Energy Performance Enhancement in Institutional and Commercial Buildings

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The built environment has been identified as a major contributor to the energy consumption as well as the GHG emissions across the world. Enhancing the energy performance of the building sector is crucial in meeting the current climate action targets, as well as in improving the economic outcomes and welfare of building owners and occupants. With the current energy and foreign exchange reserve crises faced by Sri Lanka, it is clearly evident that reducing the energy use in buildings as well as the reliance on imported fossil fuels are important. When it comes to greenhouse gas emissions curbing and climate action initiatives, demand side management initiatives appear to be more promising for Sri Lanka compared to supply side interventions, as the latter have higher costs of mitigation [3]. The effectiveness of the energy efficiency enhancement strategies employed in buildings depends on the archetype of the building as well as locational parameters such as climate conditions [1].

Approximately 56% of the total building energy consumption in tropical regions is expended in providing thermal comfort to occupants via air conditioning [2]. The public, hotel, commercial, and industrial buildings account for around 60% of Sri Lanka's energy demand, and in a typical air-conditioned SL building, space cooling accounts for more than 75% of the demand. Yet, in many buildings across Sri Lanka, use of active space conditioning is limited due to the high energy costs involved, and this can negatively affect the wellbeing and productivity of the occupants. This is particularly evident in institutional buildings such as those in schools, universities, and public sector offices. Thus, it can be said that the lack of affordability of energy services, or "energy poverty" detrimentally affects the Sri Lankan building occupants.

In addition to ventilation and air conditioning, the other energy end uses in the tropics are lighting, appliances and machinery, service water heating, and in some rare cases, space heating. Improvements made to the building envelope, heating, ventilation, and air conditioning (HVAC) systems, electrical distribution systems, lighting, and other equipment can reduce the energy use in buildings. Due to rising global temperatures and pollution, maintaining comfortable and healthy indoor environments for the occupants with low heat stress and good air quality is challenging.

The latest Energy Efficiency Building Code of Sri Lanka (EEBC 2020) published by the Sri Lanka Sustainable Energy Authority is one regulatory effort to improve the energy efficiency of commercial buildings and industrial facilities, by encouraging better design, construction, operations, and maintenance practices.

The Department of Mechanical Engineering is involved in an ongoing research project to develop life cycle thinking-based decision support frameworks for energy efficient building design. Such decision supports frameworks will enable building developers to identify the best energy performance enhancement strategies in compliance with EEBC 2020 for Sri Lankan institutional and commercial buildings considering the triple bottom line life cycle performance, and to develop guidelines for new construction and retrofitting of institutional/commercial buildings.

As the first phase of the project a case study was done to identify methods to improve envelope thermal performance of an institutional building at University of Moratuwa [4]. The building envelope (foundation, roof, walls, doors, and windows) and the operation period of the HVAC system are the main factors affecting the total energy consumption of the building. For the analysis eQUEST and OpenStudio software packages were used. Building envelope directly affects the building HVAC and lighting energy loads. Therefore, envelope thermal performance enhancement strategies should reduce HVAC energy loads and lighting energy loads through daylighting.

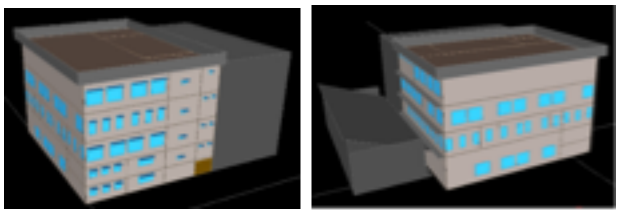


Figure 1: Building model drawn with eQUEST

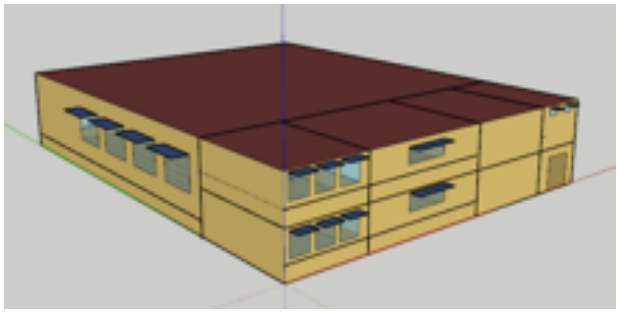


Figure 2: Building model drawn with OpenStudio (two stories only)

Building envelope thermal performance

Building envelope thermal performance is evaluated using envelope thermal transfer value (ETTV). When calculating ETTV heat conduction through walls and windows, solar absorptance of opaque walls and solar heat gain through windows are considered. The results of the study shows that building cooling energy loads are highly correlated with ETTV, as shown in Figure 3. Therefore, for improved thermal performance ETTV value should be reduced as much as possible, which can be done by using building material with better thermal resistance, using insulations, minimizing solar heat gains through windows by using better glazing materials as well as by optimizing window to wall ratio (WWR). The use of hollow bricks and keeping air gap inside the wall are two most cost-effective methods to reduce thermal heat gains through wall. This study has observed that by using such interventions can reduce ETTV values between 16-21%.

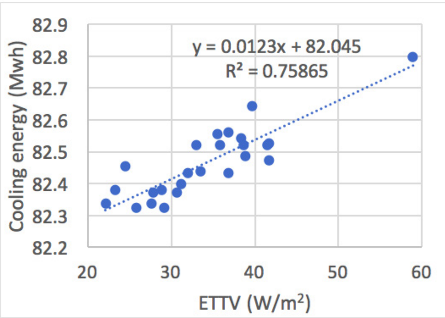


Figure 3: Cooling energy variation with ETTV

Window to wall ratio (WWR)

In addition to the effect on ETTV, windows directly affect the lighting energy loads of the building. One of the main advantage of windows are, their ability to provide daylighting to the building. However, increased WWR can increase the solar heat gains affecting negatively to the building cooling energy loads. Figure 4 shows building cooling and lighting energy variation for selected WWRs of the building. According to EEBC WWR should not increase 40%. By analysing cooling and lighting energy loads, the optimum WWR can be found for a particular building.

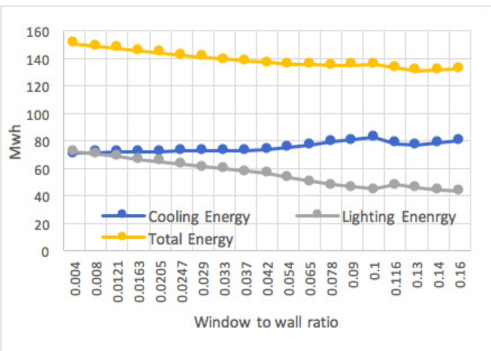


Figure 4: Effect of WWR on building energy loads

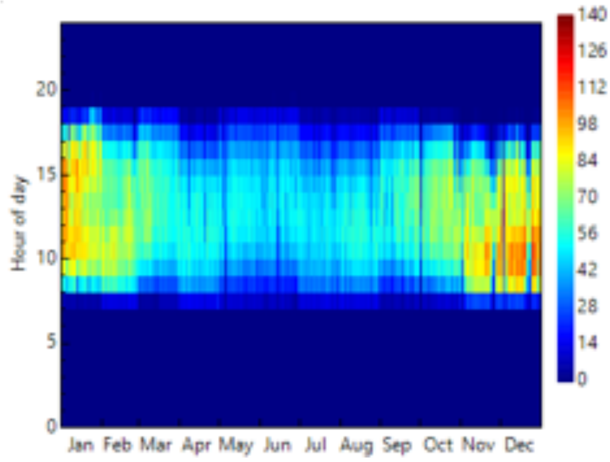


Figure 5: Amount of daylighting (lux) received to a selected room of the building

Especially when it comes to institutional buildings, daylighting can save significant amount of energy due to the fact that they use extensive amount of electric lighting. Figure 5 shows the amount of daylighting received by one of the building rooms throughout the year. During the mid-year daylighting is reduced due to the sun being closer to the equator which makes solar altitude closer 90 0.

Effect of window overhangs

Window overhangs are used to minimize the solar heat gains through windows. Overhang depth is calculated according to the sun path diagrams. Using eQUEST and OpenStudio software packages building energy load variation with overhang depth can be modelled as shown in Figure 6. According to that increased overhang depth reduces the cooling energy loads. However, the relationship with lighting energy loads is quite the opposite.

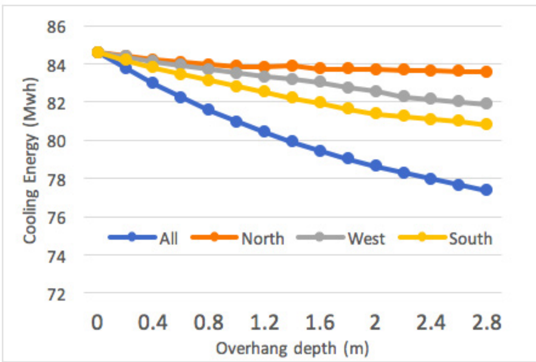
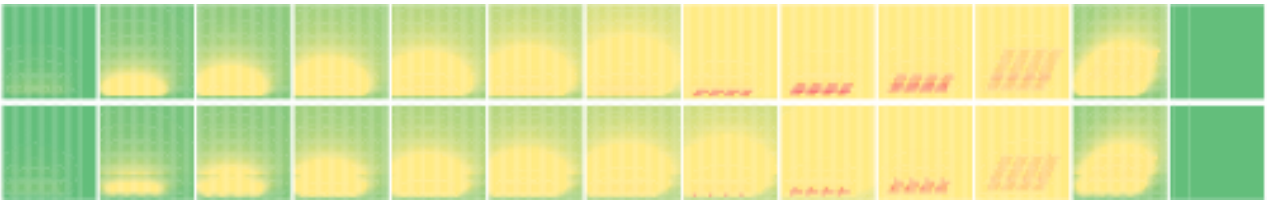


Figure 6: Effect of window overhang depth and direction

Further, the Figure 6 shows that south facing walls are mostly affected by overhang depth. This is mainly due to the higher WWR of the south wall. Figure 7 shows how the room is affected by daylighting and window overhang depth. Daylighting effect of Figure 7.a is slightly lower than that of Figure 7.b due the effect of overhangs. Further Figure 8 shows the daylighting variation of south facing wall and west facing wall. The graphs clearly illustrate that during the morning west wall has lower daylighting effect and during the evening daylighting effect has increased significantly.

The current findings under this study clearly indicate the importance of properly analyzing the envelope thermal performance and identifying design interventions to improve envelope thermal performance. Further these intervention decisions need to be improved integrating life cycle thinking approach, which will be covered in the next phase of the study.



6 am 7 am 8 am 9 am 10 am 11 am 12 am 1 pm 2 pm 3 pm 4 pm 5 pm 6 pm

Figure 7: Effect of daylighting modelled using OpenStudio (the room has 4 windows facing west); a). Room with 2ft window overhang length; b). Room with no window overhang

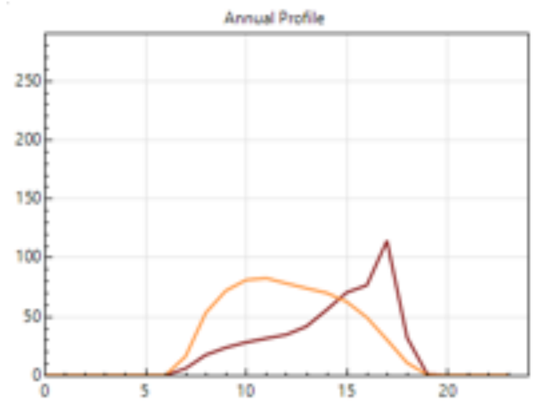


Figure 8: Annual profile of daylighting for south facing wall (orange) and west facing wall (red) of the building

The findings from this research project will support the enhancement of the building sector sustainability in Sri Lanka, while also providing a much-needed evidence-based framework for low-impact and energy efficient building construction for maximum triple bottom line benefits in Sri Lanka. The study also supports the climate action targets of the country and the National Research and Development Framework that aims for energy demand reduction and emissions mitigation.

References:

[1] National Renewable Energy Laboratory, "Strategy Guideline: Energy Retrofits for Low-Rise Multifamily Buildings in Cold Climates," Denver, 2013.

[2] I. El-Darwish and M. Gomaa, "Retrofitting strategy for building envelopes to achieve energy efficiency," Alexandria Eng. J., vol. 56, no. 4, pp. 579–589, 2017, doi: 10.1016/j.aej.2017.05.011.

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[4] R. G. R. N. . Ariyaratne, H. . Karunathilake, and H. K. . Punchihewa, "Effect of envelope energy performance enhancement strategies on building energy loads: Case study for a tropical institutional building," in 2022 Moratuwa Engineering Research Conference (MERCon), 2022, pp. 1–6, doi: 10.1109/MERCon55799.2022.9906180.

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