Cooling the High-Rise

INSPIRATIONS FROM THE TROPICS

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Abstract

The tropical region has the highest number of rapidly developing cities (Bay and Ong 2012). The paradigm shift towards the 'glassbox' workspace has increased thermal discomfort and consequently negatively impacts occupant health and productivity. This causes a heavy reliance on mechanical cooling, to achieve comfortable indoor conditions, that is neither environmentally friendly nor energy sustainable. While the facade is designed to lend a unique and stylized characteristic to the building, the critical role it plays in modulating the energy performance and interior functioning of the building is increasingly being ignored.

This article discusses interesting examples of projects in the tropical climate that use vernacular design principles to create passive cooling strategies in modern buildings to provide occupant comfort. Built examples have been specifically selected from the urban context since it deals with complex parameters.

The examples also illustrate the significance of incorporating such strategies in the early design stages. They also point that office building may still depend on mechanical cooling during peak summer afternoons. However, the incorporation of various passive cooling techniques, as a part of a mixed-mode system, can significantly reduce the annual energy consumption.

Introduction

"Countries in the tropical belt have seen an unprecedented growth in the last 50 years and are poised to escalate in terms of economic, technological and material developments" (Bay and Ong 2012). This escalation gave rise to different building typologies such as the high-rise towers. There was a time when building "green" was the only way of designing. Vernacular or traditional architecture is based on the principle of responding to climatic implications.

Figure 1: Skyline of Mumbai, India

The change in density of today's cities have added many more layers to the basis of design, taking precedence over the structure's relationship with its environment. The affordability and sense of control achieved by air-conditioning has influenced the perception of desired thermal comfort. Maintaining this *'thermal monotony'* is not only energy-intensive (Brager et al. 2015), but also detrimental to the immediate micro-climate. Further, the relevance of achieving this monotony is questioned by Arens et al. (2010) as the acceptability of the comfort conditions it provides is not significantly greater when compared to a building that is more responsive to the climate.

Today, people spend a greater part of their time indoors. The building envelope mediates between the indoor and the outdoor, creating a micro-climate suitable for occupants. Hence, the article aims to take a step back and find inspirational passive cooling strategies that can be employed in high-rise modern office buildings in the tropics.

This article looks at two examples from about two decades ago (1980s and 1990s) when the high-rise *culture* started becoming a business-as-usual practice in tropical cities. At a time when the conversation on "green buildings" was still at its nascent stages, some architects were already pushing the envelope by creatively employing principles of vernacular architecture to create design systems that reduce dependency on air-conditioning while not compromising on the design requirements of modern offices.

Climate Characteristics

The tropical region experiences a hot and humid climate. Since, this region lies between 23°N and 23°S latitude, it experiences high solar radiation with maximum summer temperature of 30°C (now, 35°C) and minimum winter temperature of 21°C. The diurnal range however remains stable, fluctuating in a range of about 8°C. This is coupled with high humidity levels varying between 60% - 100% and a monsoon season with the annual mean rainfall exceeding 1000mm.

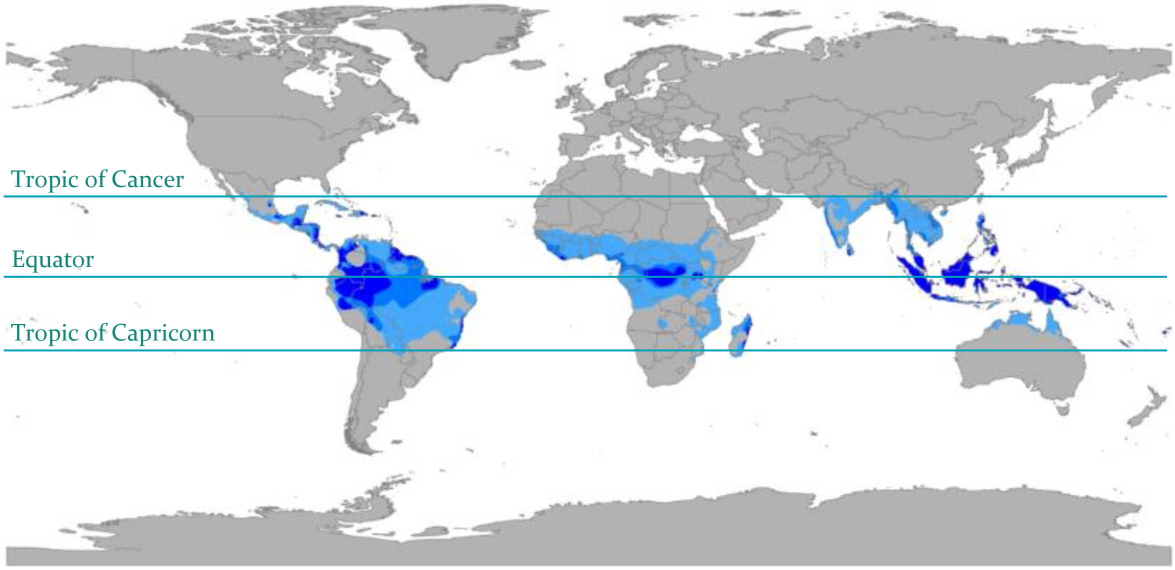

Figure 2: Tropical Belt

Climate variables the affect a structure the most in the tropics are:

- High humidity
- High Outside air temperatures
- Intense Solar radiation
- Heavy Rainfall

Lets now discuss two examples where interesting design strategies have been implemented in response to these climate characteristics.

State Mortgage Bank Building

Colombo, Sri Lanka

Designed by one of the most prolific architects in the tropical region - Geoffrey Bawa, this building is often described as “the best example of a bio-climatically responsive tall building to be found anywhere in the world” (Yeang 1999). The building serves as “the prototype for office buildings in a tropical city” (Robson 2002) and the design innovations have been validated by various studies like the Hawkes environmental design checklist.

Bawa exploited the irregular shape of the site to create a plan that aerodynamically responded to the prevailing south-west and northeast winds (Figure 3); an aspect that most contemporary office buildings ignore in a bid to create symmetrical and modern-looking facade. The plan is not deeper than 15m at any point which results in draught free cross-ventilation and adequate daylight. This SW-NE facing orientation, not only maximizes ventilation but also minimizes the solar gain from the east and west facades. Bawa stressed on the importance of natural light by creating an open plan office space with minimum columns.

Bawa designed the cross-section of the facade (fig 4) in way that natural ventilation could be used throughout the year, including the monsoons months. He installed ventilation grills, protected by an overhang that ends with a downward fascia parapet, above the main window to maintain air movement at ceiling height.

Project Data:

Year of completion: 1978

Height: 12 stories

Plan depth: Varies from 6m to 15m

Climate Data:

Location: Colombo, Sri Lanka (6.93° N, 79.84° E)

Average wind speed: 0 to 7 m/s

Mean annual temperature: 27.5°C

Average daytime temperature time during the hottest months: 31°C (Feb to April)

Mean Annual Precipitation: 2,404 mm

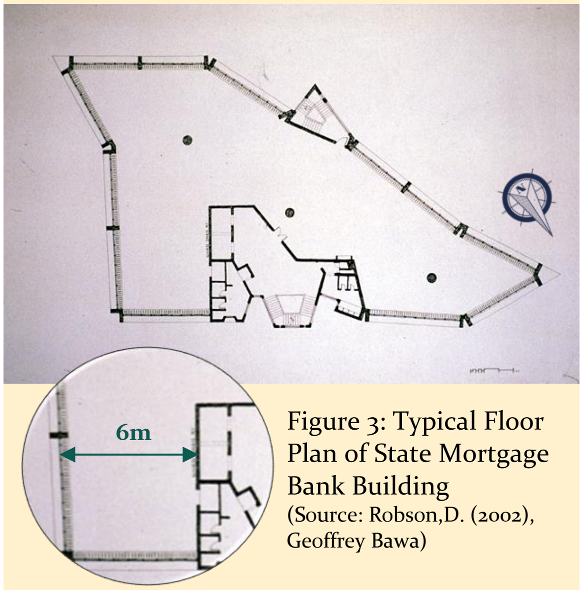

Figure 3: Typical Floor Plan of State Mortgage Bank Building
(Source: Robson,D. (2002), Geoffrey Bawa)

Inset: Enlargement of the floor plan

The overhang and deep fascia not only prevent rain penetration but also cut the incident low solar angle from heating up the interiors. The main windows are vertically pivoted to naturally light up most of the interiors at all times of the year. This is possible as the distance between the window and core is within a range of 6m to 12m. A study by Hawkes et al (2002) shows how natural lighting reduces the energy consumption to 60% of an artificially lit building.

Keeping in mind the heavy rainfall this area experiences, he designed for horizontal openings at sill level as can be seen in fig (5) that could be left open during monsoon when the main windows would be closed. Vents were also provided above the exterior windows and in the internal to encourage cross-ventilation across the floor plate. This is clearly evident in the section shown in fig (6).

At the time this building was being constructed, high- rise were not common and hence, the electrical infrastructure was unreliable. This was one of the reasons that Bawa planned the service core on the external facade. A naturally-lit staircase would provide for a safe exit from the building, in case of a power-failure or elevator breakdown. Peripheral service cores also eliminate the need for artificial lighting, mechanical ventilation and fire-protection ducts (Yeang 2000). Ken Yeang, employed this technique while designing the Revenue House in Singapore which helped reduce the annual energy consumption by 30%.

Figure 4: Elevation of State Mortgage Bank Building

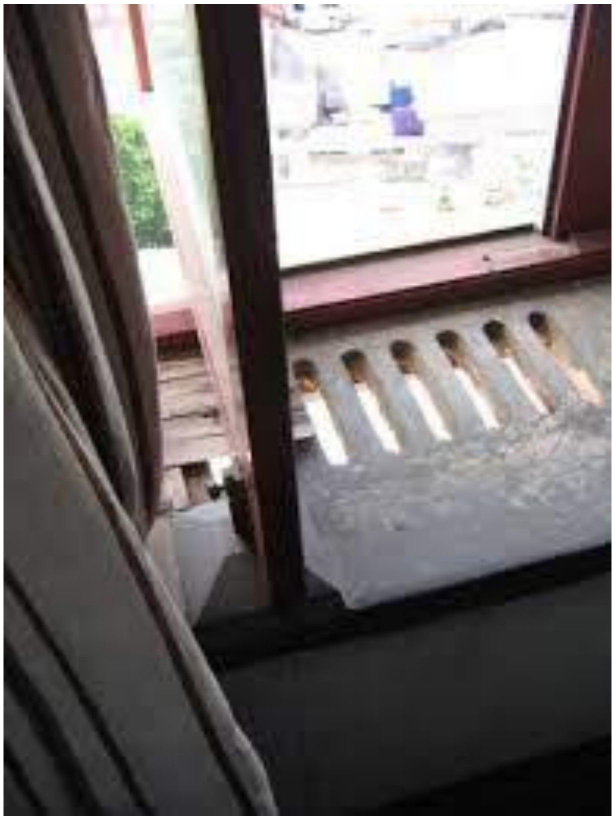

Figure 5: View of Monsoon window

The building's design further gained academic interest and was used as a precedent to study

- the way air moves through a floor
- ways in which inlets and outlets can be designed to increase internal air speed that can in turn improve the air change rate (ACH) through the floor

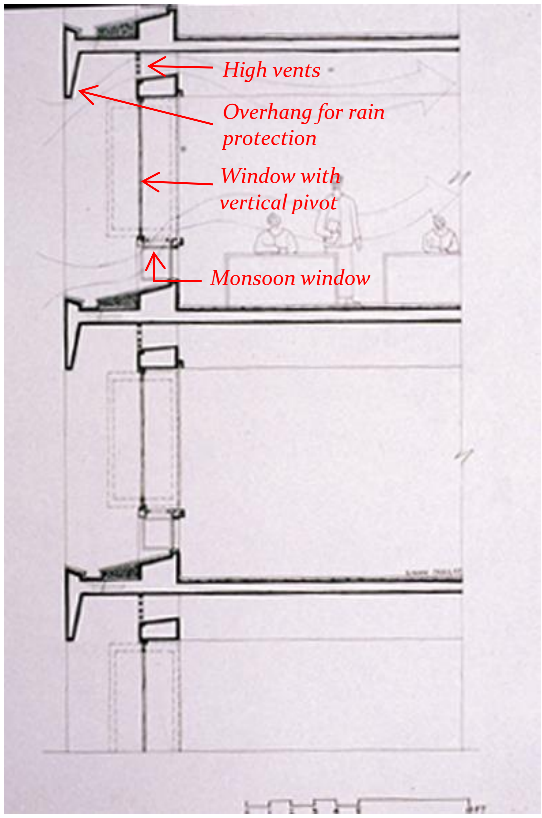

Figure 6: Original sketch section as intended illustrating the 3 levels of ventilation

Since, the building was built at a time when computer simulations were not a part of design processes, a wind tunnel test experiment was carried out by Hong, S. et al, 2007 at the School of design and environment, National University of Singapore.

A 1:20 scale model of a 6-window bay of this building was made. At the wind-ward side, the façade opening details were made: a 1.2m overhang and high vents, body level windows, monsoon window slots with a 900mm parapet wall below window. At the leeward side, a wall with high-level slots represents the outlet.

Air speeds were measured at consistent intervals from the inlet (at desk height of 900mm) for the following different opening configurations:

1. Only main window open

2. Only monsoon window open

3. Only high vents open

4. All open

The comparison of indoor wind velocity vs distance from inlet, for the above inlet scenarios have been illustrated as follows:

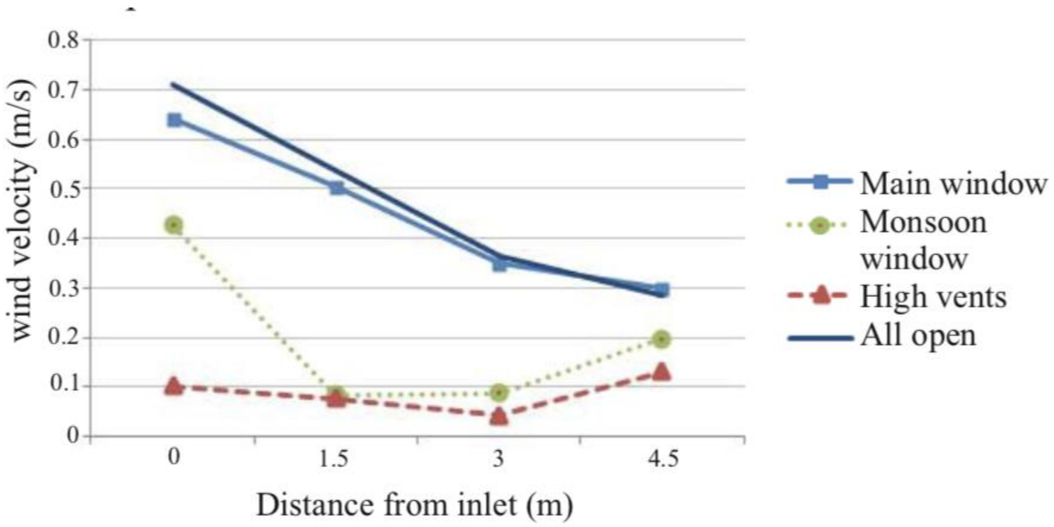

Figure 7: Indoor air velocity comparison between all four inlet scenarios
(Source: Hong, S. et al, 2007)

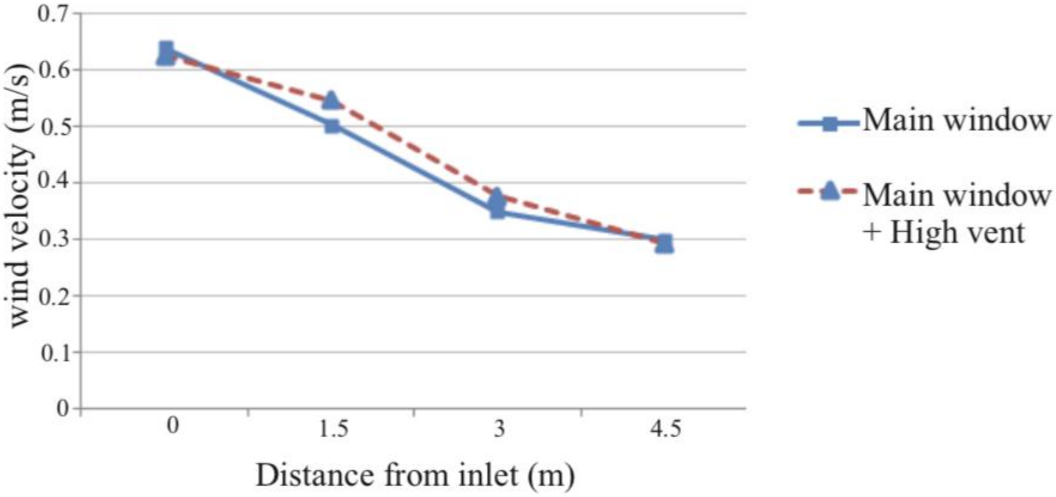

Figure 8: Indoor air velocity comparison between inlet scenario 1 and when the main window + high vents are open

(Source: Hong, S. et al, 2007)

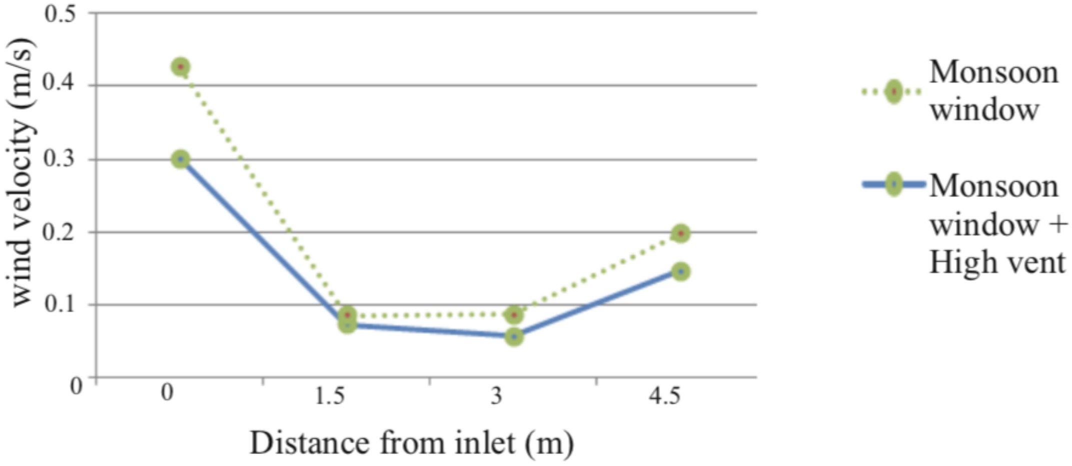

Figure 9: Indoor air velocity between inlet scenario 2 and when the monsoon window + high vents are open
(Source: Hong, S. et al, 2007)

The study concluded the following [as per figure 7, 8, 9]

- The velocity of wind decreases from the inlet through the space and apparently shows an increase near to the outlet, which reinstates conventional cross ventilation principles.
- The main window is the primary source of ventilation. When the main window is closed during rainy days, the monsoon window becomes the secondary source for ventilation, whereas the high vents did not help much in ventilation during that time.
- Monsoon window is only effective up to 1.5m away from the window even though it did help to encourage air movement throughout the room.
- High vents above window did not help in improving the ventilation at the occupant's level
- When the main window and high vents are both open, the vents change the air flow by 8% in the middle of the room.
- When the main window is closed on rainy days and only monsoon window and high vents are in use, the ventilation effect of the monsoon window is diluted by the use of high vents. Thus, it is better off to have just the monsoon window open in this scenario.

Thus, in the example, it is evident that a lot of thought has gone into ensuring adequate natural ventilation since that is the main passive cooling strategy required in a tropical climate. Bawa has made the façade as porous as possible to allow ventilation while also providing shading and rain protection. All these design strategies culminated into a modern high-rise commercial building that was ahead of its times when it was built.

I think it is certainly possible to adapt these principles today as well.

Menara UMNO

Penang, Malaysia

The UMNO tower was developed by the celebrated architect, Ken Yeang, at the city center of Penang, Malaysia.

While most of his skyscrapers were based on his bioclimatic theories, Yeang's primary focus while designing this tower was improving natural ventilation. Site constrains resulted in a building orientation where large parts of the facade are exposed to the unwanted north-west and south-east. Hence, he had to develop 'Wing Walls' to bring in the prevalent south-westerly winds.

The tower is rectangular in plan with a slight curve on southwest as shown in Figure (11). The shallow plan ensures that no desk is more than 6.5m away from a window ensuring adequate access to natural light and ventilation to every occupant. The northwest glazed facade is shaded with perforated aluminum screens. The perforations are more opaque towards the west to reduce solar gains in the afternoon and transparent towards the north.

To minimize solar gains from the harsh south-east, the service core (elevator and staircase) and restrooms are placed along this facade to act as a 'solar shield', blocking out direct solar radiation into the office space. As studied in the previous example, locating the service core on the periphery is energy effective and Yeang ardently promoted this arrangement (Yeang, 1999).

The wing wall system increases the indoor air speed thus providing psychological cooling to the occupants. The wing wall on the southwest corner (fig 11) is the inlet and creates pressure to catch the prevailing wind and direct it to the balcony zone attached to it which in turn acts as an air-lock. The balcony has a full-height sliding door to adjust the

Project Data:

Year of completion: 1998

Height: 21 stories (94 m)

Plan depth: 14m (from core)

Climate Data:

Location: Penang, Malaysia (5.18° N, 100.16° E)

Average wind speed: 2.6 m/s

Mean annual temperature: 28°C

Average daytime temperature time during the hottest months: 32°C (Feb to April)

Mean Annual Precipitation: 2,398 mm

Figure 10:View showing the wing walls in the southwest and the 'air-lock balconies
(Source: Salib and Wood, 2012)

rate and distribution of air flow within the office space. The main outlets are located on the north east elevation for cross-ventilation to increase the number of air changes per hour. The design also ensured that if the interior spaces are partitioned later, the balcony will still serve as air locks and aid in cross-ventilation, due to its location.

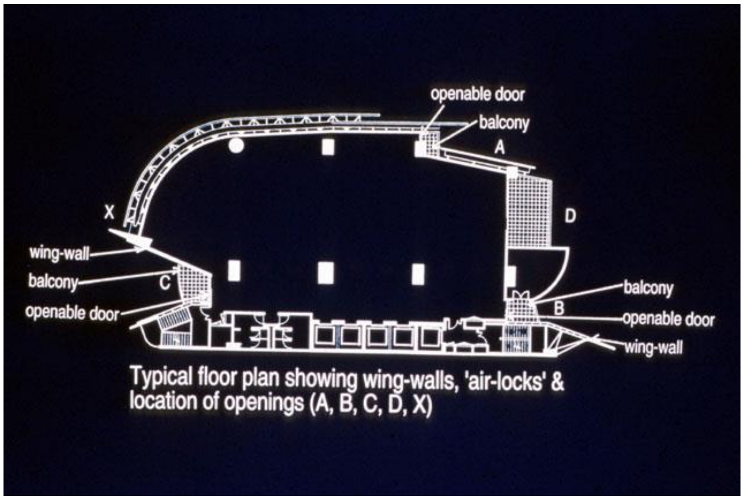

Figure 11: Typical Office Floor plan illustrating how the 'wing walls' capture the prevailing winds

CFD analysis proves that this system works well and can be developed further in other projects in the tropics. The analysis concluded that natural ventilation would not be effective without the wing walls. Fig (12) illustrates the high pressure contours caused by the 'wing walls'. The wing walls help funnel air into the office resulting in large air changes per hour ranging from 1 to 33.8. Thus, the adjustable opening control would facilitate a comfortable indoor environment.

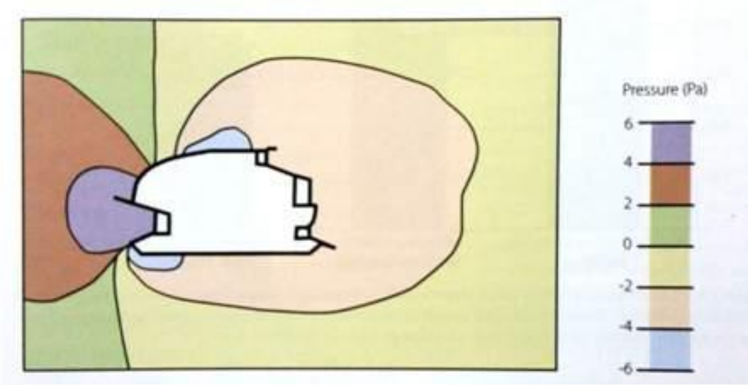

Figure 12: CFD simulation of air pressure contours which show wind flow around the building in plan

Figure 13 clearly shows that the combined strategies of natural ventilation and the shading reduce the cooling load of the building to 180kWh/m2, which is a 25% reduction compared to a typically air-conditioned building in Malaysia (Jahnkassim & Ip 2006).

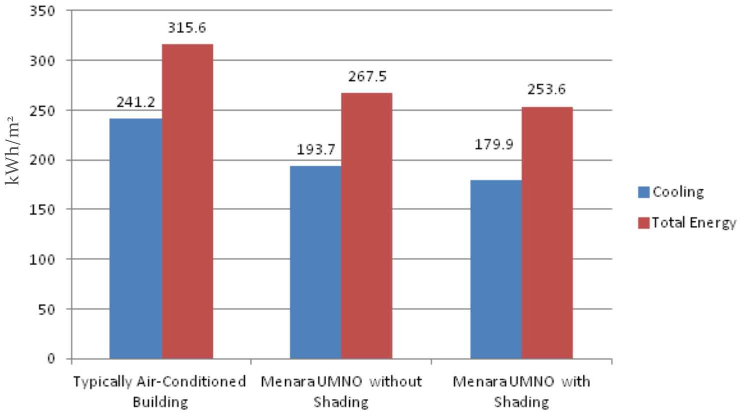

Figure 12: Comparison of energy use in Menara UMNO compared to a typical air-conditioned building in the region (25% reduction), as well as a positive impact of shading (7% reduction)

Conclusion

The two examples discussed here show creative applications of the fundamental passive design principles for cooling can result in energy conservation as well as interesting architecture that is climate responsive. In a particularly challenging tropical climate, shading and ventilation are the two key strategies to provide thermal comfort. Some of the design solutions discussed here can still be applied today. It does call for an integrated design approach where the concepts are worked out early in the design process with every stakeholder involved from the beginning.

The respective use of the 'monsoon window' by Geoffrey Bawa in Sri Lanka and 'wing walls' by Ken Yeang in Malaysia particularly illustrate the importance of employing passive cooling strategies in the initial design stages. Clearly, such design elements cannot be just a *add-on* towards the end of design.

The examples also point out that the function of a space could change over time due to change in the end user or other socio-economic reasons. Original design strategies that do not easily modify to adapt these changes are often ignored or become defunct, bringing back increased dependency on mechanical cooling.

What is to be observed is that simple and well-thought low-tech solutions can contribute to *high-performance* as well. They are also easier to maintain over the long run unlike façade elements that have moving parts. Perhaps, we need to step back and think about the way we apply technology in building design today. Is it making things more complex that it needs to be? Maybe finding a middle-path to between low-tech and high-tech to ensure sustainability is the key. I hope you found the examples interesting and it has triggered new ideas !

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