The Applicability of the Bio-Climatic Facade in a Hot and Humid Climate

A Study of Geoffrey Bawa's Architectural Works

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ABSTRACT: Achieving desirable comfort conditions in a place where the climate is hot and humid can be challenging. This paper investigates the environmental performance of a number of buildings by Geoffrey Bawa. The first part of the paper reviews Bawa's architectural works in a chronological order and studies his approach to facade design for controlling internal comfort conditions., The second part of the paper investigates the environmental performance of the 'Monsoon Window' and explores its potential wider application in the hot and humid climate zone. The limitation of the original 'Monsoon Window' was identified through simulation with parametric variations. The findings show that selective use of a well designed 'Monsoon Window' can enhance the indoor environment and substantially reduce the reliance on air conditioning in office buildings.

Keywords: Bio-climatic facade, Hot and Humid region, Monsoon Window, Natural Ventilation

INTRODUCTION

Before sustainable architecture became an important issue, even before the energy crisis of the 1970s or the vogue for critical regionalism in architecture for the Asian context, Geoffrey Bawa (1919-2003) was developing a design approach which embraced these concepts. He learnt from and applied traditional techniques in his work, which were under-valued qualities in the discussion about architecture in the tropical Asian context. Banham suggested that the humid and tropical climate requires a 'Selective' approach to environmental design, employing structure not just to maintain desirable environmental conditions, but to admit desirable conditions from outside [1]. The distinction between 'selective' and 'exclusive' modes has also been discussed by Hawkes [2]. A similar approach was adopted in Bawa's design work, from low-rise residential buildings, such as Carmen Gunasekera House (1958), to high-rise non-domestic buildings, such as the State Mortgage Bank (1978).

In this study, five buildings have been selected to reveal the designer's exploration of bioclimatic architecture under his own 'Selective' mode.

THE BIOCLIMATIC FACADE

A study of Bawa's works reveals that even though they were functionally different, there was a common theme in the architectural language by which these buildings achieved their bioclimatic purposes. The five cases shown in this study were the most representative of this idea in Bawa's work.

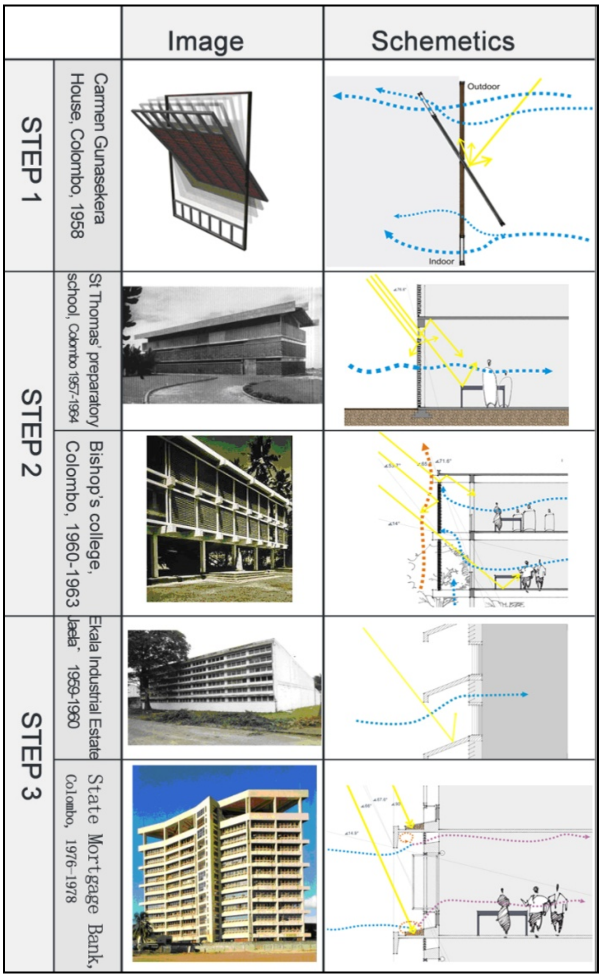


Figure 1: The evolution of Bawa's bioclimatic facade.

According to the typology of each case, they evolved in three stages representing the development of his 'Breathing Wall' concept (Fig 1).

Bawa appreciated the role of the breathing wall as an environmental filter: 'avoiding direct solar penetration, admitting currents for air and indirect light, excluding heavy rain and beating wind, allowing visual and spatial contact between inside and outside, excluding unwanted noise and providing security from intruder' [3]. This interpretation of the development of the 'Breathing Wall' concept in Bawa's works is the author's view. This evolution occurred by trial and error, and at the time did not have the benefit of evidence-based analysis. The question therefore remains of 'How well did it work?' The air-flow study described below, which focuses on the facade of the State Mortgage Building, investigated the environmental performance of this unique design and explored its potential wider application for the building in the hot and humid climate zone.

THE STATE MORTGAGE BANK

The State Mortgage Building still can be regarded as a good example of a 'sustainable' building by today's standard because it meets most of the critical parameters for a 'low carbon' office for this climate [4]. This section investigates the 'Selective' mode, implemented by applying the 'Monsoon Window' facade as a response to site and microclimate.

Climate of Colombo

The psychrometric chart for Colombo, Sri Lanka (Fig 2) with an adaptive comfort zone overlay shows a very small diurnal and seasonal temperature range. There is 93% of the year that the dry-bulb temperature varies from 24°C to 38°C, and the majority of the time is outside the comfort zone.

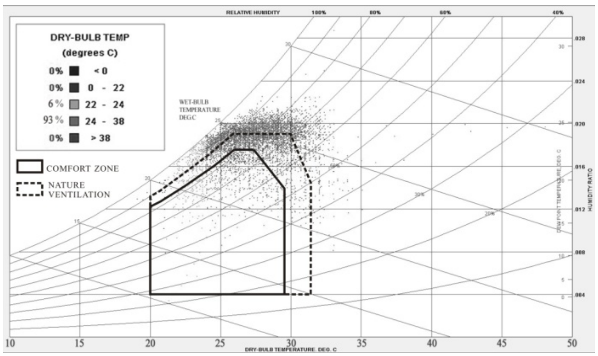


Figure 2: Psychrometric chart showing boundary of natural ventilation as a cooling approach for Colombo, Sri Lanka (Source: Climate Consultant 4)

By following Givoni's boundaries definition [5] of climatic conditions with respect to the impact on indoor thermal comfort from natural ventilation, for the majority of the year, natural ventilation could be adopted to provide comfortable internal conditions.

Design Principles

Ken Yeang has suggested: '[The State Mortgage Bank] is probably the best example of a bioclimatically responsive tall building to be found anywhere in the world' [6]. On an irregular shaped site, Bawa firstly created a building that can harness the prevailing wind because of its orientation and form (Fig 3), although this also makes it vulnerable to solar gain. Secondly, the big open working area with service cores on the perimeter of the building ensured good daylight and cross ventilation. Lastly, the terrace roof and the stilt structure of the ground floor acted as buffer spaces to the building mass. In detail, the building envelope was mainly covered by the 'Monsoon Window' facade: A clearstory protected by an overhang above, a central pivot window in the middle and a retracted window sill with a horizontal air intake below. The ventilation slot on the window sill is the key element of this façade, allowing unimpeded airflow into the building regardless of the operation of the window pane. This type of façade provides the air changes required on rainy days when the windows have to be closed.

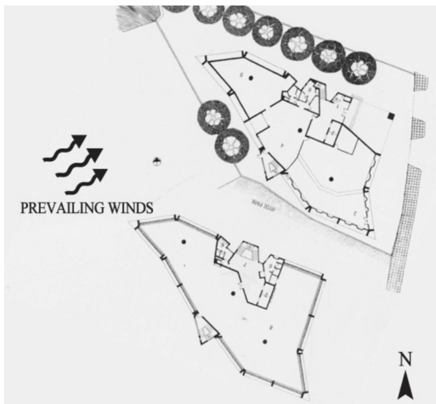


Figure 3: Site plan and floor plan with prevailing wind

The design of the vent opening achieved not only the path for airflow during rainy days, but also revealed its status (open or closed) to the occupants. This may be compared with an example from CIBSE AM10 [7] showing a concealed damper in the site-built enclosure beneath the louvers of sills of French windows. It presents a similar air vent path to the monsoon window, but with a negative outcome, as it resulted in heat loss in winter due to its unclear indication of control status. The monsoon window, by contrast, set the opening in the height of the windowsill revealing a visible operational status, which was more evident to occupants (Fig 4). Furthermore, the detailed design of the 'monsoon window' facade was very carefully considered with regard to its function. For instance, the central pivot window was easy to operate and maintain; the overhung eave with vertical baffle provided shading, and the sloping upper surface and the gutter help to drain off rainwater. The fenced high vents and monsoon windows also guaranteed the feasibility of night-time ventilation without risk to security.

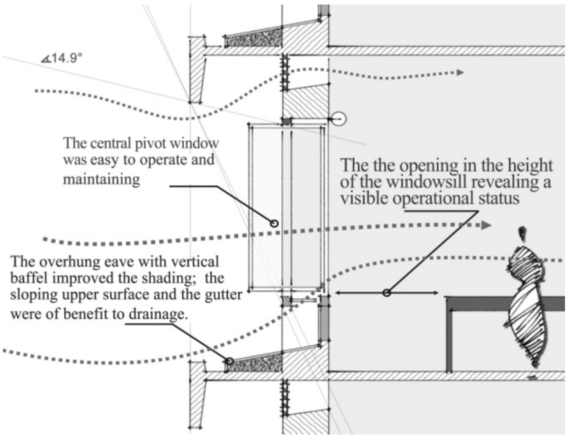


Figure 4: The 'Monsoon Window' facade.

MONSOON WINDOW

In order to underline the importance of experiencing a building, Bawa once said: 'A building can only be understood by moving around and through it…' [8] Unfortunately, the original design of the State Mortgage Bank was altered due to the change of the ownership for several times, hence the original design was lost and the computer simulation was required to evaluate performance. There have been many studies based on computer and physical model testing for State Mortgage Building. Robson and Tan reported on a holistic environmental review of this building [4] and Tan et al finished a convincing study dealing with the ventilation performance of the monsoon window [9]. In this paper, the thermal performance of the 'monsoon window' facade has been studied, to provide a further assessment of this type of facade design. The simulation tool adopted here is TAS [10].

Model Setup

The model was restricted to a 'shoe-box' form to minimise the influences of other variables such as the irregular shape of the building or the position of service cores. The basic dimensions of this model were 14.4m deep, 3.6m high and 45m wide, which followed certain environmental principles to guarantee that the internal space can be lit and ventilated naturally. The model faced the prevailing wind direction of Colombo as for the State Mortgage Bank building (south-west). The terrace roof and stilt structure were also represented; additionally, the two main facades of this linear model were equipped with the 'Monsoon Window' façade which complies with the original details including 1.2m overhangs, high vents, windows and monsoon window slots.

Test Cases

In order to characterise the thermal performance of the building reflected in this model, three office spaces on different level were selected (Fig 6). The locations are:

A. The first floor (from 3.6m)
B. The fourth floor (from 14.4m)
C. The seventh floor (from 25.2m)

Four scenarios for simulation

To understand how the facade design performs, the efficacy of each element on this facade needed to be defined. Four conditions were tested and they are:

1. All windows are open.
2. Only high vents are open, main windows and monsoon windows are closed.
3. Only monsoon windows are open, main windows and high vents are closed.
4. monsoon windows and high vents are open, main windows are closed (Fig 5)

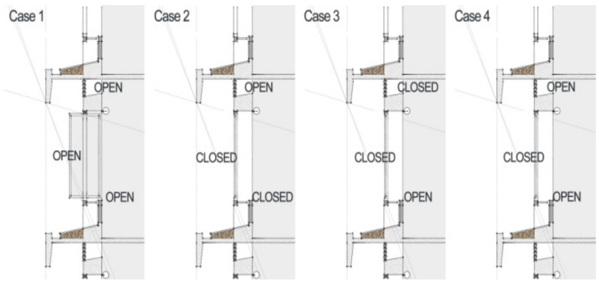


Figure 5: The test scenarios of 'Monsoon Window' facade

Result

The model tested four scenarios using TAS software. The thermal performance in May (the hottest month) is selected here for the following interpretation.

- Comparative analysis of the scenarios

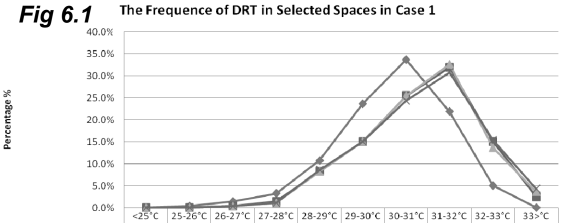
With the simulation from TAS, the thermal performance of three selected spaces in four conditions, with same internal heat gain, are represented. The results for May indicate:

1. Scenario 1 showed internal temperatures only 1-2 degrees above the external temperatures, and only 20% of the time were they above 32°C. Compared with the other scenarios, this scenario provides the best results, since it possessed the biggest opening areas for ventilation (Fig 6.1).
2. In the cases where only high vents or monsoon windows are open respectively, the issue of overheating appeared due to the limited

opening area for removing internal heat gains. Internal temperatures were above 33°C for more than 35-45% of the time (Fig 6.2 and Fig 6.3).

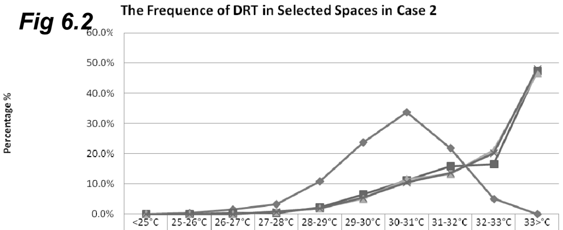
3. By opening high vents and monsoon windows, the thermal performance revealed the second-best outcome which decreased the overheating problem remarkably and 60% of the time was under 32°C (Fig 6.4).
4. In each scenario, the space on the higher level showed slightly better thermal performance.

Fig 6.1 **The Frequence of DRT in Selected Spaces in Case 1**



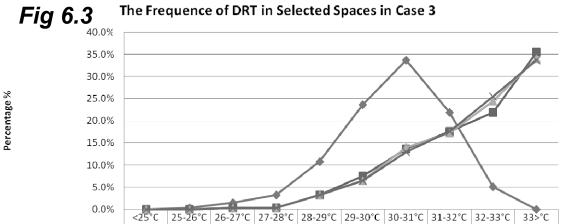
	<25°C	25-26°C	26-27°C	27-28°C	28-29°C	29-30°C	30-31°C	31-32°C	32-33°C	33>°C
External Temp (° C)	0.0%	0.4%	1.4%	3.2%	10.8%	23.7%	33.7%	21.9%	5.0%	0.0%
1st Floor (° C)	0.0%	0.0%	0.4%	1.4%	8.2%	15.1%	25.4%	31.9%	15.1%	2.5%
4th Floor (° C)	0.0%	0.0%	0.4%	1.1%	8.2%	15.1%	25.4%	32.6%	13.6%	3.6%
7th Floor (° C)	0.0%	0.0%	0.4%	1.1%	8.6%	15.1%	24.4%	30.8%	15.4%	4.3%

Fig 6.2 **The Frequence of DRT in Selected Spaces in Case 2**



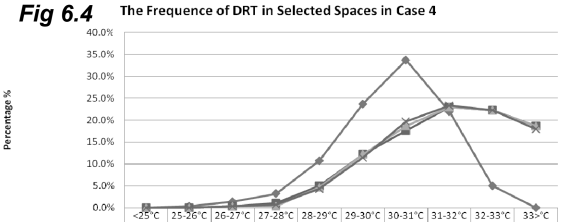
	<25°C	25-26°C	26-27°C	27-28°C	28-29°C	29-30°C	30-31°C	31-32°C	32-33°C	33>°C
External Temp (° C)	0.0%	0.4%	1.4%	3.2%	10.8%	23.7%	33.7%	21.9%	5.0%	0.0%
1st Floor (° C)	0.0%	0.0%	0.4%	0.4%	2.2%	6.5%	11.1%	15.8%	16.5%	47.3%
4th Floor (° C)	0.0%	0.0%	0.0%	0.7%	1.8%	5.0%	11.5%	13.3%	21.1%	46.6%
7th Floor (° C)	0.0%	0.0%	0.0%	0.7%	1.8%	5.4%	10.4%	13.6%	20.1%	48.0%

Fig 6.3 **The Frequence of DRT in Selected Spaces in Case 3**



	<25°C	25-26°C	26-27°C	27-28°C	28-29°C	29-30°C	30-31°C	31-32°C	32-33°C	33>°C
External Temp (° C)	0.0%	0.4%	1.4%	3.2%	10.8%	23.7%	33.7%	21.9%	5.0%	0.0%
1st Floor (° C)	0.0%	0.0%	0.4%	0.4%	3.2%	7.5%	13.6%	17.6%	21.9%	35.5%
4th Floor (° C)	0.0%	0.0%	0.4%	0.4%	3.2%	6.5%	14.0%	17.2%	24.4%	34.1%
7th Floor (° C)	0.0%	0.0%	0.4%	0.4%	3.2%	6.5%	12.9%	17.6%	25.4%	33.7%

Fig 6.4 **The Frequence of DRT in Selected Spaces in Case 4**

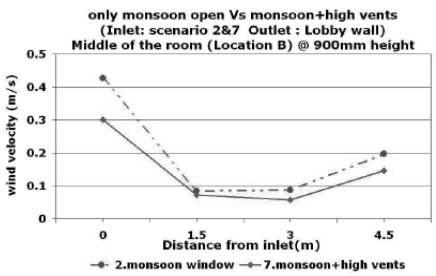


	<25°C	25-26°C	26-27°C	27-28°C	28-29°C	29-30°C	30-31°C	31-32°C	32-33°C	33>°C
External Temp (° C)	0.0%	0.4%	1.4%	3.2%	10.8%	23.7%	33.7%	21.9%	5.0%	0.0%
1st Floor (° C)	0.0%	0.0%	0.4%	1.1%	5.0%	12.2%	17.6%	22.9%	22.2%	18.6%
4th Floor (° C)	0.0%	0.0%	0.4%	0.4%	4.7%	12.2%	18.6%	22.9%	22.2%	18.6%
7th Floor (° C)	0.0%	0.0%	0.4%	0.7%	4.3%	11.5%	19.7%	23.3%	22.2%	17.9%

Figure 6: The frequency of dry-bulb temperature in May of the selected spaces in different cases.

- Comparative analysis with literature

Compared to the study from Tan et al, the results of this study largely support their findings regarding the ventilation effect of the 'Monsoon Window' facade. The outcomes showed that the main window is the primary source of ventilation and the high vent or monsoon windows was unable to supply thermal comfort individually. However, there was a difference between the two studies. Fig 7 showed that, in Tan's et al study, by only opening the monsoon window, the wind velocity in the tested space is better than the case that the high vents and the monsoon windows were both open, which was described by Tan et al as a type of 'dilution' [9]. It contradicted Fig 6.4 in which the related thermal result was the best after scenario 1. The reason for such difference is potentially derived from the different configuration of the model tested in the two studies. As can be seen from the acrylic model in the study by Tan et al, in order to get the explicit results, the 'Monsoon Window' facade had only been equipped on the windward side whereas the leeward side was a wall with high-level slots representing a separate office. However, in Bawa's original design, it was an open working area with similar facade design on the perimeter. The study by Tan et al represented the high vents on the leeward side (which played the role of the outlet enhanced by buoyancy effect) but there were more advantages embedded in the original design: Firstly, the coupled facade design also showed an advanced air flow mode when the windward and leeward had switched. Secondly, the reason that high vents had been valued by Bawa in his design was because the opening on the higher level could help the upper structure to remove heat, which was very useful for the roof structure of low-rise buildings and also high-rise buildings with internal floors (Fig 8). These two reasons may explain why having high vents opened when the monsoon window was operating is important thermally. This is supported by the outcome shown in Fig6.4.



Scenario/ Distance	0	1.5	3	4.5
2. monsoon alone	0.427	0.085	0.087	0.197
7. monsoon +high vents	0.301	0.073	0.057	0.146

Figure 7: Result from study by Tan et al (Source: [9])

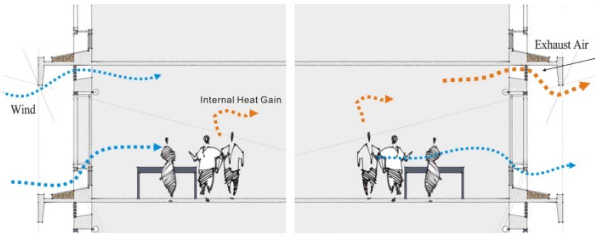


Figure 8: The schematic diagram showing the potential air-flow between the coupled 'monsoon window' facades.

Variation of Materials

The daylight simulation of Tan and Robson's study [4] showed that, in State Mortgage Bank building, the overhangs with down-stand fascias prevented the direct solar intrusion most months of the year. On the other hand, it also implied that the overhung structure also provided a thermal bridge for the majority of the year. Fig 9 illustrates diagrammatically how the overhung structure, may collect heat from solar radiation, and increase the internal heat gain through a combination of conduction and convection.

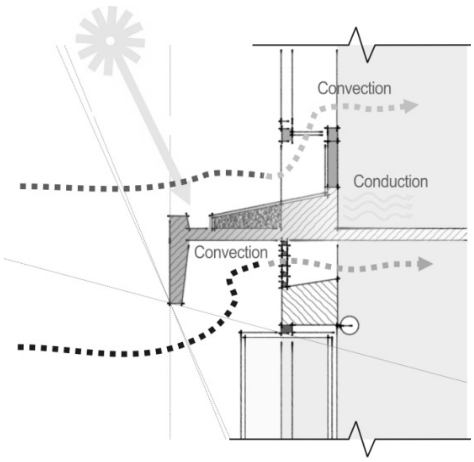


Figure 9: Potential thermal bridge of overhang.

In order to test this hypothesis, the following study explored whether the thermal performance would be changed by switching different materials of the overhangs. In this test, only high vents and monsoon windows were open for amplifying the air flow path beside the overhangs. There are three scenarios mentioned for the test and they are (Fig 10):

Case A: The original structure (concrete, 200mm thick)

Case B: The variant structure made by timber (90mm)

Case C: The variant structure made by steel (6mm)

The model tested in three scenarios was simulated in TAS. The climatic condition of the test date was defined so that the overhangs on the windward side could receive direct sunshine. Accordingly, the 3rd April was selected to provide these conditions.

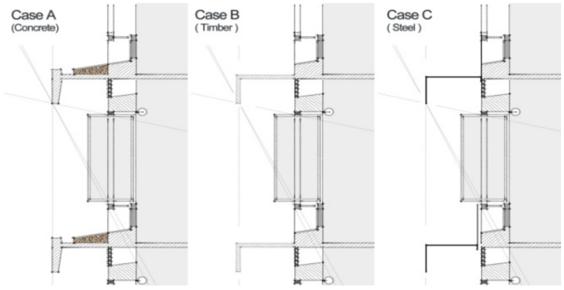
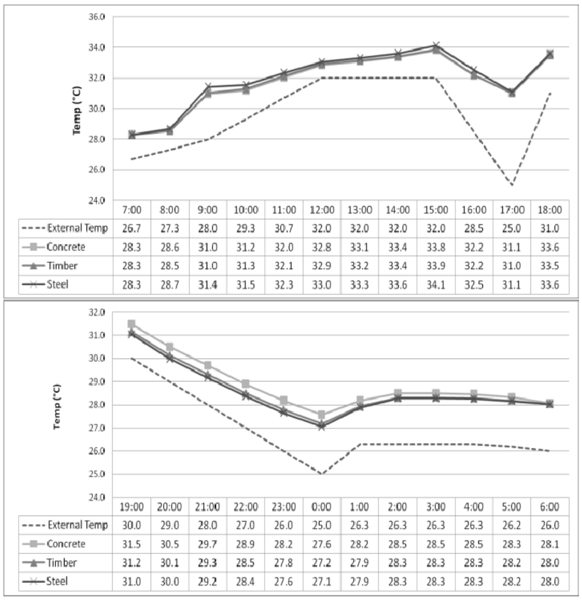


Figure 10: Three types of overhung eaves.

- Result of thermal bridge test

Comparative results for the air temperature of the office space on the 4th floor with different overhung structures are shown in Fig 11.



	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
External Temp	26.7	27.3	28.0	29.3	30.7	32.0	32.0	32.0	32.0	28.5	25.0	31.0
Concrete	28.3	28.6	31.0	31.2	32.0	32.8	33.1	33.4	33.8	32.2	31.1	33.6
Timber	28.3	28.5	31.0	31.3	32.1	32.9	33.2	33.4	33.9	32.2	31.0	33.5
Steel	28.3	28.7	31.4	31.5	32.3	33.0	33.3	33.6	34.1	32.5	31.1	33.6

	19:00	20:00	21:00	22:00	23:00	0:00	1:00	2:00	3:00	4:00	5:00	6:00
External Temp	30.0	29.0	28.0	27.0	26.0	25.0	26.3	26.3	26.3	26.3	26.2	26.0
Concrete	31.5	30.5	29.7	28.9	28.2	27.6	28.2	28.5	28.5	28.5	28.3	28.1
Timber	31.2	30.1	29.3	28.5	27.8	27.2	27.9	28.3	28.3	28.3	28.2	28.0
Steel	31.0	30.0	29.2	28.4	27.6	27.1	27.9	28.3	28.3	28.3	28.2	28.0

Figure 11: the hourly dry-bulb temperature in three cases (concrete case, timber case and steel case). Daytime (above) and Night time (below)

This suggests that there is little difference in the thermal performance of the tested space when different materials are used for the overhangs. By only opening the high vents and monsoon windows on 3rd April, the office space is warmer than the outside during the daytime. When comparing the difference between these cases, it was clear that the internal temperature of the case applying steel overhangs was slightly higher than concrete cases in the daytime by about 0.3°C. In the case of the timber shade, the office space was also warmer than the original case by 0.1°C. However, after sunset, the condition was reversed. The temperature difference during the night for the concrete case became nearly 0.5°C higher compared with the other two cases. The shading structure which was made of steel or timber reacts to solar radiation more quickly than the concrete structure in the day time. At night, the heavyweight concrete structure gave the heat back to the interior when the surroundings became cooler. On the premise of applying 'monsoon window' facade, it would be more beneficial for non-domestic buildings to use the overhang built from materials with high thermal mass, which guarantees a slower heat transmission in the daytime balanced by a thermal recovery at night. In contrast, using more lightweight material in residential buildings can help the indoor to stay cooler at night when only high vents and monsoon window are open for nocturnal ventilation.

CONCLUSION

Geoffrey Bawa's facade design could be viewed as an architectural solution successfully responding to the tropical climate, and reflecting the Asian culture. The concept of a 'Breathing Wall' contained in his work has wider potential applicability. The integrated design which deals with both daylight and ventilation is the key theme of the facade design for the hot and humid climate zones representing the 'Selective' approach to internal environmental control.

The test results in this paper indicate that evidence-based design can be used retrospectively to confirm the positive benefits of a bio-climatic design approach. In the case of the State Mortgage Bank, the efficacy of the main centre pivot windows on ventilation is more significant than other openings due to its greater operable area. This implies that the size of the alternative apertures, namely the high vents and the monsoon window need to be enlarged if a better outcome is required. Secondly, the selection of material is also important because of the impact on thermal performance, which should be considered with the building type due to the occupied period. Finally, the facade should be seen as a part of the whole building, rather than merely a perimeter layer when considering the environmental performance of a space, since the building envelope and the internal space work together holistically, they cannot be considered in isolation.

Further work could be done to find the parametric validity of each element of the breathing wall and to improve the facade design. This will increase the possibility of applying bioclimatic facades in today's building design, and reduce over-reliance on air conditioning in hot and humid climates.

ACKNOWLEDGEMENTS

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REFERENCES

1. Banham,R., (1984). Architecture of the Well-Tempered Environment. 2nd ed. Chicago: University of Chicago Press. p 23.
2. Hawkes,D. (1996). The theoretical basis of comfort in 'selective' environments. In: Hawkes,D The Environmental Tradition: Studies in the architecture of environment. London: E&FN Spon. p28-35.
3. Robson,D., (2007). Beyond Bawa. London: Thames & Hudson Ltd . p 258.
4. Tan B and Robson, D., (2006).Bioclimatic skyscraper – Learning from Bawa, The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, September 6-8
5. B. Givoni, (1976) Man, climate and architecture, London: Applied Science Publishers, ISBN 085334678x
6. Keniger,M., (1996). Bawa: Recent Projects 1987-95, Brisbane: Queensland Chapter of the RAIA
7. Irving,S; Ford, B; Etheridge,D., (2005). Nature Ventilation in Non-Domestic Buildings, CIBSE Applications Manual AM10. London: The Chartered Institution of Building Services Engineers London. P 21.
8. Taylor, B., (1989). Geoffrey Bawa, Architect in Sri Lanka. 2nd ed. London: Concept Media Ltd. P 17.
9. Tan, B; CR, U; Hong, S (2006). Natural ventilated tall office building in the tropics— learning from Bawa. The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, September 6-8.
10. Jones, A.M., Software Package for the Thermal Analysis of Buildings, TAS, EDSL ltd., UK