The Fluid Mechanics of Emptying Boxes

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Abstract

The research presented herein examines the evolution of the density stratification in a rectangular box connected to a large external environment through high and low-level openings. The flow through the box is driven by buoyancy forces created by the density difference between the interior and the exterior. The research was approached using small-scale experiments combined with theoretical modelling.

A series of experiments was performed in water, where the density differences were created using salt. This allowed the ensuing flows to be visualised using a combination of shadowgraph and dye-attenuation techniques. The results showed four distinct flow patterns were possible. These flow patterns were characterised by the level of mixing within the box and the presence or absence of a bidirectional flow through the lower opening. It was found that three geometrical parameters control the flow pattern seen.

Theoretical models have been developed to predict the transition between the flow regimes. The first considers the value of a local Froude number and determines whether significant mixing will be observed within the box for a given set of parameters. The second considers the position of the neutral pressure level within the box and predicts whether a bidirectional flow occurs at the lower opening.

The motivation behind this project has been the natural ventilation of buildings. In order to compare the emptying-box flows and building ventilation flows in general, three new efficiency measures have been developed. These are based on the effectiveness of buoyancy removal from space. The first two measure the overall space, one providing a time-averaged measure and the other an instantaneous measure. The

second examines the efficiency at a chosen location. Thus, using this measure vertical profiles of efficiency may be determined.

These measures were used to examine the flows seen in the experiments. It was observed that generally significant mixing reduces the ability of a flow to removal buoyancy. However, counter-intuitively, there are a number of cases where the mixing flows provide the better ventilation.

These measures were also used to examine the flow in a full-scale room. It was found that using them significant information can be extracted from a simple temperature trace.