solar heater to determine the air flow speed. It is used in cases that require dense smoke and measure speeds less than 0.3 m/s, look at Figure (3-22).

charcoal

harmal

metal plate with funnel and tube

Figure (3-22) components of Smoke production using charcoal and harmal

3.5. Measurement Procedures

1-Ambient and Outlet Air Temperature: The ambient air temperature, measured in a shaded environment, and the temperature of the air exiting the solar air heater were determined using calibrated Digital thermometer with small LCD screen. To ensure precision at elevated temperatures, a TP300 digital thermometer with enhanced resolution was employed for readings exceeding 100°C.

2-Air Velocity Measurement: Airflow velocity was measured using a anemometer placed at outlet for natural and forced convection velocity. At low velocities (below 0.3 m/s), where anemometer sensitivity may be compromised, a vapor-based technique was employed. A vape visible smoke, and the transit time for the smoke to traverse the known distance was recorded. Air velocity was calculated as the ratio of the distance to the transit time, providing a reliable measure of flow speed in low-velocity conditions. In cases where thick smoke is required due to the spread of air and thus the inability to see it, charcoal is used after burning it and adding harmal to it, as indicated in Figure (3-23).

After the coal burns and turns red, we add the harmal to it and then close it with the funnel attached to the tube that was inserted into the solar heater.

Figure (3-23) Smoke production using charcoal and harmal

3.6. Conducting experiments

On the morning of March 18, 2025, optimal meteorological conditions were achieved for initiating the experimental evaluation of the solar air heater (SAH) at a test site in Iraq, University of Misan. The sky was clear with no cloud cover, and ambient air was calm, ensuring consistent solar radiation and minimal external interference. The SAH was configured with an absorber comprising recycled aluminum soda cans.

The SAH was meticulously prepared to ensure thermal integrity and accurate measurements. The enclosure was inspected to confirm complete insulation. The soda can columns were precisely aligned with the 11 inlet openings (We leave a closed opening between every two columns.) to ensure exclusive airflow through the absorber channels, preventing bypass leakage. A single non-reflective glass panel (170 cm x 75 cm x 0.6 cm) was securely installed to encapsulate the system, optimizing solar radiation transmission while reducing convective and radiative heat losses. The SAH was oriented with its inlet openings facing south and the outlet opening (8 cm diameter) facing north, tilted at a 30-degree angle to maximize solar exposure, given the sun's position in the southern hemisphere during the test period. This orientation was calculated based on Iraq's geographical latitude to enhance solar energy capture.

After 30 minutes, temperature measurements were recorded in the shaded area, along with the temperature of the air exiting the SAH. Due to limitation of the anemometer at speeds less than 0.3m/s, airflow velocity could not be directly measured. As an alternative, smoke was introduced into the opening to serve as a tracer for airflow visualization. The time taken for the smoke to traverse a known distance through the device was measured using a stopwatch, allowing for the calculation of air velocity. In cases where the air temperature exiting the solar heater exceeded 100°C, TP300 digital thermometer was employed to enhance measurement accuracy and validate the readings. A final set of measurements was taken at 1pm of this configured. A second experimental session was conducted on March 24, 2025, using the same SAH structure but incorporating forced convection. Weather conditions on this date were again favorable, with clear skies and minimal wind. The system was first inspected to ensure no damage had occurred during storage. Subsequently, a fan and speed controller were installed and connected to the electrical supply.

The device was allowed to warm up from 9:00 a.m., after which baseline, measurements were taken for 30 minutes under natural convection conditions. The fan was then activated, and airflow readings were recorded at multiple speeds. Data collection followed a sequential process: after each change in fan speed, measurements were taken following a 30-minute stabilization period. The experiment concluded with final readings recorded at 12:00 p.m. The previous two experiments were applied to the remaining configurations: Configuration is made of disposable aluminum bowls which used in two ways: the first is facing upwards and the second is facing downwards.

Chapter Four: Results and Discussions

4.1. Calculation

After taking the temperature and speed, the heat transfer rate can be determined through simple calculations. To find the heat transfer rate Q:

$$\boldsymbol{Q = \rho \times A \times V \times C_P \times \Delta T}$$

Where:

Cp=1.005 kJ/kg-K

The area of Air outlet Where (D=0.08m): $A=\pi D^2/4=5.026\times10^{-5}m^2$

The air density is calculated assuming the fluid as an ideal gas by the expression**:**

$$\boldsymbol{\rho = \frac{P}{RT_{OUT}}}$$

Where:

P=101,325pa for sea level atmospheric pressure

R=287 J/kg*k gas constant for air

$$\rho = \frac{353.048}{T_{OUT}}$$

4.1.1. Nomenclature

Ti: Ambient temperature (°C)

Tout: Temperature of outlet air of SAH (°C)

V: Velocity of outlet air of SAH (°C)

ΔT: Temperature difference (°C)

ρ: The air density (kg/m^3)

Q: The heat transfer (w)

C_p: Specific Heat at Constant Pressure (*kJ/kg K)*

D: dimeter of outlet hole (m)

A: area of the outlet hole (m^2)

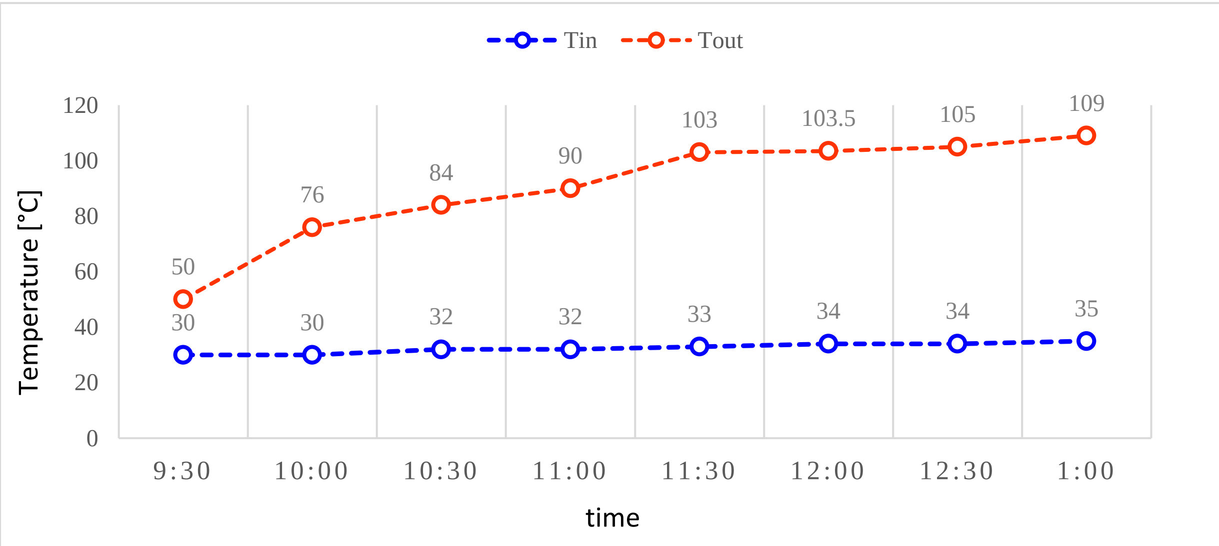
4.2. Results and Discussions

4.2.1. Configuration made of soda cans (Natural flow)

On the March 18, 2025 we take these reads from Configuration made of soda cans at natural flow. Also, we do the calculation of density and heat transfer.

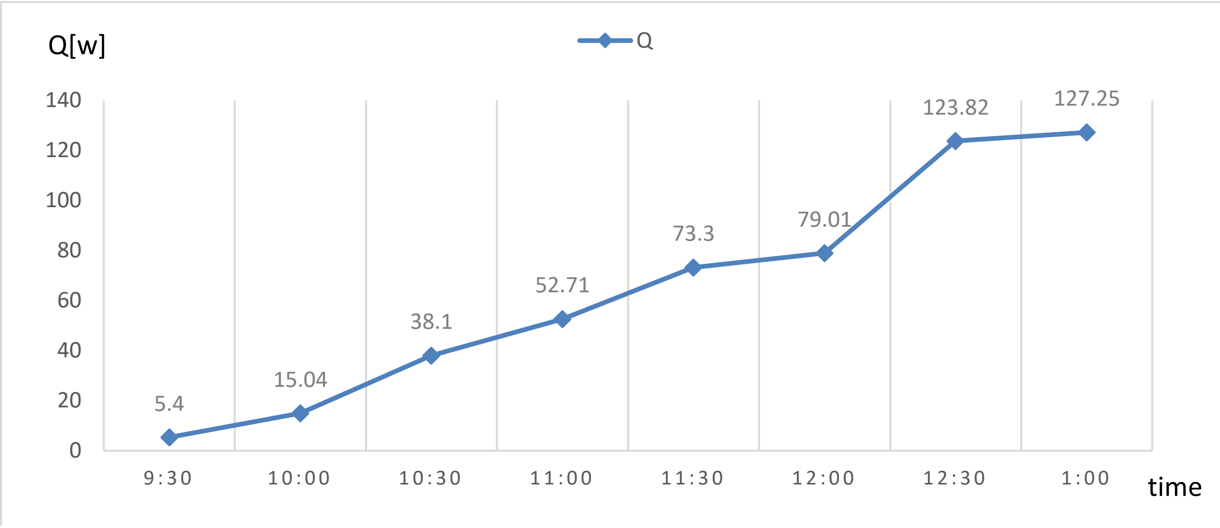
Table 1 Configuration made of soda cans at natural flow

Time	T_{in}[°C]	T_{out}[°C]	ΔT[°C]	V[m/s]	ρ[kg/m^3]	Q[w]
9:30	30	50	20	0.049	1.09	5.40
10:00	30	76	46	0.064	1.011	15.04
10:30	32	84	52	0.148	0.98	38.10
11:00	32	90	58	0.185	0.9725	52.71
11:30	33	103	70	0.221	0.938	73.30
12:00	34	103.5	69.5	0.24	0.9377	79.01
12:30	34	105	71	0.37	0.933	123.82
1:00	35	109	74	0.37	0.92	127.25



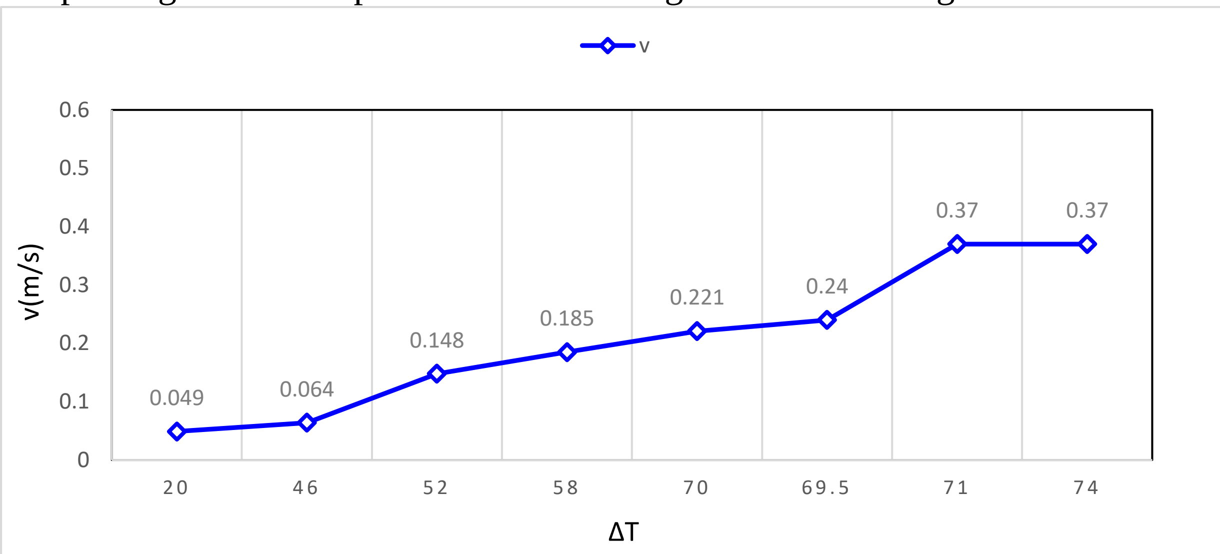
[Graph-1] Temperature versus time for configuration made of soda cans at natural flow

[Graph-1], shows a significant increase over the period experiment, starting at 58°C at 9:30 AM and reaching 109°C by 1:00 PM. This steady rise in outlet temperature indicates that the solar air heater is effectively absorbing solar energy and transferring it to the air as it passes through the system.



[Graph-2] Heat transfer versus time for configuration made of soda cans at natural flow

[Graph-2], shows the heat gained by the air (Q) also increases over time, starting from 5.4 watts and reaching about 127.25 watts by 1:00 PM. This increase corresponds with the rising outlet temperature, confirming that the solar air heater effectively absorbs and transfers solar energy to the air, improving its thermal performance as sunlight becomes stronger.



[Graph-3] velocity of air versus temperature difference for configuration made of soda cans at natural flow.

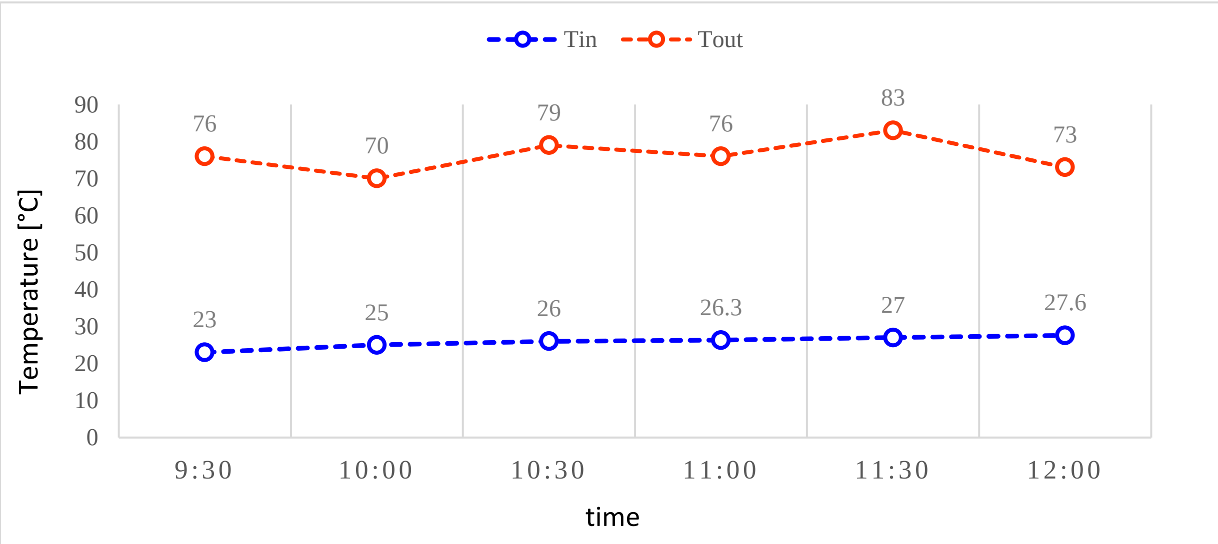
[Graph-3], shows the relationship between air velocity (v) and temperature difference (ΔT), where the velocity increases as the temperature difference grows, reaching a maximum of 0.37 m/s. This suggests that as the heater becomes more effective at raising the air temperature, the movement of air through the system also increases, likely due to enhanced thermal buoyancy or airflow.

4.2.2. Configuration made of soda cans (forced flow)

On March 24, 2025 we take these reads from Configuration made of soda cans at forced flow. Also, we do the calculation of density and heat transfer.

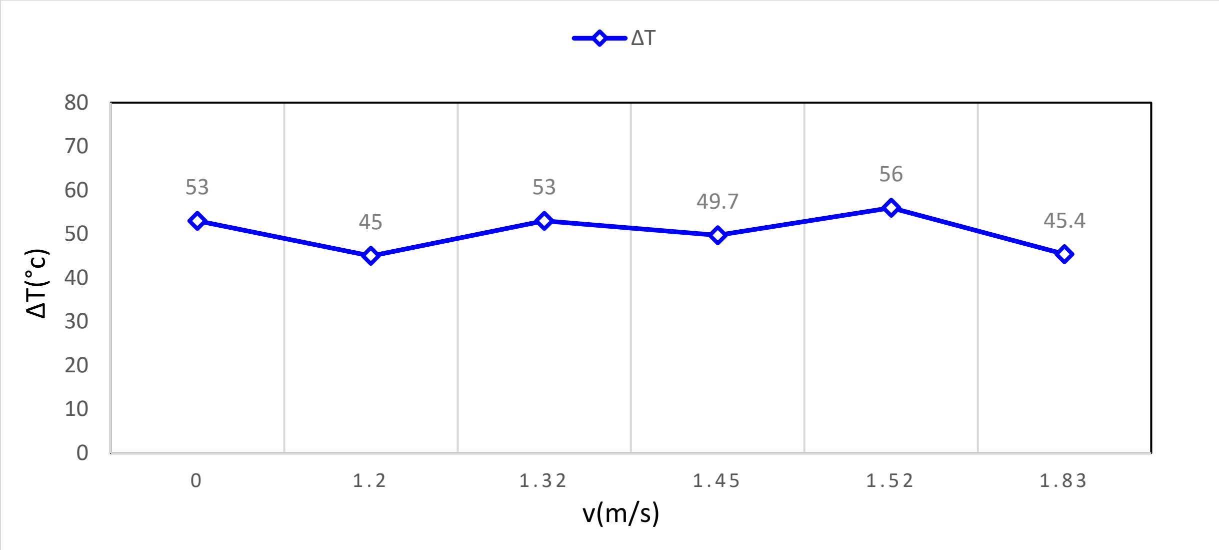
Table 2 Configuration made of soda cans at forced flow.

Time	T_{in}[°C]	T_{out}[°C]	ΔT[°C]	V[m/s]	ρ[kg/m^3]	Q[w]
9:30	23	76	53	0	1.011	0
10:00	25	70	45	1.2	1.029	280.7
10:30	26	79	53	1.32	1.002	354.1
11:00	26.3	76	49.7	1.45	1.011	368.1
11:30	27	83	56	1.52	0.991	426.1
12:00	27.6	73	45.4	1.83	1.02	428.1



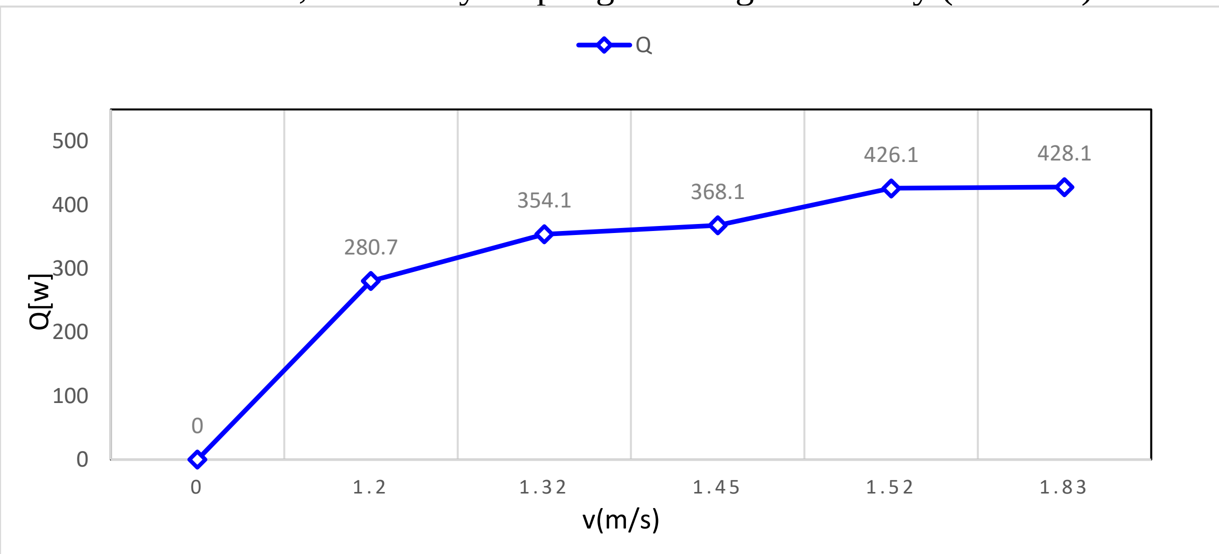
[Graph-4] Temperature versus time for configuration made of soda cans at forced flow.

[Graph-4], show the presence of a fan in the solar air heater system causes forced airflow, which increases the rate at which air passes through the heater. As a result, the air spends less time inside the collector, absorbing less heat from the solar energy. This leads to a decrease in the outlet temperature compared to what it would be under natural convection (without a fan).



[Graph-5] Temperature difference versus velocity of air for configuration made of soda cans at forced flow.

[Graph-5], shows how the temperature difference between outlet and inlet air (ΔT) changes with airflow velocity. As the velocity increases from zero to about 1.52 m/s, the temperature difference first decreases, then rises to a maximum of 56°C, and finally drops again at higher velocity (1.83 m/s).



[Graph-6] Heat transfer versus velocity of air for configuration made of soda cans at forced flow.

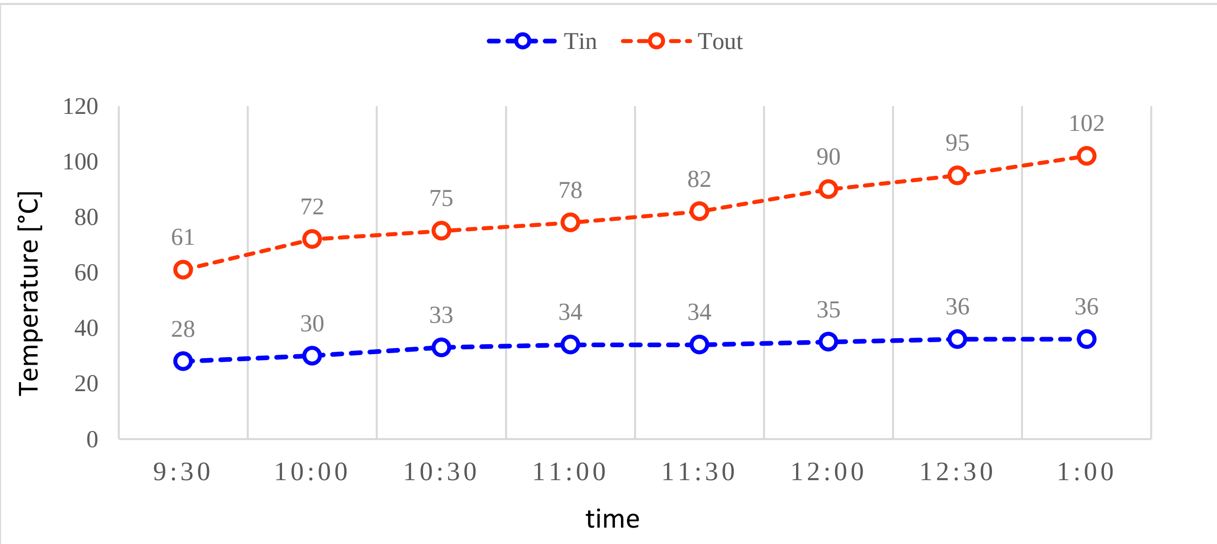
[Graph-6], shows the useful heat output (Q) as a function of airflow velocity. As the velocity increases, the heat output rises sharply and then levels off at higher velocities, reaching a maximum of about 428 W at 1.83 m/s. This means that even though the temperature difference may decrease at higher velocities, the total amount of heat delivered to the air continues to increase because more air is being heated per unit time.

4.2.3. Configuration is made of disposable aluminum bowls s directed upwards (Natural flow)

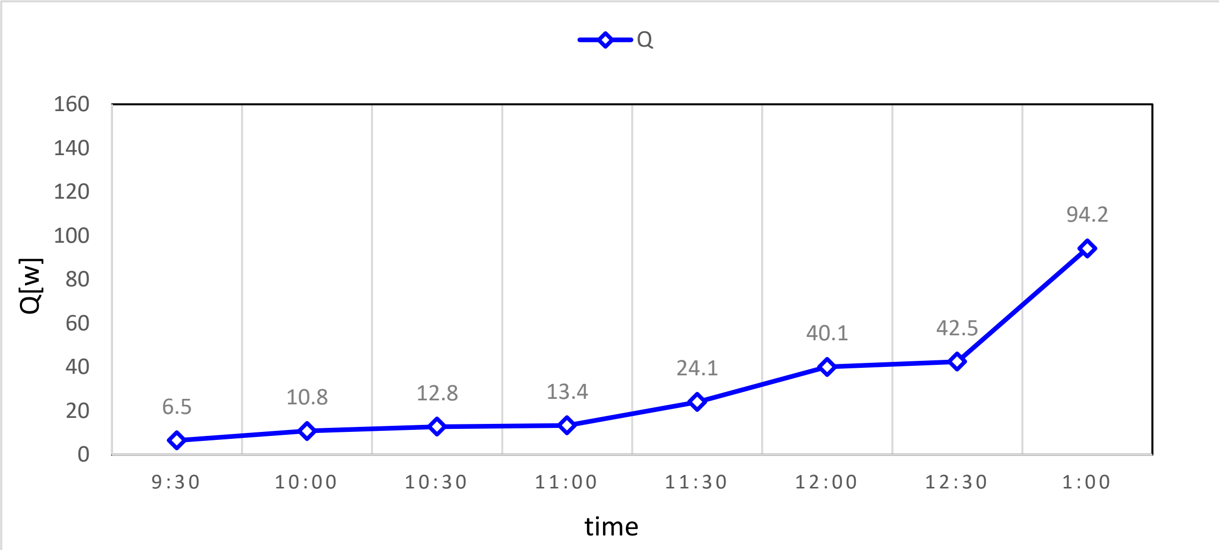
On April 8, 2025 we take these reads from Configuration is made of disposable aluminum bowls s directed upwards at natural flow.

Table 3 Configuration made of disposable aluminum bowls s directed upwards at natural flow.

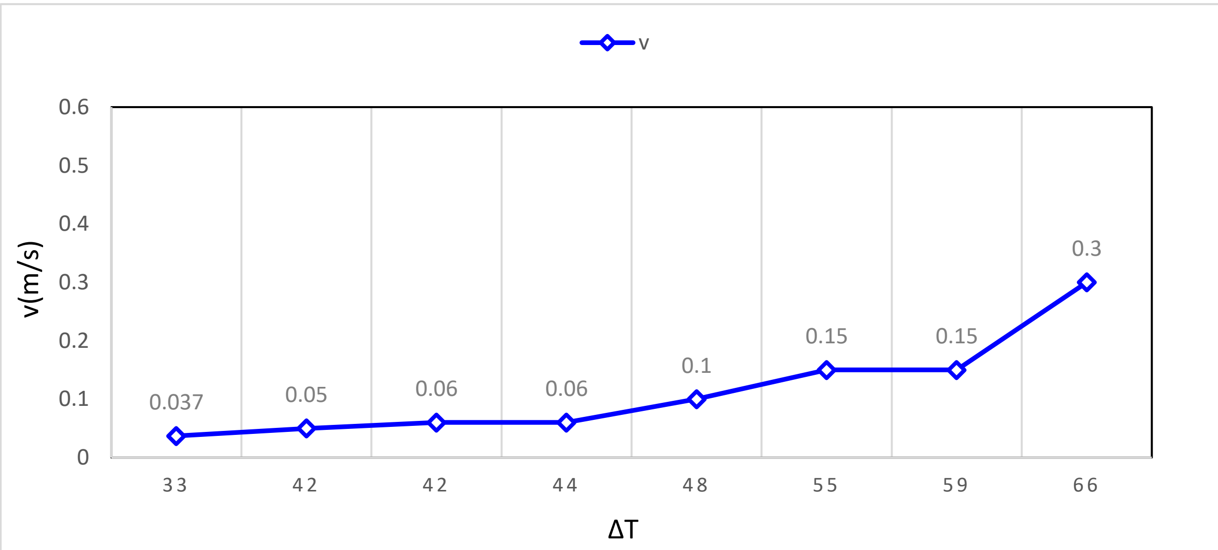
Time	T_{in}[°C]	T_{out}[°C]	ΔT[°C]	V[m/s]	ρ[kg/m^3]	Q[w]
9:30	28	61	33	0.037	1.057	6.5
10:00	30	72	42	0.05	1.0233	10.8
10:30	33	75	42	0.06	1.0145	12.8
11:00	34	78	44	0.06	1.005	13.4
11:30	34	82	48	0.1	0.9945	24.1
12:00	35	90	55	0.15	0.972	40.1
12:30	36	95	59	0.15	0.959	42.5
1:00	36	102	66	0.3	0.9414	94.2



[Graph-7] Temperature versus time for configuration made of disposable aluminum bowls directed upwards at natural flow.



[Graph-8] Heat transfer versus time for configuration made of disposable aluminum bowls directed upwards at natural flow.



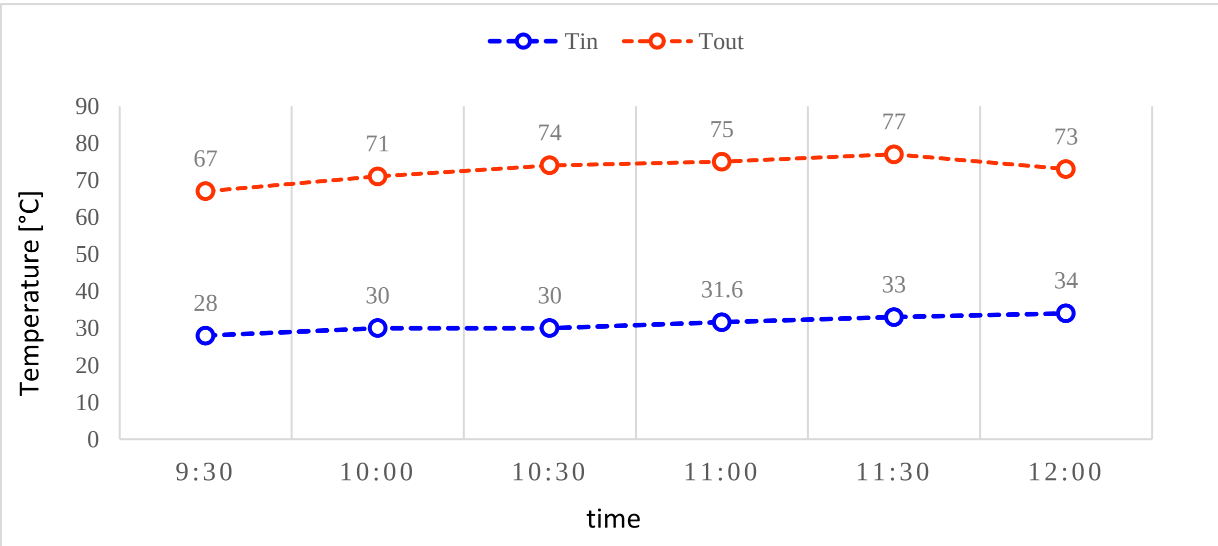
[Graph-9] velocity of air versus temperature difference for configuration made of disposable aluminum bowls s directed upwards at natural flow.

4.2.4. Configuration is made of disposable aluminum bowls s directed upwards (forced flow)

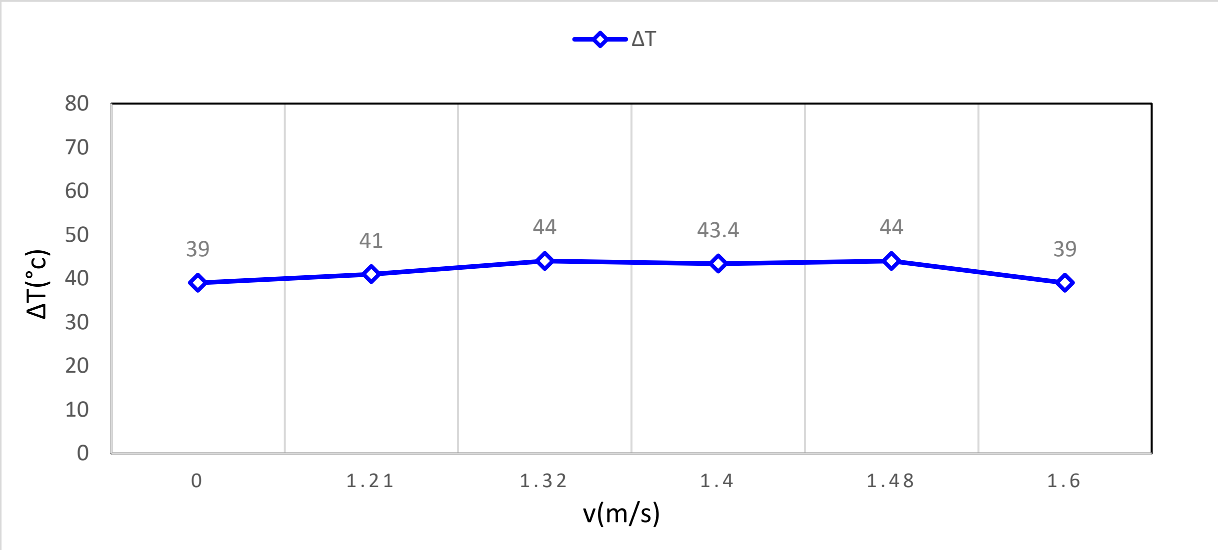
On April 9, 2025 we take these reads from Configuration is made of disposable aluminum bowls s directed upwards at forced flow. Also, we do the calculation of density and heat transfer

Table 4 Configuration made of disposable aluminum bowls s directed upwards at forced flow.

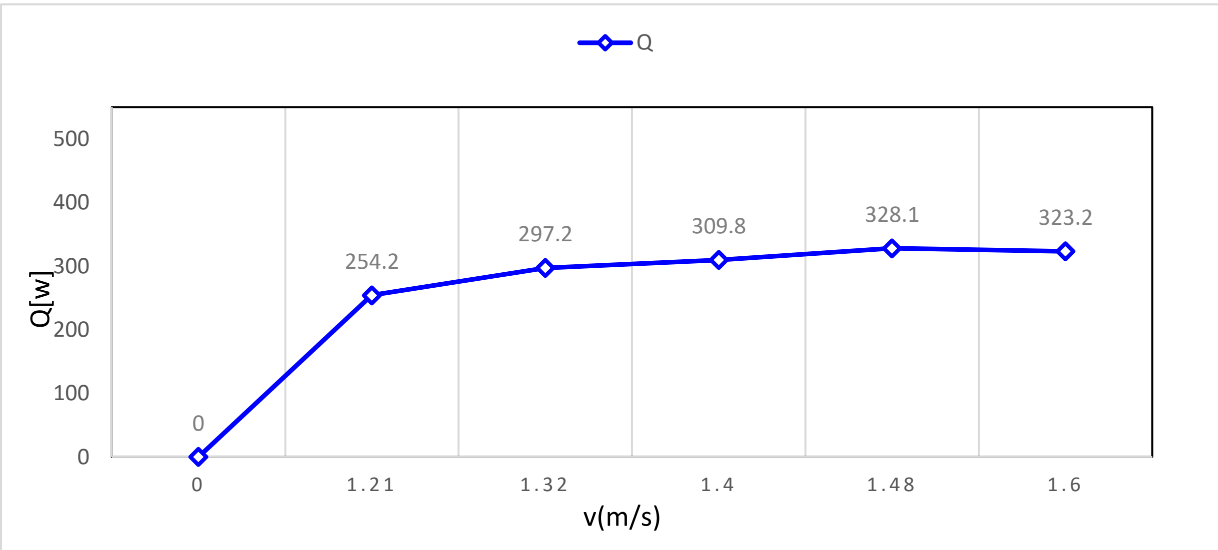
Time	T_{in}[°C]	T_{out}[°C]	ΔT[°C]	V[m/s]	ρ[kg/m^3]	Q[w]
9:30	28	67	39	0	1.038	0
10:00	30	71	41	1.21	1.026	254.2
10:30	30	74	44	1.32	1.017	297.2
11:00	31.6	75	43.4	1.4	1.014	309.8
11:30	33	77	44	1.48	1.0087	328.1
12:00	34	73	39	1.6	1.0203	323.2



[Graph-10] Temperature versus time for configuration made of disposable aluminum bowls directed upwards at forced flow.



[Graph-11] Temperature difference versus velocity of air for configuration made of disposable aluminum bowls directed upwards at forced flow.



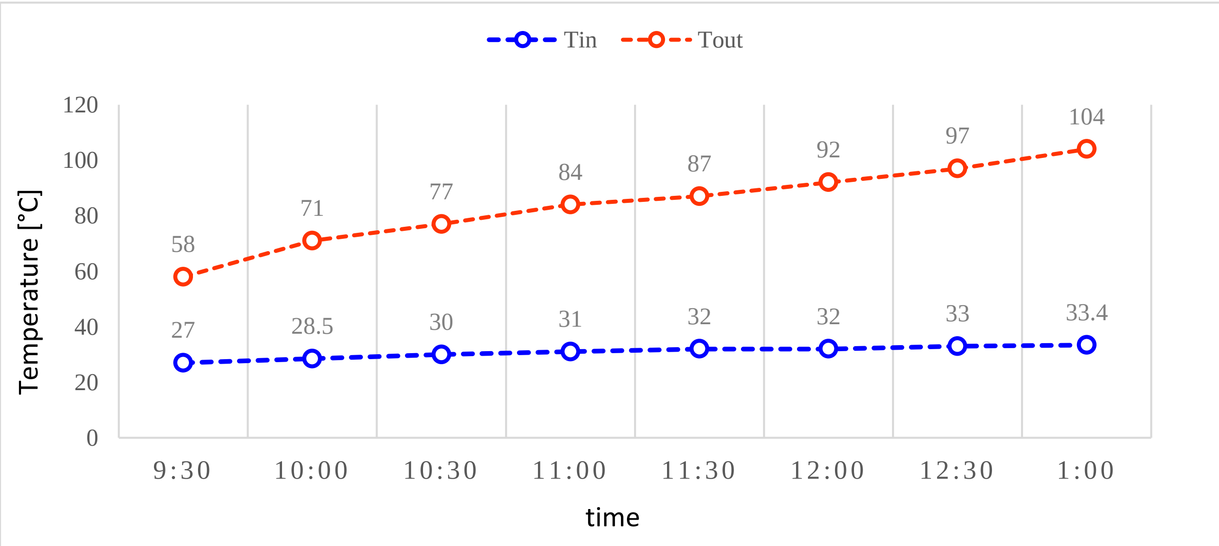
[Graph-12] Heat transfer versus velocity of air for configuration made of disposable aluminum bowls directed upwards at forced flow.

4.2.5. Configuration is made of disposable aluminum bowls directed downwards (natural flow)

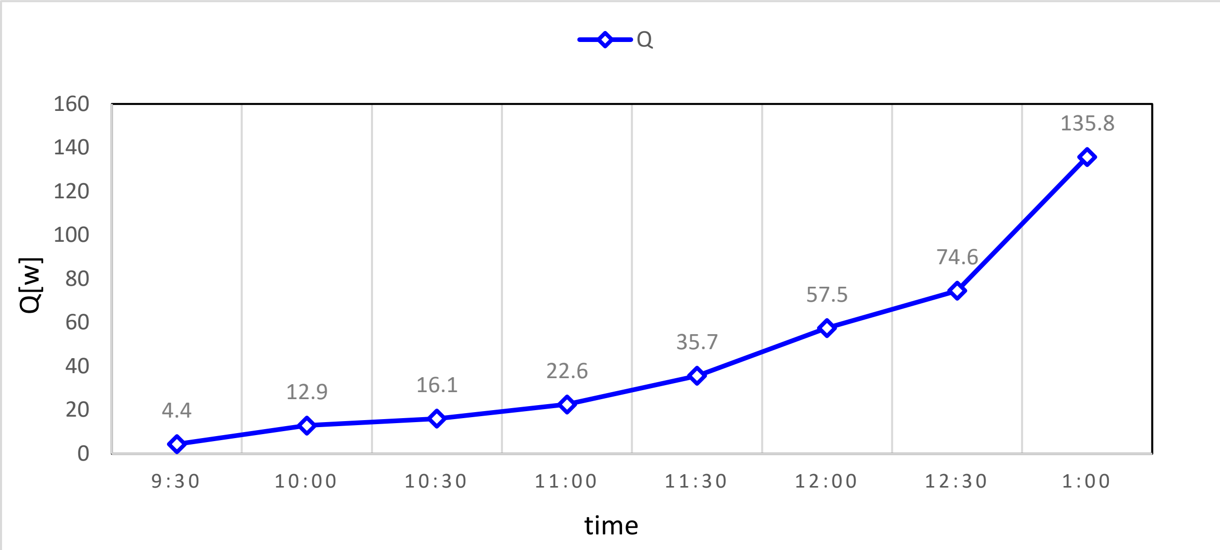
On April 20, 2025 we take these reads from Configuration is made of disposable aluminum bowls directed downwards at natural flow. Also, we do the calculation of density and heat transfer.

Table 5 Configuration made of disposable aluminum bowls directed downwards at natural flow.

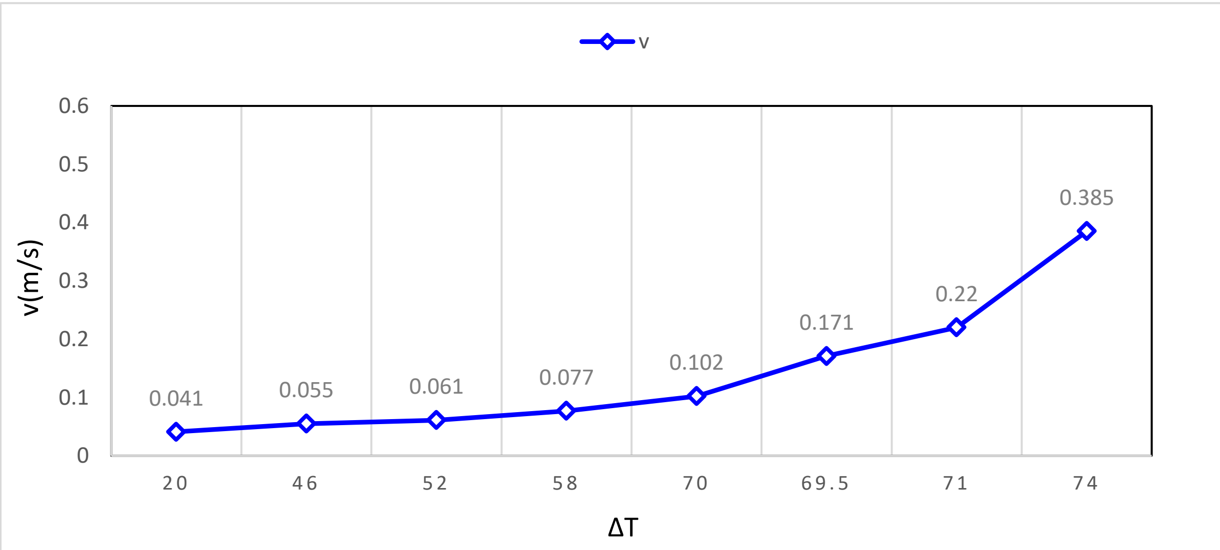
Time	T_{in}[°C]	T_{out}[°C]	ΔT[°C]	V[m/s]	ρ[kg/m^3]	Q[w]
9:30	27	58	20	0.041	1.066	4.4
10:00	28.5	71	46	0.055	1.026	12.9
10:30	30	77	52	0.061	1.0087	16.1
11:00	31	84	58	0.077	0.9889	22.6
11:30	32	87	70	0.102	0.98	35.7
12:00	32	92	69.5	0.171	0.967	57.5
12:30	33	97	71	0.22	0.9541	74.6
1:00	33.4	104	74	0.385	0.936	135.8



[Graph-13] Temperature versus time for configuration made of disposable aluminum bowls directed downwards at natural flow.



[Graph-14] Heat transfer versus time for configuration made of disposable aluminum bowls directed downwards at natural flow.



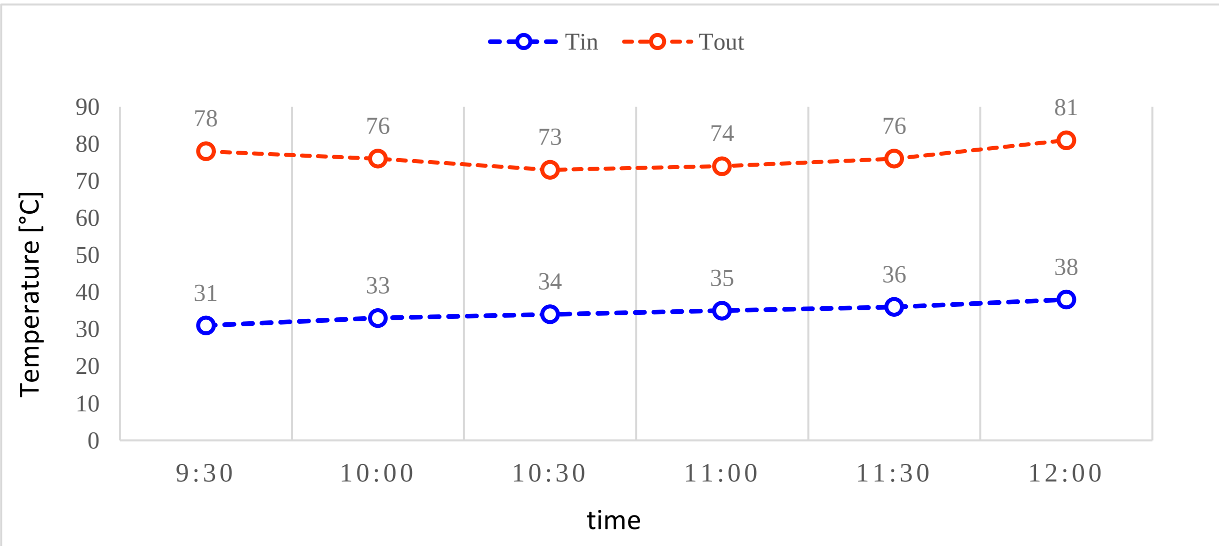
[Graph-15] velocity of air versus temperature difference for configuration made of disposable aluminum bowls directed downwards at natural flow.

4.2.6. Configuration is made of disposable aluminum bowls directed downwards (Forced flow)

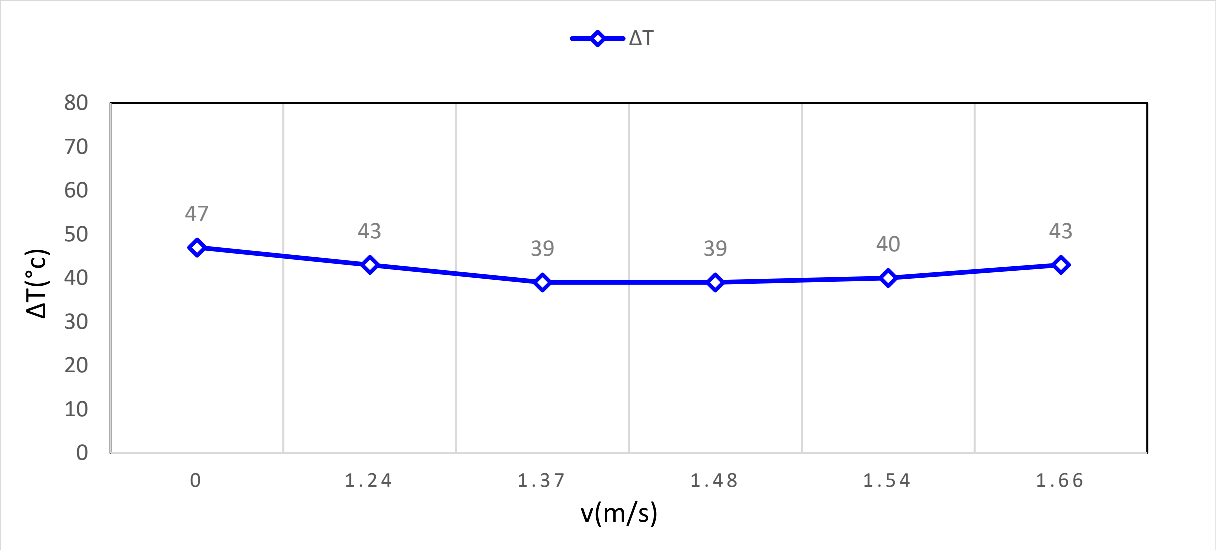
On April 21, 2025 we take these reads from Configuration is made disposable aluminum bowls directed downwards at forced flow. Also, we do the calculation of density and heat transfer.

Table 6 Configuration made of disposable aluminum bowls directed downwards at forced flow.

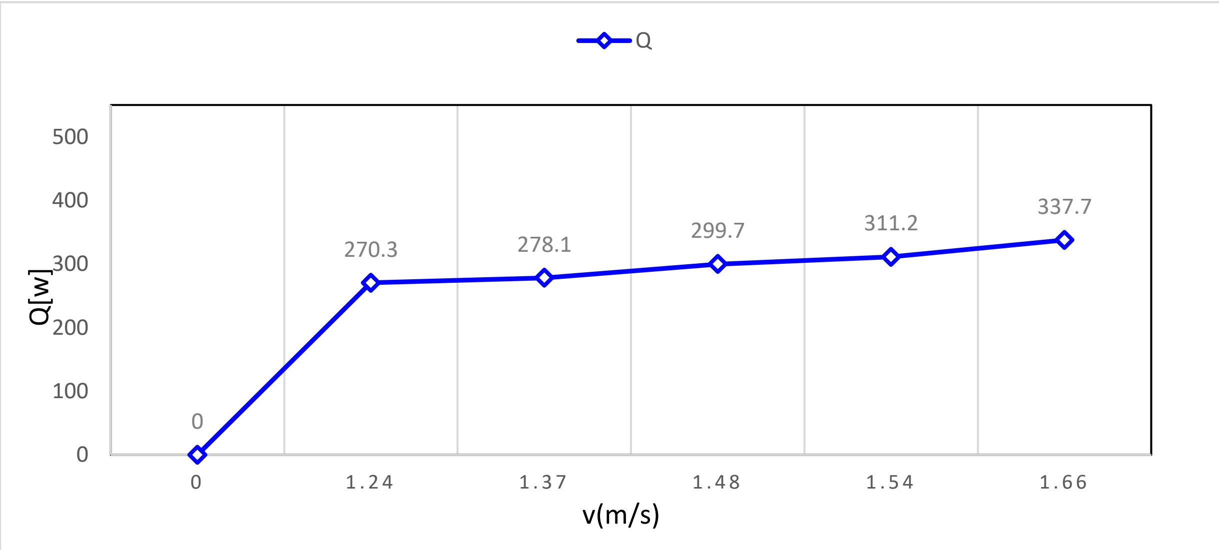
Time	T_{in}[°C]	T_{out}[°C]	ΔT[°C]	V[m/s]	ρ[kg/m^3]	Q[w]
9:30	31	78	47	0	1.005	0
10:00	33	76	43	1.24	1.011	270.3
10:30	34	73	39	1.37	1.02	278.1
11:00	35	74	39	1.48	1.017	299.7
11:30	36	76	40	1.54	1.0116	311.2
12:00	38	81	43	1.66	0.997	337.7



[Graph-16] Temperature versus time for configuration made of disposable aluminum bowls directed downwards at forced flow.



[Graph-17] Temperature difference versus velocity of air for configuration made of disposable aluminum bowls directed downwards at forced flow.



[Graph-18] Heat transfer versus velocity of air for configuration made of disposable aluminum bowls directed downwards at forced flow.

Chapter Five: Conclusion

The differences in thermal efficiency are especially clear when looking at the temperature differentials and airflow velocities. Natural convection systems consistently show higher ΔT values because air moves more slowly and thus absorbs more heat per unit of air. However, the slower movement also means that the volume of air heated is much smaller, resulting in lower overall energy output. Forced systems, despite having lower ΔT values, move air quickly enough to more than make up for the smaller per-unit temperature gain, leading to higher cumulative energy extraction. The differences in thermal efficiency are especially clear when looking at the temperature differentials and airflow velocities. Natural convection systems consistently show higher ΔT values because air moves more slowly and thus absorbs more heat per unit of air. However, the slower movement also means that the volume of air heated is much smaller, resulting in lower overall energy output. Forced systems, despite having lower ΔT values, move air quickly enough to more than make up for the smaller per-unit temperature gain, leading to higher cumulative energy extraction.

Another point of interest is the influence of absorber configuration itself. The soda can configuration, used in Cases 1 and 2, showed the best performance under forced convection, suggesting that this design has features—perhaps increased surface area, improved heat transfer characteristics, or better internal air movement—that pair well with high airflow rates. The third configuration made of disposable aluminum bowls directed downwards (used in Cases 5 and 6) showed the best performance under natural convection, indicating that it may be optimized for passive heating, potentially through design features that promote natural buoyancy-driven flow like vertical channels or materials with high thermal conductivity. The second configuration (Cases 3 and 4), while adequate, underperformed relative to the other two in both natural and forced flow conditions, suggesting either a less efficient heat transfer design or airflow resistance issues.

Time-dependent performance also highlights the impact of solar intensity throughout the day. All systems show an increase in output as solar irradiance peaks around noon. However, forced convection systems respond more dynamically to this increase, ramping up airflow and maintaining higher heat outputs, while natural systems plateau earlier, restricted by their inability to push more air through the system without mechanical assistance.

The data indicates that optimizing a solar air heater requires balancing absorber design with the type of airflow management. If the goal is to create a system with no electrical input, then a configuration like the one in Case 5 provides the best natural convection performance. However, if energy input for fans is acceptable, forced convection systems like Case 2 offer far superior thermal outputs, particularly when using an absorber design that is receptive to high airflow rates. Fan speed modulation also plays a role in efficiency, as extremely high speeds may reduce temperature rise too much, while too low a speed limits mass flow. The optimal point lies in balancing temperature gain and air volume for maximum energy extraction.

From a manufacturing perspective, the configuration made of disposable aluminum bowls directed downward is simpler to assemble due to its design, is susceptible to air leakage if not meticulously compressed and sealed within the enclosure. This potential issue compromises its airtightness and thermal efficiency over time. unlike the configuration made from soda cans, which remains durable over time despite its relative difficulty in manufacturing compared to the other configuration. Configuration made of disposable aluminum bowls s directed upward is better in this respect, as it is open and does not face the problem of leakage, in addition to being easy to assemble and use, so that sometimes it does not need adhesive or to carry out operations that require effort compared to the rest. The solar air heater system investigated in the study demonstrates a straightforward and resourceful approach to utilizing solar energy for heating and drying, relying on relatively simple designs that vary in absorber configuration and airflow type. When viewed in the context of other available thermal technologies used in heating and drying processes, this system stands out for its simplicity, low operational cost, and eco-friendly characteristics. The system's ability to operate either through natural convection or with the support of forced airflow makes it adaptable to different needs and environments. Under natural convection, the system utilizes the buoyancy-driven flow of air, which is sustainable and does not require external power. However, the efficiency and heat transfer rates are limited by the slower airflow, making it less effective in high-demand scenarios. Forced convection, on the other hand, significantly boosts thermal output by increasing air velocity through the system, which facilitates more efficient heat extraction and makes it suitable for more intensive heating or drying tasks.

In agricultural applications, such as the drying of herbs, fruits, vegetables, seeds, or grains, the solar air heater system from the study is particularly well-suited. It meets the necessary temperature range and provides sufficient airflow to reduce moisture content effectively while avoiding the risks of contamination and nutrient degradation associated with open sun drying. Furthermore, solar air heaters support the trend of decentralizing post-harvest processing by enabling farmers to preserve produce at the farm level, which contributes to food security and economic resilience.

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