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Theoretical predictions of transient natural displacement ventilation

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Abstract

The transient natural displacement ventilation driven by a localized heat source at the floor of a room is examined to understand the airflow behavior and the relevant thermal stratification characteristic. Two modified theoretical models are developed on the basis of classical plume theory and Kaye and Hunt's model. The buoyant layer is modeled as composed of a near-ceiling layer and a warm layer rather than being well-mixed. Some assumptions on the buoyancies of the near-ceiling layer and the outflow through the upper opening are made in the two modified models for simplicity. Comparisons are made between the predictions of Kaye and Hunt's model and the two modified models and experimental data reported in the literature. Two modified models are shown to perform better than Kaye and Hunt's model. Meanwhile, the predictions of the modified model I seem to agree slightly better with the experimental data than those of the modified model II. Typically, the average relative deviation between the three models' predictions of the lowest interface height and the experimental data are about 4.2% (modified model I), 4.6% (modified model II), and 4.9% (Kaye and Hunt's model).

Keywords

natural displacement ventilation,
localized heat source,
transient process,
theoretical model,
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1 Introduction

When there is a localized heat source on the floor of a room with high and low level openings to a uniform exterior, the turbulent plume produced by the heat source sets up a two-layer stratification within the space, which drives a ventilation flow through the room (Linden et al. 1990; Andersen 1995; Li 2000; Linden and Kaye 2006). If the flow through each opening is assumed to be unidirectional, and the mixing between the incoming fluid and the buoyant layer is assumed to be negligible, the displacement flow is then established and maintained (Chen and Li 2002; Kaye and Hunt 2004; Hunt and Kaye 2006). The natural displacement ventilation is one of the major types of natural ventilation. Many studies focused on the steady-state natural displacement ventilation and the associated thermal stratification characteristics, and proposed some theoretical models (Linden et al. 1990; Li 2000; Chen and Li 2002; Flynn and Caulfield 2006; Kaye and Hunt 2010; Cooper and Hunt 2010). Two typical examples of these models are the "emptying water-filling box" model (Linden et al. 1990) and the "emptying air-filling box" model (Li 2000).

However, the transition to steady-state natural ventilation can also be important, especially in public buildings such as theatres, where the timescale of the transient flow may be comparable with the time of occupancy (Fitzgerald and Woods 2007; Bolster et al. 2008; Fitzgerald and Woods 2010; Stoakes et al. 2011). Previous studies on unsteady natural displacement ventilation are relatively limited because of the complexity of the time-dependent flow pattern (Kaye and Hunt 2007; Bower et al. 2008; Sandbach and Lane-Serff 2011). Kaye and Hunt (2004) presented a transient model based on the "emptying water-filling box" model and modeled the buoyant layer as a well-mixed space during the transient. They investigated the transient evolution of the density stratification and airflow rate. They also demonstrated the possibility of the upper layer depth overshooting its steady-state depth during the initial transient. Sandbach and Lane-Serff (2011) proposed a modified filling-box model to calculate the temporal stratification. They modeled the upper layer as a series of layers of different buoyancy and employed Germeles's approach (Germeles 1975) to integrate

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