Analysis of energy efficiency improvement opportunities in hotels of Jaipur city

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This work is dedicated to my parents

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

This is to certify that the thesis entitled to "**Analysis of energy efficiency improvement opportunities in hotels of Jaipur city"** is being submitted by (**Mr. Rajesh Chedwal I D No. 2009RME102)** to the Malaviya National Institute of Technology, Jaipur for the award of the degree of **Doctor of Philosophy** in Mechanical Engineering is a bonafide record of original research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirement for the submission of this thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.

Date :

Jyotirmay Mathur **Ghanshyam Das Agrawal**

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(Rajesh Chedwal)

Abstract

Buildings are responsible for at least 40% of energy use in most countries, and the absolute figure is rising rapidly, as construction sector is booming due to economic growth in developing country like India. It is essential to act now, because buildings can make a major contribution to deal with climate change and energy use. In such scenario, it is imperative to invest in energy efficient building construction and reduce energy waste due to inefficient and high energy consuming building structures and equipment. To promote energy efficiency, various policy instruments have been in place since the 1970s. To curb energy consumption in buildings, the Indian government launched the Energy Conservation Building Code (ECBC) in 2007, which applies to commercial buildings with a connected load of 100 kW or 120kVA. Nevertheless, energy efficiency improvements still lag behind their potential in the building sector, which indicates that there is a lack of knowledge about the various technological options available to achieve building energy efficiency. To encourage energy efficiency in buildings, there is a need for research to gain knowledge and experience about the understanding of available technologies and their impact on building energy performance. Present study has been carried out in Jaipur city; data related to energy consumption in buildings was collected and it was found that hotel sector of Jaipur city has most significant energy consumption as compared to other sectors due to much faster growth and higher energy intensity. Therefore, present study is focused on estimating energy saving potential in the hotel sector. The study is carried out by categorizing the hotel sector in three categories and subsequently selecting three representative hotels in each of the three categories for detailed analysis. Energy efficiency measures are adopted through two set of measures one is ECBC building code and other is through adoption of advanced Energy Efficiency Measures (EEMs) which are beyond the measures prescribed by ECBC building code. The energy savings have been estimated for case study hotel buildings and the results have been used to project energy savings for the complete hotel building sector of Jaipur city. Analysis was further been extended to include potential of using rooftop SPV systems for reducing electricity load on the grid. Adoption of ECBC code to the selected hotel buildings revealed that use of ECBC compliant HVAC system gives significant energy savings but unitary system is most economically viable due to lower capital cost as compared to chillers. Roof insulation

is more cost-effective than wall insulation especially for small sized hotel buildings. Glass film on window glazing for ECBC compliance is more cost-effective for single glazed glass than double glazed glass. Retrofitting of lighting fixtures is the most attractive option among all technological options considered in this study. In advanced measures replacing existing HVAC system with Ground Heat Exchanger system gives very high energy savings especially when the existing system is unitary type HVAC system but due to high capital cost of GHX system it is not highly cost-effective. Increasing thickness of wall and roof insulation to attain better U-value of the building envelope in order to reduce heat gain further; reduces the heat gain marginally but the cost of insulation increases proportionately therefore IRR is reduced. Applying better window film to the double glazed glass although reduces the heat gain, but it is not as cost-effective as compared to applying window film to single glazed glass. Therefore, average energy saving obtained through adoption of ECBC and advanced measure to selected hotel buildings is 23.2% and 39.7% respectively. Payback period through retrofitting of HVAC, wall, roof, window glazing and lighting fixtures ranges from 4-6 years for ECBC compliance. Adoption of ECBC and advanced measures qualifies Category-1 hotels for four and five star energy ratings whereas Category-3 hotels qualifies for two to four star ratings of Bureau of Energy Efficiency, India. Rooftop SPV system installed at the hotel building seems to be economically viable option for few hotel buildings to reduce demand on the grid, since the IRR ranges from 5.76 % to 11.77 %. The annual energy consumption of existing hotel buildings (total 589 hotels) in Jaipur city is estimated to be 107.8 GWh/year and with the implementation of ECBC and advanced measures the annual energy saving would be 23.2 GWh/year and 40.0 GWh/year respectively. GHG emissions due to energy consumption in existing hotel buildings in 2014 are 89.5 ktCO_2/year. Adoption of ECBC building energy code and advanced measures would reduce GHG emission by 19.2 ktCO_2/year and 31.3 ktCO_2/year respectively, in the year 2020. Although, the percentage energy saving potential is highest in Category-1 hotels but the impact of energy savings on hotel sector of Jaipur city is highest in Category-3 hotel building due to higher total energy consumption. This study, therefore, concludes that there is a large potential of energy savings through the implementation of ECBC building code in hotel buildings. If the building components like wall, roof, glazing, lighting and HVAC system use specifications better than specifications prescribed by ECBC, the energy saving can be increased further.

The results of the study can help to choose the best strategy to save maximum energy in the respective hotel category and can also be useful to implement the EEMs in other similar commercial buildings. Since, Jaipur city is India's one of the most visited tourist place and rapid growth in hotel buildings is resulting into higher energy consumption and there is a need to adopt energy saving measures.

Overall, the study strongly recommends implementation of ECBC in hotel buildings and also suggests that level of energy efficiency through ECBC should be enhanced since a viable level of higher energy efficiency has been identified through this study.

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Nomenclature

BIPV	:	Building Integrated Photovoltaic
C_vRMSE	:	Coefficient of Variance Root Mean Square Error
EPD	:	Equipment Power Density (W/m^2)
EPI	:	Energy Performance Index ($kWh/m^2/yr$)
kVA	:	kilovolt-ampere
kW	:	kilowatt
kWh	:	kilowatt-hour
$kWh/m^2/year$	:	kilowatt-hour per square meter per year
LPD	:	Lighting Power Density (W/m^2)
MBE	:	Mean Bias Error
TR	:	Ton Refrigeration
U_{wall}	:	Thermal transmittance of wall (W/m^2-^oK)
U_{Roof}	:	Thermal transmittance of roof (W/m^2-^oK)
U_{Glass}	:	Thermal transmittance of glass (W/m^2-^oK)
W	:	Watt
W/m^2	:	Watts per square meter
$W/m^{2\text{-}0}K$	:	Watts per square meter per degree Kelvin

List of abbreviations

BEMS	:	Building Energy Management Systems
BIPV	:	Building Integrated Photo Voltaic
BIPV	:	Building Integrated Photovoltaic
CST	:	Centre for Sustainable Technology
COP	:	Coefficient of Performance
CFL	:	Compact Fluorescent Lamp
CFL	:	Compact Fluorescent Lamp
CII	:	Confederation of Indian Industry
CAV	:	Constant Air Volume
DeST	:	Designer's Simulation Toolkits
DBT	:	Dry Bulb Temperature
EEM	:	Energy Efficiency Measures
EEMs	:	Energy Efficiency Measures
EPD	:	Equipment Power Density
CEN	:	European Committee for Standardization
FCU	:	Fan Coil Unit
FHRAI	:	Federation of Hotel & Restaurant Associations of India
GSHP	:	Ground source heat pump
ITC	:	Imperial Tobacco Company
ISHRAE	:	Indian Society of Heating, Refrigerating, and Air-Conditioning Engineers
EATHE	:	Integrated Earth Air Tunnel Heat Exchanger
IPCC	:	Intergovernmental Panel on Climate Change
IEA	:	International Energy Agency
JVVNL	:	Jaipur Vidyut Vitaran Nigam Limited
LULUCF	:	Land Use, Land-Use Change and Forests
LED	:	Light Emitting Diode
MPC	:	Model Predictive Control
NREL	:	National Renewable Energy Laboratory
PTAC	:	Package Terminal Air-conditioner
PVVT	:	Package Variable Volume Variable Temperature
PCM	:	Phase Change Materials

RH	:	Relative Humidity
STC	:	Satyam Learning Centre
SPV	:	Solar Photovoltaic
TERI	:	The Energy and Resource Institute
TES	:	Thermal Energy Storage
VFD	:	Variable Frequency Drive
VRF	:	Variable Refrigerant Flow
WSHP	:	Water Source Heat Pump
WIPRO	:	Western India Palm Refined Oils Limited
WTTC	:	World Travel and Tourism Council
WTO	:	World Travel Organisation

CHAPTER 1
INTRODUCTION

Energy plays an important role in the economic growth, progress, development and security of any nation. Economic growth mainly depends on the long-term availability of energy from sources that are affordable, accessible, and environment friendly. Energy is an important factor in all the sectors of a country's economy. After the oil shock of the 1970s, energy supply has become scarce, expensive and unreliable. With growing economy infrastructural development is taking place rapidly. New office space, information technology enabled offices, data centers, multispecialty hospitals, luxury hotels, retail malls etc. are being constructed with high-quality standards. They are becoming more and more energy-intensive resulting into heightened environmental and social impacts. Building sector in a developing country like India is also growing rapidly. Chaturvedi et al. (2014) presented that, without specific sectoral policies for Indian building sector to curb energy use, the final energy demand of the Indian building sector is expected to grow five times by the end of this century, due to rapid growth in income and population. Buildings in India follow conventional construction practices and use less energy efficient technologies and equipment, therefore, buildings become energy intensive that results into high energy consumption and GHG emissions. This puts forward the need for more sustainable approaches and policies to reduce energy consumption in buildings through energy efficiency. Consequently, studies on energy planning and modeling have become a very active area of research in all parts of the world.

1.1 Growth in building sector

Building sector is growing in fast-growing economies, such as China, India, and some Latin American countries, which has increased energy demand in the building sector. India being a developing country, huge infrastructural development is coming up and it is expected to increase further mainly due to increasing population, increased demand for housing, strong demographic impetus, expansion of organized retail, increased demand for IT spaces by multinationals and Information Technology (IT) hubs; setting up of Special Economic Zones (SEZ). Change in life style and other similar factors, India has doubled the floor space between 2001 and 2005, and it is expected to add 35 billion m^2 of building floor space further by the end of 2050, as reported by Shnapp and Laustsen (2013). The study carried out by International Energy Agency (IEA, 2008) reveals that although the total energy consumption by Indian buildings is not very high but the growth of energy consumption is very high as compared to other countries as shown in Fig. 1.1.

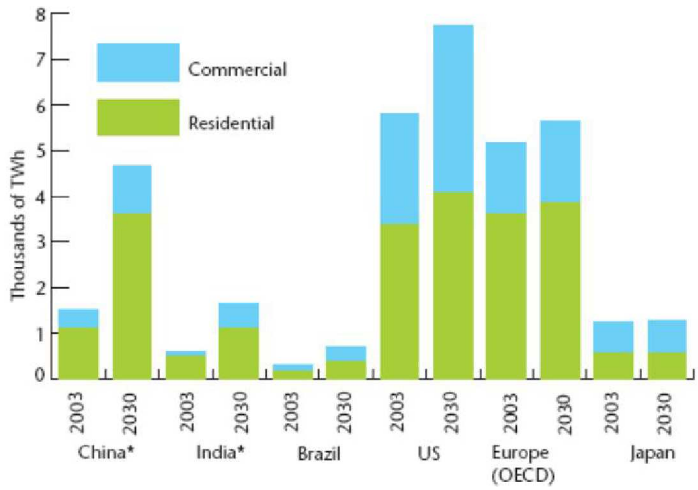


Fig.1.1 Building energy projection in year 2003 and 2030
(Source: IEA, 2008)

As per The Energy Research Institute (2010), the gross built-up area added to commercial and residential spaces in India was about 40.8 million square meters in 2004-5, which is about 1% of annual average constructed floor area around the world and trends show a sustained growth of 10% in the coming years. Figure 1.2 depicts growth pattern in building sector, India and it shows that hospitality sector has the highest growth rate of 10%.

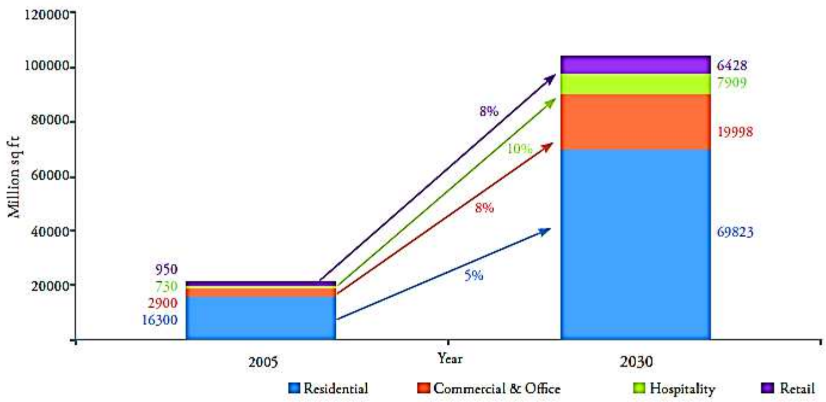


Fig. 1.2 Growth rate in built-up area in building sector, India

(Source: CWF, 2010)

Ramesh and Khan (2013) reported that with the boom in economic growth in India, the estimated growth is to be 12% in the construction sector and 23% in commercial sector. According to their projections, India will add 80% floor space by 2030. In a similar study, Chaturvediet. al (2014) projected per capita floor space in urban residential sector and commercial sector, is expected to increase over three times and ten times respectively, between 2005 and 2050.

1.2 Energy consumption and GHG emissions in buildings

Buildings account for 30-40% of energy use as well as 30% of CO_2 emissions worldwide as reported by Balaras et al. (2004), Klein (2007), Lombard et al. (2008), McKinsey and Company (2009); Bribian et al. (2009), Sabapathy et al. (2010), and Byrne and Donnelly (2012). Projections of the energy consumption by buildings of India, China and US by International Energy Outlook (2013) in Fig.1.3 shows that India's residential building's energy consumption trend resembles that of China at 3.7 per cent per year, and India's commercial sector building energy consumption growth is projected to increase at an average rate of 5.4 per cent per year up to year 2030, which is also the world's highest.

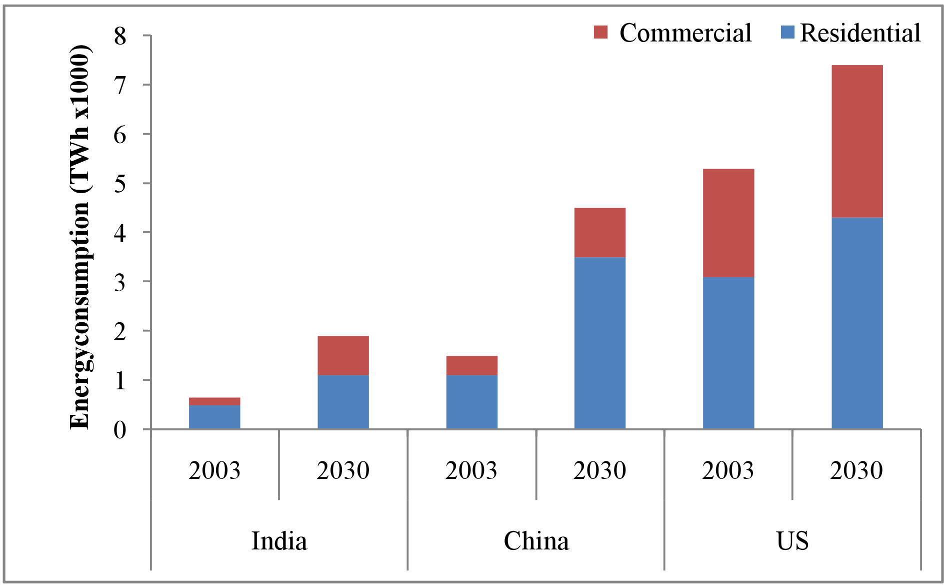


Fig. 1.3 Projection of energy for buildings by region, 2003-30
(Source: International Energy Outlook, 2013)

Energy use in buildings in India is growing at 8% annually as reported by Rawal et al. (2012). According to UNEP (2011), India currently ranks sixth in the world regarding primary energy demand, and the building sector is currently the third largest consumer of energy in India. This growth in energy demand will arise from improvements in wealth, lifestyle changes, access to modern energy services, adequate housing, and urbanization. Kumar et al. (2011), and Jayswal (2012) reported that as per Indian energy consumption survey, building energy consumption has increased from 14% in the 1970's to nearly 33% in 2004-5.Over the next 30 years, energy consumption in the building sector is expected to grow dramatically, reported by Sabapathy et al. (2010).

Energy consumption in building sector has resulted in GHG emissions, which account for nearly 30% of total global CO_2 emissions from energy use; 19% from the residential sector and 10% from the commercial sector as presented by Stephen (2012). Lee and Yik (2004) showed that over one-third of the global CO_2 emissions are due to the combustion of fossil fuels to meet the energy demands in buildings. The study conducted by IPCC (2010) projected that the building sector accounted for 32% of the world's energy use and around one-third of carbon emissions, which are emissions from fossil fuels. Furthermore, the IPCC showed that by 2050, energy demand in the building sector will double and CO_2 emissions will increase by 50-150%.Price and Worrell (2006) reported that buildings are responsible for 7.85 Gt, or 33% of all energy-related CO_2 emissions worldwide and these emissions are expected to increase between 11 Gt to15.6 Gt by2030.

In India, the total GHG emissions in 2007 were 1727.7 million tonnes of CO_2 equivalent, out of which 1221.7 million tonnes of CO_2, 20.6 million tonnes of CH_4 and 0.57 million tonnes of N_2O. Fig. 1.4 shows the annual increase in CO_2 emissions in buildings. Ramesh et al. (2012) stated that while India's total energy requirement is expected to grow at 6.5% between 2010-11 and 2016-17 to support the country's projected growth rate, India is en route to becoming the world's second largest emitter of GHG.

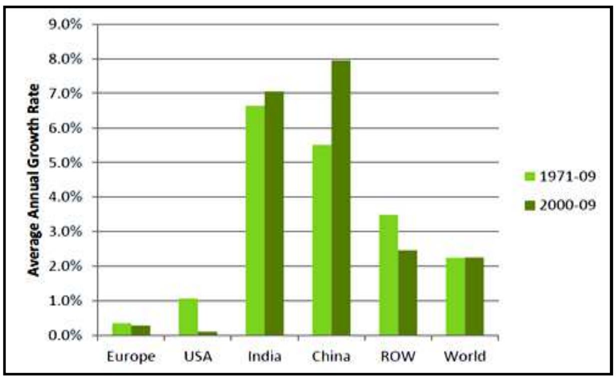


Fig. 1.4. Annual growth rate of CO_2 emissions by buildings
(Source: Building Energy Efficiency Best Practice Policies, LBNL, 2012)

1.3 Energy scenario in hotel buildings

Hotel building is one of the most energy intensive sector in the building sector due to its physical and operational characteristics that affect energy usages. Hotels are found to be among the most energy intensive building categories all over the world. As expected, there are number of factors contributing to their high energy consumption, some of which are related to hotel building designs and operations, such as extensive use of fenestration, large number of lighting fixtures in lobbies and restaurants, continuous use of air conditioning or heating of large common spaces. Various studies have been carried out worldwide to estimate energy intensity in hotel buildings and have also compared it with other sectors. Deng and Bernett (2000) reported an average energy intensity of 564 kWh/m^2/yr for 16 Hong Kong hotels. Santamouris et al. (1994) collected energy consumption data from 158 Hellenic hotels and estimated annual average energy consumption of 273 kWh/m^2/yr while, annual energy consumption for office and school buildings were 187 kWh/m^2/yr and 92 kWh/m^2/yrrespectively. Zmeureanu et al. (1994) investigated the energy performance of 16 hotels in Ottawa (Canada), and average energy intensity was found to be 612 kWh/m^2/yr. The Asia-Pacific Economic Cooperation (APEC) Energy Benchmark (1999) database contains energy consumption data from 29 Singapore hotels and average energy use intensity of these hotels found to be 468 kWh/m^2/yr. A study on 800 Indian commercial buildings in India was conducted to benchmark building energy consumption under USAID ECO-III project (Reference). The study estimated EPI of the shopping mall as 222 kWh/m^2/yr, multi-specialty hospital as 281 kWh/m^2/yr, government hospital as 68 kWh/m^2/yr, private office as 158 kWh/m^2/yr, public sector office as 116 kWh/m^2/yr and hotel as 254 kWh/m^2/yr. The study revealed that the hotels have high energy intensity as compared to other commercial buildings in India. Benchmark study conducted on 48 luxury hotels (4-5 star)and 136 non-luxury hotels (1-3 star) in India by USAID ECO-III Project (2010) revealed that the benchmark EPI for non-luxury hotels and luxury is 266 kWh/m^2/yr and 274 kWh/m^2/yr, respectively. These studies show that the hotel buildings worldwide and also in India have high energy intensity resulting into large energy wastage.

Hotel sector on one hand has high energy intensity and on the other hand this sector is growing rapidly worldwide. The hotel sector over the past decades has grown to become the single largest business sector worldwide and the number of people traveling for business or pleasure would continue to increase. A study by Global hospitality insights (2015) estimated that there are approximately 1.3 million new guestrooms are yet to be built, worldwide. India is becoming the number one tourist destination in the world with the demand growing at 10.1% per annum, as predicted by World Travel and Tourism Council (WTTC). A study carried out by World Travel Organization (WTO) stated that India was expected to receive 25 million tourists by 2015 and a greater number of Indians and foreign tourists traveling to domestic destinations than before as reported by Ministry of Tourism, India (2013) and presented in Fig. 1.5.

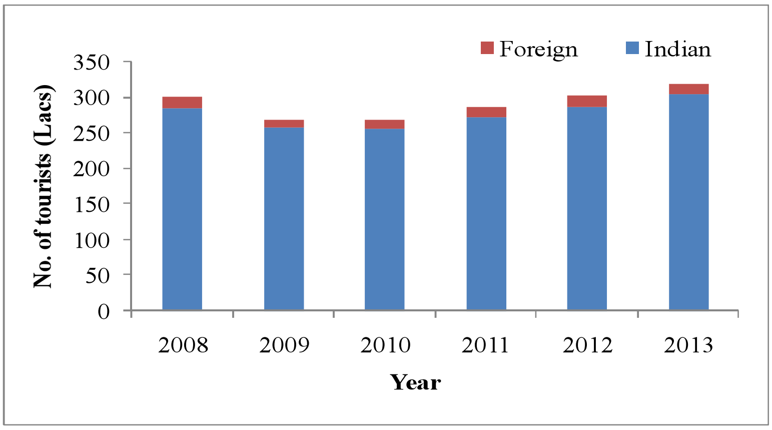


Fig. 1.5 Inflow of foreign and Indian tourists in India

(Source: Ministry of Tourism, India, 2013)

India currently has over 2,00,000 hotel rooms spread across all hotel categories and guest-houses and is still facing a shortfall of over 1,00,000 rooms reported by Federation of Hotel & Restaurant Associations of India, 2013 (FHRAI). The country is witnessing an unprecedented growth in hotel constructions and it is expected that 1,14,000 hotel guest rooms are yet to be built over the next five years as reported by HVS International (2015). In another study by World Travel and Tourism Council (2015), the expected growth of demand for travel and tourism in India will grow up to 8.2% by the year 2019. In the FHRAI's memorandum presented recently to the Indian government, presently there are 1,05,000 hotel rooms in the three to five-star hotels and it is expected that at least 1,50,000 additional rooms are required to meet the target of 5 million foreign tourist arrivals in 2015 and around 150 hotel projects will be built in the coming years. Research conducted by HVS research estimated the number of rooms expected in next five years is shown in Fig. 1.6.

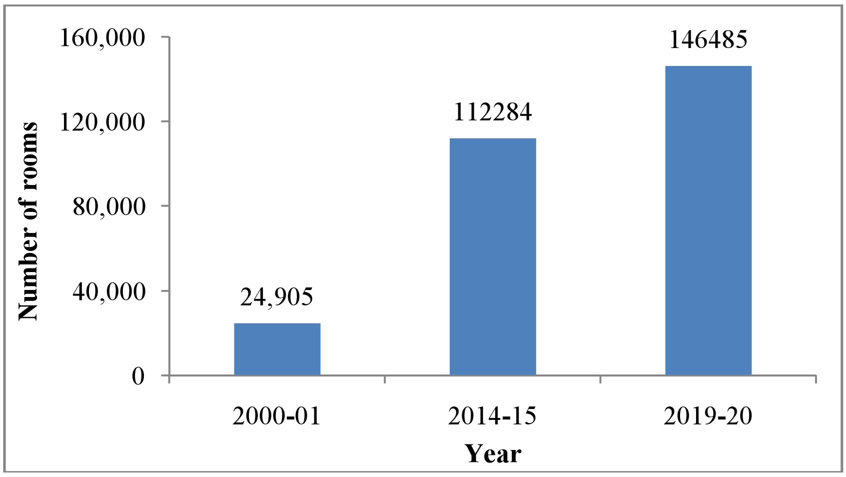


Fig. 1.6 Growth of hotel rooms in India
(HVS Research, 2014-15)

The study conducted by HVS research estimated that, a pipeline comprising approximately 1,119 rooms is expected at 22% growth to enter the market by the end of 2019-20 in Jaipur city. Jaipur city continues to be among the top leisure destinations in the country, and the city has witnessed fast growth in the number of hotels as shown in Fig.1.7 and with large meeting facilities that have led to the growth of Jaipur as a popular destination for weddings, meetings, workshops, conferencing and exhibitions as cited by Indian hotel industry survey, 2013-14.

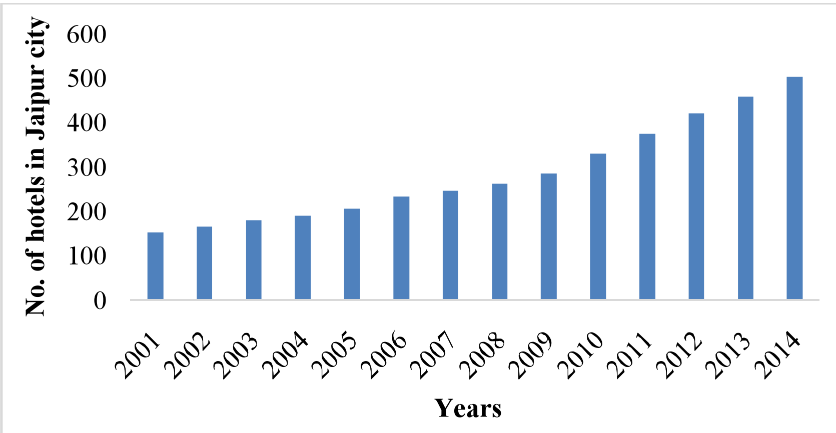


Fig. 1.7 Growth of hotels in Jaipur city
(Source: Hotel association of India, Jaipur, 2014)

Out of all sectors of commercial building sectors, the hotel sector uses substantial amounts of energy for providing all sorts of comfort and services to its guests, typically with an alarmingly low level of energy-efficiency resulting into high emissions. In the present study, data of electricity consumption for commercial buildings of Jaipur city with connected load more than 100 kW were collected from Jaipur Vidyut Vitaran Nigam Limited (JVVNL) for the year 2014.The data revealed that government office, private office and hotel sector have comparatively higher energy consumption as shown in Fig. 1.8 and energy consumption in private office and hotel buildings is growing at a faster rate as compared to other sectors which is shown in Figure 1.9.

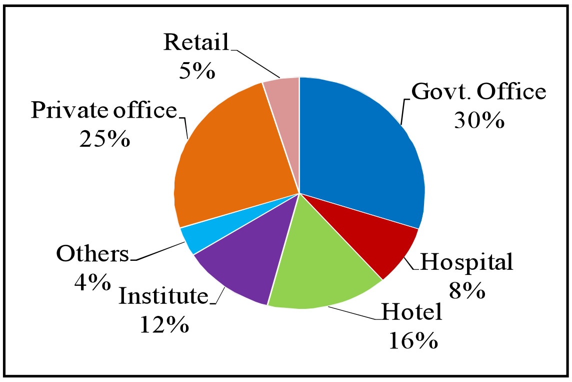


Fig. 1.8 Energy consumption of commercial sector of Jaipur city
(Source – JVVNL, Jaipur, 2014)

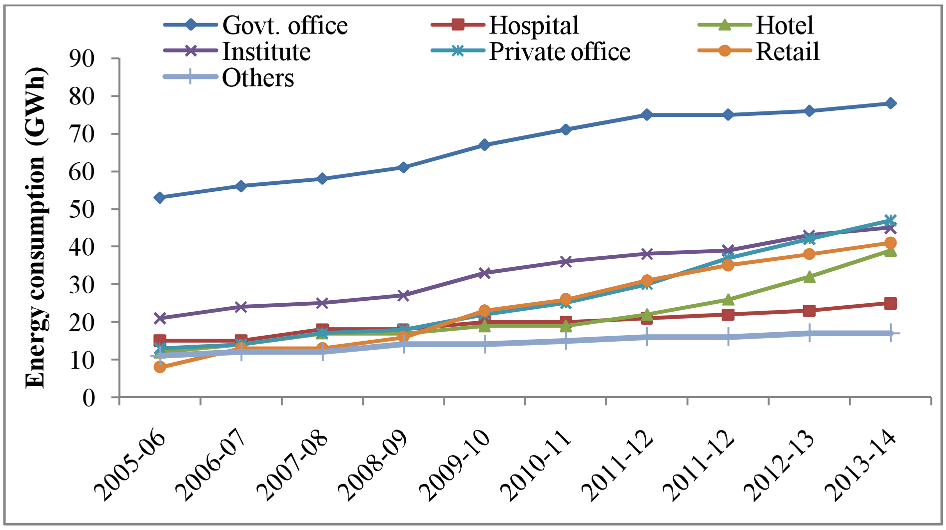


Fig. 1.9 Growth rate of energy consumption in commercial sector of Jaipur city
(Source – JVVNL, Jaipur, 2014)

The electricity consumption by hotel buildings in Jaipur city is found to be high, and presently, it is growing rapidly. Data of hotel buildings obtained from JVVNL, Jaipur with connected load above 100 kW, is used to project energy consumption of hotel sector of Jaipur city by the end of year 2024. These growth projections show that the electricity consumption in hotel buildings is expected to reach 127 GWh of electricity by the end of the 2020 from 39 GWh in 2014 as shown in Fig.1.10.

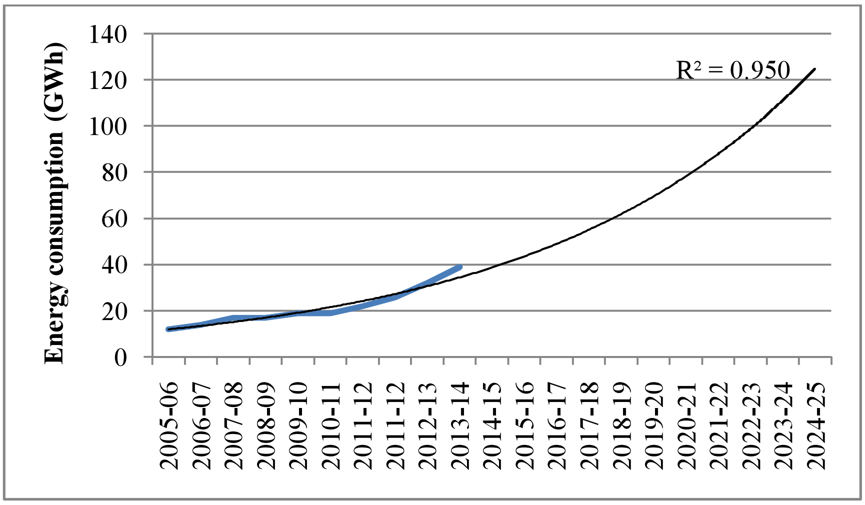


Fig. 1.10 Growth projections of electricity consumption by hotels of Jaipur city
(JVVNL, Jaipur, 2014)

1.4 The present study

High share in energy consumption by hotel buildings in Jaipur city has led the present study to find out opportunities to reduce energy consumption through adoption of energy efficiency. Therefore, in the present study, various case studies and research studies have been discussed where various technologies are adopted for energy efficiency. With the development of advance technology and low-energy design strategies through adoption of building code significant reduction in energy consumption in buildings has been made possible. A study conducted by Liu and Hong (2010) on 80 commercial buildings in Hong Kong concluded that energy consumption can be reduced to 68% and 75% with the adoption of Chinese and UK building codes respectively. According to another study by USAID ECO-III Project (2010) suggested that with the adoption of Indian building code, 30-40% of energy reduction can be achieved. Various commercial buildings in India have adopted ECBC building code such as Imperial Tobacco Company (ITC) Hotel, Gurgaon that has demonstrated that adopting ECBC to building envelope, lighting, HVAC system, Variable Frequency Drive (VFD) to blowers have reduced EPI from 161 kWh/m^2/yr to 73 kWh/m^2/yr. Efficient lighting reduced lighting energy from 53,290 kWh/yr to 25,109 kWh/yr. Kerala Tourism Development Corporation Samudra Hotel (KTDC), Kerala through the adoption of wall roof insulation, double glazed glass, VFD, T5 tube lights, solar water heating, efficient DG sets etc. have reduced EPI from 270.56 kWh/m^2/yr to 154.49 kWh/m^2/yr. Various other buildings in India such as Telecommunications Consultants India Ltd (TCIL), Gurgaon; Microsoft Office, Hyderabad; Western India Palm Refined Oils Limited (WIPRO), Bangalore; through the adoption of ECBC building code have reduced energy consumption by 30%. The studies on energy efficiency demonstrated that adoption of building codes and other energy efficiency measures can reduce energy consumption significantly. Therefore, the present study is focused on energy efficiency in hotel sector that constitutes one of the most energy and resource intensive buildings in the commercial sector. Significant amount of energy is consumed in providing comfort and services to guests, many of them are accustomed to and willing to pay for exclusive amenities, treatment, and entertainment. In the present study, hotel buildings are categorized into three. Three representative hotels are selected in each category based on Energy Performance Index (EPI). Energy savings through adoption of ECBC and advanced energy efficiency measures are estimated. Energy savings obtained through case study hotel buildings are used to estimate projected energy savings and GHG emissions reduction potential for whole hotel building sector of Jaipur city.

1.5 Origin of the problem

Indian buildings constitute significant energy consumption and GHG emissions, and it is growing rapidly, as construction booms, due to faster economic growth. Since, use of inefficient technologies and materials in building design and construction is also responsible for high energy use in buildings, therefore, it is essential to act now. Research by Mckinsey and Company (2009) showed that changes in building design and construction could reduce 6 billion tons of GHG emissions through effective measures such as retrofitting of building envelope, glazing, water heating, air-conditioning, lighting, etc. With the advancement of knowledge and technology today, the energy consumption in buildings can be reduced significantly, while at the same time with the same level of comfort. Energy efficiency in buildings is compelling since it is cost effective and can help consumers to save money, meet energy targets and resource energy shortage. Therefore, a need was felt to assess energy saving potential of the commercial building sector of Jaipur city through the adoption of energy efficiency measures.

Therefore, in the present study data from commercial sector of Jaipur city was collected, and further, it was observed that hotel sector has significant energy consumption due to much faster growth and higher energy intensity as compared to other sectors. The ECBC building energy code and advanced energy efficiency measures that are beyond ECBC have been adopted for selected hotel buildings to estimate energy savings and GHG reduction potential for hotel sector of Jaipur city.

1.6 Research Objectives

Identifying the research gaps, following objectives have been chosen for the current research work:

- Energy modeling and simulation of hotels in Jaipur City for estimating energy conservation potential.
- Assessment of greenhouse gas mitigation potential through energy efficiency and use of renewable energy.

1.7 Thesis outline

Present thesis has been organized into six chapters. The first chapter of the thesis introduces energy consumption in buildings and energy efficiency measures adopted worldwide. This chapter also describes the aims and scopes of the present research along with the research objectives. A detailed literature review has been carried out in Chapter 2. It elaborates available energy efficiency measures for the buildings and simulation tools for detailed analysis of adoption of various energy efficiency options. Chapter 3 describes criterion for selection of hotel sector and also the criterion for selection of nine case study hotel buildings. This chapter also discusses the approach and methods adopted for modeling and calibration of hotel buildings in order to assess energy savings through energy efficiency measures. Chapter 4 describes nine case study hotel buildings including details of building envelope, HVAC equipment, and lighting load details. Further, this chapter discusses simulation results for the nine case study hotel buildings. The energy savings obtained through adopting various energy efficiency measures to the nine case study hotel buildings along with their cost-benefit analysis has been discussed in chapter 5. Chapter 6 presents a summary of the work and conclusions coming out of the present study.

CHAPTER 2
LITERATURE REVIEW

Buildings provide comfortable working and living environment to occupants and also protect them from the extremes of climate. Services in buildings such as thermal comfort, illumination, communication, entertainment, sanitation and hygiene as well as other amenities require various systems and equipment. These systems and equipment such as air-conditioner, fan, refrigerator, water heater, lighting fixtures, computers etc. used for leisure and comfort in buildings are responsible for a significant share of energy use in buildings worldwide. Bureau of Energy Efficiency, India (2010) has reported that the energy consumption in the building sector is very high and is expected to increase further, because of improvements in living standards and increase in the world's population. The high energy consumption is also attributed to the conventional practices followed in building construction in India. Energy efficiency in buildings has recently become a major issue due to rapidly depleting fossil fuels, and increased GHG emissions. Therefore, the energy efficiency of buildings is attracting significant interest from the research community, as the world is moving towards sustainable building design. The building energy efficiency can be dealt with various approaches as measures or ways to improve the building energy performance. The building energy consumption, methods and approaches to achieve building energy efficiency through research findings have been presented in this chapter.

2.1 Energy consumption in buildings

Buildings accounts for 45% of energy consumption worldwide, which also results into a significant amount of GHG emissions as reported by Kumar et al. (2011) and Yu et al. (2011). Several studies worldwide show that 80-90% of the building energy is consumed during its operational phase for heating, cooling, lighting, and equipment as reported by Sabapathy et al. (2010). This situation is further aggravated by buildings built in environments that do not always encourage the use of efficient technologies reported by Henrique et al. (2013). According to the World Business Council for Sustainable Development (2007), building block accounts for 40% of total energy consumption. Das and Paul (2013) mentioned that residential and commercial sectors showed a steady increase in consumption from 10% in 1995–96 to 15% in 2005–06.

Over the years, electricity demand has also increased drastically in the commercial building sector. Zografakis et al. (2012) in his study concluded that energy consumption in commercial buildings is very high, and commercial buildings in developing countries account for three-quarters of this total consumption. Can and Price (2008) reported that energy consumption in commercial buildings is very high, and commercial buildings account for three-quarters of this total consumption in developing countries. With expanding development and population growth, India's building sector is expected to grow five times from 2005 to 2050, as two-thirds of the high-rise commercial and residential structures are yet to be built by the end of the year 2030 as illustrated by Chaturvedi et al. (2014). The commercial building sector is growing very fast in India; the floor area of commercial building sector in 2010 was 659 million m^2 and it expected to reach 1900 million m^2 in the year 2030 as estimated by USAID ECO-III Project (2010). According to NRDC (2012) report, commercial building sector of India accounts for 6.5% of total electricity consumption, and it is growing at a rate of 11% to 12% over last few years. Higher energy intensity and growth of commercial buildings in India have resulted into significant energy consumption. Study carried out by Xu (2013) estimated energy intensities of commercial buildings in India. This study estimated energy intensity of various building sectors as 8.14 kWh/ft^2 to 18.55 kWh/ft^2 for offices, 11.87 kWh/ft^2 to 28.43 kWh/ft^2 for shopping malls, 3.62 kWh/ft^2 to 10.08 kWh/ft^2 for IT parks, 11.70 kWh /ft^2 for hospitals and 30.13 kWh/ft2 to 37.20 kWh /ft^2 for hotels. This study found that the highest energy intensity is of hotel buildings, and large ranges indicate the potential to improve building energy performance either through design or operation. Therefore, there is a need to understand new technologies adopted worldwide discussed in various studies that can be adopted to achieve energy efficiency in buildings.

2.2 Energy efficiency in buildings

Since the first oil shock in 1973, several steps have been taken such as improving the building/equipment standards with higher energy efficiency have been taken worldwide as reported by Lopes et al. (2005). Recent major advances in building design, technology, know-how, and policy have made it possible for global building energy use to decline significantly. Some low energy and passive buildings, both retrofitted and newly constructed, demonstrating that high level of building energy performance can be achieved. Energy efficiency in buildings provides excellent opportunities to reduce energy consumption in buildings as well as encouraging implementations of other sustainability such as environment protection, rational resources use, and occupants' healthcare. Countries all over the world are discussing strategies to enhance building energy efficiency and implementing energy regulations to reduce buildings energy consumption as mentioned by Santin et al. (2009), Chvatal et al. (2005), Silva et al. (2009), Beerepoot and Beerepoot (2007), Casals (2006), Pezzini et al. (2010), and Wang et al. (2013). Energy efficiency in buildings is a prime objective today, for the formulation of energy policy at regional, national and international levels as suggested by Lombard et al. (2008). Energy efficient measures through technologies that are tested in practice are commercially available and can substantially reduce energy consumption while providing the same level of services. Melo et al. (2012) mentioned that countries all over the world are discussing strategies to improve building energy efficiency and implementing energy regulations to reduce building energy consumption. There are some studies carried out worldwide to estimate energy savings by adopting various energy efficient technologies for residential and commercial buildings.

Radhi and Sharples (2009) analyzed the impact of the Bahrain energy code in the context of commercial buildings. Radhi (2009) also carried out a study to extrapolate the implications of global warming on CO_2 emissions for residential buildings by analyzing insulation of residential villas in Al Ain (UAE). Turki and Zaki (1991) investigated the effect of insulation and energy storing layers upon the cooling load. Bolatturk (2006) calculated the optimum insulation thicknesses and payback periods. Durmayaz et al. (2000) estimated the heating energy requirement in building based on degree-hours method on human comfort level. Hasan (1999) optimized the insulation thickness for the wall. Freiss et al. (2012) studied wall insulation on residential buildings in Dubai. Also, a series of residential building simulations were carried out by Radhi (2009) with the aim of analyzing the thermal comfort characteristics of varying fenestration and insulation options, and thermal mass effects on building energy. Thermal mass, in combination with night time ventilation strategies for cooling load reduction for Hong Kong buildings, is discussed by Yang and Li (2008). Chowdhury et al. (2008) focused on specific low energy cooling technologies for hot and humid climates. Major energy savings can be obtained by better lighting system design and control: more efficient reflectors, varying light levels according to function; use of occupancy lighting sensors and efficient use of natural light reported by Santamouris et al. (1994), IEA (1989), Jacob (2009), Murakami et al. (2007) and Wang and Boubekri (2011) in their studies. Furthermore, by managing the lighting in secondary spaces can lead to considerable energy savings reported by Dubois and Blomsterberg (2011) and Graeber and Papamichael (2011).

Therefore, energy efficiency technologies found through literature survey from various studies can be categorized are as follows:

- Building Envelope - wall insulation, roof insulation, cavity wall, roof with reflective coating, window glazing film
- HVAC system – efficient equipment, better operating parameters, hybrid system, , energy storage through dessicant material, Ground source heat pump (GSHP) system
- Lighting system – efficient lighting fixtures, lighting controls
- Passive strategies – daylight integration, thermal energy storage, earth air heat exchanger, window shading
- Building Energy Management System and controls – controls of HVAC components such as chiller, AHU, boiler, cooling tower
- Advance energy efficiency measures – wall and roof insulation, , efficient equipments
- Integration of Solar Photovoltaic

Energy efficiency measures have been used by buildings worldwide through adoption of building codes and energy efficiency standards which often serve as the efficiency target to new and existing buildings. There are various approaches found in the literature studies through which the building code compliance can be done.

- Prescriptive approach - It prescribes minimum energy efficiency parameters for various components and systems of the proposed building
- Energy cost budget method – This method sets a budget of energy cost which is met by trading off various energy efficiency measures.
- Whole building approach - It offers considerable design flexibility by allowing code compliance through optimizing the energy use by various building components and systems to find the most cost-effective solution. This is done by various building simulation tools which help in finding the most optimum solution

to achieve energy efficiency in buildings.

Therefore, various studies carried out on energy efficiency in buildings through adoption of building energy codes and other energy efficiency measures is discussed in detail in this chapter.

2.2.1 Building Envelope

The building envelope is the boundary between the conditioned interior of a building and the outside environment. The energy performance of a building depends upon envelope components such as external walls, floors, roofs, ceilings, windows and doors, is critical in determining how much energy is required for heating and cooling. Energy loss through the building envelope depends on numerous factors, such as building age and type, orientation, climate, construction technique, geographical location and occupant behavior. In most of the world, the energy performance of building envelopes has been neglected. The quality of building envelopes is one of the most important factors that affect the energy consumed by the building equipment. Therefore, building envelope has been the focus of some studies so as to understand its importance to reduce energy consumption in buildings.

World Studies

1. A study by Kuusk et al. (2014) analyzed the energy usage of brick apartment buildings in Estonia through simulation of four reference buildings and concluded that among individual measures, insulating external walls has the highest effect on the reduction of the energy consumption. Meriem et al. (2013) studied an office building in Tunisia and showed that the use of wall insulation and cool roof can guarantee savings of 46% in winter and 80% in summer compared to an ordinary building. Haberl and Cho (2004) have performed a literature review and based on 27 articles; they reported that cooling energy saving from the application of cool materials (mainly white roofing systems) on residential and commercial buildings vary from 2% to 44% with an average of 20%. Friess et al. (2012) carried out a study in hot and humid climate of Dubai (UAE) and demonstrated 30% energy saving by full perimeter building insulation. Similarly, Chirarattananona et al. (2012) conducted a study on tropical climate of Thailand and concluded that the use of wall insulation decreased the cooling coil load from 83.0 to 44.1 kWh/m2/yr. Bolattürk A. (2008) conducted study on buildings of Turkey to find optimum insulation thicknesses for building walls with respect to cooling in the warmest zone of Turkey. The results

show that the optimum insulation thickness varies between 3.2 and 3.8 cm; the; and the payback period varies between 3.39 and 3.81 years depending on the cooling degree-hours. Study carried out by Yin et al. (2012) at commercial buildings in Shanghai, China and he studied effect of glass window film on the performance of the curtain wall glazing system varies greatly, depending on the type of film and method of application. The study observed that the film can decrease the shading coefficient and solar heat gain coefficient by 44% and 22% if applied on the outside and inside of the existing windows. Study carried out at school building in Athens, Greece by Synnefa et al. (2012) demonstrated that application of white elastomeric cool coating on roof, increases its reflectance from 0.20 (cement and gravel screed) to 0.89, resulting in the reduction in indoor air temperature by 1.5–2°C during summer and 0.5°C during winter and reduction of annual cooling energy load by 40%.

Indian studies

A cost-benefit analysis performed by Bhatia et al. (2009) for a cool roof at Satyam Learning Centre (SLC), Hyderabad (composite climatic conditions) obtained 2.37 year as payback period. Chedwal et al. conducted a study on three hotel buildings and concluded that building envelope can reduce 5-10% of energy. Parikh (2012) in her study emphasised the need of energy-conscious architecture in current times. It involves the use of eco-friendly and less energy intensive building materials, incorporation of passive solar principles in building design, use of insulation, passive cooling and heating, day-lighting features, waste water recycling, integration of renewable energy technologies and use of energy efficient appliances in buildings.

2.2.2 HVAC system

India has temperate climate, therefore, for most of the time in a year it is hot and degree days for cooling are higher in a year therefore, for air-conditioned building HVAC system has a major share in total energy consumption of the building. Building air conditioning is the most energy-intensive activity, followed by electricity use for lighting and appliances as reported by Harvey (2009). A study carried out by Bureau of Energy Efficiency (BEE) on commercial buildings in India revealed that the HVAC system and lighting consume a significant amount of energy as shown in Fig. 2.1.

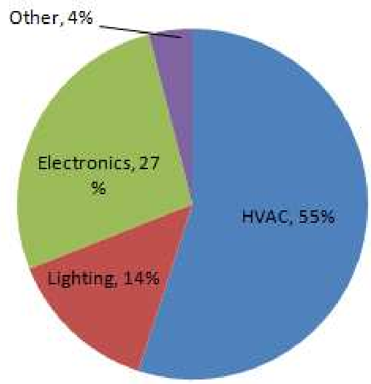


Fig. 2.1 Commercial building energy use in India
(Source: BEE, 2007)

International Energy Agency (2011) estimated that half of global energy consumption is used for space heating and cooling in buildings. Air conditioning sales is largest in Asia-Pacific region in the world. Building Services Research and Information Association (2009) illustrated that air conditioner sales in India was 3.88 million units in 2010 as compared to 2.8 million units in 2009. According to the research done by Studies conducted by The Energy Research Institute reveals that 50% - 60% of energy consumed in commercial buildings is by air conditioning in India. This energy consumption would further increase due to increase in global temperature. Offices and commercial buildings are using more and more air conditioning systems which is going to have major impact on electricity demand.

World Studies

Fasiuddin and Budaiwi (2011) in their study for commercial buildings of Saudi Arabia on HVAC system found that the HVAC system is the largest end-users of energy, particularly in hot climates. They concluded that energy saving up to 25% can be achieved using various HVAC operation strategies such as increased set point temperature, proper selection of system and fan schedule. Kim et al. (2011) employed data mining to compare the data of HVAC options, 127 roof structures, 88 wall materials, and 12 building orientations to calculate energy consumption for these different options. They found that HVAC had the greatest effect on building energy consumption, with an annual energy savings of US$ 1507 and building orientation had the least effect on energy consumption, with an efficient energy annual savings of only US$11 to US$17. Bellia et al. (2013) studied hybrid air conditioning system coupled with desiccant dehumidification the system was analyzed for Italian climate. The result showed that for retail store process air pre-cooling upstream the desiccant provides 22% of saving, for theatre application savings are in the range of 23%-43%. In both applications, energy consumption is reduced up to 55%.

Indian Studies

Buildings in India have a high cooling load. Therefore, inefficient HVAC system contributes large energy consumption. A study carried out at Microsoft office building; Hyderabad retrofitted conventional unitary HVAC systems with COP of 2.9 with the centrifugal chiller of COP 6.3, it was found that the electrical load reduced by 30%. Khan et al. (2015) found that saving of 17.5% and 30.3% was achieved by radiant cooling system integrated with Fan Coil Unit (FCU) and integrated with DOAS respectively.

2.2.3 Lighting system

Lighting contributes significantly to energy use and increasing energy prices emphasize the need to reduce the cost of lighting energy. Energy consumption associated with lighting systems can be reduced significantly when energy efficient lighting practices are adopted. In India lighting contributes one-fifth of electricity consumption and large portion of total lighting is used in an inefficient lighting system.

World Studies

Ke et al. (2013) in his study on the office building in Taiwan concluded that increase or decrease of lighting power density by 50%, results in overall energy consumption decreases by 31.19% or increases by 30.78%, respectively. Fathabadi (2014) in his study presented a smart system, including a multi-channel dimmer and a Fan Coil Unit (FCU) together with an exact multi-channel feedback mechanism, which automatically regulates and manages to light in buildings. Experiment explicitly showed that a considerable electric energy saving (about 27%) in the sample building was achieved. Wang and Holmberg (2015) carried retrofit measures on four types of typical Swedish residential buildings. Retrofits in the archetypes were defined, analyzed and ranked to indicate the long-term energy savings and economic profits. The model indicated that the energy saving potential of retrofitting was 36–54% in the archetypes. Kircher et al. (2010) modeled cleanroom in New York and found that lighting controls reduced energy consumption by 0.3% and a payback period of 1.5 years. Consequently, the energy consumption in the lighting system can be reduced by efficient lighting systems, efficient lighting devices (ballasts, luminaires, lamps) and optimal control of the lighting system (dimming, day lighting) concluded by Seo et al. (2012), Fonseca et al. (2013), Gorgulu and Ekren (2013), Soori and Vishwas (2013) and Wang et al. (2013) .

Indian studies

A study carried out by Bureau of Energy Efficiency (BEE) on Microsoft office building, Hyderabad and ITC Green Building, Gurgaon an LPD of 8.15 W/m^2 and 7.3 W/m^2 with daylight integration, dimming controls; the electrical load was reduced by 12% and 17% respectively. A study carried out by BEE at IIT; Kanpur revealed that adoption of lighting optimization reduced EPI from 208 kWh/m^2/year to 168 kWh/m^2/year. In a similar study at Fortis Hospital, New Delhi adoption of lighting optimization reduced EPI from 593 kWh/m^2/year to 476 kWh/m^2/year. Study conducted energy efficiency of Triburg building Gurgaon adopted lighting optimization and control reduced EPI from 65 kWh/m^2/year to 120 kWh/m^2/year. Chauhan and Sharma (2012) conducted a simulation study on a building in Kolkata, India and concluded that adoption of reduced LPD of 0.15 W/sqft at parking space reduced energy consumption by 1.5% with a payback period of 1.5 years

2.2.4 Passive strategies

Passive cooling of buildings relies on the use of techniques that enable controlling and dissipating the solar radiation and thermal gains during summer, whereas, heat passive features take advantage of sunlight and its heating effect through absorbing solar radiation, storing and releasing heat inside the building. Hence, low-energy or 'zero-energy' buildings incorporate efficient passive features that guarantee indoor conditions within comfort range without consuming any primary energy. A large number of researches and experimental studies have been carried out for residential and non-residential buildings to analyse passive heating and cooling techniques and their effect on the comfort conditions.

World Studies

Castelloti et al. (2005) used a technique to reduce heat gain by covering the roof with vegetation that reduces the heat gain through the roof and reduces the thermal load of the building of about 60% in a hospital in Vicenza, Italy. Bouden (2007) studied integrating glass curtain walls in Tunisian buildings to investigate the impact of glass curtain walls of different glazing sizes and different glass types on a typical administrative building thermal performance. The study demonstrated that glass curtain walls could be used in Tunisian buildings if the appropriate orientation and glazing type are selected. This passive solar gaining technique performs better than ordinary masonry walls when small windows covering 20% of the total wall area were used in the glass curtain wall. Ballestini et al. (2005) to increase the thermal performance of the walls, attached a glass double- facade to the existing wall surface separated by an air gap of 0.65 m to an archaeology factory is located in Venice, Italy. Simulations showed satisfying results if the upper and the lower louvres of the glass skin wall are properly opened in summer to avoid overheating by the greenhouse effect. In addition, Ballestini et al. (2005) concluded that the glass double-skin wall is considered to be a valuable solution to building since it helps to avoid the intervention in the old wall layers that are a difficult and expensive operation, but the appropriate glass type and ventilation process should be selected to avoid overheating problems and attain optimal comfort conditions. There are various other studies conducted by Batainch and Fayez (2011), Cheung et al. (2005), Gijon et al. (2011), Hughes et al. (2011), Sadineni et al. (2011) which dealt with the investigation of the solar heating and cooling passive strategies, optimizing other specific building characteristics such as the building form, orientation, HVAC systems, windows and walls composition. Each one of these studies reported the analysis of the considered technology, its efficiency, the gains it provides as well as its limitations. Various studies have been found in literature worldwide, discussing Thermal Energy Storage (TES) techniques in buildings to achieve increased energy efficiency for heating and cooling. TES has increased share of renewable energy since it has potential to reduce energy demand, peak heating and cooling loads. TES can reduce variations in the indoor temperature by using passive storage through increased thermal mass of a building, resulting in avoiding active cooling in a building. Urge-Vorsatz et al. (2015) studied TES in buildings using thermo-chemical energy storage and latent heat. Sustainable cooling with TES in buildings can be achieved through passive systems in building envelopes, Phase Change Materials (PCM) in active systems. Kuznik et al. (2015) suggested that chemisorption is a promising solution for long-term heat storage with a high energy density. Considering application to buildings, heat storage can be used for space heating and domestic hot water production. Kensby et al. (2015) in their study presented the results from a pilot test where the potential to function as thermal energy storage was tested for five multifamily residential buildings in Gothenburg, Sweden. The signals from the outdoor temperature sensors were adjusted in different cycles during a total of 52 weeks. The delivered heat and indoor temperature were measured during the test. The results indicated that large buildings, with a structural core of concrete, can tolerate relatively large variations in heat deliveries while still maintaining a good indoor climate. Degree hours are instead proposed as a simple yet adequate measurement for the thermal energy storage capacity in buildings. Storing 0.1 kW h/m^{2}floor area of heat will very rarely cause variations in indoor temperature larger than ±0.5 °C in heavy building. De Gracia and Cabeza (2015) have shown that TES is a way to achieve thermal comfort in buildings lowering the cooling and heating demand, but also other purposes can be pursued when using TES in buildings, such as peak shaving or the increase of energy efficiency in HVAC systems. Lazos et al. (2014) studied the importance of considering weather forecasting inputs in energy management systems is established by highlighting the dependencies of various building components on weather conditions. The issues of the difficulty in implementation of integrated weather forecasts at the commercial building level and the potential added value through energy management optimization were also addressed. Finally, a novel framework is proposed that utilizes a range of variable weather predictions to optimize certain commercial building systems

Indian studies

Kumar et al. (2012) suggested that to meet the increasing energy needs, particularly in developing and less developing countries, the climate responsive buildings or passive solar buildings with advanced active systems seem to be most appropriate and efficient solutions to this problem. Bansalet. al. (2012) evaluated the performance analysis of integrated Earth Air Tunnel Heat Exchanger (EATHE) evaporative cooling system over a complete year. He showed that the use of integrated EATHE evaporative cooling system provides comfortable air for 34.16% additional hours in one year, where the simple EATHE system can provide comfortable air for only 23.33% additional hours while ambient air itself is comfortable for 25.6% of the hrs. A study conducted on Hindustan Lever Limited, Bangalore with passive strategies such as longer facades and shaded windows; along with LPD of 6.3 W/m^2 and occupancy sensors reduced cooling load by 30% and electricity load by 27%. Chel et al. (2008) modeled trombe wall in a honey storage building located at Gwalior in India. They studied passive heating technique of storage wall its effects on heating load and the amounts of CO_2 released by replacing an electrically driven room air heater. Their study demonstrated that the trombe wall ensures adequate temperature for the building, and results in energy savings up to 3312 kWh/year and a reduction in CO_2 emissions by 33 tonnes/year.

2.2.5 Building energy management system and controls

Building Energy Management Systems (BEMS) are computer-based systems that help to manage, control and monitor building technical services such as HVAC, lighting, equipment, and other energy consuming devices used by the building. BEMS provides the information and the tools that building managers need both to understand the energy usage of their buildings and to control and improve their buildings' energy performance. BEMS send operational parameters to operator workstation through the controllers, such as Air Handling Units (AHU), chiller & boiler sequencing, exhaust fan control, set points and time schedules and performance information.

World Studies

Brambley et al. (2005) and Roth et al. (2002) have illustrated that systems linked to a BMS typically represent 40% of a building's energy usage; if lighting is included, this number approaches 70%. BEMS systems are a critical component to managing energy demand. Therefore, with the advancement of instrumentation and control; and information technology a large number of commercial buildings have adopted BEMS and various studies have been conducted. Lamedica et al. (2015) presented the results of a research activity in the framework of electric load management in buildings. These buildings are connected to the electric network, but they are also equipped with PV plants for integration of the electric energy with the relevant storage batteries. The idea behind is to use batteries of electric vehicles (present in the parking areas of the buildings) as supplementary storage systems. An algorithm is discussed, based on optimization techniques that allow maximizing the number of electric appliances that can be fed in conditions of power limitation. Kumar et al. (2015) presented the fundamental drivers behind the rise of sensing technology for the management of energy in urban built environments, and they highlighted major challenges for their large–scale deployment. Yu et al.(2011) proposed an Integrated Air-Handling Unit (IAHU) control theory so as to improve the energy efficiency in office buildings by utilizing the regional and operation differences among multiple AHUs. This study also presented the method to implement and evaluate the performance of IAHU in an open-plan office building with multiple AHUs. An office building with multiple AHUs is selected to assess the performance of IAHU. The study concluded that the innovative IAHU with the easy-to-implement strategy can be readily implemented to achieve high energy efficiency in open space office buildings.

Indian studies

Kirubakaran et al. (2015) estimated HVAC system parameters based on real-time control and process data using centralized Explicit Model Predictive Control (MPC) design and proposed for the given system. It is concluded that by reducing the energy consumed by the HVAC system using intelligent control schemes, it is possible to introduce green building concepts in even older buildings by simple modifications to existing control algorithms designed using a model of the building derived using closed loop control/process data. A study carried out by BEE at IIT; Kanpur revealed that adoption of electronic controls reduced EPI from 133 kWh/m^2/year to 98 kWh/m^2/year. In a similar study at Fortis Hospital, New Delhi adoption of HVAC controls reduced EPI from 346 kWh/m^2/year to 312 kWh/m^2/year. Study of Triburg building Gurgaon adopted lighting and HVAC optimization, and control reduced EPI from 165 kWh/m^2/year to 98 kWh/m^2/year.

2.2.6 Advance energy efficiency measures

Building codes and energy standards for minimum energy efficiency set minimum requirements for energy efficiency for all new buildings. In many case studies and research studies, it has been seen that it is possible and feasible to build with a much higher efficiency thereby improving the economy over the long term. No building codes or energy standards limit constructors or future owners to go for higher energy efficiency. Advancement of technologies for the air-conditioning system, new building materials, and energy efficient lighting fixtures have offered opportunities to conserve energy beyond prevailing practice as well as efficiency levels specified in buildings codes. Therefore, some buildings worldwide have adopted these advance technologies. Various research studies carried out to evaluate energy saving potential through the adoption of these advance technologies have been discussed below.

World Studies

Jiang et al. (2008) illustrated that through the adoption of advance design to the hotel building can save 50% of energy for each climate zone in the USA. He proposed replacing existing HVAC system with Water Source Heat Pump (WSHP), set point setting on unoccupied period in the guest rooms, installation of air side economizer. Energy recovery ventilators, efficient equipment, reflective coating for roof, extra glazing layers for windows, lighting occupancy sensors, efficient lighting, integrating lighting system with BEMS. A study carried out by Friess et al. (2011) conducted on residential buildings of Dubai they compared different options for wall insulation and found that 160 mm expanded polystyrene insulation and 15 mm gypsum layer on a wall constructed of the precast block of 200 mm reduced energy savings by 29.8 %. In another study by Nutphuang et al. (2011) wall insulation of different thickness was applied on external surface and it was found that with 75 mm thickness of insulation, the overall U-value of wall became 0.33 W/m/K and the energy intensity reduced from 334.3 kWh/m^2/year to 293.8 kWh/m^2/year.

United Nation Development Programme (2012) discussed some case studies of the hospital, educational and hotel buildings that showed that employing environmentally sensitive designs can lead to energy savings of 20- 50% however; initial investment will increase by 10-15%, with a payback period of 3 to 7 years.

Indian studies

There are some commercial buildings in India which have adopted energy efficiency measures beyond ECBC codes and realized much higher energy savings. The Energy and Resources Institute (TERI) India, carried out a project as 'High Performance Commercial Buildings in India' under Asia-Pacific Partnership on Clean Development and Climate to establish relevance and impact of low energy passive strategies and ECBC recommended measures and to further improve energy performance of commercial buildings in the five climatic zones of India. Under this project at Microsoft office building, Hyderabad it was observed that building if constructed with conventional practices had EPI of 208 kWh/m^2/year and adoption of ECBC specification on building envelope, LPD and air-conditioning reduced EPI to 145 kWh/m^2/year. Specification beyond ECBC such as passive design, advance lighting, efficient chillers, double layered glazing with reflective coating further reduced EPI to 129 kWh/m^2/year and, therefore, resulting into net energy savings of 41%. In similar project carried out at another building at ITC Green Centre, Gurgaon the additional advance energy efficiency measures were adopted. Such as 70 mm stone cladding on the outer layer of wall, 76 mm ISO board insulation on roof surface, double glazed high-performance glass with optimum window-wall ratio (SC-0.26), low LPD

Lighting 7.2 W/m^2, water cooled screw chiller with COP of 6.1 whereas ECBC recommended COP is 5.4.Therefore, the EPI with conventional practice was 125 kWh/m^2/year, with ECBC specification of building envelope, LPD and air-conditioning the EPI became 73 kWh/m^2/year, and which further reduced to 59 kWh/m^2/year with the use of specification beyond ECBC and resulted into energy savings of 64%. Wipro, Banglore an office building adopted advance measures such as 250 mm brick cladding and 50 mm extruded polystyrene insulation on the roof surface; double layer high-performance glass, CFL with occupancy sensor (LPD 11.2 W/m^2), water-cooled screw chiller with COP of 6.4 while ECBC recommended COP is 6.3. Parikh (2012) recommends that ECBC compliant buildings saved 30% of energy and advanced technologies beyond ECBC if adopted could save up to 50% of energy.

Although, many barriers hamper energy efficiency in new and existing buildings. When new buildings are designed and constructed, concern for energy efficiency in buildings may be low for most buildings focus is on construction costs. Most decision makers do not have the data or capability to calculate a building's lifetime costs and estimate the consequences of early design decisions. Therefore, there is an urgent need for the studies assessing the impact of building code and other energy efficiency measures on building sector.

2.2.7 Ground Source Heat Pump (GSHP) system

Energy consumption for space conditioning is increasing around the world every year; each country intends to reduce their energy consumption from fossil fuels due to harmful GHG emissions and wants to promote renewable energy technologies. In developed and developing countries the considerable amount of energy is being used for space heating and cooling; therefore, researchers are focusing on developing efficient and new technologies, which can reduce the energy consumption. One of the important technologies is replacing conventional HVAC system by Ground Source Heat Pump (GSHP) system, which is very popular in Western and European countries for space heating. Working of GSHP system is explained in Fig. 2.2. It works on the principle of vapor compression system that utilizes constant earth temperature for winter heating and summer cooling and its COP is higher than the conventional system. A geothermal heat pump has an evaporator, compressor, a condenser, and expansion device, also a reversing valve to allow both heating and cooling. A geothermal heat pump transfers heat between the refrigerant circuit and the ground instead of between the refrigerant circuit and the air. The ground is a much milder heat source since there is little variation in the ground temperature and it is almost uniform throughout the year. However, the outside temperature varies significantly over the year, making a geothermal heat pump much more energy efficient than a traditional air conditioner or heat pump. A geothermal heat pump compressor also operates at lower pressures because of the milder heat source/heat sink (the ground), resulting into longer life. During heating mode, GSHP absorbs heat from the ground and supplies to room.

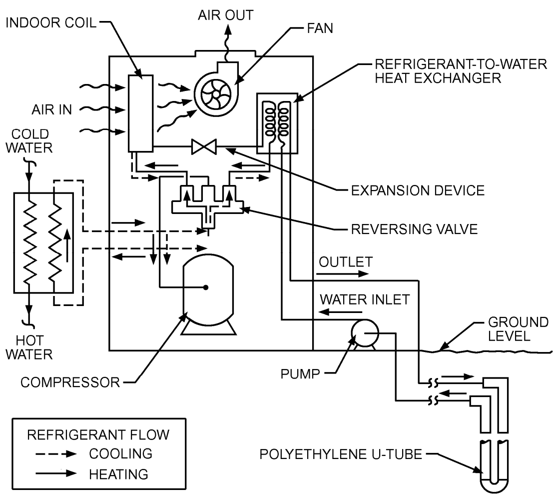


Fig. 2.2 GSHP system

World Studies

Aikins and Choi (2012) in his study demonstrated that in cooling mode GSHP absorbs heat from the room and rejects heat into the ground. Also, GSHP system occupies less space compared to the other conventional building HVAC systems. Naili et al. (2013) mentioned that from the year 2000 to 2005, the total number of GSHP system installations has increased by 170,000 in 33 countries. According to Lee (2009) in Korea, installation of GSHP systems have rapidly increased in both private and public sectors and is expected to increase by 51 times by the year 2030. Yu et al. (2011) conducted year round experimental study on GSHP system installed in Shanghai; China and results showed that the GSHP system was able to meet the required building archives design code of China. Park et al. (2013) studied the cooling performance of a Ground Source Heat Pump (GSHP) system with different flow configurations and compared it with a conventional GSHP system and found its performance much better than the conventional GSHP system.

Indian studies

In India, some GSHP systems have been installed till date, but some foreign companies have started their branches in India to utilize India's market potential of GSHP. Sivasakthivel et al. (2012) studied the electricity saving and CO_2 saving potential of GSHP system in India for space heating. They considered ten states of the northern part of India for analysis and they assumed only 10% of the families in a state use electric heater and GSHP system. The conventional systems were emitting 5270–26,352 million kg of CO_2 in a year for space heating and cooling, but with the use of GSHP, the CO_2 emissions reduced to 4022 to 12,071 million kg. Geothermal India has installed 200 TR capacity GSHP in Apollo Hospital, Hyderabad and achieved an energy savings of 43.6% with GSHP and other retrofitting measures. The GSHP has also been installed in Hotel Four Seasons, Mumbai and its monthly power bill is expected to drop to Rs 10 to 15 lacs from the current bill of Rs 40 lacs. Indian school of Business, Mohali, Chandigarh has also installed GSHP system in the campus buildings, spread over 70 acres. The system was designed to save 1.2 million kWh of power and 143.3 million liters of water annually with expected annual financial saving of Rs 87.16 lacs/year. Kapil et al. (2015) studied about the capability of GSHP system, both in heating and cooling cycle has been tested in India and results are quite satisfactory. In view of Indian climatic conditions and requirements, According to a rough estimate by Razdan et al. (2008), Kumar et al. (2012) and Gera et al. (2013); India has potential of 45000 GWh capacity of geothermal energy, which needs to be harnessed not only to explore a reliable energy alternate to meet future energy crisis but also to save our environment.

2.2.8 Integration of Solar Photovoltaic

The most intense solar radiation in the India is being received in Rajasthan, (where Jaipur city lies) and it receives solar radiations on about 300-330 clear sunny days and average daily solar incidence of 5-7 kWh/m^2, best in the country that is comparable to deserts of California, Nevada, Colorado and Arizona as analyzed by Rajasthan Renewable Energy Corporation Limited (RRECL).

World Studies

Shan et al. (2013) considered solar photovoltaic, a direct conversion of solar radiation to electricity by semiconductor modules, is one of the most promising technologies to utilize solar power. Braun (2010) suggested that the direct generation of electricity from sunlight through the photovoltaic effect presents itself as one of the best ways of generating electrical power. Thus, Lesourd (2001), Braun (2010), Jardim et al. (2008) suggested that inclusion of photovoltaic systems in the national energy supply, in a complementary way, could bring great benefits to the energy sector, as well as to the economic, environmental and social development. The photovoltaic (PV) system integrated with onsite building envelope, typically a roof and a facade, are known as Building Integrated Photovoltaic (BIPV) system. Such installations are on the rise since they serve the dual purpose of regulating the indoor environment and also generating energy. Further, energy saving through the integration of SPV systems with distribution networks (grid-connected) could reduce the maximum demand charge and energy losses as concluded by Bakos (2002). However, higher initial costs, large installation spaces required and limited output energy, SPV applications are not very popular in local building developments as illustrated by Li et al. (2009). Semi-transparent Building Integrated Photo Voltaic (BIPV) panels can provide electricity and adapt to day lighting schemes that enhance visual comfort, reduce peak electrical and cooling demands, and conserve building energy expenditures illustrated by Wong et al. (2008), Miyazaki et al. (2005). A study by Akwa et al. (2014) estimated monthly power generated as 250–300 kWh with a panel area of 16.5 m^2 and at an efficiency of 14.1% through photovoltaic panel containing 60 multi-crystalline silicon solar cells installed in the city of Lajeado, Brazil. Yang et al. (2004) studied the performance of crystalline silicon BIPV installed for a floor area of 250 m^2 on a building in Hong Kong produced 177 kWh/m^2 with a cost of 40 HK$/ Wp. Radhi (2010) in his study explores the variation of the total energy of BIPV as a wall cladding system applied to the UAE commercial sector. In this study, it was shown that the total energy requirement to produce and install 1 m^2 of PV system on a building façade was 1450 kWh and for the southern and western facades in the UAE, the embodied energy payback time for the photovoltaic system was within the range of 12 to 13 years. Weiss et al. (2012) assessed the effects of installing a BIPV roof on an office building in Yuma. Daily PV energy production per PV surface area was about 0.4kWh/m^2 during the summer and 0.15kWh/m^2 during the winter, corresponding to about 25% and 20% of building electrical energy use in each season. Liu et al. (2012) in his study at Queensland stated that PV system is an effective way to decrease electricity bill and mitigate carbon dioxide emission where a 6 kW PV system in can deal with 61% of the total electricity load and saves more than 90% of electricity payments and reduce approximately 95% of carbon dioxide emission.

Indian studies

Chel and Tiwari (2011) presented a rigorous experimental outdoor performance of a 2.32 kW_P Stand-Alone Photovoltaic (SAPV) system in New Delhi (India). The existing typical 2.32kW_P SAPV system had PV modules (total array size of 1.12 kW_P) and eight years old PV modules (total array size of 1.2kW_P) generates power about 1296 kW h/year. Agrawal and Tiwari (2010) carried out a study using the opaque type BIPV system fitted on the laboratory building at the Centre for Sustainable Technology (CST), Indian Institute of Science, Bangalore and found that the system fitted on the roof area of 65 m^2 yields a net electrical and exergy gain of 548 kWh/year and 1430 kWh/year, respectively. Nadkarni et al. (2013) illustrated a study at Center for Sustainable Technologies in the Indian Institute of Science, Bangalore campus, where building integrated photovoltaic system was installed in the form of a roof, at rated capacity of 5.25 kWp. The average efficiency of the entire system was 6% over the year with a performance ratio 0.5. The average inverter efficiency was found to be 91% and 4000 kWh/year of electrical power was supplied to the grid. Nadkarni et al. (2013) mentioned that they reduce the land requirement for off-site PV installations and distribution losses.

2.3 Building energy codes

Building energy codes play an important role to achieve GHG reduction targets. A study by LBNL, (2012) suggested that new buildings must be developed to zero energy standards to achieve significant GHG mitigation in the building sector. The building energy codes have been adopted worldwide and various studies have been carried out to assess energy saving opportunities through their implementation.

2.3.1 World scenario

Adoption of energy efficiency methods and technologies in buildings vary according to geographical location, climate, building type and location. Also, the developed and developing countries use different technologies for energy savings. There is also contrast between retrofitting existing buildings and new buildings. In all cases different standards are followed for enhancing building energy performance. Therefore, many countries have adopted different energy codes for building energy efficiency. In developed countries like North-America, Europe, and the Pacific region building codes are usually mandatory to new residential and commercial buildings. ASHRAE (2004) and Energy Efficiency standards IECC (2004) are used in US and Canada. European Union adopted European Energy Performance in Buildings Directive (EPBD) for energy efficiency in new buildings. In consideration of the dissimilar energy performance most countries have started with one common standard. Over the time countries have developed separate standards for simple and small residential buildings and large, complex or non-residential buildings. Fig. 2.3 shows the status of building energy codes implementation for non-residential buildings.

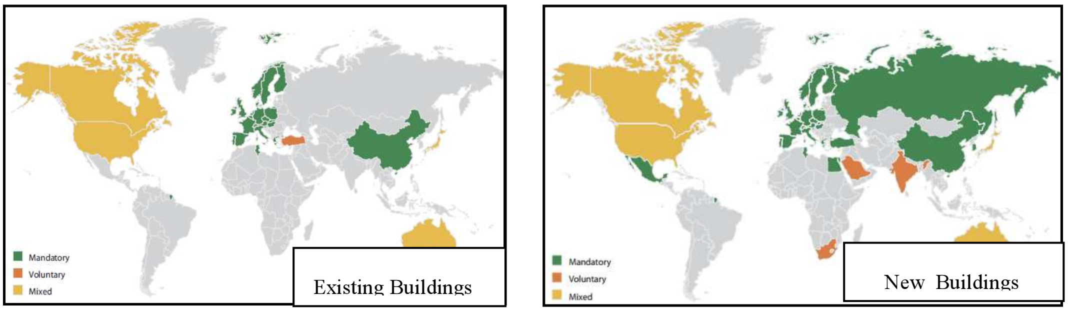


Fig. 2.3 Status of building energy codes implementation for non-residential buildings

Various studies have been carried out worldwide to assess the energy savings in buildings through the implementation of building codes. Parikh (2012) recommends that ECBC compliant buildings saved 30% of energy and advanced technologies beyond ECBC if adopted could save up to 50% of energy. E.Mata et al. (2015) conducted simulation study on adoption of building codes and the modeling shows that the energy demand of the Spanish building stock could be reduced by 55% and the associatedCO2emissions reduced by 65% by implementing all the ECMs. Yu et al. (2014) evaluated the impacts of building codes on building energy and found that building energy codes would reduce Chinese building energy use by 13– 22% depending on building code scenarios. Melo A. P. et al. (2014) studied implication of adopting Brazilian building energy codes on commercial building and the results for show that with adoption of Brazilian regulation energy consumption is reduced up to 23% with use of heat recovery, VRF system, reduced wall and roof transmittance, and low LPD.

A study by Xu et al. (2013) investigated the energy saving potential for residential buildings in hot summer and cold winter zone under a different level of energy efficiency standards (China local, China national, and UK standard). The building energy savings in Chongqing could achieve 31.5% and 62.8% for residential and public building sections respectively if the Chinese national standard were satisfied, the energy saving would increase to 45.0% and 62.8% respectively when the Chongqing local standard was met; the value would further increase to 53.4% and 75.9% if the UK standard were satisfied. Kneifel (2010) focused on life cycle energy assessment of commercial buildings by adopting three variations of building design for 12 prototype buildings in 16 US cities, according to ASHRAE 90.1 design standards. The extensive modeling exercises showed that even conventional energy efficiency measures help to reduce at least 20% of energy consumption and 16% of carbon emissions. Sabapathy et al. (2010) in his study observed that an average energy saving of about 34% can be achieved for LEED-rated buildings as compared to similar non-LEED rated buildings. Turner and Frankel (2008) found that the LEED-certified building can achieve more than 28% of energy savings than conventional buildings.

2.3.2 Indian scenario

Bureau of Energy Efficiency, Government of India developed Conservation Building Code (ECBC) by to improve energy efficiency in buildings illustrated in USAID (2009). Several Indian states adopted the code including Rajasthan and hence it applies to the buildings of Jaipur city. The code is applicable to commercial buildings that have a contract demand of 120 kVA or connected load equal to or greater than 100 kW. Minimum energy efficiency standards have been prescribed by ECBC for building components, systems, and sub-systems. Energy Performance Index (EPI) of commercial buildings in India ranges from 200-400 kWh/m^2/year whereas similar buildings in Europe and North America have EPI lower than 150 kWh kWh/m^2/year. The building code prescribes standards for various building components such as building envelope, HVAC system, service hot water lighting, etc. ECBC complaint buildings have energy saving potential in the range 30% - 35%. Currently, most of buildings in India are not ECBC-compliant. The United Nations Development Programme estimated that code compliance in India would reach 35% by 2015 and 64% by 2017 (UNDP, 2011). ECBC compliant buildings save 30% of energy as estimated by Parikh (2012). Dhaka et al. (2012) in his study on commercial buildings in Jaipur city estimated that ECBC compliant buildings saves 40% energy than buildings following conventional practices which can result intoannual saving of 1.7 billion kWh units if adopted by all Indian commercial buildings. A study carried out by Kumar and Suman (2013) found that thicknesses of 50 mm, 60 mm, 70 mm, 80 mm and 150 mm is required for wall insulation with elastospray insulation, PUF, EPS, Fiber glass and concrete foam insulation, respectively for ECBC compliance. Tulsyan et al. (2013) in his study on six categories of commercial buildings of Jaipur city (India) and observed minimum 17% and maximum 42% of energy savings, with ECBC compliance in the case of institutional building and hospital, respectively. Benchmark study conducted on 48 luxury hotels (4-5 star hotels) and 136 non-luxury hotels (1-3 star hotels) in India by USAID ECO III Project (2010) revealed that the benchmark EPI for non-luxury hotels and luxury is 266 kWh/m^2/year and 274 kWh/m^2/year respectively. Building Energy Benchmark Report (2014) estimated average benchmark EPI for hotel buildings of Singapore and estimated an average EPI of 292 kWh/m^2/year. The star labeling scheme devised by Bureau of Energy Efficiency, India based on data from around 300 office buildings in three climatic zones namely hot & dry, warm & humid and composite. EPI was used as the key performance indicator. Table 2.1 below shows EPI is used for calculating the Star Rating for commercial buildings. Separate tables are available for different climatic zones and percent of conditioned area in the building. The table below shows the star ratings by EPI of buildings for composite climate of India and which are having an air-conditioning area above 50%.

Table 2.1. Energy Performance Index and Star rating for commercial buildings in India

EPI (kWh/m^2/year)	Star rating
190-165	1 Star
165-140	2 Star
140-115	3 Star
115-90	4 Star
Below 90	5 Star

However, Harper et al. (2012), Nordeen (2013), Stellberg (2013) and Yu et al. (2014) emphasized in their study that improvement in the stringency of energy codes does not matter when the compliance rate is low since robust enforcement and high compliance rate is critical to achieve intended energy savings.

2.4 Compliance approaches in building energy codes

The estimation of energy efficiency measures through adopting various technologies to the building envelope, HVAC system, lighting and integration of BIPV can be can be carried out through various approaches. The energy consumption behavior of every building is different and different opportunity for energy savings. Each building owner or user has different requirements also climate conditions are different. Flexibility is needed by engineers and architects in designing buildings that address these diverse requirements. Adoption of building code with trade-off option permits trade-offs among building components for code compliance. Building code compliance can be done through two approaches prescriptive and whole building performance method which is more flexible and used for evaluating energy efficiency.

2.4.1 Prescriptive approach

The ECBC Code specifies a set of prescriptive requirements for building systems and components by meeting or exceeding the specific levels described for building components. The code provides the maximum U-factors of the overall assembly and minimum R-values of insulation for walls and roofs for the five climate zones. Prescriptive requirements the HVAC system, furnace, electric resistance heater, or baseboards connected to a boiler, use less than 1,400 liters/second of outside air, and this air is less than 70% of supply air at design conditions. Prescriptive requirements for lighting describe LPD based on a building area method or a space function method and all other HVAC systems must comply with ASHRAE Standard 90.1-2004.

2.4.2 Energy cost budget method

Energy cost budget method is the compliance method by ASHRAE 90.1 which requires energy modeling with a different set of rules. standard, must generate two separate sets of energy models as proposed design and prescriptive building design. Building energy performance is evaluated in its entirety or the whole building approach through trade-off across building systems. This approach gives credit for innovation in energy saving features of one system which can compensate for energy consumption by another system. The interactive sysnergies of the mechanical, electrical and architectural components are accounted for this method. The annual energy cost of the proposed design has to be less than the cost of base prescriptive building design. Advanced technologies such as chilled beams, radiant cooling, high-performance envelope can be traded off with other architectural elements. Energy cost budget method is used for compliance with this standard by design energy cost calculations. This method does not predict costs of the proposed design after construction or actual energy consumption. Actual results differ from results obtained from calculations due to variations in building operation and maintenance, building design, occupancy, energy rates and weather.

2.4.3 Whole building approach

Whole Building Performance (WBP) approach offers considerable design flexibility. It allows code compliance through optimization of energy use by various building components to find the most cost-effective solution. Energy performance of building is predicted during the design phase. There is increased use of energy simulation tools for analysis of buildings energy performance, as reported by Augenbroe et al. (2004), Aksamija (2009), Aksamija (2010), Wetter (2011) and Aksamija (2012). Simulation tools help in making comparisons between different design options to identify the most cost-effective and energy-efficient design solution with the help of computer software program. Building simulation helps in making necessary modifications in the building design before the building is constructed in order to make buildings energy-efficient. Building simulation helps in the understanding of how a given building operates and enables comparisons of different design alternatives.

Energy planning and modeling studies have become a very active area of research worldwide. Pan et al. (2007) used calibrated energy simulation and then analyzed the energy consumption of two high-rise commercial buildings in Shanghai. Chimack (2001) determined the peak cooling loads by calibrated DOE-2 model and assessed energy of a 107-year-old science museum. Raftery et al. (2011) reported that most studies analyze model error using monthly data, or combine monthly data with further daily. Pedrini et al. (2002) used simulation and calibration to model more than 15 office buildings in Brazil. ASHRAE (2002) also suggests when building simulation should be used and when pre or post-retrofit whole building metered data are not available.

2.5 Building energy simulation tools

Energy simulation tools predict the energy performance of a given building through input parameters such as building geometry, HVAC system, internal loads, weather data, operating strategies and schedules and enable comparisons of different design alternatives. Energy performance of a building is a complex process and not totally understood today, energy simulation programs approximate their predictions with qualified equations and methods. The choice of simulation program might vary therefore there is the need to investigate different programs so that they can be compared, analyzed, and documented.

2.5.1 Energy Plus

Energy Plus is a whole building energy simulation program that helps engineers, architects, and researchers to model plug loads such as heating, cooling, ventilation, lighting, and process loads. Energy Plus is based on an integrating system simulation and system loads. Energy Plus leads to more accurate temperatures predictions in spaces and, therefore, a better estimate of various resulting parameters, such as thermal comfort as reported by Crawley et al. (2002). AHSRAE's preferred heat-balanced-based approach is the basis of load calculations as reported by Strand (2001). Energy Plus enables auto-sizing of many component-specific parameters. But Energy Plus doesn't have graphical user to allow faster and more convenient user input interface therefore a simple but flexible user interface is needed which is done by Design Builder.

Design-Builder

Design-Builder is graphical interface tool based on Energy Plus simulation engine and it is integrated with Energy Plus to carry out simulations with ease. Design Builder has been specifically developed around Energy Plus allowing most of the Energy Plus data as input. Databases of building envelope, materials are provided. The workflow of Design-Builder develops specific thermal building model geometry with the integrated CAD interface. It also provides a variety templates or different countries for selection of various parameters. Other parameters include internal loads occupancy, construction types, windows, doors, lighting, and HVAC systems. After defining all parameters design day and annual simulations and validation of the thermal model of the building against the energy code can be performed. It defines HVAC systems as simple and compact and does not include detailed information of the components. It forces the user to recreate a 3D geometry model for energy analysis due to inability to import EnergyPlus input files.

2.5.2 TRNSYS

TRNSYS is a transient systems simulation program in which the user specifies the components that constitute the system through recognition of a system description language. Its library includes components commonly found in thermal and electrical energy systems, an input of weather data. TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not included in the standard and is well suited to detailed analyzes of any system whose behavior is dependent on the passage of time. TRNSYS has become reference software for researchers and engineers around the world.

2.5.3 DeST

Designer's Simulation Toolkits (DeST) is used to estimate energy consumption, ratio of loads satisfied by the HVAC systems and hourly building thermal performance, for detailed analysis of building. It also estimates economic cost results and makes it possible at different stages to choose the best option in the design process. DeST software has five options, i.e. DeST-c for commercial buildings, DeST-h for residential buildings, DeST-r for building ratings, DeST-e for building evaluation, and DeST-s for solar buildings. Various large buildings in China have been using this tool because it not only has AutoCAD interface but also Chinese operation interface which makes it easy for users to build the building in AutoCAD.

2.5.4 ESP

The construction projects with regard to energy and environmental performance is supported by mathematical software tool ESP-r (Energy Simulation Software tool), in a realistic and accurate way. The software tool coordinates the data, performs simulation, CAD applications, different tools for evaluating performance. The ESP-r deal with all aspects at the same time such as construction, geometry, operation, distribution, heat dissipation, etc. through the use of several complex equations. These equations in response to the influences of the occupants, and climate control systems are integrated in successive time steps. The building geometry allows the specification of the geometry of buildings to be set in CAD software tools or other similar tools and the models created in this software can be exported to Energy Plus. Building parameters such as HVAC systems, areas of Computational Fluid Dynamics (CFD), insulation, electricity, lighting, combined heat and power generation, renewable energy, natural ventilation, SPV systems for control of indoor air quality can also be included in the models pre-determined. Building simulation with ESP-r can vary in a range from one minute to one hour. The outputs of the simulations can be viewed by the interactions between the domains of assessment or exported to other graphics software. Many innovative technologies can be simulated by ESP-r and it is extremely useful and a powerful tool for this kind of simulation. However, the program requires long learning process and a great knowledge and expertise [Haugaard, 2003].

2.5.5 IES VE

Integrated Environmental Solutions – Virtual Environment simulation software works on the geometric representation tool and provides variety of variables in simulation analysis of buildings to the design professionals. Dynamic thermal simulation of heat transfer processes of buildings is incorporated by this tool. The simulation software has qualified as a dynamic model tool since it was tested using the IES ASHRAE 140. IES VE through taking into account criteria such as comfort and energy provides an environment for the detailing of the building systems and allow their optimization. The dynamic tool ApacheSim can be dynamically linked to the HVAC Apache dynamic tool and Macro FLO dynamic tool. It is done to consider natural ventilation and perform analysis of air leaks, natural lighting and shading [].

2.5.6 DOE-2

The DOE-2 engine can simulate the thermal behavior of spaces in a building. It can model and simulate heat loads, such as air conditioning loads, equipment loads, lighting loads, solar gain, people loads. The user input has construction library and materials layers into the Building Description Language (BDL) input processor. The input into a computer readable format is transformed by BDL processor that is later used by the four subprograms as loads, systems, plant, and economics. These subprograms are executed sequentially then load in a space is calculated considering only external and internal loads. DOE-2 engine has several limitations; first of all, different modules have missing feedback, restricting the simulation results. The space conditions are less accurate as compared to simulations with feedback. Therefore, accuracy of the resulting energy usage and thermal comfort simulation is low. HVAC systems that make use of stratification cannot be adequately represented since the DOE-2 model is based on the uniform temperature assumption.

2.5.7 eQUEST

eQUEST provides whole building performance analysis to energy professionals architects, engineers and designers. All available parameters in eQUEST can be defined as per definitions available in the DOE-2 engine. Energy-Efficiency Measures sub-system enables fast comparisons of specific input parameters. User can change input data to default values through eQUEST wizards screen that contain several wizard screens. eQUEST runs faster than Energy Plus especially with a large number of zones.

Therefore, there are number of simulation tools available for evaluation of building energy performance and the choice of simulation program depends on the applicability and usability of the program according to our need. Various studies have been carried out using simulation tools to evaluate building energy performance. Fumo et al. (2010) suggested that energy consumption analysis of buildings is a difficult task due to presence of multiple variables, dynamic behavior of the weather conditions. In building simulation calibrated simulation is an appropriate method to measure and determine energy savings. However, Pan et al. (2007) reported that simulation models cannot be used when it is possible to analyse measures without simulation, or when buildings and its components cannot be readily simulated. Dong et al. (2013) analysed retail store building energy performance through parameters such as control logics, temperature set points, etc. The results obtained an energy saving of 14.5% on HVAC systems, and 4% to the total building energy use. Cerrieri (1999) modeled a large commercial building using DOE-2, and the model were validated using monitored data and evaluated some conservation measures that included window glazing, occupancy sensors, cold deck temperature set point and reduced ventilation air. Kircher (2010) identified and assessed the efficacy of clean room energy efficiency strategies. The model was validated by comparing a full year simulation of the clean room's electricity, steam and chilled water consumption with the 2008 metered values; error values of 8% were achieved in all fields as studied by Kircher et al. (2010). Ke et al. (2013) in his study applied IPMVP's Option D and used the eQUEST tool to examine the energy consumption circumstances for an office building in Taiwan. The parameters were calibrated between the simulated energy consumption and the actual values to increase model accuracy. Zhu (2006) in his study has indicated that computer-based simulation is a valuable technique to assist facility managers in determining energy conservation solutions and he concluded that the simulation offers a reusable and effective tool for energy efficiency studies.

Therefore, eQUEST has been widely used as a building simulation tool to assess its energy performance. Present study uses eQUEST version 3.64 building simulation tool for analysis of hotel buildings due to following reasons.

eQUEST is a powerful graphic user interface for the DOE-2. The new modeling capabilities of eQUEST make it possible to model new and complex building technologies that cannot be modeled by other whole building energy simulation programs. The user interfaces for eQUEST DOE-2 are currently more developed in comparison to the interfaces for Energy Plus. The energy-efficiency measures provides another functionality of this tool, which enables fast comparisons of specific input parameters. eQUEST is easy to use and quick in producing results that would especially help in the taking critical decisions during the design phase. eQUEST supports a number of graphical results and provides outputs for single-run results, comparative results and parametric reports and it can be used at every stage of building development, from the early designs to final stages. eQUEST is a powerful tool for the DOE-2 engine and includes a lot of useful features furthermore, eQUEST depends on DOE-2 and, therefore, inherits all of its limitations.

2.6 Summary and research gaps

Studies carried out worldwide have illustrated that buildings consume a significant amount of energy. In developing countries, there is a rapid growth in building sector which has resulted into depletion of energy resources and high GHG emissions attributed to this sector. In recent years, several building codes & standards have been developed for reducing energy consumption in buildings. Therefore, literature study can be summarized as

- Buildings across the world consume a significant energy resulting into high GHG emissions. Commercial buildings are among the most energy-intensive; especially hotel buildings since they have all luxuries.
- Therefore, the share of hotel buildings into energy consumption & GHG is high among commercial buildings.
- Studies have shown that in India, energy consumption in buildings can be reduced to 30% to 40% by implementing ECBC code and can further reduce by more than 50% with the adoption of advanced technologies and materials, to building envelope, HVAC equipment, lighting fixtures, and other equipment.

- The study has found that there is significant growth of hotel buildings in Jaipur, and, therefore, energy use in hotels can be reduced to a great extent.
- It is observed that few studies are available on hotel building sector focusing on implementation of ECBC for energy efficiency.
- As such, very few studies are found which addressed energy efficiency and energy saving potential in the hotel sector, the composite climatic region of Jaipur city.
- Energy saving potential through the adoption of measures beyond ECBC and adoption of new technologies such as ground heat exchanger as an alternative to conventional HVAC for hotel buildings is yet to be explored in India.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

The present study aims to evaluate energy saving potential for different categories of hotel buildings through the adoption of Energy Conservation Building Code (ECBC) and advance Energy Efficiency Measures (EEMs), on building components such as HVAC system, building envelope and lighting system. Solar Photovoltaic (SPV) system is also analyzed for roof top installation for case study hotel buildings for further energy savings. Cost-benefit analysis of these measures has been carried out, and this study also estimated the expected energy savings and Greenhouse Gas (GHG) reduction potential for hotel sector of Jaipur city. This chapter describes the methods and procedures for selection, modeling and simulation of case studies.

3.2 Study work flow chart

In the present study, a preliminary survey is carried out to collect data for ninety-two hotel buildings through questionnaire and site visit. It was observed that hotel buildings have variations in building envelope properties, HVAC system, equipment, operating parameters and status of energy efficiency measures. For energy analysis, nine hotels were selected and grouped into three categories considering three hotel buildings in each category. These nine case study hotel buildings were modeled and calibrated using the criteria specified under International Performance Measurement & Verification Protocol (IPMVP). The calibrated models were further simulated to obtain energy savings through various energy efficiency measures. Economic analysis of energy saving measures is also carried out for case study hotel buildings.

The study also projected number of hotel buildings coming in next five years and corresponding energy consumption and GHG emissions pertaining to these hotel buildings. The results of energy savings from case study hotel buildings have been utilized to project expected energy savings and GHG mitigation potential of hotel sector of Jaipur city. The work flow chart for the research methodology is presented in Fig. 3.1

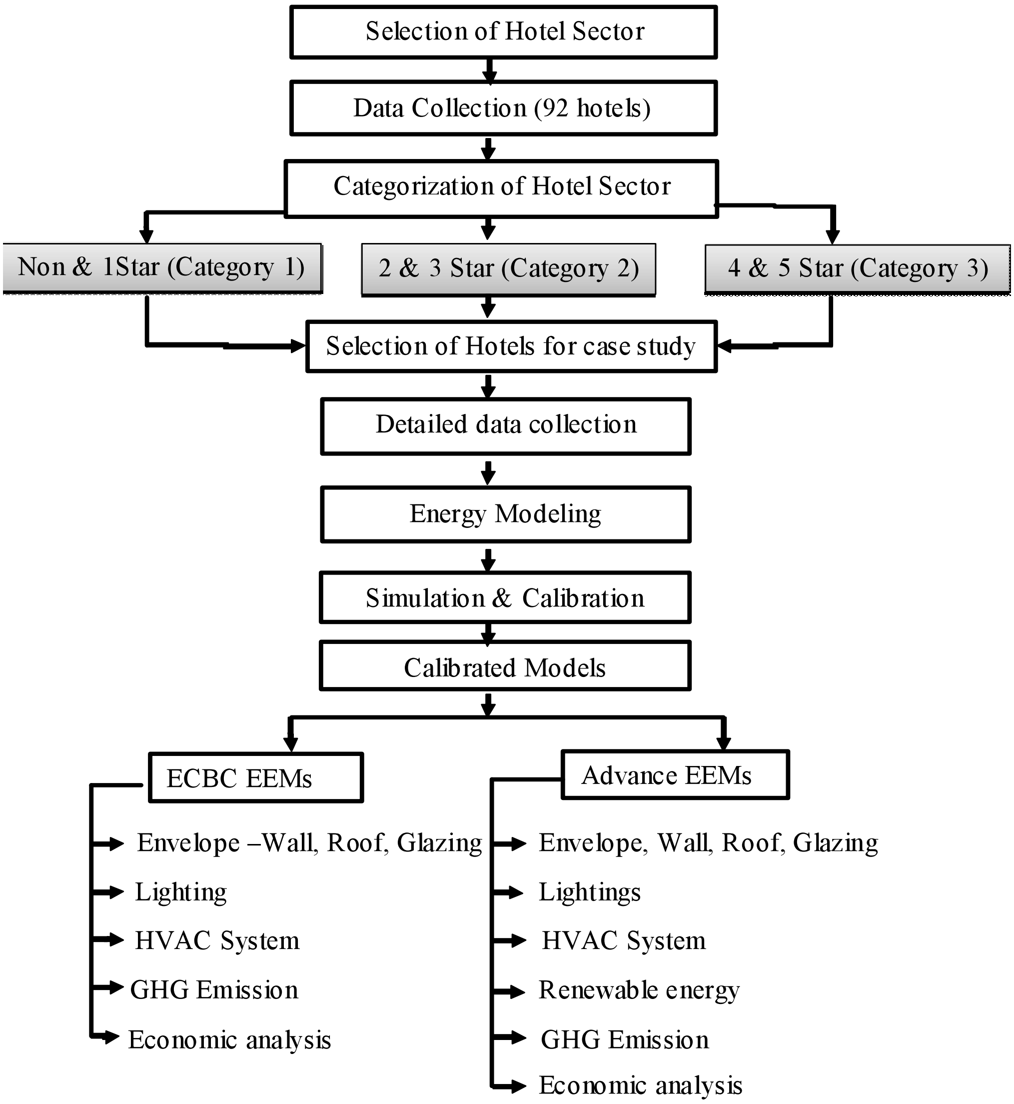


Fig. 3.1 Work flow chart for research methodology

3.3 Climate of Jaipur city

The study is carried out at Jaipur city (26.9°N, 75.8°E), the capital of Rajasthan, India. The city lies under the composite climatic zone of India. National Building Code-2005 and thereafter, Bureau of Energy Efficiency (BEE) have considered India to be divided into five climatic zones namely; hot and dry, warm and humid, temperate or moderate, cold and composite as shown in Fig. 3.2.

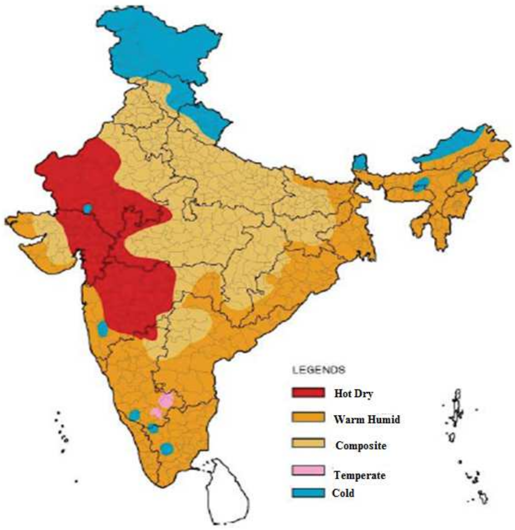


Figure 3.2 Climatic map of India
(Source: BEE, 2007)

Weather data of Jaipur city was obtained from ISHRAE (2013). Relative humidity in Jaipur city varies between 20 -100% and outside air temperature is observed to be as high as 45°C during summer as reported by ISHRAE, thereby, resulting into high cooling load on the HVAC system. The observed cooling hours for a base temperature of 23°C are 1976 hrs/year. During winter the dry bulb temperature drops to 4°C resulting into 781 heating degree hours in a year at 23°C base temperature. Fig. 3.3 shows yearly variation of outdoor dry bulb temperature, wet bulb temperature and precipitation in Jaipur city. Therefore, extreme climatic conditions are the main characteristics of this climatic zone.

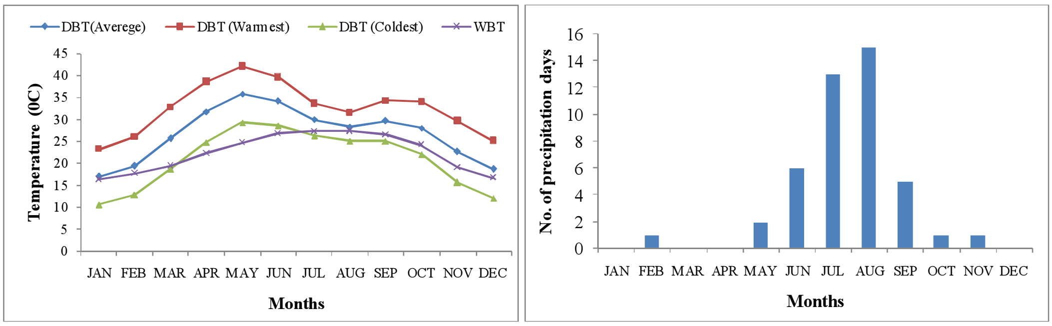


Fig. 3.3 Monthly variation of DBT, WBT and precipitation at Jaipur city

3.4 Selection of hotel building sector

Commercial sector of a city includes hospitals, hotels, institutes, government offices, private offices, retails and other commercial centers. Jaipur is the capital city of Rajasthan, therefore, there has been a rapid growth in the above mentioned commercial sector buildings, resulting in higher energy consumption. Data of commercial sector of Jaipur city is collected in the present study. Energy consumption data is compared and analyzed for the hotel sector selected for the present study. Description of various reasons for selection of hotel sector has been discussed in the following section.

3.4.1 Energy Intensity of hotels

Energy Performance Index (EPI) worldwide commonly assesses energy intensity of a building. It is defined as calculated total weighted specific use of delivered energy consumed in the course of standard use of the building. Through various studies worldwide, it has been observed that for estimating energy saving potential of different buildings the EPI is the most crucial factor. A study on 800 Indian commercial buildings to benchmark building energy consumption under USAID ECO-III project is carried out. The study estimated EPI of the shopping mall, multi-specialty hospital, the government hospital, private office and public sector office. The study revealed that the hotels have high energy intensity in terms of EPI as compared to other commercial buildings shown in Fig. 3.4. In another study by Indian Hotel Industry Survey 2009-10, it is observed that only 25% of Indian hotels have energy management system. This includes 12% of non-star and one-star category hotels and 33% of five-star hotels. Therefore, the scope for energy saving is higher for the hotel sector.

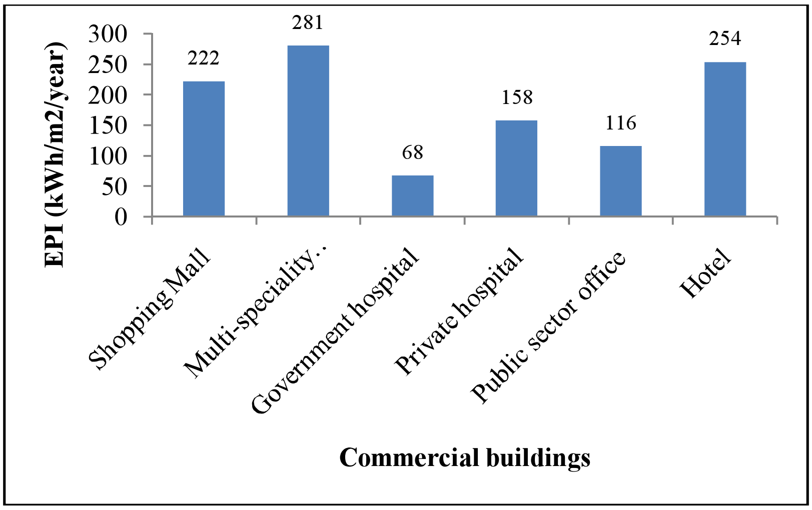


Fig. 3.4 EPI of commercial buildings in India
(Source: USAID ECO-III)

3.4.2 Share in energy consumption by hotels of Jaipur city

Data of electricity consumption for commercial buildings of Jaipur city with connected load more than 100kW is collected from Jaipur Vidyut Vitaran Nigam Limited (JVVNL), Jaipur which is a state government electricity department responsible for compilation of energy data of Jaipur city. The government offices have high energy consumption due to large number of buildings but the energy intensity of these offices is lower due to an excessive share of un-conditioned spaces. Therefore, the scope for energy saving is low and not considered in the present study. The private offices have tremendous growth in last few years in Jaipur city. The private office buildings mainly have data centers, financial institutions, telecom offices; which are widely distributed and have scattered data, therefore, data collection and compilation is a difficult task. A building has a number of private offices at different floors, and their data compilation and procuring common building drawing from different private offices is difficult. Therefore, this sector is also not considered in the study. Looking to the limitations of other buildings, hotel sector which is one of the most energy intensive buildings, has been therefore considered in the present study.

From the collected data it is observed that government offices (30%), private offices (25%) and hotel buildings (16%) have larger share of energy consumption as compared to other buildings in commercial sector of Jaipur city. Hotel buildings of Jaipur city account for 16% of total electricity consumption.

3.4.3 Growth of energy consumption

In the recent past, Jaipur has witnessed a fairly large increase in hotel rooms. Approximately 500 new hotel rooms were added to the market in 2011-12 as compared to 82 rooms in 2010-11 and resulted into growth in occupancy across the city as compared to the previous year. Approximately, 1000 more hotel rooms were also added in the market by 2013-14 making further occupancy pressure imminent. The inflow of foreign tourists in India was 46 lakhs in 2006 which increased to 56 lakhs in 2010. In the long term, an additional 2,300 rooms are proposed in the city, of which approximately 50 % are in the upscale segment illustrated by Indian Hotel Industry Survey 2011-2012. Therefore, the hotel buildings are growing rapidly and expected to grow in future which may result into high energy consumption by this sector. In the present study, energy consumption data are collected from JVVNL, Jaipur city for all commercial buildings it is noted that hotel buildings have high growth of energy consumption.

3.4.4 Organized availability of information

A preliminary survey of commercial buildings conducted during the study revealed that hotels have comparatively organized data and in most of the hotel building owners usually have a separate technical staff to maintain records of the energy data. The data regarding occupancy, operating parameters of equipment, technical details of all equipment and machinery is compiled and monitored at one place. Hotels are single unit buildings with single point metering of energy bills, therefore, the compilation of data becomes easier.

3.4.5 Possibility of implementing recommendations

Most of the hotel buildings have a single owner and single building, therefore, it is convenient to assess and implement energy efficiency measures. Because hotels are quite energy intensive, therefore, most of the hotel owners are found to be interested in implementing energy efficiency measures. In a study carried out by Confederation of Indian Industry (CII), 2012, with a view to bringing out the relevant hotel industry insights, 20 eminent CEOs from various hotels are interviewed and their responses formed the basis of this survey. All hotel chains (Indian and international) having five or more operational properties in India have been considered for this survey. The survey results showed that energy conservation strategy is the most important option to reduce operational cost for the hotels as shown in Fig.3.5.

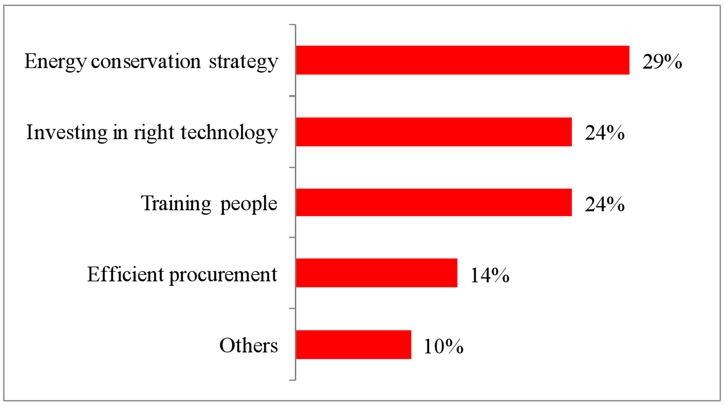


Fig. 3.5 Options to reduce operational cost in hotels
(Source: CII, 2012)

3.5 Categorization of hotel buildings

Jaipur city is one of the most visited tourist places in India; having 589 hotels in the year 2014. A survey of 92 hotel buildings of different categories has been carried out through a questionnaire; and it is observed that the energy consumption pattern of different categories of hotels varied qualitatively and quantitatively. Ministry of

Tourism, Government of India, categorized Indian hotels (non-star to five-star) based on certain parameters such as a number of rooms, public facilities, recreational facilities, luxury services, building architecture, total air-conditioned space, eco-friendly practices, energy conservation practices, etc. There is a difference in the level of luxury and recreational facilities among hotels of various categories and the differences in hotel facilities are identified. The facilities affect energy consumption and by their impact to energy consumption hotels of different categories are studied. Although, there are significant differences in different hotel buildings it is also seen that there are similarities in building envelope construction, energy consumption, type of HVAC system etc. between non-star and one-star, two-star and three-star, four-star and five-star hotel buildings. Therefore, non-star and one-star hotel buildings are grouped together as Category-1 in the present study. Similarly, two-star and three-star hotels are grouped together as Category-2; and four-star and five-star hotel buildings are grouped into Category-3.

During the survey it was noticed that Category-1 hotel building (58 hotels) are having thick wall construction, unitary type of HVAC systems and average energy consumption in this category is about 1 lac kWh/year/hotel. Category-2 hotel buildings (18 hotels) are mostly having R.C.C. column-beam construction with single brick walls and rooms are equipped with packaged air-conditioner units and few with unitary units and the average energy consumption in this category is 4.7 lac kWh/year/hotel. Single brick wall with both side cement plaster construction is used in Category-3 hotels and the HVAC system used is the chiller type cooling system with average energy consumption of hotel buildings in this category is 21.4 lac kWh/year. Hotel buildings in Category-1 have only basic facilities, Category-2 have moderate luxuries and Category-3 hotels have almost all luxuries and facilities such as large room sizes, swimming pool, banquet hall, laundry, restaurant, conference hall, etc.

3.5.1 Category-1

The hotels in this category (non-star and one-star) have generally three to five floors and ten to thirty rooms that follow old construction practices. As observed in the preliminary survey also, most of the hotels hardly have any concern for energy efficiency. The building envelope is constructed by following conventional practices in India; the walls are constructed with brick and cement plaster cladding with ordinary paint. The HVAC system is mostly unitary system with either no star or poor star ratings; even old air conditioner units are in operation. The lighting fixtures are conventional tube lights with magnetic chokes, although there is awareness regarding lighting fixtures, some of the owners are in the process of replacing old lighting fixtures with LED and CFL.

3.5.2 Category-2

The hotels in this category (two-star and three-star) have thirty to eighty rooms and five to eight floors construction. The hotel buildings in this category have some concern for energy savings and are in the process of replacing their old equipment with energy efficient equipment. New hotel buildings have energy efficient equipment while the old buildings are using the old inefficient equipments. The HVAC systems in these buildings are mostly direct expansion system as packaged terminal units. Some of the hotel buildings are having packaged units at some portion of the building and unitary units at some other portion of the building. The lighting fixtures are mostly replaced with energy efficient equipment.

3.5.3 Category-3

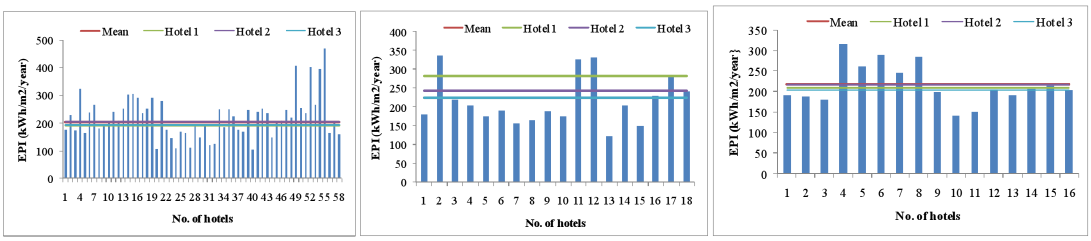
The hotels in this category (four-star and five-star) have forty to two hundred rooms and seven to thirteen floors construction. These hotel buildings are adopting energy saving measures. Equipment that require lesser capital cost are being replaced with energy efficient equipment. The floors are equipped with tiles and carpet; the roofs are coated with the waterproof coating. The windows have double glazed tinted glass and projections. The HVAC system is chiller type in most of the hotels; only few hotels have air cooled chiller otherwise most of the hotels are having water-cooled chillers.

3.6 Selection of hotels for detailed study

Selection of case study building is an important aspect for analyzing the impact of energy efficiency measures. It is well-known fact that selection of an appropriate case study building is free from extraneous variation and helps to define the limits for generalizing the findings. It is, therefore, evident that the case study building has a significant influence on the effectiveness of the study. Therefore, selection of case study hotel building is carried out with detail analysis of data. Data collected from 92 hotel buildings included building details, monthly energy consumption, building envelope, lighting, and major electrical equipment, HVAC system (system type, make and model, system specifications), thermostat set point temperature of the air-conditioner, occupancy, building operating schedules, etc. Out of these parameters initially, five parameters are considered for selection of hotel buildings such as EPI, constructed area, energy consumption, number of guest rooms and connected load.

3.6.1 Energy performance index

Energy Performance Index (EPI) signifies the energy intensity of the building and it is expressed as EPI. A similar EPI can provide valuable energy performance metrics for the design energy modeling and assessment of building energy performance. EPI designations are used throughout the building industry as targets for codes, standards, and incentive programs, and as benchmarks for building operation. EPI is the most commonly used basis for assessing building energy consumption, and also benchmarking of building energy use and provides valuable insights on energy efficiency potentials. It facilitates energy accounting, comparing a facility's energy use to similar facilities to assess opportunities for improvement and quantifying/verifying energy savings. EPI includes factors such as the age of technology, type of equipment, maintenance being practiced for the equipment and hotel building, energy saving measures, etc. EPI is the measure for spotting energy wastage and to find various ways to identify energy saving opportunities in the hotel building, therefore; it is realized that the selection of the building should be based on such factors where the generalization of energy saving opportunities in all hotel buildings in their respective category is justified. EPI is chosen as the main parameter to compare case study hotels with other hotels in their respective category. EPI is the most crucial deciding factor for selection of hotel building. Therefore, such hotel buildings are selected, which have an EPI value closer to average EPI in their respective category as shown in Fig. 3.6.



a) b) c)

Fig. 3.6 Comparison of EPI of selected hotel with other hotels

a) Category-1 b) Category-3 c) Category-3

Energy consumption

Energy consumption can provide valuable information about overall energy consumption of the hotel buildings. Hotel buildings with larger constructed area and higher star ratings have high energy consumption which is due to large number of rooms, more common areas and various facilities and services which are not there in small hotel buildings. EPI considered as selection criteria already includes energy consumption. Therefore, energy consumption has not been considered as criteria for hotel building selection.

Constructed area

Data collected from 92 hotel buildings include there constructed area. Through data analysis, it is observed that higher constructed area does not necessarily results into high energy consumption. Secondly, constructed area has already been included in EPI. Therefore, constructed area is not considered for selection.

3.6.2 Number of guest rooms

Some guest rooms in a hotel building contribute the significant amount of energy. The pattern of energy consumption in a typical guest room is almost similar with other guest rooms due to the similar type of equipment, electronic gadgets and facilities. Therefore, the energy efficiency measures may be applied uniformly to each room. A correlation is also established between number of rooms and energy consumption from data collected for 92 hotels of Jaipur city, and it is observed that the total energy consumption of hotel building has good correlation with a number of rooms as shown in Fig. 3.9.

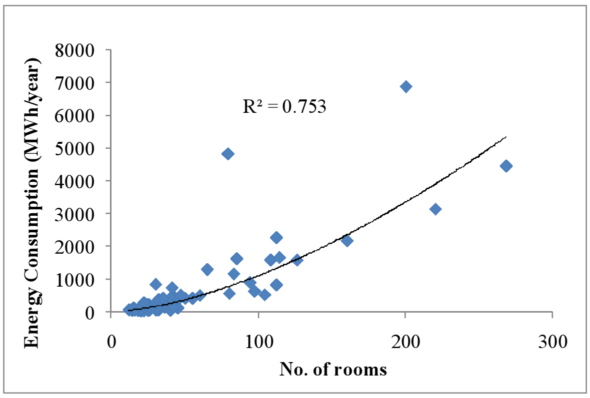


Fig. 3.7 Correlation between energy consumption and number of rooms

Therefore, number of rooms is considered as criterion for the selection of case study hotels therefore those hotels, which have number of rooms value reasonably closer to mean values in their respective category is selected as case study hotel as shown in Fig 3.10.

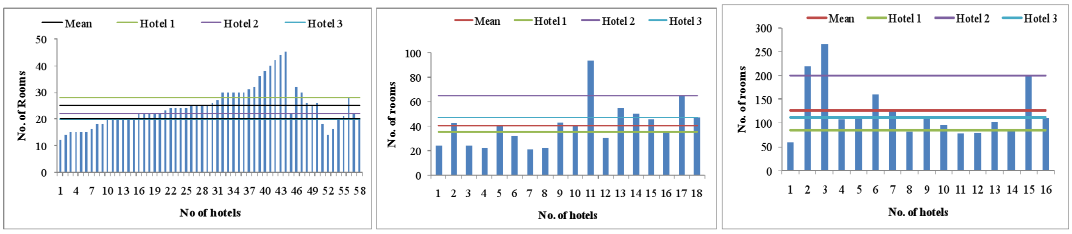


Fig. 3.8 Comparison of number of rooms of selected hotel with other hotels for three categories

3.6.3 Connected load

The hotel building has wide variety of facilities to fulfill important function of providing the atmosphere and comforts demanded by the guests and in constant quest for better guest service and comfort with the help of various electrical devices such as air-conditioners, room heaters, hot and cold water system, lighting, refrigeration, TV, computer vertical transportations like elevators and escalators, electronic entertainment, computing, and cooking etc. The number of such devices and their capacity determine the connected load of the hotel building. Connected load signifies expected amount of energy consumption. Therefore, the connected load has a direct relation with energy consumption by hotel building. This may further be justified with the establishing correlation between connected load and energy consumption by data collected for 92 hotel buildings as shown in Fig. 3.11 and it is noticed that to a greater extent energy consumption increases with increase in connected load.

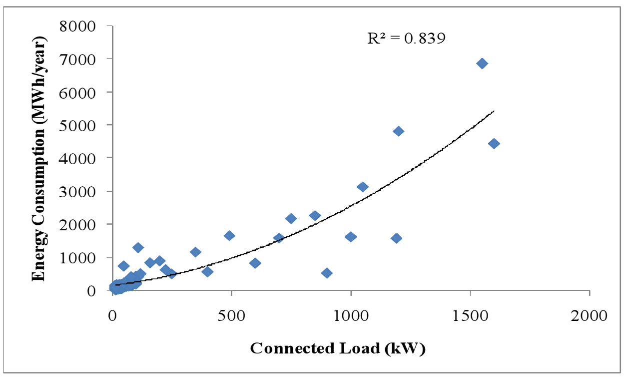


Fig. 3.9 Correlation between energy consumption and connected load

Similarly, those hotel buildings are selected on basis of connected load among the hotels which already have EPI closer to the average EPI. Therefore, such hotel buildings are selected, which have connected load value reasonably closer to average values in their respective category as shown in Fig 3.12

Fig. 3.10 Comparison of connected load of selected hotel and other hotels for three categories

3.6.4 HVAC type

The HVAC system has a significant contribution to the total energy consumption of a hotel building. The energy savings through energy efficiency in HVAC system may play a vital role. Therefore, considering the type of HVAC system for hotel building selection has been one of the criterions in the present study. The hotel buildings in Jaipur city have different types of HVAC systems mainly depending upon the size of the building or number of rooms. The Category-1 hotel buildings that are small sized buildings invariably have a unitary system, Category-2 which are medium sized buildings have mostly package system along with few unitary system also, whereas in Category-3, hotels are mostly large sized buildings, have chiller type HVAC system. The case study hotel buildings in Category-1 have a unitary type of HVAC system; Category-2 has package system, and one hotel building has the unitary system, whereas Category-3 has chiller type HVAC system.

Therefore; EPI, number of guest rooms, connected load and HVAC type are considered for selection of case study hotel buildings. In this study total, 92 hotels are surveyed which includes 58, 18 and 16 hotels in Category-1, Category-2 and Category-3 respectively. Hotel buildings with EPI closer to the average EPI of the hotel buildings in their respective category is selected as case study hotel building. Similar procedure is followed for connected load and number of rooms and it is observed that the buildings selected for case study are representative of the hotel buildings in their respective category.

Energy Performance Index, energy consumption, constructed area, number of guest rooms, connected load and HVAC type have been considered as criterion for selection of the case study hotel building. Energy intensity of the hotel building in terms of EPI has been the main criteria for selection of case study hotel building. Since, EPI is used as a representative values for comparing actual building energy performance with similar types of other buildings. Connected load, number of rooms and HVAC type have also been finally considered for case study hotel building selection. EPI already includes energy consumption and constructed area therefore not considered for selection. Type of HVAC system significantly affect energy consumption by a building therefore, hotels that are using similar type of HVAC system in their respective category has been considered for case study.

3.7 Data collection of hotels for detailed study

A questionnaire presented in Annexure-I is designed to gather information related to energy data such as building envelope, lighting, major electrical equipment, and HVAC system and operating schedules for the study. The data collected from case study hotel building is voluminous, and this data is compiled and used to develop the simulation models. The data is collected through utility bill records, architectural drawings, site visits and surveys as well as observation of specific equipment installed in the building. To ensure that the data should be correct and comprehensive to get an accurate model, due care has been taken in data collection. Three hotels for each category and total nine hotels are selected for detailed data collection during the study. Data related to monthly energy consumption, building envelope, lighting, and major electrical equipment, HVAC system (system type, make and model, system specifications), thermostat set point temperature of the air-conditioner, schedules of equipment etc. are collected through the questionnaire and also with the help of architectural drawings, design documents and onsite observations. Three category hotel buildings have been discussed in detail. The developed questionnaire included all the data required for eQUEST modeling which included:

Utility Bill Records: Latest utility bills of twelve consecutive months that include date, kWh consumption, peak electricity demand, connected load, etc.

Architectural drawings: Floor plans of the building that included wall and roof thickness, window-door sizes, fenestration size, window projections, etc.

Site survey data: Comprehensive equipment and system data.

HVAC systems: Primary equipment (e.g., chillers and boilers) - capacities, number, model, serial numbers, age, condition, operating schedules, etc.

HVAC systems: Secondary equipment (e.g., air-handling units, terminal boxes) – fan types, motor sizes and efficiencies, design-flow rates and static pressures, economizer operation, and type of controls, HVAC system controls, including the location of zones, temperature set-points, and schedules.

Lighting systems: Number and types of lamps, with nameplate data for lamps and ballasts, lighting schedules, etc.

Building occupants: Population counts, occupation schedules in different zones.

Other major energy-consuming loads: Type and capacity (industrial process, air compressors, water heaters, elevators, refrigerator, office equipment, kitchen equipment), schedules of operation.

Plug loads: Summarize major plug loads per zone.

Building envelop and thermal mass: Dimensions and type of interior and exterior walls and roofs, their construction details, properties of windows, and building orientation and shading from nearby objects.

Weather data: representative site weather data for the period.

Operator interviews: Building and equipment operators were interviewed to provide above listed information and also collected data was discussed with the operators and corrected as per their suggestions.

It was observed during the data collection that either some of the data were not available, or they were improperly documented at the site, for example, latest specification of equipment, efficiencies, the variation of zone occupancy, equipment schedule of operation, etc. To collect unavailable data; survey team members carry out onsite observation. Some hotel owners are not prepared and showed unwillingness to share information like hotel equipment details, operating conditions, and occupancy, therefore, suitable assumptions have been taken and discussed later in this chapter.

3.8 Development of calibrated models for energy simulation

The base model is developed with the help of collected data from the survey data obtained through consultation with the facility design teams and technical team. The missing data are appropriately assumed to determine the necessary inputs for modeling and simulation. Dynamic thermal simulation tool eQUEST version 3.64 is used for modeling and simulation of nine hotel buildings. Calibration is done using

International Performance Measurement and Verification Protocol (IPMVP) criterion which suggests four options for calibrating the simulation model.

Option-A is used for retrofitting where either performance factors (e.g., end-use capacity, demand, power) or operational factors (lighting operational hours, cooling hours) can be spot or short-term measured during the baseline and post installation periods. Whereas, Option-B is used for retrofitting where either performance factors (e.g. end-use capacity, demand, power) and operational factors (lighting operational hours, cooling ton-hours) that can be measured at the component or system level. Option-C encompasses whole-facility or main-meter verification procedures that provide retrofit performance verification for those projects in which whole-facility baseline and post-installation data are available.

Option D is appropriate for complex projects in buildings where multiple ECMs are installed or where tracking complex building operation conditions is necessary. Because a computer simulation allows a user to model the complex interactions that govern building energy use, it can be a very powerful tool to use in estimating a project's energy savings.

Therefore, Option-D of IPMVP protocol was observed to be suitable for building model calibration since this option-D is appropriate for complex projects in buildings where multiple EEMs are to be installed, which is the purpose of the present study.

The protocol suggests error limits (Equation 3.1 to 3.5), which are used for the calibration of simulation models. The equation 3.1 shows Monthly Error (ERR_{month}) and equation 3.2, 3.4 and 3.5 show the calculation of mean monthly utility bills, Mean Bias Error (MBE) and Coefficient of Variance Root Mean Square Error (C_VRMSE) respectively.

$$ERR_{month}\ (\%) = \frac{(M-S)_{month}}{M_{month}} \times 100 \quad (3.1)$$

$$ERR_{month} = \sum_{Year} \frac{ERR_{month}}{N_{month}} \quad (3.2)$$

$$A_{month} = \frac{\sum_{year} M_{month}}{N_{month}} \quad (3.3)$$

$$MBE\ (\%) = \frac{\sum_{month}(M-S)_{hr}}{\sum_{month} M_{hr}} \times 100 \quad (3.4)$$

$$C_v(RMSE_{month}) = \frac{RMSE_{month}}{A_{month}} x100$$

(3.5)

Where, M and S indicate the measured and simulated kWh; and N_{month} represent the number of utility bills in a year.

Table 3.1 IPMVP calibration criterion and their limits

(Source : IPMVP, 2008)

S No.	IPMVP Criteria	Formula	Limit (%)
1.	MBE (%)	$= \frac{\sum_{month}(M-S)hr}{\sum_{month} M_{hr}}$ x 100	5
2.	(C_vRMSE_{month})	$= \frac{RMSE_{month}}{A_{month}}$ x100	10

Lower values of MBE and C_vRMSE, demonstrate better calibration of the simulation model and their permissible error limits ensures how well the model predicts whole-building energy usage. The MBE, and CvRMSE should be within permissible limits of ± 5 % and ± 10 %, respectively as prescribed in Option-D and as shown in Table 3.2.

While filling the questionnaire, some parameters are likely to have variations in their value despite having a certain numerical value filled by the facility manager. The calibration of building model is carried through these input parameters such as envelope properties, lighting properties, lighting schedules, equipment schedules, thermostat set point, occupancy, etc. obtained through observation, discussion, heuristics, past experience and personal observation of survey team members. These parameters are chosen for calibration since they influence subjective nature of replies of the facility owner and observer. The calibration of building model is done by varying numerical values of building input parameters within certain predefined range as discussed below.

3.8.1 Defining operating conditions

It was observed that buildings have different energy use profiles than their predicted models. This is often due to changes in operating schedules from the schedules predicted by the model. Operating schedules are dependent on a number of variables, and they have a complex relation with number of parameters. Also, there can be the large variation in operating schedules at same operating conditions due to involvement of human behavior. Therefore, this study observed operating schedules at different time and place as shown in Annexure-II. Due to time constraints and interference in day to day working few samples of operating schedules are observed and used for building the simulation. Due to non-availability of some schedules, suitable assumptions from reference studies have been taken. Building simulation is started with these schedules and modifications are made based on experience with monitoring real buildings to account for differences in zone-level and equipment operations, and lighting and plug loads. Lighting, equipment, occupancy and thermostat set point temperature schedules have been discussed here.

a. Defining lighting

A hotel building has various zones with different LPD, since the requirement of lighting intensity is zone specific. Each zone has its own lumens requirement which determines the LPD of that particular zone. Various zones have been categorized broadly into two/three zones with respect to LPD requirements.

b. Defining equipment

Therefore, operating schedules of hotel buildings have been taken from National Renewable Energy Laboratory (NREL), USA reference hotel building. Suitable variations in operating schedules have been carried out from discussions with technical staff of the respective hotel building.

c. Defining occupancy

Hotel buildings have different zones and each zone has its own occupancy. Although the occupancy of each zone is different but for simplicity the zones have been broadly divided into two zones for small hotels and three zones for large hotels such as the guest room and restaurant; office space and common areas on the basis of similarity in occupancy.

d. Defining thermostat set point temperature

It is observed that there is wide variation in the thermostat set point temperature, especially in guest rooms, although the office space and common area have little variation in the set point temperature. Therefore, zones have been divided into broadly two zones for small hotels and three zones for large hotels one with larger variations in thermostat set point temperature includes guest rooms and other which have small variations includes common areas.

3.8.2 Defining HVAC

Considering the age of the HVAC system the approximate COP of the system is used initially, for the pre-calibrated model, and then the model is calibrated by choosing an appropriate value within the rated COP and present COP of the existing system, considering the drop in COP with time. Considering the equipment schedules and COP, the envelope properties and occupancy schedules are further improved as the next level of calibration.

3.8.3 Defining envelope properties

The wall and roof of hotel buildings are modeled as per the details of wall and roof construction available in the architectural drawing and observation. It was found that the thickness of cement plaster varied between 12 mm to 25mm therefore, U-value of the wall is altered by varying thickness of cement plaster at both sides of the wall. The U-value, which gave an optimized value of MBE and C_VRMSE, is chosen as an input value in the calibrated model. Analysis of product catalogs of building glass manufacturers showed that the shading coefficient for nearly similar looking glass varied over a wide range. Model calibration has been carried out through selecting a value within the minimum and maximum range of shading coefficient. The building models are calibrated to get values of MBE, and CvRMSE within permissible limits of ± 5 % and ± 10 %, respectively as prescribed in Option-D.

3.9 Energy conservation opportunities

In the present study, two scenarios of energy efficiency measures are considered. In the first scenario, building meets prescriptive requirements of Energy Conservation Building Code (ECBC). However in the second method, advanced EEMs in which the building surpassed ECBC requirements and adopted specifications better than ECBC with SPV integration has been considered.

3.9.1 Implementation of ECBC

The study adopted implementation of ECBC developed by Bureau of Energy Efficiency, Government of India to improve energy efficiency in buildings. This building code has been adopted throughout the country and applicable to the building components such as building envelope, HVAC system, service hot water, lighting and electrical equipment. ECBC compliant buildings have 30% -35% energy saving potential as compared to conventional buildings as reported by USAID (2009) report. The ECBC code is applied for the simulation of selected nine hotel buildings of Jaipur city. Hotel buildings with poor star ratings of air-conditioners (non-star, one-star and two-star ratings) are proposed for replacement by energy efficient five-star units to meet ECBC compliance. Hotel 1 and Hotel 3 under Category-2 are already equipped with higher system COP 3.8 and 3.88 respectively as recommended by ECBC code; therefore, the systems are not proposed for replacement. Chiller type HVAC system is replaced by same type of efficient chiller with higher COP to meet ECBC compliance. Wall and roofs are retrofitted in both the scenarios by applying polystyrene insulation on the outer surface, window glazing is proposed to be retrofitted by applying low-E laminated films. The inefficient lighting fixtures are replaced by low LPD, LED lighting fixtures. The energy savings are obtained through retrofitting HVAC, wall, roof, glass, and lighting such that these building components have values as per the recommendations of ECBC building code as shown in Table 3.3.

Table 3.2 ECBC recommended values of building parameters

Parameter	Unit	ECBC recommended values
Wall U-value	$W/m^2 K$	0.44
Roof U-value	$W/m^2 K$	0.26
Glass shading coefficient	-	0.29
Unitary air-conditioner	COP	3.3
Air-cooled chiller $\geq$ 150 TR	COP	3.05
Centrifugal chiller (water cooled) $\leq$ 150 TR	COP	5.8
Rotary screw chiller (water cooled) $\geq$ 300 TR	COP	5.75
LPD	W/m^2	10.8

3.9.2 Implementation of advance energy efficiency measures

Technology advancement in the air-conditioning system, new building materials, and energy efficient lighting fixtures have offered opportunities for further energy savings as compared to conventional buildings as well as ECBC specified buildings. Therefore, besides implementing ECBC, advance energy efficiency measures suggested and adopted in the recent studies to achieve values higher than required by ECBC code compliance are implemented to nine case study hotels. HVAC system in all nine case study hotels are proposed to be replaced with Ground Heat Exchanger (GHX), that has efficiency better than conventional HVAC system. Ground loop heat exchanger with a vertical borehole of 30 mm of nominal diameter, depth 50–180 m with 5-6 m spacing between bore holes and a number of well fields between 5 to 50 depending upon case study hotel building is considered in the study. Vertical borehole type ground loop heat exchanger is considered in all case studies hotel buildings due to space limitations. For the modeling in the present study thermal conductivity, thermal diffusivity and heat capacity of sub-soil at depth of 3m in Jaipur city are measured onsite, using TPS 500 thermal analyzer instrument and found to be 0.52 W/m K, 0.057 m^2/day and 0.91 kJ/kg K respectively and it is observed that these values are within the recommended range as prescribed by ASHRAE, (2008) and found suitable for GHX installation. Wall and roof are proposed to adopt better insulation thickness to achieve values which have been adopted by similar type of buildings. Building envelope properties such as U_{wall} and U_{roof} are taken as 0.261 W/m^2 K and 0.232 W/m^2 K from the study carried out using advanced building envelope properties as prescribed by Jiang et al (2015) and 'The Energy and Resource Institute (TERI). The present study used shading coefficient (0.2) as suggested by TERI - India and a lower value of LPD of 6.9 W/m^2 taken from another study carried out at TERI.

3.9.3 Integration of solar photovoltaic system

Building Integrated Photovoltaic (BIPV) system is proposed in the present study, which consists of integrating photovoltaic modules with the building roof. As per the consultation with the engineers and hotel building owners 50% of roof area can be utilized for the installation of SPV panels. Therefore, SPV system of capacity corresponding to the panel size that covers 50% of roof area is proposed for the hotel buildings. The PV array module of multi-crystalline silicon standard model of size 6.21x4.21 ft^2 with maximum 55 volts, maximum current 5.65 amperes, capacity 0.226 kW and efficiency of 9.3 % that is most common in India is adopted for roof installation, and the generator capacity is determined accordingly.

3.10 Assessment of energy saving potential

The present study estimated energy savings in nine hotel buildings by adopting two types of energy efficiency measures. The impact of energy efficiency measures for complete hotel sector of Jaipur city is estimated to assess overall energy saving potential and GHG mitigation potential. There were total 589 hotels in Jaipur city (in 2014) out of which 516 hotels are grouped in Category-1 (non-star and one-star), 42 hotels in Category-2 (non-star and one-star)and 31 hotels in Category-3 (non-star and one-star) for the estimation of total energy savings yearly where energy consumption of all 589 hotels is required. The energy consumption data and connected load are available for 92 hotels (58 of Category-1, 18 in Category-2 and 16 in Category-3 hotels) among 589 hotels. A mathematical correlation is established between connected load and annual energy consumption for Category-1, Category-2 and Category-3 hotels as shown in Fig. 3.11, Fig.3.12 and Fig. 3.13 respectively. Through the developed correlation, annual energy consumption of remaining hotels of Jaipur city is estimated. Existing growth trends of the hotel sector in Jaipur city is used to project hotel buildings coming in year 2020, and it is estimated that there would be 798 hotels in Jaipur city after five years with 641, 106, and 51 hotels in Category-1, Category-2, and Category-3 respectively, as presented in Fig. 3.14. The energy saving potential for the year 2018 is also estimated for the hotel sector of Jaipur city through energy savings obtained by case study hotels.

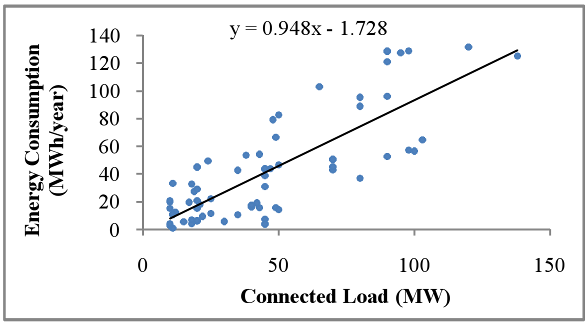


Fig. 3.11 Correlation between connected load and energy consumption for Category-1 hotels

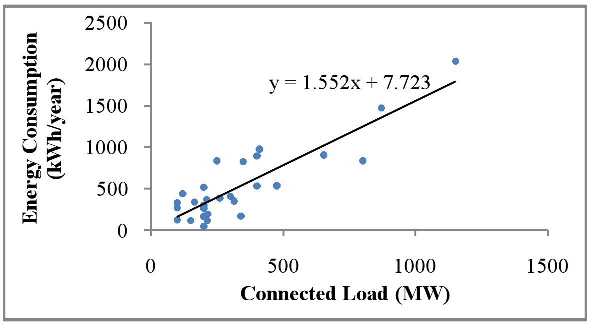


Fig. 3.12 Correlation between connected load and energy consumption for Category-2 hotels

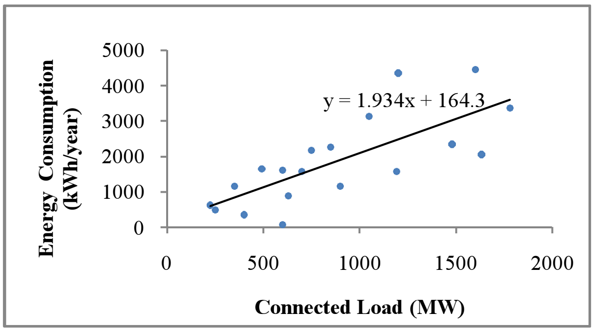


Fig. 3.13 Correlation between connected load and energy consumption for Category-3 hotels

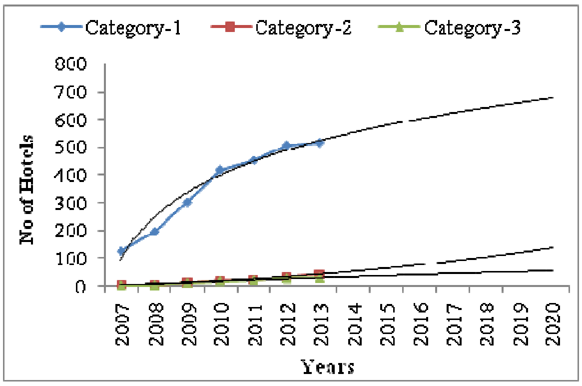


Fig. 3.14 Growth rate of hotels in Jaipur city up to 2020

3.11 Economic analysis

Economic analysis for retrofitting of HVAC (with higher star rating), wall and roof (use on insulation), film on window glazing and LED lighting fixtures considering two energy efficiency scenarios is carried out in the present study. Cost of the unitary system, air-cooled chiller system, water cooled chiller system considered in the economic analysis are INR 24000, 40000, 50000 per TR respectively, as per the market survey (Prasheetan Aircon, Jaipur) conducted in Jaipur city. Polystyrene insulation cost considered is INR 275/m^2 for 25 mm thickness (Kushal Engineers Enterprises, Jaipur) and cost of LED lighting fixtures considered is INR 1200 per unit are taken from the local market. Cost of window film considered as for ECBC compliance for single glazed and double glazed is INR 2152/m^2 and INR 1722/m^2; whereas for advanced measure for single glazed and double glazed INR 3229/m^2 and INR 2368/m^2 respectively (Vedant Enterprises, Jaipur). Minimum salvage value of HVAC equipment has been considered as per market survey for economic analysis. Maintenance cost of old and new HVAC equipment have been considered as 1.5% of capital cost as per Annual Maintenance Contract (AMC) rates prevailing in market of Jaipur city. AMC for GHX considered is INR 0.75% which is half of conventional

HVAC system (www.climatemaster.com). Cost of SPV system without battery is INR 60,000/ kW (Renewables 2015, Global Outlook) which is most commonly installed in the Jaipur city; that has been considered in the present study. The cost-benefit analysis in terms of Internal Rate of Return (IRR) is carried out up to the life cycle of the equipment and components. Finally; net Payback Period (PBP) for ECBC and advanced measures is estimated for retrofitting of all equipment and components.

3.12 Summary

This chapter describes the methodology adopted in the present study to evaluate energy saving potential for different categories of hotel buildings through the adoption of ECBC and advanced Energy Efficiency Measures (EEMs), on building components such as building envelope, lighting, and HVAC system and SPV. It describes criterion of selection of hotel buildings for the case study. The models of case study hotels are developed and calibrated; and simulated to estimate energy savings through adoption of various energy efficiency measures. Furthermore, the chapter describes the method of estimating energy savings and GHG reduction potential for hotel sector of Jaipur city. Cost-benefit analysis of these measures has been carried out for the nine case study hotel buildings.

CHAPTER 4
DEVELOPMENT OF CALIBRATED MODELS FOR SIMULATION

Building energy consumption is a function of the type of construction, usage pattern, operating parameters, climatic region and type of energy consuming devices installed in the building. Therefore, in the present study to develop the model of case study hotel buildings, parameters that affect the building performance significantly have been identified. Details of parameters affecting energy consumption such as building envelope, lighting fixtures, major electrical equipment, HVAC system (system type, make and model, system specifications), thermostat set point temperature, equipment operating schedules, etc. are collected for selected hotel buildings through the combination of questionnaire based survey, architectural drawings, design documents and onsite observations. Using the collected data, energy models of selected nine hotels are developed and calibrated to carry out energy simulation and the details have been discussed in this chapter.

4.1 Description of hotel buildings

Data related to building envelope, HVAC system, lighting system, equipment, and other building details through site visits and survey are collected. Data analysis shows that conventional constructional practices are followed in most of the hotel buildings. The details of various hotel building components have been discussed in the following section.

4.1.1 Building envelope

The construction material used for wall, roof and other building envelope components are found to be more or less similar, irrespective of the hotel category and building size. A construction detail of nine hotel buildings was collected through questionnaire, and through data analysis it is found that for wall and roof construction conventional practices are followed in all hotel buildings. The walls are constructed with burnt clay brick with the standard dimension of 230mm x110 mm x 70mm and a cement plaster layer of thickness varying from half an inch to one inch is applied at both sides of the brick construction. A thin layer of finish plaster of white cement putty is applied to cement plaster. Similarly, conventional practices are also followed for roof construction; the roof is constructed with Reinforced Concrete Cement (RCC) mixture of six-inch thickness. A layer of cement plaster with coarse gravel of half to one inch is applied at both sides of the RCC. Fig. 4.1 shows typical layer by layer construction of building wall and roof.

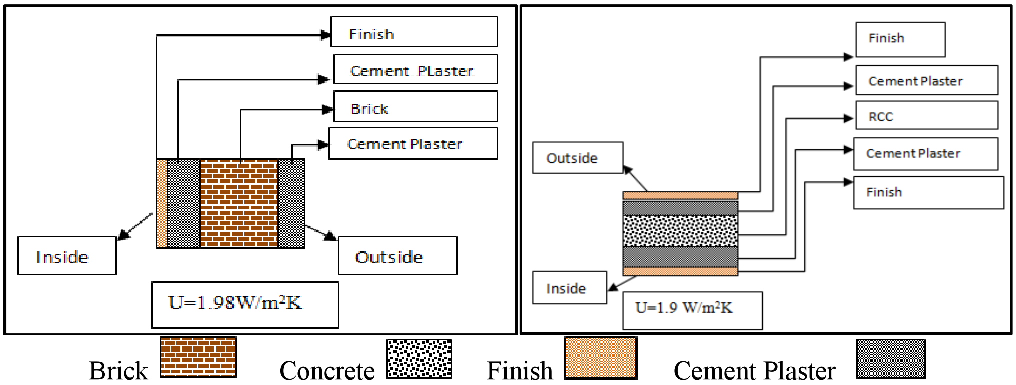


Fig.4.1 Wall and roof construction layers of typical building

Building envelope details of the nine case study hotel buildings have been shown in Table 4.1. The details of the layers were obtained through architectural drawings, observation and in case of non-availability of the data suitable assumptions have been taken. The envelope properties such as U-values of wall, roof and glass; and shading coefficient of glass are obtained through simulation of building model.

Table 4.1 Specifications of building envelope components

Component	**Category-1**			**Category-2**			**Category-3**		
	Hotel-1	**Hotel-2**	**Hotel-3**	**Hotel-1**	**Hotel-2**	**Hotel-3**	**Hotel-1**	**Hotel-2**	**Hotel-3**
Wall layers (inch)	Cm(1) + B(8) + Cm(1/2) +F(1/4)**	F(1/4) + Cm(1/2) + B(8) + Cm(1/2)**	Cm(1/2) B(8) + Cm(1/2)	Cm(1/2) + B(4) + Cm(1/2)+Bd	F(1/4)* + Cm(1/2) + B(4) + Cm(1/2)*+ F(1/4)	F(1/4)* + Cm(1/2) + B(8) + Cm(1/2)* *	F(1/4) + Cm(1/2) + B(4) + Cm(1/2)+	F(1/4) + Cm(1/2) + B(4) + Cm(1/2)	F(1/4)* + Cm(1/2) B(4) + Cm(1/2)+ PF
U_{Wall} (W/m²-°C)	0.379	0.341	0.373	0.355	0.416	0.376	0.419	0.412	0.480
Roof layers (inch)	Cm(1) + Cc(6) + Cm(1/2)	F(1/4)* + Cm(1/2) + Cc(6) + Cm(1/2)	Cm(1) + Cc(6) + Cm(1/2)	Cm(1/2) + Cc(6) + Cm(1/2)	GB + Cm(1/2) + Cc(6) + Cm(1/2)	Cm(1/2) + Cc(6) + Cm(1/2)	F(1/4) + Cm(1/2) + Cc(6) + Cm(1/2)*	S(4)+ F(1/4) + Cm(1/2) + Cc(6) + Cm(1/2)	F(1/4) + Cm(1/2) + Cc(6) + Cm(1/2)
U_{Roof} (W/m²-°C)	0.344	0.328	0.296	0.334	0.254	0.345	0.261	0.232	0.282
Glazing (mm)	G(6)	G(8)	G(6)	G(6)+ A(12) + G(6)*	G(6)+ A(12) + G(6)	G(6)+ A(12) + G(6)	G(6)+ A(12) + G(6)	G(6)+ A(12) + G(6)	G(6)+ A(12) + G(6)
U_{Glass} (W/m²-°C)	5.6	5.0	5.7	2.8	2.8	2.7	2.8	2.7	2.8
SC	0.49 (Silver)	0.42 (Blue)	0.49 (Brown)	0.54 (Clear)	0.47 (Brown)	0.57 (Blue)	0.51 (Clear)	0.57 (Blue)	0.56 (Blue)

PF-Paper felt, Bd – Insulation bed, G – Glass C – Coating, A – Air, P – Planitherm (low E), SC-Shading coefficient, F – Finish, Cm – Cement Plaster, B – Brick, Cc – Concrete, P – Polystyrene, GB – Gypsum bed, S- Soil

* [G(6)+ A(12) +G(6)] means Glass 6mm thickness, air gap 12mm thickness and glass 6mm thickness

** layers starting from outside surface

Thermal properties of building construction materials used for building model shown in Table 4.2 are thermo-physical properties of material used, that have been considered for defining construction in the simulation models.

Table 4.2 Thermal properties of Wall and Roof layers

Layer	Density (Kg/m^3)	Conductivity (W/m^oK)	Specific heat (J/KgK)
RCC	2242.5	1.31	837.3
Brick	1922.2	0.73	837.3
Cement Plaster	1858.1	0.72	837.3
Finish	1249.4	0.42	1088.5
Insulation bed	288.0	0.054	1256.0
Paper felt	0.32	0.05	1674.6
Polystyrene	28.83	0.034	1214.1
Gypsum bed	800.92	0.159	837.3
Soil	1601.8	0.164	1046.7

4.1.2 HVAC system

Data collected through the questionnaire reveals that different categories of hotel buildings have different type of HVAC system. Table 4.3 shows that the Category-1 hotel buildings have unitary type of HVAC system. This category of hotel buildings have non-star to five-star unitary type HVAC systems. Two hotel buildings from Category-2 have VRF system type HVAC system which has higher COP as compared to unitary system. Category-3 hotel buildings are large sized buildings and have chiiller type of HVAC system. Most of the hotel buildings in Jaipur city have electric type room heating since only few days in winter have heating requirement. Few of the Category-1 hotel buildings have heating arrangements whereas most of the Category-2 and Category-3 hotel buildings have room heating arrangements.

Table 4.3 Cooling and heating system details in hotel buildings

Category	**Category-1**			**Category-2**			**Category-3**		
Hotel	Hotel-1	Hotel-2	Hotel-3	Hotel-1	Hotel-2	Hotel-3	Hotel-1	Hotel-2	Hotel-3
HVAC type	Split	Split	Split	VRF	Split	VRF	Chiller	Chiller	Chiller
HVAC capacity (TR)	62	31.5	28.5	100	109	130	185	650	130
COP	2.3-2.8	2.3-3.1	2.5-3.3	3.68	2.3-3.1	3.8	2.92	4.2	4.2
Heating type	Electric	No heating	No heating	Heat pump	Electric	Heat pump	Electric	Electric	Electric

4.1.3 Lighting fixtures

Table 4.4 shows details of lighting fixture which have been collected through onsite survey of the hotel buildings. The lighting fixture details include lighting fixtures of typical floor only since, it was not possible to get details of lighting fixtures of every floor of hotel buildings due to privacy issue; therefore LPD of typical floor has been used in the study for energy consumption analysis. It is found that hotel buildings in all categories are still using conventional lighting fixtures; therefore there is lot of scope for energy savings through retrofitting lighting system.

Table 4.4 Lighting fixtures in case study hotel buildings (Typical floor)

Category	Hotel	INCD	FTL 12	FTL 8	FTL 5	CFL	LED	Area of floor (m^2)	LPD (W/m^2)
		100W	55W	38W	28W	18W	12W		
Category-1	Hotel-1	9	50	-	-	20	20	222.4	19.37
	Hotel-2	-	40	-	-	6	-	152.0	15.28
	Hotel-3	-	35	-	3	4	-	136.6	15.28
Category-2	Hotel-1	-	28	10	15	100	40	298.8	15.50
	Hotel-2	-	60	40	25	50	20	458.6	14.53
	Hotel-3	-	30	-	20	60	20	224.0	18.29
Category-3	Hotel-1	-	50	-	40	80	160	770.0	18.94
	Hotel-2	-	40	180	200	600	1600	3807.8	11.80
	Hotel-3	-	20	-	60	88	40	368.7	13.13

4.2 Description of hotels for Category-1

Hotels in this category are non-star and one-star as specified by Ministry of Tourism, Government of India. Hotel-1 and Hotel 2 have one basement and have four floors including ground floor whereas Hotel-3 has one basement and three floors including ground floor and only two rooms costructed on third floor. This category of hotel buildings have smaller constructed area, fewer rooms, lower connected load as compared to Category-2 and Category-3 hotels as shown in Table 4.5. The hotel buildings also have lower window to wall ratio and lower air-conditioned area as compared to Category-2 and Category-3 hotels. Three hotel buildings have been selected for case study in this category and building details have been shown in Table 4.5.

Table 4.5 Building details of Category-1 hotels

Hotel	Hotel-1	Hotel-2	Hotel-3
Category	1 star	Non- star	Non- star
Connected load (kW)	20	15	15
Constructed area (m^2)	1112	760	615
Roof area (m^2)	219	190	157
Conditioned area (%)	75	70	70
No. of rooms	28	22	20
Floors	G+3+1B	G+3+1B	G+3+1B
WWR (%)	8.2	20.2	4.5

The HVAC system used by this category of hotel buildings is unitary type split air-conditioning system. The specifications of the air-conditioners have been observed during site visit; although there are number of companies with different specification but for simplicity specification of some standard air-conditioner has been used for modeling as shown in Table 4.6.

Table 4.6 Specifications of unitary type split air-conditioners for Category-1 hotels

Star rating	Non-star	1-star	2-star	3-star	4-star	5-star
Nominal capacity (TR)	1.5	1.5	1.5	1.5	1.5	1.5
Cooling capacity (Watts)	4600	4725	4860	4900	4950	4975
Power input (Watts)	2000	1860	1750	1685	1595	1505
EER (Watt/Watt)	2.3	2.54	2.78	2.91	3.1	3.3
Maximum airflow (CFM)	430	430	430	430	430	430

Building components such as building parameters, equipment, building envelope, lighting, equipment etc. have been discussed in this section.

- **Category-1: Hotel-1**

The subject hotel building is facing west with window to wall ratio as 8.2% and single glazed window glasses. The basement is used for restaurant cum banquet hall, and the ground floor has another banquet hall, office, and kitchen. The remaining of the three floors have twenty-eight guest rooms. The building is equipped with unitary HVAC system, having non-star to three-star labels as per Bureau of Energy Efficiency (BEE), India certification. Other major equipment includes elevator, water pumps, electric geysers in each room, refrigerators in the kitchen, office equipment, etc. Fig.4.2. Shows hotel building, simulation model, and typical floor plan of the non-star hotel building.

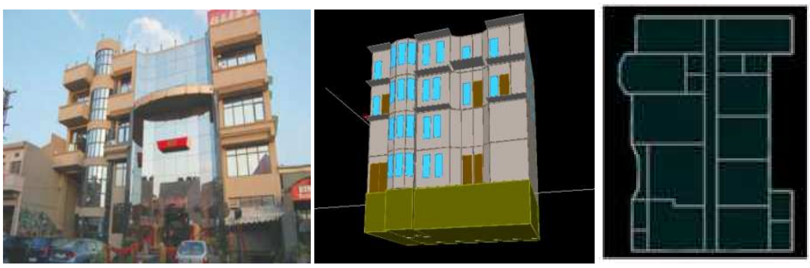


Fig.4.2. Category-1 Hotel-1building (a) simulation model (b)) and typical floor plan (c)

- **Category-1: Hotel-2**

The subject hotel is east facing and has a high window to wall ratio as 20.2% and single clear window glazing. Figure 4.3 shows actual hotel building (a), typical floor plan (b) and a simulation model of a subject hotel (c).The building has one basement, ground floor (having office, kitchen), and three floors having twenty-two guest rooms. The hotel is equipped with Package Terminal Air-Conditioner (PTAC) system with non-star to four-star ratings, water- pumps, electric geyser in rooms, refrigerators in a kitchen, office computer, printer, fax machine.

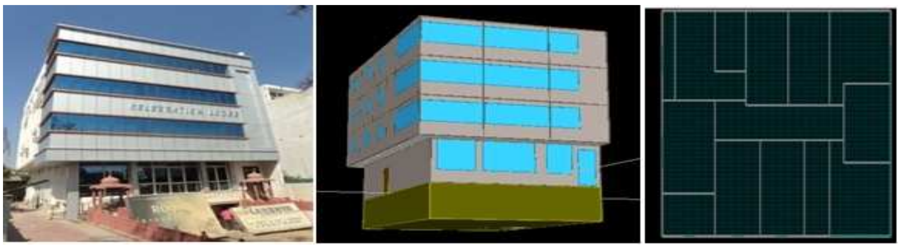


Fig.4.3. Category-1 Hotel-2 building (a) simulation model (b) and typical floor plan (c)

- **Category-1: Hotel-3**

The hotel building is south facing and has lower WWR as 4.5%; and one basement (used as the banquet hall), ground floor (used for office and kitchen), and three guest floors (having twenty guest rooms). Figure 4.4 shows actual hotel building (a), typical floor plan (b) and the simulation model of the subject hotel (c). The hotel is equipped with unitary type HVAC system with one-star to five-star rating, water-lifting pumps, refrigerators, office equipment such as computer, printer, fax machine.

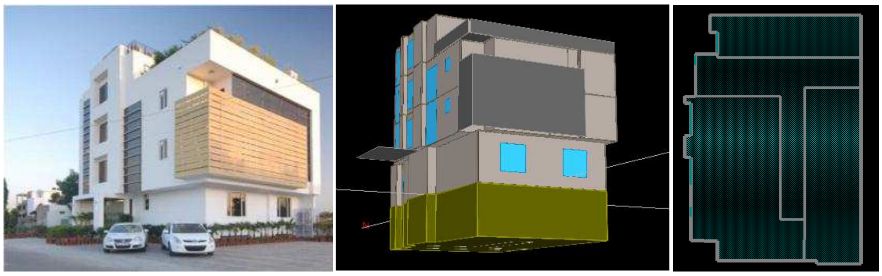


Fig.4.4. Category-1 Hotel-3 building (a) simulation model (b) and typical floor plan (c)

4.3 Description of hotels for Category-2

Two-star and three-star hotels are included in this category and these hotel buildings have medium sized construction, an average number of rooms, medium connected load and electricity consumption. The HVAC system in Hotel-1 and Hotel-3 is Variable Refrigerant Flow (VRF) and in Hotel-2 is the package type unitary split system. For the present study three case study, hotel buildings are selected out of 18 hotels surveyed. Table 4.7 shows building details of selected hotels in Category-1. This category of hotel buildings have higher air-conditioned area and higher WWR.

Table 4.7 Building details of Category-2 hotels

Hotel	Hotel-1	Hotel-2	Hotel-3
Category	2- star	3-star	3-star
Connected load (kW)	80	110	120
Constructed area (m^2)	1793	4586	1568
Roof area (m^2)	305	476	226
Conditioned area (%)	95	80	100
No. of rooms	35	65	47
Floors	G+3+2B	G+8+1B	G+4+1B
WWR (%)	15.8	19.5	24.3
Heating type	Heat pump	Electric	Heat pump

- **Category-2 : Hotel-1**

The hotel building is east facing; and it has two basements, ground floor, and three guest floors with thirty-five guest rooms. Figure 4.5 shows actual hotel building (a), the simulation model (b), and typical floor plan of study hotel (c). The roof has HVAC equipment; lower basement is used for parking; upper basement is used for office purposes and service floor and the ground floor is reserved for banquet hall and reception. The hotel building is equipped with Variable Refrigerant Flow (VRF) type

Package Terminal Air-conditioner (PTAC) system. The hotel building has five condenser units of capacity 21 HP each located at the rooftop, and each condenser unit is connected to around 12 evaporator units of capacity 1.5 TR and 2 TR. The specification HVAC components observed during site visit has been shown in Table 4.8. Other major equipment used in the hotel include four elevators, water-lifting pumps, and electric geysers in rooms, refrigerators in the kitchen as well as equipment used in the rooms and office.

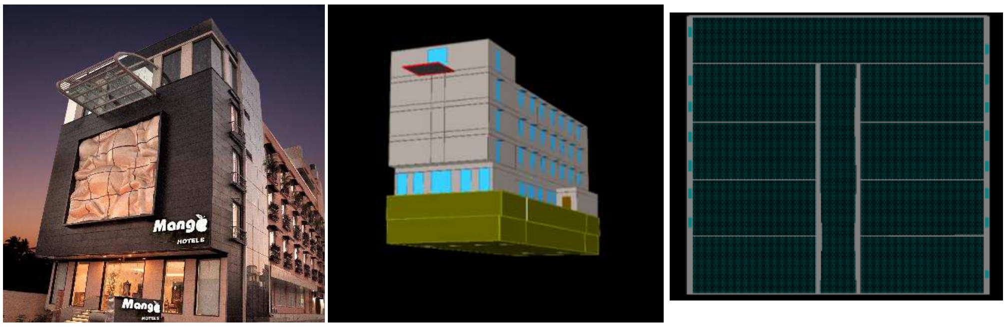


Fig.4.5 Category-2 Hotel-1 building (a) simulation model (b) and typical floor plan (c)

Table 4.8 Specifications of VRF unit

	Parameter	**Unit**	**Value**	
Outdoor Unit	Nominal capacity	HP	21	
	Star rating	-	5	
	Cooling capacity	kW	63	
	Heating capacity	kW	78	
	Power input (Cooling)	kW	17.1	
	Power input (Heating)	kW	18.8	
	COP (Cooling)	-	3.68	
	COP (Heating)	-	4.14	
	Condenser	-	Tube fin type	
	Fan type	-	Axial flow	
	No. of Fans	-	2	
	Compressor type	-	Scroll	
Indoor Unit	Nominal capacity	TR	**1.5**	**2**
	Nominal Capacity (Cooling)	W	5274	6450
	Nominal Capacity (Heating)	W	5860	7000
	Airflow	CFM	424	470

- **Category-2 : Hotel-2**

The selected hotel building under this category faces north-east, and it has one basement, ground floor, and seven guest floors. Figure 4.6 shows actual hotel building (a), typical floor plan (b) and the simulation model of study hotel(c). The basement is used for parking; the ground floor is used for office purposes and service floor, and the first floor is kept for restaurant and banquet hall. Seven floors of the hotel have sixty-five guest rooms. The hotel building is equipped with total 109 TR capacity unitary type split air-conditioners and the specifications have been shown in Table 4.6. Major equipment used in the hotel include five lifts, water-lifting pumps, electric geysers, refrigerators in the kitchen as well as equipment used in the guest rooms, common spaces, and office.

Fig.4.6. Category-2 Hotel-2 building (a) simulation model (b) and typical floor plan (c)

- **Category-2 : Hotel-3**

The hotel building is facing east and has large size glass over all facades. The hotel building has two basements (used for office and parking), ground floor (used for banquet hall), and four floors conference hall and forty-seven guest floors as shown in Fig. 4.7. The hotel building is having Package Terminal Air-conditioner (PTAC) system of Variable Refrigerant Flow (VRF) type with four outdoor unit of 30 HP capacity and indoor unit of 1.5 TR capacity each. The specification of the HVAC system of VRF type observed during site visit is shown in Table 4.9.

Table 4.9 Specifications of VRF unit

	Parameter	Unit	Value
Outdoor Unit	Nominal Capacity	HP	30
	Star rating	-	5
	Cooling capacity	kW	75
	Heating capacity	kW	94.5
	Power input (Cooling)	kW	26.79
	Power input (Heating)	kW	21.54
	COP (Cooling)	-	3.8
	COP (Heating)	-	4.38
	Condenser	-	Tube fin type
	Fan type	-	Axial flow
	No. of fans	-	2
Indoor Unit	Nominal capacity	TR	1.5
	Nominal Capacity (Cooling)	W	5300
	Nominal Capacity (Heating)	W	5700
	Airflow	CFM	500

Fig.4.7. Category-2 Hotel-3 building (a) simulation model (b) typical floor plan (c)

4.4 Description of hotels for Category-3

As per the specification of Ministry of Tourism, Government of India four-star and five-star hotels have been included in this category of hotels and these hotel buildings have the higher constructed area, the greater number of rooms, heavy connected load and higher energy consumption. Three case study hotel buildings are selected out of 16 hotels surveyed in the present study. Table 4.10 shows building details of Category-3 hotels. This category of hotel buildings large constructed area and high air-conditioned area. These buildings are tall buildings and have seven to ten floors. It is also observed that this category of hotel buildings also have a high WWR.

Table 4.10 Building details of Category-3 hotels

Hotel	Hotel-1	Hotel-2	Hotel-3
Category	4-star	5-star	4-star
Connected load (kW)	1000	1550	600
Constructed area (m^2)	7700	41886	4056
Roof area (m^2)	692	6091	697
Conditioned area (%)	80	85	90
No. of rooms	85	200	112
Floors	G+6+2B	G+7+3B	G+9+1B
WWR (%)	23.0	19.1	34.5
Heating type	Electric	Electric	Electric

- **Category-3 : Hotel-1**

This north facing hotel building has large windows on three sides and a plain wall on the remaining side. Lower basement has HVAC system and parking; upper basement is used for office purpose and service floor, the ground floor has reception office, banquet hall and guest rooms, remaining four floors has one conference room and eighty-five guest rooms. The hotel building is equipped with Constant Air Volume (CAV) type HVAC system having air-cooled chiller of 185 TR capacity. The HVAC system uses a twin-screw semi-hermetic compressor, air cooled condenser and direct expansion shell and tube evaporator the detail of HVAC system is shown in Table 4.11.

Electrical resistance heaters are used for space heating whereas electric geysers are used for room water heating. Fig.4.8 shows building, typical floor plan, and the simulation model of a four-star hotel building.

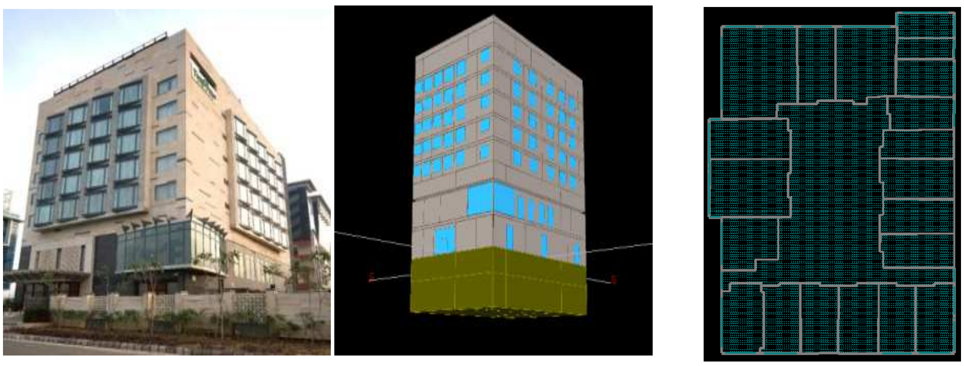


Fig.4.8. Category-3 Hotel-1 building (a) simulation model (b) typical floor plan (c)

Table 4.11 Specification of HVAC system Hotel-1 of Category-3

	Parameter	Unit	Value
Chiller	Type	-	Twin-screw semi hermetic
	Net Cooling Capacity	TR	185
	Power input	kW	222
	COP	kW	2.92
Condenser	Type	-	Air-cooled
	Fan type	-	Propeller
	Air flow rate	m^3/h	184000
Evaporator	Capacity Type	litres	194
	Water flow rate (min/max)	m^3/h	40/135
AHU	Fan type	-	Constant speed

- **Category-3 : Hotel-2**

This hotel building is one of the largest hotel buildings of Jaipur city regarding accommodation, covered area and facilities. The hotel building is divided into two blocks; small block and main block. The small block is in the south direction, and it is fully constructed but not operative. Therefore, it has a significant shading effect on the main block as shown in Fig. 4.9. The hotel building in this category has large windows in east, west and south walls. This hotel has three basements, ground floor, and seven floors having two conference halls along with two hundred guest rooms. The three basements have various facilities such as service floor, parking, laundry, office, HVAC equipment, etc. The hotel building use HVAC with rotary screw and scroll type compressor with two water cooled chiller of 325 TR capacity each and constant speed type air distribution. The details of HVAC system is shown in Table 4.11.

Table 4.12 Specifications of chiller type HVAC system

	Parameter	Unit	Value
Chiller	Type	-	Rotary screw and scroll type
	Net Cooling Capacity	TR	325
	Power input	kW	272
	COP	-	4.2
Condenser	Type	-	Shell and tube
	Cooling type	-	Water-cooled
	Fluid entering temperature	^{o}C	29
	Fluid leaving temperature	^{o}C	34
	Condenser flow	gpm/ton	3
Evaporator	Fluid entering temperature	^{o}C	14
	Fluid leaving temperature	^{o}C	8
AHU	Fan type	-	Constant speed
Cooling tower	Type	-	Open
	Fan	-	Single speed

Figure 4.9 shows actual hotel building (a), simulation model (b) and typical floor plan (c). The reception, banquet hall, and restaurant are located on ground floor. Other electrical equipment includes nine elevators, several water-lifting pumps, kitchen refrigerators, and office equipment. This hotel building uses electrical resistance heaters for space heating and electric geysers for water heating.

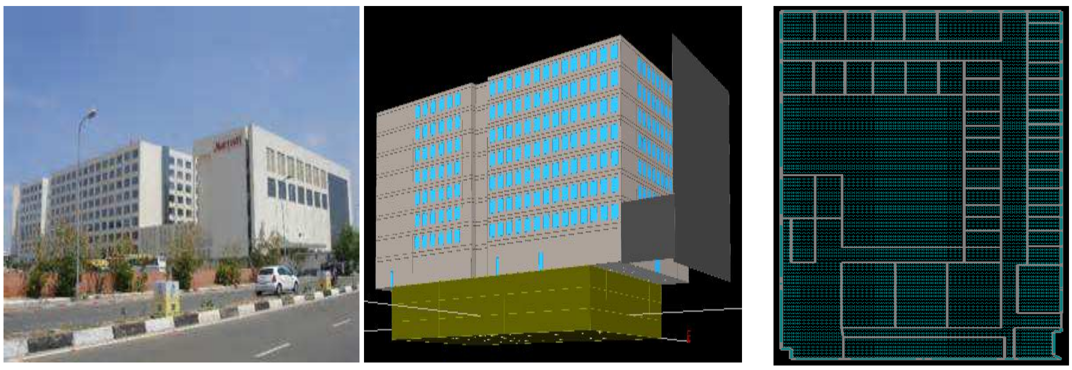


Fig.4.9. Category-3Hotel-2 building (a) simulation model (b) typical floor plan (c)

- **Category-3 : Hotel-3**

The selected hotel building in this category has large windows in east and west façade, a non-glazed wall in the remaining facades. The study hotel has one basement, ground floor, and nine floors including service floor, facility floor, and the remaining are guest floors with one hundred and twelve guest rooms. Figure 4.10 shows actual hotel building (a), simulation model (b) and typical floor plan (c). The Lower basement is utilized for working of HVAC system equipment and parking facilities; the ground floor has reception, banquet hall, and guest rooms. The remaining four floors have one conference room and guest rooms. The hotel building is having Constant Air Volume (CAV) type air distribution and centrifugal chiller of 130 TR capacity and the detail of HVAC system is shown in Table 4.13.

Table 4.13 Specifications of chiller type HVAC system.

	Parameter	**Unit**	**Value**
Chiller	Type	-	Rotary screw
	Net cooling capacity	TR	130
	Power input	kW	108
	COP	kW	4.2
Condenser	Type	-	Shell and tube
	Cooling type	-	Water-cooled
	Fluid entering temperature	^{o}C	30
	Fluid leaving temperature	^{o}C	35
	Condenser flow	gpm/ton	3
Evaporator	Fluid entering temperature	^{o}C	12
	Fluid leaving temperature	^{o}C	7
AHU	Fan type	-	Constant speed
Cooling Tower	Type	-	Open
	Fan	-	Single speed

Other major equipment included four lifts, water-lifting pumps, electric geysers in each room, and refrigerators in the kitchen and office equipment. Electrical resistance based heaters are used for space heating whereas electric geysers are used for water heating.

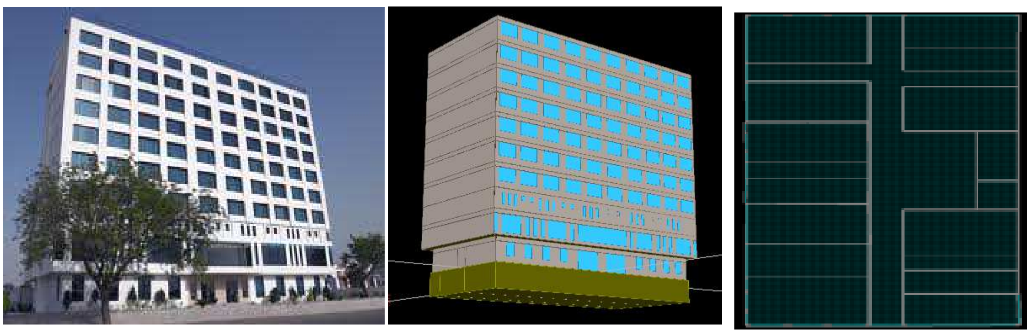


Fig.4.10. Category-3 Hotel-3 building (a) simulation model (b) typical floor plan (c)

Other building parameters of nine case study hotel buildings have been shown in

Table 4.7

4.5 Development of hotel building models

Building models are used for predictive purposes to report a range of anticipated energy performance for the actual building. The analysis in the present study is based upon developing the building model and various design considerations before adopting them. These simulations can help to visualize the actual performance of the design as well as help in making key decisions over various design changes due to the adoption of various energy efficiency measures. In this way, energy modeling can help to optimize various alternatives and allow the design. Therefore, selected hotel buildings are modeled by using eQUEST version 3.64 and calibrated by following ASHRAE 1051RP process by selecting most influential parameters by using criterion specified in IPMVP standard and which have been already discussed in section 3.8 of chapter 3. Building components are modeled through various considerations and modeling of some important components of the hotel buildings has been discussed below.

4.5.1 Modeling of building envelope

Hotel buildings are modeled by combination of data related to building envelope such as floor plans and size of the doors and windows available in the architectural drawing. Hotel buildings have some thermal zones which are referred as portions of a building served by similar HVAC system, similar function and have similar heating and cooling loads; and similar operating schedules, have been considered as single zone whereas, those parts of a building that have significantly different hours of operation have been separated into different zones. Portions of the building containing unconditioned spaces that have no or little impact on building energy use are ignored. Unconditioned spaces that do not have thermostat control to maintain the desired temperature nor have a system designed to deliver heating or cooling to space are considered as unconditioned space. Examples include vented attics, elevator penthouses, parking garages, mechanical rooms, etc.

Building envelope properties of wall, roof and window glass are either available through building drawing or collected through site visits and other reference studies.

- ***Wall and roof***

The thickness of basic structure of wall and roof is available in building drawings. Thickness of different layers such as the thickness of cement plaster and other layers were not available in building drawing therefore, have been taken from the conventionally followed practices by Indian buildings. Similarly, the thermal properties considered in building model have been taken from thermal properties of the conventional materials available in different references.

- ***Glass***

Details of glass layers are either available in building drawing or observed through site visits. The thermal properties considered in modeling have been taken from properties available in catalogs of the same glass manufacturers.

4.5.2 Modeling of HVAC system

The case study hotel buildings are found to be having unitary, VRF, air-cooled chiller and water-cooled chiller type HVAC systems, which have different criteria for modeling. The modeling considerations of various HVAC systems have been discussed in the section below.

- ***Unitary system***

The building is divided into some thermal zones, and these thermal zones are divided into air-conditioned and un-conditioned spaces. A unitary system is assigned for each air-conditioned zone. Set point temperature, cooling Energy Efficiency Ratio (EER), and single speed compressor are selected as per the available data, to model the unitary type HVAC system. The specifications of a typical non-star to five-star rated split air-conditioner used for developing model is shown in Table 4.6

- ***VRF***

Variable Refrigerant Flow (VRF) systems are multi-zone units that circulate refrigerant from an outdoor compressor to multiple indoor fan coil units. Different combinations of indoor ductless and ducted units can be used for these systems depending on the application and layout of the building. VRFs incorporate inverter driven compressors and fans that modulate the flow of refrigerant in the system in response to the actual cooling and heating demand. Multi-splits include multiple indoor units connected to a single outdoor unit. Heat is transferred to or from space directly by circulating refrigerant to indoor units (evaporators or condensers) located near or within the conditioned space. When the indoor units are in the cooling mode they act as evaporators and when they are in the heating mode they act as condensers. VRF have condensers that use variable frequency drives to control the flow of refrigerant to the evaporators. eQuest does not incorporate a VRF specific system type within the program, but it can be modeled selecting Package Variable Volume Variable Temperature (PVVT) option. Outdoor units have been assigned to the building as per available specifications is considered as found at the facility. Set point temperature is entered for different zones as collected from the data and variable speed compressor is selected for modeling. Heating and cooling EER are considered according to the available HVAC specifications.

- ***Chiller***

The system consists of a chiller, cooling tower, building cooling load, chilled water and condensing water pumps and piping. Chiller is modeled through selecting type of compressor from the eQUEST library which is similar to the type of compressor found in the hotel building. Type of condenser is selected from the eQUEST library and condenser loop is connected to the chiller. Efficiency of the chiller in terms of electric input ratio is entered as per the available specifications.

- ***GSHP***

A ground source heat pump plant consists of either centralized or distributed heat pumps that reject heat to, or accept heat from, the ground via a "ground loop" heat exchanger. A closed loop vertical borehole heat exchanger is selected due to the scarcity of water and space limitations. The existing system is replaced with centralized ground source heat pumps that heat/cool a water loop that then distributes this heat to fan coils/radiant panels and other heaters in the zones. Distributed heat pump systems have small heat pumps distributed in the zones that absorb, or reject, heat to a common hydronic loop. A vertical borehole with following specifications is considered for the present study, and other details are shown in Table 4.14.

Table 4.14 Design parameters of GHX system

Parameter	**Unit**	**Value**
Outside pipe diameter	m	0.032
Inside pipe diameter	m	0.026
Spacing of pipes	m	2.0
Distance between two legs	m	0.11
Conductivity of pipe	W/m-K	0.43
Borehole diameter	m	0.160

4.5.3 Modeling of lighting

The specification of different lighting fixtures of one typical floor are collected through site visit and used for modeling lighting system. Interior lighting includes all permanently installed general and task lighting available at the facility. Automatic lighting shutoff details number of lamps, wattage of the lamps, lighting control and schedules are collected through site visit at the facility. LPD of the building at the typical floor is calculated using building area method as per ECBC building code. This method provides the procedure of calculating total watts per square meter for the entire building based on its type. The LPD of the particular zone is entered in the building model. The Lighting Power Density (LPD) of a typical floor is estimated by dividing the overall capacity of all lighting fixtures with the carpet area of that typical floor

4.5.4 Modeling of equipment

Specifications of major equipment such as elevator, water pumps, electric geysers in each room, refrigerators in the kitchen, office equipment are collected, and their EPD is calculated and used for energy model. Details of small equipments were not available therefore, default values have been assumed. Details of type and capacity of miscellaneous equipment such as water lifting pump, elevators, refrigerators, office equipment, laundry equipment, etc. are collected and overall Equipment Power Density (EPD) of the hotel building is estimated by dividing total capacity with constructed area of the hotel building.

4.6 Results of uncalibrated models

The selected hotel buildings have been modeled following the procedure discussed in the earlier section. The developed models are verified using IPMVP criteria and it is found that MBE and C_VRMSE values are not within the range precribed by IPMVP criteria as shown in the Table 4.15. Therefore, the developed hotel buildings models required calibration and the section below discusses the methodology of the calibration performed for developed hotel building models.

Table 4.15 Modeling results of hotel buildings

Category	Hotel	MBE (5%)	C_VRMSE (10%)	Conclusion
Category-1	Hotel-1	-12.9	14.5	Model is not calibrated
	Hotel-2	18.8	65.4	Model is not calibrated
	Hotel-3	45.5	50.2	Model is not calibrated
Category-2	Hotel-1	15.8	20.3	Model is not calibrated
	Hotel-2	12.4	43.3	Model is not calibrated
	Hotel-3	20.3	5.8	Model is not calibrated
Category-3	Hotel-1	20.0	21.2	Model is not calibrated
	Hotel-2	15.8	55.0	Model is not calibrated
	Hotel-3	9.15	31.7	Model is not calibrated

4.7 Calibration of hotel building models

A calibrated model helps in analysis of the thermal behavior of an existing situation that closely represents the actual behavior of the building under study. Calibrated model truly represents actual building and gives a better the understanding of how a given building operates according to certain criteria and enables comparisons of different design alternatives. Calibration of hotel building models is done through varying various inputs to the program so that predictions match closely with observed energy use. To bring the simulated energy consumption with actual energy consumption fan pressure and infiltration rate were varied within predetermined range obtained through discussion with the maintenance engineers.

4.8 Parameters identified for calibration

Building energy models are developed on the basis of various parameters and their numerical values obtained through questionnaire and other sources. Parameters which are likely to have variations in their value despite having a certain numerical value filled by the facility manager are chosen for calibration since they influence subjective nature of replies of the facility owner and observer. The calibration of building model is done by varying numerical values of building input parameters within certain predefined range. Further, calibration is carried out to adjust a set of parameters so that the model agreement is maximized on a set of actual data. The calibration of building model is carried through these input parameters such as envelope properties, lighting properties, lighting schedules, equipment schedules, thermostat set point, occupancy, etc. by varying numerical values of building input parameters within certain predefined range. Lighting schedule, thermostat set point temperature, Coefficient of Performance (COP) and equipment schedule are found to be most influential parameters; therefore, calibration is initially performed using these parameters and later on, building envelope and occupancy are also used for fine calibration of the model unless, good congruence between measured and simulated output is obtained. Alterations to above-mentioned design parameters-schedules (lighting, occupancy, equipment schedules and thermostat set points) and building parameters are carried out within permissible limits.

These parameters influence the building energy consumption differently; therefore, for model calibration most influential parameters are identified through sensitivity of input parameters as shown in Figure 4.11.

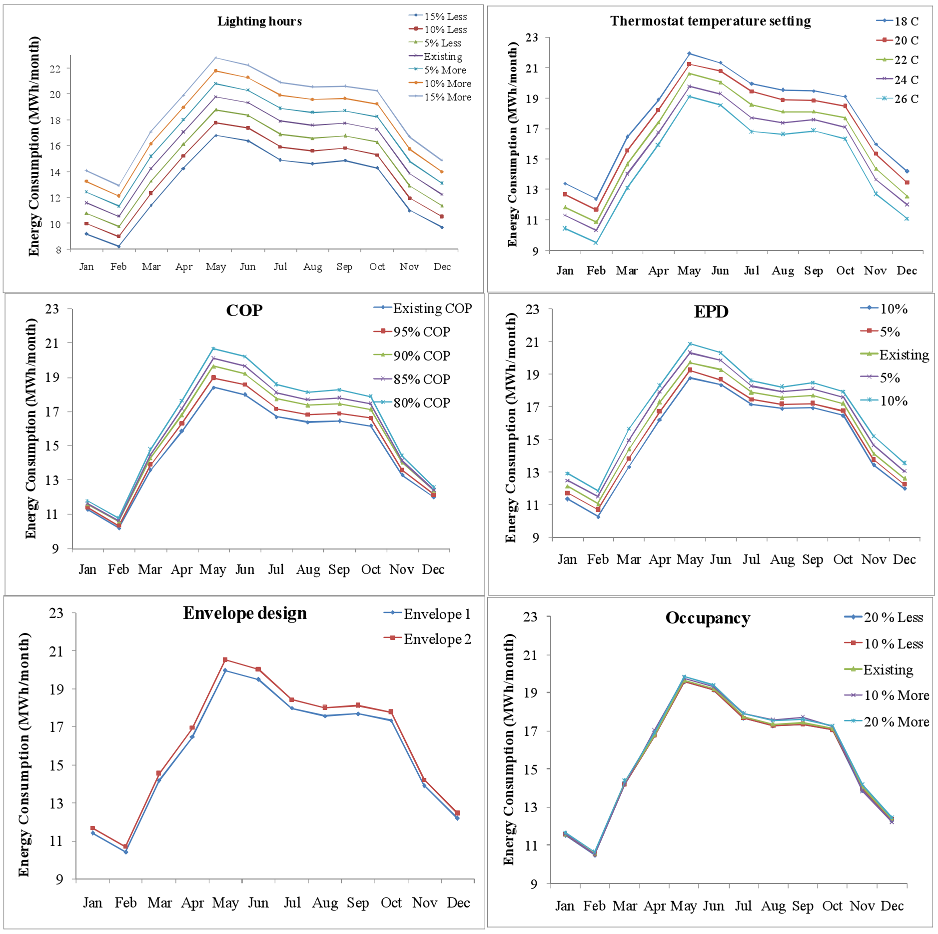


Fig. 4.11 Sensitivity of parameters for calibration of building model

Lighting schedule, thermostat set point temperature, Coefficient of Performance (COP) and equipment schedule are found to be most influential parameters; therefore, calibration is initially performed using these parameters and later on, building envelope and occupancy are also used for fine calibration of the model. Alterations to the parameters such as schedules (lighting, occupancy, and equipment and thermostat set points) and building parameters are carried out within permissible limits.

Hotel building models are developed by using a maximum number of data available at the site, and suitable references and assumptions have been considered due to non-availability of data. Considerations for different parameters in the calibration of three categories of hotel building models have been discussed in this section.

4.8.1 Modifying coefficient of performance

Performance and energy consumption of air-conditioning equipment depends on various factors such building envelope, internal gains, dry bulb temperature and Coefficient of Performance (COP) of the air-conditioning equipment. In the sensitivity analysis, it has also been observed that COP is an important parameter, therefore; it has been used in calibration of simulation models. Due to continuous operation of HVAC equipment in hotel buildings, the performance of equipment would not be same as the new equipment, and it degrades with time due to fouling of condenser tubes, leakage, and ambient temperature. According to ASHRAE, oil fouling of the heat transfer surfaces of air conditioning and refrigeration systems, will cause a loss of about 7% efficiency the first year, 5% the second year, and 2% per year the following years. Therefore, COP of the existing equipment is estimated according to the age of the system that is lower than rated COP of the existing air-conditioning equipment. Variation in COP is considered an important variable, and it is used in calibration of simulation model. An appropriate value within the rated COP and existing COP (considering the drop in COP with time) is estimated. The COP is found to vary from average value in steps of 0.25 within the predetermined range for closer values of MBE and C_VRMSE.

4.8.2 Modifying equipment schedule

Hotel buildings have a large number of equipment working at different location and time. Their exact operating conditions can be monitored only through various sensors and data loggers. It is practically not possible to interfere with the hotel operations. Therefore, operating schedules of hotel buildings have been taken from National

Renewable Energy Laboratory (NREL), US reference hotel building. Discussing with the technical staff of the respective hotel building it is observed that there is 10% to15% variation in EPD of the equipment from the average value. Therefore, calibration is performed by varying value of EPD fraction value within 10% to15% deviation for different hotels from the values considered in the study. Suitable variations in operating schedules have been carried out from discussions with the technical staff.

4.8.3 Modifying lighting schedule

A hotel building has various zones with having different LPD, since the requirement of lighting intensity is different, for different zones. Each zone has its lumens requirement that determines the LPD of that particular zone. The present study categorized various zones broadly into two zones for Category-1 and Category-2 hotels; and three zones for and Category-3 hotels, on basis of different lighting intensity requirements by different zones. It is observed in hotel buildings that some of the zones are having lighting switched off for the whole daytime; therefore lighting fraction is lower in daytime whereas, it is higher during the night; has been considered in modeling hotel buildings.

4.8.4 Modifying thermostat set point schedule

It is observed that there is wide variation in the thermostat set point temperature, especially in guest rooms; although the office space and common area has little variation in the set point temperature. Zone with larger variations in thermostat set point temperature includes guest rooms; and other zones which have small variations include common areas, and that has been considered for model development. Hotel buildings in Category-2 and Category-3 have variety of common areas therefore, various zones have been categorized into two zones for Category-1 hotels; and three zones for Category-2 and Category-3 hotels, respectively.

4.8.5 Building envelope properties

The wall and roof of hotel building are modelled as per the details of wall and roof construction available in the architectural drawing. Details of wall and roof layers for three categories hotel buildings have been discussed in earlier sections. The thickness of cement plaster was not available in architectural drawing, and the conventional practice is to use 12.7 mm (1/2") to 25.4 mm (1") thickness of the cement plaster on brick wall construction. Therefore, U-value of the wall was altered by varying thickness of cement plaster at both sides of the wall. For example for Hotel building-1 from Category-1, cement plaster of thickness 19 mm was considered in pre-calibrated model then the thickness was changed in a step of 2 mm between 12.7 mm and 25.4 mm resulting into corresponding variation in U-value of wall assembly from 1.99 W/m^2 °C to 2.26 W/m^2 °C; whereas U-value of roof assembly varied between 1.88 W/m^2 °C to 2.14 W/m^2 °C. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), was chosen as the input value in the calibrated model.

Analysis of product catalos of building glass manufacturers showed that the shading coefficient for nearly similar looking glass varied over a wide range. For example in the case of Hotel-1 from Category-1, glass shade having 0.46 shading coefficient was used in pre-calibrated model whereas catalos revealed that similar shade could offer a shading coefficient in the range of 0.46 to 0.54. Therefore, in the calibration process variation of shading coefficient of glass in the range was considered in a step of 0.01. Variations in U-value of wall and roof, the shading coefficient of glass were examined simultaneously. For the combination of wall U-value 2.2 W/m^2 °C, roof U-value 2.02 W/m^2 °C and glass shading coefficient 0.46, the model showed the minimum error for Hotel-1 in Category-1.

4.8.6 Modifying occupancy schedule

Occupancy of guests has wide variation throughout the year since Jaipur city has hot climate and most of the months are summer, therefore, there is large variation in occupancy in a year. The occupancy is very high during the winter season by the end of December it is maximum in all hotels and especially in luxury hotels. Hotel buildings have different zones, and each zone has its occupancy. Although, the occupancy of each zone is different but for simplicity the zones have been broadly categorized into two zones such as the guest room and restaurant where there is the large variation in occupancy; and office space and common areas where there is the small variation in occupancy. Three categories of hotel buildings are modeled and calibrated with following procedure and considerations.

Similar calibration process was adopted for other hotel building models. Model calibration has been carried out through selecting a value within the lowest and highest range of parameters-schedules such as lighting, occupancy, equipment and thermostat set points schedules. The simulated building models of different hotel categories demonstrated ERR, MBE, and CvRMSE within permissible limits of ± 15 %, ± 5 % and ± 10 %, respectively as prescribed in Option-D.

4.9 Results of model calibration

4.9.1 Category-1 hotels

These category hotel buildings do not have a proper data monitoring and management system therefore, suitable assumptions have been taken for developing the hotel building models. Operating equipment schedule for this category hotels have been taken from National Renewable Energy Laboratory (NREL), US as a reference schedules and a deviation of ±15% is found in observed EPD values. Therefore, calibration is performed by varying value of EPD fraction value with ±15% deviation from the observed value to obtain closer MBE and C_VRMSE values. Various zones are broadly categorized into two zones such as common area and guest rooms with respect to LPD, for simulation. It is observed through data collection and also from discussion with technical staff of the hotel building that, ±10% and ±15% of variation are possible in lighting fraction in common area and guest rooms respectively. Therefore, lighting fraction is varied within ±10% and ±15% for common area and guest rooms respectively, from the existing values. It is observed that there is wide variation in the thermostat set point temperature, especially in guest rooms, although the office space and common area has little variation in the set point temperature. Therefore, thermal zones are categorized broadly into two zones; one with larger variations in thermostat set point temperature includes guest rooms and other which have small variations, includes common areas. There is the large variation in occupancy that has been considered for developing the model. Modeling results of various steps and modeling considerations for this category of hotel buildings are as follows:

- **Category 1: Hotel-1**

Hotel-1 is modeled and calibrated by varying selected parameters within certain pre-determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.16 and the calibration results have been shown in Fig. 4.12.

Table 4.16 Model calibration steps for Hotel-1 of Category-1

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)	-	-	160.9		-12.9	14.5
Lighting schedule (fraction)	0.05-0.8	0.15-0.9	160.9	172.9	-7.1	9.6
Thermostat set point (°C)	22.5	20.1	172.9	180.9	-3.4	7.5
COP (Average)	2.34	2.08	180.9	184.7	-1.6	5.4
EPD schedule (W/m^2)	0.2-0.9	0.3-1.0	184.7	186.1	0.3	4.1
Wall 'U' (W/m^{2}K) Roof 'U' (W/m^{2}K) Glass 'SC'	2.15 1.95 0.49	2.21 2.13 0.52	186.1	187.3	1.30	4.8
Occupancy schedule	0.2 to 0.8	0.26-0.86	187.3	188.2	1.8	3.6

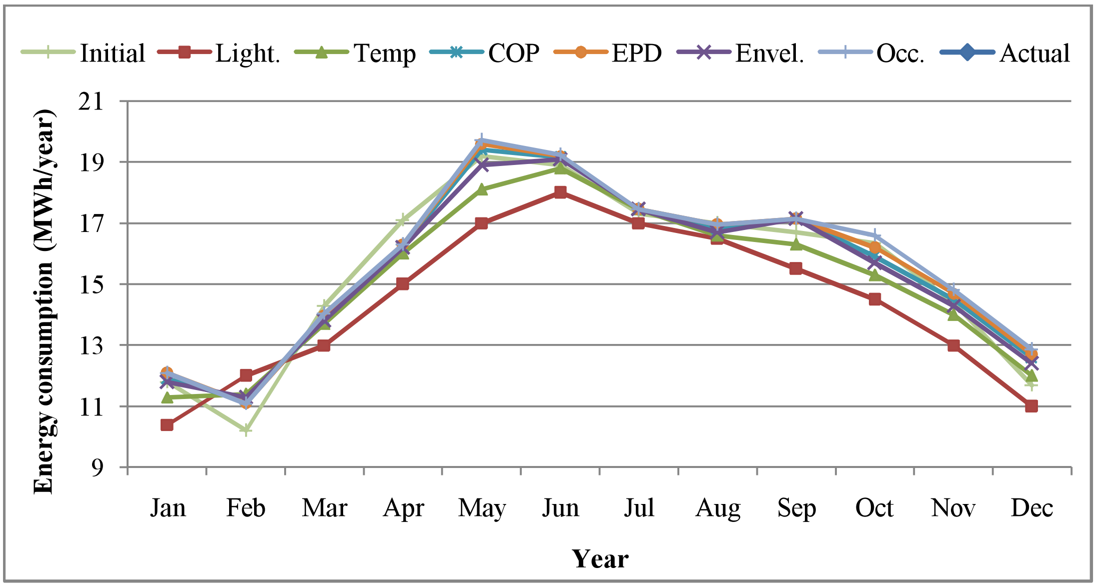


Fig. 4.12 Calibrated v/s actual energy consumption for Hotel-1 of Category-1

a. COP

During the site visits, it is observed that mostly air-conditioners are non energy star, one-star and two-star rated. Therefore, COP of various units was found between 2.3 and 2.9, which results into average COP of 2.6. In the case of unavailability of COP for some of the old unitary air-conditioners, COP of non-star rated air-conditioner is assumed. The average age of air conditioner units is observed to be six years, therefore COP is degraded from 2.6 to 2.08 after six years; therefore, an average COP assumed for the pre-calibrated model is 2.34. To calibrate the model using COP, initially lower values of COP is used then decreased in steps within the range and model is simulated to increase the energy consumption in order to bring closer values of MBE and C_VRMSE.

b. Schedules

The lighting fraction of the hotel building is ranging from 0.05 to 0.8 for different zones; therefore, for calibration lighting fraction is increased within ±15 range for both zones for model calibration as shown in Table 4.15. Equipment operating percentage in schedule is increased within ±15% range to bring closer values of MBE and C_vRMSE for model calibration and final value used is shown in Table 4.15. Thermostat set point temperature of guest rooms is found to be 19^0C-26^0C. Calibration is started with average temperature and finally, 21.4^{o}C is used for the model. Daily occupancy varying in the range from 0.2 to 0.8 with a variation of ± 20% in the occupancy is observed therefore the occupancy is increased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.15 W/m^{2}K and 1.95 W/m^{2}K respectively. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), is chosen as an input value in the calibrated model as shown in the Table 4.15.The glass shade having 0.49 shading coefficient is used in the pre-calibrated model, and finally, 0.51 is used finally for the model.

- **Category 1:Hotel-2**

  Hotel-2 is modeled and calibrated by varying selected parameters within certain pre-determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.17 and the calibration results have been shown in Fig. 4.13.

Table 4.17 Model calibration steps for Hotel-2 of Category-1

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)	-	-	185.8		18.8	65.4
Lighting schedule (fraction)	0.01-0.79	0.01-0.71	185.8	173.5	11.1	36.0
Thermostat set point (°C)	22	24.7	173.5	167.7	8.3	24.4
Average COP	2.45	2.70	167.7	161.9	3.7	13
EPD schedule (fraction)	0.2-0.9	0.1-0.8	161.9	158.0	3.2	11.6
Wall'U'(W/m^{2}K) Roof'U'(W/m^{2}K) Glass 'SC'	1.93 1.86 0.42	1.78 1.74 0.38	158.0	156.1	0.3	2.4
Occupancy schedule (fraction)	0.12-0.79	0.22-0.82	156.1	155.8	-0.09	0.3

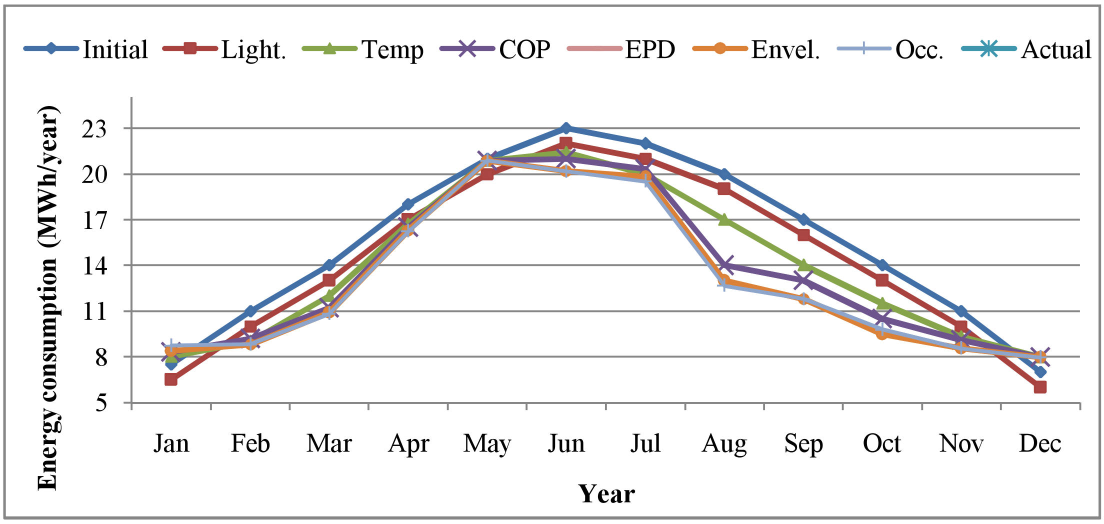


Fig. 4.13 Calibrated v/s actual energy consumption for Hotel-2 of Category-1

a. COP

During the site visits, it is observed that mostly air-conditioners are non energy star, one-star and two-star rated. Therefore, COP of various units was found between 2.3 and 3.1, which results into average COP of 2.7. The average age of air conditioner units is observed to be five years, therefore COP is degraded to 2.21 after five years; therefore, an average COP assumed for the pre-calibrated model is 2.45. To calibrate the model using COP, initially lower values of COP is used then increased in steps within the range and model is simulated to increase the energy consumption in order to bring closer values of MBE and C_VRMSE.

b. Schedules

The lighting fraction of the hotel building is ranging from 0.01-0.79 for different zones; therefore, for calibration lighting fraction is increased within ±15 range for both zones for model calibration as shown in Table 4.16. Equipment operating percentage in schedule is increased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.15. Thermostat set point temperature of guest rooms is found to be 180C-260C. Calibration is started with average temperature of 22°C and finally, 24.2°C is used for the model. Daily occupancy varying in the range from 0.12-0.79 with a variation of ± 20% in the occupancy is observed therefore the occupancy is increased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.15 W/m^{2}K and 1.95 W/m^{2}K respectively. The glass shade having 0.49 shading coefficient is used in pre-calibrated model whereas catalos revealed that similar shade could offer a shading coefficient in the range of 0.46 to 0.54. Therefore the model is calibrated by using the glass shading coefficient values within this range.

- **Category 1: Hotel-3**

Hotel -3 is modeled and calibrated by varying selected parameters within certain pre determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.18 and the calibration results have been shown in Fig. 4.14.

Table 4.18 Model calibration steps for Hotel-3 of Category-1

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)	-	-	140.6		45.5	50.2
Lighting schedule (fraction)	0.02-0.77	0.02-0.61	140.6	128.6	33.0	39.35
Thermostat set point (°C)	22.5	24.3	128.6	117.7	24.0	26.5
Average COP	2.66	2.9	117.7	110.0	13.8	17.7
EPD schedule (fraction)	0.2-0.9	0.1-0.8	110.0	100.0	4.3	8.9
Wall'U'(W/m^2K) Roof'U'(W/m^2K) Glass 'SC'	2.12 1.67 0.49	1.93 1.52 0.46	100.0	93.9	1.8	3.9
Occupancy schedule (fraction)	0.15-0.78	0.38-0.88	93.9	96.89	0.27	2.93

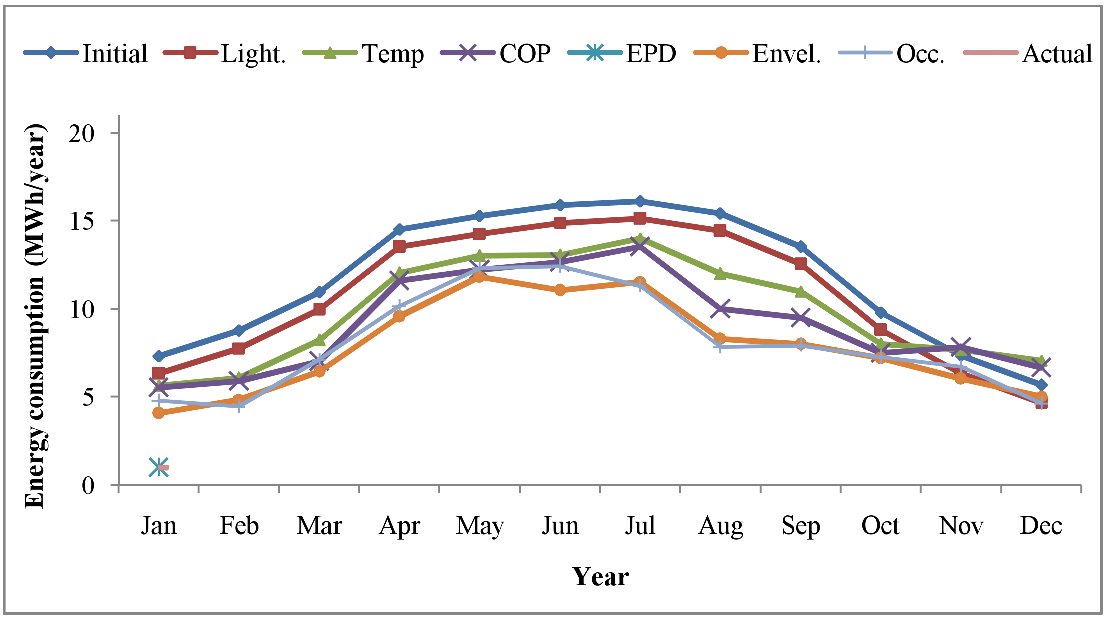


Fig. 4.14 Calibrated v/s actual energy consumption of Hotel-3 of Category-1

a. COP

It is observed that COP of various air-conditioner units was found between 2.5 and 3.3, which results into average COP of 2.9. The average age of air conditioner units is observed to be four years, therefore COP is degraded to 2.43 after five years; therefore, an average COP assumed for the pre-calibrated model is 2.66. To calibrate the model using COP, initially lower values of COP is used then increased in steps within the range and model is simulated to increase the energy consumption in order to bring closer values of MBE and C_VRMSE.

b. Schedule

The lighting fraction of the hotel building is ranging from 0. 0.02-0.77 for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.15. Equipment operating percentage in schedule is increased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.15. Thermostat set point temperature of guest rooms is found to be 20°C-25°C. Calibration is started with average temperature of 21.5 °C and finally, 24.3°C is used for the model. Daily occupancy varying in the range from 0.15-0.78 with a variation of ± 20% in the occupancy is observed therefore the occupancy is increased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.15 W/m^{2}K and 1.95 W/m^{2}K respectively. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.49 shading coefficient is used in pre-calibrated model whereas catalogs revealed that similar shade could offer a shading coefficient in the range of 0.46 to 0.54. Therefore, in the calibration process variation of shading coefficient of glass is carried out within this range.

4.9.2 Category-2 hotels

Hotel buildings in this category have adopted certain energy efficiency measures such as double glazed window glass, VRF type HVAC system, LED lighting fixtures, etc. however wall and roof construction follow conventional practices. The COP of HVAC system is higher since the load on VRF system is regulated by automatically varying the refrigerant flow. Due to unavailability of equipment schedules NREL, US; a reference hotel building schedules have been considered however, the EPD of major equipment has been estimated in the study. Through discussion with technical staff deviation of ±10% could be possible in the EPD values. Therefore, calibration is performed by varying value of EPD fraction value with ±10% deviation from the observed value to obtain closer MBE and C_VRMSE values. Various zones are divided broadly into two zones on LPD, for simulation. It is observed through data collection of lighting schedules of that the hotel building that, ±8% and ±12% of variation is possible in lighting fraction in the common area and guest rooms respectively. Therefore, lighting fraction is varied within ±8% and ±12% for common area and guest rooms respectively, from the existing values. Zones are categorized broadly into two zones one with larger variations in thermostat set point temperature i.e. 5°C, includes guest rooms and other which have small variations of 3°C, includes common areas. There is a large variation in daily occupancy and yearly occupancy. Various modeling steps and modeling considerations for this category of hotel buildings are as follows:

- **Category 2: Hotel-1**

Hotel -1 is modeled and calibrated by varying selected parameters within certain pre-determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.19 and the calibration results have been shown in Fig. 4.15.

Table 4.19 Model calibration steps for Hotel-1 of Category-2

Parameters	Before calibration	After calibration	Annual energy Consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)	-	-	464.63		15.8	20.3
Lighting schedule (fraction)	0.05-0.78	0.05-0.69	464.63	440.63	11.3	13.6
Thermostat set point (°C)	21	23.6	440.63	426.6	7.5	11.2
Average COP	3.57	3.82	426.6	413.3	5.1	6.3
EPD schedule (fraction)	0.2-0.9	0.1-0.8	413.3	400.24	2.3	5.2
Wall'U'(W/m^2K) Roof'U'(W/m^2K) Glass 'SC'	2.01 1.89 0.54	1.86 1.74 0.50	400.24	392.3	-2.7	3.2
Occupancy schedule (fraction)	0.15-0.78	0.4-0.8	392.3	403.7	-1.09	3.78

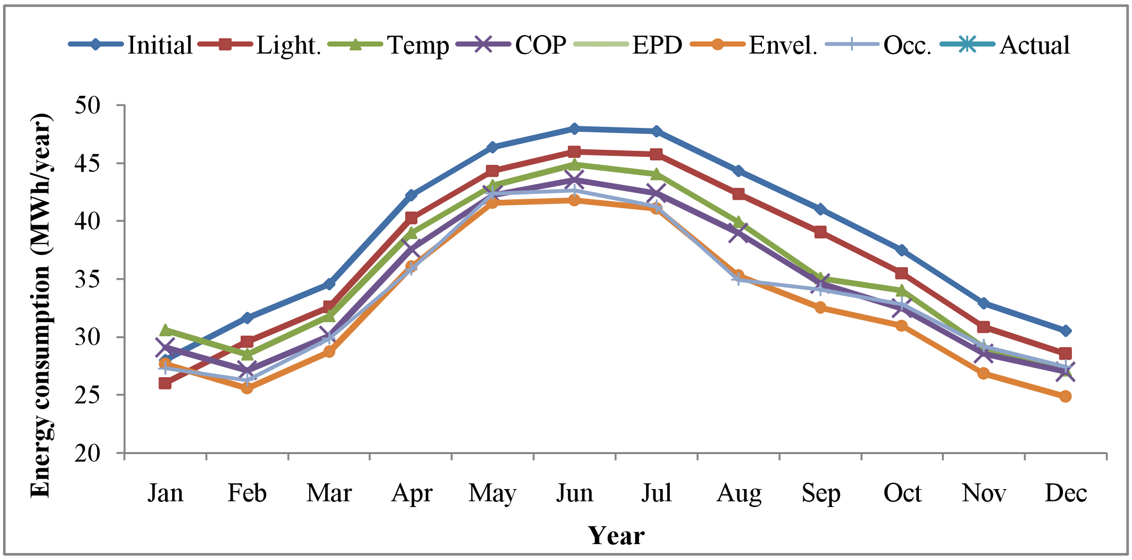
COP

Age of air conditioner units is observed to be four years and due to degradation, COP after four years would be reduced to 3.26; therefore, an average COP assumed for the pre-calibrated model is 3.57. The COP is increased to reduce energy consumption of the model for calibration.

a. Schedule

The lighting fraction of the hotel building is ranging from 0.05-0.78 for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.15. Equipment operating percentage in schedule is decreased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.15. Thermostat set point temperature of guest rooms is found to be 18°C-24°C. Calibration is started with average temperature of 21.0 °C and finally, 23.6°C is used for the model. Daily occupancy varying in the range from 0.15-0.78 with a variation

Fig. 4.15 Calibrated v/s actual energy consumption of Hotel-1 of Category-2



of ± 20% in the occupancy is observed therefore the occupancy is increased for model calibration.

b. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.01 W/m^2K and 1.89 W/m^2K respectively. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.54 shading coefficient is used in the pre-calibrated model, and finally, 0.50 is used finally for the model.

- **Category 2: Hotel-2**

Hotel -2 is modeled and calibrated by varying selected parameters within certain pre-determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.20 and the calibration results have been shown in Fig. 4.16.

Table 4.20 Model calibration steps for Hotel-2 of Category-2

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)	-	-	1427.5		12.4	43.3
Lighting schedule (fraction)	0.04-0.8	0.04-0.7	1427.5	1373.5	5.8	20.3
Thermostat set point (°C)	21.5	24.5	1373.5	1310.8	2.4	11.4
Average COP	2.41	2.65	1310.8	1293.7	1.9	6.7
EPD schedule (fraction)	0.2-0.9	0.1-0.8	1293.7	1277.2	1.3	2.2
Wall'U'(W/m^{2}K) Roof'U'(W/m^{2}K) Glass 'SC'	2.93 1.44 0.47	2.80 1.36 0.43	1277.2	1270.3	0.6	1.1
Occupancy schedule (fraction)	0.10-0.8	0.17-0.72	1270.3	1265.9	-0.2	0.8

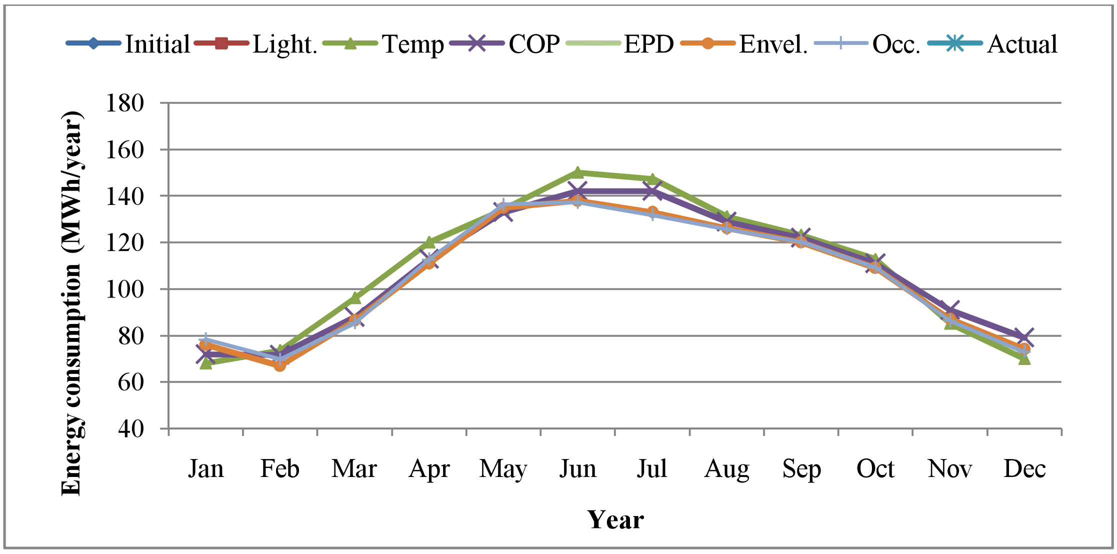


Fig. 4.16 Calibrated v/s actual energy consumption of Hotel-2 of Category-2

a. COP

This hotel building has unitary type air-conditioning units it is observed that COP of various air-conditioner units was found between 2.3 and 3.1, which results into average COP of 2.65. The average age of air conditioner units is observed to be five years, therefore COP is degraded to 2.17 after five years; therefore, an average COP assumed for the pre-calibrated model is 2.41. To calibrate the model using COP, initially lower values of COP is used then increased in steps within the range and model is simulated to increase the energy consumption in order to bring closer values of MBE and C_VRMSE.

b. Schedule

The lighting fraction of the hotel building is ranging from 0.04-0.8 for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.15. Equipment operating percentage in schedule is decreased within ±15% range to bring closer values of MBE and C_vRMSE for model calibration and final value used is shown in Table 4.15. Thermostat set point temperature of guest rooms is found to be 18^oC-25^oC. Calibration is started with average temperature of 21.5 ^oC and finally, 24.5^oC is used for the model. Daily occupancy varying in the range from 0.10-0.8 with a variation of ± 20% in the occupancy is observed therefore the occupancy is decreased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.94 W/m^2K and 1.44 W/m^2K respectively. The U-value which gave an optimized value of ERR_{month}, MBE and (C_VRMSE) is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.47 shading coefficient is used in the pre-calibrated model and finally, 0.43is used finally for the model.

- **Category 2: Hotel-3**

Hotel -3 is modeled and calibrated by varying selected parameters within certain pre-determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.21 and the calibration results have been shown in Fig. 4.17.

Table 4.21 Model calibration steps for Hotel-3 of Category-2

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)			630.6		20.3	5.8
Lighting schedule (fraction)	0.03-0.79	0.2-0.7	630.6	612.6	12.7	4.2
Thermostat set point (°C)	21	22.2	612.6	591.5	10.1	3.8
Average COP	3.49	3.75	591.5	555.7	6.3	3.1
EPD schedule (fraction)	0.2-0.9	0.1-0.8	555.7	531.5	2.6	2.1
Wall'U'(W/m^2K) Roof'U'($W/m^2 K$) Glass 'SC'	2.13 1.96 0.57	1.96 1.82 0.49	531.5	517.9	1.2	1.4
Occupancy schedule (fraction)	0.14-0.79	0.08-0.69	517.9	508.4	-0.01	1.1

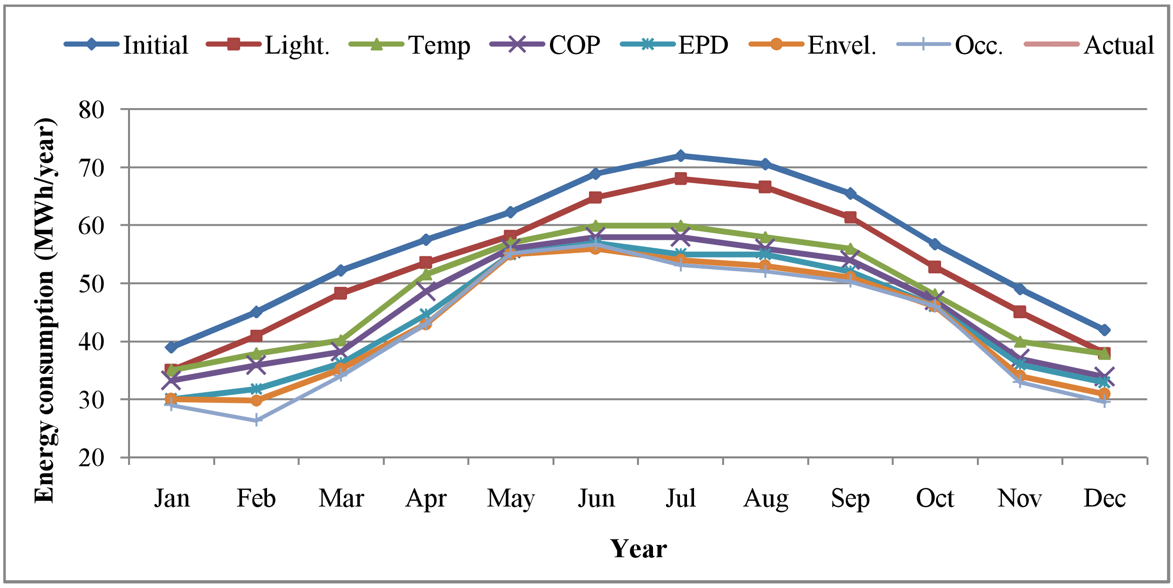


Fig. 4.17 Calibrated v/s actual energy consumption of Hotel-3 of Category-2

a. COP

Age of air conditioner units is observed to be four years and due to degradation, COP after four years would be reduced to 3.19; therefore, an average COP assumed for the pre-calibrated model is 3.49. The COP is increased to reduce energy consumption of the model for calibration.

b. Schedule

The lighting fraction of the hotel building is ranging from 0.03-0.79 for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.15. Equipment operating percentage in schedule is decreased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.15. Thermostat set point temperature of guest rooms is found to be 18°C-24°C. Calibration is started with average temperature of 21 °C and finally, 22.2°C is used for the model. Daily occupancy varying in the range from 0.14-0.79 with a variation of ± 20% in the occupancy is observed therefore the occupancy is decreased for model calibration.

*c. **Envelope properties***

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.13W/m^{2}K and 1.96 W/m^{2}K respectively. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.57shading coefficient is used in the pre-calibrated model, and finally, 0.49is used finally for the model.

4.9.3 Category-3 hotels

Hotel buildings in this category have adopted certain energy efficiency measures such as wall and roof coating; double glazed window glass, chiller type HVAC system, LED lighting fixtures, etc. This category of hotel buildings are large buildings, and they have a number of common areas such as conference hall, restaurant, lobby, banquet hall, kitchen, laundry, office, the air-conditioning, lighting and other requirements are different. Therefore, the zones of hotel buildings have been categorized into three.

Due to unavailability of equipment schedules NREL, US; a reference hotel building schedules have been considered, however, the EPD of major equipment has been estimated in the study. Through discussion with technical staff deviation of ±10% could be possible in the EPD values. Therefore, calibration is performed by varying value of EPD fraction value with ±10% deviation from the observed value to obtain closer MBE and C_VRMSE values. Various zones are divided broadly into three zones on LPD, for simulation. It is observed through data collection of lighting schedules of that the hotel building that, ±8% and ±12% of variation is possible in lighting fraction in the common area and guest rooms respectively. Therefore, lighting fraction is varied within ±8% and ±12% for common area and guest rooms respectively, from the existing values. Zones are categorized broadly into three zones one with larger variations in thermostat set point temperature i.e. 5°C, includes guest rooms and other which have small variations of 3°C, includes common areas and offices. There is a large variation in daily occupancy and yearly occupancy. Various modeling steps and modeling considerations for this category of hotel buildings are as follows:

- **Category 3: Hotel-1**

Hotel -1 is modeled and calibrated by varying selected parameters within certain pre-determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.22 and the calibration results have been shown in Fig. 4.18.

Table 4.22 Model calibration steps for Hotel-1 of Category-3

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)			1928.3		20.0	21.2
Lighting schedule (fraction)	0.06-0.81	0.2-0.75	1928.3	1806.3	12.5	14.4
Thermostat set point (°C)	22	25.5	1806.3	1712.1	6.7	9.4
Average COP	2.92	3.12	1712.1	1665.2	3.7	6.3
EPD schedule (fraction)	0.2-0.9	0.1-0.8	1665.2	1629.4	2.2	4.3
Wall'U'(W/m^{2}K) Roof'U'(W/m^{2}K) Glass 'SC'	2.38 1.48 0.51	2.22 1.34 0.46	1629.4	1607.2	1.4	3.6
Occupancy schedule (fraction)	0.16-0.83	0.2-0.7	1607.2	1601.7	-0.23	4.22

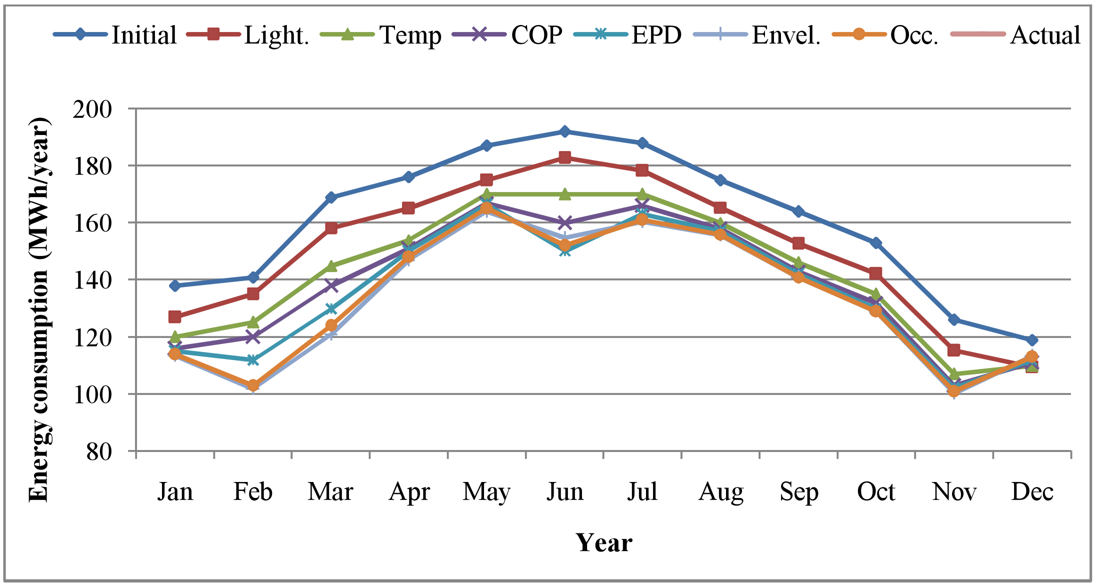


Fig. 4.18 Calibrated v/s actual energy consumption of Hotel-1 of Category-3

a. COP

Age of air conditioner units is observed to be four years and due to degradation, COP after four years would be reduced to 2.33; therefore, an average COP assumed for the pre-calibrated model is 2.63. The COP is increased to reduce energy consumption of the model for calibration as shown in Table 4.21.

b. Schedule

The lighting fraction of the hotel building is ranging from 0.06-0.81for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.15. Equipment operating percentage in schedule is decreased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.21. Thermostat set point temperature of guest rooms is found to be 18°C-26°C. Calibration is started with average temperature of 22 °C and finally, 25.5°C is used for the model. Daily occupancy varying in the range from 0.16-0.83 with a variation of ± 20% in the occupancy is observed therefore the occupancy is decreased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.38 W/m^{2}K and 1.48 W/m^{2}K respectively. The U-value, which gave an optimized value of ERR $_{month}$, MBE and (C_VRMSE), is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.51 shading coefficient is used in the pre-calibrated model and finally 0.46 is used finally for the model.

- **Category 3: Hotel-2**

Hotel-2 is modeled and calibrated by varying selected parameters within certain pre determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.23 and the calibration results have been shown in Fig. 4.19.

Table 4.23 Model calibration steps for Hotel-2 of Category-3

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)			7765.2		15.8	55.0
Lighting schedule (fraction)	0.07-0.83	0.05-0.68	7765.2	7405.2	10.5	36.6
Thermostat set point (°C)	21.5	23.5	7405.2	7159.4	6.4	18.9
Average COP	3.74	3.94	7159.4	6988.7	2.9	10.3
EPD schedule (fraction)	0.2-0.9	0.1-0.8	6988.7	6904.6	1.8	7.4
Wall'U'(W/m^{2}K) Roof'U'(W/m^{2}K) Glass 'SC'	2.34 1.31 0.57	2.21 1.18 0.51	6904.6	6815.2	0.8	3.5
Occupancy schedule (fraction)	0.17-81	0.09-0.73	6815.2	6811.8	0.362	1.26

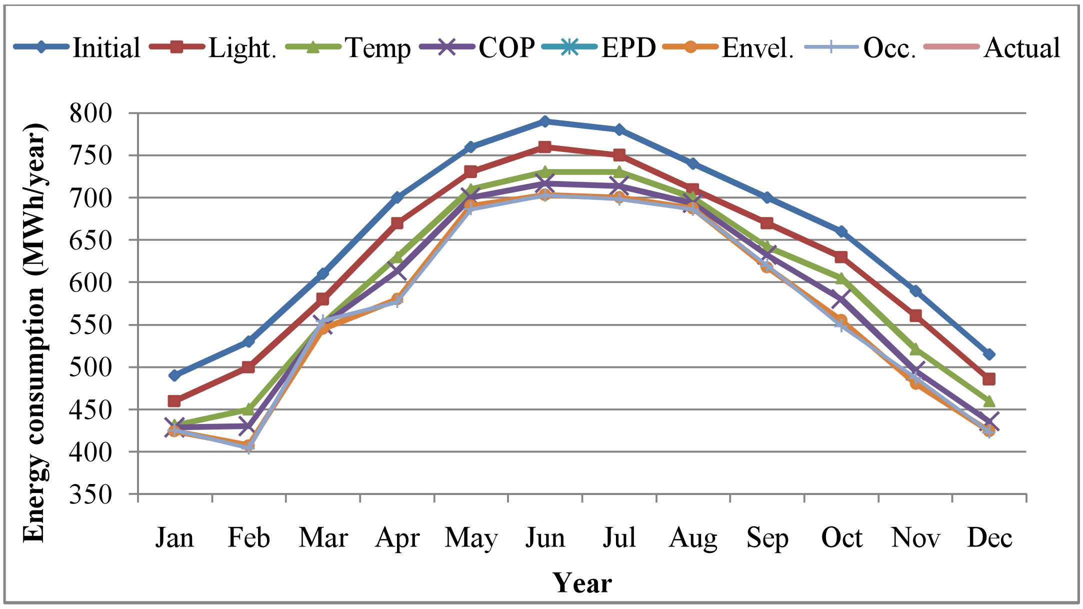


Fig. 4.19 Calibrated v/s actual energy consumption of Hotel-2 of Category-3

a. COP

Age of air conditioner units is observed to be seven years and due to degradation, COP after seven years would be reduced to 3.27; therefore, an average COP assumed for pre-calibrated model is 3.74. The COP is increased to reduce energy consumption of the model for calibration as shown in Table 4.22.

b. Schedule

The lighting fraction of the hotel building is ranging from 0.07-0.83 for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.22. Equipment operating percentage in schedule is decreased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.21. Thermostat set point temperature of guest rooms is found to be 18°C-25°C. Calibration is started with average temperature of 21.5 °C and finally, 23.5°C is used for the model. Daily occupancy varying in the range from 0.17-0.81 with a variation of ± 20% in the occupancy is observed therefore the occupancy is decreased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.34 W/m^2K and 1.31 W/m^2K respectively. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.57 shading coefficient is used in the pre-calibrated model and finally 0.51is used finally for the model.

- **Category 3: Hotel-3**

Hotel -3 is modeled and calibrated by varying selected parameters within certain pre determined range to obtain closer values of MBE and C_VRMSE as shown in Table 4.24 and the calibration results have been shown in Fig. 4.20.

Table 4.24 Model calibration steps for Hotel-3 of Category-3

Parameters	Before calibration	After calibration	Annual energy consumption (MWh/year)		MBE	CvRMSE
			Before calibration	After calibration		
Energy consumption (Uncalibrated model)			886.9		9.15	31.7
Lighting schedule (fraction)	0.02-0.77	0.03-0.63	886.9	838.9	3.24	11.23
Thermostat set point (°C)	22	23.1	838.9	831.0	3.12	8.4
Average COP	3.69	4.02	831.0	821.3	1.08	3.74
EPD schedule (fraction)	0.2-0.9	0.1-0.8	821.3	809.1	0.9	2.4
Wall'U'(W/m^2K) Roof'U'(W/m^2K) Glass 'SC'	2.72 1.60 0.56	2.68 1.49 0.51	809.1	799.2	0.9	2.1
Occupancy schedule (fraction)	0.15-0.8	0.21-0.88	799.2	807.7	-0.59	2.05

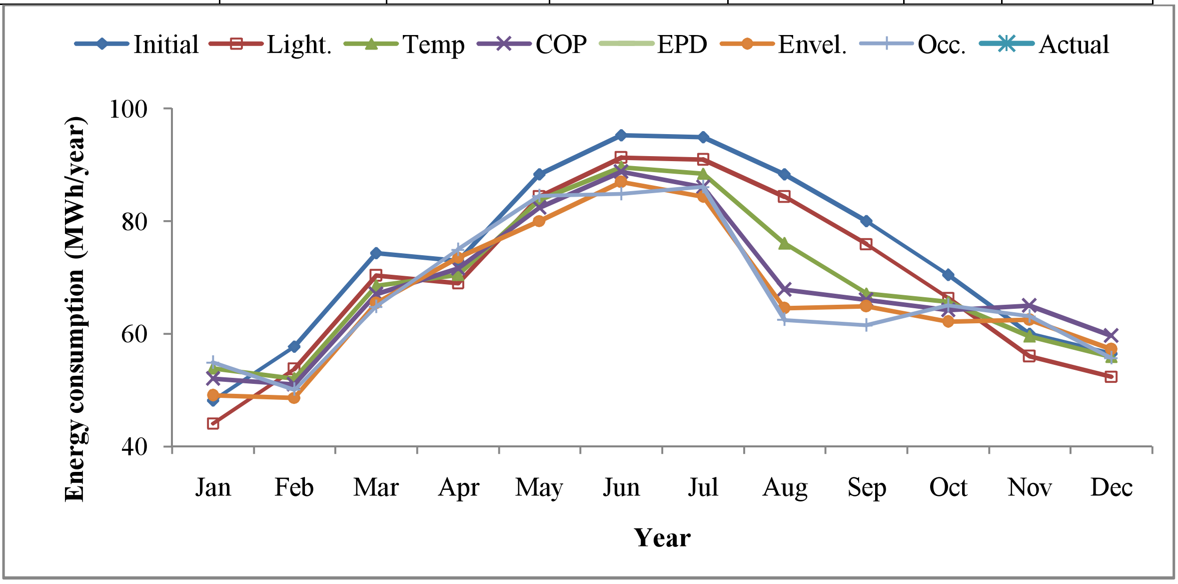


Fig. 4.20 Calibrated v/s actual energy consumption of Hotel-3 of Category-3

a. COP

Age of air conditioner units is observed to be eight years and due to degradation, COP after eight years would be reduced to 3.19; therefore, an average COP assumed for the pre-calibrated model is 3.69. The COP is increased to reduce energy consumption of the model for calibration as shown in Table 4.23.

b. Schedule

The lighting fraction of the hotel building is ranging from 0.02-0.77 for different zones; therefore, for calibration lighting fraction is decreased within ±15 range for both zones for model calibration as shown in Table 4.23. Equipment operating percentage in schedule is decreased within ±15% range to bring closer values of MBE and C_VRMSE for model calibration and final value used is shown in Table 4.21. Thermostat set point temperature of guest rooms is found to be 18°C-26°C. Calibration is started with average temperature of 22 °C and finally, 23.1°C is used for the model. Daily occupancy varying in the range from 0.15-0.80 with a variation of ± 20% in the occupancy is observed therefore the occupancy is decreased for model calibration.

c. Envelope properties

The wall and roof of hotel building are modeled as per the details of wall and roof construction available in the architectural drawing. The initial value for U-value of wall and roof taken are 2.72W/m^{2}K and 1.60 W/m^{2}K respectively. The U-value, which gave an optimized value of ERR_{month}, MBE and (C_VRMSE), is chosen as the input value in the calibrated model as shown in the Table 4.13. The glass shade having 0.56 shading coefficient is used in the pre-calibrated model and finally 0.51is used finally for the model.

Although, utmost care is taken while selecting the modeling parameters to match the simulation with the measured billing energy consumption but there is a mismatch between these two variables. The mismatch is probably due to following reasons:

1. Occupancy, lighting, equipment schedules are observed to vary on the daily and yearly basis in the building, whereas, due to modeling limitations, only a few schedules have been used to represent building model.
2. Weather file provided by Indian Society of Heating, Refrigerating, and Air-Conditioning Engineers (ISHRAE) by changing the Dry Bulb Temperature (DBT) and Relative Humidity (RH) which may differ with actual on-site measured values. Non availability of direct solar radiation data (on-site) and variation of actual solar radiation from the ISHRAE weather file is also the cause of some mismatch.
3. Construction details and material used in the building are available but thermal and physical properties of actual materials used in the building are not available. Material properties available in various standards and the case studies of various Indian buildings have been used which may vary with the properties of the material used in the building.

4. Complete details of Heating Ventilation and Air Conditioning (HVAC) system and other equipment being used on-site are not available therefore some default properties available in eQUEST are used which may differ from actual values.
5. Some of the parameters used for equipment are taken from rated values available in equipment specification.

The mismatch obtained between measured values, and simulated values have been removed by the calibration process. Through the calibration process, the results of the simulation with measured data are matched with the simulation until its results closely match the measured data.

Calibration of building model is done according to various options of IPMVP (International Performance Measurement and Verification Protocol) classified according to kind of energy saving intervention required. Fig.4.21 shows the simulated and actual annual energy consumption for three categories of the hotel building. Table 4.24 shows that criterion of IPMVP standard is fulfilled for calibrated models and the final values of MBE and C_VRMSE.

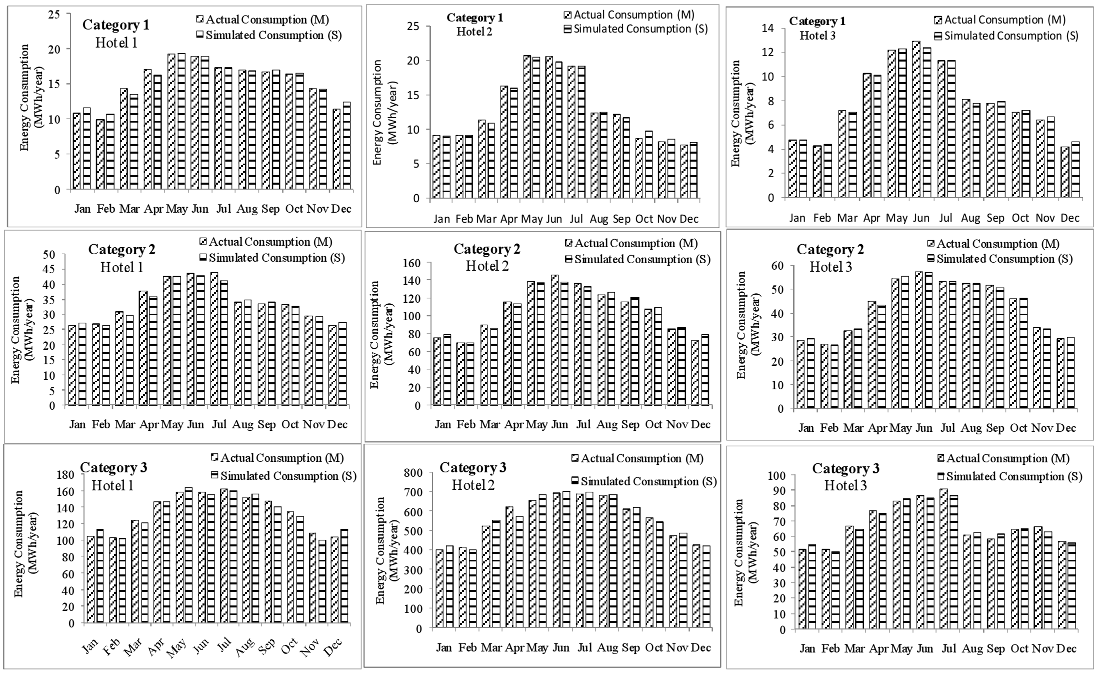


Fig.4.21. Simulated and actual energy consumption for three categories of hotel buildings

Table 4.25. Calibration details for three categories of hotel buildings

Category-1	Hotel	Energy consumption (MWh/year)		MBE	C_VRMSE	Remark
		Actual	Simulated			
Category-1	Hotel-1	184.94	188.29	1.81	3.63	Model is calibrated
	Hotel-2	156.04	155.89	-0.09	0.33	Model is calibrated
	Hotel-3	96.62	96.89	0.27	2.93	Model is calibrated
Category-2	Hotel-1	408.2	403.74	-1.09	3.78	Model is calibrated
	Hotel-2	1268.92	1265.90	-0.23	0.82	Model is calibrated
	Hotel-3	508.5	508.40	-0.01	2.16	Model is calibrated
Category-3	Hotel-1	1605.4	1601.70	-0.23	4.22	Model is calibrated
	Hotel-2	6786.28	6811	0.362	1.26	Model is calibrated
	Hotel-3	812.6	807.78	-0.59	2.05	Model is calibrated

The simulated building models of hotel categories demonstrated errors such as ERR, MBE, and CvRMSE within permissible limits of ± 15 %, ± 5 % and ± 10 %, respectively as prescribed in Option-D. Following assumptions have been taken for modeling and simulation of three categories of hotel buildings.

While carrying out the modeling and simulation following assumptions were considered:

- Building envelope (such as wall, roof and glazing) properties considered in the study were taken from the other Indian studies carried out for commercial buildings with typical wall and roof construction.
- During questionnaire survey, lighting load was recorded (number of lighting fixtures, wattage, and lighting fixture type) for a typical floor only and similar lighting load was considered for other floors.
- HVAC system and other equipment specifications like capacity, efficiency, etc. considered in the study were taken as per system specifications available at the facility.
- Equipment operating schedules were observed for few sample days and considered to be applicable for other days.

4.10 Summary

The energy use varies substantially between different types of hotels and is affected by hotel size, category, the number of rooms, equipment, occupancy, as well as by the types of services, activities and amenities provided to guests. Category-1 hotel buildings are found to be following conventional practices for the envelope, HVAC system, lighting fixtures and other equipment as compared to the Category-2 and Category-3hotel buildings. Category-1 hotel buildings are using direct expansion type HVAC system that has low COP, therefore, the share of energy consumption by HVAC system is found to be significant. The simulated building models values of MBE and CvRMSE are found to be having within as within permissible limits of ± 5 % and ± 10 %, respectively as prescribed in Option-D.

CHAPTER 5
RESULTS AND DISCUSSION

This chapter summarizes possibilities of energy savings through the adoption of Energy Conservation Building Code (ECBC) and advanced energy efficiency measures for nine case study hotel buildings and their projections on the entire hotel sector of Jaipur city. The present study seeks insights into the potential of energy savings through ECBC building code compliance by adoption of technological options to building components and systems such as Heating Ventilation and Air Conditioning (HVAC) system, wall, roof, window glazing, and lighting. In advance energy efficiency measures retrofitting of above components are done by using technological options better than the level of ECBC.

5.1 Energy savings through adoption of ECBC building code

The ECBC building code is applied to the simulated models of nine hotel buildings of Jaipur city. To the simulated models ECBC building code is assumed to be implemented through retrofitting of HVAC system, wall, roof, window glazing and lighting system; and corresponding energy savings are estimated.

5.1.1 Retrofitting of HVAC equipment

HVAC system in the existing hotel buildings is considered to be replaced with a system of same capacity but with higher efficiency, as per the recommendations of ECBC. In Category-1 and Category-2 hotels, unitary systems of star ratings non-star, one-star and two-star are considered to be replaced with energy efficient HVAC systems (five-star rating). However, hotels already having HVAC systems in compliance with ECBC building code are not considered to be replaced. Chilled water based type HVAC systems (in Category-3 hotels) are considered to be replaced with an efficient chiller of the same type as per the recommendation of ECBC. The simulation results show that for chiller type of HVAC system besides reduction in cooling energy; energy consumption for heat rejection operating equipment and pump also gets reduced. Table 5.1 shows building and cooling energy savings for all categories of hotel buildings through retrofitting ECBC compliant HVAC equipment and percentage energy savings.

Table 5.1 Energy saving through ECBC compliant equipment

C	Hotel	Building energy consumption (MWh/year)			Cooling energy consumption (MWh/year)			Building energy savings (%)	Cooling energy savings (%)
		Before retrofitting	After retrofitting	Net energy savings	Before retrofitting	After retrofitting	Net energy savings		
C 1	Hotel 1	188.3	165.86	22.4	105.5	83.1	22.4	11.9	27.0
	Hotel 2	155.89	142.15	13.74	73.94	60.2	13.74	8.8	22.8
	Hotel 3	96.16	87.61	8.55	48.26	39.71	8.55	8.9	21.5
C 2	Hotel 1	407.33	407.33	-	131.91	-	-	-	-
	Hotel 2	1273.9	1154.1	119.8	659.9	540.1	119.8	9.4	22.2
	Hotel 3	503.1	503.1	-	202.3	-	-	-	-
C 3	Hotel 1	1605.9	1578.9	27	631.9	604.6	27.3	1.7	4.5
	Hotel 2	6773.7	6039.7	734	2569.6	1845.4	724.2	10.8	39.2
	Hotel 3	813.76	719.43	94.3	328.6	237	91.6	11.6	38.6

C: Category, C1:Category1, C2:Category-2 and C3:Category-3

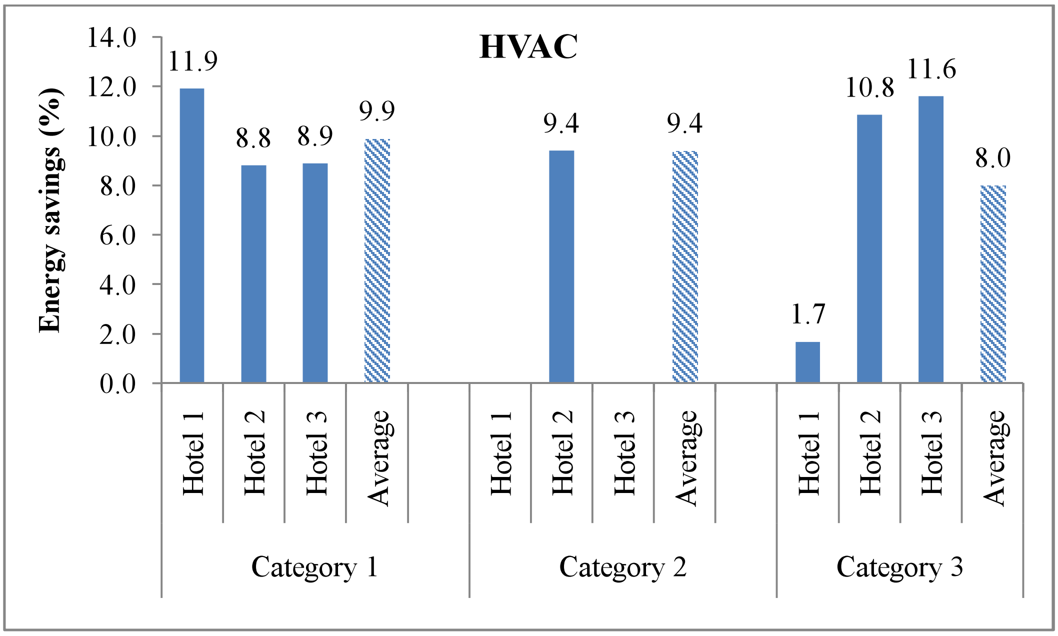


Fig. 5.1 Percentage energy savings by ECBC compliant HVAC system

Results presented in Fig. 5.1 clearly show that ECBC compliant HVAC equipment give significant energy savings (1.7% to 11.9%),

- For Category-1 hotels, replacing existing unitary system with ECBC compliant system results in an energy saving in the range of 8.8% to 11.9% since most of the unitary units are old units with poor star ratings.
- Hotel-1 and Hotel-3 of Category-2 were found to be already equipped with VRF type HVAC system, which are having a higher COP, at par with the COP

recommended for ECBC system. Therefore, HVAC system shows no energy savings for these hotels as shown in Fig. 5.1and therefore HVAC system is not recommended to be replaced. However, Hotel-2 in Category-2 is using unitary system (lower COP) and retrofitting with ECBC compliant HVAC system resulted in identification of significant energy saving potential.

- Hotel-2 and Hotel-3 in Category-3 are using water-cooled type chiller which is used as a central air conditioning system that gives significant energy savings, up to 11.6% with a similar type of ECBC compliant HVAC system. Since, there is significant difference in COP of the existing system in both Hotel-2 and Hotel-3 with ECBC compliant HVAC system, resulting into higher energy savings. HVAC system in Hotel-1 of Category-3 is having air-cooled type chiller system and having a COP of 2.92 which is quite close to ECBC recommended COP (3.05) for air-cooled chiller, therefore resulted into low energy savings.
- Fasiuddin and Budaiwi (2011) in their study for commercial buildings of Saudi Arabia on HVAC system found that the energy savings up to 25% can be achieved using various HVAC operation strategies such as increased set point temperature, proper selection of system and fan schedule. Whereas, in the present study energy savings through retrofitting of HVAC is higher, that is up to 39%. Higher energy savings are obtained through ECBC compliant HVAC system since the whole HVAC unit is being proposed to be replaced in this study.
- Hu J.S. (2006) carried out a case study at hotel building of Hong Kong (ambient temperature ranges from 16^0C to 29^0C) to estimate energy savings through replacing air cooled chiller with water-cooled chiller, replacing pump and new control system. The COP of existing chiller was 4 and COP of proposed chiller was 5.88. The results of the study show that the saving in cooling energy varies from 14.4% to 28.8%. Whereas, in present study for hotel building-2 and hotel building-3 of category-3, replacing existing chiller having COP 4.2 to new chiller with COP 5.8 the energy saving is around 40%. The higher energy saving in present study is due to higher ambient temperature in summer which reaches up to 44^0C.

The cost-benefit analysis for retrofitting of HVAC system in nine case study hotel buildings is carried out. Cost of the unitary system, air-cooled chiller system, water cooled chiller system considered in the economic analysis are INR 24000, 40000, 50000 per TR respectively, as per the market survey conducted in Jaipur city. In economic analysis Internal Rate of Return (IRR) is calculated for the lifecycle of the new equipment. The results of economic analysis are shown in Table 5.2, which depicts IRR for ECBC compliant HVAC system and advanced system.

Table 5.2 IRR for retrofitting existing HVAC equipment

Category	Hotel	HVAC Type	ECBC		
			Retrofitting cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	Unitary	7.56	1.40	11.9
	Hotel 2	Unitary	4.32	0.85	13.7
	Hotel 3	Unitary	2.88	0.53	11.9
Category 2	Hotel 1	VRF	-	-	-
	Hotel 2	Unitary	34.66	7.48	16.0
	Hotel 3	VRF	-	-	-
Category 3	Hotel 1	Chiller	74.00	1.68	-6.2
	Hotel 2	Chiller	300.00	45.87	10.0
	Hotel 3	Chiller	50.00	5.89	6.2

- IRR for retrofitting of unitary HVAC units with ECBC compliant units is between 11.9 % to 16.0 % for Category-1 and Category-2 hotels respectively, whereas, for Category-3 hotels, IRR through replacing ECBC compliant chiller for Hotel-2 and Hotel-3 is 10.0 % and 6.2 % respectively. Low IRR in these hotels is due to high capital cost of chiller type HVAC system. Therefore, replacing unitary type of HVAC system can be economically viable solution whereas replacing existing chiller with ECBC compliant HVAC system is not economically viable solution. Hotel-3 has very low IRR (-6.2 %) is because there is Marginal difference in COP of existing HVAC system and ECBC recommended HVAC system (2.92 and 3.05) therefore, the energy saving is lower whereas the capital cost is high resulting into low IRR.

5.1.2 Wall insulation

The external walls of the case study hotel buildings are proposed to be insulated with polystyrene insulation that is commonly used by commercial buildings in Jaipur city. The thickness of insulation considered for external walls of the hotel buildings corresponds to the thickness that gives an overall U-value of the wall assembly similar as recommended by ECBC building code. The corresponding energy savings through the reduction in heat gain, obtained by polystyrene insulated wall is shown in Table 5.3, and percentage energy saving is shown in Fig.5.2.

Table 5.3 Energy saving through reduction in heat gain by wall insulation

Category	Hotel	Window/ Wall ratio (%)	Wall area/Yearly energy consumption (m^2/MWh/year)	ECBC Wall		
				Energy consumption before insulation (MWh/year)	Energy consumption after insulation (MWh/year)	Energy savings (MWh/year)
C1	Hotel 1	8.2	4.1	165.86	150.55	15.31
	Hotel 2	20.2	3.3	142.15	134.31	7.84
	Hotel 3	4.5	7.2	87.61	75.01	12.60
C2	Hotel 1	15.8	3.0	407.33	382.22	25.11
	Hotel 2	19.5	2.1	1154.10	1085.00	69.10
	Hotel 3	24.3	2.2	503.10	481.16	21.94
C3	Hotel 1	23.0	1.4	1578.90	1535.10	43.80
	Hotel 2	19.1	1.7	6039.70	5838.20	201.50
	Hotel 3	34.5	2.6	719.43	695.60	23.830

Wall insulation considered to be applied on the external surface of case study hotel buildings, reduces the heat gain and results in energy savings.

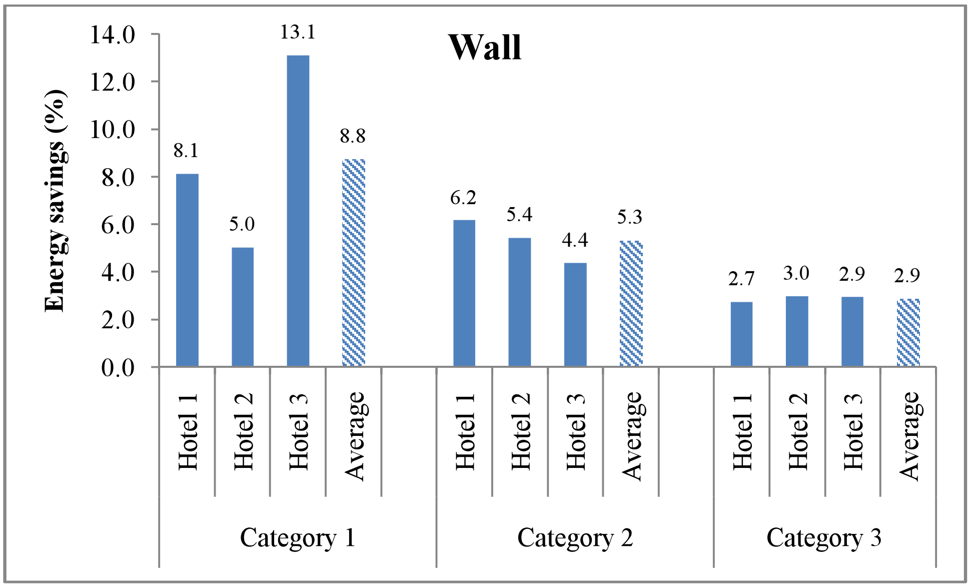


Fig. 5.2 Percentage energy savings by wall insulation

- Energy savings obtained through wall insulation of Category-1 hotels is higher as compared to Category-2 and Category-3 hotels. Since, Category-1 hotels are small buildings, and ratio of external wall area to energy consumption of a small building is higher therefore, the energy saving through wall insulation is higher. Energy saving also depends upon the window to wall ratio that is higher for the building that has a low window to wall ratio i.e. large wall area as shown in Table 5.3. Hotel-3 of Category-1 has low window to wall ratio i.e. large wall area resulting into higher energy savings through wall insulation for this hotel.

- Friess et al. (2012) conducted a study in Dubai, UAE residential buildings to estimate effect of full perimeter external wall insulation strategies on prefabricated concrete block and realized energy savings of up to 30%. In the present study the energy savings through wall insulation is up to 13% whereas higher energy savings by Friess et al. is due to combined effect of wall and roof insulation.
- Similarly, rexults of the study conducted by Bolattürk A. (2008) on finding optimum wall insulation thickness on commercial building shows that the optimum insulation thickness varies between 3.2 and 3.8 cm; and the payback period varies between 3.39 and 3.81 years. In the present study the payback period is 5-7 years due to use of higher insulation thickness for ECBC compliance and not the optimum thickness.
- The wall insulation gives IRR in the range of 5.9 % to 16.9 % in ECBC compliance and as shown in Table 5.4. Hotel-3 of Category-3 has low IRR because it has very high window to wall ratio therefore the wall insulation is not effective since heat gain takes place through windows.

The IRR of the wall insulation is estimated and has been shown in Table 5.4.

Table 5.4 IRR for wall insulation

Category	Hotel		ECBC		
		External Wall area (m^2)	Insulation cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	772.3	5.08	0.95	11.5
	Hotel 2	515.6	3.39	0.49	7.4
	Hotel 3	696.0	4.58	0.78	10.0
Category 2	Hotel 1	1222.7	8.04	1.56	12.1
	Hotel 2	2654.8	17.46	4.31	16.9
	Hotel 3	1092.7	7.18	1.37	11.7
Category 3	Hotel 1	2294.8	15.09	2.37	10.9
	Hotel 2	11290.3	74.23	12.59	9.8
	Hotel 3	2084.9	11.47	1.48	5.9

5.1.3 Roof insulation

The outer surface of the roof of case study hotel buildings is retrofitted by applying polystyrene insulation. The thickness of insulation considered for the hotel buildings corresponds to the thickness that gives a U-value at par as recommended by ECBC building code. Table 5.5 shows energy saving through reduction in heat gain by roof insulation

Table 5.5 Energy saving through reduction in heat gain by roof insulation

Category	Hotel	U-value (W/m^2-°C)	Roof area/energy consumption (m^2/MWh/year)	ECBC Roof		
				Energy consumption before insulation (MWh/year)	Energy consumption after insulation (MWh/year)	Energy savings (MWh/year)
Category 1	Hotel 1	0.34	1.16	150.55	140.10	10.45
	Hotel 2	0.32	1.22	134.31	127.32	6.99
	Hotel 3	0.29	1.63	75.01	69.87	5.14
Category 2	Hotel 1	0.33	0.75	382.22	372.05	10.17
	Hotel 2	0.25	0.37	1085	1060.50	24.50
	Hotel 3	0.34	0.45	481.16	471.95	9.21
Category 3	Hotel 1	0.26	0.43	1535.1	1508.40	26.70
	Hotel 2	0.23	0.90	5838.2	5662.00	176.20
	Hotel 3	0.28	0.86	695.6	675.02	20.58

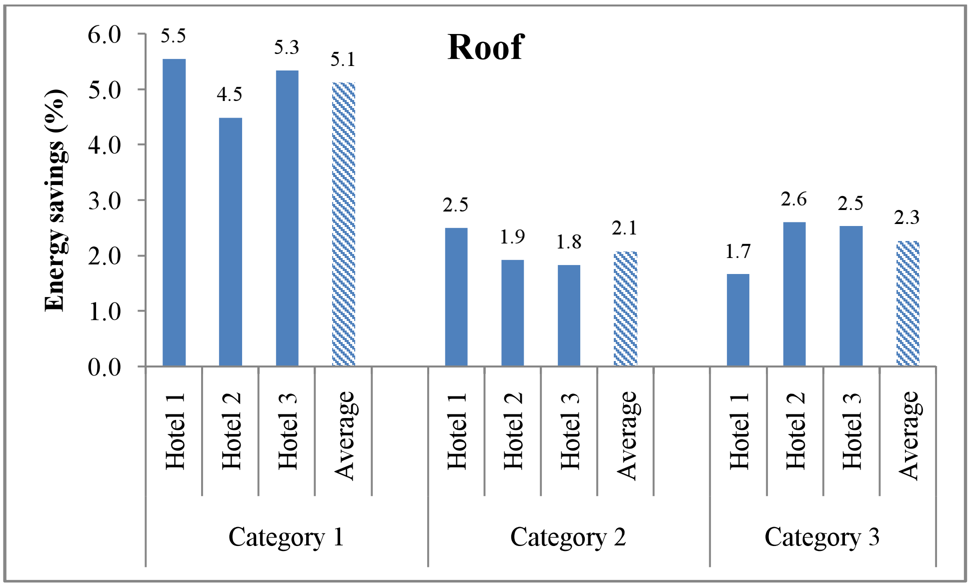


Fig. 5.3 Percentage energy savings by roof insulation

- Energy savings obtained through the insulating upper surface of the roof results in significant energy savings as shown in Table 5.5 and this saving is highest for Category-1 hotels as shown in Fig.5.3. Since, the roof area as compared to the energy consumption is higher also the U-value of existing roof of Category-1 hotels is higher as compared to Category-2 and Category-3, therefore, insulating roof in such buildings results into higher energy savings.
- Castleton H. F. (2010) in his study in Europe considered roof insulation on existing roof with U-value ranging from 0.26 W/m^2K- 0.40W/m^2K. The U-value

of roof was improved to 0.24 W/m^{2}K- 0.34 W/m^{2}K by insulation, resulting of overall energy savings to 2%. In the present study the overall energy savings through roof insulation ranges from 3% to 7% which is higher. The higher energy savings in the present study are due to higher reduction in U-value approximately from 0.4 W/m^{2}K to 0.26 W/m^{2}K and also present study is carried out at hot climate resulting into higher reduction in cooling loads.

Table 5.6 IRR for roof insulation

Category	Hotel	Roof area (m^2)	Insulation cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	772.3	1.67	0.65	30.0
	Hotel 2	515.6	1.45	0.43	21.8
	Hotel 3	696.0	1.20	0.32	18.0
Category 2	Hotel 1	1222.7	2.33	0.63	19.3
	Hotel 2	2654.8	3.64	1.53	32.7
	Hotel 3	1092.7	1.73	0.57	24.7
Category 3	Hotel 1	2294.8	5.29	1.66	23.2
	Hotel 2	11290.3	46.59	11.01	15.9
	Hotel 3	2084.9	5.33	1.28	16.4

- The IRR through retrofitting of roof insulation is very high as shown in Table 5.6, because the area of roof insulation is low resulting in low cost of insulation whereas, the corresponding energy savings are higher.

5.1.4 Window glass film

Hotel buildings in Category-1 have windows with single glazed glass; whereas Category-2 and Category-3 have windows with double glazed glass. ECBC building code compliance is attained through applying window film to glazing of Category-1, Category-2 and Category-3 hotels such that the shading coefficient value of these window glasses becomes same as per ECBC building code requirement. The energy savings through retrofitting of window glasses is shown in Table 5.7.

Table 5.7 Energy savings through retrofitting of window glass film

Category	Hotel	U_{Glass} (W/m^2-°C)	Shading coefficient	Window /Wall Ratio	ECBC Glass Energy consumption before retrofitting (MWh/year)	Energy consumption after retrofitting (MWh/year)	Energy savings (MWh/year)
C1	Hotel 1	5.6	0.49	8.2	140.10	134.80	5.3
	Hotel 2	5.0	0.42	20.2	127.32	119.72	7.6
	Hotel 3	5.7	0.49	4.5	69.87	65.79	4.0
C2	Hotel 1	2.8	0.54	15.8	372.05	363.99	8.0
	Hotel 2	2.8	0.47	19.5	1060.5	1035.23	25.2
	Hotel 3	2.7	0.57	24.3	471.95	459.71	12.2
C3	Hotel 1	2.8	0.51	23.0	1508.40	1483.80	24.6
	Hotel 2	2.7	0.57	19.1	5662.00	5580.70	81.3
	Hotel 3	2.8	0.56	34.5	675.02	634.04	40.9

Window to wall ratio and orientation of hotel building on solar radiation has a significant effect on net energy savings by window glass retrofitting i.e. hotels having higher window to wall ratio seems to have higher energy savings as shown in Fig. 5.4.

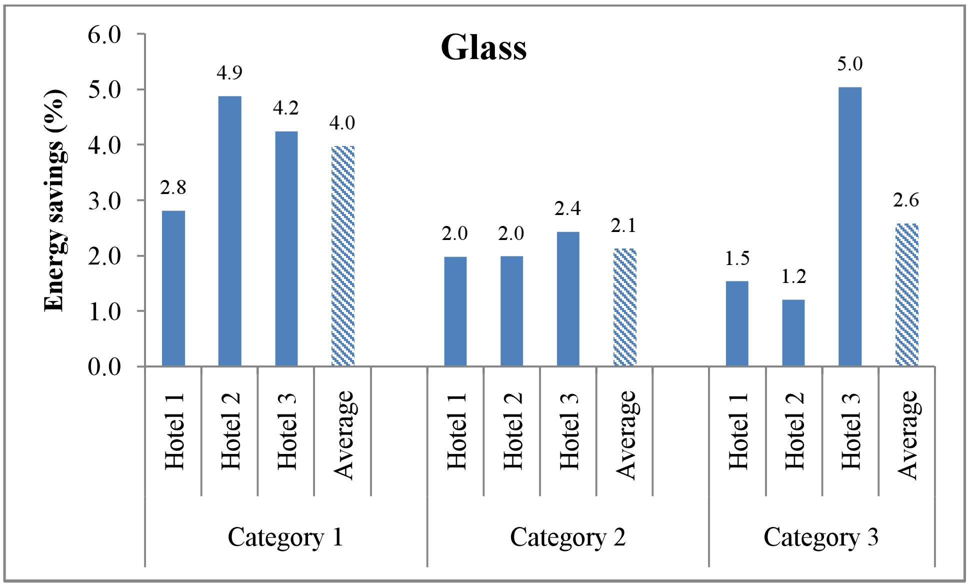


Fig. 5.4 Percentage energy savings through retrofitting of window glass

- Energy savings achieved in Category-1 hotel buildings through applying window film to the glazing is higher as compared to Category-2 and Category-3 hotel buildings. The U-value of window glass of Category-1 hotels is higher and applying window film to the glass significantly reduce the U-value resulting into higher energy savings whereas for Category-2 and Category-3 hotels already have lower U-value and applying window film does not result into significant reduction in U-value therefore energy savings in these category hotels is not higher.

- Energy savings in hotel-3 of Category-3 is higher because the hotel building has very high window to wall ratio therefore, large window area.
- Study carried out by Yin et al. (2012) at commercial buildings in Shanghai, China studied effect of glass window film on existing glass with SHGC ranges from 0.385 to 0.712. The study observed that the film can decrease the shading coefficient and solar heat gain coefficient by 44% if applied on the outside of the existing windows. Whereas in the present study the solar heat gain coefficient is reduced by 50%. The hotel buildings in Jaipur city have been using single glazed glass which has high SHGC up to 0.57, whereas the recommended value of SHGC by ECBC code is 0.29. Therefore, higher difference in in existing and recommended SHGC results higher reduction in SHGC with window glass film.

Table 5.8 IRR for retrofitting of window glass

Category	Hotel	Glass Area (m^2)	ECBC		
			Retrofitting cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	772.3	1.36	0.33	16.0
	Hotel 2	515.6	2.24	0.47	13.0
	Hotel 3	696.0	0.89	0.25	20.2
Category 2	Hotel 1	1222.7	3.32	0.50	7.9
	Hotel 2	2654.8	8.93	1.57	10.7
	Hotel 3	1092.7	4.48	0.76	10.0
Category 3	Hotel 1	2294.8	10.30	1.53	7.6
	Hotel 2	11290.3	37.05	5.08	6.2
	Hotel 3	2084.9	16.26	2.56	8.5

- The IRR for Category-1 hotels is higher because these hotel buildings have single glazed glass windows resulting into higher heat gain and applying film to the glass results into higher savings in energy cost as shown in Table 5.8.

5.1.5 Retrofitting of lighting system

Inefficient lighting fixture such as fluorescent tube lights, incandescent bulb, and other lighting fixtures are considered to be replaced with LED lighting fixtures to make the Lighting Power Density (LPD) at par with ECBC building code requirement. Retrofitting of lighting fixtures in both cases gives a significant energy savings as compared to other measures as shown in Table 5.9.

Table 5.9 Energy savings through retrofitting of lighting system

Category	Hotel	LPD (W/m^2)	ECBC Lighting		
			Energy consumption before retrofitting (MWh/year)	Energy consumption after retrofitting (MWh/year)	Net energy savings (MWh/year)
Category 1	Hotel 1	19.1	134.80	119.49	15.31
	Hotel 2	15.2	119.72	112.78	6.94
	Hotel 3	15.2	65.79	58.68	7.11
Category 2	Hotel 1	15.5	363.99	343.88	20.11
	Hotel 2	14.5	1035.23	1015.60	19.63
	Hotel 3	18.3	459.71	431.77	27.94
Category 3	Hotel 1	18.9	1483.80	1406.80	77.05
	Hotel 2	11.7	5580.70	5480.70	100.06
	Hotel 3	13.1	634.04	615.36	18.68

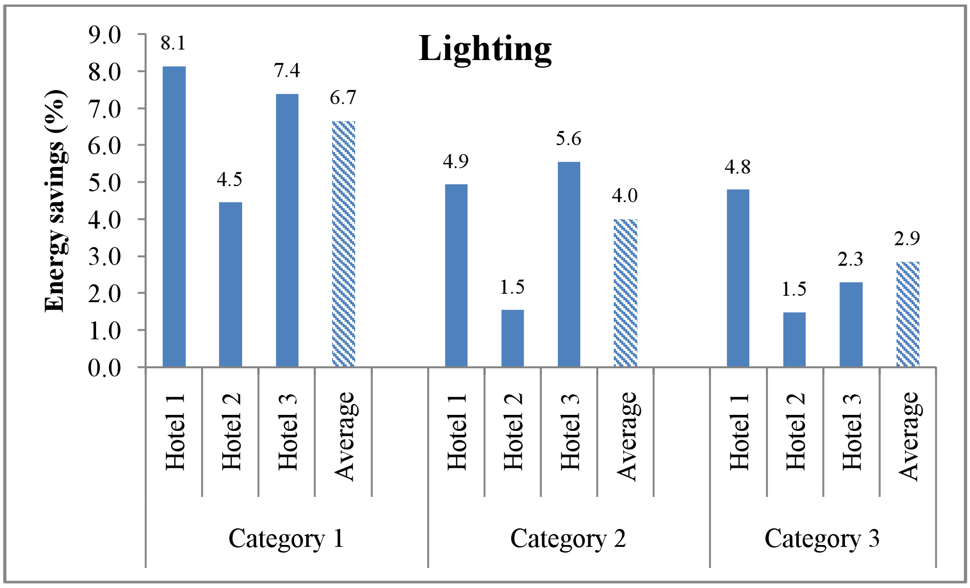


Fig. 5.5 Percentage energy savings by retrofitting of lighting system

- Energy saving is higher in Category-1 hotels as compared to other category hotels since the existing LPD of the hotel building in Category-1 hotels is higher it is also evident from Fig. 5.5 that buildings with higher LPD gives more energy savings.

Table 5.10 IRR for retrofitting of lighting system

Category	Hotel	ECBC lighting		
		Retrofitting cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	0.52	0.95	159.1
	Hotel 2	0.21	0.43	177.0
	Hotel 3	0.19	0.44	204.9
Category 2	Hotel 1	0.46	1.25	238.7
	Hotel 2	0.54	1.22	201.0
	Hotel 3	0.67	1.74	230.7
Category 3	Hotel 1	1.69	4.81	253.1
	Hotel 2	1.68	6.25	332.7
	Hotel 3	0.48	1.16	215.6

- Energy savings through retrofitting of lighting system gives a significant energy savings, and the retrofitting cost of lighting is very low. Therefore, the IRR of retrofitting of lighting fixtures is very high as shown in Table 5.10.
- Energy savings through retrofitting of existing lighting fixtures for all categories of the hotels give an excellent return in both ECBC cases and the investment is returned within few months through energy savings.
- Kircher et al. (2010) modeled cleanroom in New York and found that lighting controls reduced energy consumption by 0.3% and a payback period of 1.5 years. In the present study reduction in energy consumption is 5% to 10% since whole lighting fixtures are proposed to be replaced and the LPD of existing lighting fixtures is high resulting into higher energy savings and better PBP.
- Ahmed F. Et al. (2016) in their study at hospital in Egypt estimated energy saving by retrofitting existing lighting in order to reduce LPD by 10% this resulted into 2.6% of overall energy savings. In present study 30% to 40% reduction in LPD resulted into 5% to 10% of overall savings. Therefore, the ratio of energy savings to LPD is almost similar in both cases.

5.2 Energy efficiency through adoption of advanced measures

Advanced energy efficiency measures suggested and adopted in the recent studies to achieve values higher than required by ECBC code compliance are implemented to nine case study hotels. Advanced technological options in spite of technological options required for ECBC building code compliance are adopted to the existing hotel building models to analyze as to how much additional energy savings can be obtained through these advanced technological options. These technological options include use of Ground Source Heat Exchanger in place of existing HVAC system, wall and roof insulation with higher thickness, window glass film and low LPD lighting as required for ECBC compliance. Summary of the results is presented in following sections.

5.2.1 Retrofitting of HVAC equipment

To see the potential of energy savings through advanced measures, the existing HVAC systems (unitary system, VRF systems and chiller) are considered to be replaced with Ground Heat Exchanger (GHX) system. Energy savings opportunity through replacing existing HVAC system with GHX system in advanced measures is shown in Table 5.11. Hotel buildings in Category-1 and Hotel-2 in Category-2 with split type unitary system have slight difference between net energy savings in building and cooling energy since replacing unitary system with GHX system reduces cooling energy and fan ventilation energy whereas pump energy is increased. Hotel-1 and Hotel-3 in Category-2 with VRF type HVAC system; the space heat and ventilation fan energy decreases but pump energy increases. Therefore, the net energy savings in building energy through replacing VRF with GHX system is lower due to significant increase in pump energy. For Category-3 hotel buildings chiller type HVAC system when considered to be replaced completely with GHX system there is significant increase in pump energy in Hotel-1 since the existing system is air-cooled. Whereas, Hotel-2 and Hotel-3 in this category have water-cooled chiller which is when considered to be replaced by GHX system; the pump energy increases but heat rejection and ventilation fan energy decreases significantly; therefore, the building energy savings are higher than cooling energy as shown in the Table 5.11.

Table 5.11 Energy saving through retrofitting of HVAC equipment with GHX system

Category	Hotel	Building energy consumption (MWh/year)			Cooling energy consumption (MWh/year)			Building energy savings (%)	Cooling energy savings (%)
		Before retrofitting	After retrofitting	Net energy savings	Before retrofitting	After retrofitting	Net energy savings		
Category 1	Hotel 1	188.3	133.9	54.4	105.5	48.5	57.0	28.9	54.0
	Hotel 2	155.9	1200.0	35.9	73.9	40.1	33.8	23.0	45.7
	Hotel 3	96.2	66.5	29.6	48.3	19.4	28.9	30.8	59.8
Category 2	Hotel 1	407.3	351.9	55.4	131.9	72.3	59.6	13.6	45.2
	Hotel 2	1273.9	1038.5	235.4	659.9	417.4	242.5	18.5	36.7
	Hotel 3	503.1	433.0	70.1	202.3	128.1	74.2	13.9	36.7
Category 3	Hotel 1	1605.9	1303.6	302.3	631.9	265.7	366.2	18.8	58.0
	Hotel 2	6773.7	5433.7	1340.0	2569.6	1256.4	1313.2	19.8	51.1
	Hotel 3	813.8	644.2	169.6	328.6	175.4	153.2	20.8	46.6

Table 5.11 also shows the building and cooling energy savings through retrofitting of HVAC equipment with GHX system. The net building energy savings are higher in Category-1 hotels (23.0 to 30.8) since, these hotel buildings have direct expansion system with air cooled condenser which is considered to be replaced by energy efficient GHX system which has water-cooled condenser.

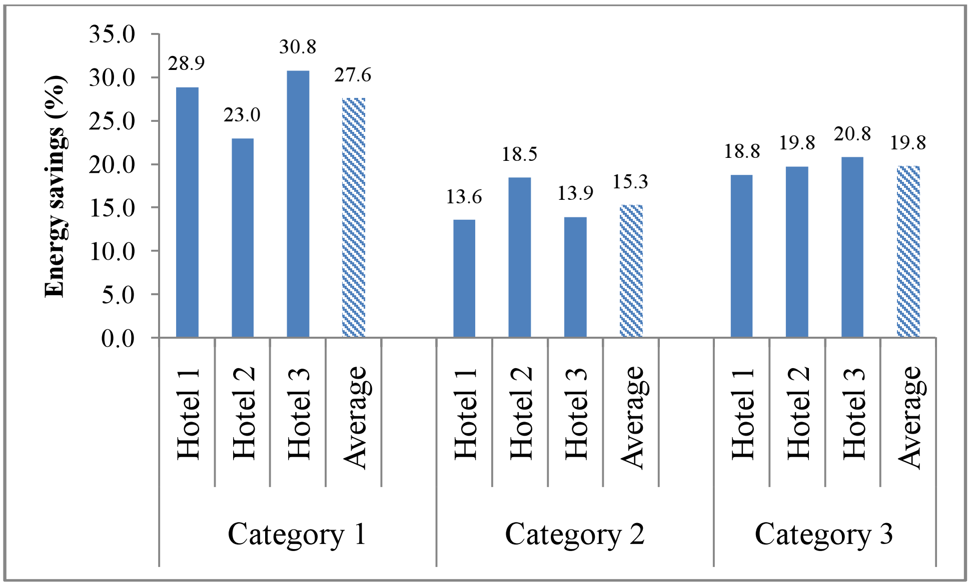


Fig. 5.6 Percentage energy savings by retrofitting of HVAC equipment

Results presented in Fig. 5.6 clearly show that that energy savings are further increased by adopting advanced measures (13.6% to 30.8%). Key findings from retrofitting of

HVAC equipment are:

- For Category-1 hotels, estimated energy saving ranges from 23.3% to 30.4%. HVAC system in Category-1 hotels are unitary type split air-conditioner systems based on direct expansion system whereas, Category-2 and Category-3 hotels have water cooled condenser type system and therefore has higher COP. Therefore, Category-1 hotels observed the highest energy saving as compared to other categories with the adoption of water cooled condenser of GHX system.
- Replacing existing HVAC system with GHX system resulted highest energy savings in Category-1 hotels that ranges from 23% to 30.8%.

The cost-benefit analysis for retrofitting of existing HVAC system with GHX system in nine case study hotel buildings is carried out. Cost of the GHX system considered in the economic analysis is INR 60000 per TR. In economic analysis Internal Rate of Return (IRR) is calculated for the lifecycle of the new equipment. The results of economic analysis are shown in Table 5.12, which depicts IRR for HVAC system replaced with GHX system.

Table 5.12 IRR for retrofitting existing HVAC system

Category	Hotel	HVAC Type	TR/m^2	Advanced		
				Retrofitting cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	Unitary	5.6	24.02	3.39	8.9
	Hotel 2	Unitary	4.1	16.30	2.24	8.7
	Hotel 3	Unitary	4.6	14.58	1.85	7.6
Category 2	Hotel 1	VRF	5.6	55.80	3.46	-1.0
	Hotel 2	Unitary	2.4	93.52	14.71	10.5
	Hotel 3	VRF	8.3	61.38	1.60	2.43
Category 3	Hotel 1	Chiller	2.4	107.30	18.89	12.1
	Hotel 2	Chiller	2.0	373.75	83.75	17.3
	Hotel 3	Chiller	3.2	74.75	10.60	9.4

- The energy savings through replacing existing system with GHX system in advanced measure is significant although the IRR through replacing unitary system varies in the range from 7.6 % to 10.5 % for three hotels of Category-1 and Hotel-2 of Category-2 due to higher capital cost as compared to energy savings cost. However, IRR in Category-3 hotel ranges from 9.4 % to 17.3 % due to high energy savings and lower capital cost due to its lower capacity (TR per unit constructed area).

- IRR of GHX system for Hotel-1 and Hotel-3 in Category-2 is quite low because the existing HVAC system is VRF system with high COP and improvement in COP of existing system through replacement with GHX is marginal, which resulted in low energy savings whereas the cost of replacement is higher.

5.2.2 Wall insulation

The external walls of the case study hotel buildings are insulated with polystyrene insulation that is commonly used by commercial buildings in Jaipur city. The thickness of insulation considered for external walls of the hotel buildings corresponds to the thickness that gives a U-value, which has been attained by similar buildings in India as referred by various studies. The corresponding energy savings through the reduction in heat gain, obtained by polystyrene insulated wall is shown in Table 5.13, and percentage energy saving is shown in Fig.5.7.

Table 5.13 Energy saving through reduction in heat gain by wall insulation

Category	Hotel	w/W ratio (%)	Advanced wall		
			Energy consumption before insulation (MWh/year)	Energy consumption after insulation (MWh/year)	Energy savings (MWh/year)
Category 1	Hotel 1	8.2	133.91	122.34	11.57
	Hotel 2	20.2	120.00	113.40	6.60
	Hotel 3	4.5	66.52	56.33	10.19
Category 2	Hotel 1	15.8	351.90	330.77	21.13
	Hotel 2	19.5	1038.50	996.10	42.40
	Hotel 3	24.3	433.03	412.71	20.32
Category 3	Hotel 1	23.0	1303.60	1266.20	37.40
	Hotel 2	19.1	5433.70	5276.00	157.70
	Hotel 3	34.5	644.15	619.00	25.15

Wall insulation applied on the external surface of case study hotel buildings plays an important role in reducing the heat gain and resulting in energy saving. Increasing the thickness of insulation after certain limit does not necessarily enhance heat gain reduction at the same rate.

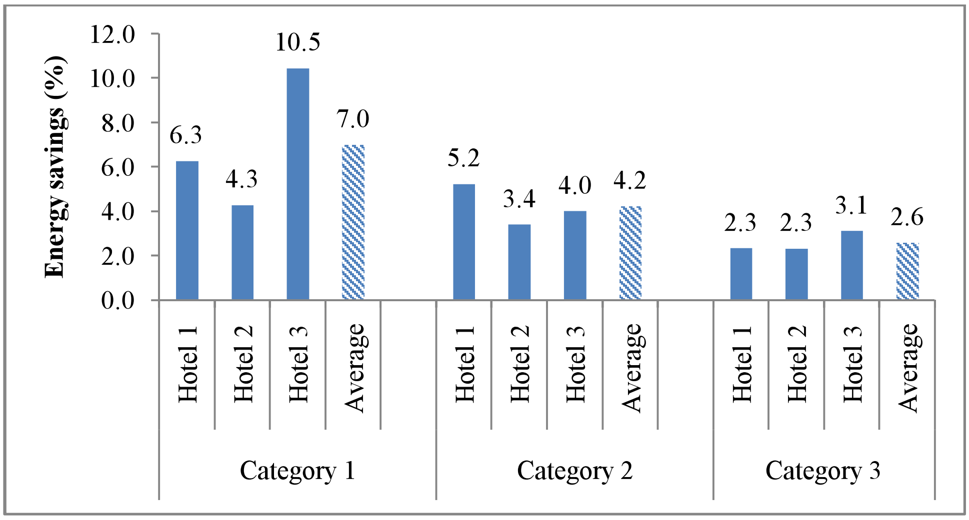


Fig. 5.7 Percentage energy savings by wall insulation

- Energy savings obtained through wall insulation of Category-1 hotels in advanced measures is higher as compared to Category-2 and Category-3 hotels due to similar reasons discussed in section 5.1.2.
- The wall insulation gives IRR in the range of 4.4 % to 9.4 % in advance measure as shown in Table 5.14, but with increasing thickness of the insulation further, the energy saving is not as high as shown in Fig. 5.7. Therefore, with increasing the thickness of insulation the rate of increase in energy saving reduces whereas, the cost of insulation increases proportionately, that results in lowering of IRR in an advanced measure.

Table 5.14 IRR for wall insulation

Category	Hotel		Advanced		
		External Wall area (m^2)	Insulation cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	772.3	5.41	0.72	6.3
	Hotel 2	515.6	3.61	0.41	4.4
	Hotel 3	696.0	4.87	0.63	6.0
Category 2	Hotel 1	1222.7	8.56	1.32	8.3
	Hotel 2	2654.8	18.58	2.65	7.2
	Hotel 3	1092.7	7.65	1.27	9.4
Category 3	Hotel 1	2294.8	16.06	2.33	7.5
	Hotel 2	11290.3	79.03	9.85	5.4
	Hotel 3	2084.9	13.73	1.57	4.4

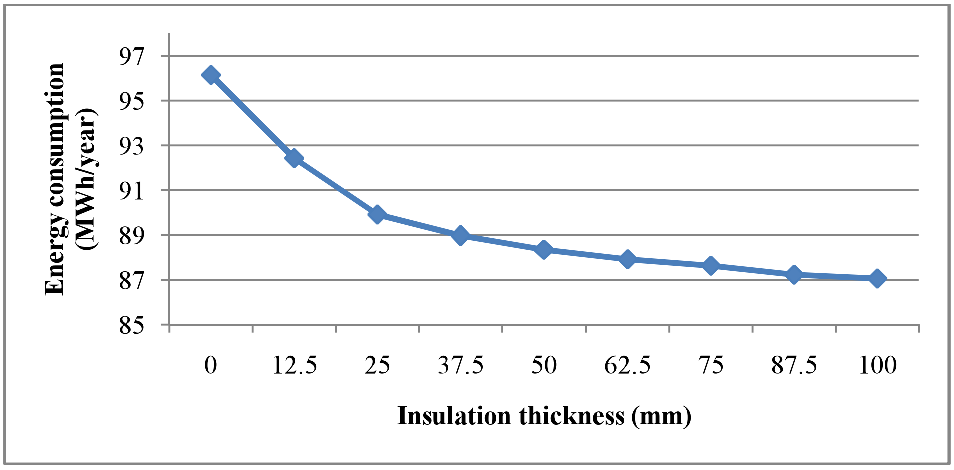


Fig.5.8 Energy consumption and insulation thickness on wall

5.2.3 Roof insulation

The outer surface of the roof of case study hotel buildings is retrofitted by applying polystyrene insulation with higher thickness. The thickness of insulation considered for the hotel buildings corresponds to the thickness that gives a U-value, which has been obtained in commercial buildings in India as referred by various studies. Table 5.15 shows energy saving through reduction in heat gain by roof insulation.

Table 5.15 Energy saving through reduction in heat gain by roof insulation

Category	Hotel	Advanced roof		
		Energy consumption before insulation (MWh/year)	Energy consumption after insulation (MWh/year)	Energy savings (MWh/year)
Category 1	Hotel 1	122.34	111.65	10.69
	Hotel 2	113.40	105.96	7.44
	Hotel 3	56.33	51.16	5.17
Category 2	Hotel 1	330.77	321.78	8.99
	Hotel 2	996.10	975.65	20.45
	Hotel 3	412.71	402.34	10.37
Category 3	Hotel 1	1266.20	1240.10	26.10
	Hotel 2	5276.07	5112.20	163.80
	Hotel 3	619.06	592.59	26.41

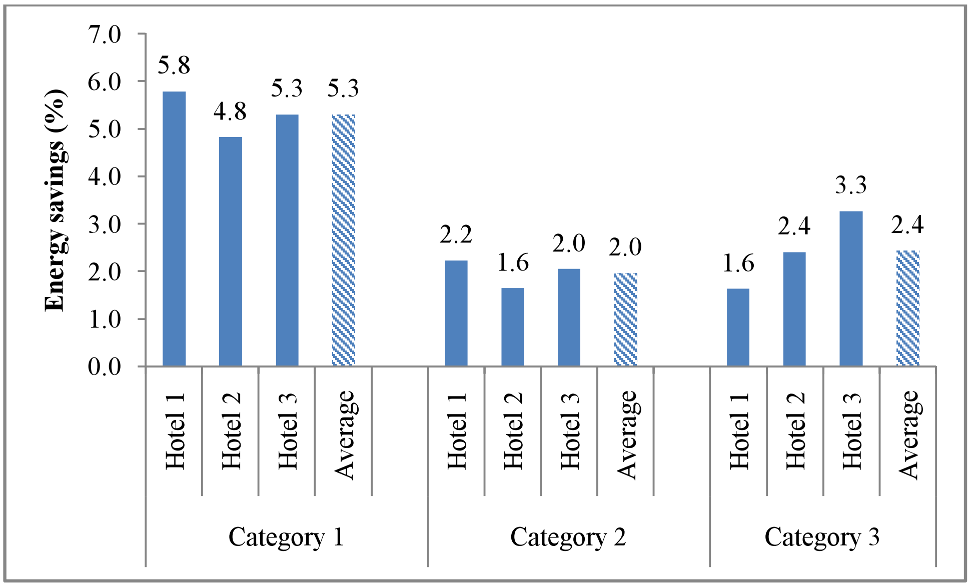


Fig. 5.9 Percentage energy savings by roof insulation

- Energy savings obtained through the insulating upper surface of the roof results in significant energy savings and this saving is highest for Category-1 hotels as shown in Fig.5.9 due to similar reasons as discussed in section 5.1.3. Since, the U-value of existing roof of Category-1 hotels is higher as compared to Category-2 and Category-3; therefore, insulating roof in such buildings results into higher energy savings.

Table 5.16 IRR for roof insulation

Category	Hotel		ECBC			Advanced		
		Roof area (m^2)	Insulation cost (INR lakh)	Energy savings cost (INR lakh)	IRR	Insulation cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	772.3	1.67	0.65	30.0	2.23	0.66	21.7
	Hotel 2	515.6	1.45	0.43	21.8	1.94	0.46	16.2
	Hotel 3	696.0	1.20	0.32	18.0	1.60	0.32	12.8
Category 2	Hotel 1	1222.7	2.33	0.63	19.3	3.10	0.56	10.8
	Hotel 2	2654.8	3.64	1.53	32.7	4.86	1.27	18.4
	Hotel 3	1092.7	1.73	0.57	24.7	2.30	0.64	20.1
Category 3	Hotel 1	2294.8	5.29	1.66	23.2	7.05	1.63	15.5
	Hotel 2	11290.3	46.59	11.01	15.9	62.12	10.23	9.3
	Hotel 3	2084.9	5.33	1.28	16.4	7.10	1.65	15.6

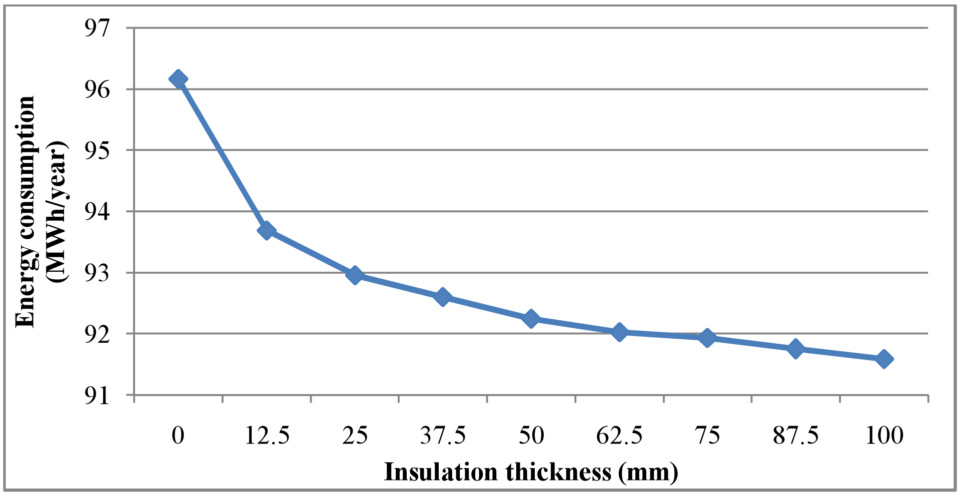


Fig.5.10 Energy consumption and insulation thickness on roof

- The IRR through retrofitting of roof insulation is very high as shown in Table 5.16, because the area of roof insulation is low resulting in low cost of insulation whereas, the corresponding energy savings are higher.
- The retrofitting of the roof with the adoption of insulation gives a good IRR but with further increase in the insulation thickness in advance case, there is a marginal increase in the energy savings as shown in Fig. 5.10, whereas, the cost of insulation increases proportionately. Therefore, increasing insulation thickness beyond a certain limit is not economic resulting in low IRR. Fig. 5.5 shows that with the increase in insulation thickness, heat gain through the roof decreases.

5.2.4 Window glass film

Hotel buildings in Category-1 have windows with single glazed glass; whereas Category-2 and Category-3 have windows with double glazed glass. The window glazing of the three category hotel buildings are proposed to be covered with a film such that the window glazing attains a value of shading coefficient lower than required by ECBC compliance and has been as attained by other commercial buildings in India. The energy savings obtained in such a way through retrofitting of window glasses is shown in Table 5.17.

Table 5.17 Energy savings by retrofitting of window glass

Category	Hotel	w/W ratio	Advanced Glass		
			Energy consumption before retrofitting (MWh/year)	Energy consumption after retrofitting (MWh/year)	Energy savings (MWh/year)
Category 1	Hotel 1	8.2	111.65	105.95	5.7
	Hotel 2	20.2	105.96	97.46	8.5
	Hotel 3	4.5	51.16	46.92	4.2
Category 2	Hotel 1	15.8	321.78	310.77	11.0
	Hotel 2	19.5	975.65	945.30	30.3
	Hotel 3	24.3	402.34	385.68	16.6
Category 3	Hotel 1	23.0	1240.10	1211.30	28.8
	Hotel 2	19.1	5112.20	5030.00	82.2
	Hotel 3	34.5	592.59	547.43	45.1

Window to wall ratio and orientation of hotel building on solar radiation has a significant effect on net energy savings by window glass retrofitting i.e. hotels having higher window to wall ratio seems to have higher energy savings as shown in Fig. 5.11.

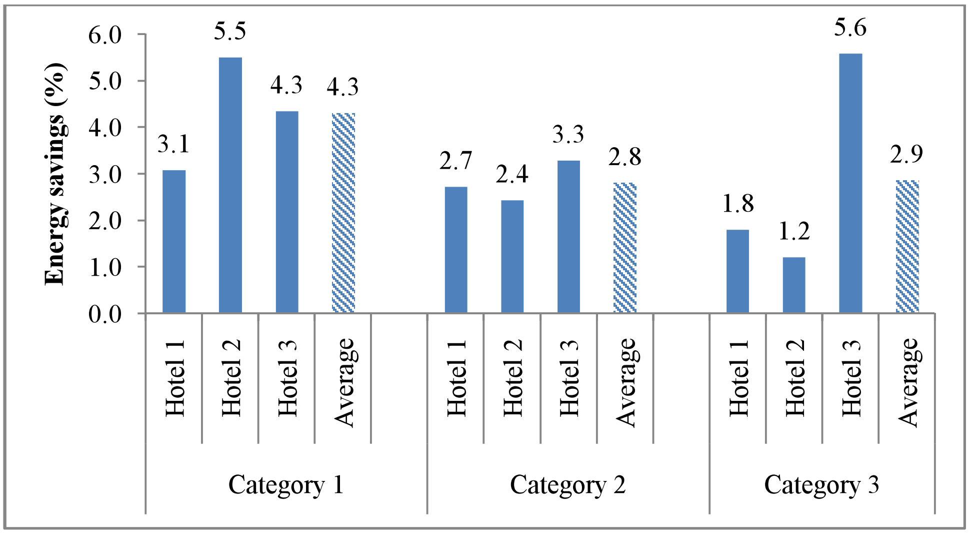


Fig. 5.11 Percentage energy savings by retrofitting of window glass

Table 5.18 IRR for retrofitting of window glass

Category	Hotel	Glass Area (m^2)	Advanced		
			Retrofitting cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	772.3	2.05	0.35	9.1
	Hotel 2	515.6	3.36	0.53	7.4
	Hotel 3	696.0	1.33	0.26	11.6
Category 2	Hotel 1	1222.7	4.57	0.68	6.6
	Hotel 2	2654.8	12.28	1.89	7.0
	Hotel 3	1092.7	6.17	1.04	8.6
Category 3	Hotel 1	2294.8	14.17	1.80	4.0
	Hotel 2	11290.3	50.94	5.13	3.8
	Hotel 3	2084.9	22.36	2.82	3.9

- In advance measures, window glasses in three categories of hotel Therefore, the IRR is very low for all categories of hotel buildings as shown in Table 5.18.

5.2.5 Retrofitting of lighting system

Inefficient lighting fixture such as fluorescent tube lights, incandescent bulb, and other lighting fixtures are considered to be replaced with LED lighting fixtures to make the lower value of Lighting Power Density (LPD) which has been attained by similar commercial buildings in India. Retrofitting of lighting fixtures in both cases gives a significant energy savings as compared to other measures as shown in Table 5.19.

Table 5.19 Energy savings through retrofitting of lighting system

Category	Hotel	LPD (W/m^2)	Advanced Lighting		
			Energy consumption before retrofitting (MWh/year)	Energy consumption after retrofitting (MWh/year)	Net energy savings (MWh/year)
Category 1	Hotel 1	19.1	105.95	78.56	27.39
	Hotel 2	15.2	97.46	81.78	15.68
	Hotel 3	15.2	46.92	34.08	12.84
Category 2	Hotel 1	15.5	310.77	256.02	54.75
	Hotel 2	14.5	945.30	907.90	37.40
	Hotel 3	18.3	385.68	344.64	41.04
Category 3	Hotel 1	18.9	1211.3	1109.19	82.11
	Hotel 2	11.7	5030	4680.20	349.80
	Hotel 3	13.1	547.43	518.40	21.03

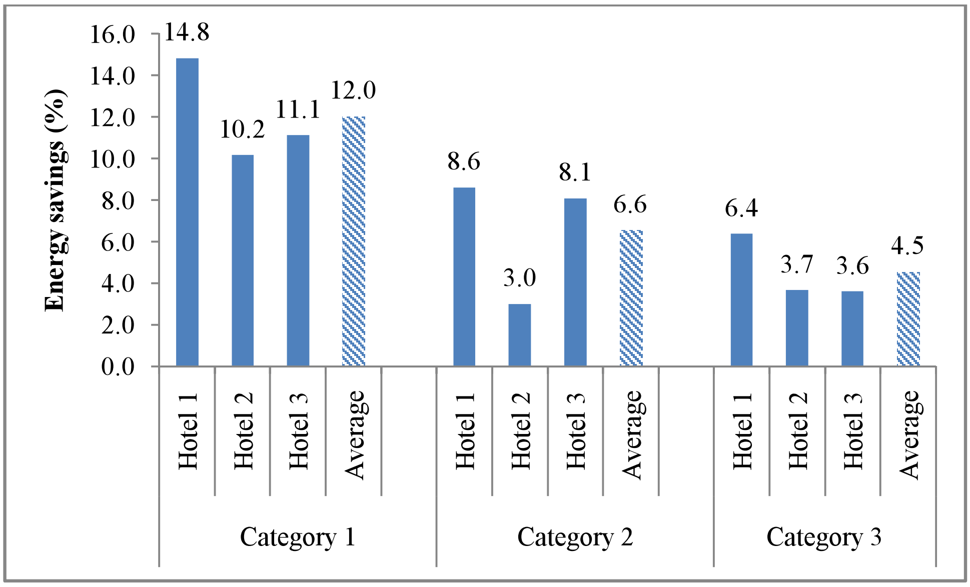


Fig. 5.12 Percentage energy savings by retrofitting of lighting system

- Energy saving is higher in Category-1 hotels as compared to other category hotels and also it is evident from Fig. 5.12 that buildings with higher LPD gives more energy savings.

Energy savings through retrofitting of lighting system gives a significant energy saving, and the retrofitting cost of lighting is very low. Therefore, the IRR of retrofitting of lighting fixtures is very high as shown in Table 5.20.

Table 5.20 IRR for retrofitting of lighting system

Category	Hotel	Advanced		
		Retrofitting cost (INR lakh)	Energy savings cost (INR lakh)	IRR (%)
Category 1	Hotel 1	0.88	1.71	169.6
	Hotel 2	0.36	0.98	241.9
	Hotel 3	0.31	0.67	228.3
Category 2	Hotel 1	1.60	2.17	187.9
	Hotel 2	1.20	2.33	171.5
	Hotel 3	1.56	2.50	143.8
Category 3	Hotel 1	1.57	6.38	291.3
	Hotel 2	11.28	15.61	170.0
	Hotel 3	0.48	1.81	243.4

- Energy savings through retrofitting of existing lighting fixtures for all categories of the hotels give an excellent return in both ECBC and advanced cases and the investment is returned within few months through energy savings.

  Average energy savings realized through ECBC and advanced measures for case study hotel buildings is estimated. Fig. 5.13 shows percentage energy savings obtained through retrofitting building components for ECBC and advanced energy efficiency measures. Maximum energy savings are realized by retrofitting of HVAC system in both ECBC and advanced measures. Share of energy saving increases for HVAC system and lighting system in advance measures whereas, it reduces for building envelope.

Average energy savings realized through ECBC and advanced measures for case study hotel buildings is estimated. Fig. 5.13 shows percentage energy savings obtained through retrofitting building components for ECBC and advanced energy efficiency measures. Maximum energy savings are realized by retrofitting of HVAC system in both ECBC and advanced measures. Share of energy saving increases for HVAC system and lighting system in advance measures whereas, it reduces for building envelope.

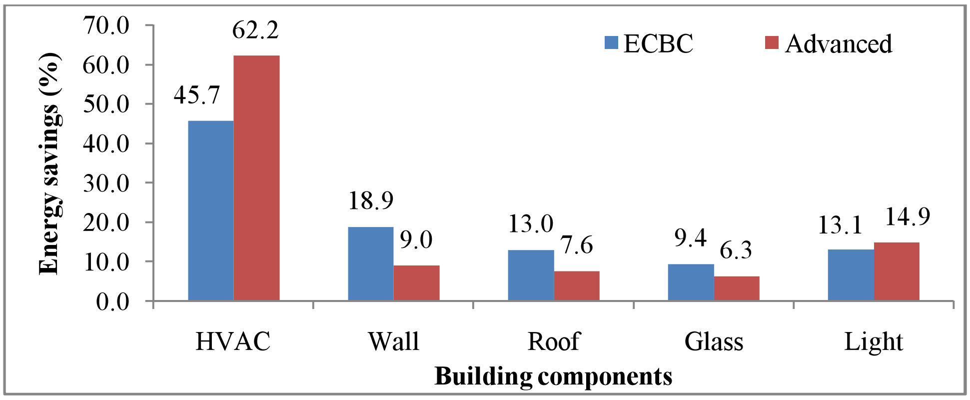


Fig. 5.13 Percentage energy savings by building components in nine case study hotels

5.3 Gross energy savings through ECBC

The net energy savings through adoption of ECBC are significant, and it is observed that the energy saving in Category-1 hotels is highest as compared to other categories. Since, Category-1 hotel buildings have been using inefficient equipment and technology in HVAC system of low COP, high transmittance of wall and roof, single glazed window glass and higher LPD. The energy saving through ECBC compliance in Hotel-1 and Hotel-3 of Category-2 is lower as compared to Hotel-2 because the HVAC system is not considered to be replaced and all energy savings pertains to building envelope and lighting only. Energy savings in Hotel-1 of Category-3 is low because there is a slight difference in COP of existing HVAC system and new system. Fig. 5.14 shows the gross energy savings realized through adoption of ECBC measures. The energy savings ranges from 12.4 to 39.0 and maximum energy savings are realized by Category-1 hotel buildings due to use of poor technology whereas, lowest of energy savings are realized by Category-2 hotel buildings since, the energy savings are due to retrofitting of building envelope and lighting system only.

Parikh (2012) in her study affirms that ECBC compliant buildings through retrofitting of HVAC, envelope, lighting and efficient equipment saved 30% of energy and advanced technologies beyond ECBC if adopted could save up to 50% of energy. In present study with adoption of ECBC average 23% of energy savings is estimated and with advanced measures average 40% of energy savings is estimated. The lower energy savings in the present study is because two hotel buildings already had ECBC compliant HVAC system hence not proposed to be replaced. A study by Xu et al. (2013) investigated the energy saving potential for residential buildings in hot summer and cold winter zone under a different level of energy efficiency standards (China local, China national, and UK standard). The building energy savings in Chongqing could achieve 31.5% and 62.8% for residential and public building sections respectively if the Chinese national standard were satisfied, the energy saving would increase to 45.0% and 62.8% respectively. When the Chongqing local standard was met; the value would further increase to 53.4% and 75.9% if the UK standard were satisfied. Adoption of ECBC results into lower energy savings because Chinese and UK standards are much stringent as compared to ECBC building codes as mentioned in the study by McDonald et al. (2013). Tulsyan et al. (2013) in his study on six categories of commercial buildings of Jaipur city (India) and observed minimum 17% and maximum 42% of energy savings, with ECBC compliance. The results are similar with present study since both studies are carried out for commercial sector of Jaipur city. Mata E. et al. (2015) carried out simulation study on implementation of ECM package on residential and non-residential buildings. The modeling shows that the energy demand of the Spanish building stock could be reduced by 55% and by implementing all the ECMs. Whereas, in the present study with ECBC compliance 39% of energy can be saved. The higher savings claimed through ECMs in Spanish buildings is because the ECMs are more comprehensive and includes retrofitting of floor, ventilation system, heat recovery, equipment, boiler replacing fuel etc. and also they are more stringent.

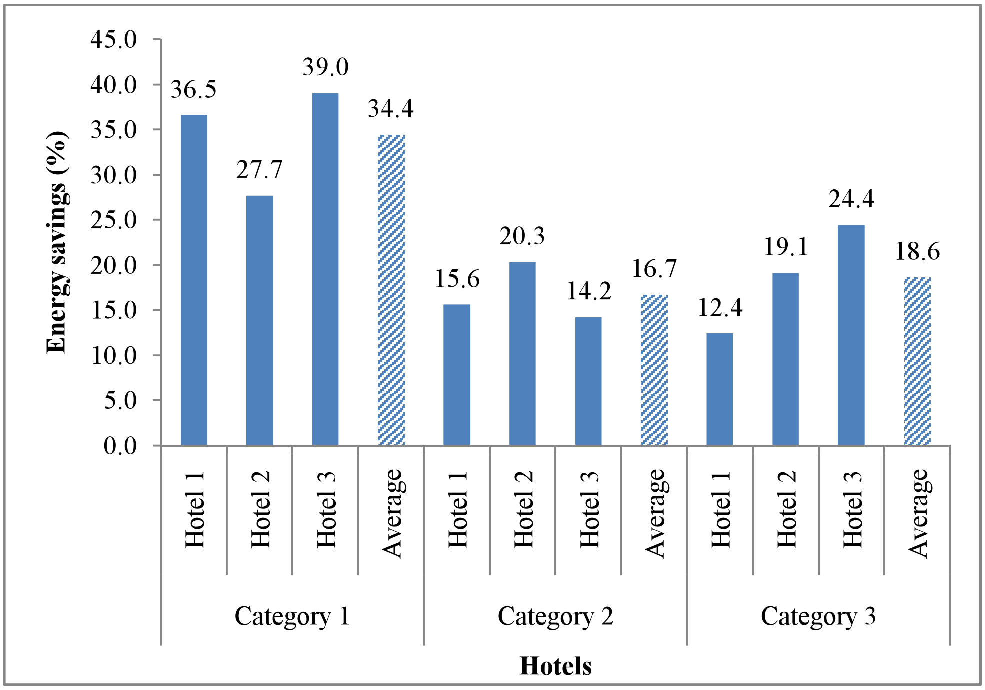


Fig. 5.14 Gross energy saving through ECBC measures

Economic analysis of all retrofitting measures is carried out by estimating simple payback period since the life cycle cost of building components is different. The PBP for ECBC measures ranges from 3.5 to 8.8 as shown in Table 5.21.

Table 5.21 Simple Payback Periods (PBP) with ECBC measures

Category	Hotel	ECBC measures		
		Retrofitting cost (INR Lakhs)	Energy saving cost (INR Lakhs)	Simple PBP (Years)
Category 1	Hotel 1	17.6	4.3	4.1
	Hotel 2	13.9	2.7	5.2
	Hotel 3	10.6	2.3	4.6
Category 2	Hotel 1	13.9	3.9	3.5
	Hotel 2	64.7	16.1	4.0
	Hotel 3	20.8	4.4	4.7
Category 3	Hotel 1	105.7	12.1	8.8
	Hotel 2	457.2	80.8	5.7
	Hotel 3	82.5	12.4	6.7

5.4 Gross energy savings through advanced measures

The net energy savings through adoption of advanced EEMs are significant, and it is observed that the energy saving in Category-1 hotels is highest as compared to other categories. Since, Category-1 hotel buildings are using inefficient equipment and technology such as direct expansion system and air cooled type HVAC system that has low COP, high transmittance of wall and roof, single glazed window glass and higher

LPD. The energy saving through advance measures in Hotel-1 and Hotel-3 of Category-2 is lower as compared to Hotel-2 because the HVAC system already has high COP and there is a marginal difference in energy savings between existing and new HVAC system. Energy savings in Category-2 and Category-3 hotel buildings is lower as compared to Category-1 hotel buildings because these category hotel buildings are using better technology as compared to Category-1 hotel buildings. Fig. 5.15 shows energy savings realized through adoption of advance measures in hotel buildings and their adoption gives a significant energy savings from 28.7 to 62.5. Jiang et al. (2008) illustrated that through the adoption of advance design to the hotel building can save 50% of energy for each climate zone in the USA. He proposed replacing existing HVAC system with Water Source Heat Pump (WSHP), set point setting on unoccupied period in the guest rooms, installation of air side economizer energy recovery ventilators, efficient equipment, reflective coating for roof, extra glazing layers for windows, lighting occupancy sensors, efficient lighting. In the present study with advanced measures an average 40% of energy saving is estimated which is lower than savings obtained by Jiang. Since study by Jiang also included other efficient equipment such as air economizer, energy recovery ventilators, efficient equipment, extra glazing layers for windows, lighting occupancy sensors etc. which were not considered in the present study. Geothermal India has installed 200 TR capacity GSHP in Apollo Hospital, Hyderabad and achieved an energy savings of 43.6% with GSHP and other retrofitting measures. In the present study the simulation results show that up to 54% of cooling energy can be saved through ground heat exchanger since Jaipur city is hot climate as compared to Hyderabad increasing efficiency of geothermal.

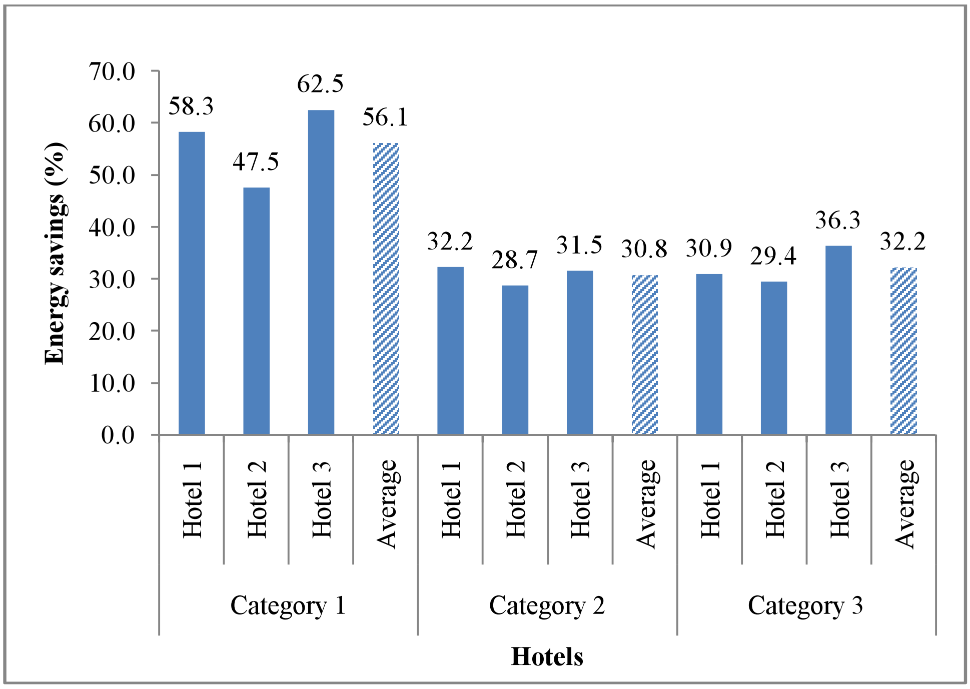


Fig. 5.15 Gross energy saving through advanced measures

Economic analysis of all retrofitting measures is carried out by estimating simple payback period since the life cycle cost of building components is different. The PBP for advance measures the PBP ranges from 5.2 to 12.3 as shown in Table 5.22. Therefore, we can conclude that energy savings for advance measures are higher; therefore the PBP for advanced measures is better.

Table 5.22 Simple Payback Periods (PBP) with advanced measures

Category	Hotel	Advanced measures		
		Retrofitting cost (INR lakhs)	Energy saving cost (INR lakhs)	Simple PBP (Years)
Category 1	Hotel 1	36.0	6.8	5.3
	Hotel 2	27.8	4.6	6.0
	Hotel 3	23.6	3.7	6.3
Category 2	Hotel 1	79.5	8.2	9.7
	Hotel 2	146.1	22.9	6.4
	Hotel 3	86.9	7.1	12.3
Category 3	Hotel 1	164.2	31.0	5.3
	Hotel 2	642.0	124.6	5.2
	Hotel 3	146.9	18.5	8.0

5.5 Reduction in energy intensity of hotel buildings

Hotel buildings in three categories have high energy intensity however with advanced energy efficiency measures hotel buildings in Category-1 qualifies for four-star and five-star ratings of BEE as discussed in the chapter on the literature review. Similarly, as Fig.

5.16 depicts that two hotel buildings in Category-2 qualify for one-star and two-star ratings, and hotel buildings in Category-3 qualify for three-star and four-star ratings of BEE.

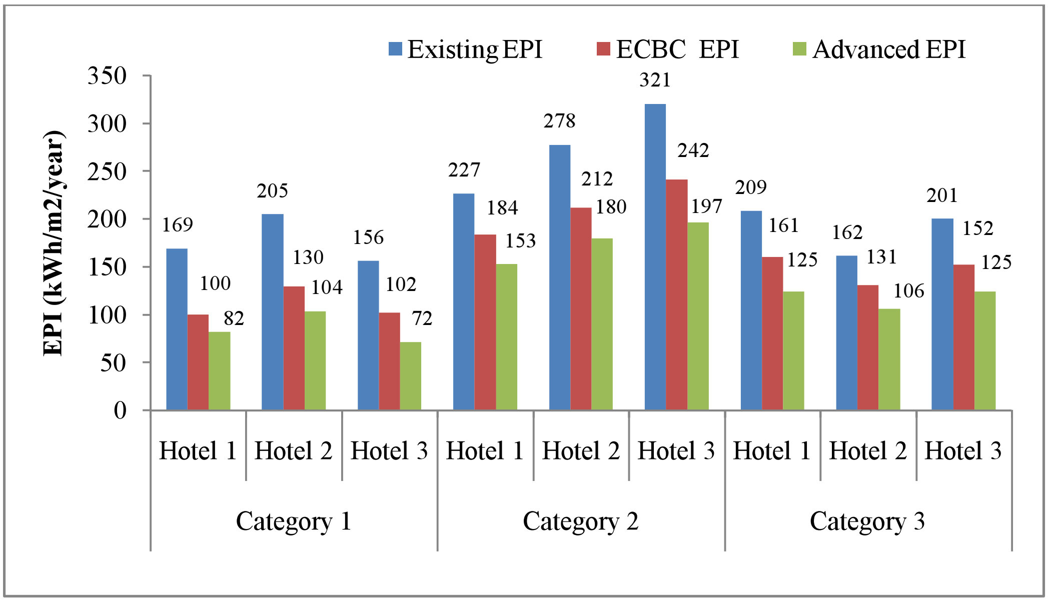


Fig. 5.16 EPI of case study hotels for existing, ECBC and advanced cases

5.6 On-site energy generation through SPV

The present study also estimated the potential of energy generation through the installation of the SPV panels at the 50% of the available roof area of the case study hotel buildings. The annual energy generated by corresponding capacity SPV installed at hotel buildings is shown in Fig. 5.18. The share of energy generated by SPV as compared to their yearly energy consumption is shown in Fig. 5.19.

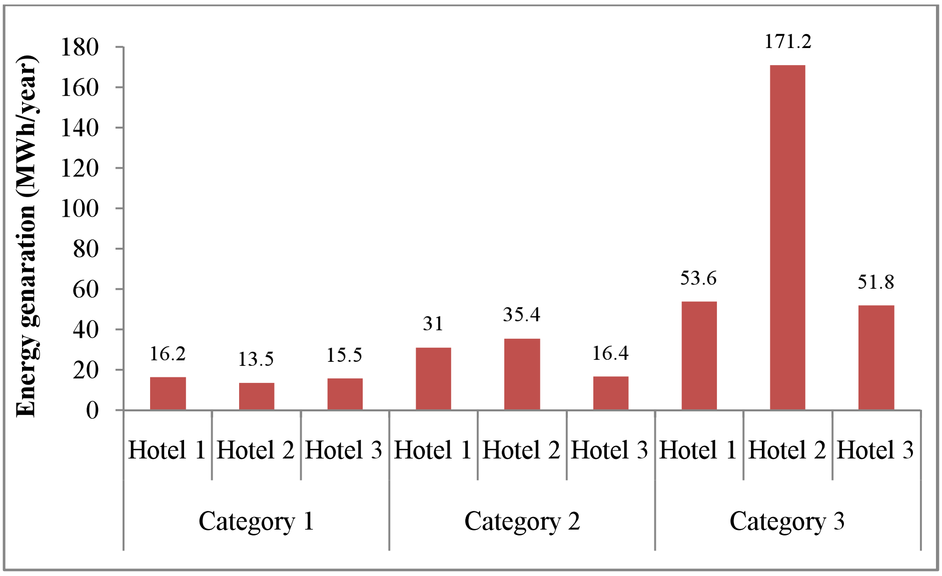


Fig. 5.17 Generation of energy by SPV at case study hotels

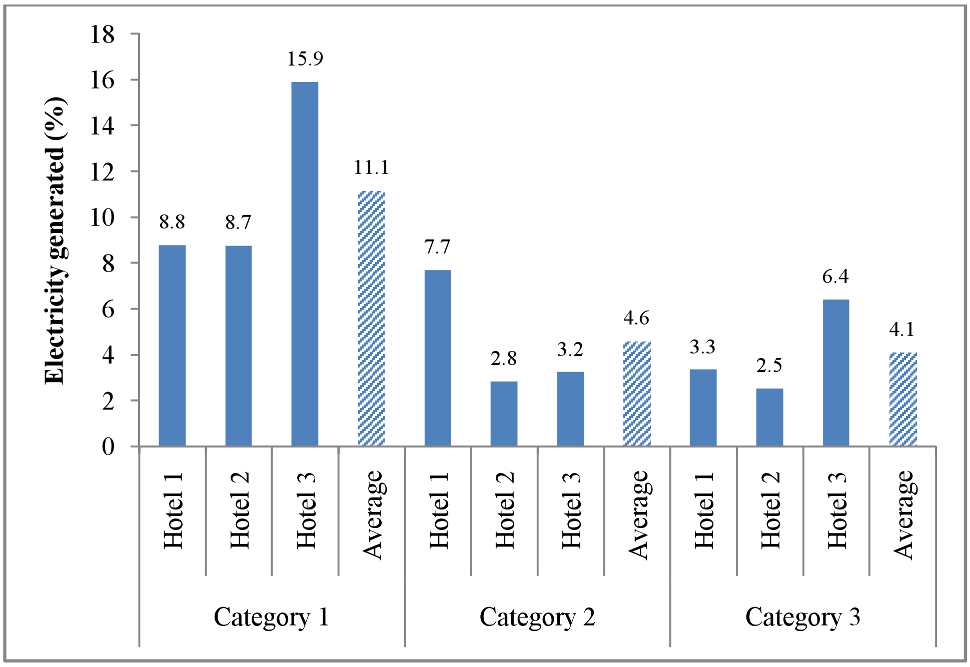


Fig. 5. 18 Percentage of energy generated by SPV in case study hotels.

Table 5.23 IRR for SPV system installed at hotel building

Category	Hotel	Capacity (kW)	Energy generated (MWh/year)	IRR (%)
Category 1	Hotel 1	12	16.2	5.76
	Hotel 2	9	13.5	7.46
	Hotel 3	10	15.5	8.01
Category 2	Hotel 1	18	31.0	9.87
	Hotel 2	23	35.4	7.89
	Hotel 3	9	16.4	10.93
Category 3	Hotel 1	31	53.6	9.95
	Hotel 2	90	171.2	11.77
	Hotel 3	30	51.8	9.92

Table 5.23 shows the IRR of the SPV system of capacity corresponding to 50% of roof area covered with SPV installed at the roof of the hotel buildings. The results of the economic analysis show that the IRR ranges from 5.76 to 11.77.

5.7 Energy saving and GHG mitigation potential of hotel sector of Jaipur city

The annual energy consumption of existing hotel buildings (total 589 hotels) in Jaipur city is estimated to be 107.8 GWh/year and with the implementation of ECBC and advance measures the annual energy saving would be 23.2 GWh/year and 40.0 GWh/year respectively, as shown in Fig. 5.20. GHG emissions due to energy consumption in existing hotel buildings in 2014 are 89.5 $ktCO_2$/year. Adoption of ECBC building energy code and advanced measures would reduce GHG emission by 19.2 $ktCO_2$/year and 31.3 $ktCO_2$/year respectively in the year 2020.

The projections of energy consumption of hotel building sector and corresponding energy savings have been carried out in the present study. Total hotel buildings in Jaipur city would increase from 589 (in 2014) to 798 (in 2020), and corresponding annual energy consumption would increase from 107.8 GWh (2014) to 189.7 GWh (2020) as shown in Fig. 5.21.

Adoption of ECBC and advanced energy efficiency measures would save 32.9 GWh/year and 68.5 GWh/year. Reduction in GHG emissions through adoption of ECBC and advanced energy efficiency measures would be 32.9 $ktCO_2$/year and 56.9 $ktCO_2$/year respectively.

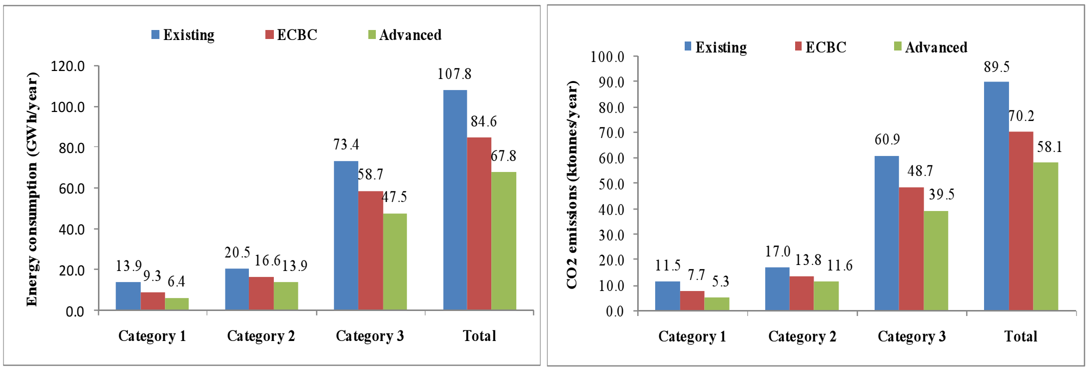


Fig. 5.19 Energy consumption and GHG emissions by hotel sector of Jaipur city in 2014

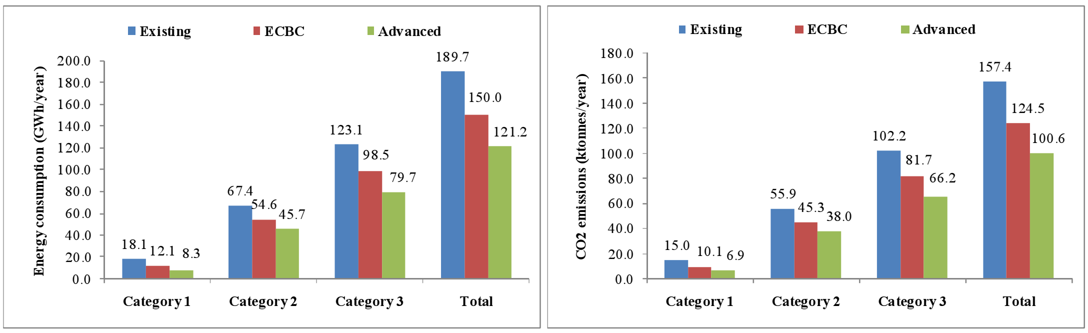


Fig. 5.20 Energy consumption and GHG emissions by hotel sector of Jaipur city in 2020

The CO_2 emissions in India in the year 2012 are 1.97 billion tones/year and under Intended Nationally Determined Contributions (INDC) India has targeted to reduce its emissions by 33% to 35% by the year 2030 from 2005 level. The results of the study show that adoption of energy efficiency measures can help to achieve these targets in hotel buildings. Also, results of the study can help to choose the best strategy to save maximum energy in the respective hotel category and can also be useful to implement the EEMs in other similar commercial buildings. Since, Jaipur city is India's one of the most visited tourist place and hotels are fastly growing, which results in higher energy consumption and there is a need to adopt energy saving measures.

Hotel buildings in Jaipur city share high energy due to high energy intensity and fast growth. Hotel buildings in Jaipur city also using conventional practices and technology, resulting into inferior energy performance as compared to the level targeted through ECBC implementation. Adoption of ECBC code by hotel buildings of Jaipur city can significantly reduce energy consumption in order to reduce GHG emissions. The energy consumption can further be reduced through adoption of advanced energy efficiency measures. Hotel building components like wall, roof, glazing, lighting and HVAC system when retrofitted gives significant energy savings. HVAC system with GHX has vast potential for energy saving in hotel buildings. Installation of SPV system at the rooftop of hotel buildings in Jaipur city can be an economically viable option to meet the growing electricity requirement. The Category-1 hotel buildings have highest scope for energy efficiency but the highest energy saving potential lies with Category-3 hotels. Therefore, results of the study suggest that there is a need and scope for energy savings in order to reduce greenhouse gas emissions in hotel building sector of Jaipur city.

CHAPTER 6
CONCLUSIONS

The present study has been carried out in hotel buildings of Jaipur city, which is defined under the composite climatic zone of India. In the study, total nine hotel buildings of different categories are analysed which are from composite climatic region of Jaipur city in order to find energy savings and GHG mitigation through energy efficiency measures. The study adopted two set of energy efficiency measures, one as per building code of India i.e. ECBC, and another is advanced energy efficiency measures, which are beyond ECBC building code. The study further estimated the energy savings and GHG reduction potential in hotel sector, through the adoption of these energy efficiency measures. Economic analysis of energy saving measures has also been carried out for the case study hotel buildings. Further, the study concludes that there is a large potential of energy savings through implementation of ECBC building code and advanced energy efficiency measures in hotel buildings. The key conclusions are as follows:

- Hotel buildings share significant energy consumption in the commercial sector of Jaipur city due to high energy intensity, major growth and largely due to using of conventional practices and technology, resulting into inferior energy performance.

6.1 Energy efficiency through ECBC code compliance

- Energy savings through retrofitting of unitary air-conditioner and water-cooled chiller by similar type of efficient HVAC system is almost similar but retrofitting unitary air-conditioner appears more economically viable due to lower capital cost.
- Wall and roof insulation give significant energy savings. Roof insulation is better as compared to wall insulation. Wall and roof insulation are more economically viable for small hotel building as compared to large hotel buildings.
- Window glass film on single glazed glass is more economically viable as compared to window film on double glazed glass.
- Retrofitting of lighting fixtures is the most attractive option among all technological options considered in this study since, the capital invested is returned within few months.

- Average energy saving obtained through adoption of ECBC to selected hotel buildings is 23.2%.

6.2 Energy efficiency through advanced EEMs

- Energy savings through replacing existing HVAC system by GHX (Ground Heat Exchanger) system is very high especially hotel buildings which have unitary system since the air-cooled condenser is replaced with water-cooled condenser. Despite high energy savings result in high capital cost of GHX system that gives an average IRR.
- Energy savings through increasing thickness of wall and roof insulation increases energy savings marginally but cost increases proportionately therefore IRR reduces
- Window glass film to attain shading coefficient value lower than the value prescribed by ECBC, although reduces heat gain through the window, but due to high capital cost, it is not economically viable.
- Replacing all types of lighting fixtures by LED lighting fixtures to get LPD values lower than prescribed by ECBC values for hotel buildings although reduces energy consumption but the IRR is also reduced.
- Average energy saving obtained through adoption of advanced measure to selected hotel buildings is 39.7%.
- Maximum energy savings can be obtained through retrofitting of HVAC system in both ECBC and advanced cases.

6.3 Reduction in energy intensity

- Most of the hotel buildings have payback period ranging from 4-6 years with ECBC compliance and the payback period increases slightly in advanced cases.
- Adoption of ECBC and advanced measures qualifies Category-1 hotels for four and five star energy efficiency ratings of BEE and Category-3 for two to four star ratings whereas, Category-2 hotels are at margin to attain BEE energy star ratings due to their large energy intensities.

6.4 Energy generation through SPV

The IRR of installing rooftop SPV system ranges from 5.76 % to 11.77 %, therefore SPV can be economically viable option for few hotels to reduce energy demand on grid. With increase in tariff of electricity and reduction in SPV panel cost the rooftop SPV can become more attractive.

6.5 Projections of energy efficiency measures for hotel sector of Jaipur city

- Annual energy consumption of existing hotel buildings (total 589 hotels) in Jaipur city is estimated to be 107.8 GWh/year. Adoption of ECBC and advance measures by entire hotel sector of Jaipur city would save 23.2 GWh/year and 40.0 GWh/year respectively.
- GHG emissions due to existing hotel buildings are 89.5 $ktCO_2$/year. Adoption of ECBC building energy code and advanced measures would reduce GHG emission by 19.2 $ktCO_2$/year and 31.3 $ktCO_2$/year respectively. Although, the energy saving is significant in Category-1 hotels but the impact of energy savings is the highest in Category-3 hotel building due to higher energy consumption.

This study, therefore, concludes that there is the large potential of energy savings through the implementation of ECBC in three category hotel buildings. If the building components like wall, roof, glazing, lighting and HVAC system are specified better than specifications of ECBC, the energy saving increases significantly. It also highlighted the fact that there exists a significant variation in the order of energy savings in different category hotel buildings. The results of the study can help to choose the best strategy to save maximum energy in the respective hotel category and can also be useful to implement the EEMs in other similar commercial buildings. Since, Jaipur city is India's one of the most visited tourist place and hotels are growing significantly, which results in higher energy consumption and there is a need to adopt energy saving measures. Significant energy savings is possible from changes in building construction, climate sensitive design, use of locally appropriate material, and operations. The findings in this report suggest that there are both needs and opportunities for supporting improved energy efficiency and reduced greenhouse gas emissions from the building sector. A number of specific recommendations also emerge from data collected and this study.

6.6 Recommendations from the study

Hotel buildings in Jaipur city are growing rapidly; and adopt conventional practices and therefore, they have high energy intensity, resulting in significant energy consumption and GHG emissions. Adoption of ECBC by hotel sector of Jaipur city has large scope for energy savings and GHG mitigation, which can be further increased by adoption of advanced measures. Present study strongly recommends retrofitting of inefficient unitary HVAC system with energy efficient HVAC system that is most economically viable as compared to replacing other type of HVAC system. Wall and roof insulation are economically viable, especially roof insulation in small hotel buildings can be an attractive option to reduce heat gain. Applying window films on single glazed glass for ECBC compliance is more cost effective as compared to applying window glass film to double glazed unit. The study strongly recommends retrofitting of lighting fixtures since this option is the most economically viable among all other options considered in this study. Overall the study strongly recommends implementation of ECBC in hotel buildings. It is also suggests enhancement in level of energy efficiency of ECBC since a viable level of higher energy efficiency has been identified through this study.

The interventions have been adopted for the selected hotel building models and the results obtained have been projected for hotel building sector of Jaipur city. This study is focused in Jaipur city, since selected hotel buildings are representative hotel buildings of Jaipur city, the modeling data and operating parameters used are as per local weather conditions. The retrofitting material and equipment proposed for hotel buildings to achieve energy efficiency are easily available and have lower cost in the local market of Jaipur city. Although, this methodological framework can be applied worldwide through suitable modifications.

- Results of the present study are based on sample-hotel buildings selected from surveyed hotel buildings of Jaipur city. This methodology can be applied globally through sample of buildings selected on basis of the available data from that particular region and sector.
- Hotel buildings have been modelled in the present study on the basis of data collected for equipment, fixtures and their operating parameters as per requirements according to local conditions. Therefore, building energy model can be developed using data of equipment and operating conditions as per availability and requirement at that particular region.
    - Building energy codes are area and country specific, designed as per the requirement and availability of technology varying from country to country and region to region. Therefore, the energy efficiency through adoption of building

codes can be obtained through adopting building codes developed for particular country or region.

- The retrofitting measures adopted in the present study for energy efficiency are one of the best equipments and materials at lowest cost available locally. Therefore, for other regions the materials and equipments can be selected as per availability locally.
- India being a tropical country has tremendous scope of generating solar energy due to its geographical location. Solar photovoltaic has been adopted for improving energy efficient features through passive solar design in the buildings. Therefore, present study adopted rooftop solar photovoltaic at the of hotel buildings for replacing some grid energy. With advanced and cheap solar panels photovoltaic energy is becoming economically viable. But in other countries wind energy, geothermal energy, biofuel energy etc. can be explored based on technical feasibility and economic viability. Therefore, renewable energy for energy efficiency to buildings can be adopted as per suitability of the renewable energy option available at particular region.

The results of the study have been compared with some of the studies discussed in the literature of the present study.

6.7 Implications of the study

The implications of this research study will be useful to academicians, researchers, and for practitioners/industries. Thereafter, possible future directions for research are suggested as below:

- Academic community

The present study makes significant theoretical contributions. Very few methodological constructs used in the present study have been explored by previous researchers and since they have focused on one or two of the buildings. There is no standard literature incorporating the study by using these methodologies. Thus, the present study contributes to the existing theory and provides useful insights for both academicians and researchers. One of the major implications of this study is that the building energy model can serve as a productive framework about problem solving through energy efficiency in buildings. Since the present study focuses at Jaipur-India, and primarily no such studies have been conducted for the same. The present research will contribute by providing the information in the form of results and recommendations of this study. Since, India is witnessing fast-paced economic changes, rapid globalization resulting into fast growing building sector therefore this study will be of value to researchers and academicians. Most perspectives existing in the area are primarily theoretical or prescriptive in nature. By deploying a research design of by collecting primary data through a research instrument and energy modelling by making use of research methods can bring new insights in building energy efficiency. As part of the present research effort, a research instrument has also been developed and validated.

- Practitioner community

Data collected in this study shows that conventional practices are followed in building construction, equipment and operating conditions. Adoption of ECBC and other technological options have favourable financial implications. Replacing unitary HVAC system, wall and roof insulation and low LPD lighting should be adopted by small and large buildings. In fact, roof insulation and low LPD lighting have been observed to be most economically viable options. The results obtained in the present study will allow the formulation of benchmarks for different categories of commercial buildings (in the various climatic zones). This component will evaluate and recommend incentive options for the production, commercialization and/or purchase of energy efficient building materials, new construction techniques and retrofitting of existing buildings in order to make them to be more energy efficient.

- Research community

Majority of the studies in this area have been conducted in developed countries, the present research contributes by drawing its sample from India, where there is evidence of a fast-paced economic change resulting into growth of building sector. The methodological framework designed in the present study can be adopted by such studies worldwide through suitable modifications. The findings of the research are expected to throw light on the energy modeling of buildings for energy efficiency for various building sectors.

6.8 Limitations and future scope

Present research provides new insights to the building energy efficiency through new technological interventions but there are certain limitations of this research. This section highlights some of the limitations of the present research which opens up new areas and directions for future research.

- Due to time constraints and limitations to access the data, sample data has been used in the study for model development. Building energy models can be more accurate if they are developed through detailed data of operating equipments and conditions.
- The study discussed technological options as per ECBC compliance. Various other technological options may be explored for energy efficiency and GHG reductions, depending on specific geographical locations and types of hotels.
- The analyses of hotel sector in Jaipur city may be more impactful if large sample size of representative hotels would have been included in the study.
- The reliability and accuracy of calibrated models depends on the quality of the measured data used to create the models. Throughout the course of this research study, it has been observed that it is very difficult to obtain the level of data required for detailed calibration in modern buildings with relatively large quantities of data. Limitations of simulation modelling also influence the results and thus impact simulated performance data significantly. Errors in measured data occur due to various reasons such as non-availability of data, lack of data monitoring, irregular operating schedule of equipment, data tracking errors, etc. can lead to error in measured data.
- The future work should focus on modeling and validation of additional building system components over yearly time periods. The investigations should include various calibration scenarios and provide recommendations on adequate selection of calibration data.
- The study discussed technological options as per ECBC compliance and some advanced technological options. Due to advancement of technology worldwide various other technological options are available therefore may be explored and large number of scenarios must be generated for energy efficiency for comparative assessment. This kind of research can be carried out in other commercial sectors also by using the sample data of that particular sector.

However, this study emphasizes the need for a large sample size, detailed data collection continuous monitoring of data, other technological options for more accurate and better results.

REFERENCES

[1] Agrawal B., Tiwari G. N. 2010. Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions. Applied Energy; 87, pp. 417–426.

[2] Ahmed F. Radwan , Ahmed A. Hanafy , Mohamed Elhelw , Abd El-Hamid A. El-Sayed, Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt Alexandria Engineering Journal (2016).

[3] Aikins, K.A., Choi, J.M. 2012. Current status of the performance of GSHP (ground source heat pump) units in the Republic of Korea. Energy; 47(1), pp.77-82.

[4] Akbari H., Levinson R., Rainer L. 2007. Monitoring the energy-use effects of cool roofs on California commercial buildings, Energy and Buildings; 37, pp. 1007–1101.

[5] Aksamija A. 2009. Integration in architectural design: Methods and implementations.Design Principles and Practices: An International Journal; 3.6, pp. 151-160.

[6] Aksamija A. 2010. Analysis and computation: Sustainable design in practice. Design

[7] Aksamija A. 2012. BIM-Based Building Performance Analysis.Proceedings of ACEEE, 2012, Summer Study on Energy Efficiency in Buildings.

[8] Akwa, Vicente J., Konrad O., Kaufmann G. V., Machado C. A. 2014. Evaluation of the photovoltaic generation potential and real-time analysis of the photovoltaic panel operation on a building facade in southern Brazil.Energy andBuildings 69; pp. 426–433.

[9] Al Turki A., Zaki G.M. 1991. Cooling load response for building walls comprising heat storing and thermal insulating layers, Journal of Energy Conversion Management; 32, pp. 235-247.

[10] APEC.1999. http://www.egnret.ewg.apec.org/reports/1999/Benchmarking.pdf

[11] Ardehali M., Smith T., House J., Klassen C. 2003. Building energy use and control problems: an assessment of case studies. ASHRAE Transactions; 109, pp. 111–121.

[12] Asdrubali F., Bonaut M., Battisti M., Venegas M. 2008. Comparative study of energy regulations for buildings in Italy and Spain. Energy and Buildings; 40, pp. 1805–1815.

[13] ASHRAE, ANSI/ASHRAE Standard 90.1-2004: Energy Standard for Building Except Low-rise Residential Buildings, ASHRAE, Atlanta, 2004.

[14] ASHRAE, Handbook Fundamentals, ASHRAE Inc., Atlanta, USA, 1997.

[15] Augenbroe, G. and Hensen, J., 2004. Simulation for better building design.Building and Environment, 39(8), pp.875-877

[16] Bakos G.C., 2002. Feasibility study of a hybrid wind/hydro power-system for low-cost ctricity production. Applied Energy; 72(3), pp.599-608.

[17] Balaras C.A., Gaglia A.G., Georgopoulou E., Mirasgedis S., Sarafidis Y., Lalas D. P. 2007. European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. Build Environ 42; pp. 1298–314.

[18] Ballestini G., De Carli M., Masiero N., Tombola G. 2005. Possibilities and limitations of natural ventilation in restored industrial archaeology buildings with a double- skin facade in Mediterranean climates. Building and Environment; 40, pp. 983–995.

[19] Bansal N. K., Bhattacharya A. 2009. Parametric equations for energy and load estimations for buildings in India.Applied Thermal Engineering; 29.17–18, pp. 3710–3715.

[20] Bataineh K.M., Fayez N.2011. Analysis of thermal performance of building attached sunspace. Energy and Buildings; 43, pp. 1863–1868.

[21] BEE.2007.http://beeindia.in/about_bee/documents/annualreports/2007-08E.pdf

[22] Beerepoot M., Beerepoot N. 2007. Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector. Energy Policy; 35, pp. 4812–4825.

[23] Bellia, L., De Falco, F. and Minichiello, F., 2013. Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates. Applied Thermal Engineering, 54(1), pp.190-201

[24] Bhatia, A., Garg, V. and Mathur, J., 2009. Determination of energy saving with cool roof concept using calibrated simulation: case of a learning centre in

composite Indian climate. TR/2009/177. Hyderabad: Centre for Agriculture and Rural Development, International Institute of Information Technology.

[25] Bodart M., De Herde A. 2002. Global energy savings in offices buildings by the use of daylighting. Energy and Buildings; 34(5) pp. 421–429.

[26] Bolatturk A. 2006. Determination of optimum insulation thickness for building walls with respect to various fuels and climate zones in Turkey.Journal of Applied Thermal Engineering; 26, pp. 1301- 1309.

[27] Bolattürk A. 2008 Optimum insulation thicknesses for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey, Building and Environment Volume 43, Issue 6, June 2008, Pages 1055–1064

[28] Bouden C. 2007. Influence of glass curtain walls on the building thermal energy consumption under Tunisian climatic conditions: The case of administrative buildings. Renewable Energy; 32, pp. 141–156.

[29] Brambley, M.R., D. Hansen, P. Haves, D.R. Holmberg, S.C. McDonald, and K.W.R.P. Torcellini, 2005: Advanced sensors and controls for building applications: Market assessment and potential R&D pathways, US DOE Office of Energy Efficiency and Renewable Energy, Building Technologies Program, Pacific Northwest National Laboratory.

[30] Brasil, Portaria 185, de 22 de junho de 2009, Regulamento de Avaliac¸ ão da Conformidade do Nível de EficiênciaEnergética de EdifíciosComerciais, de Servic¸ os e Públicos, InstitutoNacional de Metrologia, Normalizac¸ ão e Qualidade Industrial (INMETRO), Rio de Janeiro, 2009 (in Portuguese).

[31] Braun P.G. 2010.AIntegrac¸ ão de SistemasSolaresFotovoltaicosemLargaEscala no Sistema Elétrico de Distribuic¸ ão Urbana. Doctoral thesis. Federal University of Santa Catarina, Florianópolis, Brazil (in Portuguese).

[32] Bribián, I.Z., Usón, A.A., Scarpellini, S. 2009. Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. Building and Environment; 44(12), pp.2510-2520.

[33] BSRIA. 2009. Global air conditioning sales reaches US$70 billion in 2008. Available from http://www.bsria.co.uk/news/global-air-conditioning-sales-reach-us70-billion-in-2008/ [16 April 2012]

[34] Building Energy Benchmark Report. 2014. https://www.bca.gov.sg/GreenMark/.../BCA_BEBR_Abridged_FA.pdf

[35] Bureau of Energy Efficiency Confederation of Indian Industry Department of Economic Affairs Ministry of Power US Agency for International Development. 2010

[36] Byrne, E., Donnelly, E. 2012. Carbon Emissions, Transport and Location: a Sustainability Toolkit for Stakeholders in Development.

[37] Carriere, M, G J Schoenau, and R W Besant. 1999. "Investigation of some large building energy conservation opportunities using the DOE -2 model." 40.

[38] Casals X.G. 2006. Analysis of building energy regulation and certification in Europe: their role, limitations and differences. Energy and Buildings; 38, pp. 381–392.

[39] Castletona H. F., V. Stovinb, S.B.M. Beckc, J.B. Davisonb, Green roofs; building energy savings and the potential for retrofit Energy and Buildings 42 (2010) 1582–1591

[40] Castellotti F., Lazzarin Renato M.,Busato F. 2005.Experimental measurements and numerical modelling of a green roof. Energy and Buildings; 37, pp. 1260–1267.

[41] Chaturvedi V., Eom J., Clarke L.E., Shukla P.R. 2014. Long term building energy demand for India: Disaggregating end use energy services in an integrated assessment modeling framework. Energy Policy; 64, pp. 226-242.

[42] Chaturvedi V., Eom J., Clarke L.E., Shukla P.R. 2014. Long term building energy demand for India: Disaggregating end use energy services in an integrated assessment modeling framework. Energy Policy; 64, pp. 226-242.

[43] Chel A., Nayak J.K., Kaushik G. 2008.Energy conservation in honey storage building using Trombe wall. Energy and Buildings; 40, pp. 1643–1650.

[44] Chel A., Tiwari G. N. 2011.A case study of a typical 2.32Â kWP stand-alone photovoltaic (SAPV) in composite climate of New Delhi (India), Applied Energy; 88.4, pp. 1415-1426.

[45] Chen S., Yoshino H., Levine M., Li Z.2009. Contrastive analyses on annual energy consumption characteristics and the influence mechanism between new and oldresidential buildings in Shanghai, China, by the statistical methods. Energy and Buildings;41.12, pp. 1347-1359.

[46] Cheung C.K., Fuller R.J., Luther M.B.2005. Energy-efficient envelope design for high- rise apartments. Energy and Buildings; 37, pp. 37–48.

[47] Chimack M. J. 2001. Determining base line energy consumption and peak cooling load of a 107 year old science museum using DOE 2.1 E. Seventh International IBPSA Conference; pp. 191-197.

[48] Chirarattananona S., Hienc V. D., Tummua P., 2012. Thermal performance and cost effectiveness of wall insulation under Thai climate, Energy and Buildings 45, 82–90.

[49] Chouhan, Tej Singh, Prof Ashish, and Dutt Sharma. 2012. "Assessment of Building Energy Performance for EEMs – A Case Study in Mumbai." 1(4): 1–5.

[50] Chowdhury A.A., Rasul M.G., Khan M.M.K. 2008. Thermal-comfort analysis and simulation for various lowenergy coolingtechnologies applied to an office building in a subtropical climate. Applied Energy; 85, pp. 449–462.

[51] Chvatal K.M.S., MaldonadoE.A.B., CorvachoM.H.P.2005. Study of the impact of the increase of the thermal insulation of the building envelope upon its thermal performance, in: PALENC—Passive and Low Energy Cooling for the Built Environment, Greece.

[52] Crawley, E., Russo, F., Yoshikawa, S. 2002. Thermal evaluation of thin material. Smart Materials Bulletin.

[53] Da Fonseca R.W., DidoneE.L., PereiraF.O.R. 2013.Using artificial neural networks to predictthe impact of daylighting onbuildingfinal electric energy requirements. Energyand Buildings; 61, pp. 31–38.

[54] Danowicz P., Churie-Kallhauge A., Martinac I. 2001. Energy-efficiency and conservation in hotels–towards sustainable tourism. International Symposium on Asia Pacific Architecture, Havai.

[55] Das A., Paul S.K. 2013. Changes in energy requirements of the residential sector in India between 1993 – 94 and 2006 – 07.Energy Policy; 53, pp. 27–40.

[56] De Gracia, A. and Cabeza, L.F., 2015. Phase change materials and thermal energy storage for buildings. Energy and Buildings, 103, pp.414-419.

[57] Debnath, A., Singh, S.V., Singh, Y.P. 1995. Comparative assessment of energy requirements for different types of residential buildings in India.Energy and Buildings; 23(2), pp.141-146.

[58] DeIa Rue du Can S., Price L. 2008. Sectoral trends in global energy use and greenhouse gas emissions. Energy Policy;36, pp.1386–1403.

[59] Deng, S.M., Burnett, J. 2000. A study of energy performance of hotel buildings in Hong Kong. Energy and Buildings; 31(1), pp.7-12.

[60] Dhaka S., MathurJ., GargV. 2012. Combined effect of energy efficiency measures and thermal adaptation on air conditioned building in warm climatic conditions of India.Energy and Buildings; 55, pp. 351–360.

[61] Dong, B., Gorbounov, M., Yuan, S., Wu, T., Srivastav, A., Bailey, T., O'Neill, Z., 2013. September. Integrated energy performance modeling for a retail store building. In Building Simulation; 6(3), pp. 283-295. Tsinghua University Press.

[62] Dubois M. C., Blomsterberg A. 2011. Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: a literature review. Energy Build; 43, pp. 2572–2582.

[63] Durmayaz A., Kadioglu M.,Sen Z. 2000.An application of the degree-hours method to estimate theresidential heating energyrequirement and fuel consumption in Istanbul, Journal of Energy; 25, pp. 1245-1256.

[64] Eagles P. F. J. 2001. International ecotourism management: using Australia and Africa as case studies. IUCN World Commission on Protected Areas, Protected Areas in the 21st Century: From Islands to Networks. url: http://www.ahs.uwaterloo.ca/rec/ecotour.htm, accessed on 13.2.2001.

[65] Eaton Haughton, M. I. 1997. Plant E, Energy efficiency in the hotel sector in Jamaica. Roundtable on energy efficiency – Tourism sector, Kingston, Jamaica, 9– 11.12.1997, http://www.idrc.ca/industry/jamaica_e9.html, as accessed 1.12.2000.

[66] Energy policies and programmes of IEA countries. OECD/IEA, Paris.International Energy Agency; 1989.

[67] Energy Statistics. 2013. Report accessed on 7.7.2013. url mospi.nic.in/mospi_new/ upload / Energy_Statistics_2013.pdf

[68] Fadzli, Mohamad, Hazlina Selamat, Rubiyah Yusof, and Salinda Buyamin. 2013. Review of HVAC scheduling techniques for buildings towards energy-efficient and cost-effective operations. Renewable and Sustainable Energy Reviews 27: 94–103.

[69] Fasiuddin M, Budaiwi I. 2011. HVAV Systems strategies for energy conservation in commercial buildings in Saudi Arabia. Energy and Buildings; 43(12):3457- 66

[70] Fathabadi H. 2014. Ultra high benefits system for electric energy saving and management of lighting energy in buildings.Energy Conversion and Management; 80, pp. 543–549.

[71] Feijoo M.L., Franco J.F., Hernandez J.M. 2002. Global warming and the energy efficiency of Spanish industry. Energy Econ; 24.4, pp. 405–423.

[72] FHRAI.2013. url: www.fhrai.com/annualReport.htm.

[73] Flaga-maryanczyk A., Schnotale J.,Radon J., Was K. 2014. Experimental measurements and CFD simulation of a ground source heat exchanger operating at a cold climate for a passive house ventilation system.Energy and Buildings 68; pp. 562–570.

[74] Friess W. A., Rakhshan K., Hendawi T. A., Tajerzadeh. 2012. Wall Insulation Measures for Residential Villas in Dubai□: A Case Study in Energy Efficiency. Energy and Buildings; 44, pp. 26–32.

[75] Fumo, N., Mago, P. and Luck, R., 2010. Methodology to estimate building energy consumption using EnergyPlus Benchmark Models. Energy and Buildings, 42(12), pp.2331-2337.

[76] Garg, V., Somal S., Arumugam, R., Bhatia, A. 2016. Development for cool roof calculator for India, Energy and Buildings: 114, pp.136–142.

[77] Gayathri A., Pillai R., Mani M. 2013. Energy for Sustainable Development An Insight into Real-time Performance Assessment of a Building Integrated Photovoltaic (BIPV) Installation in Bangalore (India). Energy for Sustainable Development. 17.5;pp. 431–437.

[78] Gera R. K., Rai H.M.,ParvejY.,Soni H. 2013.Renewable energy scenario in India: opportunities and challenges. Indian Journal of Electrical and Biomedical Engineering; 1, pp. 10-16.

[79] Gijon-Rivera M., Álvarez G., Beausoleil-Morrison I., Xamán J.2011. Appraisal of thermal performance of a glazed office with a solar control coating: cases in Mexico and Canada. Building and Environment; 46, pp. 1223–1233.

[80] Global Hospitality Insights. 2015. http://www.ey.com/Publication/vwLUAssets/ey-global-hospitality-insights-2015/$File/ey-global-hospitality-insights-2015.pdf

[81] Gorgulu S., EkrenN. 2013.Energy saving in lighting systemwith fuzzy logic controller which uses light-pipe and dimmable ballast.Energy and Buildings; 61, pp.172–176.

[82] Graeber N., Papamichael K. 2011. Smart corridors light the way to energy efficiency: managing the lighting in secondary spaces such as stairwells, lobbies and ser- vice rooms based on occupancy can carve a big chunk out of overall energy use. Light Des Applicat: LDandA;41, pp. 52–54.

[83] Guerra S. O., ItardL., VisscherH. 2009. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings; 41, pp. 1223–1232.

[84] Guo Qiang , Yong Wu , Yan Ding , Wei Feng , Neng Zhu, Measures to enforce mandatory civil building energy efficiency codes in China, Journal of Cleaner Production 119 (2016) 152

[85] Haberl J., Cho. S. 2004. Literature Review of Uncertainty of Analysis Methods (Cool Roofs), Report to the Texas Commission on Environmental Quality. Energy Systems Laboratory, Texas AandMUniversity, College Station, TX.

[86] Harper B., Badger L., Chiodo J., Reed G., Wirtshafter R. 2012. Improved code enforcement: a powerful policy tool – lessons learned from New York State. Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, pp 8114-8126.

[87] Harvey L.D.2009. Reducing energy use in the building sector: measures, costs, and examples. Energy Efficiency; 2.2, pp. 139–163.

[88] Hasan A. 1999. Optimizing insulation thickness for buildings using life cycle cost. Journal of Applied Energy; 63, pp. 115-124.

[89] Hassan R. 2010. Energy analysis of façade-integrated photovoltaic systems applied to UAE commercial buildings. Solar Energy; 84.12, pp. 2009–2021.

[90] Henrique A., Tadeu M., Fagá W., and Moutinho E., 2013. Electrical Power and Energy Systems The risks of an energy efficiency policy for buildings based solely on the consumption evaluation of final energy," International Journal of Electrical Power and Energy Systems, vol. 44, no. 1, pp. 70–77.

[91] HouriA., El KhouryP. 2010.Financial and energy impacts of compact fluorescent light bulbs in a rural setting. Energy and Buildings; 42, pp. 658–666.

[92] http://www.climatemaster.com

[93] http://www.gibss.in

[94] Huang Y., Niu J., Chung T. 2013. Study on performance of energy-efficient retrofitting measures on commercial building external walls in cooling-dominant cities.Applied Energy; 103, pp. 97–108.

[95] Hughes B.R., Chaudhry H.N., AbdulGhani S.2011.A review of sustainable cooling technologies in buildings. Renewable and Sustainable Energy Reviews; 15, pp. 3112–3120.

[96] Hu J S, Philip C W Kwong, and Christopher Y H Chao. 2006, Energy saving study in a hotel hvac system.

[97] HVS.2014. Report accessed on 5.9.2014. url: www.hvs.com/article/7219/ us-hotel-development-cost-survey-2014-15.

[98] IECC.2004. url: https://law.resource.org/pub/us/code/ibr/icc.iecc.2004.pdf

[99] Indraganti M., Ooka R., Rijal H. B. 2013. Field investigation of comfort temperature in Indian office buildings: a case of Chennai and Hyderabad.Building and Environment; 65,pp. 195-214.

[100] Indraganti, M., Ooka, R., andRijal, H. B..Developing the adaptive model of thermal comfort for indian office buildings Chennai months Hyderabad months.".

[101] Intergovernmental Panel on Climate Change.2010. Report accessed on 6.10.2010. url: https://www.ipcc.ch/publications.../publications_and_data_reports.shtml.

[102] International Energy Agency. 2008. Report accessed on 9.8.2008. url: www.worldenergyoutlook.org/media/weowebsite/2008.../weo2008.pdf

[103] International Energy Agency. 2011. Technology Roadmap: Energy-Efficient Buildings: Heating and Cooling Equipment. OECD/International Energy Agency. Available from /http://www.iea.org/publications/freepublications/publication/buildings_roadmap.pdf. [16 April 2012]

[104] Jacob B. 2009.Lamps for improving the energy efficiency of domestic lighting. Light Res Technol;41, pp. 219–228.

[105] Jardim C. S., Ruther R., Salamoni T., Viana T. S., Rebechi S.H., Knob P.J. 2008. The strategic sitting and the roofing area requirements of building-integrated photovoltaic solar energy generators in urban areas in Brazil, Energy and Buildings; 40, pp. 365–370.

[106] Jayswal M. 2012. To examine the energy conservation potential of passive and hybrid downdraught evaporative cooling□: A study for commercial building sector in hot and dry climate of Ahmedabad.Physics Procedia; 30, pp. 1131–1142.

[107] Jiang W., Jarnagin R.E., Gowri K., McBride M. 2008. Technical support document□: the development of the advanced energy design guide for highway lodging buildings. Pacific Northwest National Laboratory.

[108] JVVNL, Jaipur. www.jaipurdiscom.com

[109] Kapil J. C., Satyawali, Ganju A. 2015. Scope and implementation of ground source heat extraction technology in India for multiple energy saving applications; pp. 19–25.

[110] Kapoor R., Deshmukh A., Lal S. 2011. Strategy roadmap for net zero energy buildings in India. USAID ECO-II Project; International Resources Group, AADI Building, New Delhi.

[111] Ke M., Yeh C., Jian J. 2013. Analysis of building energy consumption parameters and energy savings measurement and verification by applying eQUEST software.Energy and Buildings; 61, pp. 100–107.

[112] Khan, Y., Khare, V.R., Mathur, J. and Bhandari, M., 2015. Performance evaluation of radiant cooling system integrated with air system under different operational strategies. Energy and Buildings, 97, pp.118-128

[113] Kim H., Stumpf A., Kim W. 2011. Analysis of an energy efficient building design through data mining approach, Automation in Construction; 20, pp. 37–43.

[114] Kircher, K., Shi, X., Patil, S., Zhang, K.M. 2010. Cleanroom energy efficiency strategies: Modeling and simulation. Energy and buildings; 42(3), pp.282-289.

[115] Kirubakaran, V., Sahu, C., Radhakrishnan, T.K. and Sivakumaran, N., 2015. Energy efficient model based algorithm for control of building HVAC systems. Ecotoxicology and environmental safety, 121, pp.236-243

[116] Klein M. 2004. Government support for energy saving projects. In Electronic Government. Springer Berlin Heidelberg; pp. 97–101.

[117] Kneifel J. 2010. Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. Energy Build;42.3, pp. 333–340.

[118] Kumar M., Mahapatra S.,Atreya S.K. 2011. Solar passive features in vernacular architecture of North-East India.Solar Energy; 85.9, pp. 2011–2022.

[119] Kumar S. 2010. Energy use in commercial buildings-Key findings from the national benchmark study. Benchmarking of Energy Consumption and Labeling of Commercial Buildings , July 2010, New Delhi.

[120] Kumar S., Rathi M., Palit A.,Nandrajog P. 2012. Future scenario of renewable energy in India. International Journal on Theoretical and Applied Research in Mechanical Engineering; 2, pp. 140-146.

[121] Kumar, A., Suman, B.M. 2013. Experimental evaluation of insulation materials for walls and roofs and their impact on indoor thermal comfort under composite climate. Building and Environment; 59, pp.635-643.

[122] Kumar, P., Martani, C., Morawska, L., Norford, L., Choudhary, R., Bell, M. and Leach, M., 2016. Indoor air quality and energy management through real-time sensing in commercial buildings. Energy and Buildings, 111, pp.145-153

[123] Kushal Engineers Enterprises, Jaipur, http://www.kushal-engineers.com

[124] Kuusk, K., Kalamees, T. and Maivel, M., 2014. Cost effectiveness of energy performance improvements in Estonian brick apartment buildings. Energy and Buildings, 77, pp.313-322

[125] Kuznik, F., Johannes, K. and Obrecht, C., 2015. Chemisorption heat storage in buildings: State-of-the-art and outlook. Energy and Buildings, 106, pp.183-191

[126] Laar M., Rath A. 1997. Energy efficiency and tourism: focus on the Caribbean – A discussion paper.Roundtable on energy efficiency – tourism sector, Kingston, Jamaica, December 9-11, 1997.url: http://www.idrc.ca/industry/jamaica_e7.html, accessed on 2.10.2000.

[127] Lam J.C.W., Hui J.C.Y., Jain P.K. 2012.A dimmable high power factor single-switch electronic ballast for compact fluorescent lamps with incandescent phase-cut dimmers. IEEE Trans. Ind. Electron; 59.4, pp. 1879–1888.

[128] Lamedica, R., Teodori, S., Carbone, G. and Santini, E., 2015. An energy management software for smart buildings with V2G and BESS. Sustainable Cities and Society, 19, pp.173-183

[129] Lazos, D., Sproul, A.B. and Kay, M., 2014. Optimisation of energy management in commercial buildings with weather forecasting inputs: A review. Renewable and Sustainable Energy Reviews, 39, pp.587-603

[130] LBNL.2012. url: https://eaei.lbl.gov/sites/all/files/GBPN_Final.Oct_.2012.pdf

[131] Lee J .Y.2009. Current status of ground source heat pumps in Korea.Renewable and Sustainable Energy Reviews; 13 (6,7), pp. 1560-1568.

[132] Lee W.L., Yik F.W.H. 2002.Regulatory and voluntary approaches for enhancing energy efficiency of buildings in Hong Kong. Applied Energy; 71, pp.251–274.

[133] Lee W.L., YikF.W.H. 2004.Regulatory and voluntary approaches for enhancing building energy efficiency. Progress in Energy and Combustion Science;30, pp. 477–499.

[134] Lesourd J.B. 2001. Solar photovoltaic systems: the economics of a renewable energy resource, Environmental Modelling and Software; 16, pp. 147–156.

[135] Li, C.H., Zhu, X.J., Cao, G.Y., Sui, S., Hu, M.R, 2009. Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology. Renewable Energy; 34(3), pp.815-826.

[136] Liu G., Rasul M.G., Amanullah M.T.O., Khan M.M.K. 2012. Techno-economic simulation and optimization of residential grid- connected PV system for the Queensland climate, Renewable Energy; 45, pp. 146–155.

[137] Liu X., Hong T. 2010. Comparison of energy efficiency between variable refrigerant flow systems and ground source heat pump systems.Energy and Buildings; 42.5, pp. 584–589.

[138] Lombard L.P., Ortiz J., Pout C. 2008.A review on buildings energy consumption information.Energy and Buildings; 40, pp.394–398. information.

[139] Lopes L., Hokoi S., Miura H., Shuhei, K. 2005. Energy efficiency and energy savings in Japanese residential buildings—research methodology and surveyed results. Energy and Buildings; 37.7, pp. 698-706.

[140] Mata, É, G Medina Benejam, A Sasic Kalagasidis, and F Johnsson. 2015. "Modelling opportunities and costs associated with energy conservation in the Spanish building stock." Energy & Buildings 88: 347–360.

[141] McDonald and Lausten 2013, CLASP 2011, Italy: Il Presidente della Repubblica 2005, Japan: Evans, Shui, and Lee 2009

[142] McKinsey and Company. 2009. Environment and energy sustainability – an approach for India, Mumbai, India, 2009.

[143] Melo A.P., M.J. Sorgato, R. Lamberts, 2014 Building energy performance assessment : comparison between ASHRAE standard 90.1 and Brazilian regulation, Energyand Buildings 70 (2014) 372–383.

[144] Melo, A P, D Cóstola, R Lamberts, and J L M Hensen. 2012. "Assessing the accuracy of a simplified building energy simulation model using BESTEST□: The case study of Brazilian regulation." Energy & Buildings 45: 219–228.

[145] Meriem S., Balghouthi M., Guizani A. 2013.Energy performance analysis of a solarcooled building in Tunisia□: passive strategies impact and improvement techniques. Energy and Buildings; 67, pp. 374–386.

[146] Ming D., Burnett J. 2000.A study of energy performance of hotel buildings in Hong Kong. Energy and Buildings; 31, pp. 7-12.

[147] Ministry of Tourism. 2013. India Tourism Statistics at a glance, Ministry of Tourism, Government of India. url: www.tourism.gov.in/.../Incredible%20India%20final%2021-7-2014%20english.pdf.

[148] Miyazaki, T., Akisawa, A., Kashiwagi, T. 2005. Energy savings of office buildings by the use of semi-transparent solar cells for windows. Renewable energy; 30(3), pp.281-304.

[149] Murakami Y., Terano M., Obayashi F., Honma M. 2007. Development of cooperative building controller for energy saving and comfortable environment.Springer Berlin Heidelberg;pp. 1078–1087.

[150] Nadkarni, A., Maktal, A., Karady, G.G., Alteneder, K., 2013, July. Value analysis of 2 kW/4.4 hour energy storage in residential PV systems in Arizona. In Power and Energy Society General Meeting (PES), IEEE(pp. 1-5).

[151] Naili, N., Attar, I., Hazami, M., Farhat, A. 2013. First in situ operation performance test of ground source heat pump in Tunisia.. Energy Conversion and Management; 75, pp.292-301.

[152] Nelson F., Mago P., Luck R. 2010. Methodology to estimate building energy consumption using energy plus benchmark models. Energy and Buildings; 42.12, pp. 2331–2337.

[153] NEN, NEN 2916 – Energy Performance of Non-residential Buildings – Determination Method, NNI, Delft, The Netherlands, 1994 (in Dutch).

[154] Nordeen G. 2013. The Washington State experience residential energy code compliance. Washington State University Extension Energy Program.

[155] Nutphuang, C., Chirarattananon, S., Hien, V.D. 2011. Application of CFD for air flow analysis underneath natural ventilation with forced convection in roof attic.

In Proceedings of World Academy of Science. Engineering and Technology; 75, pp. 205-212.

[156] Pan Y., Huang Z., Wu G. 2007. Caliberated building energy simulation and its application in a high rise commercial buildings in Shanghai. Energy and Buildings; 39, pp. 651-657.

[157] Parikh K.2012. Sustainable development and low carbon growth strategy for India.Energy Policy; 57, pp. 253–262.

[158] Park H., Lee J.S., Kim W., Kim Y. 2013. The cooling seasonal performance factor of a hybrid ground-source heat pump with parallel and serial configurations. Appl Energy;102, pp. 877–884.

[159] Paul B., Miriel J., Lenat Y.2012. Modelling and simulation of a heat pump for simultaneous heating and cooling; pp. 219–232.

[160] Pedrini A., Westphal F. S., Lamberts R. 2002. A methodology for building energy modelling and calibration in warm climates. Building and Enviornment; 37, pp. 903-912.

[161] Perez-Lombard L., Ortiz J., Coronel J. F., Maestre I. R. 2011. A review of HVAC systems requirements in building energy regulations. Energy and buildings; 43.2, pp. 255-268.

[162] Perez-Lombard L., Ortiz J., Pout C. 2008. A review on buildings energy consumption information. Energy and Buildings; 40, pp. 394–398.

[163] Pezzini P., Gomis-Bellmunt O., Frau-Valenti J., Sudria-Andreu A. 2010. Energy efficiency optimization in distribution transformers considering Spanish distribution regulation policy. Energy; 35, pp. 4685–4690.

[164] Piette M.A., KinneyS.K., HavesP. 2001. Analysis of an information monitoring and diagnostic system to improve building operations. Energy and Buildings; 33, pp. 783–791.

[165] Portugal, RCCTE—Regulation of the Buildings Thermal Behaviour Characteristics (in Portuguese), Ministry of Public Works, Transportation and Communications, Decree-Law n◦ 80/2006 of April 4, 2006.

[166] Prasheetan Aircon, Jaipur, www.prasheetanaircon.com

[167] Price, L., Worrell, E. 2006. September. Global Energy Use, Co2 Emissions, and the Potential for reduction in the Cement industry. In International Energy Agency Workshop on Cement Energy Efficiency, Paris.

[168] Prime Aluglass Creation Pvt Ltd. B-41-A, Vidhyadhar Nagar, Jaipur-302039

[169] Principles and Practices: An International Journal;4.4, pp. 291-314.

[170] Radhi H. 2009.Evaluating the potential impact of global warming on the UAE residential buildings: a contribution to reduce the CO2 emissions, Building and Environment; 44, pp. 2451–2462.

[171] Radhi H. Sharples S. 2009. Energy Performance Benchmarking (EPB): a system to measure building energy efficiency, Architecture.Ucd.Ie.

[172] Radhi H., Eltrapolsi A., Sharples S. 2009. Will energy regulations in the Gulf States make buildings more comfortable: a scoping study of residential buildings. Applied Energy; 86, pp. 2531–2539.

[173] Radhi. H. 2009. Can envelope codes reduce electricity and CO2 emissions in different types of buildings in the hot climate of Bahrain? Energy; 34, pp. 205–215.

[174] Raftery, P., Keane, M., O'Donnell, J. 2011. Calibrating whole building energy models: An evidence-based methodology. Energy and Buildings;43(9), pp.2356-2364.

[175] Ramesh S. P., Khan E.2013. Energy efficiency in green buildings – Indian concept. ICERTSD; 3.3, pp. 329–336.

[176] Ramesh S. P., M Emran Khan. 2013. Energy Scenario and Energy Efficiency: Programme and Policies of Booming India; pp. 199–207.

[177] Ramesh. S. P., 2011. Appraisal of vernacular building materials and alternative technoligies for roofing and terracing options of embodied energy in buildings. Energy procedia; pp. 1–6.

[178] Rawal R., Vaidya V., Ghatti V., Ward A., Seth S., Jain A., Parthasarathy T. 2012. Energy code enforcement for beginners: a tiered approach to energy code in India. Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings,pp 4313- 4324. Pacific Grove, CA.

[179] Razdan, P. N., AgarwalR.K., Singh R. 2008.Geothermal energy resources and its potential in India. Earth science India;I ,pp. 30-42.

[180] Reddy T.A., Maor I. 2006. Procedures for reconciling computer-calculated results with measured energy data. ASHRAE Research Project 1051-RP. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[181] Renewables 2015 Global Outlook, Pricewaterhouse Coopers Research

[182] Roth, K., P. Llana, W. Detlef, and J. Brodrick, 2005: Automated whole building diagnostics. ASHRAE Journal, 47(5).

[183] Ryckaert W.R., LootensC., GeldofJ., HanselaerP. 2010.Criteria for energy efficient lighting in buildings. Energy and Buildings; 42, pp. 341–347.

[184] Sabapathy S. K. V,Ragavan M.,Vijendra,Nataraja A.G. 2010. Energy efficiency benchmarks and the performance of LEED rated buildings for Information Technology facilities in Bangalore , India,Energy and Buildings;42.11, pp. 2206–2212.

[185] Sadineni S.B., Madala S., Boehm R.F.2011. Passive building energy savings: a review of building envelope components. Renewable and Sustainable Energy Reviews; 15, pp. 3617–3631.

[186] Santamouris M., Argiriou A., Dascalaki E., Balaras C., Gaglia A. 1994. Energy characteristics and savings potential in office buildings. Solar Energy; 52, pp. 59–66.

[187] SeoD., ParkL., IhmP., KrartiM. 2012. Optimal electrical circuiting layout and desk location for daylighting controlled spaces. Energy and Buildings; 51, pp. 122–130.

[188] Shan F., Lei C., Guiyin F. 2013. Dynamic performances modeling of a photovoltaic thermal collector with water heating in buildings. Energy and Buildings; 66, pp. 485–494.

[189] Shnapp S. Laustsen J. 2013. Mitigation potential from India's buildings.Global Buildings Performance Network; Paris, France.

[190] Shrinivas S. 2005.Green Building Movement in India. 2005. By Principal Counselor, CII - Sohrabji Godrej green Business Centre.ICERTSD.

[191] Silva P., Almeida M., Braganc a L., Mesquita V. 2009. Methodology to enhance the Portuguese thermal regulation accuracy for existing buildings inproceedings of the Building Simulation, Glasgow.

[192] Sivasakthivel T., Murugesan K., Sahoo P.K. 2012. Potential reduction in CO2 emission and saving in electricity by ground source heat pump system for space heating applications-a study on northern part of India. Proc Eng ;38, pp. 970–979.

[193] Sivasakthivel T., Murugesan K., Sahoo P.K. 2014. A study on energy and CO 2 saving potential of ground source heat pump system in India.Renewable and Sustainable Energy Reviews; 32, pp. 278–293.

[194] Soori P.K., Vishwas M. 2013.Lighting control strategy for energy efficient office lighting system design. Energy andBuildings; 66, pp. 329–337.

[195] Steemers, Manchanda S. 2010. Energy efficient design and occupant well-being□: Case studies in the UK and India.Building and Environment; 45.2, pp. 270–278.

[196] Stellberg S. 2013. Assessment of energy efficiency achievable from improved compliance with U.S. building energy codes: 2013 – 2030. Institute for Market Transformation; Washington, D.C.

[197] Stephen W., Selvam V., Lingyun L., Kian S., 2012. Seng C. Jonathan C., Analytical performance monitoring of a 142.5 kWp grid-connected rooftop BIPV system in Singapore, Renewable Energy, Vol. 47, pp. 9-20.

[198] Strand, R.K., 2001, October. Modeling a radiant slab coupled to a cooling tower using the new national energy analysis program. In Proceedings of the Cooling Frontiers Symposium, Arizona State University.

[199] Synnefa, A., Saliari, M. and Santamouris, M., 2012. Experimental and numerical assessment of the impact of increased roof reflectance on a school building in Athens. Energy and Buildings, 55, pp.7-15

[200] Tadeu H.M., Faga W., Moutinho E. 2013. The risks of an energy efficiency policy for buildings based solely on the consumption evaluation of final energy.International Journal of Electrical Power and Energy Systems; 44.1, pp. 70–77.

[201] TERI, High performance commercial Buildings in India: ECBC Complaint Building, Microsoft India Development Centre, Hyderabad. Supported by US Department of State and Bureau of Energy Efficiency (BEE).

[202] The Alliance to Save Energy (2000) Energy efficiency opportunities in Mexican hotels.url: http://www.ase.org/programs/inter…mexico/energy/energyefficiencymexico.htm accessed on 1.12.2000.

[203] Torrcellini P., Pless S., Deru M. 2006. Lessons learned from case studies of six high- performance buildings. NREL; pp. 1–151.

[204] Tulsyan S.,Mathur J.D., Vardhan J. 2013. Potential of energy savings through implementation of Energy Conservation Building Code in Jaipur city, India.Energy and Buildings; 58, pp. 123–130.

[205] Turner C., Frankel M. 2008. Energy performance of LEED for new construction buildings. New Buildings Institute. Vancouver, WA.

[206] UNDP. 2011. Energy efficiency improvements in commercial buildings. United Nations Development Programme India: Global Environment Facility Project Document.

[207] UNDP. 2012."Bureau of Energy Efficiency Confederation of Indian Industry Department of Economic Affairs Ministry of Power US Agency for International Development."

[208] UNEP Sustainable Buildings and Climate Initiatives, (2009), Buildings and climate change: Summary of decision-makers, UNEP DTIE Sustainable Consumption and Production Branch, Paris.

[209] Urge-Vorsatz, D., Cabeza, L.F., Serrano, S., Barreneche, C. and Petrichenko, K., 2015. Heating and cooling energy trends and drivers in buildings. Renewable and Sustainable Energy Reviews, 41, pp.85-98

[210] USAID, Energy Conservation Building Codes user Guide, Bureau of energy efficiency, USAID ECO-III Project, 2009.

[211] USAID.2010. http://eande.lbl.gov/sites/all/files/eco-iii_presentation_at_lbnl-dc_7_july_10-_final.pdf

[212] USEIA, International EnergyOutlook2010.U.S.Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S.Department of Energy, Washington, DC20585.

[213] Vedant Enterprises, Jaipur, http://solutions.3m.com/wps/portal/3M/en_US/Window_Film/Solutions

[214] W.A. Friess, K. Rakhshan, T.A. Hendawi, S. Tajerzadeh, Wall insulation measures for residential villas in Dubai: a case study in energy efficiency, Energy and Building 44 (2012) 26–32.

[215] Wang N., Boubekri M. 2011. Design recommendations based on cognitive, mood and preference assessments in a sunlit workspace. Light Res Technol; 43, pp. 55–72.

[216] Wang N., Chang Y.C., Dauber V. 2010. Carbon print studies for the energy conservation regulations of the UK and China. Energy and Buildings; 42, pp. 695–698.

[217] Wang Q., Holmberg S. 2015. A methodology to assess energy-demand savings and cost effectiveness of retrofitting in existing Swedish residential buildings.Sustainable Cities and Society; 14, pp. 254-266.

[218] Wang S.C., ChenY.L., LinH.B., ShenK.Y., HuangK.C. 2013. Realization of a high-efficiency T5 ballast with multi-dimming mechanisms based on lamp arc modeling. 8th IEEE Conference on Industrial Electronics and Applications (ICIEA), pp. 1077–1082.

[219] WBCSD.2007. www.wbcsd.org

[220] Weiss, W., I. Bergmann, and G. Faninger, 2005: Solar heating worldwide, markets and contribution to the energy supply 2003. IEA Solar Heating and Cooling Programme, Graz, Austria.

[221] Wetter M. 2011. A view on future building system modeling and simulation.BuildingPerformance Simulation for Design and Operation; pp. 1-28.

[222] Wong, P.W., Shimoda, Y., Nonaka, M., Inoue, M., Mizuno, M. 2008. Semi-transparent PV: Thermal performance, power generation, daylight modelling and energy saving potential in a residential application. Renewable energy; 33(5), pp.1024-1036.

[223] World Bank (2015) http://data.worldbank.org/indicator

[224] World Travel and Tourism Council.2015.Link www.wttc.org/research/economic-research/economic.../country-reports/

[225] Hotel Association, Jaipur www.hotelassociationofindia.com/j.html

[226] www.hvs.com

[227] Xu P., Joe H., Pengyuan Shen, Xiaowen Ma, Xuefei Gao, Qiaolin Xu, Han Jiang, Yong Xiang.2013. Commercial building energy use in six cities in Southern China Energy Policy 53 76–89

[228] Xu, L., Liu, J., Pei, J., Han, X. 2013. Building energy saving potential in Hot Summer and Cold Winter (HSCW) Zone, China—Influence of building energy efficiency standards and implications. Energy Policy; 57, pp.253-262.

[229] Yang H., Zheng G., Lou, C., Burnett J. 2004. Grid-connected building-integrated photovoltaics: a Hong Kong case study. Solar energy; 76.1, pp. 55-59.

[230] Yang L., Li Y. 2008.Cooling load reduction by using thermal mass and night ventilation, Energy and Buildings; 40, pp. 2052–2058.

[231] Yin, R., Xu, P. and Shen, P., 2012. Case study: energy savings from solar window film in two commercial buildings in Shanghai. Energy and Buildings,45, pp.132-140

[232] Yu S., Eom J., Evans M., Clarke L. 2014. A long-term, integrated impact assessment of alternative building energy code scenarios in China. Energy Policy; 67, pp. 626-639.

[233] Yu X., Wang R.Z., Zhai X.Q. 2011. Year round experimental study on a constant temperature and humidity air-conditioning system driven by ground source heat pump. Energy;36.2, pp.1309–1318.

[234] Zhai X. Q., YuX., YangY., WangR. Z. 2013. Experimental investigation and performance analysis of a ground-coupled heat pump system.Geothermics; 48, pp. 112–120.

[235] Zhao X., Ma C.,Gu P. 2012. Energy saving methods and results analysis in the hotel.Energy Procedia;14, pp. 1523-1527.

[236] Zhu, Y., 2006. Applying computer-based simulation to energy auditing: A case study. Energy and buildings, 38(5), pp.421-428

[237] Zmeureanu R. G., Hanna Z. A., Fazio P., Silverio J. G.1994. Energy performance of hotels in Ottawa. ASHRAE Transactions; 100.1, pp. 314-322.

[238] Zografakis N., Karyotakis K., Tsagarakis K.P. 2012. Implementation conditions for energy saving technologies and practices in office buildings: Part 1, Lighting.Renewable and Sustainable Energy Reviews; 16.6, pp. 4165–4174.

[239] Zuo J., Zhao Z. 2014. Green building research – current status and future agenda: A review Why? How? Why? What? Renewable and Sustainable Energy Reviews; 30, pp. 271–281.

[240] Haugaard, Per. Investigation and implementation of building simulation software toolmes - especially ESP-r. (Undersøgelse og anvendelse af bygningssimuleringssoftware toolmer - specielt ESP-r). July 2003. BYG DTU.

[236] https://www.iesve.com/software/ve-for-engineers/module/ModelIT

Publications :

1. Chedwal, R., Mathur, J., Agarwal, G. D., Dhaka, S. (2015). Energy saving potential through Energy Conservation Building Code and advance energy efficiency measures in hotel buildings of Jaipur City, India, Energy and Buildings, 92, 282–295. (Published).

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August 1994 to till date	Lecturer (Selection Scale) Department of Technical Education, Govt. of Rajasthan, Jaipur
July 2009 to till date	Ph.D. (Part Time)
July 2006 to June 2008	M. Tech. (Full Time)
Branch	Energy Engineering
Institute	MNIT, Jaipur
July 1989 to June 1994	B.E.
Branch	Mechanical Engineering
Institute	MNIT, Jaipur
Selection	Indian Engineering Services (1995)

Questionnaire – Hotel data

Annexure-I

Jaipur City (Composite Climate)

Date: Time:

1. Hotel building detail

Name						
Hotel category	Non-star	1	2	3	4	5
No of floors			No of rooms			
Address						
Email ID			Contact No.			

2. Building Specifications

Built up area (m^2)	Roof Area (m^2)	Conditioned area (m^2)	Unconditioned area (m^2)

3. Electricity consumption

Connected load (kW)	Maximum demand

Monthly energy consumption (kWh)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Diesel consumption (L)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

4. HVAC systems

System type	Unitary	Packaged	VRF	Central system
Air distribution	Direct	Ducted	CAV	VAV
Age				
No. & capacity (TR)				
COP				
Compressor type	Rotary	Screw	Reciprocating	Centrifugal
Cooling type &capacity	Air cooled		Water cooled	

5. Lighting

Type	Incandescent	FTL			CFL	LED	Other
		T5	T8	T12			
Watt							
No							
Total							

Questionnaire – Hotel data

6. Building Envelope

Wall					
Layer	1	2	3	4	5
Construction name					
Thickness (mm)					
Roof					
Layer	1	2	3	4	5
Construction name					
Thickness (mm)					

7. Window Glazing

Layer	1	2	3	4	5
Company					
Model					
Thickness (mm)					
Colour					
SHGC					
Uvalue					
VLT					

8. Miscellaneous

	Shading	Blinds	Louvers
Y/ N			

9. Major equipments

Equipments	**No.**	**Load/ capacity**	**Total laod**
Elevators			
Refrigerators			
Oven			
Pump			
Office equipment			
Other equipment			

10. Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb																								
	May																								
	Aug																								
	Nov																								
CA	Feb																								
	May																								
	Aug																								
	Nov																								

Questionnaire – Hotel data

11. Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb																								
	May																								
	Aug																								
	Nov																								
CA	Feb																								
	May																								
	Aug																								
	Nov																								
OS	Feb																								
	May																								
	Aug																								
	Nov																								

12. Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb																								
	May																								
	Aug																								
	Nov																								
CA	Feb																								
	May																								
	Aug																								
	Nov																								
OS	Feb																								
	May																								
	Aug																								
	Nov																								

13. Equipment schedule (%)

6:00am	7:00	8:00	9:00	10:00	11:00	12:Noon	1:00	2:00	3:00	4:00	5:00
6:00	7:00	8:00	9:00	10:00	11:00	12:MN	1:00	2:00	3:00	4:00	5:00

GR-Guest room, CA-Common area, OS- Office space

Signature (optional)

Annexure-II

Category-1 Hotel-1

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5
GR	Feb	80	76	56	43	40	35	24	20	20	20	20	24	35	43	55	74	78	80	81	80	80	80	80	80
	May	55	50	44	35	30	25	25	20	20	20	20	20	30	30	35	45	50	55	55	55	55	55	55	55
	Aug	65	60	60	50	43	40	32	30	30	30	30	30	35	35	40	46	52	55	60	65	65	65	65	65
	Nov	80	76	56	43	40	35	24	18	18	15	18	24	35	43	55	74	78	80	81	80	80	80	80	80
CA	Feb	55	60	75	80	70	50	45	60	70	65	50	40	40	55	60	70	70	40	30	20	20	20	20	20
	May	40	50	65	70	65	50	40	40	65	60	50	40	35	45	50	60	60	30	20	10	10	10	10	10
	Aug	45	50	65	65	65	50	40	40	65	60	50	40	40	45	50	60	60	30	25	25	20	20	20	20
	Nov	65	60	75	80	70	60	45	50	65	65	50	40	40	50	60	65	65	50	30	20	20	20	20	20

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5
GR	Feb	30	25	20	10	10	10	10	05	05	05	05	10	20	30	70	80	70	50	30	20	20	20	20	10
	May	25	20	15	10	10	10	05	05	05	05	05	10	10	20	50	60	60	40	25	20	10	10	10	10
	Aug	25	15	15	10	10	10	05	05	05	05	05	15	20	20	60	60	60	40	25	20	10	10	10	10
	Nov	30	25	20	10	10	10	10	05	05	05	05	10	20	30	70	80	70	50	30	20	20	20	20	10
CA	Feb	30	20	10	10	10	10	10	10	10	10	10	20	30	30	40	40	40	30	30	20	20	20	20	20
	May	20	10	10	10	10	10	10	10	10	10	10	20	20	20	30	40	40	30	30	20	20	20	20	20
	Aug	20	10	10	10	10	10	10	10	10	10	10	20	20	20	30	40	40	30	30	20	20	20	20	20
	Nov	30	20	10	10	10	10	10	10	10	10	10	20	30	30	40	40	40	30	30	20	20	20	20	20

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	23	22	19	21	22	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-1 Hotel-2

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	76	73	54	42	39	33	21	17	16	12	15	22	34	39	52	73	76	78	79	79	79	79	79	79
	May	52	48	43	33	28	22	21	19	18	17	16	19	28	27	34	44	48	52	52	52	52	52	52	52
	Aug	62	56	54	49	40	36	31	28	27	26	29	29	32	34	36	44	49	51	59	63	63	63	63	63
	Nov	76	74	53	42	36	33	21	14	14	14	15	23	33	40	51	72	75	76	80	80	80	80	80	80
CA	Feb	56	57	72	71	68	59	43	43	41	41	49	50	51	54	58	67	66	68	50	45	30	20	10	10
	May	38	47	61	69	63	46	38	37	63	57	46	39	32	41	49	57	56	29	18	7	9	7	6	6
	Aug	40	48	61	62	64	46	38	37	61	58	47	36	38	42	46	58	59	28	21	22	18	18	17	16
	Nov	55	58	70	78	67	59	41	48	61	58	48	37	38	46	58	62	61	48	27	16	16	15	14	14

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	28	22	19	8	7	7	6	3	2	1	4	8	16	27	66	79	79	46	27	18	18	17	17	9
	May	22	16	13	9	8	6	4	3	2	1	4	5	7	19	48	58	56	37	24	18	7	7	6	5
	Aug	23	11	12	9	8	7	1	3	4	0	0	13	17	19	58	58	56	39	23	17	6	6	5	5
	Nov	29	23	17	6	8	7	6	4	3	0	0	8	19	28	67	79	67	49	27	18	15	16	16	7
CA	Feb	26	17	11	9	8	7	6	6	6	6	8	19	28	27	39	39	40	29	28	16	16	15	10	10
	May	17	8	8	8	7	7	6	6	6	6	9	19	19	20	26	38	37	29	28	16	15	15	14	10
	Aug	18	9	8	8	7	7	6	6	5	5	8	17	17	19	26	39	40	29	29	16	16	16	15	12
	Nov	26	18	9	9	8	7	6	6	6	5	8	19	28	28	36	37	40	28	26	19	19	18	17	16

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	19	18	18	20	22	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-1 Hotel-3

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	78	74	54	40	37	32	21	16	16	15	15	21	32	40	53	72	76	78	78	78	78	78	78	78
	May	53	48	41	32	27	22	23	18	18	18	17	17	27	27	32	42	48	53	53	54	54	54	54	54
	Aug	63	58	58	47	40	37	29	27	28	28	27	27	32	32	37	43	49	53	58	64	64	64	64	64
	Nov	78	74	54	40	37	32	21	15	16	13	15	21	32	41	53	72	77	79	80	79	79	79	79	79
CA	Feb	52	57	72	78	68	48	43	57	67	62	48	38	38	53	57	67	67	37	28	18	18	18	18	18
	May	37	47	63	68	63	48	37	37	62	57	48	38	33	43	48	58	57	27	17	7	7	7	7	7
	Aug	42	47	62	63	63	48	38	38	62	57	48	38	38	43	48	58	58	27	22	22	17	17	17	17
	Nov	62	57	72	78	68	58	43	48	62	62	48	38	38	47	57	62	62	47	27	17	17	17	17	17

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	27	22	17	8	8	8	8	2	2	2	3	8	18	28	67	77	67	47	28	18	18	18	18	18
	May	22	17	13	8	8	8	2	2	2	2	3	8	8	18	48	58	57	37	22	17	10	10	10	10
	Aug	22	12	12	8	8	8	3	3	2	2	3	13	18	18	58	58	58	37	22	17	12	12	12	12
	Nov	27	22	17	8	8	8	8	3	2	2	3	8	18	27	67	77	67	47	27	17	15	15	15	15
CA	Feb	28	18	8	7	7	7	7	8	8	8	7	17	27	27	38	38	38	28	29	20	20	20	20	20
	May	18	8	7	7	7	7	8	8	8	8	7	17	17	17	27	37	38	28	28	10	10	10	10	10
	Aug	18	8	8	7	7	7	7	7	8	8	7	17	17	17	27	37	37	28	28	12	12	12	12	12
	Nov	28	18	8	7	7	7	7	7	8	8	7	17	27	28	38	38	39	29	29	15	15	15	15	15

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	23	22	20	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-2 Hotel-1

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	78	74	54	40	37	32	21	16	16	15	15	21	30	35	50	70	76	78	78	77	77	77	77	77
	May	53	48	41	32	27	22	23	18	18	18	17	17	27	27	32	42	48	53	53	54	54	54	54	54
	Aug	63	58	58	47	40	37	29	27	28	28	27	27	32	32	37	43	49	53	58	64	64	64	64	64
	Nov	78	74	54	40	37	32	21	15	16	13	15	21	32	41	53	72	77	79	80	79	79	79	79	79
CA	Feb	52	57	72	78	68	48	43	57	67	62	48	38	38	53	57	67	67	37	28	18	18	18	18	18
	May	37	47	63	68	63	48	37	37	62	57	48	38	33	43	48	58	57	27	17	7	7	7	7	7
	Aug	42	47	62	63	63	48	38	38	62	57	48	38	38	43	48	58	58	27	22	22	17	17	17	17
	Nov	62	57	72	78	68	58	43	48	62	62	48	38	38	47	57	62	62	47	27	17	17	17	17	17

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	26	20	18	10	10	10	10	5	5	5	5	10	20	28	67	77	67	47	28	18	18	18	18	18
	May	22	17	13	8	8	8	2	2	2	2	3	8	8	20	50	60	57	37	22	17	10	10	10	10
	Aug	22	12	12	8	8	8	3	3	2	2	3	13	18	18	58	58	58	37	22	17	12	12	12	12
	Nov	27	22	17	8	8	8	8	3	2	2	3	8	18	27	67	77	67	47	27	17	15	15	15	15
CA	Feb	28	18	8	7	7	7	7	8	8	8	7	17	27	27	38	38	38	28	29	20	20	20	20	20
	May	18	8	7	7	7	7	8	8	8	8	7	17	17	17	27	37	38	28	28	10	10	10	10	10
	Aug	18	8	8	7	7	7	7	7	8	8	7	17	17	17	27	37	37	28	28	12	12	12	12	12
	Nov	28	18	8	7	7	7	7	7	8	8	7	17	27	28	38	38	39	29	29	15	15	15	15	15

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
OS	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-2 Hotel-2

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb	80	75	55	40	35	33	23	10	10	10	17	25	34	40	50	72	77	78	80	80	80	80	80	80
	May	54	48	42	33	28	25	20	18	18	18	18	18	30	30	35	43	49	54	54	54	54	54	54	54
	Aug	64	58	58	48	40	35	30	30	30	30	30	30	35	35	35	44	50	53	59	63	64	64	64	64
	Nov	78	74	54	40	38	35	25	20	20	20	20	25	34	42	54	73	76	78	78	78	78	78	78	78
CA	Feb	40	60	74	79	65	48	45	59	65	65	49	45	38	50	50	50	50	35	30	10	10	10	10	10
	May	35	50	64	68	64	48	40	50	64	60	49	38	34	43	49	58	59	28	19	8	8	8	8	8
	Aug	45	50	64	64	64	50	40	35	60	58	48	40	40	43	48	60	60	29	24	24	19	19	19	19
	Nov	60	65	74	78	69	58	44	48	64	64	50	38	39	49	59	64	64	50	28	19	18	18	18	18

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb	29	24	18	8	8	8	9	4	4	4	4	9	20	28	65	80	70	45	29	15	15	15	15	15
	May	20	18	16	9	9	9	3	3	3	3	3	8	8	19	49	55	55	39	25	15	8	8	8	8
	Aug	24	15	15	8	8	8	3	3	3	3	5	15	25	25	59	59	59	35	25	18	8	8	8	8
	Nov	35	30	22	9	8	8	8	3	3	3	3	8	18	34	68	78	68	48	29	19	19	19	19	9
CA	Feb	28	18	8	8	9	9	9	9	9	9	9	20	28	30	38	38	38	28	29	19	19	19	19	19
	May	20	15	10	10	9	8	8	9	9	9	9	19	19	19	28	38	38	28	28	18	18	18	18	18
	Aug	25	8	8	9	9	9	9	8	8	8	8	19	19	19	30	35	35	28	28	18	18	18	18	18
	Nov	28	18	8	9	9	9	9	9	8	8	8	18	28	28	39	39	39	28	28	18	18	18	18	18

Thermostat temperature setting (^0C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	25
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	25
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
OS	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-2 Hotel-3

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	79	75	70	55	38	33	22	16	16	14	17	23	33	41	53	72	76	78	79	79	79	79	79	79
	May	54	49	44	33	28	23	23	19	19	19	10	10	25	30	33	43	48	52	54	54	54	54	54	54
	Aug	64	59	58	48	41	39	31	29	28	28	25	25	30	30	38	45	50	54	58	64	64	64	64	64
	Nov	79	75	55	40	38	33	22	25	25	15	15	20	33	40	53	73	77	79	80	80	80	80	80	80
CA	Feb	53	58	73	79	69	49	44	58	68	62	48	40	40	45	50	52	52	50	28	18	18	18	18	18
	May	38	48	64	69	64	48	38	38	64	59	49	38	33	43	49	59	59	29	18	8	8	8	8	8
	Aug	42	47	64	64	64	49	39	37	62	59	49	39	37	42	47	59	59	29	22	22	17	17	17	17
	Nov	62	58	74	79	69	59	44	48	63	63	49	39	39	48	58	63	64	48	28	18	18	18	18	18

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	20	22	25	10	10	9	9	4	4	3	3	9	19	29	69	79	69	48	28	10	10	10	10	10
	May	22	18	13	9	9	9	4	4	4	2	2	7	8	18	48	55	55	60	24	18	7	7	7	7
	Aug	22	13	13	9	9	9	4	3	3	3	3	12	17	17	55	55	65	40	22	15	7	7	7	7
	Nov	27	22	17	8	8	8	8	4	4	4	3	8	18	28	68	79	69	49	29	15	15	15	15	15
CA	Feb	27	17	8	8	8	8	8	8	8	7	7	18	29	29	39	39	38	28	28	25	25	25	25	25
	May	17	8	8	8	7	7	7	7	7	7	8	18	18	19	29	39	38	28	28	18	18	18	18	18
	Aug	18	8	8	8	7	7	7	7	8	8	8	18	18	18	28	39	39	28	28	20	20	20	20	20
	Nov	27	17	7	8	8	8	9	9	9	9	9	18	28	29	39	39	39	28	27	25	25	25	25	25

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
OS	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-3 Hotel-1

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
GR	Feb	85	77	57	44	42	37	26	20	20	16	19	25	37	45	57	76	80	82	83	81	81	81	81	81
	May	55	51	46	37	32	27	27	21	21	21	22	22	32	32	37	47	52	56	56	56	56	56	56	56
	Aug	65	61	62	52	45	41	33	31	32	32	31	32	37	36	42	47	54	56	62	66	66	66	66	66
	Nov	85	77	57	45	42	37	26	20	19	16	19	26	37	45	57	75	79	81	82	81	81	81	81	81
CA	Feb	55	62	77	81	71	51	46	62	72	67	52	41	41	56	61	72	72	42	32	22	22	22	22	22
	May	45	52	66	71	66	52	42	42	66	61	51	42	37	47	51	61	61	31	22	12	12	12	12	12
	Aug	50	53	66	66	66	51	41	43	68	61	51	41	43	48	53	61	61	31	28	28	23	23	23	23
	Nov	68	62	76	81	71	61	46	52	67	67	51	41	41	52	62	67	66	52	32	22	22	22	22	22

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	33	28	22	12	11	11	11	6	6	7	7	11	21	31	71	81	71	52	32	23	23	23	23	13
	May	28	22	17	11	11	11	6	6	6	8	8	13	12	22	52	61	61	41	26	23	13	13	13	13
	Aug	28	17	17	11	11	11	6	7	7	7	7	18	23	23	61	61	61	41	28	23	13	13	13	13
	Nov	33	28	23	12	12	12	12	6	6	6	7	12	22	32	72	81	71	51	31	23	23	23	23	13
CA	Feb	33	23	12	12	12	12	12	12	12	13	13	22	31	31	41	41	42	32	32	32	32	32	32	32
	May	23	12	12	12	13	13	13	13	13	13	12	22	22	21	31	41	42	32	30	30	30	30	30	30
	Aug	22	12	12	12	13	13	13	13	12	12	12	22	22	22	32	41	41	32	28	28	28	28	28	28
	Nov	27	17	7	8	8	8	9	9	9	9	9	18	28	29	39	39	39	28	32	32	32	32	32	32
OS	Feb	17	17	17	8	3	0	0	0	0	0	4	9	19	29	29	19	9	8	7	0	0	0	0	0
	May	17	18	18	9	0	0	0	0	0	0	0	0	18	28	28	18	8	8	7	0	0	0	0	0
	Aug	17	18	18	9	0	0	0	0	0	0	0	0	19	29	29	18	8	8	7	0	0	0	0	0
	Nov	16	16	17	7	3	3	0	0	0	0	8	9	19	29	29	19	9	8	8	0	0	0	0	0

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
OS	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-3 Hotel-2

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	82	78	58	46	43	38	27	20	20	17	21	27	38	46	57	76	80	81	81	81	81	81	81	81
	May	57	52	47	38	33	28	27	22	22	22	23	23	33	33	38	48	52	57	57	56	56	56	56	56
	Aug	67	62	62	53	46	43	35	33	32	32	33	33	38	38	43	49	55	57	62	66	66	66	66	66
	Nov	82	78	58	46	43	38	27	21	20	17	21	27	38	45	57	76	79	81	82	81	81	81	81	81
CA	Feb	58	63	78	82	72	52	47	63	73	68	52	42	42	57	63	73	73	43	32	22	22	22	22	22
	May	43	53	67	72	67	52	43	43	68	63	52	42	37	47	52	62	63	33	23	13	13	13	13	13
	Aug	48	53	68	67	67	52	42	42	68	63	52	42	42	47	52	62	62	33	28	28	23	23	23	23
	Nov	68	63	78	82	72	62	47	52	68	68	52	42	42	53	63	68	68	53	33	23	23	23	23	23

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	33	28	23	12	12	12	12	8	8	8	7	12	22	32	73	83	73	53	32	22	22	22	22	12
	May	28	23	17	12	12	12	8	8	8	8	7	12	12	22	52	62	63	43	28	23	13	13	13	13
	Aug	28	18	18	12	12	12	7	7	8	8	7	17	22	22	62	62	62	43	28	23	13	13	13	13
	Nov	33	28	23	12	12	12	12	7	8	8	7	12	22	33	73	83	73	53	33	23	23	23	23	13
CA	Feb	32	22	12	13	13	13	13	12	12	12	13	23	33	33	42	42	42	32	31	21	21	21	21	21
	May	22	12	13	13	13	13	12	12	12	12	13	23	23	23	33	43	42	32	32	21	21	21	21	21
	Aug	22	12	12	13	13	13	13	13	12	12	13	23	23	23	33	43	43	32	32	21	21	21	21	21
	Nov	32	22	12	13	13	13	13	13	12	12	13	23	33	32	42	42	41	31	31	21	21	21	21	21
OS	Feb	23	23	22	12	6	1	1	2	2	2	7	11	21	31	31	21	11	12	12	3	3	3	3	3
	May	23	22	22	11	1	1	1	0	0	0	0	0	22	32	32	22	12	12	13	0	0	0	0	0
	Aug	23	22	22	11	0	0	0	0	0	0	0	0	21	31	31	22	12	12	13	3	0	0	0	0
	Nov	21	21	22	13	8	8	3	0	0	0	12	11	21	31	31	21	11	12	12	0	0	0	0	0

Thermostat temperature setting (^{0}C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	25
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	25
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
OS	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35

Category-3 Hotel-3

Occupancy schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	78	74	54	40	37	32	21	16	16	13	15	21	32	40	53	72	76	78	80	79	79	79	79	79
	May	53	48	41	32	27	22	23	18	18	18	17	17	27	27	32	42	48	53	53	54	54	54	54	54
	Aug	63	58	58	47	40	37	29	27	28	28	27	27	32	32	37	43	49	53	58	64	64	64	64	64
	Nov	78	74	54	40	37	32	21	15	16	13	15	21	32	41	53	72	77	79	80	79	79	79	79	79
CA	Feb	52	57	72	78	68	48	43	57	67	62	48	38	38	53	57	67	67	37	28	18	18	18	18	18
	May	37	47	63	68	63	48	37	37	62	57	48	38	33	43	48	58	57	27	17	7	7	7	7	7
	Aug	42	47	62	63	63	48	38	38	62	57	48	38	38	43	48	58	58	27	22	22	17	17	17	17
	Nov	62	57	72	78	68	58	43	48	62	62	48	38	38	47	57	62	62	47	27	17	17	17	17	17

Lighting schedule (%)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	08:00	9	10	11	12	1	2	3	4	5
GR	Feb	27	22	17	8	8	8	8	2	2	2	3	8	18	28	67	77	67	47	28	18	18	18	18	18
	May	22	17	13	8	8	8	2	2	2	2	3	8	8	18	48	58	57	37	22	17	10	10	10	10
	Aug	22	12	12	8	8	8	3	3	2	2	3	13	18	18	58	58	58	37	22	17	12	12	12	12
	Nov	27	22	17	8	8	8	8	3	2	2	3	8	18	27	67	77	67	47	27	17	15	15	15	15
CA	Feb	28	18	8	7	7	7	7	8	8	8	7	17	27	27	38	38	38	28	29	20	20	20	20	20
	May	18	8	7	7	7	7	8	8	8	8	7	17	17	17	27	37	38	28	28	10	10	10	10	10
	Aug	18	8	8	7	7	7	7	7	8	8	7	17	17	17	27	37	37	28	28	12	12	12	12	12
	Nov	28	18	8	7	7	7	7	7	8	8	7	17	27	28	38	38	39	29	29	15	15	15	15	15
OS	Feb	17	17	18	8	4	0	0	0	0	0	3	9	19	29	29	19	9	8	8	0	0	0	0	0
	May	17	18	18	9	0	0	0	0	0	0	0	0	18	28	28	18	8	8	7	0	0	0	0	0
	Aug	17	18	18	9	0	0	0	0	0	0	0	0	19	29	29	18	8	8	7	0	0	0	0	0
	Nov	19	19	18	7	2	2	0	0	0	0	8	9	19	29	29	19	9	8	8	0	0	0	0	0

Thermostat temperature setting (^0C)

Space	Month	6am	7	8	9	10	11	12	1	2	3	4	5	6	7	8:	9	10	11	12	1	2	3	4	5am
GR	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
CA	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	22	22	22	22	22	22	23	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	23	23	23	23	23	23	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
OS	Feb	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18
	May	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Aug	26	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
	Nov	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	20	18	18	18	18	18

Equipment schedule (%)

:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:Noon	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm
35	70	90	95	90	70	40	30	25	20	20	20
6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:0pm	12:00MN	1:00am	2:00am	3:00am	4:00am	5:00am
30	50	60	50	50	35	35	35	35	35	35	35