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Unbalanced Exchange Flow and its Implications

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Abstract

Passive ventilation of buildings at night forms an essential part of a low-energy cooling strategy, enabling excess heat that has accumulated during the day to self-purge and be replaced with cooler night air. Instrumental to the success of a purge are the locations and areas of ventilation openings, and openings positioned at low and at high levels are a standard choice as there's then the expectation that a buoyancy-driven displacement flow will establish and persist. Desirable for his or her efficiency, displacement flows guide excess heat out through high-level openings and cooler air in through low-level openings. Herein we show that displacement flow can't be maintained for the complete duration of a purge. Instead, the flow must transition to an 'unbalanced exchange flow', whereby the cool inflow of air at low level is maintained but there's now a warm outflow and a cool inflow occurring simultaneously at the high-level opening. The internal redistribution of heat caused by this exchange alters the rate at which heat is self-purged and the time thought necessary to complete a purge. We develop a theoretical model that captures and predicts these behaviours. Our approach is distinct from all others which assume that a displacement flow will persist throughout the purge. Based on this enhanced understanding, and specifically that the transition to unbalanced exchange flow changes the rate of cooling and resultant emptying times, we anticipate that practitioners will be better placed to design passive systems that meet their target specifications for cooling.

Introduction

An important a part of the summertime ventilation strategy of the many naturally ventilated buildings is night cooling. This is often the practice of utilising ventilation openings during the night, when the external air temperature is at its coolest, so as to purge the building of excess heat that has accumulated during the day. This purge also has the effect of cooling the thermal mass of the building, reducing radiative temperatures during the subsequent day.

The intended flow pattern for night cooling one space, as against one connected to others, e.g. by an atrium or corridor, is usually either a displacement flow or a balanced exchange flow-the latter also referred to as mixing flow. As are going to be shown and discussed herein however, a 3rd flow pattern is feasible, namely, that of unbalanced exchange flow. Whereas, with a displacement flow, there's equal flow in through the low-level opening and out through the high-level opening, and with a balanced exchange flow there's equal flow into and out of the high-level opening, with an unbalanced exchange flow the flow rates into and out of the high-level opening aren't equal. There are well-established theoretical models for predicting the ventilation flow rates related to displacement flow, for instance, where the flow is driven by hydrostatic pressure differences, and balanced exchange flow, where the flow is driven by the Rayleigh-Taylor instability. Unbalanced exchange flow, against this, has only been theoretically modelled recently by considering the superposition of displacement flow and balanced exchange flow, in other words, by recognising that the general flow comprises both displacement and exchange flow components.

In this paper we revisit the elemental problem of predicting theoretically the night purging of an area by natural ventilation as, until now, a key aspect of the purge has been overlooked. We specialise in what could also be considered the only case, namely of an oblong room with a gap positioned at high level to let heat out and a gap at low level to let cool night air in. initially sight, this configuration of openings would seem to drive a classic displacement flow and, thus, the matter would seem to possess been solved previously. However, this is often not the case, as during the purge a displacement flow must transition to an unbalanced exchange flow. This transition was first identified by Hunt and Coffey although the implications for an evening purge had, until now, not been considered. As displacement flow can't be maintained for the complete duration of a purge, and specifically as following transition there's the unique situation of cool night air entering the space via both high-level and low-level openings, heat is redistributed internally. This redistribution then alters the speed at which heat is self-purged and, as a consequence, begs the question of how reliable displacement flow theory alone is for predicting the duration (and other characteristics) of an evening purge. The interests of developing a theoretical model that better describes an actual night purge, we develop herein a theoretical model that comes with both the initial displacement flow phase and therefore the subsequent unbalanced exchange flow phase.

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