NEW FRAMEWORK OF DSM IN COMMERCIAL BUILDING FOR ENERGY EFFICIENCY

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
in
Power Systems

Submitted by

Ishant Jagotra
Regd No.802042009

Under the Guidance of
Dr. Pawan Kumar
Assistant Professor, EIED

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

2022

Electrical and Instrumentation Engineering Department
Thapar Institute of Engineering & Technology, Patiala
(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)
Post Bag No. 32, Patiala – 147004
Punjab (India)

DECLARATION

I hereby certify that the work which is presented in dissertation entitled, **"NEW FRAMEWORK OF DSM IN COMMERCIAL BUILDING FOR ENERGY EFFICIENCY"**, in partial fulfillment of the requirements for the award of the degree of **Master of Engineering in Power Systems**, submitted to Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering & Technology (Deemed to be University) is as authentic record of my own work carried under the supervision of **Dr. Pawan Kumar**. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Place: Patiala

Date: 28/07/2022

(Ishant Jagotra)

Roll No.: 802042009

Dr. Pawan Kumar
AP, EIED

29/7/22

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Ishant Jagotra

(802042009)

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ABBREVIATIONS

EEB	- Energy efficiency in Buildings
P. R	- performance ratio
IAM	- Incidence angle modifier
D.G	- Distributed generation
NZEB	- net-zero energy building
DSM	- demand side management
ACE	- affordable Clean Energy
NCES	- non-conventional energy sources
MPP	- maximum power point
DF	- diversity factor
MF	- maintenance factor
UF	- utilization factor
RCR	- room cavity ratio
RI	- room index
NL	- number of luminaires
CFM	- Cubic feet per minute
EEF	- energy efficiency of the fan
N_F	- Number of fans
NP	- number of persons
NPR	-number of people ratio

ABSTRACT

Buildings are the big energy consumer, and the energy efficiency in buildings (EEBs) mainly depends upon the time of operation and the type of components to be operated. The proposed work focuses on the energy efficiency of a commercial building with and without DSM based on yearly energy and environmental data collection. In the proposed framework, the scope of PV generation is explored for a commercial building using PV Syst 7.2.15, and simulation is performed on collecting meteorological data for the solar system. Also, a comprehensive energy efficiency analysis is performed by considering several energy auditing parameters, and the operating constraints have also been identified. Further, a correlation between energy efficiency and the operating constraints, including temperature, number of persons, light intensity, humidity, etc., are developed. Smart counters and energy meters are installed in different building blocks for real-time data on a daily basis. The energy, environmental, and personnel data are used to develop a new framework of hybrid AC-DC microgrid for energy efficiency in commercial buildings with and without DSM. The proposed algorithm is simulated in the MATLAB environment, and the results show a significant difference in energy consumption in both cases. Also, in the proposed approach, it has been observed that there is not only a reduction in energy consumption, but it also reduces the number of energy components.

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

In the modern world, the use of conventional resources has increased, due to which they are depleting gradually with the increase in demand for electrical energy. Non-conventional energy sources (NCES) are considered while producing electrical power to prevent the depletion of conventional energy sources. Therefore, energy efficiency is characterized as the stability between the energy saved and energy consumed, and government policies are involved with the Affordable Clean Energy (ACE) rule. It is sensible for the government to invest in clean energy for commercial buildings. To get more significant energy efficiency, the supervision of the energy usage is a must, which in turn will help us to develop a new framework of DSM to save energy in end-use.

Buildings are the big consumer of electricity, and as per the survey conducted by different agencies, the energy consumption in buildings is found to be 34-40% of the total generation. The commonly used energy resources in commercial buildings are electricity and natural gas. A heating and cooling plant can be more effective occasionally when there are numerous commercial buildings nearby, such as academic institutions. District energy systems use both conventional and non-conventional energy resources. Commercial buildings, such as office and mercantile buildings, use the most energy. A building owner or manager should keep energy efficiency at the top of their mind. Many explanations can help us save energy costs, such as renewable power generation.

Some researches show that there is a scope of 10-20% energy saving in the buildings. In addition, the rooftop area of the building can be utilized for PV generation to meet the energy requirements at a low cost. Therefore, it requires exploring the various energy efficiency and PV generation schemes under different operating constraints on a seasonal basis in an Indian scenario at a specific location.

Loads of the building mainly involve; a lighting system, heating, and ventilating system, and air conditioning (L-HVAC). The energy demand due to these power components varies differently in different seasons. Therefore, the energy efficiency evaluation of the building should involve the technical, social, and environmental constraints in the problem formulation.

1.2 ENERGY EFFICIENCY PARAMETERS AND OPERATING CONSTRAINTS

The EEGs are illustrated in this research using annual data from a particular region that are divided into three categories: high, low, and mild temperature. Based on the availability of power supply, the building's load requirement is assessed. Here, PV Syst. 7.2.15 software is used to analyze the PV generation for the building. In a commercial building, the operation of various power components may vary with the environmental conditions. In this case, the lighting system may be affected by the sunlight intensity outside the buildings as it varies with the season throughout the year. Similarly, the fan and air conditioner operation is temperature and humidity-dependent. In summer, the temperature is relatively high compared to the winter season; therefore, the energy consumption is significantly elevated due to excessive use of air conditioners.

In this work, two adjacent buildings are considered where various parameters in EEB for lighting, ventilation, and air conditioning systems are identified, and the energy efficiency is explored. The light parameters are room index, room cavity ratio, installed load efficacy, diversity factor, etc. For ventilation, the EE depends upon fan size, fan energy efficiency, and air circulation in cubic feet per minute. However, for air conditioning, the operation is affected by the cooling effect required in a specified region based on per unit area or volume. Before implementing energy efficiency measures in commercial buildings, it requires strategic energy auditing. The information obtained from auditing data is to be segregated based on the type of power devices installed in the building. The real-time energy data is obtained through smart meters and smart counters installed in the building under consideration. However, the scope of PV generation has been analyzed with the help of Power Syst 7.2.15 software for both buildings.

The thesis is organized as follows; Chapter 1 presents the introduction to the energy efficiency in buildings and the scope for commercial buildings. Chapter 2 presents the literature review of the existing approach related to the proposed work. Chapter 3 explores the PV generation for commercial buildings. In chapter 4, a comprehensive energy auditing is presented, whereas in chapter 5, the correlation of the various environmental and social constraints is demonstrated with respect to energy consumption. Chapter 6 presents the demand side management for EEB, and finally chapter 7 presents the conclusion of the proposed approach.

CHAPTER 2
LITERATURE SURVEY

2.1 OVERVIEW

The energy efficiency of residential and commercial buildings is a significant challenge in today's world of rising energy consumption. Demand-side management (DSM) and strategic energy auditing (SEA) are the two components that make up the energy efficiency in buildings (EEBs). The EEB aids in load management and load reduction at the consumer end. EEBs concentrate on lowering energy use without sacrificing comfort, output, or duration.

2.2 LITERATURE SURVEY

The world's population is growing every day which stress to explore energy resources in order to meet the growing demands. The PV generation is most suitable resource planning for local demand. However, due to technological issues and lack of confidence for long term return the end customs' involvement is very limited as far as developing countries. Kumar et al. [1] have explored the DSM for commercial building through strategic auditing where load demand for particular building was fixed. However, in this approach author focuses the AC load and in the absence of local power generation. Conversely, in [2] authors have presented the home energy management where personal priority are considered under different economic conditions. Here, two different aspects of EEBs are emphasized on considering the energy storage and market price with different types of priorities and control agent inputs. The optimization problem is solved using meta-heuristic approach.

Kumar et al. [3] presented the several environmental constraints including technical standard and social behavior of the working personal in the commercial buildings in India. In this approach, in order to maintain the required level of comfort the different performance indices are developed. Authors, have presented five steps for the implementation of DSM scheme for EEBs and the optimization is performed using heuristic method. In this work, the sample building is equipped with several light sources, fans and air conditioning. These power devices are operated through grid supply and no emphasis have been laid over the PV generation and its scope under given operating scenario. Therefore, the operating strategies of this work are useful to develop a new framework of AC-DC hybrid microgrid with AC or DC loads. Conversely, Fiaschi et al. [4] have conferred that in developed states the total energy consumption of commercial building is nearly 40% and the scope of EEBs varies differently across different interventions. Also, the authors have evaluated the electricity consumption of 60% which is a major contribution of primary energy consumption in the commercial buildings in Italy. In addition, authors have presented an extensive review of EEBs with and without PV generation on the roof of public buildings including schools, sports complex, car parking etc. In the proposed review, authors were more focused on the energy efficiency of academic institutions where school buildings are the major concern. However, this work has presented the evaluation of energy efficiency whereas, loads and their behavior is ignored.

Monica [5] et al. have also presented the EEBs and explored the scope of PV generation for household buildings for the reduction in electricity consumption and dependence on grid power. Here, authors have identified the different energy efficiency measures on dividing the area under consideration in four zones based on the climatic conditions in Portugal. With the difference in climatic conditions the a multiobjective meta-heuristic approach is developed and optimization is performed for the reduction in energy cost. Similarly, in [6] authors have conferred that the there is the correlation between the number of persons and energy consumption in residential building in Mexico. This in turn indicates the households' energy consumption is affected with socioeconomic status, percentage of income allocated to electricity, oversizing of power components and therefore, the causes of higher energy consumption were established. Also, Rabani et al. [7] have proposed the retrofitting measures in the buildings for energy efficiency in Norway and explored the optimization for cost reduction.

Zekai Sen [8] presented the energy saving approach based on the outdoor and indoor temeprature variation of a building and probabilistic distribution function have been developed for energy efficiency measures in Turkey. However, this approach is limited to a specific parameter which can have its direct impact on the energy consumption whereas, the other effects of single parameter need to be evaluated under different environmental conditions. In [9], a net zero energy housing scheme is developed using heuristic approach under different climatic zone in USA. Here, author have empirically evaluate energy consumption and production data and later identify the temporal variability of energy consumption and production data at different time scales. Conversely, Regnier et al. [10] proposed a multitechnology approach for energy saving due to lighting, heating, ventilating and air conditioning in USA. In this approach the utility incentive programs are the important component to support the deployment of EEBs. Here, energy savings have been evaluated on benchmarking which includes assumptions about a building's characteristics and conditions that lead to its annual energy usage. But there are numerous constraints which can have their impact on the overall consumption and they are missed in this work. Fernandez et al. [11] have also evaluated the energy demand of buildings and explored the solar generation for thermal and electrical energy requirements in Spain, EU. Delgarm et al. [12] considered four climatic condition in their analysis and the energy saving opportunities for lighting and annual cooling system in Iran. Here, authors have proposed a multi objective optimization algorithm to facilitate decision-making in early phases of a building design in order to enhance its energy efficiency. In this work four different climatic conditions are considered in a year. Therefore, the energy saving found to be different under different operating scenario.

Astiaso et al. [13] have presented the energy efficiency scheme for the university campus equipped with PV generation on its roof top and emphasized to evaluate the energy used for winter heating and summer cooling and its related management system costs differently. Here, authors have considered the four-year energy data and energy performance index is proposed to evaluate the EEB with local constraints of the geographical area in Italy. Kumar et al. in [14] have proposed a framework of smart power system for home where authors synchronized PV generation, grid power and storage battery for effective utilization of energy resources. However, in this approach no comment on the operating constraint have been derived and therefore limited to the operation of individual source operation at one time, as per the availability. Conversely, in [15] the review of DSM approach for a large commercial building have been presented and the scope of energy efficiency measures are correlated with the type of load demand in a university campus where energy consumption varies differently in the official working hours in Indian scenario. Similarly, in [16] authors have proposed a approach for the design of the energy renovation of existing buildings, considering both Energy Supply Systems and the adoption of energy saving measures to reduce the demand of buildings in retrofitting towards the nearly Zero Energy Building standard.

Martirano et al. [17] have proposed a hybrid microgrid for residential and commercial buildings. Here, author observed that the single building has little effect on the grid power and but, the consumer may be benefited only when the cost of energy is flexible with significant differences in cost according to the time of operation. In this work, aggregation of users in a residential and commercial building is developed with point of connection between a user and distribution system operator. Authors in [18] present an IoT enabled hypothetical model that treats energy supply and usage in buildings as a self-managing energy system. Here, it is realized that the buildings such as offices, shopping malls, and other infrastructures are the largest consumers of energy and consume almost 40% of energy in majority of developed countries.

Maria et al. [19] highlighted the household standards and the socioeconomic factors for the energy consumption in buildings. For EEBs, the university campus is selected which is located in Central Europe and is characterized by social and demographic parameters. This shows the importance of the energy consumption in academic institutions where technical and social constraints have their huge impact over the energy consumption. Also, in [20] cost effective energy management system is reviewed and presented for a low energy building with environmental constraints. Conversely,

Omar et al. [21] presents a conversion strategy from the conventional educational building to a net-zero energy building (NZEB) in Egypt. Author adopted three stage strategies for the EEBs including lighting system, air conditioning and PV generation system integrated into power grid. Here, also the research motivations are environmental, energy security and technical constraints. However, in [22] authors have presented a multi-objective approach for EEB whereas Kumar et al. [23] presented an extensive review of the DSM approach for EEBs and empathized the need to develop a new framework of internet of energy in order to create facilities for centralized monitoring and control of electrical equipment. In [24], several single or multi-objective optimization techniques appears for power and energy systems under different operating constraint applicable for EEBs. Authors in [25] and [26] presented a framework of internet of energy with and without presence of local power generation for EEBs.

1.2 OBJECTIVES

The literature review presented above revealed that the EEB is a big challenge in the present scenario when the energy consumption in the building has gained significant attention from worldwide researchers. The energy consumption in residential and commercial buildings worldwide varies with the change in climatic conditions, and further research has addressed this issue in their optimization formulations by considering the operating constraint of the geographical region. Due to this, it can be realized that the EEB depends upon the technical, environmental, and social conditions that differ in different areas, even in the same country. Therefore, this work presents the EEBs in the Indian scenario where energy consumption is minimized considering the various constraints described in the literature in the presence of PV generation for an academic institution. Here, two adjacent buildings are taken, and energy performance is evaluated through several indices for lighting, ventilation, and air conditioning systems during official working hours. Based on the above literature review, the objectives of this research are listed as follows:

1. To identify the scope of distributed generation (PV generation) for commercial buildings.
2. Energy efficiency analysis of commercial buildings.
3. To develop a correlation between average energy consumption on weekdays and operating constraints (Light intensity, Relative humidity, Temperature, Number of persons involved in the working area)
4. To develop a new framework of DSM in commercial buildings for energy efficiency.

2.3. CONCLUSION

This chapter presents an extensive literature review on building energy efficiency (EEBs). From the literature, it has been noticed that the EEB is a multi-objective approach where operating constraints play a vital role. The primary power components in a building involve; a lighting system, heating and ventilation system, and air conditioning system (L-HVAC). The operation of L-HVAC is found to vary under different climatic conditions all over the world. In this work, the research objectives are framed for EEB in the Indian scenario.

CHAPTER-3

PV GENERATION FOR COMMERCIAL BUILDING

3.1 OVERVIEW

Most of the energy is produced by using conventional energy resources in India. Conventional energy resources are depleting day by day due to excessive use. The use of conventional energy resources harms the environment and effecting the air quality. That is the main reason to use renewable energy resources to produce energy because they are environment friendly and cost-efficient. The main goal is to generate renewable energy on the rooftop of B1 and B2. Distributed energy resources are a number of small, grid-connected, or distribution system-connected gadgets that generate electricity locally. These resources are expanding rapidly. The cost of these resources is falling; that is why they are net-positive and improving consistently**.** In this report, two buildings are taken into consideration. For fulfillment of energy consumption of both the buildings, there is a plan to generate solar power over both the buildings. Then down there is a report on both the buildings, which have been simulated using PV-Syst 7.2.15 software. Here, energy production per year, performance ratio, how many PV modules and where they can be installed, and loss diagram is analyzed.

3.2 TYPE OF DISTRIBUTED GENERATION

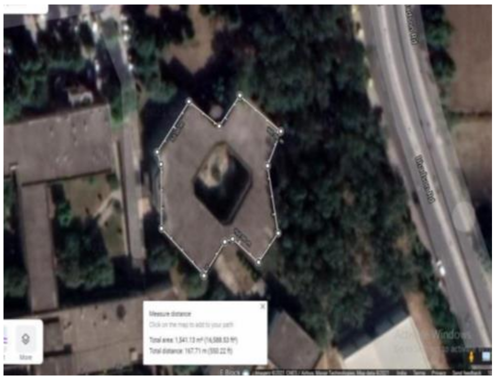
Distributed generation refers to the production of electricity from several small and or distributed energy sources. The fact that distributed generation is situated close to the final customer is its main benefit over conventional, centralized energy production. With distributed generation, there are many advantages, including reduced distribution and transmission losses, enhanced grid security and stability, and less impact on the environment. There are many types of distributed generation plants like as; solar plants, wind plants, microturbines, and natural gas-fired fuel cells. One of the most prevalent kinds of DG systems is a solar photovoltaic (PV) system. In the PV generation system, sunlight is converted into electricity with the help of solar PV panels.

In this project, the two adjacent buildings are considered. There is a plan to generate solar power over both buildings to satisfy their energy needs. Then, further down is a report on the two buildings that were modeled using the P.V-Syst programmed 7.2.15. Loss diagram analysis was obtained based on the energy production per year, performance ratio, number of PV modules that can be installed, and potential installation locations.

3.3 SCOPE OF PV-GENERATION

The biggest consumers of power are commercial buildings [3]. Currently, the power generation with the conventional energy resource is responsible for several environmental issues. There are several other naturally available energy resources that can be used to produce electricity locally. PV generation is the one that and most suited for commercial buildings. The rooftop areas of commercial buildings can be used to generate solar power, which can be essential for maintaining a steady supply of electricity for an extended period. The PV generation system can function either as an independent unit or one that is connected to the grid. PV systems can produce power in either AC or DC forms. DC power can be obtained straight from the PV panels; however, an inverter circuit must be installed before the load for AC power generation. In this study, EEB is assessed when PV generation is AC and DC exclusively. The rooftop area and site selection of the buildings under consideration are shown in Fig. 1 (a-d). Google Map data shows that the first building's rooftop area is 1126.53 m2, while the second building's rooftop area is 1241.13 m2.

(a) Site selection of building-1



(b) Satellite view of building-1

(c) Site selection of building-2

(d) Satellite view of building-2

Fig 1 Site selection Satellite view of two commercial buildings under consideration

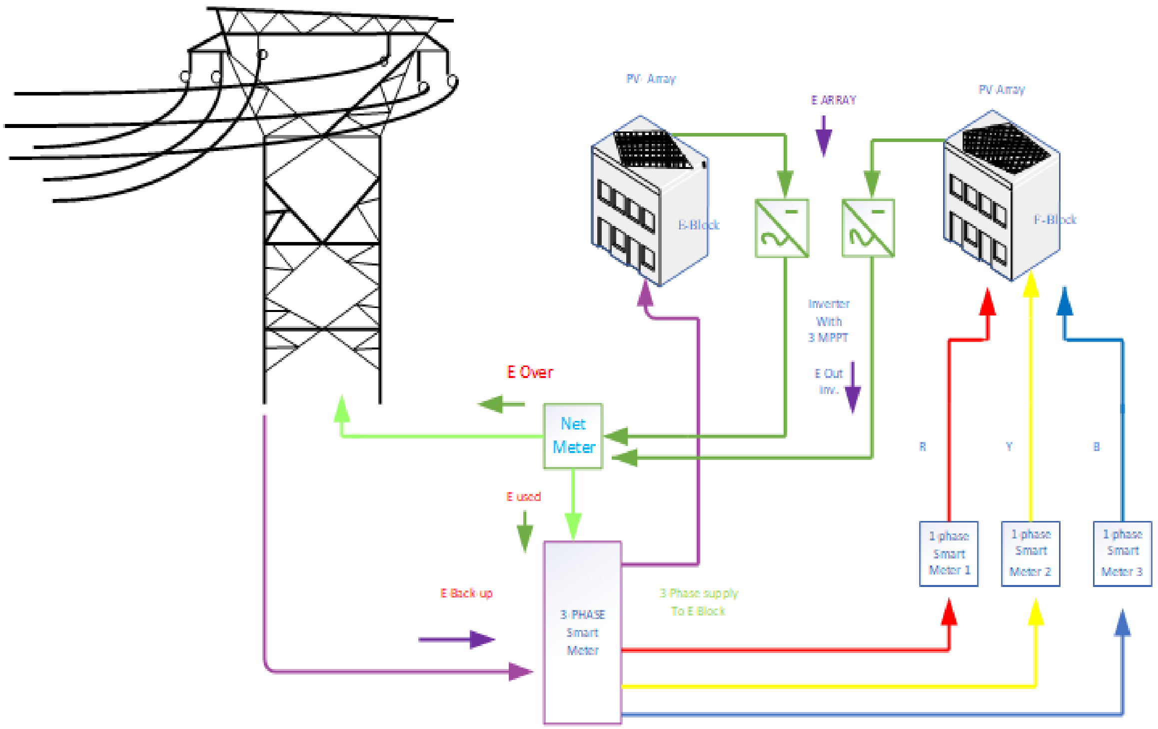


Fig. 2 Equivalent model of grid connected PV generation system

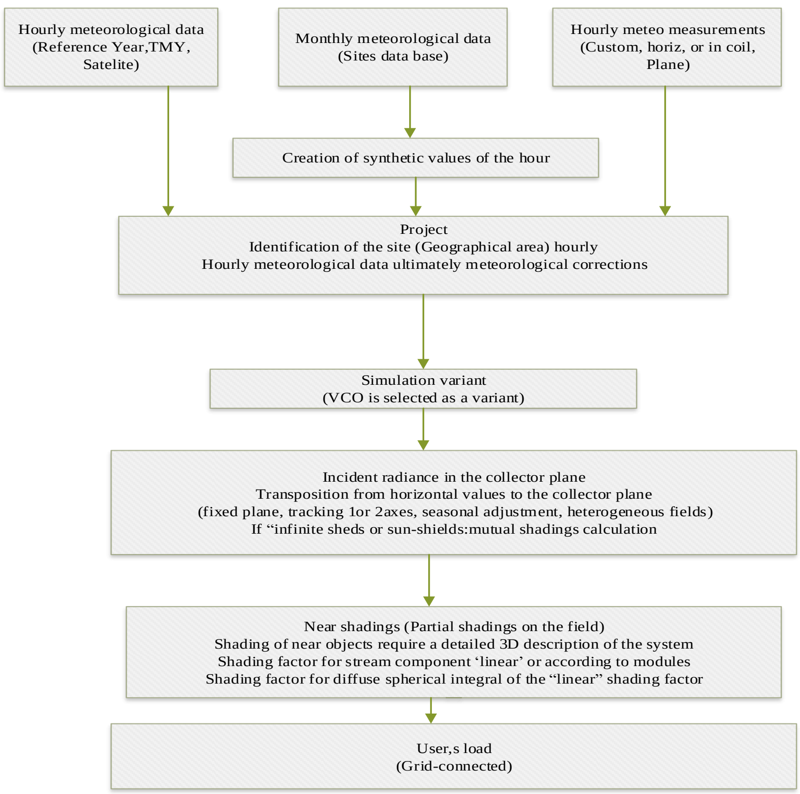


Fig. 3 Flowchart of whole process of PV Syst. 7.2.15

The grid-connected PV generation system for commercial buildings is represented in Fig. 2. The procedural steps developed for PV generation using PV Syst 7.2.15 for the commercial building under consideration is described in Fig. 3. Here, the hourly values of humidity, temperature, etc., are computed from monthly meteorological data. Additionally, hourly meteorological data for panel orientation with tilt angle 32° and azimuth angle 0° is utilized as the project's geographic coordinates. This data includes reference year, satellite, synthetic values, and hourly meteorological measurements. A detailed layout for this system has; the number of strings, the type of inverter, the output, and other factors. The simulation runs after setting up all of these parameters. However, near shading in the system can change the detailed losses. For a full module layout of the project, there are many factors associated to the building design, such as building dimensions, panel facing, panel dimension, number of sheds, number of modules, and strings, and they are pre-defined using PV Syst 7.2.15. Out of a number of various modules, the PV array of the LG 310 N1K-A5 type is chosen for simulation in this work. The selected model consists of 220 modules of 1.016 m * 1.686 m for 310Wp capacity. The number of cells is 60, and therefore, the output of the system is defined as;

$$\text{Output of system} = \text{Capacity of one module x No. of mudules}$$
$$= 310\text{x}220 = 68.2\text{kWp} \tag{3.1}$$

For this project, a 60kW inverter and the Sinenq String Solar Inverter SP-60K-L model are acceptable, as they are sufficient for the above-mentioned generating capacity.

This inverter is equipped with a cooling fan configuration, string monitoring protection, and rapid troubleshooting. It operates in the temperature range between 25°C and 60°C with a power threshold of 300W, three maximum power point tracking, and twelve operating strings, along with an IP65 water protection rating. The capacity of the plant and the type of PV modules also affect the number of modules. The annual generation capacity is determined using roughly 365 days. Shadow analysis reports are used to determine whether or not PV modules are free of shadows, and the shadow analyses were carried out using the PV Syst 7.2.15 software.

3.3.1 PERFORMANCE RATIO

The output of PV generation using PV Syst 7.2.15 is obtained as 68.2kW with 220 modules and each module has a capacity of 310Wp 27v. It is also known as $P_{nominal}$. The performance ratio (PR) of PV System is calculated using 3.2;

$$\text{PR }\% = \frac{\text{E} - \text{Grid} * 1000}{\text{G} - \text{II} * \text{Pnom PV}} \tag{3.2}$$

Whereas;

G − II = Irradiance in inclindeplane

Pnom PV= Installed array PV capacity

3.3.2 IAM LOSSES

The incidence effect, also referred to as the "Incidence Angle Modifier," is the difference between the amount of light that would normally reach the PV cells' surface and the amount that actually does. The glass cover's reflections, which amplify as the incidence angle rises, are mostly to blame for this reduction.

$$\text{IAM losses} = 1 - \mathrm{k}\left(\frac{1}{\cos(\text{incidence angle on plane}) - 1}\right) \qquad (3.3)$$

Here, ‘k’ is variable parameters which is different for different types of modules.

3.4 PV MODULE PLAN FOR COMMERCIAL BUILDINGS

As described in the above section, 220 modules with a southward facing orientation were designed in the PV Syst 7.2.15 software in an Indian scenario. There are five pairs of sheds and twenty-four modules in the sheds that face south. Buildings 1 and 2 have a tilt angle of 32° and 31° degrees, respectively. South-facing sheds have lengths of 22.16 meters and 2.05 meters, whereas sheds 5 have lengths of 10.22 meters and 4.12 meters. All other sheds have measurements of 8.51 m in length and 4.12 m in height.

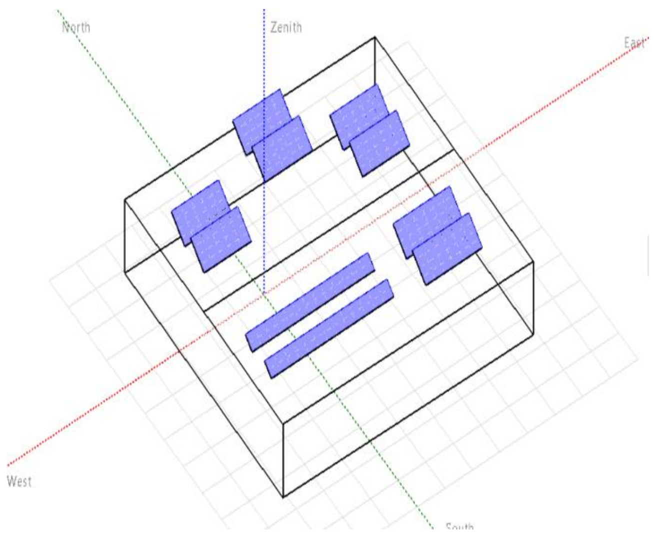


Figure 4: Perspective of the PV-field and surrounding shading scene of B-1

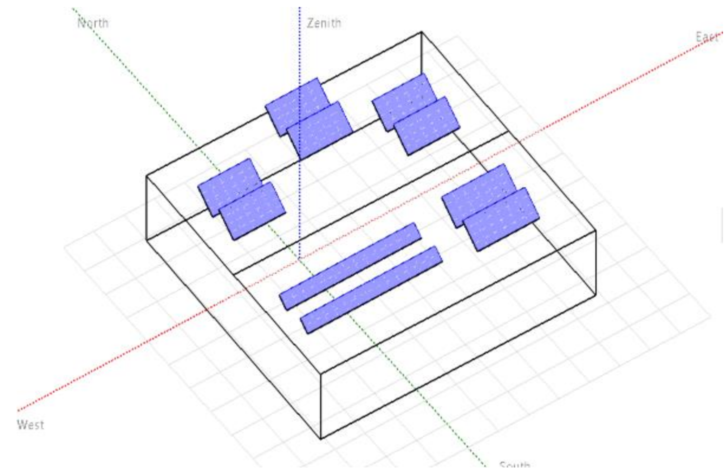


Figure 5: Perspective of the PV-field and surrounding shading scene of B-2

3.5 ISO-SHADINGS DIAGRAM

The iso-shading diagram represents the shading factor table graphically. On top of the sun's rays, it shows lines with specific shade properties. Blue lines are used to depict the plane's tangential bounds (i.e. when the sun rays are parallel to the plane). This diagram allows you to assess how the shade varies throughout the year depending on the season and time of day. The lines' erratic appearance is caused by interpolations across discrete calculation points. On the iso-shading graphic, azimuth angle and altitude are displayed. The shortest day of the year, December 22, is shown on line 7, whereas June 22 is shown on line 1. (longest day of the year). The spaces between the lines show shading losses. The diffuse attenuation coefficient (Kd), which measures the rate of decay of light with increasing water depth, is 0.054. The quantity of diffusely reflected solar radiation expressed as a percentage of total solar radiation is known as a body's albedo, which varies from 0 to 1 and in this study is 0.443, as illustrated in Fig. 5 (6-7). Here, the tilt angle of two buildings are is 32^0 and 31^0 whereas the K_d and Albedo are 0.051 and 0.404 for the second buildings.

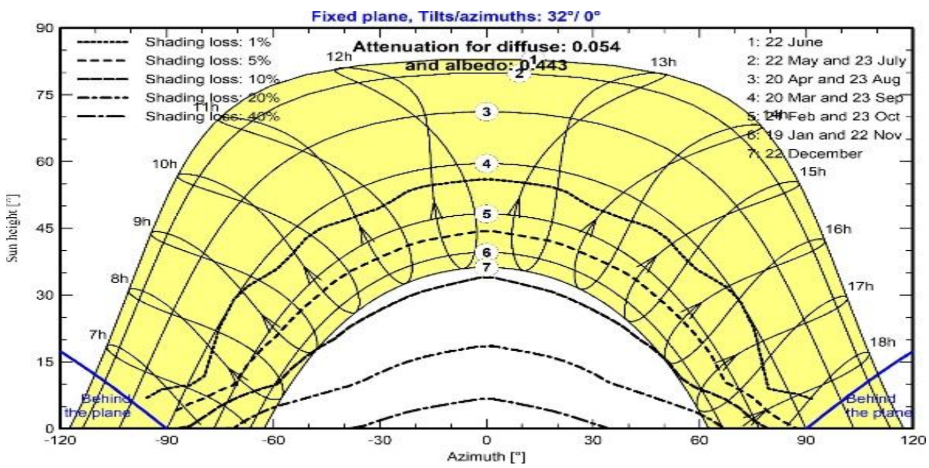


Fig. 6 Iso-shading Diagram of B-1

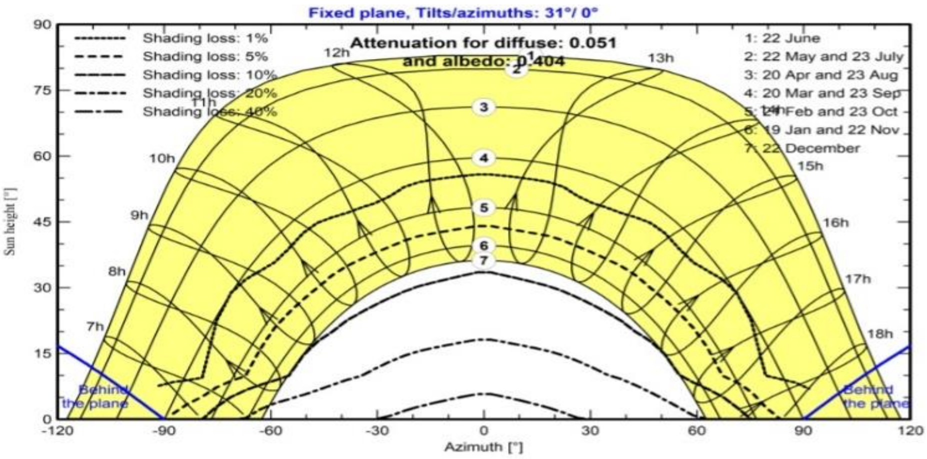


Fig. 7 Iso-shading Diagram of B-2

3.6 EVALUATION OF RESULTS OF PV SYST 7.2.15

Table 1 displays the test results for the PV Syst 7.2.15. Figure 8 and 11 displays a graph of normalized energy for each month of the year. The useable energy output is represented by the red bars in Figures 8 and 11, which are 5 and 5.19 kWh/kWp/day for Buildings 1 and 2, respectively. The green portion of the bars represents system losses, which in this case amount to 0.06 kW/kWp/day. The purple portion of the bars, on the other hand, displays collecting losses as 1.03kW/kWp/day. A total of 129.1 MWh and 129.3 MWh of energy are produced annually by building 1 and building 2, respectively. However, Fig (8), (11) display the performance ratio and time in months graphically. The particular production for two buildings is 1893 and 1896 kWh/kWp/year, with an average performance ratio of about 82.72 and 82.56 percent, respectively.

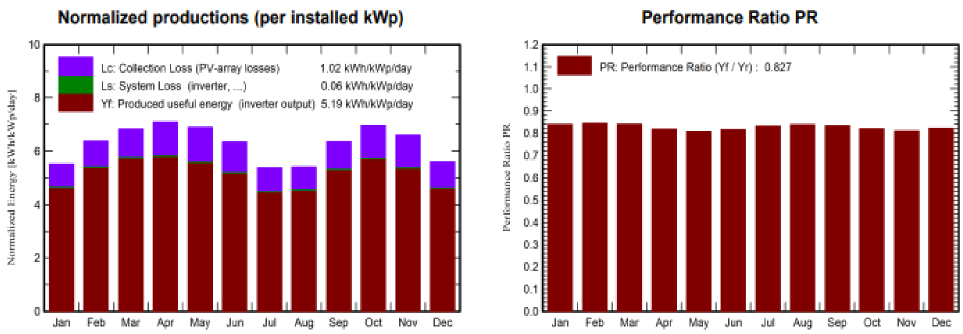


Fig. 8 Graphical representation of normalized production and performance ratio (B-2)

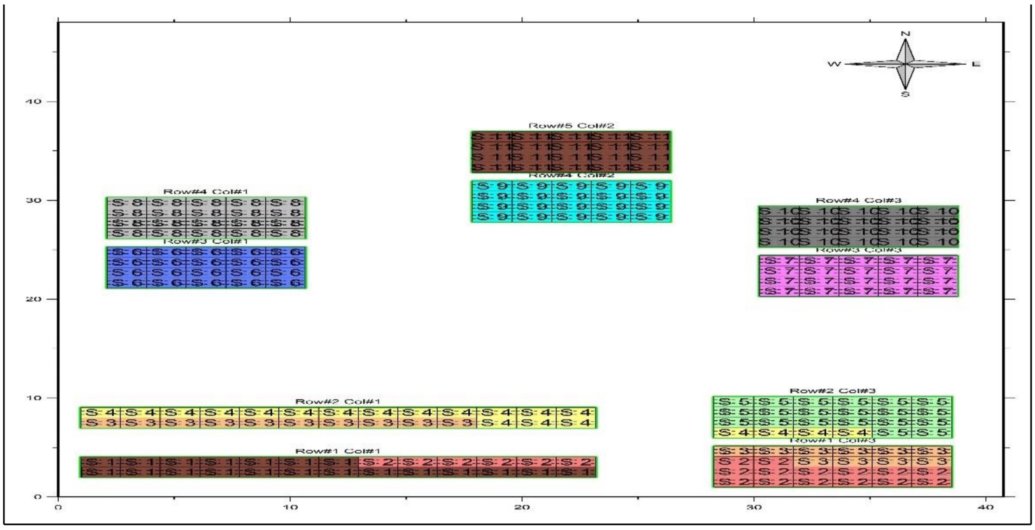


Fig. 9 PV module layout

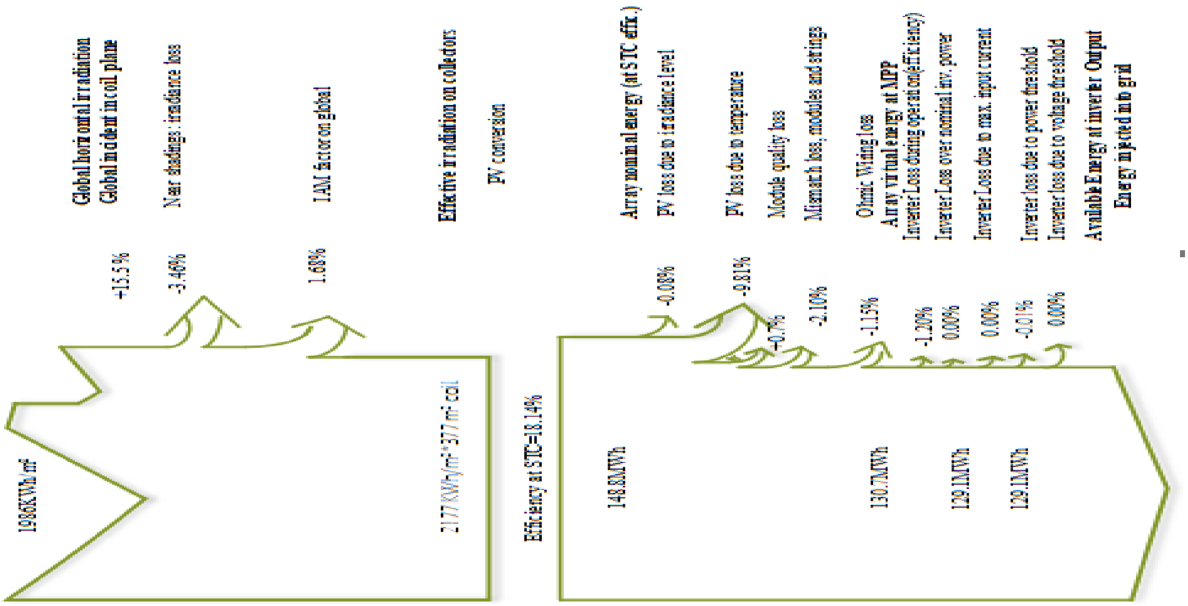


Fig. 10 Loss diagram of PV generation for building-1

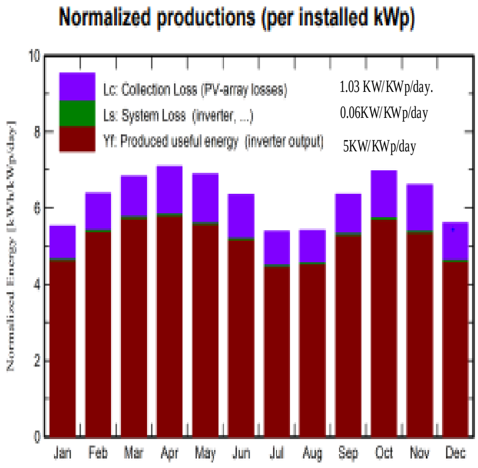


Fig. 11 Graphical representation of normalized production and performance ratio (B-1)

Table 1 PV module and specifications

Data for building-1		**Data for building-2**	
Field type	**Fixed Tilted Plane**	**Field type**	**Fixed Tilted Plane**
Plane tilt/azimuth	$32^0/0^0$	Plane tilt/azimuth	$31^0/0^0$
Compatibility between System and Shadings		Compatibility between System and Shadings	
Full system orientation	tilt/azim = 32° / 0°	Full system orientation	tilt/azim = 31° / 0°
1 Sub-array	P_{Nom} = 68 kWp, Modules area = 377 m²	1 Sub-array	P_{Nom} = 68 kWp, Modules area = 377 m²
Shading 3D fields	10 Tables, Total rough area, 386 m²	Shading 3D fields	10 Tables, Total rough area, 386 m²
System parameters		**System parameters**	
Sub-array #1	PV Array	Sub-array #1	PV Array
PV modules:	11 strings (20 modules each)	PV modules:	11 strings (20 modules each)
P_{nom} = 310 Wp	P_{nom} Array = 68 kWp, Area = 377 m²	P_{nom} = 310 Wp	P_{nom} Array = 68 kWp, Area = 377 m²
Inverters	1 MPPT inputs, Total 60 kWac	Inverters	1 MPPT inputs, Total 60 kWac
3D shadings parameter		**3D shadings parameter**	
Fields area	385.8 m²	Fields area	385.8 m²
Field #1 with 2 sheds	Shed area = 45.5 m² Total area = 90.9 m²	Field #1 with 2 sheds	Shed area = 45.5 m² Total area = 90.9 m²
Field #2-4 with 2 sheds (each)	Shed area = 35.1 m² Total area = 70.2 m²	Field #2-4 with 2 sheds	Shed area = 35.1 m² Total area = 70.2 m²
Field #5 with 2 sheds	Shed area = 42.1 m² Total area = 84.3 m²	Field #5 with 2 sheds	Shed area = 42.1 m² Total area = 84.3 m²

Every single PV module specification utilized in a project plane is displayed in the module layout, including orientation parameters, shading compatibility, and system parameters. The PV system's quality is determined using the loss diagram. Global irradiance, array nominal energy at standard test conditions (STC), and array maximum power point are used to evaluate nominal energy in order to quantify array loss (MPP). Array losses are defined as situations when the available output energy of the array is panelized relative to the nominal power of the PV modules under STC conditions. The ideal array will generate one kWh of electricity under one kWh of installed irradiance. According to the loss diagrams, Fig. 10 and 12, all losses are expressed as a percentage of the amount of energy that was lost previously.

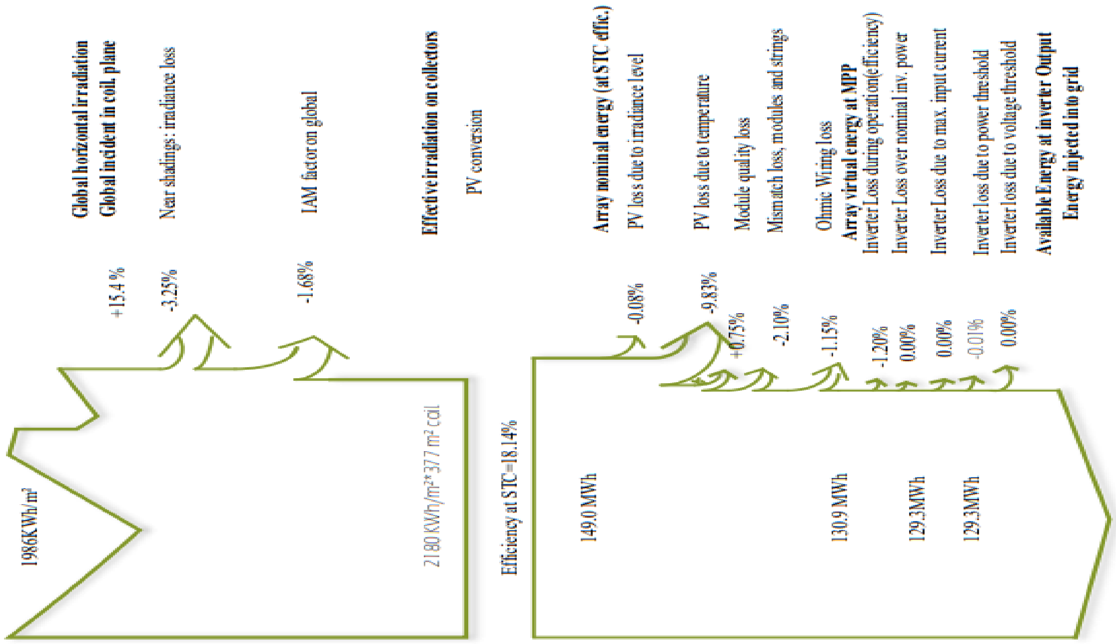


Fig. 12 Loss diagram of PV generation for building-2

Table 2 Financial analysis

Parameters	Items	Quantity	Per unit cost (INR)	Total cost (INR)
PV modules	LG 310 N1K-A5	220	11780	2591600
	Support for Modules	220	8370	1841400
	Inverter	1	200000	200000
	SP-60K-L 3 MPPT	60	20	1200
Monitoring components	Accessories fasteners	5	4200	21000
	Wiring	2	1600	3200
	Monitoring system, display screen	5	534	2670
	Measurement system, pyranometer	1	2000	2000
	Surge arrester	2	4500	9000
Studies Analysis	Engineering	1	500	500
	Environmental studies	1	500	500
Installation	Global installation cost per module Global	220	930	204600
	Installation cost per inverter	1	500	500
	Grid connection	1	50000	50000
	Building insurance	1	5000	5000
Operating cost	Maintenance Salaries	1	240000	240000
	Depreciable cost			
Grand Total				4933170/-

Table 3 shows the PR ratio and monthly average PV generation using PV Syst 7.2.15 for B-1

Months	GlobHor KWh/m²	DiffHor KWh/m²	T_Amb °C	Globlnc KWh/m²	GlobEff KWh/m²	E Array MWh	PR ratio	Hourly Average kWh
January	110.7	27.90	10.44	172.4	157.3	9.97	0.838	26.8
February	129.1	29.40	13.21	179.5	169.1	10.45	0.843	31.1
March	177.0	42.16	18.81	212.0	204.7	12.29	0.840	33
April	204.3	48.30	24.60	212.0	205.5	11.98	0.818	32.27
May	230.0	56.73	28.14	212.0	204.8	11.85	0.809	31.5
June	213.6	63.60	29.16	189.0	182.0	10.62	0.815	29.5
July	182.6	72.54	27.01	165.8	159.1	9.54	0.834	25.65
August	169.3	66.65	25.77	167.5	161.3	9.68	0.837	26.02
September	168.6	48.30	24.06	190.7	184.5	10.98	0.834	30.5
October	164.0	30.38	20.72	216.7	206.6	12.25	0.819	32.94
November	129.6	21.60	16.36	199.7	183.6	11.16	0.809	31
December	106.9	23.87	12.11	175.4	158.1	9.93	0.820	26.69
Year	1985.7	531.43	20.90	2293.2	2176.6	130.70	0.826	29.8

Table 4 shows the PR ratio and monthly average PV generation using PV Syst 7.2.15. for B-2

Months	GlobHor KWh/m²	DiffHor KWh/m²	T_Amb °C	Globlnc KWh/m²	GlobEff KWh/m²	E_Array MWh	PR ratio	Hourly Average kWh
January	110.7	27.90	10.44	171.1	156.5	9.81	0.841	26.38
February	129.1	29.40	13.21	178.7	168.6	10.30	0.845	30.65
March	177.0	42.16	18.81	211.7	204.7	12.14	0.841	32.63
April	204.3	48.30	24.60	212.7	206.4	11.88	0.819	33
May	230.0	56.73	28.14	213.8	206.6	11.80	0.809	31.72
June	213.6	63.60	29.16	190.5	183.9	10.60	0.816	29.4
July	182.6	72.54	27.01	167.0	160.6	9.48	0.832	25.48
August	169.3	66.65	25.77	167.8	161.9	9.60	0.839	25.8
September	168.6	48.30	24.06	190.6	184.7	10.86	0.835	30.1
October	164.0	30.38	20.72	215.9	206.1	12.08	0.821	32.47
November	129.6	21.60	16.36	198.3	182.7	10.98	0.812	30.5
December	106.9	23.87	12.11	174.0	157.3	9.76	0.823	26.23
Yearly data	1985.7	531.43	20.90	2291.9	2180.2	129.29	0.827	29.5

It has been determined from the study above that 129MWh of energy are produced annually overall. The levelized cost of energy is therefore determined to be INR 4.586 per kWh. Additionally, a payback period of 8.3 years for a project with a 20-year life span was determined. According to the research above, the annual total energy output for buildings 1 and 2 is 129.1 MWh and 129.3 MWh, respectively. As a result, for PV generation in these buildings, the levelized cost of energy is determined to be INR 4.59 and 5.47 per kWh, respectively. Additionally, the payback period for a project with a 20-year lifespan is calculated to be between 8.3 and 9.3 years

Table 5 Detailed economic results of B-1

Year	Electricity Sale	Loan principal	Loan interest	Run. Costs	Deprec. allow	Taxable Income	Taxes	After Tax-profit	Cumul. profit	% Amorti.
2023	1033	120	345	240	0	448	0	328	328	9.1%
2024	1044	129	337	240	0	467	0	338	666	18.5%
2025	1054	138	328	240	0	486	0	348	1014	38.7%
2026	1064	147	318	240	0	506	0	359	1373	38.7%
2027	1075	158	308	240	0	527	0	369	1742	49.3%
2028	1085	169	297	240	0	548	0	379	2121	60.5%
2029	1095	181	285	240	0	570	0	390	2511	72.0%
2030	1106	193	272	240	0	593	0	400	2911	84.0%
2031	1116	207	259	240	0	617	0	410	3322	96.6%
2032	1126	221	244	240	0	642	0	421	3742	109.6%
2033	1137	237	229	240	0	668	0	431	4147	123.1%
2034	1147	253	212	240	0	695	0	441	3161	164.1%
2035	1157	271	195	240	0	723	0	452	4077	182.6%
2036	1168	290	176	240	0	752	0	462	5003	201.4%
2037	1178	310	155	240	0	783	0	473	5940	220.4%
2038	1189	332	134	240	0	815	0	947	6887	239.6%
2039	1199	355	110	240	0	848	0	957	7844	259.0%
2040	1209	380	86	240	0	884	0	968	8812	278.6%
2041	1220	407	59	240	0	921	0	978	9790	298.4%
2042	1230	435	30	240	0	959	0	988	10778	318.5%
Total	22632	4933	4382	4800	0	13452	0	10778	10778	318.5%

Table 6 Detailed economic results of B-2

Year	Electricity Sale	Loan principal	Loan interest	Run. Costs	Deprec. allow	Taxable Income	Taxes	After Tax-profit	Cumul. profit	% Amorti.
2023	1032	357	345	240	0	447	0	90	90	9.1%
2024	1042	382	320	240	0	482	0	100	189	18.8%
2025	1053	409	294	240	0	519	0	110	300	29.3%
2026	1063	437	265	240	0	558	0	121	420	40.7%
2027	1073	468	234	240	0	599	0	131	551	52.8%
2028	1084	501	202	240	0	642	0	141	692	65.8%
2029	1094	536	167	240	0	687	0	152	844	79.7%
2030	1104	573	129	240	0	735	0	162	1006	94.6%
2031	1115	613	89	240	0	786	0	172	1178	110.6%
2032	1125	656	46	240	0	839	0	183	1361	127.6%
2033	1135	0	0	240	0	895	0	895	2256	145.7%
2034	1146	0	0	240	0	906	0	906	3161	164.1%
2035	1156	0	0	240	0	916	0	916	4077	182.6%
2036	1166	0	0	240	0	926	0	926	5003	201.4%
2037	1177	0	0	240	0	937	0	937	5940	220.4%
2038	1187	0	0	240	0	947	0	947	6887	239.6%
2039	1197	0	0	240	0	957	0	957	7844	259.0%
2040	1208	0	0	240	0	968	0	968	8812	278.6%
2041	1218	0	0	240	0	978	0	978	9790	298.4%
2042	1228	0	0	240	0	988	0	988	10778	318.5%
Total	22602	4933	2091	4800	0	15711	0	10778	10778	318.5%

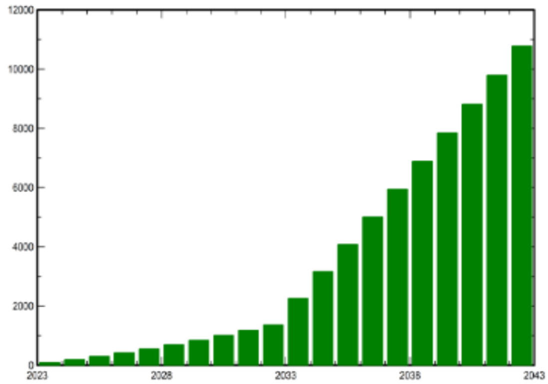


Figure 13 Cumulative cashflow for building-1

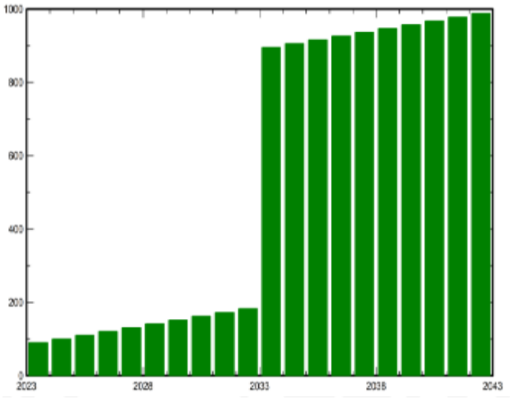


Figure 14 yearly cash flow for building-1

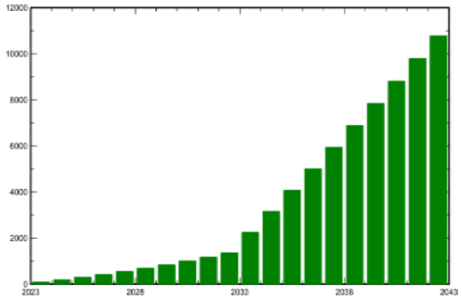


Figure 15 Cumulative cashflow for building-2

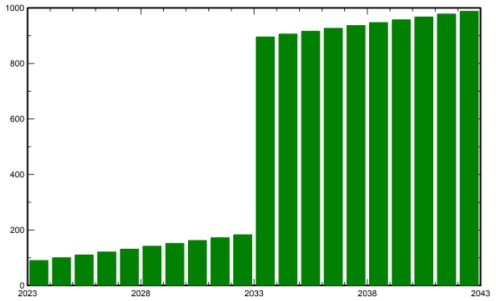


Figure 16 yearly cash flow for building-2

Table 7 System lifecycle emissions

Items	LCE	Quantity	Subtotal ($kgCO_2$)
Modules	1713 kgCO2/kWp	68.2 kWp	116808
Supports	6.24 kgCO2/kg	2200 kg	13735
Inverters	619 kgCO2/units	1.00 units	619

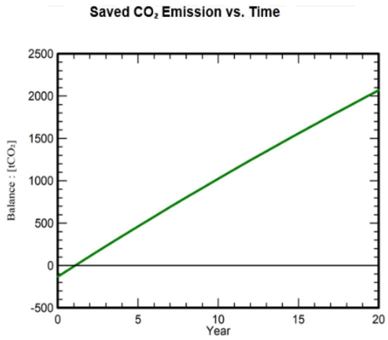


Fig. 17 Saved CO_2 Emission vs Time

Fig 17 shows the CO_2 emission vs time graph. With the grid life cycle emission of 936g CO_2/kWh the lifecycle emission of the project is evaluated and represented in Table 7.

3.7 CONCLUSIONS

This chapter presents the PV generated renewable energy on the rooftop building under consideration. The project is simulated using PV Syst 7.2.15 software. It is noticed that it is sustainable to generate energy on the rooftop of both the building after considering losses. Financial analysis also conducted to show the recovery of the invested cost and recovery is found to be 8.3 years of (B-1) and 9.3 years of (B-2) respectively. The PV modules have warranty of 20 years and it shows that it is a profitable. The CO_2 emissions balance have also been tracked which shows initially it would be high but for longer periods of time it will cause less emission. Therefore, overall system is financially and environmentally sustainable.

CHAPTER-4

ENERGY EFFICIENCY EVALUATION

4.1 OVERVIEW

It is crucial to investigate more energy-saving options and the environmental restrictions along with operating duration, energy density and cost, in order to evaluate the energy efficiency of commercial buildings (EEBs). The strategies developed under specific operating conditions may not be applicable depending on the demand response requirements. Therefore, before implementation of DSM schemes, it required to perform strategic energy auditing for the building under consideration.

Energy auditing is the most economical method for determining requirements and managing their functioning in this case. The three main components of commercial buildings are lighting, heating & ventilation, and air conditioning. The components are installed based on the area covered and operational requirements like minimum lumens, air circulation in feet^3/min, temperature (in °C), and humidity level (in percent). So, it aids in the customer's understanding of their energy bills and permits identification of methods, scope, and time for energy management [25].

4.2 ENERGY AUDITING

Three systems, namely lighting, ventilation, and air conditioning, make up the electricity usage in commercial buildings. These systems are often installed depending on the working and non-working space, as well as the operating needs for comfort under the given environmental circumstances, such as minimum lumens, air circulation in cubic feet per minute, temperature, and relative humidity level. At the Thapar Institute of Engineering & Technology in Patiala, two academic blocks' energy data have been gathered and analyzed in this work. While multiple smart energy meters have been put in the area of the buildings under consideration for energy data, the power components are visually inspected. The information included how much energy each block's fans, air conditioners, tube lights, lamps, power outlets, and other installed devices consumed. Though, an academic institution is a commercial building where energy consumption depends upon surrounding temperature, relative humidity, number of persons in the working area and sun light intensity.

4.2.1 DATA COLLECTION & ANALYSIS OF BUILDING-1

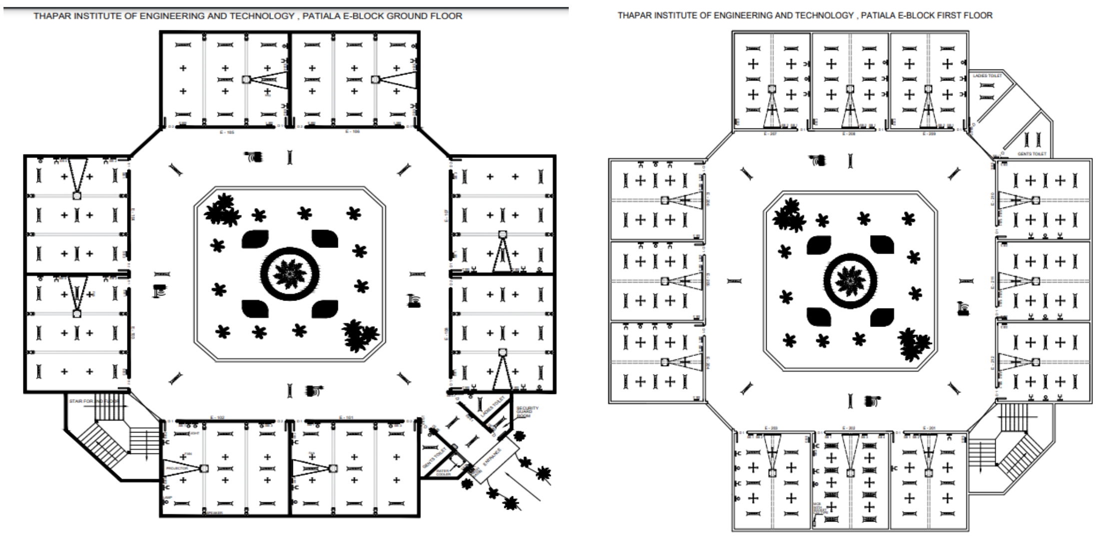


Fig 18 Plan for E-Block Ground floor of B-1

4.2.2ELECTRICAL PLAN OF THE BUILDING-1

Fig 18 shows the electrical plan of the B-1. Building-1 has two floors and ground floor of the B-1 consist of eight rooms, one security guard room, gents and ladies' toilet etc. as given in the plan and first floor consists of twelve rooms, gents and ladies' toilet etc. All the symbols used in this plan are given in the index below. B-1 consist of four sub-distribution boards and six extra sub-distribution boards. These sub-boards show how many components are connected to them and how much load they are taking.

Table 8 List of power components installed in building-1

Location	Fan	F.T Double	F.T Single	L. H	5 A Soc.	15A Soc. P.	15A Soc L.	15A Soc	SPK	Total W
E-101	6	0	8	3	7	1	1	0	4	2095
E-102	6	0	8	4	7	1	1	0	8	2295
E-103	6	0	8	1	7	1	1	0	4	1895
E-104	6	0	8	1	7	1	1	0	4	1895
E-105	6	0	8	1	7	1	1	0	4	1895
E-106	6	0	8	1	7	1	1	0	4	1895
E-107	6	0	8	1	7	1	1	0	4	1895
E-108	6	0	8	1	7	1	1	0	4	1895
SB E1	0	0	8	0	2(wifi)	0	0	0	0	360
SB E2	0	0	0	0	0	0	0	2	0	2000
SB LT	1	0	3	1	1(wifi)	0	0	0	0	332
SB.GT	1	0	1	1	0	0	0	0	0	192
SB SG	1	0	1	0	0	0	0	0	0	92
SB W	1	0	0	0	0	0	0	2	0	2000

E-201	5	0	6	0	6	1	1	0	0	1483
E-202	6	16	0	1	2	1	1	0	0	1455
E-203	5	0	6	2	5	1	1	0	0	1583
E-204	5	0	6	2	5	1	1	0	0	1583
E-205	5	0	6	1	6	1	1	0	0	1583
E-206	5	0	6	1	5	1	1	0	0	1483
E-207	5	0	6	1	6	1	1	0	0	1583
E-208	5	0	6	1	5	1	1	0	0	1483
E-209	5	0	6	1	5	1	1	0	0	1483
E-210	5	0	6	1	5	1	1	0	0	1483
E-211	5	0	6	1	5	1	1	0	0	1483
E-212	5	0	6	1	4	1	1	0	0	1383
SB E	0	0	8	1	4	0	0	1	0	1560
SB LT	1	0	2	0	1	0	0	0	0	212
SB GT	1	0	2	0	0	0	0	0	0	112
Total load										40688

4.2.3 DATA COLLECTION & ANALYSIS OF BUILDING-2

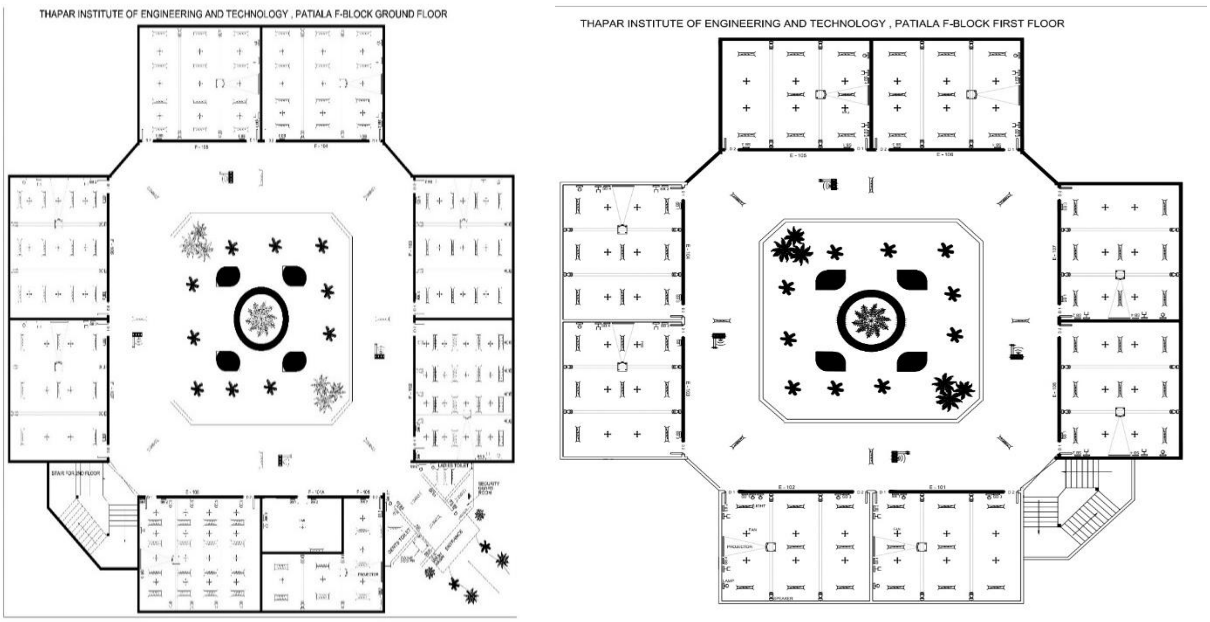


Fig 19 Plan for F-Block Ground floor of building-2

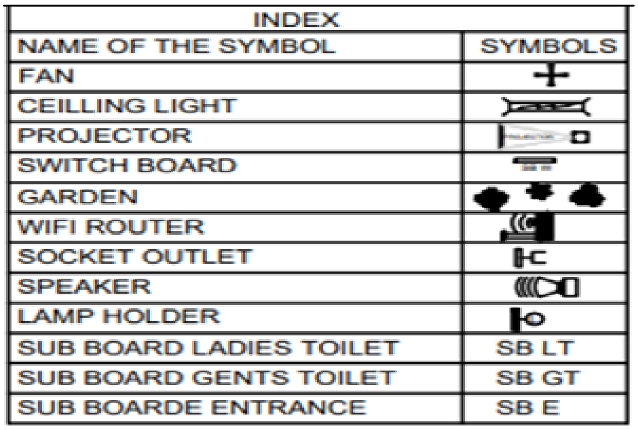
4.2.4 ELECTRICAL PLAN OF THE BUILDING-2

Here down, there is electrical plan of the building-2. Auto-Cad 2016 has been used for making this plan. Building-2 has two floors where ground floor consists of eight rooms; (F-101 to F-108), one security guard room, gents and ladies' toilet etc. as given in the plan and first floor consists of eight rooms; (F-201 to F-208), gents and ladies' toilet etc. All the symbols used in this plan are given in the index below. It has four sub-boards and six extra sub-boards. These sub-boards show how many components are connected to them and how much they are taking.

Table 9 List of power components installed in building-2

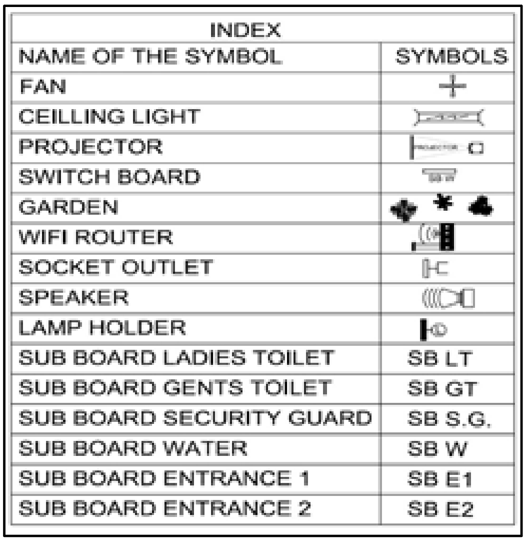
Room no.	Fan	F.T Double	F.T Single	L.H	5 A Soc.	15A Soc.Power	15A Soc L.	15A Soc	SPK.	Total
F-101	6	0	8	3	7	1	1	0	4	2095
F-102	6	0	8	4	7	1	1	0	8	2295
F-103	6	0	8	1	7	1	1	0	4	1895
F-104	6	0	8	1	7	1	1	0	4	1895
F-105	6	0	8	1	7	1	1	0	4	1895
F-106	6	0	8	1	7	1	1	0	4	1895
F-107	6	0	8	1	7	1	1	0	4	1895
F-108	6	0	8	1	7	1	1	0	4	1895
SB E1	0	0	8	0	2 (wifi)	0	0	0	0	360
SB E2	0	0	0	0	0	0	0	2	0	2000
SB LT	1	0	3	1	1 (wifi)	0	0	0	0	332
SB.GT	1	0	1	1	0	0	0	0	0	192
SB SG	1	0	1	0	0	0	0	0	0	92
SB W	1	0	0	0	0	0	0	2	0	2000
F-201	5	0	6	0	6	1	1	0	0	1483
F-202	6	16	0	1	2	1	1	0	0	1455
F-203	5	0	6	2	5	1	1	0	0	1583
F-204	5	0	6	2	5	1	1	0	0	1583
F-205	5	0	6	1	6	1	1	0	0	1583
F-206	5	0	6	1	5	1	1	0	0	1483
F-207	5	0	6	1	6	1	1	0	0	1583
F-208	5	0	6	1	5	1	1	0	0	1483
SB E	0	0	8	1	4	0	0	1	0	1560
SB LT	1	0	2	0	1	0	0	0	0	212
SB GT	1	0	2	0	0	0	0	0	0	112
Total load										40.688 KW

Table 10 Electrical symbols for building-1



INDEX	
NAME OF THE SYMBOL	SYMBOLS
FAN	
CEILLING LIGHT	
PROJECTOR	
SWITCH BOARD	
GARDEN	
WIFI ROUTER	
SOCKET OUTLET	
SPEAKER	
LAMP HOLDER	
SUB BOARD LADIES TOILET	SB LT
SUB BOARD GENTS TOILET	SB GT
SUB BOARDE ENTRANCE	SB E

Table 11 Electrical symbols for building-2



INDEX	
NAME OF THE SYMBOL	SYMBOLS
FAN	
CEILLING LIGHT	
PROJECTOR	
SWITCH BOARD	
GARDEN	
WIFI ROUTER	
SOCKET OUTLET	
SPEAKER	
LAMP HOLDER	
SUB BOARD LADIES TOILET	SB LT
SUB BOARD GENTS TOILET	SB GT
SUB BOARD SECURITY GUARD	SB S.G.
SUB BOARD WATER	SB W
SUB BOARD ENTRANCE 1	SB E1
SUB BOARD ENTRANCE 2	SB E2

4.3 ENERGY AUDITING PARAMETERS

Lighting, ventilation, are all subject to various energy auditing criteria that are not correlated. As a result, it is necessary to conduct a separate analysis of the auditing parameters depending on the temperature range and/or environmental factors. Below is a table listing the different parameters.

Table 12 Energy auditing parameters

Part-A: Specifications for Lighting Systems			
S. No.	Parameters	Symbols	Remarks
1.	Room index	RI	Required to identify the number of illuminances measuring points in working and non-working areas
2.	Room cavity ratio	RCR	Required to identify the space to be illuminated
3.	Average illuminance in working and non-working areas	Eav; task Eav, non-task	Average illuminance in working and non-working areas helps to calculate the number of illuminating points
4.	Number of luminaires	N_L	To decide the uniform distribution in a specified area the number of luminaires needs to be calculated
5.	Lumens per unit watt	$ln\ /\ w$	It is the illuminance developed by the installed lighting system
6.	Load efficacy ratio	ILE	The efficacy of the luminaires depends upon the lumens per unit of its rating in W or kW
7.	Installed load efficacy ratio	ILER	It is the ratio of existing ILE to the recommended ILE in the specified area; if it is less than 0.5, a necessary action needs to be taken
8.	Diversity factor	DF	It describes the effective utilization of the light source in the working area; ideally, it should be 3
9.	Maintenance factor	MF	The lumen developed by the light source deteriorates with time
10.	Utilization factor	UF	It depends upon the room size and the material used in the construction for plastering, flooring, etc.
Part-B: Fans' Parameters			

1.	Cubic feet per minute	CFM	It is the amount of air circulated by the fan in one minute
2.	The energy efficiency of the fan	EEF	It is the CFM developed by the fan per unit of its wattage at a given speed
3.	Number of fans	N_F	The number of fans in a specified area depends upon the CFM and EEF
	Part C: Air conditioning		
BTU per unit area	BTU/m2		The criterion for AC selection mainly depends upon the BTU required in a unit area

However, it has been noticed that the energy consumption resulting in the presence of a certain number of people in a region varies proportionally. From 8 AM to 6 PM, a smart counter is used to count the people who are present during the day.

Fig 20 Installation of smart counter in Building-1

Fig 21 Installation of smart counter in Building-2

Fig 22 Installation of smart energy meters

4.4 ENERGY DATA COLLECTION

Throughout the day, week, month, or season, load varies for lighting, ventilation, and air conditioning. Additionally, depending to the number of people occupying the working space and the technical quality, variations in load demand can be seen. In order to measure the degree of humidity, temperature, movement, and light intensity, the suggested model uses four separate sensors. But in addition to these four criteria, it is also necessary to examine technical norms and guidelines. In order to build and use the computational techniques, this will make the data analysis complex and need for perfect networking and communication. The yearly data can be separated into six seasons based on the environmental conditions, as shown in table 8 for the Indian scenario.

Table 13 Division and duration for data collection

S. No.	Season	Symbol	Month	Parameters to be measured
1	Vasant (Spring)	S1	March-April	a) Light intensity, b) Temperature, c) Humidity, d) Air Quality, e) Number of persons in a specified area
2	Grisma (Summer)	S2	May-June	
3	Varsha (Monsoon)	S3	July-August	
4	Sharad (Autumn)	S4	September-October	
5	Hemant (Pre-winter)	S5	November-December	
6	Shishir (Winter)	S6	January-February	

The annual data is gathered using smart energy meters for analysis, and it is afterwards segmented based on the changes in temperature throughout the course of the year. Temperatures below 25°c, between 25°c and 35°c, and over 35° are the three groups into which the annual data is broken. The energy used by fans, air conditioners, and lights in the sample buildings 1 and 2 is shown in Tables 14 and 15, respectively.

It can be seen from Tables 6 and 7 that the hourly load demand is not uniform. This is because all power components connected to buildings do not work simultaneously; rather, the operation of each power component is dependent on the number of occupants in each building. As a consequence, the highest energy consumption is observed at Grisma (Summer) and Varsha (Monsoon), whereas the least consumption is observed at Vasant (spring) and Hemant (Prewinter) and Shishir (Winter).

Table 14.1 EEB-1 Without Energy Auditing

Working hour	Vasant (Spring)			Grisma (Summer)			Varsha (Monsoon)		
	TnF	AC	Total	TnF	AC	Total	TnF	AC	Total
8:00-9:00	2.5	0	2.5	7.987	33.04	41.027	8.987	35.3	44.287
9:00-10:00	2.73	0	2.73	9.9	28.48	38.38	9.9	25.9	35.8
10:00-11:00	2.89	0	2.89	10.8	27.56	38.36	10.2	27.34	37.54
11:00-12:00	2.87	0	2.87	11.2	20.15	31.35	11.1	20	31.1
12:00-13:00	2.87	0	2.87	5.5	39.09	44.59	8.5	23	31.5
13:00-14:00	3.61	0	3.61	6.84	25.71	32.55	7.84	32	39.84
14:00-15:00	2.88	0	2.88	9.12	16.75	25.87	8.12	18.9	27.02
15:00-16:00	3.7	0	3.7	6.89	32.92	39.81	7.8	28.3	36.1
16:00-17:00	2.33	0	2.33	3.54	36.68	40.22	5.54	24.9	30.44
17:00-18:00	2.04	0	2.04	3.19	26.96	30.15	3.19	41.5	44.69

Table 14.2 EEB-1 Without Energy Auditing

Working hour	Sharad (Autumn)			Hemant (Prewinter)			Shishir (Winter)		
	TnF	AC	Total	TnF	AC	Total	TnF	AC	Total
8:00-9:00	5.9	34.3	40.3	5.58	0	5.58	3.5	0	3.5
9:00-10:00	7.9	24.9	32.8	5.38	0	5.38	3.3	0	3.3
10:00-11:00	8.8	26.3	35.1	5.55	0	5.55	3.5	0	3.5
11:00-12:00	11.2	19	30.2	5.45	0	5.45	3.4	0	3.4
12:00-13:00	7.5	23	30.5	4.79	0	4.79	3.7	0	3.7
13:00-14:00	5.8	31.8	37.6	5.15	0	5.15	3.1	0	3.1
14:00-15:00	8.1	17.9	26	5.47	0	5.47	3.4	0	3.4
15:00-16:00	5.8	27.3	33.1	5.59	0	5.59	3.5	0	3.5
16:00-17:00	4.5	23.9	28.4	5.15	0	5.15	3.1	0	3.1
17:00-18:00	3.2	40.5	43.7	3	0	3	2.0	0	2.0

Table 15.1 EEB-2 Without Energy Auditing

Working hour	Vasant (Spring)			Grisma (Summer)			Varsha (Monsoon)		
	TnF	AC	Total	TnF	AC	Total	TnF	AC	Total
8:00-9:00	3.5	0	3.5	6.987	36.04	43.027	10.987	39.32	50.307
9:00-10:00	3.73	0	3.73	8.9	33.48	42.38	10.97	29.97	40.94
10:00-11:00	3.89	0	3.89	9.8	34.56	44.36	11.83	32.34	44.17
11:00-12:00	3.87	0	3.87	11.7	31.15	42.85	12.79	36.03	48.82
12:00-13:00	3.87	0	3.87	6.5	45.09	51.59	10.5	40.05	50.55
13:00-14:00	4.61	0	4.61	7.8	35.71	43.51	8.84	43.8	52.64
14:00-15:00	3.88	0	3.88	10.12	31.75	41.87	10.12	35.95	46.07
15:00-16:00	4.7	0	4.7	7.8	32.92	40.72	9.8	39.38	49.18
16:00-17:00	3.33	0	3.33	4.5	36.68	41.18	5.54	36.95	42.49
17:00-18:00	3.04	0	3.04	2.19	26.96	29.15	4.19	42.57	46.76

Table 15.2. EEB-2 Without Energy Auditing

Working hour	Sharad (Autumn)			Hemant (Prewinter)			Shishir (Winter)		
	TnF	AC	Total	TnF	AC	Total	TnF	AC	Total
8:00-9:00	7.98	42.32	50.3	12.1	0	12.1	4.5	0	4.5
9:00-10:00	9.9	34.97	44.8	12.8	0	12.8	4.3	0	4.3
10:00-11:00	10.83	36.34	47.17	12.6	0	12.6	4.5	0	4.5
11:00-12:00	12.79	35.03	47.82	12	0	12	4.4	0	4.4
12:00-13:00	9.5	32.05	41.55	11	0	11	4.7	0	4.7
13:00-14:00	6.84	33.8	40.64	10.5	0	10.5	4.1	0	4.1
14:00-15:00	7.12	30.95	38.07	10	0	10	4.4	0	4.4
15:00-16:00	6.89	37.38	44.27	10.8	0	10.8	4.5	0	4.5
16:00-17:00	5.54	33.95	39.49	10.6	0	10.6	4.1	0	4.1
17:00-18:00	4.19	40.57	44.76	12.6	0	12.6	2.0	0	2.0

4.5 ENERGY AUDITING FOR LIGHTING SYSTEM

In reality, the majority of the light emitted by the lamp is absorbed by the luminaire, wall, floor, etc., and does not reach the working area. Illuminance is expressed in lumens/m2, which indicates that illumination is available per square meter of the measurement plane. Target illuminance efficiency (lm/watts) is the ratio of lumens at a work area under the best illuminance efficiency of the source, room reluctance, mounting height, and the power consumption of the lamp circuit. With ageing, the amount of light coming from the source decreases, the room's surface wears out, and the illumination degrades, which deflects light away from the workspace. Install load efficiency ratio (ILER) is a measure of the workplace's illumination efficiency to achieve illumination efficiency (ILER).

The average light intensity, its value in task and non-task regions, lumens, ILE and ILER, and diversity factor in the rainy, winter, and summer seasons are all shown for each room in Tables 16 and 17 for monthly data readings. This entire collection of information comes from both buildings.

Table 16 Energy auditing of the lighting system for B-1

Room No.	**Eav (Lux)**	**Lumens**	**ILE**	**ILER**	**Eav task (Lux)**	**Eav, non-task (Lux)**	**DF**
E-101	144.9	11639.5	25.3	0.5	133.8	135	0.9
E-102	150.6	12092.3	21.5	0.5	139.8	138.6	1.0
E-103	149.1	11976.6	46.0	1.0	138.5	137.3	1.0
E-104	151.8	12188.6	46.8	1.0	145.6	130.3	1.1
E-105	144.3	11591.2	44.5	1.0	136.1	128.6	1.0
E-106	150	12044.1	46.3	1.0	176.6	63.3	2.7
E-107	149.1	11966.9	46.0	1.0	176	62	2.8

E-108	149.4	11995.9	46.1	1.0	163.3	88.3	1.8
SB LT	147.8	2060.1	12.8	0.3	139.6	131.3	1.0
SB.GT	138.9	1936.5	16.1	0.4	131.1	123.6	1.0
SB GT	246.6	2290.7	114.5	3.1	234.3	216.3	1.0
E-201	150	7732.9	24.1	0.5	153.0	155.0	0.9
E-202	152	7836.1	12.6	0.2	155.5	155.3	1.0
E-203	151	7784.5	14.9	0.3	148.6	152.6	0.9
E-204	149.7	7717.5	14.8	0.3	180.8	167	1.0
E-205	150	7732.9	35.1	0.7	168.8	193.3	0.8
E-206	153	7887.7	18.7	0.4	224.8	248	0.9
E-207	150	7732.9	18.4	0.4	322.5	399	0.8
E-208	150	7732.9	35.1	0.7	296.1	344.6	0.8
E-209	150	7732.9	18.4	0.4	242.6	344.6	0.7
E-210	155	7990.7	19.0	0.4	193.1	197.3	0.9
E-211	146	7526.7	17.9	0.3	242.5	217.3	1.1
E-212	148.9	7676.2	18.2	0.3	235.6	357.3	0.6
SB LT	150	2090.1	548.5	10.9	1213.1	1247.3	0.9
SB GT	150	2090.1	52.2	1.4	139.6	131.3	1.0

Table 17 Energy Auditing of the Lighting System for B-2

Room No.	Eav (Lux)	Lumens	ILE	ILER	Eav task (Lux)	Eav, non-task (Lux)	DF
F-101	144.7	5259.1	131.4	3.1	134.1	133.6	1.0
F-102	150.6	1158.5	9.6	0.2	139.8	138.6	1.0
F-103	150	19532.8	26.3	0.6	311.1	355.0	0.8
F-104	151.8	14710.5	43.2	1.0	145.6	130.3	1.1
F-105	144.3	13989.5	41.1	0.9	136.1	128.6	1.0
F-106	150	14536.0	42.7	0.9	176.6	63.3	2.7
F-107	149.0	14443.0	42.4	0.9	176.0	62.0	2.8
F-108	149.4	5429.2	15.9	0.3	163.3	88.3	1.8
SB LT	147.8	2060.0	12.8	0.3	139.6	131.3	1.1
SB GT	138.9	1936.2	16.1	0.4	131.1	123.6	1.0
SB SG	246.6	2290.7	114.5	3.1	234.3	216.3	1.1
F-201	165.9	16282.4	50.8	1.1	153.0	155.0	0.9
F-202	167.8	16470.8	26.5	0.5	155.5	155.3	1.0

F-203	162.0	15893.9	30.5	0.6	148.6	152.6	0.9
F-204	190.3	18672.4	35.9	0.7	180.8	167.0	1.0
F-205	191.1	18754.8	85.2	1.8	168.8	193.3	0.8
F-206	251.1	24641.5	58.6	1.2	224.8	248.0	0.9
F-207	375.8	36874.1	87.7	1.9	322.5	399.0	0.8
F-208	337.3	33094.7	150.4	3.2	296.1	344.6	0.8
SB LT	147.8	2060.0	51.5	1.4	1213.1	131.3	0.9
SB GT	138.9	1936.2	48.4	1.3	139.6	123.6	1.0

From the results in table for 16-17 it is shown that the average value of illuminance is different for different seasons for the same room. The value of ILE, ILER, and DF found varying in different rooms. The lower value of ILER indicates the low level of luminance. Table 18 shows the various auditing parameters for lighting system of building 1 and 2.

Table 18 Room index and cavity ratio, IMP, and the number of light sources for B-1

Room No.	**RI**	**RCR**	**IMP task**	**IMPnon-task**	**NL**
E-101	1.72	2.9	12.6	5.4	8.0
E-102	1.72	2.9	12.6	5.4	8.0
E-103	1.72	2.9	12.6	5.4	8.0
E-104	1.72	2.9	12.6	5.4	8.0
E-105	1.72	2.9	12.6	5.4	8.0
E-106	1.72	2.9	12.6	5.4	8.0
E-107	1.72	2.9	12.6	5.4	8.0
E-108	1.72	2.9	12.6	5.4	8.0
SB LT	0.47	7.0	5.6	2.4	2.0
SB.GT	0.70	7.0	5.6	2.4	2.0
SB SG	0.58	8.5	5.6	2.4	1.5
E-201	1.35	3.7	22.4	9.6	5.61
E-202	1.35	3.7	22.4	9.6	5.61
E-203	1.35	3.7	22.4	9.6	5.61
E-204	1.35	3.7	22.4	9.6	5.61
E-205	1.35	3.7	22.4	9.6	5.61
E-206	1.35	3.7	22.4	9.6	5.61
E-207	1.35	3.7	22.4	9.6	5.61
E-208	1.35	3.7	22.4	9.6	5.61
E-209	1.35	3.7	22.4	9.6	5.61

E-210	1.35	3.7	22.4	9.6	5.61
E-211	1.35	3.7	22.4	9.6	5.61
E-212	1.35	3.7	22.4	9.6	5.61
SB LT	0.67	7.4	12.6	5.4	1.76
SB GT	0.67	7.4	12.6	5.4	1.76

Table 19 Room index and cavity ratio, IMP, and the number of light sources for B-2

Room No.	**RI**	**RCR**	**IMP task**	**IMP non-task**	**NL**
F-101	1.03	4.84	12.6	5.4	4.2
F-101A	1.03	9.34	12.6	5.4	1.0
F-102	1.03	2.29	12.6	5.4	17.4
F-103	1.03	2.63	12.6	5.4	9.7
F-104	1.03	2.63	12.6	5.4	7.7
F-105	1.03	2.63	12.6	5.4	7.7
F-106	1.03	2.63	12.6	5.4	7.7
F-107	1.03	4.84	12.6	5.4	2.9
F-108	0.53	2.29	12.6	5.4	17.4
SB LT	0.47	7.08	5.6	2.4	2.7
SB.GT	0.70	7.08	5.6	2.4	2.7
SB SG	0.58	8.50	5.6	2.4	2.0
F-201	1.91	2.61	22.4	9.6	12.1
F-202	1.91	2.61	22.4	9.6	12.1
F-203	1.91	2.61	22.4	9.6	12.1
F-204	1.91	2.61	22.4	9.6	12.1
F-205	1.91	2.61	22.4	9.6	12.1
F-206	1.91	2.61	22.4	9.6	12.1
F-207	1.91	2.61	22.4	9.6	12.1
F-208	1.91	2.61	22.4	9.6	12.1
SB LT	0.67	7.45	12.6	5.4	1.76
SB GT	0.67	7.45	12.6	5.4	1.76

4.6 ENERGY AUDITING OF VENTILATION SYSTEM

The linearization of cubic feet per minute (CFM) for requirement of fans is evaluated in table 20. Although the room area was substantially bigger than the data indicated, it was nevertheless possible to develop a linear aggression function from equations (4.1) to (4.3). This information illustrates how many fans should be installed in a certain space in accordance with recommendations. The formula for a linear line is;

$$\hat{y} = mx + c \tag{4.1}$$

Where m shows the slope and c shows y-intercept (y-value for which x is 0).

$$m = \frac{n \Sigma xy - (\Sigma x)(y)}{n \Sigma (x^2) - n(\Sigma x)^2} \tag{4.2}$$

$$c = \frac{(\Sigma y)}{n} - \frac{m(\Sigma x)}{n} \tag{4.3}$$

In equation 4.1, $\hat{y}$ is expected value of y. The linear regression line shows in equation 4.1 for which m and c are obtained from equations (4.2) -(4.3) and from calculation the values were 23.72 and 2841.94 respectively. Figure 22 shows graph between area of the room (in square feet) and CFM.

Table 20 Computations in mathematics for fan analysis

S. No.	Room Area (x)	CFM Recommended	Average CFM (y)	$x * y$	x^2	Linearized Value of New CFM $\hat{y} = 23.72x + 2841.94$
1.	36	3000–4500	3750	13,500	1296	3695.86
2.	100	4000–5500	4750	475,000	10,000	5213.94
3.	144	6200–7500	6850	986,400	20,736	6257.62
4.	225	7000–9000	8000	1,800,000	50,625	8178.94
Sum	505	-	23,350	3,396,400	82,657	-

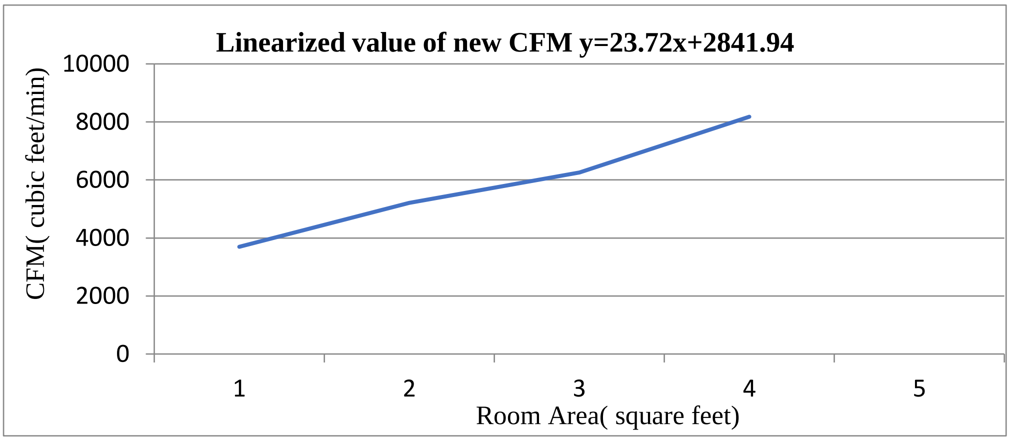


Figure 23.CFM regression curve in cubic feet per minute

Table 21-22 provides the room space and volume to calculate the CFM needed in a certain area, which also aids in determining the necessary number of fans. Here, it can be seen that the recommended number of fans for each room was different as determined by linear regression. Therefore, using this criterion, the rooms with the same area would also have the same number of fans.

Table 21 Detailed information and data analysis of fans in B-1

Room No.	Area		Volume		Fan Size (56 inches)	
	ft²	m²	ft^3	M^3	CFM	Fan
E-101	864.36	80.29	10372.32	367.1	23344.56	4.63
E-102	864.36	80.29	10372.32	367.1	23344.56	4.63
E-103	864.36	80.29	10372.32	367.1	23344.56	4.63
E-104	864.36	80.29	10372.32	367.1	23344.56	4.63
E-105	864.36	80.29	10372.32	367.1	23344.56	4.63
E-106	864.36	80.29	10372.32	367.1	23344.56	4.63
E-107	864.36	80.29	10372.32	367.1	23344.56	4.63
E-108	864.36	80.29	10372.32	367.1	23344.56	4.63
SB LT	149.99	13.93	1800	63.7	6399.94	1.26
SB.GT	149.99	13.93	1800	63.7	6399.94	1.26
SB SG	99.99	9.28	1200	42.46	5213.94	1.03
E-201	554.9	51.55	6659.63	235.69	16005.81	3.18
E-202	554.9	51.55	6659.63	235.69	16005.81	3.18
E-203	554.9	51.55	6659.63	235.69	16005.81	3.18
E-204	554.9	51.55	6659.63	235.69	16005.81	3.18
E-205	554.9	51.55	6659.63	235.69	16005.81	3.18
E-206	554.9	51.55	6659.63	235.69	16005.81	3.18
E-207	554.9	51.55	6659.63	235.69	16005.81	3.18
E-208	554.9	51.55	6659.63	235.69	16005.81	3.18
E-209	554.9	51.55	6659.63	235.69	16005.81	3.18
E-210	554.9	51.55	6659.63	235.69	16005.81	3.18
E-211	554.9	51.55	6659.63	235.6901	16005.81	3.18
E-212	554.9	51.55	6659.63	235.6901	16005.81	3.18
SB LT	149.9	589.09	76099.35	2693.223	153265	30.40
SB GT	149.9	13.93	1800	63.70358	6399.94	1.26

Table 22 Detailed information and data analysis of fans in B-2

Room No.	Area		Volume		Fan Size (56 inches)	
	ft²	m²	ft^3	M^3	CFM	Fan
F-101A	391.2	36.3	4563.1	135.5	12121.2	2.40
F-101A	82.81	7.6	965.9	28.6	4806.1	0.95
F-102	1401.8	130.2	16351.1	485.5	36092.6	7.16
F-103	1043.2	96.9	12168.3	361.3	27586.6	5.473
F-104	1043.2	96.9	12168.3	361.3	27586.6	5.47
F-105	1043.2	96.9	12168.3	361.3	27586.6	5.47
F-106	1043.2	96.9	12168.3	361.3	27586.6	5.47
F-107	391.2	36.3	4563.1	135.5	12121.2	2.40
F-108	1401.8	130.2	16351.1	485.5	36092.6	7.16
SB LT	150	13.9	2145.1	63.7	6399.9	1.26
SB.GT	150	13.9	2145.1	63.7	6399.9	1.26

SB SG	100	9.2	1430.1	42.4	5213.9	1.03
F-201	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-202	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-203	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-204	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-205	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-206	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-207	1056.1	98.1	15103.6	448.5	16005.8	5.53
F-208	1056.1	98.1	15103.6	448.5	16005.8	5.53
SB LT	150	589.0	2145.1	63.7	6399.9	30.40
SB GT	150	13.93	2145.1	63.7	6399.94	1.26

4.7 ENERGY AUDITING OF THE AIR CONDITIONING SYSTEM

Auditing details of the AC installation are displayed in Table 23 and 24 below. In this case, the rooms with air conditioning were considered; all other rooms without air conditioning were disregarded.

Table 23 Detailed information about the AC system in B-1

Room No.	Recommended BTU/kW in the Different Room		AC Size in Tons Using Different Methods Based on			
			Area		Volume	
	BTU-Recommended	KW	BTU calculations	Criterion 1	Criterion 2	Criterion3
E-101	9000	2.7	21609	1.80075	2.94	10.37
E-102	18000	5.28	21609	1.80075	2.94	10.37
E-103	24000	7.04	21609	1.80075	2.94	10.37
E-104	21000	6.16	21609	1.80075	2.94	10.37
E-105	21000	6.16	21609	1.80075	2.94	10.37
E-106	21000	6.16	21609	1.80075	2.94	10.37
E-107	9000	2.64	21609	1.80075	2.94	10.37
E-108	24000	7.04	21609	1.80075	2.94	10.37
E-201	21000	6.16	13870	1.15	1.8153	6.65
E-202	21000	6.16	13870	1.15	1.8153	6.65
E-203	21000	6.16	13870	1.15	1.8153	6.65
E-204	21000	6.16	13870	1.15	1.8153	6.65
E-205	21000	6.16	13870	1.15	1.8153	6.65
E-206	21000	6.16	13870	1.15	1.8153	6.65
E-207	21000	6.16	13870	1.15	1.8153	6.65
E-208	21000	6.16	13870	1.15	1.8153	6.65
E-209	21000	6.16	13870	1.15	1.8153	6.65
E-210	21000	6.16	13870	1.15	1.8153	6.65
E-211	21000	6.16	13870	1.15	1.8153	6.65
E-212	21000	6.16	13870	1.15	1.8153	6.65

Table 24 Detailed information about the AC system in B-2

Room No.	Recommended BTU/kW in the Different Room		AC Size in Tons Using Different Methods Based on			
			Area		Volume	
	BTU-Recommended	KW	BTU calculations	Criterion 1	Criterion 2	Criterion3
F-101A	9000	2.64	9780	0.815	1.97	4.69
F-101A	18000	5.28	2072.525	0.17	0.91	0.99
F-102	18000	5.28	35045	2.92	3.74	16.82
F-103	24000	7.04	26080	2.17	3.22	12.51
F-104	21000	6.16	26080	2.17	3.22	12.51
F-105	21000	6.16	26080	2.17	3.22	12.51
F-106	21000	6.16	26080	2.17	3.22	12.51
F-107	9000	2.64	9780	0.815	1.97	4.69
F-108	24000	7.04	35045	2.92	3.74	16.82
F-201	21000	6.16	2.20	1.81	12.6	12.67
F-202	21000	6.16	2.20	1.81	12.6	12.67
F-203	21000	6.16	2.20	1.81	12.6	12.67
F-204	21000	6.16	2.20	1.81	12.6	12.67
F-205	21000	6.16	2.20	1.81	12.6	12.67
F-206	21000	6.16	2.20	1.81	12.6	12.67
F-207	21000	6.16	2.20	1.81	12.6	12.67
F-208	21000	6.16	2.20	1.81	12.6	12.67

4.8 CONCLUSION

This chapter presented the environmental restrictions along with operating time and energy density of building 1 and 2. The energy efficiency of both the buildings analyzed with the help of electrical layout and by taking record of every energy consuming components. The energy data have been taken on daily bases for a year to record the variations with the change in season. The auditing parameters have also been taken into consideration to find out the best place to fix components for energy efficiency.

CHAPTER-5

CORRELATIONS AND CONSTRAINTS

5.1 OVERVIEW

From the study above, it can be shown that the sample building's energy usage varies and is not equally distributed during a single day. As a result, daily, weekly, and monthly average data have been collected to examine energy use. The annual data is collected and segmented according to seasonality or environmental limits, where temperature, humidity, and sun light intensity all play important roles. Figures 24 to 26 represent the daily energy usage on weekdays when the temperature is below 25°, between 25° and 35°, and over 35°, respectively. On Thursday, the energy consumption is shown in Fig. 24 to be at its highest between 11:00 AM and 12:00 PM and its lowest between 12:00 PM and 1:00 PM.

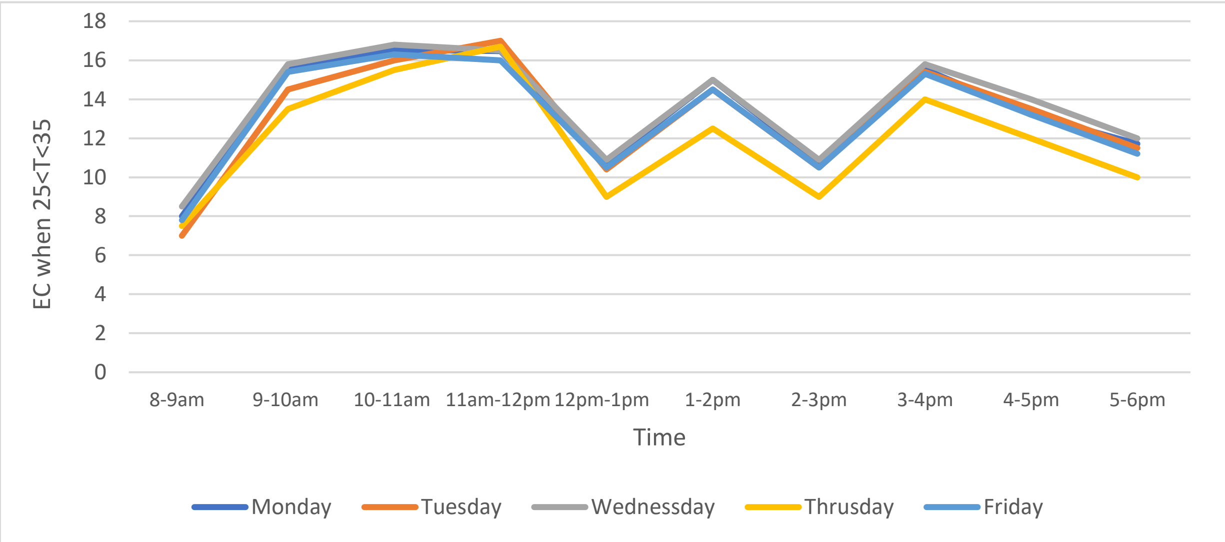


Fig 24. Average energy consumption in week days when 25 < T < 35.

On the other hand, the highest and minimum energy consumption in Fig. 25 are discovered to be at 10:00–11:00AM and 5:00–6:00PM, respectively, and they will be on Thursday and Friday. Additionally, the variation in energy usage differs greatly from the variation in Fig. 16.

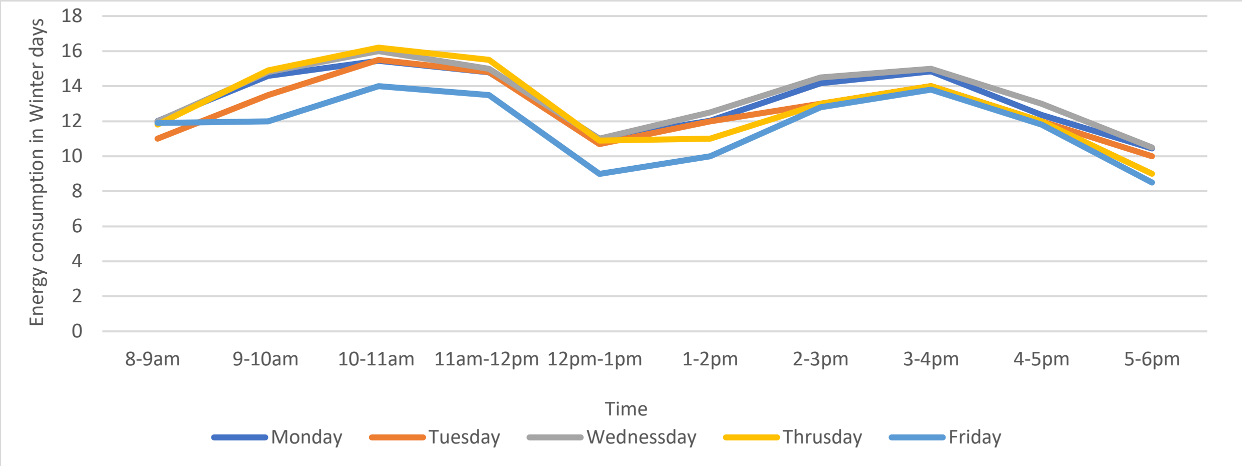


Fig 25. Average energy consumption in week days when T < 25

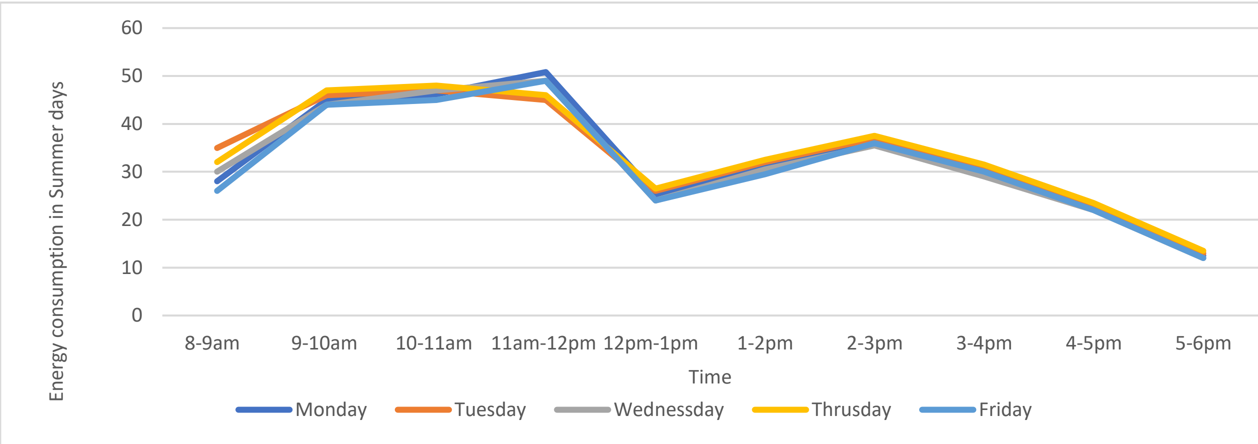


Fig 26. Average energy consumption in week days when T > 35

However, as seen in Fig. 26, energy usage has significantly increased when the temperature is high. The patterns of energy usage have radically shifted in this instance. Now, the least demand is between 5:00 and 6:00 PM, while the peak demand is between 11:00 and 12:00 Noon. The trends for energy consumption in Figs. 24 through 26 indicate a constant pattern of demand with respect to temperature fluctuation. As a result, a relationship between energy use and operational restrictions has been established. A correlation is a connection between two variables that is shown by the relationship [28].

$$r = \frac{n\sum xy - \sum x \cdot \sum y}{\sqrt{(n\sum x^2 - (x)^2 * \sqrt{(n\sum y^2 - (\sum y)^2}}} \quad (5.1)$$

The correlation coefficient in this case is called "r," and if it is near to 1 then the variables are positively correlated, and if it is -1 then the variables are negatively connected. However, if 'r' is close to 0, there is no correlation between the two variables. Figures 27 -32 show the relationship between energy use and temperature and energy use and the number of occupants in the sample buildings, respectively.

5.2 CORRELATION FACTOR CALCULATIONS WHEN 25°C< T < 35°C

To find out correlation between energy efficiency and temperature, regression method has been proposed, it shows a positive week relationship between temperature and energy efficiency. To find out correlation between energy efficiency and number of persons regression method has been proposed, it shows a positive week relationship between number of persons and energy efficiency.

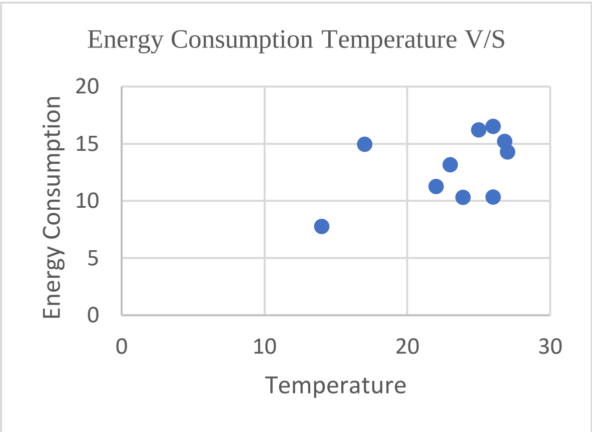


Figure 27 Temp. v/s EC when 25°C< T < 35°C

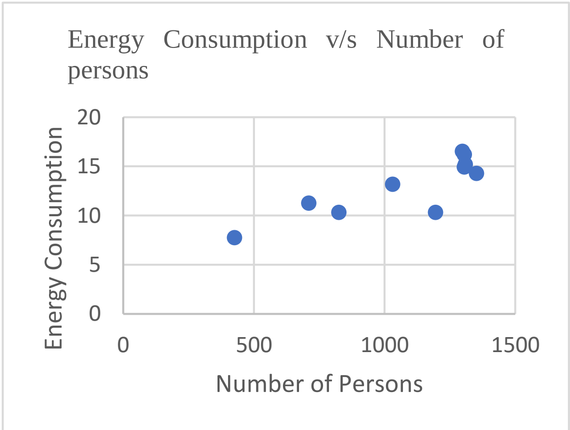
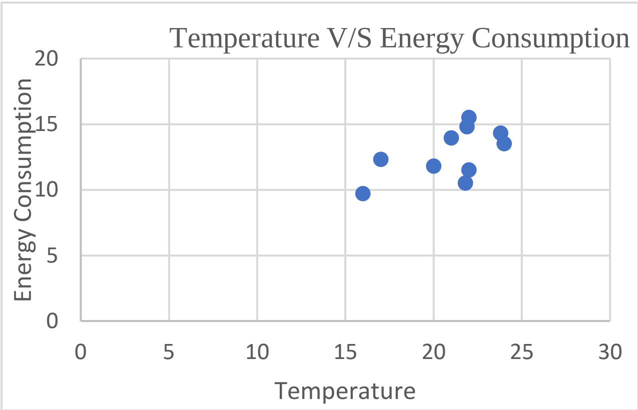


Figure 28 Temp. v/s N.P when25°C< T < 35°C

5.3 CORRELATION FACTOR CALCULATIONS WHEN T<25°C

To find out correlation between energy efficiency and temperature regression method has been proposed, it shows a positive week relationship between temperature and energy efficiency. To find out correlation between energy efficiency and temperature regression method has been proposed, it shows a positive week relationship between number of persons and energy efficiency.



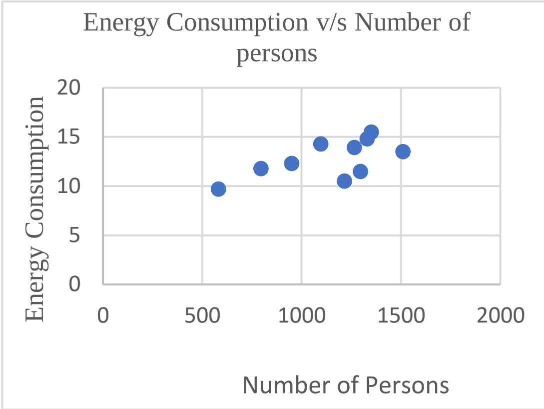
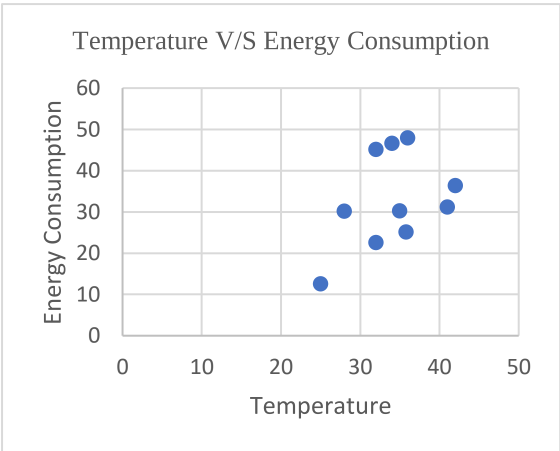


Fig. 29 Energy consumption v/s Temperature when t<25°C Fig. 30 Energy consumption v/s N.P when t<25°C

5.4 CORRELATION FACTOR CALCULATIONS WHEN T > 35

To find out correlation between energy efficiency and temperature regression method has been proposed, it shows a positive week relationship between temperature and energy efficiency. To find out correlation between energy efficiency and temperature regression method has been proposed, it shows a positive week relationship between number of persons and energy efficiency.



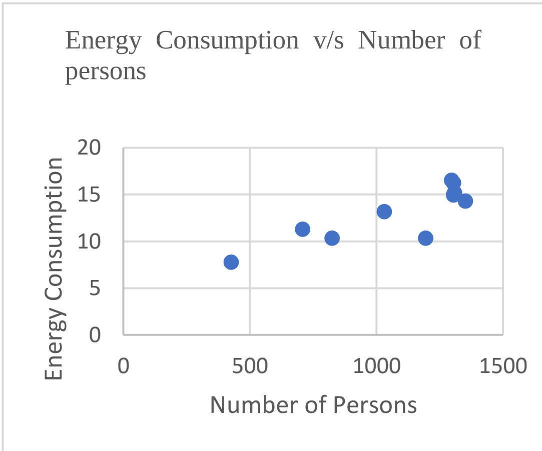


Fig. 31 Energy consumption v/s Temperature (when t>35°c) Fig. 32 Energy consumption v/s N.P (when t>35°c)

5.5. CONCLUSIONS

This chapter presented the correlation between operating constraints i.e. temperature, humidity and number of persons involved in the building in the working hours from 8:00AM to 6:00PM. From the relationship it can be observed that some constraints show linear relationship whereas others are having the non-linear relationship under different operating conditions.

CHAPTER-6
DSM IN COMMERCIAL BUILDINGS

6.1 OVERVIEW

By changing the load profile, DSM is a practical way to lower peak load demand [26]. In commercial structures, changing the load is uncommon; instead, it must be handled in accordance with needs. It makes it possible for various power components to be operated in accordance with the framework created for their working schedule. The operating schedule of various components may vary depending on their recommended application. Under these circumstances, operating schedules applicable under certain conditions may differ from those applicable to other systems of the same size at the same time. As a result, DSM schemes should be flexible enough to meet power-saving objectives and, therefore, increase energy efficiency without compromising comfort [27].

6.2 DEMAND SIDE MANAGEMENT AND ITS SIGNIFICANCE

Demand side management (DSM) is an essential procedure to lower electricity use, particularly when demand is at its peak. A high demand for electricity puts strain on the electricity grid, which leads to power interruptions in addition to rising electricity prices. The grid is stabilized and the use of expensive fossil fuels that can harm the environment is reduced by reducing load during peak hours. Energy-efficient investment and time-variant costing are among the goals of DSM initiatives (e.g., time-of-use rates). Utilizing the DSM services has several advantages.

6.2.1 SUSTAINABLE ENERGY CONSERVATION

The client can maintain and reduce their energy needs and consumption in a more effective and environmentally responsible way with the help of demand side management.

6.2.2 PROVIDES AUTONOMY TO CONSUMER

Electricity is generated by distributed generation units using renewable energy resources. Since DG is a plant that may be located on-site without the need for transmission cables, the line losses are reduced.

6.3 PROPOSED ALGORITHM AND FLOWCHART

6.3.1 PROPOSED ALGORITHM

The computational procedure for the proposed DSM approach is divided into four phases where; at the first phase, the PV generation, energy, and environmental data are obtained through strategic auditing, and later it is segregated based on the temperature variation in a year. In the second stage, the PV generation on a monthly and hourly basis is computed using PV Syst 7.2.15, and it is compared with the demand for net metering.

On the other hand, in the third stage, the various scheme of DSM is developed by considering the operating constraints, as discussed in the previous section. Here, the operating strategies for lighting, ventilation, and air conditioning are different since their operation is highly dependent on environmental conditions. Here, it can be noticed that the operation of the lighting system can be managed based on the sunlight intensity, whereas the operating hours and number of components to be operated for fan and AC depends upon the temperature and the relative humidity level.

In the last phase, the results obtained through the proposed approach are compared and analyzed based on the practical data which was obtained on recording for a year.

Fig 19 shows the flow chart of the proposed algorithm, whereas the procedural steps involved are described under,

The steps involved in the proposed DSM-based algorithm are described below.

Step-1 Initially, the energy and environmental data of the sample building are obtained through smart meters, smart counters, and a smart sensor for a complete year.

Step-2 Read the monthly average PV generation and compute the hourly average for a complete month, segregating it according to the temperature criterion into three categories.

Step-3 Segregate the energy and environmental data into three categories based on the energy consumption when the monthly average $T<25$, $T>35$, and $25<T<35$. Set $TR=1$, $TRmax=3$

Step-4 Select the building and set $B=1$ for building-1 and $B=2$ for building-2, $Rmax=25$ or 34 for building 1 and 2, respectively.

Step-5 Define the loading scenario as AC load and DC load. Set $L=1$ for AC load and $L=2$ for DC load.

Step-6 Set the hours as $H=1$ and $Hmax=10$.

Step-7 Define the number of rooms (Rmax) and pre-auditing, and after auditing, power equipment will be installed in each room with ratings. Set R=1 and AU=1 for pre-auditing and AU=2 for after-auditing.

Step-8 Define the operating scenario for each type of power component as described in Tables 25 and 26 considering technical standards and environmental constraints.

Step-9 Calculate the energy consumption of the room in a respective hour and compare it with PV generation. Compute the net-metering energy for an hour.

6.3.2 PROPOSED DSM-BASED FLOWCHART

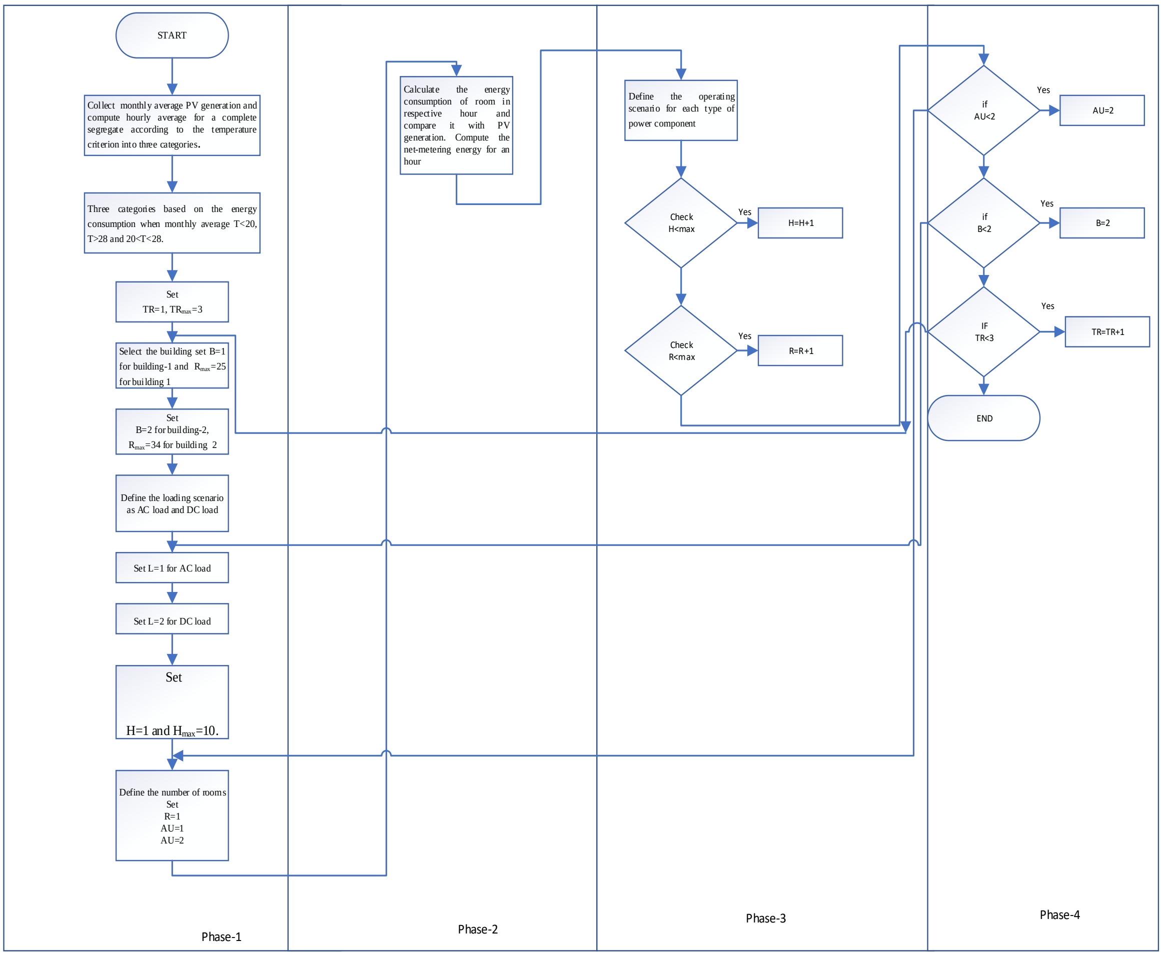


Figure 33 DSM-based Flowchart

Step-10 Check for H<Hmax, it yes, set H=H+1 else go to next step.

Step-11 Check for R<Rmax, if yes, set R=R+1 else go to next step.

Step-12 Calculate the daily energy consumption of each room and the building. Compute the daily net metering energy for a building under consideration.

Step-13 Check if AU<2, if yes, set AU=2 and repeat step 7 to 12 and print the DSM results.

Step-14 Check if B<2, if yes, set B=2 and repeat step 5 to 13 and print the DSM results.

Step-15 Check if TR<3, if yes, set TR=TR+1 and repeat step 4 to 14 till TR=3.

Step-16 Print the overall DSM results and stop the process.

6.4 PROBLEM FORMULATIONS

In order to minimize the costs of DSM, it was created the objective function to save energy. The proposed DSM approach is implemented for two adjacent buildings in order to minimize the costs of energy consumption. The real time energy and environmental data is collected on hourly basis and optimization problem is formulated as under. The DSM problem for energy conservation seeks to optimize the following objective function:

$$Ob(i) = [\sum_{u=1}^{NLD} * \sum_{v=1}^{T} P(u,v).* t(v) * CE(u,v)] \tag{6.1}$$

$$Ob(ii) = \left[\sum_{u=1}^{NLD} * \sum_{v=1}^{T} PD(u,v) * CD(u,v)\right] \tag{6.2}$$

$$OC = Ob(i) \;\; + Ob(ii) \tag{6.3}$$

Here, the objective function has two components (i) cost due to energy consumption i.e. Ob(i) and (ii) cost due to the type of demand i.e. Ob(ii). The Ob(i) depends upon the power demand (P) of load type ‘u’ for interval ‘v’ and the cost of energy (CE) for the time duration ‘t’ whereas, in (6.2), the Ob(ii) depends upon the average power demand (PD) and the cost of demand (CD) of load type ‘u’ for ‘v’ intervals. However, without affecting the cost of energy consumption, the objective function can be improved merely by changing the cost of the type of demand and vice versa.

6.4.1ENERGY CONSUMPTION

The overall cost of energy consumption depends upon the total consumption and therefore, the new consumption i.e. consumption after DSM, should be less than the consumption before DSM. This constraint is represented using (6.4).

$$\Sigma\, \mathrm{EC}_{\mathrm{N\varepsilon w,rt}} \leq \; \Sigma \mathrm{EC}_{\mathrm{OLd,rt}} \tag{6.4}$$

6.4.2ILLUMINANCE LEVEL

With power rating of each light source the lumens per watt varies differently for different makes. Therefore, the required level of illumination should be within the recommended level while operating the light sources. Lesser the light sources lower will be the light intensity and vice versa. Therefore, in order to maintain the required level of light intensity the following is to be satisfied.

$$E_{avg,min} < E_{avg} < E_{avg,max} \tag{6.5}$$

6.4.3 PERSONS INVOLVED

For the operation of power components there should be minimum number of persons involved in the specified area of rooms. Therefore, the operating strategies has to be defined when the following is satisfied,

$$NP_{min} < NP < NP_{max} \tag{6.6}$$

6.4.4 TEMPERATURE AND HUMIDITY

The number of fans and air conditioners that must be operated is influenced by the temperature (T) and relative humidity (RH) in the surrounding area. The relative humidity level is often high during both winter and rainy seasons. However, high temperatures can only influence fan operation on dry days. Therefore, the operating scenario on imposing temperature and humidity limitations is to be decided according to (6.7) and (6.8) respectively.

$$T_{min} < T < T_{max} \tag{6.7}$$

$$RH_{min} < RH < RH_{max} \tag{6.8}$$

6.5 OPERATING SCENARIO FOR DSM

It is clear from the research above that a number of factors affect how much energy a commercial building use. The association between these factors and energy usage may not be robust over short time periods, but it shows significant fluctuation when seen from a broad viewpoint. The number of people, ambient temperature, relative humidity, and sun light intensity all fluctuate throughout the course of a day, so the potential for energy efficiency.

The electricity components must be operated in a specific location or set of buildings in a different way in order to evaluate the EEBs. Additionally, as indicated in Table 3, there are differences in the average temperature and humidity determined from the meteorological data on NASA's website. Due to this, Table 25 and 26 defines the operating scenario for the power components, such as the light source, fan, and ACs. Here, "NP" stands for the total number of people present in the designated space or room, "VS" for the total number of ventilation systems, "LS" for the total number of light sources, and "AC" for the total number of air conditioners to be used in accordance with the "NP" total number of people. The operating environment for power components is also the same in the proposed work when estimating energy consumption before and after strategic auditing.

Table 25 Operating scenario for Demand Side Management in B-1

S. No.	NP	VS	LS	AC
1	0	0	0	0
2	6	2	2	1
3	11	3	2	1
4	21	4	4	1
5	31	5	5	1
6	41	5	6	1
7	51	6	11	2
8	61	6	13	2
9	71	6	14	2
10	81	6	15	2
11	85	6	16	2

Table 26 Operating scenario for Demand Side Management in B-2

S. No.	NP	VS	LS	AC
1	0	0	0	0
2	5	2	2	1
3	10	3	4	1
4	20	4	8	1
5	30	5	10	1
6	40	5	12	1
7	50	6	14	2
8	60	6	16	2
9	80	6	16	3
10	100	6	16	3
11	105	6	16	4

Based on real-time data collected from smart meters and smart counters for sample buildings, the operating scenario is developed. Although these buildings' energy consumption may differ, their utilization is the same, hence the operational situations are kept the same.

6.6 RESULTS ANALYSIS BEFORE AND AFTER AUDITING USING DSM

MATLAB is used to get the test results for the building under consideration. Table 27 displays the environmental data, including temperature (TP), relative humidity (RH), light intensity (LI), and the number of people ratio (NPR). The data are measured and averaged hourly throughout the seasons. Here, it can be seen that while the LI changes as temperature changes, the RH varies differently depending on the season. On the other hand, NPR variation is purely random. As a result, it is necessary to analyses the energy consumption in accordance with the operating limits since they may not be the same during different seasons.

Table 27 Environmental data and number of person ratio

Season	Hours / Parameter	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00
Vasant (Spring) S1	NPR (%)	0.39	0.40	0.45	0.44	0.37	0.43	0.47	0.29	0.29	0.134
	TP (°C)	21	22	23	22.5	23	26	23	20	18	15
	RH (%)	72	69	56	42	38	27	33	35	42	52
	LI (lux)	18000	23000	27000	28000	33000	39677	38677	37177	36177	31000
	E.C B1 Without AC	2.5	2.73	2.89	2.87	2.87	3.61	2.88	3.70	2.33	2.04
	E.C B2 Without AC	3.5	3.73	3.89	3.87	3.87	4.61	3.88	4.70	3.33	3.04
Grisma (Summer) S2 Ap-jun	NPR (%)	0.18	0.52	0.50	0.64	0.62	0.62	0.62	0.53	0.4	0.26
	TP (°C)	32	34	36	38	42	44	44	41	39	38
	RH (%)	35	37	38	40	42	42	42	43	39	40
	LI (lux)	57000	63000	63000	66000	70000	73565	72565	71065	69565	67065
	E.C B1 Without AC	7.987	9.9	10.8	11.2	5.5	6.84	9.12	6.89	3.54	3.19
	E.C B1 With AC	33.04	28.48	27.56	20.15	39.09	25.71	16.75	32.92	36.68	26.96
	E.C B2 Without AC	6.987	8.9	9.8	11.7	6.5	7.8	10.12	7.8	4.5	2.19
	E.C B2 With AC	36.04	33.48	34.56	31.15	45.09	35.71	31.75	32.92	36.68	26.96
	NPR (%)	0.18	0.52	0.50	0.64	0.62	0.62	0.62	0.53	0.4	0.26
	TP (°C)	31	34	38	40	39	40	39	39	38	36

Varsha (Monsoon) S3 jun- aug	RH (%)	79.2	80.66	77.83	71.25	72	70.5	72	75.3	78.83	77
	LI (lux)	29000	32000	35000	38000	42000	45565	40565	38065	36565	34065
	E.C B1 Without AC	8.987	9.9	10.2	11.1	8.5	7.84	8.12	7.8	5.54	3.19
	E.C B1 With AC	35.3	25.9	27.34	20	23	32	18.9	28.3	24.9	41.5
	E.C B2 Without AC	10.987	10.97	11.83	12.79	10.5	8.84	10.12	9.8	5.54	4.19
	E.C B2 With AC	39.32	29.97	32.34	36.03	40.05	43.80	35.95	39.38	36.95	42.57
Sharad (Autumn) S4 Aug-sep	NPR (%)	0.28	0.52	0.50	0.64	0.62	0.62	0.62	0.53	0.4	0.26
	TP (°C)	24	26	30	30	34	34	33	33	30	28
	RH (%)	60	63	65	65	66	67	7	66	69	68
	LI (lux)	30000	33000	36000	39000	43000	46565	41565	39065	37565	35 065
	E.C B1 Without ac	5.987	7.9	8.8	11.2	7.5	5.84	8.1	5.8	4.5	3.19
	E.C B1 With AC	34.3	24.9	26.3	19	23	31.8	17.9	27.3	23.9	40.5
	E.C B2 Without AC	7.98	9.9	10.83	12.79	9.5	6.84	7.12	6.89	5.54	4.19
	E.C B2 With AC	42.32	34.97	36.34	35.03	32.05	33.80	30.95	37.38	33.95	40.57
Hemant (Pre-winter) S5	NPR (%)	0.138	0.45	0.47	0.46	0.40	0.46	0.28	0.45	0.35	0.24
	TP (°C)	14	17	25	24	23.9	27	26	26.8	23	22
	RH (%)	72	50	45	34	35	28	39	47	60	75
	LI (lux)	24000	27000	31000	36000	38000	40927	39927	38927	37927	36927
	E.C B1	5.58	5.38	5.55	5.45	4.79	5.15	5.47	5.59	5.15	3.0
	E.C B2	12.1	12.8	12.6	12.0	11.0	10.5	10.0	10.8	10.6	12.6
Shishir (Winter) S6	NPR (%)	0.38	0.39	0.44	0.43	0.36	0.42	0.45	0.28	0.28	0.14
	TP (°C)	20	21	22	21.5	21	25	22	19	17	12
	RH (%)	75	72	60	45	40	30	35	38	45	55
	LI (lux)	17000	22000	26000	27000	32000	38677	37677	36177	35177	30000
	E.C B1	3.5800	3.38	3.55	3.45	3.79	3.15	3.47	3.59	3.15	2.0
	E.C B2	4.58	4.38	4.55	4.45	4.79	4.15	4.47	4.59	4.15	2.0

Considering the above fact, the energy consumption of buildings 1 and 2 is assessed for before and after auditing with AC and DC load scenarios in the presence of PV generation.

6.6.1 EEB BEFORE AUDITING WITH DSM

Table 28 shows the evaluation of EEB using the data before auditing. The energy consumption and savings for building 1 and 2 is evaluated in different seasons. For building 1, the savings found to be negative and positive at different time instant. This is because in these buildings the load demand varies with the variation in temperature, humidity, sun light intensity and number of persons involved in the working area. From the test result it can also be noticed that the energy consumption is found different in different seasons too.

Table 28 Evaluation of EEB before auditing with DSM

Building/ season	Hours / EC & Savings	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00
B1, S1	EC (kWh)	3.28	2.88	3.26	3.04	3.74	3.96	3.42	6.02	3.32	2.78
	Savings (kWh)	-0.78	-0.15	-0.37	-0.17	0.87	0.35	0.54	2.32	0.99	0.74
B1, S2	EC (kWh) Without ac	7.6680	5.76	6.26	5.76	7.48	7.48	7.56	7.56	8.06	6.4
	EC (kWh) With ac	53.26	51.3	51.86	51.36	53.16	53	53.16	53.16	53.6	52
	Savings (kWh) without a c	0.319	4.14	4.54	5.44	-1.9	-0.6	1.56	-0.6	-4.5	-3.2
	Saving (kWh) With ac	-20.22	-22.8	-24.3	-31.2	-14	-27.2	-36.4	-20.2	-16.9	-25.0
B1, S3	EC (kWh) Without ac	8.90	6.7	7.74	8.28	8.5	8.1	8.42	8.52	7.38	8.02
	EC with ac	54.50	52.32	53.34	53.88	54.02	53.62	54.02	54.04	53.45	53.62
	Savings (kWh) without	-7.12	0.68	-9.2	-3.4	-4.96	6.96	2.06	2.40	-4.76	14.29
	Saving with ac	-19.20	-26.4	-26	-33.8	-31	-21.6	-35.1	-25.7	-28.5	-12.1
B1, S4	EC (kWh) Without ac	4.5680	3.84	6.30	6.56	6.7	6.3	6.7	6.72	6.41	5.14
	Ec with ac	50.16	49.44	51.90	52.16	52.30	51.90	52.3	52.3	52.01	50.74
	Savings (kWh) without ac	1.419	4.06	2.5	4.64	0.8	-0.46	1.4	-0.92	-1.91	-1.95
	Savings with ac	-15.86	-24.5	-25.6	-33.1	-29.3	-20.1	-34.4	-25	-28.1	-10.2
B1, S5	EC (kWh)	9.2	8.5	8	8.28	7.3	7.26	7.64	8.1	8.08	3.54
	Savings (kWh)	3.62	3.12	2.45	2.83	2.51	2.11	2.17	2.51	2.93	0.54
B1, S6	EC (kWh)	4.36	3.58	3.84	3.9	5.14	3.18	4.56	5.86	5	2.3
	Savings (kWh)	0.7800	-0.2	0.29	0.45	1.35	-0.03	1.09	2.27	1.85	-0.3
B2, S1	EC (kWh)	6.24	5.84	5.76	5.46	4.38	6.41	4.7	2.78	2.72	2.62

	Savings (kWh)	- 2.7040	-2.11	-1.87	-1.59	-0.51	-1.800	-0.82	1.92	0.61	0.42
B2, S2	EC (kWh) Without ac	8.9280	5.61	5.61	5.68	7.27	7.27	7.27	7.27	7.27	5.61
	EC (kWh) With ac	45.40	45.4	44.37	44.44	45.96	45.96	45.96	43.68	45.96	44.44
	Savings (kWh) without a c	-1.941	3.29	4.19	6.02	-0.77	0.53	2.85	0.53	-2.77	-3.42
	Saving (kWh) With ac	-9.368	-11.9	-9.81	-13.2	-0.87	-10.2	-14.2	-10.7	-9.28	-17.4
B2, S3	EC (kWh) Without ac	9.9480	9.13	9.0	10.52	10.68	10.28	10.67	10.56	9.13	9.24
	EC with ac	48.7	45.7	45.68	47.16	49.51	48.84	49.32	47	48	45.72
	Savings (kWh) without	1.039	1.84	2.83	2.27	-0.18	-1.44	-0.55	-0.76	-3.59	-5.05
	Saving with ac	-9.38	-15.7	-13.3	-11.1	-9.46	-5.04	-13.3	-7.62	-11.0	-3.15
B2, S4	EC (kWh) Without ac	6.49	6.79	8	9.13	9	8.81	9	9.13	7.98	6.84
	Ec with ac	45.25	43.3	44.57	47.92	45.49	45.17	47.88	45.68	46.85	43.42
	Savings (kWh) without ac	1.488	3.11	2.83	3.66	0.5	-1.97	-1.88	-2.24	-2.44	-2.65
	Savings with ac	-2.932	-8.34	-8.23	-12.8	-13.4	-11.3	-16.9	-8.3	-12.9	-2.85
B2, S5	EC (kWh)	3.98	3.5	5.8	5.56	5.48	5.88	6.16	6.33	5.30	5.28
	Savings (kWh)	1.60	1.88	-0.25	-0.11	-0.69	-0.73	-0.69	-0.74	-0.15	-2.28
B2, S6	EC (kWh)	4.28	6.45	5.61	6.10	5.79	5.80	4.83	2.94	3.02	3.80
	Savings (kWh)	0.3000	-2.07	-1.06	-1.65	-1.0	-1.65	-0.36	1.65	1.13	-1.8

6.6.2 EEB AFTER AUDITING WITH DSM

Table 29 shows the test results for EEB after auditing when air conditioners are installed in the building under consideration and in their absence. For B1 in season 1, the energy consumption is found increased at 8:00-9:00AM whereas, for other time durations the demand has reduced after auditing with DSM implementation. The similar pattern can also be observed for other seasons in a year where ACs are operated in summer, monsoon and autumn seasons. As a result, the energy consumption has increased in these seasons, as shown in table 29.

Table 29 Evaluation of EEB after auditing with DSM

Building/ season	Hours / EC & Savings	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00
B1, S1	EC (kWh)	2.36	2.14	2.16	2.2	1.28	1.38	1.12	1.06	1.02	1.12
	Savings (kWh)	-0.14	0.59	0.73	0.67	1.59	2.23	1.76	2.64	1.31	0.92
B1, S2	EC(kWh) Without ac	4.91	4	4	4	5.76	5.76	5.76	5.76	5.76	4
	EC (kWh) With ac	68.75	68.7	49.63	65.59	49.63	51.36	51.36	51.36	69.60	67.87
	Savings (kWh) without a c	3.077	5.9	6.8	7.2	-0.26	1.08	3.36	1.13	-2.22	-0.81
	Saving (kWh) With ac	-35.71	-40.2	-22	-45.4	-10.5	-25.6	-34.6	-18.4	-32.9	-40.9
B1, S3	EC (kWh) Without ac	6.152	4.9	5.27	6.56	6.7	6.3	6.7	6.7	5.3	5.3
	EC with ac	69.97	50.5	66.8	52.1	52.3	51.9	52.3	52.3	69.1	69.1
	Savings (kWh) without	2.756	1.8	2.47	1.72	1.8	1.8	1.72	1.82	68.55	2.72
	Saving with ac	-34.67	-24.6	-39.46	-32.1	-29.3	-19.9	-33.4	-24	-44.2	-27.6
B1, S4	EC (kWh) Without ac	2.696	2.11	3.83	4.83	4.97	4.57	4.97	4.99	3.87	2.43
	Ec with ac	66.53	47.7	65.39	50.43	50.57	50.1	50.57	50.59	67.71	66.27
	Savings (kWh) without ac	3.291	5.79	4.97	6.37	2.53	1.27	3.13	0.81	0.63	0.76
	Savings with ac	-32.23	-22.8	-39.09	-31.43	-27.57	-18.3	-32.67	-23.29	-43.81	-25.77
B1, S5	EC (kWh)	5.58	5.38	5.55	5.45	4.79	5.15	5.47	5.59	5.15	3.0
	Savings (kWh)	2.02	1.9	1.7	1.52	1.1	1.66	1.46	1.5	1.36	1
B1, S6	Savings (kWh)	2.34	1.66	2.14	2.22	0.98	1.32	1.28	1.1	1.14	1.92
	Savings (kWh)	1.2400	1.72	1.41	1.23	2.81	1.83	2.19	2.49	2.01	0.08
B2, S1	EC (kWh)	4.6080	4.77	4.58	4.83	3.46	4.47	3.61	2.22	1.76	2.3
	Savings (kWh)	-1.1080	-1.04	-0.69	-0.96	0.40	0.13	0.26	2.48	1.57	0.74
B2, S2	EC (kWh) Without ac	7.596	5.61	5.61	7.2	7.2	7.2	7.2	7.2	7.12	5.61
	EC (kWh) With ac	82.83	80.8	78.57	77.43	77.88	78..88	76.74	84.72	82.44	80.85
	Savings (kWh) without ac	3.391	5.36	6.22	5.59	3.3	1.64	2.92	2.6	-1.58	-1.42
	Saving (kWh) With ac	-43.51	- 50.83	-46.23	-41.4	-37.83	-35	-40.79	-45.34	-45.49	-38.28
B2, S3	EC (kWh) Without ac	8.576	7.91	7.91	9.23	9.5	9.14	9.5	9.5	7.9	7.9
	EC with ac	83.8	83.1	79.73	84.74	87	82.14	74.40	83.52	83.1	83.1
	Savings (kWh) without	-0.596	1.99	2.92	3.56	0	-2.3	-2.38	-2.61	-2.36	-3.71
	Saving with ac	-41.48	- 48.13	-43.39	-49.71	-54.95	-48.34	-43.45	-46.14	-49.15	-42.53
B2, S4	EC (kWh) Without ac	5.12	5.6	6.7	7.87	7.9	7.59	7.9	7.9	6.7	5.6
	Ec with ac	79.36	79.71	79.2	76.27	78.59	80.55	82	78.59	80.86	79.71

	Savings (kWh) without ac	1.372	1.19	1.3	1.26	1.1	1.22	1.1	1.23	1.28	1.24
	Savings with ac	-34.10	-36.4	-34.63	-28.35	-33.1	-35.38	-34.12	-32.91	-34.01	-36.29
B2, S5	EC (kWh)	2.84	2.92	4.56	3.93	3.98	5.61	5.54	5.30	3.72	4.23
	Savings (kWh)	2.7400	2.46	0.98	1.51	0.80	-0.46	-0.07	0.28	1.43	-1.23
B2, S6	EC (kWh)	3.0800	4.92	4.06	4.75	3.98	5.28	4.17	2.18	2.08	2.76
	Savings (kWh)	1.5000	-0.54	0.48	-0.30	0.80	-1.13	0.29	2.41	2.07	-0.76

6.6.3 COMPARISON OF EEBS AND ECONOMICS

Table 30 shows the results for PV generation and energy consumption in case of before auditing and after auditing with DSM. Here, it can be noticed that the energy consumption in season 1, 5 and 6 is significantly less as compared to the season 2, 3 and 5, and this is due to the air conditioning system's operation in buildings. As a result, the saving for season 2, 3 and 5 is found to be negative and building's energy demand need to be met partially from grid supply.

Table 30 Daily energy generation, consumption and economics with DSM

	Analysis with AC load					Analysis with DC load				
Building/ season	PV_{avg} (AC)	EC_{avg} Before Auditing	EC_{avg} After Auditing	Savings Before Auditing	Savings After Auditing	PV_{avg} (DC)	EC_{avg} Before Auditing	EC_{avg} After Auditing	Savings Before Auditing	Savings After Auditing
B1, S1	347.4	35.7	15.84	311.7	331.56	353.4	17.85	7.92	329.55	345.48
B1, S2	391.6	69.98	49.71	321.62	341.89	397.6	34.99	24.855	356.61	372.745
B1, S2	391.6	525.8	593.8	-134.2	-202.2	397.6	262.93	296.92	128.67	100.68
B1, S3	366	80.56	59.88	285.44	306.11	372	40.28	29.941	325.72	342.059
B1, S3	366	536.8	586.3	-170.8	-220.3	372	268.40	293.18	97.6	78.82
B1, S4	310	59.23	39.26	250.77	270.7	316	29.61	19.633	280.39	296.367
B1, S4	310.0	515.2	565.8	-205.2	-255.8	316	257.60	282.93	52.4	33.07
B1, S5	380.6	75.9	51.11	304.7	329.4	386.6	37.95	25.555	342.65	361.045
B1, S6	346.1	41.72	16.1	304.38	330	352.1	20.86	8.05	325.24	344.05
B2, S1	342.1	46.88	36.6	295.22	305.5	348.1	23.44	18.3	318.66	329.8
B2, S2	393.7	67.788	67.54	325.912	326.16	399.7	33.894	33.773	359.806	365.927
B2, S2	393.7	451.5	722.2	-57.8	-328.5	399.7	225.78	361.13	167.92	38.57
B2, S3	366.7	99.15	87.06	267.55	279.64	372.7	49.579	43.533	317.121	329.167
B2, S3	366.7	475.63	824.63	-108.93	-457.9	372.7	237.81	412.31	128.89	-39.61
B2, S4	307.6	81.17	68.88	226.43	238.72	313.6	40.585	34.44	267.015	279.16
B2, S4	307.6	455.53	794.84	-147.93	-487.2	313.6	227.765	397.42	79.835	-83.82
B2, S5	375.4	53.27	42.63	322.13	332.77	381.4	26.635	21.315	348.765	360.085
B2, S6	340.3	48.62	37.26	291.68	303.04	346.3	24.31	18.63	315.99	327.67

Table 31 Seasonal energy supplied to the grid

Load	Season/Building	S1 kWh	S2 kWh	S2 (with AC) kWh	S3 kWh	S3 (with AC) kWh	S4 kWh	S4 (with AC) kWh	S5 kWh	S6 kWh
B1-with AC load	Before auditing	311.7	321.6	0	285.4	0	250.77	0	304.7	304.38
	After auditing	331.56	341.8	0	306.1	0	270.7	0	329.4	330
B1-With DC load	Before auditing	329.5	356.6	128.6	325.7	97.6	280.3	52.4	342.6	325.2
	After auditing	345.4	372.7	100.6	342.0	78.82	296.3	33.07	361.0	344.0
B2-With AC load	Before auditing	295.22	325.9	0	267.5	0	226.43	0	322.13	291.68
	After auditing	305.5	326.1	0	279.6	0	238.72	0	332.7	303.0
B2-With DC load	Before auditing	318.6	359.8	167.9	317.1	128.8	267.0	79.83	348.7	315.9
	After auditing	329.8	365.9	38.5	329.1	-39.61	279.1	-83.8	360	327.6

Table 31 shows the seasonal energy supplied to the grid system before and after auditing. Here, it can be noticed that in season 2, 3 and 4 when buildings are equipped with air conditioning system the energy supplied to the grid is zero. However, in other seasons the energy supplied to the grid, with PV-generation system on the roof top, has significant contribution when loads are operated on DC supply. In this case, the power supplied to the grid will be zero in season 3 and 4 for building-2 only.

Therfroe, from the test results obtained in the work shows that there is a huge scope of energy efficiency in building with DSM and PV-generation which is benificial to the utilities and customer with no extra cost. The EEB can contribute to an ambitious project of Government of India of national mission of enhanced energy efficiency.

CHAPTER-7

CONCLUSIONS

7.1. SUMMARY

This work presented the energy efficiency of two adjusted buildings where the number of persons in a working area vary on a seasonal basis throughout the year. The operation of the electrical devices in these buildings is managed according to the technical, social, and environmental constraints. The energy requirement of the sample building is met with grid power and PV generation. In this work, the EEB is evaluated before and after auditing with DSM in the presence of PV generation. Hare, a correlation is developed between temperature and other parameters with energy consumption. From the test results, it has been observed that the total PV generation is more than the demand in four seasons in a year, whereas the demand was found to be more in two seasons due to the operation of the air conditioning system. Further, the EEP is evaluated with AC and DC load scenarios, which are found to be different in both buildings. However, the results are obtained assuming that grid power and PV generation are always available, whereas contingency due to power failure is ignored. Therefore, in the future, the robustness of the proposed needs to be evaluated considering this aspect in a practical scenario.

7.2. FUTURE DIRECTIONS

The proposed approach presents the EEB with PV generation and demand side management. The PV generation is directly scaled with the load demand on an hourly basis. As a result, the PV generation is found sufficient to meet the load demand at a particular time instant whereas, when load demand due to air conditioning has increased, the saving even in the presence of PV generation becomes negative. In this scenario, it is required to evaluate the energy efficiency of the buildings with an extensive energy storage system in the presence of the PV generation for AC and or DC loads.

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Appendix A

Table A1. Coefficient of utilization using the zonal cavity method [29]

	RCC %		70%		
	RW %	70	50	30	0
RCR	0	1.16	1.16	1.16	1
	1	1.07	1.03		0.87
	2	0.99	0.92	0.86	0.75
	3	0.91	0.82	0.76	0.66
	4	0.84	0.74	0.67	0.58
	5	0.78	0.67	0.6	0.52
	6	0.73	0.61	0.54	0.46
	7	0.68	0.56	0.48	0.42
	8	0.63	0.52	0.44	0.38
	9	0.6	0.48	0.4	0.35
	10	0.56	0.44	0.37	0.32

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