Environmentally responsive architecture; passive design for school in southern India

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ABSTRACT

This paper outlines the findings of a research project undertaken as part of the design for St. Anthony’s School, a primary school in the town of Gudalur situated in tropical southern India. The objective of this paper is to demonstrate a design approach through the analysis of internal environmental factors and requirements with a brief discussion on defining acceptable comfort zones for this particular climate. The paper further concentrates on a classroom and specifically investigates the implications of changing occupancy for ventilation requirements.

1. INTRODUCTION

Gudalur is located in southern India at 11.5°N latitude and 76.5°E longitude at 960m altitude. The design process began with establishing a comfort zone for the classrooms using a combination of Fanger’s PPD/PMV methodology, DeDear and Brager’s research for naturally ventilated buildings (De Dear and Brager, 2002) and a study by Wong and Khoo in Singapore (Wong & Khoo, 2003). An analysis of ventilation requirements and daylighting was then used to establish orientation and aperture sizes of openings and shading devices. The analysis also explored a variation of occupancy density and its effect on ventilation requirements and indoor temperatures.

2. CLIMATE

Situated on the northern foothills of the Nilgiri Hills, at 960m above sea level, the climate at Gudalur is mild tropical. Owing to its altitude, average temperatures in Gudalur and in the Nilgiri Hills are generally below those on the low lying plains to its east (Fig. 1).

A typical annual cycle can be divided into four main seasons, with monsoons comprising almost half the year. Mild winters last only three months from December through February. Relatively cooler summers follow, for three months, from March through May. South-west (westerly) monsoons arrive around the beginning of June and last until the end of September. Most of the rainfall received in the Nilgiri district and in Gudalur is during this period. The two months of October and November receive North-east monsoons, before the onset of winter. These are relatively calmer than the SW monsoons.

3. SITE & BRIEF

The site designated for the new St. Anthony’s primary school is located on a gentle slope eastward with steep incline to the west. This west hill helps form a natural barrier against the wind driven rains during southwest monsoons as well as protecting from the late afternoon summer sun (Fig. 2).

The school requires a total built-up space of approximately 1500 m². Classroom spaces comprise 41% of the total school programme (Fig. 3). Considering also the long occupancy periods in classrooms, it clearly puts emphasis on the need for a well designed classroom space. Based on this fact, the research concentrated on analysing and designing classrooms.
S Khoo (2003) on thermal comfort in schools in Singapore concluded that an acceptable upper level of temperature ranges from 27.1°C to 29.3°C which relates to PPD of 20% or less which would satisfy the ASHRAE Standard 55. This validates the upper limit of the established comfort zone (Fig. 4).

Figure 3: St. Anthony’s School programme

Figure 4: Adaptive comfort for classrooms

The ASHRAE Standard 55 recommendations for naturally ventilated buildings is based on a study by de Dear and Brager (2002). In their research, de Dear and Brager establish new adaptive comfort standard (ACS) for naturally ventilated (NV) buildings in warmer climate zones. A simplified expression calculates the comfort temperature (Tcomf) as a function of the mean outdoor dry bulb temperature (Ta, out);

\[ T_{comf} = 0.31 \times T_{a, out} + 17.8 \]

Since the data used to establish the expression above was gathered in office buildings, it must be used with caution in terms of St. Anthony’s school building. Even though the density of an office space is very different to that of a classroom, the activity levels are certainly similar, but then again the metabolic rates vary between adults and children. Due to these uncertainties, this study only makes a brief comparison of the comfort zones established by the PMV model earlier and extrapolating ACS using de Dear’s expression above. For Ta, out, the mean daily maximum and minimum average temperatures are used to draw the graph defining the Tcomf lines (Fig. 4). The comfort zone with 90% acceptability then stretches approximately 5°C above and below the Tcomf lines.

To conclude from the analysis and research explained above, the upper limit of the comfort zone can be safely established at 30°C. Since summers are short in Gudalur, it can be recommended to only allow for a maximum of 80 occupied hours above 30°C with a maximum limit of 32°C. Since the lower temperature levels are of less concern due to the fact that temperatures will be mostly moderate during the school’s daily calendar, the lower limits are not discussed beyond the PPD/PMV model.

3.2 Spatial Layout & Density Limitations in a Classroom

To begin exploring the optimum design for a group space some existing guidelines are examined. The local building authorities for school buildings in Gudalur require a minimum space of 10 ft² (0.93 m²) per student. As per this requirement, at St. Anthony’s School, in a classroom of 400 ft² (37.16 m²), 40 students will be accommodated. By European standards this seems like a highly dense module. Even if comparatively, sub-standards are acceptable due to lack of resources in Gudalur, the difference in the ratio should not be significant. Space requirement guidelines published in Building Bulletin 99 (BB99) by the ‘Department for Education & Skills’ (DfES) of UK recommends appropriate space requirements for a classroom in the UK (Wadsworth, 2005), and can be a used as a benchmark for the study. BB99 provides a formula for calculating the minimum space requirements for each classroom type (Fig. 5). For a small classbase, similar to St. Anthony’s classrooms, this is defined by the formula 4+1.5G, where ‘G’ is the number of pupils. If we compare the minimum space requirement as per local Gudalur’s authorities with the BB99 recommendations, it immediately becomes evident that the 10 ft² per pupil space is considerably (42.2%) below the minimum required by BB99 (Fig. 5). If we maintain the size of the classroom at 400 ft², and reduce the number of pupils to 30, the ratio is still about 19% lower than that recommended by BB99.

To assess an appropriate number of pupils in the classroom (G), is to understand the internal environmental implications of increasing the pupil density. The most obvious impact of changing density will be the change in requirements for natural ventilation.

Figure 5: Min. classroom size as per BB99 and comparision with local Gudalur codes (Source; after BB99, 2005)
3.3 Implication On Ventilation Due To Increased Pupil Density

Apart from general discomfort caused by a larger group of pupils in a classroom, there are other internal environmental consequences. The most important being the increase in volume of air changes not just for minimum fresh air requirements but also for heat dissipation from the classrooms during summer months. This in turn will require appropriately sized inlets for ventilation. To understand the impact of increased number of pupils in a given classroom space, using well established equations (Butcher, 2005), the internal heat gains, required air changes for heat dissipation and required opening sizes for different volumes of air changes is calculated. The opening sizes are calculated for two ventilation strategies, single sided wind driven ventilation and crossflow wind driven ventilation (Tab. 1).

Table 1: Ventilation requirements and openings chart for heat removal with changing number of pupils

<table>
<thead>
<tr>
<th>Number of Pupils (G)</th>
<th>Heat Gains (W/m²)</th>
<th>Vach (m³/s)</th>
<th>Opening Size for Single Sided Ventilation (m²)</th>
<th>Opening Size % of Floor Area (Single Sided)</th>
<th>Opening Size for Crossflow Ventilation (m²)</th>
<th>Opening Size % of Floor Area (Crossflow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>49.09</td>
<td>0.55</td>
<td>13.27</td>
<td>36.07%</td>
<td>5.73</td>
<td>15.58%</td>
</tr>
<tr>
<td>32</td>
<td>52.13</td>
<td>0.59</td>
<td>14.08</td>
<td>38.26%</td>
<td>6.08</td>
<td>16.53%</td>
</tr>
<tr>
<td>34</td>
<td>55.18</td>
<td>0.62</td>
<td>14.97</td>
<td>40.70%</td>
<td>6.47</td>
<td>17.59%</td>
</tr>
<tr>
<td>36</td>
<td>58.22</td>
<td>0.66</td>
<td>15.78</td>
<td>42.90%</td>
<td>6.82</td>
<td>18.53%</td>
</tr>
<tr>
<td>38</td>
<td>61.27</td>
<td>0.69</td>
<td>16.59</td>
<td>45.09%</td>
<td>7.17</td>
<td>19.48%</td>
</tr>
<tr>
<td>40</td>
<td>64.31</td>
<td>0.72</td>
<td>17.40</td>
<td>47.28%</td>
<td>7.52</td>
<td>20.43%</td>
</tr>
</tbody>
</table>

The average wind speed used in these equations is 0.83m/s. This represents the high number of hours in the wind rose for Gudalur for summer months. For single sided wind driven ventilation, the constant value (C) is assumed at 0.05. For cross-flow ventilation a conservative value for the difference in pressure coefficient (ΔCp) is assumed to be 0.3. With higher pressure coefficient difference the crossflow ventilation for a given opening size will have larger volume of air flow and can be controlled by allowing the users to adjust the openings.

The result of the analysis shows that using cross-flow ventilation, a fairly small percentage of openings (roughly 20%) are ample to provide air volume needed for heat dissipation even for 40 students (Fig. 6). We can thus conclude that the number recommended by local Gudalur authorities can be acceptable to achieve internal comfort and that daylighting requirements will dictate the opening sizes for the classrooms.

4. DESIGN CONCEPT & VENTILATION STRATEGIES

Since St. Anthony’s School is not situated in a restricted urban site, a linear form can be used to allow for a shallow plan. A shallow plan will enhance daylighting and allow for cross-flow ventilation which is critical during summer months for heat dissipation and during monsoon months for moisture removal from the building (Fig. 7).
Further more, if the linear plan is broken up and reassembled as shown in Figure 8, it can further improve air movement through the internal and semi-outdoor spaces (Fig. 9). The broken-up form can also enable the design of semi-outdoor spaces which can serve as protected play areas for the pupils. The wastage of space can be minimized by adding spaces on both sides of the circulation path. Historically, the tree canopy has commonly been used to provide environmental cover in rural India. This provides an inspiration for the architectural design both in form and function, since the tree canopy successfully protects from the high sun, yet its porous property allows air movement. St. Anthony’s school’s design literally derives from the tree taking its advantageous qualities and improving upon it (Figs 10 & 11).

5. CONCLUSION

Using the tools available appropriate architectural design solutions can be applied to achieve desired comfort levels. Architectural design need not be compromised and can be driven by environmental conditions. Using the tree structure as its inspiration (Fig. 11), the design then utilizes the findings of this research to refine the structure and achieve comfortable internal conditions.

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REFERENCES


