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Using a Louvre to Enhance Solar Chimney Performance for Building Ventilation

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1. INTRODUCTION

Solar chimney (SC) is a promising passive strategy for sustainable building ventilation, but its performance is often undermined by non-uniform velocity and temperature distributions across the channel width. In natural convection research, using blockage structures such as cylinders, fins, or baffles to generate vortices and in turn disturb thermal boundary layer (TBL) is proved to be an effective strategy to enhance thermal mixing. However, most existing channel-based studies have considered symmetric heating configurations [1, 2], whereas asymmetrically heated channels, such as SC, remains largely unexplored. Inspired by the effectiveness of fighter jet canards as vortex generators, this study explores using a thin plate mimicking a canard cross-section, referred to as a louvre-shaped blockage, to enhance thermal mixing and ventilation efficiency in SC.

2. APPROACH

A two-dimensional (2D) numerical model (refer to Fig. 1) is developed to investigate the influence of the louvre-shaped blockage on the overall SC ventilation performance and flow field development. The SC has a fixed absorber height (H) and channel width (W), yielding an aspect ratio (H/W) of 10. Both the horizontal inlet and vertical outlet have the same length as the channel width. The adiabatic louvre has an aspect ratio (L/T_l) of 7, with its centre placed on the centreline of the SC channel. Its orientation is defined by the attack angle (α), varied anticlockwise from 15° to 90°. A uniform heat flux (q'') is applied to the absorber, while the remaining walls, including the glazing panel, are treated as adiabatic. The tested Rayleigh Number ($Ra = g\beta q'' {H_a}^4/(\kappa\upsilon K)$) ranges from 7×10^{10} to 2.8×10^{12}. Simulations are performed using ANSYS Fluent R2021. The ventilation performance of the SC is quantified by air change per hour ($ACH = Q \times 3600/27$), based on the inlet volumetric flow rate (Q) and a 27-m^3 space. The ventilation enhancement factor ($E = (ACH_l - ACH_c)/ACH_c$) is calculated to quantify the potential of louvre-integrated SC against the conventional configuration. Here, the subscript l refers to louvre-integrated SC, and c refers to conventional SC. The velocity and temperature presented below are normalised by $VH_a/[\kappa(RaPr)^{2/5}]$ and $Wq''/(2k)$ respectively.

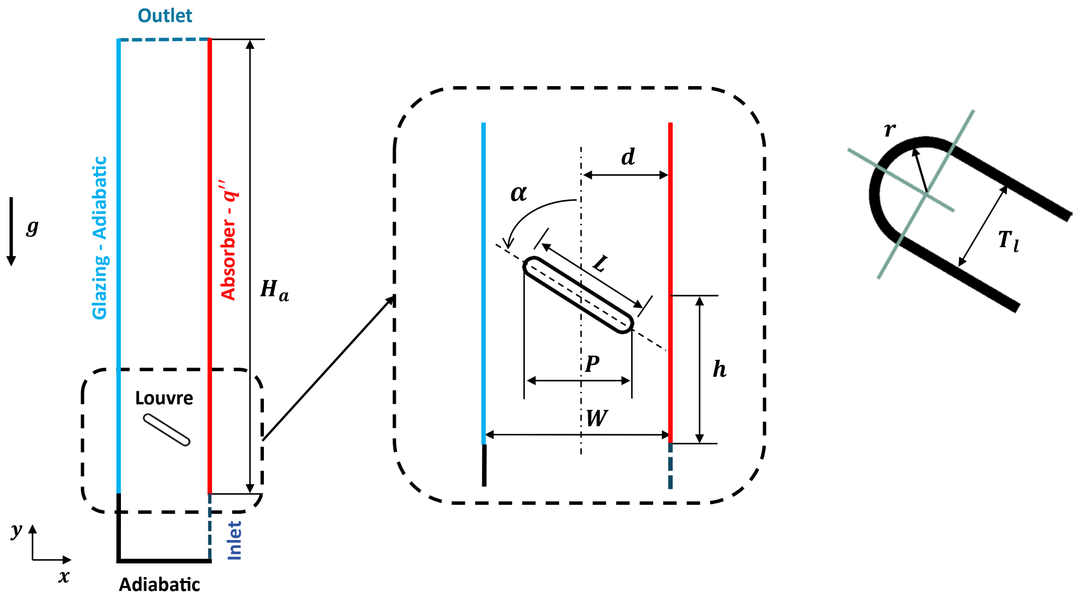

Fig. 1. The geometry of a louvre-integrated SC and major boundary conditions.

3. RESULTS

For the case with a 60° louvre, a Kármán vortex street is triggered in the wake region across all Ra. The alternating vortices promote lateral mixing across the width of the SC channel (Fig. 1a), which in turn enhances overall buoyancy driven flow through the channel. As a result, the reverse flow at the outlet, which occurs when the louvre is absent, is suppressed (Fig. 1b). It is found that the louvre-integrated SC achieves a minimum ventilation enhancement factor of 1.1 at the minimum Ra, and the enhancement factor approaches 1.8 for $Ra \geq 7 \times 10^{11}$.

A parametric analysis of the louvre attack angle has revealed the existence of an optimum angle for a fixed geometry and installation location (Fig. 1c). At a small attack angle ($\alpha = 15°$), the performance is nearly identical to the conventional SC because minimal flow impingement induces negligible wake unsteadiness. For $\alpha \geq 15°$, distinct alternating vortices appear behind the louvre which disturb the TBL along the absorber, thus enhancing thermal mixing in the channel. However, the louvre also causes blockage to the convective flow, especially at large attack angles. As a result, reverse flow may occur at large attack angles, leading to relatively lower enhancement factor compared with that at intermediate angles. Nevertheless, even at the 90° attack angle, the louvre-integrated SC still delivers a clear performance improvement over the conventional configuration.

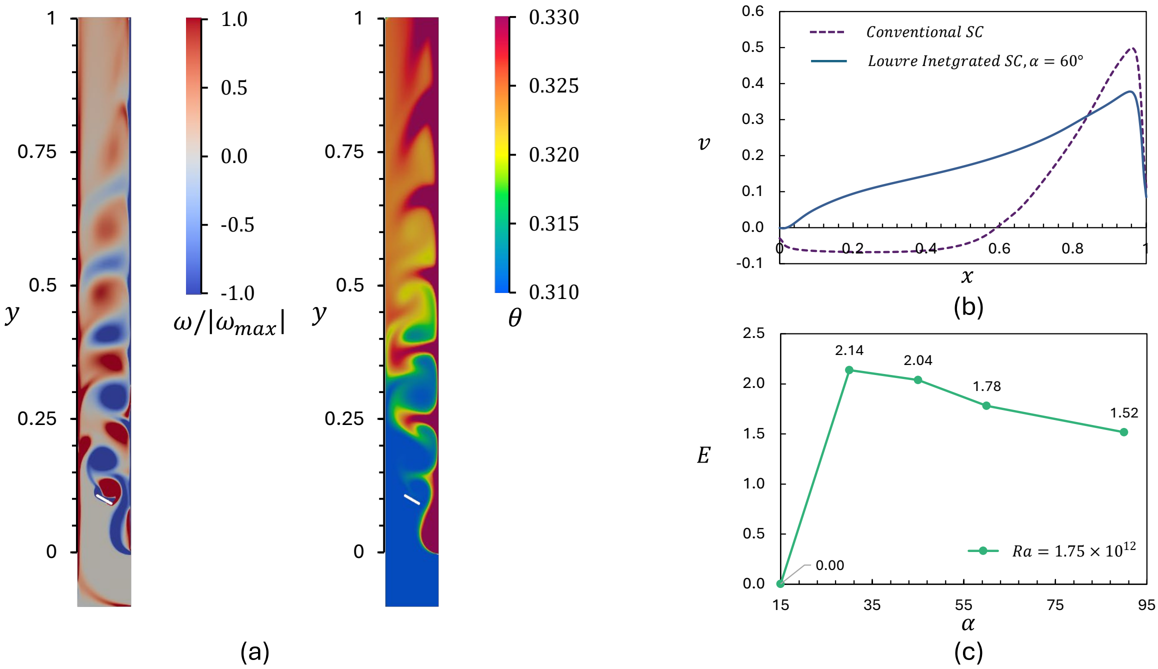

Fig 2. Thermal flow structures and ventilation performance of the louvre-integrated SC at $Ra = 1.75 \times 10^{12}$. (a) Instantaneous isotherm and vorticity contours with $\alpha = 60°$; (b) The streamwise velocity profile at the outlet; and (c) Enhancement factor at varying louvre attack angles.

4. CONCLUSIONS

In summary, integrating a louvre into the SC channel shows strong potential in enhancing ventilation performance through vortex-induced thermal mixing in the wake region. The study also identifies the existence of an optimum attack angle for a given louvre geometry and installation location. Future work will extend the analysis to three-dimensional (3D) simulations to reveal 3D flow behaviour and perform experimental studies to validate the numerical model.

REFERENCES

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