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LAMINAR-TO-TURBULENT TRANSITION OF BOUYANCY-DRIVEN FLOW IN A SOLAR CHIMNEY

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Abstract

A solar chimney is a vertical channel fixed to the exterior of a building consisting of a glazed external surface and an absorbing internal wall that is open to the outside air at the top and the building's interior space at the bottom. It is a passive approach for ventilating buildings, in which thermal buoyancy induces ventilation, providing fresh air and maintaining the indoor temperature at a comfortable level. Reviewing the numerical investigations of solar chimneys reveals that the airflow inside the vertical channel is typically treated as being either fully laminar or fully turbulent, with the latter modeled via Reynolds-averaged Navier Stokes (RANS) simulations. However, it is known that the flow may be laminar, transitional, turbulent, or a combination of them, depending on the relative magnitudes of the buoyancy, inertial, and viscous forces. Accordingly, applying RANS-based turbulence models onto the entire flow domain is likely to yield significant modeling errors that may degrade the predictive ability of the simulations for estimating ventilation performance.

To improve the understanding about instability and transition in solar chimneys, the three-dimensional buoyant airflow in a vertical rectangular channel is studied by means of direct numerical simulation (DNS). The boundary conditions imposed at the isothermal and adiabatic walls yield a Grashof number of $Gr = 6.1 \times 10^{10}$. The steady base flow is first developed, consisting of a laminar wall jet along the heated wall superimposed with a bulk motion and laminar boundary layer along the adiabatic wall. Three types of temporal fluctuations (pressure, temperature, and velocity) were then introduced at the inlet, and their spatiotemporal amplification is analyzed. The results show that the disturbances are optimally-unstable as predicted by linear stability theory. Linear amplification is observed for all disturbances, although at distinct growth rates, followed by a nonlinear growth phase. Subsequently, the disturbances evolve into a complex three-dimensional state characterized by streamwise-aligned packets of coherent structures that resemble structures in a transitional boundary layer. The effect of the type and initial amplitude of the imposed disturbances on transition is investigated. Besides, the spatial growth of the disturbances is studied, and different types of vortical coherent structures that exist in the flow are identified. A scenario about the evolution of the flow is proposed by means of studying the evolution of these structures in time, and their effects on the bulk convection heat transfer and mass flow are discussed.