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Effective natural ventilation in modern apartment buildings

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ABSTRACT

This paper addresses the challenge of evaluating for natural ventilation in modern apartment buildings. A number of natural ventilation design rules of thumb from published literature are listed. Their incorporation into one code for Australia (the Residential Flat Design Code, or RFDC) and India (the National Building Code, or NBC), in relation to apartment buildings is examined. Practical limitations to converting these rules of thumb into effective natural ventilation systems for apartment building designs are discussed. Apartment designs in the moderate locations of Sydney, Australia and Bengaluru, India are also reviewed to assess their effectiveness for natural ventilation. Simulation analysis presented indicate large energy savings are possible if apartments are retrofitted/designed to the proposed code requirements and designs compliant with thumb rules are capable of delivering effective natural ventilation if users choose to operate the apartment in "free running mode" during times when the outside dry bulb temperatures lie in an appropriate band. The paper also discusses how sub-optimal design solutions, affluence and adaptation to more stringent thermal conditions can negate the potential for natural ventilation and calls for proactive efforts to maintain climate responsive design standards and education/policy to encourage the benefits of natural ventilation over airconditioning.

INTRODUCTION

Apartment buildings have become one of the most affordable residential building configurations in cities around the world. In many locations, they purport to incorporate natural ventilation design elements, usually based on the minimum mandatory requirements of applicable codes and standards. Anecdotally, an increasing number of such apartments are also being fitted with air-conditioning systems. These are either fitted by the builder (usually in developed countries like Australia, or upmarket offerings in developing countries like India), or retro-fitted by the occupant.

Easy access to air-conditioning brings with it the possibility of its increased use, even when conditions outside are conducive for natural ventilation to provide adequate thermal comfort. Therefore, the challenge faced in the design of modern apartment buildings is to ensure that the natural ventilation "system" is effective at providing thermal comfort at appropriate times, and to make the natural ventilation "mode" easily accessible to occupants.

Evaluating the effectiveness of natural ventilation in real building designs has always been difficult. The analyst is limited to using simplified equations developed for idealised room configurations, or complex energy simulation programs that can solve heat transfer and airflow network equations

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simultaneously in the same time step. Computational Fluid Dyamic (CFD) can solve for velocity and temperature gradients in discrete volumes, but these are limited to instances in time with specific boundary conditions. It requires significant processing power and time to run CFD analysis in time step increments so as to make a judgement of the effectiveness of system A against system B.

This paper came about because of a review (Thomas and Venkatesan, 2012) of the thumb rules for natural ventilation included as part of the Residential Flat Development Code (RFDC) carried out for the state government of NSW, Australia. The objective of the review for the RFDC was to develop a series of simple rules to allow a planner to approve a design on its merit. The method followed to develop these rules was as follows:

- review the body of currently available knowledge listing the attributes for effective natural ventilation
- turn them into a design calculation procedure simple enough to be carried out using hand calculations or a spreadsheet program, and
- document an application process that can be reviewed and accepted by a planning official

This approach has been implemented on apartment buildings in Sydney and Bengaluru. A two bedroom and a three bedroom apartment each from Sydney and Bengaluru have been selected for analysis. These represent the most common typology for Sydney and upmarket developments for Bengaluru.

PROCEDURE FOR EVALUATING POTENTIAL FOR EFFECTIVE NATURAL VENTILATION

The procedure devised and proposed to evaluate an apartment design for its potential for effective natural ventilation for the RFDC was based on common rules of thumb found in existing literature (Lechner, 2001). They include the following:

- The ratio of room depth (W) to floor-to-ceiling height is to be W< 5H for *cross ventilated rooms*; however for a standard ceiling height of 2.7m, the room depth may be extended to 15m when other conditions are met.
- The ratio of room depth (W) to floor-to-ceiling height is to be W< 2H for *single sided rooms*; however for a standard ceiling height of 2.7m, the room depth may be extended to 6m for living spaces. The ratio of room depth (W) to floor-to-ceiling height can be increased to 2.5H for rooms designed to have single sided ventilation when stack ventilation can be induced by providing a 1.5m height separation between inlet and outlet sections of the window.
- The *Effective Openable Area* for windows is at least 5% of the total floor area. Effective openable area of the window is defined as the area of the window that can take part in providing natural ventilation to achieve occupant comfort. It considers the portion of the window that is openable. Window openable area is reduced by 50% when insect screens are fitted. In the case of a full height sliding door, the openable area is reduced, in elevation, when it is within 2m of a solid balustrade.
- Windows are located so they are equally distributed on windward and leeward sides of the building. Windows on the leeward side (or “outlet” windows) may be allowed to be slightly larger than on the windward (or “inlet” windows) side of the building thereby utilising air pressure to draw air through the apartment.

Similar guidelines are found in the proposed draft for the new Part 11 of the National Building Code of India (NBC), (BIS, 2012) on Sustainability. It proposes the following criteria:

- Naturally ventilated building should take advantage of predominant wind, and enhance stack ventilation by providing low level inlets and high outlets
- Floor depths of more than 15m are difficult to naturally ventilate
- The total area of openings (inlet and outlet) should be 20 to 30 percent of floor area

The NBC does not distinguish between single sided and cross ventilation. To our knowledge, none of the building codes in either country provide explicit recommendations for mixed mode operation, which is crucial to realizing the potential of thermal comfort with reduced energy use.

CLIMATE ANALYSIS FOR BENGALURU AND SYDNEY

Bengaluru, India has always been regarded as the "garden city" with a temperate climate, being situated on the Deccan Plateau at a height of approximately 914m above sea level. Sydney, Australia is also well known for its mild climate, and is at sea level on the south eastern coast of Australia.

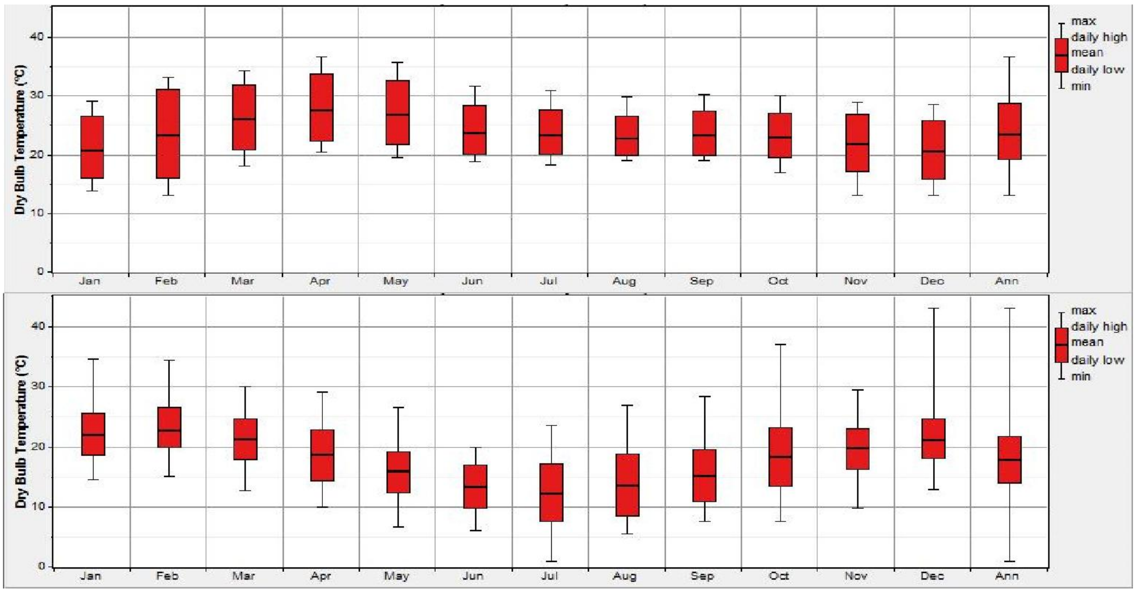

Figure-1: Temperature ranges for Bengaluru (top) and Sydney (below)

An analysis of the range of dry bulb temperatures for the IWEC reference weather files for Bengaluru and Sydney is shown in Figure-1 (and later in Table-1), and clearly shows the reversal of seasons due to the two cities being located on the north and south hemispheres on Earth. Figure-1 also reveals the variability of temperatures between the two cities. There are only small differences between the daily average mean high (or low) and the maximum recorded high (or low) temperatures for any one month (ie., the distance between the box and whisker) for Bengaluru, but the data for Sydney shows large variations between the box and whisker for each month. This effect is most clearly seen in the Sydney data for the months of October and December.

While there are many ways to analyse climate data in a comparative manner, the significance for this study is to determine the approximate number of hours when the outside dry bulb temperature falls within a nominated "comfort range". This would allow us to "bookend" the theoretical number of potential "discomfort" hours at each location. Regulation, and design skills could then be focused on reducing the number of discomfort hours by incorporating the principles of effective natural ventilation, thermal mass, shading, orientation etc.

It is difficult to find definitive regulatory information stipulating a "comfort range". In Australia, the NSW government does not provide any specific guidelines in the RFDC. The NatHERS (Nationwide House Energy Rating Scheme), referenced in the National Construction Code (ABCB 2013) uses a setpoint of 25.5°C for Sydney. Above this temperature an air-conditioner is assumed to cool residential spaces for the regulatory energy analysis. Heating setpoints in living spaces are to be maintained at 20°C during waking hours, ie, 7:00am to midnight, while bedroom spaces are allowed to drop to lower temperatures at night (http://nathers.gov.au/). For Bengaluru, the National Building Code (BIS 2003) of India does not seem to differentiate between residential and other buildings, and defines narrow temperature ranges for winter (21-23°C) and summer (23-26°C) for all building and climate types (Indraganti, 2010). While the appropriateness of these temperature ranges can be argued, they are sufficient for the purpose of bookending the potential "discomfort hours", based on ambient dry bulb temperature, for the two locations.

Inferences from Figure-1 and Table-1 provide important insights to the two climates. From Table-1, Bengaluru has less total "discomfort hours" (about 55% of the year), but they are divided almost equally into the too hot and too cold ends of the spectrum. Figure-1 indicates that highest temperatures will not be more than a few degrees higher than the daily average highs for that month, e.g, April. In contrast, only 4-6% of the year can be considered to be too hot in Sydney, but they can include some extreme days, note the 40°C day in December. However, about 75% of the year falls into the too cold category.

location	hours above 26C	hours below 21C	"discomfort" hours		hours above 26C	hours below 21C	"discomfort" hours
Bengaluru	2,265	2,520	4,785		26%	29%	55%
Sydney	367	6,178	6,545		4%	71%	75%
location	hours above 25.5C	hours below 20C	"discomfort" hours		hours above 25.5C	hours below 20C	"discomfort" hours
Sydney	482	6,008	6,490		6%	69%	74%

Table-1: Dry bulb temperatures above and below cooling and heating setpoint temperatures

Therefore, for Bengaluru, apartment design must be equally adept at dealing with overheating (comfort ventilation) and cold climate (passive solar gain, insulation, reducing infiltration). For Sydney, the focus should be on managing cold conditions. This means an emphasis on insulation requirements, which is addressed by the BASIX (Dept of Planning and Environment, 2013) for Sydney and mandatory building code (NCC) for the rest of Australia. However, the inferences from Figure-1 suggest that while there are few hours of over heating, they can be quite extreme when they do occur.

APARTMENTS SELECTED FOR ANALYSIS

Plans for a two bedroom apartment and a three bedroom apartment were selected at each location. The plans selected for analysis for this study reflect these differening views of apartment living in the two cities. Each of the apartments has been evaluated using the procedure discussed earlier. The selection of apartment plans for analysis is predisposed to layouts that were cross ventilated and of optimum depth. This is because we wanted to identify plan typologies that showed the potential for natural ventilation, where the limiting factor for mixed mode operation (and energy savings) were due to the potential, and attitude, for user control. The plans selected for Sydney were recommended as better design practice solutions in the RFDC technical document. These plans performed well when analysed for effective natural ventilation with respect to the proposed RFDC criteria (Thomas and Venkatesan, 2012). The plans selected for Bengaluru were procured from websites of prominent builders who marketed their layouts as being luxiourious upmarket/green. The Bengaluru apartment plans were tested against the proposed draft NBC Part 11 criteria.

Proposed RFDC Criteria (Sydney)	Ratio of room depth W to floor to ceiling height H is W<5H.	Effective openable area of window is atleast 5% of the total floor area	Inlet area equal to outlet area
2 Bed corner Apartment (Cross Ventilation)	Yes	Yes	No
3 Bed Apartment (Cross Ventilation)	Yes	Yes	No
Draft NBC Part 11 Criteria (Bengaluru)	**Apartment depth not greater than 15m**	**Opening Area of window is 20%-30% of the total floor area**	
2 Bed Apartment (Cross Ventilation)	Yes	Yes	
3 Bed Apartment (Cross Ventilation)	Yes	Yes	

Table-2: Application of procedure to determine potential for Effective Natural Ventilation

Table-2 indicates that all four apartment plans selected satisfy the building envelope design criteria for effective natural ventilation. Based on prior studies (Thomas and Venkatesan, 2012) the Sydney apartments (Figure-2), will therefore meet thermal comfort and minimum energy performance requirement for BASIX; and hence the energy use for air-conditioning will be low. Analysis from Table-2 indicates that users have the potential to effectively operate the apartments in a natural ventilation mode to further reduce energy consumption. Therefore, no further analysis has been carried out for these.

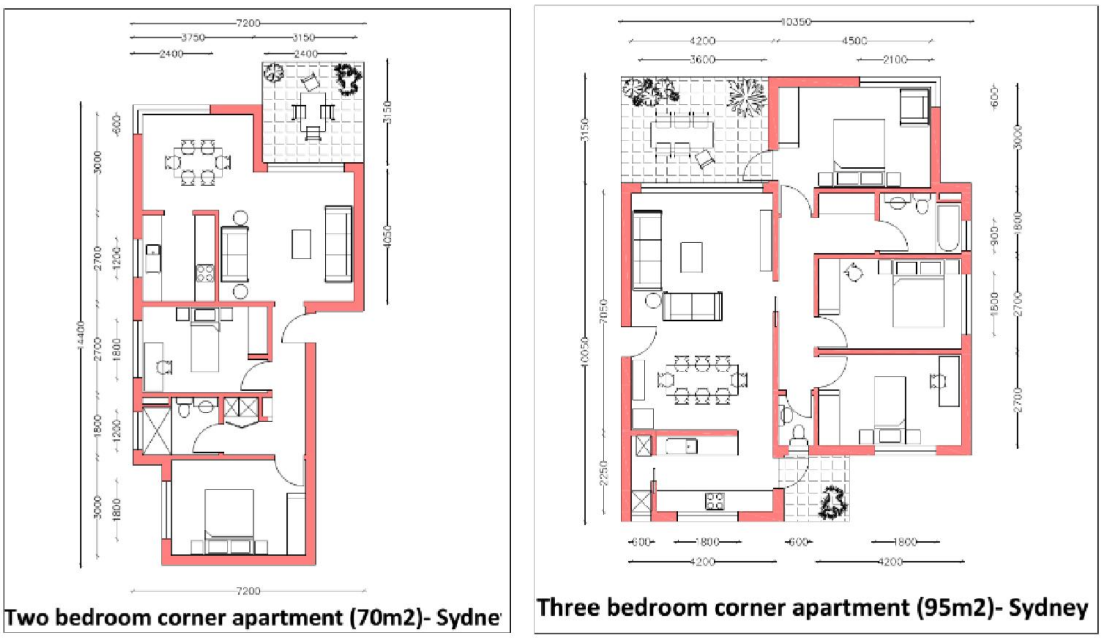

Figure-2: Floor plans of apartments analysed for Sydney, Australia

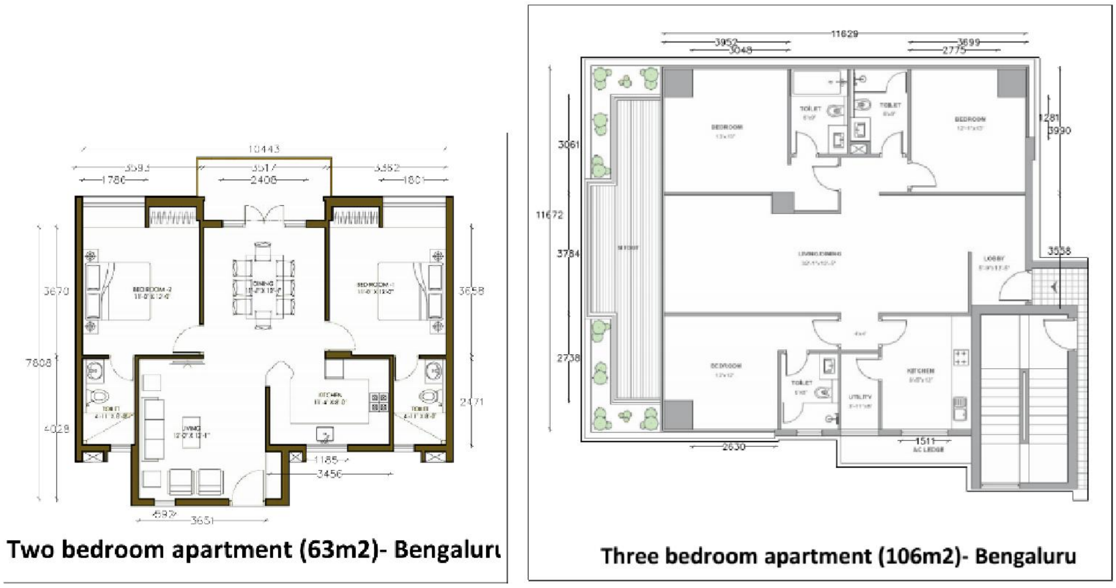

Figure-3: Floor plans of apartments analysed for Bengaluru, India

The three bedroom apartment in Bengaluru is proposed as a high rise block, as a part of a very large residential layout. The layout of the apartment shows good potential for cross ventilation capability. The apartments are being marketed as being fitted with split A/C units to living and all the bedrooms. They are also to be fitted with “clear float glass” with UPVC frames for all the windows. This last statement implies the use of single clear glass with no particular performance requirements.

An energy simulation model for the apartment was constructed using DesignBuilder/EnergyPlus that separated the living and sleeping zones. Floor and ceiling zones were modeled to be adiabatic, thus representing a typical middle floor apartment. Thermostat setpoints were set as previously discussed at 26°C for cooling and 21°C for heating. A design COP of 2.5 was used for cooling, and single zone split systems were modeled. Nominal internal loads were modeled, and these were identical for both runs. The annual energy consumption was predicted for two cases:

- for an uninsulated building envelope and clear single glass, and
- retrofitted with NBC levels of insulation and glazing performance requirements (external wall insulation of R2.0; SHGC=0.3-0.4 for WWR of 60-40%)

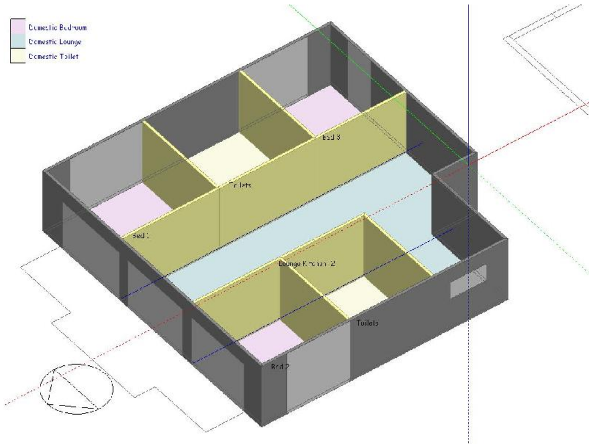

Figure-4: Representation of 3 bedroom apartment for energy simulation; floor plate has been divided into bedroom areas (night), lounge/kitchen area (day) and toilets (unconditioned)

The results predict minimal heating was required for both cases tested. Therefore only the cooling energy consumption was considered, and this dropped by 44% when the original design was remodeled with NBC recommendations (see Table-3). A significant portion of this reduction can be attributed to the improved glazing.

	Cooling Energy, KWh/m2-yr
3 Bed apartment with uninsulated building envelope and single clear glazing	40.8
3 Bed apartment retrofitted Insulation to fabric and Glazing performance as per Draft NBC section 11	22.7
reduction in cooling energy	44%

Table-3: Results of energy simulation for 3 bedroom apartment in Bengaluru

Figure 5 below indicates the predicted cooling load across the year in the bedroom (night time) and lounge/kitchen (day time) zones for the draft NBC compliant apartment if it resorted to airconditioning to maintain temperatures below the 26°C setpoint during occupied hours. While this suggests reliance on cooling beyond peak summer in daytime zones, field work in naturally ventilated buildings (Indraghati 2010, Manu etal 2014) suggests subcontinental occupants are tolerant to higher temperatures such as 28°C based on an adaptive model of comfort especially as increased air flow via ceiling fans can further ameliorate discomfort.

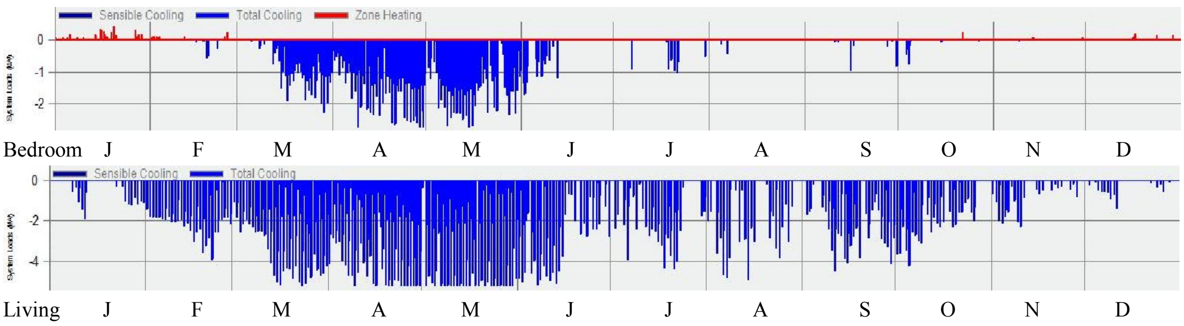

Figure-5: Predicted Cooling Load (kW) across the year for Bedroom and Living Zones (Bengaluru).

A final simulation run was carried out with the building allowed to operate in "free running mode" with controls that allowed windows to be open so that 30% of window area could take part in natural ventilation air exchange. The results indicate that this configuration allows the internal zone air temperatures to closely track the ambient outside temperatures (Figure-6, for both the Lounge Kitchen (Graph 1) and Bed 3 located in the south-east – the hottest corner (Graph 2). This confirms that effective natural ventilation is possible in the selected apartment design, when outdoor dry bulb temperatures are in the "comfort range".

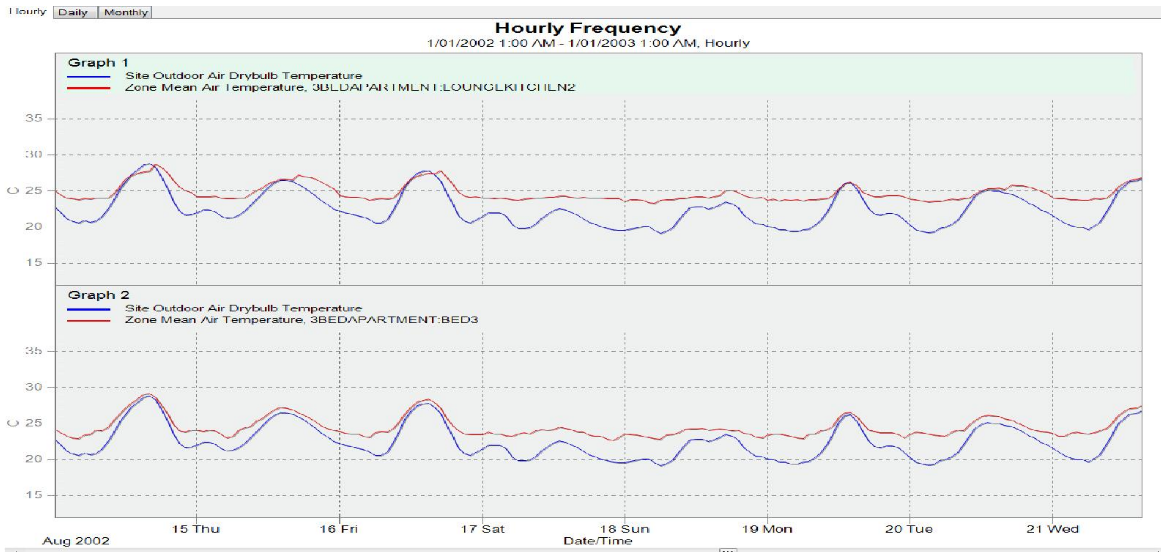

Figure-6: Outdoor dry bulb temperature and zone mean air temperature in free running mode for lounge/kitchen (Graph 1) and bedroom (Graph 2, Bed 3 in Figure 4), for 3 bedroom apartment in Bengaluru

BARRIERS TO EFFECTIVE NATURAL VENTILATION

In Australia, apartments are located in the Central Business District (CBD) areas of the metropolitan cities, or in areas where land is very expensive, along transport corridors (near train and bus routes) and also in the less affluent suburbs. In many instances, apartments may be regarded as a stepping stone towards the goal of an independent house and land package. One reason for this view is because real estate is a reasonably liquid asset in places like Sydney, where a sale transaction can be completed in a manner of weeks. Apartments also attract strong investor interest based on potential rental returns. Therefore, a significant proportion of apartment residents are rental tenants whose options to retrofit do not extend beyond installing a pedestal fan or an electric heater. Strata laws prohibit the owner from making alterations to the external common building elements like walls and windows and the installation of flooring and curtains/blinds are the prerogative of the owners. While energy costs are increasing steadily in Australia and can add considerable budget pain to the middle class, most new apartments come with reverse cycle DX type air-conditioning sstems pre-installed. This easy access to air-conditioning, coupled with design solutions that are less than perfect that may present barriers to the effective use of natural ventilation.

Three examples of such design solutions identified[1] in some Sydney apartment buildings are shown in Figure 7. They include deep, narrow floor plates which do not allow for effective cross ventilation (Figure 7 a), and deep set "snorkel" windows and deep "notch" corridors that effectively impede air exchange (Figure 7 b).

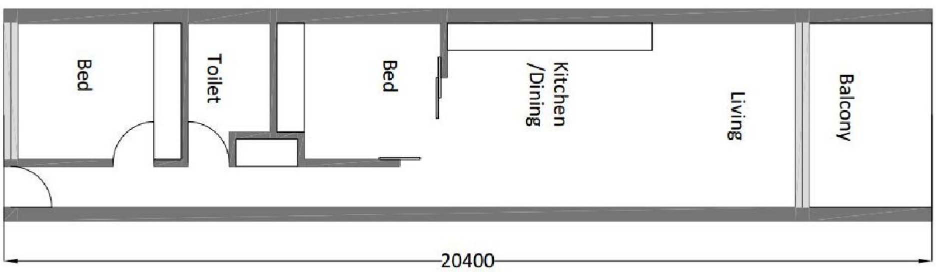

Figure-7a: Example of design solutions that reduce effectiveness of natural ventilation

[1] Zanardo, M. 2012, Personal discussion and review of apartment plans for Sydney

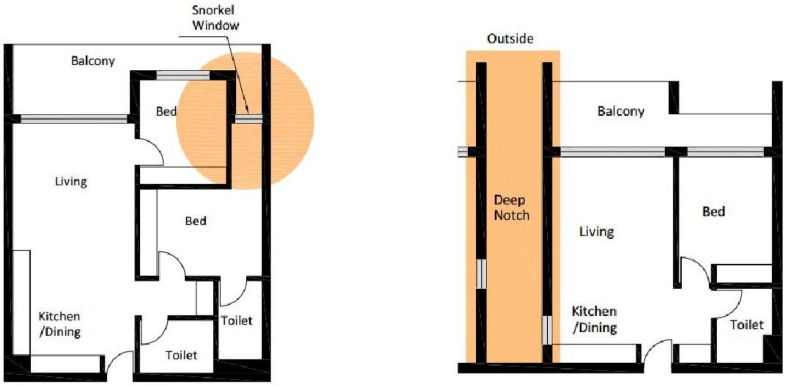

Figure-7b: Examples of design solutions that reduce effectiveness of natural ventilation

In places like Bengaluru, apartments are permanent homes, with many new developments offering high levels of luxury within the security of a gated community. Such luxury developments do have adequate spacing between apartment blocks to have an increased potential to operate in a naturally ventilated mode. However, such luxury apartments are also generally pre-fitted with A/C systems, and this easy access to air-conditioning diminishes the incentive for occupants to adapt to ambient conditions. This is exacerbated for the modern knowledge-worker, who aspires to live in such luxury apartments; regularly works in air-conditioned offices, and whose tolerance for temperatures beyond the closely controlled temperature band in the office drops with increasing adaptation to air-conditioning.

CONCLUSIONS

In a world where there is increasing evidence of rapid anthropogenic climate change, it is critically important that apartment designs provide easy access to the real potential for reduced CO2 emissions, so occupants can minimise their use of non-renewable energy use with little extra effort.

It is clear that the apartment designs selected for the two cities indicate that they pass the critical requirements to be able to provide Effective Natural Ventilation. The simulation analysis undertaken here predicts that

- large energy savings are possible if apartments are retrofitted/designed to the proposed NBC requirements of Part 11, and
- effective natural ventilation is possible if users choose to operate the apartment in “free running mode” during times when the outside dry bulb temperatures lie in an appropriate band

However, it is argued that this potential for effective natural ventilation, and energy efficient living can be easily subverted. As discussed in this paper, sub-optimal design solutions, affluence and adaptation to more stringent thermal conditions can negate the potential for natural ventilation even in the relatively mild climates such as Sydney and Bengalaru. This calls for proactive efforts to maintain climate responsive design standards and education/policy to encourage the benefits of natural ventilation over airconditioning.

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