IMPACT OF NATURAL VENTILATION UPON BUILDING ENERGY RATING WITH PARTICULAR REFERENCE TO SINGLE SIDED APARTMENTS

M.J. Glanville[1] and S. King[2]

1. Richard Heggie Associates Pty Ltd, Level 2, 2 Lincoln Street, Lane Cove, NSW, 2066.
2. CSBE, University of New South Wales, Sydney, NSW, 2052.

Abstract

Rapid development of natural ventilation simulation tools within building energy rating software packages will require congruent experimental support and validation. In response, this paper utilises numerical simulation to compare an extreme cross-ventilated apartment scenario of multiple openings with a worst case single sided apartment. Results from the study suggest single sided apartments can potentially receive ample levels of natural ventilation for the purposes of space heat flushing particularly if due design consideration is given to the interaction of the whole building with the local wind environment. Important factors to be considered include building massing, façade articulation and orientation, exposure to prevailing breezes if available and, importantly, the unsteady turbulence characteristics of the approach flow.

Background

At its most basic, ventilation is required to exhaust air from an interior, and replace it with 'fresh' air. Since the 19th-century, minimum ventilation rates have been invoked in various building codes and standards, usually by way of prescriptions for required openings. However, the most important role of ventilation in warmer climates is to remove accumulated heat gains during overheated periods. In all of these cases, ventilation is intended to achieve *predicted rates of volumetric air change.*

Also important in warmer climates is the role of ventilation in directly improving the perception of thermal comfort by occupants of a space. This is achieved when, by passing over the skin, moving air aids the evaporation of perspiration. As long as there is some air movement, most people will tolerate somewhat higher temperatures before they complain of discomfort. In this context, ventilation is intended to achieve *useful air velocities directed over the occupant*. There is a practical limit on the air velocity useful for comfort ventilation. At 1m/s air speed, hair and papers begin to move. By 1.4m/s (or 5km/h) conditions are noticeably draughty, and considered a nuisance by most.

Aspects of residential apartment amenity have acquired a new importance in NSW, due to the influence of State Environmental Planning Policy 65 - Design of Residential Flat Buildings. Whilst SEPP 65, Principle 7 - Amenity - refers to "natural ventilation", supporting documents specify or describe "cross ventilation". The problem quickly becoming manifest is that both designers and planning officers are applying a rote interpretation of what constitutes a cross ventilated apartment — simply looking for the openings in two different facades. Little if any attention is being paid to whether good natural ventilation will actually be realized, such as in severely elongated 'cross-over units'. Worse, the often acceptable ventilation performance of single sided units is being completely ignored. This potential to mask desirable natural ventilation performance in residential construction by use of simplistic prescribed measures will increase substantially with the imminent introduction in NSW of the more complex mandated sustainable design compliance tool BASIX.

In 2002, CSIRO, the owners of CHENATH computation engine that resides within NatHERS accredited house software, were contracted to increase the tool's capacity to more accurately model building energy performance, — in particular to improve the ventilation modeling to better reward good design practice in hot humid climates. A network model for calculating air flow rates through openings has been fully integrated, with the air flows calculated at each hourly time step. It is reported that implementation of these changes has resulted in predicted cooling loads in warm humid climates being significantly reduced in the network ventilation model, [2]. Details of the ventilation network model are not published at this time, but appear to incorporate some features to account for single sided ventilation of single dwellings.

Rapid development of natural ventilation simulation tools within building energy rating packages such as NatHERS will require congruent experimental support and validation using techniques such as numerical simulation, wind tunnel testing or full-scale measurement. In particular the 'rule of thumb' guidelines contained within Principle 7 of SEPP 65 need further scrutiny, applied with some scientific rigour.

Natural Ventilation Prediction

Ventilation flow rate Q needed to displace a given amount of heat from a building space can be calculated from the equations below if the rate of energy consumption to meet sensible and latent heating and cooling loads are known [1].

$$q_s = Q\rho c_p \Delta t \qquad 1$$

where
q_s = sensible heat load, W
Q = airflow rate, m^3/s
ρ = air density, kg/m^3
c_p = specific heat of air J/kg. K°
Δt = temperature difference between indoors t_i and outdoors t_o, K°

$$q_l = Q\Delta W \Delta t \qquad 2$$

where
q_l = latent heat load, W
ΔW = humidity ratio difference between indoors and outdoors

Sensible heat is added directly to the building space by conduction, convection and radiation whilst latent heat occurs when moisture is added to the space (e.g. from vapour added by occupants and equipment). These loads can now be calculated by any number of commercial software packages within the limitations imposed by natural ventilation simulation capacity.

Natural ventilation and infiltration through building facades can be driven by either wind pressure differences across a building envelope (pressure driven flow) or by buoyancy effects caused by air density differences (stack pressure). Flow caused by thermal stack effect can be expressed by:

$$Q = C_D A \sqrt{2g\,\Delta H (T_i - T_o)/T_i} \qquad 3$$

where
A = cross sectional area of a building opening m^2
C_D = discharge coefficient for opening
ΔH = height difference between building openings
T_i = indoor temperature (K°)
T_o = outdoor temperature (K°)

The greater the vertical distance between openings the greater the ventilation rate potential due to thermal stratification. For single level houses and apartments the opportunity to maximise ΔH is usually restricted although stack effect can be used to some advantage in multi-storey developments and even double storey dwellings with dominant floor openings between levels. One passive design strategy that has been incorporated with some success into split level apartments utilises radiant solar heat penetration through ground floor glazing to heat the thermal mass of a ground floor slab. Buoyancy forces of the stratified space then draw air through ground level inlet vents to flow vertically through the apartment space and be released through ceiling voids. This design scenario relies on an optimal combination of environmental conditions (e.g. clear sky, calm winds) with best performance occurring during the winter months when ventilation is normally least required (in temperate climates for cooling). Furthermore extended periods of window or vent opening have associated acoustics and air quality issues critical in urban environments.

Flow caused by wind pressure has a far greater propensity to generate suitable natural ventilation through most single and double level dwellings, particularly in coastal climates. The rate of wind induced natural ventilation through a building inlet can be determined from the following equation:

$$Q = C_v A U \qquad 4$$

where
U = wind speed m/s
C_v = effectiveness of openings.

Wind speed U is estimated by applying terrain and height corrections to wind rose data obtained from nearby anemometer weather stations. In many locations around Australia regular local winds such as katabatic winds in hilly locations or sea breezes in coastal areas are available for extended periods with suitable intensity, temperature and humidity levels for human comfort. Well known to Sydney residents is the southerly 'buster' cold front providing heat relief at the end of many a hot summer day. Heat build-up within dwellings through sweltering daytime summer temperatures can be quickly purged with the arrival of these fronts that may only last

10-15 minutes. Weatherboard homes with low thermal mass (thermal lags of less than half an hour) can be returned to optimal space temperatures following the passage of these fronts within minutes.

Empirical estimates of C_v could be determined from wind tunnel testing, numerical simulation or published data depending upon the level of accuracy required. Values of C_v will depend upon the Reynolds Number of the flow, geometry and porosity of the building and the location and number of the façade inlet(s). Values of C_v provided in ASHREA [1] range from 0.5 to 0.6 for winds perpendicular to a façade and 0.25 to 0.35 for diagonal winds.

To maintain continuum of mass flow the integrated net flow Q across the surface of a single opening in an apartment otherwise sealed to the atmosphere will be zero. Of course in reality the same opening will act simultaneously as an inlet and outlet of flow providing a heat purge capacity. For the purpose of this study the capacity of a single sided vs multiple opening apartment to purge heat from the interior space is studied in terms of time for Δt to reach zero under a typical summer time cooling load scenario.

CFD Simulation of Natural Ventilation through a Model Apartment

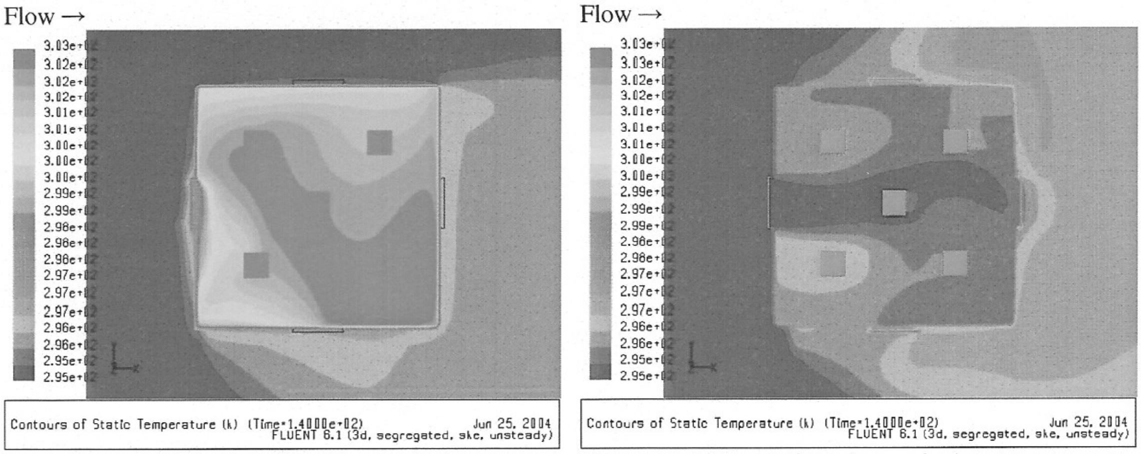
A 3-dimensional CFD model was assembled of a simplistic four sided apartment of square plan form 10m × 10m, 2.7m floor to ceiling height and windows 2m × 2m at the centre of each frontage. The unit was modelled as the middle floor apartment in a 5 storey block and was subject to wind flow perpendicular to one of the facades. A regular matrix of rectangular prisms was included inside the apartment to generically represent blockage effects of obstacles such as furniture. The CFD model was prepared using FLUENT finite element software to solve the Navier-Stokes conservation equations for mass, momentum and energy in the computational domain. Geometry was created using GAMBIT software with a computational domain covered by a mesh of approximately 800,000 hexahedral cells and 900,000 nodes with seven degrees of freedom (p,u,v,w,k,ε,energy)

A category 2 [3] profiled velocity inlet was modelled 50 metres upstream of the building and a flow outlet was positioned 50 m downstream to simulate wind flow over the model building. A transient, unsteady flow analysis incorporating time varying inlet velocity and yaw about a mean was used to simulate low frequency macro-scale atmospheric turbulence. Higher frequency micro-scale turbulence was simulated using a standard k-ε model. Average inlet wind speed was set to a magnitude of approximately 5.5 m/s at 10m height corresponding to a gentle-moderate breeze on the Beaufort wind scale.

Two extreme ventilation scenarios were investigated using the CFD model, namely; a single sided opening on the upstream façade to represent single sided ventilation and four simultaneous openings of equal size on each of the four orthogonal faces to represent the extreme cross-vented case. For both scenarios temperature inside and outside the apartment was initially set to $30C^{\circ}$ under the unsteady wind velocity described. An instant drop in ambient temperature of the approach flow to $22C^{\circ}$ was then simulated and the time for the internal apartment space to shift in temperature recorded. The effect of building thermal storage was not modelled with cool air buoyancy and pressure driven displacement providing the only simulated mode of space cooling.

Figures 2 a) and b) below illustrates temperature distribution inside the modelled apartments in each scenario 2 minutes after the arrival of the simulated cool breeze at the building location. Contours of static temperature across a horizontal plane 1.4 metres above ground level are shown throughout the apartment interior and extending into the immediate apartment exterior.

It is evident almost the entire apartment volume of the fully open apartment has reduced to the ambient external temperature after 2 minutes whilst approximately 50% of single sided apartment volume remains at the initial temperature over the same time period. Continuation of the analysis revealed that it took approximately 25 minutes for the single sided apartment fully purge all heat and reach ambient external conditions. Also noteworthy is the maximum velocity in each scenario with maximum velocities of 1 m/s and 4 m/s within the single and multiple opening cases respectively.



a) Single sided opening- 2 minutes *b) Multiple openings – 2 minutes*

Figure 2 Contours of static temperature (K°) across a horizontal plane 1.4 meters above ground level.

Evident during the study was the high dependence of heat purging capacity of the single sided units upon the unsteadiness of the flow. Precursory analysis revealed ideal modelling the approach flow as uniform and perpendicular to the façade without temporal or spatial variation iterates to a steady state solution with time invariant apartment temperature and zero heat flushing capacity. Variation in yaw and intensity of the approach flow was observed to be a prerequisite to providing heat flushing during the numerical simulation.

Not included in the modelling were thermal lag effects of building slabs and walls that could potentially prolong heat purge time depending upon the thermal mass of the building. Simple design strategies such as optimised window shading can be readily incorporated into most apartment designs to complement natural ventilation cooling by providing appropriate heat absorption and release cycles.

Discussion

The rate of heat purge from the multi-opening apartment is dramatically higher than that for a single sided apartment as would be intuitively expected from common experience. Nevertheless the total time needed to purge heat from the single opening space is in the order of 25 minutes and needs to be considered in a practical context. As already discussed most cooling breezes will persist for at least this order of time providing ample opportunity to displace the internal volume of heated apartment air. Furthermore the magnitude of velocity within the single sided apartment throughout the flushing period remained below draught levels whilst the extreme cross-vented façade experienced magnitudes within the range likely to lead occupants to limit the opening sizes.

With respect to the steadiness of the flow it is observed that wind direction normal to a facade is extremely rare and would normally have limited temporal and special extent on a typical apartment building in atmospheric flow. Wake flow from upstream structures combined with flow perturbation induced by the massing and façade articulation of the building itself will almost guarantee no apartment is likely to experience extended periods of the limiting condition of perpendicular yaw. If an apartment has no useful wind exposure, it is likely to be because it is more generally sheltered, either by orientation with respect to prevailing breezes, or by elevation, etc. Furthermore, contemporary residential facade design is explicitly more detailed than the 'hole in the wall' windows modelled here. Finally, when one apartment may experience stagnation conditions because its exposure approximates a steady state near normal wind incidence, others in the same facade will not because of the variation in the relevant local yaw, i.e., there is a potential for a probabilistic estimate of variations in purge times in similarly oriented apartments at different levels and positions in the same facade.

Conclusion

Results from the study suggest single sided apartments can potentially receive ample levels of natural ventilation for the purposes of space heat flushing particularly if due design consideration is given to the interaction of the whole building with the local wind environment. Important factors to be considered include building massing, façade articulation and orientation, exposure to prevailing breezes if available and, importantly, the unsteady turbulence characteristics of the approach flow.

References

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