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ADVANCES IN NATURAL VENTILATION DESIGN PROCEDURES

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ABSTRACT

A number of new techniques have been developed in recent years, by various researchers, to assist in the sizing and positioning of natural ventilation openings. These may be of considerable assistance in the natural ventilation design process, while still allowing architectural freedom. This paper reviews some of the available techniques. The complexity of the configurations accounted for by the procedures ranges from two openings with the indoor air at a uniform temperature to a technique that allows for multiple openings throughout a multi-zone structure.

KEYWORDS

Natural ventilation, design, opening sizing, indoor air quality, night cooling, thermal comfort

INTRODUCTION

The main problem to be solved in natural ventilation design is, given certain meteorological design conditions, to find the minimum size (and location) of openings required to achieve a certain ventilation rate for a building. A number of new techniques have been developed in recent years, by various researchers, to assist in the sizing and positioning of openings. These may be of considerable assistance in the natural ventilation design process, while still allowing architectural freedom. Some of them are simplified procedures. Simplified design procedures can be very important in the early stages of any design process, because they allow rapid evaluation of initial ideas. This paper reviews some of the available techniques. The configurations accounted for by the procedures range from two openings with the indoor air at a uniform temperature to a technique that allows for multiple openings throughout a multi-zone structure. However, even ostensibly simple configurations of two openings into a single zone may be more generally applicable and sometimes lead to complex behaviour.

The range of references included is not intended to be exhaustive, but only to illustrate some of the work that has been taking place. Some of these are theoretical investigations, which nevertheless yield a rich source of information that is of direct practical relevance. They are able to predict qualitative, as well as quantitative features of natural ventilation air flows over a large range of driving forces. Qualitative information can be useful at the design stage because potential problems may be readily foreseen. The EU NatVent Project (NatVent 1999) has revealed much about cases when natural ventilation has been successfully applied and what can be learnt from situations where it could be improved. It has also itself generated a computer based natural ventilation design tool for predicting air change rates and indoor temperatures, and another for studying indoor air quality.

This is just a single aspect of natural ventilation design. One more of particular importance is the setting of accurate boundary conditions for calculations during the later, more detailed stage of the design process. (See for instance Aynsley 1999 and Orme 1999 on this topic.) In fact, Orme (1999) identifies a range of ventilation and air infiltration models that may be used to consider more detailed design issues. These can be powerful tools for application to a variety of situations. (Draught risk within the internal space arising from the placement of openings is another complicating factor, but this will not be discussed here.)

DESIGNS USING EMERGING TECHNOLOGIES

'Self-Regulation' for Controlling Driving Forces

There are a number of types of 'self-regulating' natural ventilation opening devices. These are devices that act to either increase airflow as demand increases (e.g. humidity or presence controlled) or to decrease it if the natural driving forces are too high (e.g. pressure controlled). However, if a building is not sufficiently airtight, then uncontrolled air infiltration may lead to over ventilation, even if purpose-provided openings are self-regulating. These devices have characteristic flow relations which must be incorporated into any design procedure using them.

'Hybrid Ventilation' for Overcoming Insufficient Driving Forces

While self-regulating natural ventilation devices are available that limit excessive ventilation, they do not provide additional driving forces to compensate for insufficient naturally available forces. 'Hybrid ventilation' systems use both natural and mechanical ventilation at different times of the day or seasons of the year. They are 'intelligent' systems with control mechanisms that can automatically switch between natural and mechanical operation in order to minimise energy use and to maintain a satisfactory indoor environment (Annex 35, 1999). However, it is still necessary to appropriately design the 'natural' part of the system.

DESIGN CONDITIONS

Heating Season Indoor Air Quality

It is essential during periods of active air heating that ventilation rates are no higher than required, as this would waste energy. This will influence opening sizing to maintain acceptable indoor air quality during the heating season. When designing for natural ventilation, an initial estimate is necessary for the required opening areas. Briefly, this involves using the minimum required ventilation rates and solving the 'inverse problem' of finding the minimum area of opening to achieve this.

Thermal Comfort

If the outdoor air temperature is lower than the indoor temperature, and cooling is required for occupant thermal comfort, then the outdoor air may be used (perhaps partially) to achieve indoor cooling. This will certainly be true if internal heat gains from either solar, occupant or equipment sources are excessive. If a building has high exposed thermal mass, this may provide sufficient 'damping' to moderate temperature variations. Designing for thermal comfort has the added complexity that the thermal performance of the building must be determined, usually over a number of days. The internal temperature within a zone in a building is the essential parameter that must be characterised.

Night Cooling

Night cooling is a ventilation strategy sometimes adopted in sufficiently dry climates to avoid (or at least reduce) the need for active cooling, by using night-time air to cool the building fabric. Sensible cooling of incoming air is then achieved during the day-time, as the building reaches thermal equilibrium with its environment. NiteCool (Kolokotroni et al, 1997), for example, calculates the effect of night cooling on daytime indoor temperatures. The NiteCool program has been designed to assess the feasibility of using night-time cooling of the fabric of office buildings, achieved with natural or mechanical ventilation, for day-time sensible cooling of the indoor air. It is a simplified design tool for predicting internal temperatures and energy savings relative to a reference system. Also, the night cooling control strategy may be varied. A further example is provided by the tool LESOCOOL (Roulet et al. 1996). This was also developed to predict the night-time cooling potential for buildings.

DESIGN PROCEDURES

Santamouris and Dascalaki (in Allard 1998) summarise 6 existing simplified empirical design methods. They have made a comparison on an example calculation using these and also a network model to undertake a sensitivity analysis on the example. The range of predicted opening areas was from several values almost identical to the network approach, to about 60% higher. Andersen (1998) derives buoyancy design formulae for single zone buildings with two openings and a linear temperature gradient. He includes an example design based on cooling a building atrium with a linear temperature gradient with outdoor air. Furthermore, Etheridge and Riffat (1997) have devised a range of non-dimensional graphs for natural ventilation design. These may assist in the sizing of openings and stacks under the conditions of buoyancy alone for heating and cooling design or together with wind for heating design conditions. They also allow the possibility of accounting for air infiltration in heating design and non-uniform internal temperatures. A design tool for sizing openings is outlined in CIBSE (1997). It enables design for either buoyancy or wind acting alone, or a combination of both. A worked example using this method for a 3 storey building with a stratified stack illustrates the difference between the designs obtained with and without wind. The 'with-wind' openings in the example were found to be between 30% to 50% of the size of the 'without-wind' openings. This implies the importance of selecting appropriate design conditions.

As a further development to the CIBSE technique, Axley (1999) uses the point of view that the air flow paths in a building form a system of 'loops', around each of which the total pressure change equals zero. He presents a quite general natural ventilation design procedure that may be used for multi-zone buildings. The detailed methodology allows, for example, the sizing of 'traditional' passive stack ventilation systems, or more advanced systems using self-regulating (pressure limiting) air inlets or outlets. It may also be used to account for annual design conditions and air infiltration. Further design examples consider cross-ventilation, and a balanced stack system, both with and without mechanical assistance. (In fact the balanced stack system with mechanical assistance is a form of 'hybrid ventilation'. This concept is discussed earlier). Moreover, Axley stresses that there is rarely a unique design solution, but rather a set of 'admissible solution curves'. Figure 1(a) is a simple example from Axley (1999). It presents boundary conditions for a dwelling with one window opening and a passive stack. Feasible design curves for this example are given in Figure 1(b), for the window area and the stack diameter, for the case of thermal buoyancy acting with and without wind. It can be observed from Figure 1(b) that there are 'asymptotic' values below which no feasible design exists. These set the minimum possible values for the design parameters.

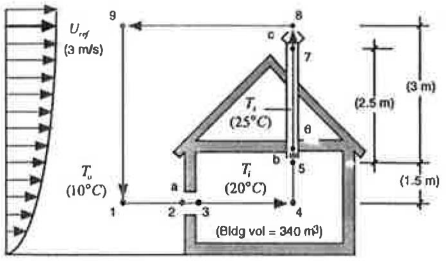

Figure 1(a): Design example - dwelling with conventional passive stack ventilation (from Axley 1999).

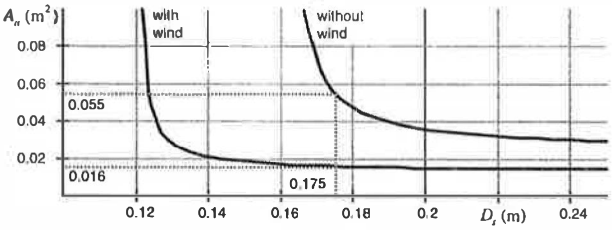

Figure 1(b): Feasible design curves to achieve 0.35 ach for an example dwelling - window area, A_a, and duct diameter, D_s (from Axley 1999).

Investigated using scale modelling and a theoretical model, Hunt and Holford (1998) report on the practicality of natural ventilation with 'top-down chimneys' (TDC). Figure 2(a) shows a visualisation of 'top down' displacement ventilation from a scale model experiment, while Figure 2(b) presents design curves for the required percentage increase in effective area A_j^* needed to compensate for the addition of a TDC.

DYNAMIC BEHAVIOUR

Dynamic air flow behaviour may have implications for any design methodology relying on the air flow rate being unique and stable. It has been found that this can be true when internal heat sources are present. For instance, Hunt and Linden (1998) have studied displacement air flow in a naturally ventilated lecture theatre. This included a theoretical prediction, supported by experiments using scale modelling with saline water ('salt box' modelling). In fact, it exhibits a 'critically damped' response, as the thermal plume from a point heat source causes a warmer upper layer to form. The depth of this upper layer then increases until it overshoots the equilibrium level, which it eventually reaches. Their work demonstrates how the internal geometry of a space may influence transient air flow characteristics.

A note of caution should be taken from work recently produced by Li and Delsante (1998) concerning coupled thermal and ventilation modelling. They derive explicit relationships between the ventilation rate and the buoyancy and wind forces for a single zone building of negligible thermal mass, an internal heat source, a uniform internal temperature, and both with and without heat loss through the walls. The calculations include both wind opposing and assisting the buoyancy driven flows through two ventilation openings. With the same boundary conditions, they report an illustrative example,

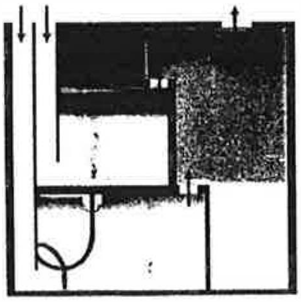

Figure 2(a): Top-down displacement flow in a two-storey enclosure (from Hunt and Holford 1998).

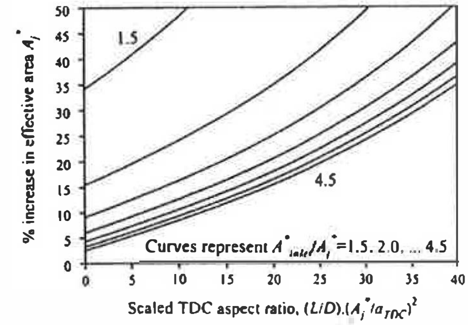

Figure 2(b): Percentage increase in effective opening area needed to compensate for the addition of a top-down chimney (TDC) (from Hunt and Holford 1998).

which is solved for the internal to external temperature difference and the air flow rate through the openings. Under certain conditions, this example turns out to have three possible solutions satisfying the same boundary conditions for wind opposing the thermal buoyancy. (Two of these are 'stable', but the air flow rates have different directions.) Figure 3 is a sketch of the solution curves for the opposing wind case. In this Figure, α is a parameter that depends on the strength of the internal heat source and q is the ventilation rate. Solutions lying on curve A-B are unstable, and so would not be expected to be observed. Other factors such as a large transient change in driving forces (such as would arise from wind turbulence) may be sufficient to change the state of such a system, from one stable state to another. This type of dynamics has also been demonstrated experimentally by Hunt and Linden (2000) for non-uniform internal temperature. In this research, two stable states were observed, one corresponding to displacement (upwards) flow and the other to mixing (downwards) flow. Once again, identical boundary conditions apply to these states.

CONCLUSIONS

A brief survey has been given here of some recent advances in natural ventilation design procedures. Some of these studies present design curves (graphs), which provide perhaps the most immediate initial solution, as long as their underlying assumptions are acceptable. Other, computer based tools are often very versatile, allowing assumptions to be modified. Additionally, developments have taken place to produce more general and detailed procedures. It has also been observed that dynamic behaviour is exhibited by air flows in naturally ventilated buildings, especially when heat sources (or gains) are present. This may be overlooked by steady state analyses.

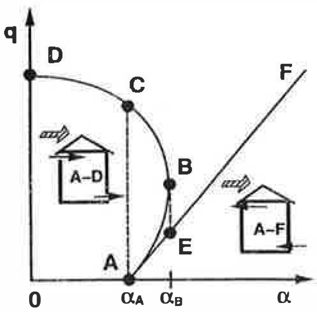

Figure 3: Analytic solution curves - opposing wind case (from Li and Delsante 1998).

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