Abstract

The inexorable rise in population combined with economic prosperity is driving a fast and unavoidable wave of urbanization, particularly noticeable in developing nations. Due to higher population density and scarcity of available land, high-rise residential and commercial buildings are now increasing in big cities. India too has seen a significant rise in high-rise residential buildings as these cater to the increasing city population density. Building energy efficiency has eventually emerged as a critical issue for such buildings. Energy consumption in these high-rise buildings can vary significantly depending on factors such as location, climate, overall design, construction materials, occupancy, the efficiency of electro-mechanical systems used for building services, and several others. Space cooling for occupants' thermal comfort consumes a major share of energy for high-rise buildings in tropical countries. A review of the scientific literature has revealed 158 country-initiated policy measures to improve energy efficiency in the building sector. In India too, the Bureau of Energy Efficiency (BEE), initiated Energy Conservation Building Codes (ECBC) in 2007 to enhance building energy efficiency in the country. ECBC, 2017 for commercial buildings and Eco-Niwas Samhita, 2018, (Part-I) and Eco-Niwas Samhita, 2021, (Part-II) for residential buildings are the latest codes introduced in India.

Anticipating the enormous potential of energy savings in energy-intensive urban residences, the present study attempts to assess the energy performance improvement potential of typical high-rise residential apartment buildings using early design stage strategies in the warm-humid climate of Kolkata. To determine the optimized solution, the methodology followed is an integrated iterative process involving whole-building energy simulation, parametric analysis, and statistical analysis. The uncertainty in the variables influencing energy performance is probed into through sensitivity analyses. Monte Carlo simulation is used to deal with the risks involved in different variables during techno-economic analysis.

Studies have been carried out to assess the extent of possible improvement in the energy performance of typical high-rise residential buildings of Kolkata through the implementation of Eco-Niwas Samhita, 2018 (Part-1) and ECBC, 2017. The results demonstrate the substantial savings potential in overall operational energy consumption (8-26%) and even more in cooling energy consumption (11-36%) for high-rise residential buildings by adhering to these standards. Statistical association of the energy performance with different variables regarding building geometry and envelope material properties is also investigated. Residential envelope transmittance value (*RETV*), roof thermal transmittance value (U_{roof}), and visible light transmittance (*VLT*) amongst envelope material properties and Roof area (A_{roof}), and Envelope area ($A_{envelope}$) amongst building geometry parameters are identified as the key influencing factors. The critical factors influencing energy performance are identified through sensitivity analyses. It identifies that the thermal properties of the envelope materials (in terms of *RETV*) and the efficiency of the HVAC systems (in terms of *EER*) are going to play critical roles in cooling energy optimization.

The combined energy efficiency and environmental performance study compared the operational and embodied energy performance and associated greenhouse gas (GHG) emissions for typically practiced exterior wall assembly materials along with recent research trends for sustainable alternatives. Autoclaved aerated concrete block (AACB) walls demonstrated the highest energy efficiency and GHG emission reduction among alternatives, with a 10% operational and 13% overall improvement in energy performance and a 10% operational and 10% overall decrease in GHG emissions compared to existing typically practiced burnt clay brick walls. Fly ash brick and AACB walls displayed moderate

enhancements in embodied energy performance compared to brick walls, indicating their potential as viable alternatives with improved sustainability characteristics. Conversely, dense concrete block walls and solid burnt clay brick walls exhibited the poorest performance in terms of energy efficiency and GHG emission reduction.

The choice of external wall materials and its construction layer, paired with the corresponding air conditioning system as active cooling integration, is optimized for the best energy efficiency while minimizing cost for high-rise developments. This energy-cost optimization study confirms that the combination of autoclaved aerated concrete block (AACB) wall and 5-star split air conditioner emerges as the optimum, being 38% more energy efficient and 24% more cost-effective than the typically practiced baseline option. The required initial higher capital investment is well compensated for lower annual expenditure for operational energy when fifteen years' cash flow is considered.

Finally, the outcomes of this thesis have the potential to contribute to the possible design strategies and show pathways for low-energy, low-carbon, and economically feasible high-rise buildings. The final outcome also contributes to a deeper comprehension to align design practices with regulatory codes from the outset and highlight the importance of embodied energy for further code improvement.