Transient buoyancy-driven flows in multi-storey buildings – the fluid mechanics of linked vessels

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Abstract

The research focuses on the development of mathematical models for describing transient flows within and between connected fluid-filled vessels. The fluid mechanics of connected vessels is of broad interest and numerous examples may be found in industry, the built environment and the laboratory. This work focuses primarily on the interaction between three connecting vessels and considers two main areas of application: (i) the so-called 'double-tank' method, as used by experimental fluid dynamicists to stratify environments, and (ii) the passive transient ventilation of multi-storey buildings.

An analytical description of the double-tank method, a classic example of liquid exchanges under controlled (constant) flow rates between horizontally connected vessels, was developed. Subsequently, a new technique was proposed, modelled and tested which enabled a broader range of density stratifications to be set up and without the use of pumps. This technique enabled liquids to drain freely under gravity from one vessel to another – the rates of liquid transfer no longer constant but functions of the instantaneous liquid depths.

Modelling the fluid mechanics of multi-storey building ventilation added additional tiers of complexity as air and heat exchanged between rooms drive turbulent mixing and there is complex feedback between the individual rooms. Three vessels were again considered, two storeys connected to a common atrium, and the development of the buoyancy-driven flow following the activation of heat sources was investigated. A description of the transient response of the ventilation in an atrium building leading to a steady state, as typically achieved during the course of a day, was developed. Wind pressure variations and solar heat gains in the atrium were also incorporated. The effect of atria

geometry on the ventilation of adjoining rooms was established and shown to be analogous to either an ‘assisting’ or an ‘opposing’ wind. When ‘opposing’, the ventilation flow rate reduced. For a strongly ‘opposing’ atrium, a reversal in the direction of flow through the storey occurred, revealing the possibility of multiple flow regimes during the transients – the dynamics of which were explored. Finally, the building ventilation model was generalised to n storeys ($n > 2$) connecting to a common atrium. Controversially, the implications of the predictions indicate that current atrium designs do not guarantee enhanced flow as is generally accepted.