Rajapaksha.U, et al (eds), 2016, "Building the Future - sustainable and resilient environments": *Proceedings of the 9th International Conference of Faculty of Architecture Research Unit (FARU), University of Moratuwa, Sri Lanka,* pp. 354 - 365 ©

INTERACTIVE ARCHITECTURE AND CONTEXTUAL ADAPTABILITY: **ISSUES OF ENERGY SUSTAINABILITY IN CONTEMPORARY TALL OFFICE BUILDINGS IN COLOMBO – SRI LANKA**

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Abstract:
Interactive Architecture (IA) and contextual adaptability promotes operational energy efficiency of buildings by enabling building – climate interaction. However, Tall buildings tend to be non – interactive and climate isolated due to focus on other design considerations. Three recent office buildings in Colombo were selected for investigation to examine the level of interactive contextual adaptability, following a qualitative short – listing. After a general evaluation of energy use intensity (EUI), the designs were analyzed using a theoretical framework, and a thermal behavior investigation. The research revealed that low levels of building – climate interaction results in susceptibility to indoor overheating. Particularly, peripheral passive zones indicated elevated temperature levels attributed to increased solar exposure due to poor envelope design. Elevations in indoor temperatures, ranging from 3° to 4° Celsius were observed, which corresponded with 30% to 50% increase of space cooling energy load.

Keywords: *Tall buildings, Energy Efficiency, Indoors Overheating, Interactive Architecture, and Contextual Adaptability*

1. Introduction

Architecture is the convergence of human and environmental communication. It is a discourse between its occupants, users, the functions it serves, and its regional climate, all tied together in a harmonious aesthetic. (Fox & Kemp, 2009) Buildings of the current age facilitate unique applications that address dynamic, flexible, and constantly evolving activities of the current zest of human life.

Global socio – economic trends play a significant role in this interplay. Much of the economy has shifted from the primary and secondary sectors to the tertiary sector, becoming service oriented. This has resulted in more corporate office buildings in the nexus of the global built environment. 80% of the building stock of Colombo, Sri Lanka is office buildings. (Rajapaksha, Jayasinghe, & Rajapaksha, 2015)

Due to unsustainable development, global warming, climate change, and quantum depletion of non – renewable sources of energy are some key issues faced by the contemporary global society. (IPCC, 2014) Statistics indicate that Colombo's office buildings are high energy intensive. 64% of the country's total energy consumption can be accounted to its building stock, of which 26% are non – domestic buildings. (Rajapaksha et al., 2015)

Building operational energy, which is energy that powers the building's habitability through indoor thermal moderation (space cooling and heating, lighting, water heating etc.). accounts for the significant majority of energy use in buildings over its useful life. Typically, 90% of a building's energy is consumed in operation over its complete lifespan. (Mohammad & Saraswat, 2014)

Up to 32% of operational energy used in commercial buildings is spent on HVAC (heating, ventilation, and air – conditioning). In warm regions, increased energy is used for space cooling of building interiors to achieve required comfort levels. Mitigating space cooling energy demand through the manipulation of the architectural design by employing strategies of building climate interaction leads to energy sustainability.

2. Interactive Architecture and Contextual Adaptability

Interactive Architecture is simply architecture that is reactive and responsive to its users, climate, and context by achieving design, operational, and functional goals through the use of technological, social, and contextual developments of its age. (Achten, 2013)

Figure 27 – Interactive Architecture

The convergence of embedded computation (intelligence), and a physical counterpart (kinetics), facilitates buildings to be interactive. Kinetics could be described as an aspect of pragmatic adaptability, where the building form follows performance implications; expanding, contracting, and adapting to meet spatial, functional, humanistic and contextual demands. (Fox & Kemp, 2009)

The energy dimension of interactive architecture is based on climatic awareness and response. The definition of contextual adaptability in the kinetics of interactive architecture is synonymous with ecological design, i.e., design that respects the symbiotic relationship between all links of human made and natural systems. (Yeang, 2008)

Integrating strategies of building climate interaction at the onset of the architectural design process by propagating the concept of Architecture towards building behavior, and ways of engagement of interactive modes, leads to better energy efficiency. Conversely, non-interactive architecture leads to context isolation and increased energy use for indoor climate moderation of buildings.

3. Building Climate Interaction: The Low Energy Practice

Filtering favorable weather effects from unfavorable ones, using interactive strategies through exchanges (i.e. thermal energy, wind forces etc.), between building elements and climate elements is the way forward in energy efficient design. In architectural design, interactive strategies needs to be applied at four different inter – connected levels, the micro – climate, plan form, sectional form, and building envelope to optimize energy, at the very onset of the design process. (Rajapaksha. U, 2013)

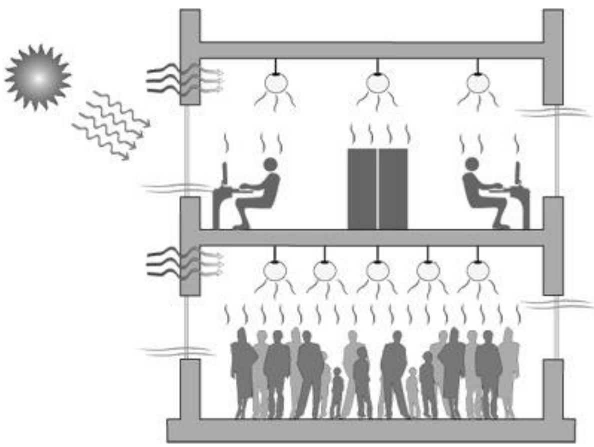


Figure 28 – External and internal heat loads acting on a building. External loads are solar irradiance; internal loads are heat emitted by occupants and equipment. (Source: Whole building design guide, National institute of building sciences, Washington DC)

Microclimate of a building is the climate conditions in its immediate context, which is affected by climate elements of the region, topography, soil structure, ground cover (vegetation), and urban forms. (M. Santamouris & D.

Asimakoloulos, 1996) Interactive strategies are applicable to the micro – climate, such as placing the built form on the site in a symbiotic manner.

Plan form of a building is majorly of two types, the deep plan form and the shallow plan form. ASHRAE 90.1 states that a floor should be divided into a ‘core’ and a ‘perimeter’ zone, the perimeter is defined as a space within 5m distances from the façade. Moreover, if the aspect ratio (length to width ratio) is less than 1, the floor plan is a deep plan form.

The shallow plan form has more capacity to interact with the climate than the deep plan form due to higher exposure to the envelope. This is beneficial in cold climates for passive solar gain to heat the interior. In tropical climates, the deep plan form promotes interior cooling through shaded areas, which is beneficial for enclosed air – conditioned buildings with limited climate interaction. (Hyde, Rajapaksha, Rajapaksha, O Riain, & Silva, 2012)
Passive and active zones need to translate 3 dimensionally from the plan form to the sectional form and building envelope. Interactive means between solar radiation and shading devices, window openings, building material properties, and roof geometry can be manipulated to achieve passive means of indoor environment modification. (Hyde et al., 2012)

Window to wall ratio (WWR) has a significant effect on building energy consumption. Lower WWR promotes higher energy saving for both cooling and heating. Optimum WWR depends on glazing type, and the climate. In the tropics, 50% or less WWR prevents excess solar exposure. (Raji, Tenpierik, & van den Dobbelsteen, 2015) Shading devices can reduce unwanted solar exposure.

According to The Council on Tall Buildings and Urban Habitat (CTBUH), a tall building is a building in which “tallness” strongly influences planning, design, construction and use, which includes height relative to context (taller than the urban norm), proportion (slender appearance), and use of technologies specific to tall building structures. Tall buildings generally operate in full air – conditioned mode.

Buildings that are not interactive and adaptive are susceptible to indoor overheating conditions, a phenomenon where indoor temperature exceeds the comfort zone. In air-conditioned buildings, the general set point temperature for thermal comfort in tropics is between 24°C to 26°. Indoor overheating may occur when air – conditioning is turned off (in weekends). The elevation of indoor temperature during non air-conditioned periods gives an indication of the air – conditioning load.

5. Research Methodology

Methodology of study included four distinctive phases, i.e., selection of cases, Energy Use Index (EUI) evaluation, Theoretical Assessment, and Thermal Investigation. Three recent office buildings in Colombo were selected following a qualitative short-listing; corporate headquarters of Citizen's development business finance (**CDB**), People's Leasing Co. (**PLC**), and Dialog – Axiata (**Dialog**).

5.1 Selection of Cases

All three cases are freestanding buildings, i.e., they are not structurally or otherwise attached to other buildings on any side. This was in order to assess each building individually without thermal effects from other buildings. All three cases were constructed within the past 5 years (CDB and Dialog in 2015, PLC in 2010). All three cases were fully air-conditioned buildings.

Figure 29, Left: CDB headquarters, Center: PLC headquarters, Right: Dialog headquarters.

5.2 Energy Use Index (EUI) Evaluation

Accepted level of good practice of energy use for air – conditioned buildings is within the range of **110 – 120 kWh/m^2** per year. (Hyde et al., 2012) EUI was calculated for a typical office floor of each building.

Case	**EUI** (kWh/m^2 .per annum)
• CDB	126
• PLC	118
• Dialog	106

Table 5 – Energy Use Index (EUI) of each case

CDB exceeds the upper limit of accepted energy use. PLC is within accepted levels, but above the lower limit. Hence, both buildings indicate potential for improved energy performance. Dialog's EUI is below the lower limit of the accepted practice, which indicates good energy use behavior.

	CDB	PLC	Dialog
Net office area	320 m^2	530 m^2	485 m^2
No. Of occupants	83	63	86
Occupant density	0.231	0.119	0.177
Equipment usage	98.75W/m^2	51.321W/m^2	75.052W/m^2
Lighting usage	19.688 W/m^2	8.321W/m^2	21.649W/m^2

Table 6 – Lighting, occupancy, and equipment usage data

5.3 Theoretical Assessment

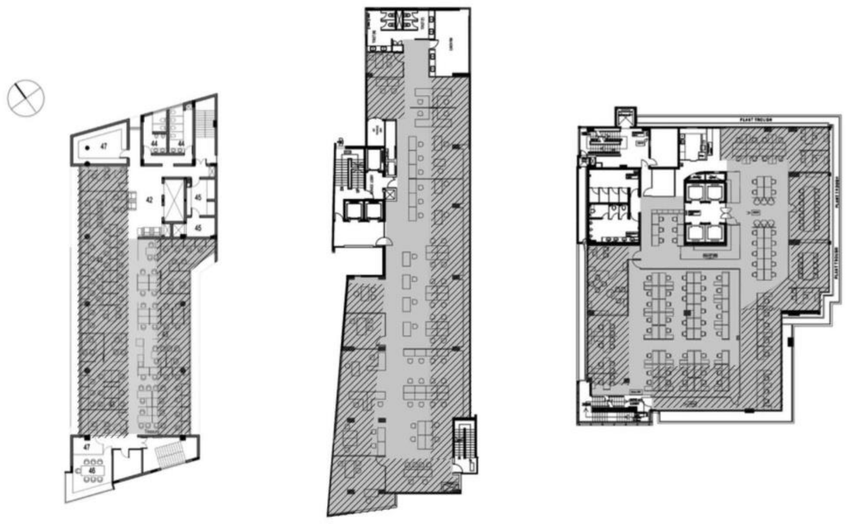


Figure 30, Plan forms of each case. From left to right, CDB, PLC, and Dialog. Lighter shaded area indicates the central zone, and the darker shaded area indicates the peripheral zone.

CDB is 8 stories in height, while PLC is 12 stories in height, and Dialog is 15 stories. Service and vertical circulation cores are located peripherally in CDB and PLC, which benefit interactive contextual adaptability by cutting off direct solar radiation and conductive heat gain. All three buildings are of northeast, and southwest orientation. CDB and PLC have shallow, linear plan forms, while Dialog has a deep plan form configuration.

Glazing used in all three buildings is 8mm thick laminated clear glass. CDB WWR is 0.4. PLC WWR is 0.4 and 0.2. Windows are in horizontal band type configuration. Dialog WWR is 0.4 and 0.6. Windows are placed lengthwise from top to bottom. WWR less than 0.5 are good practice for the tropical context. This is good practice to cut off direct solar radiation. Dialog building is landscaped vertically along a 1m wide recess. The plants reduce glare, however the recess is not sufficient to significantly cut off direct solar radiation.

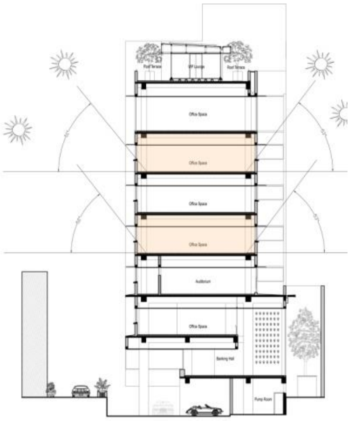


Figure 31, the sectional form of CDB. It can be seen that solar angles lower than 53° in altitude results in direct solar radiation exposure of the typical office floors. Much lower angles does not affect the building due to the tight urban context.

The glazed envelope of the Dialog building's front stairwell admits direct westerly radiation into its interior. However, heat build up is effectively removed by stack effect. This technique is a good example of interactive contextual adaptability, in specific situational use. The stack effect of the stairwell also removes heat build up in the typical office floors

5.4 Thermal investigation

Thermal investigation validates interactive design strategies and effects of qualitative elements discussed in the theoretical evaluation, and investigate the overheating potential. Thermal measurements were recorded using electronic data logging apparatus; mainly HOBO data logger thermometers and thermo couples. These were used to measure and record air as well as surface temperatures.

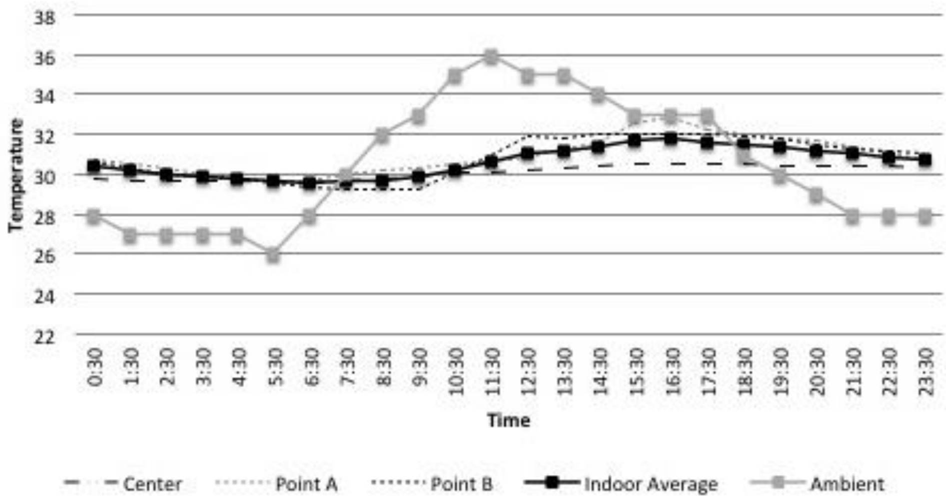
Air temperature readings were taken over non-air conditioned and air conditioned hours. Ambient weather data of Colombo city was obtained from the government Met. Department. Satellite measurements of it, was obtained from ‘world weather online’ website. Daytime hourly air temperature in Colombo Sri Lankan can reach above 33° Celsius during the period from October to April. All three cases were investigated in April 2016 during this critical period.

The climate of Colombo Sri Lanka (Latitude, 6.9271° N and Longitude, 79.8612° E) is a warm humid, tropical climate. During the period of study, a sunlit, hot and humid weather pattern was observed. Average max. Temperature was 36°C, and min. temperature was 26°C. A high level of relative humidity was experienced (nighttime 80% and daytime 60%). Cloud cover was less than 50%. Generally, the sky was clear and there was no rain.

The following comparisons were made in order to ascertain the thermal performance:

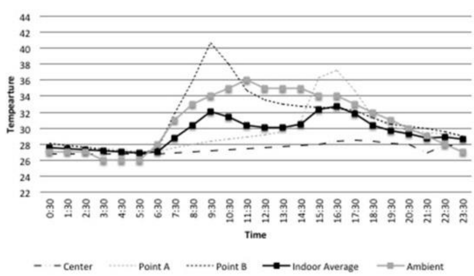
- Temperature variations in central and peripheral zones of a typical office floor. In this way, the shallow plan form and deep plan form effects on thermal behavior could be evaluated.
- Difference between Colombo’s ambient temperature and indoor temperature variations of the office floors. In this way, overheating conditions and potential could be determined.
- The daytime temperature elevation within the typical office floor. In this way, the proportionate energy demand for space cooling could be indicated.
- The patterns of temperature behavior between peripheral indoor temperature and outdoor micro – climate temperature. In this way, the thermal behavior of the typical office floors could be analyzed against effects of the urban micro context.

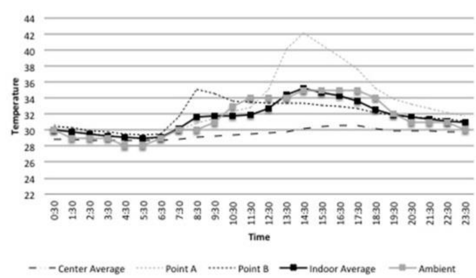
5.5 Results and Analysis



Graph 1, Indoor temperature variation of a typical office floor of CDB during the non – air conditioned period.

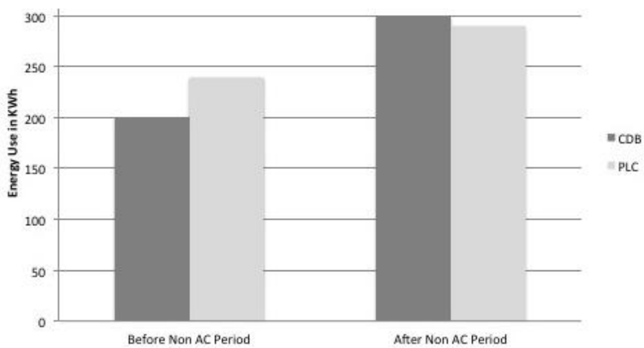
Graph 1 indicates that all internal temperatures of CDB were below the ambient temperature of Colombo at the time of measurement. The building was not overheated. A daytime temperature elevation of 3°C is indicated. The peripheral measurements (A and B) are 2°C to 3°C higher than the center average. Temperature elevation during the non – air conditioned period 4°C.





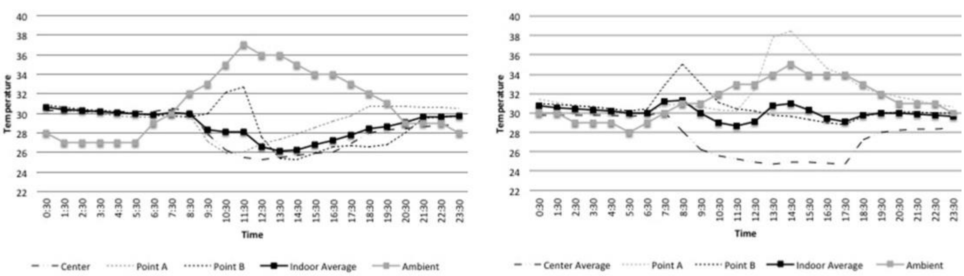
Graph 2 and Graph 3, Indoor temperature variation of a typical office floor of PLC (left) and Dialog (right), during the non – air conditioned period.

Graph 2 indicates that PLC and Dialog buildings overheat relative to the sun's position during the day. Hence, all three cases show solar exposure to the peripheral zones. The overheated level corresponds to the WWR. In both Dialog and PLC, the side with higher WWR is more overheated. PLC indoor thermal elevation is 6°C during the non – air conditioned period. Dialog does not have a temperature elevation; the building has effectively cooled down by the end of the nighttime.



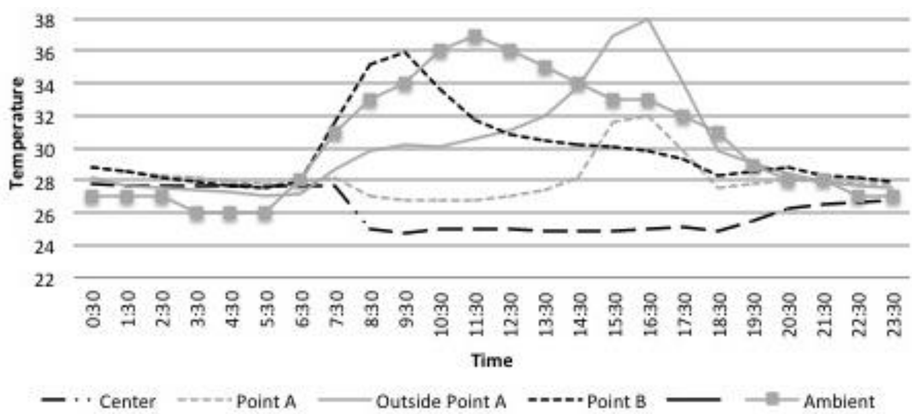
Graph 4, Energy use increase following temperature elevation after Non AC Period. Graph indicates more energy is needed after heat build up.

Graph 4 includes energy data taken from the building management systems of CDB and PLC. The graph indicates that excess energy is required for space cooling following the heat build up during the non air conditioned period.



Graph 5 and Graph 6, indoor temperature variation of a typical office floor of CDB (left) and PLC (right), during the air conditioned period.

Graphs 5 and 6 indicate that CDB and PLC are failing to maintain the indoor temperature at consistent levels during the air – conditioned period. The indoor average is above the set point temperature. Particularly the peripheral zone temperature behavior is unfavorable.



Graph 7, indoor temperature variation of a typical office floor of Dialog during the air conditioned period.

Graph 7 indicates that the Dialog building's center average temperature is consistent with the set point temperature. This is due to the benefit of the deep plan form configuration. The microclimate thermal behavior indicates that the building design has failed to design its microclimate advantageously for building – climate interaction. This was observed in all three cases during both air conditioned and non – air conditioned periods.

6. Conclusion

Interactive architecture and contextual adaptability is synonymous with ecological design. Adaptable, dynamic, and interactive buildings promote operational energy reduction through building climate interaction. Space cooling energy accounts for majority of building energy use in the tropical context. Indoor climate moderation via passive means by manipulating the building microclimate, plan form, sectional form, and building envelope can reduce space cooling energy load.

In the tropical context, the imperative is to prevent heat gain, and promote heat loss. Interactive strategies are case and context specific. The study of cases indicates that contemporary tall office buildings in Colombo are high energy intensive due to climate response failures in the architectural design. The investigation revealed that low levels of building – climate interaction results in susceptibility to indoor overheating.

The peripheral zones of all the cases were susceptible to overheating, indicating poor envelope performance and microclimate design. The deep plan form configuration showed better thermal performance at consistent levels. Indoor temperature elevation indicates the excess load on space cooling energy. The case study indicates that elevations ranging from 3° to 4° Celsius were observed, which corresponded with 30% to 50% increase of space cooling energy load.

7. Acknowledgement

Authors would like to acknowledge the support given by Mechanical Engineering Department of University of Moratuwa and National Research Council Grant 13-109.

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