681: Environmentally Responsive Architecture; Passive Design for School in Southern India

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Abstract

This paper outlines the findings of a research and design project based on work undertaken for the MSc in Sustainable Environmental Design at the Architectural Association School of Architecture, London in 2005-06. The objective of this paper is to demonstrate that a well understood external environment as well as all aspects of internal environment can result in a successful passively designed architecture which can not only reduce energy demand, but also create a significantly healthy building

This paper focuses mainly on the internal environmental factors and requirements and begins with a discussion on defining acceptable comfort zones. Stepping away from Fanger's defined PPD/PMV chart, the paper validates a more flexible and expanded comfort zone that responds to its specific climate and occupants (in this a case a mild tropical climate with children as occupants) and is supported by various research papers (including de Dears research, ASHRAE 55 for NV buildings and others) as well as the writer's own empirical analysis.

The paper further concentrates on the indoor environmental and design requirements for a classroom. It specifically investigates the implications of changing occupancy for ventilation requirements. How can such requirements be fulfilled through passive architectural design? Using available equations and analysis tools (such as CFD), window orientations and sizes are established to optimize required ventilation. A classroom design is thus developed and tested for other indoor factors such as temperature and daylighitng using various energy and daylighting tools. The result is a design which is not only responsive to its external environment but also creates acceptable indoor environments through natural means and reduces energy loads whilst being expressive in its form.

Keywords: energy, comfort

1. Introduction

The process of creating healthy and sustainable buildings begins at the concept design stage of any given project. With well understood climate of the site and required indoor environmental conditions for the building typology, the architectural response can perform efficiently without loosing out on innovation or its aesthetic quality (Fig. 01). Furthermore, the use of simple equations can help refine the design to enhance the indoor environment by natural means and even question the normally accepted standards. This paper, using a classroom design process as an example, presents an approach to environmentally responsive passive architecture.

Although the original work by the author in the form of a dissertation covered all aspects of environmental issues and architectural design, for the purposes of this paper, the focus will be on 1) understanding and applying the adaptive comfort principles in a classroom located in Southern India and 2) using architecture to optimize daylighting and ventilation strategies.
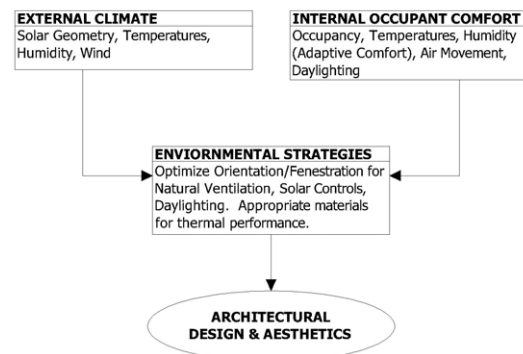

Fig 1. Environmentally responsive design approach diagram

The school building for St. Anthony's School is located in the town of Gudalur in southern India (11.5ºN Lat., 76.5ºE Long., Alt. 900m or 2,950 ft.). Although the climate of the surrounding region is tropical with high temperatures and humidity during summers, Gudalur experiences milder climate due to its higher altitude (Fig. 2).

Fig 2. Monthly diurnal chart for Gudalur, India
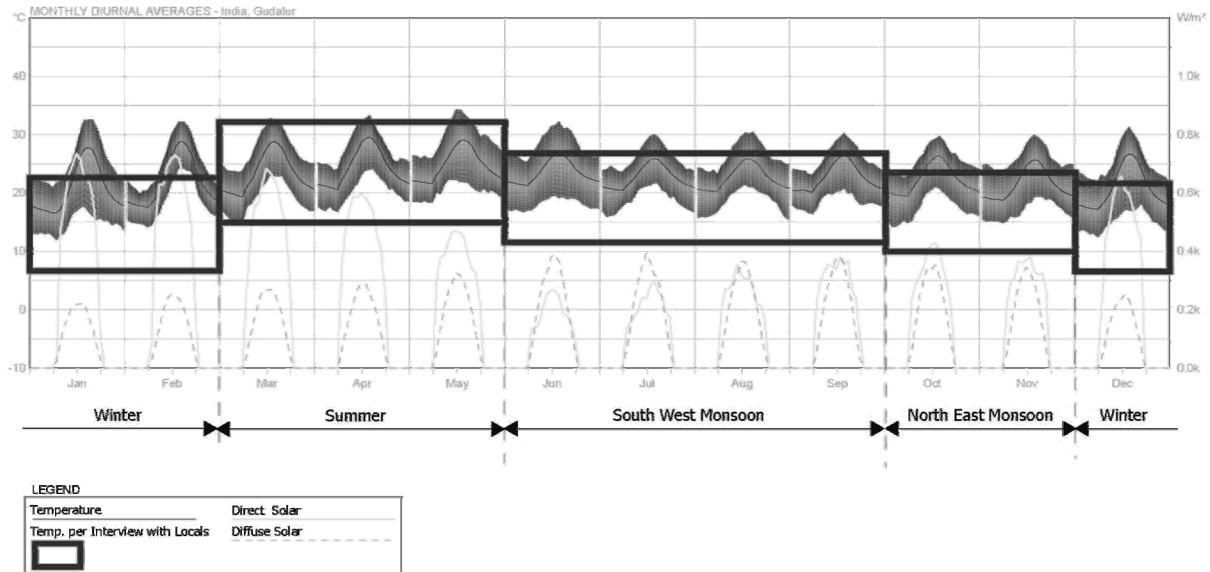
2. Environmentally Driven Design Overview

Since St. Anthony's School is in not situated in a restricted urban site, a linear form can be used to allow for 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. Further more, if the linear plan is disintegrated (Fig. 03), it can further improve air movement through the internal and semi-outdoor spaces. The disintegrated 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 the both sides of the circulation path.

The classroom is the most important space in the design of St. Anthony's School. A careful study of the classroom in terms of its programmatic and environmental requirements must be done to inform a more intelligent design solution. The classroom has evolved in the developed world over time and now accommodates more activities than just formal teaching where the whole group faces the board and the teacher, especially in primary schools. The Classroom can now be more loosely defined as a 'Group Space' (Building Bulletin 95, 2002). In developing countries like India and especially in a rural town such as Gudalur, teaching methods remain mostly formal with pupils facing the black-board and the teacher. In the future, this is most likely to change and a more successful design will be one that can foresee and adapt to the coming changes in educational methods.

In terms of its environment, the classroom must take into account that it is probably the most densely occupied space with longer patterns of occupation. This can put the priority for

ventilation and daylighting above the thermal requirements (Yannas, 1994).
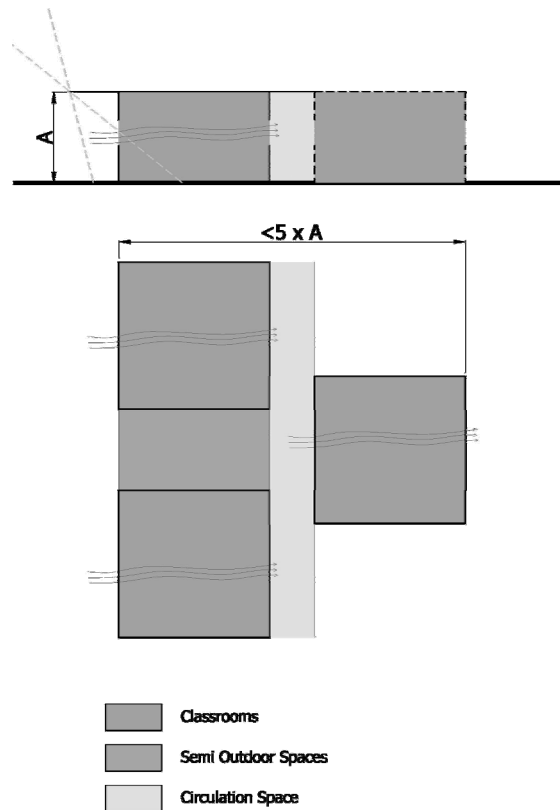

Fig 3. Proposed disintegrated plan for St. Anthony's School

3. Adaptive Thermal Comfort

Fanger's PPD/PMV methodology ignores an important factor in defining comfort, the outside temperature (t_o). A research done by by N H Wong and S S Khoo (National University of Singapore) on thermal comfort in schools in Singapore concluded that an acceptable upper level of temperature ranges from 27.1ºC (80.8ºF) to 29.3ºC (84.74ºF) which fulfils 20% of

dissatisfaction criterion. This validates the upper limit of the established comfort zone (Fig. 04).

Another important source researched is the revised ASHRAE Standard 55 recommendations for naturally ventilated buildings based on a study done by Richard de Dear and Gail Brager (2002). In their research, de Dear and Brager establish new adaptive comfort standard (ACS) which takes into account the external temperature and allows for warmer indoor temperatures in naturally ventilated (NV) buildings during summers and in warmer climate zones. Their research based on 21,000 raw data gathered across the globe, establishes that Fanger's PMV model is suitable only for buildings with centrally controlled heating, ventilation and air-conditioning systems (HVAC) and did not apply to NV buildings (de Dear, Brager, 2002). The results of their findings concludes with a simplified expression to calculate the optimum comfort temperature (Tcomf) in relation to the mean outdoor dry bulb temperature (Ta, out);
Tcomf = 0.31 x Ta, 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. 04). The comfort zone with 90% acceptability then stretches approximately 5ºC above and below the Tcomf lines (as suggested by de Dear & Brager).

To conclude from the analysis and research explained above, the upper limit of the comfort zone can be safely established at 30ºC (86ºF). During summers, the PMV model with a factor +1.5 allows for the upper limit at 32ºC (89.6ºF). Since summers are short in Gudalur, it can be recommended to only allow for a maximum of 80 occupied hours above 30ºC with a maximum limit of 32ºC. 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 PMV model.

4. Spatial Layout & Density Limitations in a Classroom

To begin exploring the optimum design for a group space some existing guidelines shall be examined. The local building authorities for school buildings in Gudalur require a minimum space of 10ft² (0.93m²) per student. As per this requirement, at St. Anthony's School, in a classroom of 400ft² (37.16m²), 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, and can be a used as a benchmark for
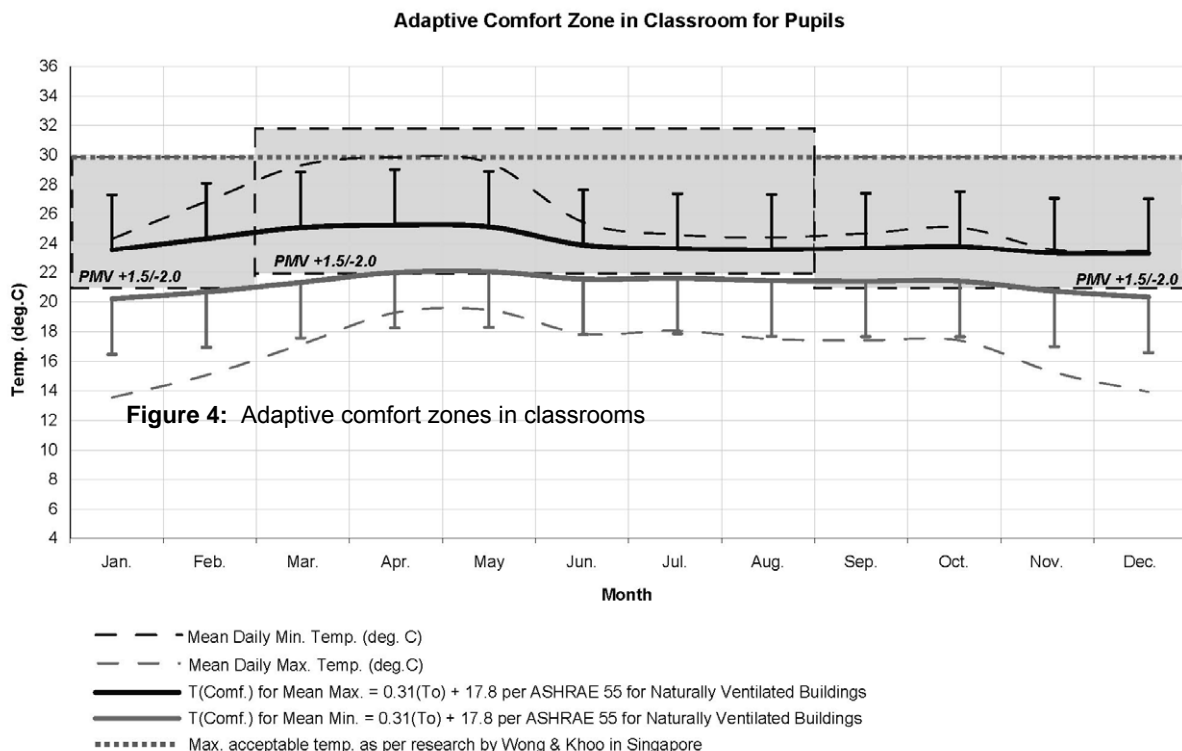

Figure 4: Adaptive comfort zones in classrooms

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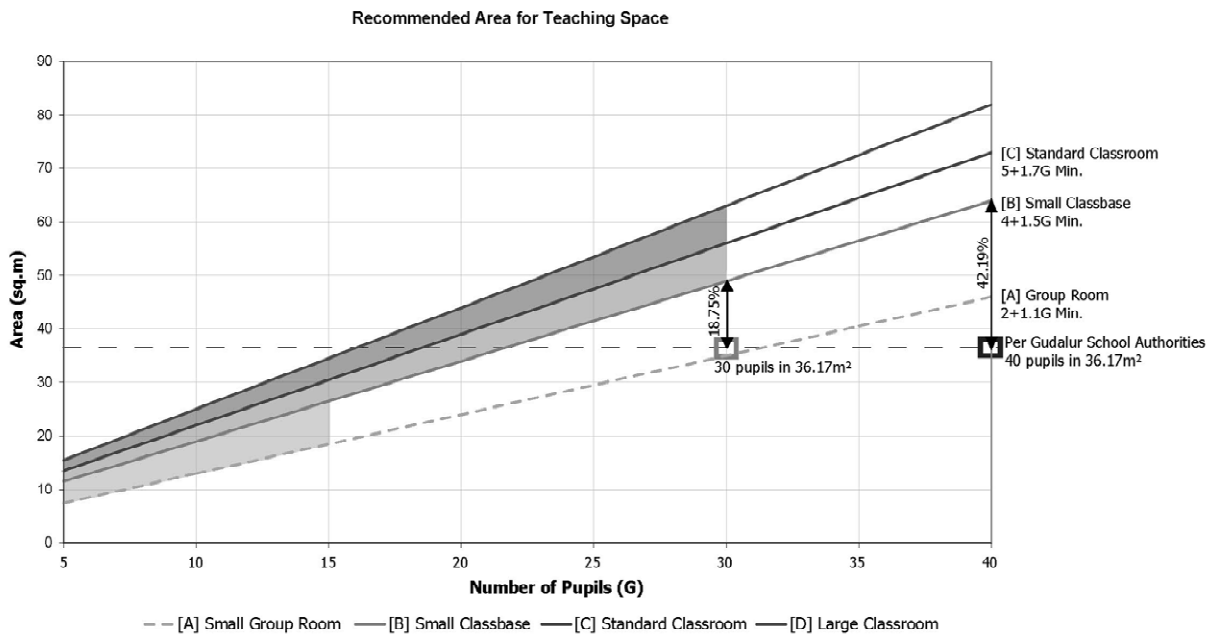Recommended Area for Teaching Space

Fig 4. Min. classroom size recommendations as per BB99 and comparisons with local Gudalur building requirements (Source; after BB99, 2005)

the study.

BB99 recommends that in a classroom the maximum number of pupils should be limited to not more than 30. This already puts the number of pupils in St. Anthony's 33% more than the BB99 recommendation. BB99 provides formulae to calculate the minimum recommended space requirements for each classroom type (Fig.05). For a class base, which is most 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 Gudular's authorities with the BB99 recommendations, it immediately becomes evident that the 10ft² per pupil space is much below (42.2%) the minimum required by BB99 (Fig.05). If we maintain the size of the classroom at 400ft², and reduce the number of pupils to 30, the ratio is still about 19% lower than that recommended by BB99.

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

5. 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. Provided the internal air temperature is higher than the external air temperature, the external air will work as an environmental heat sink (Yannas, 1994). This in turn will require larger inlets for ventilation. To understand the impact of increased number of pupils in a given classroom space, three steps of calculations are done in this study. Firstly, the internal heat gains for metabolic rates, then the required air change for heat dissipation and finally the required opening size for different volumes of air changes. The opening sizes are calculated for two ventilation strategies, single sided wind driven ventilation and cross-flow wind driven ventilation.

The first step is to calculate increased internal heat-gains due to the increased number of pupils. Thermal Comfort Tool (from IDEA) lists the metabolic rate of a person seated and at rest to be 58W/m² and for a person standing and at rest is 70W/m². Using these numbers and the average multiple factors for adults and children we can calculate the following;

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

Opening Size Calculations for **Heat Removal** using equation where; U = 0.83m/s & ΔT = 4ºC Room Size used for calculations is 18'(W) x 22'(L) x 12'(H) with Vr = 4752ft³ (134.5m³)						
Number of Pupils (G)	**Heat Gains (W/m²)**	**Vach (m³/s)**	**Opening Size for Single Sided Ventilation (m²)**	**Opening Size % of Floor Area (Single Sided)**	**Opening Size for Crossflow Ventilation (m²)**	**Opening Size % of Floor Area (Crossflow)**
30	49.09	0.55	13.27	36.07%	5.73	15.58%
32	52.13	0.59	14.08	38.26%	6.08	16.53%
34	55.18	0.62	14.97	40.70%	6.47	17.59%
36	58.22	0.66	15.78	42.90%	6.82	18.53%
38	61.27	0.69	16.59	45.09%	7.17	19.48%
40	64.31	0.72	17.40	47.28%	7.52	20.43%

Heat Gains for Pupils (children) = 58 x 0.8 = 56W
Heat Gains for Teachers (adults) = 70 x 1.8 = 126W

These values can then be used to calculate the overall heat-gains in the classroom for different number of pupils (Tab.01).

Following the heat-gain calculation, the required air changes are evaluated. For this calculation, a worse case scenario is assumed, where the external temperature is 30˚C and the internal temperature is 34˚C (ΔT = 4˚C). The following equation was used to calculate the volume of air changes required for heat removal.
Vach = QT/0.33*ΔT where;
Vach = Volume of Air Change
QT = Total Gains
ΔT = Change in Temp. (Ti - To)

To compare the opening sizes required to satisfy the needed volume of air for increasing number of pupils, explicit equations are used to calculate these sizes. The average wind speed considered is 0.83m/s which represents the high number of hours in the wind rose for Gudalur for summer months.
For single sided wind driven ventilation, given the ventilation rate (q), which is the same as Vach in m²/s and the wind speed (U in m/s), we can solve for the required window opening using the equation;
A = q/(C x U)
(CIBSE Applications Manual AM10, 2005), where C is a constant value based on the geometry of the opening, the position at which the wind is measured and the flow field around the building. Reported values range from 0.01 to 0.05. For the purpose of this study the value of C is considered 0.05.

For cross-flow ventilation strategy the equation used is;
A = q/(Cd x U x √(ΔCp/2)) where;
Cd = Discharge Coefficient which is typically 0.6 (CIBSE, 2005)
ΔCp = Difference in Pressure Coefficient (Cp1 - Cp2)

For this study, a conservative value of ΔCp is assumed to be 0.3. With higher pressure coefficient difference the cross-flow 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.

Further CFD studies were done using the *Star Design* tool to streamline the design for enhanced ventilation (Fig. 06). Daylighting analysis is performed using *Ecotect* and *Radiance* software to evaluate illumination levels in both classrooms with changing opening sizes.
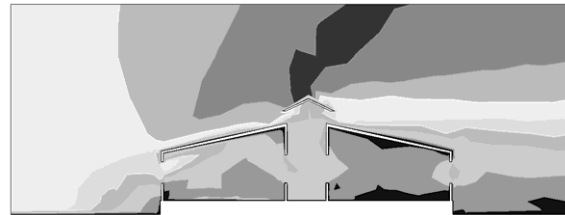

Fig 6. CFD analysis of classrooms

The results show that daylighting takes precedence over ventilation requirement in the classroom. Around 20% opening of the floor area is sufficient to provide ventilation for heat removal for 40 pupils but 30% openings must be provided to achieve an acceptable level of 500-600 lux of illumination. Where as larger openings might become a heat-loss issue in colder climates such as that of the UK, it is not the case in Gudalur and hence is a possibility.
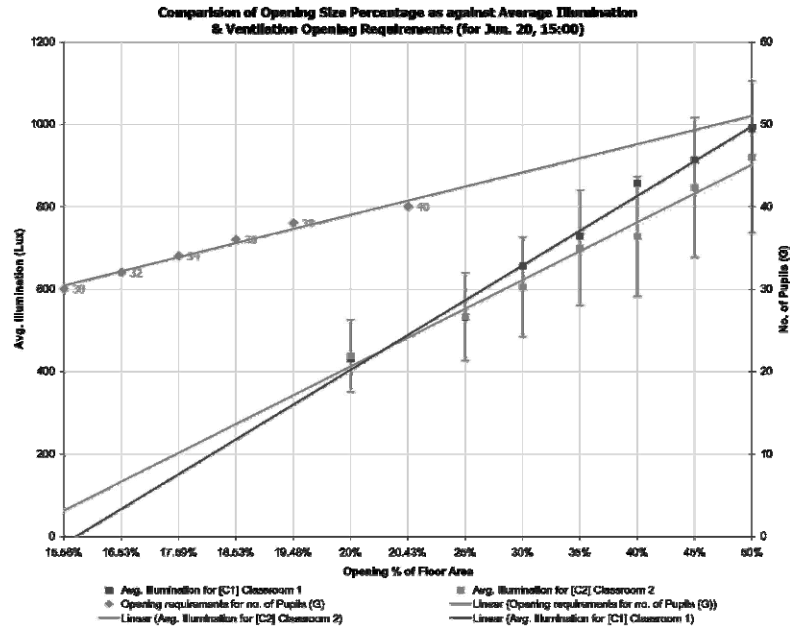
Fig 7. Comparing opening size percentage as against average illumination (for Jun. 20. 15:00) and ventilation requirements for varying number of pupils

6. Summary

When considerable thought is given to environmental issues from day one of the design process, the architecture will almost naturally respond to its conditions and needs. A classroom design for St. Anthony's school is a small task compared to some larger and more complex projects and hence it was feasible to meet its indoor environmental conditions without active systems. If a similar approach is taken on more complex projects, the architecture can become more efficient and thus reducing, if not eliminating, the active mechanical systems. The architectural design itself doesn't need to be compromised. In the case of St. Anthony's school, the building design is inspired by a tree structure (Fig. 08), but employs all environmental strategies tested earlier.
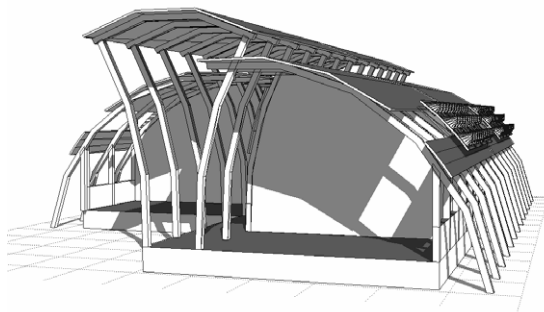

Fig 8. St. Anthony's Design inspired by a tree structure

7. Acknowledgement

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