HYBRID VENTILATION: SOFTWARE COUPLING FOR THE ANALYSIS OF A MIXED MODE DESIGN IN A TROPICAL MONSOON CLIMATE

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ABSTRACT
The project is a design for a mixed mode system using either cross flow or stack effect natural ventilation with ceiling mounted fan coil units, in the 42,000m² British International College campus in Yangon, Myanmar, designed by Tangram Architects in collaboration with Terrell Group Engineering. The engineering design process uses numerical models combining a commercial CFD code, Urbawind, with a dynamic thermal simulation program, Energy Plus. In today’s building engineering environment this method provides key answers at an early design stage while cost effective for both design team and client.

INTRODUCTION
Hybrid ventilation
The purpose of ventilation in buildings is to provide acceptable indoor air quality (IAQ), and thermal comfort to all occupants. A hybrid ventilation system (IEA-ECBCS Annex 35, 2002), provides IAQ and thermal comfort using natural and mechanical systems at different times of the day or seasons of the year.

Both mechanical and natural wind driven forces combine to form a two-mode system reacting to any variations in the weather. The design for this project is of the simplest form, natural cooling provided by the natural buoyancy of the air (J. Khedari et al. 2000, S. Chungloo et al. 2006, T. Chenvidyakan 2007, T. Kleiven 2003) and the pressure differences across facades and, when insufficient to provide cooling, a chilled water systems is activated to provide mechanical cooling through terminal AC. The hybrid system switches automatically between natural and mechanical modes, minimizing energy consumption.

The success of any natural ventilation system depends on the understanding of the wind flow around the building and on the site (T. Stathopoulos 2009, W.D Jansen et al. 2012, 2013). The wind is influenced not only by the size and shape of the surrounding buildings but also by the surrounding terrain (K. Fahssis et al. 2013, G. Caniot et al. 2013). Whether it is open water or dense forest, each of these elements will have an effect on any natural ventilation system. A first complete wind flow analysis at an urban level was conducted for the basis of this report, taking into account the surrounding buildings and terrain.

The next calculations were done at building level, helping to validate the design assumptions in providing a detailed analysis of the buildings behavior over a short period of time (one calculation every five minutes over a two week period).
SIMULATION: URBAN LEVEL

Pressure coefficients $C_p$

Wind flow patterns have a direct impact on the driving force for natural ventilation, these are called pressure coefficients ($C_p$). They are dependent on wind direction and obstacles (natural or otherwise). The pressure exerted on any point on a building is expressed as:

$$P_w = 0.5 \rho C_p v^2$$

(1)

The uncertainties in using pre-defined data sets or the difficulties and obvious expense of wind tunnel testing (D. Costola et al. 2009 and B. Wang et al. 2012), led to the use of a commercial based CFD code. An architectural model of the building and its surroundings (500m radius) was imported into Urbawind in order to determine the pressure for each point of the domain. This calculation provides us with the required pressure coefficients.

Figure 2 Large-scale model used for $C_p$ calculations.

CFD methodology

Urbawind uses the Reynolds Averaged Navier Stokes equations for solving the averaged equations of mass and momentum conservation for steady flow and incompressible fluids:

$$\frac{\delta (\rho \bar{u}_i \bar{u}_j)}{\delta x_j} - \frac{\delta \bar{P}}{\delta x_i} + \mu \left( \frac{\delta \bar{u}_i}{\delta x_j} + \frac{\delta \bar{u}_j}{\delta x_i} \right) - \rho \bar{u}_i \bar{u}_j = 0$$

(2)

The calculation is done on an unstructured rectangular grid that automatically refines itself near obstacles such as buildings. The tool delivers the tri-dimensional mean velocity field and the mean pressure for each point of the domain. This calculation provides us with the required pressure coefficients for:

- Each wind direction at 45° increments
- Each façade of building including inner and outer facades (courtyard)

SIMULATION: BUILDING LEVEL

EnergyPlus Airflow network

After having conducted our first study at the site level, we must continue our investigation at building, zone and node level with the use of dynamic thermal simulation software (P.Haves et al. 2004, I. Oropeza-Perez et al. 2011). Thermal comfort is not only dependant on temperature but also on airflow and air movement within the building (R. de Dear 2002) and this from one zone to the other, we also have to be able to take into account a control system that can switch from natural ventilation to mechanical cooling. EnergyPlus is capable of simulating this movement through multizone wind driven airflows with hybrid ventilation control.

The Airflow network model (EnergyPlus Input Output reference guide pp773-791 and L. Gu 2007) consists of input specifications described as objects within the programme. The following objects are of particular interest to the study:

- AirflowNetwork:SimulationControl: basic run parameters and specifies whether the wind pressure coefficients are input by the user or not
- AirflowNetwork:Multizone:Zone: specifies the ventilation control that applies to all of the openable exterior windows
- AirflowNetwork:Distribution:Linkage: represents a linkage between two nodes objects such as a Multizone:Zone
- AirflowNetwork:Multizone:Surface: for the input of wind pressure coefficients which is linked with ExternalNode, WindPressureCoefficientArray and WindPressureCoefficientValues

EnergyPlus calculates automatically assigns default wind pressure coefficients. These are valid only for a rectangular or low-rise building (M.S. de Wit 1999). In this case, the defaults were not used due to the complex geometry. The surrounding wind pressure coefficients are calculated and manually introduced into the model.

Design inputs

Design inputs typically include activity data, building envelope data, and in this case details of openings (inner and outer vents, windows...), temperature set points and simulation details. Table 1 resumes the main design inputs for the study.

Table 1 Design data

<table>
<thead>
<tr>
<th>ACTIVITY DATA CLASSROOMS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy</td>
<td>Average 25 per classroom</td>
</tr>
<tr>
<td>Schedule</td>
<td>Weekdays only</td>
</tr>
<tr>
<td></td>
<td>8 - 9 : 100%</td>
</tr>
<tr>
<td></td>
<td>9-10 : 25%</td>
</tr>
<tr>
<td></td>
<td>10-12 : 100%</td>
</tr>
<tr>
<td></td>
<td>12-16 : 100%</td>
</tr>
<tr>
<td></td>
<td>16-18 : 50%</td>
</tr>
<tr>
<td>Metabolic activity</td>
<td>Standing/walking (corresponds to classroom activity)</td>
</tr>
<tr>
<td>Clothing</td>
<td>0.5 (summer clothing)</td>
</tr>
<tr>
<td>Equipment</td>
<td>2 W/m²</td>
</tr>
</tbody>
</table>

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Climate and wind analysis of site
The first step in this analysis is the study of the wind patterns on the site. The main relevant characteristics of the Yangon climate are:

- Warmest months are March and April, dry bulb of 40°C, RH 60%
- Monsoon season, June to September, maximum temperatures observed between 33-34°C, however a RH of 89% (the air is almost fully saturated)
- Coolest months are December through to January, dry bulb average of 25°C and RH of 60%
- Sunshine duration averaging 10 hours daily
- Main wind direction are between 108° (East South East) and 225° (South South West) with average wind speeds between 1.4 to 2.1 m/s

The Yangon climate can be characterised by three seasons: winter, summer, monsoon, all with low wind speeds. The average annual temperature is 26°C with RH of 60%. This climate is ideally suited for the human metabolism, but low wind speeds could be a negative factor for a wind driven ventilation design. There is no insulation and windows are single glazing with exterior shading devices made from locally sourced materials.

Pressure coefficients: \( C_p \)
The software calculates two different values of \( C_p \). The first, represented in Figure 4, are a graphical representation. The \( C_p \) values are not intended for export into other models, and are expressed by the following equation:

\[
C_p = \frac{P}{0.5 \rho_{\text{air}} u (H_{\text{ref vent}})^2}
\]  

(3)

In this case, the \( C_p \) values are normalized by an average wind speed at the reference height \( H_{\text{ref vent}} \). This is set by default at 10m. This enables the software to calculate pedestrian wind comfort, this is not within the scope of this study. However, when we export the coefficient for use in the simulation model...
are normalised by the dynamic pressure at reference point at 100m height, as expressed in EQUATION (1).

In Figure 4, we have an illustration of the output from the Urbawind, giving the $C_p$ values. The darker spots on this figure correspond to positive values, these are located around the buildings, the project is in the forefront and directly above (due North) the Star City complex. Notice the obvious influence of the surrounding buildings on the $C_p$ values. When wind flows directly on to a building surface, a positive pressure is induced on the upwind face. This flow separates at the corners of the building resulting in negative pressure regions on the side of the building, inner courtyard and leeward facade. These buildings effectively block the wind and have a negative impact on the natural ventilation strategy of the building.

The data is extracted from each wind direction and adapted to the incoming wind angle and then inserted into the EnergyPlus model:

```plaintext
AirflowNetwork:MultiZone:WindPressureCoefficientValues,
2%FrsrlrClssrms:Chimney%2_Wall_1_0_0_0_0_0_Vent,
! Name
  Cp Data,     !- CP Array
  -.44,        !- Wind direction #1 (deg)
  .07,         !- Wind direction #2 (deg)
  .24,         !- Wind direction #3 (deg)
  1.08,        !- Wind direction #4 (deg)
  3.,          !- Wind direction #5 (deg)
  .17,         !- Wind direction #6 (deg)
  -.24,        !- Wind direction #7 (deg)
  -.54;        !- Wind direction #8 (deg)
```

Energy model
A whole building analysis was deemed too time consuming and unnecessary due to the architectural design of the building. The building is designed to suit the local climate, each classroom is linked by open walkways and only the administrative offices and school restaurant are fully enclosed and air conditioned and do not fall under the scope of this study.

A detailed model was created using Design Builder an EnergyPlus GUI. The model included precise details of the façade and a complete representative portion of the building (Figure 5) including the following strategies:

- Hybrid cross ventilation classrooms
- Hybrid chimney ventilated rooms
- West facing rooms that receive most of the afternoon and early evening solar radiation

**First cast: comments and analysis**

The first calculations play a pivotal role in the design process because it helps to validate the main design assumptions and hypothesis for the solar chimneys and natural ventilation strategy. These calculations help to benchmark the design and the results help to define the following optimization process that is required to ensure that the proposed design fulfills its role in providing optimal thermal conditions.

Often, in order to increase the chimney stack effect it has been preferable to insulate the interior of the chimney (M. Gontikaki et al. 2010, L. Neves et al. 2011,). This limits heat exchange between the chimney wall and the outside ambient air, reducing heat loss and maintaining buoyancy of the warmer air induced by the stack effect. This was not the case in our calculations; this discrepancy will require further investigation however the following assumptions may help to explain this behavior:

- The Yangon climate is described as that of a tropical, monsoon country with winter temperatures rarely below 20°C and a yearly average temperature of 26°C.
- Direct normal solar radiation during the cooler months is on a daily average, between 6 to 8 kW/m². This radiation could be used to increase the temperature within the chimney by the use of an absorptive coating on the outside (as was modeled)
The first simulations included three distinctive room types and ventilation strategies:

- **Hybrid A**: chimney using brick for structure and mass, 5cm insulation and a light colored protective coating on the outside (insulated chimney).
- **Hybrid B**: chimney using brick for structure and mass, light colored protective coating (uninsulated).
- **Hybrid C**: chimney using brick for structure and mass, dark, absorbing (solar radiation) protective coating on outside.

The calculation showed that the uninsulated chimney had an average temperature of 2°C above the other types during the day; which helped to increase the stack effect that in turn helped the natural ventilation airflow through the classroom. This discrepancy had economic repercussions, an insulated chimney was proving to be difficult to execute on site and costly.

**Operative Temperature**

A series of simulations were conducted in order to compare operative temperatures to outside dry bulb temperatures in the summer and winter hoping to differentiate between construction types. The results proved inconclusive in ruling out any construction choice. Another method of differentiation was required.

It appears that during the peak of the monsoon season, the hybrid ventilation is less effective. It can be supposed that the lack of wind that reduces the effectiveness of the system. It is obvious that the rain will be a factor in cooling down the chimney; however this was not taken into account in these calculations.
The precision of the calculations enables to determine when the natural ventilation is effectively venting the excess calories from the zone and when the traditional AC system is in operation, triggered by the Hybrid ventilation set points. The resulting heat balance shall be used for comparative purposes, the part of active cooling used in each system shall be the deciding factor (represented in dark grey in the following graphs).

In Figure 11 it can be observed when the room temperature is above the given set point the active cooling system takes over and the windows are closed. This corresponds to the transition in the figure between the two systems, natural ventilation taking place in the morning on warm days and on cooler days it continues in to the afternoon. It must be noted that irrespective of the design option active cooling is always required.

The most encouraging results were found to be from the Hybrid B model, where can observe the natural cross ventilation is used throughout an entire day. This is not observed with the Hybrid C system and leads us to the following comment:

- The inertia of the brick has both a positive and negative effect on the performance of the hybrid system. The system performs well when the chimney is insulated however we can observe better results when there is no insulation. This is due to the inertia of the material which can store and release energy and this can be put to good effect in our case (Hybrid A). The temperature within the chimney stack increases and thus optimizing the effectiveness of the system, by increasing the airflow. The downside however is the darker absorbing surface will increase the heat load within the room (Hybrid C), causing probable occupant discomfort.

The classrooms that will benefit the most from correct cross flow ventilation are those located on the side of each building. Initial analysis ruled out using crossflow ventilation using the inner courtyards due to the lack of substantial pressure differences.

In Figure 14 we can clearly see the days without any active cooling whatsoever, represented in light grey, representing the amount of external air flowing through the system that maintains adequate internal temperatures. This validates the model within EnergyPlus from the absence of systematic need of active cooling during certain period of the year.
In this study we do not take into account different construction types, an optimization of window opening surfaces and types was not within the field of this study.

The results appear to be more encouraging for the crossflow ventilation treatment; by the following comments resume the results for the analysis of crossflow ventilation:

- During the run period it is observed that natural ventilation is used for a total of 3 days without having to change over to the AC system in order to provide comfort.
- As for the Hybrid chimney ventilated classrooms, during the warmer months the system works in natural mode during the early hours only, limiting the effect of natural ventilation during this period.

CONCLUSION

The simulation tools used for the purpose of this study were invaluable in the overall design process, key issues were addressed earlier in the design, saving time and cost to both client and architect.

The use of CFD software for the determination of the $C_p$ coefficients is, as yet, not widespread, due to both a lack of scientific validation in the use of such a tool and the general inertia of traditional design offices in adapting new tools. This requires further development but the time gain is undeniable in this case, the results were obtained in under a week rather than a period running into several weeks or months depending on the complexity of the model.

EnergyPlus software was chosen for the AirFlow network model which is fully documented and the use of which is widespread in both the scientific and engineering communities. The precision of the results enabled the design team to understand how the building performed and which key elements influenced the design.

The overall saving were not only in the design process but also in the running costs of the building, this is a key element in the use of hybrid systems. The difference in energy consumption was between 40-70% for an identical classroom using a conventional AC system, hybrid crossflow ventilated classrooms presented the greatest potential for savings. This resulted in an estimated energy cost saving between 100 -150 k $ a year.

Another key advantage of the hybrid system over a conventional AC system is in the increased airflow rates. A hybrid system can induce up to 15-20 air changes per hour (ACH) of any given volume in comparison to a traditional AC system, which is between 1-2 ACH due to equipment sizing. This argument was not developed in this study but is a key designing and proposing hybrid systems and may well be a deciding factor when incorporating indoor air quality into the decision process.

REFERENCES


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