Thermal and acoustic environmental requirements for green buildings in Malaysia

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Passive design concepts as a strategy for achieving energy efficiency as well as optimum indoor thermal comfort in workspaces are being increasingly applied with the increased awareness of Green Buildings. The challenging task for the building designers in the hot-humid tropics is the provision of indoor thermal comfort for the occupants of the building while reducing energy consumption in the office spaces. Acoustic quality is also an important element in ensuring a healthy working environment. One of the aims of a green building is to minimise its impact on health and performance of the occupants of the building. This has been emphasized in most green building rating systems under requirements for Indoor Environmental Quality (IEQ), highlighting the four main points for achieving an improved indoor environment, viz., indoor air quality, acoustics, visual comfort (lighting) and thermal comfort. Although acoustics was mentioned in the IEQ criteria, according to previous surveys and studies acoustic quality in green buildings are not improving. Acoustics performance is bound to be relegated unless it is considered early in design stage. This paper makes an attempt at how green building design strategies contribute to the degradation of acoustical environment in green office buildings. The design strategies implemented to cater for green building requirements such as provision of natural ventilation, daylight, reduction of finishes and office layout leads to an unintended decrease in the acoustical quality. This needs to be addressed and corrected by the building professionals.

Keywords: *Thermal comfort, facade design, acoustic quality, green building*

1. INTRODUCTION

With the establishment of the Green Building Rating (GBI) in the Malaysian context, development of energy efficient buildings are imperative. Besides the obvious M&E system design, responsive building facade is one of the important components to achieve energy efficiency by reducing the need for cooling, lighting and ventilation (Kibert, C. J. 2005). Facade design and construction has great potential in controlling its interior environment, through use of insulation, energy efficient windows and passive solar design techniques. The usage of glass facade has become a standard design for office buildings due to its aesthetics and visual transparency.

Acoustics is related closely with human well-being by its influence on human stress level, motivation and productivity (Singh, A., Syal, M., Grady, S. C., & Korkmaz, S. 2010, Salter, C., Powell, K., Begault, D., & Alvarado, R. 2003, Bradley, J. S., 2003). Noise exposure in working environment has been found to influence occupants' health, performance and productivity. It was also reported to create physical health problems such as cardiac problems, sickness related absenteeism and self-reported fatigue. Poor acoustic environment would not only cause harm to occupants' physical health, but also on their psychological health (Leather, P., Beale, D., & Sullivan, L., 2003). Noisy and uncomfortable working space will create disturbance and break concentration and eventually result in stressful occupants (Evans, G. W., & Johnson, D, 2000).

Acoustic environment can also manipulate a person's ability to work. A person's productivity will decrease when they are in a noisy and uncomfortable workplace and vice versa, it can enhance productivity when it supplies an environment which supports easy verbal communication (Hodgson, M, 2008).

According to a survey done by The Centre for the Built Environment (CBE), University of California, Berkeley, USA; over 50% of occupants working in cubicles reported that the poor acoustics in their offices distract them from getting their work done (Jensen, K. L., Arens, E., & Zagreus, L.,2005).

One of green building focus is to create a built environment which would reduce the impact to human health and the environment (Hodgson, M., 2008). U.S. Environmental Protection Agency (EPA) states that the reduction of building impact on human health and environment shall be done in 3 manners: by efficient use of energy, water and other resources; by protecting occupant health and improving employees' productivity; and by reducing waste, pollution and environmental degradation.

Green building's aim of reducing building impact on human health was emphasized under the Indoor Environmental Quality (IEQ) criteria. The four major criteria highlighted in green building rating tools are: *indoor air quality, acoustics, visual comfort (lighting) and thermal comfort.* Despite the fact that acoustics is one of the main criteria under IEQ, it is often overlooked and neglected (Hodgson, M. 2008), Coudriet, G.A. 2009).

According to the survey carried out by CBE, University of California, Berkeley, USA; it was reported that the satisfaction level for acoustic quality were on the negative side. This applies to both green and conventional buildings. Despite green buildings concern on improving the IEQ level, the occupant satisfactions on acoustic quality in green buildings are lower than occupant satisfaction in conventional buildings (Abbaszadeh, S., Zagreus, L., Lehrer, D., & Huizenga, C.,2006).

2. PASSIVE DESIGN STRATEGIES FOR FAÇADE

These are some of the passive design criteria to reduce energy consumption in the building,

A building design should firstly understand how climate response can influence its facade performance. Tropical climate buildings would require a facade that able to keep the building cool however the cold countries would prefer to keep the building warm.

Besides the climate, the site condition and landscape are also important design factors. The facade may be warmed up by the hot air through convection. Green roof, green wall and water features may lower down the surrounding air temperature and provide higher moisture in the air. Trees are also good shading devices to protect glazing from direct sunlight, and lower the indoor air temperature (Tang et al, 2004).A building shape, form and orientation may determine the receipt of solar radiation. It was found that a spherical building consumes lesser energy. In Malaysia, east and west facing windows are getting direct absorption of heat into the building. Thus, most building windows are facing north or south.

Office buildings have major glazed facades. In Malaysia, the work stations shall be located along the building perimeter to encourage the full use of daylight and good views. The secondary function rooms shall be located at the core of the building.

Insulation material is essential to act as a barrier from heat transferring in and out from the building.

i. The recommended maximum window to wall ratios for Malaysian buildings is always high for south & north facades but lower for east & west facade (Tang et al, 2004).

ii. The shading devices are preventing direct solar heat gain for good visual and thermal comfort. Punch hole window with light shelves is best in shading direct radiation, and also bounces natural light deeper into building interiors. The adjustable louvers with shading fins are widely used at most of the office building windows (Tang et al, 2004)

iii. Designing the facade with more openings between two building blocks, big opening at facade, ample size and number of windows and sufficient ventilation louvers may assist in cross-ventilation.

iv. Windows may influence occupant thermal comfort by heat gain or heat loss through the glass, which either raises or lowers the room air temperature, and by radiation exchange between occupant and the glass and other surroundings.

v. The application of glass facade can influence the charm of a building through the exterior outlook, high visible for indoor and outdoor views and good visual comfort

3. CASE STUDY ON FAÇADE DESIGN AND ENERGY PERORMANCE

Table 1 compares the passive design features for LEO Building and GEO Building. It was found that LEO Building has greater passive design features with its green roof design, internal cooling items and

Table 1 Facade design strategies in LEO & GEO Buildings

Design Factors	*Ministry of Energy, Water and Communications - LEO*	*Malaysia Energy Centre - GEO*
Climate Conditions	Hot & humid Daily temperature variations 27 to 35 deg C	Hot & humid Daily temperature variations 27 to 35 deg C
Site condition	Well planned office complex	Low density area with manufa turing companies & shop lots
Landscape design	Low-rise plants & young trees	Low-rise plants, young trees, negligible water feature
Roof garden	Roof garden exists	No roof garden
Building orientation	Main facades are facing north and south	Main facades are facing north and south
Internal cooling effects	Artificial water wall, interior landscape	Limited low-rise pots plants
Window to wall ratios	Minimum number of windows at east and west facades	Minimum number of windows at east and west facades
Building size	GFA: 38,700m^2 (height: 7 storeys)	GFA: 4,000m^2 (height: 3 storeys)
Building form and shape	L-shape on plan Affected by punch hole windows, light shelves & overhangs	L-shape on plan Affected by split windows, light shelves & self-shading facade
Interior space layout	Perimeter – Workstations Core – secondary function rooms	Perimeter – Workstations Core – secondary function rooms
Natural ventilation	Atrium – thermal stack effect	Atrium – open air concept

the atrium design for thermal stack effect. All these features are not found in GEO Building. However, GEO Building has a unique design feature which is not found in LEO building i.e. the self-shading facade, which shades against the direct solar radiation into the building.

Figures 1 and 2 show that both buildings are L-shaped on plan with the main facades facing north and south. Most office areas are designed along the facades to maximise the use of daylight.

Figure 1: The interior space layout of LEO Building shows the office areas are designed along the facades to maximise the use of daylight

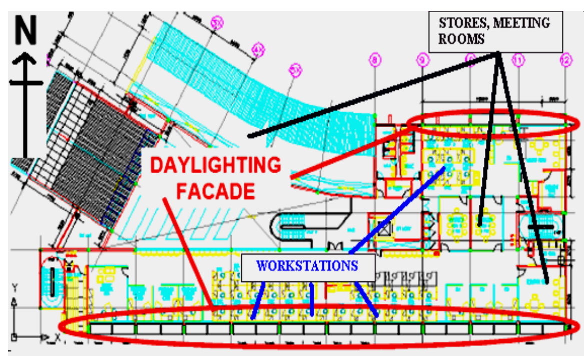

Figure 2: The interior space layout of GEO building shows the workstations are designed along the facades. The building is also L-shape on plan and the daylighting facades are also facing north and south

Table 2 compares the wall energy performances in LEO Building and GEO Building. The designs of the wall in both of the buildings lead to high reduction in the use of electricity for cooling. However, .the solar absorption, U-Value, conductivity, internal and external surface temperatures of Thermowall in GEO building were generally showing more energy efficient results compared to the Aerated Lightweight Concrete Wall in LEO Building.

Table 2: Thermal performance of walls in LEO Building & GEO Building

OPAQUE WALL	*LEO Building* 200mm Aerated Lightweight Concrete Wall	*GEO Building* 100mm Thermowall
Wall surface area	Large (7-storey high)	Small (3-storey high)
Solar absorption	Low (light brown/ grey & white painted surfaces)	Lower (white and nearly white painted surfaces)
U-Value	0.6 W/m^{2}K	0.56 W/m^{2}K
Conductivity	0.12 W/mK	0.056 W/mK
Internal Surface Temperature	Average: 27.79 °C	Average: 27.02 °C
External Surface Temperature	Average: 34.13 °C	Average: 34.86 °C

Table 3 compares the glass energy performances in LEO Building and GEO Building. The spectrally selective low-e double glazing used in GEO Building windows is greater compared to the light green tinted tempered glass in LEO building, as its low-e coating is able to reflect majority of the infrared (IR) and ultraviolet (UV) light back to the ambient. The Argon gas layer between the panes decreases the heat transfer activity through conduction and convection

The comparison study results on their SHGC, U-Value, conductivity, internal and external surface temperatures also demonstrate greater thermal performance of the spectrally selective low-e double glazing. Besides, the spectrally selective low-e double glazing VT is only 50%. Hence the illuminance readings obtained from GEO are lower compared to LEO Building, but has achieved the visual comfort for all clerical and office works. However, the illuminance taken for LEO building is higher and not within the visual comfort range for all clerical and office works. Therefore, internal shading devices are always applied in LEO Building.

Table 4 compares the occupants' perception on the building interior comforts and aesthetic value on the application of glass facade in LEO Building and GEO Building. Generally, GEO Building respondents were more satisfied on the daylight quality in their working place compared to LEO Building respondents, where they preferred to use daylight more than other lighting sources for all clerical and office works. This indicates positive remark for the spectrally selective low-e double glazing, which provides ample daylight without discomfort glares into the building, based on the occupant perceptions.

4. ACOUSTICS IN GREEN BUILDINGS

The analysis will be done by reviewing previous literature on acoustical performance in green buildings. Most of the literature reviews are the outcome of analysis, studies and surveys done on offices and educational buildings in the U.S. These buildings are rated as green building based on LEED (Leadership in Energy and Environmental Design) which was developed by U.S. Green Building Council (USGBC) in 1998.

The literature studies reviewed mainly focus on occupants' satisfaction in green buildings and comparing them to satisfaction from occupants in conventional buildings. The types of acoustical complaints were also being surveyed to determine the major acoustical problems occur. Among the studies, only Hodgson (2008) reported the result of the acoustical measurement done. Table 5 shows the measurement parameters and acceptability criteria used in Hodgson's study.

Hodgson (2008) indicates the acceptable background noise for meeting and conference rooms is NC 30-35 and NC 35-40 for workspace. However, in others such as Cavanaugh (1999), NC 34-43 was recommended as acceptable level for executive office and NC 42-52 for conference rooms, office and workspaces. Beranek, as cited in Maekawa et al. (2011) recommended the acceptable noise level for offices are between 38-48 dBA for small offices and conference room and 48-58 dBA for general offices.

As for the Speech Intelligibility Index (SII), Bradley (2003) and Newsham et al. (2003) both indicated the suitable SII for an office environment is <0.2; which is agreeable with Hodgson's acceptability criteria.

4.1 Analysis and Findings

The analysis found that the acoustical quality in green office buildings was not at par with the standard and recommended level. The noise level was reported to be NC 45-60 which is higher than the suggested NC 35-40. Reverberation was also found

Table 3 Performance of Glazings in LEO Building & GEO Building

	LEO BUILDING	***GEO BUILDING***
Type of Glass	12mm Light green tinted tempered glass (Single)	6mm Tempered Coated Low-E Glass + A16 with Argon gas + 4mm Clear Tempered Float Glass
Window to wall ratios	• North & south – High (30-40%) • East – Low (≈ 25%) • West – Lowest (negligible)	• North & south – High (30-40%) • East – Low (≈ 20%) • West – Lowest (negligible)
Window shading systems	• Punch hole windows with light shelves (lower floors) • Exterior louvres (higher floors)	• Split windows with mirror light shelves
Daylight penetration	Punched hole windows and light shelves reflecting some of the light further into the room.	Diffused daylight →mirror light shelves → highly reflected fixed blind (top of split window) → reflective mirror at the ceiling → inside the building for a deeper distance.
Illuminance (Lux)	• Full Daylit area – average 959 lux (without internal shading devices) • Semi Daylit area – average 686 lux (with the aid of artificial lights)	• Full Daylit area 1– average 695 lux (without internal shading devices) • Full Daylit area 2– average 488 lux (with the aid of skylights)
VT (%)	63.1	50.0
SHGC	0.50	0.29
U-Value	5.70 $W/m^2/K$	1.10 $W/m^2/K$
Conductivity	0.068 W/mK	0.029 W/mK
Int. surface temperature	Average: 29.7^{o}C	Average: 27.6^{o}C
Ext. surface temperature	Average: 35.8^{o}C	Average: 33.7^{o}C

to be unsatisfactory (0.6-1.0 s) especially in area with minimum finishes. Speech Intelligibility Index (SII) also showed terrible results in green buildings. While the SII recommended should be below 0.2 s, the reported SII in was between 0.3-0.6 s and worse in area with natural ventilation which is between 0.7-0.8 s ((Hodgson, M. 2008).

All these results were reinforced by the occupant's satisfaction survey which reported various acoustical complaints. The surveys indicated huge occupant dissatisfaction on acoustic quality in green buildings compared to conventional buildings, especially in working spaces which utilizes the open plan office layout. The main acoustic problems established are the lack of speech privacy and the problem with intermittent noise. Major acoustic complaints made were people talking on the phone; people talking in neighbouring area, people overhearing their private conversation, getting caught up in others' conversation and telephone ringing. Other complaints were also received on noises projected by office equipment, mechanical system, office lighting, outdoor traffic and people in corridors.

It was found that there are four major green building design strategies which might be the explanation for the poor acoustical performance. They are natural ventilation, daylighting, reduced use of finishes and open plan office layout.

4.1.1 Natural Ventilation

The utilization of natural ventilation as one of green building design strategies could assist in achieving many green building requirements. Field & Digerness (2008) state that there are many advantages of natural ventilation. One of the core benefit is it helps in improving the indoor air quality (IAQ). Other important benefits are it enhances the thermal comfort condition of interior spaces, give the

Table 4 Perceptions of occupants on the building interior comfort and aesthetic value of the application of the glass facade

	LEO BUILDING	*GEO BUILDING*
Respondents' sitting position	Majority 49% - east	Majority 60% - south
Importance of glass facade	Majority 76% agree	Majority 80% agree
Reason of glass facade is highly preferred	Maximisation of daylight use - 76% agree	Maximisation of daylight use - 100% agree
Most comfortable factor of sitting nearby the glass facade	Sufficiency of visible daylight - 73% agree	Sufficiency of visible daylight - 100% agree
Improvement of health & productivity	58% agree	52% agree
Lighting condition	▪ 39% preferred combination of both natural daylight & artificial light ▪ 46% are using natural daylight only	• 56% preferred natural daylight only • 64% are using combination of both natural daylight & artificial light
Frequency of internal shading devices are opened	Majority (55%) - seldom	Majority (52%) - always
Daylight quality & visual comfort nearby the glass facade	• 58% – daylight provided is ideal for PC work • 55% – never feel glare from daylight source • 48% – experienced the shadow for all clerical and office works • 39% – experienced insufficient daylight for both paper work and PC work.	• 60% – daylight provided is ideal for PC work • 68% – never feel glare from daylight source • 48% – never experience the shadow for all clerical and office works • 48% – experienced insufficient daylight for paper work
Reason of glass facade is aesthetic	67% – elegant of its transparency & modular system & can observe outdoor view and scenery	68% – elegant of its transparency & modular system
Thermal comfort of sitting nearby glass facade	48% – unbiased (not warm and not cool)	44% – unbiased (not warm and not cool)

advantages for personal environmental control, reducing space requirement for mechanical plant and most importantly it cuts down the energy consumption by reducing the usage of mechanical ventilation (Field, C. ,2008, De Salis, M. H. F., Oldham, D. J., & Sharples, S. , 2002). Natural ventilation would not only help for the building benefit, but also could help in human health and productivity. IAQ could affect occupants' health condition and eventually affect their work performance. Thus, improved IAQ and thermal comfort will help in reducing poor health conditions and increase occupants' productivity.

Natural ventilation requires openings on building façade or operable windows. Unfortunately, openings which are the main mode of access for natural ventilation would also be an access way for external noise ingress. This will lead to increase noise level. Hodgson (2008) reported the noise level for occupied green office building with the windows open are between NC 45-60, which is considered very high compared to the acceptable noise level which is NC 35-40.

4.1.2 Daylighting

Green building promotes the exploitation of daylight as a mean to improve the IEQ criteria for lighting quality and at the same time minimize the energy consumption used for electric lighting.

The chief design strategy for daylighing utilization is to have a huge number of windows to allow daylight to penetrate into the building interior. At present, this

Table 5: Measurement parameters and acceptability criteria (Hodgson's study)

Measurement parameter	Acceptability criteria
Background-noise level, NC in dB	NC 30-35 in meeting and conference rooms NC 35-40 in workspaces
Reverberation Time (mid-frequency), RT_{mid} in s	<0.75 s for comfort, easy verbal communication
Speech Intelligibility Index, SII	>0.5 (0.75) for acceptable (high) speech intelligibility <0.2 (0.1) for acceptable (high) speech privacy

prerequisite is in line with the current architectural trends which are the usage of curtain wall systems and glass façade.

In effort to maximize the utilization of daylight, the use of elements such as low partition, light shelves and interior glazing or glass partitions is applied. These elements were implemented to allow daylight to infiltrate further into the interior spaces.

Although the use of glass is justified for daylight maximization, acoustical problems would take its place as glass has a significantly low sound isolation capability. Moreover, glass also has a very low acoustic absorption (Muehleisen, R. T., 2010). Furthermore, lightshelves used to spread daylight into the interior spaces have hard and reflective surface (Field, C., 2008). Low sound isolation capability of glass would assist in the transmission of external noise and also reduce the sound isolation in between the interior spaces. On the other hand, low acoustic absorption of glass would contribute to excessive reverberation in the interior spaces and consequently lead to the issue of speech clarity. Poor speech clarity would interfere with occupants' productivity as communication is essential in creating a comfortable working environment. Hodgson's finding reported that the reverberation time recorded for green open office building with low sound absorption was between 0.6-1.0 s which is higher compared to the recommended <0.75 s.

4.1.3 Finishes

Green buildings have a unique characteristic of having an exposed aesthetic which features its original building materials. Some of the reasons behind these trends are designers tried to utilize the thermal mass and radiant heating and cooling to better control the thermal environment of the building thus reducing the energy consumption. Other reason is related to the utilization of natural ventilation which requires high ceiling level. Exposed aesthetic also minimize the usage of natural resources. The elimination of carpeting for example, is considered essential because of its chemical composition, adhesive off-gassing and also for its short life-cycle.. General reason for having minimum finishes and more exposed surfaces is to achieve better IAQ and because it require less maintenance.

Although the removal of these finishes are convincing for environmental benefits as it provide better IAQ; with less finishes, acoustical problems are more likely to happen. The obvious reasons are these eliminated finishes, such as the acoustical ceilings and carpeting were previously the main elements which provide acoustic absorption for the interior spaces of a building.

Coudriet states that finishes such as acoustical ceiling manages the acoustic environment of a space by controlling reverberation and noise levels which would provide distraction and annoyance to building occupants. With its absence, acoustic problems such as excessive reverberation and poor speech intelligibility will occur. Reverberation time was measured in green building office and the result is different between areas with high and low sound absorption (with finishes and without finishes). While high sound absorption area achieved result between 0.2-0.4 s, low sound absorption area attained a high result of 0.6-1.0 s. This shows how reducing finishes would affect the reverberation of a space, thus resulting in problems such as poor speech intelligibility and privacy.

4.1.4 Open Plan Office Layout

Open plan office layout is closely related to maximizing natural ventilation and daylight. Even though having an open plan office layout is considered a modern design trends and has become a typical format of office space, it is also a part of design elements to ensure the success of natural ventilation and daylight design strategies.

Open plan layout usually uses limited solid partition, uses low height partitions or glass partitions as a mean of separation between the workstations. This, as mentioned earlier are to cater for green building requirement which are to achieve better indoor air quality, thermal comfort and better lighting by utilizing natural ventilation and daylight.

Open plan office layout would result in reduced sound isolation and eventually poor speech intelligibility. This was proven by the result shown by Hodgson which state the SII for speech privacy in green buildings was recorded to be higher than 0.2. The SII recorded range from 0.3 to 0.8 which is considered very low speech privacy.

5. CONCLUSIONS

Although ZEO Building is more energy efficient on the overall performance compared to LEO Building, however the facade design considerations with natural environment are greater in LEO building. The design features of green roof, internal landscape and the atrium design for thermal stack effect in LEO Building are not found in building. Both buildings facade designs have contributed to very little energy consumption by reducing the use of electricity mainly for lighting and cooling. However, the thermowall with rockwool insulation, split window system with spectrally low-e double glazing and mirror light shelves in building are found to be more advanced compared to the aerated lightweight concrete wall and punch hole window with light shelves in LEO Building.

It can be concluded that without careful implementation of green building design strategies, acoustic quality is easily compromised. Architects and designers should not overlook on these influence as it could jeopardize the acoustical environment. It is hoped that this analysis can be a guide in analysing the potential acoustical problems that might occur in Malaysia's green building community

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