Baseline Scenario of Energy Consumption of Urban Multi-Storey Residential Buildings in India

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KEY WORDS:
Urban residential buildings, Energy monitoring, Energy Performance Index

ABSTRACT:

This paper presents results of monitoring of energy consumption in sample urban residential buildings in India. The work was carried out under the Indo-Swiss Building Energy Efficiency Project (BEEP) as background research leading to the development of energy efficiency guidelines for the design of new residential buildings in the composite and warm-humid climatic regions of India.

The work involved:

a) Collection of monthly energy consumption data for a period of 1-year for 732 households in Delhi-NCR (composite climate) and 426 households in Chennai (warm-humid climate).

b) Detailed monitoring of four residential flats (two each in Delhi and Chennai) for one year duration. The monitoring included: discrete logging of hygrothermal properties of individual rooms & ambient conditions; electricity consumption of comfort conditioning equipment like fans, desert coolers and air-conditioners.

c) Analysis of the collected data to calculate Energy Performance Index 1 (EPI), monthly energy consumption profiles, share of energy consumption for comfort conditioning etc.

The information from the analysis of monthly energy consumption data and monitoring campaign is intended to be used to define inputs and validate outputs of energy simulation models for typical residential flats in the two climatic regions. The energy simulation models will be further used to evaluate the potential of passive and active strategies for reducing energy consumption and improving thermal comfort in the residential buildings.

1 Energy Performance Index (EPI) for the analysis in the paper is defined in terms of annual purchased electricity (in kWh) divided by built-up area (in m²) of the flat. The built-up area includes covered area of the flat and does not include balcony areas, semi-covered areas and common areas like lifts and lobbies etc.
INTRODUCTION

India is experiencing an unprecedented urbanization due to the cities transforming into economic hubs. According to 2011 census data, about 31% of the India’s population was residing in the urban centers, and this percentage is expected to increase to 40% by 2030. It is estimated that the total constructed built-up area would increase from 8 billion square meters in 2005 to 41 billion square meters in 2030 (about 5 fold increase) (Mckinsey & Company, 2009). This situation is significantly different from the developed countries, where bulks of the buildings are already constructed. This provides both challenges and opportunities to building sector stakeholders to develop this building stock appropriately.

As per CEA report (CEA 2005), residential sector consumes 21% of the total electricity generated in India, which is about 3 times more than that of commercial buildings. One of the reasons for this is that the built-up area of residential buildings is about 7 folds more than that of commercial buildings (Mckinsey & Company, 2009). The energy use intensity of the residential buildings is expected to grow because of increase in air conditioned area, better access to electricity and increase in ownership and usage of appliances.

There is an inevitable rise in the density of residential urban development due to scarcity of land and the desire to curtail suburban sprawl. It is now common for city planning authorities to encourage Floor Space Index (FSI) of up to 4; FSI of 1.5 to 2 is becoming commonplace. As per census data, urban residential household will increase by ~2 folds from 2014 to 2032; Greentech Knowledge Solutions Pvt. Ltd. based on EMPORIS (EMPORIS data, 2014) data projected that during this period the share of highrise building will increase by ~ 5 folds.

CONTEXT AND METHODOLOGY FOR DEVELOPING THE GUIDELINES

The guidelines for residential buildings design will focus on the recommendations for the reduction of operational energy, reduction of embodied energy and improvement of thermal comfort of the residents. The flowchart showing the complete methodology for development of design guidelines for residential buildings is shown in Figure 1. The work presented in this paper concerns only with the monitoring and analysis of monthly energy consumption and is highlighted in grey boxes in Figure 1.

Monthly energy consumption data for one year duration was collected from 732 residential units in Delhi - NCR (from 4 residential complexes) and 426 residential units in Chennai* (from 6 residential complexes) to understand the baseline scenario of energy consumption in the composite climate (represented by Delhi-NCR) and warm-humid (represented by Chennai). The composite2 and warm-humid3 climatic regions of India. This constitutes almost two third of the total geographical area of India (see Figure 2).

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2 As per National Building Code 2005, “Climatic zone that does not have any season for more than six months may be called as composite zone”. In India, composite climate is characterized by hot summer season and moderate winter season.

3 As per National Building Code 2005, “Warm-humid climate are characterized by two factors: monthly mean maximum temperature (MMMT) and mean monthly relative humidity (MMRH) percentage. e.g. MMMT above 30 °C with MMRH of above 55% and MMMT above 25 °C with MMRH of above 75%
Figure 1. Flowchart showing approach for development of design guidelines for residential buildings under Indo-Swiss Building Energy Efficiency Project (BEEP)
The selected residential complexes were multi-storey apartment buildings of 3 to 15 storeys. The built-up area of residential units ranged from 80 m² to 130 m². The residential units were having 2 or 3 bedrooms and a drawing/dining room. The residents of these houses primarily represents middle and middle upper income group of India.

A mathematical model was used to filter monthly electricity consumption values, which were either too high or too low. After data filtering, 89% of the data from the residential units in the composite climate and 90% of the data from the warm-humid climate was considered for further analysis. The filtered data was statistically analyzed in terms of Energy Performance Index (EPI) distribution, monthly energy consumption profiles, share of electricity for space comfort conditioning. Time series data (for 2 years) from one of the residential complexes in Delhi was used to infer the trend of energy consumption.

Subsequent to the collection of monthly electricity data, a monitoring campaign was carried out in the four selected residential units (two each in Delhi and Chennai). The monitoring included discrete logging of space and ambient hygrothermal conditions and energy consumption monitoring of space comfort conditioning equipment (Figure 3).

Information from the monthly energy consumption data analysis and monitored data will be used to define inputs and validate outputs of the baseline energy simulation models for both the climatic
zones. Potential of individual and group of strategies will be evaluated by conducting parametric runs on baseline simulation models. Inferences drawn from the simulation analysis and recommendations for reducing the energy requirements for common facilities will be used to formulate climate specific design guidelines for reducing operational energy and improving thermal comfort in the residential buildings.

This paper discusses the baseline scenario of energy consumption of urban residential buildings in both composite and warm-humid climatic regions of India.

RESULTS AND ANALYSIS

A. Results of analysis of monthly electricity consumption data for sample flats in composite and warm-humid climates

Figure 4(a) and 4(b) shows EPI distribution graphs for residential units belonging to composite and warm-humid climates. The mean EPIs for residential flats in composite and warm-humid climate are calculated as 48 kWh/m².year and 43 kWh/m².year respectively.

Figure 4(a) EPI distribution of residential units in the composite climatic region

Figure 4(b) EPI distribution of residential units in the warm-humid climatic region

Figure 5 shows average monthly energy consumption profile of two residential complexes, one each in composite (78 residential units) and warm-humid climates (243 residential units). The monthly electricity consumption for the residential complex in composite climate shows steep increase in energy consumption during the summer and monsoon months (May-August). This is attributed to the operation of comfort conditioning equipment. November can be considered as base month\(^4\), when the need for comfort cooling or heating is minimum.

Monthly electricity consumption for the residential complex in warm-humid climate (Figure 5) shows a flatter profile during April to November, with peak appearing during the June and July months. This is due to extended warm and humid seasons, when comfort conditioning is required. December and January can be considered as base month when the requirement for comfort cooling or heating is minimum.

EPI range distribution for both composite and warm-humid climate (Figure 6(a) & 6(b)) shows that 16% of the residential units in the composite climate and 22% in the warm-humid climate have a high EPI of more than 70 kWh/m².year.

\(^4\)“Base month” is the month during which there is almost no comfort cooling or heating requirements in the climatic region. During this time the energy consumption will be from refrigerator, lighting, washing machine, electric geysers, kitchen appliances, TV, computers, etc.
Figure 5 Average monthly energy consumption profiles of two residential complexes in composite and warm-humid climates

Figure 6(a) EPI range distribution for residential units in composite climate

Figure 6(b) EPI range distribution for residential units in warm-humid climate

Time series energy consumption data for year 2007 and 2009 was collected for one of the residential complexes (78 residential units) in Delhi. Figure 7 shows that there is an increase in the average EPI of the complex by 16% in the year 2009 compared to 2007. This increase in average EPI is primarily attributed to the increase in energy consumption (by 20%) during the summer and monsoon periods (April to September). This reflects higher ownership and use of air-conditioning equipments with the increase in disposable income and availability of easy financing options and an aspiration for higher comfort.

Figure 7 Time series plot of a residential complex in Delhi
7(a) Mean EPI
7(b) Cumulative energy consumption per flat for summer and monsoon months (April-September)
Figure 8(a) & 9(b) show that there is an increase in average EPI of residential units with the increase in ownership of number of air-conditioners in both composite and warm-humid climates respectively. There is an overall trend of increase in number of residential units with higher EPI.

![Figure 8(a) Distribution of average EPI with respect to air conditioners ownership for residential units in composite climate.](image)

![Figure 8(b) Distribution of average EPI with respect to air conditioners ownership for residential units in warm-humid climate.](image)

**B. Results of detailed energy monitoring in three flats of the composite climate**

Analysis of energy consumption in 3 flats in the composite climate: a) Flat A having a below average EPI (in the range of 30 to 40) b) Flat B having an above average EPI (in the range of 60 to 70), and c) Flat C having high EPI (> 70EPI) is presented below:

Figure 9 shows monthly energy consumption and monitored energy consumption for comfort conditioning equipment for Flat A in Delhi. This flat used convective ceiling fans from mid-March to mid-October, 2 evaporative desert coolers were used from April to June and 2 air conditioners were used from June to July. The EPI of this flat was 35 kWh/m².year. Monitored data shows that almost 33% of the annual energy consumption is attributed to operation of comfort space conditioning equipment. Balance, 67% of the electricity (referred in this paper as base energy consumption i.e. energy used for purposes other than comfort cooling) is used for refrigerator, lighting, washing machine, electric geysers, kitchen appliances, TV, computers, etc.

![Figure 9 Monthly energy consumption profiles for below average EPI in composite climate.](image)

Figure 10 shows monthly energy consumption of two more residential units in the same residential complex. Residence-B uses 2 air-conditioners predominantly for comfort cooling and have an EPI of 65 kWh/m².year (~1.8 times compared to Residence-A). Residence-C with 4 air conditioners have an EPI of 117 kWh/m².year (~3.3 times compared to Residence-A). If energy consumption during February is
considered as base energy consumption\(^5\) for Residence B and Residence C, then the contribution of energy consumption for comfort space conditioning can be as high as 38% for Residence B and 65% for Residence-C.

**Figure 10** Monthly energy consumption profiles of three residential units in composite climate

**CONCLUSIONS**

a) The mean EPIs for sample residential flats of 2-3 bedrooms in composite (732 flats) and warm-humid climate (426 flats) for the year 2009 are calculated as 48 kWh/m\(^2\).year and 43 kWh/m\(^2\).year respectively

b) Energy consumption for comfort cooling is a significant part of the electricity consumption. Detailed analysis of energy consumption in three sample flats shows that the contribution of energy consumption for comfort space conditioning, increases with the increase in EPI (and increased usage of air-conditioners) and for the three flats was estimated to vary between 33% to 65% of the total energy consumption.

c) Analysis of time-series data for one residential complex for 2007 and 2009 shows 16% increase in average EPI, which indicates towards the trend of increase in energy consumption in the urban residential buildings d) Detailed energy consumption monitoring of a flat, which utilizes a combination of fans, evaporative coolers and ACs for cooling, shows potential of large energy savings by appropriate and energy-efficient use of comfort cooling appliances.

With bulk of the construction in building sector bound to happen in housing sector in the next two decades, there is an urgent necessity for guidelines for designers to effectively integrate the potential strategies for reducing energy consumption and for augmenting thermal comfort as well as guidelines for residents to use energy efficiently for space cooling.

**ACKNOWLEDGEMENT**

The authors would like to acknowledge the support of the Swiss Agency for Development and Cooperation and Bureau of Energy Efficiency, the two implementing agencies of BEEP, for support and guidance in the work on the development of energy efficient residential building design.

The authors would also like to acknowledge the contribution of Tara Nirman Kendra of Development Alternatives and Conserve Consultants Pvt. Ltd. for assisting BEEP in the collection of monthly energy consumption data and monitoring of residential units in Delhi-NCR and Chennai respectively.

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\(^5\) Base energy consumption is the energy consumption excluding the comfort space conditioning. This also excludes energy consumption for space heating.