Natural Ventilation Research at Cambridge University - the Combined Effects of Stack and Wind

Research at the Fluid Dynamics Laboratory at the Department of Applied Mathematics and Theoretical Physics, Cambridge University, supported by the BRE under the DOE EnREI (Energy Related Environmental Issues in Buildings) Programme, is being conducted to examine natural ventilation flows driven by combined buoyancy and wind forces. Laboratory techniques to simulate these flows at small-scale have been developed. A transparent Perspex box is used to represent an arbitrary building and a number of openings in the side walls allow a variety of different flows to be investigated. The box is immersed in a flume tank containing fresh water and a horizontal flow is generated which simulates the wind. In order to produce flows at small-scale that are dynamically similar to those which occur at full-scale, water, rather than air, is used as the working fluid. Experimental measurements of fluid velocity and density can then be scaled, and accurate *quantitative* predictions made about the flow at full-scale. Density differences are achieved by dissolving salt in the water within the box; the density of salt water being greater than the surrounding fresh water. For the case of a warm room the box is inverted and viewed through an inverted video camera so that the dense solution appears to "rise" and in this way simulates the buoyancy-driven flow, The following discussion is based on a room initially containing warm air.

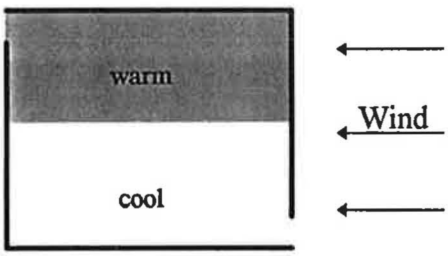

Fig. 1a) Wind and buoyancy forces reinforce one another.

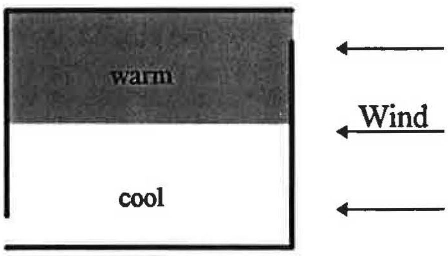

Fig. 1b) Wind and buoyancy forces oppose one another.

Experiments show conditions for which the wind and buoyancy forces *reinforce* one another, see Fig 1(a), and *oppose* one another, see Fig 1(b). A parameter used in the description of these flows is the ratio of the buoyancy and the wind-induced velocities at the onset of the ventilation flow. This parameter is known as the initial Froude number Fr, and for a fixed building geometry and temperate difference, increasing Fr may be thought of as increasing the wind speed. By varying Fr a wide range of flows may be examined. When the wind and buoyancy forces reinforce one another, a displacement flow is maintained for a range of Fr and the effect of the wind force is to enhance the ventilation rate. At higher values of Fr the flow short-circuits and a mixing flow is established.

However when the forces oppose one another the flow is more complex and a number of interesting and counter-intuitive flow phenomena have been observed. The four different stages of this flow when the initial buoyancy force exceeds the wind force, ie for Fr< I, are depicted in Fig 2. Initially, warm fluid flows out of the high-level opening and directly into the wind, This is replaced by cool fluid which enters through the low-level, leeward opening and a displacement flow is established, see Fig 2(a) and 2(b).

The enclosure continues to be flushed by displacement ventilation until the buoyancy force is matched by the wind force. However, a condition of equilibrium is not reached. Instead, an oscillatory flow is observed with periods of exchange flow and periods of inflow through the windward opening, and the interface descends. Cool fluid entering the enclosure mixes with the warm fluid, decreasing its temperature, and creating wave-like disturbances on the fluid interface, see Fig 2(c). The temperature decrease is indicated by the change in the shading, from a dark grey (Fig 2(b)) to a lighter grey (Fig 2(c)). When the interface reaches the base of the enclosure, see Fig 2(d)), the oscillatory flow stops and a mixing mode of ventilation ensues. The temperature inside the space is then approximately uniform and exponentially approaches the temperature of the exterior. If the wind force exceeds the buoyancy force at the onset of the ventilation flow, ie for Fr>1, the mixing mode of ventilation is immediately established.

New mathematical models have been developed to predict the temperature and stratification within the space and these are in good agreement with the results of the experimental studies. Future research aims to consider i) the effects of internal heat gains on the temperature and stratification and ii) to provide "rules of thumb" for use by architects and ventilation engineers. For further information contact the following personnel at the University of Cambridge.

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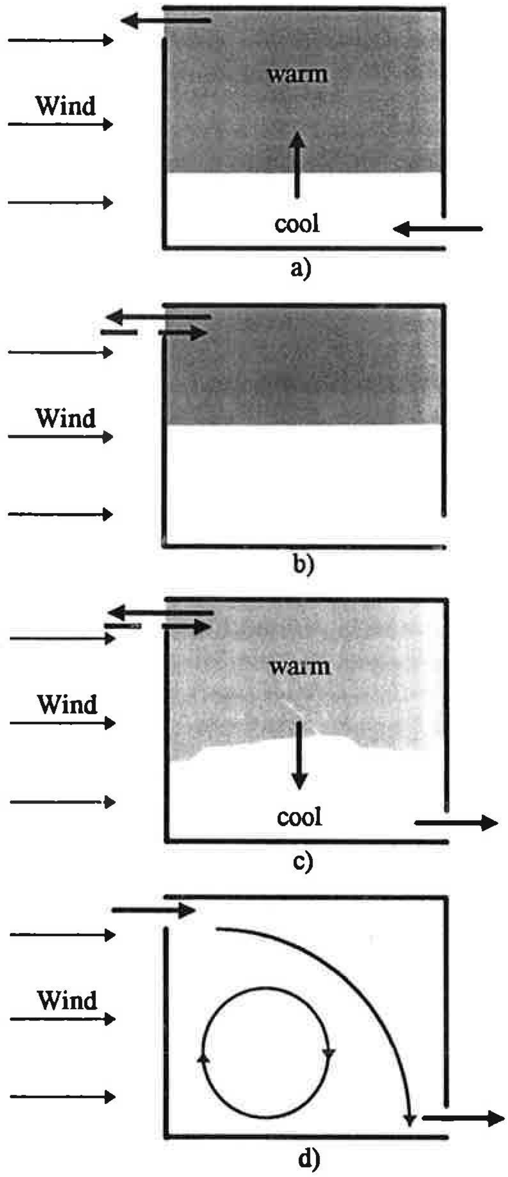

Figure 2. A schematic diagram of the air movement within a space which is naturally ventilated by the opposing forces of wind and buoyancy, Fr <1. a) initial displacement flow phase, b) start of the oscillatory flow phase, c) displacement/mixing flow and d) mixing flow.

References

1. HUNT, G.R. & LINDEN, P.F. (1996) The Natural Ventilation of an Enclosure by the Combined Effects of Buoyancy and Wind. Proceedings of ROOMVENT '96, *The Fifth International Conference on Air Distribution in Rooms,*Yokohama, Japan, 3, pp.239-246.

2. HUNT, G.R., LINDEN, P.F.,KOLOKOTRONI, M & PERERA, M.D.A.E.S (1997) Salt bath modelling of air flows, *Building Services Journal,* CIBSE, January 1997, 43-44.

Ventilation and Air Pollution: Buildings Located in Urban and City Centres

Martin W Liddament (Head of the Air Infiltration and Ventilation Centre) reports on this recent BRE/CIBSE Natural Ventilation Group Seminar

Urban pollution has an enormous affect on the indoor environment, particularly on buildings that rely on natural ventilation since the potential for air cleaning is limited. Due to increasing concern about urban pollution and its impact on the indoor environment, this seminar focused on the underlying issues, examining current research and identifying solutions.

In his presentation, David Warriner, (Assistant Director of the Environmental Group at BRE) reviewed current concerns. Urban areas are an essential aspect of economic infrastructure with a preference for renewal rather than further encroachment of green field sites. However, the demands of society result in increased pollutant emissions and air quality problems. While the impact on the indoor environment can be reduced by sealed air conditioned buildings, this adds to energy demand and is not seen as a solution. The challenge is to find low energy solutions and for this reason, the role of natural ventilation is of interest.

Les Fothergill of the DOE outlined the development and role of regulations in meeting health and energy efficiency needs, The overlying objective is to reduce the level of harmful pollutants both inside and outside buildings. Much research is initiated through the needs of regulations and there is strong co-operation between the DOE, various agencies, universities and industry to progress realistic regulations.

Professor Patrick O'Sullivan OBE, Dean of Faculty for the Built Environment, University College, London reflected on problems associated with indoor and outdoor air. In support of natural ventilation Professor O'Sullivan highlighted the dangers that step changes in environmental conditions (particularly thermal) when entering an air conditioned building had on the human auto-immune system. However, from a property owner's view, air conditioned buildings attract higher rents.

He reported that for air quality analysis, a good dispersion model was still needed. However the following basic "rules of thumb" were suggested by Professor O'Sullivan for minimising the impact of poor outdoor air quality on the office environment.

* Kerbside pollution is always greater than indoors.
* The concentration of many outdoor contaminants generally decreases with height above ground.
* Pollutant concentration is less at the back of a building than at the front.

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