Use of Energy Modelling for Promoting Energy Performance in Buildings

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Overview

The global building and construction sector accounted for almost 36% of final energy use and 40% of carbon dioxide emissions in 2018 [1, 2]. Final energy use in buildings has increased from 118 EJ in 2010 to approximately 128 EJ in 2019 [4]. It is predicted that the energy demand in buildings will continue to grow around 3% per year mainly due to improved access to energy and increase in the floor area of buildings [3]. Space cooling and electrical appliance usage are the main building end-use factors driving electrification in the buildings sector [4]. According to IEA [4], electricity accounted for one third of the energy consumption in buildings in 2019. Fossil fuel use increased at a very marginal annual average rate of 0.7% since 2010. As a result, direct emissions from the buildings sector reached approximately 3 Gigatonne of CO₂ in 2019, which is almost a 5% increase since 2010. If appropriate action is not taken to improve the energy performance of buildings, energy demand in the global buildings sector could increase by another 50% by 2050 [1]. It is observed that approximately 80% of this growth has taken place in developing countries and emerging economies. There is plenty of room in these countries for improving the energy performance of buildings. In this context, there is high emphasis on enhancing the energy performance and resource utilization in buildings. The ever-increasing energy demand in buildings has made energy efficiency and energy conservation a priority in formulating the energy policies in most nations around the world.

Approaches for Enhancing Energy Performance

Approaches adopted to enhance energy performance in buildings fall into two generic categories: prescriptive and performance-based. In the prescriptive approach, every individual component of the proposed building should meet a prescribed minimum energy requirement. This includes building envelope, heating, ventilation and air-conditioning (HVAC) equipment, lighting system, water system, power supply and auxiliary equipment. In the performance-based approach, the analysis is

based on stipulated performance metrics established by pre-determined methods. This approach mainly applies to building performance modelling and computational tools. The performance-based approach considers estimation of peak design loads, calculation of lighting and receptacle power allowance, estimation of annual energy consumption, parametric analyses and energy efficiency measures. Energy Modelling is considered as one of the state-of-the-art performance-based tools that has gained a wider acceptance in the building sector.

The performance-based approach is normally completed with a verification process which complies with verification protocols considered as best practice.

Energy Modelling

Energy modelling is carried out based on the concepts of energy and mass conservation in a building. This is an approach that can analyse thermal aspects, daylighting, moisture, acoustics, airflow and indoor air quality of buildings (Mumovic & Santamouris, 2009). This facilitates designers, engineers and architects to understand the behaviour of complex building systems. This provides access to detailed information on its energy performance. In energy modelling, inputs are received from different sources as shown in Figure 1.

Figure 1: Inputs for the Energy Modelling Process [5]

In energy modelling, the geometry of the building is represented by a solid model or by a

computer-aided drafting (CAD) format. It is divided into several thermal zones to facilitate the modelling of different components and processes. Properties of construction materials, glazing and shading aspects are also given as inputs. Internal and external loads are necessary to conduct an energy balance in a particular thermal zone. External loads are strongly influenced by weather conditions of the building location and hence weather data is used in the energy modelling process. Internal loads of the building include thermal and electrical loads for lighting, occupancy and equipment. Eventually, simulations are carried out to predict the energy consumption of the building for a specified period, generally for a year.

Case Study: Design of an Energy-Conserving Building Envelope

The conceptual design of a single-storey building has overall dimensions of 12.0 m x 14.0 m x 3.5 m. The building is intended to be constructed in the Ratmalana area. The envelope design is in compliance with the relevant prescriptive standards imposed by the respective local authority. The computational model of the same is shown in Figure 2. The model is comprised of two thermal zones. Thermal and electrical loads of the building are given in Table 1.

Figure 2. Computational model of the building (Bandara & Attalage, 2014)

Table 1: Thermal and Electrical Loads of the Building

Load or System	Rating and Description
Occupancy	20 occupants involved in general office work with a specified occupancy schedule
Heating	Liquefied petroleum gas-fired boiler system with a seasonal efficiency of 85%
Cooling	Direct application of electrical energy using DX units
Temperature control	Dual set point, where 20 °C for heating and 25 °C for cooling
Rated artificial lighting	400 W (3.33 W/m ²)
Rated electrical equipment	1 kW (8.33 W/m ²)
Building lighting control mechanism	Continuously dims artificial lights to match an illumination set point of 400 lx at two reference points at a working plane of 0.8 m above the floor level, with the variation of daylight

Construction details of the building envelope are given in Table 2.

Table 2: Construction Details of the Building Envelope

Element	Construction Details
Walls	9-inch-thick brickwork
Pitched Roof	Pitch angle of 15° with 25 mm thick Calicut tiles
Slab	150 mm thick reinforced concrete slab
Floor	10 mm thick ceramic tiles on a 150 mm thick reinforced concrete slab
Doors	Each of 1.1 m x 2.0 m, made of plywood
East side Windows	Two 3.0 m x 2.0 m double pane windows with 4 mm thick glass and 2 mm thick air space. There exists 0.2 m of wall below the windows and 0.5 m of wall above the windows. The edge of the two windows is located 1.5 m and 2.5 m from the corresponding wall edge respectively.
West side Window	3.0 m x 2.0 m double pane window with 4 mm thick glass and 2 mm thick air space. There exists 0.2 m of wall below the window and 0.5 m of wall above the window. The edge of the window is located 2.5 m from the wall edge.

South side Window	3.0 m x 2.0 m double pane window with 4 mm thick glass and 2 mm thick air space. There exists 0.2 m of wall below the window and 0.5 m of wall above the window. The edge of the window is located 3.0 m from the wall edge.
Shading overhangs on all windows	Depth 0.5 m with 0.1 m height above the window. Tilt angle is 90°.

Table 3 compares the values of envelope variables related to the two approaches.

Table 3: Comparison of Values of the Envelope Variables

Envelope Element	Value of Variable	
	Prescriptive (Base Case)	Energy Modelling
Building Azimuth Angle (°)	0	99
Window-to-Wall Ratio (WWR) (%)	20.9	5.0
Horizontal position of east window 1 (m)	1.50	2.50
Vertical position of east window 1 (m)	0.20	0.80
Horizontal position of east window 2 (m)	8.50	9.50
Vertical position of east window 2 (m)	0.20	0.80
Horizontal position of west window (m)	8.50	9.50
Vertical position of west window (m)	0.20	0.80
Horizontal position of south window (m)	3.00	4.00
Vertical position of south window (m)	0.20	0.80

Table 4 shows a comparison between the annual energy consumption of the prescriptive design and that of Energy Modelling.

Table 4: Comparison of Annual Energy Consumption

Approach	Annual Energy Consumption (kWh)				Saving (%)	PMV**
	Energy for Cooling	Energy for Heating	Energy for Lighting	Total Energy Consumption*		
Prescriptive (Base Case)	41,880.6	0.9	683.3	42,563.9	-	0.43
Energy Modelling	39,402.8	0.9	752.8	40,155.6	5.7	0.39

*Total annual primary energy consumption for heating, cooling and lighting

**Predicted Mean Vote of the occupied space
Table 4 shows that it is possible to save 5.7% of the total energy consumed annually by the design produced through energy modelling compared to the base design recommended by the prescriptive approach. Furthermore, the new envelope design has marginally improved the average thermal comfort of occupants as well. The case study presented here was limited only to the building envelope. Hence, it is evident that it is possible to achieve substantial savings through the energy modelling approach while meeting the design intent.

Conclusion

The prescriptive approach is expected to meet the minimum performance levels whereas the Energy Modelling approach has a potential to optimize the performance of buildings. Through energy modelling substantial savings can be achieved. The case study presented in the paper elaborated only a fraction of the capability of Energy Modelling. However, it demands mastering of the competencies relevant to modelling and computational tools to make use of its full potential. Hence, Energy Modelling can highly contribute to uplift the Sri Lankan buildings sector, which is identified as a key area for national development. The real-life cases should have the verification process incorporated into the process.

References

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