An Analysis of the Cost-Benefit of Sustainable Transformation

by

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B.S., Operations Research

Columbia University in the City of New York, 2021

SUBMITTED TO THE PROGRAM IN REAL ESTATE DEVELOPMENT IN CONJUNCTION WITH THE CENTER FOR REAL ESTATE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF

MASTER OF SCIENCE IN REAL ESTATE DEVELOPMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEPTEMBER 2022

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Abstract

The real estate industry is a behemoth when it comes to scale by any measure: contributing 10% to the global GDP, and 40% of the planet's carbon emissions. Sustainable real estate has been on the rise over the last decade with almost all stakeholders across the real estate lifecycle now demanding sustainably built environments. Sustainable transformation ranges intervention in any phase(s) spanning the real estate lifecycle. So, both an asset under construction in its design-development phase, and an operational core asset considering a sustainable retrofit can undergo sustainable transformation.

As countries make commitments to go green and achieve carbon neutrality, sustainable transformation across industries is required to achieve the bold goals set in international arenas like COP26. While there yet exists explicit industry-wide regulations that mandate sustainable real estate globally, some regulatory bodies are pushing sustainable transformation by means of penalties incurred for non-compliance like New York's Local Law 97. Until governing bodies mandate regulation for sustainable real estate, the industry is dependent on incentivizing asset owners to sustainably transform their assets. The positive statement of capital and equity markets awarding sustainably superior real estate with capital premiums for asset purchase is crucial for the support of sustainable real estate.

In the private sector, the final decision for sustainable transformation of an asset lies with its asset owner. Hence, an asset owner's buy-in is integral for a real estate asset to undergo sustainable transformation. This thesis proposes a framework that aids real estate owners to evaluate investment into the sustainable transformation of their real estate assets. Whilst the thesis only evaluates the assessment of the cost-benefit of sustainable transformation by building HVAC electrification, the framework can, in general, aid decision-making for any application involving building transformation, as long as it has its corresponding input data.

The framework will be applied on two strikingly different office buildings in two cities in terms of climate, regulation, and market: an office asset of 6.9 million square feet in its design-development phase in Hyderabad, India, and an indicative office asset of 0.9 million square feet in New York, US.

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Acknowledgements

Advisor
Siqi Zheng, Faculty Director, MIT Centre for Real Estate and MIT Sustainable Urbanization Lab

Partners
Geddam Jacob Nixon, Senior Vice President, RMZ Corp
Isha Anand, Vice President, RMZ Corp
Jayakumar K, Senior Managing Director, RMZ Corp

Friends
Alejandro Valdez Echeverria, MIT S.M. Technology and Policy Program
Juan Palacios, Head of Research, MIT Sustainable Urbanization Lab

Thank you all for your support and contributions.

Photographs and Illustrations
All photographs and illustrations are by author unless otherwise noted.

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Definitions and Abbreviations

This section will define terms that will be used in the thesis, for the reader's easy understanding.

Definitions:

- Heating, Ventilation, and Air Conditioning (HVAC): system used to regulate heated and cooled air between the inside and outside of a building.
- Environmental, Sustainability, and Governance (ESG): an approach taken by firms to maximize social goals beyond the maximization of profits.
- Stock: Includes all constructed/completed buildings (existing buildings plus new completions).
- Market rental: A fair estimation of asking rent and deal closure rent.
- Market cap-rate: A fair estimation of asking cap-rate and deal closure cap-rate.
- Market vacancy: Total vacant space as a percentage of stock.
- Leasing activity: Sum of all leases including expansion, relocation, and consolidations.
- Construction starts: Total volume of new construction commenced in a year.
- U-value: a measure of the insulating capacity of the glass

Abbreviations:

- Opex: operational expenditure.
- Capex: capital expenditure.
- sqft: square feet.
- Back of house (BOH): space available to the employees and not the public.
- EUI: energy use intensity
- Dedicated Outside Air System, or DOAS HVAC, is a system wherein the outdoor air is conditioned separately from the air that controls the building's space temperature.
- IT-BPM: Information Technology Business Process Management
- IPC: International Property Consultant
- CAGR: Compounded annual growth rate
- Bps: basis point
- VFD: variable frequency drive
- LPD: lighting power density
- CHW: chilled water system
- WWR: window-to-wall ratio
- COP: coefficient of performance
- CFM: cubic feet per minute
- EPD: Environmental Product Declaration— a document that communicates transparent and comparable information about the life-cycle environmental impact of products.
- IPLV: Integrated part-load value— metric used to measure energy efficiency of chillers and air conditioners.
- CO sensor: carbon monoxide sensor
- SHGC: Solar heat gain coefficient— measures how well a window blocks heat from the sun.
- NYCECC2020: New York City Energy Conservation Code 2020

Chapter 1: Introduction

1.1 Purpose and Motivation

This thesis is motivated by a specific interest in sustainable real estate and the opportunity to sustainably transform the real estate industry. It seeks to use, as case studies, two diametrically different commercial real estate markets: Hyderabad, India and Manhattan, United States (US) to create a framework for Indian real estate owners to learn from counterparts in the US and also adapt the same to the Indian context to assess the financial feasibility of sustainably transforming their asset. The sustainable transformation described in this thesis is the upgradation of a building's HVAC system towards electrification. The study will evaluate and compare the cost and benefit, economically and environmentally, of exclusively electricity and non-electric solutions for HVAC systems of office buildings in India. By doing so, the thesis seeks to create a framework that guides Indian real estate owners when making the decision of whether to invest in the sustainable transformation.

The purpose of creating a framework is to identify the right incentives for real estate owners to invest in sustainably transforming their real estate. Given that regulations to mandate sustainable real estate are still being formulated globally (and quite unevenly: Europe leads the US; India is behind), the industry is a few years away from witnessing complete sustainable transformation. And even once formulated, implementation may have its own challenges if stakeholders lack information and are hence slow to adopt the mandated changes.

Therefore, to minimize any delay during implementation, caused by a lack of information and tools on why one must consider sustainable real estate investment, the thesis proposes a framework to aid real estate owners in assessing sustainable real estate investment. Additionally, to speed up the implementation of sustainable transformation, the framework seeks to expose and educate real estate owners on the financial feasibility and merit of sustainable investment, so they are equipped to quickly implement sustainable transformation once mandated. Finally, the framework hopes to earlier kickstart the process of sustainable transformation prior to the formal mandating of sustainable real estate by hoping to incentivize real estate owners to invest in sustainable transformation.

1.2 Parameters of The Study

The study will focus on collecting raw data from two commercial real estate assets respectively. The raw data will be categorized into natural environment market, asset data, and regulatory data.

The market data will include:

- environmental data:
    - temperature
    - humidity
    - precipitation
    - snowfall (only in New York)
- office market data:
    - leasing volume
    - construction starts
    - market rental
    - market vacancy
    - market cap-rate
    - stock
    - asset sales

The asset data will include:

- financial
    - opex per sqft:
    - capex per sqft:
    - rent premium:
    - cap-rate premium:
    - loss in leasable area (post retrofit):
- energy
    - base energy source price:
    - energy cost savings:
    - energy efficiency savings: energy source
    - energy efficiency
    - energy consumption breakdown
    - baseline energy intensity

The regulatory data will include:

- city-regulations and actions
    - local laws for net-zero
    - city's decarbonization plan
    - policy-makers commitment:
- office asset stakeholders' commitments and actions
    - developer's commitment:
    - market preference for net-zero:
    - tenant's commitment net-zero commitment year

The raw data collected will include historic data. The analysis of this data will inform the decision-making framework. In addition, the analysis of present and historic data will help make financial forecasts that would aid in enabling the decision-making framework.

1.3 Research Methodology and Thesis Structure

The thesis structure will follow, first, an introduction of the markets studied with a description of the selected assets, the respective markets' decarbonization plans and their natural environments. Second, it will present the current landscape followed by the proposed sustainable technologies, the elected sustainable technology and energy usage and optimization of each asset. Third, the decision-making framework will be explained, followed by the financial model for the thesis' selected application. Fourth, the analysis of the data for both assets will be presented, highlighting the net benefit of sustainable transformation for each proposal. Finally, a conclusion will be considered and shared for the stakeholders impacted by sustainable transformation in the real estate lifecycle.

Chapter 2: Overview of Markets, Environment and Climate Regulation in Two Case Cities

2.1 Market Overview

2.1.1 Hyderabad Office Market

Hyderabad is a city located in the South of India and the capital and largest city of Telangana State. The city is also the de jure capital of Andhra Pradesh state. Hyderabad has been India's fastest expanding real estate market, thanks to aggressive government policies, good infrastructure, and the availability of talent, among other things.[1]

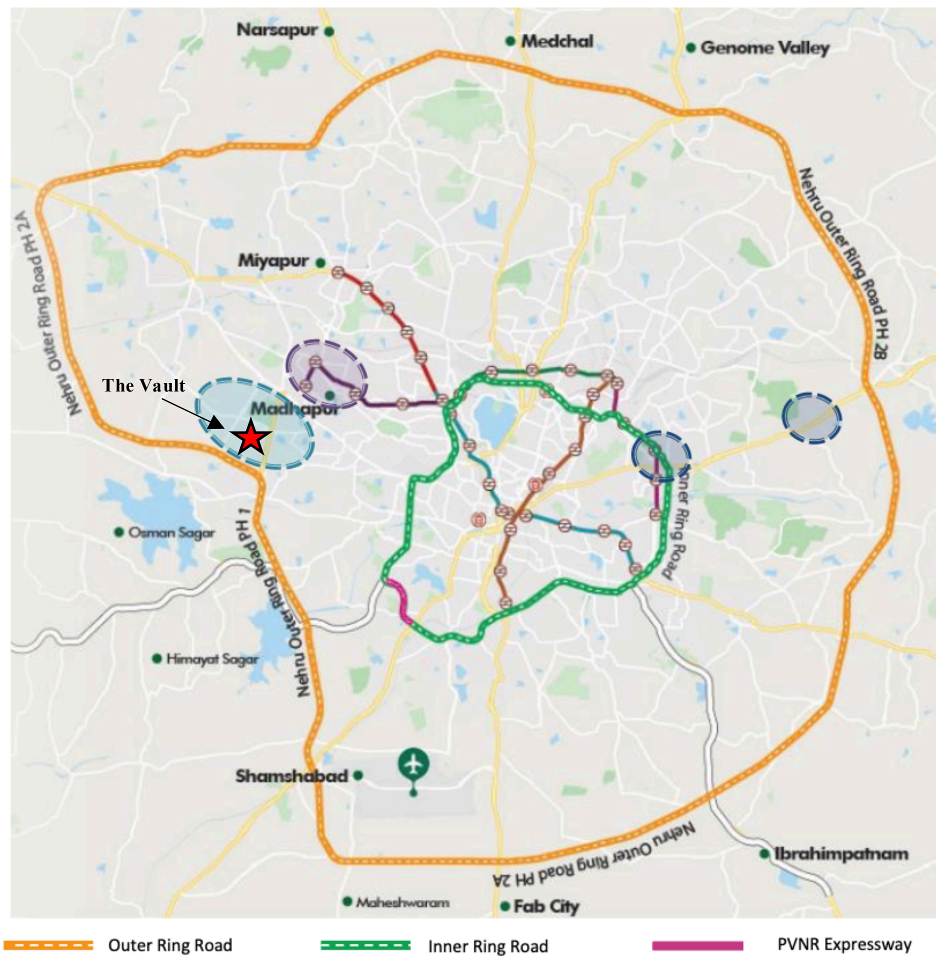


Figure 1: Hyderabad office market map. Source: RMZ Corp

During 2020 and portions of 2021, the pandemic hindered office leasing activity in the city. However, leasing activity began to rebound in the second half of 2021, as seen in Figure 2. The Hyderabad market gained traction in Q1 2022, with a quarter-on-quarter rise of 19.6% fueled by

[1] Savills Asia Research. (2021). Hyderabad Offices. Asian Cities – 2H 2021. Spotlight Savills Research. Retrieved 05/23/2022, from https://pdf.savills.asia/asia-pacific-research/asia-pacific-research/hyderabad-office-2h-2021-asian-cities-report.pdf

new leases. Another noteworthy feature is the city's growing percentage in the country's total absorption. It has slowly improved from a distant sixth place in 2015 to a commanding second place in 2020 and 2021.

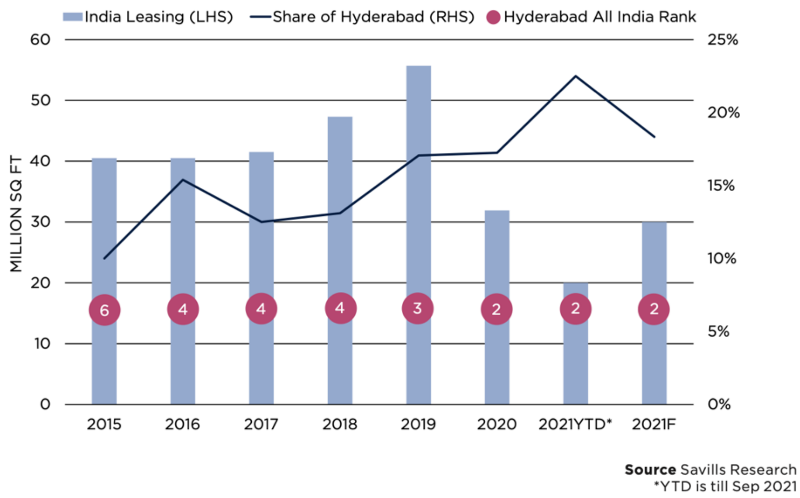


Figure 2: Hyderabad leasing activity recovery

IT-BPM continues to be the primary driver of growth, accounting for 50% of the total signed leases, with flex spaces accounting for 16%. With new leases nearing completion, leasing activity in the city is likely to pick up in the near future.[2]

The city's proportion of office demand in the entire country, which was just 10% in 2015, is expected to rise to 18-20% by the end of 2021. On the supply side, the entire stock of premium-grade office buildings is presently approximately 70 million square feet, with more than 20 million square feet of new supply added in the previous three years, meaning considerable volume injection every quarter.

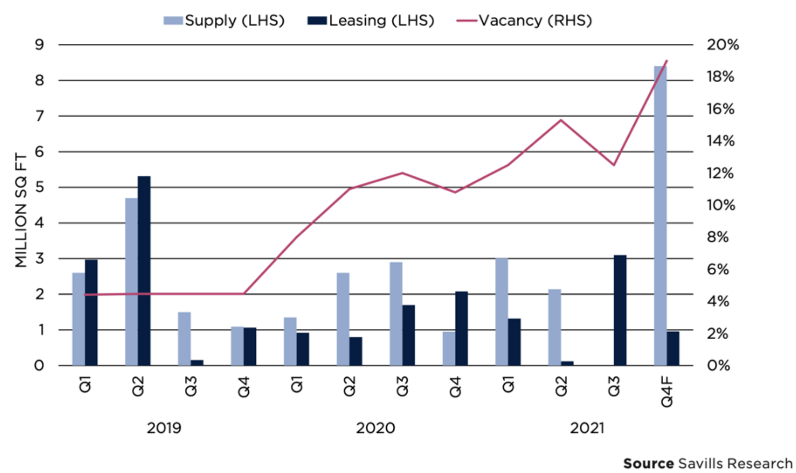


Figure 3: Hyderabad demand-supply gap and vacancy levels

Q3 2021, on the other hand, was notable for the lack of supply increase due to delays in building completion due to pandemic-related factors. This resulted in a significant decrease in vacancy, which fell from 15.3 percent in Q2 2021 to 12.5 percent in Q3 2021, as seen in Figure 3.

Over the following twelve to eighteen months, the city's pipeline of under-construction projects is substantial and the city's entire stock of commercial office space is likely to reach close to 80 million square feet by the end of 2021. The city is likely to continue its position as one of India's top IT destinations, aided by favorable legislative efforts and infrastructural upgrades, hence remaining a prominent participant in the country's commercial office market.[3]

[2] Cushman & Wakefield (2022, April 04). India. Insights. Hyderabad MarketBeat Reports *22/04/2022*. Retrieved 05/24/2022, from https://www.cushmanwakefield.com/en/india/insights/hyderabad-marketbeat

[3] Savills Asia Research. (2021). Hyderabad Offices. Asian Cities – 2H 2021. Spotlight Savills Research. Retrieved 05/24/2022, from https://pdf.savills.asia/asia-pacific-research/asia-pacific-research/hyderabad-office-2h-2021-asian-cities-report.pdf

Hyderabad's market is divided into three districts: Secondary Business District I (SBD I), Secondary Business District II (SBD II), and Peripheral Business District (PBD). SBD I includes Madhapur, Kondapur and Raidurg. SBD II includes Gachibowli, Nanakramguda and Manikonda. PBD includes Pocharam and Uppal.

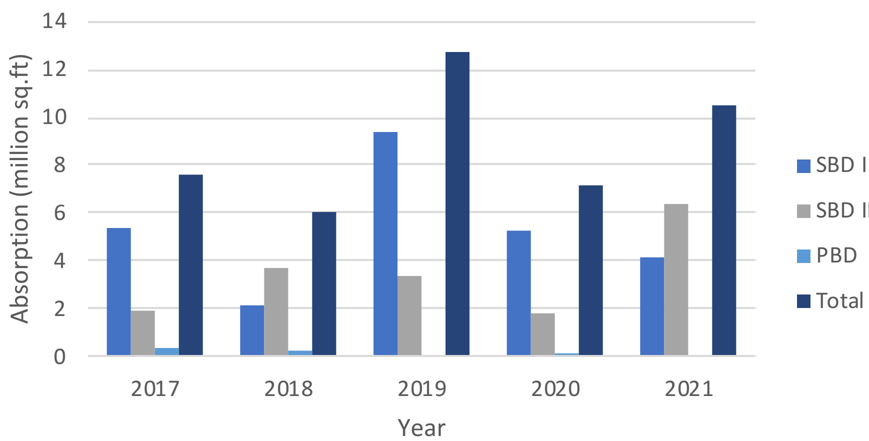


Figure 4: Hyderabad market absorption. Source: RMZ Corp

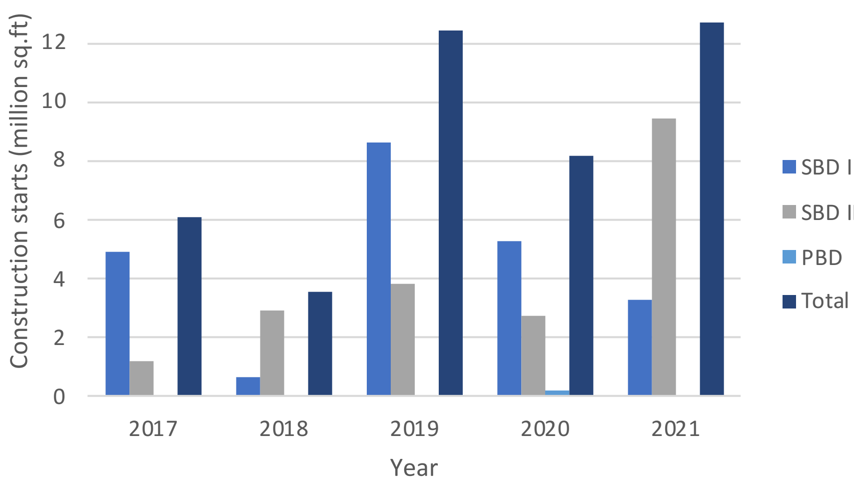


Figure 5: Hyderabad market construction starts. Source: RMZ Corp

Of the three districts, SBD II, particularly Gachiboli[4], has recently witnessed a rapid transformation in terms of commercial and residential real estate spaces due to the presence of major IT-BPM companies.

Over the last 2 years, SBD II has seen a near 3x increase in absorption, as shown in Figure 4. Given the pandemic-related uncertainties, IPCs are refraining from currently making any forecasts.

Construction starts in Hyderabad markets has been on the rise. Despite the fall in 2020 due to the pandemic, construction starts have picked up and were at a record high in 2021. SBD II has witnessed a near 3.5X growth in starts over the last 2 years, and its level has been at its highest over the last 5 years.

[4] Anarock (2018, April). Micromarket Overview Report. *April 2018*. Gachibowli, Hyderabad. Retrieved 05/25/2022, from https://api.anarock.com/uploads/research/Gachibowli%20-%20Micro%20Market%20Overview%20Report.pdf

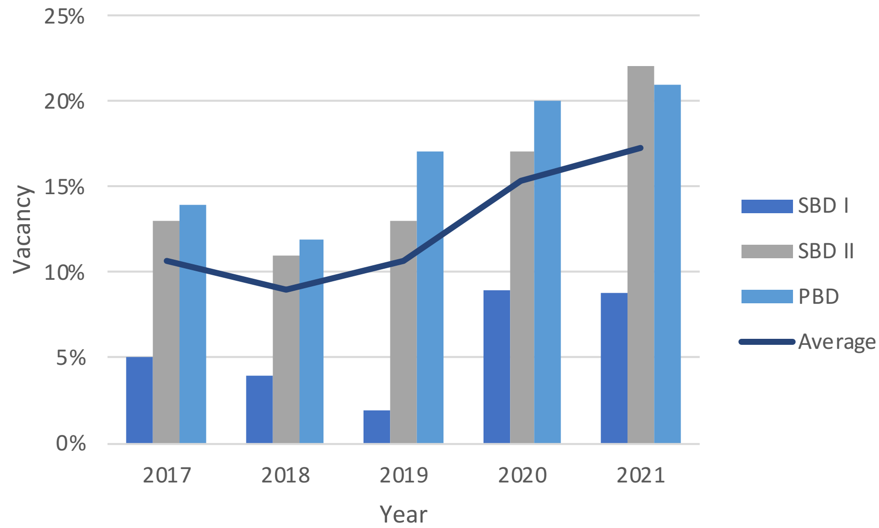


Figure 6: Hyderabad market vacancy. Source: RMZ Corp

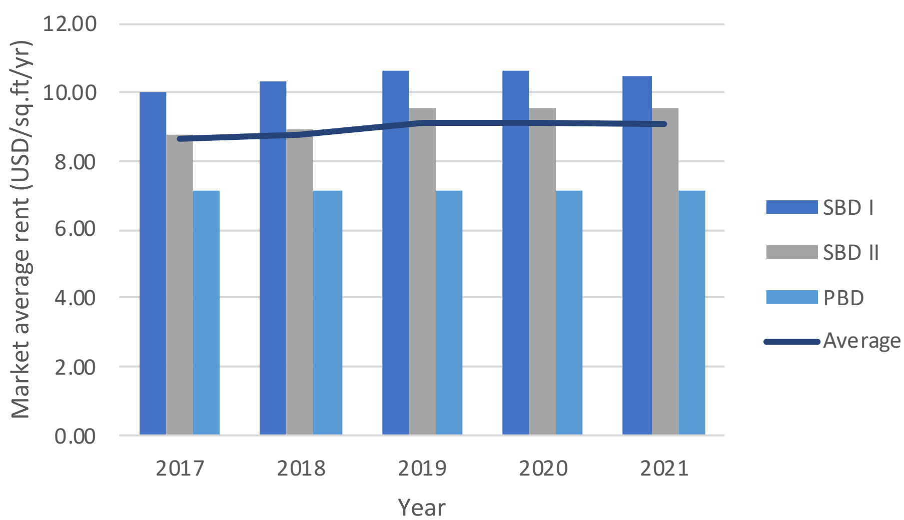


Figure 7: Hyderabad market average rent. Source: RMZ Corp

Market vacancy has risen over the past 4 years. The SBD II sub-market experienced the highest vacancy in 2021 followed by PBD and SBD I, as seen in Figure 5. Gachibowli[5] has seen a fresh supply of 1.1 million square feet, with a vacancy rate of 26.7 percent (a 110 bps rise quarter-on-quarter).

For the remainder of 2022, about 8.5 million square feet of fresh supply is planned in Gachibowli, increasing the vacancy rate to around 29-30% by Q4 2022.

The market average rent has remained fairly consistent over the last 5 years, as seen in Figure 7. There has been an approximately 5% increase in annual rent over the last 5 years across the market. Of the submarkets, SBD II has experienced a near 9% rent increase over the last 5 years.

Hyderabad has recently seen a noticeable increase in leasing activity and has solidified its position as a top three contender in the country's office market. The city's leasing business is still driven by the IT and related sectors. In the present year, the sector accounts for over 70% of the city's leasing activities. Financial and pharmaceutical companies have also demonstrated their belief in Hyderabad's economic growth by taking up additional space in the city's main submarkets.

The Gachibowli market rents at approximately $10/sqft per annum. The Hyderabad asset, The Vault, is located in Gachibowli.

[5] Cushman & Wakefield (2022, April 22). India. Insights. Hyderabad MarketBeat Reports *22/04/2022*. Retrieved 06/01/2022, from https://www.cushmanwakefield.com/en/india/insights/hyderabad-marketbeat

2.1.2 The Vault: Developed By RMZ

Figure 8: The Vault development rendering. Source: RMZ Corp

Designed by Skidmore Owings & Merrill and developed by RMZ Corp, The Vault is a 6.9 million sqft commercial development. It will have 6 towers, each of which has an area of approximately 1 million sqft. The 6 towers— named T10, T20, T30, T40, T50, and T60— will have heights that range from 91m-110m. The project is spread over a site area of 22.55 acres.

Each tower will have a floor plate of approximately 45,000 sqft. The towers will each be 22-25 floors tall and have 5 basements for underground parking. The parking ratio will be 1 car park per 1,000 square feet leased.

Figure 9: Development cross-section. Source: RMZ Corp

There will be a promenade and concourse level that runs through the development which enables the inclusion of voluminous lobby spaces with triple-height ceilings.

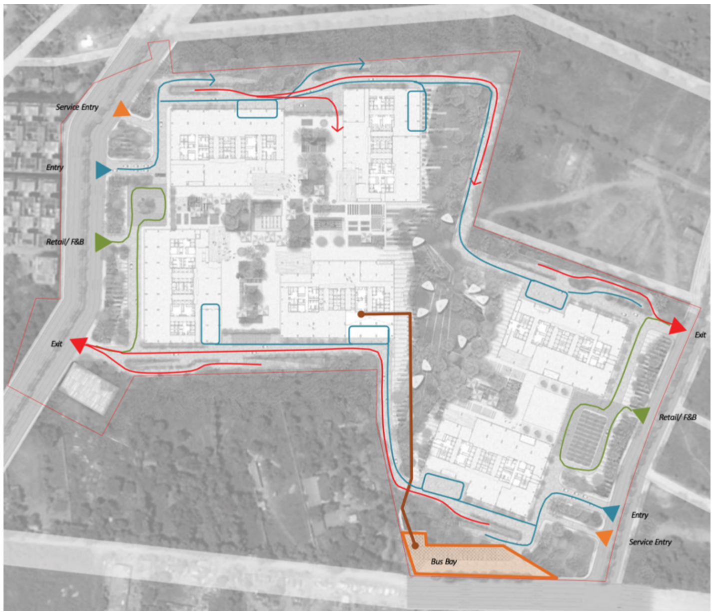


Figure 10: Development traffic-flow mapping. Source: RMZ Corp

The site is advantageously located in a region with supreme urban infrastructure. Parallel to a major highway that connects SBD II to the airport in only 30 minutes – an important metric for consideration by building occupiers, the site has great urban connectivity through a network of easily accessible roads, and a bus stop and train station located within 10 minutes away from the site. In addition, the site has multiple points of arrival for efficient traffic flow management, as shown in Figure 10.

This is crucial as it enables phasing during development and allows for efficient management of traffic when the site is at capacity with close to 85,000 visitors a day.

Gachibowli is an upcoming neighborhood where there is rapid construction. Gachibowli's[6] real estate boom did not come out of nowhere; it has been in the works for the better part of a decade and is still evolving. Consistent infrastructure improvements, such as the metro train extension and the execution of a Strategic Road Development Plan (SRDP), have provided great connectivity in and around the city, boosting core real estate potential.

Furthermore, investor-friendly legislations such as the Information Communication Technology (ICT) Policy 2.0 have played a vital role in piquing the attention of multinational corporations. The new IT policy emphasizes digital citizen empowerment, innovation, and entrepreneurship. It features a Start-up Telangana platform, which seeks to serve as a one-stop shop for the state's complete startup ecosystem.

The development will be a Grade A commercial office development with retail and social experiences on the ground floor. The social experiences include a museum, art galleries, a marketplace, a restaurant collection, wellness facilities, and an event space, to name a few. These experiences will total 223,000 square feet of space.

The Vault has been designed with the approach of creating an urban environment that employs social, biophilic and hydrological elements in design.

[6] Savills Asia Research. (2021). Hyderabad Offices. Asian Cities – 2H 2021. Spotlight Savills Research. Retrieved 06/11/2022, from https://pdf.savills.asia/asia-pacific-research/asia-pacific-research/hyderabad-office-2h-2021-asian-cities-report.pdf

2.1.3 Manhattan Office Market

New York City's office market spans close to a billion square feet of commercial office space, has a market vacancy of 12.2%, and a nation-leading 17.7 million square feet of space under construction. The city's market is made up of the five boroughs: Bronx, Brooklyn, Manhattan, Queens, and Staten Island. However, much of its stock comes exclusively from Manhattan.

Manhattan has close to 600 million square feet of commercial office space and is spread across several submarkets, as shown in Figure 12. With office rents ranging from $70-$140/sqft and 12-month space absorption of 6.1 million square feet, Manhattan is amongst the world's most dynamic office markets.

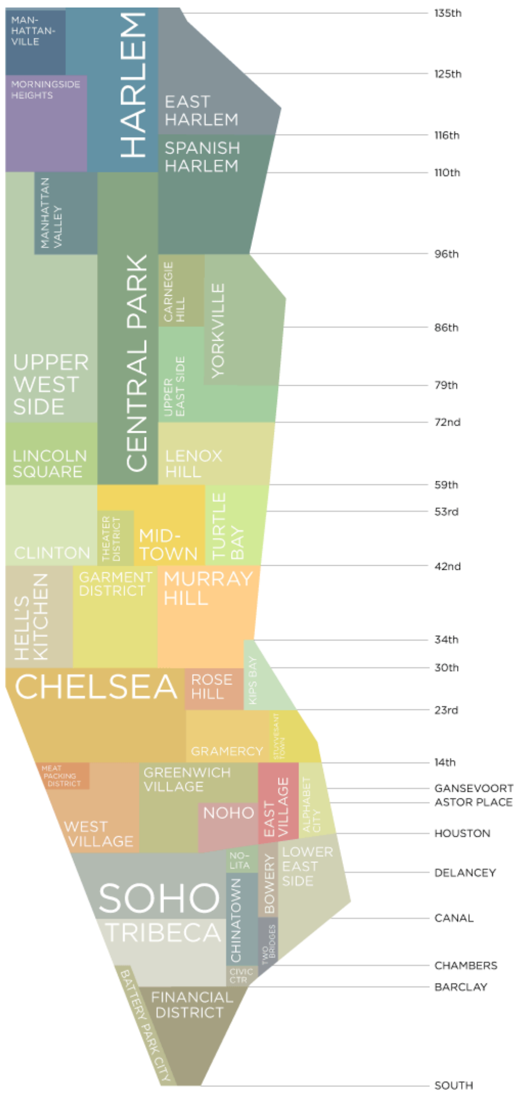


Figure 11: Manhattan Office Submarkets. Source: RI Manhattan Realty Commercial Real Estate Services

The pandemic continues to have an influence on New York City's office market, since the prominence of remote work has resulted in New York office utilization being substantially below pre-pandemic levels. In several submarkets, leasing activity has been limited, the number of sublease space has increased, and the availability rate has remained at all-time highs. The fall in tenant demand and the increase in vacancies continue to have a negative influence on rents, albeit they appear to have steadied. Vacancy expected to remain at peak levels throughout 2022.

The submarkets between 59th and 30th street new lease activity increased significantly in Q1 2021, reaching a nine-quarter high of 5.0 million square feet, outpacing the first seven months of 2021 by 11.0 percent, and falling just short of the 2017–2019 average of 5.3 million square feet.

The Garment District, which includes Penn Plaza, has been the hottest market recently in terms of leasing activity, construction starts and market rent growth. Touching the Garment District, at the intersection of Midtown and Murray Hill, lies the submarket Grand Central, defined by the many skyscrapers, like the recently built One Vanderbilt, that are occupied by a bevy of Fortune 500 Companies.

The Grand Central submarket remains one of the most premium in the city, with some properties fetching more than $100 per square foot.

The Manhattan asset used as a case-study is located in Grand Central, a market with recently built Grade A office supply.

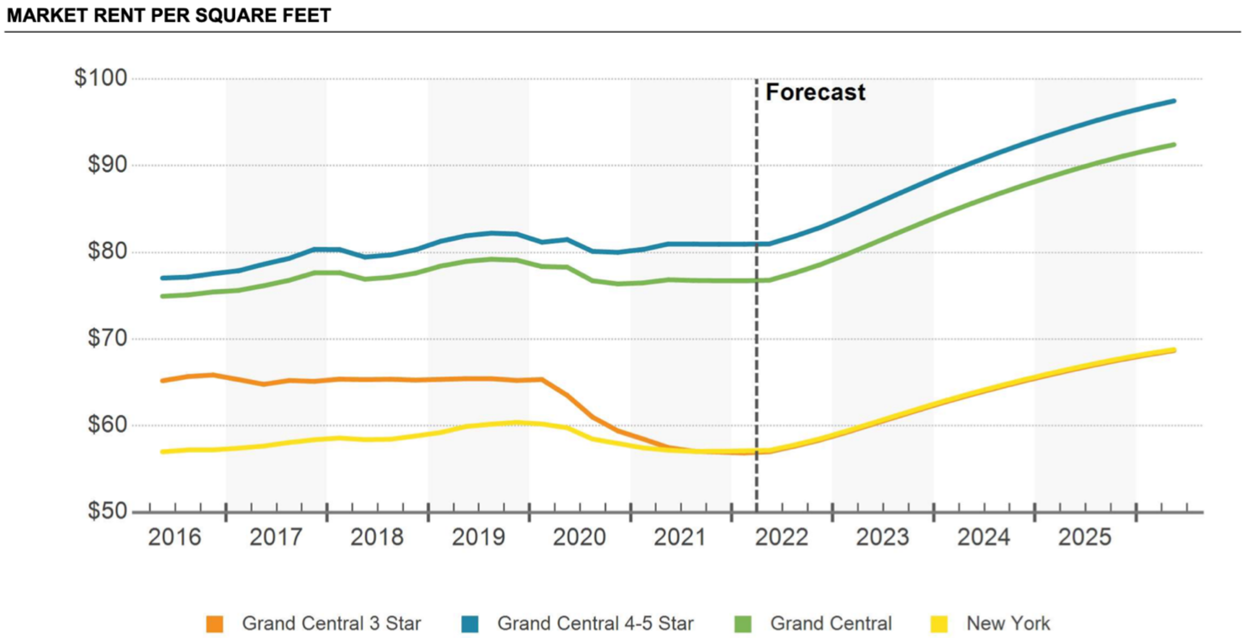


Figure 12: Grand Central market rent per square foot. Source: CoStar

Grand Central has attracted both institutional and retail investors, and the strong increase in price per square foot has helped boost the yearly sales volume while lowering cap rates to slightly about 4%. From 2017 through 2019, yearly sales reached $2 billion. The $900 million sale of 330 Madison Avenue spurred activity in the first quarter of 2021. The leased 852,000 square feet asset was sold by the Abu Dhabi Investment Authority to Munich RE. The purchase price ($1,056/square foot) indicates the value of a complete ownership share in a high-quality asset.

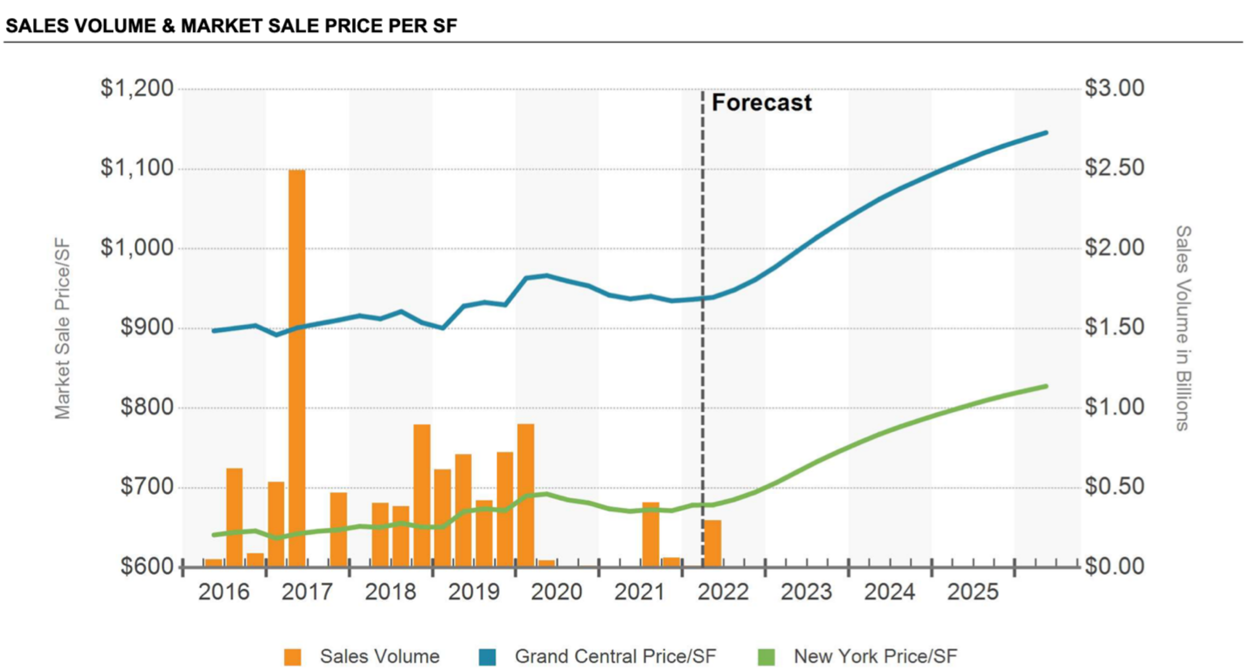


Figure 13: Grand Central sales volume & market sale price per square foot. Source: CoStar

Prominent tenants such as JPMorgan Chase, Price Waterhouse Coopers, Bloomberg L.P., and Barclays Capital have an office presence in Grand Central. The submarket has witnessed a 13.3% vacancy rate, 0% rent growth, and a negative 1.1 million square feet space absorption over the last 12 months.

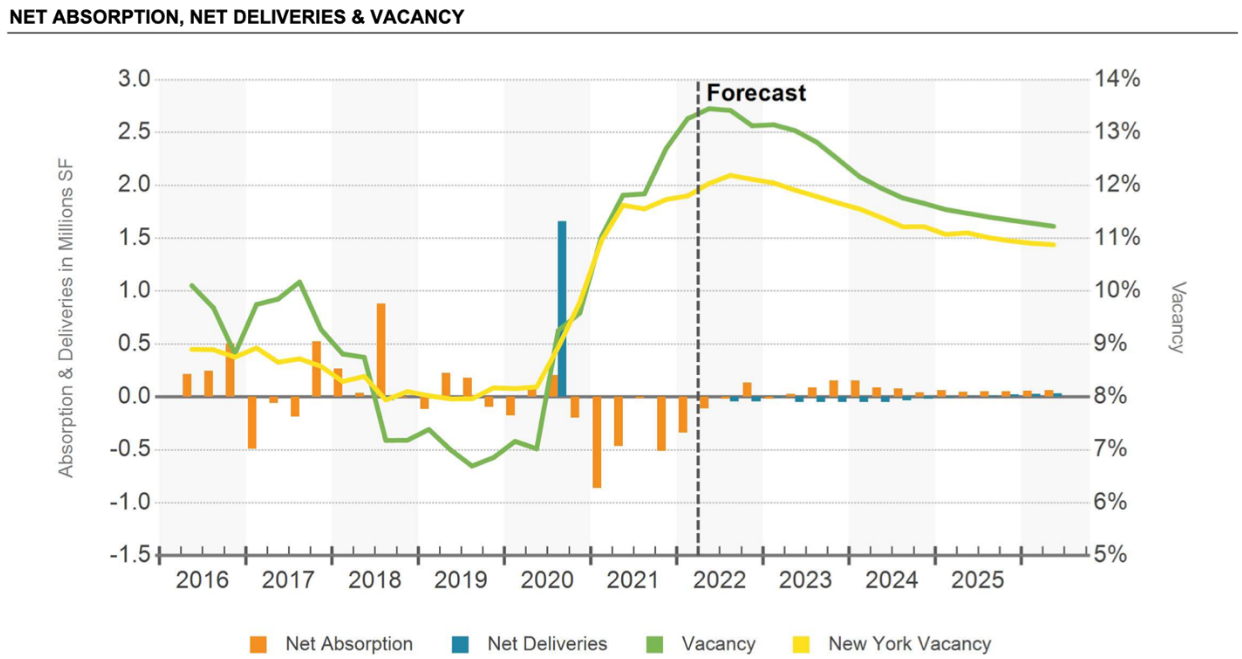


Figure 14: Grand Central net absorption, net deliveries & vacancy. Source: CoStar

The area's competitiveness as a leading commercial district was harmed by a lack of contemporary office buildings. The passage of the Midtown rezoning proposal in 2017 allowed owners of historic properties around the neighborhood to sell unused development rights. The rezoning has made it possible for the Grand Central Submarket to receive much-needed new buildings. 1.7 million square foot, One Vanderbilt has led the charge, with developments like the ongoing project in 343 Madison Avenue.

Over the last few years, the industry has been increasing its focus on sustainability as corporations on a global scale started studiously upholding ESG principles and evolving their operations to become ESG compliant.

2.1.4 An Office Asset in Manhattan

An indicative asset has been used in Manhattan to assess the benefit of sustainable investment in real estate. The asset is a 45-story structure that will rise from a 23,640-square-foot rectangular site between East 43rd and 44th Streets. The site is currently occupied by a 15-story building. The new tower will yield approximately 900,000 square feet of office space, with ground floor retail space, and subterranean circulation paths to Grand Central Terminal and the future East Side Access project.

The building will be a Grade A commercial office skyscraper with retail on the ground floor. An amenity program, wellness components, and both private and communal outdoor spaces are all likely to be included in the office. Two levels of basement will be allocated to BOH spaces, parking, utilities, and a direct link to the Long Island Railroad.

To limit west sun exposure and enable more flexible leasable workspace per level, the elevators' side core will run on the building's west façade, which will remain entirely opaque.

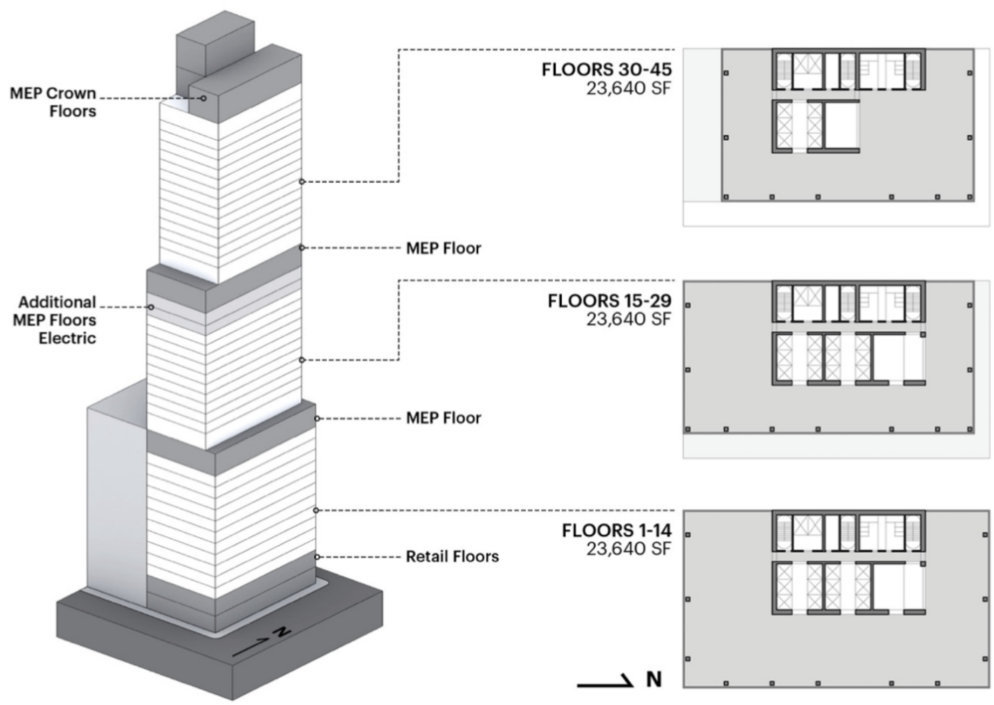


Figure 15: Schematic floorplan and axonometric view of the tower. Source: MIT SRE_pset 3

A high-performance curtainwall (complying with NYC Energy Conservation Code 2020), a DOAS HVAC solution with enhanced heat recovery, and high-efficiency lighting, mechanical, and electrical systems may be included in the development. In addition, the feasibility and long-term cost implications of a fully electrified building, as an alternative to a typical natural gas-based solution for space heating and hot water, will be assessed in this thesis, considering LL97 and the recently passed Local Law 154 (LL154), which require large new commercial buildings to eliminate fossil fuels on-site by the end of the decade.

2.1.5 Key Comparisons

The key differences to note between the office market in Hyderabad and that in Manhattan are captured in Table 1. It is clear that Manhattan's Grand Central sub-market is far more mature than Hyderabad's Gachibowli sub-market which rents at nearly an eighth of that of Grand Central, and has a vacancy approximately twice of that of Grand Central.

Table 1: Office market key comparisons. Source: Multiple, listed as footnotes

	Hyderabad	Manhattan
Sub-Market Name	Gachibowli	Grand Central
Sub-Market Avg Rent	$10/sqft per annum	$77/sqft per annum
Sub-Market Vacancy	26.7%[7]	13.3%
Sub-Market Cap Rate	~7.0%	~4.0%
Construction Starts	1.1 million sqft[7]	0 million sqft
Asset Size	6.9 million sqft	0.9 million sqft
Asset Target Rent	$11.16/sqft per annum	$106/sqft per annum

It is interesting to note that the Hyderabad asset aims to seek a near 11% premium over average sub-market rental, while the Manhattan asset seeks a near 38% premium over average sub-market rental. However, in Grand Central's case, since construction starts are very low, and the existing comparable supply consists of assets that are at least a decade old, the average market rent is far lower than what a new construction in the sub-market would target for its rentals. This is because the existing supply may be locked in long-term lease agreements, paying historic rentals with little opportunity to mark those rentals up to market. Also, because most of these assets are dated, their design specifications and quality is far inferior from the newer supply that is renting north of $100/sqft per annum.

The two assets also differ grandly in size: the Hyderabad asset is nearly 7 times greater than the Manhattan asset. However, given Manhattan is a more mature and stabilized market than Hyderabad, it seeks cap-rates that are near 4%, while Hyderabad seeks around 7%. And so, the capital value of the Manhattan asset is nearly double that of Hyderabad.

Gachibowli is a market with greater competition to lease new space than Grand Central. Gachibowli's greater market vacancy and higher construction starts testify the same. Gachibowli's crowded nature creates an ideal platform for developers to seek effective ways to differentiate from another, and compete for clients who are seeking space in a surplus office market. With ESG becoming a big focus for tenants' companies, their inclination to seek the most sustainable space could now be at an all-time high. Thus, having the most sustainable office is now a strong incentive for developers as it may increase the likelihood of their space being taken up.

Manhattan, on the other hand, is a market not new to sustainable real estate. With almost all new developments possessing green building infrastructure, and the city's decarbonization plans nearly mandating it, building sustainable real estate has subtly become a requirement to stay competitive.

[7] Cushman & Wakefield (2022, April 22). India. Insights. Hyderabad MarketBeat Reports 22/04/2022. Retrieved 06/01/2022, from https://www.cushmanwakefield.com/en/india/insights/hyderabad-marketbeat

2.2 Decarbonization Plan and Climate Regulation

2.2.1 Hyderabad: Ministry of Environment, Forest, and Climate Change

Telangana established an Energy Conservation Building Code (ECBC) for commercial buildings in 2014. The code is named as Telangana – Energy Conservation Building Code (TS-ECBC), and it is intended for energy-efficient building design and construction. Building envelope, HVAC system, SHW system, interior and outdoor lighting, and electrical power and motors are all covered by the TS-ECBC.

The TS-ECBC Code was created to help expedite the implementation of ECBC in Telangana. TS-ECBC Code compliance can be attained by following the code's necessary requirements and demonstrating conformity using the prescriptive technique, or the total building performance method. The total building performance method compares energy savings between the proposed building and an energy code compliant building (referred to as the baseline building). The basic model is created using the TS-ECBC as a guide. The mechanical, electrical, and plumbing (MEP) design reports are used to create the suggested model.[8]

The TS-EBC code applies to buildings in excess of 20,000 square feet. Its provisions apply to:

- Building envelopes, except for unconditioned storage spaces or warehouses;
- Mechanical systems and equipment, including heating, ventilation, and air conditioning;
- Service hot water heating;
- Interior and exterior lighting; and
- Electrical power and motors.

Compliance with TS-ECBC is required for the passage of the construction permit issued by the Ministry of Environment, Forest, and Climate Change (MOEF).

Table 2: Cooling equipment minimum efficiency requirement. Source: Telangana State Renewable Energy Development Corporation Ltd.

Equipment Class	Minimum COP	Minimum IPLV
Air Cooled Chiller < 530kW	2.9	3.16
Air Cooled Chiller ≥ 530kW	3.05	3.32
Centrifugal Water Cooled Chiller ≤530kW	5.0	5.25
Centrifugal Water Cooled Chiller ≥ 530 kW and <1050 kW	5.55	5.9
Centrifugal Water Cooled Chiller ≥ 1050 kW	6.1	6.4
Reciprocating Compressor Water Cooled Chiller all sizes	4.2	5.05
Rotary Screw and Scroll Compressor Chiller < 530 kW	4.7	5.49
Rotary Screw and Scroll Compressor Chiller ≥ 530 kW and < 1050 kW	5.4	6.17
Rotary Screw and Scroll Compressor Chiller ≥ 1050 kW	5.75	6.43

An excerpt of the requirement for HVAC is shown in Table 2. All heating, ventilation, and air conditioning equipment and systems shall comply with the mandatory requirements and the prescriptive criteria. The mandatory requirements include Load Calculations, Natural Ventilation, Minimum Equipment Efficiencies, Controls (Thermostatic), and so on.

Table 2 and 3 highlight the minimum efficiency requirements that cooling equipment must meet or exceed to qualify for TS-ECBC.

[8] Telangana State Renewable Energy Development Corporation Ltd. (TSREDCO) (2017, December). Telangana Energy Conservation Building Code (TSECBC) Guidelines. *December 2017*. Retrieved 06/03/2022, from https://tsredco.telangana.gov.in/PDFs/ECBC/4_TS_ECBCGuidelines.pdf

Table 3 also highlights the minimum efficiency requirements (air cooled) for Electrically Operated Variable Refrigerant Flow Air Conditioners.

Table 3: Minimum efficiency requirements (air cooled). Source: Telangana State Renewable Energy Development Corporation Ltd.

Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency
<19 kW	All	VRF multisplit system	3.81 $SCOP_c$
≥19 kW and <40 kW	Electric resistance (or none)	VRF multisplit system	3.22 COP_c 3.60 $ICOP_c$
≥19 kW and <40 kW	Electric resistance (or none)	VRF multisplit system with heat recovery	3.16 COP_c 3.55 $ICOP_c$
≥40 kW and <70 kW	Electric resistance (or none)	VRF multisplit system	3.11 COP_c 3.46 $ICOP_c$
≥40 kW and <70 kW	Electric resistance (or none)	VRF multisplit system with heat recovery	3.05 COP_c 3.40 $ICOP_c$
≥70 kW	Electric resistance (or none)	VRF multisplit system	2.78 COP_c 3.11 $ICOP_c$
≥70 kW	Electric resistance (or none)	VRF multisplit system with heat recovery	2.73 COP_c 3.05 $ICOP_c$

[a] $SCOP_c$ - seasonal coefficient of performance—cooling

All HVAC components shall be tested as per the provisions listed in Table 4.

Table 4: HVAC Testing requirements. Source: Telangana State Renewable Energy Development Corporation Ltd.

Component	Standard
Natural Ventilation	NBC 2016 PART 8 Section 1
Unitary Air Conditioner	BEE Star Rating IS 1391 PART 2
Split Air Conditioner	BEE Star Rating IS 1391 PART 2
Packaged Air Conditioner	ISO 8148
Boilers	IS 13980
Air Cooled Chillers Water Cooled Chillers	AHRI 551 AHRI 591
VRF system	AHRI 1230
Duct Work and Piping Insulation	ASTM C 518
Fan Efficiency	AMCA 205
Duct Insulation R-value	Measured on a horizontal plane in accordance with ASTM C518 at a mean temperature of $24°C$ at the installed thickness.

Non-compliance with all of the requirements listed by the MOEF, like the HVAC requirements shown above, would result in the non-passage of the MOEF issued permits, which are crucial to break ground and start construction.

Looking at all three Tables, it is clear that TS-ECBC's requirements provide developers with guidelines on the type of equipment they can choose today, based on their respective COPs. The Tables however, fail to capture forecasts on how the requirements should look in the future. Additionally, as for now, the guidelines are applicable only for new construction, and do not yet require already built real estate to undergo potential retrofits to make them TS-ECBC compliant.

2.1.2 New York: Local Law 97

Furthermore, in New York real estate, the implementation of laws like the Local Law 97 (LL 97), has been instrumental in informing real estate owners that they must meet new energy efficiency and greenhouse gas emission limits by 2024, with stricter limits coming into effect in 2030. The law's goal is to reduce the emissions produced by the city's largest buildings: 40% by 2030 and 80% by 2050.

The local government of New York City passed the Local Law 97 (LL97) in 2019 – a pioneering law that caps the greenhouse gas (GHG) emissions that buildings can release. The law sets individual emission caps for properties larger than 25,000 square feet. When buildings exceed their caps, real estate owners need to pay a fine or purchase greenhouse gas offsets. For all buildings, LL97 sets the carbon intensity limit (i.e., the amount of carbon-based energy that can be used per square foot), that becomes progressively stricter over time.

Local Law 97 generally covers, with some exceptions:

- Buildings that exceed 25,000 gross square feet.
- Two or more buildings on the same tax lot that combined, exceed 50,000 square feet.
- Two or more buildings owned by a condo association that are governed by the same board of managers and that combined, exceed 50,000 square feet.

Table 5: Emissions Cap by LL97. Source: NYC Sustainable Buildings, NYC.gov

Time Period	LL97 Cap
2025-2029 (kgCO_2e/ft2.y)	8.46
2030-2034 (kgCO_2e/ft2.y)	4.53
2035-2039 (kgCO_2e/ft2.y)	2.68
2040-2044 (kgCO_2e/ft2.y)	1.4*
2045-2050 (kgCO_2e/ft2.y)	1.2*
2050-2060 (kgCO_2e/ft2.y)	0*

** marked figures have been forecasted, as guidelines beyond 2040 are not yet defined.*

In the next 10 years, the cost of electric heating in comparison to other options based on fossil fuels in the city might significantly vary due to the price of pollution, prospective new legislation, or rises in gas prices, for example.

The choice of energy source for a building's heating system has become a crucial consideration for real estate developers between 2022 and 2030 (when electrification will be needed in NYC). Property owners may be uncertain as to the degree of system decarbonization in New York City.

Grid decarbonization

The building's ability to comply with LL97 and the choice to electrify the heating system of the building will be hampered by the rate of grid decarbonization and natural gas costs.

In this instance, the case supposes that New York City can decarbonize its grid in accordance with the state's strategy. The Climate Leadership and Community Protection Act (CLCPA) of New York State aims to produce all of the state's power from renewable sources between the years 2030 and 2040, at which point all emissions associated with electrical systems will be eliminated.

Table 6: Electricity decarbonization New York City Grid. Source: MIT SRE_pset 3

	(1) Electricity GHG per CLCPA
2020-2024 (kgCO2e/kBtu)	0.0900
2025-2029 (kgCO2e/kBtu)	0.0847
2030-2034 (kgCO2e/kBtu)	0.0550
2035-2039 (kgCO2e/kBtu)	0.0220
2040-2044 (kgCO2e/kBtu)	0
2045-2049 (kgCO2e/kBtu)	0
2050-2054 (kgCO2e/kBtu)	0
2055-2059 (kgCO2e/kBtu)	0

kBtu: kilo-British thermal unit

As Hyderabad does not have any clear guidelines like LL97 to regulate carbon emissions in the future, it is challenging to similarly track the risks posed by its decarbonization plan as done for Manhattan in Table 8.

Key Comparisons

- TS-ECBC is far less evolved than LL97, as LL97 defines requirements that can apply to both completed, as well as under-construction buildings.
- LL97 has guidelines for the future, while TS-ECBC applies only to the present (only for the passage of permits).
- TS-ECBC also does not cap the CO_2 emissions of buildings per sqft, while LL97 does.
- The TS-ECBC guidelines seem more concerned with regulating the development phase of the real estate lifecycle, while LL97 seeks to also capture the operational (or asset management) phase of the real estate lifecycle.
- LL97 has an explicit per sqft for non-compliance, whereas TS-ECBC does not. However, TS-ECBC's penalty for non-compliance still impacts the developer monetarily, due to delays caused in construction by failure to receive development permits, even though not explicitly mentioned.

2.3 Natural Environment

2.3.1 Hyderabad

The climate of Hyderabad is tropical, with both rainy and dry seasons. It has high temperatures all year round and is prone to drought. Most mornings and evenings are chilly due to the city's comparatively higher elevation. Summer lasts from March through June, with hot temperatures. The monsoon season begins in June and lasts until September.

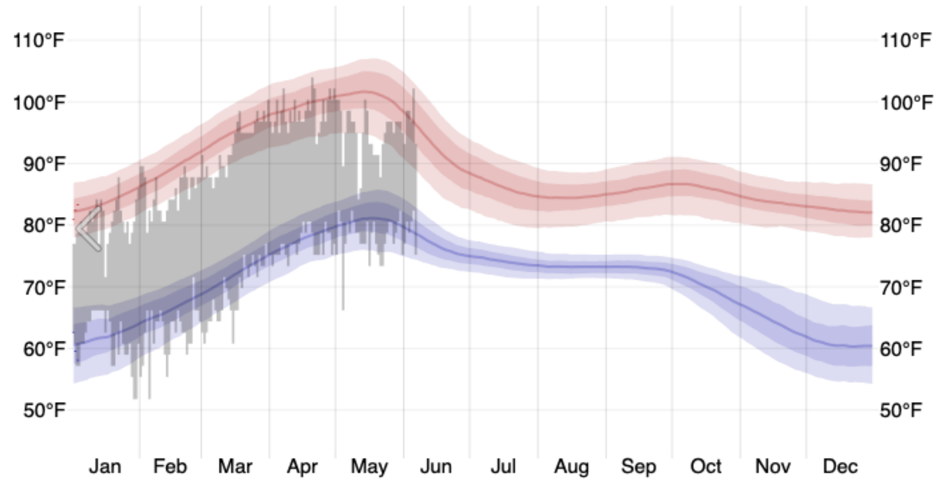


Figure 16: Temperature history 2022. Source: Rajiv Gandhi Intl. Airport weather station

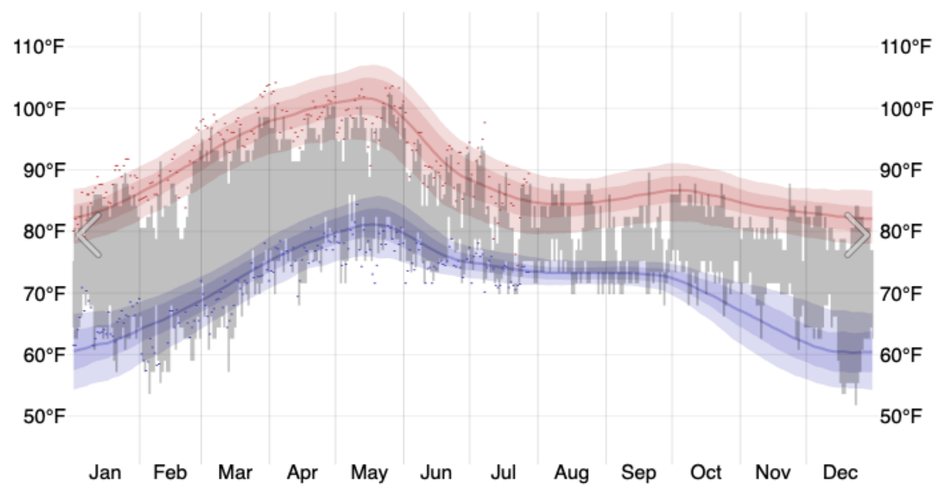


Figure 17: Temperature history 2021. Source: Rajiv Gandhi Intl. Airport weather station

The gray bars represent the daily range of reported temperatures. The bands represent the 25th to 75th and 10th to 90th percentiles, respectively.

The temperature varies approximately 52ºF with a low of approximately 52ºF and a high of 104ºF. May experienced the highest temperature, whereas December experienced the lowest temperature in 2021. The forecast is expected to follow last year's trends, with May-June having temperatures above 100ºF. The temperature extremes require buildings to invest in robust construction technologies, particularly energy efficient HVAC systems. In Hyderabad, real estate owners have been evaluating energy efficient solutions such as heat recovery wheels to address their heating and cooling requirements.

From March 10 to November 22 there are 8.4 months of rain, with a typical 31-day rainfall of at least 0.5 inches. With an average rainfall of 6.1 inches, August is the wettest month in Hyderabad. From November 22 to March 10, 3.6 months pass without a drop of rain. With an average rainfall of 0.1 inches, December is the driest month in Hyderabad. December through April remains quite dry.

While building system technology like HVAC equipment can operate in the rain, flooding can hinder building systems operations. Hence tracking precipitation is crucial in assessing the feasibility of investing in building system technologies like HVAC equipment.

Being in the South of India, where there exists a tropical climate, Hyderabad does not receive any snow fall.

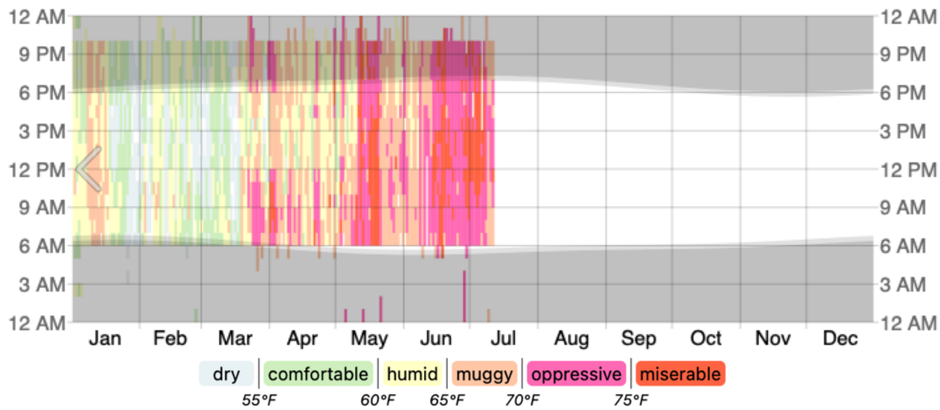


Figure 18: Humidity 2022. Source: Rajiv Gandhi Intl. Airport weather station

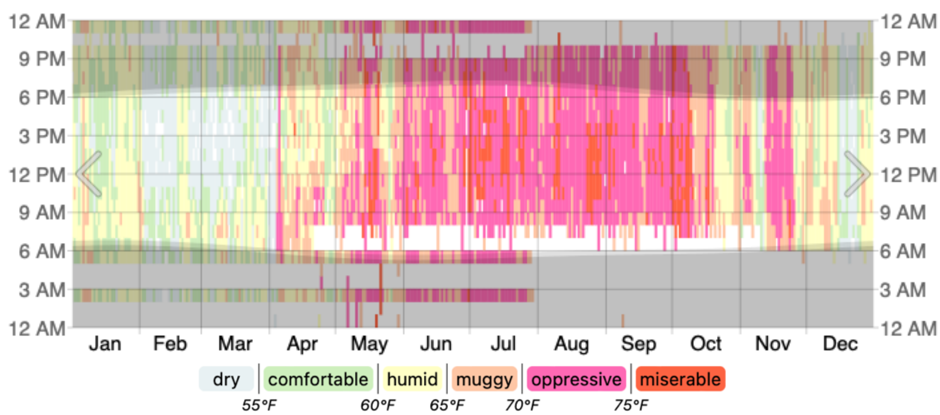


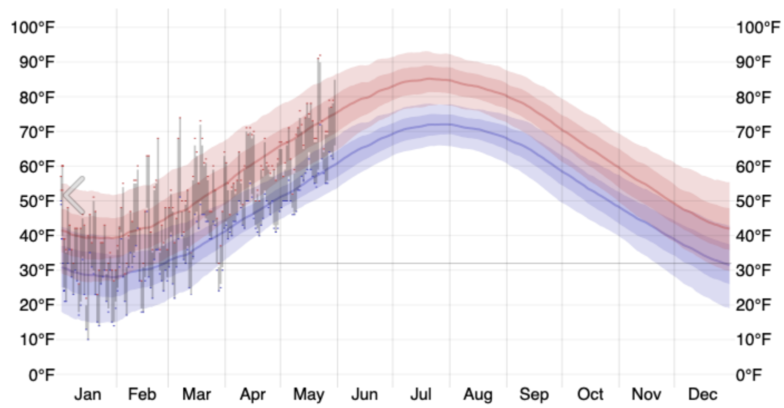
Figure 19: Humidity 2021. Source: Rajiv Gandhi Intl. Airport weather station

Hyderabad is dry-to-humid for most of the cooler months: mid-November to mid-March. The oppressive and humid phases of the year coincide with the monsoon. Its average humidity is around 65%.

Humidity can affect energy consumption and efficiency. In addition, increased humidity can result in greater system depreciation, increased wear and tear, and ultimately, a shortened system lifespan.

2.3.2 Manhattan

Manhattan experiences seasonal weather year-round. The city is exposed to temperature extremes that vary from as low as 15ºF to as high as 100ºF. The city also experiences heavy snow fall in winter and heavy rains year-round. The average annual percentage of humidity is 63%: April is the least humid month, and September is the most humid month.



The gray bars represent the daily range of reported temperatures. The bands represent the 25th to 75th and 10th to 90th percentiles, respectively.

Figure 20: Temperature history 2022. Source: La Guardia Airport weather station

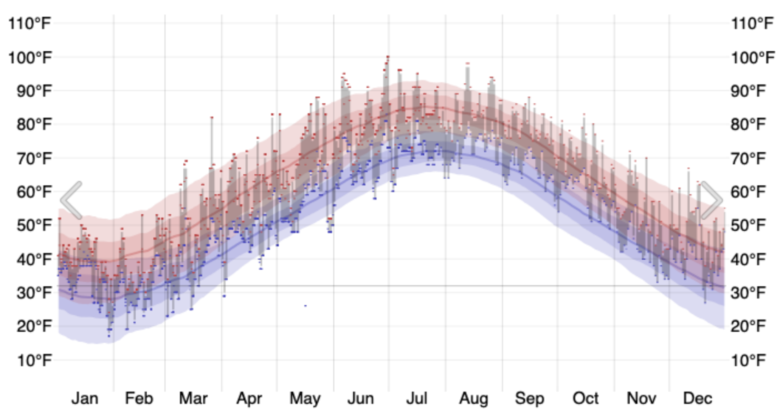


Figure 21: Temperature history 2021. Source: La Guardia Airport weather station

Temperature in the year varies as much as nearly 85ºF. June experienced the highest temperature, whereas January experienced the lowest temperature in 2021. The forecast is expected to follow last year's trends, with June-July having temperatures above 90ºF. The temperature extremes require buildings to invest in robust construction technologies, particularly energy efficient HVAC equipment systems. In Manhattan, real estate owners have been evaluating energy efficient solutions like electric heat pumps to address their heating and cooling requirements.

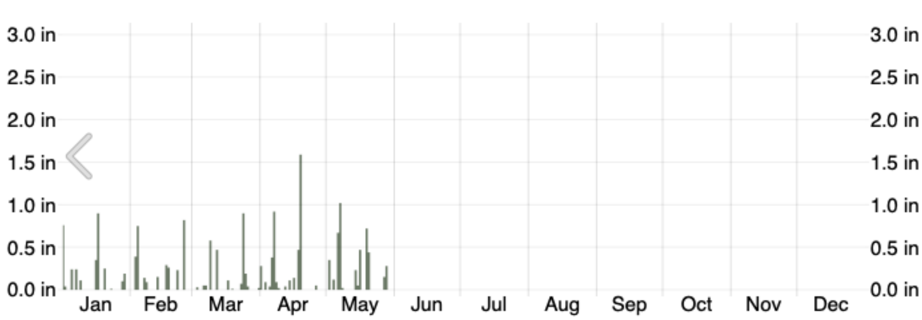


Figure 22: Daily precipitation 2022. Source: La Guardia Airport weather station

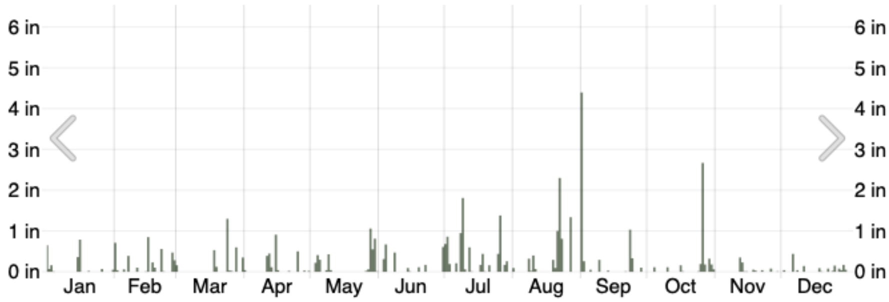


Figure 23: Daily precipitation 2021. Source: La Guardia Airport weather station

The daily precipitation in Manhattan had a maximum of nearly 4.5 inches in September in 2021, followed by approximately 2.7 inches in October. In 2022, the maximum has been about 1.6 inches in April. While building system technology like HVAC equipment can operate in the rain, flooding can hinder building system operations. Hence, tracking precipitation is crucial in assessing the feasibility of investing in building system technologies like HVAC equipment.

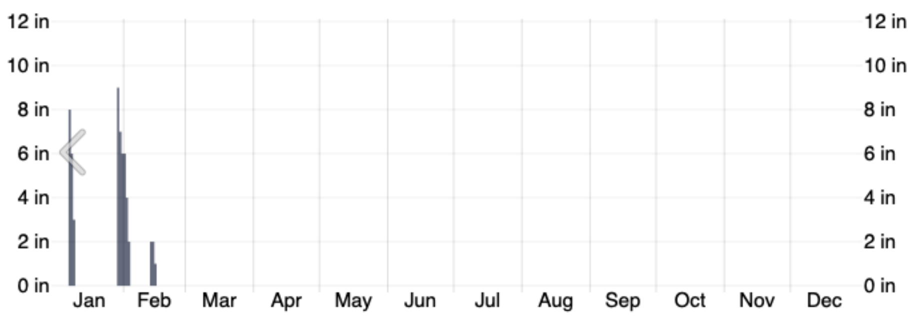


Figure 24: Snow depth 2022. Source: La Guardia Airport weather station

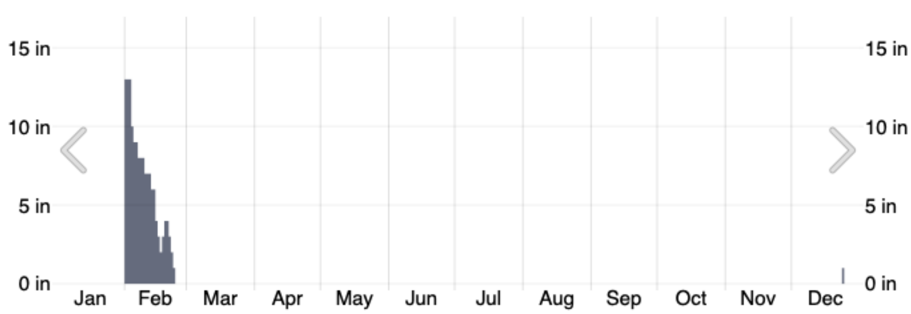


Figure 25: Snow depth 2021. Source: La Guardia Airport weather station

Snow depth in 2021 was greater than that of 2022. 2021 saw close to 12.5 inches of snow in January. 2022, on the other hand saw about 9 inches of snow in January. Snow depth is an important metric as snowfall can hinder the functioning of building technologies. In a heat pump, for example, if snow were to cover the unit, the amount of air available to circulate to the heating coil would be restricted, impacting the functioning of the system.

2.3.3 Key Comparisons

Table 7: Environment key comparisons

	Hyderabad	Manhattan
Maximum Temperature	104º F	100º F
Minimum Temperature	52º F	15º F
Temperature Range	52º F	85º F
Average Humidity	65%	63%
Maximum Rainfall	> 6.1 inch.	4.5 inch.
Snow depth	n/a	~10 inch.

Hyderabad's tropical climate requires year-round cooling. Its low temperatures of 52º F are rare and often occur in the early hours of the morning before sunrise – a time when office spaces are almost always unoccupied. Hence, heating equipment is not required for office buildings in Hyderabad. Additionally, the lack of snowfall and cold winters are reasons supporting the nonrequirement for heating equipment.

Given these climatic conditions, some HVAC equipment, that are sustainable may not necessarily be best suited for this climate. Electric heat pump is an example of such a HVAC equipment. It is observed that when operated in Hyderabad, the energy efficiency of Electric heat pumps are lower than if they were operated in Manhattan. As seen in Tables 9 and 13, the EUI of electric heat pumps in Hyderabad is 58.5 kBtu/sqft per year, whereas in Manhattan it is far lower at 52 kBtu/sqft per year, indicating superior energy efficiency.

The presence of moisture in the air, with humidity levels of 65%, and high rainfalls during the Monsoon in Hyderabad pose a potential risk to all HVAC equipment due to flood risks and rust. In Manhattan as well, humidity levels of 65%, coupled with heavy snowfall and moderate rain year-round may result in HVAC equipment deterioration, or damage. Though not within the scope of this thesis, it may be worth also considering equipment depreciation and lifetime when making a financial analysis.

Chapter 3: Energy Usage and Optimization of Two Office Assets

3.1 Current landscape

3.1.1 Hyderabad

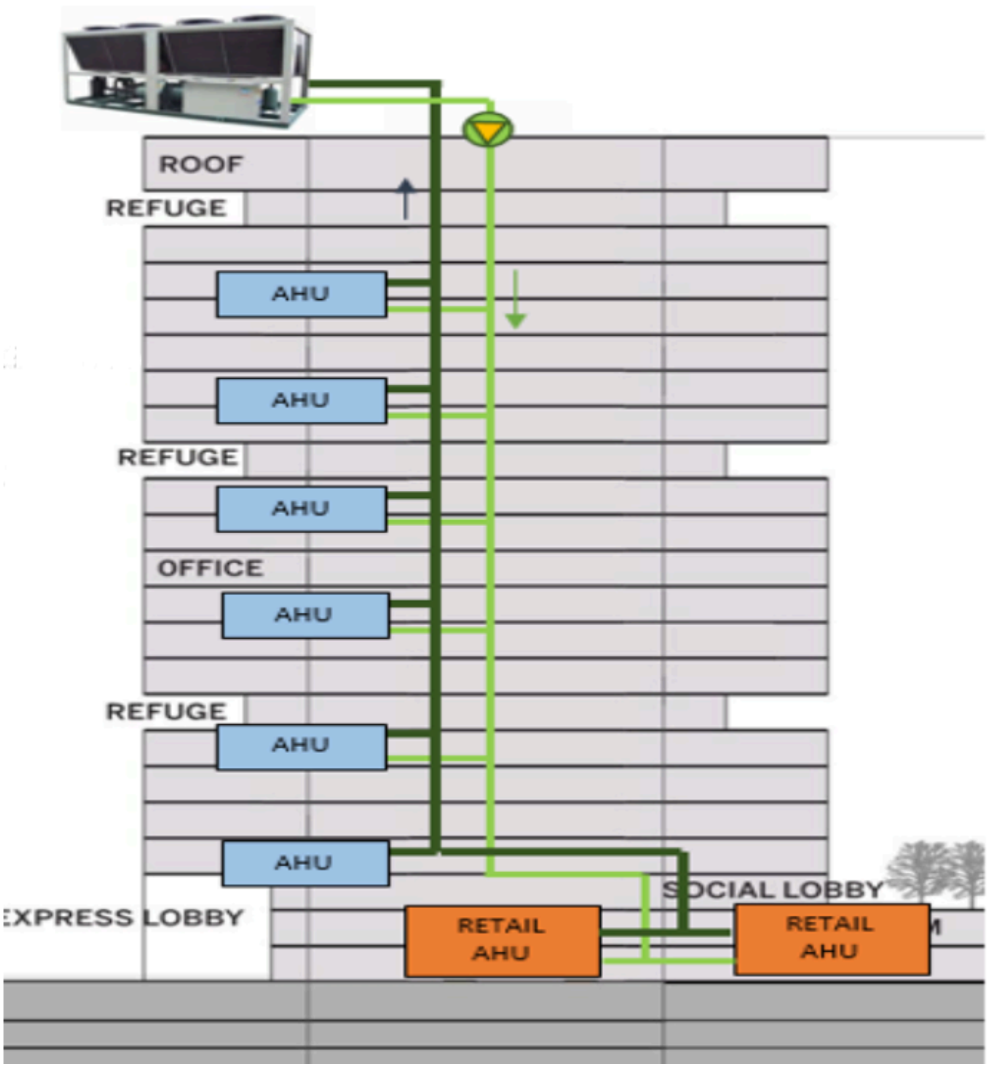


Figure 26: Air-based Electric AC schematic design. Source: RMZ Corp

Office developers in Hyderabad have historically elected the air-based Electric AC for their HVAC system. This is a standard HVAC equipment that is popularly used in the city.

In Hyderabad, cooling is the primary conditioning requirement, and there is no need for heating all year round. The minimal energy efficiency criteria is established by the Energy Conservation Code which establishes standards for thermal performance and anticipated Energy Use Intensity (EUI) or the Energy Performance Indices (EPI).

The Vault's lobby levels and amenity areas rely on the standard air-based Electric AC, as shown in Figure 26.

To successfully install and operate the standard air-based Electric AC, the following list of building systems is necessary as design requirements in the building:

1. Mechanical Ventilation: Basements, offices, restrooms, dining establishments, and MEP Equipment zones are all covered by a ventilation system. For the office, ventilation regulations are maintained at 5.0 cubic feet per minute per person, or 0.06 cubic feet per minute per square foot, with an extra 30% fresh air, in compliance with LEED and WELL (IWBI Guidelines). The HVAC system is put under additional strain because, while the tonnage may be sufficient to maintain the set point temperatures, the increased ventilation or cubic feet per minute demand would necessitate the use of bigger units.

2. Space Cooling: Electric air conditioning, a system with variable refrigerant flow or volume, or both are required for space cooling. Tonnage and cubic feet per minute, which define the notional cooling capacity of the outside unit and ventilation (air changes in cubic feet per minute) capacity of the system, are the two features of electric air conditioning.

3. Envelope Performance: The façade of the building will employ a standard unitized curtainwall system with insulated spandrel (0.4 W/sqm.k 0.07 Btu/hr.sqft.deg.F Spandrel with 75mm Rockwool insulation) and double pane glazing units with argon filled frames and a low-e coating (0.5 W/sqm.k 0.26 Btu/hr.sqft.deg.F). These are required by the TS-ECBC, however further improvement may be possible with innovation in design. Additionally, TS-ECBC is the more lenient ASHRAE 90.1-2016 Appendix G Baseline, which serves as the USGBC LEED baseline.

3.1.2 Manhattan

Office developers in Manhattan tend to elect natural gas for space heating and for servicing hot water production, while they use electricity to cover other needs, such as space cooling, lighting, ventilation, plug loads and elevators. The energy split is 20% natural gas, and 80% electricity.

By delivering the minimal energy efficiency necessary to meet with the NYCECC2020 standards for façade thermal performance and anticipated Energy Use Intensity (EUI), the design aims to reduce capital investment today. The finished structure is anticipated to consume 65 kBtu/sqft per year of energy annually, with natural gas accounting for 35% of that total. The building's less-optimized space heating demands will necessitate a water temperature that is difficult or impossible to achieve with present ASHP technology, therefore the design will never be able to switch to an electric heating system.

The following list of building systems is necessary:

1. Mechanical Ventilation: Using an innovative latent heat recovery system and filtration, fresh air will be supplied for ventilation through a Dedicated Outdoor Air System (DOAS), with one central Air Handling Unit (AHU) per mechanical floor servicing the other levels.
2. Space Cooling: Four evaporative cooling towers on top of a building are connected to four water-cooled centrifugal electrical chillers in a central plant that deliver chilled water for cooling. Cooling is provided by chilled water that is delivered to the AHU by bank (low temperature) and the DOAS boxes on the ceiling of each level.
3. Space Heating & SHW: Condensing natural gas boilers create hot water for space heating and services. A combination of ceiling DOAS boxes and fin tube perimeter heating distributes high-temperature hot water to the AHU.
4. Envelope Performance: The building façade will use a typical unitized curtainwall system with insulated spandrel (U value = 0.13) and double pane glazing units, Argon filled, with thermally broken frames and a low-e coating (U value = 0.34). These features will give the building a window to wall ratio (WWR) of 55 percent. The resultant façade will be prescriptive in accordance with NYCECC2020, but neither low temperature heating nor the effective use of heat pumps will be possible.

3.2 Proposed technologies

3.2.1 Hyderabad: The Vault

In addition to air-based Electric AC, there exists 3 additional sustainable building technologies for HVAC systems in Hyderabad office developments. These are Water/air-based cooling, Heat recovery wheel, and Electric heat pump.

The goal of most developers who presently have projects under construction today is to invest in building systems that do not rely on gas. India has undertaken major measures to speedily implement the decarbonization of its power sources, transitioning from 0.90 tCO_2/Mwh in 2018, to 0.79 tCO_2/Mwh, now.

Water/Air-based chiller: in a water-based chiller, or chilled water system, pre-cooled water, acts as a secondary refrigerant, helping cool the air and reduce the system's reliance on ozone depleting chemicals that are harmful for the environment. The water-based system is an efficient chiller system with a high COP, indicating its high energy savings. It is a cost-efficient HVAC building technology, particularly for developments of scale. However, to accommodate for this building technology, a greater amount of terrace space is required, in comparison to that required for the standard air-based Electric AC HVAC building technology. The air-based chillers are reliant on refrigerants for cooling fresh air again based on a central air-cooled chiller plant. A central system helps achieve efficiency based on diversity i.e. 100% utilisation is not required for all air-conditioned zone.

Heat recovery wheel: in a heat recovery wheel, energy is transferred between the fresh and exhaust air streams via a thermal wheel that spins between the two. With the aid of this wheel, outdoor warm air, that is supplied for proper ventilation, is preheated and exchanged with cooled exhaust error that passes through the system. Thus, by precooling exhaust air or preheating the fresh air, and exchanging it with one another, the energy required for cooling or heating is reduced. Hence, heat recovery wheels result in improved indoor air quality and cost savings. A greater amount of terrace space is required to accommodate for this building technology in comparison to that required for the air-based Electric AC HVAC building technology.

Electric heat pump: The concept behind how an electric heat pump operates is thermal exchange made possible by refrigerants. The refrigerant cools the air inside by absorbing heat from it. By releasing the heat to the outside, the vaporized refrigerant cools the area once again and gets it ready for cyclic cooling via thermal exchange. The equipment for refrigerant liquid expansion and compression will make the heat exchange process easier.

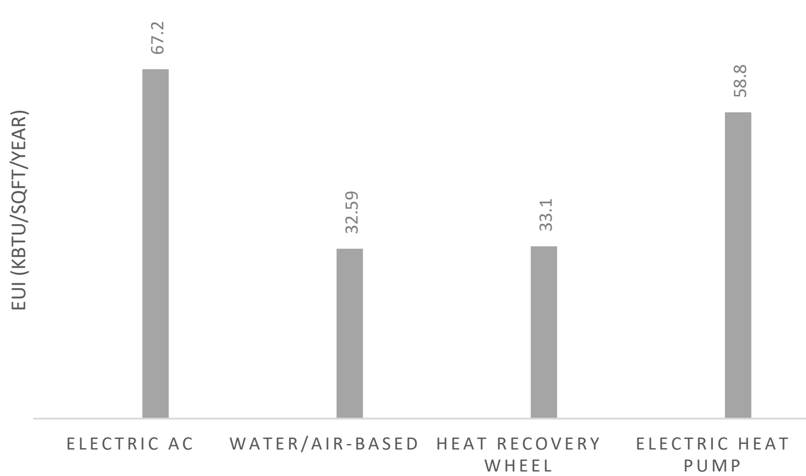


Figure 27: Energy efficiency comparisons. Source: RMZ Corp

Figure 27 showcases the EUI of the 4 HVAC equipment under analysis in Hyderabad. The first one is the base case, which is the least efficient. While it may work well in Manhattan, the electric heat pump is the second least efficient HVAC equipment in Hyderabad. Both the water/air-based chiller and heat recovery wheel are closely matched in terms of their efficiency, and can be used nearly interchangeably, given their almost equal net present values to both developer and tenant.

3.2.2 Manhattan: Case Office Building

The building is intended to totally rely on electric systems (air source heat pumps) and heat recovery in order to supply space heating and service hot water under the planned sustainable building technology. 100% of the energy will come from electricity.

At the price of a greater initial capital expenditure and floor space devoted to MEP systems, the goal in this case has been to reduce energy consumption and GHG emissions in the building, both now and in the future. MEP components and an updated façade are extra costs associated with this. It is anticipated that the finished structure would consume 52 kBtu/sqft per year.

With the following exceptions, the systems are identical to the design that is now being used by the market:

1. Space Heating & SHW: In order to create hot water for heating and services, ASHPs and condenser side heat recovery from heat rejected in cooling are combined. This suggested sustainable building technology necessitates the addition of an additional mechanical floor, resulting in the loss of leasable floor area, due to the need for ASHPs to be completely exposed to outside air through a fully louvered façade and the greater floor area needs in comparison to a boiler plant. Numerous ASHPs will supply hot water distributed to AHUs and floor heating DOAS boxes on that floor. The design also includes an ice tank for thermal storage and peak load reduction in order to further improve efficiency and decrease the number of heat pumps. Only if heating demands by the façade are reduced enough to be covered by "low temperature" hot water heating in the office perimeter, can this combination be feasible.
2. Envelope Performance: The design goes above and beyond what is required by code to ensure minimal perimeter heating (and cooling) loads. The building's façade will have a WWR of 50% and be made of a high-performance unitized curtainwall system with triple pane glazing units filled with argon, thermally broken frames, and a low-e coating (U value = 0.22) and insulated spandrel backed with additional continuous interior insulation (U value = 0.07). The finished façade goes beyond code requirements by 5 to 10%.

3.3 Elected Sustainable Technology

3.3.1 The Vault: Water/Air-Based Chiller

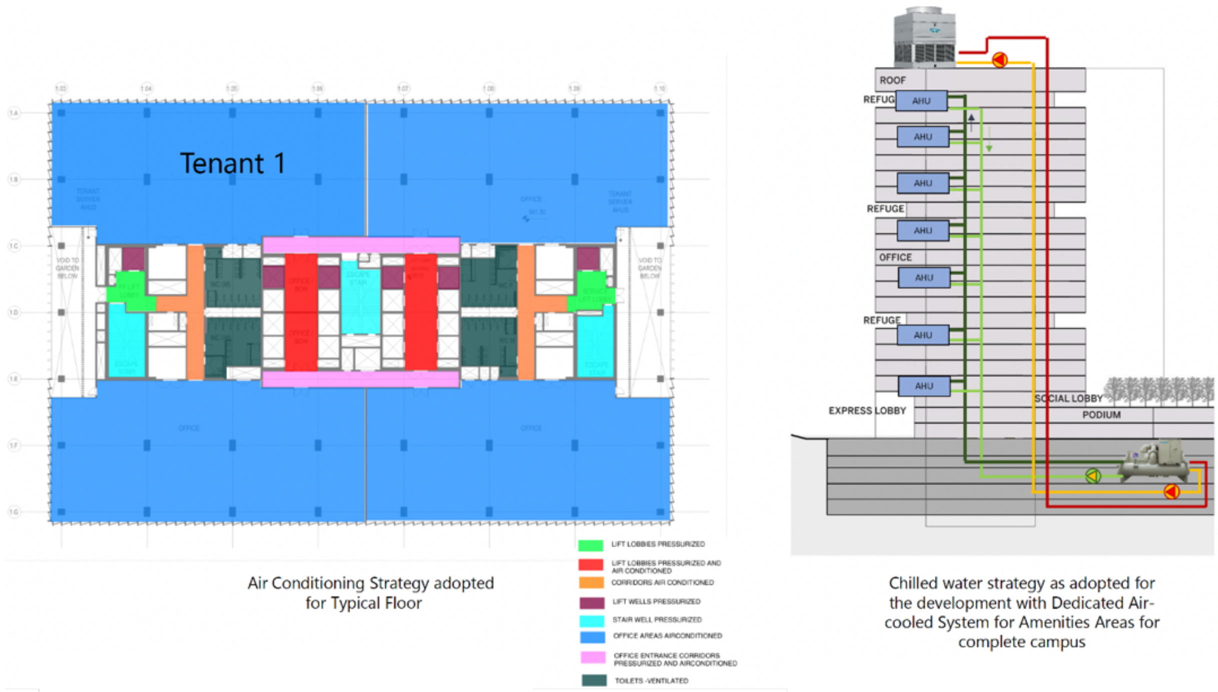


Figure 28: Water/air-based design scheme for The Vault. Source: RMZ Corp

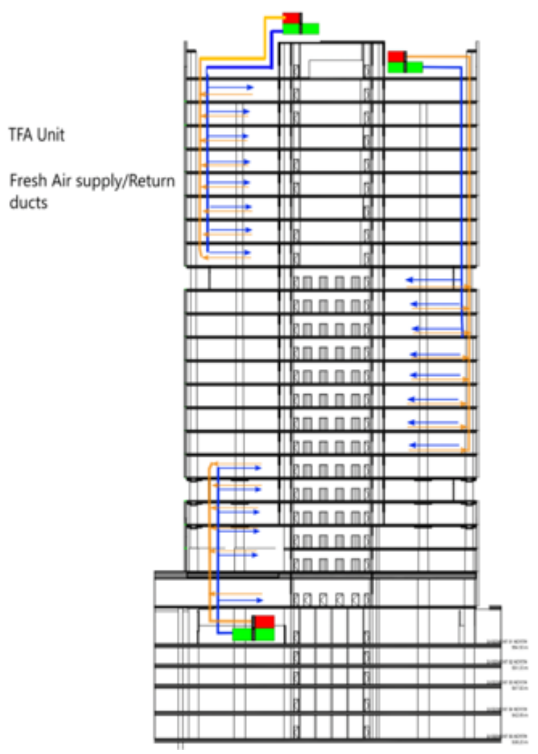


Figure 29: Water/air-based design. Source: RMZ Corp

The building is intended to totally rely on electric systems in order to supply space cooling. 100% of the energy will come from electricity. As indicated in Figure 28, the G + 23 floors have 3 zones: G + 1 and plaza is based on an air-cooled system; the office floors are based on a water-cooled system. The recycled grey and black water, as shown in Figure 28, supply the water for the water-cooled systems.

There is room for two air handling units on each office level, allowing for independent operation in the event that a floor is divided between two tenants. Additionally, 3 treated fresh air (TFA) units deliver fresh air to the building's three equally sized vertical zones: 4 in the basement, 4 in the lower roof, and 4 in the upper roof. The TFA handles outside air sensible and latent load. The water/air-based HVAC system has a COP of 6.3, greater than that proposed by ASHRAE 90.1-2016 Appendix G baseline with VFD for all AHUs. Furthermore, the façade specification for the Roof, walls and glass are also better than the baseline. These too are of 10.7% better performance than the baseline.

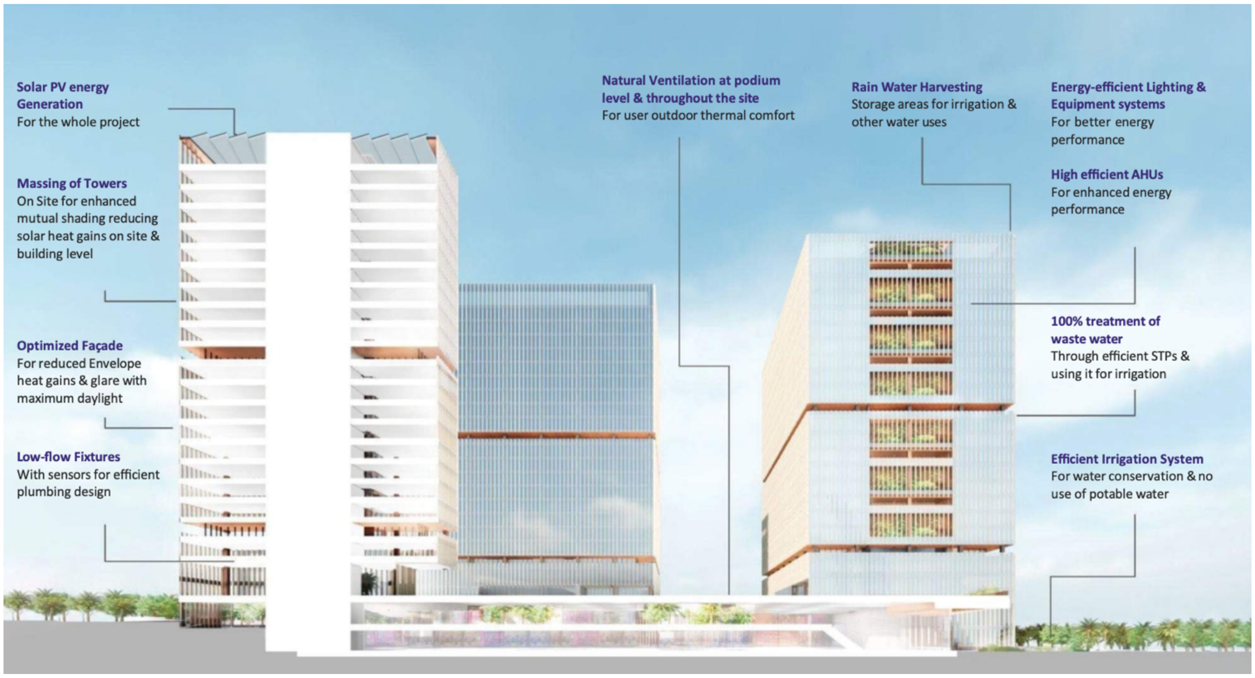


Figure 30: The Vault's sustainable design. Source: RMZ Corp

The Vault incorporates sustainable design principles to minimize environmental impact during its development and operation phases. As highlighted in Figure 27, the project utilizes an optimized façade that reduces heat gain and glare, an efficient rainwater harvesting and irrigation system for close to net zero usage of water, and solar energy generation amongst many other principles.

The design takes a logical approach and sets out a path to net zero energy. The structure is meant to be climate sensitive, with proper orientation and a self-shading façade that lowers solar heat gain.

The cooling demands of the building are reduced by 15% as a result of these passive solutions. Furthermore, a gradual, step-by-step approach to assessing the impact of building conservation measures aids in further lowering the demand load. In comparison to a standard building of this size, the active measures assist lower demand load by a further 21%.

The use of on-site renewable energy generating measures is then investigated. Solar panels, BIPV (Building integrated photovoltaics) on the building façade, and micro turbines that create electricity by harnessing increased windspeeds at the terrace level, all help to fulfill an additional 30% of the building's energy needs. As a result of these efforts, the building's energy consumption is reduced by 512.7% when compared to a traditional building design.

3.3.2 Manhattan Asset: 100% Electric

The building is intended to totally rely on electric systems (air source heat pumps) and heat recovery in order to supply space heating and service hot water under the planned sustainable building technology. 100% of the energy will come from electricity.

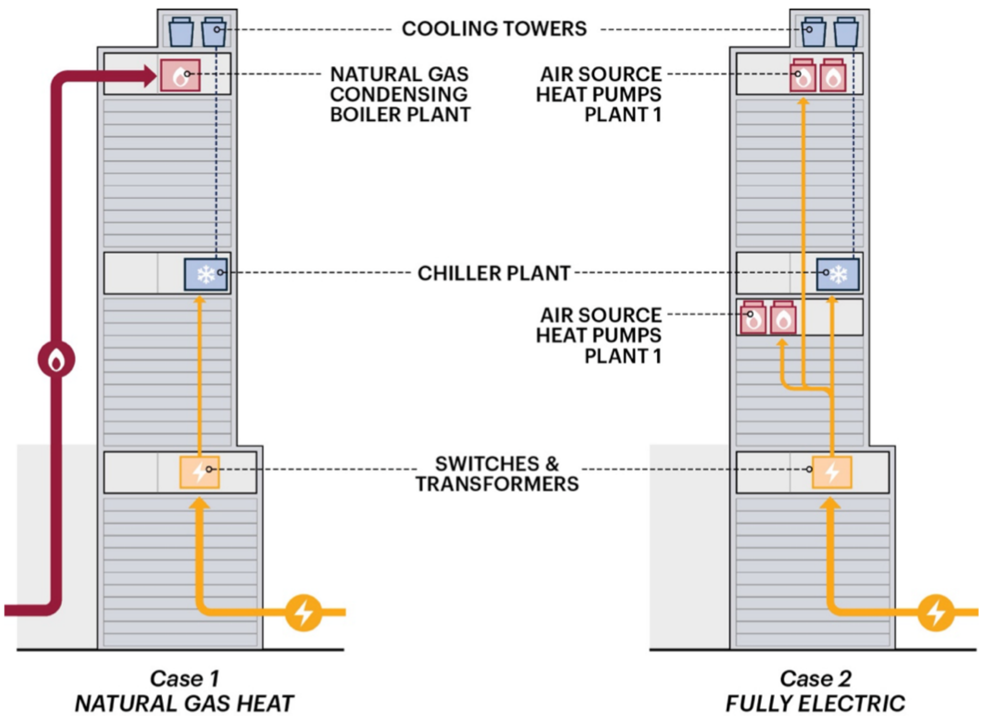


Figure 31: Axonometric view of building with both proposed designs. Source: MIT SRE_pset 3

As indicated in Figure 41, the office floors (plus retail and facilities) are separated into three banks of 13–15 floors, with one dedicated mechanical level located above each bank. Figure 41 shows both the Natural Gas, represented as Case 1, and the 100% Electric, represented as Case 2, design schemes.

According to the Natural Gas design, each mechanical floor (14th, 28th, and 44th) will have one central Air Handling Unit (AHU) that serves the floors below. Four evaporative cooling towers on the building's top level are connected to four water-cooled centrifugal electrical chillers that are housed in a central plant on the 28th floor (45th floor). On the 44th level are 12 condensing natural gas boilers that provide hot water for heating and services. The AHU by bank, as well as a mix of ceiling DOAS boxes and fin tube perimeter heating on each level, are all supplied with high-temperature hot water.

All system design is preserved from Case 1 in accordance with the 100 percent design, with the exception of hot water being generated entirely electrically for heating and services using a mix of ASHPs and condenser side heat recovery from heat rejected in cooling. As a result, a new mechanical level (the 27th) is added, which reduces the amount of leasable floor space. Eight ASHPs will supply hot water distributed to AHUs and floor heating DOAS boxes on that floor. The design also includes an ice tank for thermal storage and peak load reduction in order to further improve efficiency and decrease the number of heat pumps.

The building façade will also have a WWR of 50%, a high-performance unitized curtainwall system, insulated spandrel backed with additional continuous interior insulation (U value = 0.07), and triple pane glazing units, Argon filled, with thermally broken frames and a low-e coating (U value = 0.22) to ensure low perimeter heating and cooling loads. The finished façade goes beyond code requirements by 5 to 10%.

3.4 Energy Usage and Optimization

3.4.1 The Vault

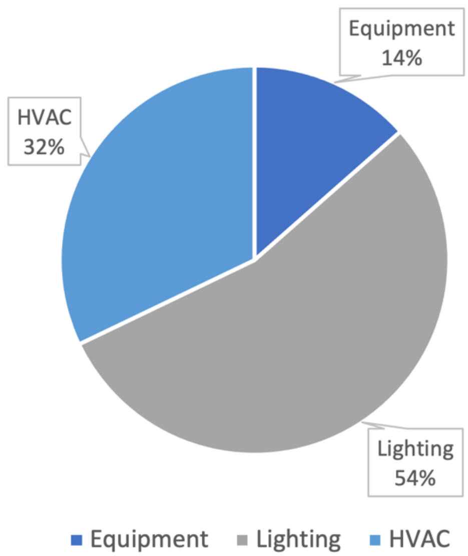


Figure 32: The Vault energy consumption distribution. Source: RMZ Corp

Figure 32 highlights the building's energy end use consumption distribution. Lighting consumes the greatest energy followed by HVAC. The Vault aims to cater to the energy demand of lighting using renewable energy that is powered on-site. For the HVAC, however, the developer must consider energy efficient technologies that are sustainable.

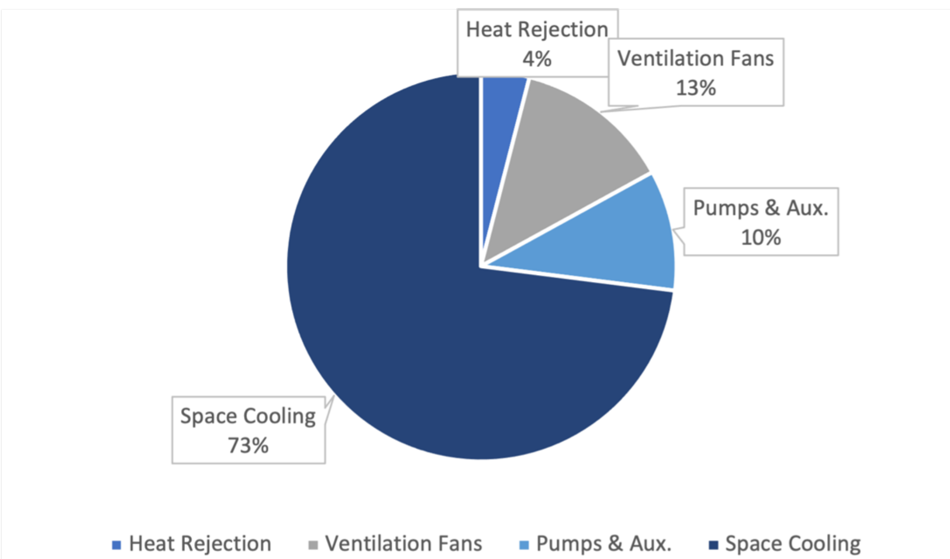


Figure 33: The Vault HVAC energy consumption distribution. Source: RMZ Corp

The Vault's energy distribution for its HVAC system is shown in Figure 33. The majority of energy is consumed by space cooling. This is expected given Hyderabad's scorching climate throughout the year. Such a consumption distribution is common for HVAC systems across the hot and arid regions in the country. It provides RMZ Corp with the opportunity to evaluate energy efficient HVAC solutions that efficiently address the building's cooling requirements by using a lesser quantum of energy.

Telangana state produces coal and as a result, most of the grid's supply today comes from thermal power plants. Solar and wind partly contribute to the grid's supply. So, an asset today cannot be entirely green.

The Vault's current HVAC design includes a chilled water and air handling unit system. The system's chiller is used to generate cold water which circulates in the air handling unit's coils, providing cool air to the development's occupants. The system is electric, and the electricity provided comes from the city's energy grid supply, powered by one of the country's power distribution companies (DISCOM). To enhance the development's energy performance, RMZ has incorporated various Energy Conservation Measures

(ECMs) post rigorous analysis. To achieve this, various areas of the building which affect its energy consumption were analyzed, and suitable ECMs were identified for the development. Table 7 provides details on the various ECMs identified for The Vault. Such efforts, if resulting in monetary savings for occupiers, leads to rent premiums when compared to competitive offerings.

The market accepts 30% of direct operational costs saved as a rent premium. Further increasing savings by means of investing in sustainable building technologies would result in a greater market rent premium.

According to a study [9] released by the Central Energy Authority (MoP, GOI) for the CO2 Baseline Database for the Indian Power Sector, the combined margin (CM) of the Indian Grid for FY 2017–18 (adjusted for cross-border electricity flows) was 0.91 tCO2/MWh. The operating CO2 emissions and energy consumption of The Vault would be 82,422.9 tCO2 and 90,574.6 MWh, respectively.

Table 8: ECMs for The Vault. Source: RMZ Corp

ECM #	Description	Energy Savings over TS – ECBC Baseline
-	Design Case savings	7.33%
ECM 1	Water Cooled Chiller - 6.5 COP	7.73%
ECM 2	Air Cooled Chiller - 3.3 COP	8.50%
ECM 3	VFD on Chiller	9.07%
ECM 4	VFD on Cooling Tower	9.60%
ECM 5	Basement Parking LPD 0.1 W/sqft	10.24%
ECM 6	Office LPD 0.6 W/sqft	11.94%
ECM 7	Office LPD 0.5 W/sqft	13.70%
ECM 8	WWR reduction - 60% WWR	14.18%
ECM 9	Effective SHGC 0.20 (High performance Glass + Façade Shading Devices)	14.43%
ECM 10	Effective SHGC 0.16 (High performance Glass + Façade Shading Devices)	14.88%
ECM 11	Implementing CHW Reset Control	15.29%
ECM 12	CO Sensors in Basement Parking	17.44%
ECM 13	Office Fan Power (0.0005 Bhp/CFM)	18.42%
ECM 14	EPD 1.5 W/sqft	20.11%
ECM 15	Solar PV 50% of the clear roof area (excl. 20% for Cooling Tower area)	21.36%
ECM 16	Solar PV 75% of the clear roof area (excl. 20% for Cooling Tower area)	21.99%
ECM 17	Solar PV 100% of the clear roof area (excl. 20% for Cooling Tower area)	22.61%

[9] Central Electricity Authority, Government of India Ministry of Power. (2018, December) CO2 Baseline Database for the Indian Power Sector. User Guide Version 14.0. *December 2018*. Retrieved 06/15/2022, from https://cea.nic.in/wp-content/uploads/baseline/2020/07/user_guide_ver14.pdf

3.4.2 Manhattan Asset

Natural gas is currently the primary energy source used to heat office buildings, accounting for more than half of the energy production used for space heating in NYC, as seen in Figure 34. One of the largest sources of GHG emissions in NYC and a hindrance to a carbon-neutral future is the generation of hot water or steam for space heating or consumption by the on-site combustion of natural gas.

More than 40% of all NYC carbon emissions, more than all electricity and district steam consumption put together, and more than 50% of emissions from buildings are produced by fossil fuel furnaces, boilers, and hot water heaters. Additionally, 20–40% of emissions from commercial buildings and 55–65% of emissions from residential buildings are now caused by natural gas.[10] Gas appliances might last 15 to 20 years and require extra pipe and HVAC infrastructure investments.

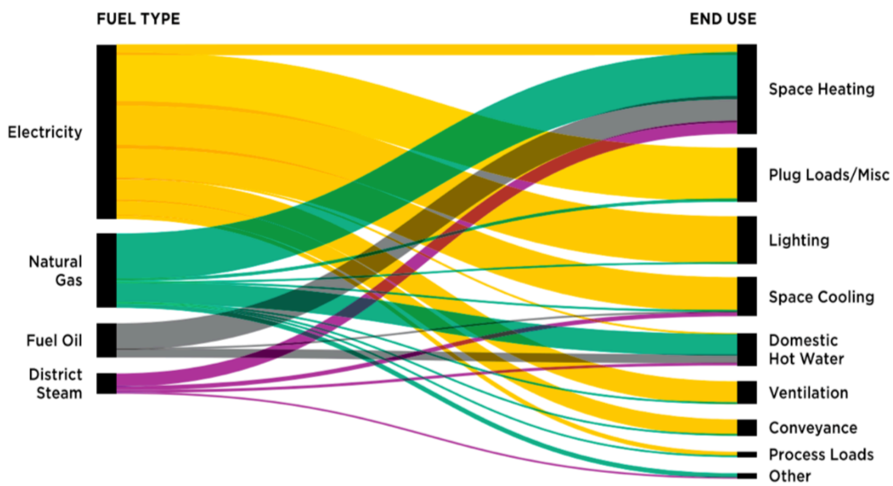


Figure 34: Flow of Fuel Types to End Uses (LL97). Source: Urban Green Council, 2016.

Since office buildings consume the majority of their energy from electricity, excluding space heating and hot water, the majority of their emissions are connected to the grid.

Therefore, even if office buildings do not significantly increase their energy efficiency, their emissions will rapidly fall over the next two decades if the grid decarbonizes, with the exception of natural gas emissions related to space heating and hot water, which will remain constant.

In both new and old buildings, this issue may be resolved by electrifying space heating and hot water with extremely effective Air Source Heat Pump (ASHP) technology.[11] Electric heating is significantly more expensive than natural-gas heating – around three times more expensive in NYC.

3.4.3 Key Comparisons

- In Hyderabad, there is no need for space heating, given the year-round tropical climate.
- Hyderabad's grid has no power supply generated by natural gas, unlike Manhattan.
- Solar and wind are contributors to the grid in Hyderabad.

[10] Urban Green Council, The City of New York. (2016, August). New York City's Energy And Water Use 2013 Report. *August 2016*. Retrieved 06/16/2022, from https://www.urbangreencouncil.org/sites/default/files/nyc_energy_water_use_report_2016.pdf

[11] Michael Tobias (2021, February 07). NY Engineers. Can Electric Heating Have a Lower Cost Than Gas Heating? *February 7, 2021*. Retrieved 06/18/2022, from https://www.ny-engineers.com/blog/can-electric-heating-have-a-lower-cost-than-gas-heating

Chapter 4: Decision-making Framework of Net-zero Pathways

4.1 Stakeholder Analysis

Sustainable real estate requires a commitment from three key stakeholders involved in the development and operation of a commercial real asset. They are the developer, the tenant, and the government.

The developer's goal is to develop ultra-efficient buildings that in the future get rewarded with a green premium for embodying principles of sustainable real estate and being a sustainable member of the built environment. The premium sought by developers would be rental premiums and lower cap-rates. The tenant's goal is to have ultra-efficient operations and offices with the lowest cost. In addition, the tenant seeks to achieve their ESG mandate by working in a sustainable space. Finally, the government's goal is to have smart and green infrastructure, which will be the fruit of developers alike taking the step to invest in sustainable building technologies, and sustainably transforming their assets.

The three are unified by their desire to have an integrated approach for efficient building operations to sustainably transform the built environment as seen in Figure 35.

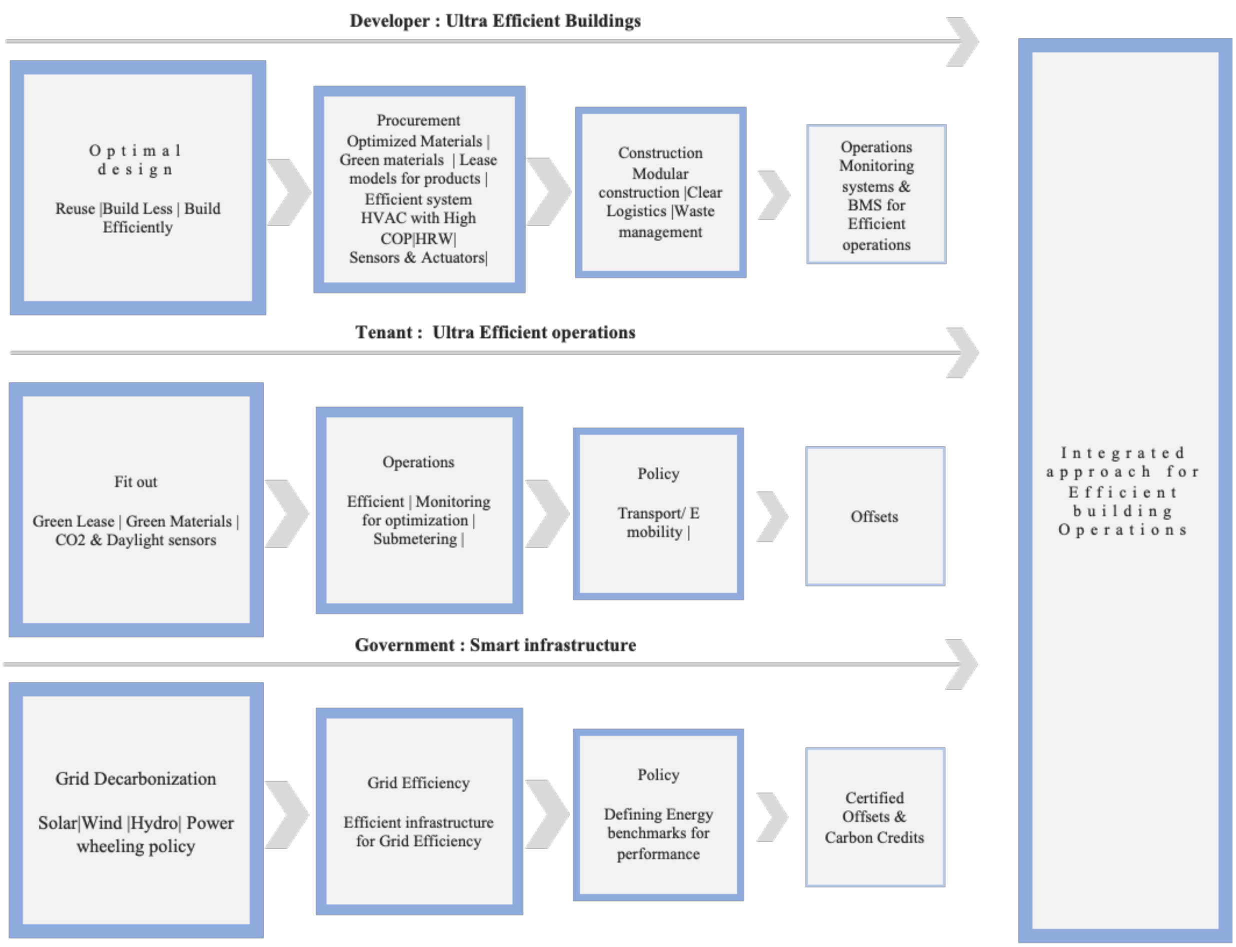


Figure 35: Stakeholder analysis

4.2 Decision-making framework

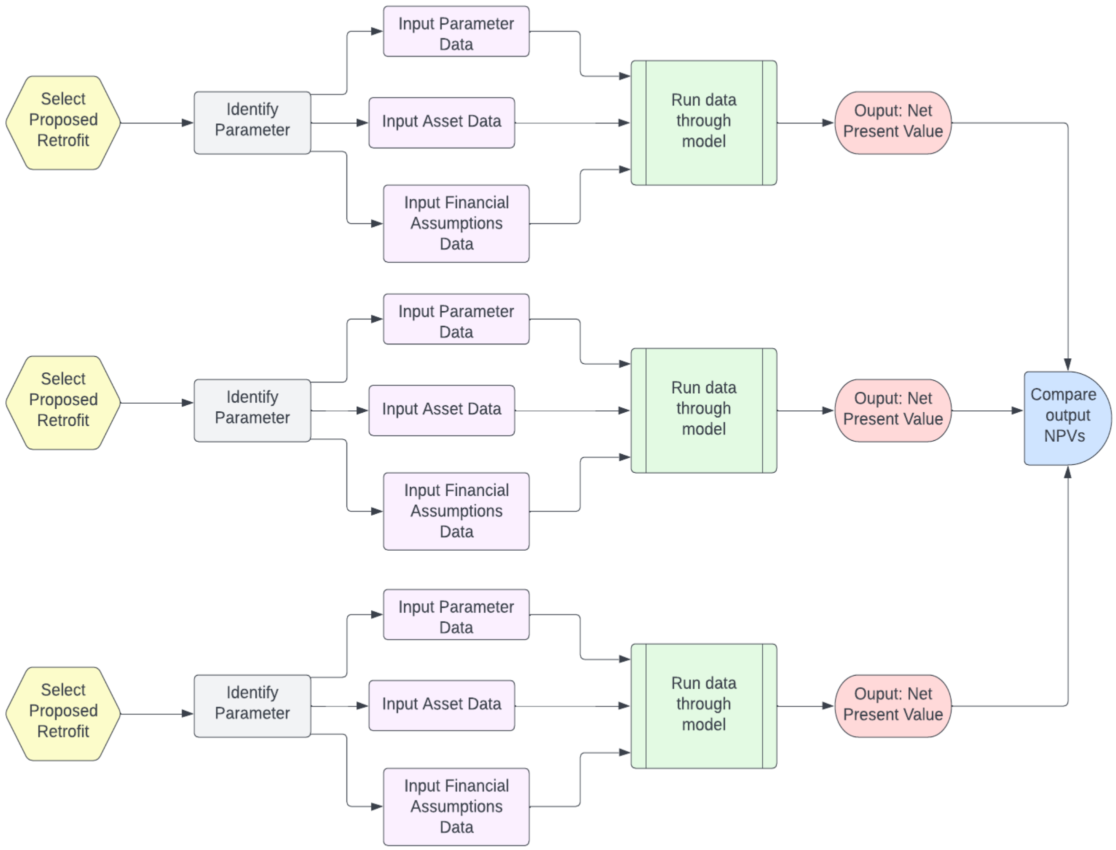


Figure 36: Complete decision-making framework process flowchart

Figure 36 captures the complete process flow for the decision-making framework. The above demonstrated process flow is common to all design retrofits suggested; however, this thesis only analyses the application of the decision-making framework for sustainable HVAC equipment. The decision-making framework compares the net present value for both developer and tenant, upon investing into sustainably transforming an office real estate asset. The thesis applies the framework to a case in Hyderabad, and Manhattan.

Per branch, a proposed retrofit is first selected. In Hyderabad, an example of a selected proposed retrofit is 'water/air-based' or 'electric heat pump', and in Manhattan, the example of a selected proposed retrofit is 'all electric.'

Once a proposed retrofit has been selected for a particular branch, the framework demands the identification of universal parameters (the same for all branches) that would provide a metric for comparing various proposals, which would be found on the other branches. For example, in this case of comparing sustainable HVAC equipment, 'Energy Consumption' is a parameter used to compare the different sustainable HVAC equipment which are proposed retrofit options, as seen in the diagram.

The next step is to collect and input the data for the identified parameter, the asset, and the financial assumptions (driven by market conditions).

The parameter, 'Energy Consumption', data is broken into:

- energy use intensity for gas (kBtu/sqft/year)
- energy use intensity for electricity (kBtu/sqft/year)
- electricity price ($/kBtu)
- gas price ($/kBtu)
- annual gas price inflation (%)
- annual greenhouse gas emissions (kgCO_2e/kBtu)
- energy savings: gas and electric (%)

The asset data is broken into:

- gross leasable area (sqft)
- leasable area (%)
- leasable area lost to technology installation (%)
- total project cost ($/sqft)
- technology cost premium ($/sqft)

The financial assumptions are given in the parameters:

- rent ($/sqft)
- rental rate annual escalation (%)
- lease structure
- discount rate (%)

Upon inputting all of the required data, the model is run. The model is a proforma which calculates as its output the net present value of each for each of the proposed retrofits. Then, the different net present values are compared, calculating the net benefit of investing into each proposed retrofit, compared to the base case standard design.

Chapter 5: Empirical Analysis of Electrification Decision-making in Two Office Assets

5.1 Financial analysis

5.1.1 Hyderabad: The Vault

The decision-making framework compares the net present value for both developer and tenant, upon investing in sustainably transforming an office real estate asset in Hyderabad. The left-most column in Table 9 is the current elected design by the market for HVAC systems in Hyderabad. The other columns each showcase the feasible sustainable building HVAC system technologies.

Table 9: Input data for decision-making framework

Design Attributes:	Electric AC	Water/air-based	Heat recovery wheel	Electric heat pump
Total Project Construction Cost / ft2	$64.88	$63.50	$63.63	$65.23
Technology Cost Premium / ft2	$0.00	$0.00	$0.00	$0.35
Gross area (ft2)	6,900,000	6,900,000	6,900,000	6,900,000
% Leasable area	70%	70%	70%	70%
% Leasable area lost by tech instl.	3%	0%	0%	5%

Energy Consumption:	Electric AC	Water/air-based	Heat recovery wheel	Electric heat pump
Energy Use EUI (kBtu/ft2.y)	67.2	32.59	33.1	58.8
Gas EUI (kBtu/ft2.y)	0	0	0	0
Electric EUI (kBtu/ft2.y)	67.2	32.59	33.1	58.8
Gas GHG (kgCO2e/kBtu)	0.0531	0.0531	0.0531	0.0531
Gas Price 2022 ($/kBtu)	$0.00	$0.00	$0.00	$0.00
Annual inflation rate gas price	0%	0%	0%	0%
Elect. Price ($/kBtu)	$0.037	$0.037	$0.037	$0.037

Rental Income:	Electric AC	Water/air-based	Heat recovery wheel	Electric heat pump
Rent (/ft2)	$11.16	$11.16	$11.16	$11.16
Rental rate annual escalation	2%	2%	2%	2%
Lease structure	Gross	Gross		Gross
Discount rate	10%	10%	10%	10%

Given that the table ‘Energy Consumption’, as shown in Table 9, would remain constant for all developers in the market, only data in tables ‘Design Attributes’ and ‘Rental Income’ need to be manually filled in by each developer using the framework.

The highlighted rows in the ‘Energy Consumption’ table have input “0” for each cell. This is because Gas is currently not used as an energy source in office buildings. Even in the corresponding ‘Energy Saving’ table present in Table 10, the gas data has an input “0” in each cell.

Table 10: Input data for decision-making framework

Energy Saving:	Electric AC	Water/air-based	Heat recovery wheel	Electric heat pump
Electricity	0%	51.50%	50.75%	12.50%
Gas	0%	0%	0%	0%

The decision-making framework had inputted data for RMZ Corp's office development, The Vault.

The framework calculates the net present value of each of the technologies, comparing each to the market's base case, Electric AC. The net present value has been calculated for both the developer and for the tenant, based on their respective cashflows over the next 40 years.

Table 11: Developer net present value: The Vault

Net Present Value		Marginal Benefit	**Rank**
Electric AC	**($8,741,394)**	**$0**	**4**
Water/air-based	**$124,923,518**	**$133,664,912**	**1**
Heat recovery wheel	**$123,677,619**	**$132,419,013**	**2**
Electric heat pump	**$20,044,525**	**$28,785,919**	**3**

The framework suggests that the water/air-based HVAC system rakes for the developer the highest marginal benefit in investing in that sustainable building technology. Additionally, it is important to note that all of the proposed sustainable building technologies highlight a positive net present value, and a positive marginal benefit to the developer. Hence indicating that investing in sustainable building transformation yields positive financial returns.

As shown in Table 11, the most beneficial sustainable HVAC transformation is Electric AC to Water/air-based, followed by Electric AC to Heat recovery wheel. The least beneficial of the three, though still beneficial to the developer, is Electric AC to Electric heat pump.

Table 12: Tenant net present value: The Vault

Net Present Value / ft2		Marginal Benefit	**Rank**
Electric AC	**$63.61**	**$0.00**	**4**
Water/air-based	**$86.00**	**$22.39**	**1**
Heat recovery wheel	**$85.82**	**$22.21**	**2**
Electric heat pump	**$66.65**	**$3.04**	**3**

The framework suggests that the water/air-based HVAC system has the highest marginal benefit for the tenant as well. Like in the case of the developer, all of the proposed sustainable building technologies have a positive net present value, and a positive marginal benefit, highlighting the merit of investment into sustainable transformation for the tenant.

As shown in Table 12, the most beneficial sustainable HVAC transformation for the tenant is Electric AC to Water/air-based, followed by Electric AC to Heat recovery wheel. The least beneficial of the three, though still beneficial to the tenant, is Electric AC to Electric heat pump.

Both the developer's and the tenant's net present value results indicate the financial merit of investing in sustainable transformation, and that sustainably transforming to the Water-air based HVAC system yields the greatest financial benefit to both the developer and the tenant.

5.1.2 Manhattan: Case Office Building

The decision-making framework compares the net present value for both developer and tenant, upon investing in sustainably transforming an office real estate asset in Manhattan. The left-most column in Table 13 is the current elected design by the market for HVAC systems in Manhattan, natural gas. The other column showcases the feasible sustainable building HVAC system technology, 100% electric.

Table 13: Input data for decision-making framework

Design Attributes:	Natural Gas	All Electric
Total Construction Cost / ft2	$600	$616
ASHP Cost Premium / ft2	$0	$6
Gross area (ft2)	922,010	922,010
% Leasable area	65%	65%
% Leasable area lost to electr.	0%	3%

Energy Consumption:	Natural Gas	All Electric
Energy Use EUI (kBtu/ft2.y)	65	52
Gas EUI (kBtu/ft2.y)	23	0
Electric EUI (kBtu/ft2.y)	42	52
Gas GHG (kgCO2e/kBtu)	0.0531	0.0531
Gas Price 2022 ($/kBtu)	$0.009	$0.009
Annual inflation rate gas price	0%	0%
Elect. Price 2024-2060 ($/kBtu)	$0.053	$0.053

Rental Income:	Natural Gas	All Electric
Rent ($/ft2)	$100	$106
Rental rate annual escalation	3%	3%
Lease structure	Gross	Gross
Discount rate	10%	10%

Time Period	Electricity GHG per CLCPA
2020-2024 (kgCO2e/kBtu)	0.0900
2025-2029 (kgCO2e/kBtu)	0.0847
2030-2034 (kgCO2e/kBtu)	0.0550
2035-2039 (kgCO2e/kBtu)	0.0220
2040-2044 (kgCO2e/kBtu)	0
2045-2049 (kgCO2e/kBtu)	0
2055-2059 (kgCO2e/kBtu)	0
2050-2054 (kgCO2e/kBtu)	0

Time Period	LL97 Cap
2025-2029 (kgCO2e/ft2.y)	8.46
2030-2034 (kgCO2e/ft2.y)	4.53
2035-2039 (kgCO2e/ft2.y)	2.68
2040-2044 (kgCO2e/ft2.y)	1.4
2045-2050 (kgCO2e/ft2.y)	1.2
2050-2060 (kgCO2e/ft2.y)	0

Penalty for Emissions	$0.268	/ton/year

Gas Price 2035 ($/kBtu)	$0.009	for all options
Gas Price 2030 ($/kBtu)	$0.009	for all options

Given that the table 'Energy Consumption', 'Electricity GHG per CLCPA', 'LL97 Cap', 'Penalty for Emissions', 'Gas Prices' as shown in Table 13, would remain constant for all developers in the market, only data in tables 'Design Attributes' and 'Rental Income' need to be manually filled in by each developer using the framework.

The decision-making framework had inputted data for the indicative Manhattan asset office development. The framework calculates the net present value of the proposed technology, comparing it to the market's base case, Natural Gas. The net present value has been calculated for both the developer and for the tenant, based on their respective cashflows over the next 40 years.

Table 14: Developer net present value: Manhattan asset

Net Present Value		Marginal Benefit	Rank
Natural Gas	$205,761,753	$0	2
100% Electric	$206,067,642	$305,889	1

The framework suggests that the 100% Electric building design rakes for the developer the highest marginal benefit in investing in that sustainable building retrofit. Hence indicating that investing in sustainable building transformation yields positive financial returns.

As shown in Table 14, the sustainable transformation from Natural Gas to a 100% Electric design, yields a marginal benefit to the developer, given the positive marginal benefit.

Table 15: Tenant net present value: Manhattan asset

Net Present Value / ft2		Marginal Benefit	**Rank**
Natural Gas	**$823.35**	**$0.00**	**2**
100% Electric	**$843.50**	**$20.15**	**1**

The framework suggests that the 100% Electric building design has the highest marginal benefit for the tenant as well. Like in the case of the developer, the proposed sustainable building transformation has a positive marginal benefit, highlighting the merit of investing in sustainable transformation for the tenant.

As shown in Table 15, even the tenant benefits, by $20.15/sqft from the proposed sustainable transformation from Natural Gas to a 100% Electric design.

Both the developer's and the tenant's net present value results indicate the financial merit of investing in sustainable transformation, and that sustainably transforming to the 100% Electric building design yields the greatest financial benefit to both the developer and the tenant.

5.2 Sensitivity Analysis

5.2.1 Hyderabad

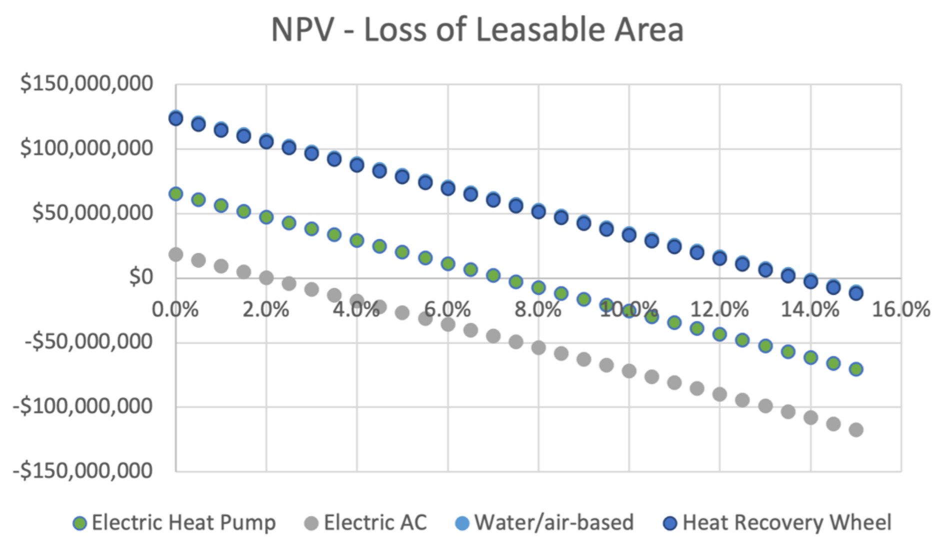


Figure 38: NPV - Loss in Leasable Area sensitivity analysis

For the four technologies, it was observed that any percentage loss in leasable area results in a decrease in the developer's NPV. All four technologies maintained a negative direct proportion when comparing the developer's NPV for each of the technologies with the loss in leasable area for electing the technology. This is seen in Figure 38.

Water/air-based and Heat Recovery Wheel have near overlapping trend lines in their data. Though unclear in Figure 38, Water/air-based has a higher NPV than Heat Recovery Wheel for every variable along the x-axis. The implementation of both Electric AC and the Electric Heat Pump technologies result in losses in leasable areas; whereas Water-air based, and Heat Recovery Wheel have no loss in leasable area upon installation. This is supported in Figure 38, highlighting that a technology resulting in a loss in leasable area inherently has a lower NPV than those that do not result in any loss of leasable area, when keeping all else equal.

Electric AC has a loss in leasable area of 3%, whereas Electric Heat Pump has a loss in leasable area of 5%. Despite, the latter having a greater loss of leasable area, it has a higher NPV as it commands a rental premium over Electric AC.

Given that regulations to implement building sustainability are still nascent in Hyderabad and aren't as explicitly defined, as Manhattan's LL97, market acceptance to sustainable transformation is heavily reliant on the developer's ability to market the costs and benefits of sustainably transforming a real estate asset. Developers in Hyderabad are responsible of illustrating the net gains to their tenants when presenting their motive to sustainably transform their building to make it more sustainable than what the market offers. In order for a sustainable transformation to make financial sense to a developer, a rental premium is often charged above market to merit the developer's efforts in sustainably transforming real estate.

Today, for any operational cost of the tenant that's saved by the developer by means of improving the building's efficiency or investing in better building infrastructure, the tenant accepts a rental premium equally 30% of the operational cost saved. This is, however, without a sustainable transformation as proposed. Figure 38 captures a sensitivity analysis for the building's NPV for each of the four building technologies. Thus, showcasing to the developer, the NPV for various splits, from 0% to 100%, of operational expenditure saved that will get calculated as the building's rental premium.

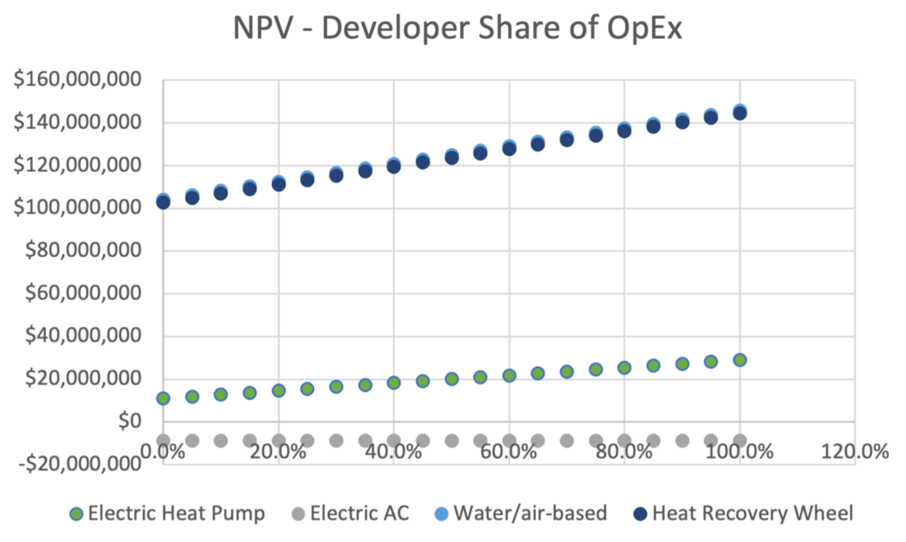


Figure 39: NPV – Developer Share of OpEx saved sensitivity analysis

For the four technologies, it is observed that for every additional percent share of opex that the developer takes toward a rental premium, there is an increase in the developer's NPV. All of the four proposed HVAC building technologies maintained a positive direct proportion when comparing the developer's NPV for each of the technologies with the developer's share of the opex saved as rent premium.

Water/air-based and Heat Recovery Wheel have near overlapping trend lines in their data. Though unclear in Figure 39, Water/air-based has a higher NPV than Heat Recovery Wheel for every variable along the x-axis. Figure 39 showcases that, irrespective of the share of opex that the developer takes toward a rental premium, investing in any of the three technologies gives the developer a higher NPV than the base case, which commonly exists in the market, Electric AC. The share of opex saved today is 30% just for operational efficiency brought to the building, and not a 'sustainable retrofit.' Hence, the number for the sustainable retrofit will be greater.

5.2.2 Manhattan

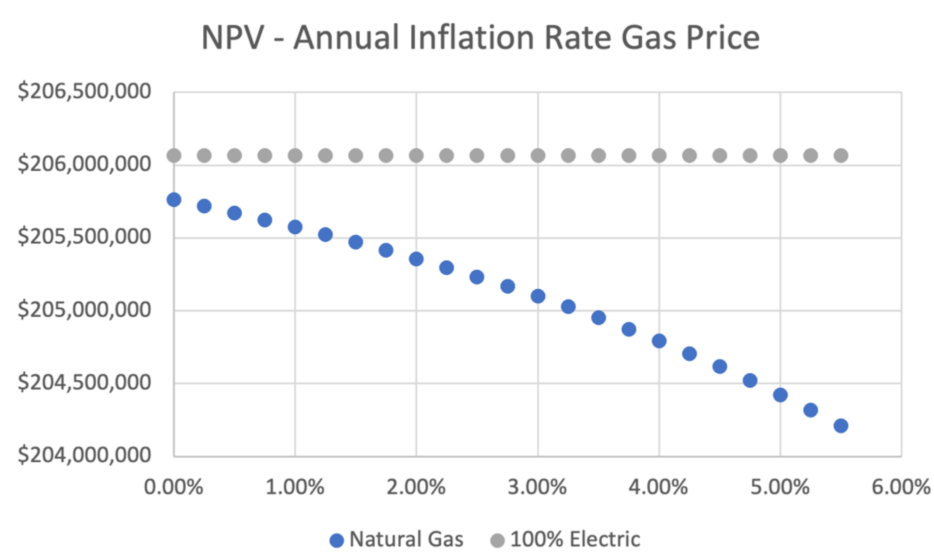


Figure 40: NPV - Annual Inflation Rate Gas Price sensitivity analysis

Figure 40 captures the developer's NPV for both the building technologies. For the 100% Electric design, any increase in annual inflation rate for the gas price has no impact on the developer's NPV with this design. For the Natural Gas design that has 20% Natural Gas, any increase in gas price, by means of inflation, will cause an in-turn decrease in the developer's NPV.

For the model, since gas prices have never historically followed a yearly escalation rate and are unlikely to do so in the future, there is no genuine "correct" annual escalation for gas prices. To demonstrate how a rise in gas costs might impact the value of the gas buildings, the model simply selected to utilize an annual escalation rate. Instead of assuming an annual escalation, gas prices are predicted using a fixed price (i.e., no increase).

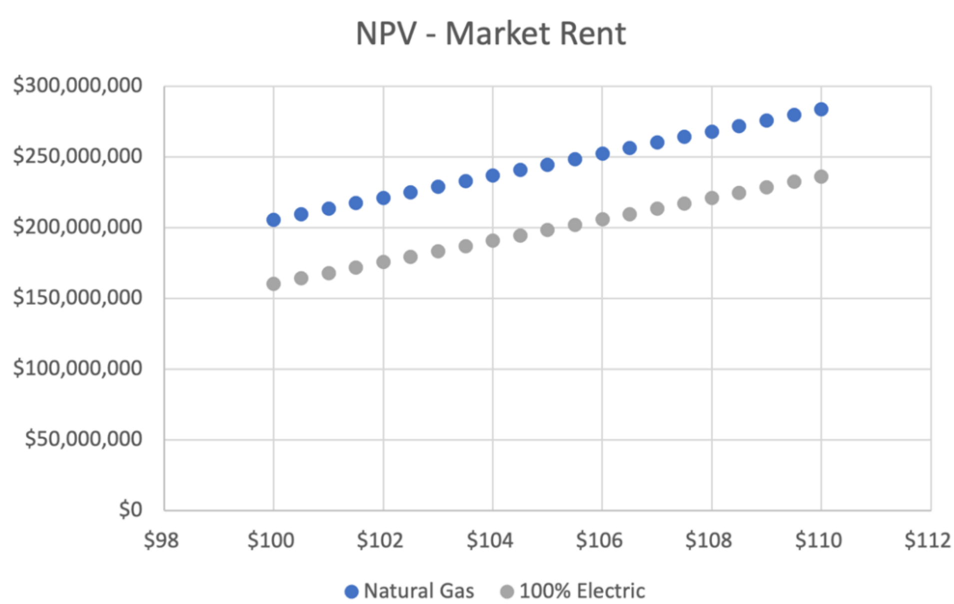


Figure 41: NPV - Market Rent sensitivity analysis

At every inflation rate for gas prices, the 100% Electric design yields a greater NPV for the developer, highlighting that sustainable real estate has a higher NPV.

Figure 41 shows the correlation between market rent and NPV for both technologies. It is expected that as market rent increases, NPV increases. Despite having a higher construction cost, the 100% Electric design has a higher NPV at every market rent. The 100% Electric design's improved energy efficiency, and lower energy costs are reason for its higher NPV.

Chapter 6: Conclusions

The thesis applied the decision-making framework developed to analyze the financial worthiness of investing into sustainable transformation of building HVAC equipment. It used a case study of an indicative office asset in Manhattan, where it analyzed the net benefit of sustainably retrofitting it with a more sustainable 100% electric HVAC system. The thesis' decision-making framework compared the net present value for both developer and tenant, upon making investment into sustainably transforming the office real estate asset. The same decision-making framework was applied to a second asset that was used as a case study in the thesis – an office asset in Hyderabad. The decision-making framework repeated the same process with the Hyderabad asset's corresponding data. Therefore, demonstrating that the developed decision-making framework can be used across geography for a selected application: the sustainable transformation of building HVAC equipment, as done in this thesis.

It was observed that Manhattan is further ahead of Hyderabad in its decarbonization plans for the real estate industry, with strict guidelines to curtail carbon emissions in the future. Thus, market acceptance for sustainable transformation, and rent premiums for sustainable real estate was greater in Manhattan given the market's familiarity with both concepts. Since this was not yet the case in Hyderabad, it gives developers investing in sustainable real estate, like RMZ Corp, the opportunity to evolve the market's current perception.

Today, the market accepts 30% of direct operational costs saved as a rent premium for investment into more efficient building technology. So, further decreasing operational costs by investment into sustainable building technologies should result in a greater market rent premium. This percentage appears to still be open to negotiation given the nascency of sustainably transformed real estate in Hyderabad. A developer's tenant relations, brand power and ability to market a premium for sustainable real estate will strongly influence what this number may be. For the near term, it is likely that this number may look different for different developers, until sustainable real asset as a concept is institutionalized in Hyderabad. Steps taken by institutions like RMZ Corp as first movers in this field will kickstart this process.

RMZ Corp believes that by taking a step ahead of the market and sustainably transforming an asset, a developer may be able to command a premium of 50% of the operational expenditure saved with the investment into a sustainable building technology. Thus, 50% was used in the model for The Vault. The model proved the water/air-based HVAC system to be the most efficient, informing RMZ Corp's choice of this system for The Vault. The asset is in its design-development phase and is scheduled to be complete in 4 years.

At the time of completion, I hope this thesis motivates other developers to also invest in sustainable real estate in India. And, for policy makers to evolve environmental regulations and cities' decarbonization plans in India to the detail of Manhattan's LL97.