

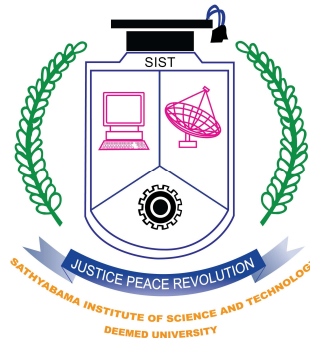
NEARLY ZERO ENERGY BUSINESS CENTRE IN WARM AND HUMID CLIMATE OF CHENNAI

A Thesis

Submitted in partial fulfilment of the requirements for the award of
Master of Architecture degree in Sustainable Architecture

By

Harrine R (40890005)



**DEPARTMENT OF ARCHITECTURE
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

MAY 2022



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BONAFIDE CERTIFICATE

This is to certify that this Report is the bonafide work of **Harrine R (40890005)** who carried out the Thesis entitled "NEARLY ZERO ENERGY BUSINESS CENTRE IN WARM AND HUMID CLIMATE OF CHENNAI" under our supervision from January 2022 to May 2022.

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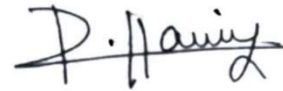
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DECLARATION

I **Harrine R** hereby declare that the Thesis Report entitled “NEARLY ZERO ENERGY BUSINESS CENTRE IN WARM AND HUMID CLIMATE OF CHENNAI” is done by me under the guidance of **Dr Devyani Gangopadyay** (Internal) and **Ar. Krithikha Muthukrishnan** (External) at Sathyabama Institute of Science and Technology is submitted in partial fulfilment of the requirements for the award of Master of Architecture degree in Sustainable Architecture.

DATE: 06/05/2022

PLACE: Chennai

A handwritten signature in black ink, appearing to read 'H. Harrine', with a stylized flourish at the end.

SIGNATURE OF THE CANDIDATE

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I am pleased to acknowledge my sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this Thesis project and for completing it successfully.

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ABSTRACT

40% of the world's energy is consumed by buildings and 21% of the Green House Gas emissions come from buildings. Energy demand within the construction sector is constantly in the increase due to better access to energy in developing countries, the use of energy- intensive devices and ever-increasing user expectations for thermal comfort. As per global per capita energy consumption ranking, India ranks 7th, but 379.1mi (35.44% globally) of the population do not have access to electricity ^[1]. So, though India ranks 7th as per consumption, more than a third of the population is not a contributor. To satisfy the energy requirement of this growing nation, a smarter alternative must be formulated. Awareness among the public is on the rise as the ramification of Global warming is more apparent. Policies by the government for energy efficiency and building certifications by various bodies serve as a catalyst to the green initiatives flooding the market. This has encouraged the public to consciously take the Net Zero route. But India has much more potential to produce Net Positive Energy Buildings (NPEB) by solving many other crises that a developing nation faces, such as increased waste generation and energy crisis to name a few. As the exploration into sustainable and energy efficient buildings in India is still in its nascent stage, this research aims to explore the current scenario of the status of nZEB in India, the opportunities and threats, and address them.

In this report, the current scenario of energy consumption in India is studied and the necessity of Net Positive Energy Buildings is highlighted. This report explores the present situation of Net Zero Energy Buildings (nZEB) in India in the Academic and Commercial sectors in Warm and Humid climate to understand the approach of each typology to attain nZEB status. It is found that Academic sector can achieve nZEB status by applying passive techniques and Commercial buildings require a combination of passive and active techniques to attain nZEB status. The common implementation seen in the study for both sectors is the implementation of Solar passive techniques for passive ventilation. For Commercial buildings, installing efficient active systems activated by sensors and constant energy monitoring are important. In conclusion, for a building, new or retrofitted, to become a nZEB, it has to first reduce the required amount of energy by passive interventions, and for the reduces energy requirement, highly efficient active systems must be implemented. Renewable sources can produce energy for the resulting energy requirement. When the building produces more energy than is required, it becomes a Net Positive Energy Building.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

As per global per capita energy consumption ranking, India ranks 7th but 379.1mi (35.44% globally, ranking 1st) of her population do not have access to electricity. So, though India ranks 7th as per consumption, more than a third of the population is not a contributor. To satisfy the energy requirement of this growing nation, a smarter alternative must be formulated.

Table 1.1 Per Capita Energy Consumption by different countries

Table 1 Per capita energy consumption by different countries.

S. no.	Country	kWh/capita
1	USA	13228.00
2	France	7366.00
3	UK	6158.00
4	Russia	5350.00
5	Brazil	1843.00
6	China	1184.00
7	India	421.00

Source: IEA (2005).

Table 1.2 Country-wise population without electricity

Table 2 Country-wise population without electricity.

S. no.	Country	Population without access to electricity (million)	% of world total
1	India	579.10	35.44
2	Bangladesh	104.40	6.39
3	Indonesia	98.0	6.00
4	Nigeria	76.15	4.66
5	Pakistan	65.00	3.98
6	Ethiopia	61.28	3.75
7	Myanmar	45.30	2.77
8	Tanzania	30.16	1.85
9	Kenya	27.71	1.7
10	Nepal	19.50	1.19
11	DPR of Korea	17.8	1.09
12	Mozambique	16.42	1.00
13	World total	1634.2	100

Source IEA 2002.

This is where Net Positive Energy Building comes in. A building that generates clean energy to fulfil its own energy requirements as well as surplus to provide for other buildings. This will be a sustainable route to approach the energy crisis and to generate and manage electricity.

To achieve the goal of Net Zero Energy Building, the building should be manipulated such that it generates the required energy as much as it is consumed. Then it can be designed to generate more than it consumes.

Energy conscious buildings are on the rise but there are still very few nZEB. This is due to the high initial cost of implementation. High certification fee from the certification bodies such as LEED and GRIHA that tends to lack recognition for small scale projects that consequently leads to a lack of available official data and validation of such small scale nZEBs in India.

CRAVEzero is an EU-Horizon 2020 project that focuses on proven and new approaches to reduce costs and improve nZEBs at all stages of the life cycle. The main goal is to identify and eliminate the extra costs for nZEBs related to inefficient processes and technologies and to promote innovative business models taking into account the cost-effectiveness for all the stakeholders.

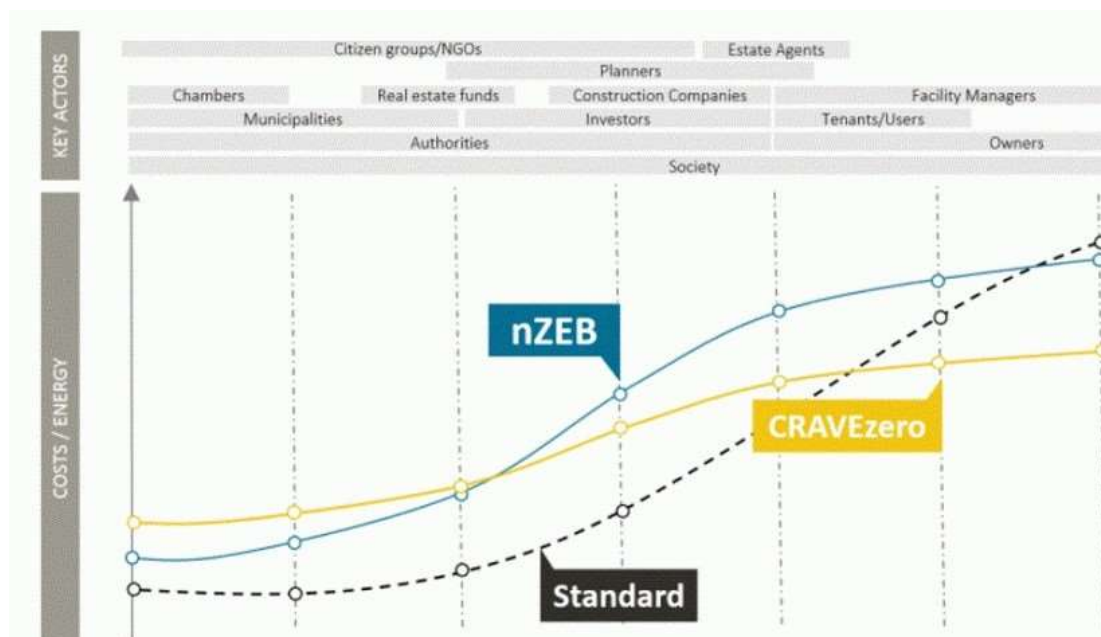


Fig 1.1 Cost Reduction and market Acceleration for viable nearly Zero-Energy Buildings

Studies show that employees in nearly zero energy buildings perceive a positive effect of their working environment and productivity. A study has noted a decline in absenteeism in nearly zero energy buildings. To assess the direct monetary value of a building, there are various co-benefits for the individual stakeholders, which often cannot be assessed directly in monetary terms and therefore do not appear in the life cycle cost analysis, like marketability, rentability, value development, comfort, image, climate protection, etc.

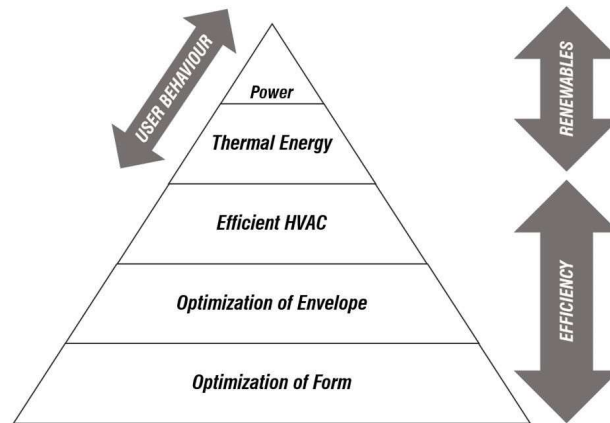


Fig 1.2 Steps to reach nZEB standard

1.2 Aim

To design a nearly zero energy Business centre in Chennai's Warm and Humid Climate.

1.3 Research Questions

- What are the properties of a Nearly Zero Energy Building (NZEB)?
- What are the major energy consuming components of an office building?
- What are the factors that affect the energy performance of a building?
- How should HVAC be designed for an office building?
- How much of an influence does the envelope have on cooling requirements indoor?

1.4 Objective

- To study the properties of a nearly Zero Energy Building.
- To identify the major energy consumers of an office building.
- To identify and address the factors that affect the energy performance of a building.
- To calculate and propose various HVAC systems.
- To theoretically measure the envelope's impact on indoor cooling.

1.5 Sub Objectives

- To study the impact of building major components on electrical consumption on the building.
- To implement passive strategies where ever possible to bring down the electrical load.
- Efficient envelope design.
- To identify the major energy users and find a sustainable solution.
- To learn HVAC sizing and designing.

1.6 Need for Study

To satisfy the energy requirement of this growing nation, a smarter alternative must be formulated. Awareness among the public is on the rise as the ramification of Global warming is more apparent. Policies by the government for energy efficiency and building certifications by various bodies serve as a catalyst to the green initiatives flooding the market. This has encouraged the public to consciously take the Net Zero route. But India has much more potential to produce Net Positive Energy Buildings (NPEB) by solving many other crises that a developing nation faces, such as increased waste generation and energy crisis to name a few. As the exploration into sustainable and energy efficient buildings in India is still in its nascent stage, this research aims to explore the current scenario of the status of nZEB in India, the opportunities and threats, and address them.

1.7 Scope for Study

Policies by the government for energy efficiency and building certifications by various bodies serve as a catalyst to the green initiatives flooding the market. This has encouraged the public to consciously take the Net Zero route.

But India has much more potential to produce Net Positive Energy Buildings (NPEB) by solving many other crises that a developing nation faces, such as increased waste generation and energy crisis to name a few.

As the exploration into sustainable and energy efficient buildings in India is still in its nascent stage, this research aims to explore all the opportunities available globally and translate it to Indian context.

CHAPTER 2 LITERATURE REVIEW

2.1 Literature Study – 1

Topic - Net- and Nearly- Zero Energy Buildings: A Review of the Definitions and Case Studies

Author(s) - Ala Hasan, Ayman Mohamed, Mohamed, Hamdy

Aim - In this paper the definitions, terminologies, calculation methods and the targets in the two concepts of Net- Zero Energy Buildings (NZEB) and Nearly-Zero Energy Buildings (nZEB) are reviewed.

Inference - The two concepts aim to eventually reach the zero-balance status, however, the intermediate steps and the details of the approaches are different.

Place of study – Finland

Reason for selecting this paper - A simple and direct introduction for the topic

Codes/ Guidelines mentioned in this paper - Finnish Building Code 2012

Software used - IDA-ICE software and TRNSYS were used to find the case studies' annual energy demand.

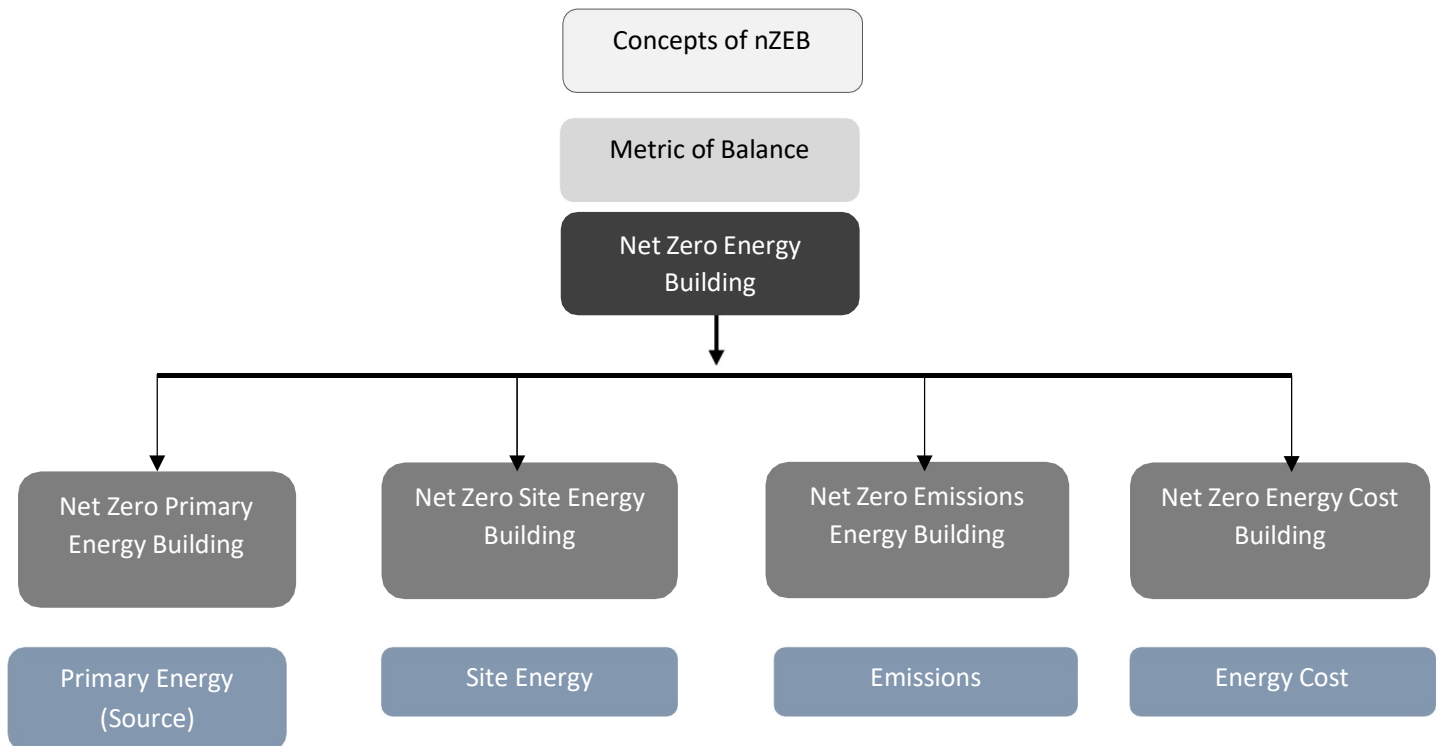


Fig 2.1 Metrics of balance

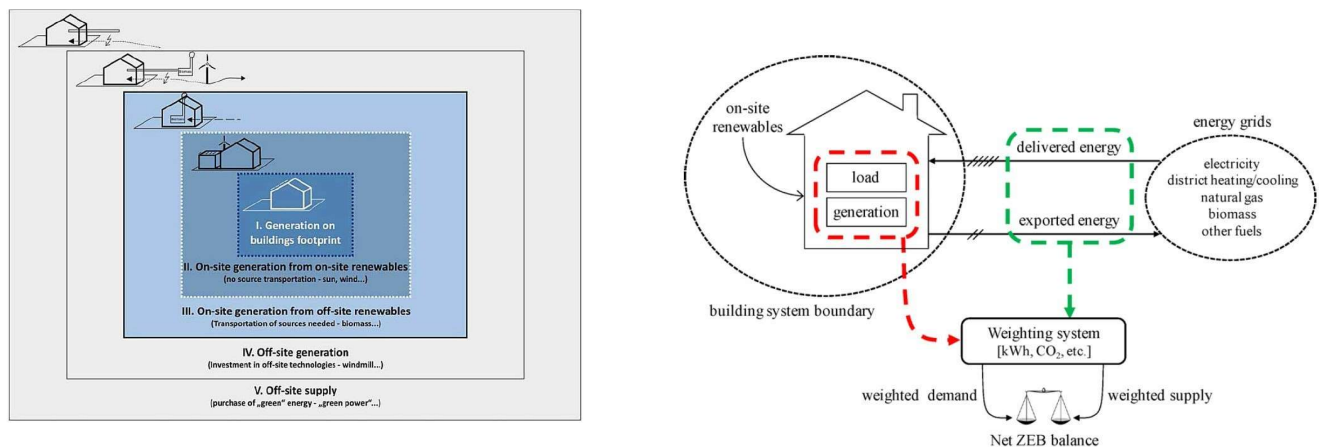


Fig 2.2 nZEB approaches

A Net-Zero Energy Buildings (NZEB) is an energy efficient building that balances its total energy needs by on-site generation over a pre-defined period of time.

Nearly-Zero Energy Buildings (nZEB)

“A nearly zero energy building is a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”

- Article 2 of the Energy Performance of Buildings Directive

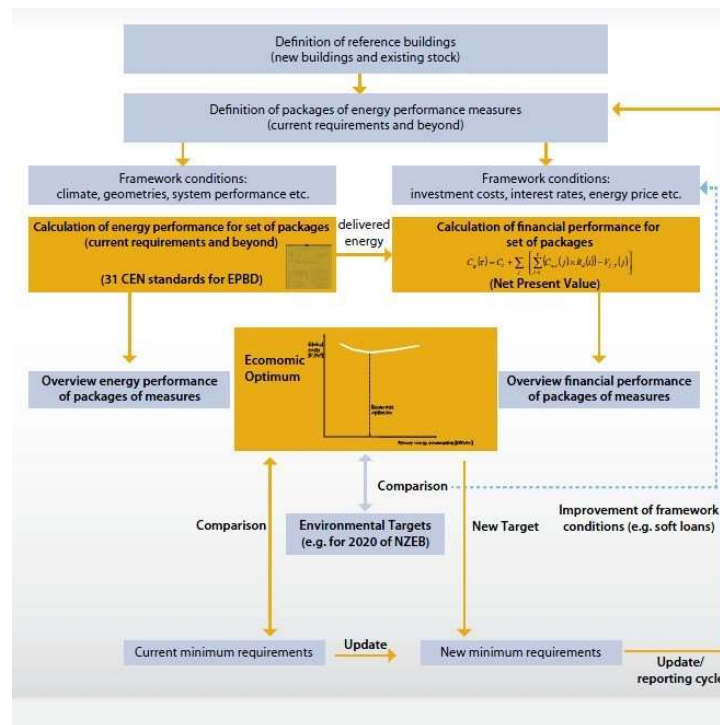


Fig 2.4 Nearly Zero building approach

Conclusion

Net-Zero Energy Buildings (NZEB)

The NZEB aims at achieving the balance between the imported and exported energy in terms of a defined metric during a pre-defined period of time. The zero-balance depends mainly on the credit factors of different imported and exported types of energy and fuels.

Nearly-Zero Energy Buildings (nZEB)

2.1 Nearly Zero Energy Buildings combines the lifecycle cost and primary energy performance of different packages of measures in the building envelope, HVAC systems and the energy supply systems and describes a comparative methodology for finding the cost-optimal and Nearly- Zero Energy Building solutions. It establishes a comparative framework using the cost optimality method to achieve cost-optimal levels for new buildings and renovations.

2.2 Literature Study - 2

Topic - Evaluation of the energy performance for a nZEB office building under specific climatic conditions

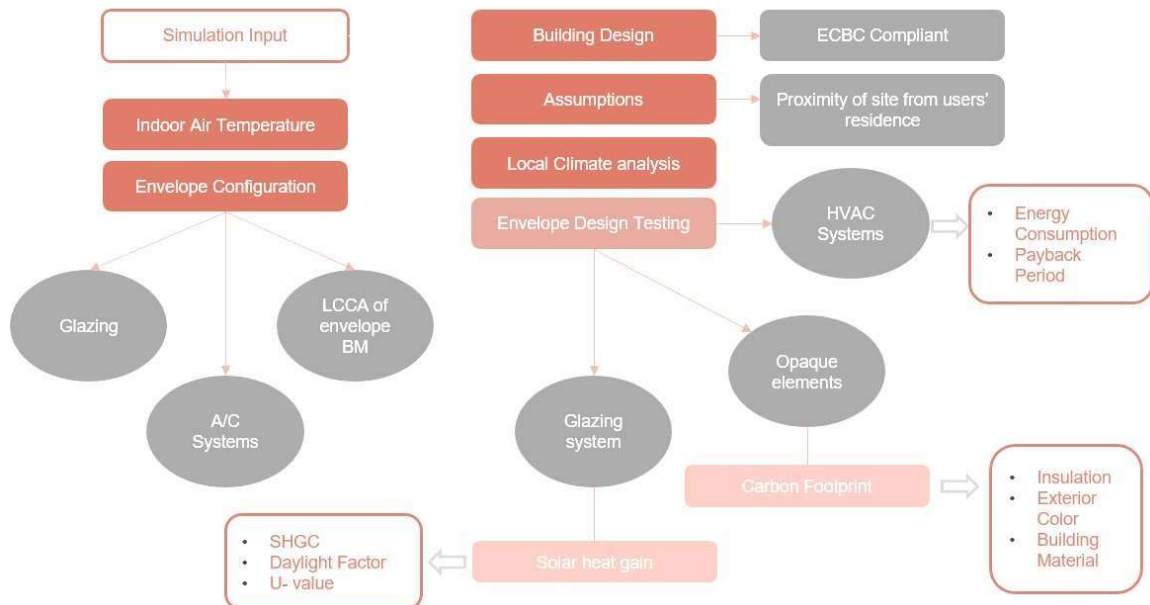


Fig 2.5 Workflow chart

Author(s) - Nicolae Bajenaru, Andrei Damiana, Rodica Frunzulica

Aim - This study concentrates on energy efficient measures that proved to be cost effective in a Life Cycle Cost Analysis, in order to cope with the rapid increase of greenhouse gas emissions.

Inference - The Energy required for cooling is reduced by making the building ECBC compliant. Then, the energy needs are fulfilled by solar panels. This made the building Net Positive while improving the indoor conditions of the building.

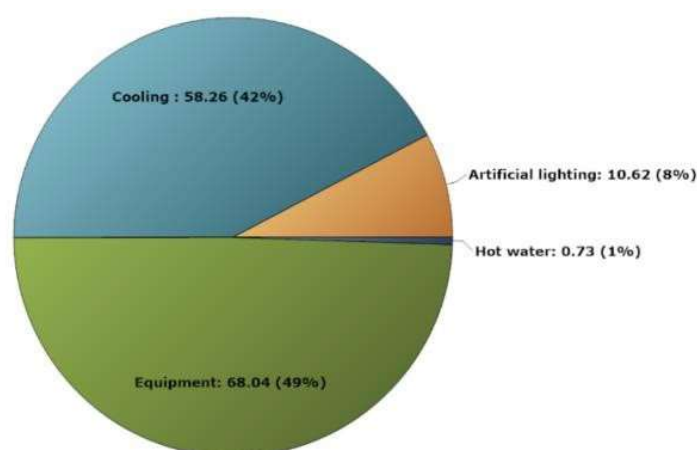
Place of study – New Delhi

Reason for selecting this paper - This paper relates thermal comfort to energy efficiency (EE) and Life Cycle Cost Analysis (LCCA)

Codes/ Guidelines mentioned in this paper - This paper relates thermal comfort to energy efficiency (EE) and Life Cycle Cost Analysis (LCCA)

Software used - Design Builder + Energy Plus and System Advisor Model (SAM)

Methodology followed- Simulated research



Evaluation of the energy performance for a nZEB office building under specific climatic conditions- Nicolae Bajenaru, Andrei Damiana, Rodica Frunzulica

The building obtained the net/nearly zero energy building (nZEB) status as it produces more energy in a year that it consumes. A total of 64260 kWh of electrical energy are produced whereas only 61086 kWh are consumed, the remaining 3174 kWh are sold to the local energy supplier. On a yearly basis, the positive energy balance is maintained only during winter when the requirement for cooling very less.

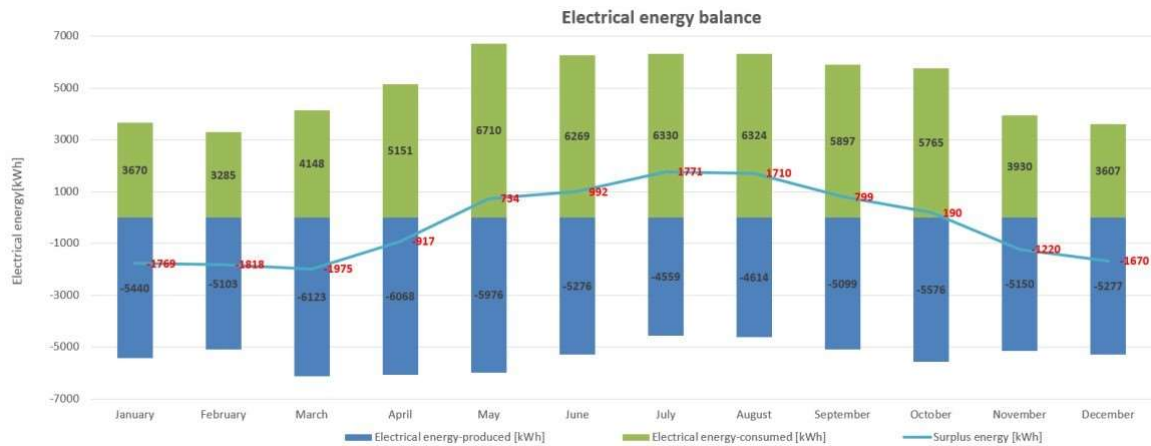


Fig 2.7 Annual electrical energy balance for the building studied

2.3 Literature Study – 3

Topic - Role of net zero energy building in energy security

Author(s) - Santosh D Jadhav

Aim - This paper discusses the net zero energy building concept and briefly reviews the policy context that will make them common.

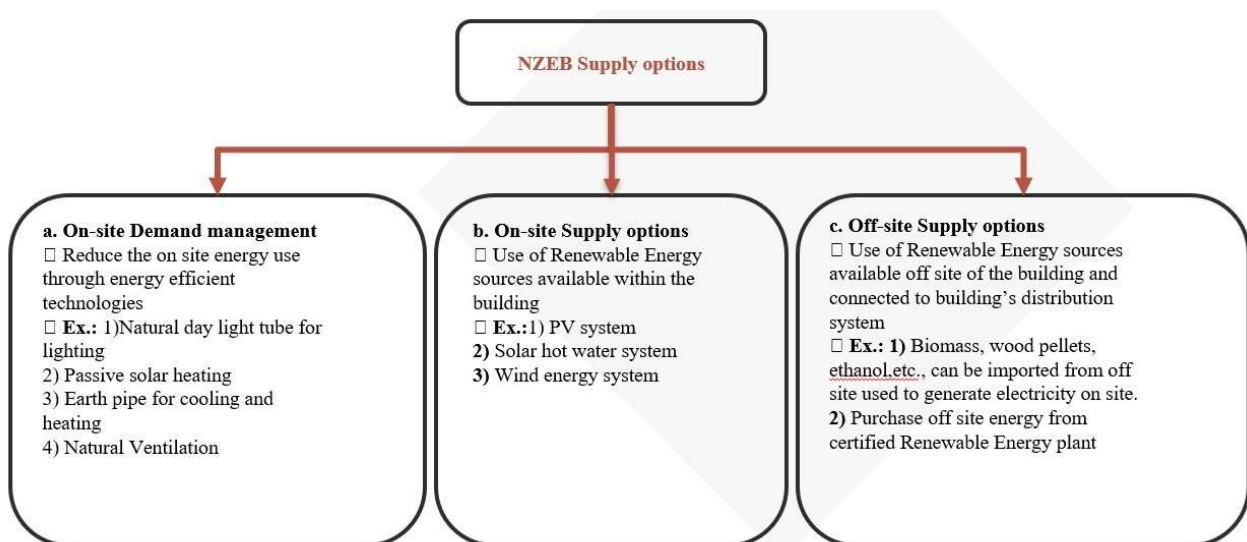
Inference - The overview on energy supply systems for nZEB and case studies provides clarity on the subject.

Place of study – India

Reason for selecting this paper - This paper outlines the nZEB initiatives around the globe.

Codes/ Guidelines mentioned in this paper - ASHRAE Vision 2020 report, The AIA 2030 Challenge, Passivhaus, ecoENERGY Technology initiative

Between 2008 and 2013, researchers from Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, India, North Korea, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and USA **worked together in the joint research program “Towards Net Zero Energy Solar Buildings” under the umbrella of International Energy Agency (IEA).** This paper gives us an over view on the countries’ progress in going NZB route.



2.4 Literature Study - 4

Topic - Net Zero Energy Consumption building in India: An overview and initiative toward sustainable future

Author(s) - Lohit Saini, Chandan Swaroop Meena, Binju P Raj, Nehul Agarwal and Ashok Kumar

Aim - This paper aims to review the fundamental aspects for approaching net zero energy consumption buildings (nZECB) keeping into consideration the effect of building physics and challenges faced in the pathway and its feasibility.

Inference - Optimal sizing of components is overlooked on the other papers read. This paper points out that the sizing of renewable energy system and energy storage system is very important. LCPA must be performed during the designing phase to determine the performance declination rate of the system and how long a building can maintain to achieve its net-zero energy goal.

Place of study – India

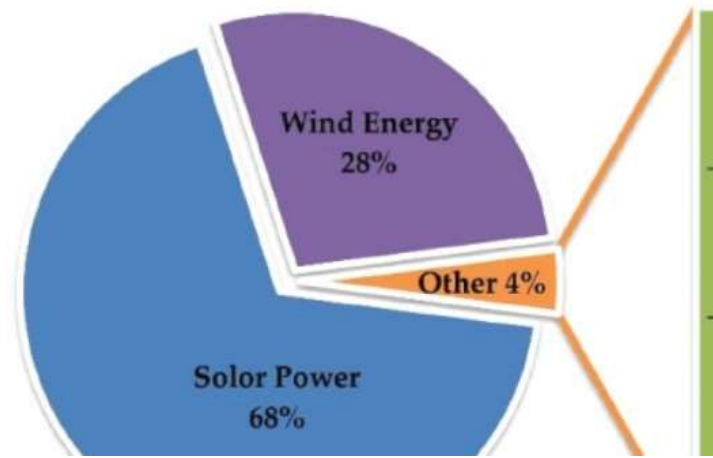
Reason for selecting this paper - This paper gives an indepth insight on nZEB- Limitations, approaches, challenges, opportunities, current scenario, policies locally and globally and certifications.

Energy efficiency programmes mentioned - Passivhaus, Zero Carbon Australia Plan, California Zero net energy plan, Energy Independence and Security Act (EISA), EPBD Directive, Renewable Energy Sources Act, European Performance Building Directives (EPBD), Energy Conservation Act, Buildings Energy Efficiency Programme, Energy Efficiency Services Limited

Energy certifications - LEED, BREEAM, CASBEE, Building and Environmental Performance Assessment Criteria, ASHRAE, IGBC, GRIHA,

Net Zero Energy Consumption building in India: An overview and initiative toward sustainable future - Lohit Saini, Chandan Swaroop Meena, Binju P Raj, Nehul Agarwal and Ashok Kumar

Through various studies, it has been found that there are only limited resources that can be used as renewable energy sources and energy alternatives for a building to be an nZECB.



**Fig 2.9 Estimated Potential for Renewable Energy in India
(Energy Statistics 2019)**

Indian policies aiming for an Energy efficient future:

National Mission for Enhanced Energy Efficiency, Jawaharlal Nehru National Solar Mission, Integrated Energy Policy, National Mission for Sustainable Habitat, National Mission for a Green India, Indian Cooling Action Plan

Retrofit for existing buildings

Rules, regulations, and guidelines are being projected and implemented mainly for new constructions only, and for preexisting buildings, the policies are absent for retrofits. To retrofit a preexisting building, the deciding factor is the net energy consumption of a building in all seasons throughout the year that decides the amount of energy to be saved in a building and the amount of energy to be generated through renewable energy sources. The second factor is optimizing the energy of the systems installed that are consuming high energy and through installing alternate energy-efficient systems (LED). *Through optimizing the lighting system up to 11% of building cooling load can be saved.*

Energy consumption in India:

- Building Sector consumes 33% of total consumption
- India ranks 4th globally in CO₂ emissions
- Power generation sector emits 1/2 of the total CO₂ emissions in India.
- Energy consumption in residential/ domestic sector is ~24% (2nd highest energy consuming sector in India) with a compound annual growth rate of 7.58% from 2008-2019

- Considering this, the GOI introduced Energy Conservation Act, which led to Energy Conservation Building Code (ECBC) being formulated.

Conclusion

- **Improving and optimizing** the building physics and components of building envelope.
- Pre optimizing the **size of the system** such as HVAC, energy storage, and energy generation system to avoid oversizing and under-sizing to reduce the capital cost and avoiding the reduced performance respectively.
- **LCPA and LCCA** are important studies for the efficient performance of an nZECB. Through evaluation of LCPA and LCCA, the duration for efficient performance and the need for subsidies or incentives can be well figured.
- The need for economic and technological enhancement is much awaited to compute a well-designed nZECB.
- **Region and climatic factors** need to be well determined. All construction elements should be considered according to the local climatic conditions prior to the building construction.
- **Retrofitting** is a probable solution that will direct to increase the efficiency within already existing buildings by changing the source of primary energy and improving components such as HVAC, lighting can readily reduce the consumption of energy.

CHAPTER 3 METHODOLOGY

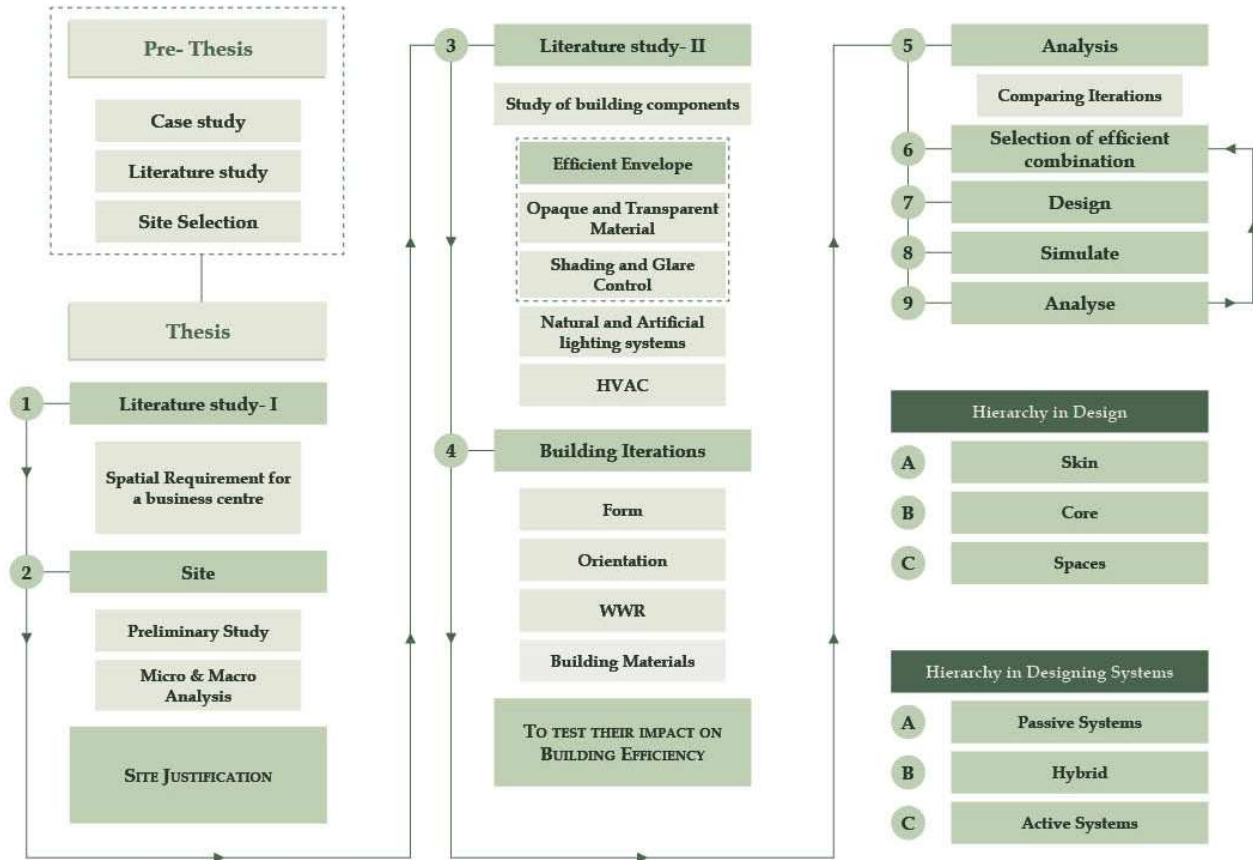


Fig 3.1 Workflow Diagram

CHAPTER 4

ANALYSIS AND RESULTS

4.1 Case Study Design Analysis

Table 4.1 Case Study Comparative Design Analysis

Project name	Typology	Aim	Design Interventions				
			Lighting		Ventilation		Thermal protection
			Passive	Active	Passive	Active	
zero Energy Building (ZEB)	Office/ Academic	To retrofit a building to make it a <u>nZEB</u>	- Light Tubes 1. Basic 2. Mirrored - Mirrored Ducts - Light Shelves	- Light Sensors - Task Lighting	Solar chimney (+PV system+ Floor Diffusers)	- Personalized Ventilation - Floor Diffusers - Chillers with high EER - CO2 Sensors	- Green Wall - PV Integrated Sunshades - Light Shelves - BiPV clad Stairwell
<u>Avasara Academy</u>	Academic	To reduce dependency on mechanical systems for ventilation	Building oriented as per space usage	-NDA-	- Solar Chimney+ Earth Tube - Double <u>storey</u> spaces - Cross Ventilation	Ceiling Fans	- Deep corridors and stairwell in the South. - Deep sunshades on N, E and W. - Bamboo screens designed for the corresponding face.
<u>SIERRA'S eFACILITY</u>	Office	To reduce Carbon Footprint of the building	- Sky light - Motorized internal blinds.	Automated LED Lighting	Zonal bi-directional heat recovery ventilation system	Sensors help to intelligently maintain temperature and fresh air supply.	- Motorized internal blinds. - Automated LED Lighting - Deep sunshades - BiPV Windows to reduce thermal ingress

4.2 Case Study Energy Analysis

Table 4.2 Case Study Comparative Energy Analysis

Project name	Typology	Area (sqm)	Operational energy	Energy demand reduction	Renewable energy	Energy balance	EPI kWh/ m2/yr
zero Energy Building (ZEB)	Office/ Academic	418	- Space conditioning - Lighting - Appliances - Building Operations	- Passive daylight strategies to reduce demand on artificial lighting - Efficient envelope- reduces thermal gain, produces electricity and maximizes daylight utility - Solar passive design- Solar chimney, PV array, BIPV - CO2 monitoring for IAQ with controlled ventilation - More efficient HVAC system by reducing load by coupling with passive strategies - State-of-the-art building management system	- Rooftop solar photovoltaics - BIPV	80%	23
Avasara Academy	Academic	1,148	- Lighting - Building Operations	- Bamboo screens for shading - Shades and overhangs to avoid heating - Solar passive design strategy - Earth duct for passive heating and cooling - Natural ventilation	- Rooftop solar photovoltaics - Solar water heating	85%	-
SIERRA'S eFACILITY	Office	2,323	- Thermal comfort - Space conditioning - Lighting - Appliances - Building Operations	- Motorized internal blinds. - High performance reflective glazing with WWR < 40% 86% Natural daylight and skylight - More efficient HVAC system - CO2 monitoring for IAQ with controlled ventilation - Automated LED Lighting - State-of-the-art building management system	- Roof top solar Photovoltaics - BIPV - Bi- facial roof top solar PV	80%	56.2

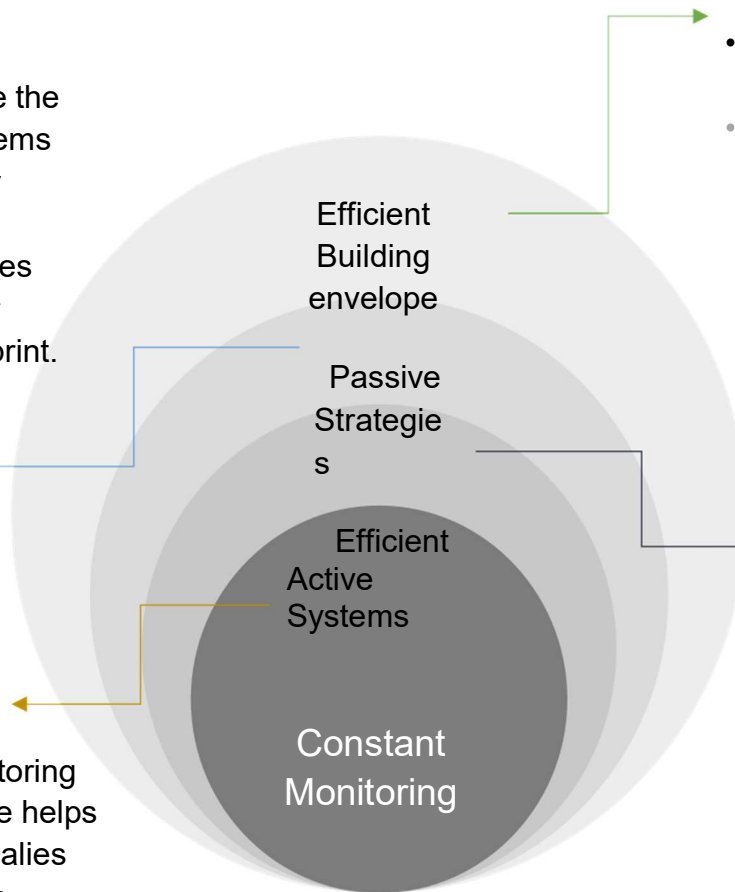
4.3 Case study inference

- Employing passive strategies to reduce the load on active systems reduces the energy consumed.
- Utilizing opportunities the site has to offer reduces CO2 Footprint.

02

04

- Constantly monitoring the energy usage helps identifying anomalies and rectify errors immediately, saving cost and unnecessary wastage of energy.



01

- Protection from solar heat gain
- Smart fenestration- Prevents glare, reduced heat gain, useful daylight transmission

03

- Employing systems with high efficiency reduces the operating and maintenance cost.
- It also reduces emission during operation.
- Sensors make the system smarter.

Fig 4.1 Case study inference

4.1 Case Study + Literature review

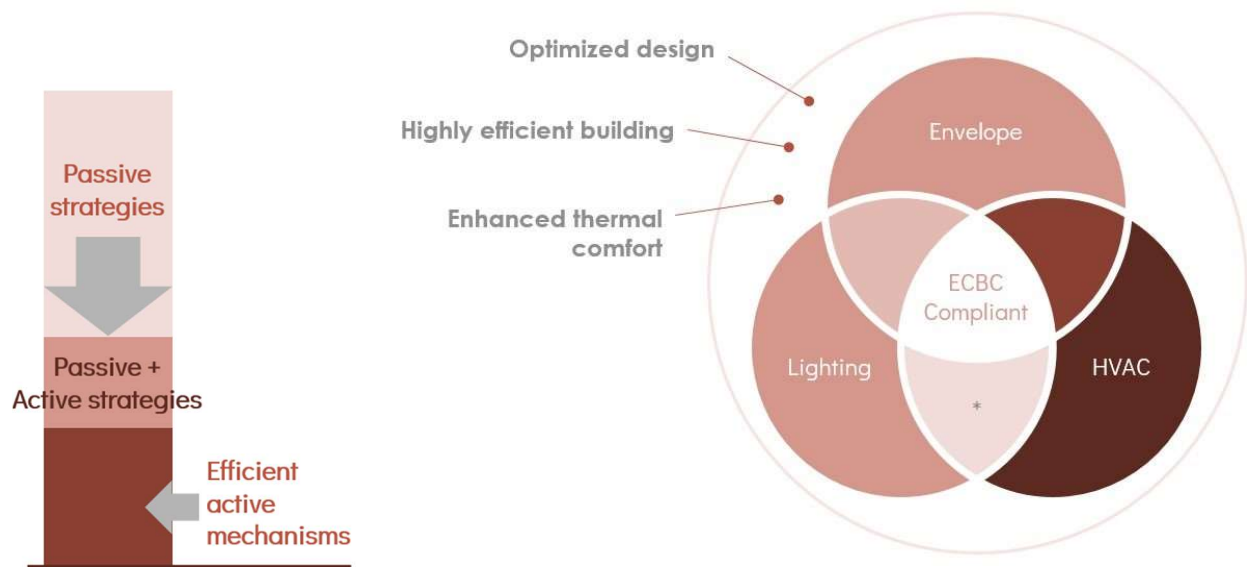


Fig 4.2 Case study and Literature review inference

Note: For how long a building can remain nZEB depends on the approach. It has to be monitored constantly.

CHAPTER 5

SITE

5.1 Site Selection



Fig 5.1 Site Location

Aarti Chambers and AASI Centre, Thousand Lights, Anna Salai.

The site is located in the older parts of Chennai, on Anna Salai. Many buildings are left abandoned along this stretch as Chennai expanded and business hub moved away from the heart of the city^[*]. This site is selected for (1) **its good proximity to the public transport** (bus stops situated less than 1km and metro station access right within the site) which should encourage the users to opt to more sustainable means of transport, (2) the **buildings on site are in a dilapidated condition** (aarti chambers is still operating, posing a threat to the occupants and users and AASI towers are left unused).



Fig 5.2 Site Photos

CHAPTER 6

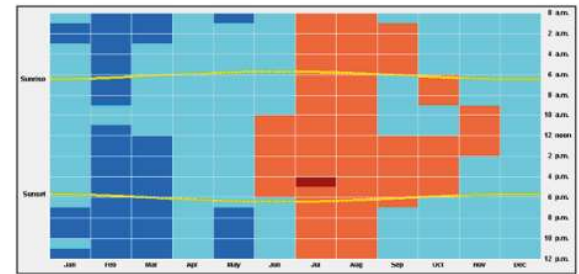
CLIMATE ANALYSIS

6.1 Climate study

6.1.1 Chennai climate

climate consultant analysis

Season	Months	Temp Range	Monthly diurnal Avg.	Humidity		Seasonal winds	Design Strategies
				Minimum	Observation		
Summer	Mar	Do not fall under comfort band.	High Global Radiation	>60	Highest during Summer	South, South-East	0.0% 1 Comfort(1 hrs) 31.0% 2 Sun Shading of Windows(24 hrs) 9.0% 14 Dehumidification Only(232 hrs) 59.4% 15 Cooling, add Dehumidification if needed(2648 hrs)
	Apr			~58			
	May						
	Jun						
Monsoon	Jul	Do not fall under comfort band.	High Global Radiation			West, WWS, South-West	0.0% 1 Comfort(1 hrs) 38.9% 2 Sun Shading of Windows(12 hrs) 13.3% 14 Dehumidification Only(384 hrs) 46.8% 15 Cooling, add Dehumidification if needed(2557 hrs)
	Aug						
	Sep						
	Oct			>60	Highest during Monsoon		
Winter	Nov		High humidity	>70	Highest during Winter	North, NNE, North-East, East	1.8% 1 Comfort(16 hrs) 24.3% 2 Sun Shading of Windows(756 hrs) 51.1% 6 Two-Stage Evaporative Cooling(48 hrs) 2.0% 7 Natural Ventilation Cooling(68 hrs) 2.1% 6 Two-Stage Evaporative Cooling(48 hrs) 2.0% 7 Natural Ventilation Cooling(68 hrs) 2.0% 9 Internal Heat Gain(71 hrs) 2.0% 11 Passive Solar Direct Gain High Mass(52 hrs) 38.3% 14 Dehumidification Only(1835 hrs) 53.2% 15 Cooling, add Dehumidification if needed(2557 hrs)
	Dec						
	Jan						
	Feb						



mahoney recommended specification

Layout	Orientation North and South (Long Axis East - West)
Spacing	Open spacing for breeze penetration but protection from hot and cold wind
Air Movement	Rooms single banked, permanent provisions for air movement
Opening	Large openings, 40 to 80 %
Walls	Light walls, short time-lag
Roofs	Light, insulated roofs

Chennai city experiences a warm and humid climate as it lies near the coast and thus does not have any sort of extreme seasonal temperature. Chennai gets most of its annual rainfall from mid-October to mid-December. The heat in Chennai is due to its proximity to the equator and the coast of Bay of Bengal. As the sun shines strongly on the tropics, particularly on the warm oceans, the overlying atmosphere becomes very humid.

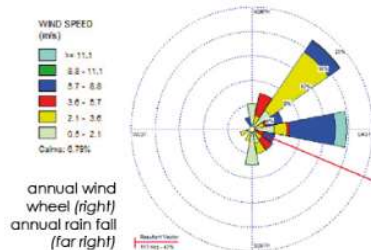
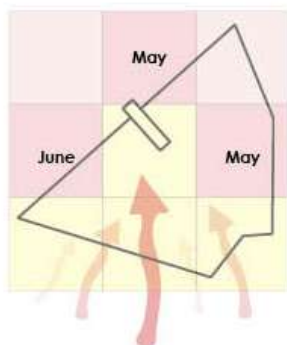


Fig 6.1 Climate and Site

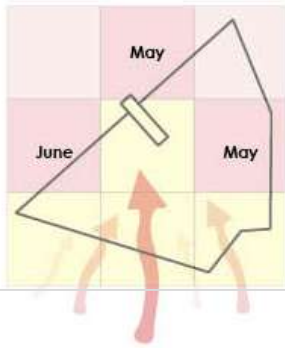
6.1.2 Site level Climate analysis and inference

SUMMER
MARCH - JUNE



CHAPTER 7

SUMMER MARCH - JUNE

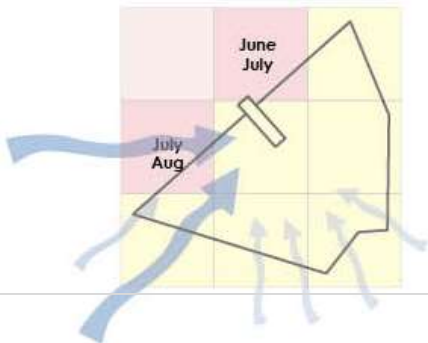


- CONDITIONS**
- High global radiation (May and June)
 - High wind velocity (May)
 - Highest humidity during May and April
 - High cloud cover in April and lowest in May

- PROBLEMS**
- High heat & humidity and low cloud cover & high humidity, both causes high levels of discomfort.
 - May month has high global radiation which results in heat waves and high sensible heat.

- SOLUTIONS**
- Efficient solar shading devices provides protection from radiation.
 - Space cooling provides relief and comfort.

MONSOON JULY - OCTOBER

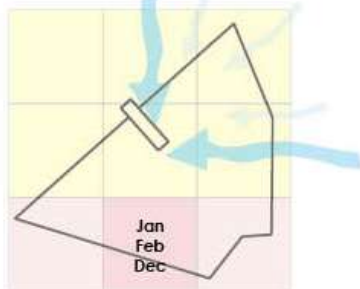


- CONDITIONS**
- August and September has high global radiation.
 - High sky cover reveals throughout the season.
 - Humidity peaks towards the end of monsoon.

- PROBLEMS**
- High cloud cover, radiation and humidity leads to high discomfort.
 - High cloud cover results in uneven lighting.
 - Driving rain from west and southwest.

- SOLUTIONS**
- The humidification is necessary. Cooling is required.
 - Efficient shading to cut off radiation but not hinder lighting is required.

WINTER NOVEMBER - FEBRUARY



- CONDITIONS**
- High humidity during November.
 - High direct radiation during Jan and Feb.
 - High wind velocity during Nov.
 - Cloud cover is high during December and low during Feb.

- PROBLEMS**
- High radiation on the south.
 - Diffused radiation during December and high amount of direct radiation during Feb.

- SOLUTIONS**
- Efficient solar shading devices provides protection from radiation.
 - The humidification is necessary.
 - Cool breeze and weak radiation provides natural comfort.

FORM EVOLUTION

The Metro exit within the site poses a challenge as 7m wide setback has to be give on all three sides of the structure and no intrusions above is possible either. Thus, the options are limited. The three forms that were selected are shown in Fig. 7.1 and more iterations for them were tested out.

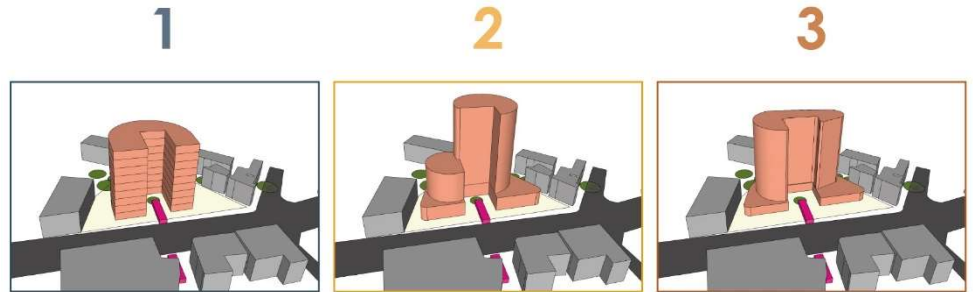


Fig 7.1 Primary forms for which iterations were tested

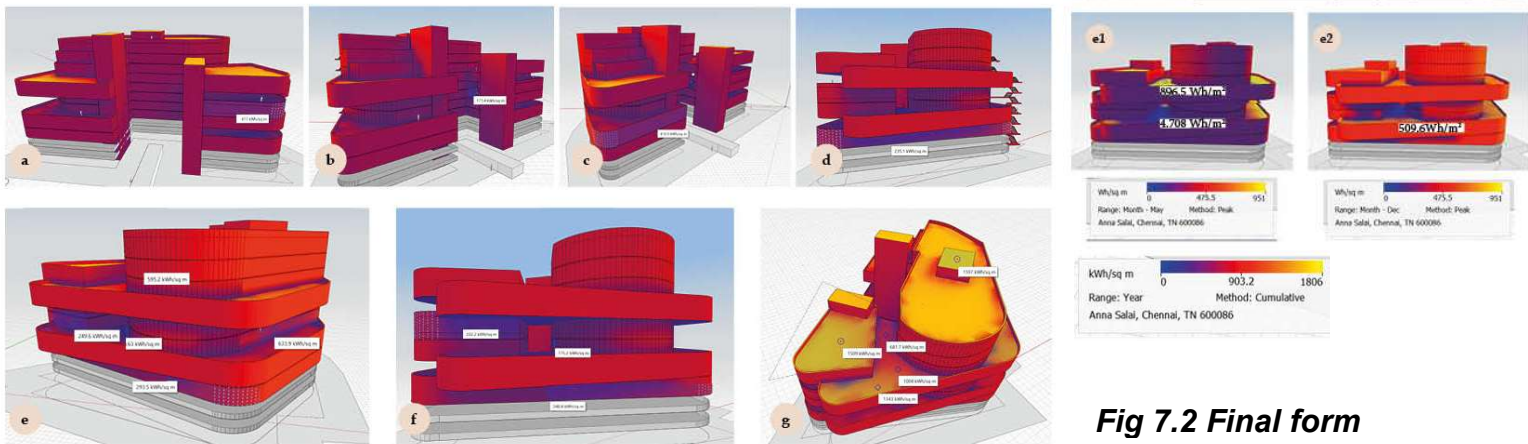


Fig 7.2 Final form

Thermally Comfortable open spaces for outdoor recreation that can double as outdoor workspaces are created. The projecting floors provide shaded outdoor spaces that can compensate for the lack of outdoor spaces on the ground level. The projection on Southwest also shades the floor below there by controlling the amount of radiation that falls on that face. As it can be seen from e1 and e2, the west is well shaded during May which is peak summer month. Southwest receives 500 Wh/m² during December when the climate is cooler and so the week winter sun does not cause much discomfort. The outdoor face should be design so as to reduce glare from evening sun.

SHADING DEVICE DESIGN

The base case without sunshade has 15% glare. **40% WWR has been divided between the clerestory window strip and large windows.** Efficient shading devices can cut down the glare. Shading devices are calculated with the help of is:sp.41.1987. The windows are shaded by a sunshade and horizontal shade at the middle if the window and the exterior spaces are shaded by carefully designed deep louvres. To control the glare on the west, louvres are coupled with tall shrubs on the green terrace. The north east corner also faces glaring issues but to retain optimal lighting within the building shading is provided only to a certain height and vegetative ground cover is provided to eliminate glare.



CHAPTER 9

MATERIAL STUDY

9.1 Opaque Assembly

Table 9.1 Comparative Opaque Wall Material Analysis

	Conventional Brick Assembly	115mm Brick/ 20mm air gap/ 230mm brick	115mm Brick/ 50mm insulation/ 230mm brick	Hollow Concrete block Without insulation (200 mm)
Total Thickness	255mm	340mm	367.4mm	482mm
Total U Value	1.997	1.24	0.886	0.62
Time Lag	7.35	11.55	11.35	10.57
Assembly view				
Assembly Section				

Hollow Concrete block With insulation (200mm)	Double brick wall with extruded polystyrene		Hollow Concrete block wall with 2.4" extruded polystyrene	
	Insulation- 2.4"	Insulation- 3"	Without Insulation	With Insulation
482mm	311mm	320mm	404mm	404mm
0.423	0.422	0.357	0.392	0.315
10.59	9.45	9.65	7.9	10.72

Table 4-7 Opaque Assembly Maximum U-factor (W/m².K) Requirements for a ECBC compliant Building

	Composite	Hot and dry	Warm and humid	Temperate	Cold
All building types, except below	0.40	0.40	0.40	0.55	0.34
No Star Hotel < 10,000 m ² AGA	0.63	0.63	0.63	0.63	0.40
Business < 10,000 m ² AGA	0.63	0.63	0.63	0.63	0.40
School <10,000 m ² AGA	0.85	0.85	0.85	1.00	0.40

Table 4-10 Vertical Fenestration Assembly U-factor and SHGC Requirements for ECBC Buildings

	Composite	Hot and dry	Warm and humid	Temperate	Cold
Maximum U-factor (W/m ² .K)	3.00	3.00	3.00	3.00	3.00
Maximum SHGC Non-North	0.27	0.27	0.27	0.27	0.62
Maximum SHGC North for latitude ≥ 15°N	0.50	0.50	0.50	0.50	0.62
Maximum SHGC North for latitude < 15°N	0.27	0.27	0.27	0.27	0.62

See Appendix A for default values of unrated fenestration

Fig 9.1 ECBC Prescribed values for wall assembly and fenestration for warm and humid climate

Conventional wall assembly is selected as the base case and other alternatives have been compared. The selection is based on two criteria – High U Value and High Thermal Lag. Opaque Software has been used to simulate the assemblies' properties. It is seen that adding insulation helps achieve ECBC prescribed U Value. Hollow concrete block, (both with and without insulation within) with extruded polystyrene was seen to be the best in terms of thermal properties, but the thickness of the assembly will eat up the usable floor space. Thus, double brick wall with 3" extruded polystyrene is chosen.

Standard thicknesses : 6-8-10 mm (other on request)

Average performance values of DGU (6+12+6 mm) with coating on surface #2, according to the standards ISO 9050 ml /EN 673² and to the standards NFRC 100



Product	Norm	Light Transmittance LT (%)	Solar Factor g-value	Shading Coefficient SC	External Light Reflectance LRe (%)	Internal Light Reflectance LRI (%)	U-Value W/(m ² .K)		Available colors*
							12mm air	16mm argon	
SKN 144 II	ISO	40	0.23	0.26	20	12	1.6	1.1	SKN 044 II SKN 744 II SKN 444 II SKN 544 II
	NFRC	40	0.22	0.26	20	12	1.64	1.42	

Green Blue Bronze Extra clear

Fig 9.2 Fenestration material selection

7.2 Fenestration

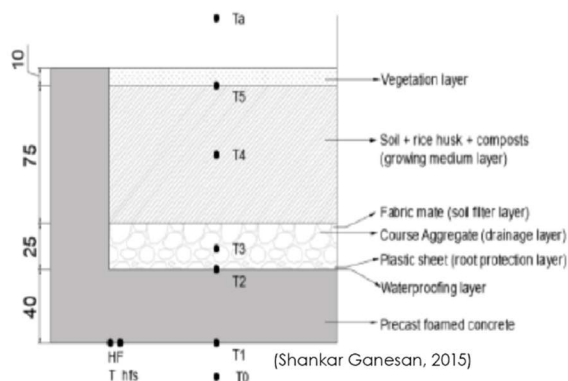
- Maximum allowable Window Wall Ratio (WWR) is 40%
- Minimum allowable Visual Light Transmittance (VLT) is 0.27
- Assembly U-factor includes both frame and glass area weighted U-factors
- Assembly SHGC includes both frame and glass area weighted SHGC

7.3 Roof Material

Table 9.2 Comparative Analysis of Roof Assemblies

Roof	RT (m.K/W)	U (w/Mk)
Conventional Roof	0.623	1.61
Cool Roof	2.764	0.36
Foamed Concrete Roof	3.786	0.26
Green roof	8.445	0.12
Foamed concrete + Green roof	9.32	0.11

Foam concrete is a light weight high strength building material that is new to the industry. Structural stability of the material is still in the research stages but its porous property is found to make this product an excellent insulator.



Foam is added to the mix to make it aerated and porous. the more the foam, more porous and light weight it is (Rommel, 2019) and adding additives and aggregates strengthens it without adding more weight. Coconut fibre is found to make the concrete thermally efficient at 0.38W/mK. **Coir fibre as natural biodegradable product has high**

percentage of hemicellulose and lignin which contribute to the high heat resistant (Shankar Ganesan, 2015). Green roof reduces the indoor and

outdoor temperature tremendously. Coupling it with foam concrete enhances the heat reduction. The latter is much more efficient than just the foam concrete roof. **The outdoor temperature is reduced by 56% and indoor temperature by 57% with foam concrete green roof. There is a 28% reduction in indoor air temperature** (Abdul Munir, 2019).

CHAPTER 10

HVAC

10.1 HVAC in Office Buildings

Designing a HVAC system to provide comfort all-round the year is essential. But in practical, for warm and humid climate of Chennai, the cooling needs during the hottest period is more important. Designing for that month ensures comfort condition year through and also reduces the overall operating cost. This helps elongate the design's lifetime by increasing the efficiency of the cooling system.

First, the thermal gain through the envelope, i.e, walls, roof and fenestration around the space under consideration is calculated. Then the barriers, such as walls, ceiling and partitions are calculated. this will give is the total heat gain for the building. The tonnage of the AC plant must be designed to remove the heat gain so calculated.

Designing a HVAC system to provide comfort all-round the year is essential. But in practical, for warm and humid climate of Chennai, the cooling needs during the hottest period is more important

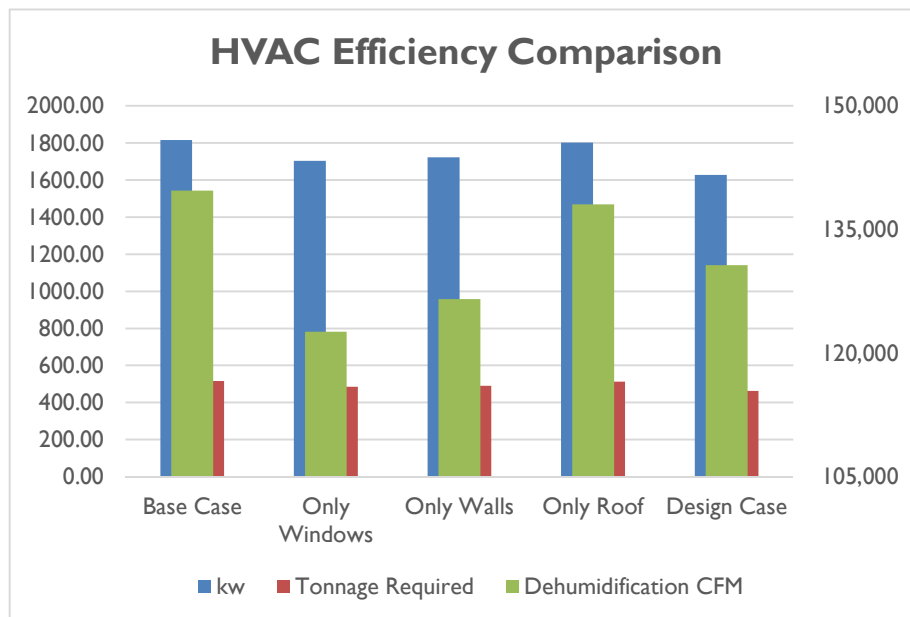


Fig 10.1 Comparative analysis of the impact of building elements on the HVAC system

For Chennai's climate, Cooling as well as Dehumidification is necessary for indoor comfort. Therefore, while designing the HVAC system, both, the tonnage required for cooling the space, as well as the dehumidification CFM must be calculated. The impact of the envelope elements is tested by changing each of the element individually.

It can be seen that there is not a massive difference in the tonnage requirement, but the dehumidification requirement is greatly reduced by changing the base case single glazing to double glazed argon filled glass with low-e coating.

4.6.1 Conventional cooling vs Underfloor air distribution (UFAD)

In conventional cooling method, the air ducts run at the top of the room, either within the false ceiling or exposed. the air is pumped from the AHU, pushed through the ducts and pushed out with a certain force so that the cool air will reach the occupants below.

In Underfloor air distribution system, the ducts ho underneath a sub-floor, and air diffusers at the floor pushes air up to the occupancy level.

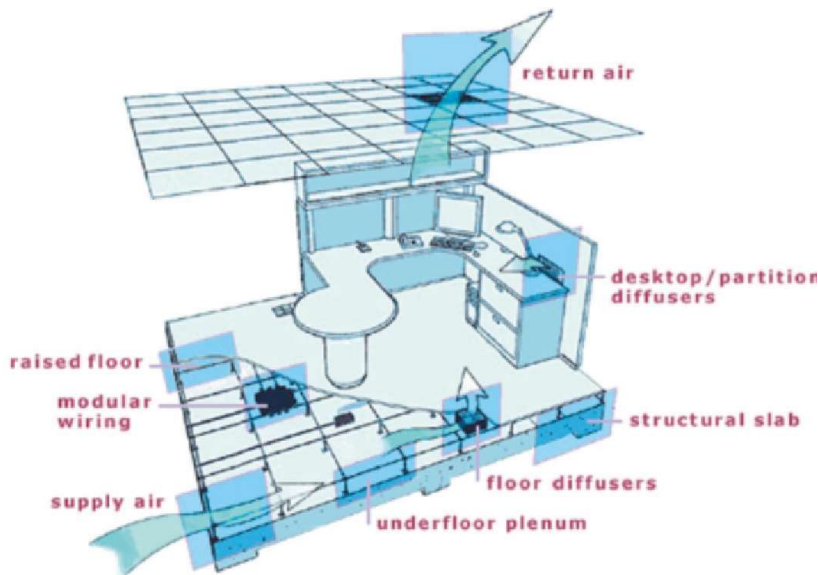


Fig 10.2 Working of UFAD with subfloor for ducting.

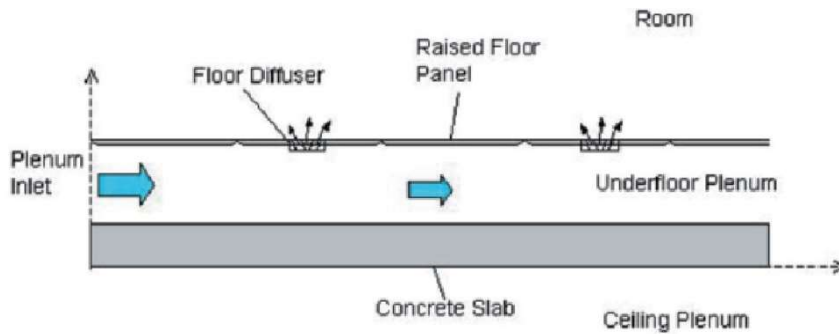


Fig 10.3 UFAD Floor Diffusers

Which is more beneficial?

Cooling is done for occupants' comfort. The air has to reach the occupants and so the temperature at occupants' level is measured. When the desired indoor temperature is reached, the AHU need not provide air at full volume.

Thus, the system that helps achieve occupant comfort faster is more efficient. The floor diffusers Pushes air and cools the occupancy zones much faster and thus achieves occupancy comfort sooner.

Pros:

- Reduced life cycle building costs
- Improved thermal comfort
- Improved ventilation efficiently and indoor air quality
- Reduced energy use
- Improved productivity and health

Cons:

- Technological needs
- New and unfamiliar technology
- Lack of Information and design guidelines
- High costs
- Limited applicability to retrofit construction

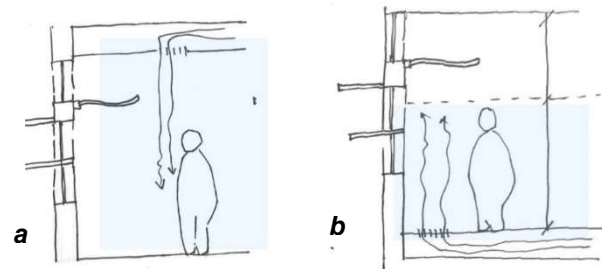


Fig 10.4 a) Conventional cooling with overhead ducts and b) UFAD with subfloor for ducting.

4.6.2 Energy Recovery Ventilator (EVR)

An EVR captures the exhaust air which is cool. uses the chilled air to cool the incoming hot air. This reduces the energy that must be spent on cooling the fresh air 100%. It has proved to remove 70% of the heat of the incoming air, thereby reducing the overall energy load on the AHU.

CHAPTER 11

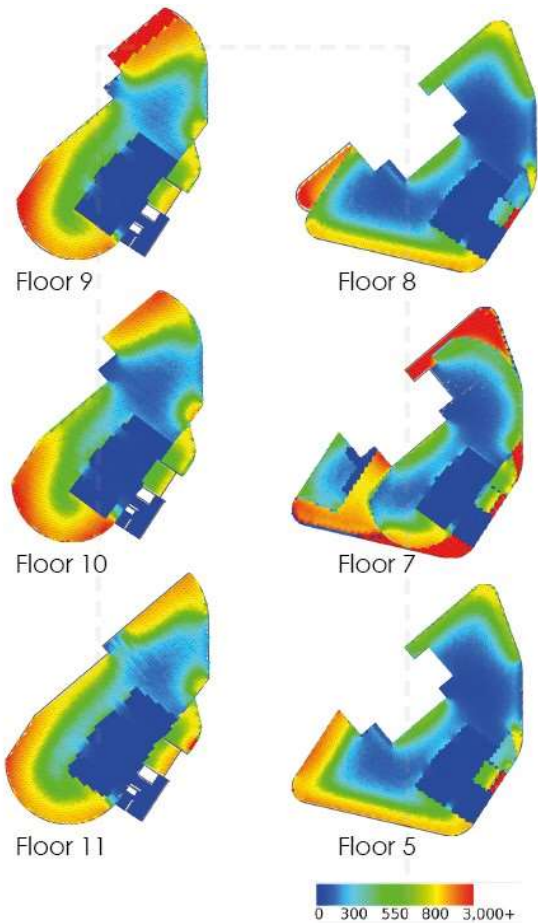
Lighting

4.6.2 Daylighting

Lighting for December was simulated as December has high cloud cover. The edges of the building have high Lux level during the time of simulation- 12pm. This is due to the low angle of the sun during December. Occupant control shading devices are required for their comfort.

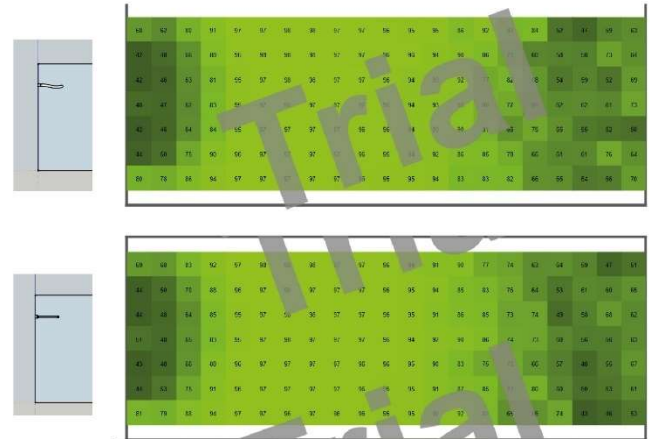
Light shelf is installed at the base of clerestory window to enhance the indoor lighting and cut down on glare. A specially designed light shelf is compared with the conventional one and the difference in performance was negligible. But bright shelf did take light a bit farther into the room in comparison and hence was chosen.

Manufacturer	BrightShelf
Product	Complies with NAAMM "Metal Finishes Manual"
Material	Aluminium
Lighting Sheet Finish: (Top Reflective Sheet)	clear anodized bright finish
Total Reflectance (TR)	98%



Total Reflectance (TR)	97%
Shelf Projection	2'-1"
Sustainable aspect	Made with and is recyclable. Unique design provides more light than a normal light shelf. Low emitting materials= Better IAQ. Movable= Occupancy Control. Utilize highly reflective (specular) lighting sheet that does not absorb heat to the extent of more matte finishes.

Fig 11.1 PIT Daylight simulation for the month of December



4.6.2 Artificial Lighting

The lights required is calculated and the energy consumed is calculated by Lumen's method. The lighting energy consumption for Base case and Design case is calculated. Refer appendix for the details of the lights selected.

Fig 11.2 Comparison between flat light shelf and BrightShelf

CHAPTER 12

Conclusion

The building material that was chosen reduces the cooling energy needs thereby reducing the load on the HVAC system. Changing the fenestration type showed tremendous reduction in dehumidification needs as the sensible heat gain is reduced by switching inefficient single pane windows to highly efficient double pane windows. Furthermore, employing variable frequency drive (VFD) provides cooling only when necessary, thereby reducing the hours of usage. Further savings can be seen in the long term if underfloor air distribution is implemented.

Base case:

Tonnes required for 1day= 516

1 tonne = 1.5 kw

Therefore $516.50 \times 1.5 = 774.75$ which is kw required per hour.

Therefore, kw required per day = 18594 kwh

As per slab rate cost per day= Rs.1,48,752

Design case:

Tonnes required for 1day= 462.65

1 tonne= 1.5 kw

Therefore $462.65 \times 1 = 462.65$ which is kw required per hour.

Therefore, kw required per day= 16655.4 kwh

As slab rate cost per day= 1,33,243.2

The difference in cost between base case and design case per day = Rs. 15,508.8

For a year the design case saves Rs 56,60,712.

Table 12.1 Energy Consumption (kWh per yr)

	Base case	Design case
Light Consumption	5,98,406	5,09,176
HVAC Consumption	67,86,810	42,55,455
Overall Consumption	73,85,216	47,64,631

The Overall energy consumption of the building is reduced by 32.5% because of the selection of efficient building material and HVAC design. The required amount of electricity for the base case can be entirely produced with rooftop solar panels in 250sqm of area. The design case requires much lesser energy thereby making this a nearly zero energy building. The surplus energy can be sent back to the grid.

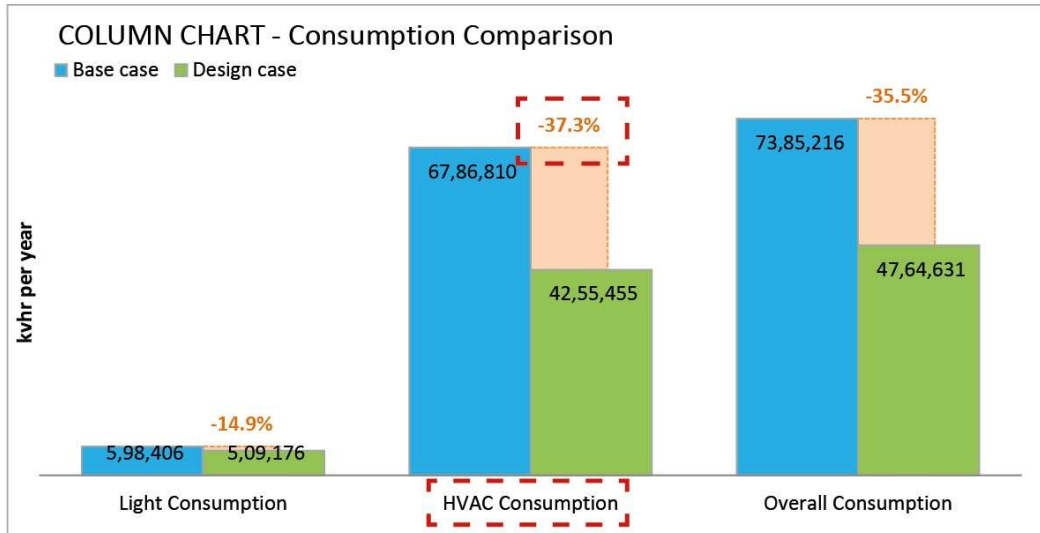


Fig 12.1 Energy Consumption (kWh per yr)

It can be seen that sizing the HVAC system to the requirement creates a massive reduction in energy consumption. The second largest energy consuming component of a commercial building is artificial lighting. Addressing both these components creates an overall reduction of 35.5%.

The energy required can now be produced on site with rooftop solar panels. The panels selected are bi-facial solar panels. These panels, when coupled with white roof produces more electricity than a conventional solar panel. The light reflected off the white roof hits the back of the panel which also produces electricity, thereby maximizing the energy output of the PV System.

RESULTS

7,905,529 kWh/Year*

Month	Solar Radiation (kWh / m ² / day)	AC Energy (kWh)
January	6.45	798,441
February	6.97	766,483
March	7.05	851,537
April	6.69	776,547
May	5.71	689,956
June	5.07	597,034
July	4.64	569,773
August	4.66	573,428
September	4.95	585,284
October	4.83	595,023
November	3.80	460,432
December	5.15	641,592
Annual	5.50	7,905,530

Source: <https://pvwatts.nrel.gov/pvwatts.php>

Appendix

Lighting

Artificial Lighting- Calculation

For time period between 8am to 5pm

Area : 2227 Sq mts ; Timings: 8am to 5 pm; Hours : 9 hrs

No of lights reqd:

$$N = E \cdot A / (F \cdot UF \cdot MF)$$

$$N = 200 \cdot 2227 / (4800 \cdot 0.5 \cdot 0.85) = 218.33$$

Aprox. 218 LED light fixtures are required to light the whole building during the time period.

Wattage calculation:

For 218 light fixtures electricity consumption is as follows:

For a year at 9 hours per day

$$9 \cdot 365 = 3285 \text{ hours}$$

$$3285 \cdot 218 \cdot 43 = 30,793,590 \text{ WH}$$

(i.e) 30,793 Kwh consumption ----- (a)

For the lighting area of 2227 Sq mts, it is

$$30,793 / 2227 = 13.83 \text{ KWh/Sq mts}$$

For time period between 5pm to 8am

Area : 8289.88 Sq mts ; Timings: 5pm to 8 am; Hours : 15 hrs

No of lights reqd:

$$N = E \cdot A / (F \cdot UF \cdot MF)$$

$$N = 500 \cdot 8289.88 / (4800 \cdot 0.5 \cdot 0.85) = 2,031.83$$

Aprox. 2032 LED light fixtures are required to light the whole building during the time period.

Wattage calculation:

Chopstick LED light fixture comes in 4800 lux and 43 watt

For 2032 light fixtures electricity consumption is as follows:

For a year at 15 hours per day

$$15 \cdot 365 = 5475 \text{ hours}$$

$$5475 \cdot 2032 \cdot 43 = 478,383,600 \text{ WH}$$

(i.e) 4,78,383 Kwh consumption ----- (b)

For the lighting area of 8,289.88 Sq mts, it is

$$4,78,383 / 8289.88 = 57.71 \text{ KWh/Sq mts}$$

For one day consumption is 2032 lights * 43 watts * 24 hrs

ie 20,97,024 w per day

2097.02 kwh per day

Total consumption of electricity for a particular year will be

$$30,793 + 478,383 = 509,176 \text{ Kwh} \text{----- (a + b)}$$

BASE CASE

For time period between 8am to 5pm

Area : 2631 Sq mts ; Timings: 8am to 5 pm; Hours : 9 hrs

$$N = 200 \cdot 2631 / (3650 \cdot 0.5 \cdot 0.85) = 339.21 \text{ approx } 400$$

With 3650 lumens and 200 flux, lights reqd is 400

Wattage calculation:

For a year at 9 hours per day
 $9 \times 365 = 3285$ hours
 $3285 \times 400 \times 37 = 48,618,000 \text{ Wh}$
 (i.e.) 48,618 Kwh consumption -----(c)
 For the lighting area of 2631 Sq mts, it is
 $48,618 / 2631 = 18.48 \text{ KWh/Sq mts}$
 For time period between 5pm to 8am - (15 hours need full lighting)
 Area : 8421.44 Sq mts ; Timings: 5pm to 8 am; Hours : 15 hrs
 $N = E \times A / (F \times UF \times MF)$
 $N = 500 \times 8421.44 / (3650 \times 0.5 \times 0.85) = 2714.4$
 With 3650 lumens and 500 flux, lights reqd is 2714

Wattage calculation:
 For 2714 light fixtures electricity consumption is as follows:
 For a year at 15 hours usage per day
 $15 \times 365 = 5475$ hours
 $5475 \times 2714 \times 37 = 549,788,550 \text{ WH}$
 (i.e.) 5,49,788 Kwh consumption -----(d)
 For the lighting area of 8421.44 Sq mts, it is
 $549,788 / 8421.44 = 65.3 \text{ KWh/Sq mts}$

2714 lights reqd
 $2714 \times 37 \times 24 = 24,10,032 \text{ Whr}$
 i.e 2410.03 kwh per day

Total consumption of electricity for a particular year in the BASE CASE will be $48,618 + 5,49,788 = 5,98,406$
 Kwh ----- (c + d)

Artificial Lighting- Light Selection

Base Case

Technical specifications

Type	RC383B	
System Wattage (W)	28	37
IP Rating	IP 20	
Lumen Output (lm)	2850	3650
System Efficacy (lm/W)	100	
Color Temperature (K)	4000, 6500	
CRI	80	
Housing	CRCA	
Cover	High efficiency diffuser	
Mounting	Recessed	
THD	<10%	
PF	>0.9	
Operating Voltage	220-240V, 50/60 Hz	



Design Case

Technical specifications

Type	Chopstick	
System Wattage (W)	43	32.5
IP rating	IP20	
Lumen Output (lm)	4800	3600
System Efficacy (lm/W)	110	
Color Temperature (K)	6500	
CRI	80	
Housing	Metallic, CRCA powder coated	
Cover	High efficiency diffuser	
Mounting	Suspended, Wall	
THD	<10	
PF	>0.9	
Operating Voltage	220-240V, 50/60 Hz	



HVAC Calculations

Base Case

Cooling Load Calculation

Table A: Cooling and Heat Load Estimate (Base Case)

ITEM	AREA		TEMP DIF		FACTOR			BTU/HR
SOLAR GAIN GLASS								
GLASS-N	2268.5	X	39	X	0.68			60161
GLASS-E	2125	X	11	X	0.68			15895
GLASS-S	3406.2	X	11	X	0.68			25478
GLASS-W	510.21	X	158	X	0.68			54817
GLASS-NE	2946.3	X	11	X	0.68			22038
GLASS-NW	2585.1	X	148	X	0.68			260162
GLASS-SE	1626	X	11	X	0.68			12163
GLASS-SW	2952.2	X	66	X	0.68			132497
SKYLIGHT								
SOLAR & TRANS GAIN - WALLS & ROOF								
WALL-N	3346.1	X	18	X	0.35			21080
WALL-E	5364.4	X	32	X	0.35			60081
WALL-S	3868.5	X	30	X	0.35			40619
WALL-W	1527.3	X	26	X	0.35			13898
WALL-NE	3249.8	X	24	X	0.35			27298
WALL-NW	2889.9	X	20	X	0.35			20229

WALL-SE	3546	X	32	X	0.35			39715
WALL-SW	2987.9	X	28	X	0.35			29281
ROOF SUN-INSL	25596	X	49	X	0.10			125422
TRANS GAIN - EXCEPT WALLS & ROOF								
ALL GLASS	18420	X	28	X	1.13			582795
PARTITION	300	x	23	x	0.3			2070
CEILING	78253	x	23	x	0.39			701929
FLOOR	91059		23		0.39			816799
INFILTRATION AND OUTSIDE AIR								
INFILTRATION		X		X	1.08			
OUTSIDE AIR	11214	X	28	X	0.1	X	1.1	33910
INTERNAL HEAT								
PEOPLE	1150	X	245					281750
					SUB-TOTAL			#####
SAFETY FACTOR					12.50%			422511
EFFECTIVE ROOM SENSIBLE HEAT								#####
OUTSIDE AIR	11214	X	68	X	0.1	X	0.7	51851
PEOPLE	1150	X	1150					1322500
					SUB-TOTAL			#####
SAFETY FACTOR					5.00%			68718
EFFECTIVE ROOM LATENT HEAT								#####
OUTSIDE AIR HEAT								
OUT AIR-SENS	11214	X	28	X	0.9	X	1.1	305188
OUT AIR-LAT	11214	X	68	X	0.9	X	0.7	466662
(ERSH+ERLH+OASH+OALH)					SUB-TOTAL			#####
SAFETY FACTOR					3%			180526
GRAND TOTAL HEAT								#####
					TONS			516.50

Dehumidification Calculation

Table B: Dehumidifying Load Estimate (Base Case)

EST FOR	MAY	LOCAL TIME	#####		
COND	DB	WB	RH-%	DP	Gr/Lb
OUTSIDE	103	82			133
ROOM	75		50		65
DIFF	28				68
FRESH AIR					
PEOPLE	1150	CFM/P	5	5750	CFM
AREA	91058.9	CFM/SQF	0.06	5464	CFM
			FA	11214	CFM
SENSIBLE HEAT FACTOR					
ERSH	3802599		SHF	0.72	
ERLH	1443069				
TOTAL	5245668				
INDICATED ADP		47	SELECTED ADP		
DEHUM RISE		(1-BF)X (ROOM TEMP-ADP)			25.20
DEHUM CFM		EFFECTIVE ROOM SEN HEAT			139719
		1.08 X DEHM RISE			

Table C: Cooling and Heat Load Estimate (Design Case)

Design Case

Cooling Load Calculation

ITEM	AREA		TEMP DIF		FACTOR			BTU/HR
SOLAR GAIN GLASS								
GLASS-N	2268.51	X	39	X	0.32			28311
GLASS-E	2125.03	X	11	X	0.32			7480
GLASS-S	3406.16	X	11	X	0.32			11990
GLASS-W	510.21	X	158	X	0.32			25796
GLASS-NE	2946.32	X	11	X	0.32			10371
GLASS-NW	2585.08	X	148	X	0.32			122429
GLASS-SE	1626.01	X	11	X	0.32			5724
GLASS-SW	2952.24	X	66	X	0.32			62351
SKYLIGHT								
SOLAR & TRANS GAIN - WALLS & ROOF								
WALL-N	3346.1	X	18	X	0.06			3614
WALL-E	5364.35	X	32	X	0.06			10300
WALL-S	3868.47	X	30	X	0.06			6963
WALL-W	1527.3	X	26	X	0.06			2383
WALL-NE	3249.76	X	24	X	0.06			4680
WALL-NW	2889.92	X	20	X	0.06			3468
WALL-SE	3545.98	X	32	X	0.06			6808

WALL-SW	2987.87	X	28	X	0.06			5020
ROOF SUN-INSL	10745.7	X	49	X	0.10			52654
ROOF SUN-WT	10745.7	X	49	X	0.05			24221
ROOF SUN-GR	9319.148	X	49	X	0.02			8676
TRANS GAIN - EXCEPT WALLS & ROOF								
ALL GLASS	18419.56	X	28	X	1.13			582795
PARTITION	300	x	23	x	0.3			2070
CEILING	78252.99		23		0.39			701929.32
FLOOR	91053.32		23		0.39			816748.28
INFILTRATION AND OUTSIDE AIR								
INFILTRATION		X		X	1.08			
OUTSIDE AIR	11213.2	X	28	X	0.1	X	1.08	33909
INTERNAL HEAT								
PEOPLE	1150	X	245					281750
					SUB-TOTAL			2822439
SAFETY FACTOR					12.50%			352805
EFFECTIVE ROOM SENSIBLE HEAT								3175244
OUTSIDE AIR	11213.2	X	68	X	0.1	X	0.68	51850
PEOPLE	1150	X	1150					1322500
					SUB-TOTAL			1374350
SAFETY FACTOR					5.00%			68717
EFFECTIVE ROOM LATENT HEAT								1443067
OUTSIDE AIR HEAT								
OUT AIR-SENS	11213.2	X	28	X	0.9	X	1.08	305178
OUT AIR-LAT	11213.2	X	68	X	0.9	X	0.68	466648
(ERSH+ERLH+OASH+OALH)					SUB-TOTAL			5390138
SAFETY FACTOR					3%			161704
GRAND TOTAL HEAT								5551842
					TONS			462.65

Table D: Dehumidifying Load Estimate (Design Case)

Dehumidification Calculation

EST FOR	MAY	LOCAL TIME	04:00 PM		
COND	DB	WB	RH-%	DP	Gr/Lb
OUTSIDE	103	82			133
ROOM	75		50		65
DIFF	28				68
FRESH AIR					
PEOPLE	1150	CFM/P	5	5750	CFM
AREA	91053.3	CFM/SQF	0.06	5463.2	CFM
			FA	11213.2	CFM
SENSIBLE HEAT FACTOR					
ERSH	3175244		SHF	0.69	
ERLH	1443067				
TOTAL	4618311				
INDICATED ADP		50	SELECTED ADP		
DEHUM RISE		(1-BF)X (ROOM TEMP-ADP)			22.50
DEHUM CFM		EFFECTIVE ROOM SEN HEAT			130668
		1.08 X DEHM RISE			

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