Comparison of Indigenously developed Green Building Rating System – Outlining the subtle distinct features

A Thesis Submitted
In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF TECHNOLOGY

in

Mechanical Engineering

With
specialization in

"Production and Industrial Engineering"

by

Mohd Ashraf Khan
(Enrollment No. 1300101249)

Under the Supervision of

Er. Mohammad Nawaz Khan
(Assistant Professor)

DEPARTMENT OF MECHANICAL ENGINEERING

INTEGRAL UNIVERSITY, LUCKNOW

August 2020

INTEGRAL UNIVERSITY

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CERTIFICATE

Certified that **Mohd Ashraf Khan** (1300101249) has carried out the research work presented in this thesis entitled **"Comparison of Green Building Rating Systems – Outlining the subtle distinct features"** for the award of **Master of Technology** from Integral University, Lucknow under my supervision. The project / thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

Mohammad Nawaz Khan
Assistant Professor
Department of ME, Integral University, Lucknow

Date:

ACKNOWLEDGEMENTS

A project is culmination of hard work and efforts of many people put together. I would like to take this opportunity to express indebtedness to all those who contributed towards the completion of this task.

Firstly, I would like to thank the Almighty Allah for showering His blessing upon me and making this thing easier for me as learning a new thing is not easy and enabling me to complete this report on "Comparison of Indigenously developed Green Building Rating System – Outlining the subtle distinct features".

From the start to the final successful completion of the project, it requires help from several individuals. I too have taken guidance and help from different people for the preparation of this report. I cannot express enough thanks to my mentor and MTech guide Mr. Nawaz, for his continued effort and commitment towards this project. Even in this ongoing pandemic, his efforts and guidance were unmatched.

I would also like to extend my gratitude towards the entire faculty of Mechanical Engineering and the administration department of Integral University for providing me an environment ambient to encourage the students to take up the challenges and for being ready to support whenever the need be.

Lastly, I would like to thank my family and friends for their extended support.

MOHD ASHRAF KHAN

MTech 2nd Year

Production and Industrial Engineering

Department of ME

Integral University

Lucknow

ABSTRACT

In India back in year 2001 with the formation of Indian Green Building Council (IGBC), the green building movement in India was triggered off - CII-Sohrabji Godrej Green Business in India was awarded with the first and highly acclaimed Platinum rated green building rating in India.

Since, then the green building sector has grown rapidly, evolving with time, and enhancing their criteria for green building even more. Green Building is a term that covers a vast area of building industry and takes a holistic approach at bringing the best practices to the masses. It contains a set of modules that have some mandatory requirements and some credits. A minimum threshold for achieving a status of green building is defined, a minimum number of credits must be attempted along with complying with the mandatory requirements. Many studies have been conducted in the past, covering the details as to what areas have been covered in those rating systems along with the number credits that are allotted for each of the modules. In this work, our main area of concern will be the “Energy” module in the green building rating systems. The main focus of this study is to outline the subtle distinct features in the “Energy” modules in green building grating systems i.e. Green Rating system for Integrated Habitat Assessment (GRIHA) and Indian Green Building Council (IGBC). For which we will start up with the building model being simulated in an energy simulation software/tool that are certified by competent authorities. The results as obtained from the simulation of the proposed building model will be used. Since, there are different benchmarks for allotting credits for achieving minimum energy efficiency such as Energy Performance Index (EPI) in GRIHA and % savings in energy consumption cost in case of IGBC.

Hence, how these green building rating systems differ minutely in their modules and credit structuring is of our concern. The energy simulation software to be used in this study is “eQuest”, a highly acclaimed software. For the proposed building to be modelled a set of plans that are required for it shall be provided.

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List of Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ANSI	American National Standards Institute
LEED	Leadership in Energy and Environmental Design
GRIHA	Green Rating for Integrated Habitat Assessment
IGBC	Indian Green Building Council
BREEAM	Building Research Establishment Environmental Assessment Method
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
USGBC	U.S. Green Building Council
ECBC	Energy Conservation Building Code
NBC	National Building Code
BEE	Bureau of Energy Efficiency
IEA	International Energy Agency
OECD	Organization for Economic Cooperation and Development countries
BTU	British Thermal Units
WCED	World Commission on Environment and Development
BSA	Building Sustainability Assessment
AHP	Analytical Hierarchical Process
TERI	The Energy and Resources Institute
CII	Confederation of Indian Industry
GBCA	Green Building Council of Australia
IEO	International Energy Outlook
GDP	Gross Domestic Product
HVAC	Heating, ventilation, and air conditioning
SEER	Seasonal energy efficiency ratio
EER	Energy Efficiency Ratio

COP	Coefficient of Performance
LPD	Lighting Power Density
EPI	Energy Performance Index
kWh	kilowatt-hour

1. Introduction

Buildings are key to a sustainable future because their design, construction, operation, and the activities in buildings contribute significantly to high energy consumption – reducing energy demand in buildings can play a pivotal role in reducing energy consumption and solving challenges that lies ahead.

Energy services in buildings – HVAC systems for thermal comfort, refrigeration needs, lighting systems installed, communication and entertainment (such as Television's, Laptop's, other accessories), as well as other amenities are majorly responsible for a significant share of energy use worldwide.

The building sector and people's activities in buildings are responsible for approximately 31% of global final energy demand, approximately one-third of energy-related CO2 emissions, approximately two-thirds of halocarbon, and approximately 25–33% of black carbon emissions.

Several energy-related problems affecting human health and productivity take place in buildings, due to poor indoor air quality or inadequate indoor temperatures. Hence, this issue must also be addressed to improve occupant's health and increase efficiency of people working inside these buildings.

Buildings and residential energy demand consist of more than 45% in India's final energy consumption. With burgeoning population of 1.37 billion people in India as of 2019 is expected to surpass that of china's. With this population growth, increased urbanization and increasing income of public, it can be reasonably assumed that energy demands for the building sector will also increase thereby posing a huge challenge for energy policy in the country.

A future involving buildings that are highly energy-efficient, can result in significant associated benefits, such as avoiding impacts of climatic change in the future. One of the most important future benefits is mitigation of the building sector's contribution to climate change. Other benefits include improvements in energy security and sovereignty, elimination of or reduction in indoor air pollution, improved health benefits, alleviation of energy poverty, increased occupant's comfort, well-being, and improved productivity.

A member of the World Bank Group, The International Finance Corporation (IFC), has published their latest report that reveals insight into the tremendous potential of green structures in developing markets.

Pooling resources in green buildings permits market players to oversee potential risks that comes from the worldwide transition to low-carbon economies. As per IFC, the building sector consumes more than half of all electricity for heating, cooling, and lighting and accounts for 28% of greenhouse-gas emissions that are energy-related.

The report, named "Green Buildings: A Finance and Policy Blueprint for Emerging Markets," features that by 2030, in developing markets alone, green structures will offer a tremendous $24.7 trillion investment chance, which will stimulate economic growth and enhance sustainable development.[1]

The report features the financial benefits that the investors, banks, developers, and owners, including governments, can expect when entering the market of green building.

An estimated $24.7 trillion investment potential in green structures somewhere between 2018 and 2030 in developing market urban centres will be because of the sharp increment in building development that is anticipated over the next few decades and the need to ensure that these buildings are built green will result in developing this opportunity.

The report takes note of that there is a solid business case for developing the green buildings market. Developing proof shows that green buildings, or buildings that use energy and water more proficiently, are a higher-esteem, lower-chance asset than standard structures. While building green could range from savings of 0.5 to 12% in extra costs, green buildings or structures can effectively decrease the operational costs by up to 37%, they tend to accomplish higher deal premiums of up to 31% and quicker deal times, have up to 23% higher occupancy rates and have higher rental pay of up to 8%.

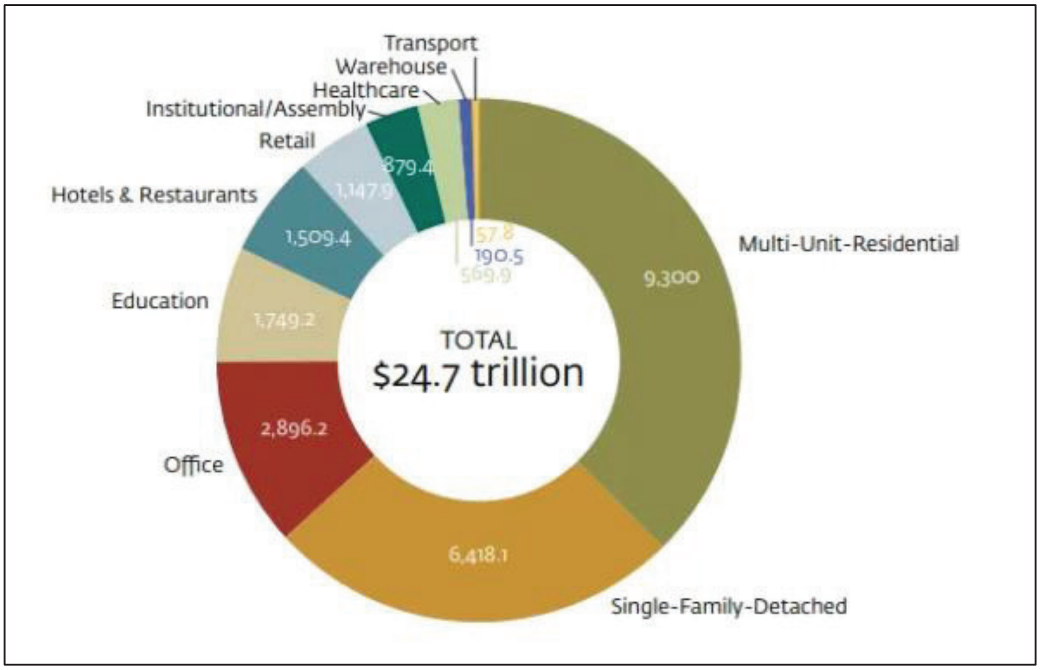


Figure 1 - Total Investment Opportunity by building type (USD billions)

According to the report, the greater part of the 4.1 billion people anticipated to live in urban zones by 2030 are relied upon to be in South Asia and the East Asia Pacific regions, and their accommodation will require additional private and commercial building floor space. The East Asia Pacific area alone will introduce a venture chance of $16 trillion in green structures.

In India, the circumstance is the same, as it alone will need an estimated 60 million extra lodging units to be worked upon somewhere between 2018 and 2022 to meet the current deficiency. To fulfil the needs, the Indian government has propelled "Housing for All" by 2022, a policy that expects to overcome any issues in urban housing with expanded private sector participation.

It is essential to note here that since December 2015, 194 nations have submitted national plans that feature the governments' system for decreasing emissions through climate solutions and arrangements, including sustainable power source and low-carbon urban sprawls.

The report includes that India's National Development Council is centered around the building sector based on energy conservation, vowing to make its Energy Conservation Building Code (ECBC) stricter, featuring its local building rating system GRIHA (Green Rating for Integrated Habitat Assessment), which is used for scaling the green building and energy efficient projects in the country.

The most ideal way to diminish the utilization of conventional resources during a building's life cycle is to integrate green measures during its design, plan and development stages. For instance, India refreshed its Energy Conservation Building Code (ECBC) for commercial buildings in 2017 and its ECBC-R for residential buildings in 2018. The ECBC currently incorporates energy performance standards for commercial buildings, requires renewable energy sources to be integrated into building design, and makes it compulsory for the new structures to establish energy savings of at least 25% to be considered as a code compliant structure.

India's Perform, Achieve, and Trade program is an administrative cap and trade instrument that aims to lower the energy consumption in specific energy-intensive sectors by making use of a market-based mechanism by which customers can get certification for and trade excess energy savings. The program was initially conceptualized for large industrial businesses, yet later it got extended to hotels for the year 2020–2021.

The report further notes that the expanded take-up of green bonds in several markets is chiefly because of the national banks and regulators that are providing clear rules on how to issue these bonds.

The People's Bank of China distributed its "Green Bond Guidelines" in 2015. Similarly, India, the Association of Southeast Asian Nations, Chile, Peru, and Egypt are just a couple of examples of countries that have issued green bond guidelines.

The Indian corporate is likewise playing a crucial role in promoting green buildings/structures. Driven by the CEOs of leading infrastructure developmental organizations and financial institutions, the Sustainable Housing Leadership Consortium is a first-of-its-kind voluntary private sector consortium that intends to standardize the green buildings in India. The consortium is progressing in this direction by building and certifying all its new housing as green, thereby adding 110 million square feet of green housing by 2020.

According to a smart city indicator survey conducted by Ireland-based multinational, Johnson Controls, concluded that India had only 4% of the building that can be classified as 'green.' However, the study also showed that 38% of buildings in India want to get the 'green building certification' in the future when compared to the global percentage of 44. Approximately 46% are willing to pay a extra amount to lease space in a certified green building in India when compared to the global average of 51%.

Previously, the Bureau of Energy Efficiency and the Central Public Works Department signed a memorandum of understanding (MoU), thereby starting their partnership to cooperate to promote energy efficiency in buildings. The MoU is expected to remain in force for a period of five years unless cancelled by either of the party. As per the MoU, BEE and CPWD will work together on promoting energy efficient designs and construction of Energy Conservation Building Code (ECBC) compliant new buildings, star rating of CPWD managed buildings across the country with no registration or renewal fee, awareness on energy efficiency in different developmental sectors such as building sector and development of capacity building of CPWD officials in ECBC.

1.1.Global Scenario

Almost 60% of the world's electricity is consumed in residential and commercial buildings. Per capita final energy use in buildings in a cold or temperate climate in an affluent country, such as the US and Canada, can be 5-10 times higher than in low income regions, such as Africa or Latin America.

The global direct total final energy use in buildings was 108 EJ in 2007 and resulted in emitting 8.6 GtCO2e (IPCC, 2007), 33% of global energy-related CO^2 emissions (IEA, 2008a). Globally, biomass is the most important energy carrier for energy use in buildings, followed by electricity, natural gas, and petroleum products. Almost 60% of the world's electricity is consumed in residential and commercial buildings (IEA 2008a) [Diana Ürge-Vorsatz et.al., (1)].

Energy used in the buildings sector which includes residential and commercial structures accounted for 20% of global delivered energy consumption in 2018. In *International Energy Outlook 2019* (IEO2019) Reference case, the U.S. Energy Information Administration (EIA) projects that global energy consumption in buildings will grow by 1.3% per year on average from 2018 to 2050. As per EIA projection, the countries that are not a part of Organization for Economic Cooperation and Development (non-OECD countries), the energy consumed in buildings will grow by more than 2% per year, or about 5 times the rate of OECD countries.

Electricity is the main energy source for lighting, cooling/heating, appliances, and equipment (process loads) and is the fastest-growing energy source in residential and commercial buildings. EIA expects that rising population and standards of living in non-OECD countries will lead to an increase in the demand for electricity-consuming appliances and personal equipment.

EIA expects that in the early 2020s, total electricity use in buildings in non-OECD countries will surpass electricity use in OECD countries. By 2050, it is estimated that buildings in non-OECD countries will collectively use about twice as much electricity as buildings in OECD countries.

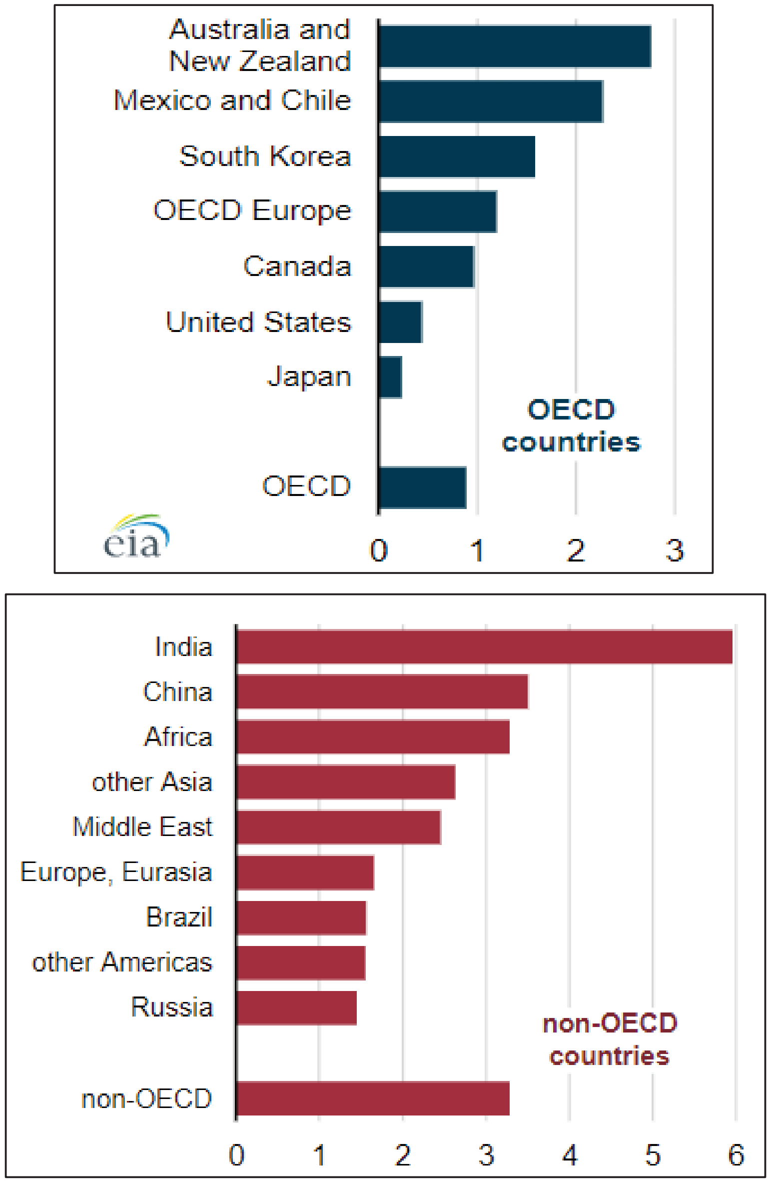


Figure 2 - Average annual change in buildings sector electricity consumption (2018-2050)

With rapid urbanization, as the quality of life improves, more and more people are being lifted above poverty line, and easy access to electricity. EIA projects that electricity's share in the total use of energy in buildings will nearly double in non-OCED countries, from 21% in 2018 to 38% in 2050 as compared to electricity's share of delivered energy consumption in OCED countries buildings will decrease from 24% to 21%.

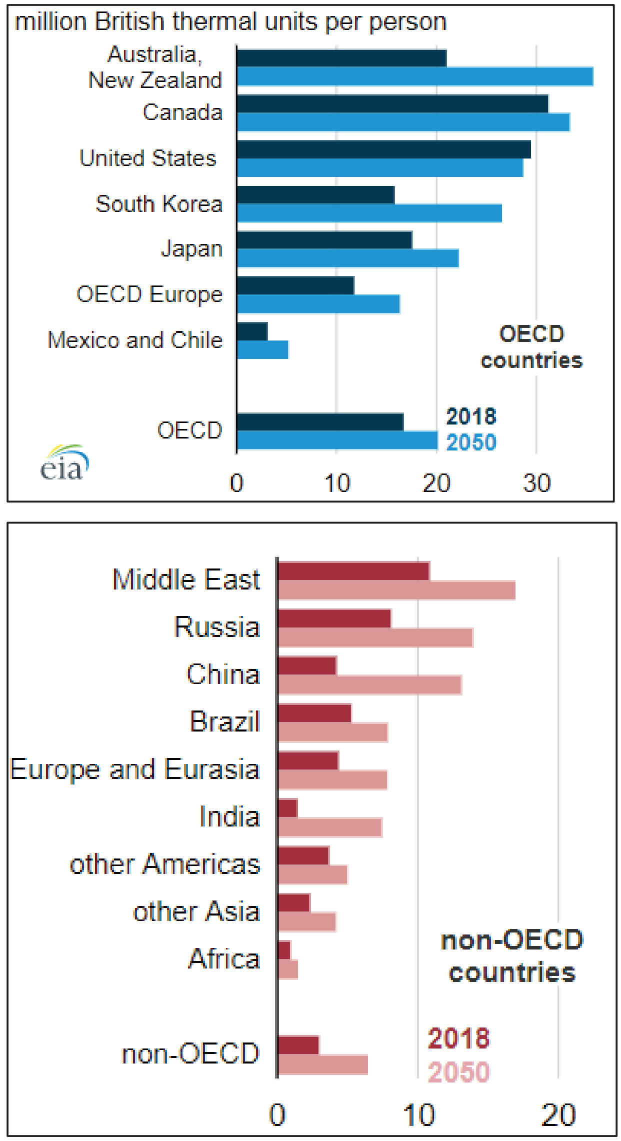


Figure 3 - Building sector electricity consumption per capita by region (2018-2050)

The per capita use of electricity in buildings in OECD countries will increase 0.6% per year between 2018 and 2050. The relatively slow growth is a result of improvements in building codes and improvements in the efficiency of appliances and equipment. Despite a slower rate of growth than non-OECD countries, OECD per capita electricity use in buildings will remain higher than in non-OECD countries because of more demand for energy-intensive services [U.S EIA, 2019, (2)].

1.2. Indian Scenario

India is the world's third-largest consumer of oil, the fourth-largest oil refiner and a net exporter of refined products. India has made important progress towards meeting United Nations Sustainable Development Goals, notably Goal 7 on delivering energy access. India's per capita emissions today are 1.6 tonnes of CO_2, well below the global average of 4.4 tonnes, while its share of global total CO_2 emissions is some 6.4%. The government's major programs targeting industry and business has radically pushed down the price of the products that are procured on a large-scale basis such as LEDs. As per current policies, India's energy demand would double by 2040, with electricity demand potentially tripling because of increased appliance ownership and cooling needs. India will need to add large amounts of power generation capacity to meet the demand from the 1 billion air-conditioning units the country is expected to achieve by 2050 [IEA India 2020, (3)]. EIA's International Energy Outlook 2017 (IEO2017) projects that among all the major regions of the world, the fastest growth in energy consumption in buildings through 2040 will occur in India. In the IEO2017 Reference case, delivered energy consumption for residential and commercial buildings in India is expected to increase by an average value of 2.7% per year between 2015 and 2040, that is more than twice the global average increase.

Most of this growth comes due to increased electricity and natural gas use (because of greater access to these energy sources) and the increased use of appliances and energy intensive equipment. Despite the rapid increase in energy consumption of the buildings, the IEO2017 Reference case shows that, among the IEO2017 regions, India's per capita buildings energy use through 2040 is the second lowest after Africa.

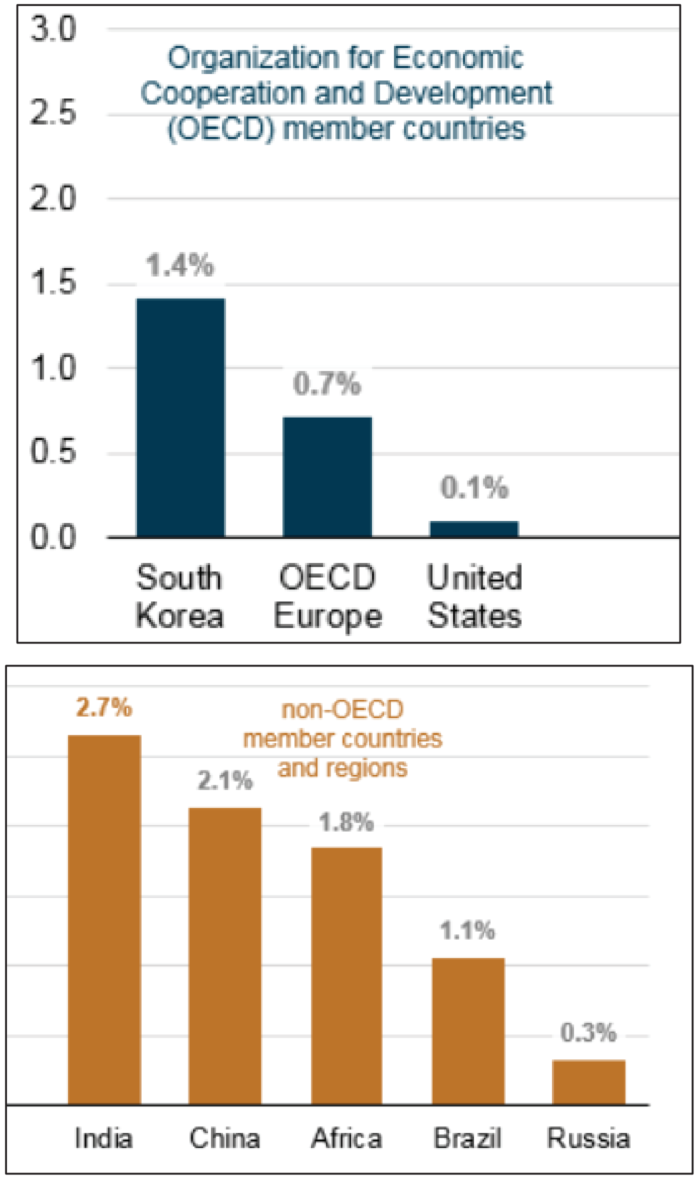


Figure 4 - Average annual change in buildings energy consumption, 2015-2040

Rapid economic growth, increasing income, growing population, and urbanization are factors in the growth in India's buildings energy consumption. Energy-use patterns vary between rural and urban populations. India has the world's highest projected gross domestic product (GDP) growth rate among the IEO2017 regions, averaging 5.0% per year from 2015 to 2040.

India is projected to account for about 19% of the increase in world's population, surpassing China as the world's most populous country in 2023. The United Nations projects India's population to become more urbanized, about 45% of the Indian population will live in urban areas by 2040. Energy consumption in buildings represented about 14% of total delivered energy consumption in India in 2015. As per EIA projection the rate of India's commercial energy growth is expected to be higher than its residential energy growth, the residential sector remains the greater consumer of buildings energy.

In the IEO2017 Reference case, residential delivered energy consumption is projected to grow by an average of 2.4% per year from 2015 to 2040, that is the fastest growth rate among IEO regions. As per EIA ,it expects household per capita disposable income to grow by an average of 3.2% per year as more people have now access to electricity and the ownership of energy intensive appliances and equipment (particularly air conditioners) grows. Consequently, EIA expects residential electricity consumption to increase nearly twice as fast as total residential sector energy use from 2015 to 2040. Electricity's share has risen from 46% of the energy delivered to Indian residences in 2015 to 68% in 2040.
India's commercial sector accounted for nearly 69% of the country's gross domestic product in 2015, and this share is expected to grow even further, leading to more energy demand in the commercial sector (as can be clearly seen from Figure 4 - Average annual change in buildings energy consumption, 2015-2040).

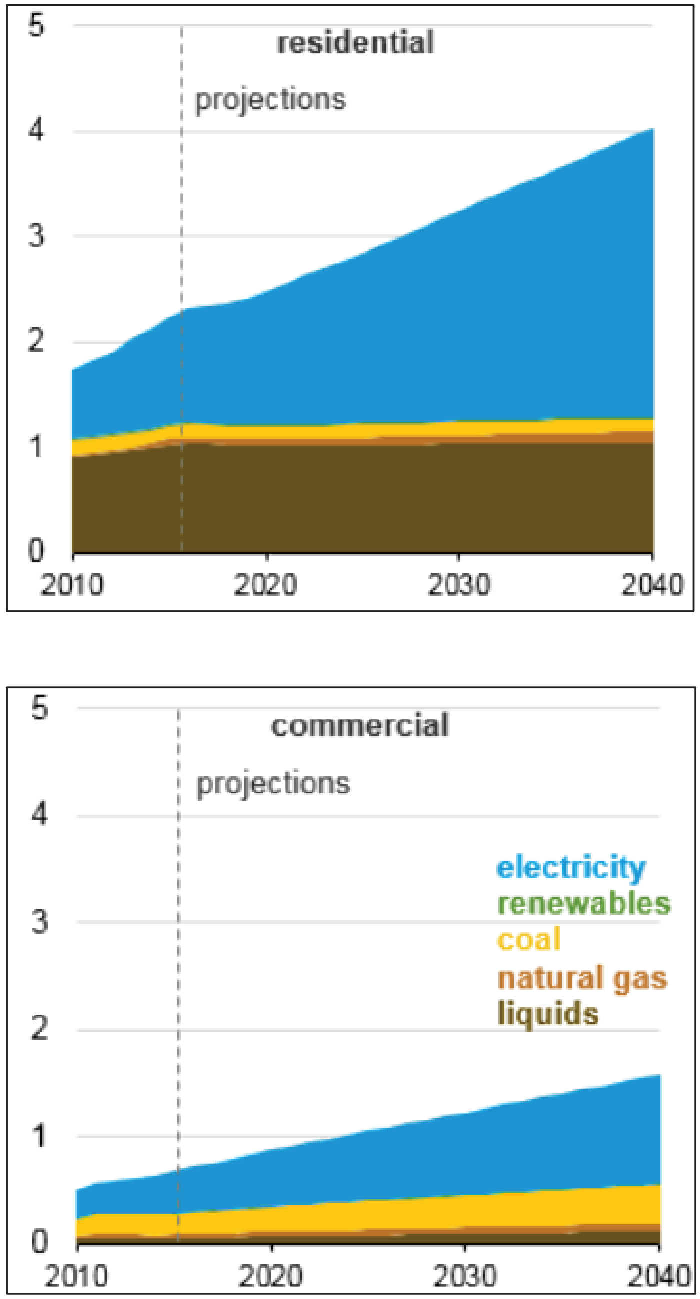


Figure 5 - Indian energy consumption by fuel, 2015-2040

EIA projects that total delivered energy use in commercial sector in India will increase by an average of 3.4% per year, that is yet again the fastest growth rate among IEO regions. India's economic growth, increasing income, and population growth are likely to increase the need for education, better hospitals and health care facilities , leisure, and other services, which EIA expects will lead towards an increased demand for lighting, space cooling, and office equipment(process loads and other equipment). In the IEO2017 Reference case, electricity and coal remain the most notable fuels consumed in India's commercial sector.

EIA projects the electricity share of India's total commercial energy consumption to continue increasing from 59% in 2015 to 65% in 2040, displacing consumption of primary energy source - coal. Buildings energy consumption in India is also affected by various energy efficiency programs such as Energy Conservation Building Code (ECBC), National Building Code (NBC).

From year 2000 to 2018, around 700 million people in India gained access to electricity, reflecting strong and effective policy implementation. India's electricity security has drastically improved by the creation of a single national power system and major investments that has taken place in thermal and renewable capacity. India's power system is currently experiencing a major shift to renewable energy [U.S EIA, 2017, (4)].

2. Literature Review

With the rapid urbanization, population explosion led to the boom in building construction sector to meet the ever-increasing demand of the society. Also, the rapid urbanization led to the exploitation of natural resources to a great extent. Hence, sustainable development became the need of the hour to mitigate the ill-effects of construction activities. The idea of sustainable development led to the several initiatives being undertaken to conserve our environment and address those pressing environmental issues that have been long forsaken. Initiatives such as the United Nations World Commission on Environment and Development (UN WCED) in 1983, Brundtland Commission Report in 1987, Kyoto Protocol in 1992 and Johannesburg Declaration on Sustainable Development at the World Summit on Sustainable Development (WSSD) in 2002 [Varma et al., 2019, (5)].

Green buildings are built on the basis of ecological principles and the effective use of natural without compromising robust facilities [Kibert, 2013, (6)]. Green building facilitates the preservation of precious natural resources and the improvement in the overall quality of life [WGBC, 2018, (7)]. The term Green Building can be easily understood in broader sense as the building or facility that consumes less amount of energy as compared to conventional buildings, reduces the dependency on energy supplied by grid, instead employs renewable energy sources, reduce their water demand through water harvesting and other techniques. The principle of “reduce, reuse and recycle” is relevant to green buildings.

Green building certification has now become a symbol of recognition that a certain building or facility employs and conforms to the best practices as per international standards and it contributes it’s share towards achieving the aim of sustainable development. The agencies that certify the buildings operate locally and globally. These agencies help facilitate the certification through green building rating schemes that available worldwide. There are several variants of certification such as New Buildings, Major Renovations, core and shell, etc. Also, residential and non-residential buildings are considered separately for the certification process under respective variants. Few green building rating systems that are available globally are LEED (Leadership in Energy and Environmental Design), and BREEAM (Building Research Establishment Environmental Assessment Method). The projects under these rating systems can be certified post-construction and also have an option of being certified in the pre-construction stage based on the guidelines of the rating systems.

Due to the presence of many rating systems, a natural question that comes to our mind is “Which of the rating system is better?”. Hence, to answer this question and to determine what are the parameters on which these rating systems should be compared to know the strengths and shortcomings of each rating systems several studies have been carried out [Doan, Ghaffarianhoseini, Naismith, Zhang & Tookey, 2017, (8); Illankoon, Tam, & Le, 2017, (9); Illankoon, Tam, Le, & Shen, 2017, (10); Li, Chen, Wang, Xu, & Chen, 2017, (11); Vyas & Jha, 2016, (12)]. However, in these studies DGNB (Germany) and GRIHA (India) were not considered. Also, many green building rating systems primarily focuses on environmental aspects of sustainability. There is a need to evaluate the coverage of social and economic aspects of sustainability in green building rating and support the development of new ratings [Zuo & Zhao, 2014, (13)].

As such a recent study carried out by [Varma et al., 2019, (5)] takes these rating systems into consideration that were previously left out along with rating systems that are prevalent in North America, Europe and Asia using the current versions of the rating systems that were then available. Environment, society, and economy are considered as the three pillars of sustainable development [United Nations, 2005, (14)], which are also called as the triple-bottom-line [AL Shayeb, 2013, (15)]. The World Commission on Environment and Development (WCED) defines sustainability based on these three pillars [Brundtland, 1987, (16)]. Environmental, economic, social, and cultural aspects are considered with due significance to promote sustainability [Mateus & Bragança, 2011, (17)]. Initially the Green rating systems were developed to mitigate the ill-effects of building construction on its surrounding environment and they focused solely on technical and environmental aspects of sustainable development. Later, social aspects were added. As a result of increased awareness and acceptance, more sophisticated rating systems were evolved to address the triple-bottom-line concept of sustainable development [Zuo & Zhao, 2014, (13)]. Apart from short-term and long-term benefits that green building provides to its occupants, a green building needs to be economically rational [Feng, 2011, (18)].

Building Sustainability Assessment (BSA) and building rating and certification are two methods adopted to verify whether buildings and facilities are sustainable or not [Bragança, Mateus, & Koukkari, 2010, (19)]. In the absence of a uniform criteria and the differences that exists between the green rating systems, some key criteria's have been identified and can be used a standard for comparing the rating systems. The important criteria are the site, water, energy, indoor environment quality, material, waste and pollution and management [Illankoon, Tam, Le, et al., 2017, (10)]. Analytical Hierarchical Process (AHP) is used to evaluate the relative significance among common components that contribute to sustainable buildings [Vyas & Jha, 2016, (12)]. Many rating systems that were studied were noticed to perform only a part of their originally intended objectives with energy efficiency taking the highest priority [Vyas & Jha, 2016, (12)]. This is due to the fact that many green rating systems are environment-oriented tools and they might not be sustainability assessment tools [Awadh, 2017, (20)]. Also, no apparent relation is found between the green building certification level and the actual energy use [Geng et al., 2019, (21)].

It is to be noted that Energy is important to the certification results and occupies a high proportion of the total scores in green building rating systems [Zhang et al., 2017, (23); Mattoni et al., 2018, (22); Illankoon, Tam, Le, et al., 2017, (10)]. One of the main things to understand is that developers, and investors are most of the times concerned with the economic performance of the green buildings as compared to the conventional buildings. Hence, the cost-benefit analysis of green buildings is widely conducted [Uğur & Leblebici 2018, (24); Zhang et al., 2018, (25); Dwaikat & Ali 2016, (26); Balaban & Oliveira 2017, (27)]. It is usually concerned with the energy costs involved with the buildings. As many as 15 green building rating systems are reviewed by [Shan and Hwang, 2018, (28)] that includes ASGB – China, CSH and BREEAM of UK, CEPAS and BEAM-Hong Kong, CASBEE-

Japan, EPRS-Abu Dhabi, IGBC-India, LEED-USA, GBI-Malaysia, GG-Canada, GM-Singapore, Green Star-Australia and GSAS- Qatar. The essential criteria used by these rating systems includes water, material, energy, indoor environment, site, land and outdoor environment and innovation. [Li et al., 2017, (11)] reviewed the comparative studies on green building rating systems that were published from 2004 to 2016. These studies were classified into 4 groups mainly: general comparison, category comparison, criterion comparison and indicator comparison. As such seven key credits (Site, Energy, Water, Indoor Environment Quality, Materials, Waste and Pollution and Management) are established in [Illankoon, Tam, Le, et al., 2017, (10)] based on the green rating systems namely (LEED-US, IGBC-India, BREEAM-UK, Green Star-Australia, Green Mark-Singapore, CASBEE-Japan, and GBI-Malaysia). Hence, it was observed that credit "Energy" has the highest consideration followed by "Water" and others.

As per [Himanshu Agarwal et al., 2017, (29)] the studied that was carried out mainly focused on the green rating systems that are more prevalent in India (LEED, GRIHA, IGBC). [Himanshu Agarwal et al., 2017, (29)] concluded that maximum points have been devoted to "Energy" credit. Also, it can be seen from [Himanshu Agarwal et al., 2017, (30)] that Green Building is considered green if it scores well in Energy Optimization (by using energy efficient systems).

As can be clearly seen from the previous studies and researches that were undertaken to study the different green building rating systems, a main conclusion can be drawn i.e. High weightage or consideration is given to "Energy" credit. The term green building comprises of many pro-active, environmentally friendly activities that the rating systems lists out, which are intended to be met with a minimum prescribed value. Therefore, it is not wise to just give more attention to a specific credit, as it will not facilitate a holistic development of the society. Hence, the rating systems must adhere to the triple-bottom line concept as much as they can with further revisions in future to facilitate a holistic development of a building/society in all aspects.

In this study two of the most widely practiced green building rating systems in India (GRIHA & IGBC) are compared with each other. Since, many previous studies have been conducted in this regard such as [Himanshu Agarwal et al., 2017, (29)] and others that have included the green rating systems that are globally used. This study aims at the comparative analysis of the two green rating systems based on the one specific criteria “Energy”, that has been shown repeatedly as the credit that has been allotted maximum points in many rating systems. Therefore, the aim of this study is to find out the energy consumption and the annual energy costs in case of both the rating systems and compare them. To achieve this aim of comparison, we will make use of an energy simulation program to evaluate the building performance (more specifically the performance of the systems installed in the building), calculate the annual energy costs and consumption. Most of the previous studies that were focused on credit structuring, how well all the credits are given weightage and how do they fare against other rating systems. In this study our main focus will be on a single credit “Energy” and will be comparing the rating systems based on that credit not by the weightage given to them in their respective rating systems, but by performing energy simulation as per the requisites of the given rating systems for that particular credit.

3. Rating Systems

3.1 Introduction

India is the seventh largest country in the world. It has a growing economy and is home to over one billion people living in various climatic zones, as India has been divided into 5 main types of climate zones. Construction plays an especially important role in the country's economy contributing 8.1% of the GDP. Commercial and residential sectors are major markets for the construction industry. These sectors consume a lot of energy throughout their life cycle of buildings, thus enabling them to become one of the main contributors of GHG's emissions. Hence, as a first step towards more sustainable and greener environment, Government of India developed several policies and mandated different organizations and institutions to incorporate green practices in their new construction. Later, new guidelines paved the path for even existing facilities to enable them to incorporate green practices.

The green building can be defined as "Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high-performance building." – [Environmental Protection Agency, (31)].

Green Buildings are designed to reduce the impact of the built environment on human health and on its environment. The benefits of Green Buildings include:

1. Reduced operating costs.
2. Improved building marketability.
3. Improved health benefits for the workers.
4. Improved occupant well-being.

Furthermore, the environmental benefits of Green Buildings include:

1. Conservation of natural resources.

2. Reduction of waste.
3. Improved air and water quality.

Green building rating systems are designed to assess and evaluate the building performance on various fronts and stages. In India, there are 3 main rating systems that are currently being used: GRIHA, IGBC, and LEED.

Globally, there are many green rating systems followed that have been created to suit the local demands. Few of them are: BREEAM (Building Research Establishment's Environmental Assessment Method) in UK, DGNB (GeSBC-German Sustainable Building Certificate) in Germany, GBAS in China, BEAM Plus in Hong Kong, Green Mark in Singapore, CASBEE in Japan.

3.2 RATING SYSTEMS IN INDIA

3.2.1 GRIHA

GRIHA stands for Green Rating for Integrated Habitat Assessment. GRIHA is derived from a Sanskrit word meaning – 'Abode'. Buildings and environment interact with each other in various ways. Throughout the life cycle of buildings, from construction to operation and then demolition, they consume resources in the form of energy, water, materials, etc. They emit wastes either directly in the form of municipal wastes or indirectly as emissions. GRIHA attempts to minimize a building's energy consumption, waste generation, and overall ecological impact to within certain nationally acceptable limits / benchmarks [GRIHA, (32)].

GRIHA is a rating tool specifically developed in India to meet Indian conditions that enables people to assess the performance of the buildings against a nationally accepted benchmark. With the rapid urbanization, surge in population an enormous demand erupted to house many employees in buildings. Hence, a building sector boomed which put pressure on available resources. Another that arose was the availability of water in urban areas. Various policies were drafted in consultation with various ministries to develop a holistic approach that would address the building sector problems. In this scenario TERI has played a crucial role in convergence of various initiatives, essential for effective implementation and mainstreaming of sustainable habitats in India. Expertise in green and energy efficient buildings, has enabled TERI to develop GRIHA (Green Rating for Integrated Habitat Assessment), which was adopted as the national rating system by the Government of India in 2007 for green buildings.

The framework of this system has been created to help 'design and evaluate' new buildings (buildings that are still at the inception stages). A building is evaluated based on its predicted performance over its entire life cycle that is from inception through operation. The stages of the life cycle identified for evaluation are:

1. Pre-construction stage: (intra- and inter-site issues like land topography, proximity to the public transport, local flora and fauna before construction starts, natural landscape and features).

2. Building planning and construction stages: (issues like conservation of resources and resource demand reduction, efficient resource utilization, resource recovery and reuse, and occupant health and well-being). The basic resources considered in this section are land, water, energy, air, and green cover (forest or farmlands).
3. Building operation and maintenance stage: (issues of operation and maintenance of building systems and processes, monitoring and recording of energy consumption, and occupant health and well-being, and issues that affect the global and local environment) [GRIHA, (32)].

   A number of buildings have been certified by GRIHA, and that includes various types of buildings such as institutional buildings, data centres, shopping complexes, hospital buildings, residential facilities, and buildings. A few buildings that have been certified by GRIHA are:

- Suzlon – One Earth situated in Pune, Maharashtra and was awarded 5 stars.
- University of Petroleum and Energy Studies situated in Dehradun, Uttarakhand and was awarded 4 stars.
- Gandhi Research Foundation situated in Jain Hills, Jalgaon and was awarded 5 stars.
- smartData Enterprises (I) LTD situated in Nagpur, Maharashtra and was awarded 4 stars.
- JIPMER International School of Public Health (JISPH), situated in Puducherry, has been awarded 4-star GRIHA Provisional Rating.
- Bhamashah State Data Centre, situated in Jaipur, Rajasthan has been awarded 4-star GRIHA Provisional Rating.
- IIM Kozhikode Campus, situated in Kozhikode, Kerala has been awarded 5-star GRIHA Provisional Rating.
- Headquarters Building for Unique Identification Authority of India (UIDAI), situated in New Delhi has been awarded 5-star GRIHA Provisional Rating.
- New Integrated Terminal Building at Tirupati Airport, situated in Tirupati, Andhra Pradesh has been awarded 4-star GRIHA Provisional Rating.

- New Interim Terminal Building (Domestic), Vijayawada Airport, situated in Krishna District, Vijayawada, Andhra Pradesh has been awarded 3-star GRIHA Provisional Rating.
- Software Technology Parks of India - Incubation and Data Centre, situated in Mohali, Punjab has been awarded 5-star GRIHA Provisional Rating.
- BEL Academy for Excellence, situated in Bangalore, Karnataka has been awarded 5-star GRIHA Provisional Rating.
- ITC Mud Fort, situated in Bangalore, Karnataka has been awarded 5-star GRIHA Provisional Rating.
- GAIL (India) Limited Office Building & Regional Gas Management Centre, situated in Navi Mumbai, Maharashtra has been awarded 4-star GRIHA Provisional Rating.
- CISF Group Headquarters, situated in Ahmedabad, Gujarat has been awarded 3-star GRIHA Provisional Rating [GRIHA – Case Studies, (33)].

3.2.2 IGBC

The Indian Green Building Council (IGBC), portion of the Confederation of Indian Industry (CII) was shaped in the year 2001. The council's vision is, "To enable a sustainable built environment for all and encourage India to be one of the worldwide pioneers in the sustainable built environment by 2025".

The Green Building movement in India started when CII-Sohrabji Godrej Green Business Centre building in Hyderabad was awarded with the first and the distinguished Platinum rated green building rating in India. From that point forward, Green Building development in India has gained tremendous momentum throughout the years.

With a modest beginning of 20,000 square feet green built-up area in the country in the year 2003, today (as on 31 May 2020) more than 5,918 Green Buildings projects coming up with a footprint of over 7.17 Billion square feet are registered with the Indian Green Building Council (IGBC), out of which 2,021 Green Building projects are certified and fully functional in India.

Green Building rating system brings together a host of sustainable practices and solutions to reduce its impacts on environment. IGBC has developed various rating systems to cater to the needs of growing building industry that comprises of different types of facilities and buildings that are intended for different purposes. Following are the different IGBC rating systems:

- IGBC Green New Buildings
- IGBC Green Existing Buildings
- IGBC Green Homes
- IGBC Green Residential Societies
- IGBC Green Affordable Housing
- IGBC Green Healthcare
- IGBC Green Schools
- IGBC Green Resorts
- IGBC Green Factory Buildings

- IGBC Green Data Centre
- IGBC Green Interiors
- IGBC Green Service Buildings
- IGBC Green Logistics Parks and Warehouses
- IGBC Green Campus
- IGBC Green Cities
- IGBC Green Existing Cities
- IGBC Green Townships
- IGBC Green SEZs
- IGBC Green Villages
- IGBC Green Landscapes
- IGBC Green Mass Rapid Transit System
- IGBC Green Existing Mass Rapid Transit System
- IGBC Green Railway Stations
- IGBC Health and Well-being

With wide variety of rating systems developed specifically for different types of facilities, the aim to effectively implement green practices can be achieved in a more cohesive manner [IGBC, (34)].

Few of the facilities certified by IGBC are:

- Lucknow Metro – IGBC Platinum Green Rating
- Kochi Metro – IGBC Platinum Green Rating
- Chennai Metro – IGBC Platinum Green Rating
- Hyderabad Metro – IGBC Platinum Green Rating

3.3 RATING SYSTEMS GLOBALLY

3.3.1 LEED

LEED (Leadership in Energy and Environmental Design) is the most widely rating system used worldwide. It is available for all the types of buildings.

In April 1993, Rick Fedrizzi, David Gottfried, and Mike Italiano convened representatives from 60 firms and several non-profits in the American Institute of Architects' boardroom for the founding meeting. It was then that thoughts were shared for an open and adjusted alliance spreading over the entire building industry and for a green structure rating framework, which would later become LEED.

LEED's development took off from the formation of USGBC in 1993 by three individuals: David Gottfried, Mike Italiano and Rick Fedrizzi, who served as president, CEO and founding chair of the organization. By 1998, USGBC had effectively evolved LEED 1.0, and it started pilot testing 19 projects. Following the achievement of the experimental run program, LEED for New Construction saw an open dispatch in March 2000 [LEED, (35)].

3.3.2 BREEAM

BREEAM (Building Research Establishment Environmental Assessment Method), first distributed by the Building Research Establishment (BRE) in 1990, is the world's longest settled technique for surveying, rating, and guaranteeing the sustainability of buildings. In excess of 550,000 structures have been BREEAM-certified and more than 2 million are enrolled for certification in excess of 50 nations around the world.

Work on making BREEAM began at the Building Research Establishment (based in Watford, England, UK) in 1988. The first version for evaluating new buildings for offices was propelled in 1990. An adaptation of BREEAM for new homes called EcoHomes was propelled in 2000. Another significant update in 2011 brought the dispatch of BREEAM New Construction, which is now used to evaluate and certify all new UK buildings [BREEAM, (36)].

3.3.3 DGNB

To make sustainable building work on a practical level, measurable and subsequently tantamount the DGNB has developed its own certification system. This system offers a variety of options for buildings, indoor environments, and districts – not only for new buildings but also for existing ones. The DGNB System is depends on three central components. These set the approach apart from other certification systems in the market:

- Life cycle assessment
- Holistic approach
- Emphasis on performance

With a piece of pie of 80% for new buildings and over 60% for the overall market, the DGNB is the pioneer among organisations offering certification systems in Germany. With regards to the certification of districts, the DGNB is again a pioneer throughout Europe. In excess of 4800 development projects have now been planned, implemented, and certified in approximately 30 nations around the world according to DGNB principles (as of 31 Dec 2018) [DGNB, (37)].

3.3.4 Green Star

Propelled by the Green Building Council of Australia in 2003, Green Star is Australia's only national, willful rating framework for buildings and communities. The Green Star rating system assesses the sustainability of projects at all phases of the built environment life cycle. Ratings can be achieved at the planning phase for communities, during the design, during the ongoing construction phase of the structure, or during the ongoing operational phase. The system evaluates and certifies buildings, fitouts and communities against a range of environmental impact categories, and aims to encourage leadership in environmentally sustainable design and construction, showcasing new innovations in green building practices, and consider occupant health and well-being, boosting productivity and ensuring savings in operation costs [Green Star, (38)].

As per report released by GBCA in 2013, The Value of Green Star, which analysed data from 428 Green Star-certified projects occupying 5,746,000 million square metres across Australia and compared it to the national building average and minimum practice benchmarks. The findings were, on an average, Green Star-certified buildings produce 62% lesser emissions of greenhouse gas and use 66% less electricity than average Australian building. Around 51% less potable water is utilised by Green star buildings as compared to average buildings. It is also found that Green Star certified buildings recycle 96% of their construction and demolition waste, compared to the average of 58% for new construction projects [GBCA, (39)].

4. Simulation Tools

To meet the ever-increasing demand, the buildings are nowadays are being equipped with more and more complex, efficient systems to meet the thermal comfort of the building occupants and at the same time ensure the well-being and health of the people residing within that facility. To meet these requirements, the systems (HVAC systems, Domestic Hot water systems, lighting systems, Building Envelope) are designed in such a way that they are well incorporated within the building.

To verify whether these systems, qualify for the set level of performance and how do these systems respond to the building behaviour in different weather conditions and to the local environment, an exhaustive analysis of building parameters needs to be carried out. With the advancement of the software industry, it has provided us with the plenty of the opportunities in forecasting the energy performance of the buildings.

The energy simulation software tools can be important for reducing the cost of energy in buildings [Clarke, 2001, (40)]. Energy Simulation software for buildings allow us to:

1. Determine the appropriate size of HVAC systems
2. Analyse energy consumption
3. Calculate the related cost energy

Energy Simulation software offers a range of advantages, one of which being extensive controls over important variables. From controlling the sizing of HVAC systems, and determining the efficiencies (SEERs and EERs) of the systems, to determining the building envelope (U-values of roof and walls), all these parameters can be extensively controlled in order to check and analyse the building performance under varying conditions.

Therefore, manipulating different parameters must be done in accordance with national/international laws or rating systems that prevails in that local region. Hence, all the building systems must abide by those rating systems/laws. An interesting case of Portugal exists wherein requirements of three regulations must be met by designers regarding thermal comfort, namely, the [RCCTE (Regulamento das Caracteristicas Térmicas dos Edifícios - Regulation of Thermal Performance Characteristics of Buildings), 2006, (41)]; the [RSECE (Regulamento dos Sistemas Energéticos e de Climatização nos Edifícios - Regulation of Energy Systems and Climate in Buildings), 2006, (42)] and the [SCE (Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios – National Energy Certification System and Indoor Air Quality in Buildings), 2006, (43)].

Since a number of variables are involved during the energy simulation, the designers nowadays need tools to answer some specific questions. The designers can use the energy simulation software to make some specific choices (pertaining to cooling and heating needs, etc). He can also perform energy simulation of building prior to their construction and give an estimate of the related energy costs.

A building's energy requirements change continuously that is based on various factors such as occupancy, weather, orientation of building, etc. Hence, one can easily see a number of sequences that can be generated by these many variables. The sequence of calculations is done a number of times to simulate an annual operation cycle. At the end, the results of all these repeated operations are compiled to obtain the annual energy consumption and costs.

Following is a list of data that is required:

1. Geographical Location
2. Geometry (Plans, Sections, Elevation)
3. Envelope (Wall, Roof, Window/Fenestration, Overhangs)
4. Internal Loads (Lighting, Daylighting, Occupancy, process loads, etc.)
5. HVAC (Types and controls)

Although an energy simulation program can evaluate the building performance by simulating various controlling parameters simultaneously in various combinations to obtain annual energy consumption and cost.

But still an energy simulation cannot precisely simulate the wide variety of building shapes, equipment's, controls, and conditions. The simulation capabilities of energy analysis programs are being extended constantly; however, they linger behind the most recent improvements in building innovation. For example, the major programs were only recently updated with the ability to simulate window shading features, different types of glazing, variable air volume (VAV) systems, temperature reset controls, variable-flow pumping, thermal storage, etc. If the user is an innovator, he/she will not find a program that easily simulates all the configurations that he/she wants to investigate [Wulfinghoff et.al., 2010, (44)].

An energy simulation program must be capable of a minimum modelling capability that would enable all capable programs to be considered for approval by the adopting authority, while not considering the programs that would not be able adequately account for the energy performance of building under ECBC. Minimum modelling capabilities are:

1. Minimum hours per year
2. Hourly variations
3. Modelling of Glazing
4. Thermal mass effects
5. Number of thermal zones
6. Part-load performance
7. Design load calculations [Wulfinghoff et.al., 2010, (44)]

A number of simulation programs exists that can perform various simulations. For Lighting simulation software's such as Radiance, ECOTECT, can be used. Each of them comes with their own set of advantages and they provide platforms to perform various types of simulation.

EnergyPlus is also one of the building energy simulation programs for modelling building heating, cooling, lighting, ventilating, and other energy flows. It is set up on most popular features and capabilities of BLAST and DOE-2 but also includes many innovative simulation capabilities such as time steps of less than an hour, multi-zone air flow and photovoltaic systems. EnergyPlus is a stand-alone simulation platform without a “user friendly” graphical interface. Other simulation programs include eQUEST and Visual DOE that are also used to run the DOE-2 simulation engine to perform energy calculations. ECOTECT can also be used to calculate heating and cooling loads for models.

In addition to this, the simulation program must be able to produce hourly reports of energy use by energy source. The simulation program shall be tested according to ASHRAE Standard 140 Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ANSI approved) and the results shall be furnished by the software provider [ECBC 2017, (45)].

Energy modelling and building simulation has become particularly important tool for design, construction and estimating the costs involved. Everyone from architects, designers, engineers, and researchers are applying simulation tools to make important performance-based decisions. Ever wondered “Which is the best building simulation software?”, a question that is difficult to be answered. As all the simulation software have their own strengths and shortcomings. Therefore, to choose a software for working it is better to know the scope of work that a person would be doing and then select a proper energy simulation tool accordingly.

A list of energy simulation software’s that are widely used by architects, engineers and consultants include:

- eQuest
- EnergyPlus
- Ecotect
- Trane Trace
- IES<VE> [Benjamin Skelton, 2011, (46)]

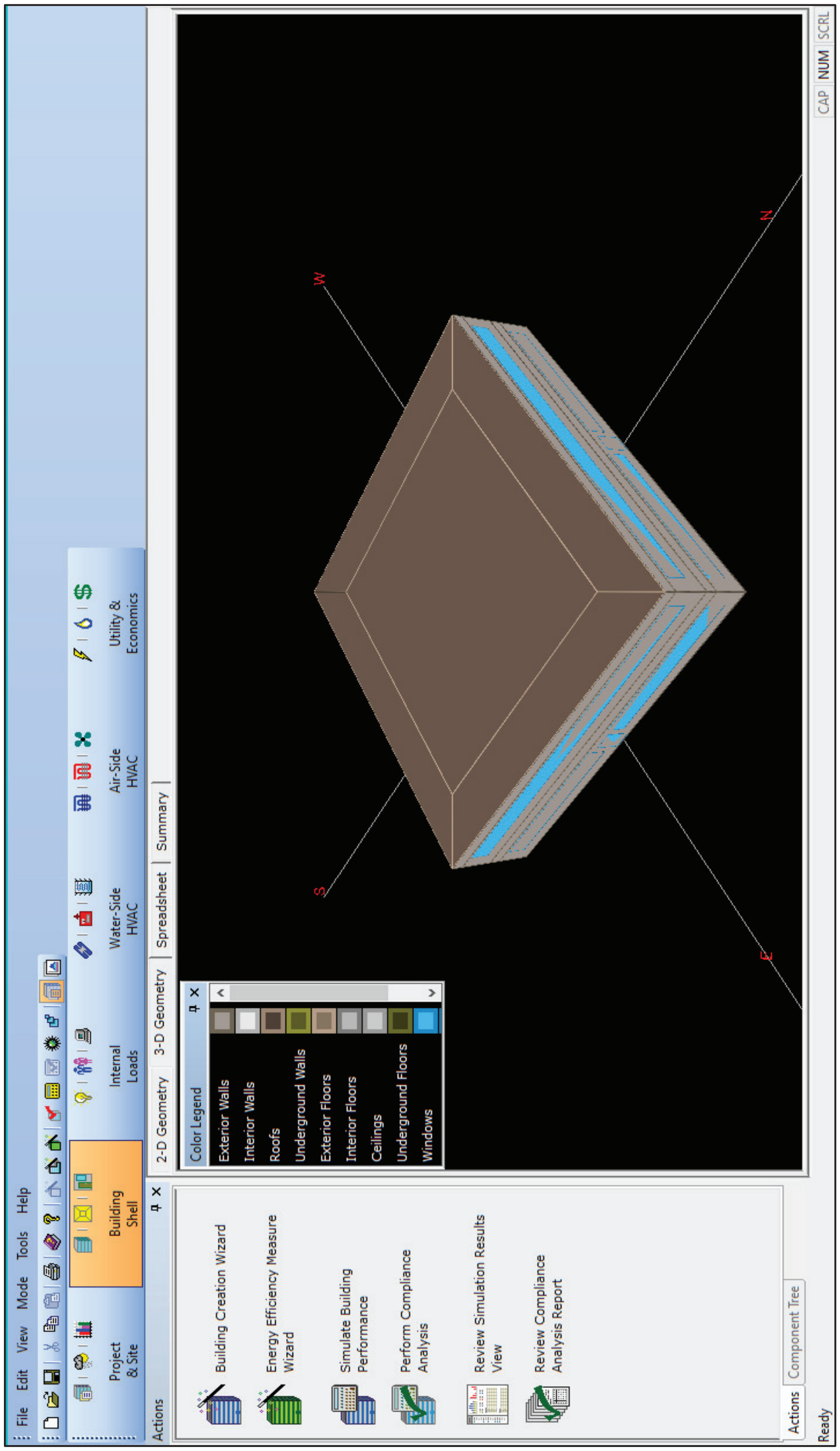


Figure 6 - Interface of eQuest

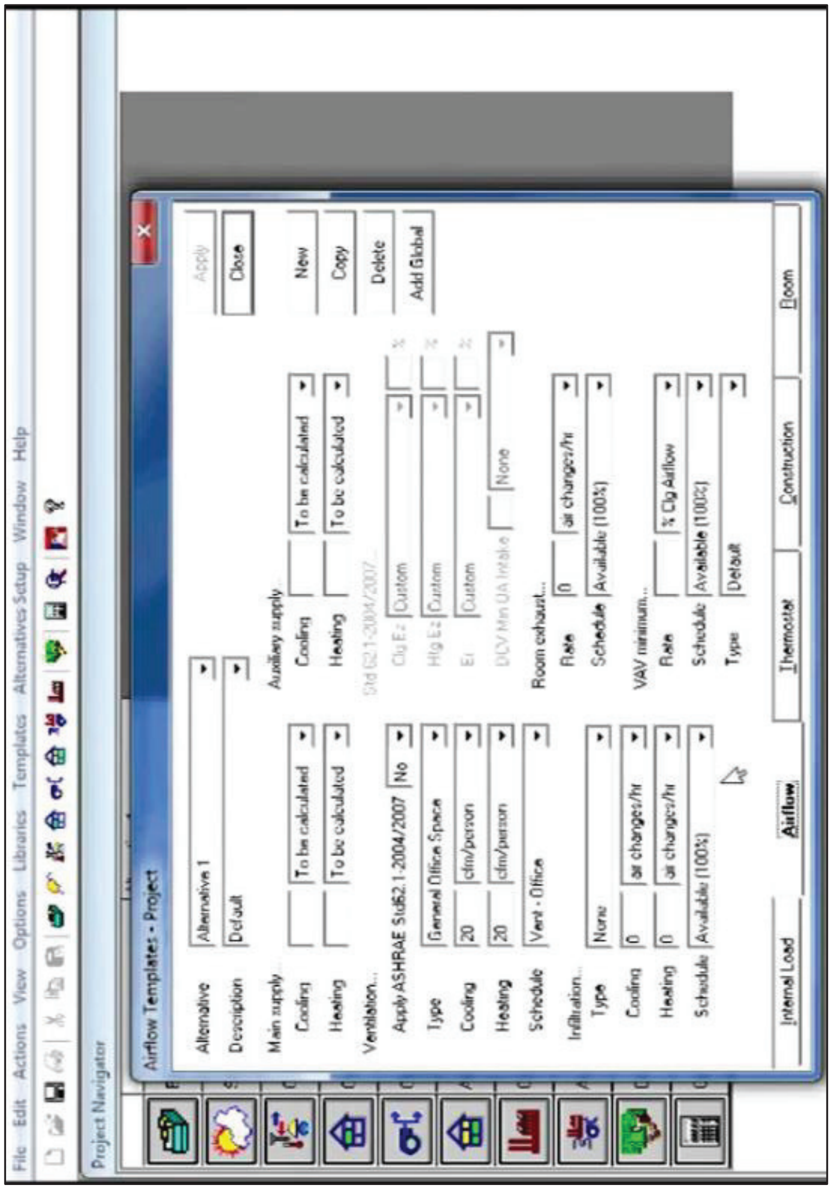


Figure 7 - Interface of Trace

5. Climate Zones in India

Indian subcontinent has been divided into five climate zones:

- Hot and Dry
- Warm and Humid
- Temperate
- Composite
- Cold

Areas having comparable characteristic highlights of a climate are grouped under one climate zone.

5.1. Importance of Climate Zones

Climate Zone plays a crucial role in determining the building envelope. As building envelope requirements as per ECBC are based on climate zones. In view of the characteristics of each climate, the thermal comfort prerequisites and their physical indication in building structure are likewise different for each climate zone. [ECBC – User Guide, 2011, (47)]

For instance, the heat gain through fenestration, and building envelope (walls and roof) depends on the climate zone in which the subject building is located. Hence, the major differences in the climatic data would translate into unique requirements for thermal comfort of buildings.

As such one can easily tell the different set-points that are needed to be maintained for achieving the thermal comfort that is required in that particular region. Also, the use of materials for fenestration (roof and walls) will also change significantly as per the climate that is prevailing in that local region. Controlling the parameters that effect the thermal effort also includes proper ventilation systems, sensors for humidity controls and CO2 levels.

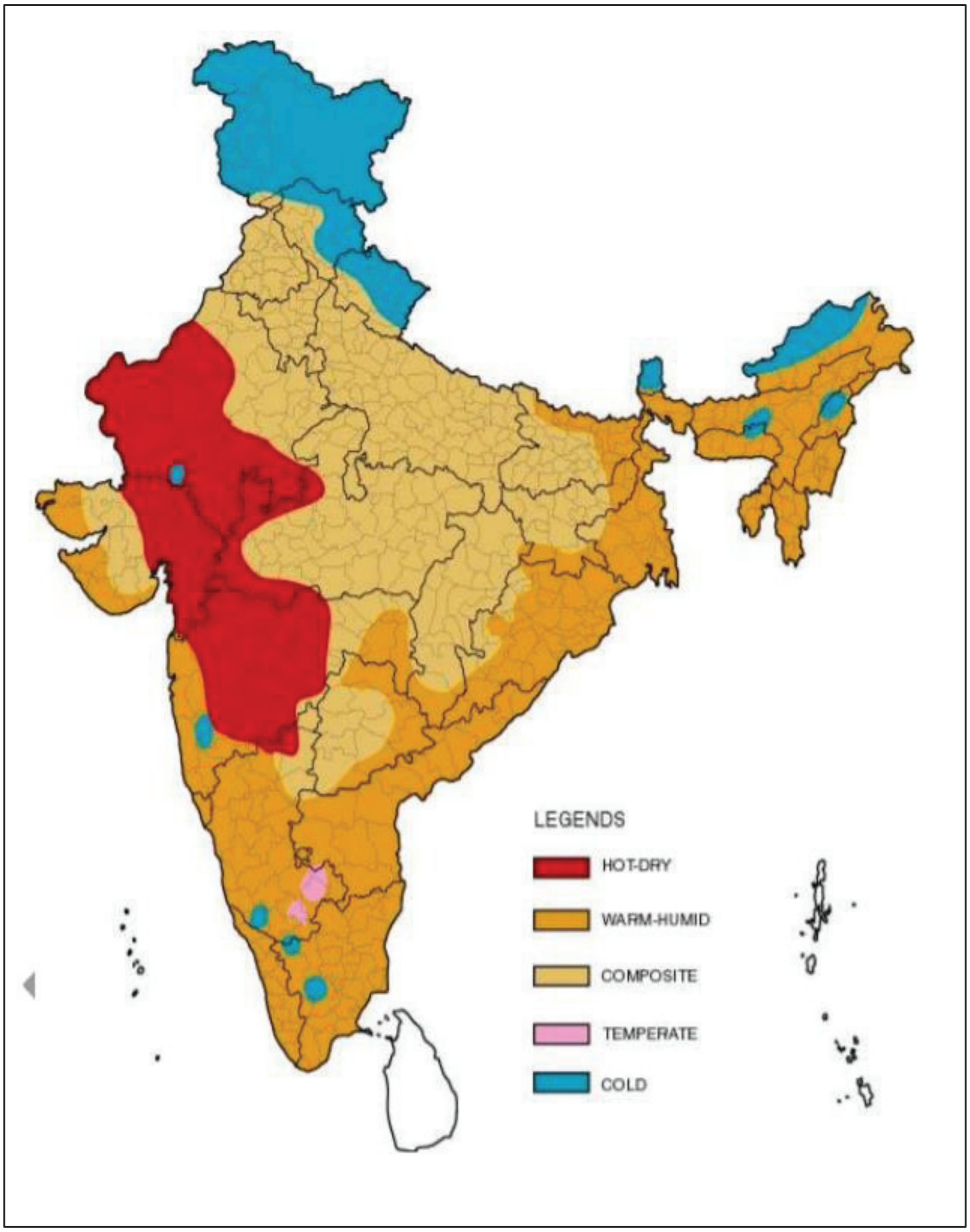


Figure 8 - Climate Zone Map of India [ECBC 2017 – Appendix B, (45)]

City	Climate Type		City	Climate Type
Ahmedabad	Hot and Dry		Kurnool	Warm and Humid
Allahabad	Composite		Leh	Cold
Amritsar	Composite		Lucknow	Composite
Aurangabad	Hot and Dry		Ludhiana	Composite
Bangalore	Temperate		Chennai	Warm and Humid
Barmer	Hot and Dry		Manali	Cold
Belgaum	Warm and Humid		Mangalore	Warm and Humid
Bhagalpur	Warm and Humid		Mumbai	Warm and Humid
Bhopal	Composite		Nagpur	Composite
Bhubaneshwar	Warm and Humid		Nellore	Warm and Humid
Bikaner	Hot and Dry		New Delhi	Composite
Chandigarh	Composite		Panjim	Warm and Humid
Chitradurga	Warm and Humid		Patna	Composite
Dehradun	Composite		Pune	Warm and Humid
Dibrugarh	Warm and Humid		Raipur	Composite
Guwahati	Warm and Humid		Rajkot	Composite
Gorakhpur	Composite		Ramgundam	Warm and Humid
Gwalior	Composite		Ranchi	Composite
Hissar	Composite		Ratnagiri	Warm and Humid
Hyderabad	Composite		Raxaul	Warm and Humid
Imphal	Warm and Humid		Saharanpur	Composite
Indore	Composite		Shillong	Cold
Jabalpur	Composite		Sholapur	Hot and Dry
Jagdeshpur	Warm and Humid		Srinagar	Cold
Jaipur	Composite		Sundernagar	Cold
Jaisalmer	Hot and Dry		Surat	Hot and Dry
Jalandhar	Composite		Tezpur	Warm and Humid
Jamnagar	Warm and Humid		Tiruchirappalli	Warm and Humid
Jodhpur	Hot and Dry		Trivandrum	Warm and Humid
Jorhat	Warm and Humid		Tuticorin	Warm and Humid
Kochi	Warm and Humid		Udhagamandalam	Cold
Kolkata	Warm and Humid		Vadodara	Hot and Dry
Kota	Hot and Dry		Veraval	Warm and Humid
Kullu	Cold		Vishakhapatnam	Warm and Humid

Table 1 - Climate Zone for Major Indian Cities [ECBC 2017, (45)]

6. Methodology

Curiosity is a strange thing, one that has helped many people unravel many scientific mysteries that were previously unknown. With the advent of green revolution around the globe, the development of green rating systems that followed, there was loads of information which needed to be sorted out. To have a clearer picture in mind as to why a thing was preferred over its competitors. As such many comparative studies were conducted that aimed at delivering the answers to the questions that many people had, studies that studied all the aspects of the rating systems and compared them with other rating systems that were available locally and globally. This study aims to look at the rating systems from different perspective i.e., green building modules. With this new outlook we aim to decipher what we stand to achieve with either of the rating systems by complying the same building through different green building rating systems that are available.

6.1 IGBC

The first compliance that we are going to show is through IGBC. It is imperative to know that since many comparative studies have been conducted in the past, the aim of this study is to just highlight the subtle difference that may show up in the results obtained through simulation. Though the green building is a major and vast subject consisting of many modules, our focus will be on "Energy" criteria wherein energy optimization or energy efficiency will be our aim.

As such energy modelling simulation of a subject building will be performed by energy simulation program – eQuest. Since, the subject building is a new construction, we will be referring to [IGBC Green New Buildings Rating System v3 – Abridged Reference Guide 2016, (48)]. As discussed earlier the IGBC rating system has been divided into 7 main modules which have some mandatory requirements that needs to be fulfilled and credits which can be opted to increase the number of points in the final certification. Hence, we will concern ourselves to the "Energy Efficiency (EE)" module, its second mandatory requirement – Minimum Energy Efficiency.

Minimum Energy Efficiency

EE Mandatory Requirement 2

Intent - Optimising energy consumption, to reduce ill effects of excessive use of energy on environment.

Compliance Options:

- **Case for Compliance of an Air-conditioned Buildings:**

Design the building to comply with Energy Conservation Building Code (Revised Version May 2008) (or) ASHRAE Standard 90.1-2010 (without amendments) through one of the following approaches:

Option 1 - Performance based approach (Whole building simulation)

Option 2 - Prescriptive approach

The total annual energy consumption of the actual/proposed building shall not exceed the total energy consumption of the baseline, as per ECBC (or) ASHRAE Standard 90.1-2010.

Note:

- Project with multiple buildings (including projects with common basement) must independently meet the Minimum Energy Performance criteria for each building.

- **Option 1 - Performance Based Approach (Whole Building Simulation)**

Showcase the compliance of the performance of the building by whole building simulation, as per the baselines outlined in ECBC (or) ASHRAE Standard 90.1-2010 (without amendments), Appendix - G. Simulation is to be carried out at comfort temperatures of 24 + 2˚C.

Notes:

- In tenant-occupied buildings, if air-conditioning equipment are installed by tenants, the developer would mandate the installation of efficient air-conditioning equipment for tenant occupied spaces in tenant agreement, with minimum efficiency requirements (COP/ EER) as per the reference standard/ code.

- In cases where air-conditioning equipment is yet to be installed, the proposed case efficiency during simulation shall be same as the base case.
- In tenant-occupied buildings, if lighting is in tenant scope, the developer would mandate the installation of efficient lighting systems in tenant agreement, with LPD values as per the reference standard/ code.
- In cases where lighting systems are yet to be installed, the proposed case LPD during simulation shall be same as the base case.

❖ **Option 2 - Prescriptive Approach**

The project should meet the applicable criteria as established in prescriptive measures of ECBC (or) ASHRAE Standard 90.1-2010 (without amendments).

6.2 GRIHA

The second compliance that we are going to show is through GRIHA for the subject building – institutional building. As discussed previously the energy simulation will be carried out with the help of an energy modelling software – eQuest. Since, the subject building is a new construction, we will be referring to [GRIHA v.2019 Abridged Manual, 2019, (49)]. The green rating system – GRIHA has been divided into 11 modules consisting of waste management, sustainable building materials, Innovation, performance monitoring, socio-economic strategies, water management, life-cycle cost, sustainable site, energy optimization, construction management, and occupant comfort. To get a building certified as a GRIHA certified green building it must attain a minimum number of points. As such it should comply with all the mandatory requirements, and credits that the project is aiming to achieve.

As discussed earlier, the focus of this study will be optimizing energy usage or energy efficiency. In this study we are more concerned with energy savings/ energy efficiency of the buildings. Therefore, we will be mainly focussing on "Energy Optimization" module, Criterion 7 – Energy Optimization. The "Energy Optimization" criterion that is "Partly Mandatory" has a maximum of 12 points.

Criterion 7: Energy Optimization

Intent – To ensure that the projects are energy efficient by reducing the energy consumption through installation of efficient systems and lighting fixtures and by improving the building envelope.

Mandatory Requirements:

- Ensure that the project demonstrates compliance with the mandatory requirements of ECBC 2017 as per Appendix 3A, Table 1.
- Ensure that the equipment installed in the subject building is either BEE-star labelled or of equivalent performance.
- Ensure that the project meets the GRIHA benchmark for EPI as per Table 2.

Operating Hours	Daytime occupancy	24-hours occupancy						
	5 days a week	7 days a week						
Climate Zones	Institutional	Office	Healthcare Facility	Hospitality	Office	Residential	Retail	Transit terminal
Composite	90	90	250	275	225	70	225	300
Hot and dry	90	90	250	275	225	70	225	300
Warm and humid	90	90	275	275	225	70	225	300
Moderate	75	75	250	250	210	50	210	300
Cold	90	120	275	300	275	100	225	275

Table 2 - GRIHA benchmark for EPI (kWh/sq.m/year) for different building typologies [49]

Credits:

- If the equipment or systems installed are labelled as 3 star or above, 1 point is awarded for that.
- Ensure that heat gain through building envelope meets the GRIHA threshold for peak heat gain, 2 points can be awarded for that.
- Demonstrate that 100% of exterior lighting fixtures (lamp + ballast) meet the luminous efficacy of 80 lm/W, 1 point is awarded for that.

- Ensure that the project demonstrates additional reduction from GRIHA benchmark as per Table 3:

Reduction from GRIHA Benchmark for EPI (x)	Points
0% ≤ x < 10%	0
10% ≤ x < 20%	1
20% ≤ x < 30%	2
30% ≤ x < 40%	4
40% ≤ x < 50%	6
x ≥ 50%	8

Table 3 - Additional reduction from GRIHA benchmark for EPI [50]

7. Input Parameters

For the energy simulation of a building or structure, a set of plans mainly:

- Architectural,
- Mechanical,
- Lighting,
- Plumbing,
- Site details and geographical, are provided to enable the consultant to get the subject building certified by the local/national laws of green building. As such these plans are submitted also acting as a proof to testify the claims of the developer.

All the relevant information including the specifications of HVAC systems that are installed in the building, letter of confirmation of weather these systems with the guidelines as laid down by the competent authority, description of lighting systems that are installed in the subject structure, the specifications of plumbing fixtures that are installed, along with the schematic representation of plumbing fittings and pipes throughout the structure, and detailed description of site.

For this study also, we have enclosed the relevant plans of building for reference, those include:

- Architectural Plans (floor plans and exterior elevation)
- Mechanical Plans
- Lighting Plans

Architectural Plans – Floor Plans

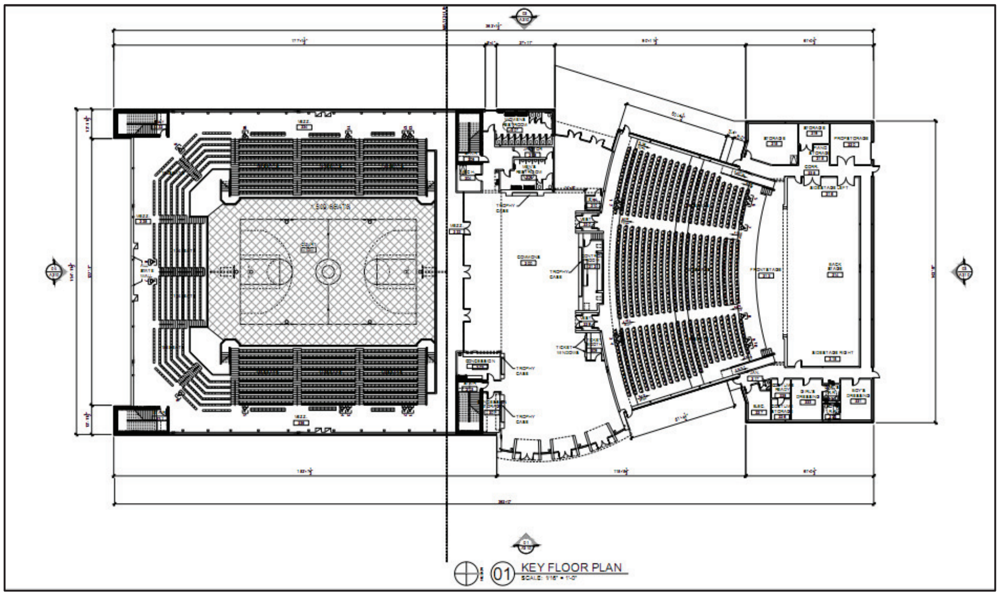
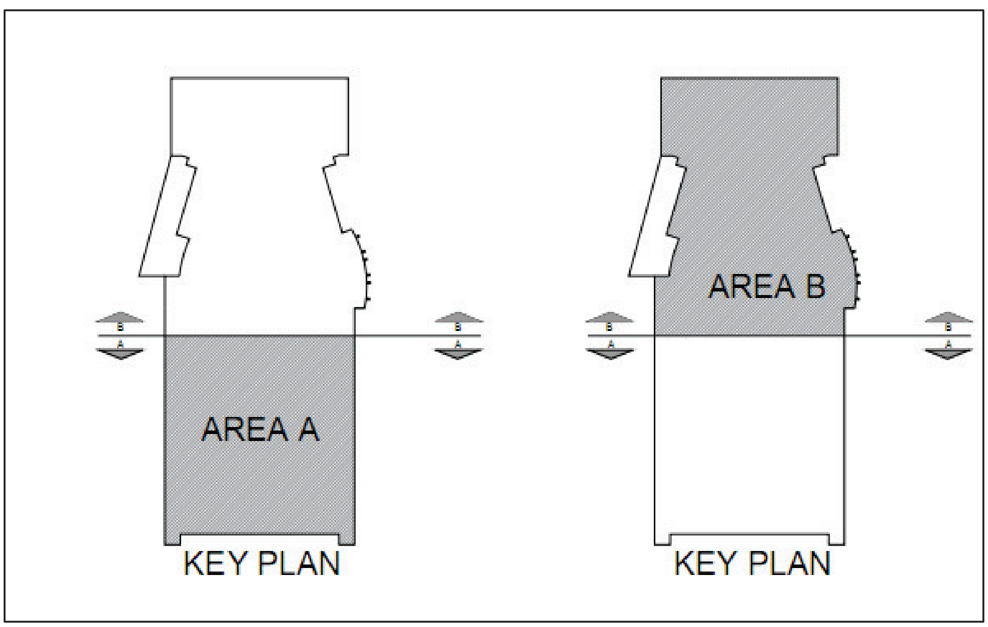


Figure 9 - Key Floor Plan

- Key plan showing different areas of the building:



- The subject building consists of Auditorium, and Gymnasium.
- It comprises of 2 levels in Gymnasium – Lower Level and Upper Level, and Auditorium.
- Area A – Gymnasium
- Area B – Auditorium
- Area of the subject building is 6530 m^2

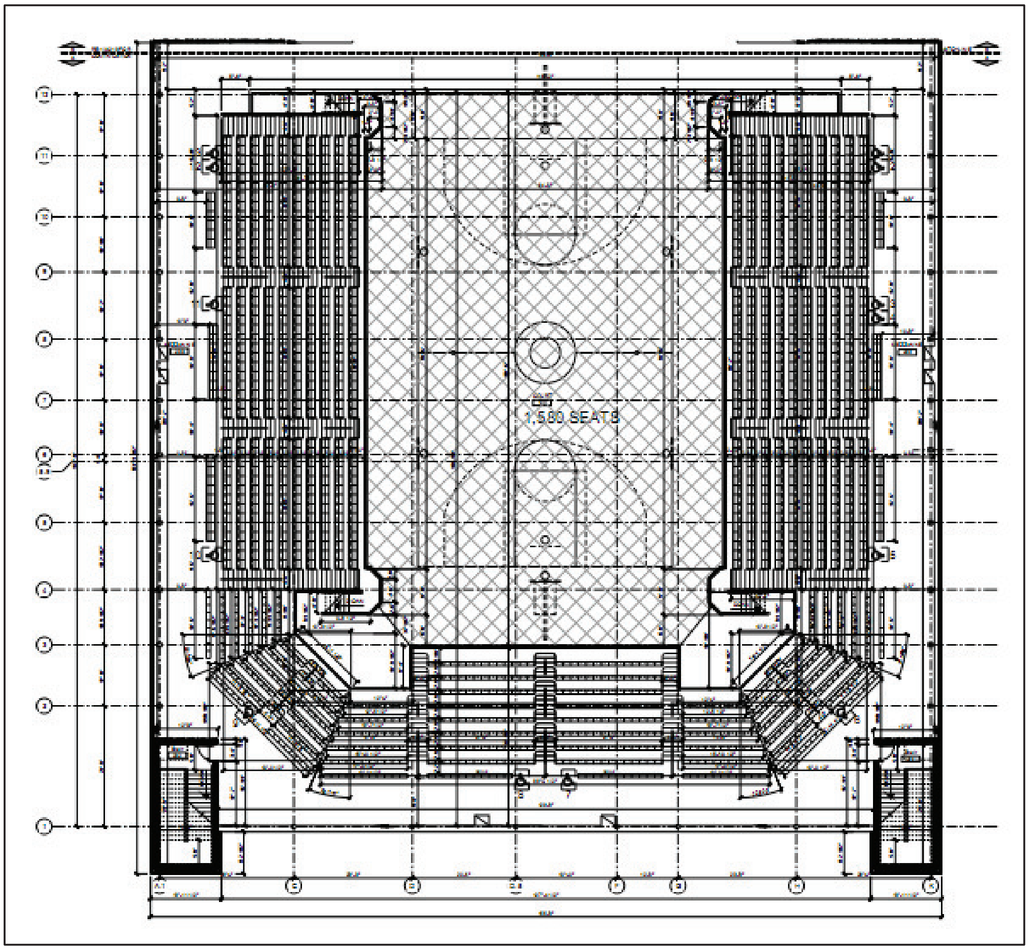


Figure 10 - Area A-Main Level

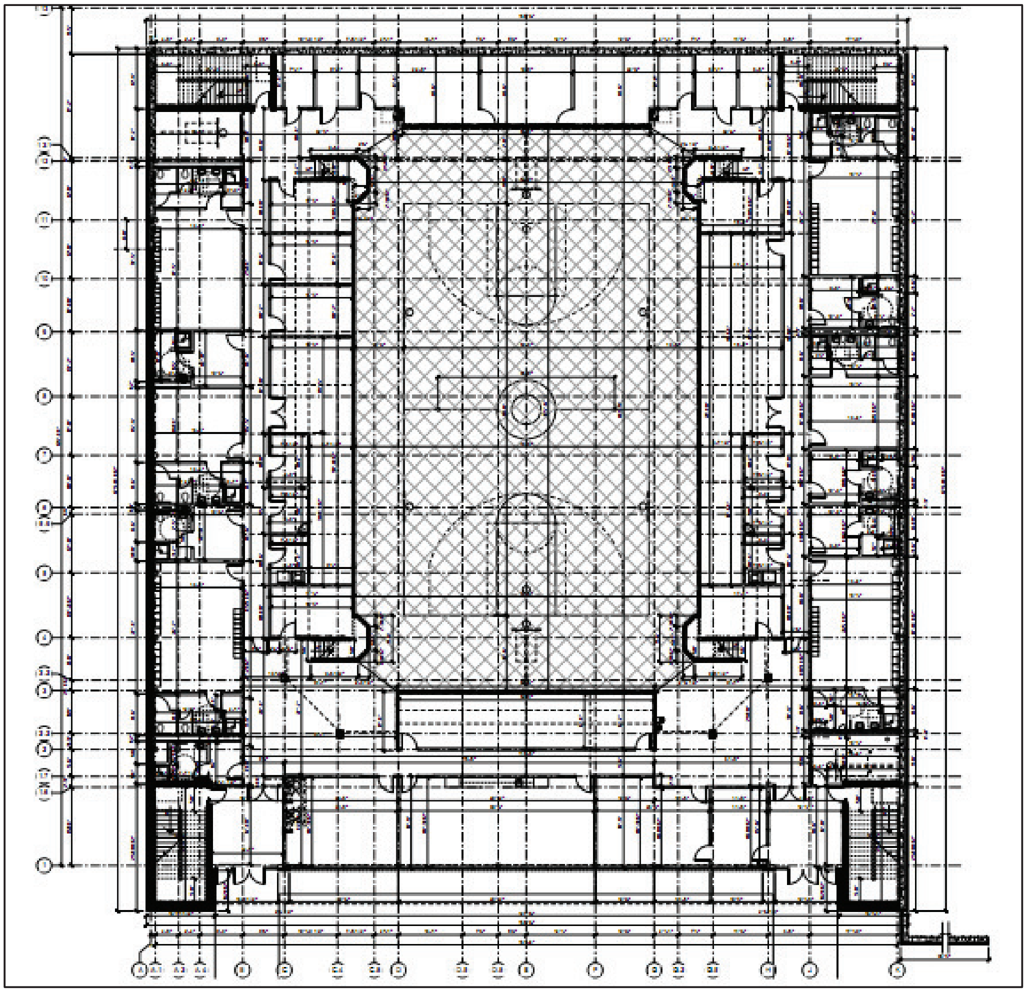


Figure 11 - Area A-Lower Level

- Area A – Gymnasium
- Area B – Auditorium

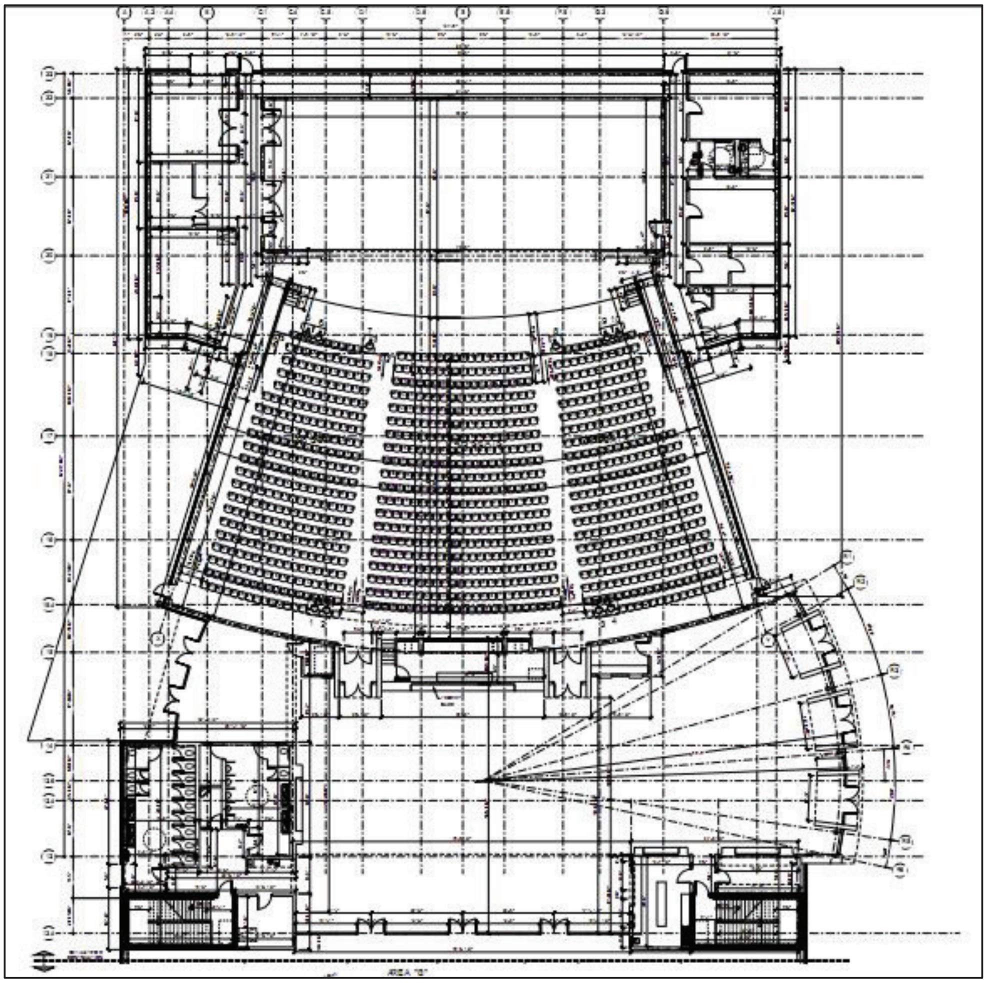


Figure 12 - Area B-Auditorium

Architectural Plans – Elevation Plans

- The following elevation plans shows the elevation of the entire facility.
- Since, the facility is divided in two areas namely – A&B, the enlarged elevation of respective areas are also given.

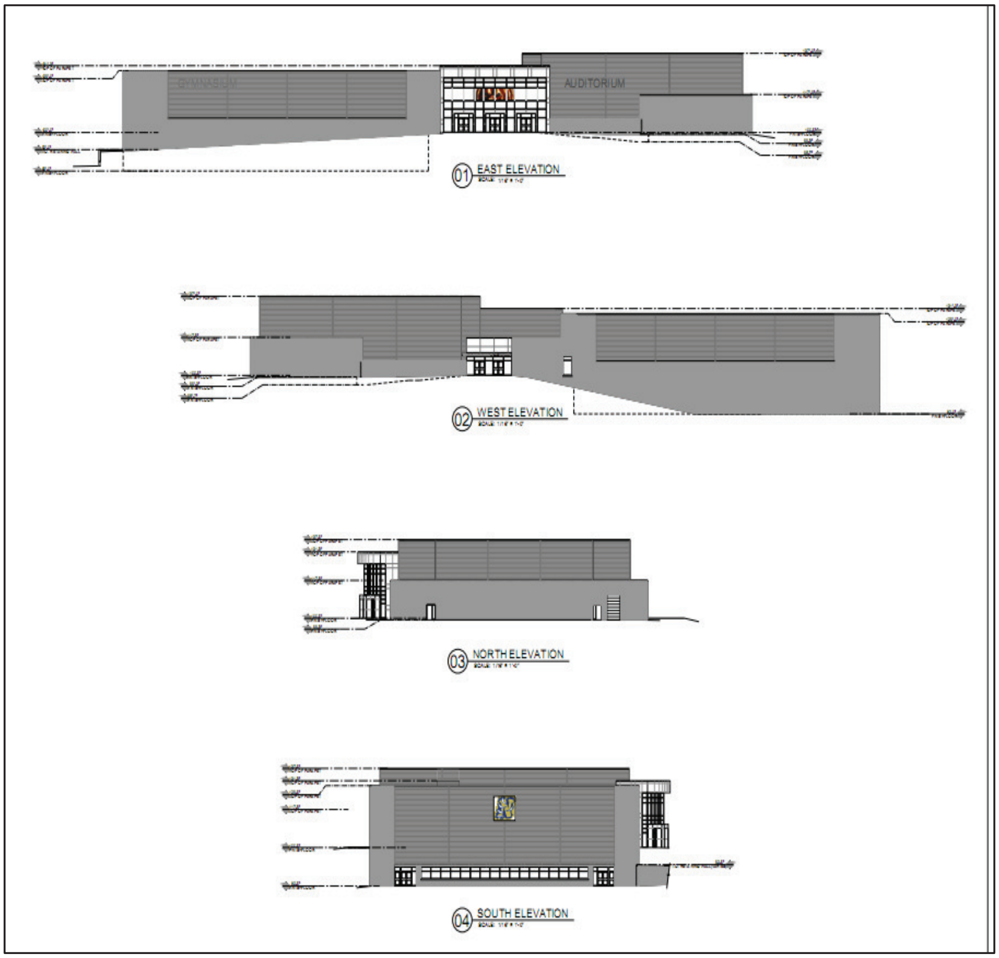


Figure 13 - Elevation-1

- The figure below provides the enlarged elevation (partial view) of the subject building.
- In this figure given below, only east, and south elevation plans are shown with greater details.

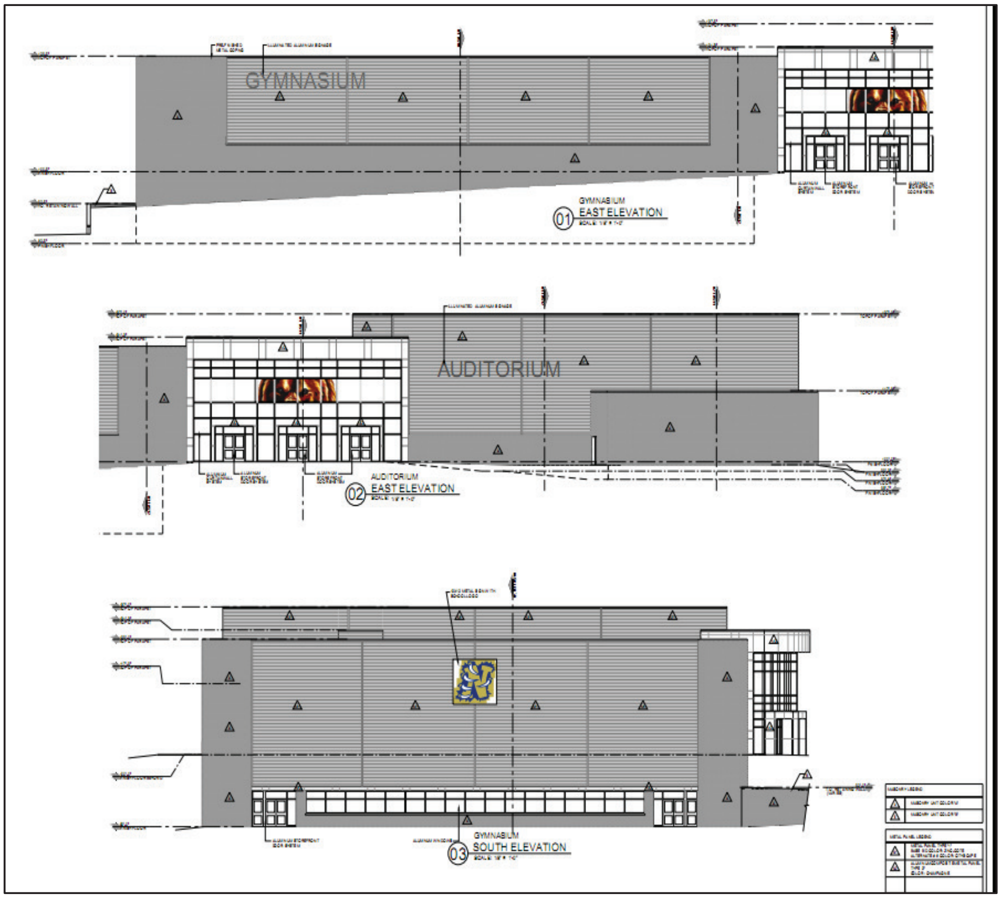


Figure 14 - Elevation-2

- The figure below provides the enlarged elevation (partial view) of the subject building.
- In this figure given below, only west, and north elevation plans are shown with greater details.

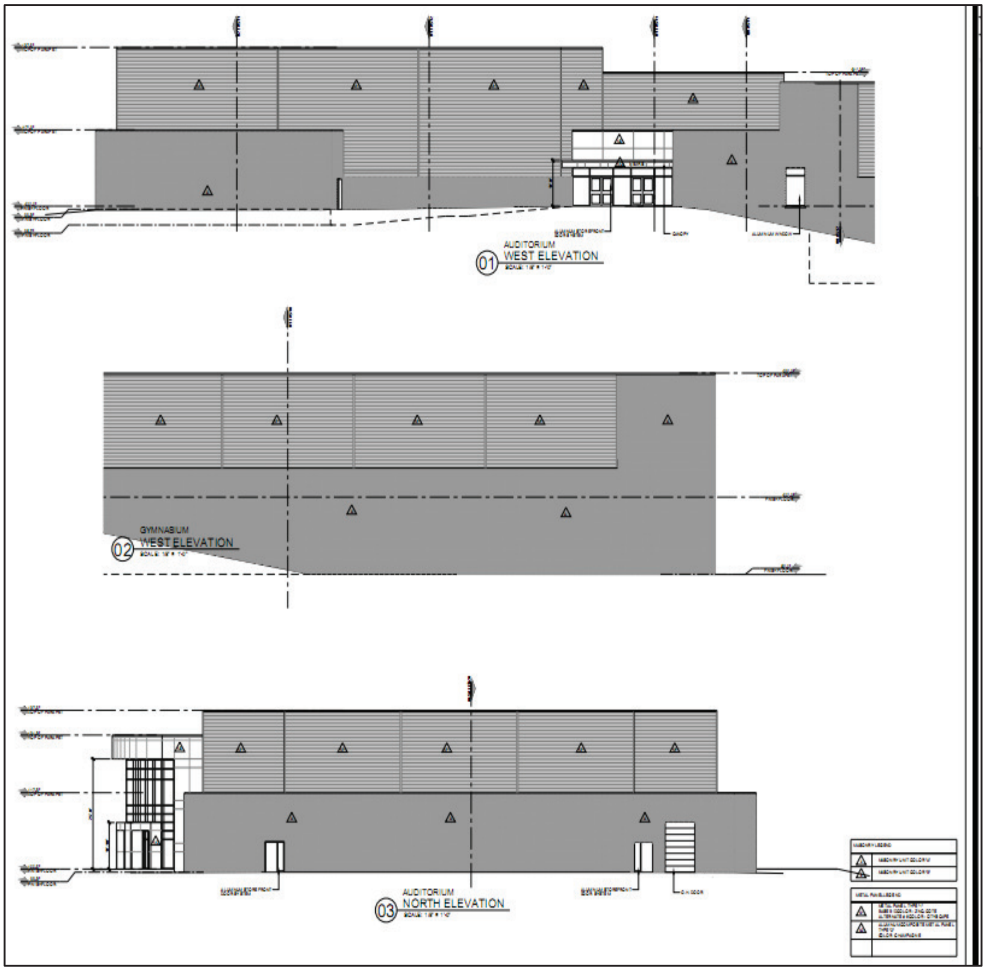


Figure 15 - Elevation-3

Lighting Plans

- LED luminaire and fixtures are installed in this facility.
- Type of lighting fixtures installed are recessed, pendant, cable and wall type.

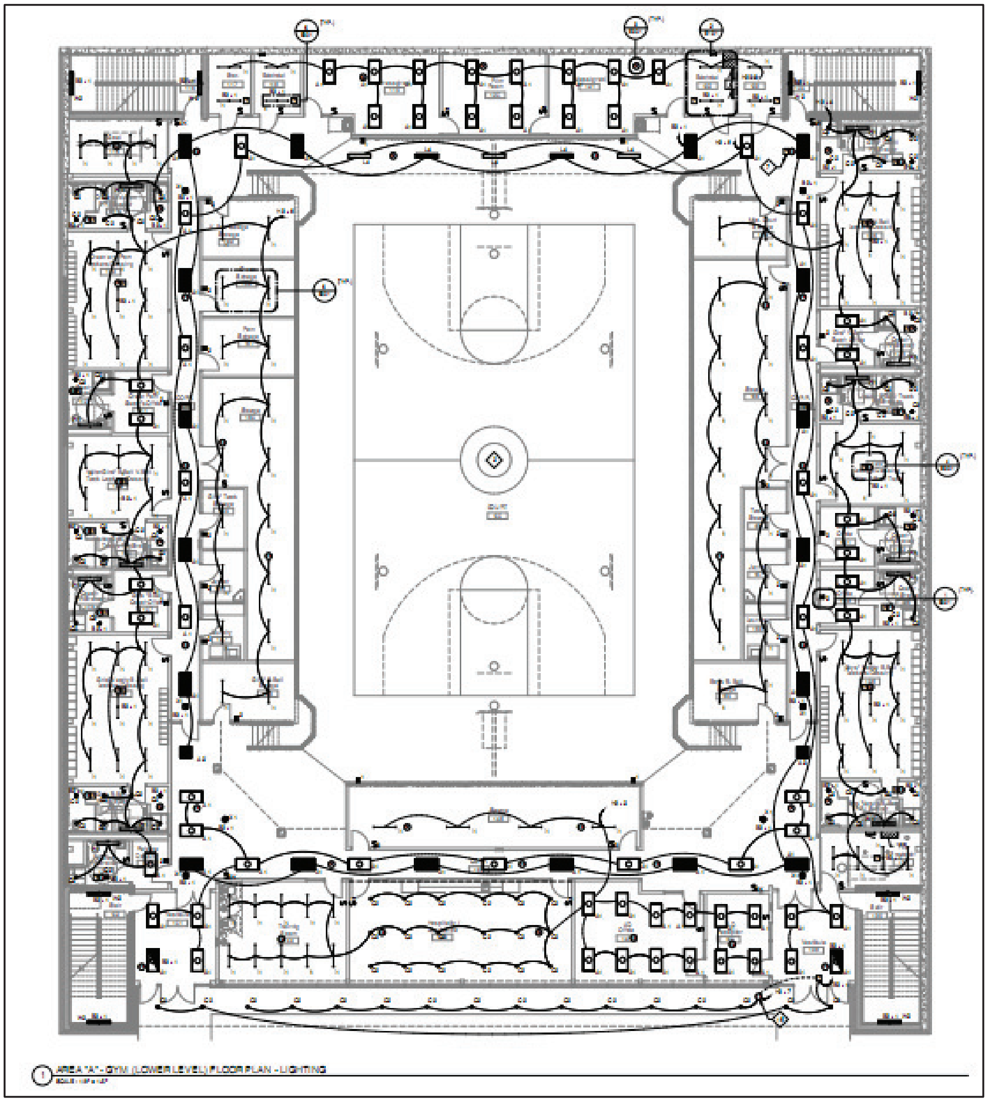


Figure 16 - Area A (Lower Level)-Lighting

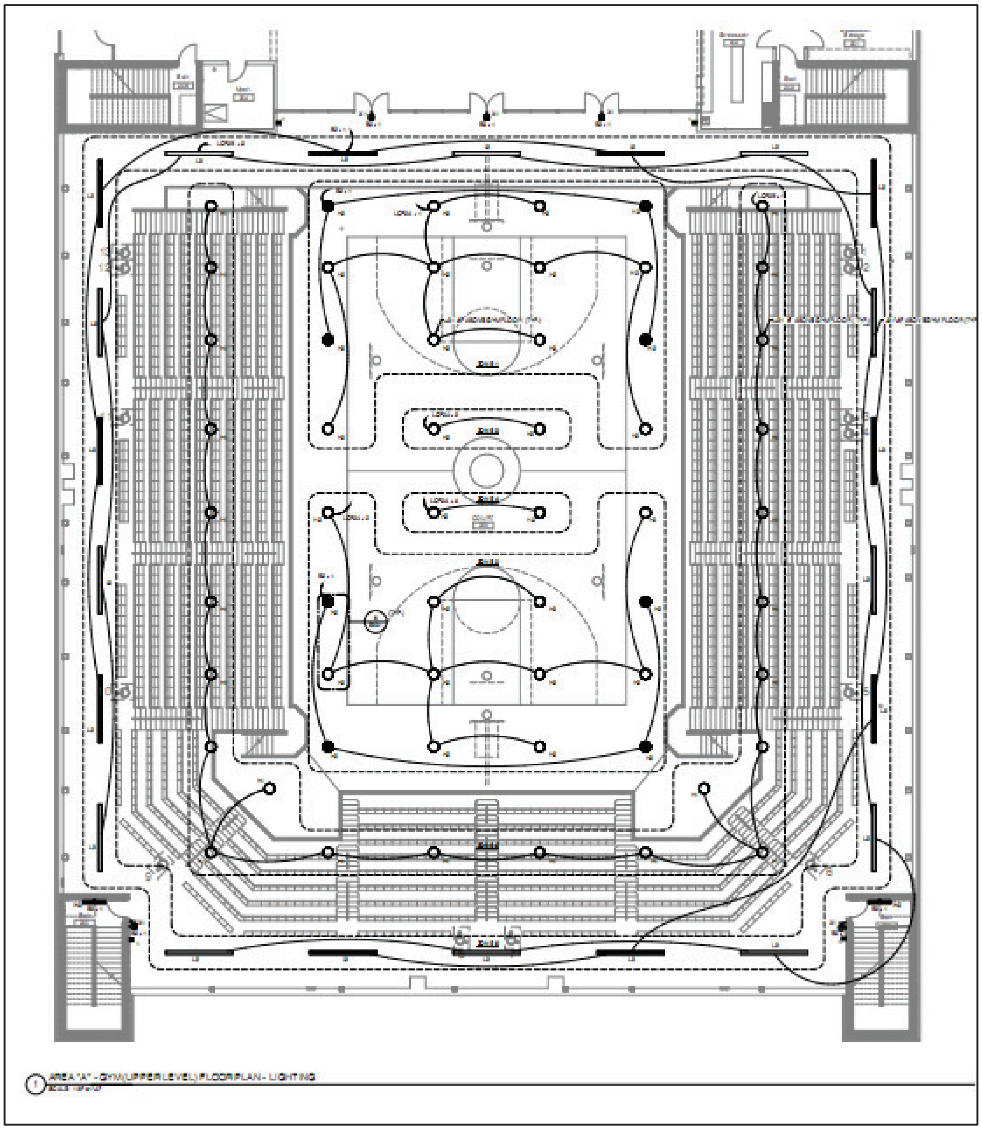


Figure 17 - Area A (Upper Level)-Lighting

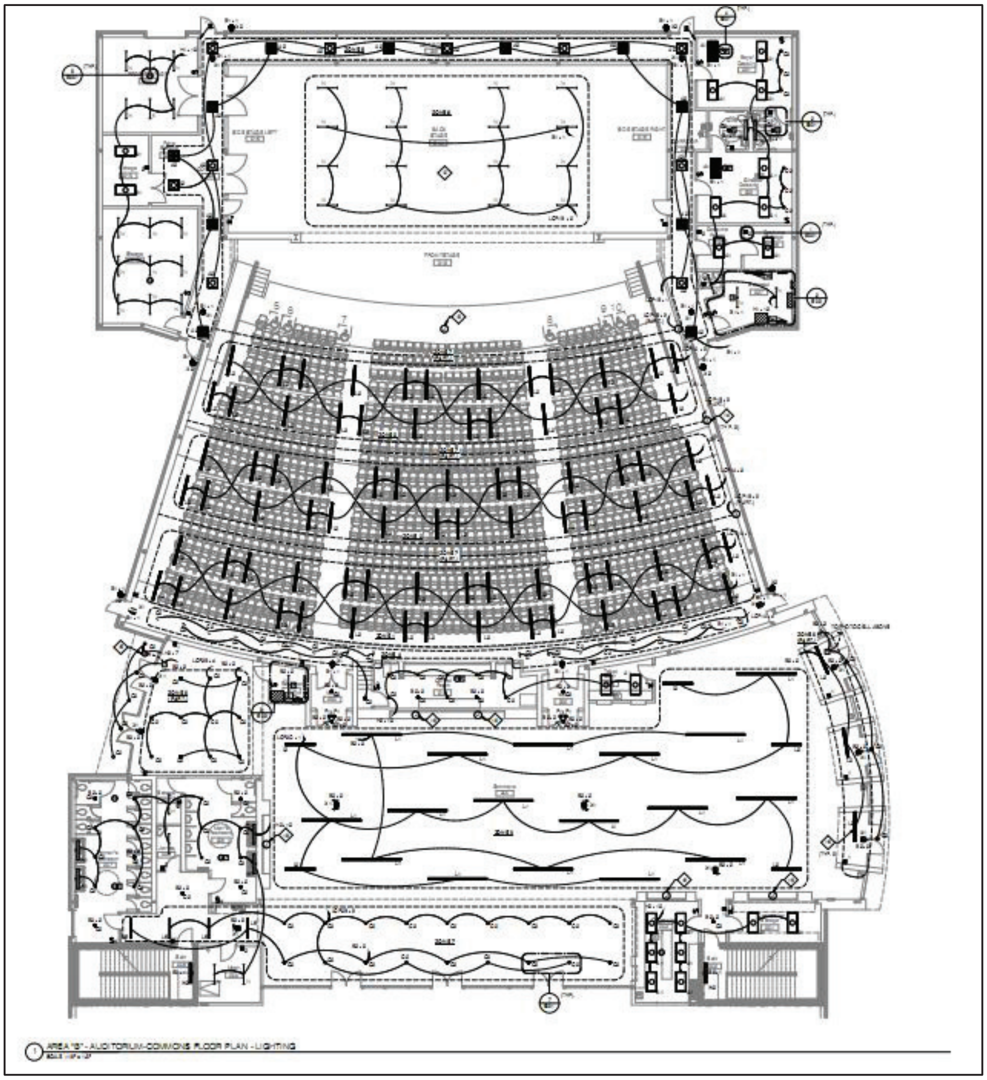


Figure 18 - Area B (Auditorium)-Lighting

Mechanical Plans

- First Floor – Roof Top Units of 80% efficiency are installed.
- Type of Roof Top Units – Gas Fired.

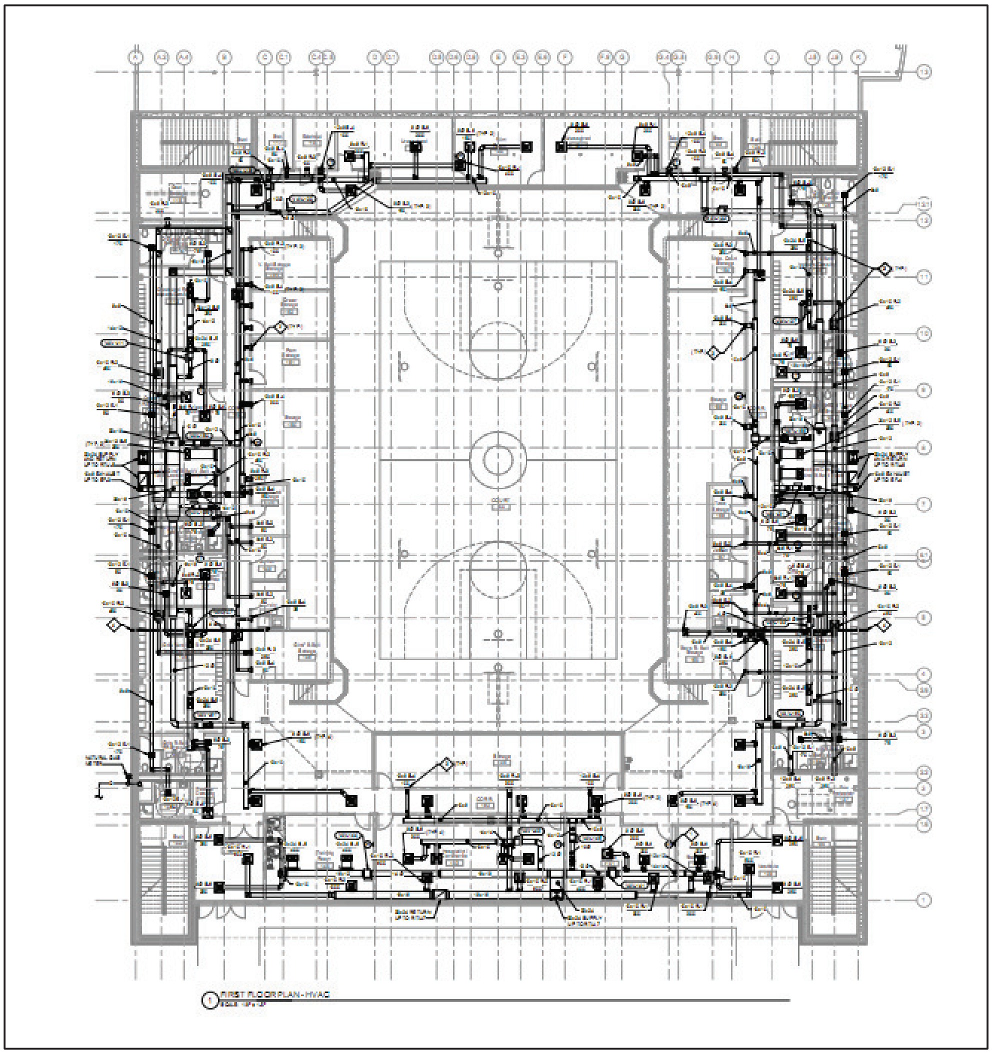


Figure 19 - First Floor Plan (Area A)-HVAC

- Second Floor – Roof Top Units of 80% efficiency are installed.
- Type of Roof Top Units – Gas Fired.

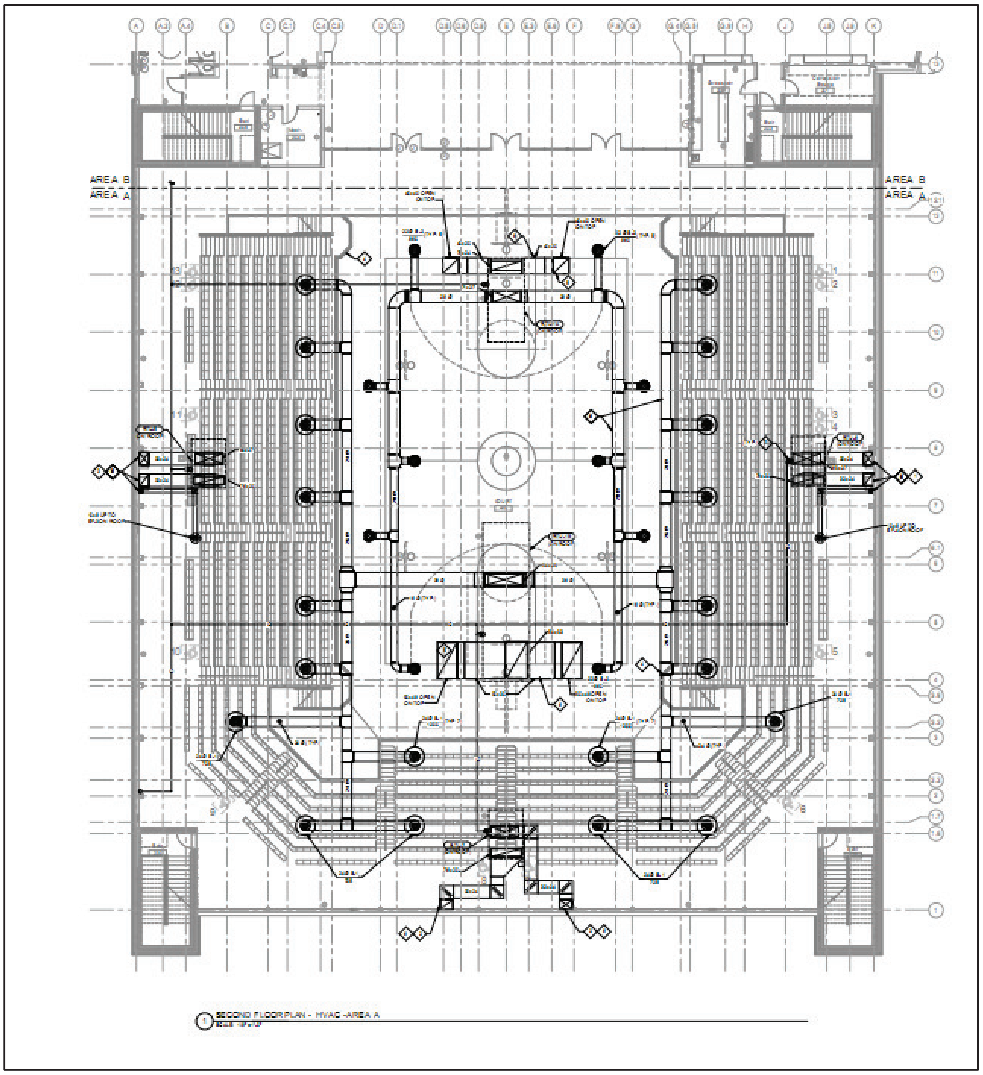


Figure 20 - Second Floor Plan (Area A)-HVAC

- Auditorium – Roof Top Units of 80% efficiency are installed.
- Type of Roof Top Units – Gas Fired.
- Roof Top Units of capacities 1,800 cfm to 20,000 cfm are installed in the facility.

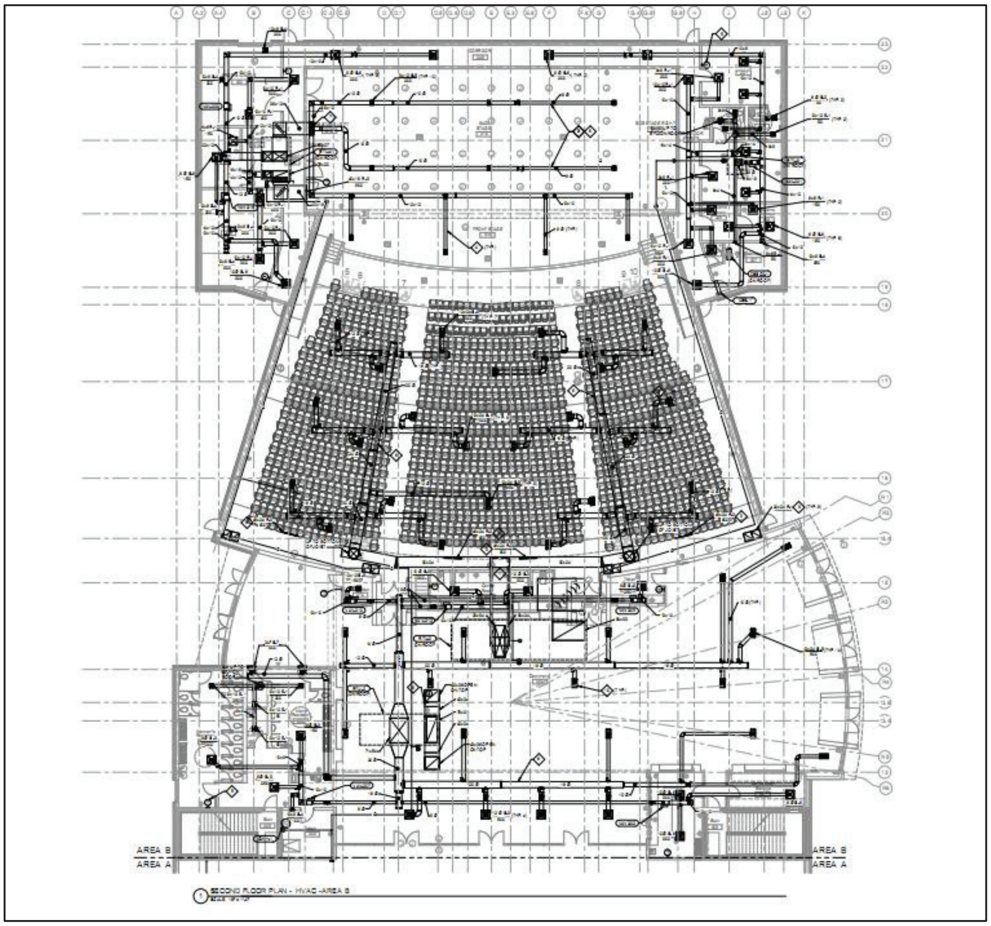


Figure 21 - Second Floor Plan (Area B)-HVAC

8. Results & Discussion

IGBC Results

The building compliance path is through ASHRAE Standard 90.1-2010, Appendix - G (without amendments) through Performance based approach (Whole building simulation). The Simulation was carried out to be carried out at comfort temperatures of 24 $\pm$ 2 deg C.

Consumption Entity	Value
Annual Consumption of the Proposed Simulation Model as per actual construction (kWh)	445551
Annual Consumption of the Baseline Simulation Model as per ASHRAE 90.1 2010 Appendix-G (kWh)	782658
Miscellaneous Equipment consumption in both the Cases which must be deducted from both the models (kWh)	47606
Percentage Savings	46%
Points allotted as per table of 90.1 2010 and IGBC NB Tables for points against savings in Air-conditioned buildings	15

Table 4 - IGBC Results Summarised

- The building simulation requires that a model of the subject (proposed) building be created, not a physical model but a virtual model with the help of a simulation tool/software.
- It should be capable of simulating the important thermodynamic parameters of the proposed building.
- A clear understanding of the operation of the proposed building is essential as it will help improve the overall accuracy of the simulation model. The virtual – proposed model on the software would now behave almost exactly as the real building.

- In this simulation model, annual consumption is to be evaluated. Hence, the energy consumption calculation hour-by-hour over an entire year is done using the weather data of that location where the subject building is located.

The graph below is an output result from the eQUEST 65 software. The unit price is INR 5.25. The dollar ($) value is 70.

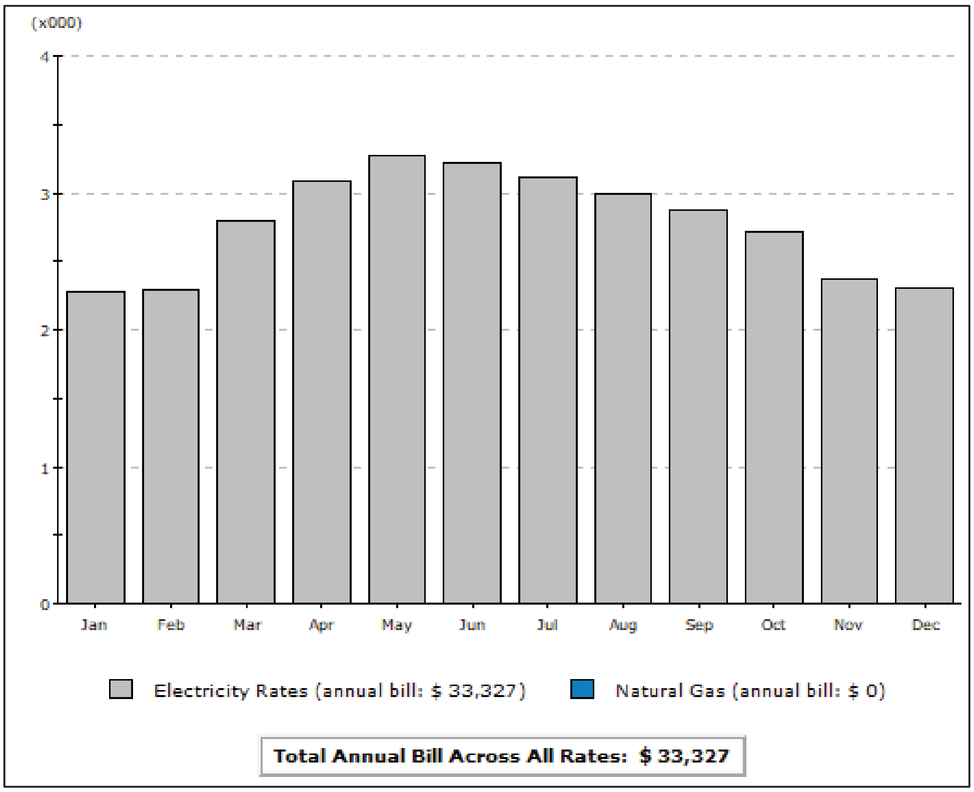


Figure 22 - IGBC Model - Proposed Case Consumption Cost

- Miscellaneous equipment consumption/ process loads must be deducted from both the proposed and baseline model consumption.
- With due diligence, the percentage savings in energy consumption i.e. ((baseline – proposed energy consumption)/ baseline energy consumption) can be calculated.
- With the results in hand, as per IGBC – NB v3.0 Table – Percentage of Energy Cost Savings over ASHRAE Standard 90.1-2010 Base case, the number of points is awarded as per percentage of savings obtained.

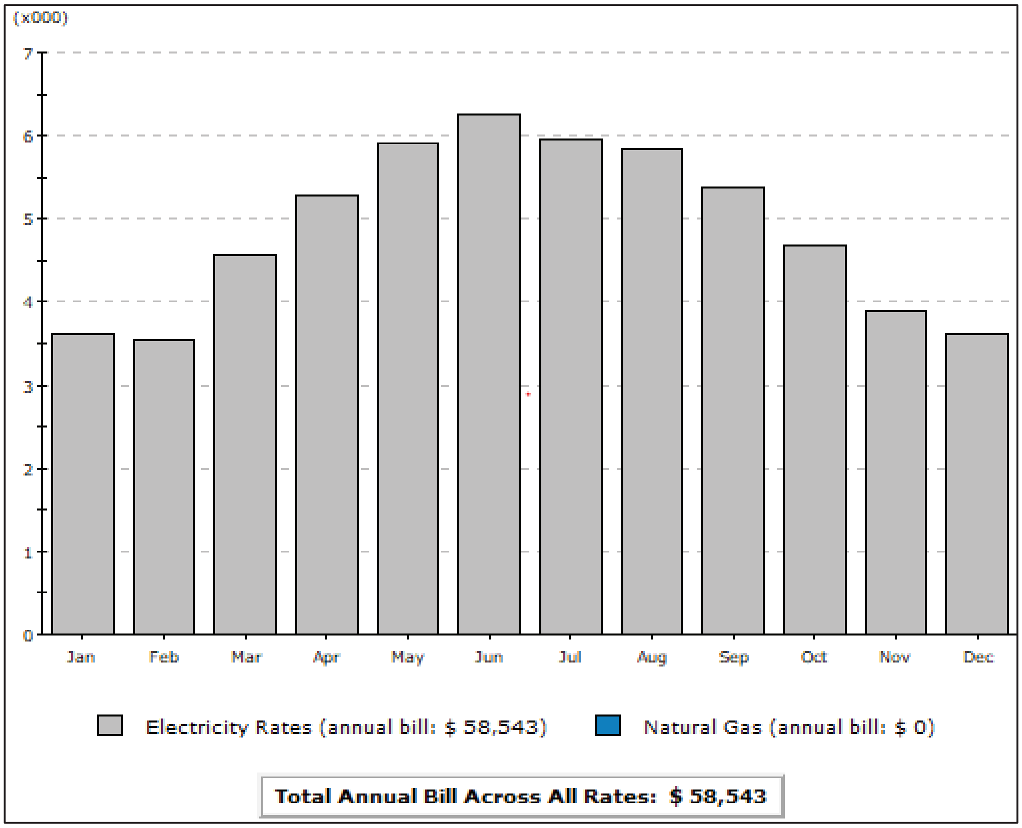


Figure 23 - IGBC Model - Baseline Case Consumption Cost

- As can be clearly seen from the results generated from the simulation, the annual cost of consumption of baseline model is more than the proposed model.
- Hence, the percentage savings are calculated from it. The points are then allotted for the corresponding percentage savings.
- Since, no natural gas is being utilised in the subject facility, the natural gas consumption is equal to zero.
- The annual consumption of the subject facility is mainly due to mechanical systems, electrical systems that are installed in the subject facility that runs on electricity.
- As per IGBC – NB v3.0 Table – Percentage of Energy Cost Savings over ASHRAE Standard 90.1-2010 Base case, considering the percentage savings obtained the points awarded to the subject facility is 15.

GRIHA Results

Consumption Entity	Value
Annual Consumption of the Proposed Simulation Model as per actual construction (kWh)	445551
Miscellaneous Equipment consumption which must be deducted from model (kWh)	47606
Area of the Building (In Square Meter)	6530
Energy Performance Index of the Proposed Building	61
GRIHA 2015 Benchmark for Institutional Building having 8-hour operation in Composite Climate	90
Percentage reduction in EPI in Proposed Building due to Energy Efficient Design & Construction	32
Points awarded to the property in accordance with Table 3.4 of GRIHA Version 2019	4

Table 5 - GRIHA Results Summarised

As stated initially, our aim is to ensure that the projects are developed as an energy-efficient projects that can be achieved by:

1. Enhancing the building envelope performance.
2. Reducing the annual consumption of the building by installing energy efficient HVAC systems.
3. Installing energy efficient LED lighting systems.

- The annual energy consumption is calculated with the help of energy simulation, by simulating the actual energy use as per the plans of the subject building.
- In GRIHA, our aim is to calculate the EPI (Energy Performance Index) of the building.
- Energy Performance Index (EPI) of a building is its annual energy consumption in kW-hr per square meter of the building.

- EPI of a building can be determined by:

  EPI = annual energy consumption (kWh)/total built-up area (excluding unconditioned basements)
- Hence, as per GRIHA benchmark for EPI for an institutional building that has an 8-hour operation in Composite climate has an EPI of 90.
- Therefore, the percentage reduction in EPI can be calculated. The percentage reduction in EPI in this scenario is 32%.
- As per [GRIHA v.2019 Abridged Manual 7.1.5, Table 3.4, 2019, (50)] – the points awarded for the percentage reduction for EPI is 4.

9. Conclusion and Future Scope

The aim of the study was to outline the common denominators and distinct features between the Green Rating Systems that are indigenously developed in India. The spectrum of credits in the rating systems deals with multiple verticals of Building Design, Construction and Commissioning. This study mainly focusses on Energy Related credits.

The common denominators between the two rating systems mainly include Mandatory Compliance with Bureau of Energy Efficiency Standard Energy Conservation Building Code (ECBC) 2017 and Availability of multiple compliance Paths i.e., Whole Building Simulation Approach and Prescriptive Method and/or Building Trade-Off Method.

The ECBC 2017 is an Energy Code developed by the Government of India to set Energy Efficiency Benchmarks for buildings with connected load above 100 kW. The compliance Path for the realization of actual compliance has Whole Building Performance Method and Prescriptive Method.

For the subject building to comply with the Whole Building Performance Method, the estimated annual energy use of the Proposed Design must be less than that of the Standard Design or a subject building complies with the certain code using the Whole Building Performance Method, when the EPI Ratio is less than or equal to 1, bearing in mind that the mandatory requirements of that particular code should be met.

The other compliance path is Prescriptive Method, in this case the subject building complies with the certain code if it meets the prescribed minimum (or maximum) values for envelope components, thermal comfort systems and lighting systems and controls in addition to meeting all the mandatory requirements.

The foremost distinct feature between IGBC and GRIHA Energy Compliance through Whole Building Simulation Approach is that the Baseline/Benchmark to be followed for GRIHA is Based on EPI Calculations for which the Baseline value is a number provided by the GRIHA Council/TERI's empirical results in conjugation with ECBC 2017. For IGBC, the Baseline value reflects Empirical benchmarks set up by ASHRAE/ANSI Standard 90.1 2010 and for path 2, the benchmarks as proposed by the IGBC.

The other distinct feature the author wishes to outline is the percentage of points allotted to the Energy credits in the two Rating Systems. GRIHA has a total of 8 Points [GRIHA v.2019 Abridged Manual 7.1.5, Table 3.4, 2019, (50)] allotted to EPI compliance for Energy Optimization where as IGBC allocates 15 points (as per IGBC – NB v3.0 Table – Percentage of Energy Cost Savings over ASHRAE Standard 90.1-2010 Base case) for Energy Efficiency compliance. An inference may be drawn that GRIHA focuses on multiple aspects of building design keeping Energy Performance (Consumption) at a lower percentage than IGBC but diversifying the scope of overall rating.

As pointed out by earlier [Varma et al., 2019, (5)], a uniform credit structuring and certification levels is lacking. It was also observed that many green building rating systems allocated the high priority to "Energy related" indicators and even among the "Energy related" indicators in different rating systems the points that are allocated varies to a great extent. Hence, a need to establish a uniform credit structure exists to eliminate the differences that arises due to non-uniformity of credit structuring as in many green rating systems the points allocated for a particular credit may vary.

The study conducted here is open to further improvements and can be taken into several directions for research. Many studies that were conducted earlier took the research in many directions and reached a common conclusion. In this study we considered only a single green building criteria "Energy" and compared this criterion with the help of an energy model to outline the subtle distinct features among the two green building systems that were considered.

A complete green building certification considering the indigenously developed green building rating system can be taken up, a comparison can be carried out on the same building and a detailed study can be carried out. A similar study considering the green building rating system for a particular building type can be carried out in different climate conditions. A study in which the green building rating systems that are used globally can also be used for the study and the findings can be based on the same building so as to keep the results uniform. A further variation in this study may include a comparison of different green rating systems that are available globally, a same building type can be used for this comparison that can be carried out in different climatic conditions. Furthermore, a study involving different green building rating systems for different building types can also be taken up. This would lead to the successful creation of the database wherein a large number of data would be available for all the building types in all the climatic conditions that would help identify the subtle differences that may exist in between them.

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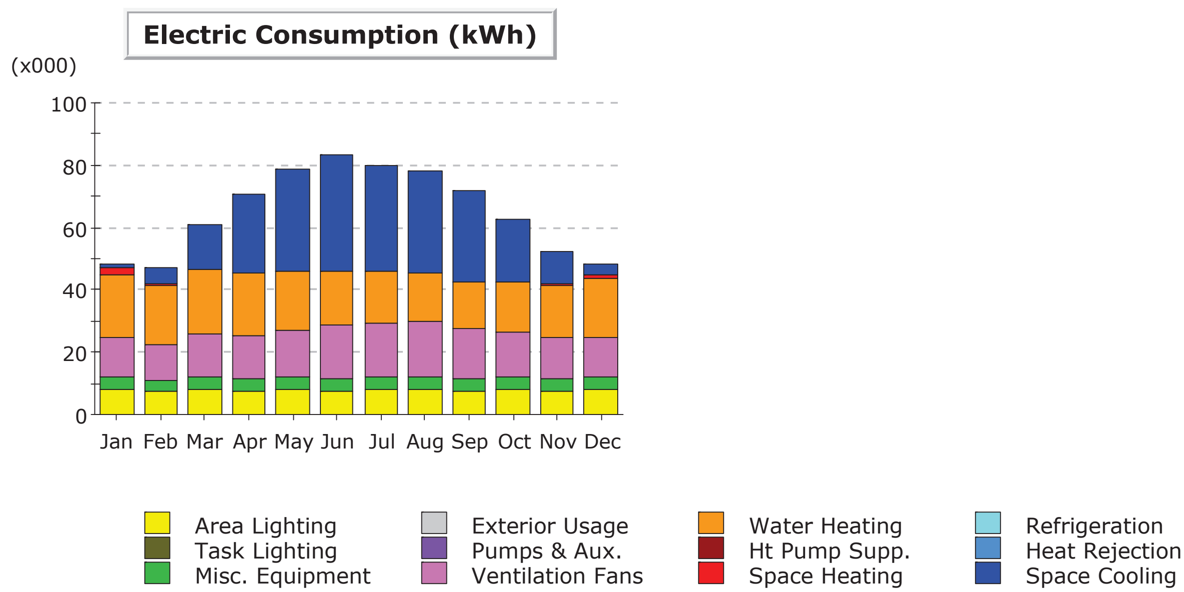
Baseline Consumption - IGBC



Electric Consumption (kWh x000)

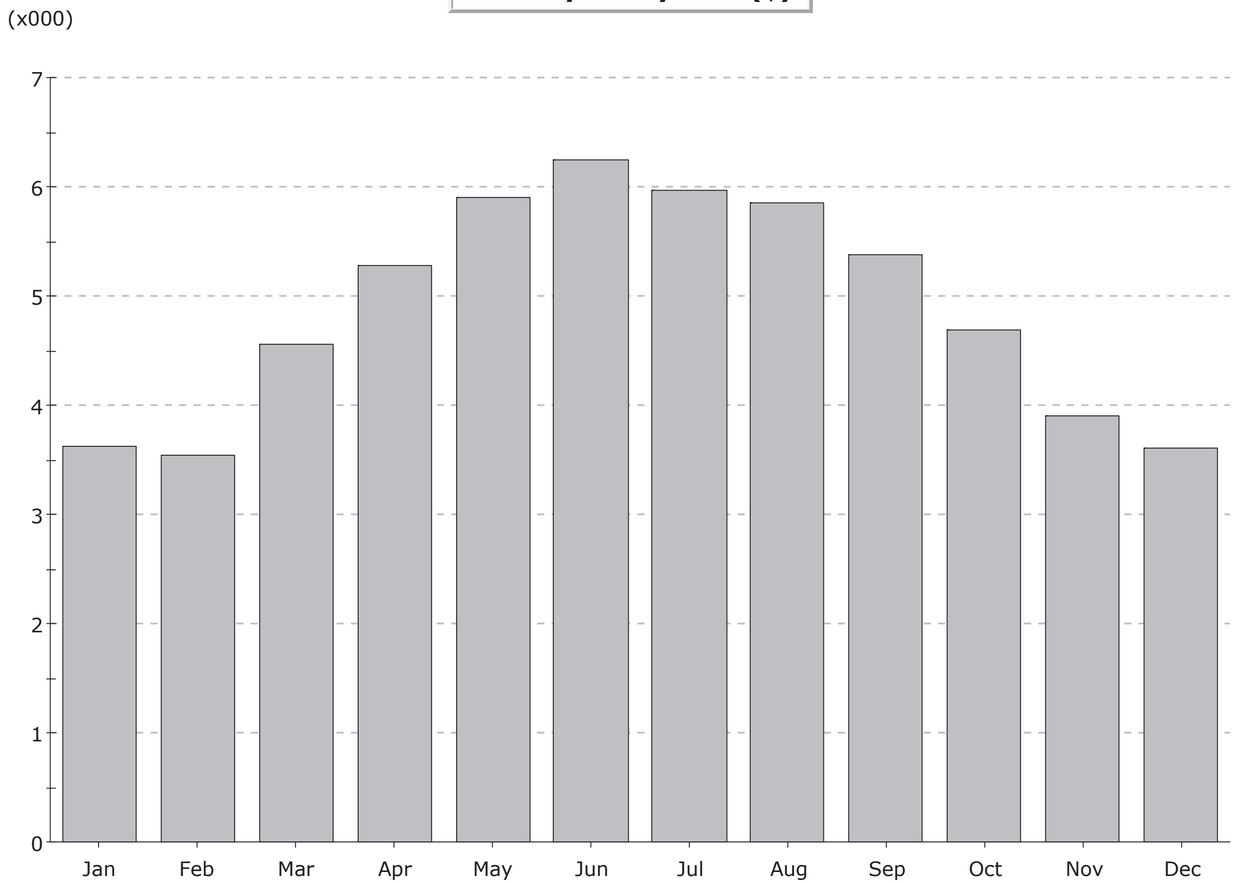
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	1.05	5.59	14.43	25.43	32.65	37.65	33.98	32.71	29.21	20.34	10.47	3.64	247.14
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	2.69	0.35	0.00	-	-	-	-	-	-	0.01	0.09	1.03	4.17
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	20.16	18.85	20.88	19.79	18.98	16.97	16.28	15.50	14.95	16.11	16.82	18.86	214.15
Vent. Fans	12.48	11.60	13.59	13.77	15.22	17.34	17.48	17.90	15.98	14.12	13.11	12.73	175.32
Pumps & Aux.	0.01	0.00	-	-	-	-	-	-	-	-	-	0.00	0.02
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.04	3.65	4.04	3.91	4.04	3.91	4.04	4.04	3.91	4.04	3.91	4.04	47.61
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	8.01	7.23	8.01	7.75	8.01	7.75	8.01	8.01	7.75	8.01	7.75	8.01	94.26
Total	48.45	47.27	60.95	70.65	78.90	83.61	79.78	78.16	71.80	62.63	52.14	48.30	782.66

Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

Baseline Cost - IGBC

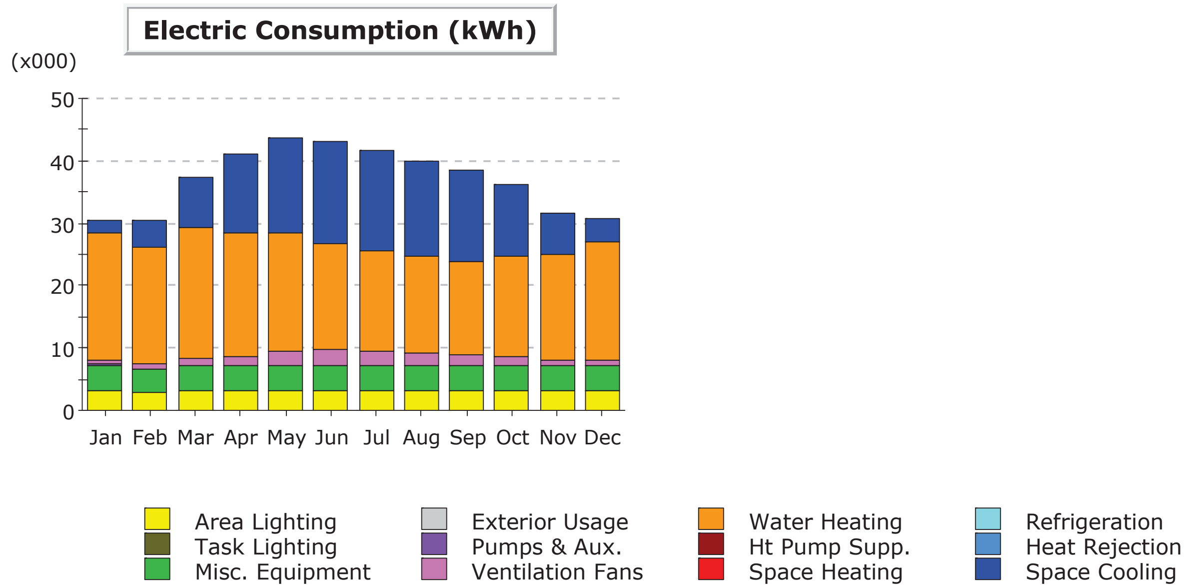
Monthly Utility Bills ($)



Electricity Rates (annual bill: $ 58,543) Natural Gas (annual bill: $ 0)

Total Annual Bill Across All Rates: $ 58,543

Proposed Consumption - IGBC



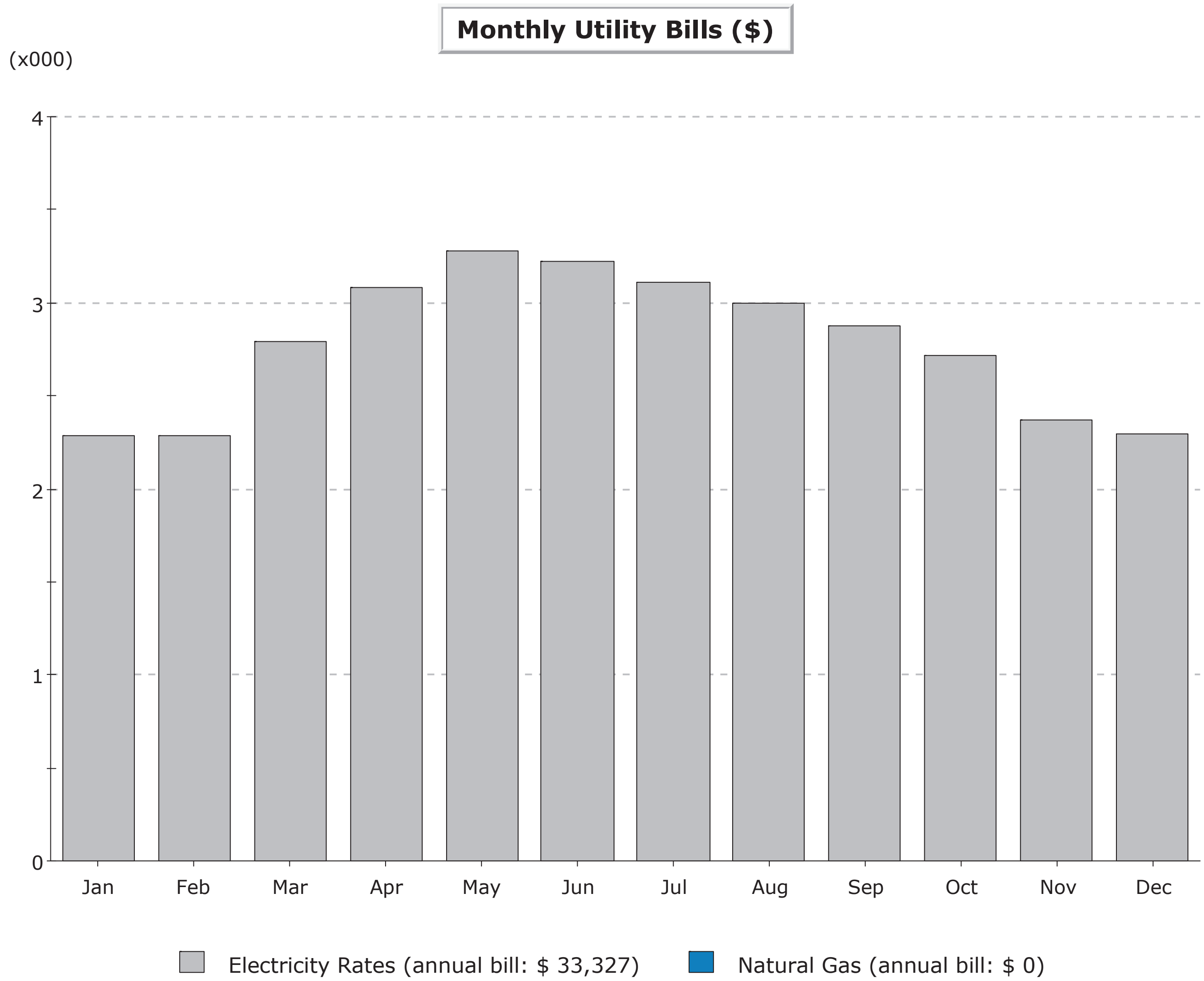
Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	2.19	4.30	8.08	12.88	15.45	16.48	15.98	15.33	14.63	11.50	6.79	3.72	127.33
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	20.16	18.85	20.88	19.79	18.98	16.97	16.28	15.50	14.95	16.11	16.82	18.86	214.15
Vent. Fans	0.83	0.83	1.15	1.49	2.10	2.62	2.07	1.96	1.87	1.45	1.05	0.86	18.29
Pumps & Aux.	0.07	0.01	-	-	-	-	-	-	-	-	-	0.02	0.09
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.04	3.65	4.04	3.91	4.04	3.91	4.04	4.04	3.91	4.04	3.91	4.04	47.61
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	3.23	2.92	3.23	3.13	3.23	3.13	3.23	3.23	3.13	3.23	3.13	3.23	38.08
Total	30.53	30.56	37.38	41.20	43.81	43.12	41.61	40.07	38.50	36.34	31.70	30.74	445.55

Gas Consumption (Btu)

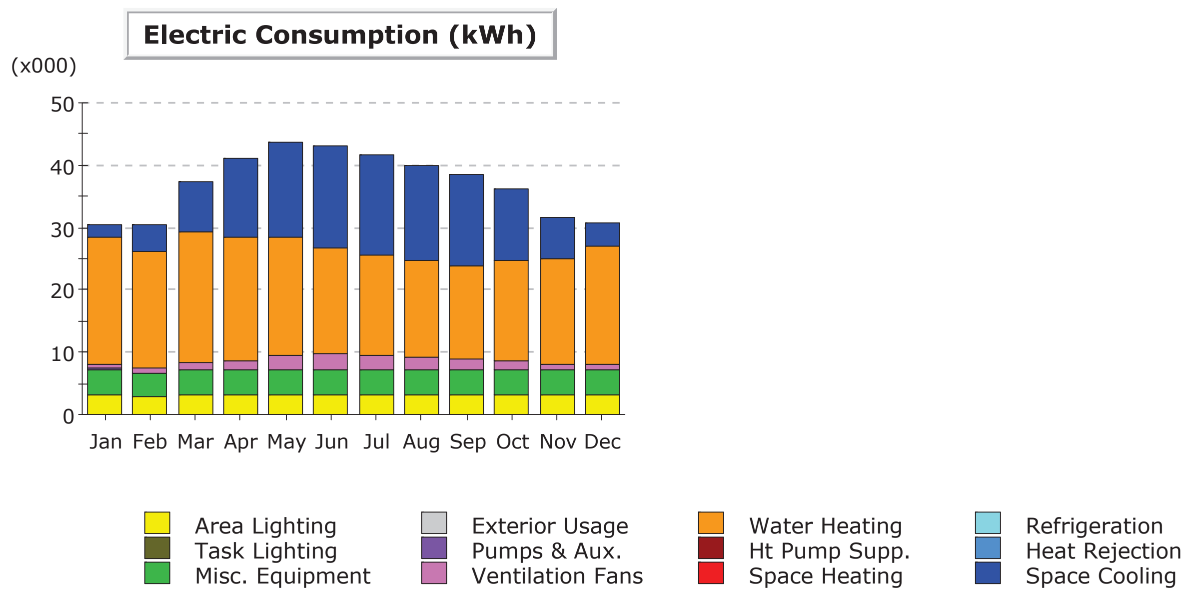
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

Proposed Cost - IGBC



Total Annual Bill Across All Rates: $ 33,327

Consumption - GRIHA



Electric Consumption (kWh x000)

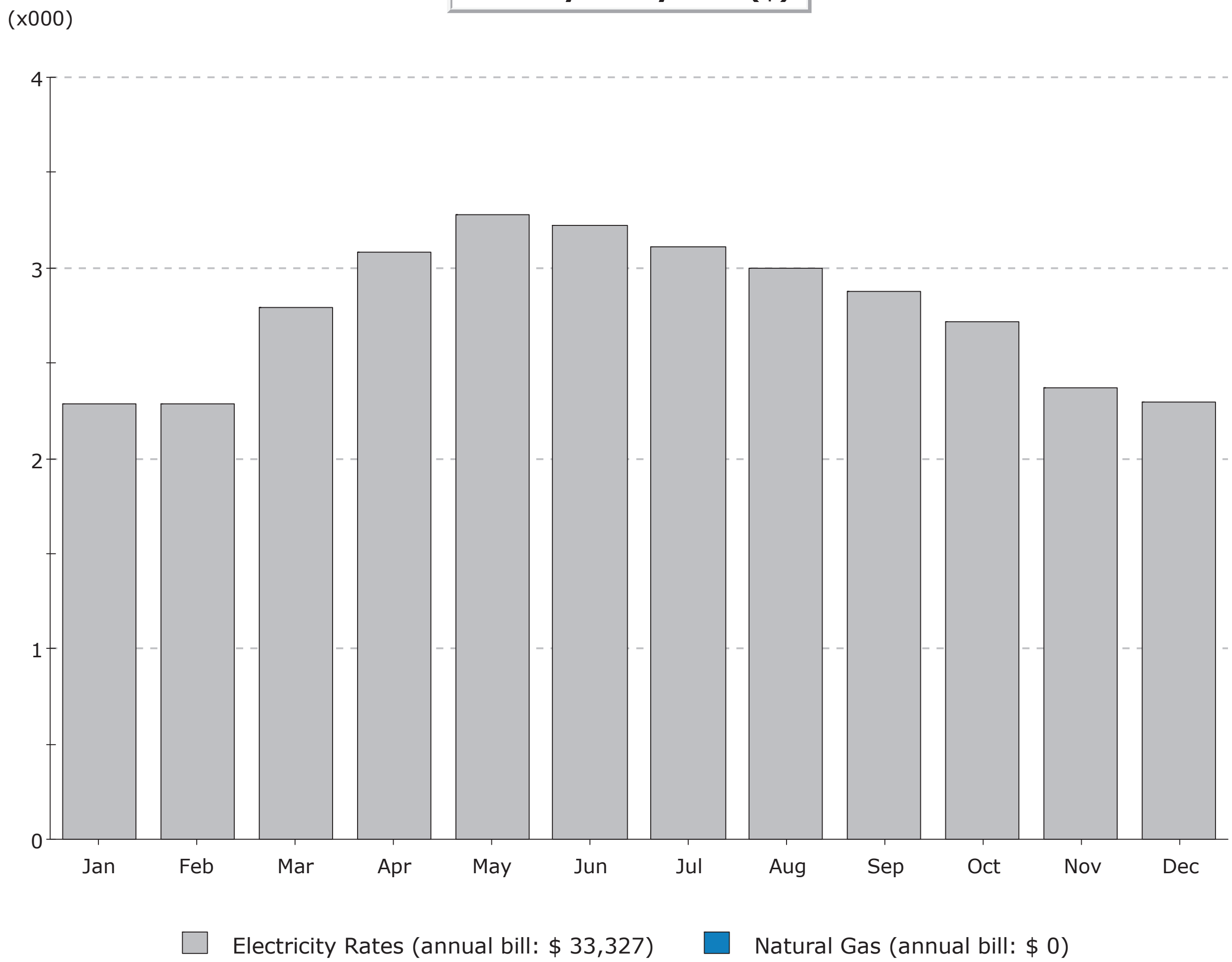
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	2.19	4.30	8.08	12.88	15.45	16.48	15.98	15.33	14.63	11.50	6.79	3.72	127.33
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	20.16	18.85	20.88	19.79	18.98	16.97	16.28	15.50	14.95	16.11	16.82	18.86	214.15
Vent. Fans	0.83	0.83	1.15	1.49	2.10	2.62	2.07	1.96	1.87	1.45	1.05	0.86	18.29
Pumps & Aux.	0.07	0.01	-	-	-	-	-	-	-	-	-	0.02	0.09
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.04	3.65	4.04	3.91	4.04	3.91	4.04	4.04	3.91	4.04	3.91	4.04	47.61
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	3.23	2.92	3.23	3.13	3.23	3.13	3.23	3.23	3.13	3.23	3.13	3.23	38.08
Total	30.53	30.56	37.38	41.20	43.81	43.12	41.61	40.07	38.50	36.34	31.70	30.74	445.55

Gas Consumption (Btu)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool													
Heat Reject.													
Refrigeration													
Space Heat													
HP Supp.													
Hot Water													
Vent. Fans													
Pumps & Aux.													
Ext. Usage													
Misc. Equip.													
Task Lights													
Area Lights													
Total													

Cost - GRIHA

Monthly Utility Bills ($)



Total Annual Bill Across All Rates: $ 33,327