SUSTAINABLE BY PASSIVE ARCHITECTURE, USING COURTYARDS IN NON-DOMESTIC BUILDINGS IN SOUTHEAST QUEENSLAND

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Summary

The paper presents results of a research arising from "Energy – Building" relationship in terms of sustainable development. The research emphasizes why and how energy conservation in building operation is achieved through "Passive Systems" using architectural design. The paper argues that passive design can minimize the use of active systems for indoor climate control and therefore contribute to mitigating greenhouse gas emission and addressing Global Warming. A courtyard building in this respect presents a greater flexibility in promoting larger areas of internal passive zones in buildings and therefore passive architecture. The research explores the potential of courtyards for passive climate control in non-domestic buildings in Queensland, Australia and proposes a theoretical design model.

1. Energy use in non-domestic buildings in Australia

Non-domestic buildings constitute a vital part of the Australian society and economy. Environmental performance of these buildings, as a consequence of energy use in the manufacturing of materials, construction, operation or demolition, has many varied impacts on the environment. For example, in 1990 greenhouse gas emission attributable to the operation of non-domestic buildings represented 8.5 per cent of Australia's total emission for that year. These emissions are growing at an annual rate of 5 per cent. A study found that the non-domestic buildings sector is expected to increase its greenhouse gas emissions to nearly twofold from 32Mt of CO_2 per annum to 63 Mt between the years of 1990 and 2010 under the business as usual scenario (AGO, 1990). Australian Greenhouse Office (AGO) reports (1999) that the use of electricity is responsible for 89% of non-domestic buildings' greenhouse gas emissions. Hence, there is a need for an alternative approach to the way the buildings are designed to improve environmental performance of non-domestic buildings and thus minimize the electricity consumption in these buildings in the efforts to minimize the greenhouse gas emissions.

1.1 Environmentally Sustainable design

The need to minimize operational energy in the running of active systems has focused attention on two sets of factors, the demand side and supply side efficiency. Supply side efficiency comes from the elements of the building that drive the need for power in the building whilst the demand side efficiency is related to elements that use power. The first important way to save energy is to use less of it, so the first goal is to cut demand, and second goal is to supply power in a manner that is benign, using renewable energy sources (solar power, hydro power, wind power and etc) (Hyde, 2000:68).

Environmentally sustainable design incorporates supply side and demand side efficiencies through low-energy technologies and passive design strategies in building. In particular, the use of passive design strategies aims at minimizing operational energy demand in buildings and therefore optimizing demand side efficiency whilst the use of low-energy technologies aims at optimizing the increased use of renewable energies in the energy supply, thus reducing the circumstances for enhanced greenhouse gas emissions and resource depletion.

2. Passive systems

Passive systems are basic directions or techniques, in which buildings make use of natural/ambient energy in the environment and its free running capability to control indoor climates of buildings for thermal comfort. The natural energy sources such as passive solar, ventilation and daylight are considered as high-grade energy sources. High-grade energy can be easily converted into useful work without conversion and waste (Greenland. J, 1991:10/2) and consequently the use of passive climate control can reduce energy use in building operation and greenhouse gas emissions. Also, significant emissions can be achieved through better design. This is viewed as a major potential yet to be exploited in the design of many larger buildings in Australia (Hyde, 2000:63). Such strategies can be integrated within the building context as well as the building form and fabric (Hyde, 2000:55).

2.1 Passive strategies

Olgyay's bio climatic chart in Figure 1 presents the basic passive strategies for indoor climate control in moderate climate of southeast Queensland. According to the chart, the comfort zone can be extended within the given outdoor temperature ranges by using the effects of following passive strategies; a), airflow b), thermal mass effect c), passive solar effect.

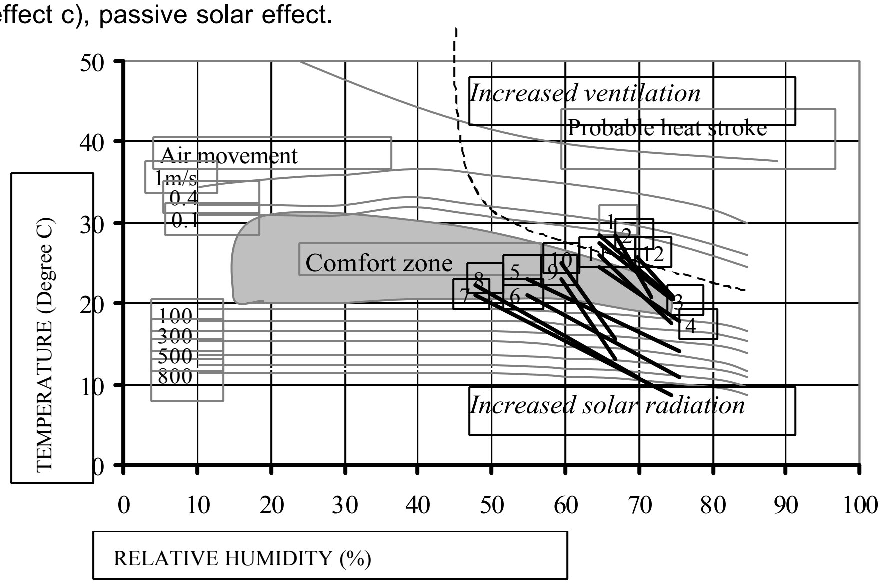

Figure 1 Olgyays's Bioclimatic chart applied to moderate climate of southeast Queensland, Australia

2.1.1 Airflow effect

To extend the comfort zone for higher humidity and higher temperatures higher airflow velocities are required. A closer look at the ambient climatic conditions in a typical summer day in this climate reveals that daytime dry bulb temperature remains around or above 33 degrees C. This is extensive given the daytime humidity around 70 percent.

Aynsley (1997) proposes higher air velocities to compensate for higher dry bulb temperature and humidity levels. However, Szokolay's (1986:14) concern about the potential convective heat input into the body at dry bulb temperatures higher than the normal skin temperature (33 degrees C) suggests that increased velocity will give an increased temperature sensation. Therefore, applicability of higher air velocities for comfort ventilation is limited to the satisfaction of maximum dry bulb temperature.

2.1.2 Thermal mass effect

Thermal mass can be useful for prevention of overheating and passive cooling. Utilization of thermal mass in the fabric promotes the modulation of heat gain. It reduces the heat flow reaching the interior and later the stored heat releases back to the external environment during the cool evening hours. The effectiveness of this procedure is significant to the extent that the building is closed during day and night (more applicable in hot and dry climates- see Givoni, 1991:183). In addition, thermal mass can be applicable during summer in southeast Queensland where the night temperature is much lower than the daytime. The large diurnal temperature swings and clear sky conditions during the night allow high thermal mass to act as heat sinks.

2.1.3 Passive solar effect

High solar radiation and clear sky conditions during the winter in southeast Queensland result in an elevation of daytime temperature close to the comfort zone, calculated from Auliciems' expression (1989). Thus, the potential for passive heating does not appear to be adverse but easier to achieve than passive cooling.

2.2 Design variables

Design variables of building design can regulate passive strategies (airflow, thermal mass and passive solar) and thus ventilation and heat transfer between the external building microclimate and building interior. This is possible by manipulating the enclosure and geometry of the building form and thermal properties of the fabric. The optimum form and fabric of a climate responsive building is considered to be,

a). one that promotes comfort ventilation, prevents indoor heat gain and removes or transfers indoor heat into natural heat sinks during summer and
b). one that loses least heat from the interior and accepts solar gain during winter

The enclosure and geometry of the building form can regulate wind forced pressure fields around a building and therefore indoor airflow behaviour. Wind forced ventilation can create heat gain in buildings in warm climates. Therefore, a reduction of the radiant heat in the incoming airflow is of great importance. Reducing radiant heat at the microclimatic level by good shading can reduce the radiant heat and temperature of incoming airflow. Under these conditions, ventilation can enhance comfort and space cooling.

Thermal mass in the building form and fabric affect the process of heat flow and thus the temperatures of both indoor air and internal surfaces. It is an important component in the building design (form and fabric) that dictates the thermal response of the building and assists with means of storing heat. This mechanism is known as the thermal effect and the thermal mass components have two major thermal functions for summer.

a). First, the thermal storage reduces and delays the amount of heat penetration through the envelope, thus reducing the peaks of the indoor air temperature swings and delaying the time that the maximum indoor air temperature occurs.
b). Second, the role of thermal mass can be extended into the night period. When the thermal mass is coupled with night ventilation and effective daytime shading, it can act as a heat sink during the day.

The use of passive solar is an important strategy for passive heating in winter climates. The enclosure and geometry of the form and thermal mass of the fabric can have positive effects on the indoor thermal conditions in the winter. They are,

a). the direct solar gain through the equator facing openings in the building enclosure and geometry
b). the solar heat reflected through the low mass floors (or thermal diaphragms)
c). the heat conducted through the building's non-opaque fabric
d). heat released from the thermal mass contained in the floors, walls and ceilings into the indoor environment at a later time in the evening

These effects are undesirable during the summer months. On the other hand, these effects do not work at their optimum in buildings that are primarily designed for ventilation and passive cooling purpose because winter breeze entering from openings removes indoor heat. This makes optimizing passive solar, thermal mass and airflow effects and the overall thermal performance of the building a more challenging task.

3. Courtyards

Buildings with courtyards have been considered to offer a substantial potential for utilizing passive strategies for indoor thermal comfort. As an open space within a building, a courtyard is a design element in most of the vernacular buildings and was originally used in the Mediterranean, Middle Eastern and Tropical regions. Agreement between building geometry, enclosure, orientation, density of the building context and access to wind flow can carry considerable architectural implications in modifying the microclimate of the courtyards. With the climate variations, this has resulted in subtle regional variations to the courtyard form of building.

The incorporation of a courtyard into a building form offers a microclimatic buffer zone between the outdoor and indoor environments of the building. From the climate design viewpoint, a courtyard building presents a greater flexibility in promoting larger areas of internal passive zones, which can benefit from natural ventilation and daylight.

4. A design model

Taking a fully enclosed square form of courtyard as a base case, a theoretical model was proposed to explore passive strategies and to examine how should this be developed to optimise conditions for non-domestic buildings in moderate climate in southeast Queensland. This has been explained in detail in Rajapaksha, U (2003). This is a highly complex interaction of design variables because their thermal performances are linked to the microclimatic conditions.

4.1 Heat transfer in the courtyard model

The courtyard as a service space can potentially bring environmental benefits if this space and the surrounding servant spaces maintain favourable environmental conditions for thermal comfort. This objective depends on the appropriate control of heat transfer between the following (Figure 2)

- the courtyard and outdoor microclimate
- the courtyard and servant spaces

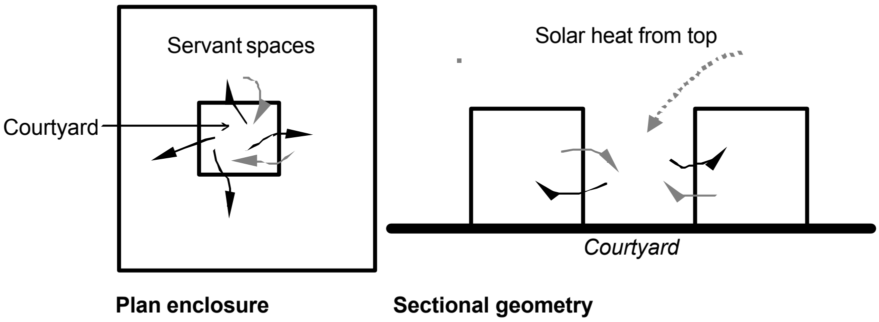

Figure 2 Heat transfer in a typical fully enclosed courtyard building form

The effects of passive strategies - the airflow, thermal mass and passive solar, regulate the heat transfer between the courtyard, its adjacent servant spaces and the outdoor environment. A general guidance of these effects can be found in Rajapaksha. U, (2003). In the tropics, the courtyard can overheat and transmit solar heat to adjacent occupied servant spaces, creating overheating. The avoidance of this problem can be promoted by the airflow effect, shading and thermal mass.

4.2 Airflow effect

Airflow is a primary effect that dictates the thermal environment inside the courtyard. The effects of airflow promote comfort cooling of occupants, structural cooling, controlling of overheating and removal of solar heat out of building interior. Airflow is caused to move through buildings by either wind pressure effect or stack effect, which can be regulated by the following,

a). wind permeability of the geometry
b). wind permeability of the enclosure

A semi enclosed courtyard promotes cross ventilation through the courtyard and attached servant spaces. Wind movement across the building enhances pressure fields around the building, creating high-pressure zones at the openings in the enclosing envelope. Thus, cross ventilation can take place from outside to the courtyard. **Figure 3** explains how the wind permeability of the enclosure promotes up wind airflow.

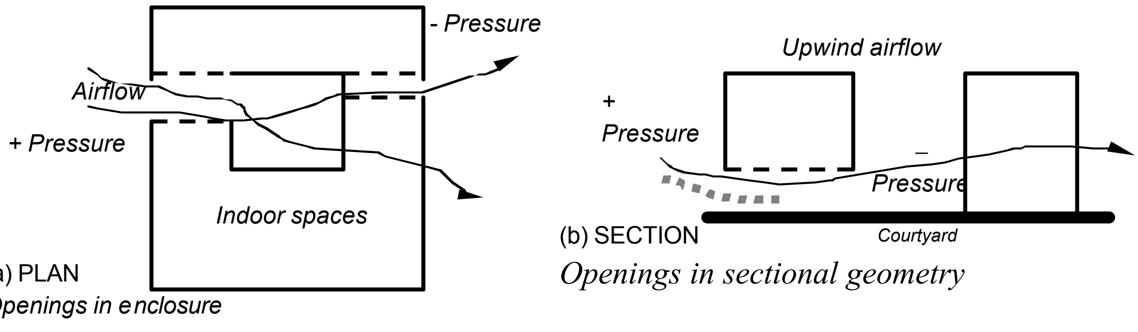

Figure 3 Semi enclosed courtyard as an air funnel, wind permeability of plan enclosure and sectional geometry affect upwind airflow

5. Climate response of courtyards in southeast Queensland

The research involved with this paper made an effort to appreciate the potential of courtyards for passive climate modification particularly with respect to non-domestic buildings in southeast Queensland climate. The overall goals, to which the research is directed, are to discuss the obstacle involved and to provide the means to justify the applicability of courtyards in the Queensland climate. This involves monitoring performance results of a real building in southeast Queensland and analysing the results. The research addresses the main research question in detail. The research questions are,

a). Has the courtyard and its servant spaces of the real building been designed according to the model?
b). How do the design variables of the building influence behaviour of airflow, solar penetration and thermal mass?
c). How do the courtyard and servant spaces perform thermal comfort?

5.1 Methodology

The methodology of this study employed a monitoring of field investigations to examine the interaction of passive strategies and design variables in non-domestic courtyard building. For this purpose, Arts Faculty building (Figure 4), a two-storey courtyard building in the University of the Sunshine Coast was monitored.

Figure 4 Arts Faculty Building in the University of Sunshine Coast, the monitored courtyard building

The research plan was identified as having three phases of thermal measurement collection.

a). In phase 1, measurements were conducted for nine weeks from the 27th July to 06th September 2000, to address modification of air temperatures and in winter.
b). The phase 2 involved taking of measurement for eleven weeks from the18th November 2000 to 5th February 2001 to record modification of air temperatures and humidity in summer. This period aimed to examine the building response to overheating conditions.
c). Phase 3 involved repeating the monitoring of summer performance and taking measurements of surface temperatures of the envelope for six weeks from the 30th January to 15th March 2003.

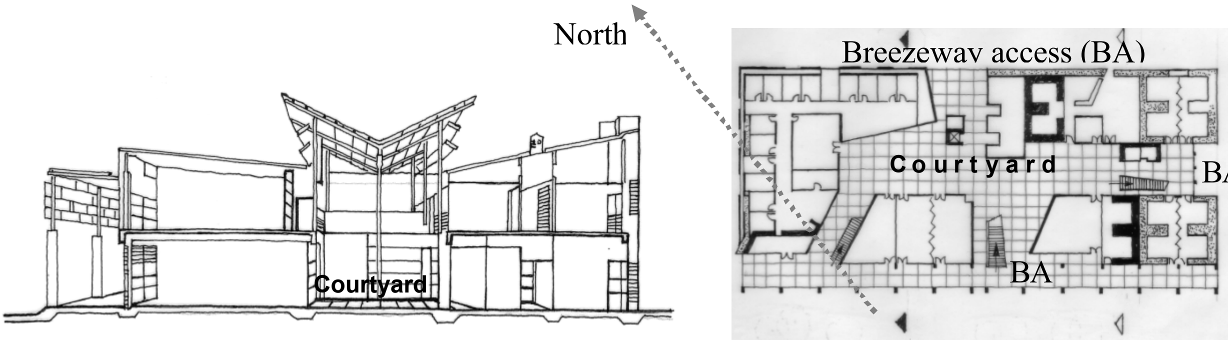

Figure 5 Cross section and plan enclosure of the monitored building showing the central courtyard

Monitoring of thermal performance involved with taking three types of measurements.

a). **Longitudinal and vertical thermal measurements**
Air temperature and relative humidity readings in the courtyard and servant spaces were taken at 30-minute intervals day and night and later averaged for hourly and daily values. Hourly ambient weather data was collected from the Maroochydore Weather Station.

b). **Spot measurements**
Spot measurements were taken for surface radiant temperatures and internal wind velocities of the building during all three phases of monitoring and recorded in the floor and adjoining walls in the courtyard and the wind entry points.

c). **Discussions with designers and users**
These monitoring results and the findings from a user response survey (BVN, 2001) were used to assess thermal comfort of occupants.

5.2 Instrumentation

The monitoring instrumentation consisted of 28 Hobo H8 data loggers, a Kanomax6511 Hot-wire anemometer and a laser guided Optex thermometer. Hobo data loggers were used for measuring and recording air temperature and relative humidity. Each logger had an additional external probe sensor connected with a five-metre long input cable. Both loggers and their external sensors were shielded against solar and reflected radiation from the surrounding surfaces by placing them in a shade. The sensors were fixed with a rubber padding to respective places at a height of about 2m above the floor. A Hot-wire anemometer was used for measuring indoor air velocities. This equipment is highly sensitive to air velocities down to 0.05m/s. Surface and radiant temperatures were measured using the laser guided Optex thermometer which has an accuracy of ± 0.2° C over 0 to 50° C range.

6. Results and analysis

The microclimatic and indoor climatic conditions showed various environmental loads, which can be attributed to the design variables in the master planning and climate variables. The empirical testing aimed to assess the environmental conditions in the following spaces of the building.

- Courtyard
- Adjacent indoor spaces (offices and classrooms)

The monitoring of these two occupied zones was carried out to determine efficiency of the design variables in promoting the effects of passive strategies and whether the design variables are incorporated in the building design according to the proposed model. The design variables are enclosure, geometry and envelope. This assessment was possible by addressing the following issue and questions.

a). With climate performance it is expected that temperature inside these two zones to be at ambient shade temperatures or below ambient in summer and above ambient in winter

b). If perform or not perform according to the above, what aspect of the building design or climate influences the behaviour of airflow effect, thermal mass effect and passive solar effect.

6.1 Courtyard's performance in summer

Monitoring the air temperature behaviour inside this space assessed thermal performance in the courtyard zone. The results showed a variety of temperature behaviours. They are,

a). The average air temperature of the courtyard and adjacent indoor spaces was 1-2.8 degrees C below the level of ambient for eleven days. This is a cooling mode.

b). An increase in the courtyard and adjacent spaces average air temperature by 1-4.6 degrees C above the ambient was seen for nine days. This is an overheated mode.

c). The average air temperatures of the courtyard and adjacent spaces closely followed the ambient temperature levels during the remaining sixty days.

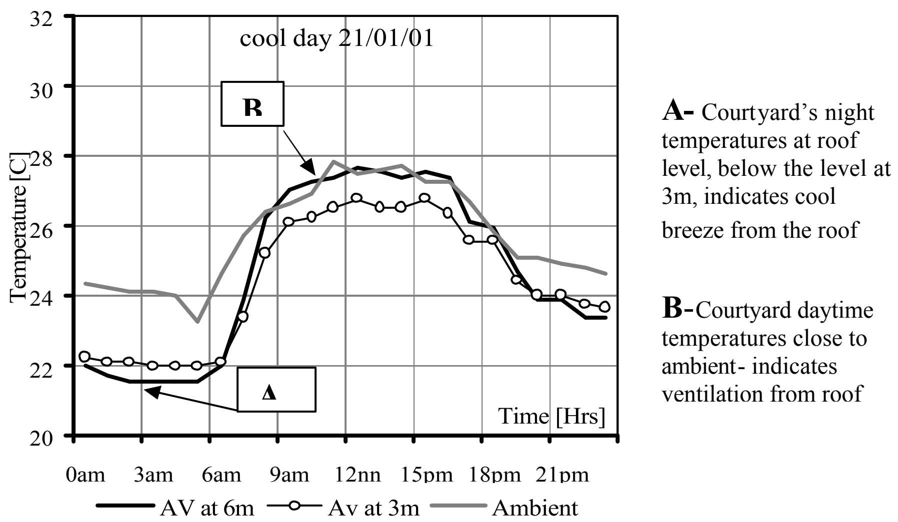

Figure 6 Air temperature behaviour in the courtyard during the days of cooling mode – eg21/01/01

Moreover, the thermal behaviour of high thermal mass in the walls and floors was investigated using surface temperatures. When thermal mass is used in the floors and walls in the courtyard, shading can influence convective heat transfer from air to mass. This imposes the potential of lowering the courtyard temperatures below the ambient levels, if the courtyard is only ventilated through an effective shade.

Table 1 Shade surface temperature in the breezeway access points to the courtyard

Date	**16th Jan. 2001**		**16th Nov. 2000**		**30th Jan. 2003**	
Time	*10.35*	*15.10*	*11.00*	*15.00*	*11.30*	*14.30*
SE access point	26°C	25.5°C	24.5°C	25°C	25°C	25°C
NE access point	30°C	28°C	27°C	26°C	27°C	26°C
SW access point towards W	29°C	32°C	28°C	32°C	28°C	31°C
SW access point towards E	28.5°C	33°C	27°C	32°C	28°C	33°C
Ambient	27.5	28	24.6	25.4	26.8	27.2

Thermal mass (concrete) is used in the ground floor and most of the walls in the monitored building as a heat sink. Thermal mass in the breezeway access points (Figure 5) and external envelope in the building was observed and to some extent quantified for its thermal behaviour (**Table 1**).

The average daytime surface temperatures of the concrete (floor and walls) used in the access points to the building showed different values with different shading conditions across the building. The southeast access point, which has shading most of the daytime, placed its daytime surface temperature around 25° C. Other access points, for example those on the southwest where the direct solar radiation incidence occurs for most part of the afternoon, showed an increase in surface temperature which began to rise by 12 noon and peaked up to around 33° C in the afternoon.

6.2 Airflow in the courtyard and adjacent spaces

Spot measurements taken in the courtyard between 10.30 and 11.00am on the 16/01/01 (when courtyard's average temperature was close to the ambient) indicated different air velocities i.e. higher air velocities (4-5m/s) at the occupied zone with lower velocities (0.3-1.8m/s) at the three-metre level in the courtyard and occupied indoor spaces. The northeast access point was recorded with wind velocities between 1.4- 4m/s when directly facing the prevailing wind at 40 degrees. The access points on the leeward side were also recorded to have wind velocities of 0.3-3.8m/s. The upper floor office rooms were measured with lower velocities (.0.4-0.6m/s) when the louvers were closed but higher velocities (1.6-1.8m/s) when they were open. These results indicate the availability of wind forced ventilation in the building.

6.3 Adjacent indoor spaces in winter

Temperature levels in the rooms facing the northeast moved 4-6 degrees C above the ambient level throughout the day. This is an indication for the potential of passive heating through direct solar gain with the absence of wind. However, direct or reflected solar gain to the room on the southwest was compromised by the built spaces on the northeast.

6.4 Operational energy use

The electrical energy demand expresses the cumulative effects of the cooling and heating of the building interiors. A comparative study of the energy consumption in the operation of the building was calculated and compared with the other buildings on the premises of the monitored building (Figure 7).

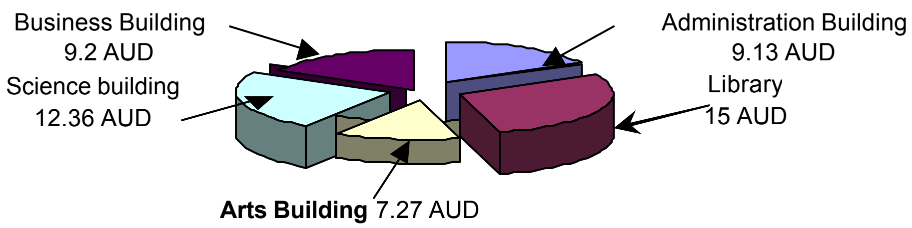

Figure 7 Comparison of the energy bills (AUD/m^2/annum) per annum
The monitored building, the Arts building, has the lowest energy bills.

The energy bills for the period from the 9th February 1999 to the 9th November 1999 were collected and the gross energy cost cumulated over this period. It is acknowledged that this method of assessment is crude and that a more exhaustive absolute method, which can relate the energy consumption to standards giving a Star rating, is warranted. The comparative study shows that the monitored naturally ventilated courtyard building, has the best performance out of the five other buildings on the premises.

7. Future directions

Present study puts forward a strong theoretical and empirical basis to our understanding of thermal performance of essential design variables of courtyard buildings i.e. the building enclosure, geometry and envelope. The degree to which courtyards encourage passive cooling and heating in non-domestic buildings in southeast Queensland climate is linked to passive strategies and design variables of the building design. The prediction of their effectiveness to minimize any compromise between the design intent and usage requires a clear understanding of the complex interaction between the design intent of the strategies, their use in the substance of the building and microclimatic conditions. More study is required to identify a number of complex issues if energy efficiency is to be achieved, particularly,

a). Need for more research into the relationship to master planning and environmental principles as these were compromised in this study

b). Importance of consideration of microclimatic control synergies needed between microclimate, form and fabric of the building

The research findings constitute a useful design support and deliberations, which can easily be integrated into the current practice. However, the lack of practice examples makes it more difficult to study the thermal behaviours of potential construction techniques used in the design. Therefore, the need for more practice examples is of great importance. Further directions are required for the future energy consumption and day lighting studies using more critical design phase assessments to ensure meeting the broader objectives of environmentally sustainable design. Future research and practice should explore these concepts and define the required mechanisms.

8. References

Auliciems, A. 1989 *Thermal comfort*, (In) Building design and human performance, (ed). Ruck, N. C, New York: Van Nostrand Reinhold, pp 3-27

Australian Greenhouse Office (AGO), 1999 Australian commercial building sector: Greenhouse gas emissions 1990-2010, Executive Summary Report, Canberra

Aynsley, R. M. 1997 *Tropical architecture: the future* Proceeding of the ANZAScA conference, Australia, pp.167-75

Bligh Voller Nield (BVN). 2001 Environmental performance evaluation Case Study 01-Faculty of Arts building, (ed) Cater. S., and Rowe, D, Interim Report

Givoni, B. 1991 "Performance and applicability of passive and low-energy cooling systems" *Energy and Buildings* Vol.17, Elsevier Sequoia, pp. 177-99

Hyde, R. 2000 Climate responsive design: a study of buildings in moderate and hot humid climates, London: E and FN Spon

Rajapaksha, U. 2003 An exploration of courtyards for passive climate control in non-domestic building in moderate climates, unpublished PhD thesis, Department of Architecture, The University of Queensland, Australia

Szokolay, S.V. 1986 Passive and low energy design for thermal and visual comfort, Proceedings of PLEA conference, Hungary

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