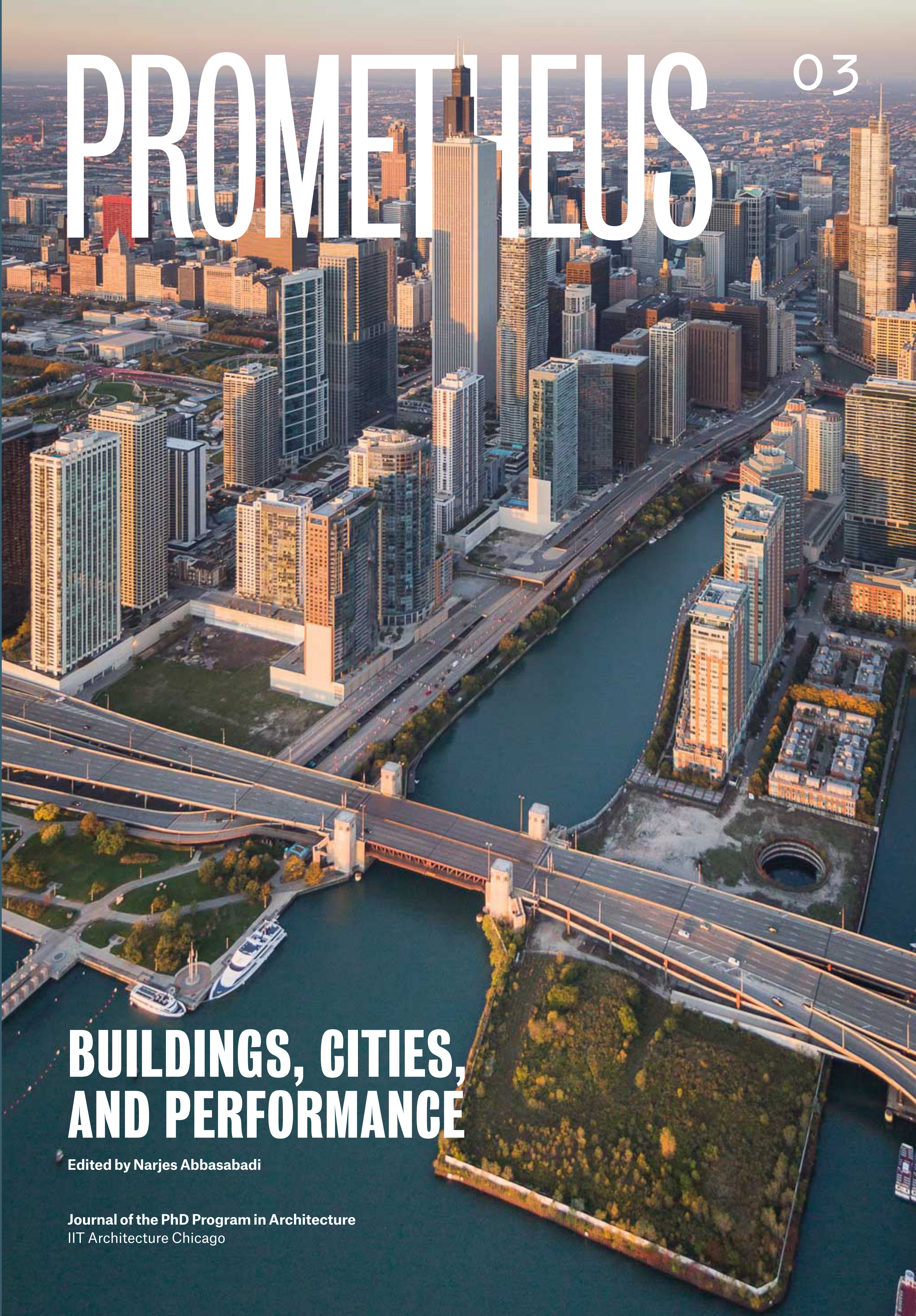

PROMETHEUS 03

BUILDINGS, CITIES, AND PERFORMANCE

Edited by Narjes Abbasabadi

Journal of the PhD Program in Architecture
IIT Architecture Chicago

PROMETHEUS BUILDINGS, CITIES, AND PERFORMANCE

03
IIT

DEVELOPMENT OF ENERGY PERFORMANCE INDEX BENCHMARK FOR COLD CLIMATIC REGIONS OF INDIA

Performance based building rating systems help build energy-efficient structures while also serving as a tool to assess the efficiency of the existing structures. In 2009, the Bureau of Energy Efficiency, Government of India, launched the Building Star Rating Program for office buildings, devising a scheme based on data collected from about 300 office buildings in three climatic zones, namely warm and humid, hot and dry, and composite. The program uses the Energy Performance Index as a key performance indicator for benchmarking. Moreover, with booming urbanization rates in the Himalayas, which covers a major portion of Indian cold climate, it is critical to adapt the rating systems to these regions in order to promote sustainable development and practices. But the lack of audit data in Indian cold climatic regions makes it impossible to develop such a benchmark using conventional methods. This paper discusses Simulation Model-based benchmarking for energy performance using simulation tools with multiple variables controlled under limits prescribed by the Energy Conservation Building Code. A total of 216 simulations were conducted after varying multiple data sets for four variables, namely location, window-to-wall ratio, envelope material quality, and equipment efficiency. The project established the energy performance benchmark for cold climatic regions of India and concluded that the Indian cold climate did not represent uniform traits all over but was divided into several climate zones.

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Keywords

Energy Performance Index, cold climate, energy simulation, Simulation Model-based benchmarking, sustainable development

Introduction

The average global temperature has increased by 0.85ºC from 1880 to 2012 leading to an increase of 19cm in the global average sea level (“Sustainable Development Goals: 13,” 2018). Each of the last three decades has been significantly warmer than the previous decade. The data observed for many years is more than enough to establish that warming of the climate is unequivocal (Pachauri & Meyer, 2014). It has been observed that over 75% of carbon emissions are contributed by cities, while they occupy roughly 3% of earth’s land (“Sustainable Development Goals: 11,” 2018). And the urban population is increasing at a rapid pace with India’s urban population growth from 286 million in 2001 to 377 million in 2011, and is expected to shoot to 850 million by 2051 (“Statistical Report,” 2013; “Urban Statistics,” 2016). Hence for India, it is critical to address the climate change in the urban and neo-urban regions which will play a crucial role in sustaining India’s high economic growth rates in the future (Ahluwalia et al., 2011).

The Himalayas cover the majority of cold climatic regions of India and despite the difficulties posed by the mountainous terrain, the region has had population growth rates as high as 23.71% in Jammu and Kashmir between 2001 and 2011 (Gupta, 2014). Thus it is equally important for India to address climate change and carbon emissions in these urbanizing cold climatic regions.

Energy benchmarking and performance based rating set practical targets developed via scientific methodology for new buildings while also helping to evaluate performance of existing buildings. In India, the energy benchmarking for commercial buildings was initiated by the Bureau of Energy Efficiency in 2009. The Building Star Rating Program, which uses the Energy Performance Index (EPI) as a key performance indicator, sets energy benchmarks for offices and IT buildings based on data collected from about 300 office buildings for warm and humid, hot and dry, and composite climate zones, and rates their performance on a scale of 1–5 stars (Sarraf et al., 2014). The program aims to improve the design, construction, maintenance, and operation of buildings by setting meaningful energy performance targets, and recognizing and rewarding exemplary performing buildings to consistently improve the standards through healthy competition and shifting markets to better performing levels (Hicks & Neida, 2005). According to Kumar et al. 2010), a database of existing buildings along with their energy consumption and related parameters is a prerequisite for any performance based rating. However, due to a lack of audit data in the cold climate regions of India, it is impossible to develop an energy performance benchmark using conventional methods.

Cold Climate of India

There are various definitions of cold climate in Indian codes and literature. The SP: 41 – 1987 states, “Regions, where mean daily minimum dry bulb temperature is 6ºC or less prevail during the coldest month of the year and where the altitude is more than 1200m above mean sea level, may be classified as cold zones,” and provides a list of representative cities for cold climate which includes Darjeeling, Dras, Gulmarg, Leh, Mussoorie, Nainital, Ootacamund (Ooty), Shimla, Skardu, and Srinagar (“SP: 41 [S&T],” (1987).

Climate	Mean Monthly Temp. (°C)	Relative Humidity (%)	Precipitation (mm)	No. of clear days
Cold & Cloudy	<25	>55	>5	<20
Cold & Sunny	<25	<55	<5	>20

Table 1: Bansal and Minke classification of Indian cold climate.

The National Building Code 2016 defines cold climate as regions with Mean Monthly Maximum temperature below 25ºC at all values of relative humidity for over 6 months in a year (“SP: 7,” 2016).

Bansal and Minke have (1988) defined cold climate based multiple factors viz. temperature, humidity, precipitation, and sky condition lasting for over 6 months in a year. They have classified cold climate into two sub-categories namely cold and cloudy, and cold and sunny. The classification is shown in Table 1.

R. Dubey et al. have argued that under circumstances, it is necessary to capture the climatic difference between cold and cloudy and cold and sunny climate zones suggesting that climate zone classification system of Bansal & Minke is more effective than the classification system of the National Building Code (Dubey et al., (2016).

Methodology

There are mainly four types of benchmarking techniques viz. Regression Model-based Benchmarking, Points-Based Rating Systems, Simulation Model-Based Benchmarking, and Hierarchical and End-Use Metrics (Nikolaou, 2015). This paper discusses Simulation Model-Based Benchmarking using the DesignBuilder Software Ltd. simulation tool. Weather data files for six cities spread across cold climatic regions of India were used for energy simulations viz. Dras, Srinagar, Sundernagar, Mukteshwar, Shillong, and Kodaikanal. Four variables that majorly affect the energy performance of a building, namely location, window-to-wall ratio (WWR), thermal efficiency of building envelope material, and electrical efficiency of electrical equipment, were varied under limits specified by the Energy Conservation Building Code (ECBC). The WWR ranged from 25% to 55%. The thermal and electrical efficiencies of building envelope material and electrical equipment were varied between maximum or minimum limits prescribed for ECBC Compliant buildings, ECBC Plus buildings, and Super ECBC buildings (“Energy Conservation Building Code,” 2017). Figure 1 illustrates the permutations of all simulations conducted. A total of 216 different scenarios were simulated to obtain EPI for each scenario.

According to GRIHA V – 2015, EPI is defined as the total annual energy consumed by HVAC system and interior lighting per unit built-up area (“GRIHA Version 2015,” 2015). This definition of EPI has been used in this paper.

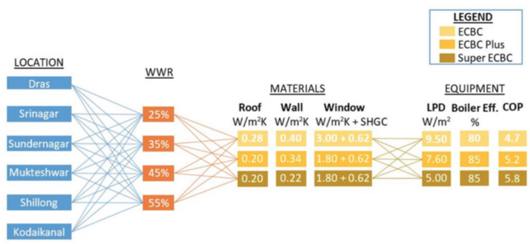

Figure 1: Run chart for permutations of simulation.

Technical Specifications

The thermal and electrical efficiencies for building material and equipment, respectively, are shown in Figure 1. Conventional materials were chosen for building envelope with U-value specified as per the maximum limit prescribed by ECBC shown in Figure 1. The material for the external wall and roof are shown in Figures 2 and 3, respectively.

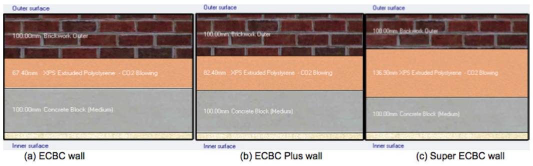

Figure 2: Material specification for the external wall.

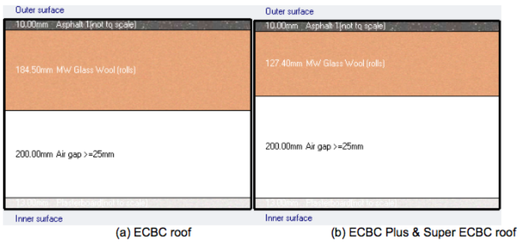

Figure 3: Material specification for roof.

The HVAC system was set as Variable Air Volume system with 100% conditioned zones. The thermal efficiency of boiler and COP of chiller were changed according to minimum limit set by ECBC (Figure 1). Table 2 gives the specifications of the HVAC system.

Parameter		*Specification*
HVAC System Type		VAV Reheat Chiller Cooled by Fluid Cooler
AHU	Fan efficiency	70%
	Capacity	766481.75 W
	Sensible eff. of Heat recovery	75%
Boiler	Type	Gas-fired condensing boiler
	Capacity	319535.33 W
	Pump configuration	Variable flow
Chiller	Type	Water-cooled Centrifugal chiller
	Capacity	99999.00 W
	Pump configuration	Variable flow
Condenser	Type	Vertical ground heat exchanger
	Capacity	50000.00 W
	Pump configuration	Constant flow

Table 1: The classification.

The building schedules were modelled as a daytime commercial building with occupancy for 8 hours a day and 5 days a week. Figures 4, 5, and 6 illustrate the occupancy, lighting, and heating and cooling schedules, respectively.

Figure 4: Occupancy schedule.

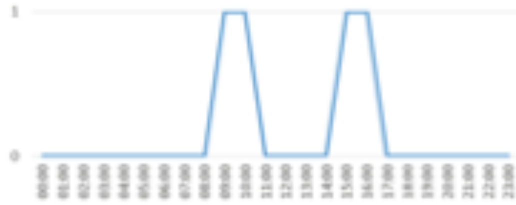

Figure 5: Lighting schedule.

Figure 6: Heating and Cooling schedule.

The other characteristics of the 3D model of the designed building are given below. The model at 25% WWR is shown in Figure 7.

— Dimension: 60x30x10.5
— Orientation: South facing
— Floors: G+2
— Zones: 9 (3 per floor)
— Typology: Commercial

Figure 7: 3D model of designed building at 25% WWR.

Results

The output from energy simulations was used to manually calculate the EPI value for all 216 scenarios to prevent changes in built-up area due to changes in wall thickness. The data points are shown for all locations in Figure 8. It was observed that with an increase in WWR, the heating load on the boiler decreases, while the mechanical ventilation load on the fan and pump increases. Similarly, with an increase in electrical efficiency of equipment, the heating load on the boiler increases, while the interior lighting load decreases. Also, the heating load on the boiler decreases with an increase in thermal efficiency of building material. Furthermore, it was observed that heating was the major component of energy consumption in Dras, while interior lighting was the major component for Srinagar, Sundernagar, Mukteshwar, Shillong, and Kodaikanal.

The EPI data set was plotted on a cumulative frequency curve separately for cold and cloudy (Figure 9)m and cold and sunny climate zones (Figure 10). Here, Dras was representative of the cold and sunny climate zone, and Srinagar, Sundernagar, Mukteshwar, Shillong, and Kodaikanal were representative of the cold and cloudy climate zone. The curves were plotted to derive median energy performance of all scenarios in a climate zone which was used to establish energy performance benchmark.

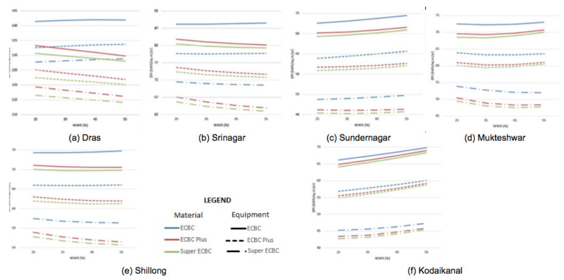

Figure 8: Energy Performance Index (EPI) vs. window-to-wall ratio (WWR) graphs representing 216 data points for all simulated scenarios.

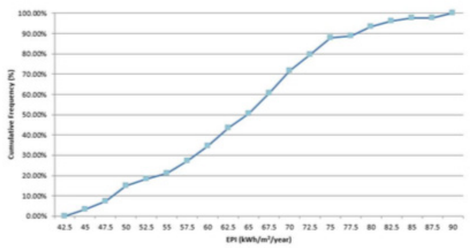

Figure 9: Cumulative frequency curve for cold and cloudy climate.

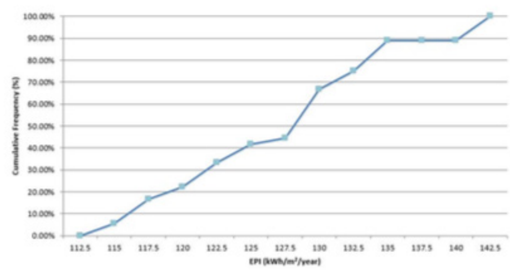

Figure 10: Cumulative frequency curve for cold and sunny climate.

Conclusions and Future Work

Energy performance benchmarking using EPI as a comparative indicator helps build more sustainable and energy-efficient structures. The main factor is consistently improving targets set through median method which sets the target according to the most occurring performance amongst a certain typology of buildings. For cold and cloudy climate zones, the EPI values for all scenarios were found to lie between 42–89 kWh/m²/year, while for cold and sunny climate zones they were found to lie between 114–142 kWh/m²/year. The drastic contrast between the energy performance under the same scenarios in cold and cloudy and cold and sunny climate zones establishes the need for separate benchmarking for both climate zones. Furthermore, it is recommended that a six zone classification for climate that deals with cold and cloudy and cold and sunny climate zones should be adopted by Indian standards and codes.

Following the definition of EPI by GRIHA V – 2015, the EPI benchmark for commercial buildings in cold and cloudy climate zones was established at 65 kWh/m²/year. Similarly, the benchmark for cold and sunny climate zones was established at 128 kWh/m²/year. It was observed that while the benchmark for cold and cloudy climate zone was lowest amongst benchmarks for all climate zones of India, the benchmark for cold and sunny climate was the highest. This implies at the magnitude of climatic difference between the two climate zones.

This is a first of its kind to attempt to establish energy performance benchmarks for cold climatic regions of India. The benchmarks will be compared to the actual performances of commercial buildings in respective cold climatic regions and accompanied by a feasibility assessment to gauge the cost implication of offsetting the benchmark for energy efficiency. Also, more locations representing a cold and sunny climate have to be included in the study; however, currently weather files are unavailable for such locations.

Acknowledgments

We would like to thank the Center for Research on Sustainable Building Science (CRSBS), and TERI for providing us with EnergyPlus Weather (EPW) files for Dras and Mukteshwar.

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