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A TALE OF FOUR CITIES:
THE POTENTIAL FOR ACHIEVING THERMAL COMFORT USING NATURAL VENTILATION IN HIGH RISE BUILDINGS IN FOUR ASIAN CITIES

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ABSTRACT

This paper briefly outlines the development of a design tool for ascertaining thermal comfort in high rise buildings in the tropics. The design tool, based on wind tunnel studies and computational fluid dynamic (CFD) simulations, was then applied to four cities in the tropics: Kuala Lumpur, Singapore, Jakarta and Hong Kong.

Can thermal comfort be achieved using solely natural ventilation? The overall conclusion was that natural ventilation alone cannot generally provide thermal comfort in high rise buildings in the tropics. Consequently, future research and design should favour a multi modal passive approach (the so called "hybrid" building) if the goal of better sustainability in high rise buildings is to be achieved in the tropics.

KEYWORDS

Natural ventilation, climate, tropics, design tool, CFD, wind tunnel.

BACKGROUND

Air conditioning uses large amounts of energy in high rise buildings in the tropics. Estimates put this usage at between 60-80% of the total energy used in running a building (Deng et al, 1994) (Lam et al, 1995) (Tham et al, 1994). Reduction of this level of energy usage is crucial if nations in the tropics, and many of these are "developing nations", are to move towards sustainability.

One option to reduce such energy usage is the application of more passive and climatic sensitive design measures and in particular for the tropics is the use of natural ventilation. Examples of this approach

outside the tropics are well documented (Daniels, 1995) (Jones, 1998). Examples in the tropics are not so common (Yeang , 1994).
Ken Yeang sums up the situation with his comment (Yeang, 1998):
"Unfortunately, many of the design propositions had to evolve through a discontinuous process of RD&D (research, design and development). This discontinuity is not necessarily detrimental but it can affect the completeness of the development of the proposition; by this we mean the RD&D work in a professional architectural firm is inevitably intermittent and in most instances involved on the run. The unfortunate consequence of this architectural practice based RD&D is that propositions can progress (and then be tested) only where they are permitted by external constraints. In other words, the RD&D can progress only as and when the various commissions and projects in the architectural practice are designed, developed and (if successful) built. The constraints on an architectural project are numerous and generally outside the control of the designer."

Despite this lack of exemplars, practitioners in the tropics and in particular SE Asia have been attempting to realise a "tropical skyscraper" where passive measures are an integral part of that concept. However, there remains limited research and minimal if any design tools.

In addition, there is a general resistance to climate sensitive building design. This in part is understandable. Natural ventilation is provided by either wind driven ventilation or by the temperature driven "stack" effect. The driving forces for both these approaches are restricted in the tropics with both diurnal temperature differentials being small and wind speeds lower than other climates away from the equator. Hence there is some basis for skepticism about the suggestion that natural ventilation is feasible in the tropics.

Moreover, design for natural ventilation in high rise buildings is complex. Designers firstly need to be able to ascertain the pressure coefficients on the face of their building for different building orientations. They then need to ascertain the velocity distribution inside each floor of their building. These need to be completed for each of many different building orientations. Finally, these calculations must be then coupled to the climatic data (for the particular site) and a suitable thermal comfort model selected. The result of this analysis is the total time that thermal comfort can be achieved. There is no design tool that can achieve this end.

Designers have responded to this complexity by sealing buildings and using air conditioning to provide a "controlled" environment thus avoiding this complexity. Thus, air conditioning is universal for high rise buildings. Yet it is clear that this universal approach must be re-examined in the face of the heavy energy usage stated above. Furthermore, research is beginning to show the link between a "better" environment and worker productivity (Rowe et al, 1993) (Jones, 1995).

Designers have pointed to this need for more natural ventilation design tools. Paul Cooper summed up the situation when commenting on the issues that must be addressed and resolved if natural ventilation is to be used on a wider scale (Cooper, 1996).

"...If we are to take advantage of the possible reduced capital and running costs of natural ventilation systems in large buildings, then the necessary modeling tools must be made generally available to facilitate a holistic approach to ventilation design".

Moreover, the need is for a design tool suitable for the early concept/sketch planning stage (Heiselberg, 1999). This is the critical stage of design where the decision to use natural ventilation or some combination of natural and mechanical must be made. Beyond this stage it is not workable to amend the design direction. It would require amendments and scrapping of work done to date by the mechanical, the electrical, structural and the services engineers. The architectural layout, plans and details would need to be revised. In addition, preliminary cost plans would also need to be revised. It could require the extra services of possibly a wind tunnel study, a passive designer and possibly expertise in computer modeling. Still further, a new town planning application and approval could be required thus adding further delays.

Clearly, such a change would ultimately require stopping the project, reassessing the concept/sketch plan and then restarting the project in the new direction. Consequently, if natural ventilation is to be part of a building design then the decision must be made at the concept/sketch plan stages. Thus, to be effective the design tool must also be able to perform at the early concept design stage.

The concept/sketch plan stage of a project is characterised by limited information (CIBSE AM11, 1998). A site will have been identified and there will be bulk and location data available. This will dictate the number of floors and overall height of the building and its location on the site. A basic floor plan locating the core areas with stairs, lifts, lift lobby and toilet areas will have been drawn up. The type of cladding would also be indicated on the preliminary elevations.

THE DESIGN TOOL

Recent research at The Australian Institute of Tropical Architecture has developed the technique for such a design tool. The background to this design tool is given elsewhere (Potangaroa et al, 1998). Briefly the tool was developed from wind tunnel and CFD studies. Boundary layer wind tunnel tests were used to ascertain the pressures on the outside of various high rise building forms. The pressures from these tests were then set as the boundary conditions for various CFD simulations. These simulations studied core and air well location. Spot readings of airflows throughout the floor of the building were then used as the base data for a spreadsheet that coupled the climate data, air flow and thermal comfort model. The adaptive comfort model proposed by Auciliems and Szokolay was used (Auciliems et al, 1997). The tool was constructed as an EXCEL spreadsheet with separate sheets for the different areas. These are summarised in table 1 below.

Table 1: Structure of SpreadSheet.

Summary	Summarises the finding for each wind direction from 1 to 16 and for each location.
Control Sheet	Drives the Process. Input the building's location (presently either Kuala Lumpur, Singapore, Jakarta or Hong Kong) and the building Orientation (1 to 16, 1 being north)
Work Area	Brings data together. If direction is 17 then % area =0, if Vreqd=0, then % is 100, otherwise the spread sheet concatenates the modified direction and the ratio of the Vpro/Vreqd and then looks up the associated % area in Thermal Comfort.
Thermal Comfort	Calculates the % area that is above stipulated bin data values. Bin values from 0 to 2 in 0.1 increments were adequate
Digitised CFD Data	Spot height data. These are modified to allow for the height factor included using a log log velocity profile for wind data measured at 10 metres.
Wind Required	Wind reqd. for thermal comfort. Reduces Climate data
Climate Data	Wind speed and direction input data.
Core Area Factors	Area factors amalgamated
Area Factors	Area calculation (for reference only)

The output from the design tool is the percentage of area where thermal comfort could be achieved in high rise buildings given optimal conditions and as such should be considered an upper limit. The only input data required for the design tool is the climatic data for the site.

CLIMATE DATA

The climate data used in this study was supplied by Professor Hiroshi Akasaka of Kagoshima University, Japan. This data was part of a larger data set of thousands of weather stations throughout the world compiled for air conditioning load calculations (Akasaka et al, 1993). It consisted of the hour by hour monthly averages of the dry bulb temperature, humidity ratio, wind direction, and wind speed.

RESULTS AND DISCUSSION

Typical results from the design tool are shown in table 2. The "Core" groups are for different core positions: "C" is central, "B" is for back corner, "MB" middle back, "F" front, "SM" side middle, "MF" middle front. "Shades" was the model with solar shading and core centrally located. The maximum natural ventilation potential of the 1 to 16 (ie at 22.5^{O} rotations) building orientations and for the four locations of Kuala Lumpur, Singapore, Jakarta and Hong Kong are also listed. These are given as the percentage of time that thermal comfort could be achieved and is averaged over every 5th floor from level 5 to 30 inclusive. It also lists the optimal building orientation and core location.

It is clear from the percentages that the critical climate is Kuala Lumpur, then Singapore, Jakarta and finally Hong Kong. The high percentages of calm periods make Kuala Lumpur's climate critical. The other conclusions are as follows:

- Aspect ratio does not appear to have any significance impact; all values for the four locations appear to be consistent.
- Cores Areas should be located central for buildings with a 1 to 1 aspect ratio (ratio of width of building to depth of building) and at the ends of the building for greater aspect ratios.
- Buildings should be orientated as listed below to achieve optimal natural ventilation potential:
  Kuala Lumpur 22.5^{O} east of South
  Singapore: 45^{O} east of South
  Jakarta: 45^{O} east of North
  Hong Kong: 67.5^{O} east of North

Moreover, the low percentages where thermal comfort is achieved suggests that natural ventilation, b itself, is not suitable for high rise buildings in Kuala Lumpur or Singapore. The potential for natura ventilation increases for Jakarta but is still marginal and is really only feasible in Hong Kong.

CONCLUSIONS

This parametric study of the influence of floor aspect ratios and location of service cores on natur ventilation potential of isolated office towers indicates the low potential in Kuala Lumpur, Singapo and Jakarta. Hong Kong offers better natural ventilation potential but poses difficulties in achievi adequate exposure to wind due to the land shortage in that city.

In the real world of high-rise office development, there are only short time windows of opportunity secure a development. Preliminary concept designs for promotional or funding brochures are oft produced in a few weeks with little opportunity for optimisation, particularly when it comes to natu ventilation. If the development is secured there is usually a strong commitment to the hastily prepared preliminary design.

The preliminary design tool described in this paper indicates that potential for natural ventilation from wind for indoor thermal comfort in open planned office towers in Southeast Asian cities is often low, even after idealised optimisation.

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Aspect Ratio 1 to 1

	Best Core Location							Best Building orientation		
	Core C	**Core B**	**Core MB**	**Core F**	**Core SM**	**Core MF**	**Shades**			
Kuala Lumpur	12.0%	11.1%	8.7%	11.1%	11.9%	8.7%	0.9%	**Core C**	14.0%	**8 or 16**
Singapore	38.7%	34.6%	32.6%	34.6%	37.8%	32.6%	14.2%	**Core C**	42.6%	**7 or 15**
Jakarta	46.0%	41.1%	39.1%	41.1%	44.7%	39.1%	18.4%	**Core C**	49.6%	**2 or 10**
Hong Kong	81.0%	76.0%	77.8%	76.0%	77.8%	77.8%	65.1%	**Core C**	86.1%	**1 or 9**

Aspect Ratio 2 to 1

	Best Core Location				Best Building orientation		
	Core C	**Core E**	**Core T**	**Shades**			
Kuala Lumpur	14.8%	15.6%	12.1%	6.5%	**Core E**	18.0%	8 or 16
Singapore	39.7%	40.9%	35.9%	28.4%	**Core E**	43.8%	7 or 15
Jakarta	46.8%	48.0%	42.7%	34.2%	**Core E**	50.7%	3 or 11
Hong Kong	80.7%	78.3%	79.0%	72.5%	**Core C**	83.7%	4 or 12

Aspect Ratio 3 to 1

	Best Core Location					Best Building Orientation		
	Core C	**Core E**	**Core T2**	**Core T4**	**Shades**			
Kuala Lumpur	11.9%	16.9%	13.2%	13.8%	4.8%	**Core E**	20.0%	**8 or 1**
Singapore	35.7%	44.4%	36.5%	39.4%	26.0%	**Core E**	49.0%	**7 or 1**
Jakarta	42.1%	51.9%	43.3%	46.3%	31.7%	**Core E**	56.1%	**3 or 1**
Hong Kong	75.2%	80.8%	78.2%	80.1%	71.2%	**Core E**	84.9%	**4 or 1**