MODELING OF EXISTING GOVERNMENT BUILDINGS FOR ECBC 2018-R COMPLIANCE

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By

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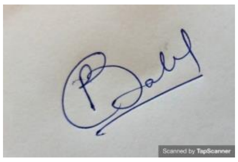
DECLARATION

I declare that this thesis submission titled ‘MODELING OF EXISTING GOVERNMENT BUILDING FOR ECBC 2018-R COMPLIANCE' has been prepared by me under the guidance of Devender Kumar Saini Associate Professor, Department of Electrical Engineering UPES. No part of this thesis has formed the basis for the award of any degree or fellowship previously.



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ABSTRACT

Techno-economic viability of rooftop solar PV systems for Indian residential buildings was undertaken in this study, 34 major cities including 15 state capitals were considered for the RET screen simulation. In addition to location, utility grid tariff, system cost, and other economic parameters were plugged into RETscreen simulation software for ascertaining the viability of 3 kWp and 2 kWp rooftops solar PV with and without subsidy. The study concluded that in the absence of subsidy, 2kWp rooftop solar PV could not achieve grid parity in any Indian state. However, in the case of 3 kWp rooftops solar PV, 5 states could match the grid tariff even in the absence of state subsidy and 7 states could achieve grid parity with government subsidy. Yet, most Indian states could not achieve grid parity for residential rooftop solar PV.

The Energy Performance Index (EPI) is an indicator by the Bureau of Energy Efficiency (BEE) for awarding energy stars to the building. The study discovers a large EPI gap exists for residential buildings to attain a five-star energy label. Based on the EPI gap, residential energy tariffs, the energy consumption, energy a grid-integrated rooftop solar Photo Voltaic (PV) system was considered for bridging this EPI gap for the higher energy star label.

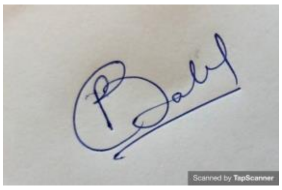
A case study of a residential building in Delhi was undertaken to explore the potential of grid-connected rooftops solar photovoltaic. RETScreen simulation software was used to assess the techno-economic potential of a grid-integrated, 3 kWp rooftops solar PV plant. The study establishes that by using a grid-integrated rooftop solar PV an additional two energy stars can be achieved by existing buildings. 3 kWp rooftop solar PV economics with a subsidy is a viable retrofit and invested amount can be recovered within 3 to 7 years in Indian cities. The Energy Star label to the residential building is awarded against the notified standard by the regulatory body and Electric Vehicle (EVs) has not been catered to as a plugged load for the residential buildings. Energy consumption of an existing residential building is taken from a study already carried out and is compared with the requirement of the Indian residential star labeling program with EV as a plugged load. An annual energy gap of 6060 kWh for the existing residential buildings under consideration in this study for five-star building energy labels increased to 7784 kWh if the EV load is added to the building load. The residential building will lose two energy stars if it caters to EV load and for bridging this energy gap, replacement of existing electrical appliances with five-star rated energy appliances, employing grid-connected rooftop solar PV, and retrofitting of the building envelope are considered. The techno-economic potential of rooftop solar PV and building envelope retrofitments for existing residential buildings are explored using RETScreen and e-QUEST software respectively. The study establishes that the installation of rooftop solar PV can cater to additional EV load and can bridge half and three-fourths of the energy gaps for achieving five energy stars for an existing building with EV and without EV respectively and it is the most economical among the options explored in this study. Target Energy Performance Index (EPI) is achievable by high-end energy consumers (12000 kWh/year) by additional measures of the replacement of inefficient electrical appliances and building envelope retro fitment in addition to the installation of rooftop solar PV.

ACKNOWLEDGEMENT

I take this opportunity to express my sincere thanks to my supervisor Dr. Devender Kumar Saini for the guidance and support. I would also like to express my sincere gratitude towards my early-stage co-supervisor Dr. Kamal Bansal who along with Dr. Madhu Sharma helped me with topic selection as well as in setting the research objectives. It was a privilege and a great experience working under the guidance of all the above supervisors.

I am also grateful to the Indian Air Force for allowing me to undertake this research. Further, I am very thankful to the UPES for providing me the opportunity of pursuing a Ph.D. in a very cordial environment.

In the end, I would like to acknowledge the contribution of my wife, children, and parents, without their support and sacrifice this work would not have been possible.



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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIXES

NOMENCLATURE

Acronyms

BEE Bureau of Energy Efficiency

CAGR Compound Annual Growth Rate

CCE Cost of Conserved Energy

CEA Central Electricity Authority

CO_2 Carbon dioxide

ECBC Energy Conservation Building Code

EER Energy Efficiency Ratio

EIA Energy Information Administration

EPI Energy Performance Indicator

EV Electric Vehicle

FAME Faster Adoption and Manufacturing of Electric Vehicles

GW Giga Watt

IEA International Energy Agency

ISEER Indian Seasonal Energy Efficiency Ratio

kWh Kilo Watt Hour

kW_p Kilo Watt peak

kVA Kilo Volt Ampere

MMRE Ministry of New and Renewable Energy

Mtoe Million tons of oil equivalent

MW Mega Watt

PAT Perform Achieve and Trade

PP Payback Period

PPP Purchasing power Parity

NPV Net Present Value

SPV Solar Photovoltaic

TWh TerraWatt Hour

TPES Total Primary Energy Supply

CHAPTER 1

INTRODUCTION

1.1 BRIEF BACKGROUND

The current trends of energy shortage and awareness of many environmental (GHG emissions) related issues have raised concerns worldwide about energy consumption and related energy efficiencies. As per the British Petroleum (BP) report the global primary energy demand has increased more in non-OECD countries as compared to OECD and EU countries in the period 2007-17. The consumption of primary energy by the country groups is tabulated below[1].

Table 1.1 Consumption of Primary energy by different country groups

Country Group	(Primary energy-Mtoe) Yr 2007	(Primary energy-Mtoe) Yr 2017
OECD	5693.9	5605.5
Non-OECD	5894.5	7906.1
EU	1823.9	1689.2
Total	**11588.4**	**13511.2**

As per a study, global oil consumption will increase by around 30% from 2007 to 2035, while other fossil fuels (coal and natural gas) consumption will grow by 50%. As per the IEA in business as usual scenario, the emissions of carbon dioxide (CO2) associated with energy-related activities will increase by a hundred percent by 2050 [2]. The building sector alone contributes more than 40% of the total energy consumption. The CO_2 emission from the residential sector of the top ten countries/groups is shown in Figure 1.1[3].

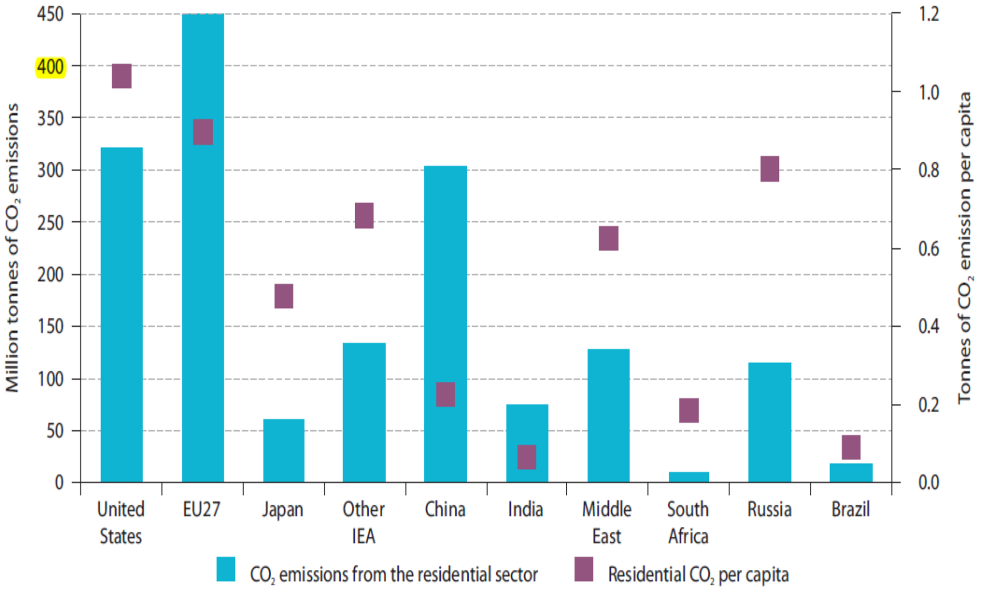

Figure 1.1 Energy consumption by the residential sector in different countries

The consumption status of different sectors of India is represented in

Figure 1.2. As per IEA data, India's residential sector is the leading consumer of electricity and the consumption has nearly grown a hundred percent between 2010 and 2019 growth of different sectors in this period is represented in Figure 1.3 [3].

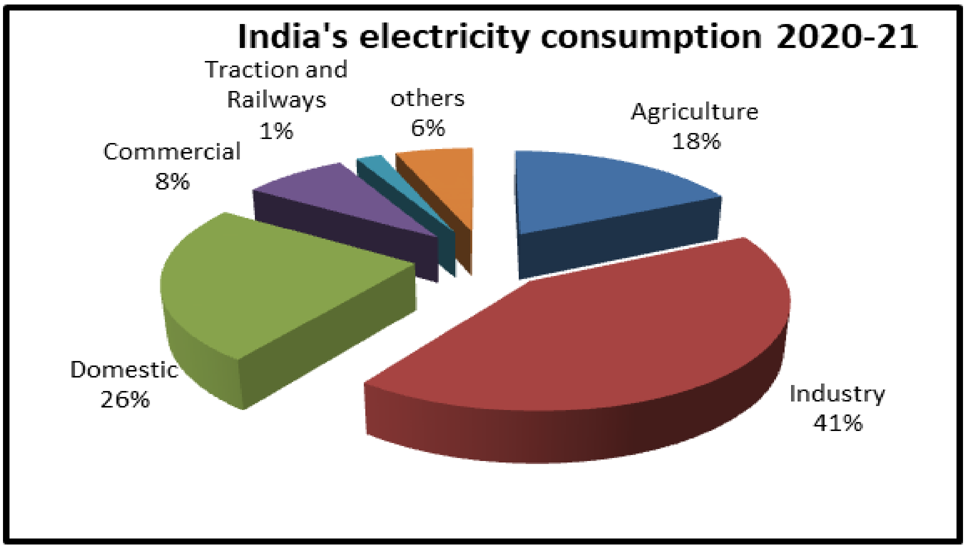

Figure1.2 Electricity consumption by different sectors in India (2020-21)

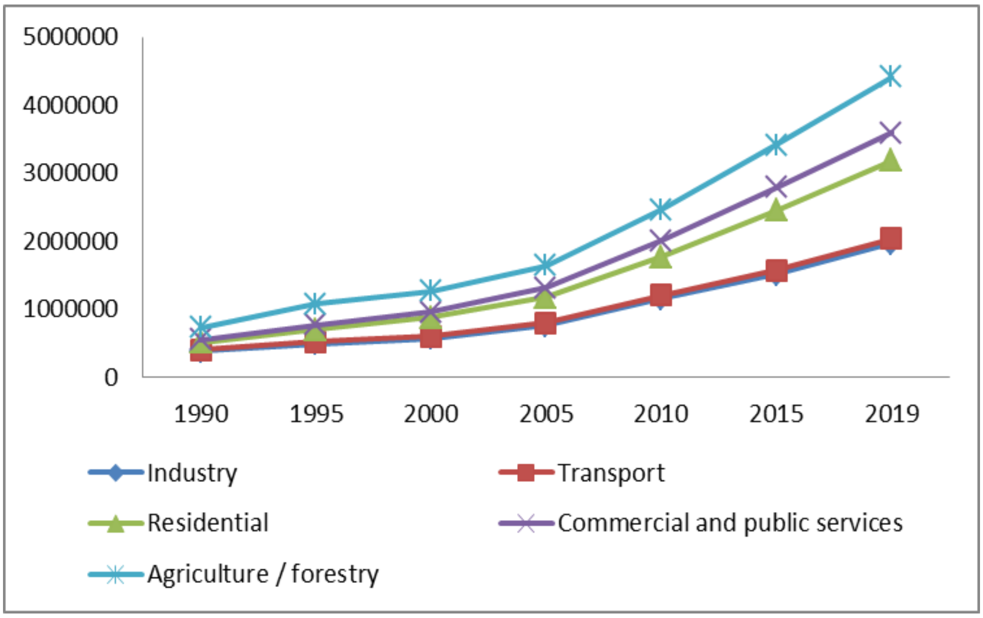

Figure 1.3 Increase in electricity consumption by different sectors (1990-2019)

Standard and Labeling (S&L) is a policy instrument adopted by countries to increase awareness of the energy performance of appliances equipment and buildings among consumers. S&L aims to channel consumers' purchases towards energy-efficient products by providing Energy Star information on the products. This is also extended to the building sector where building components have energy labeled so that building energy consumption matches the approved design.

India promulgated the Energy Conservation Building Code (ECBC) in 2007 to improve the energy efficiency of commercial buildings. Initially, this code was applied to all buildings with plugged electrical loads of more than 500 kW /contact demand of more than 600 kVA. In 2017, the code was modified for building/building complexes with an electrical load of more than 100 kW/ contract demand of 120 kVA were brought into the ambit of ECBC. Energy code provides design guidelines for improving building envelope for better energy efficiency. In 2018, a residential buildings energy code was introduced and it applies to all the residential buildings that are built on plot areas greater than or equal to 500 m^2 [4]. Star labeling program for residential buildings was also introduced in India to improve energy efficiency in the residential buildings sector [5]. For applying Energy Star for a residential building, there is no lower limit on the building built-up area or minimum connected electric load. The Energy Performance Indicator (EPI) is taken as an indicator for awarding the star label where building annual electricity consumption/m^2 is compared with benchmarked EPI promulgated by the Bureau of Energy Efficiency (BEE).

1.2 SCOPE & FOCUS OF THE STUDY

Although some guidelines are available for reducing the energy consumption of a residential building there is no holistic approach to address the potential of energy saving through active and passive measures in the Indian context for achieving the desired energy star label. Techno-economic analysis of the measures is to be gauged so that the Energy Star label for residential buildings is achieved through effective cost optimization. Installation of rooftop solar PV has been impetus by the Indian government and a flat 30% subsidy is extended for installation of rooftop solar PV up to 3 kW. Grid parity of rooftops which has not been explored by any of the studies in the Indian context can also be examined for achieving higher energy stars.

1.3 RELEVANCE OF THE STUDY

The study aims to address a live problem that is being faced by the government's existing residential buildings in attaining the energy star as proposed by the Bureau of Energy Efficiency (BEE). The cost associated with the retrofitting of the building needs optimization so that the ownership cost of the building Energy Star is minimised.

1.4 OBJECTIVE OF THE STUDY

- ✓ To propose a cost-effective solution for attaining the desired energy stars by residential buildings in hot and dry climates.
- ✓ Analysing the impact of EVs on building energy Stars and exploring the mitigation of this scenario, as an Electric Vehicle (EV) is not considered a plugged load for the Building Star label program.

1.5 OVERVIEW OF STRUCTURE

The structure of the thesis progresses from identifying problems and culminates by presenting workable solutions to mitigate the problem. Further, a summary of each chapter is described below.

Chapter 1 provides a brief introduction to energy usage and the policies initiated by the Indian government in the building sector. The scope of ECBC 2007 and 2017 and its scope are mentioned in this chapter. The study objectives derived and mentioned are mentioned here. The chapter also discusses the Scope, objectives, and relevance of this study.

Chapter 2 covers the literature survey covering a comprehensive study on the application of renewable energy in the building sector. The scope of the literature survey includes a wide range of subjects dealing with the application of solar PV in the building sector. The use of PV systems and their economics have also been discussed and compared with the conventional grid. The literature survey also discusses the barriers to rooftop solar PV in the building sector.

Chapter 3 discusses the research design and methodology. Based on deductions drawn from various topics in the literature survey it was found that the building energy stars were recently introduced for residential buildings and still not adopted by the existing residential building owners. Based on inferences drawn from the literature survey the research gaps have been identified. The problem statement was formulated.

Chapter 4 explains the concept behind building energy star grading in India. The chapter explores the economic viability of rooftop solar PV for residential buildings in the Indian context through RETscreen simulation software. The chapter also took the subsidy under consideration for analyzing its effect in achieving grid parity. Based on the outcome, Indian states are mapped for grid parity with subsidy and without subsidy scenarios.

Chapter 5 explains the methodology for achieving star grading of existing residential buildings by employing grid-integrated rooftop solar PV. For gauging the energy consumption of an existing building, a case study is undertaken where two years of energy consumption data of residential buildings in Dwarka, New Delhi are analyzed. The chapter also explores with the help of simulations, the technical feasibility and economic viability of rooftop solar PV for residential buildings in different states of India.

Chapter 6 evolved a mitigation methodology process flow. The study concludes that the first step towards mitigating the impact of Electric vehicles (EV) on building energy consumption and its effect on energy star grading of buildings. Different measures were analyzed through simulation software and techno-economic analysis carried out for the cost optimization for upgrading the energy stars for the building in EVs and without EVs scenarios.

Chapter 7 summarizes and concludes the findings. The chapter also provides recommendations on the future scope of work.

CHAPTER 2

LITERATURE SURVEY & CASE STUDY

2.0 PROLOGUE

This chapter encompasses the literature review undertaken for the study. The literature review has been divided into different sections as per the scope of the study. The literature review includes papers from leading journals, government websites, national and international reports on the subject. For the journal paper selections were searched and selected from Google Scholar with the combination of words relevant to the study. In this exercise, more than 150 papers were examined and the same are analysed to find the research gap. The relevant papers which are used for carrying out the study are suitably cited in the relevant chapters.

2.1 SCOPE OF LITERATURE SURVEY

The literature survey for exploring energy-saving measures in the building sector has been undertaken to identify and understand the economics of implementing renewable energy in the building sector. **The scope of the literature survey included a wide range of subjects dealing with the application of renewable energy in residential buildings.** The following areas were explored in the literature survey: -

- ✓ Global initiatives for establishing building energy codes.
- ✓ India’s initiative for establishing building energy codes.

- ✓ Building integrated rooftop Solar PV.
- ✓ Modeling and simulation of Building energy code compliance.

2.2 ESTABLISHING BUILDING ENERGY CODES - A GLOBAL PERSPECTIVE

High energy consumption of existing buildings is noted around the world Therefore, retrofitment of the existing buildings is to be undertaken for curtailing the energy consumption of buildings [6]. A mix of technologies helps in reducing the energy consumption of buildings [7]. Green buildings reduce energy consumption to a great extent but still, the green building market is quite low [8].

Energy Information Administration (EIA) reported that the implementation of energy codes and the latest energy efficiency standards in the US would decrease the energy consumption of the building by 3.6 quadrillions of BTU [9]. A study of the implementation of the building code in Hong Kong suggested that the code not only reduces building energy consumption but also curtails air Pollution [10]. Through Chinese national building standards, public buildings can save 62% of energy [11]. Florida's residential energy code has resulted in a decrease in electricity consumption and a 6 percent decrease in natural gas consumption [12] By implementing of passive energy strategy high-rise apartments in Hong Kong can have an energy savings of 31.4% [13]. As per the study, an energy-efficient building envelope design can result in saving 35% and 47% of total and peak cooling demands respectively [14]. A study in Greece shows that providing insulation for walls, roofs, and floors reduced energy consumption between 20% and 40% [15]. Energy savings potential measures have many financial; institutional and administrative barriers [16].

Building energy codes are also referred to as “energy standards for buildings", "thermal building regulations", "energy conservation building codes" or "energy efficiency building codes”. These codes have been developed to encourage awareness and innovation in building design. In addition, these codes provide a framework for the regulatory body to exercise a degree of control over building design. This policy instrument is adopted by many states for improving energy efficiency in the building sector. The status of the availability of building codes for new buildings across the globe is shown below [17]

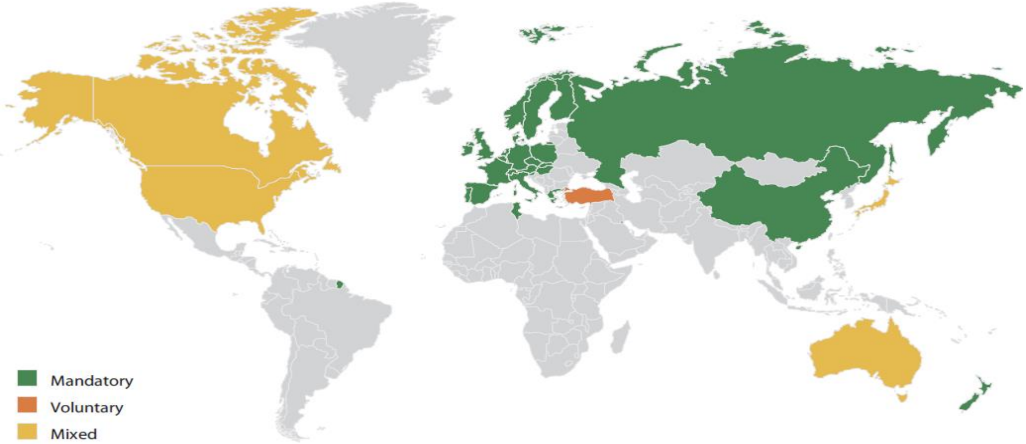

Figure 2.1 Availability of building code for new buildings across the globe [17]

Building codes and efficiency standards provide the energy efficiency yardstick for retrofitting and other energy efficiency measures for an existing building. The status of the availability of building codes for existing buildings (retrofitment) across the globe is shown below

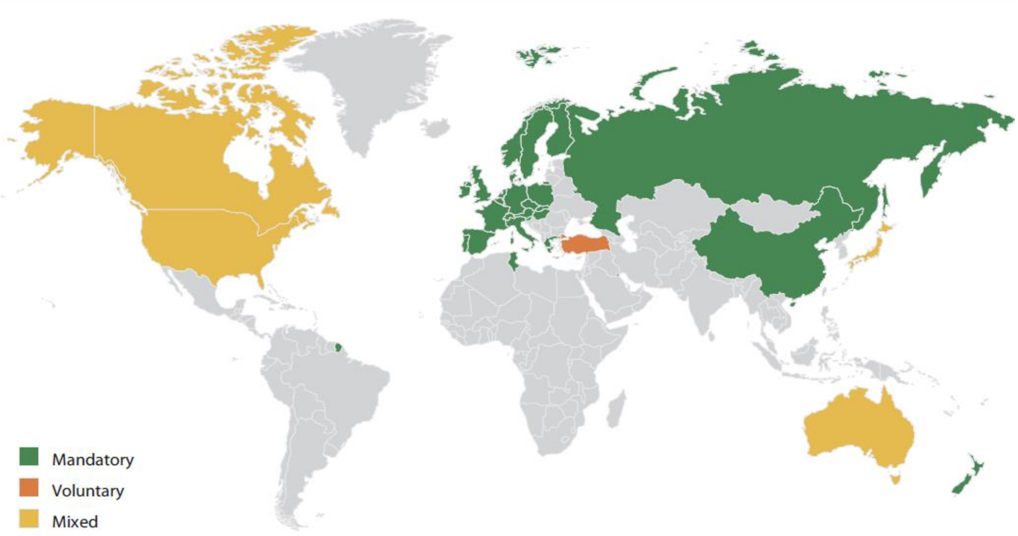

Figure2.2 Availability of building code for existing buildings across the globe [17]

A study of the Energy Star building in Arizona found that an energy-certified building consumes 8% less energy [18]. A case study highlighted the effectiveness of the Energy Star-R program effectiveness, implementation of the Florida Building Code (FBC) 1997 and FBC 2001 could save more than 10% and 20% percent energy respectively [19]. A study suggests that the top 25% of the buildings in Singapore are also eligible for Energy Stars recommended by the US [20]. Office buildings with Energy Star demand nearly 3 to 5% higher rental premium and with double certification, this premium further increases to 9% [21]. In Egypt, rooftop PV can reduce energy bills in the range of 19% to 61% [22]. A simulation study for a residential building in a Central American tropical location establishes that a passive cooling design strategy significantly reduces the risk of overheating the building [23]. A simulation study reported cooling demand savings of between 26% and 33% by employing passive cooling strategies [24].

2.3 INDIA’S INITIATIVE FOR ESTABLISHING BUILDING

The electricity generation and distribution framework for India is provided by its Electricity Act 1910. After independence, the country's new policies were made to provide impetus to social progress and development by ensuring a supply of electricity, oil, and coal. Energy conservation started in 1970 with a focus on reducing the import of petroleum by reducing consumption. The Working Group outlined the National Energy Policy, and the report was submitted by the group in 1979 which presented the energy scenarios encompassing future energy requirements, in addition, the report also suggested measures to optimize energy usage in India. In 1981, the Inter-Ministerial Working Group was formed for the Energy Conservation drive in the country. The group carried out energy audits of different sectors and estimated that Rs19.25 billion could be saved by investing in energy-saving technologies. In 2001, the Energy Conservation Bill was enacted by the Indian parliament, and the Bureau of Energy Efficiency (BEE) was constituted in 2002 with the mandate of steering energy efficiency in the country through different policies. The important milestones between 1970 and 2020 in the energy conservation initiatives for India are illustrated in Figure 2.3.

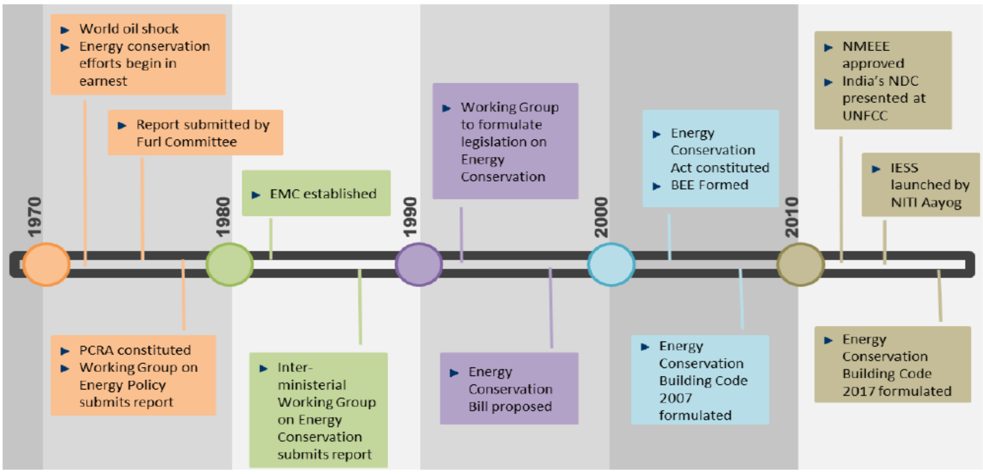

Figure 2.3 India's initiative in energy conservation [25]

Between 2005 and 2015 the residential and commercial building floor area doubled and it is estimated by 2030, it will increase to 7.0 billion m^2 and 1.5 billion m^2 respectively [8]. To enhance energy efficiency in the commercial building sector, the Government of India (GoI) promulgated the Energy Conservation Building Code (ECBC) in 2007. By implementing ECBC suggestions, small buildings can save up to 40% on energy consumption. The energy-saving potential from thermal adaptation is around 16% [26]. Implementing ECBC in Gujarat buildings could save 419,800 GWh between 2010 and 2050, which is equivalent to adding 134,400 MW of electricity generation. Parallel implementation of ECBC in residential buildings in addition to commercial buildings can result in savings of 193,700 GWh and $32 billion [27]. A study estimated that merely changing the set point of air-conditioning and changing the lighting design in all new commercial buildings could result in savings of 7500 GWh/year. Window design, shading, and providing wall and roof insulation as per ECBC norm could yield additional savings of 5900 GWh/year and 450 GWh/year respectively [28]. In 2012, the energy efficiency labeling requirement for a five-star energy air-conditioner was 3.1 (EER). This is 2017 and corresponds to a one-star air-conditioner. The EER is dynamic and revised after a period as a result the average air-conditioner EER has improved from 2.5 in 2010 to 3.3 in 2017.

In the year 2018, sixty percent of room conditioners and a hundred percent of ceiling fans sold in the market were 5-star gradings. These star-labeling appliances have resulted in a saving of 121.29 billion units since 2011[29]. India's Draft National Electricity Policy (NEP) entailed the provision of electricity at an affordable cost to all its citizens. The government intends to reduce the emissions intensity by 33% - 35% by the year 2030 taking the year 2005 as the benchmark and it is also aiming to have 40% of its electricity production from renewable energy resources thus reducing the fossil fuel-based dependency on electricity [30].

ECBC is voluntary where state and Urban Local Bodies (ULB) must play a larger role in implementation in their area of jurisdiction. As per the data available till 2017, the code was promulgated by nine states and it had been adopted by ULBs of two states only [31]. Due to no incentive attached to the building code and customer misalignment of total ownership costs most of the ULBs have avoided the enforcement of ECBC as part of regulatory requirements [32] If the ownership of the ECBC implementation is taken by the ULBs, it will improve property tax and will also open and bring new businesses to cities. Research with the cost-benefit analysis of the implementation of ECBC would educate residential building customers and this will give impetus across 4000 ULBs in India for the adoption of ECBC [33]. A study of different categories of commercial buildings in Jaipur

City (India) predicted that the implementation of ECBC can save energy by up to 42% [34].

In Ahmadabad City, a building can reduce its cooling load by 31% through the implementation of the ECBC guidelines for envelope design [35]. A similar study of ECBC implementation in the hotel buildings in Jaipur shows that buildings can easily save energy in the range of 18.42-37.2%, whereas with the implementation of advanced energy-saving technology, a building can save energy in the range between 53.92-61.75%. The invested amount can be recovered within 2.39 to 6.41 years, whereas for advanced energy-saving technology measures it is between 4.22 and 5.11 years [36]. The simulation result predicted that by the implementation of energy conservation measures recommended by ECBC, small buildings in India can save up to 40% energy as compared to the buildings built as per the business-as-usual practice [27]. Passive measures for the compliance of the build energy codes depend on are most cost-effective as they require minimal or zero investment.

Planting trees in the area near to building reduces the heat gain of the building envelope as nearly 10% of solar radiation is reflected by leaves and absorb about 70%. the building envelope is heated by the remaining 20% of solar energy [37].

In a study, it was found that on weekends an average of 23% of the buildings' energy is wasted in the unoccupied part of the building [38]. Adaptive temperature is a function of environmental temperature and a substantial amount of energy can be saved by fixing the thermostat temperature to adaptive temperature. For the tropical and humid environment of Thailand, the adaptive temperature range for naturally ventilated and air-conditioned office buildings should be 27.4˚C and 24.7˚C respectively [39]. A study of office buildings in Japan suggested that the thermal comfort temperature should be 27.2˚C [40].

In a similar study for the air-conditioned office buildings in Miami and San Francisco city of USA, the thermal set-point was found to be 24˚C and 21˚C for summer and winter respectively [41]. In another lab-based study of air-conditioned offices for seven different climatic zones of the USA, the thermal set-point was found to be 24˚C and 21˚C for summer and winter respectively [42]. A lab study of residential buildings in Bangalore, India inferred different thermal comfort temperature is between 20°C – 23.33˚C and 22.22°C – 26.66˚C for winter and for summer respectively [43]. In an experiment for residential buildings in Chennai thermal comfort band is between 27.6°C – 30.5˚C and 26°C – 31.8˚C for winter and summer respectively. [44]. For Hyderabad, the adaptive temperature range is between 26°C – 32.45˚C; whereas, for the same city ASHRAE suggested 23°C – 26˚C and 21°C – 23˚C for summer for winter respectively [45].

Deductions: A literature review on Indian building code ECBC 2017 has established that code compliance results in substantial energy saving, and code compliance is economically viable. However, no study is available for converting existing government buildings to ECBC-compliant through retro-fitment. The Indian initiative for implementing the codes is at its nascent stage. Considering the enormous potential available in this area, concerted efforts must be made to exploit this vast untapped potential through optimization of the methods available.

2.4 BUILDING INTEGRATED ROOFTOP SOLAR PV

A study predicts that the EU rooftops could be exploited for the generation of energy. Installation of rooftop solar PV could generate 680 TWh of electricity annually which is nearly one-fourth of electricity consumption and it is cost-effective for two-thirds of the consumers [46]. A similar study in Andalusia (Spain), suggests that rooftop solar PV could meet three-fourths of residential energy [47]. Lethbridge, a Canadian city has a rooftop solar PV that has the potential of 300 GWh/year which can meet 38% of its annual electricity consumed and is a better economic option as compared to the conventional grid [48]. In the US, rooftop solar PV potential was analyzed for 51 cities, and with state subsidy 18 could match the grid supply [49]. A similar study for the city of Al-Khobar in Saudi Arabia recommends that by merely utilizing one-fourth of the solar PV roof area, the residential apartment can cater for one-fifth of its electricity, and shading by PV panels reduces cooling load by 2% [50]. Socket parity by solar PV is not been achieved by the majority of the US states and only six states with subsidies could achieve socket parity [51]. A study establishes that a grid-connected residential solar PV system is feasible in Malaysia [52] A study establishes that a 5 kWp solar PV on a residential building system in Egypt can meet nearly two-thirds of the energy requirement [53]. A study of the rooftop solar photovoltaic potential for Mumbai (India) suggests that it can meet 12.8–20% of the daily energy demand [54]

The ECBC implementation in the Indian different locations countries into composite, hot & and dry, warm and humid, cold and temperate climatic regions, and the availability of global solar radiation for India is given below.

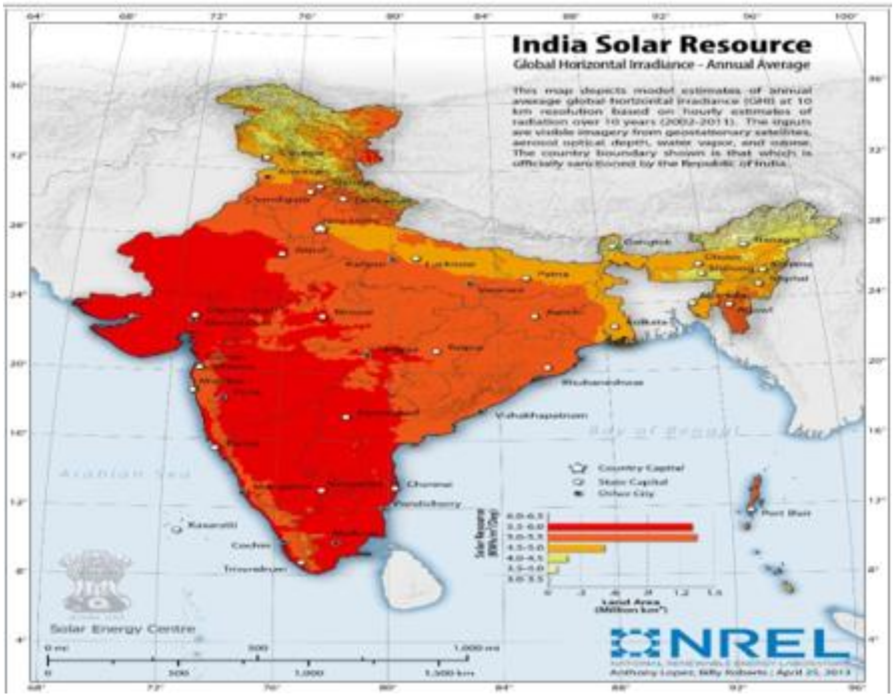

Figure 2.4 Global solar radiation map for Indian states [55]

A Study establishes that 6.4 kW rooftop solar PV in Ujjain city (India) in addition to meeting consumer demand can also feed surplus energy of 8450 kWh/year into the grid [56]. Roof-based cooling load is reduced between 73% and 90% by commissioning a rooftop solar PV system [57]. The invested amount on the installation of a 110 kWp rooftop solar PV system in the city of Bhopal (India) can be recovered within 8.2 years [58]. The net Present value of a grid-connected solar PV system becomes zero for the installation rating between 1.8 kWp and 3.4 kWp, the cost of energy is inversely proportional to the rating of the rooftop solar PV system [59].

Deduction: In India, rooftop solar PV has great potential in bridging the energy gap between desired star-building energy consumption and present energy consumption. However, its economics in different states remain unexplored.

2.5 MODELLING FOR BUILDING ENERGY CODE COMPLIANCE BY SIMULATION

Modeling and simulation help in understanding the building energy performance and provide flexibility for achieving norms of regulatory documents such as ECBC in India's context. Building simulation models are simplifications of reality however the same needs to be validated [60]. Different scenario modeling through simulation helps in the energy analysis of a building which helps managers in communicating reliable information to stakeholders at the operational and strategic levels of organizations [61]. During design-phase energy models usually underestimate the energy consumption by 36% however by incorporating calibration steps, this error can be minimized to 7%. Model calibration helps in improving simulation predictions for the instrumented energy consumption of the building. Calibration steps include plugging updated weather files and revising unregulated and regulated plug-loads of buildings [62]. Occupant behavior varies in a wide range and modeling indicates that most assumptions about occupants need careful examination. In most cases, participants are not aware of the reason for their role in occupant modeling but participants are ready to undergo training [63]. Building Energy Modeling can be made effective if it is incorporated from the design stage itself, as it provides the most desirable and cost-effective solution for energy-efficient design, and its integration with the building design process is also ensured for the optimized results [64]. The energy performance of Australian homes as compared to international home samples built before 2006 was inferior. US DTS buildings with strict code requirements for building insulation for roofs and windows result in higher-energy performance designs [65].

Urban Building Energy Modeling (UBEM) is a tool used by architects for exploring urban design scenarios and is useful in incorporating building energy during project planning [66]. A comparison of different lighting models including EN 15193:2007 is carried out and found energy savings are of big differences between simulation and EN 15193:2007 [67]. The energy-Plus model's energy consumption estimates are not accurate. Few other models estimate building annual energy consumption which is within 1% of actual measured building energy data; however, modeled homes failed to meet ASHRAE criteria of the calibrated model when compared with hourly energy data [68].

In a study, new homes in eight US states were analyzed for energy code compliance and energy savings potential. The study demonstrates that the total energy performance of new homes for a large population can be gauged by the framework proposed [69]. Impacts of code-compliance on operation costs for housing in Edmonton and Alberta carried out using HOT 2000 simulation. The study indicates that by carrying out upgrades buildings can reduce energy its energy consumption by 12% [70]. Simulation by the Global Change

Assessment Model (GCAM) estimated that implementation of ECBC in the state of Gujarat, India would reduce building electricity consumption by 20%.

The reference building is developed for India and it is established that the main energy conservation measures for buildings that are occupied for 8 hours would be through building envelope whereas for buildings that are occupied for 24 hours, building energy conservation from internal loads which include occupancy, lighting, and plugged electrical appliances. The energy performance index (EPI) of reference office buildings is better than buildings abiding by ECBC 2017 norms [71]. Electrical System Estimation and Costing Tool (ESECT) which is an add-in tool of Autodesk Revit can estimate the cost of electrical system construction for residential buildings and monthly energy bills. This can be further analyzed for electrical system modification and cost reduction [72]. Daylighting for a residential apartment in the city of Mumbai was analyzed and it has been found that a building with a southeast orientation and 20% window-to-wall ratio could save up to 26% of the energy required for lighting [73]. A study of a 30 kWp rooftop PV system shows that actual energy generated and simulated energy generation results correlate by 0.99 [74]. In a similar study for 1 MWp solar PV with simulation software PVGIS, PV Watts, and PV Syst simulation tools, errors with the actual are in the range of 5%-30% [75].

Deduction: Modeling and simulation tools bring out the energy leakages and scope of energy conservation for the building under study. Modeling and simulation can also be used for ascertaining building and energy code compliance.

2.6 EPILOGUE

The literature review suggests that the techno-economic study of the implementation of building energy codes for residential buildings is not carried out in the Indian context even though it consumes a large amount of energy. The impact of charging of EV at home is not encapsulated in the residential building energy star labeling program promulgated by the Bureau of Energy Efficiency (BEE), a regulatory body of India with the mandate of improving energy efficiency in the country. Similarly, Rooftop solar PV has been pushed by the government by providing an upfront 30% subsidy on installation on residential buildings, however, the status of grid parity of rooftop solar PV for different states of India is not available.

CHAPTER 3

RESEARCH DESIGN

3.0 PROLOGUE

Based on the literature review of the previous chapter there is a research gap for the residential building star energy program in the Indian context. The study is focused on assessing the techno-economics of the Energy Star label promulgated by the Bureau of Energy Efficiency (BEE) for residential buildings. This chapter encompasses the problem statement which is further broken down into objectives and sub-objectives. The motivation for the study is also briefly captured in one of the sections. The research methodology adopted to address the problem statement is incorporated in this chapter.

3.1 RESEARCH GAPS

Based on deductions drawn from various topics in the literature survey it was found that there are immense opportunities for implementing energy codes for residential buildings. Star labeling program for residential buildings is introduced in India to improve energy efficiency in the residential buildings sector. Based on deductions from the literature survey the following research gaps have been identified.

- ✓ Grid parity of rooftop solar PV has not been analyzed in the Indian context. The impact of subsidy also needs to be examined in attaining grid parity in different states of India.

- ✓ Existing residential buildings in Indian cities have not been investigated for energy consumption and have not been benchmarked against the proposed Energy Star label. The techno-economic potential of rooftop solar PV for attaining high-energy stars has also not been explored by any study.

- ✓ The Energy Star label to the residential building is awarded against the notified standard by the regulatory body and Electric Vehicle (EVs) has not been catered to as a plugged load for the residential buildings. Its impact on existing energy star labeling of Indian residential buildings needs to be quantified. The research needs to be further extended so that increased load due to EVs is mitigated by appropriate energy-saving measures.

PROBLEM STATEMENT: It is imperative to understand the "rooftop solar PV grid parity" for undertaking the feasibility studies of deploying rooftop solar PV in attaining high energy stars by existing residential buildings.

3.2 MOTIVATING FACTOR

From the literature survey, it emerged that there is a scope for large energy savings in the residential buildings sector. The Indian government has recently introduced Energy Star labels for residential building energy. Existing buildings can undergo retrofitting and employ renewable energy to achieve the desired energy stars. Techno-economic feasibility of solar PV reported for different countries including India by different studies but the same is not available for rooftop solar PV in Indian cities. The problem statement has not been addressed; building energy star labels and grid parity can complement each other.

3.3 OBJECTIVES

The following are the objectives to address the problem statement: -

Modeling of an existing government building for ECBC 2018-R compliance.

Sub Objectives incidental to the main objective are: -

(i) Simulation of the different scenarios for attaining residential Energy star grading and ascertaining the viability of the retrofitment.

(ii) Techno-economic assessment of renewable energy for residential buildings technologies for achieving Five-star energy grading

3.4 METHODOLOGY AND DATA COLLECTION

The study undertakes a two-pronged approach to address the live problem of achieving the five-star energy label of an existing residential building in Indian cities. In the first approach deployment of rooftop solar PV is explored. In the second approach, additional passive energy-saving measures are to be explored. A detailed research methodology followed is given below.

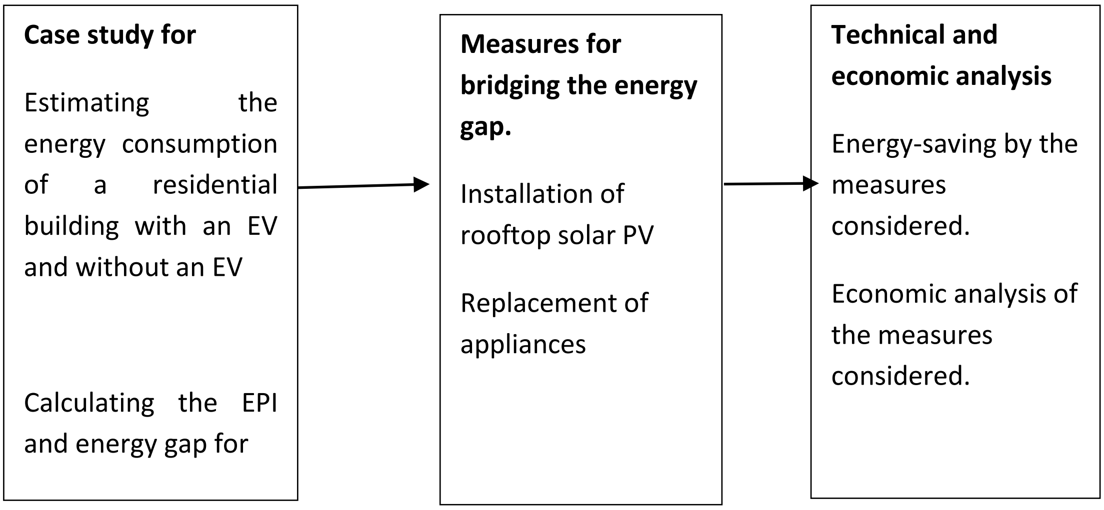

Figure 3.1 Research Methodology for rooftop solar PV

Energy Consumption data taken from a residential society in Palam, New Delhi was taken for benchmarking the energy consumption of residential consumers. RETscreen an open-source software is used for the rooftop solar PV for the residential building under study. The energy-saving potential by building envelope retrofitting and change in the appliance is undertaken by the eQUEST software. The impact of EV and on residential buildings and its impact on Energy Star is also incorporated in the study. The economics of the energy mitigation method considered is also analyzed using eQUEST. The methodology adopted for this is given in Figure 3.2

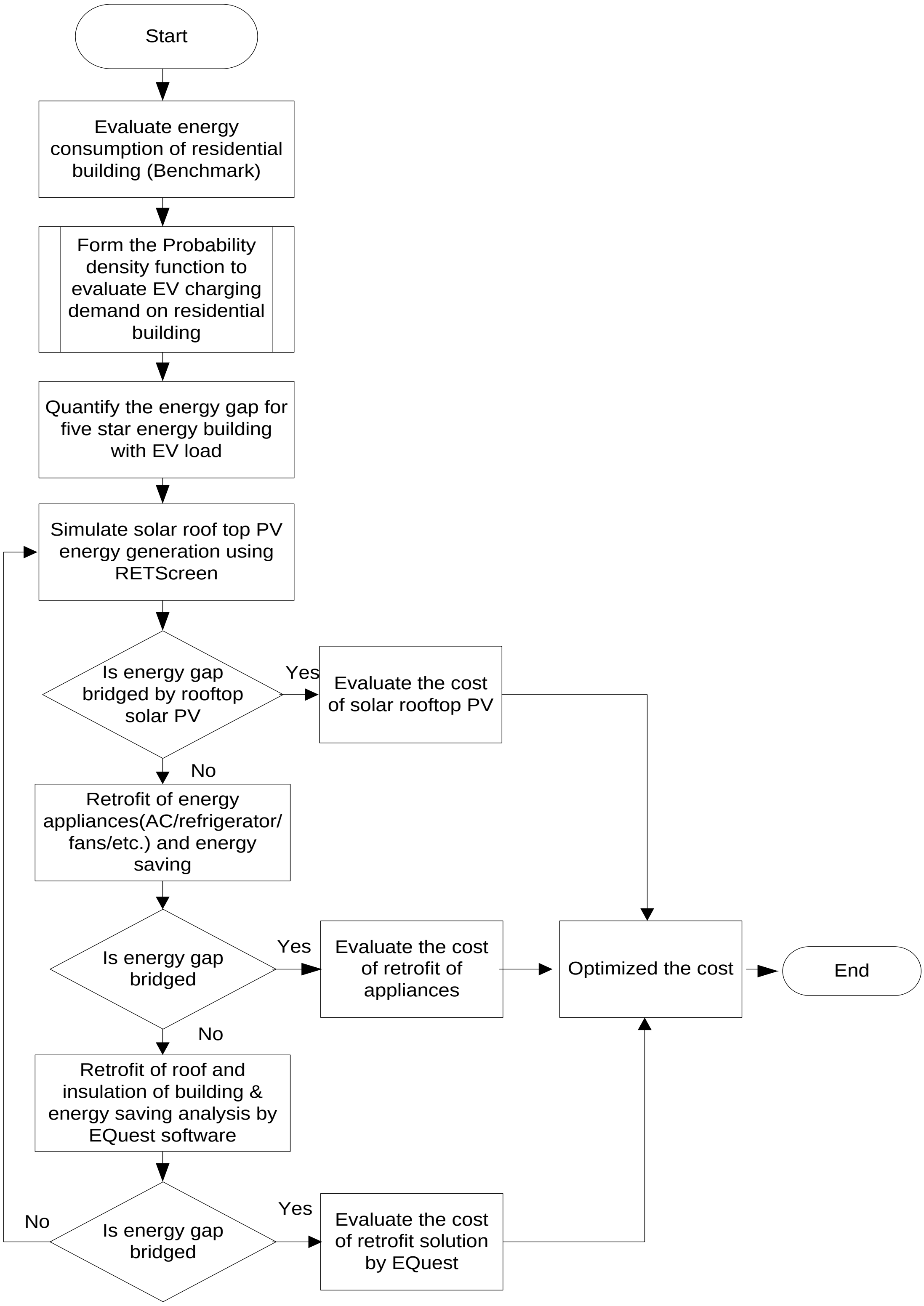

Figure 3.2 Flow chart for the study of EV scenario

3.5 EPILOGUE

A quantitative approach is undertaken to gauge the existing residential buildings' energy consumption and find out the energy gap for the Energy Star label. RETscreen and eQUEST software are utilized for the simulations of different scenarios. The study aims to evaluate the grid parity of rooftop solar PV in different states of India its scope bridging the energy gap of the existing residential buildings so that the desired energy star label can be achieved. The impact of EVs on the energy star of a building and its mitigation by rooftop solar PV and building envelope retrofit need to be evaluated.

CHAPTER 4

STATUS OF ROOFTOP SOLAR PV GRID PARITY FOR RESIDENTIAL BUILDINGS IN INDIA

4.0 PROLOGUE

This chapter explores the status of rooftop solar PV grid parity for residential buildings for different scenarios. The government of India extends upfront a 30 % subsidy on the installation of rooftop solar PV up to 3 kWp. The residential building energy tariff is a state-subject and therefore the viability varies from state to state. This chapter takes the stock of grid parity of rooftop solar PV across all the states of India. RRTscreen simulation for 3 kWp and 2 kWp with and without subsidy and for major cities across is carried out to gauge the grid parity.

4.1 GRID PARITY CONCEPT

To overcome the increasing demand for energy and more stress on clean energy, the penetration of solar PV is increasing in the global market. The cost of conventional coal energy resources is increasing whereas PV cost is reducing. India's government aims to install 175 GW of renewable energy by 2022. In this target, solar energy will lead and contribute 100 GW, and 40 percent of this would be from rooftop solar PV. India’s solar PV installation has already crossed 28 GW as of March 2019 [36]. The status of the installation of grid-connected solar PV in India is shown in Figure 4.1. Rooftop solar PV installation in India has touched 5.4 GW in December 2019. The distribution of rooftop solar PV in the different sectors is shown in Figure 4.2.

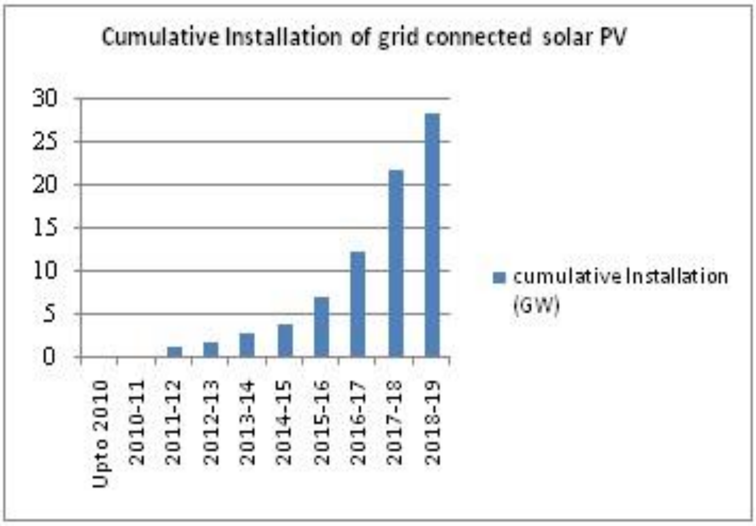

Figure 4.1 Status of grid-connected solar PV in India [76]

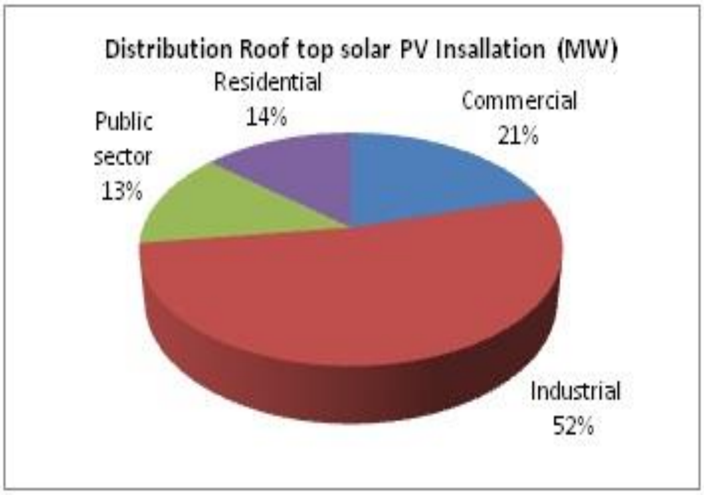

Figure 4.2 Installation status of rooftop solar PV in the different sectors [77]

Reduction in the cost of PV modules in the Global markets has made solar PV economically equivalent to fossil-based grid supply, which is termed grid/ socket parity. Grid/socket parity is a condition where the cost of energy generation from solar PV is cheaper than conventional grid electricity. In economic terms, if the levelized cost of electricity from solar (energy source) is less than the grid cost then the energy source achieved static grid parity and in dynamic grid parity, the NPV of the solar PV system is compared to the NPV returns generated by the solar PV system.

4.2 COST OF ENERGY FOR RESIDENTIAL CONSUMERS IN INDIAN STATES

Energy tariff for residential consumers is telescopic where the cost of energy increases as per the increase in energy consumption. Accordingly, the residential energy consumers can be grouped into low, moderate, and high as per energy consumption, and the same is tabulated in Table 4.1. Electricity tariff for medium and high residential consumers for selected Indian states is tabulated in Table 4.3. The electricity tariff escalation rate is evaluated by the Compound Annual Growth Rate (CAGR) from 2009-10 to 2018-19 for the medium (400kWh/month) and high (1000kWh/month) energy consumers from the Centre of Electricity Authority (CEA) annual report [18]. The calculated CAGRs of energy for medium and high residential urban consumers are 5% and 5.4% respectively.

Table 4.1 Residential energy consumer groups

Category	Classification of residential energy consumers	Monthly Electricity Consumption
A	Low	$E \leq 200$ kWh
B	Moderate	$200 < E \leq 400$ kWh
C	High	400KWh $<E$

Table 4.2 Energy charges for residential consumers [78]

State	Energy tariff Rs /kWh (Moderate consumers)	Electricity tariff Rs /kWh (High consumers)
Andhra Pradesh	7.50	8.50
Bihar	6.67	6.67
Delhi	4.50	6.50
Gujarat	5.20	5.20
Haryana	6.30	7.10
Karnataka	7.80	7.80
Maharashtra	10.36	11.82
Madhya Pradesh	6.50	6.50
Orisa	5.30	5.70
Punjab	7.30	7.30
Rajasthan	7.65	7.95
Tamil Nadu	4.60	6.60
Telangana	8.50	9.0
Uttar Pradesh	6.50	7.0
West Bengal	6.64	7.0

4.3 EVALUATION OF ENERGY GENERATION FROM ROOFTOP SOLAR PV IN INDIAN CITIES

MNRE extends a subsidy on the installation of rooftop solar PV which is 40% for solar PV plants of rating 3kWp and below however this subsidy is reduced to 20% for solar PV plants rating between 3kWp and 10kWp [20]. A residential rooftop PV system of 2 kWp and 3 kWp is considered for moderate and high energy consumers respectively. In the Indian rooftop solar PV market, Tata Solar has been the leader for the last seven years (2014-21). Tata solar rooftop system (3 kWp and 2 kWp) is considered for the study and the cost of the same is tabulated in Table 4.3.

Table 2.3 TATA solar rooftop solar PV system cost [79]

Rating	Cost in the absence of subsidy (Rs)	Cost including subsidy (Rs)
3 kWp	1,90,000	1,40,000
2 kWp	1,40,000	1,05,600

Energy generation cost from the rooftop solar PV system is calculated for the 34 Indian cities by using RETScreen version 10, a software program developed by Natural Resource Canada. The energy simulation included both the scenario (subsidy and without subsidy) for 3 kWp and 2 kWp rooftop solar PV. The results obtained for the 3 kWp and 2kWp rooftop solar PV and its comparison with grid energy charges are shown in Figure 4.3 to Figure 4.6

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
Warangal	Wa
Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

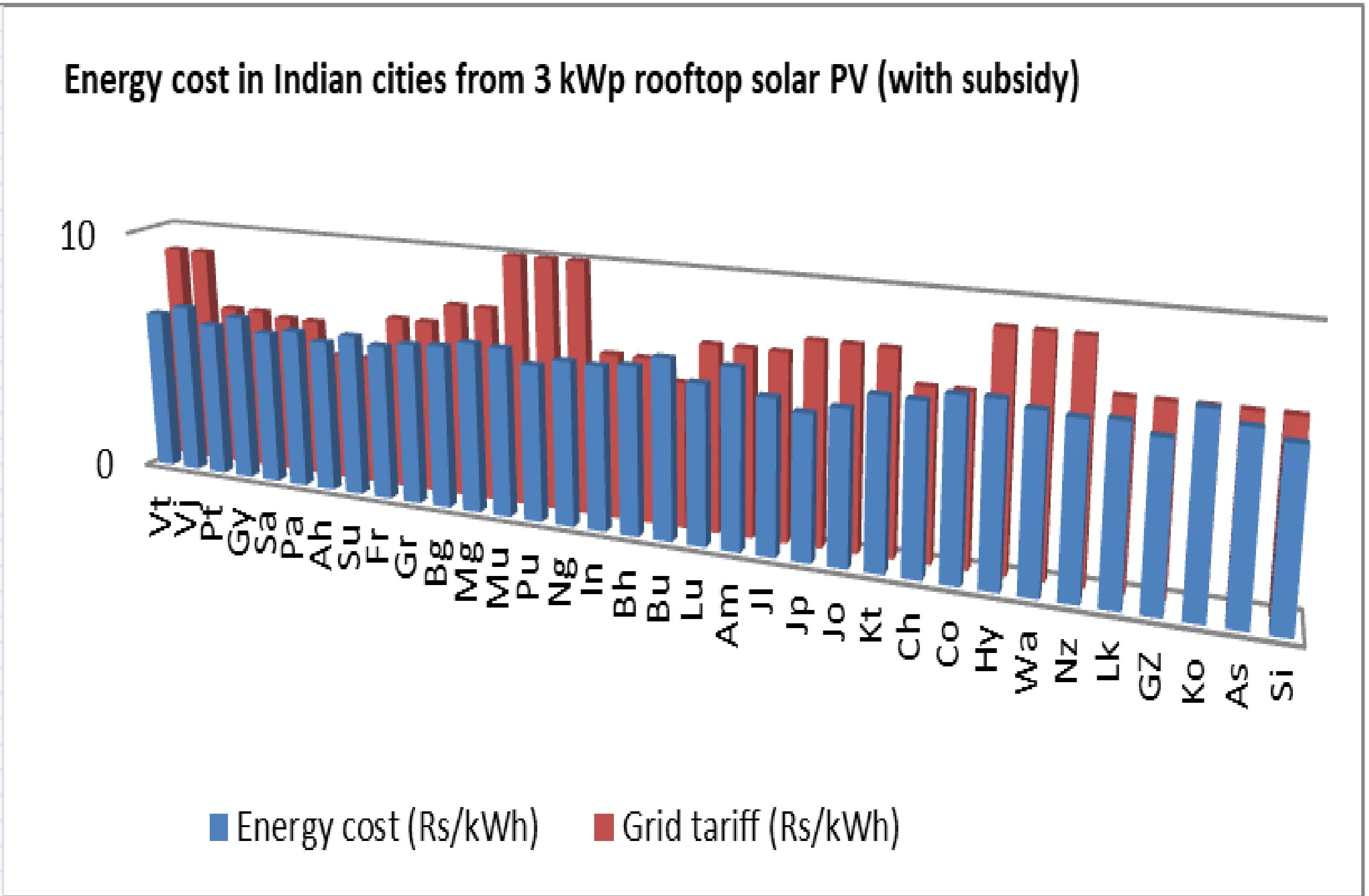

Figure 4.3 Grid parity status of 3 kWp rooftops solar PV in Indian cities (including subsidy)

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
Warangal	Wa
Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

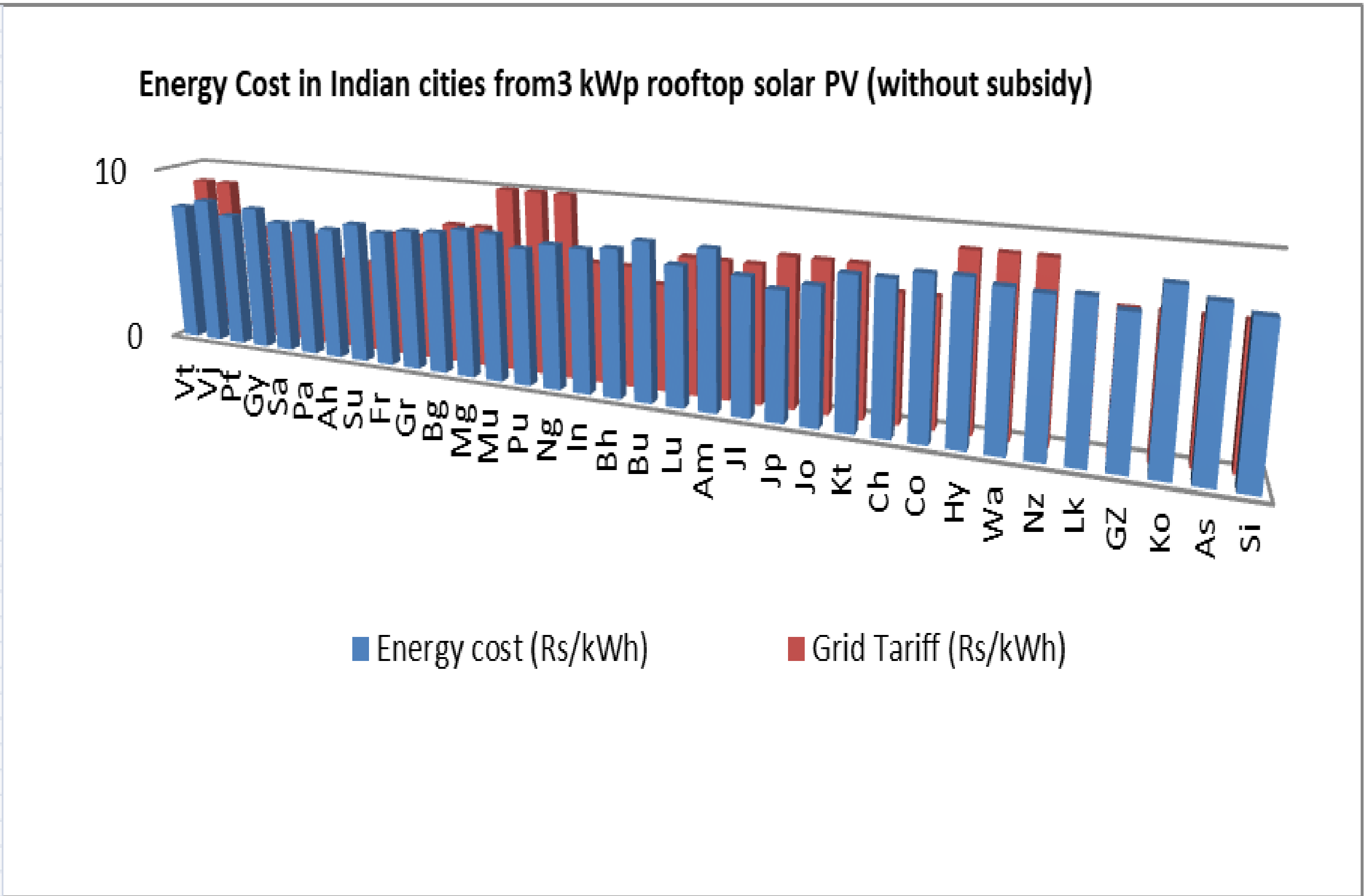

Figure 4.4 Grid parity status of 3 kWp rooftops solar PV in Indian cities (in the absence of subsidy)

City	Code
Vihakaptr	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
Warangal	Wa
Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

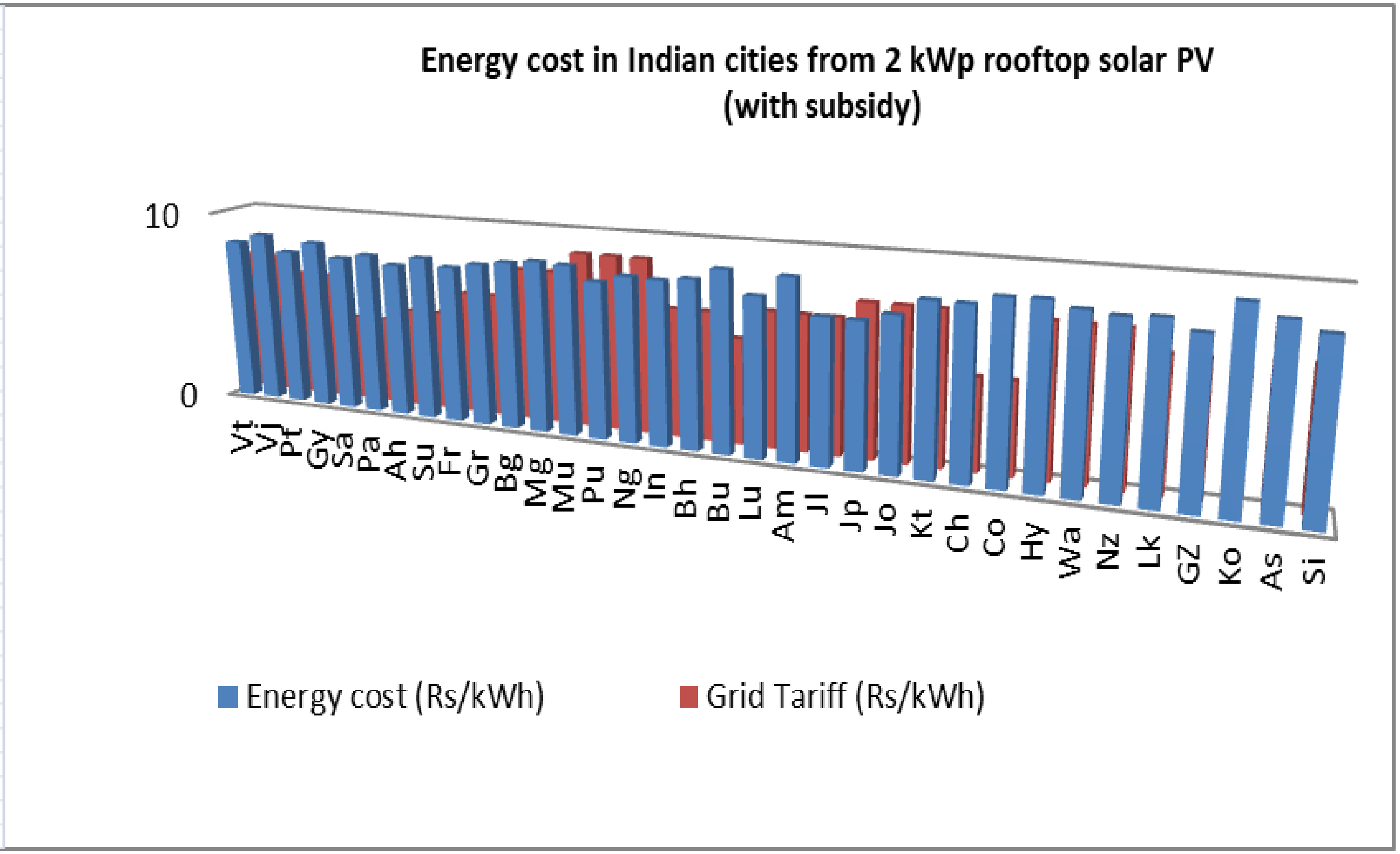

Figure 4.5 Grid parity status of 2kWp rooftop solar PV in Indian cities (including subsidy)

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
Warangal	Wa
Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

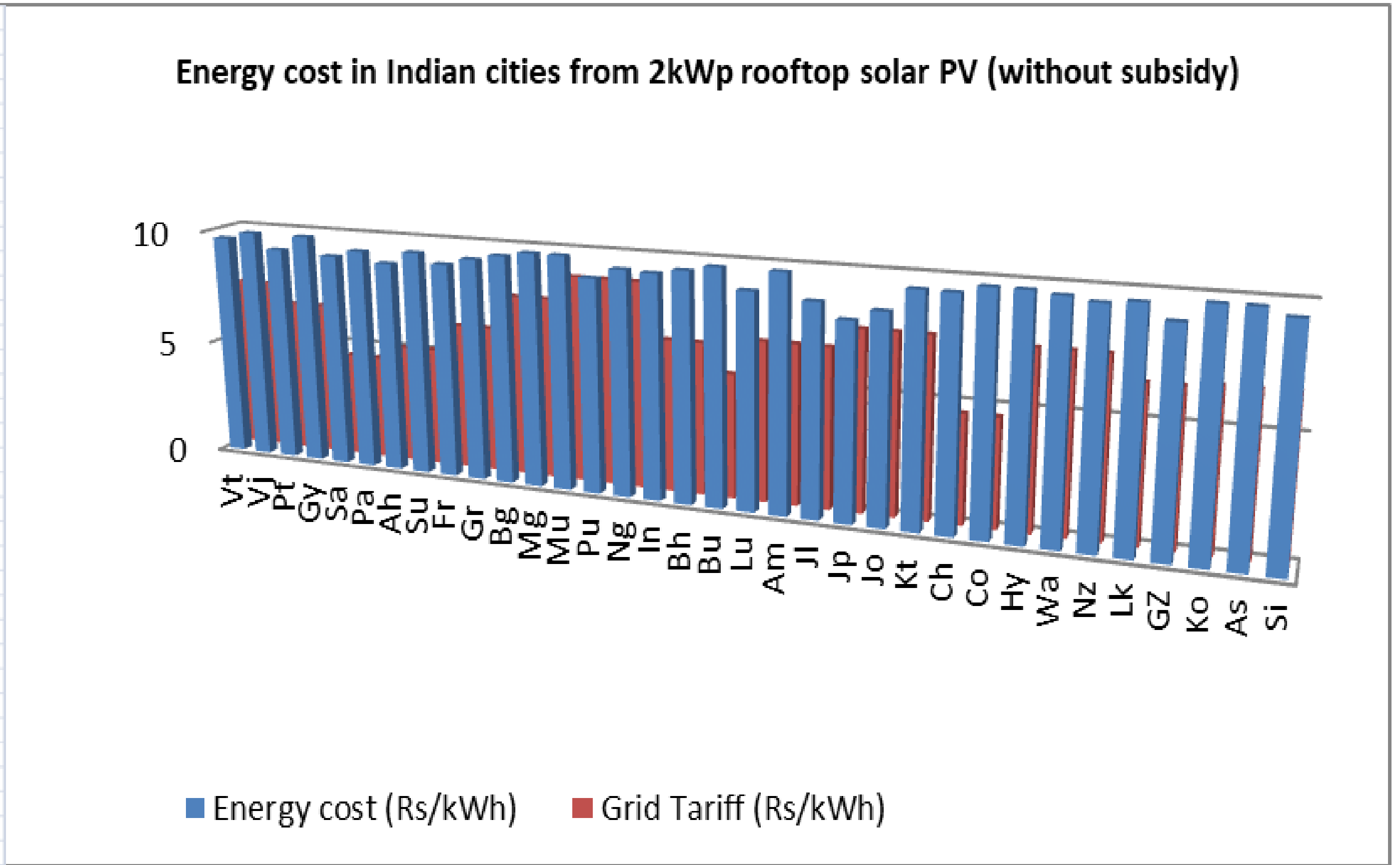

Figure 4.6 Grid parity status of 2kWp rooftop solar PV in Indian cities (in the absence of subsidy)

Result analysis of 3 kWp rooftops solar PV (with subsidy) indicates that grid parity is achievable in most of the cities, in 24 cities out of 34 cities energy generation cost of 3 kWp rooftops is less than the grid. However, if the state subsidy is removed the economic viability of 3 kWp reduces drastically and only 12 cities could have grid parity. Among the 34 cities, Jaipur city in Rajasthan state has the minimum energy cost of Rs 5.60/kWh, whereas in other cities this varies in the range of Rs 6.50/kWh- Rs 7.00/kWh. Because of the high energy tariff for residential consumers and the availability of high solar radiation throughout the year, Maharashtra state leads other Indian states in the grid parity. In addition to Maharashtra, Rajasthan, Telangana, Karnataka, and Andhra Pradesh could also breach achieve grid parity barrier even in the absence of the subsidy.

Result analysis of 2 kWp rooftop solar PV (including subsidy) simulation result indicates that with the reduction of the rating of rooftop solar PV grid parity reduces in Indian states as only 5 cities out of 34 cities could achieve grid parity. In the absence of subsidy, no Indian state could achieve grid parity as electricity tariffs for moderate energy residential consumers are low as compared to high energy consumers. Maharashtra and Rajasthan are the only two states which could only achieve grid parity for a 2 kWp rooftop with the state's 40% subsidy. Jaipur city recorded the lowest energy cost for 2 kWp rooftops solar PV i.e. Rs 6.68/kWh, whereas in most other Indian cities energy cost varies in the range of Rs 7.50/kWh-Rs 8.50/kWh.

4. .4 ECONOMIC EVALUATION OF ROOFTOP SOLAR PV PLANT

Economics analysis of 2kWp and 3 kWp rooftops solar PV carried out by evaluation of payback period, NPV, and IRR. The payback period is calculated by dividing the invested amount on the installation of rooftop solar PV by the annual saving in energy charges. For calculation of NPV and IRR in addition to the cost of rooftop solar PV, Operation and Maintenance (O&M) cost and recurring cost for replacement of the inverter in the 13th year was also plugged in RETsceeen software. Other economic parameters such as escalation in utility electricity prices considered for NPV calculation are tabulated in Table 4.4.

Table 4.4 Parameters plugged in the RETsceen module.

Parameter	Plugged value	References
Discount rate	9.36%	[80]
life of solar PV	25 years	[80]
Debt/Equity ratio	70/30	[80]
Interest on Debt	10%	[81]
Debt period	10 yrs	[80]

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
Warangal	Wa
Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

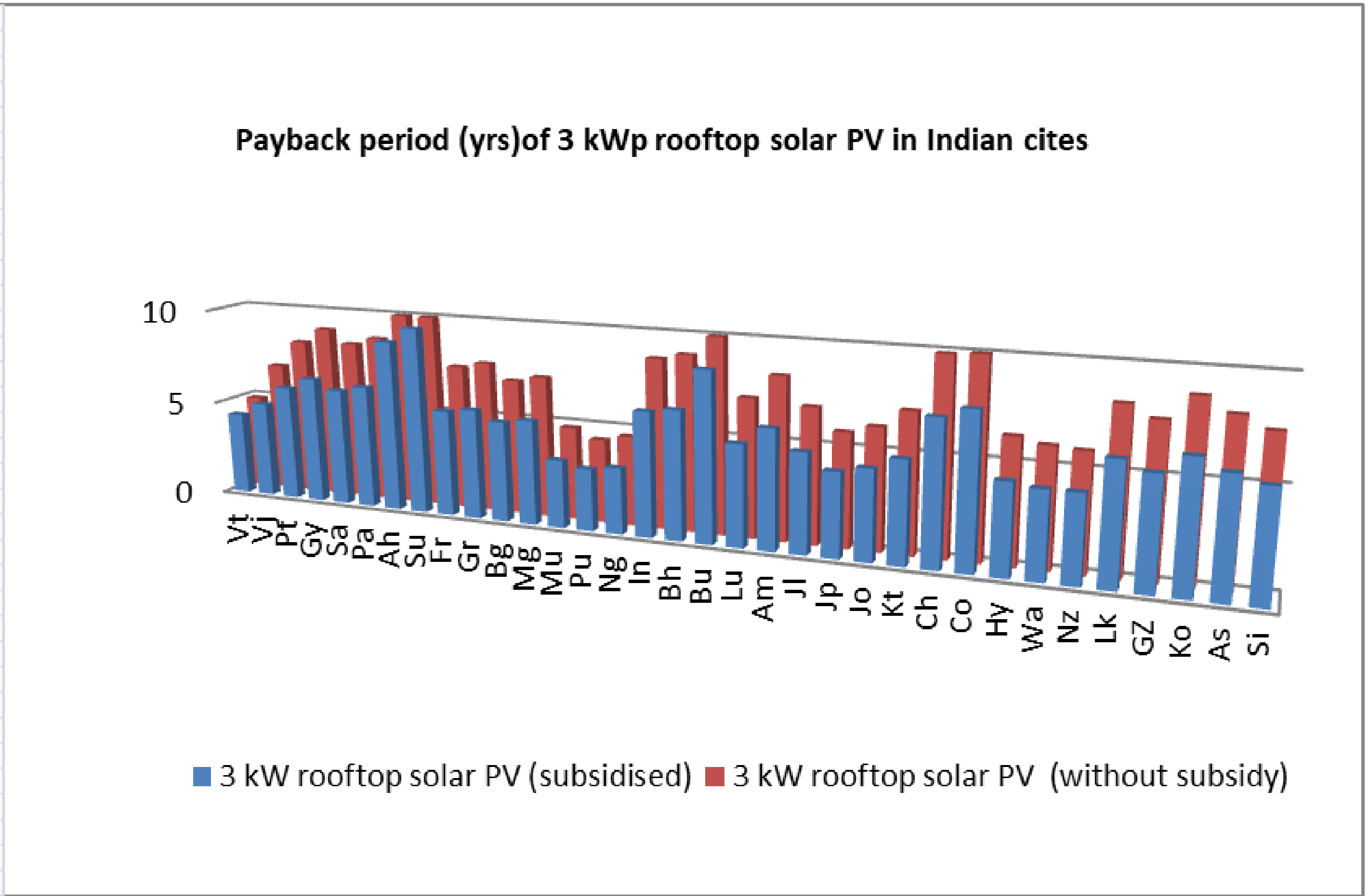

Figure 4.7 Payback period of 3 kWp rooftops solar PV in Indian cities

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
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Lucknow	Lk
Gazibad	GZ
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Asansol	As
Silliguri	Si

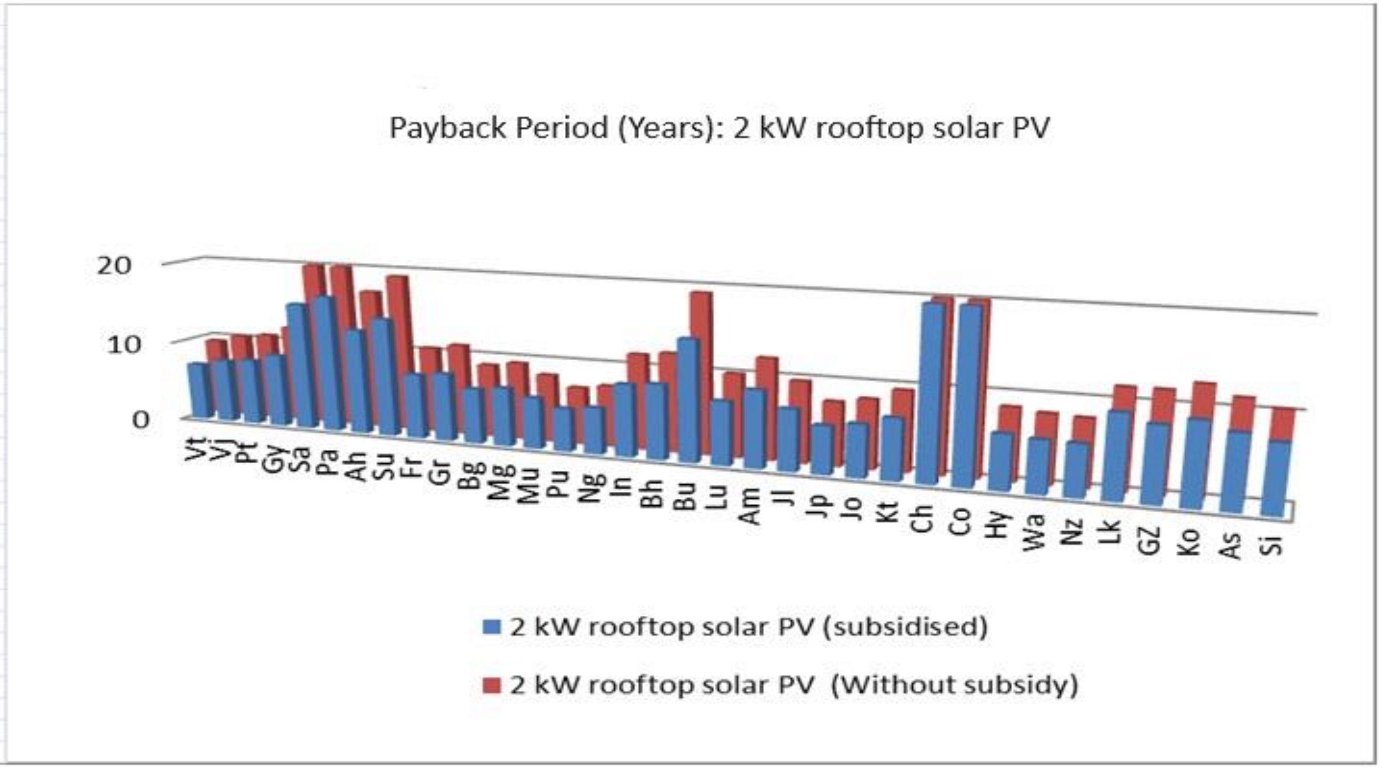

Figure 4.8 Payback period (Years) of 2 kWp rooftops solar PV

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
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Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

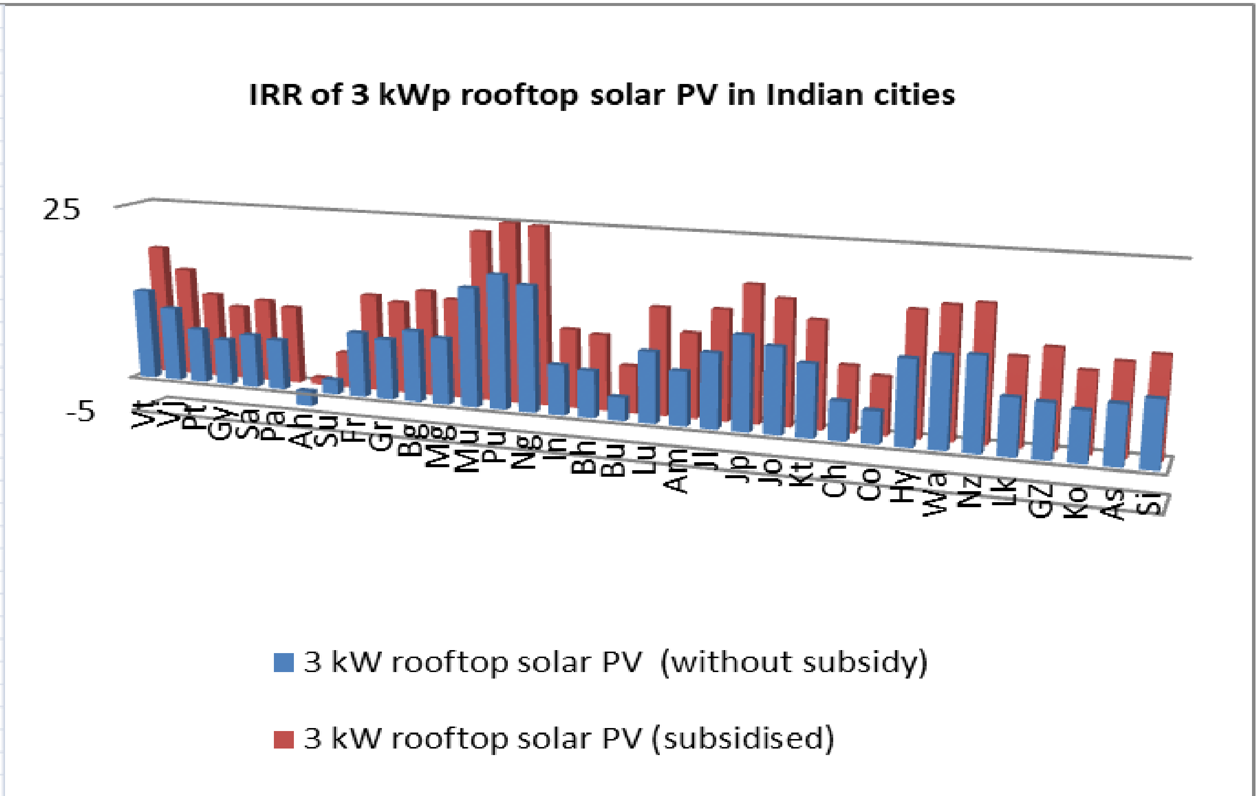

Figure 4.9 IRR Figure (Percent)of 3 kWP rooftop solar PV

City	Code
Vihakaptn	Vt
Vijaywada	Vj
Patna	Pt
Gaya	Gy
Safdarjang	Sa
Palam	Pa
Ahembda	Ah
Surat	Su
Faridabad	Fr
Guragaon	Gr
Bangalore	Bg
Mangalore	Mg
Mumbai	Mu
Pune	Pu
Nagpur	Ng
Indore	In
Bhopal	Bh
Bhuneshw	Bu
Ludhina	Lu
Amritsar	Am
Jalandhar	Jl
Jaipur	Jp
Jodhpur	Jo
Kota	Kt
Chennai	Ch
Coimbato	Co
Hyderaba	Hy
Warangal	Wa
Nizamaba	Nz
Lucknow	Lk
Gazibad	GZ
Kolkata	Ko
Asansol	As
Silliguri	Si

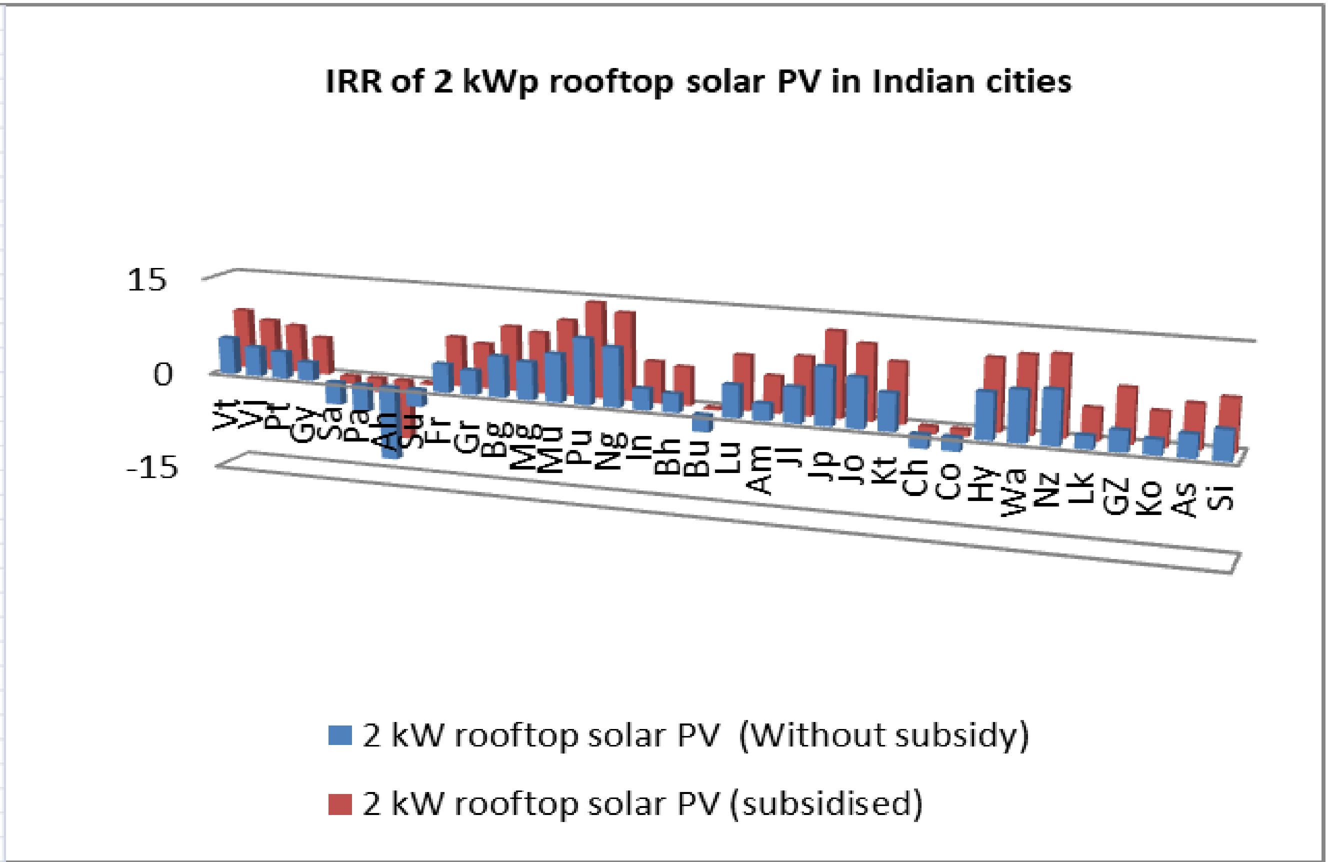

Figure 4.10 IRR (Percent) of 2kWp rooftop solar PV

3 kWp rooftop RET simulation results show with the help of state subsidy 25 cities out of 34 cities IRR is more than 11%, the rate at which solar rooftop PV owners can easily obtain a debt from any financial institution. In the absence of subsidy, 8 cities could match this competitive IRR. The economic performance of rooftop solar PV is best in Pune city in which the highest IRR and NPV (with subsidy) of 26.4% and Rs 4,32,121 is achieved. The economic performance of rooftop solar PV is worst in Ahmadabad city where IRR and NPV (with subsidy) of 0.99% and Rs -12,174 is achieved. In the absence of the subsidy, the economic performance of 3 kWp rooftops solar PV is degraded, and IRR and NPV for Pune and Ahmadabad are reduced to 18.7%, Rs 3, 79,589, and -2.1%, Rs -64,178 respectively.

2 kWp rooftop RET simulation results show with the help of state subsidy, 8 cities out of 34 cities IRR is more than 11%. In the absence of subsidy, no city could match this competitive IRR. Economic performance rooftop solar PV is best in Pune city in which the highest IRR and NPV (with subsidy) of 14.4% and Rs 1,45,162 is achieved. The economic performance of rooftop solar PV is worst in Ahmadabad city where IRR and NPV (with subsidy) of -9.19% and Rs -59,235 is achieved. In the absence of the subsidy, the economic performance of 3 kWp rooftops solar PV is degraded, IRR and NPV for Pune and Ahmadabad reduced to 10%, Rs 1,09,345 and -11.3%, Rs -95,385 respectively.

As per the RETscreen simulation results discussed above the cities can be graded as most favorable, preferred, and not favorable for 3kWp and 2 kWp rooftops solar PV in terms of grid parity. Economic parameters employed for this classification are tabulated in Table 4.5. To obtain the most favorable tag in terms of grid parity the city must satisfy all the parameters (energy generation/payback period/NPV). Based on this grid parity map of the country for 3 kWp and 2 kWp rooftops solar PV with subsidy/ without subsidy is shown in Figures 4.11,4.12 and 4.13.

Table 4.5 Parameters for Grid parity for rooftop solar PV for Indian states

Favorability Index	Energy Cost (Rs /kWh)	Payback Period (years)	NPV (Rs)
Green (Most Favorable)	Less than grid tariff	Less Than 6	More than 50% capital cost
Yellow (Favorable)	Within 10% of the grid tariff	6-7.5	Between 50%-25% of capital cost
Red (Not favorable)	More than 10% of the grid tariff	More than 7.5	Less than 25% of capital cost

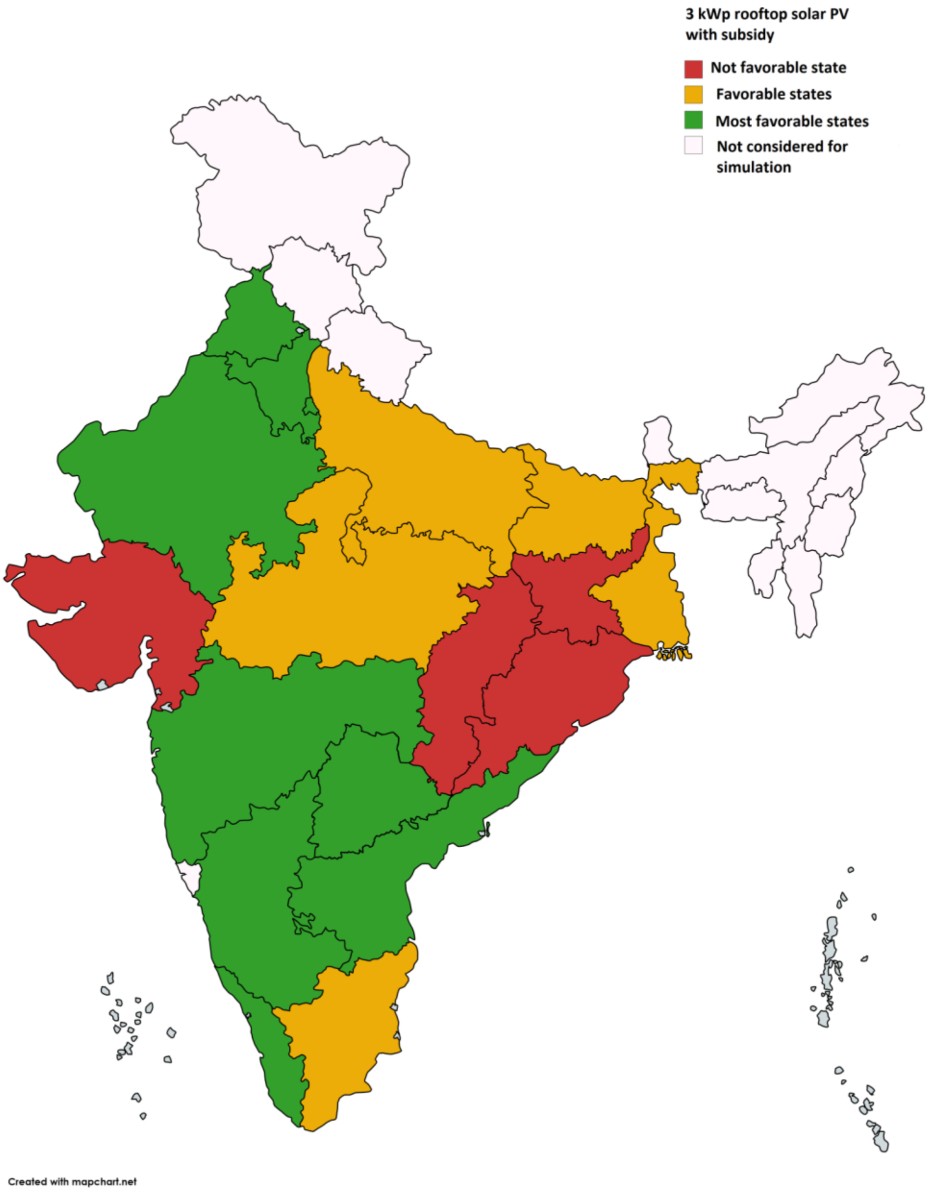

Figure 4.11 3 kWp Rooftop solar PV grid parity with subsidy

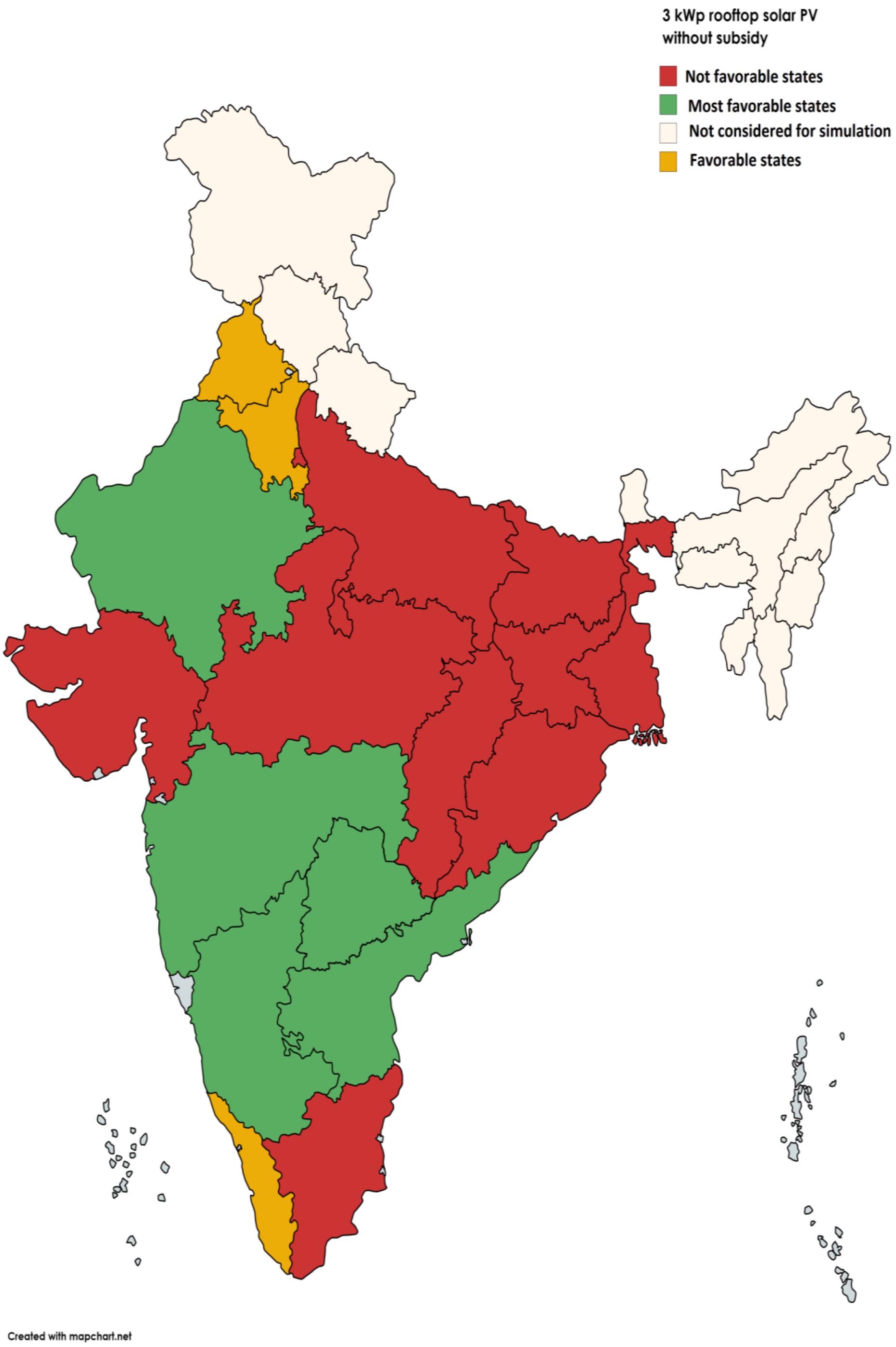

Figure 4.12 3 kWp Rooftop solar PV grid parity without subsidy

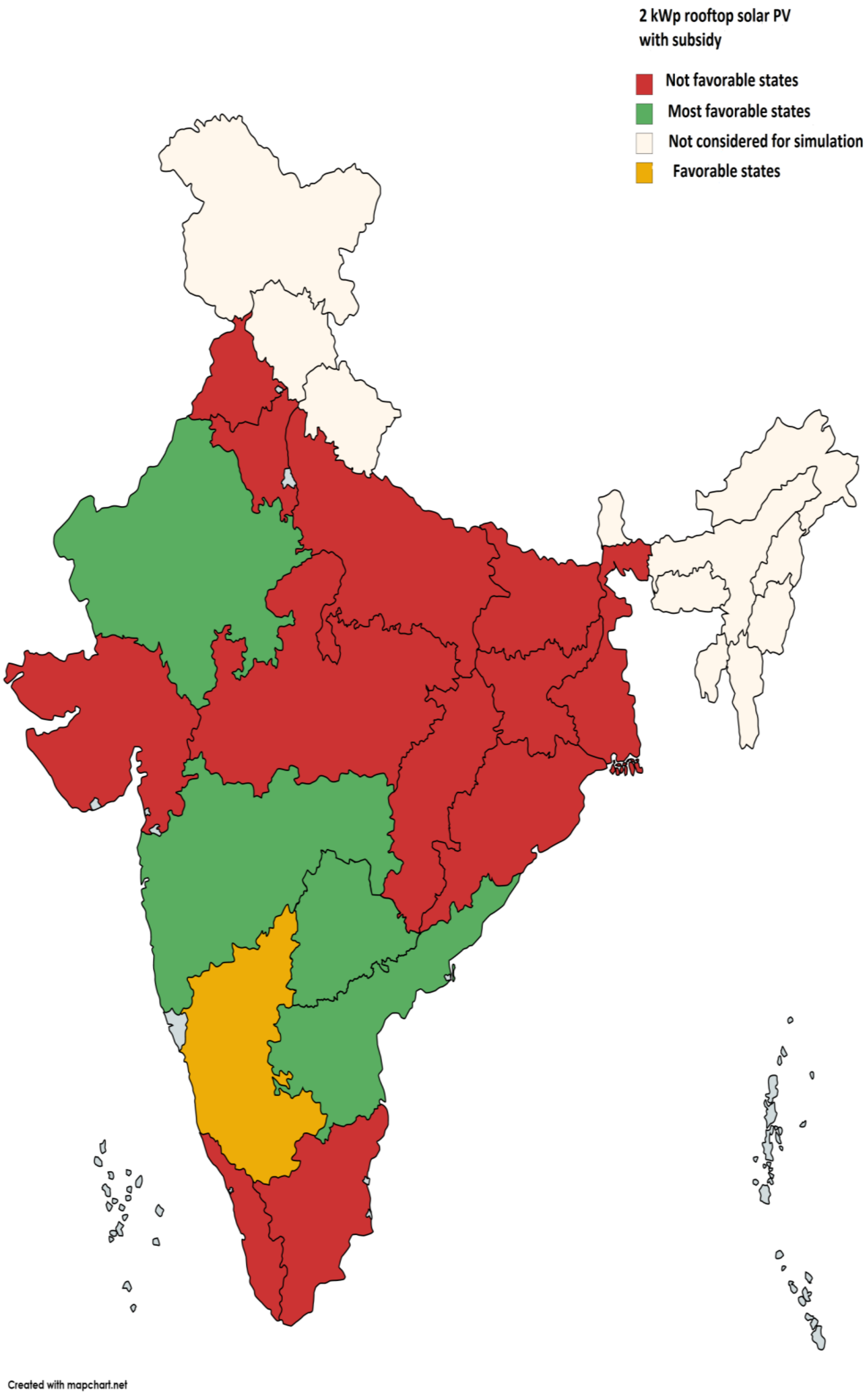

Figure 4.13 2 kWp Rooftop solar PV grid parity with subsidy

4.5 EPILOGUE

Simulation results in this chapter show that widespread grid parity across the states of India for 3 kWp and 2 kWp rooftop subsidy is achieved with the state subsidy. However, in the absence of subsidy, the grid parity of rooftop solar PV is reduced. Grid parity is largely the function of existing grid tariff in the state and solar radiation available in the state. The states are also subsidizing the grid supply to the residential consumer where consumption of consumer is less the 100-200 kWh/month. Therefore, the cities with similar solar radiation have different positions in grid parity. Rooftop solar PV is a viable energy solution for residential buildings and can be explored for higher energy star grading of buildings

CHAPTER 5

STUDY OF RESIDENTIAL BUILDINGS FOR ENERGY STARS LABELING

5.0 PROLOGUE

Energy building codes are in vogue across the world and in alignment with the energy efficiency drive India has initially promulgated energy building codes for commercial buildings. As an extension of this building code, a residential building code is also available which is voluntary for the consumers. This chapter analyses the energy consumption by residential buildings through a case study of residential buildings in a society in New Delhi and benchmarks against the Energy Star label. RET screen simulation carried out for seven major cities of the country for assessing the techno-economics potential of rooftop solar PV is explored to bridge the energy gap for the desired Energy Star label.

5.1 RESIDENTIAL BUILDINGS STAR LABEL

After the success of the star labeling program for electrical appliances, the Bureau of Energy Efficiency (BEE) introduced the star labeling program for all single and multiple-dwelling residential buildings in 2019. For a residential consumer to avail of this label there is no minimum requirement for the building area or plugged load (kW). The Energy Performance Index

(EPI) of a building (annual energy consumption in kilowatt-hours per square meter of the building) is the parameter considered for awarding the star label of the building. The EPI of the building consists of three E1, E2, and E3 components. E1 and E2 include building envelope, Lighting system, and Air conditioning system (AC). For the building only 25% of the space is assumed to be air-conditioned with 24 deg C. EPI (E3) for other building electrical appliances Such as water pump, washing machine, microwave oven, grinder, refrigerators, TV, etc. is considered in the range 7 to 9. Star labeling for different climate regions is tabulated in Table 5.1 considering the value of E2 as 8.

Table 5.1 Star labelling requirement [EPI(X)] in different climate zones [82]

Energy Stars	Composite	Warm & Humid	Hot and Dry	Temperate
★	60 < X ≤68	66 < X ≤ 72	63 < X ≤75	36 < X ≤ 39
★ ★	53 < X ≤60	57 < X ≤ 65	55 < X ≤ 63	32 < X ≤36
★ ★ ★	45 < X ≤53	47 < X ≤ 57	46 < X ≤ 55	29 < X ≤ 32
★ ★ ★ ★	37 < X ≤45	38 < X ≤ 47	37 < X ≤ 46	25 < X ≤ 29
★ ★ ★ ★ ★	X ≤ 37	X ≤ 38	X ≤ 37	X ≤ 25

5.2 CASE STUDY FOR QUANTIFYING THE ENERGY CONSUMPTION OF A RESIDENTIAL BUILDING

For ascertaining the energy consumption of residential buildings study has been undertaken for residential buildings in the Palam area of New Delhi, India details of the location are given in Table 5.2. The layout of flats as per the RETscreen location module is given in Figure 5.1.

Table 5.2 Building Location details

Latitude	28.6^0 N
Longitude	77.1^0E
Climate Zone	1B -Very Hot-Dry

Figure 5.1 Layout of flats as the RETscreen

This government residential campus has 81 building blocks, and each block has four houses. The residential block is a two-story structure consisting of four houses with two basement parking. Each house has a similar building area and carpet area of 314 m^2 and 628 m^2 respectively. This study aims to gauge the techno-economic potential of rooftop grid-connected solar PV on residential buildings and achieve five-star energy labeling for the building.

5.3 BENCHMARKING OF BUILDING ENERGY CONSUMPTION

Electricity consumption data was collated from April 2017 to March 2019 for the residential buildings. Annual energy consumption is used to distribute the houses in groups and the same is shown in Figure 5.2.

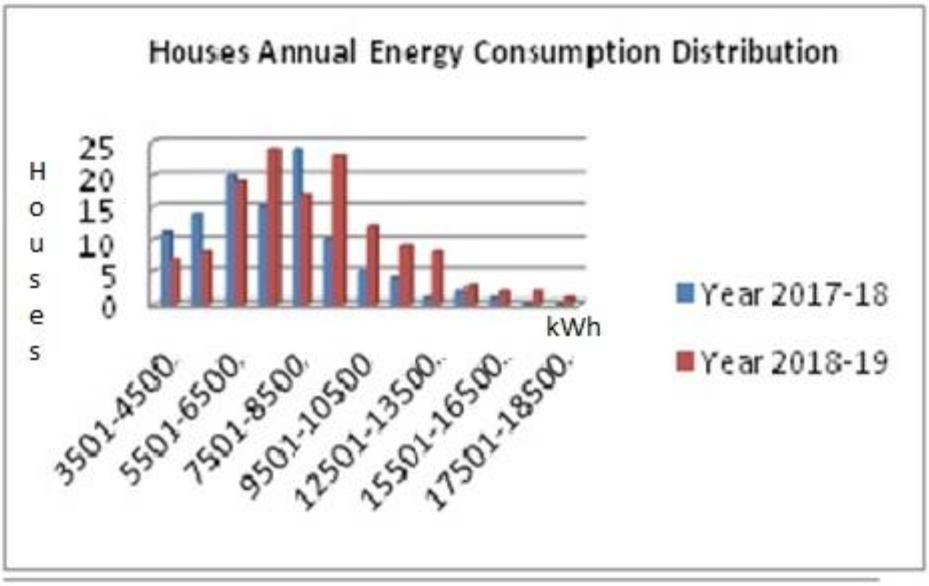

Figure 5.2 Energy consumption of residential consumers

An increase in the average annual energy consumption for residential buildings was observed from 2017-18 to 2018-19. In 2017-18 the annual energy consumption which was 7236.72 kWh increased to 8101.34 kWh in 2018-19. The commercial grid supply to the residential buildings under study is from BSES Rajdhani Power Limited (BRPL) and this is the sole electricity distribution company for south and west Delhi. The energy tariff for the year 2019-20 applicable to residential buildings is tabulated in Table 5.3.

Table 5.3 Energy tariff for Delhi residential buildings[83]

Slabs	Energy consumption (kWh)	Energy Tariff (Rs/kWh)
A	up to 200	3.00
B	201–400	4.50
C	401–800	6.50
D	801–1200	7.00
E	over 1200	8.00

As per the annual energy consumption, the residential energy consumers are classified into four classes that are tabulated in Table 5.4.

Table 5.4 Residential consumer classification based on annual energy consumption.

Class	Consumer	Annual Energy Consumption (kWh)
A	Low	$E \leq 4800$
B	Moderate	$4800 < E \leq 9600$
C	High	$9600 < E \leq 14400$
D	Very High	$E > 14400$

By analyzing the annual energy consumption for the years 2017-18 and 2018-19, more than three forth of the residential consumers' energy consumption is moderate and by suitable energy saving measures, the required five-star energy star label for the building can be achieved. Residential consumers categorized into different classes based on annual energy consumption for 2017-18 and 2018-19 are shown in Figure 5.3 and Figure 5.4 respectively.

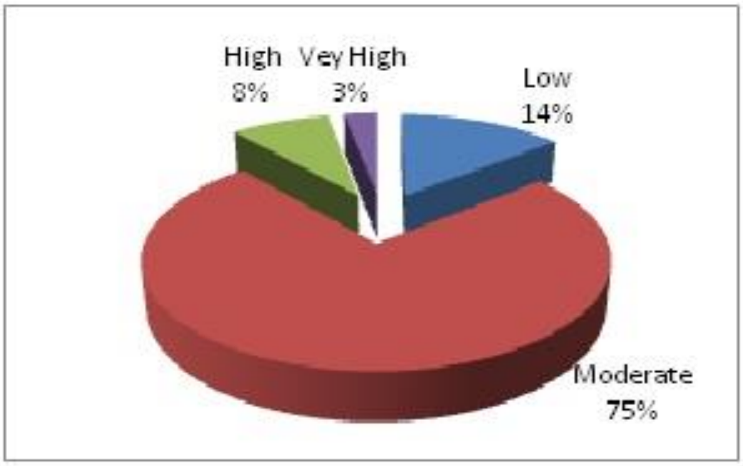

Figure 5.3 Categories of consumers based on annual electricity consumption (2017-18)

Analysis of the annual energy consumption two years data of the residential consumer it is clear that the energy consumption has increased for all the classes. As a result, there is a 10% reduction in the moderate energy consumer category, and the low-energy consumer category reduced from 14% to 10% whereas, the high-energy consumer category increased from 8% to 23%in the same period. Therefore in this study, high energy consumption is considered as the target energy consumption which needs to be addressed by suitable energy-saving measures so that it can achieve the desired 5-star energy label.

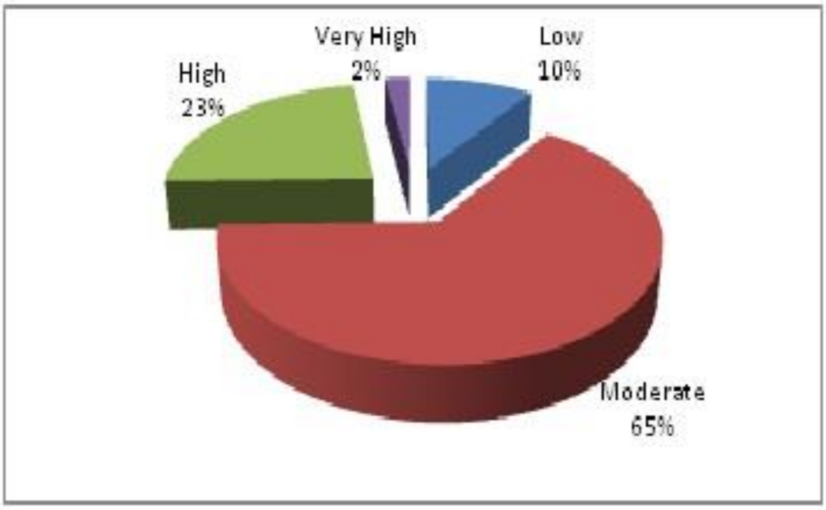

Figure 5.4 Categories of consumers based on annual electricity consumption (2018-19)

5.4 EVALUATION OF ENERGY GENERATION BY ROOFTOP SOLAR

In this section, energy generation capacity by rooftop solar PV is carried out based on the area available for the installation of rooftop solar PV, and state subsidy extended to residential buildings consumers for the installation of rooftop solar PV. As per the availability of rooftop space, solar of different capacities are considered for the installation. Energy generation of rooftop solar PV is evaluated using a rooftop solar calculator hosted on the website of the Ministry of New and Renewable Energy (MNRE). The results obtained are tabulated in Table 5.5.

Table 5.5 Energy generation by rooftop- solar calculator [84]

%Roof utilization	Roof area (m^2)	Rooftop Solar PV (kW_p)	Electricity generated (kWh/yr)	Solar PV Plant cost (Rs)
20 %	30	3	4140	75600
26 %	40	4	5520	106600
33 %	50	5	6900	139400

MNRE extends a subsidy on the installation of rooftop solar PV which is 40% for solar PV plants of rating 3kWp and below however this subsidy is reduced to 20% for solar PV plants rated between 3kWp and 10kWp. MNRE benchmark cost is considered for the proposed solar PV plant. The site under consideration receives 5.06 kWh /m^2/day solar radiation and the summary of the availability of horizontal solar as per the RETscreen is given in Figure 5.5.

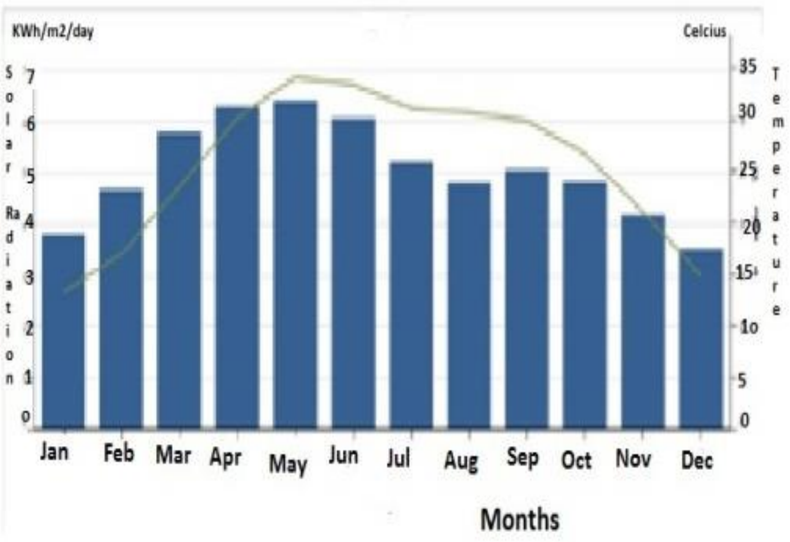

Figure 5.5 Solar radiation at the study site as per RETscreen

5.5 ECONOMIC EVALUATION OF ROOFTOP SOLAR PV

For assessing the potential of rooftop solar PV MNRE rooftop solar PV calculator is utilised which is available on the Ministry of New and Renewable (MNRE) website. The energy generation obtained from the solar calculator is tabulated in Table 5.6 and the same was validated by using NREL RETScreen simulation software [51]. Energy output from the RET screen is comparable to the MNRE solar PV calculator and within the tolerance of 5 percent.

Table 5.6 Rooftop solar PV energy simulation using RETscreen

(%Roof Utilization)	Area (m^2)	Rating of Rooftop Solar PV (kW_p)	Annual Energy Generation (kWh)
20 %	30	3	4320
26 %	40	4	5760
33 %	50	5	7200

Ministry of New and Renewable Energy (MNRE) extends a flat 40% subsidy on the installation of rooftop solar PV up to 3 kWp, therefore installation of 3 kWp rooftop solar PV is considered for this study. Installation of grid-tied 3 kWp rooftops solar PV would offer a five-star energy label to eighty percent of the houses. Building energy star distribution post installation of grid-connected rooftop solar PV for 2017-18 and 2018-19 as per the residential energy star label program of India is shown in Figures 5.6 and Figure 5.7 respectively.

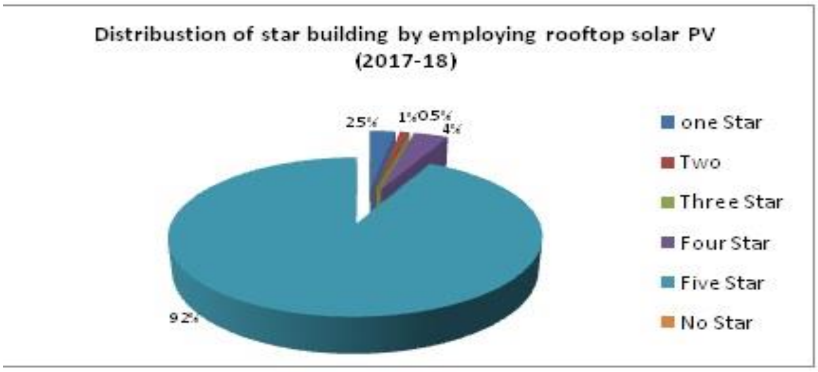

Figure 5.6 Energy star building status post installation of 3 kWp rooftops solar PV (2017-18)

Residential buildings with low and moderate energy consumption (Table 4.3) could achieve a five-star energy label by the installation of rooftop solar PV whereas other building owners with high/very high energy consumption could achieve an additional two-star energy star.

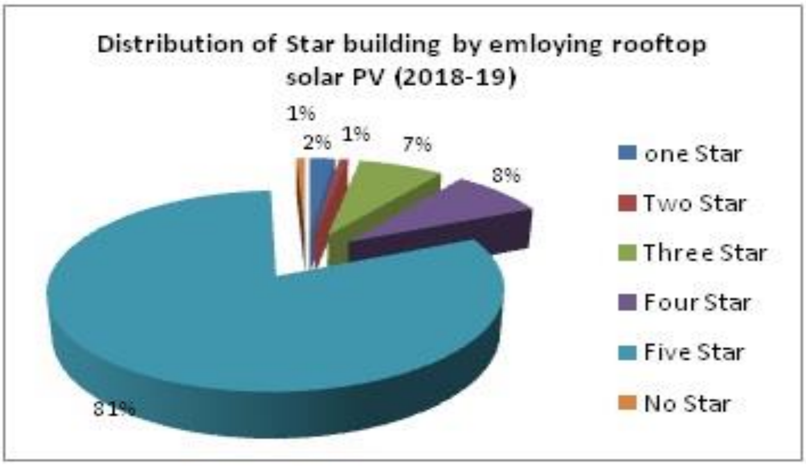

Figure 5.7 Energy star building status post installation of 3 kWp rooftops solar PV (2018-19)

The financial analysis of rooftop solar PV is carried out using the financial module of RETscreen. The net present value (NPV), Internal rate of return (IRR), and payback period were obtained by plugging the relevant value in the RETscreen. The value plugged in the RETscreen is given in Table 5 Chapter 4 and the results obtained are tabulated in Table 5.7

Table 3 NPV and Payback period of 3kW rooftop solar PV

Rooftop Solar PV	Payback period	NPV (Rs)
3 kWp	6.5 years	1,40,000

This exercise is further extended to ascertaining the feasibility of rooftop solar PV in the other cities of India located in different climatic zones, the RETscreen simulation carried out in respect of other cities and energy generation obtained by rooftop solar PV are tabulated in Table 5.8, economic results of rooftop solar PV for these cities obtained from the financial module of RETscreen are given in Table 5.9.

Table 5.8 Energy tariff and solar radiation of Indian cities

City	Location [latitude(°)/longitude(°)]	Daily solar radiation ($kWh/m^2/day$)	Energy tariff (Rs /kWh) [56]
Mumbai	19.1 / 72.9	5.12	Rs 7.51
Chennai	12.8 / 80.1	5.37	Rs 6.10
Kolkata	22.5 / 88.3	4.86	Rs 8.92
Bengaluru	13 / 77.6	5.32	Rs 7.80
Hyderabad	17.5/ 78.5	5.00	Rs 9.00
Ahmedabad	23.1/ 72.6	5.50	Rs 5.20
Pune	18.5/ 73.8	5.52	Rs 11.54

Table 5.9Techno-economic results of 3kWp rooftop solar PV

City	Annual Energy Generation (kWh)	Simple Payback Period (yrs)	NPV with 4% annual escalation of electricity tariff (Rs)
Mumbai	4274	3.5	375,956
Chennai	4330	7.3	90,872
Kolkata	4082	6.5	124,625
Bengaluru	4334	5.2	200,711
Hyderabad	4127	4.6	242,970
Ahmedabad	4646	9.2	-12,174
Pune	4614	3	432,126

CHAPTER 6

IMPACT OF ELECTRIC VEHICLES ON ENERGY STARS FOR EXISTING RESIDENTIAL BUILDINGS IN INDIA AND ITS MITIGATION

6.0 PROLOGUE

Across the globe transport sector consumes 26% of total final energy, and globally this results in 8 Gt of CO2 emissions in 2022. Forty-five percent of fossil fuel demand globally is contributed by road transport and internal combustion cars sales grew by an annual average of 3.4% from 2010 to 2017. is responsible for nearly 45% of global oil demand. To overcome the dependency on fossil fuels countries are migrating to zero-emission vehicles, In 2023, EV (Electric Vehicle) sales were 14 million and every fifth vehicle sold globally was EV. China and Europe's market share of EVs in this period was 60% and 25% respectively. India, the second-largest electric two-wheeler market globally sales grew by 40% in 2023 as compared to 2022.

6.1 EV SCENARIO IN INDIA

Globally EV sales have increased nearly 50 times in the last decade (2012-22) and the 2022 EV sale is 10 percent of global car sales [85]. EV is the sustainable alternative to IC engines in a circular economy [86]. In 2023-24 an additional 90,432 EVs were added, and its growth between 2017-18 and 2023-24 is shown in Figure 6.1 [87]. Electricity consumption of EVs in city driving conditions is 84 Wh/km and 123 Wh/km for low and high power respectively [88]. Tail-end CO and CO_2 emissions by vehicle emissions reduce by 60 % and 17 % respectively if conventional IC vehicles are migrated to EVs [89],[90]. The best part of EVs is that the charging of EVs at residential buildings matches the valley of energy demand curve [91].

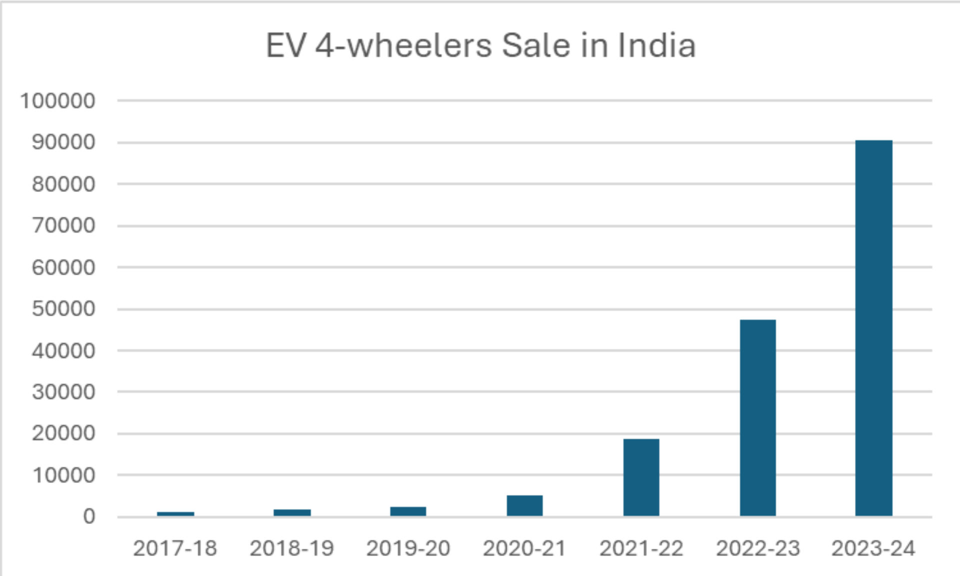

Figure 6.1 Four wheelers EV sales in India (2017-24)

Residential building energy consumption is taken from the study carried out for residential buildings located in Dwarka Delhi, India mentioned in the chapter 5. In the building's energy consumption data, EV is not a plugged load and the same is also not considered by the BEE building energy star label. Government policies have given impetus to the EV, and in the last five years, the sale of EVs has followed an upward trajectory. At present contesting policies of building energy star labeling and EVs are not gelled. The addition of EVs as plugged loads has an adverse impact on the star label of the building. Further sections of the chapter will quantify the impact of EVs on residential energy stars and explore the measures to mitigate this additional EV load. To ascertain the viability of the measures economics is also analyzed in the study.

6.2 EVALUATING EV LOAD ON BUILDING

For assessing the additional electrical load on the building due to EV charging at home TATA Nexon EV is considered for this study. The car is equipped with a 30.2 kWh lithium-ion battery and a fully charged battery provides a range of 312 km under standard conditions. For modelling the EV load on a building a PDF function has been used. The historical data of traveling patterns and vehicle numbers in a commercial building have been used to derive the standard deviation of the PDF function. The graphs have been obtained and Monte Carlo scenarios applied to generate the EV load on a building with charging duration. Probability Distribution Function (PDF) is used to evaluate the EV load profile. Using PDF for the arrival and departure of EVs on weekdays is generated. Equations 1 and 2 show the PDF for the arrival and departure of EVs respectively. The probability and cumulative probability distribution of EV on weekdays are shown in Figure 6.2 and Figure 6.3 respectively.

$$PDF_{Ar} = \left\{ \begin{array}{c} \frac{1}{\sigma_{Ar}\sqrt{2\pi}} e^{-\frac{(t+24-\mu_{Ar})^2}{2\sigma_{Ar}^2}} ; 0 < t \leq \mu_{Ar} - 12 \\ else \\ \frac{1}{\sigma_{Ar}\sqrt{2\pi}} e^{-\frac{(t-\mu_{Ar})^2}{2\sigma_{Ar}^2}} \end{array} \right\} \quad (1)$$

$d = distance\ travel\ in\ km,$ σAr is the standard deviation of arrival time and μ_{Ar} is the mean arrival

$$PDF_{Dr} = \begin{cases} \frac{1}{\sigma_{Dr}\sqrt{2\pi}} e^{\frac{(t-\mu_{Dr})^2}{2\sigma_{Dr}{}^2}} ; 0 < t \leq \mu_{Dr} + 12 \\ else \\ \frac{1}{\sigma_{Dr}\sqrt{2\pi}} e^{\frac{(t-24-\mu_{Dr})^2}{2\sigma_{Dr}{}^2}} \end{cases} \quad (2)$$

$distance\ travel\ in\ km,$ $\sigma_{Dr}$is the standard deviation of departure time andμ_{Dr} is the mean departure.

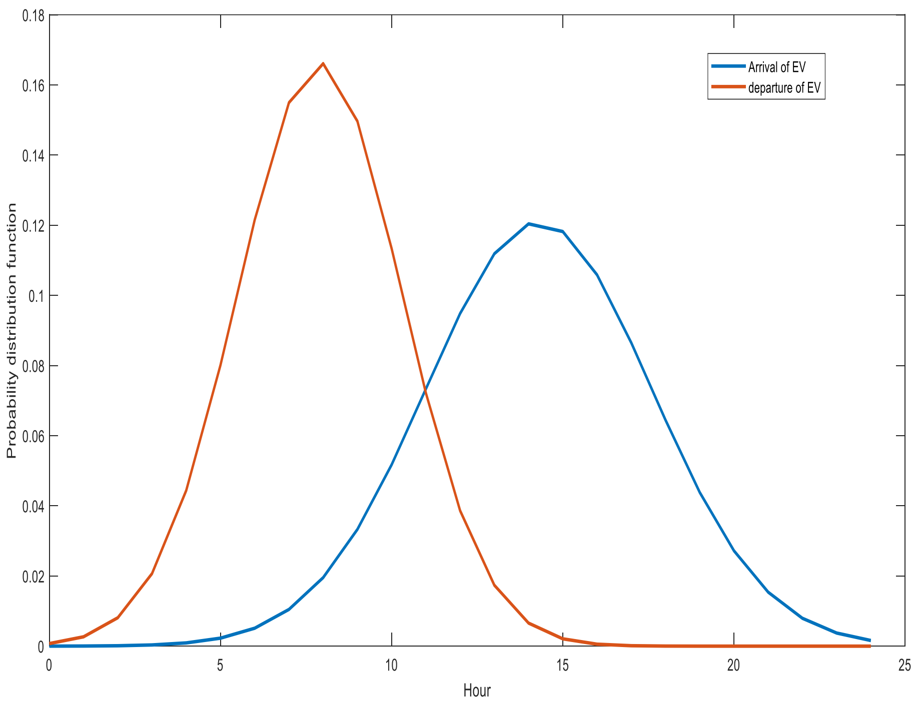

Figure 6.2 Probability distribution of arrival and departure of EV

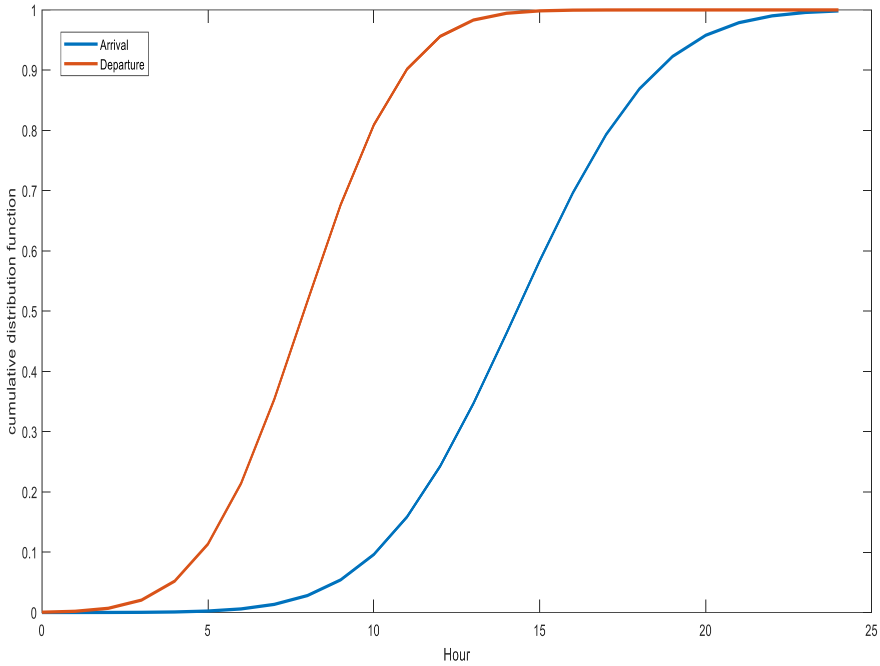

Figure 6.3 Cumulative probability distribution of arrival/departure of EV

For the distance covered by EV in a day a PDF function has been created using logarithmic distribution given in equation 3 and the plot obtained for the distribution is shown in Figure 6.4. The State of Charge (SoC) of EV batteries is calculated from equations 4 and 5. The battery charging EV load profile for residential buildings is created from Equation 6.

$PDF_{Dis} = \frac{1}{d\sigma\sqrt{2\pi}} e^{-\frac{(\ln d-\mu)^2}{2\sigma^2}}; d = distance\ travel\ in\ km$ and σ is the standard deviation (3)

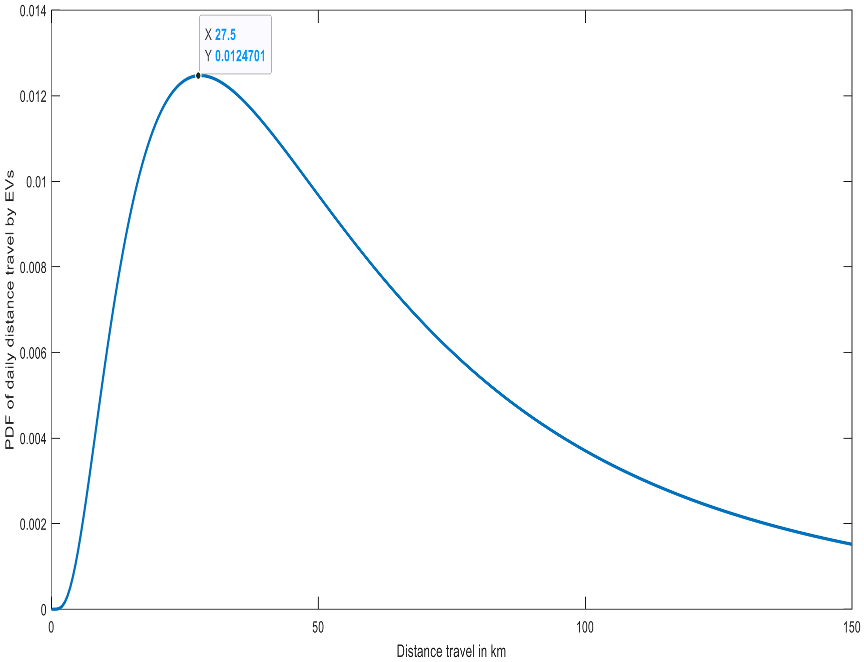

Figure 6.4 PDF of daily distance traveled by EV

$$SoC = 1 - \frac{d}{R};\ R = Range\ of\ EV\ on\ full\ charge \tag{4}$$

$$PDF_{SoC} = \frac{1}{R(1-SoC)\sigma\sqrt{2\pi}} e^{-\frac{(\ln(R(1-SoC))-\mu)^2}{2\sigma^2}} \tag{5}$$

$$T_{charing} = kWh_{battery}(1 - SoC)/(.82 \times P_{charger}) \tag{6}$$

To evaluate the additional EV load, equations 5 and 6 given above are used. The performance of EVs in city traffic is assumed 90% of standard conditions spelled out by the EV manufacturer. The charger installed at residential buildings with an efficiency of 82% will result in an energy requirement of EV 0.132Wh/km. More than 95% of the EV traveled distance in a day is less than

50 Km and considering 100% charge at the residential building will have an additional annual energy demand of 1724 kWh. This additional energy demand will reduce the two energy stars of the building as per the existing energy star label for residential buildings. As per the energy consumption of residential consumers mentioned in Chapter 5, the consumers are categorized into three categories tabulated in Table 6.1. By analyzing the annual energy consumption data of residential consumers mentioned in Chapter 5, it is evident that most consumers' annual energy consumption is below 12,000 kWh. Therefore, this is taken as benchmark consumption, whereas for the building to have a five-star energy label annual energy consumption should be less than 5940 kWh. The energy gap of 7784 kWh/annum exists for the residential building with EV and this gap reduces to 6060 kWh/annum if EV is not available for the five-star energy label.

Table 6.1 Consumer categorization based on annual energy consumption.

Category	Annual Energy Consumption (kWh)	Average energy consumption (kWh)	Energy Gap for Five-Star without EV (kWh/annum)	Energy Gap for Five-Star with EV (kWh/annum)
Moderate	$4800 < E \leq 9600$ kWh	7200	1260	2984
High	$9600 < E \leq 14400$kWh	12000	6060	7784
Very High	$E > 14400$ kWh	-	More than 6060	More than 7784

Residential energy tariff is slabbed in different categories such that a consumer who consumes more would pay more per unit consumed. The telescopic energy tariff is categorized into 5 categories which are tabulated in Table 6.2.

Table 6.2 Electricity charges for Delhi residential building [80]

Monthly energy consumption	Energy Tariff (Rs/kWh)
up to 200 kWh	Rs 3.00
201–400 kWh	Rs 4.50
401–800 kWh	Rs 6.50
801–1200 kWh	Rs 7.00
over 1200 kWh	Rs 8.00

6.3 TECHNO-ECONOMIC ASSESSMENT OF ENERGY STAR APPLIANCES FOR RESIDENTIAL BUILDINGS

The Energy Star appliance retrofit, installation of rooftop solar PV, and building envelope retrofit are the measures that are explored in this section. Economic parameters Payback Period (PP), Net Present Value (NPV), and Cost of Conserved Energy (CCE) are evaluated to ascertain the economic viability of retrofits. These parameters are defined as follows.

$PP = Co/\Delta\ OC$ where C_0 is the upfront expenditure for procurement of Energy Star label appliance and ΔOC is economic saving due to reduction in the operating cost.

NPV= $\sum_{k=1}^{n} OC/(1 + d)_k$–Co ,Co and OC as defined earlier, 'd' is the discount factor and k is the number of years

CCE=Co/$\sum_{k=1}^{n} \Delta E/(1 + d)_k$ where ΔE is energy savings by the star label appliance over its life (k years) which is discounted every year.

Building energy consumption from the plugged electrical load is primarily from room air-conditioners, refrigerators, lighting sources, and ceiling fans. In addition, water electric heaters, washing machines, televisions, and computers also contribute to the energy meter bill. The replacement of a refrigerator, room air-conditioner, and ceiling fan is considered in this study. Highly energy-efficient appliances with high energy star labels are available with additional premium charges. The operating hours of the appliances and their life are considered according to the climatic regions of India are given below in Table 6.3.

Table 4 Residential electric appliances operating parameters

Appliance	Quantity	Operating Hours/year [92]	Life of appliance (years) [92]	Energy consumption/ EER baseline [78]
Room air conditioner	02	1440	10	2.9
Ceiling Fan	02	1600	15	128 kWh/year
Refrigerator	01	8760	15	509 kWh/year

There is a wide difference in the energy efficiency of available fans in residential buildings and the super-efficient fans available in the market. The existing fan available at residential buildings consumes 75 W whereas a super-efficient fan consumes 35 W [78]. The fans have high usage in the residential building which is approximately around 1600 hours per year. The energy tariff for the residential consumer is in the range of Rs 7 to 8/kWh. The amount involved in the procurement of a star fan is recovered within 5.8 years. Similarly, the payback period for the replacement of a three-star 1.5-ton room air conditioner with an Energy Efficiency Ratio (EER) of 2.9 by a five-star energy label room air-conditioner with an EER of 5.0 is 8.5 years. The exercise of this replacement of the air conditioner involves an expenditure of Rs 25,000. The energy-saving and economics of the Energy Star label appliances are tabulated in Table 6.4 and Table 6.5 respectively.

Table 6.4 Energy saving by replacement of residential building appliances.

Residential Electric Appliance	Quantity	Energy-saving (kWh/appliance/year)	Total energy saving (kWh/year)	Economic saving [@ Rs 7/kWh] (Rs)
Room air conditioner	02	852	1,704	11,928
Ceiling Fan	02	64	128	896
Refrigerator	01	345	345	2,415
Total			2,177	15,239

Table 6.5 Economics of replacement of appliances

Residential Appliances	Payback period (yr)	NPV (Rs) (d@9.36%)	CCE (Rs/ kWh)
Room AC	8.5	5,351.60	0.650
Ceiling Fan	5.8	3,069.44	3.96
Refrigerator	9.2	4,054.35	5.51

6.4 TECHNO-ECONOMIC ASSESSMENT OF ENERGY SAVING BY ROOFTOP SOLAR PV

Three rooftops (1kWp, 2kWp, and 3 kWp) solar PV systems are considered in this study. Energy generation by rooftop solar is evaluated by the RETScreen version 8. The software is open source and is available on the Natural Resources of Canada website [93]. For assessing the investment required for the installation of grid-integrated rooftop solar PV is taken from multiple suppliers, the same is tabulated in Table 6.6. The economics of the rooftop solar PV residential consumer is evaluated in terms of payback period and Net Present Value (NPV). For estimating the NPV, operation and maintenance cost (O&M) is considered 5% of the capital cost, During the life cycle of 25 years of rooftop solar PV a major recurring cost involved in the 13th year is the replacement of an inverter which is Rs 24,500, Rs 30,500 and Rs 37,500 for 1 kWp, 2 kWp and 3 kWp solar PV plant respectively. The economic parameters plugged into the RETscreen financial module are mentioned in Table 4.4. The results obtained from the RETscreen are tabulated in Table 6.7.

Table 6.6 Rooftop Solar Installation [79]

Supplier	kWp (INR)	2 kWp(INR)	3 KWp (INR)
Supplier 1	64,636	1,02,872	1,43,308
Supplier 2	70,000	1,40,000	1,95,000
Supplier 3	76,000	1,55,000	2,25,000
Average	70,000	1,32,624	1,87,769

Table 6.7 Residential rooftop solar PV economics

Plant Capacity (kW_p)	Electricity generation kWh/year	Payback period (Yr)	NPV (Rs)	CCE (Rs/kWh)
1	1476	6.1	46,460	0.112
2	2952	4.7	1,56,500	0.112
3	4428	4.4	2,64,124	0.106

6.5. TECHO-ECONOMIC ASSESSMENT OF THE BUILDING ENVELOPE RETROFITMENT

The building under study is constructed using concrete and brick, the floor and the roof have a concrete structure; the floor surface is vinyl tiled whereas the walls are constructed using brick sand and cement with distemper available on the inner wall whereas the outer wall is plastered and not distempered but whitewashed. The building envelope (wall and roof) does not have any insulation. All the doors of the building are made of wood and the windows are standard single-glazed. The building block consists of four houses and each house is standard 3 BHK (Bedrooms, a Hall with a drawing room, and a Kitchen) with two washrooms. Requirement water pumping for the building is catered by centralized pumping which is not captured in the energy bill of the consumer. The Refrigeration and water heating requirement of the building is met by the installed electric geysers in the houses therefore these loads are clubbed with the plug load of the building. Space cooling is employed by the residential consumer from April to September for 9 hours/day. For these two rooms air conditioners of 2-ton capacity with an Energy Efficiency Ratio of 2.9 are deployed for the simulation. The occupancy of the house occupancy under study is considered four, a couple with two kids. To analyze the thermal characteristics of buildings and their impact on energy consumption eQUEST version 3.65.7175 software is used in this study. The software is user-friendly with the help of the building creation wizard tool of the software modeling the building can be carried out, and simulation results and energy consumption are graphically available for better appreciation. The eQUEST requires a weather file of the location where the building is located for the simulation, a compatible NewDelhi weather file from Energy Plus software is downloaded, and the same is used for the simulations. The impact on energy consumption of building envelopes i.e. wall and roof with and without insulation was analyzed using an EEM wizard tool available in the eQUEST software. For an economic analysis of the building envelope retrofitment, the cost of applying the insulation to the rooftop and walls is taken from the India Mart portal [94]. The building is simulated using the building wizard model and the eQUEST building energy simulation results are shown in Figure 6.5 and Figure 6.6 respectively.

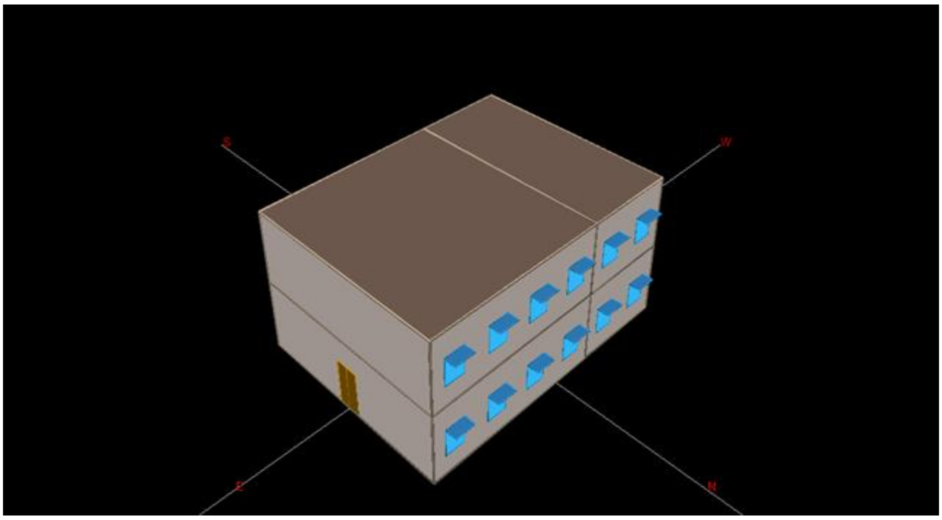

Figure 6.5 Building Model simulated by eQUEST

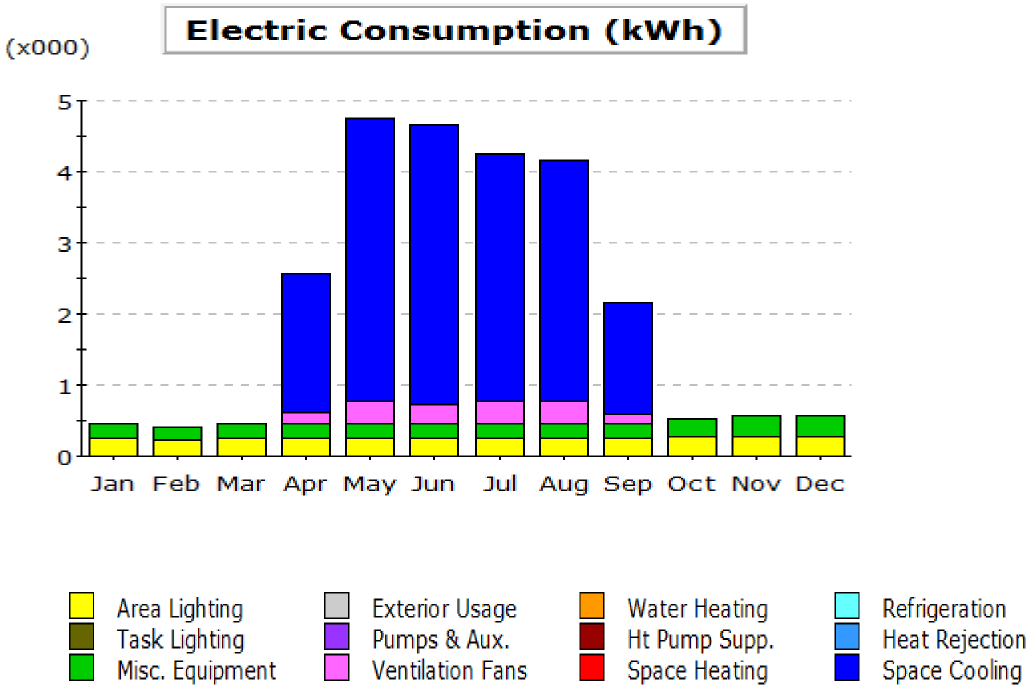

Figure 6.6 Distribution of the building's annual energy load

Table 6.8 Energy conservation by adding insulation to the building envelope

Envelope	Insulation Cost (Rs/m^2)	Area	Energy conservation (kWh/year)	Economics [@ Rs 7/kWh] (Rs)
Roof	1012	160 m^2	2,000	14,000
Wall	733	240 m^2	1,350	9450
Total			3,350	23,450

Table 6.9 Economics of Building Envelope Retrofit

Envelope (Insulation)	Payback period (years)	NPV (Rs) (d@9.36% and n=30)	CCE (Rs/ kWh)
Roof	11.5	-22,560	8.04
Wall	18.2	-65,970	12.44

6.6 EPILOGUE

The additional EV load on the residential building will reduce the two energy stars considering the present energy consumption and prevailing energy star grading standard for the residential buildings. To compensate additional energy load of EVs, rooftop solar PV is the best choice among the options considered due to its favorable economics. Replacement of electrical appliances with the best energy efficiency appliance is also an option considered, the impact of this measure on the total energy consumption is not up to the desired level so it can mitigate the impact of EVs on the energy star of the building. Building envelope retrofit has the lowest economic returns among the options considered.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

7.1 CONCLUSION

The research aimed to take the stock of recently promulgated Energy Star label program for residential buildings and to address live issues of Energy Star labeling. The objectives of the study were to explore and suggest energy-saving techniques for residential buildings so that the existing energy gap for five-star energy labels can be bridged. The sub-objectives of the study are to quantify the compromise on building energy stars by introducing EVs as the plugged load on the building. The different energy-saving measures along with the economic to mitigate the additional EV load are also captured in this study. Studies estimate that 2 kWp rooftops solar PV in the absence of state subsidy could not state could achieve socket parity in any Indian state. However, a 3 kWp rooftop solar PV plant could achieve socket parity in the absence of subsidy in five Indian states and if state subsidy is extended to consumers seven states could achieve socket parity. The study quantified the energy gap for an existing building in achieving a five-star energy label. The first step towards bridging this gap is to undertake an installation of rooftop solar PV considering the subsidy extended by the state. The study suggested the economics (payback period and NPV) of rooftop solar PV. The study also quantified the impact of EVs on the energy stars of the building and suggested mitigation of this increased building load through energy-saving measures along with its economics.

By carrying out EV charging at home the building will have two reduced energy stars as compared to the building without EV. By installing 3 kW_p rooftop grid-integrated solar PV and replacing the old electrical appliances by 5-star energy appliances can mitigate the additional electrical load on the building and five-star label to the existing residential buildings. The study suggests that at grid-connected 3 kWp rooftops solar PV can bridge three-fourths of the energy gap of the five energy stars for a building without an EV and half of the energy gap for a building with an EV as a plugged load. The invested amount for the installation of grid-connected rooftop solar PV systems can be recovered between 3 and 7 years. However, the payback period is more a function of state electricity tariff rather than solar radiation, The cities with the same solar radiations have different economies due to prevailing tariffs as each state has its energy tariff for residential consumption. For example, Pune and Ahmedabad cities receiving the same annual solar radiation have varied payback periods which are 3 years and 9 years respectively. By installing grid-intenerated rooftop solar PV, moderate energy consumers can bridge the energy gap for five-star energy labels. High-energy consumers need to take additional energy-saving measures like building envelope retrofitment and replacement of old room air conditioners with five-star air conditioners for the star energy label of the building. The replacement of ceiling fans has the best economics among other electrical appliances. Insulation of the rooftop and wall has the worst economics among the options considered in this study, but it can cater to one-third of the energy gap for the five-star energy label.

7.2 FUTURE WORK

Star labeling for a residential building in India is presently voluntary and likely to be revised, as carried out for other star label programs under the gambit of the BEE star label program. Building technologies and energy-saving techniques are continuously evolving and the same be gelled with the revised Building Energy Star label which will be promulgated in the near future. The following work related to this study extension can be undertaken in the future: -

(a) Exploring the Techno-economics analysis of Net zero residential building as BEE has recently published its grading in the form of "Sunya (Zero) and Sunya plus building".

(b) Embodied energy has not been captured in India's Building Energy Star program and the same can be explored and suitable weightage can be awarded so that the life cycle energy consumption of the building is addressed holistically.

(c) The development of a composite sustainable rating of the house needs to be explored which along with energy also encompasses water.

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APPENDIX – ‘A’

BIODATA

Wing commander Rakesh Dalal (Retd) with an experience of 23 years in the Indian Air Force in different technical assignments of expertise in planning, operations, project management, training & HR management, took premature retirement on 31 Dec 2022 and is presently employed as GM Defense solution with PCI gases India Pvt, Ltd.

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Appendix B

PLAGIARISM REPORT

Rakeshji_thesis_22Dec

ORIGINALITY REPORT

8%	3%	7%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Rakesh Dalal, Devender Kumar Saini. "Mitigation of the impacts of electric vehicle charging on energy-star ratings for residential buildings in India", Clean Energy, 2023 Publication	3%
2	Submitted to Indian Institute of Technology Jodhpur Student Paper	2%
3	academic.oup.com Internet Source	2%
4	Rakesh Dalal, Kamal Bansal, Sapan Thapar. "Bridging the energy gap of India's residential buildings by using rooftop solar PV systems for higher energy stars", Clean Energy, 2021 Publication	<1%
5	dr.ddn.upes.ac.in:8080 Internet Source	<1%
6	Rakesh Dalal, Devender Kumar Saini. "Rooftop Solar PV Socket Parity for Commercial Buildings in India", 2023 5th International Conference on Energy, Power	<1%