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Title

**Investigation of solar chimney to improve thermal residential
comfort**

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In the name of God, and may blessings and peace be upon the Messenger of God

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Summary

Dedication	I
Summary	II
List of figures	V
List of symbols	VII
General introduction	01

Chapter I: Generalities about solar chimneys and thermal comfort

I.1 Introduction	04
I.2 Definition	04
I.3 Work method	04
I.4 Types of solar chimney	05
I.4.1. The classic Trombe Wall for winter heating	05
I.4.2. The Trombe-Michel Wall for winter	06
I.4.3. Solar chimney wall with a glaze	07
I.4.4. Solar chimney with a slanted roof	07
I.4.5. Solar chimney on the roof that goes up and down	08
I.4.6. Inclined implementation of roof Solar chimney	08
I.5.1. Thermal comfort	09
I.5.2. Types of thermal comfort	09
I.5.2.1 Analytical approaches	09
I.5.2.1.1 Fanger	09
I.5.2.1.2 Gagge	09
I.5.2.2 Adaptive approach	10
Conclusion	10

Chapter II: Bibliographic research

II.1. Introduction	12
II.2. The bibliographic researches	12
II.3. Conclusion	21

Chapter III: Mathematical modeling and numerical simulation

III.1. Introduction	23
III.2. Approach for mathematical modeling	23
III.3. Development of energy balance equation for glass ,air, and absorber	24
III.3.1. Energy balance for the glass cover	24
3.2. Energy balance for air	25
3.3. Energy balance for absorber	27
III.4 Calculation of mass flow rate through the chimney	28
III.5 The matrix	29

Chapter IV : Results and discussion

Introduction	31
IV.1 Validation	31
IV.2 The effect of the inlet and outlet ratio and the inclination angle on the temperatures and the flow velocity of air	34
IV.3 The effect of the inlet and outlet ratio and the inclination angle on the mass flow	35
IV.4 The effect of the inlet and outlet ratio and the inclination angle on the temperature and the incident radiation	36
IV.5 Conclusion	36
General conclusion	37
Reference	40

Figures list

Chapter I: Generalities about solar chimneys and thermal comfort

Figure I.1 Solar chimney with inclined roof	5
Figure I.2 The classic Trombe Wall for winter heating	6
Figure I.3 The Trombe-Michel Wall for winter cooling	6
Figure I.4 Vertical implementation of roof Solar chimney	7
Figure I.5 Combined roof Solar chimney	7
Figure I.6 Glazed solar chimney wall for tropical weather	8
Figure I.7 Inclined implementation of roof Solar chimney	8
Figure I.8 ASHRAE thermal sensation scale	9

Chapter II: Bibliographic Research

Figure II.1. The graphical layout of a solar chimney's function	14
Figure II.2. Experimental set-up	15
Figure II.3. The operating mechanism of the SC integrated with PMC	16
Figure II.4. Schematic diagram of a solar chimney	17
Figure II.5. Pv/solar chimney pilot model	18
Figure II.6. Schematic diagram of solar chimney	19

chapter III: mathematical modelisation and numerical simulation

Figure III.1 Solar chimney with inclined roof	23
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Chapter IV : results and discussion

Figure (IV.1) This figure represents the variation of the air velocity curves in function of the time and solar radiation	34
Figure (IV.2) This figure represents the variation of the air velocity curves in function of the time and solar radiation	35
Figure (IV.3) This figure represents the variation of the air temperature curves in function of the time and solar radiation	36
Table IV.1 The paramertes and the characteristics of mathur's et al solar chimney	

Table IV.2 The radiation and the room temperature used in the code in function of time 32

Table IV.3 Validation of our first code with the experimental and theoretical results of Mathur et al 33

Symbols list

A_0, A_i	Cross sectional area of inlet and outlet to air flow channel (m^2)
A_g	area of glass (m^2)
A_r	ratio of A_0 to A_i
A_w	area of wall (m^2)
ACH	air changes per hour
C_d	coefficient of discharge of air channel intel (0.57)
C_{f1}	specific heat of air (j/kg k)
d	gap between absorber wall and glass (m)
h_c	conductive heat transfer coefficient for glass ($W/m^2 k$)
h_g	conductive heat transfer coefficient for glass cover and air channel ($W/m^2 k$)
h_{rs}	Radiative heat transfer coefficient between wall and glass cover ($W/m^2 k$)
h_{rwg}	Radiative heat transfer coefficient between wall and glass cover ($W/m^2 k$)
H	Incident solar radiation on inclined surface (W/m^2)
k_f	Thermal conductivity of air (W/mk)
k_{ins}	Thermal conductivity of wall insulation (W/mk)
L_g	Height of glass (m)
L_s	Stack height (m)
L_w	Height of absorber wall (m)
m	mass flow rate (kg/s)
q''	heat transfer to air stream (W/m^2)
Q	ventilation rate (m^3/s)
S_1	Solar radiation heat flux absorbed by glass cover (W/m^2)

S_2	solar radiation heat flux absorbed by inclined absorber (W/m^2)
T_a	ambient temperature (k)
T_f	mean temperature of air in channel (k)
T_{fi}	air temperature at inlet of channel (k)
T_{fo}	air temperature at outlet of channel (k)
T_g	mean glass temperature (k)
T_r	room temperature (k)
T_{sky}	sky temperature (k)
T_w	mean temperature of inclined wall (k)
U_b	Overall heat transfer coefficient between inclined wall and room ($\text{W/m}^2 \text{ k}$)
U_t	Overall heat transfer coefficient from top of glass cover to ambient ($\text{W/m}^2 \text{ k}$)
V	volume of room
V	wind velocity (m/s)
Δ_{wis}	thickness of insulation behind absorber (0.05 m)
z	inlet height along the inclined plane
α_1	absorptivity of glass (0.06)
α_2	absorptivity of absorber wall (0.95)
ε_g	emissivity of top of glass cover (0.90)
ε_w	emissivity of black absorber surface (0.95)
γ	constant for mean temperature approximation (0.74)
ι	transmissivity of glass (0.84)
θ	angle of inclination with the horizontal surface
σ	Steffan–Boltzmann constant ($5.67 \times 10^{-8} \text{ W/m}^2 \text{ k}^4$)

General Introduction

General Introduction

In light of the industrial revolution, which has been at its peak since the beginning of the 21st century, the world's demand for energy has increased. However, 85% of this energy is derived from fossil fuels—oil, natural gas, or uranium. These energy sources generate significant environmental pollution by emitting global warming gases that contribute to the expansion of the ozone hole, in addition to the radiation risks associated with nuclear energy. These factors, alongside efforts by international organizations to reduce fossil fuel pollution, have directed the world toward using renewable energy. [1]

Renewable energy is the most suitable alternative because it is endless and environmentally friendly. There are many sources of renewable energy: hydropower, wind energy, solar thermal energy, photovoltaics, geothermal energy, and biomass. Unlike fossil fuels, these resources are clean. [2]

Solar energy is among the most widely used renewable energies and continues to grow daily. It is considered the most significant renewable source because it is utilized for electricity production as well as heating and cooling.[3]

One of the methods for utilizing solar energy is the solar chimney, which represents the most important application of solar energy in the field of ventilation. Solar chimneys enhance the natural ventilation of buildings by relying on solar energy and the principle of air buoyancy (air movement). While there are different types of solar chimneys, they all share the same operating principle.[4]

Solar chimneys operate by absorbing solar radiation, creating air buoyancy that ensures building ventilation. A solar chimney is studied according to its installation site because its performance is heavily affected by the local climate, which can sometimes lead to a loss of efficiency. Can they provide better ventilation in arid regions?

The purpose of this study is to find and develop parameters and conditions for the solar chimney to enhance its efficiency in hot and dry areas like Ouargla

The first chapter of this work aims to provide a general definition of a chimney solar with natural ventilation, to identify its types and their operation, as well as to make a comparison between these types. also an understanding definition and types of the thermal comfort

- In the second chapter, we will discuss the most scientific articles important presented in the field of solar chimneys and the latest studies conducted by scientists, and we will see to what extent the development of solar chimney in buildings have reached in improving thermal residential comfort
- In the third chapter, we will make our numerical code from equations. linear using the Matlab program and will solve these equations with the gauss elemination method.
- In the last chapter, we will compare and validate the results obtained in the previous chapter with the previous results in this field using the same data and will check the validity of the digital code.
- In addition to discussing the most important factors affecting the performance of the solar chimney like the air velocity, the air temperature and the mass flow and present the results in curves
- At the end there will be a general conclusion that summarizes all of this work steps and findings

Chaptre I

Generalities about solar chimneys and thermal comfort

I.1.Introduction

Solar chimneys are sustainable energy solutions meant to improve air movement in buildings using solar power. As a key type of passive ventilation, they are integrated into the building's surface to improve indoor air quality and temperature comfort, especially in specific regions. While many studies have tried tests and computer models, judging them remains complicated and difficult. This is because their success relies on changing weather conditions and the methods used to predict air flow. As modern buildings become bigger and more complicated, experts still lack a uniform set of rules for creating these systems. Recently, there has been a growing interest in linking solar stacks with other passive cooling or heating methods to make them more efficient and lasting. however, using solar stacks in big and multi-story buildings is still a problem. Research in this area is moving slowly, often creating conflicting results due to the difficult nature of how these systems interact with big buildings.

I.2.definition

A solar chimney is a renewable energy system designed to improve natural ventilation in a building using solar energy. It is a highly representative solar-assisted passive ventilation system integrated into the building shell. It greatly useful in augmenting natural ventilation and improving thermal comfort in specific climatic situations. The improvement of ventilation in solar chimneys has been extensively investigated using numerical and experimental methods. The evaluation of solar chimney systems using passive ventilation is significantly influenced by the natural environment, experimental conditions, posing substantial challenges to quantitative analysis and studies. As the volume and complexity of building structures rise, existing research on solar chimneys has failed to establish a design strategy and appropriate guidelines [5]

I.3.Work method

Passive Heating and Cooling Solar chimneys represent one of the most straight forward and cost-effective strategies for managing a building's thermal environment. The concept starts with a simple structure, typically coated in dark or matte black materials. This choice of color is intentional; it minimizes solar reflectance and maximizes heat absorption, ensuring that the thermal energy is efficiently transferred to the air column trapped inside. To capture the highest possible solar gain, these chimneys are strategically positioned on south-facing walls in the Northern Hemisphere, taking full advantage of the sun's path throughout the day

The Heating Phase: Using a solar chimney for heating is kind of easy to understand. As solar radiation hits the chimney's surface, the air inside begins to warm up. By keeping the exterior top vents closed, we force this buoyant (air movement), warm air back into the living quarters. This creates a natural convective loop, as the air circulates and eventually cools within the room, it is drawn back into the chimney to be re-heated. In this mode, the system functions quite similarly to a traditional Trombe wall.

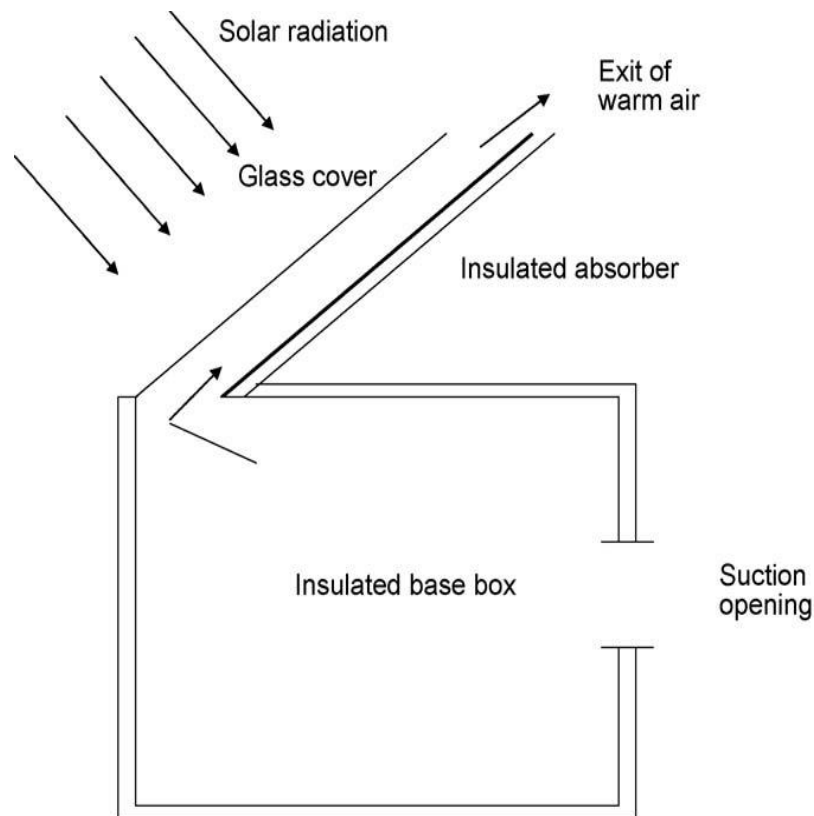


Figure I.1. Solar chimney with inclined roof[6]

I.4.Types of solar chimney

I.4.1.The classic Trombe Wall for winter heating

Description: A thick thermal mass wall made of concrete or brick that is placed behind a layer of glass on the outside.

How it works: The wall takes in solar radiation and warms the air in the space between the glass and the wall. Because of buoyancy, the warm air rises and enters the room through the top vents to heat it up. Alternatively, it can be let out to the outside to bring in fresh air to cool it down [7]

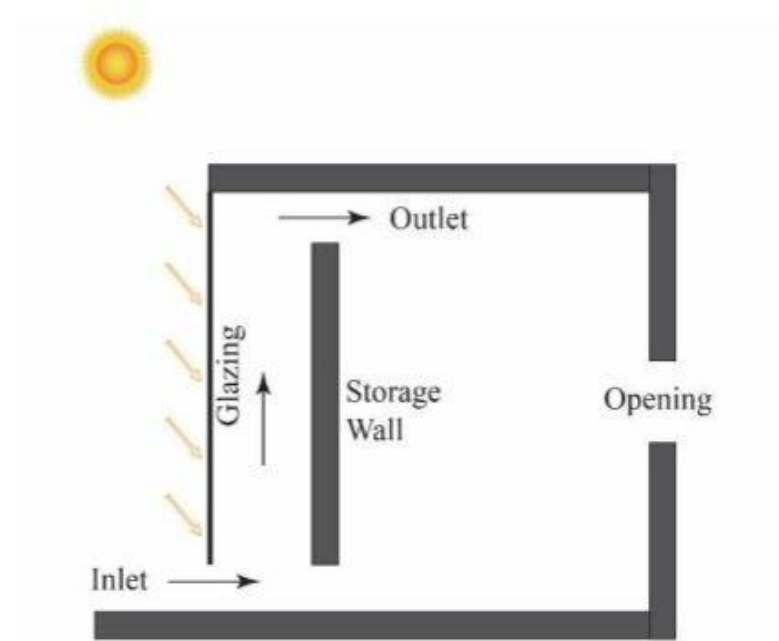


Figure I.2. The classic Trombe Wall for winter heating [7]

I.4.2.The Trombe-Michel Wall for winter cooling

Description: An improved version that has extra structures to keep heat from escaping from the inside.

Mechanism: The air is heated by convection when it comes into contact with the storage wall, not directly by solar radiation. This design is meant to keep the heat in the room longer and stop it from getting cold at night. [7]

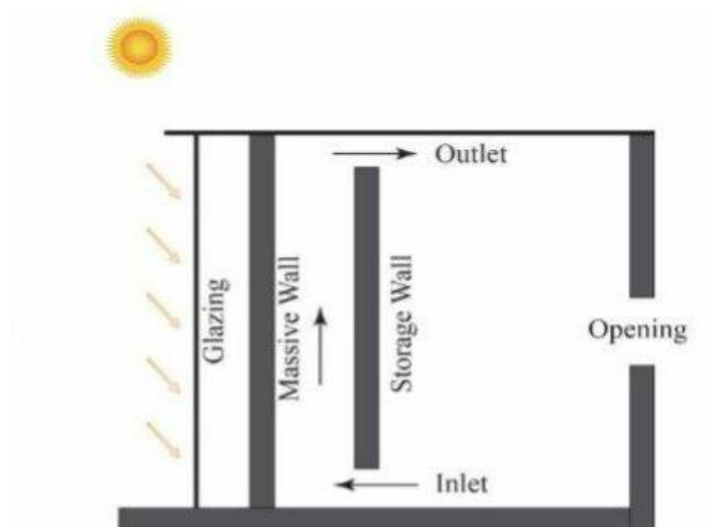


Figure I.3..The Trombe-Michel Wall for winter cooling [7]

I.4.3. Vertical implementation of roof Solar chimney

Description: It is made up of two glass panels with an air gap in between them, and it doesn't have a heavy thermal mass wall.

How it works: It works as a clear thermal buffer. The air between the panels gets hot and rises to the top exit. This creates a suction effect that pulls warm air out of the building, making it very useful in tropical climates. [7]

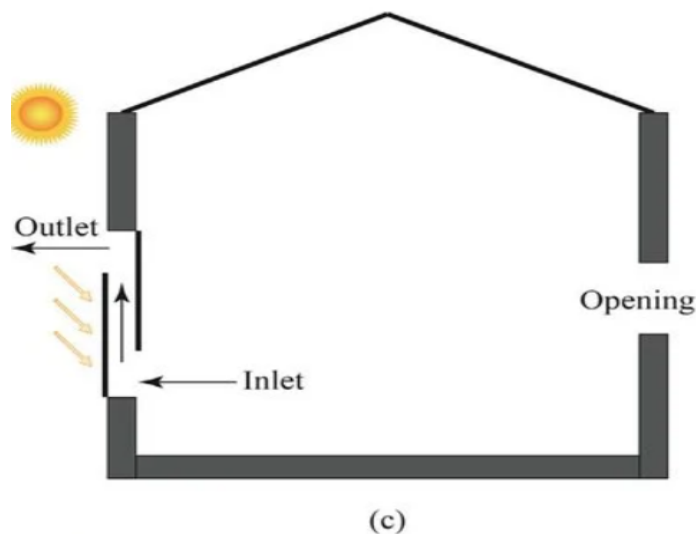


Figure I.4. vertical implementation of roof Solar chimney [7]

I.4.4. Combined roof Solar chimney

Description: A solar collector that is installed on the roof at an angle and usually has a layer for storing heat.

How it works: Air under the roof glazing is heated and rises along the slope. This upward movement makes the air pressure low, which pulls air from the living spaces up and out. [7]

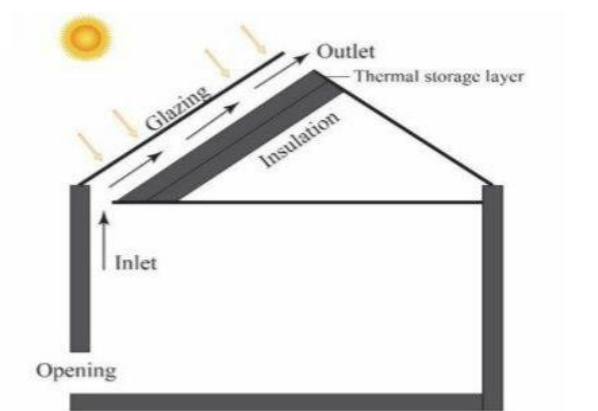


Figure I.5. combined roof Solar chimney [7]

I.4.5. Glazed solar chimney wall for tropical weather

Description: A vertical chimney structure that goes up from the roof and sometimes has separate inlets and outlets.

How it works: The "stack effect" works best when the height is vertical. The air in the vertical column quickly escapes through the top as it gets hotter, which keeps the air in the room moving. [7]

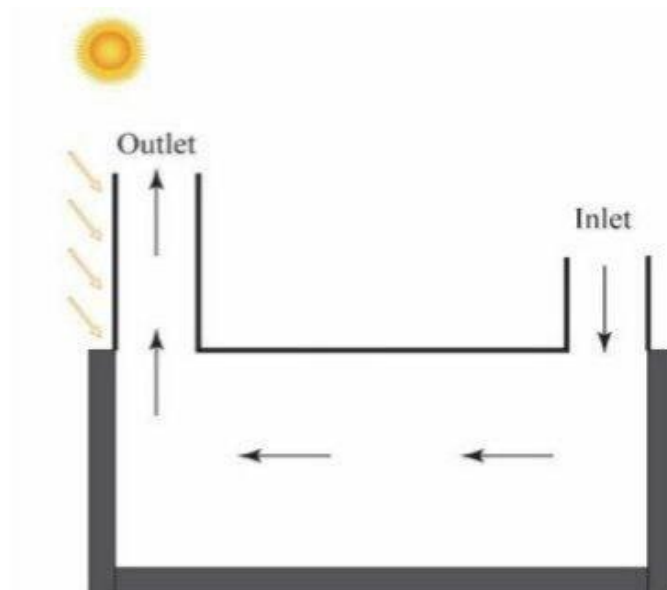


Figure I.6. glazed solar chimney wall for tropical weather [7]

I.4.6. Inclined implementation of roof Solar chimney

Description: A system that connects a solar collector on the roof to a vertical wall duct.

How it works: It uses the suction power of both the wall and the roof systems. The air is heated over a longer distance (from the wall to the roof), which makes the airflow speed and ventilation efficiency much better. [7]

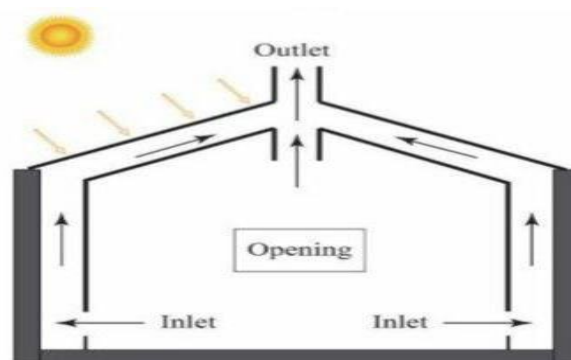


Figure I.7. inclined implementation of roof Solar chimney [7]

I.5.1. Thermal comfort

Thermal comfort is defined as "this condition of mind that expresses satisfaction with the thermal environment and estimated by a subjective assessment". Additionally, The World Health Organization states that health is a general state of physical, mental, and social well-being rather than only the absence of illnesses or disabilities and defines thermal comfort as "a condition when people are satisfied with the thermal environment." [8]

I.5.2. Types of thermal comfort

I.5.2.1. Analytical approaches

I.5.2.1.1. Fanger

The physiological parameters (skin temperature) required for thermal comfort in a fixed, indoor setting were found experimentally. The thermal feeling as a result of the differential between the body's heat flow to the environment and that which corresponds to comfortable circumstances is determined by the PMV index (Predicted Mean Vote) . On the ASHRAE thermal sensation scale, The PMV represents the mean thermal perception of a sizable population. [8]

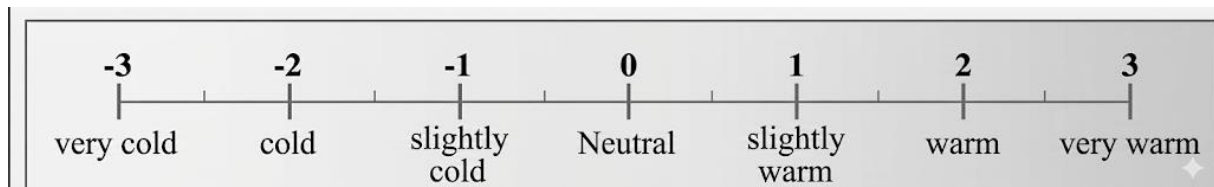


Figure I.8. ASHRAE thermal sensation scale[8]

Fanger introduced the "PPD" (Predicted Percentage of Dis-satisfied) , an additional measure that completes the PMV, because the temperature feeling is insufficient to convey comfort. This indicator makes it possible to forecast the proportion of people who are unhappy with a certain feeling.

I.5.2.1.2. Gagge

Gagge divided the human body into two concentric sections for this model, which stood for the skin and the body's core. under contrast to Fanger's static model, this dynamic model enables the prediction of physiological variables under unstable situations. Skin temperature an

skin moisture are employed at the model's output to calculate the SET (standard effective temperature), an index created by Gagge. This index shows the temperature equivalent of an isothermal enclosure at 50% relative humidity, where a person wearing a typical clothing would only exchange the same amount of heat and have the same physiological reaction in the actual enclosure. This index is related to thermal comfort. [8]

I.5.2.2.Adaptive approach

Another method has been created for thermal comfort in buildings if the analytical approach aims to a certain condition of thermal comfort using physical and physiological models that predict the thermal state of the human body. The results of examinations carried out in buildings serve as the foundation for this strategy. By measuring the physical dimensions of the thermal environment, it is possible to create a sizable database on the thermal conditions that exist in various building types for various climates and geographical areas. The occupants' subjective evaluations of the thermal quality of their surroundings are conducted concurrently with these measurements. On the ASHRAE scale, the occupants record their thermal perceptions at the moment of measurement. The temperature or a combination of variables (temperature, humidity, and air speed) that the occupants deem neutral or comfortable is then determined using statistical methods. This allows for the subsequent determination of the thermal comfort conditions in other buildings under comparable conditions. When researchers demonstrated that the comfort intended did not necessarily match the comfort observed by the occupants when applying the indices produced by the analytical technique to their database, this approach started to get greater attention. The difference was slightly more noticeable in buildings with air conditioning than in those without. In fact, the settings often resemble the climatic room's static conditions, which were used to create the analytical approach's instruments. The conditions in buildings without air conditioning, on the other hand, are dynamic and adapt to changes in the external temperature. These buildings have a broader comfort range than what the analytical approach's tools indicate. [8]

I.6.Conclusion

as what was given in this chapter, we found that the solar chimney is an solution that can be integrated into buildings to enhance air ventilation in a natural way without using any electrical outils only using a solar energy, and its types can be effective in different ways for different natures to provide a thermal comfort that matches the regeion's needs and conditions. It is still have a lot of different ways of use that will be shown on the next chapter.

Chaptre II

Research bibliograghy

Introduction

several researchers have been studying different solar chimney types and applications to improve its quality and performance, in this chapter we collected some researches and studies that will help us to understand and explain the importance and the multiple uses of the solar chimney that is helpful to improve the thermal residential comfort.

The Research bibliograghy

Ahmed et al. [9] did a research about Natural ventilation in warm climates inside buildings, particularly in warm climates. This review paper looked at the ability of natural ventilation to provide adequate thermal comfort, resilience against heatwaves, and good Indoor Air Quality in warm climates. Single sided ventilation demonstrates the poorest ability to provide thermal comfort, while cross ventilation highlights better performance in terms of reducing indoor air temperatures compared to outdoor. A potential low energy solution could be combining solar chimneys or wind catchers with water evaporation cooling. A critical synthesis of the literature suggests that these systems can generate high ventilation rates and keep indoor temperatures around 8 degrees C cooler than outdoor temperatures in warm weather (>35 degrees C). The literature supported natural ventilation being effective in removing pollution generated indoors due to adequate ventilation rates. However, using unfiltered natural ventilation for areas with high outdoor pollution can increase the indoor deposition of harmful particulate matter. With increasing air pollution, further studies are urgently required to investigate filter enabled natural ventilation, particularly with the solar chimney.

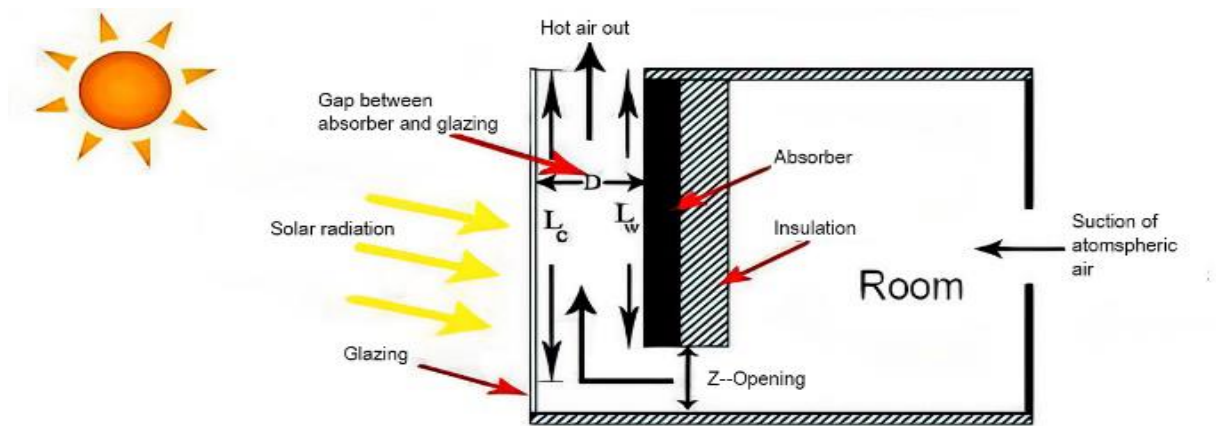
Nima et al. [10] did an Experimental investigation of the influence of inserting the metal foam to the solar chimney. The solar chimney performance is investigated by experimentally recording absorber plate and air temperatures and velocity of air. Results indicated that the using metal foam absorber plate lead to reducing the mean temperature of absorber plate as a result, the values of chimney outlet air temperature increased. The daily solar chimney efficiency enhanced by 58.7% and the useful energy received also increased. The existence of metal foam caused higher air velocity at the exit and increasing in the ventilation rate that the maximum ventilate rate obtained from the solar chimney is 5.96 1/hr. The results of the experimental work show that the addition of metal foam to the solar chimney as an absorber plate is an efficient method to enhance the characteristics of heat transfer and the thermal performance of the solar chimney in the weather condition of Iraq.

Benali Oussama et al. [11]Studied an inclined solar chimney integrated into residential buildings with different materials construction for natural ventilation in a hot-arid climate. They investigated the thermal behavior of two small rooms constructed from different materials, specifically local stone and hollow brick. The study measured variables such as indoor air temperature, the velocity of air entering the solar chimney, solar energy intensity, absorbed temperatures, room relative humidity, and overall atmospheric conditions. And the results tells that Utilizing solar chimneys for ventilation significantly lowers energy costs during the summer months, confirming the solar chimney's role as a sustainable and economically viable option for enhancing indoor environmental quality.

Lal Set al. [12]The experimental data are collected for both peak winter and summer season at CBRI Roorkee, India. There are temperatures at various points like: absorber plate, glass, wall, inlet, outlet, experimental room and reference room are measured by using thermocouples and stored in data logger. The velocity is measured at both inlet and outlet positions. The solar radiation and ambient temperature are also measured at the site. The performance of building integrated MSC has been evaluated on a typical day of December month (Peak winter). The solar chimney configured with metallic plate and with metallic box and experimentally examined, it is found the better space heating performance of metallic box solar chimney rather than conventional solar chimney. It produced better results even at night and observed 5-10°C temperature correspond to the ambient temperature and in Day rime in winter it produced 2-5°C temperature higher than ambient temperature. The conventional solar chimney produced night and daytime temperature 2-3°C and 0.4-2°C respectively correspond to the ambient air temperature. But metallic plates performed in night and daytime 1-4°C and 2-3°C respectively higher than the ambient air temperature. The plate temperature observed higher at upper side. The air temperature and velocity are observed higher near to the plate and mid of the air gap between glass and absorber respectively. The maximum energy efficiency has been observed by 26.68% during 12 hours of the particular day, and at the same time the exergy efficiency has been obtained by 3.69%. Approximately 2285kWh energy can be saved during a year through solar chimneys. CO₂ is also saved with energy conservation and 4.37 ton / year CO₂ saving have been estimated by SCWSP, on the other hand if SCWMSB had implemented then CO₂ would be saved by 5.51 ton/year.

Mehdi Khakzand et al. [13]Investigated inlet height effect on natural ventilation efficiency in vernacular house solar chimneys. The study aims to investigate the impact of inlet location on SC performance in airflow, in order to enhance the efficiency of passive natural ventilation.

On June 15, 2022, at 15:00 (the warmest time of the day), simulations were performed using the ANSYS FLUENT software on a hypothetical three-story building to investigate the impact of inlet location on SC performance in airflow and enhance the efficiency of passive natural ventilation. Two possible inlet locations, ceiling and floor level, were considered. This study addresses the accuracy of these two conditions, demonstrating that a floor-level inlet provides steady airflow at the human level with an average airspeed of 0.11 m/s and a cooler temperature as air moves away from the inlet. On the other hand, a ceiling-level inlet shows fluctuating airflow with an average airspeed of 0.15 m/s and similar air temperature values to the floor-level inlet.



FigureII.1.The graphical layout of a solar chimney's function[13]

Y Quoc Nguyen et al. [14]Evaluated the Performance of a Combined Vertical Wall–Horizontal Roof Solar Chimney for the Natural Ventilation of Buildings The study investigates the performance of a combined vertical wall–horizontal roof solar chimney numerically. A two-dimensional Computational Fluid Dynamics (CFD) model is employed to examine the flow and thermal characteristics under various influencing factors relating to the chimney's geometry, the flow resistance caused by the bend connecting the vertical and horizontal portions, the reverse flow at the outlet, and the location of the heat source. Compared to a vertical wall chimney at the same cavity height, the combined system always had a lower flow rate but had a higher thermal efficiency at some length-to-total-height ratios. Heating the upper walls induced higher flow rates but lower thermal efficiency. Particularly, the effect of the bend on the flow rate was more important than that of the reverse flow at the outlet. These results imply that a combined chimney is preferred over a vertical one for heating applications, wherein the combined chimney should have transparent upper walls. As the results indicate that the bend significantly affects the induced flow rate of the combined

chimney, potential future works may examine this factor in more detail using both numerical simulations and experiments. In addition, cost analyses may be considered alongside technical investigations.

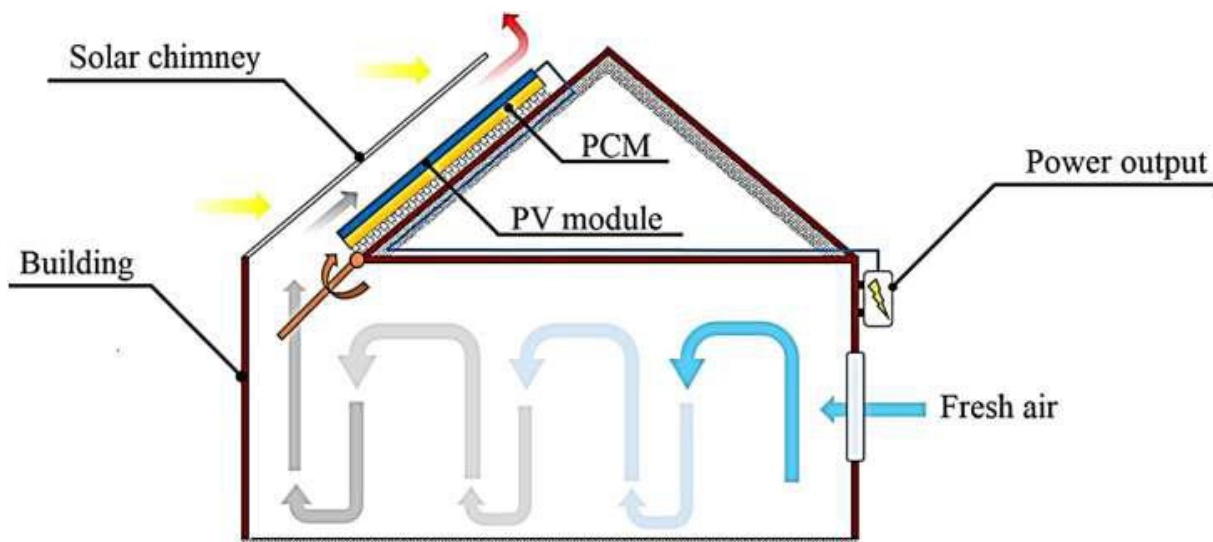
Miranda Marasigan et al. 2024 [15] studied the Development of a Hybrid Solar Chimney for Small- Scale Power Generation, PV Cooling, and Passive Ventilation. The study focuses on developing a small-scale model of a hybrid power generation system consisting of a solar chimney-turbine set up and PV solar system. The air passing thru the collector to the solar chimney shall both be performing passive ventilation of a residential building and cooling of the PV panel. Tests on an experimental setup and simulation in ANSYS Fluent are conducted to evaluate the system's performance and assess its potential as an alternative energy solution. Data collection involves measuring air velocity, temperature, and solar radiation at various points within the system. The solar panel was tested under two configurations, standalone and incorporated in the hybrid system. The results show that the hybrid system effectively harnesses solar energy, with the PV panel maintaining lower temperatures compared to the standalone setup. Furthermore, the simulations and experimental data exhibit a reasonable agreement, indicating the accuracy of the simulation model.



FigureII.2.Experimental set-up[15]

FarhanLafta Rashid et al. [16] studied Current developments, utilization, and effects of phase-change materials integrated with solar chimney, The research addressed the growing need for

sustainable energy solutions in building design by integrating phase change materials (PCMs) with solar chimney (SC) systems to enhance thermal performance and energy efficiency. Through a comprehensive review of existing studies, the study evaluated the evolution, application, and benefits of PCM- integrated SC technologies across diverse architectural environments. The findings demonstrated that the integration of PCMs significantly enhances thermal performance by stabilizing indoor temperatures, improving ventilation rates, and reducing reliance on conventional heating systems, which leads to notable energy saving sand promotes more sustainable building practices, The study concluded that addressing those challenges is critical for unlocking the full potential of PCM integrated solar chimneys in improving sustainability and energy efficiency within the built environment..



FigureII.3.The operating mechanism of the SC integrated with PMC[16]

Haihua Zhang et al. [17]studied solar Chimney Applications in Buildings. which help buildings get more fresh air, are being made right now. Here is a short summary of how to build and use a solar chimney. It has been determined which elements influence ventilation efficiency, temperature distribution, airflow patterns, and indoor air quality (IAQ). This article looks at the holes that are still in solar chimney research and the different ways to make them work better. Researchers discovered that a combined system of solar chimneys can deal with a wider range of weather conditions and give buildings useful ways to save energy. However, a single solar chimney used in one room and perfect weather conditions could still provide good indoor temperature control and better air flow. Previous research has focused on using parameter analysis to find the best design method, such as geometrically. research results have revealed the effectiveness of the multi-purpose application of solar chimneys, heating and

cooling spaces, fire prevention, and smoke control), which also makes the research of solar chimneys very promising..

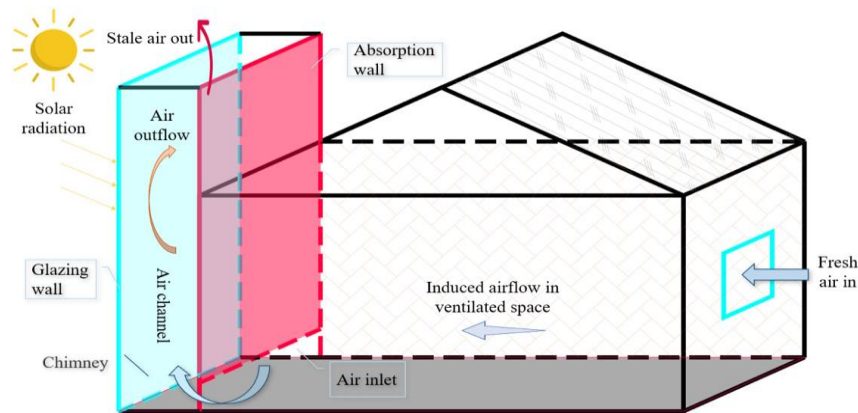
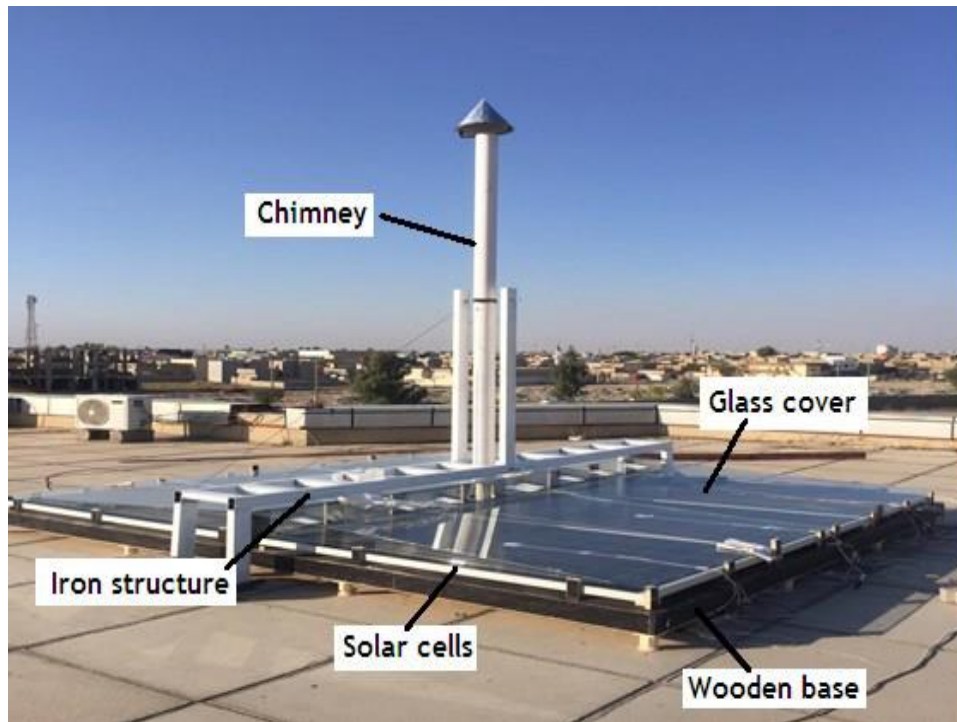


Figure II.4. Schematic diagram of a solar chimney [17]

A Hassan et al. [18] did an Experimental Study of Performance of Solar Chimney, the study was conducted with and without solar panels to show their effect on the performance of the hybrid solar chimney in the city of Kirkuk in Iraq. Six cells were placed between the base of the collector and the glass cover, which gives freedom to the air to move up and down the cells. Also, it is showed that the speed is higher when using PV until it reaches 1.8 m/s while the air leaving the collector and the energy coming out of the chimney and the efficiency of the solar collector and the efficiency of the chimney. The practical results showed that the chimney base is the ideal location for the turbine, as the air velocity is higher than other locations, and the air velocity increases during the day to reach its highest velocities at 1 pm. The maximum kinetic and electrical power and the amount of heat reached 37, 950, and 280 watts, respectively, in February at 1 pm. The results also showed that the location of the photovoltaic cell determines the degree of its temperature, as the solar cells that are in the middle are characterized by high temperature, while the solar cells that are on the ends are at a lower temperature and the solar cell temperature also depends on the surrounding weather conditions. High-efficiency values are observed for all months in the early morning hours due to the solar cells' low temperature. The highest recorded electrical efficiency values were 17.8% in December



FigureII.5.Pv/solar chimney pilot model[18]

Jing Zhang et al. [17] did a Study on the Impact of Solar Chimneys on Thermal Comfort and Energy Efficiency in Portable Toilets, this study proposes an optimisation strategy for human thermal comfort and energy conservation based on solar materials and the chimney effect. Through a heat-collecting wall-mounted vent system, CFD simulation and pollutant dispersion models are used to quantify its performance. The results show that: under extreme low temperatures of -10°C , the optimised mobile toilet achieves a maximum indoor temperature difference of 5.93°C , with the thermal comfort zone expanded by 40%, a 50% reduction in temperature gradient, and significant improvements in PMV-PPD indices during the transitional season and summer. In winter, the average PPD decreased by 58%, and in summer, the PPD reduction reached 10%. Compared to traditional models, annual ventilation energy consumption was reduced by 74.5%, thermal comfort-related energy consumption decreased by 67.2%, and the overall energy savings rate reached 58.5%. This approach holds significant reference value for improving the thermal environment of mobile toilets and advancing the achievement of carbon peaking goals. While the study lacks field experiment, the CFD models were rigorously benchmarked against established solar chimney

Vasyl Mizernyk¹ et al. [19] The study analyzes contemporary ventilation systems, evaluates climatic factors, and applies numerical modeling to assess passive ventilation effectiveness.

Findings show that solar chimneys, wind catchers, and hybrid ventilation systems improve natural air exchange and reduce reliance on mechanical systems. Despite advances in renewable energy technologies, solar chimneys are underutilized, particularly in multi-story buildings, due to limited research and the lack of validated methodologies.. The findings provide a comprehensive assessment of the effectiveness of passive ventilation systems under varying thermal conditions and structural configurations. While the solar chimney proves to be an efficient mechanism for enhancing natural ventilation, its performance is highly dependent on the architectural design and structural characteristics of the building ,The article also offers recommendations for integrating passive ventilation technologies into modern construction for more sustainable and energy-efficient design

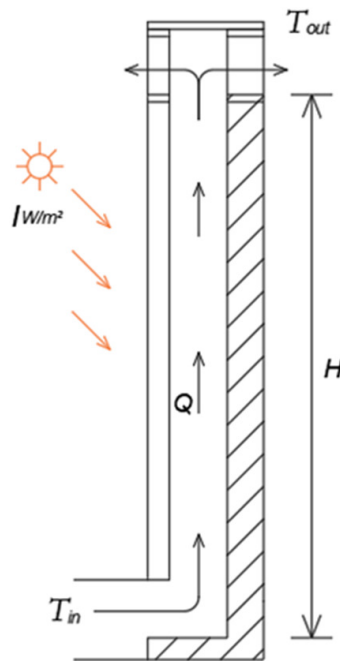


Figure II.6. Schematic diagram of solar chimney[19]

Sheikha Al Niyadi et al. [20] did a study about Advancing hybrid ventilation in hot climates by doing a review of current research and limitations Hybrid ventilation is an interesting way to lower the amount of energy needed for cooling in hot places, This study presents a comprehensive review of the effectiveness of hybrid ventilation systems in achieving thermal comfort located within hot, arid climates zones similar to the Middle East. Guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA),

the review adopted a rigorous four-step methodology for a study selection, mirroring the approach outlined by Umar (2020), Liberati et al. (2009) and Carlucci et al. (2020): identification, screening, eligibility assessment, and final inclusion (as illustrated in Figure 1). This systematic process ensured the inclusion of only the most relevant research. The selection criteria prioritised studies that: investigated mixed-mode ventilation systems (specifically combining natural and mechanical ventilation) in buildings; focused on arid climate regions; evaluated the impact of hybrid ventilation on occupant.

Nirmalen du Biswas et al. [21] Researchers have explored modifications in plant geometry and hybridization to improve efficiency. Despite extensive work in this area. This comprehensive review paper aims to provide an in-depth analysis of experimental approaches and advancements in the field of SCPPs, It provides an overview of the plants, discussing their principles and operation as innovative renewable energy systems. the effectiveness of an SCPP system depends on various parameters, including collector diameter, collector height, chimney area, chimney height, collectors lope, junction at the chimney inlet, chimney shape, air temperature, collector material, absorber material, absorber nature, and solar radiation. Researchers have conducted extensive studies to modify SCPP systems based on these parameters, with a specific focus on optimizing the system geometry. By addressing these recommendations and challenges, the potential of solar chimney power plants can be fully realized, contributing to the transition to a cleaner and more sustainable energy future making significant contributions to global energy goals and environmental sustainability.

Shiv Lal et al.[12] Experimental Studies on Solar Chimney for Building Space Heating and Ventilation Enhancement: Energy, Exergy and Economic Analysis, The experimental data are collected for both peak winter and summer season at CBRI Roorkee, India. There are temperatures at various points like: absorber plate, glass, wall, inlet, outlet, experimental room and reference room are measured by using thermocouples and stored in data logger. The velocity is measured at both inlet and outlet positions. The solar radiation and ambient temperature are also measured at the site. The performance of building integrated MSC has been evaluated on a typical day of December month (Peak winter). The experimental data are collected for both peak winter and summer season at CBRI Roorkee, India. There are temperatures at various points like: absorber plate, glass, wall, inlet, outlet, experimental room and reference room are measured by using thermocouples and stored in data logger. The velocity is measured at both inlet and outlet positions. The solar radiation and ambient

temperature are also measured at the site. The performance of building integrated MSC has been evaluated on a typical day of December month (Peak winter).

Conclusion:

This chapter showed different studies from researchers who found many ways to develop and create techniques like hybrid systems and stocks, to make the solar chimney more effective for longtime as a sustainable method, and how it can be integrated into the buildings also usable in many fiel

Chaptre III

Mathematical modeling and numerical simulation

I. Introduction

This chapter is dedicated to studying the different heat exchanges between the glass cover , the absorber, and the air in the chimney, which is the most important aspect of this study because we aim to increase its temperature (radiation and convection). The goal of this study is to determine the effect of ambient temperatures, as well as the solar radiation imposed on the absorber, on the temperature of the glass cover and the absorber, particularly the air inside the chimney, and the extent of their influence on the velocity of the airflow exiting the chimney. We present a model of the building on which we will perform the study. Then we apply the principle of conservation of energy and derive linear equations, which we will try to answer using the Matlab. Finally, we will present the data received from the temperatures and speeds, discuss them, and compare them with testing results.

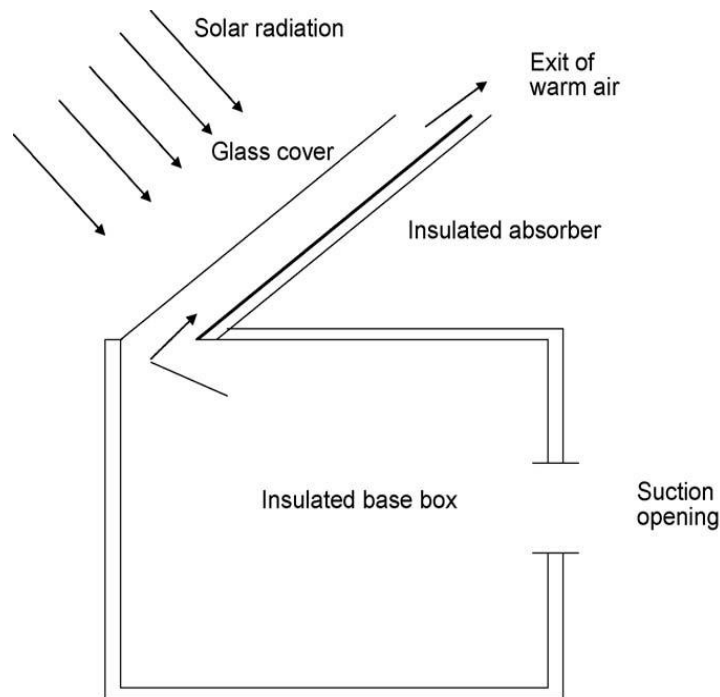


Figure III.1. Solar chimney with inclined roof

2. Approach for mathematical modeling

Objective of the Mathematical model was to predict the airflow rate through the solar chimney with angled viewer .For estimating the performance of solar chimney, study of the heat transfer through natural convection was performed. Major parameters in this study are: temperature of absorber and glass surface, temperature of air input and outlet, environmental temperature, flow rate, area of inlet and outlet hole. Writing energy balance equations for absorber surface, glass surface and air column and solving them for T_g , T_w , and T_f to calculate

airflow rate have sought a mathematical answer. Following assumptions were taken in this exercise

1. Steady state conditions were assumed to exist in the entire system.
2. All energy transfer processes through the glass cover, absorber plate and air channel were one dimensional innature.
3. Flow in air channel was laminar.
4. Absorber and glass were always parallel.
5. Temperature of air at the inlet of flow channel was equal to the ambient temperature.
6. Due to very low order of flow velocity, frictional losses were neglected.
7. All thermos physical properties were evaluated at an average temperature.

3. Development of energy balance equation for glass ,air, and absorber

3.1. Energy balance for the glass cover

Energy balance equation can be written as:

[incident solar radiation] + [radiative heat gain by glass cover from absorber wall] =
[convective heat loss to air in flow channel]
+[overall heat loss coefficient from glass to ambient]

Mathematically it can be expressed as:

Energy balance equation can be written as:[incident solar radiation] + [radiative heat gain by glass cover from absorber wall] = [convective heat loss to air in flow channel] + [overall heat loss coefficient from glass to ambient]

Mathematically it can be expressed as:

$$[S_1 A_g] + [h_{rwg} A_w (T_w - T_g)] = [h_g A_g (T_g - T_f)] + [U_t A_g (T_g - T_a)] \quad (1)$$

The above equation can be rearranged as:

$$(h_g A_g + h_{rwg} A_w + U_t A_g) T_g - h_g A_g T_f - h_{rwg} A_w T_w = S_1 A_g + U_t A_g T_a \quad (2)$$

In the above equation, area of glass and wall (A_g, A_w) can bemeasured directly, U_t , S_1 , hg, and hrwg can be calculated asdiscussed in Appendix A, leaving T_g , T_w , and T_f to be determine.

Procedure used to calculate U_t, S_1, h_g, h_{rwg} used in the energy balance equation for the glass cover

$$(h_g A_g + h_{rwg} A_w + U_t A_g) T_g - h_g A_g T_f - h_{rwg} A_w T_w = S_1 A_g + U_t A_g T_a \quad (A. 1) \quad (3)$$

(a) In the equation, U_t is the overall top heat loss coefficient from glass cover to ambient, due to the combined effect of convection by wind, radiative heat transfer from glass cover to sky and conduction through glass.

This can be written as:

$$U_t = h_{wind} + h_{rs} + h_c \quad (4)$$

The convective heat transfer coefficient due to wind as suggested by Duffie and Beckmann [22] as

$$h_{wind} = 2.8 + 3.0 V.$$

The radiative heat transfer coefficient from the outer glass surface to the sky referred to the ambient temperature was obtained from:

$$h_{rs} = \frac{\sigma \varepsilon_g (T_g + T_s)(T_g^2 + T_s^2)(T_g - T_s)}{(T_g - T_a)} \quad (5)$$

the sky temperature was calculated as; $T_s = 0.0552 T_a^{1.5}$

The conductive heat transfer coefficient ($\sigma \varepsilon_g$) for single glazing was taken as $5.91 \text{ W/m}^2 \text{ K}$.

(b) Solar radiation absorbed by the glass cover was determined by: $S_2 = \tau a_2 H$

(c) The radiation heat transfer coefficient between absorber and glass cover was obtained from:

$$h_{rwg} = \frac{\sigma (T_g^2 + T_w^2)(T_g + T_w)}{\left(\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1\right)} \quad (6)$$

(d) The convective heat transfer coefficient (h_g) between the glass cover and air in the flow channel:

$$h_g = \frac{Nu K_f}{L_g} \quad (7)$$

Where Nusselts number $Nu = 0.60 (Gr_x \cos \theta P_r)^{0.2}$

Grashof number, and, thermal conductivity of air, $K_f = [0.0263 + 0.000074(T_m - 3300)]$

3.2. Energy balance for air

The energy balance for the air between glass cover and the absorber was written as

[convection from absorber] + [convection from glass] = [useful heat gain by the air]

This energy balance can mathematically be expressed as:

$$[h_w A_w (T_w - T_f)] + [h_g A_g (T_g - T_f)] = [q"] \quad (8)$$

For a short length of wall/absorber (L), useful heat gain by air can be calculated through the following equation, assuming the temperature of glass (T_g) and wall (T_w) to be constant over the entire area.

$$q" = m C_{f1} (T_{f0} - T_{f1}) \quad (9)$$

The mean air temperature can be calculated as:

$$T_f = \gamma T_{f0} + (1 - \gamma) T_{fi} \quad (10)$$

In the above equation, value of γ (mean temperature approximation coefficient) was taken as 0.74, as suggested by These simultaneous equations were solved for T_g , T_w , and T_f by method of determinants, and the mass flow rate in the chimney for a room with two openings and a uniform room air temperature was determined as:

$$q" = \frac{m C_{f1} (T_f - T_r)}{\gamma} \quad (11)$$

Rearranging Eq. (2) and substituting the values of q obtained:

$$h_g A_g T_g - \left(\frac{h_g A_g + h_w A_w + m C_{f1}}{\gamma} \right) T_f + h_w A_w T_w = - \left(\frac{m C_{f1}}{\gamma} \right) T_r \quad (12)$$

In the above equation, C_{f1} , and g are constants, A_g , A_w can be measured directly, m, h_g , and h_w can be calculated as discussed in Appendix B, leaving T_g, T_w , and T_f to be determine.

$$m = \frac{C_d \rho_{f1} A_0}{\sqrt{1 + A_r^2}} \sqrt{\frac{2 g L_s \sin \theta (T_f - T_r)}{T_r}} \quad (13)$$

Here $A_r = \frac{A_0}{A_i}$, A_0 and A_i were outlet and inlet areas, respectively. Value of the coefficient of discharge ' C_d ' was taken as 0.57 as suggested by [23].

$$h_g = \frac{Nu K_f}{L_g}$$

Where, Nusselt's number $Nu=0.60(Gr_x \cos \theta P_r)^{0.2}$ (14)

$$Gr = \frac{g \beta S_1 (L_g)^4}{K_f \nu_f^2} \quad (15)$$

Thermal conductivity of air, $K_f = [0.0263 + 0.000074(T_m - 3300)]$ (16)

(c) The convective heat transfer coefficient between the inclined absorbing wall and the air-flow channel can be given by

$$h_w = \frac{Nu_1 K_{f1}}{L_w} \quad (17)$$

where, Nusselt's number $Nu=0.60(Gr_x \cos \theta P_r)^{0.2}$ Grashof number.

3.3. Energy balance for absorber

Similar to the energy balances for glass cover and air channel, energy balance for the absorber was written as:

[solar radiation] = [convection to air in flow channel] + [long wave re-radiation to glass] + [conduction to main room]

Mathematically it has been expressed as:

$$[S_2 A_w] = [h_w A_w (T_w - T_f)] + [h_{rwg} A_w (T_w - T_g)] + [U_b A_w (T_w - T_r)] \quad (18)$$

The above equation was rearranged in the following form:

$$-h_{rwg} A_w T_g - h_w A_w T_f + (h_w A_w + h_{rwg} A_w + U_b A_w) T_w = S_2 A_w + U_b A_w T_r \quad (19)$$

In the above equation, A_g, A_w can be measured directly, and h_{rwg}, h_w, U_b , and S_2 can be calculated as discussed in Appendix C, leaving T_g, T_w , and T_f to be determine.

Procedure used to calculate h_{rwg}, h_w, U_b , and S_2 used in the energy balance equation for the absorber

(a) Radiative heat transfer between absorber wall and glass ' h_{rwg} ' was calculated as given in Appendix A

(b) The airflow channel can be given by:

$$h_w = \frac{Nu_1 K_{f1}}{L_w} \quad (20)$$

where, Nusselt's number, $Nu_1 = 0.60(Gr_x \cos \theta P_r)^{0.2}$;

Grashof number, $Gr_1 = (g\beta S_2 \frac{(L_g)^4}{K_{f1} v_1^2})$ thermal conductivity of air, $K_f = [0.0263 + 0.000074(T_m - 3300)]$

(c) The overall heat transfer coefficient from the rear of the inclined wall (having absorber) to the room was taken as:

$$U_b = \frac{1}{(\frac{1}{h_i} + \frac{\Delta w_{ins}}{K_{ins}})} \quad (21)$$

Ignoring h_i (which is very small), the above equation was written in simplified form as given below without having significant effect on the calculations:

$$U_e = \frac{K_{ins}}{\Delta w_{ins}}$$

(d) The amount of solar radiation absorbed by blackened plate ' S_2 ' was calculated from:

$$S_2 = \tau \alpha_2 H \quad (22)$$

Calculation of mass flow rate through the chimney

This system of equations was solved for T_g, T_w and T_f by the method of determinants, and the mass flow rate in the chimney of a room with two openings and a uniform room air temperature was determined as follows [6]:

$$m = C_d \rho_{f1} A_0 \sqrt{\frac{2g L_s \sin \theta (T_f - T_r)}{(1 + A_r^2) T_r}} \quad (23)$$

Here $A_r = \frac{A_o}{A_i}$, A_o and A_i were outlet and inlet areas, respectively. Value of the coefficient of discharge ' C_d ' was taken as 0.57 as suggested by

The velocity of air in the flow channel that is finally used to calculate mass flow rate through

the chimney can be calculated through the mass flow rate using the following equation [6]:

$$v_0 = \frac{m}{\rho_{f1} A_0} \quad (24)$$

A computer program was written for the simulation study of solar chimney at different inclination angle. The intensity of solar radiation, surface azimuth angle, surface tilt with horizontal were important inputs to this program since they jointly governed the intensity of normal radiation on an inclined surface. Effects of the latitude, hour angle, declination angle and sky coefficient factor were taken into account while calculating the theoretical solar radiation falling on the inclined surface as suggested by Duffie and Beckmann[22]. The developed theoretical model and program can be used to estimate mass flow rate through solar chimney for different combinations of its geometric features, locations and time.

$$h_g A_g T_g - \left(\frac{h_g A_g + h_w A_w + m C_{f1}}{\gamma} \right) T_f + h_w A_w T_w = - \left(\frac{m C_{f1}}{\gamma} \right) T_r \quad (12)$$

$$-h_{rwg} A_w T_g - h_w A_w T_f + (h_w A_w + h_{rwg} A_w + U_b A_w) T_w = S_2 A_w + U_b A_w T_r \quad (19)$$

$$(h_g A_g + h_{rwg} A_w + U_t A_g) T_g - h_g A_g T_f - h_{rwg} A_w T_w = S_1 A_g + U_t A_g T_a \quad (2)$$

The matrix

$$\begin{bmatrix} h_g A_g + h_{rwg} A_w + U_t A_g & -h_g A_g & -h_{rwg} A_w \\ h_g A_g & - \left(\frac{h_g A_g + h_w A_w + m C_{f1}}{\gamma} \right) & h_w A_w T_w \\ -h_{rwg} A_w & -h_w A_w & (h_w A_w + h_{rwg} A_w + U_b A_w) \end{bmatrix} \begin{bmatrix} T_g \\ T_f \\ T_w \end{bmatrix} = \begin{bmatrix} S_1 A_g + U_t A_g T_a \\ \left(\frac{m C_{f1}}{\gamma} \right) T_r \\ S_2 A_w + U_b A_w T_r \end{bmatrix}$$

Conclusion

In this chapter, we presented a numerical study of the possibility of making a chimney solar thermal with natural ventilation in hot and dry areas using energy balance equations of the air and the glass cover and the absorber in order to calculate the mass flow and the flow velocity.

CHAPTER IV

Results and discussion

Introduction

After creating the numerical code to conduct this study, in this chapter we will verify its validity by comparing it to the experimental and numerical values (Mathur et al. 2006) Previous studies and study the effects of certain physical factors on the effectiveness of the solar chimney and discuss the results obtained.

Validation

After making the numerical code for this study, we will check its accuracy by comparing it to previous experimental and numerical values (Mathur et al. 2006). We will also look at how different physical factors affect the efficiency of the solar chimney and talk about the results.

We made sure our number code worked by checking it against the results of Mathur et al. [6]. The same physical properties and geometric shapes were used as in the solar stack. This information is shown in the table below. The actual and numerical results of Mathur et al. [6] were compared with the numerical code results for the temperature of the glass, the absorbent, the air, and the speed of the air. These outcomes can be seen in the table below.

The validation results showed that the numerical code and the testing results were very close to each other. This is because our numerical code was better than Mathur's numerical results for some air and glass temperatures. Although we found a superiority in Mathur's results and a somewhat significant relative error in our code's results in calculating air speed, it hit a maximum value of 27%.In the latter, we can say that our numerical code has been verified and can be introduced and improved by future research.

Table IV.1 the paramertes and the characteristics of mathur's et al solar chimney

parameteres	Numerical value
The gap between the glass and the absorber	0.35m
The length of the solar chimney	1m
The width of the solar chimney	1m
Air speed	1m/s
Steffan-Boltzman constant	$5.67 \cdot 10^{-8} \text{ w /m}^2.\text{k}^4$
The emisivity of the glass cover	0.9
The emisivity of the absorber	0.94

The glass absorbtivity	0.06
The absorber absorbtivity	0.95
The glass transmissivity	0.84
The isolation depth	0.05m
The thermal conductivity of polystyrene	0.067 W/m.K
Air channel discharge coefficient	0.57

Table IV.2 The radiation and the room temperature used in the code in function of time

Time (h)	Radiation of 30°(W/m ²)	Radiation of 45°(W/m ²)	Radiation of 60°(W/m ²)	Tr = Ta (k)
7:00	310	345	360	303,15
8:00	490	520	515	305,15
9:00	680	690	650	308,15
10:00	840	815	730	311,15
11:00	960	890	775	313,15
12:00	1020	920	790	315,15
13:00	990	900	780	317,15
14:00	890	830	740	318,15
15 :00	730	710	660	318,15
16:00	540	550	535	316,15
17:00	350	380	390	313,15

Table IV.3 validation of our first code with the experimental and theoretical results of mathur et al

Chapter IV : Results and discussion

Flow velocity at exit (m/s)	Relative error	22.76	23.80	21.78	23.95	26.31	26.90
	Relative error	11.40	10.30	9.79	8.18	8.87	8.63
	Our work	0.1344	0.1402	0.1455	0.1505	0.1571	0.1609
	Experimental	0.174	0.184	0.11948	0.1979	0.2132	0.2201
	Theoretical	0.1517	0.1563	0.1613	0.1639	0.1724	0.1761
Temperature of absorber wall (k)	Relative error	3.331	2.008	2.510	2.450	3.030	3.550
	Relative error	1.296	1.004	0.923	0.562	0.365	0.225
	Our work	340.00	347.49	354.97	363.35	369.35	374.21
	Experimental	329.04	340.65	346.28	354.66	358.49	361.38
	Theoretical	344.4653	351.0136	358.2759	365.4034	370.7026	375.0554
Temperature of air in flow channel (k)	Relative error	1.737	1.201	1.070	1.073	1.097	1.29
	Relative error	0.211	0.363	0.185	0.300	0.295	0.257
	Our work	301.60	305.24	308.88	313.42	315.57	316.61
	Experimental	306.931	308.95	312.22	316.82	319.07	320.75
	Theoretical	300.9653	304.13637	308.3095	312.48205	314.64314	315.79669
Temperature of glass (k)	Relative error	0.856	0.350	1.574	1.136	1.181	1.681
	Relative error	0.290	0.251	0.128	0.222	1.129	0.536
	Our work	311.61	316.25	320.89	326.43	329.57	331.62
	Experimental	314.3	317.36	326.02	330.18	333.51	337.29
	Theoretical	310.7082	315.4591	321.3004	327.1573	330.8334	333.4097
Ambient temperature		299.2	302.6	306	310.3	312.2	313
Radiation on absorber		500	550	600	650	700	750

IV.2 The effect of the inlet and outlet ratio and the inclination angle on the flow velocity of air

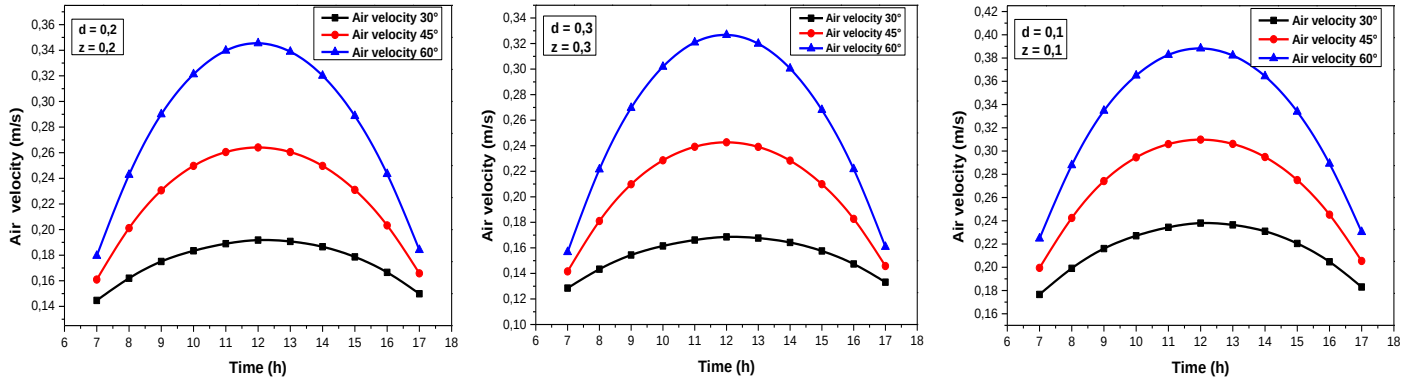


Figure (IV.1) This figure represents the variation of the air velocity curves in function of the time and solar radiation

Comment

The analysis of the measurement results of air sflow velocity at different inclination angles (30°, 45°, and 60°) and their interaction with different channel depths and slot heights (0.1m, 0.2m, and 0.3m) reveals a consistent trend: the most effective angle for improving ventilation efficiency in all tested cases is the inclination angle of 60°. This angle always produced the highest air velocities with a maximum velocity of 0.388 m/s , 0.345 m/s and 0.326 m/s for 0.1m , 0.2m and 0.3m respectively , higher than the air velocities for both 45° and 30° angles in all cases .

As a result we noticed that **Figure (IV.1)** with channel depth of(0.1m)and slot height (0.1m) got the highest air velocity at the inclination angle (60°) out of the three figures that presented the variation of the air velocity curves previously. Which lead us to conclude the best parameters for high air velocity for This solar chimney.

IV.3 the effect of the inlet and outlet ratio and the inclination angle on the mass flow

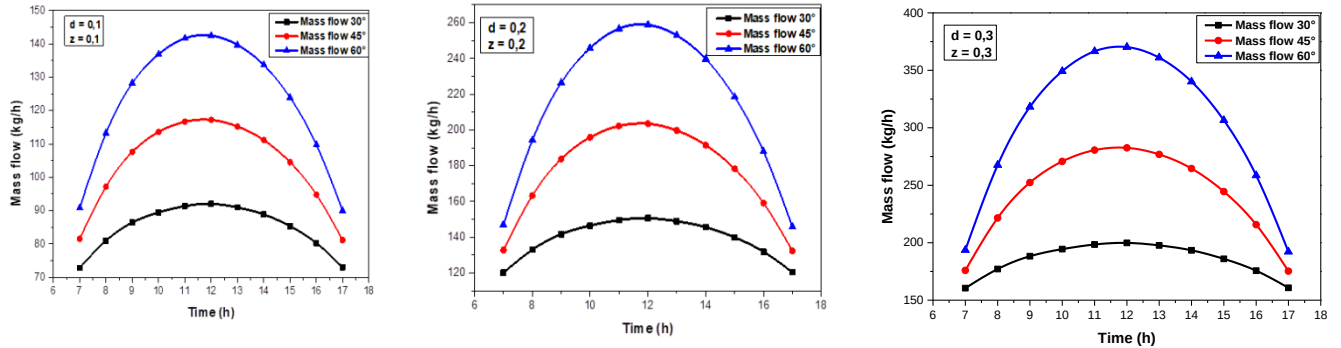


Figure (IV.2) This figure represents the variation of the mass flow curves in function of the time and solar radiation

Comment

Having analysed the results of mass flow rate measurements at different inclination angles (30°, 45°, and 60°) and their interaction with different channel depths and slot heights (0.1m, 0.2m, and 0.3m), it is clear that the 60° inclination angle consistently produces the highest mass flow rates, greatly improving ventilation efficiency in all tested scenarios. The maximum values of this angle were 142.48 kg/h, 258.82 kg/h and 370.25 kg/h respectively for the dimensions 0.1m, 0.2m and 0.3m, which are clearly better than the angles 45° and 30°.

As a result we noticed that **Figure (IV.2)** with channel depth of (0.3m) and slot height (0.3m) got the highest mass flow at the inclination angle (60°) out of the three figures that presented the mass flow variation curve previously. which lead us to conclude the best parameters for high mass flow in this solar chimney

IV.4 the effect of the inlet and outlet ratio and the inclination angle on the temperature and the incident radiation

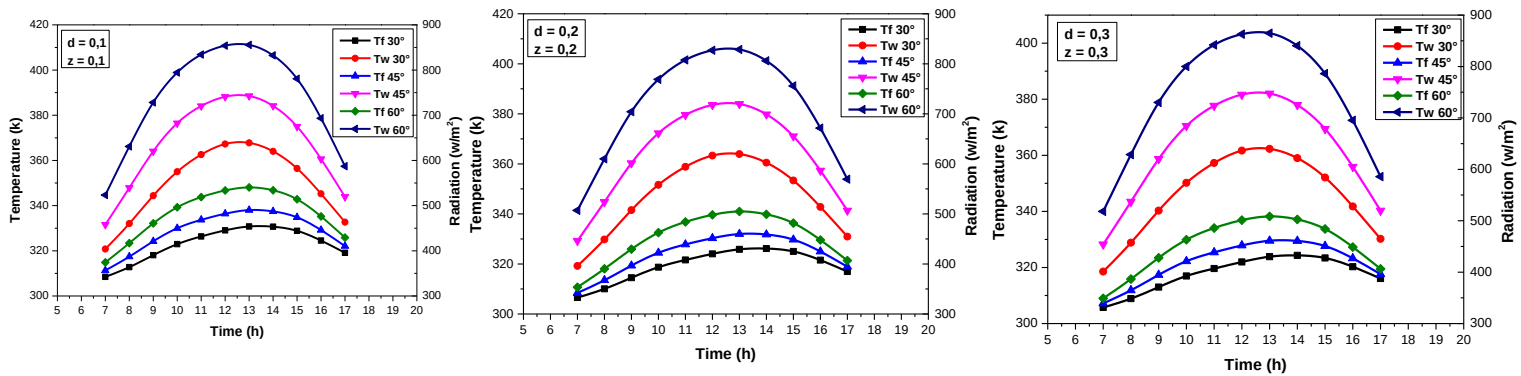


Figure (IV.3) This figure represents the variation of the air temperature curves in function of the time and solar radiation

Comment

The results show that the variation of wall temperature (T_w) and fluid temperature (T_f) for the inclination angles of 30°, 45° and 60° under the solar radiation intensities of 300, 600 and 900 W/m^2 , the inclination angle of 60° gives the best thermal performance for all channel dimensions (0.1m, 0.2m and 0.3m). The table below summarises the maximum peak temperatures that the wall and the fluid reach. This happens at around 12:30 pm and is considerably greater for 60° angle than 30°.

As a result we noticed that **Figure (IV.3)** with channel depth of (0.1m) and slot height (0.1m) got the highest wall temperature and fluid temperature at the inclination angle (60°) out of the three figures that presented the ($T_w - T_f$) variation curve previously. Which lead us to conclude the best parameters for high temperature in this solar chimney.

Conclusion

In this chapter we used the code for applying the work and the characteristics of our region after the validation of the results compared to The Experimental of Mathue et al (2006), so we can see which parameters give better temperatures, the flow velocity and the mass flow. The results showed that the most efficient angle of inclination in the area studied is 60°. and for a high mass flow taking the channel depth as (0.3m) and slot height as (0.3m) gave the highest results. For temperature and the flow velocity the highest results were found when the channel depth is (0.1m) and slot height is (0.1m).

General Conclusion

Genral Conclusion

The main purpose of this thesis was to study the thermal behaviour of a naturally ventilated solar chimney integrated in a slanted roof with the aim of assessing its potential as a passive cooling solution for residential buildings in hot arid climates and improving thermal comfort – with special reference to the meteorological conditions typical of the Ouargla region. nevertheless, a comprehensive theoretical framework was developed, from which utilizing energy balance equations were taken to identify the most important physical and geometrical parameters – forgetting the optimal chimney performance under the severe summer thermal conditions of the region as a result.

A specialised numerical simulation code was developed in the MATLAB programming environment based on this analysis base. The energy exchange taking place across each of the different parts of the chimney system, the glass cover, the internal airflow channel, and the absorber plate, was modelled in the code by formulating the corresponding energy balance equations in matrix form, and solving the resulting system to obtain the component temperatures and induced airflow velocities.

The numerical results were carefully compared with the experimental and theoretical data available in the well-known reference work of Mathur et al. (2006) to verify the validity and reliability of the developed model. The comparison showed a good agreement for all monitored variables among which were the glass cover temperature, the absorber plate temperature and the channel air temperature. The difference between the predicted air velocity was within an acceptable tolerance confirming the physical soundness of the model and its suitability for further parametric investigation. Using this validated computational framework, a systematic parametric study was performed to investigate the effect of three design variables – tilt angle (30° , 45° and 60°), channel depth and inlet and outlet slot heights – on the chimney thermal and aerodynamic performance at different times of day.

The results were compared and performance curves were used to provide a clear quantitative insight into the sensitivity of outlet air temperature and induced air velocity to each geometric parameter. The synthesis of our findings leads to a well-defined and practically actionable design recommendation: for a hot arid environment such as Ouargla, an inclined solar chimney of 1 m in length, with a tilt angle of 60° , and with a channel depth and slot opening of 0.1 m is the optimal configuration to maximise the natural ventilation and passive cooling performance. The maximum induced air velocity was obtained under these conditions and at maximum solar radiation, in addition to the highest air and absorber wall temperature increases among all

thesystems tested. Collectively, these results confirm that the inclinedroof-integrated solar chimney is not a theoretical concept, but afeasible and effective passive cooling strategy with actual potentialfor practical application in desert residential architecture,offering meaningful reductions in mechanical cooling dependency andassociated energy consumption

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Abstract

This thesis presents a comprehensive numerical investigation into the thermal behavior and aerodynamic performance of a roof-integrated inclined solar chimney, designed as a passive natural ventilation and cooling solution to improve residential thermal comfort in hot, arid regions. Focusing on the extreme summer meteorological conditions typical of the Ouargla region in Algeria, a mathematical framework was established by developing detailed one-dimensional steady-state energy balance equations for the key system components: the glass cover, the internal airflow channel, and the blackened absorber plate.

To solve the interconnected thermal network, a specialized numerical simulation code was developed in the MATLAB programming environment. The system of governing algebraic energy equations was formulated into a matrix layout and solved using the determinant method to calculate transient component temperatures, mass flow rates, and induced air velocities. The computational model was validated against established experimental and theoretical data from the literature (Mathur et al., 2006). The validation showed high statistical agreement across all monitored variables including glass, absorber, and fluid temperatures confirming the physical soundness and parametric reliability of the developed code.

A systematic parametric study was subsequently conducted to evaluate the sensitivity of the system performance to geometric modifications, specifically focusing on chimney tilt angles (30°, 45°, and 60°), internal channel depths (0.1 m to 0.3 m), and inlet/outlet slot heights (0.1 m to 0.3 m) across daily solar radiation cycles. The numerical results demonstrate that while a larger channel depth and slot height (0.3 m × 0.3 m) maximize the absolute mass flow rate (reaching a peak of 142.48 kg/h at an inclination of 60°), the optimum aerodynamic and thermal performance for localized structural cooling is achieved with narrower configurations. The findings yield a definitive architectural engineering design recommendation: for hot, desert environments like Ouargla, an inclined solar chimney with a length of 1 m, a tilt angle of 60°, a channel depth of 0.1 m, and an inlet/outlet slot height of 0.1 m represents the optimal configuration. Under these specific conditions and peak solar irradiance, the system maximizes the buoyancy-driven stack effect, yielding the highest fluid temperature differentials (with fluid temperatures reaching up to 338.21 K) and achieving a maximum induced peak airflow velocity of 0.326 m/s. Ultimately, this research validates the integration of inclined roof solar

chimneys as a highly feasible, low-enthalpy cooling strategy capable of significantly decreasing building reliance on mechanical air conditioning and minimizing residential energy consumption in desert climates.

Keywords: Solar Chimney, Passive Cooling, Natural Ventilation, MATLAB Simulation, Thermal Comfort, Hot and Arid Climate, Parameter Optimization.

Résumé

Cette thèse présente une étude numérique approfondie du comportement thermique et des performances aérodynamiques d'une cheminée solaire inclinée intégrée à la toiture. Conçue comme solution passive de ventilation et de refroidissement naturel, elle vise à améliorer le confort thermique des habitations dans les régions chaudes et arides. En se concentrant sur les conditions météorologiques estivales extrêmes typiques de la région d'Ouargla en Algérie, un cadre mathématique a été établi grâce au développement d'équations détaillées de bilan énergétique unidimensionnel en régime permanent pour les principaux composants du système : la couverture vitrée, le canal d'écoulement d'air interne et la plaque absorbante noircie.

Pour résoudre le réseau thermique interconnecté, un code de simulation numérique spécialisé a été développé sous MATLAB. Le système d'équations algébriques de l'énergie a été formulé sous forme matricielle et résolu par la méthode du déterminant afin de calculer les températures transitoires des composants, les débits massiques et les vitesses d'air induites. Le modèle de calcul a été validé par comparaison avec des données expérimentales et théoriques établies issues de la littérature (Mathur et al., 2006). La validation a démontré une forte concordance statistique pour toutes les variables surveillées notamment les températures du verre, de l'absorbeur et du fluide confirmant ainsi la validité physique et la fiabilité paramétrique du code développé.

Une étude paramétrique systématique a ensuite été menée afin d'évaluer la sensibilité des performances du système aux modifications géométriques, en se concentrant plus particulièrement sur les angles d'inclinaison de la cheminée (30° , 45° et 60°), les profondeurs des canaux internes (de 0,1 m à 0,3 m) et les hauteurs des fentes d'entrée/sortie (de 0,1 m à 0,3 m) au cours des cycles journaliers de rayonnement solaire. Les résultats numériques démontrent que, bien qu'une profondeur de canal et une hauteur de fente plus importantes ($0,3\text{ m} \times 0,3\text{ m}$) maximisent le débit massique absolu (atteignant un pic de 142,48 kg/h à une inclinaison de 60°), les performances aérodynamiques et thermiques optimales pour le refroidissement structurel localisé sont obtenues avec des configurations plus étroites. Les résultats obtenus per

mettent de formuler une recommandation de conception architecturale définitive : pour les environnements désertiques chauds comme Ouargla, une cheminée solaire inclinée d'une longueur de 1 m, avec un angle d'inclinaison de 60° , une profondeur de canal de 0,1 m et une hauteur d'ouverture d'entrée/sortie de 0,1 m, constitue la configuration optimale. Dans ces conditions spécifiques et sous un ensoleillement maximal, le système maximise l'effet de cheminée par convection naturelle, ce qui permet d'atteindre les différentiels de température du fluide les plus élevés (jusqu'à 338,21 K) et une vitesse d'air maximale induite de 0,326 m/s. En définitive, cette recherche valide l'intégration de cheminées solaires inclinées sur les toitures comme une stratégie de refroidissement à basse enthalpie très efficace, capable de réduire considérablement la dépendance des bâtiments à la climatisation mécanique et de minimiser la consommation d'énergie résidentielle dans les climats désertiques.

Mots-clés : Cheminée solaire, Refroidissement passif, Ventilation naturelle, Simulation MATLAB, Confort thermique, Climat chaud et aride, Optimisation des paramètres.

الملخص

تقدم هذه الأطروحة دراسة عددية شاملة للسلوك الحراري والأداء الديناميكي الهوائي لمُدخنة شمسية مائلة مدمجة في السقف. صُممت هذه المدخنة كحل سلبي للتهوية والتبريد الطبيعيين، بهدف تحسين الراحة الحرارية للمساكن في المناطق الحارة والجافة. بالتركيز على الظروف المناخية الصيفية القاسية التي تميز منطقة ورقلة في الجزائر، تم وضع إطار رياضي من خلال تطوير معادلات توازن طاقة أحادية البعد مفصلة لحالة الاستقرار للمكونات الرئيسية للنظام: السقف الزجاجي، وقناة تدفق الهواء الداخلية، ولوحة الامتصاص السوداء. تمت صياغة نظام MATLAB لحل الشبكة الحرارية المترابطة، تم تطوير برنامج محاكاة عددية متخصص باستخدام معادلات الطاقة الجبرية في شكل مصفوفة، وحُل باستخدام طريقة المحدد لحساب درجات الحرارة العابرة للمكونات، ومعادلات تدفق الكتلة، وسرعات الهواء المستحثة. تم التحقق من صحة نموذج الحساب من خلال مقارنته ببيانات تجريبية ونظرية موثقة من المراجع (مأثور وآخرون، 2006). أظهرت عملية التحقق توافقاً إحصائياً قوياً لجميع المتغيرات المرصودة، ولا سيما درجات حرارة الزجاج والممتص والسائل، مما يؤكد صحة النموذج الفيزيائية وموثوقية معاييرهِ. ثم أُجريت دراسة منهجية للمعايير لتقييم حساسية أداء النظام للتغيرات الهندسية، مع التركيز تحديداً على زوايا ميل المدخنة (30° ، 45° ، و 60°)، وأعماق القنوات الداخلية (من 0.1 متر إلى 0.3 متر)، وارتفاعات فتحات الدخول والخروج (من 0.1 متر إلى 0.3 متر) خلال دورات الإشعاع الشمسي اليومية. وتُظهر النتائج العددية أنه على الرغم من أن زيادة عمق القناة وارتفاع الفتحة (0.3×0.3 متر) تُعظّم معدل تدفق الكتلة المطلق (حيث يصل إلى ذروة 142.48 كجم/ساعة عند ميل 60°)، إلا أن الأداء الأمثل من الناحيتين الديناميكية الهوائية والحرارية للتبريد الهيكلي الموضوعي يتحقق مع التكوينات الأضيق. تُنتج لنا هذه النتائج صياغة توصية تصميمية معمارية نهائية: بالنسبة للبيئات الصحراوية الحارة مثل ورقلة، يُعدّ المدخنة الشمسية المائلة بطول متر واحد وزاوية ميل 60° درجة، وعمق قناة 0.1 متر، وارتفاع فتحة الدخول/الخروج 0.1 متر، التكوين الأمثل. في ظل هذه الظروف المحددة وأقصى قدر من ضوء الشمس، يُعظّم النظام تأثير

الحمل الحراري الطبيعي للمدخنة، مما يُتيح تحقيق أعلى فروق في درجة حرارة السائل (تصل إلى 338.21 كلفن) وأقصى سرعة هواء مُستحثة تبلغ 0.326 متر/ثانية. في نهاية المطاف، يُؤكد هذا البحث جدوى دمج المداخل الشمسية المائلة على الأسطح كاستراتيجية تبريد عالية الكفاءة ومنخفضة المحتوى الحراري، قادرة على تقليل اعتماد المباني بشكل كبير على تكييف الهواء الميكانيكي، والحدّ من استهلاك الطاقة السكنية في المناخات الصحراوية. الراحة الحرارية، المناخ MATLAB الكلمات المفتاحية: المدخنة الشمسية، التبريد السلبي، التهوية الطبيعية، محاكاة الحار والجاف، تحسين المعلمات