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Modelling of the Outdoor and Indoor Parameters Affecting the Thermal Performance of a Trombe Wall with Different Spaces

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***Abstract*- Passive solar technologies (PSTs) can have several positive effects on the environment and future energy-efficient when incorporated into building design and urban planning. A Trombe wall (TW) is a type of passive solar heating system that is used in building design and architecture to collect and store solar heat for later use in heating a structure. Moreover, TW plays an important role in the reduction of a building's cooling load. This paper uses a CFD ANSYS model to conduct a 3D numerical analysis of a TW to investigate the outdoor and indoor parameters that affect the TW. Additionally, the ideal distance between the ground floor and TW is identified.**

***Keywords*- Passive Solar Technologies (PSTs), Passive Solar (PS), Trombe Wall (TW), ANSYS.**

I. INTRODUCTION

A sustainable strategy that can significantly reduce energy consumption and contribute to a future that is more environmentally and energy-efficient is passive solar (PS) design. Sunlight can interact with a building by being absorbed, reflected, or transmitted through the walls as shown in **Fig. 1**. In order to maximise or minimise these effects as necessary, decisions about building materials, glazing, and orientation are all influenced by this interaction. PS design is not just for heating; it can also be used to reduce summer cooling loads. This is accomplished by employing techniques that lessen the demand for air conditioning and cooling systems, such as shading devices, reflective roof materials, and natural ventilation. Strategies for passive cooling frequently aim to regulate temperature with the least amount of conventional energy **[1]**.

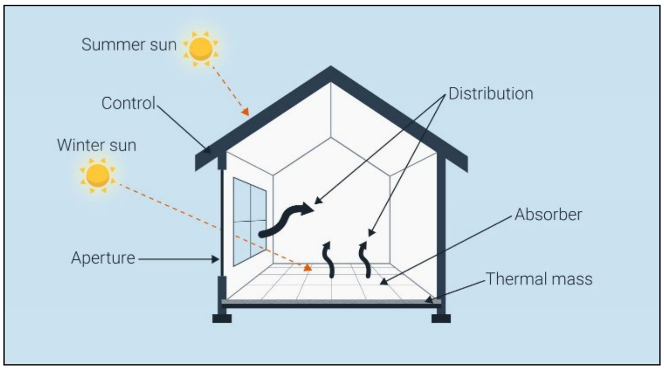
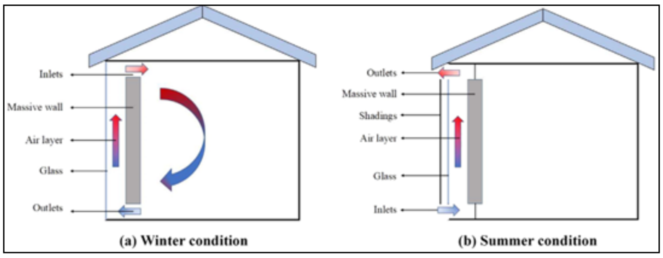


Fig. 1. Elements of passive solar design

French engineer Félix Trombe and architect Jacques Michel developed the TW, a passive solar building design that is built on the south side of the building with a glass external layer around 1960 **[2]**. A TW is typically a substantial wall constructed of stone, brick, or concrete. To receive the most daytime sunlight, it is placed on a building's south-facing side. In front of the TW, a glass layer has been installed. By serving as a PS collector, this glass allows sunlight to enter the room and warm the wall behind it. The wall gradually warms up throughout the day, storing the solar energy. The air space between the glazing and the wall warms up as heat is absorbed by the wall. The thermal energy that has been stored in the TW slowly releases into the interior space as the outside temperature drops. The building's interior temperature is aided by the radiant heat at night.



(a) Winter condition (b) Summer condition

Fig. 2. Trombe wall in winter and summer conditions

TW operation in the summer and winter is shown in **Fig. 2**. When the building needs to be heated during winter daytime operation, the high and low vents through the mass wall are opened.

All vents should be closed at night during the winter. A reverse convective loop can form if they are left open. The upper mass wall vent should be closed during the summer, when heating is not desired, while the lower mass wall vents and upper outside (glazing) vents should remain open. To encourage relatively cooler air to freely circulate through the structure and into the TW collector, a window on the north side of the building should ideally be left open. Air from the building is drawn behind the Trombe collector as it heats up and expands as it rises and flows out the vents to the outside (this is known as the chimney effect). This steady stream of relatively cool air will prevent the mass wall and collector air from overheating, keeping the building cool. Heat will leave the building if these vents are left open during the day and at night.

Many researches about TW characteristics including TW configurations and TW technology were discussed **[3-5]**. This sustainable architectural technology's benefits and drawbacks were emphasized. In Songpan County, western Sichuan,

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during the winter, **Guo et al. [6]** conducted a comparison experiment between TW buildings and glass curtain wall buildings. Two different building types' potential uses in the area were looked into. To analyse the indoor thermal environment of buildings with different air channel thicknesses, numerical simulations were run. Due to the thermal storage of TW, which supplies heat at night, the results showed that TW buildings were more effective at preventing heat loss than glass curtain wall buildings.

In order to investigate the effects of aspect ratio and inlet wind velocity on the thermal characteristics of the air flow channel under various ventilation strategies, **Wu et al. [7]** experimentally set up a C-shaped air flow channel with adjustable width on the TW and fans. The findings demonstrated that the air flow channel's thermal performance under a natural ventilation strategy peaked when the aspect ratio was around 0.05. Based on TRNSYS software, **Zhu et al. [8]** numerically investigated a novel TW with double layers of shape-stabilized phase change materials (PCMs). The simulation data showed that, when compared to conventional TW, the peak cooling load and heating load in the PCM Trombe building were each reduced by 9% and 15%, respectively. The optimal TW generated by a mathematical model, involving a height of 1.7 m, thickness of 0.3 m for the significant wall, and with an opening depth of 0.22 m, could boost the degree of comfort by 38.19% throughout a typical winter day, according to **Abdeen et al. [9]**, who investigated the heat transfer processes and air flow in a TW mathematically and numerically, along with experimental validation. The thermal, ecological, and financial effects of TW systems for housings in the Mediterranean region were mathematically examined by **Jaber and Ajib [10]**. They discovered that 37% is the ideal TW area ratio in terms of thermal and economic considerations.

The goal of this paper is to theoretically investigate the outdoor and indoor factors affecting TW in order to determine the ideal distance between TW and ground in order to achieve the highest velocity and lowest temperature inside the structure.

II. OUTDOOR PARAMETERS

The wind is very dynamic; in the case of a single building, the wind separates at the building's corners as it hits the building and moves around it in a horseshoe shape. This separation phenomenon leads to relatively higher wind speeds at the corners and the lateral facades of the building **[11]**, as shown in **Fig. 3**.

While the effect of wind on buildings embedded in the urban fabric depends on many factors, such as the density and distribution of buildings, the street aspect ratio (H/W), profile, and orientation, According to **Akube [12]**, the wind inside the street forms two regions: the ventilated region and the recirculated region, as shown in **Fig. 4**. As the street gets narrower and its aspect ratio (H/W) > 0.3, the ventilated region decreases until it disappears completely when the H/W > 0.6; in this case, the whole street lies in the recirculated region. This pattern takes place when the prevailing wind is perpendicular to the street axis, while in the case of parallel-wind streets, the flow just streams and is obstructed by the physical structures in the street.

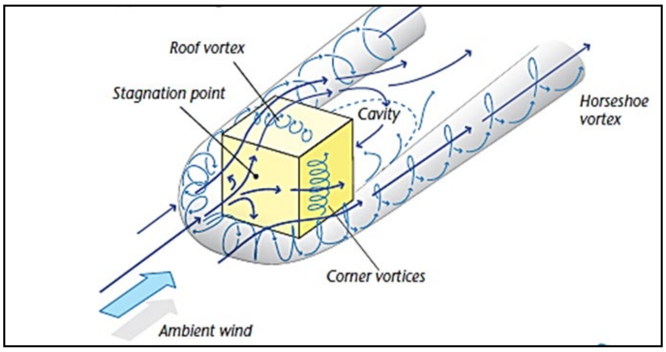

Fig. 3. Wind aerodynamics around a single building **[11]**

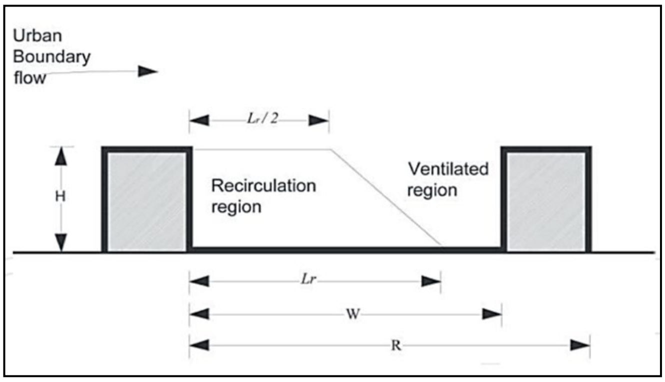

Fig. 4. The recirculation and the ventilated region in the street cross section

Cui et al. [13] recommended designing symmetric wide streets for better ventilation, while in the case of asymmetric streets with a step-down profile, the street buildings block the wind, resulting in relatively lower speeds. The study highlights the impact of TWs on enhancing the ventilation of indoor spaces. The simulated model is in the ventilated zone of a wide street where H/W <0.3, the cross section of the street is symmetric, and the wind is perpendicular to the street axis.

III. INDOOR PARAMETERS

The conservation equations for mass, momentum in each flow direction, and energy govern the issues of indoor airflow and convective and radiative heat transfer. The airflow is also thought to be primarily turbulent **[14]**. The three-dimensional airflow mass conservation equation are:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad (1)$$

Momentum conservation equations: Navier-Stokes equation for incompressible three-dimensional airflow with constant viscosity.

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+\upsilon\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x \qquad (2)$$

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$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y \quad (3)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g_z \quad (4)$$

Findings are only considered reliable for turbulent flow computations when they do not significantly change when the mesh is changed. Turbulent flow computations heavily rely on mesh creation. The substantial agreement between the data from the regular mesh and the finer mesh, which demonstrates that simulation results do not change as the mesh size is increased, serves as confirmation of the accuracy of the CFD findings. Grid independence analysis reveals that 10^{-4} is the best structural and uniform mesh size for each of the three lengths (x, y, and z) of the investigation for the rectangular duct flow configuration used in this study.

IV. MESH INDEPENDENCY

The commercial three-dimensional, parallel, finite-volume solver ANSYS FLUENT is used to solve the governing Navier-Stokes equations and the RANS turbulence model **[15]**. The substance, air, was thought of as an ideal, incompressible gas. The pressure-based solver utilised a coupled pressure-velocity coupling strategy. The second order applies to all discretizations of space. For both models with and without space for TW from the ground, a 3-D model sketch is created on ANSYS, as seen in **Fig. 5**.

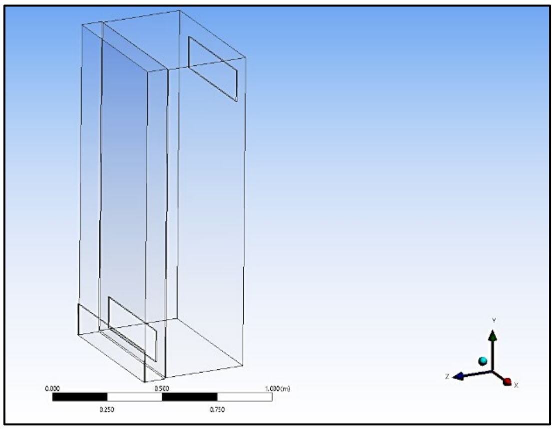

Fig. 5. A 3-D model of the building with specific space from ground

V. RESULTS AND DISCUSSIONS

In **Fig. 6**, where the velocity is high, the velocity stream line for open TW is shown. The reason for this is that the bottom of TW has an opening that allows both outside and inside air to enter the trombe gab area, increasing the velocity of the air in the trombe gab as a result.

Fig. 7 illustrates the variation of air velocity for different air gaps that allow for outside air to come through the trombe gap and air coming from inside to go up through the trombe gap. It is shown that the air velocity decreases as the air gap increases. The temperature distribution for various gaps for TW is shown in **Fig. 8.** With the height of the building, the gap widens and the temperature rises. Where there is a gap of air between TW and the ground, buoyancy forces are increased by TW. Hot air from inside the building is being pulled by the air flow from downward to upward. It is demonstrated that the ideal height for preserving a low temperature and maximum velocity inside the room is a 5 cm-gap space.

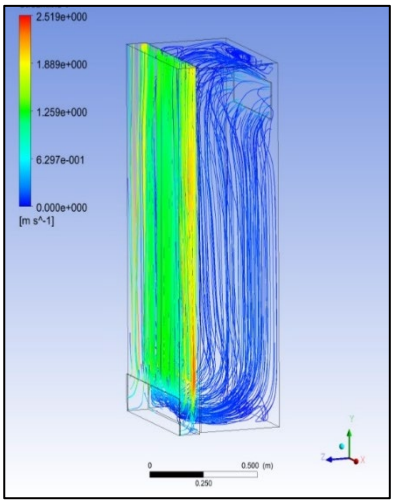

Fig. 6. Velocity stream lines for open TWs

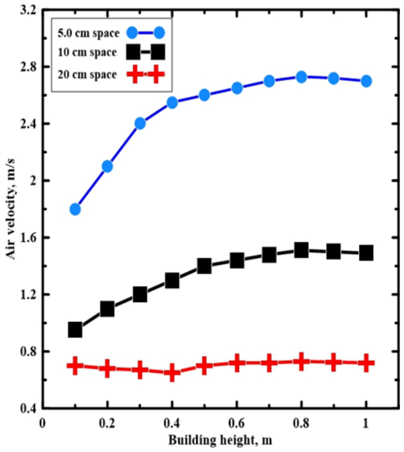

Fig. 7. Variation of air velocity with height of building for TW at different spaces

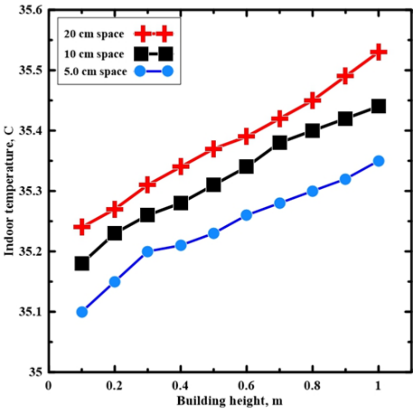

Fig. 8. Variation of indoor temperature with height of building for TW at different spaces

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VI. CONCLUSION

Trombe walls are a passive method for reducing cooling loads, particularly in Middle Eastern nations where summer solar radiation levels are very high, particularly in areas facing south. When an open TW is raised off the ground by a specific space, the effects of outdoor and indoor variables are examined and the theoretical investigation of this optimal space. The following is a summary of the major findings:

- As the street gets wider, the ventilated region increases, which consequently enhances the efficiency of TW.
- Air velocity increases as the air gap between TW and the ground decreases.
- Room temperature decreases as the air gap between TW and the ground decreases.

The reduction of a building's cooling load and, consequently, energy savings, depend greatly on the optimisation of the influencing parameters in a TW design. For upcoming work, using phase-change materials in the TW is advised.

Nomenclature

Velocity component in x-direction, m/s
Velocity components in y-direction, m/s
Velocity components in z-direction, m/s
Density, kg/m^3

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