A Thesis on

SUSTAINABILITY ANALYSIS OF A BUILDING USING CHILLED BEAM TECHNIQUE

Submitted for partial fulfillment of award of

MASTER OF TECHNOLOGY
Degree in

CONSTRUCTION TECHNOLOGY & MANAGEMENT

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2019-20

DECLARATION

I declare that the research thesis entitled **"Sustainability Analysis of a Building using Chilled Beam Technique"** is the bonafide research work carried out by me, under the guidance of **Mr. Sarthak Singh Rajput.**, **Assistant Professor, Department of Civil Engineering, Integral University, Lucknow**. Further I declare that this has not previously formed the basis of award of any degree, diploma, associate-ship or other similar degrees or diplomas, and has not been submitted anywhere else.

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CERTIFICATE

Certified that the thesis entitled ***"Sustainability Analysis of a Building Using Chilled Beam Technique"*** *is being submitted by* **Ms. Ekta Dwivedi (Roll no. 1701104002)** *in partial fulfillment of the requirement for the award of degree of Master of Technology (Construction Technology & Management) of Integral University, Lucknow, is a record of candidate's own work carried out by her under my supervision and guidance.*

The results presented in this thesis have not been submitted to any other university or institute for the award of any other degree or diploma.

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ACKNOWLEDGEMENT

It gives me a great pleasure to acknowledge with a deep sense and appreciation to all those who have extended their kind co-operation and support through the dissertation work. I would like to take this as an opportunity to express my profound sense of gratitude to my Guide **Mr. Sarthak Singh Rajput** (Assistant Professor), Department of Civil Engineering, Integral University, Lucknow for their valuable inspiration and guidance throughout the dissertation work.

I would like to express my deep sense of gratitude towards **Dr. Syed Aqeel Ahmad**(Professor and Head) of Civil Engineering Department, Integral University for their valuable guidance and their co-operation.

I acknowledge all books, journals, research papers, TROX India Pvt. LTD.& websites from which I have taken reference to complete this project .

Finally, I would like to thanks **God and my Parents,** who blessed me with the patience & perseverance to complete this project.

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LIST OF SYMBOLS, ABBREVIATIONS

ACB	Active Chilled Beam
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow
FCU	Fan Coil Unit
ASHRAE	American Society of Heating Refrigerating and air-conditioning engineers
SHGC	Solar Heat Gain Coefficient
ISHRAE	The Indian Society of Heating, Refrigeration and Air-Conditioning Engineers
HAP	Hourly Analysis Program
CFM	Cubic Feet Per Minute
DBT	Dry Bulb Temperature
LEED	Leadership in Energy & Environment Design
MBH	Mega British Thermal Hour
BTU	British Thermal Unit
USGPM	US Gallon Per Minute
HP	Horse Power

ABSTRACT

The aim of this thesis is to determine the consequences of utilizing different construction & energy efficient techniques to make the building sustainable. Sustainable building is that building that seeks to attenuate the negative environmental impact of the building & it's achieved by the installation of a number of the innovative techniques within the building (during construction or some after the completion of the building).Sustainability are often defined because the quality of causing little or no damage to the environment & meeting the requirements of this without compromising the power of future generations to satisfy their own needs. It's been observed from the studies wiped out in the past that a number of the techniques are very effective in making the building more energy-efficient & sustainable.

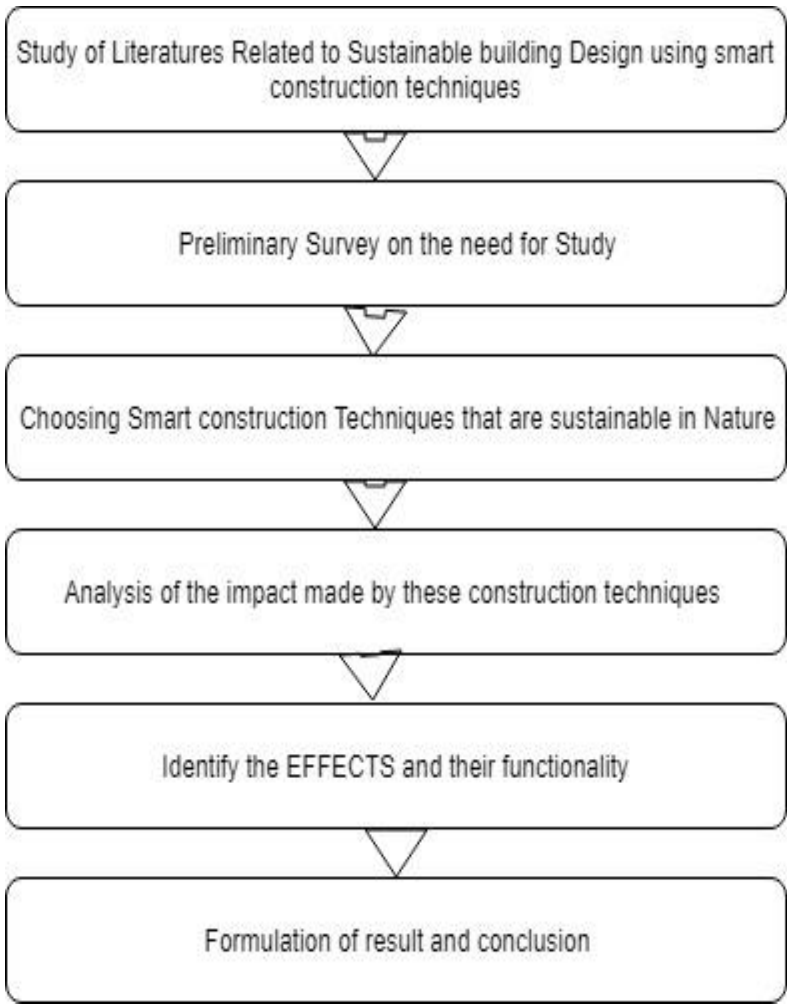
Research Problem :- The research is based on how, we can make the building sustainable and energy efficient by using some different construction technique or method.

As we all know, the system of HVAC is installed in the building and it consumes about 40-60% of the energy, if it is prior analyzed its effect on building energy savings, then it can be done much efficiently for the future needs of the building.

Hence, the one construction technique that is been analyzed here is chilled beam technique. It is one of the most efficient HVAC System.

The problem that is dealt with is analyzed its utilization in the virtual building and assess its impacts for the northern tropical region, what are the cost components will be , how much energy can be saved, is it beneficial for the Indian climate or not?

METHODOLOGY: The following steps needed in the analysis of sustainability of the building by using smart construction techniques:



CHAPTER-1 (INTRODUCTION)

1.1 Background:

In early human history, the utilization of fireside and desire for specific foods may have altered the natural composition of plant and animal communities. The Western age of the 18th to 19th centuries tapped into the vast growth potential of the energy in fossil fuels.

Coal was utilized to power rather more efficient engines and later to come back up with the electricity.

Sustainability is defined as the ability to exist constantly. Within the late 20th century, environmental problems became global in scale.

In the 21st century, it refers generally to the capacity for the biosphere and human civilization to coexist. It also sees because the method of people maintaining change in an exceedingly balanced environment, during which the exploitation of resources, the direction of investments, the time of technological development and institutional change can beat harmony and enhance both current and future potential to meet human needs and aspirations.

The 1973 and 1979 energy crises depicted the extent to which the planet community had become hooked into non-renewable energy resources.

Within the 21st century, there's an increasing global awareness of the threat posed by the atmospheric phenomenon, produced largely by forest clearing and so burning of fossil fuels.

1.2 General:

According to ISO 15392:2008, Sustainability focuses on meeting the necessities of the current without compromising the facility of future generations to fulfill their needs. The concept of sustainability is formed of three pillars: **economic**, **environmental**, and **social**—also known informally as profits, planet, and other people by a practical view of sustainability is closed systems that maintain processes of productivity indefinitely by replacing resources employed by actions of individuals with resources of equal or greater value by those exact people without degrading or endangering natural biotic systems.

Sustainability expresses responsible and **proactive decision-making and innovation** that minimizes negative influence and maintains balance between ecological flexibility, economic prosperity, political justice and cultural resonance to create a sensible and smart planet for all species now and within the long run.

1.3 Objective:

Concept of conserving resources for future generations is one in every of the most features that distinguish sustainable development policy from traditional environmental policy, which also seeks to internalize the externalities of environmental degradation. The general aim of sustainable development (SD) is the long-term firmness of the economy and environment; this is often only achievable through the blending and acceptance of economic, environmental, and social responsibility throughout the selection making process.

- **Energy Conservation& Economy:** Promote energy conservation through efficient energy use planning and building component and making it economical too. Energy efficiency building design plays a significant role because nowadays major part of the facility is consumed to run the heating ventilation air conditioning HVAC system. (The HVAC system alone totals to about 13.9% of the entire construction cost.)
- **Comparing Energy efficient technology with the conventional technology.**
- **Make use of smart Construction Techniques:** Solar panels, Rain water harvesting techniques, Waste recycling, Composting, Chilled beam, etc.
- **Actively Promote Sustainable Development:** Advocate changes at the senior levels of government, also as within the city, so as to evolve towards sustainability.

1.4 Need for the study:

The movement toward sustainable building designs is being driven largely by environmentally-sensitive building owners and their occupants. It's seen that merely refining the system within the building we'll achieve energy efficiency and overall sustainable structure. A completely effective HVAC system must also solve many other indoor environmental matters that affect occupant comfort, productivity and health like ventilation air, air distribution, humidity control, noise levels, etc. Chilled beam systems are the perfect "green" solution for several buildings. There's also an overall comfort and economy for the employment of active chilled beam systems over other of the more conventional systems choices.

According to **" India Chilled Beam Market Forecast & Opportunities,2019"**, the annual revenues for the country's chilled beam market are predicted to grow at a rate of around 108% during 2012-2019. Currently the chilled beam market in India is entirely import driven due to the absence of domestic manufacturing. More and more green buildings in India are expected to put in chilled beams instead of traditional HVAC systems during the following five year.

1.5 Scope of the study:

In this study, the area of interest is the feasibility analysis of a chilled beam technique within the commercial building and its comparison with the conventional techniques like VAV within the tropical region of India and presenting the result and checking its sustainability nature.

1.6 HVAC (Heating, Ventilation & Air-Conditioning)Technologies:

There are two basic varieties of HVAC i.e. **Centralized and Decentralized (Non-Centralized).**

- Non-Centralized consists of **Window & Split AC** that are generally installed in smaller projects like House, Shop, Stores etc. (Capacities upto 5 tons) where the utilization of separate indoor and outdoor coils are done. The split systems are a good choice for small buildings where ductwork isn't feasible.

- Centralized consists of **Packaged and Central Plant based** air conditioning (where the cooling loads are over 20 tons).
- Packaged centralized air conditioning system: This sort of system incorporate all of the working parts in to at least a unit; the evaporator, the condenser, and also the compressor are all located in one cabinet, which usually is placed on a roof or on a concrete slab next to the house's foundation. The air ducts are put along exterior walls of a house or along the roof, and they provide the flow of warm air inside the house to the unit, then back through the ducts so that cool air are often sent inside. This type of system is habitual among small commercial buildings but is hard to retrofit (install in a building that wasn't designed to receive it) because of the massive and big air ducts required.
- The Central air condition plants or the systems are used when large buildings, hotels, theatres, airports, shopping malls, etc. are to air conditioned completely. These are advantages of a central air-condition system:-Indoor comfort during warm weather – Central air conditioning helps keep your home cool and lessen humidity levels, Cleaner air. As central air-conditioning system pulls air out of the rooms in the house through return air ducts, the air is pulled through filter, which removes airborne particles like dust and so the filtered air is then routed to air supply ductwork that carries it back to the rooms, Quieter operation, Because the compressor-bearing unit is situated outside the house, the indoor sound level from its operation is way lower than that of a free-standing air- conditioning unit. The condenser, fan and compressor are located in an outdoor unit and does not take up any inside space. These are easy to operate and run.
- HVAC System under the central air conditioning system are:-

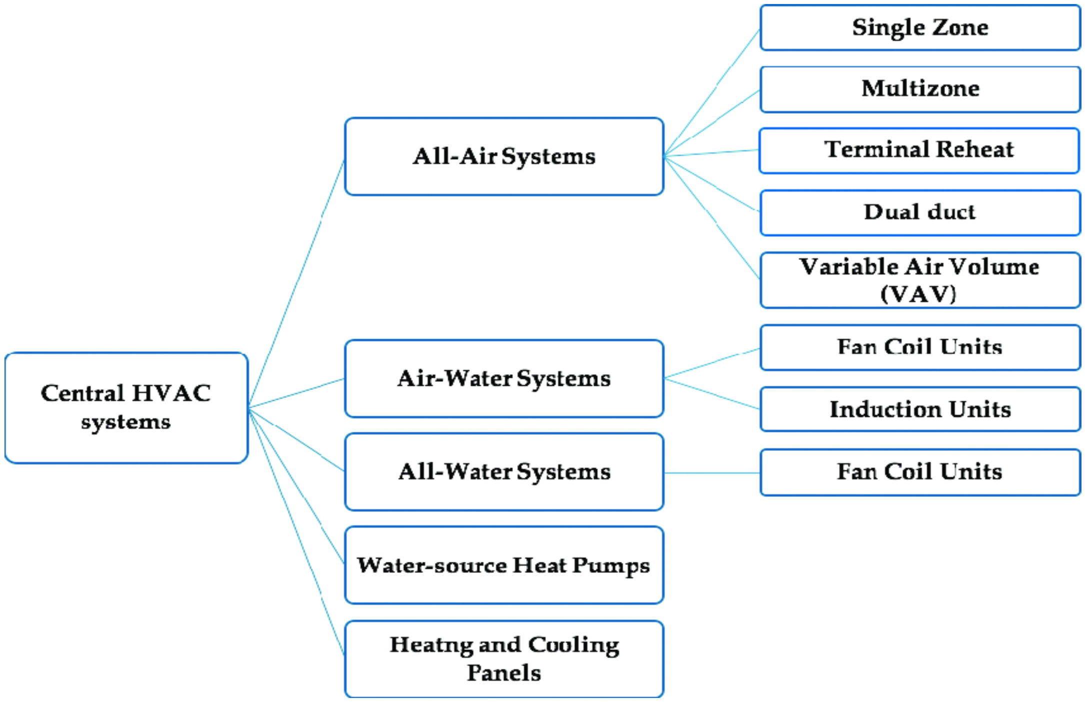


Figure:-1 Horizontal-hierarchy-representation-of-the-main-types-of-central-HVAC-systems

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1.7 All Air System

- **(Constant Air Volume):-**

CAV system that varies the temperature at a constant airflow, Constant air volume (CAV) is a type of heating, ventilating, and air-conditioning (HVAC) system. In a simple CAV system, the supply air flow rate is same, but the supply air temperature is varied to encounter the heating or cooling loads of an area. Most CAV systems are small, and distribute one single thermal zone.

- **(Variable Air Volume):-**

The thermal energy transmit medium through the building delivery systems is air. VAV units, or Variable Air Volume systems, supply same temperature air to an area while the volume of air differs as opposed to a conventional HVAC system which has same volume and varies the air temperature. A Variable Air Volume (VAV) box, may be a part of an air conditioning system. It's located inside the duct work. It is build to regulate the air flow to a particular area, called a "zone. The only VAV system includes one supply duct that, when in cooling mode, distributes 55 °F (13 °C) supply air, because the supply air temperature is constant the air flowing rate must be different to satisfy the rising and falling heat demands within the thermal zone served.Some of the disadvantages are that the system is noisy and contains far more moving parts and electronics.

- **(Variable Refrigerant Volume):-**

  Variable refrigerant flow (VRF), also referred to as variable refrigerant volume (VRV), is a HVAC technology invented by Daikin Industries, Ltd. in 1982. This refrigerant is conditioned by one or multiple outdoor condensing units, and is propagated within the building to multiple indoor units. VRFs make use of a refrigerant as the coolant and heating medium. VRV is a technology that substitutes the refrigerant volume in a system to match a building's precise requirements. With up to 64 indoor units connected to 1 outdoor unit, Each individual indoor unit decides the capacity it needs based on the current indoor temperature and requested temperature from the remote control (set point). The overall demand among all indoor units will determine how the outdoor unit adjusts the refrigerant volume and temperature accordingly.

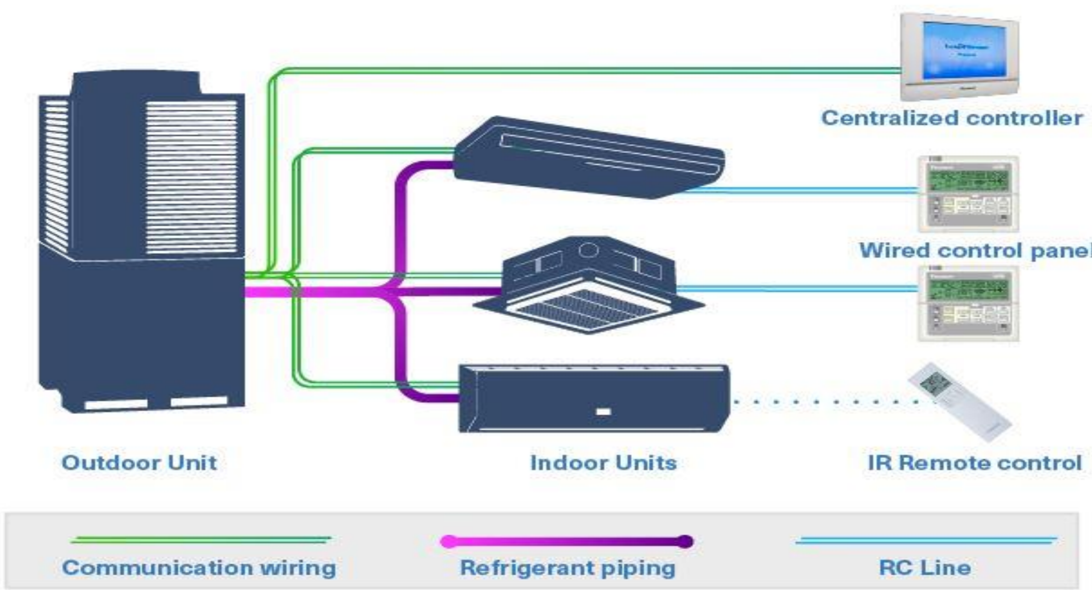


Figure:-2 VRF-air-conditioning-system

https://img3.exportersindia.com/product_images/bc-full/dir_188/5624178/vrf-air-conditioning-system-1529456428-3995257.jpeg

1.8 Air-Water System

1.8.1 Overview of the chilled beam technique:-

As relatively new in India, chilled beam systems are proven and are successfully being employed in Europe since a decade. The chilled beam system encourages outstanding thermal comfort, energy conservation and systematic use of space because of the high heat capacity of water used as heat transfer medium. It's an energy efficient HVAC technology which works on dry cooling principle.

Chilled beams system would be assessed which might show energy conservation and has potential to save 30-40% HVAC energy consumption to a traditional Air conditioned Building case.

1.8.2 History of chilled beam:-

Chilled beams were developed in Norway in 1975, originally utilized in Scandinavia.

Introduced in United Kingdom in 1990s and now used Worldwide due to its great advantages.

1.8.3 Process involved in the chilled beam technology:

Chilled beam systems utilize cold water circulating through pipes to chill the encompassing air. With the unit installed in or round the ceiling, the air it cools becomes heavy and falls towards the ground. The vacuum created by the cool air moving downwards is replaced by rising warmer air, which comes in contact with the chilled beams, and therefore the process resumes over and over, causing a constant and continuing airflow.

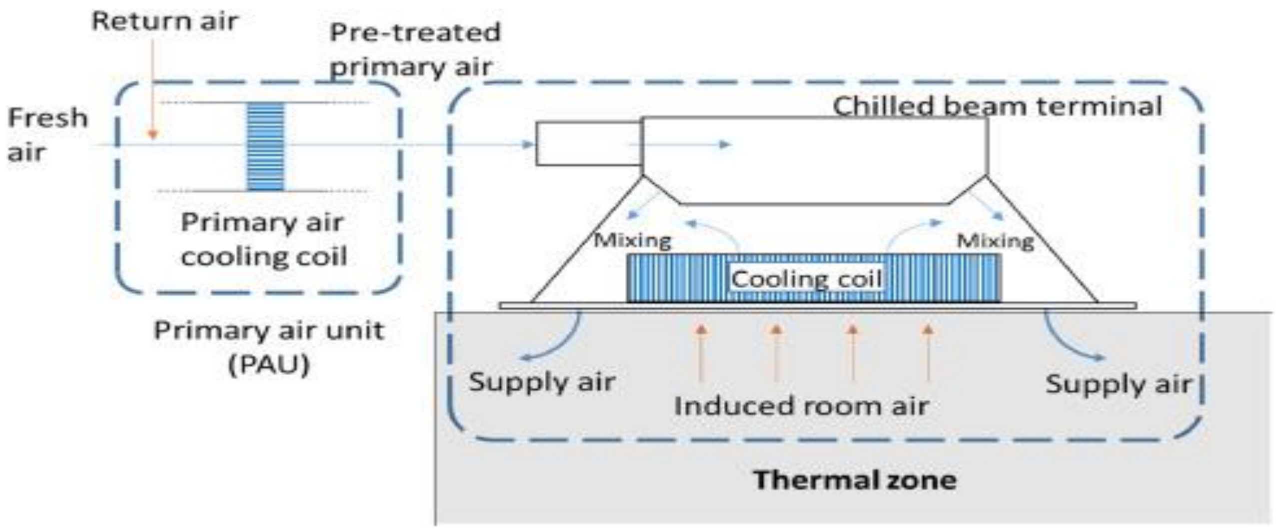


Figure:-3 Process involved in the chilled beam

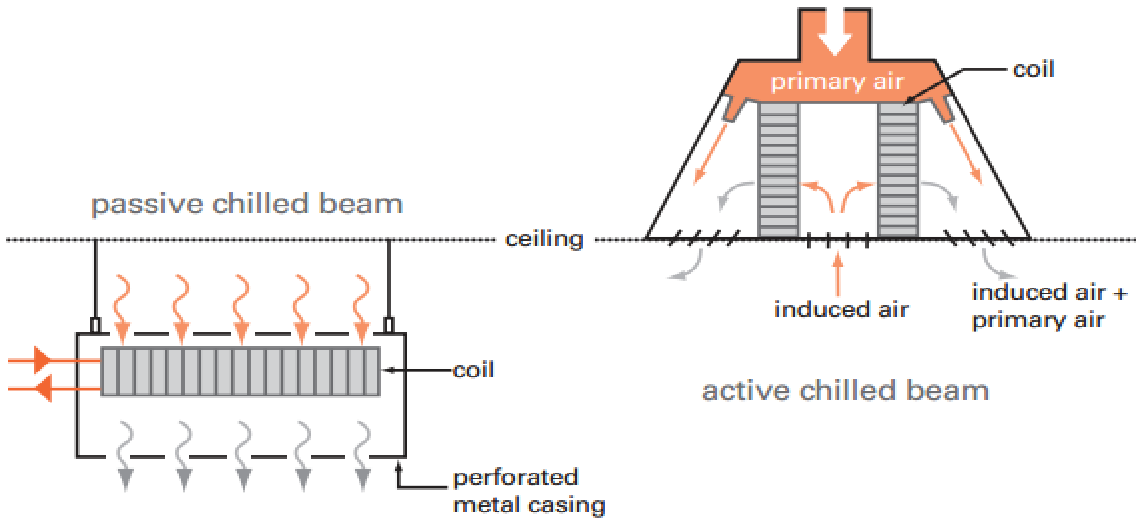
https://ars.els-cdn.com/content/image/1-s2.0-S0378778819302245-gr1.jpg

1.8.4 Types of chilled beam:-

There are two basic varieties of chilled beam:

Active chilled beams (ACB) also called an **"Induction Diffuser"** uses the momentum of ventilation air entering at relatively high velocity to induce the circulation of room air through the unit and utilizes a pre-cooled (and dehumidified) primary air using chilled water in an exceedingly quantity needed to encounter the space latent load and make sure good air quality for the occupied area. The cooled and dehumidified primary air absorbs the space latent load; while also certifying that the chilled beam coil operating without condensation. The chilled beam then cools or heats the induced air to cover the room sensible load and fulfill the room thermostat requirements. Active chilled beams work using the induction process. During induction, the primary air ejects under pressure through nozzles located within the device. High velocity incoming primary air creates a negative pressure in the inlet portion of the beam and induces room air through the beam coil where it mixes with the cold primary air. This mixed air is then transmitted through the outlet hole of the beam into the room, resulting in a total airflow quantity 3 to 4 times greater than the primary airflow. This ratio of total air to primary air is referred as the induction ratio. "A convector with integrated air supply where primary air, induced air or primary air plus induced air passing through the cooling coils. The cooling medium in the coil is water." These are connected to ventilation ductwork and water pipe work. The primary air is given to the room by the beam. This induces the room air to circulate through the beam's heat exchanger, and the beam mixes the primary and circulated air before spreading to the room.

Passive chilled beams (PCB) work using natural convection. Air cooled by the coil inside the beam becomes heavier than the surrounding room air and therefore flows downward into the room. The passive chilled beam distributes treated primary ventilation air directly to the space and not through the chilled beam. Both remixing and displacement terminal devices give good comfort in the room in combination with passive beams. The cooling medium is usually water. Chilled Beams offer a quiet indoor air free from draught. In a typical Chilled beam, the air is cooled by means of supplying chilled water and the supply of air flow rate is proportioned to meet the indoor air quality needs.



https://sites.google.com/site/ae390a5chilledbeam/_/rsrc/1399256569078/chilled-beam/Chilled%20Beams.PNG

Figure:-4 Chilled Beam (Passive & Active)

Multi –service type chilled beam These are active beams with the supplementary added components.

(Smoke Detectors, Lightning, Sprinklers, sensors, IT equipments etc).

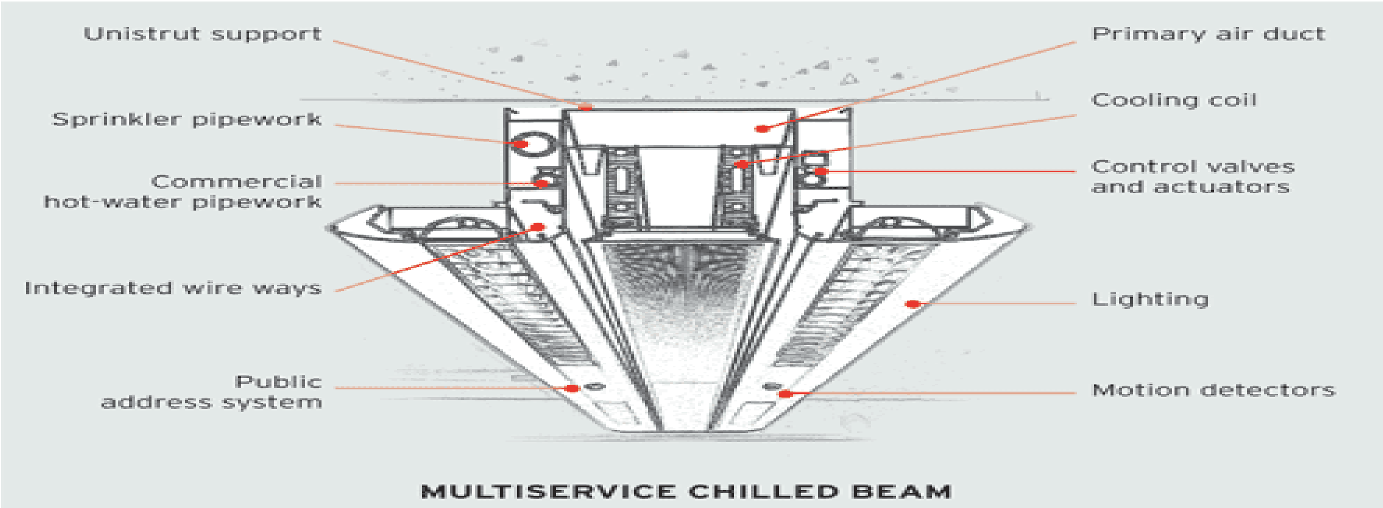


Figure:-5 Multi-Service Chilled Beam

https://www.globalspec.com/ImageRepository/LearnMore/20139/0811edit-13350df51f9b7a473f8ca60ffcd0a522bc.gif

1.8.5 Advantages of chilled beam over conventional systems.

- High energy efficiency and low life-cycle or operating costs: this advantage is specially due to the absence of a fan within the terminal unit.
- As all air-water conditioning systems, choosing a good chilled beam has the advantage of using water as a vehicle to convey the cooling or heating power to the rooms, which saves on energy because the temperature of cooled water is larger than the temperature of cooled air, but it delivers the identical cooling capacity and savings on space compared to All-Air Air conditioning systems. Additionally, the temperature of every room or Supply air nozzles independent area are often controlled by adding a 2way or 3way valves to the terminal unit.
- There could be a less need to treat great deal of outdoor air thus it saves money.
- Lowest maintenance costs: the unit contains no filter or condensate pan to place or clean and only cleaning of the coil surface is needed (recommended every 2 years).
- Low noise level.

- Optimum use of space and energy. (They offer the capability to increase the efficiency of an HVAC system by almost 45% and moreover they utilize less ceiling space that results in less floor to floor height, thereby allowing construction of additional floors in a very high rise building.)

- No draughts and cold spots in occupied area.(Fully mixes the air within the space)

- Absence of fan and motor.

- One "fix" device, doesn't require secondary ductwork, grilles etc.

- Extremely hygienic systems, since no filters and condensate pans are used.

- Space-saving: Smaller air ductwork and equipment units thus significantly lowers the overall system cost.

- 

Figure 6:- Air versus Water Duct in chilled beam

- Easy to set up.

- Sustainable buildings are a world trend. With specialize on people and their work, the standard of indoor air is today's crucial issue. Furthermore, economic reflections of energy efficiency and total life cycle accomplishment are key arguments for choosing the HVAC system. The chilled beam system offers a perfect solution to all these challenges.

- Good indoor air promotes wellbeing and productivity. The chilled beam system provides outstanding thermal comfort and draught-free conditions. Unlike other typical systems, the chilled beams operate silently, fulfilling even the best acoustic demands of working, relaxing and relieving environments. They also foster enhanced hygiene, as their operation is filter and drainage-free.

- Better indoor climate with less energy. Within the chilled beam system, most of the heating and cooling capacity is transferred through water. The system makes use of the optimal opportunity at no cost for cooling and heating. For free cooling, outdoor air, ground and sea water are often exploited. In heating, condensing boilers and warmth pumps up and run more efficiently at lower temperatures.

- In the chilled beam system, the outdoor airflow is optimized to hide up hygienic and air quality requirements. More practical ventilation uses less fan energy and smaller air-handling units and ductwork than conventional all-air systems. This ends up in a greatly efficient building structure with much lower construction costs.

- Active chilled beams (ACBs) have become favored with design consultant as a method of dealing up with large sensible cooling loads with excellent energy performance and low acoustic signatures.

- Can be Visually pleasing.

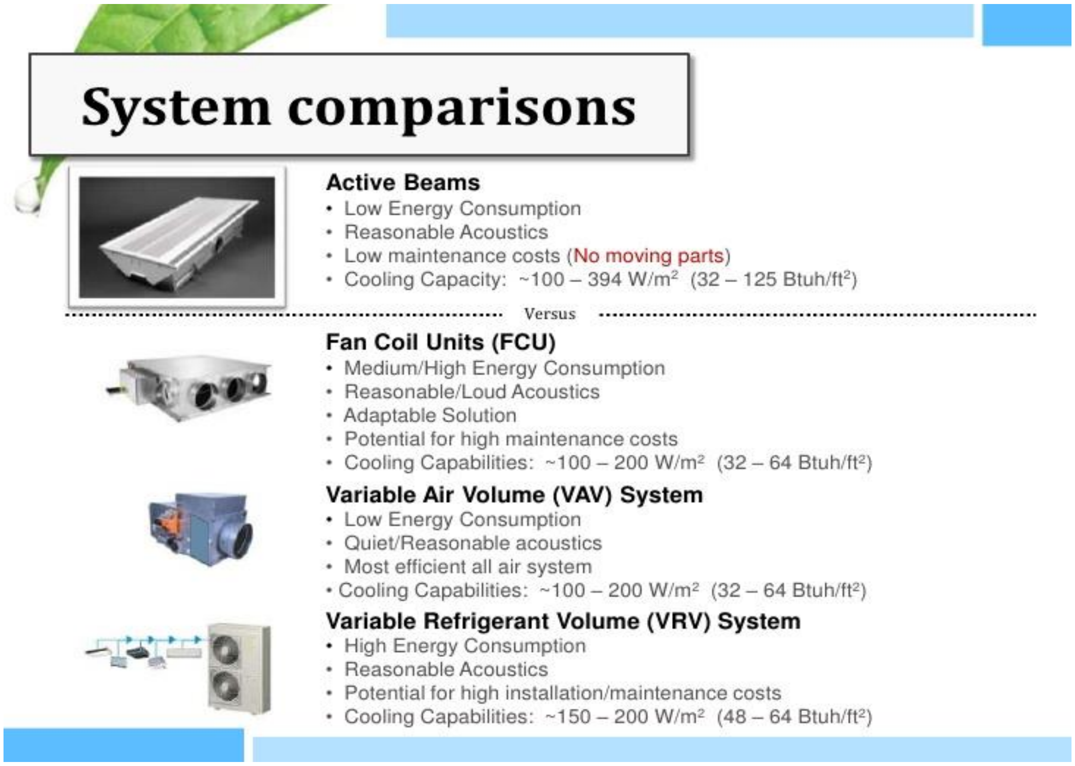


Figure:-7:- HVAC System Comparisons

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.slideshare.net%2FDarren_Alexander%2Fapr-12-2012-chilled-beampresentation.

1.8.6 Chilled Beam system typical Design Guidelines:-

a) Assume spaces with normal ceiling heights (9-10 ft), apply chilled beams in with cooling loads of 25-30 Btu/ft² of floor area. The limitation of this capacity is primarily due to the maximum possible air velocity within the space. Cooling Capacity to avert draughts within the occupied zone: Active chilled beams is usually 250 W/m (max 350 w/m), Passive chilled beams is 150 W/m (max250w/m).

b) Chilled beams uses warmer chilled water from the secondary side of the cooling plant (or from mixing of primary and secondary water) at an inlet temperature from 57-61 °F(13.889^0 celsius 16.11^0 celsius) to prevent condensation from occurring on the beam coil. This equates to a primary supply air temperature of roughly 65 °F (18.33^0 celsius).

c) Special humidity (condensation) sensors should be installed on the chilled beam coil that close the water control valve if the RH gets to 90% on the incoming chilled water pipe. Alternatively, utilizes an atmospheric RH(Relative Humidity) sensor together with an air temperature sensor to reset the supply water temperature upward closer to 60 °F during conditions when condensation might occur.

d) It's important for the DOAS (Dedicated outdoor air system) system to satisfactorily dehumidify the primary ventilation air such that it can absorb all of the latent loads in the zone. The DOAS leaving air temperature (LAT) should be within the 44-55 °F(6.67^0 Celsius to 13^0 Celsius) dry bulb range with approximately 44-45 °F dew point (DP) to ensure there's no condensation on the beam coil.

e) Chilled beams offer an easy design process with higher final efficiency. Designing with chilled beams is extremely almost like conventional system design. Chilled beams available within the U.S. generally have a 3:1 induction (room air to ventilation, or primary air) ratio, are capable of 100 to 200 CFM of primary air per 6 ft of beam, and supply from 4,000 Btuh to 8,000 Btuh of sensible cooling per 6 ft of beam.

f) Chilled beams should be installed and set correctly within the space. Normally the Chilled Beam (**Width ranges from 0.3m to 0.6m, and lengths range from 0.6m to 3.0m.)**

g) Active Chilled Beams re-circulate room air through a unit-mounted coil, driven by ventilation air (primary air) with mixing ratios as high as 6:1 (discharge air to primary air). They need comparatively shallow depth with clearance requirements generally less than 0.3m.

Chapter-2 (LITERATUREREVIEW)

2.1 Introduction

Literature review is administered by study of varied Research papers supported the concept of Sustainable building, Green building, Energy efficient techniques & Chilled beam technique its comparison and other construction details.

2.2 Literature Reviews

1) **Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector** by Peter O. Akadiri ,Ezekiel A. Chinyio and Paul O. Olomolaiye [1] in this paper the authors said that "building industry may be a vital element of any economy but includes a significant impact on the environment. They stated in their study that "A sustainable project is supposed, built, renovated, operated, or reused in an ecological and resource efficient & conservative manner. It should meet a spread of certain objectives: resources and energy efficiency; CO_2 and GHG emissions reduction; pollution prevention; reducing noise; improved indoor air quality; harmonization with the environment". An ideal project should be inexpensive to make, last forever with modest maintenance, but return completely to the planet when left. They contribute to the industry and sustainability research by demonstrating the dimensions of the issues involved, beginning with an assessment of the environmental challenges the industry faces.

2) **The Importance of Green Technologies and Energy Efficiency for Environmental Protection** by Mohd. Wira Mohd Shafiei and Hooman Abadi [2] In this paper authors have focussed on the phrase that "Economic development is closely linked with the energy development". It's feared that not only these levels of energy production and use from current energy sources are difficult to appreciate but also unsustainable. Therefore, energy use efficiency must be increased to moderate the expansion of energy, while the contribution from clean energy sources must be increased to reduce the unfavorable environmental impacts on energy usage. Green energy offers a positive alternative to traditional energy

sources. They conclude in their study that the actual fact that renewable energy accounts for fewer than a modest proportion in meeting the world's (commercial) energy demand means there's an ape-man in their potential and their implementation - barriers in their implementation. These barriers (either financial or non financial) need to be identified and addressed so as to style innovative policy approaches for international and domestic financing or renewable energy technologies. Renewable energy can play a vital role in helping to satisfy basic energy needs through the employment of recent technologies.

3) **To Identify the HVAC Energy Savings through Chilled Beam Cooling Techniques by** Mohammed Ubied Ali & Mohammed Ishaq[3] They stated that a completely effective HVAC system must also address many other indoor environmental issues that affect occupant comfort, productivity and health like ventilation air, air distribution, humidity control, noise levels, etc. they often find that chilled beam systems are the proper "green" solution for several buildings. There's also a full comfort and economy for the employment of active chilled beam systems over other of the more conventional systems choices. In India, chilled beam systems are proven and while successfully getting utilized in Europe since a decade. The chilled beam system promotes excellent thermal comfort, energy conservation, and efficient use of space due to the high heat capacity of water used as heat transfer medium. it's an energy efficient HVAC technology which works on dry cooling principle. Chilled beams system would be examined which could show energy conservation and has the potential to save lots of 30-40% HVAC energy consumption in a very standard Air conditioned Building scenario.

4) **A Comparison study for active chilled beam and variable air volume systems for an office building by** Y.H. Yau, J.H.Tam[4], They comparatively studied and analyzed two hvac systems i.e. VAV and ACB respectively, the most area of comparison deals with the price and energy efficiency by calculating the cooling load requirement they concluded in their study that ACB may be a clear winner when it involves energy efficiency and VAV wins at the angle of low initial cost. They also stated that ACB includes a lower operational cost that may be much beneficial when used for the longer period of the time.

5) **Low energy consumption Hvac systems for green buildings using chilled beam technology by** Syed Moazzam ali [5], He studied the benefits of chilled beam systems over other hvac systems available within the market and draw result on the idea of simulation results and concluded that a chilled beam system would potentially save 30-40% hvac energy consumption over conventional air conditioning building techniques.

6) **Study the role of chilled beams in improving cooling efficiency of buildings: literature review by** Saeed Reza Mohandes1, (Hossein Omrany2) [6], They stated that Chilled beams save an excellent deal of energy in terms of transferring cooling, ventilating of airflow, using higher chilled water temperature and eliminating the requirement for reheating the cooled air. To realize the simplest results of efficient cooling of chilled beam in false ceiling, the return openings of false ceiling should be located within the perimeter of the space. Furthermore, the dimensions of its area should be doubled compared to the beam. When it involves to the asymmetric workstation using chilled beams in office building, workstation shouldn't be located within the downfall area so as to not cause local draught risk. Besides, asymmetric workstation causes circulation in a room which ends in high air speed on at the ground.

7) **Design Considerations for active chilled beams by** Darren Alexander, P.Eng.; and Mike O'Rourke [7] , that they had given the detail about the specification of an active chilled beam systems, their uses , capacity and appropriateness informations.

8) **A Case Study of Energy and Condensation Analysis for Chilled Beam Systems in the Office Building Located in Hot and Humid Climate Zone** by Kuei-Peng Lee, Kuan-Ting Lin 1 and Bo-Huei Wu [8], Their findings show that the chilled beam saves 12.7% of energy consumption compared with VAV system; the chilled beam saves 10.4% of energy consumption compared with FCU system. The chilled beam system with ice storage saves 19.2% of electrical charge annually compared with the chilled beam system without ice storage; the VAV system saves 20.6% of electrical charge annually; the FCU system saves 15.2% of electrical charge annually.

9) **Chilled Beam Systems- A Green Energy Solution for Hvac Systems** by Kenneth Gong [9] In this they stated that the chilled beam is certainly a "viable green hvac solution" even within

The tropics if problem of condensation is managed properly. The limited number of chilled beam installations that are currently in operational Malaysia and Germany have demonstrated that chilled beam system can provide satisfactory comfort condition within the tropics.

10) **Green building: A case study of Indra Paryavaran Bhawan, Delhi by** Rachna dhingra*1 and Puja gupta2 [10], They stated that Green building practices can substantially reduce or eliminate negative environmental effects and improve existing unsustainable design, construction and operational practices. In this case study it had been revealed that this building achieved LEED India Platinum Rating and GRIHA 5 star rating. The fundamental design concept of the project was to form net zero energy green building. For improving Indoor Air Quality and thermal comfort The Hvac System utilized within the building is Chilled beam which reduces energy consumption by utilizing radiative cooling panels that rely on localized induction cooling by chilled water. This also reduces the AHU/FCU fan power consumption because it avoids the necessity for huge quantities if air travel from the user space to the thermal heat exchange point.

11) **Chilled beam technology overview: by** John Woollett1, Jonas Åkesson2 [11], Their findings are that Beam indoor climate technology has the power to supply a high level of comfort to the users. Model tests show that indoor climate parameters are extremely comfortable and may provide the idea of the indoor climate system for several decades with minimal maintenance at the area level. Energy usage of beam system can be significantly lower than other indoor climate systems due to the upper chiller temperatures on a system level or a minimum of reduced cooling loads at lower chilled water temperatures.

12) **Application of the Active Chilled Beam in Air-conditioning Engineering by** Wenhong Yu Hui Li, He stated that Active chilled beam system has many advantages, like high comfort, low energy consumption, low noise, long equipment life and then on. It is a replacement technology worth popularizing under the background of energy saving and emission reduction in today's green building. The active chilled beam adopts the working rule of the air conditioning system which is induced by the primary air from the nozzle, therefore the active chilled

beam has its own particularity within the design and operation control. The FCU system design experience is not any longer completely suitable. Due to the special working rule of the chilled beam, the cooling and heating capacity of the chilled beam is low, especially for curtain wall buildings with high cooling and heat load. To achieve the thermal comfort of indoor air conditioning and to achieve building energy saving, the floor convection at the exterior enclosure is recommended to adopt.

13) **Performance Evaluation of Active Chilled Beam in Real Office Conditions in a High-Performance Building in Heating by** Rohit Upadhyay Rodrigo Mora PH.D. Student Member ASHRAE [13], They had found out that the temperature and air distribution were found satisfactory which concludes that the ACB is effective in providing cooling as well as heating. Coanda effect was realized which prevents direct throw of cold and hot air to the occupied zone. The velocity and temperature distribution at the supply slots of ACB were found not even and same, this is because the heat exchanger design and duct connection to primary air plenum.

14) **Performance Evaluation of a Passive Chilled Beam System and Comparison with a Conventional Air System by** Janghyun KIM1*, James E. BRAUN1,2, Athanasios TZEMPELIKOS1,2, W. Travis HORTON1,2, [14],

The following observations were inferred from this study:

- Energy can be saved up to 12% by using a passive chilled beam system under Midwest weather condition compared to a typical conventional air system that only controls the space temperature and not space humidity.
- Using a separate chiller with higher chiller water operating temperature (14^0C) for passive chilled beams can provide an additional 11% energy savings.
- The improvement mostly comes from the reduced relative air speed rather than the increased radiation cooling effect.
- Radiation cooling of passive chilled beams is calculated as 5-7% of total cooling capacity for the configuration considered in this study and it is almost insignificant in terms of thermal comfort estimation.

15) **Design and Analysis of the Air Conditioning System using Chilled Beam Technology by**1V.Suvarna Kumar, 2 G.Prasanna Kumar, 3G. Bhasker [15]**,** They found out that the use of chilled beams although a little heavy on the pocket initially, results in a significantly lesser consumption in terms of power and cost in the long run. Apart from the savings factor, the use of Chilled Beams also results in better air quality, virtually no noise and prevent of cold drafts thereby increasing the overall human comfort significantly. Chilled Beams gives the designer to alternate large supply and return air ductwork with small chilled water pipes. This results in significant savings in terms of plenum space and increases usable floor space. The sole purpose of the project was to come up with a HVAC system which is more efficient, more energy saving and eco-friendly in nature than the conventional air conditioning systems. By using Chilled Beams, we could save approximately 35% of tonnage which is a huge difference. Although they are not the solution for every space within commercial and institutional buildings, the strengths of the Chilled Beam Air Conditioning System are becoming a more useful tool to handle challenging spaces in today's high performance and low energy consumption buildings.

16) **Virtual reality as an empirical research tool-Exploring user experience in a real building and a corresponding virtual model** 1 Saskia Kuliga, 2 Tyler Thrash, 3 Ruth Dalton [16], It is highlighted that virtual building or virtual examples can also be taken during research to investigate the result and observe the reactions.

17) **A Literature Review of Zero Energy Buildings (ZEB) Definitions** 1Marszal, 2 Anna Joanna; 3Heiselberg, 4 Per [17], The main objective of this report is to give an overview of existing ZEB definitions. The review has shown that Zero Energy Building is a different concept described with the wide range of terms and expressions. Based on the similarities and differences of the definitions from the existing worldwide literature, various approaches for ZEB definitions are differentiated.

18) **IGBC New Green Building Rating System** by Indian Green Building Council, IGBC continuously works to provide tools that facilitate the adoption of green building practices in India.

19) **Sustainability in Building Construction: General Principles ISO15392** This International Standard presents general principles of sustainability related to buildings and other construction works. These general principles form the basis for a suite of standards intended

to address specific issues and aspects of sustainability relevant to building and civil engineering of construction works.

20) **Chilled Beam Application Guidebook by REHVA Federation of European Heating, Ventilation & Air-Conditioning**

This guidebook is aimed at consulting engineers and contractors, who want to design and execute good chilled beam systems, facility owners, who want to develop life cycle cost efficient buildings and comfortable occupied spaces for people.

21) **ISHRAE COVID-19 Guidelines Document for Air-Conditioning and Ventilation by ISHRAE,** They recommend that all facilities operated with air conditioning and ventilation, on the Indian Sub-Continent, follow this guideline. In preparing this document, the COVID-19 Task Force has extracted, examined, analysed and compiled information pertaining to the Climatic regions of the Indian Sub-Continent.

22) **REHVA COVID-19 guidance document, How to operate and use building services in order to prevent the spread of the coronavirus disease (COVID-19) virus (SARS-CoV-2) in workplaces,** In this document REHVA summarizes advice on the operation and use of building services in areas with a coronavirus disease (COVID-19) outbreak, in order to prevent the spread of COVID-19 depending on HVAC or plumbing systems related factors.

23) **DADANCO ACB Active Chilled Beam Design Book** To gain the most benefit from the FAQ's, please take the time to read them all. This will provide a far better understanding of Active Chilled Beams systems in general, and specifically DADANCO unit characteristics and performance.

24) **Issues arising from the use of chilled beams in energy models by 1Fred Betz Affililated Engineers, 2 James Mcneill CedarStack** The performance modeling software available today have multiple issues with modeling active chilled beams whether it be accuracy, ease of use, and/or cost. Studies must be made in order for building designers to reliably use a software to inform design quickly and accurately.

25) **Towards Sustainable Development: A Review of Green Technologies by** Zaffar Ahmed Shaikh In this paper, we provide an overview of green technologies. The challenges faced in advancing and implementing green technologies and current trends that lead to sustainability are discussed. This paper also delineates regulatory policies and finance-related issues.

2.3 Inferences from literature review:-

As per the previous research work, encompassing this field mostly theoretical approaches and principles were discussed & the sensible studies are still not much prevalent, thanks to the strict and conservative thinking the practitioners that are been involved. Sometimes the Fund also act as an obstruction to try to such projects in practical.

Important points:-

- To find an appropriate balance between economic, environmental & social issues. Changing the way construction practitioners think.
- Total cost of the technology should be affordable for their wider use.
- LCCA should be done in order to make people understand about the long term viability of any new construction technology & method.
- Evolutionary capability of technology i.e.it should not be static(i.e. one technology can be used to provide multiple benefits and satisfy various needs simultaneously).
- Multi-purpose technologies i.e. it can be used for variety of services at a time.
- A building block accounts for 40% of the energy consumption so if we start from the building itself we will be able to achieve sustainability and a more energy efficient environment.
- Focus should be on the new and innovative technologies like Chilled beam system and analyze their effects on the building efficiency and an overall protection of natural resources.

2.4 EXPECTED OUTCOME:-

There are some ways during which the present nature of building activity are often controlled and improved to form it less environmentally damaging, without reducing the useful output of building activities. To make a competitive advantage using environment-friendly construction practices, the entire life-cycle of buildings should, therefore, be the context under which these practices are carried administered.

A review of literature has identified three general objectives which should shape the framework for implementing sustainable building construction, while keeping in mind the principles of sustainability issues (social, environmental and economic) identified previously.

These objectives are:

1. Resource conservation
2. Cost efficiency
3. Design for Human adaptation

Figure 1. Framework for implementing sustainability in building construction.

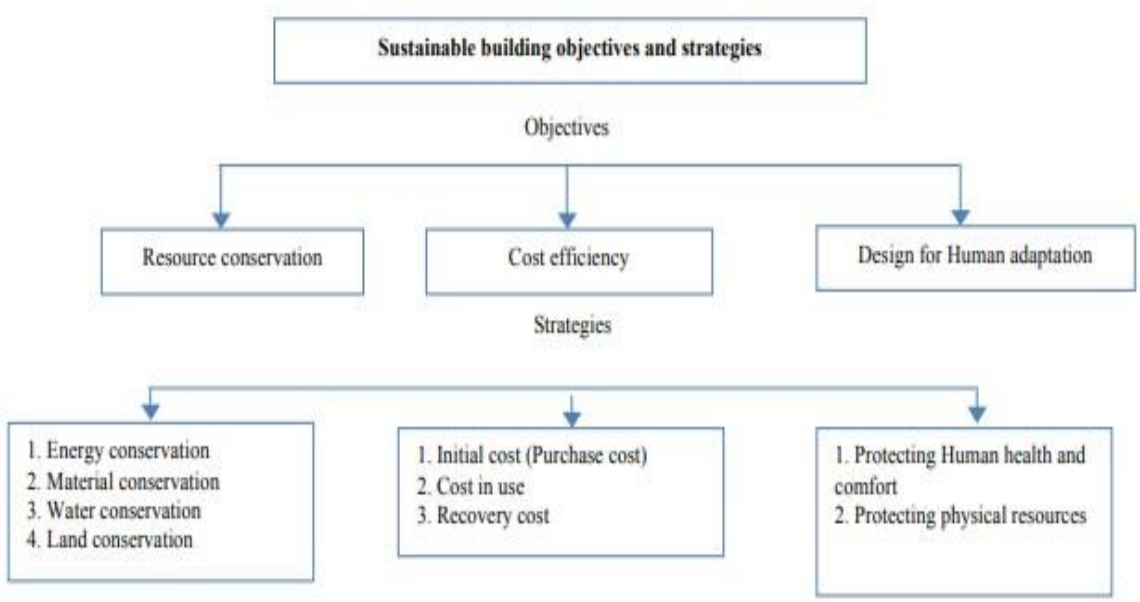


Figure:-8Framework for implementing sustainability in building construction

- **Resource conservation:** means achieving more with less. It's the management of the human use of natural resources to supply the utmost benefit to current generations while maintaining capacity to satisfy the requirements of future generations. The argument is that productivity improvement is important to attenuate impacts on the capacity of natural systems to assimilate waste materials and energy.

Methods for reducing material wastage while building construction process and providing opportunities for recycling and reuse of artifact also contribute to improving resource consumption efficiency. Since the non-renewable resources that play major role during a construction project are energy, water, material and land, the conservation of those non-renewable resources has vital importance for a sustainable future.

Figure 2. Strategies and Methods to achieve resource conservation.

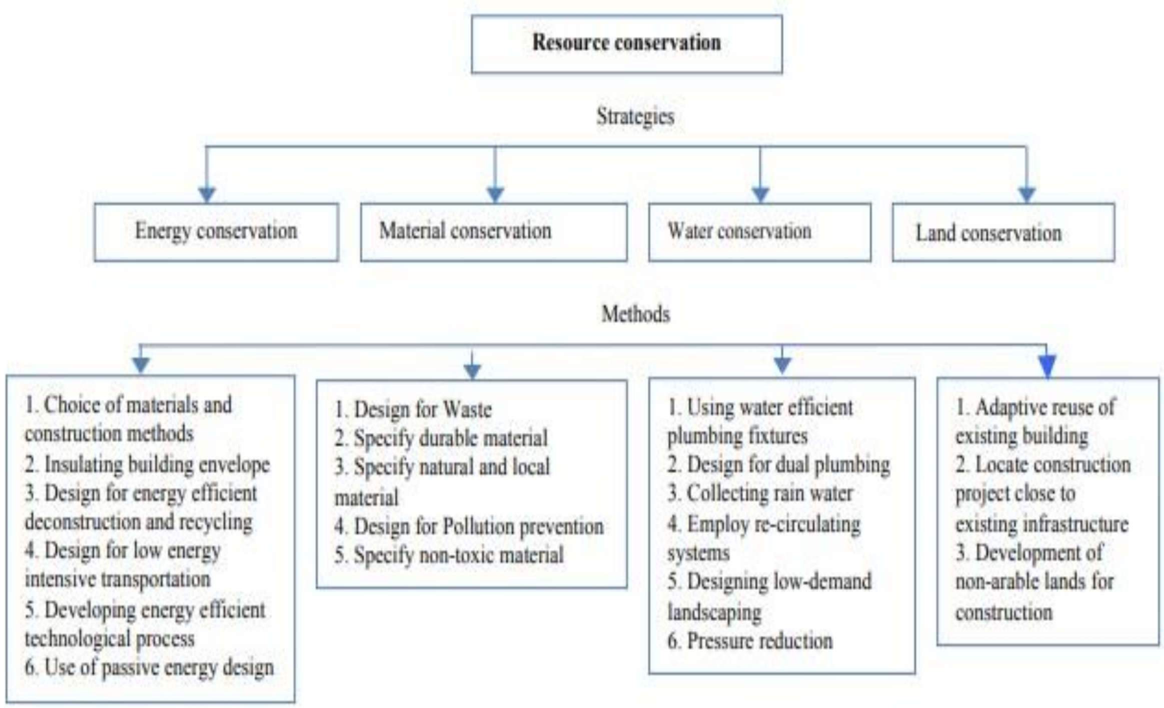


Figure:-9 Strategies and Methods to achieve Resource Conservation

Figure 4. Strategies and Methods to achieve cost efficiency.

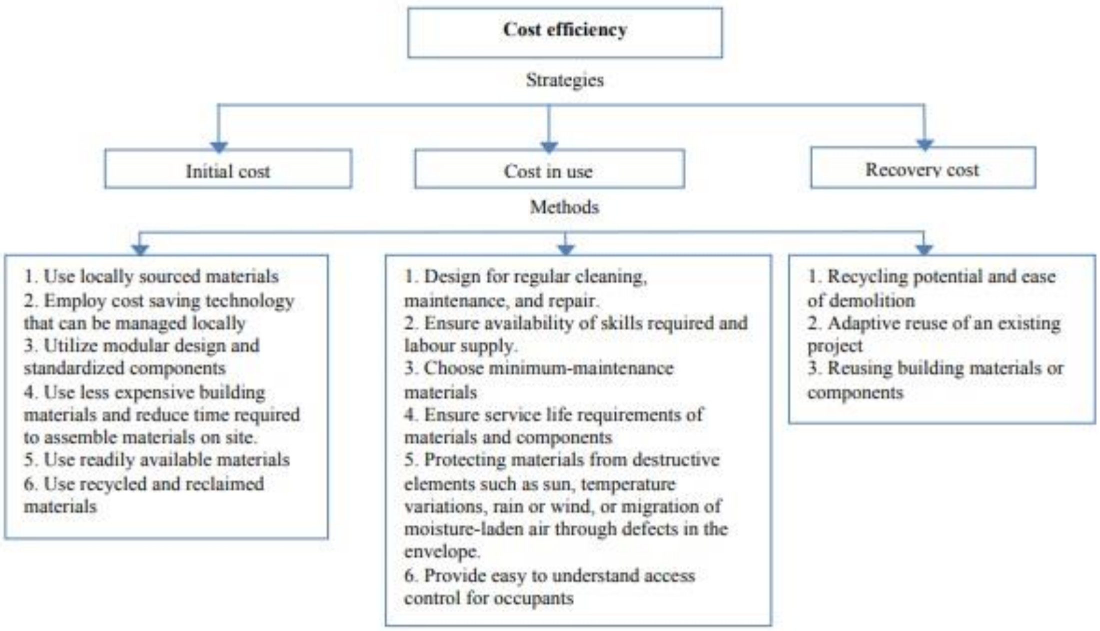


Figure:-10 Strategies and Methods to achieve Cost Efficiency

Figure 5. Strategies and Methods to achieve human adaptation.

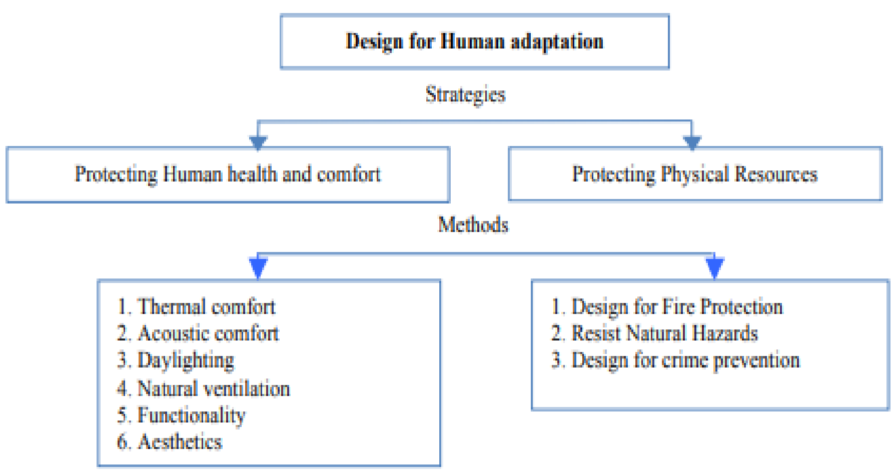


Figure:-11 Strategies and Methods to achieve Human Adaptation

- **Energy Conservation**: Energy use is one among the foremost important environmental issues and managing its use is inevitable in any functional society. Buildings are the dominant energy consumers. Buildings consume energy and other resources at each part of building project from design and construction through operation and final demolition.

1. **Choices of materials and construction methods** are important to scale back energy consumption of a building through reduced solar heat gain or loss, thus reducing air-conditioning loads. Choosing materials with low embodied energy will help to reduce energy consumed through mining, processing, manufacturing and transporting the materials. For example, aluminum features a very high embodied energy due to the large amount of electricity consumed to mine the staple. True low energy building design will consider this important aspect and take a broader life cycle approach to energy assessment.
2. **Insulating the building envelope** is the most vital of all energy conservation measures because it's the best impact on energy expenditure. A neat and installed insulation can reduce the quantity of warmth lost through the building envelope by a minimum of half. Draughts and warmth loss are going to be eliminated with an air-tightness strategy, where existing vents and chimneys will be blocked, floors and ceilings will be insulated, and walls are going to be coated with modified plaster. Heat recovery in heat areas such as kitchens and bathrooms, will achieve optimum energy efficiency through a mechanical ventilation unit that takes heat from these areas and uses it elsewhere within the house.
3. **Designing for energy efficient deconstruction and recycling of materials** cut energy consumption in manufacturing and save on natural resources. Buildings designed for deconstruction will include the dis-assembling of systems, and lessen chemical disparate binders, adhesives or coverings.
4. **Use of passive energy design** such as natural ventilation, landscaping by vegetation, use of water bodies for evaporation and cooling, orientation of building, etc. can help achieve thermal and visual comfort inside the building, so that there's significant reduction in energy consumption by conventional air cond. and artificial lightning within a building. Architects and Designers are able to achieve energy efficiency in buildings by studying the macro and micro climate of the location, applying solar-passive and bioclimatic design feature and taking advantage of the natural resources on site.

Chapter-3 (DATA COLLECTION)

3.1 Building details:-

- The research is being conducted on a virtual building.
- The building chosen is intended to be an Educational building (University).
- The building is proposed to be located in Lucknow, Uttar Pradesh.
- The building comprises of Five Floors. i.e. (G+4) building.
- The building is of rectangular shape with its length equals to 307 feet and width equals to 119 feet and 9 inches. (307*119’9”).
- The ground floor area of the building is about 36810 square feet. Hence, a total area of about 24,235.52 square feet out of the overall ground floor area is supplied with the conditioned air.
- Total Area to be air-conditioned (Primarily Cooling) in the building will be approximately equal to 129750 square feet.
- Height of each floor is taken around 12 feet.
- It comprises of different sections including the areas with and without air conditioning system.
- There are different kinds of spaces in the building as it is a commercial building such as Classrooms, Faculty rooms, Principal room, Library, Computer labs, Cafeteria, Lobby, Corridor, and many other spaces.
- The number of occupants that can be accommodated within each floor is estimated and depends upon the area for example the classes are designed for the strength of about 60 students and labs and libraries are designed for 100 students.
- The floor plan of each floor from Ground floor to fourth floor is attached below.

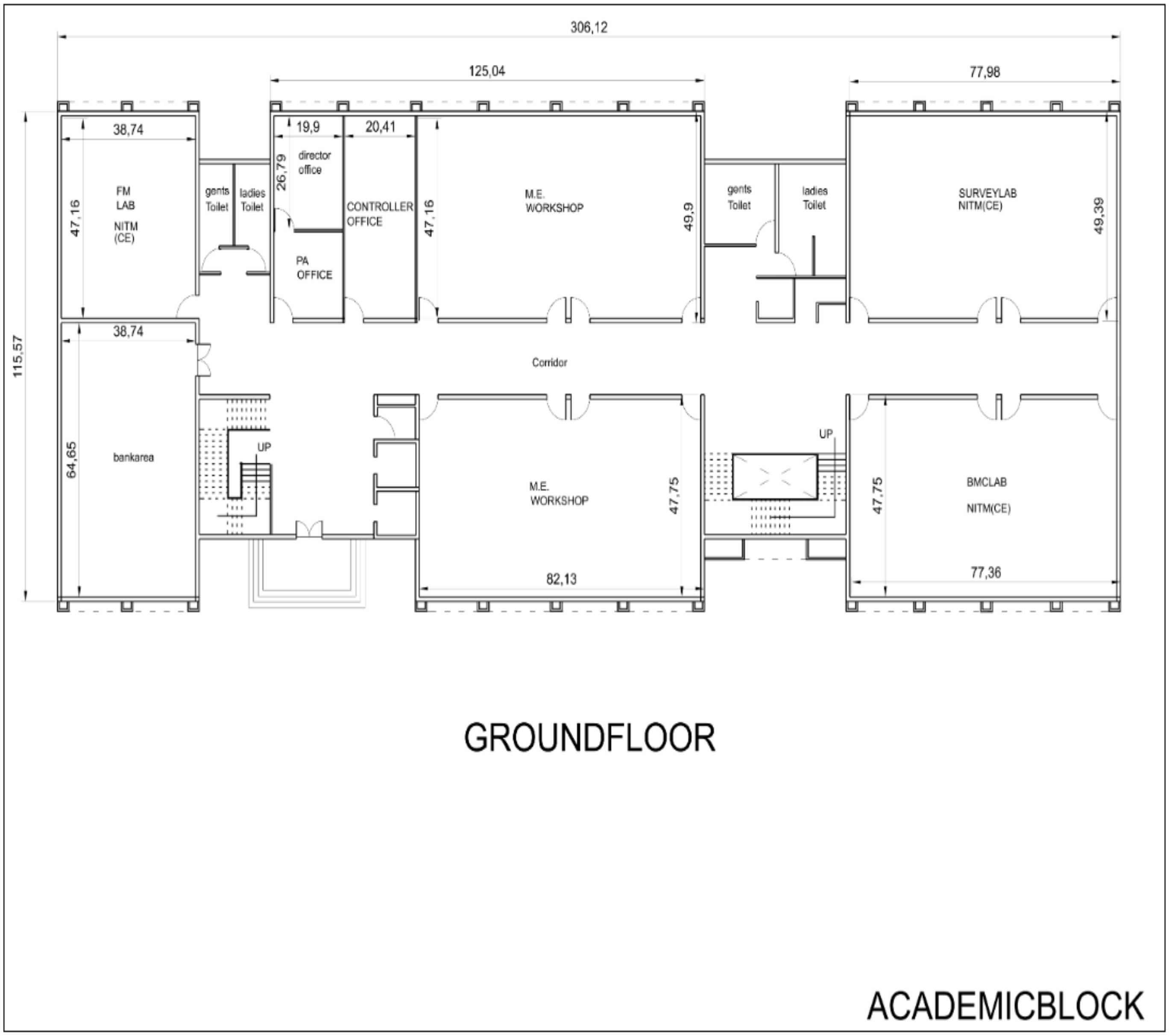


Figure:-12:- Ground Floor Plan (Proposed)

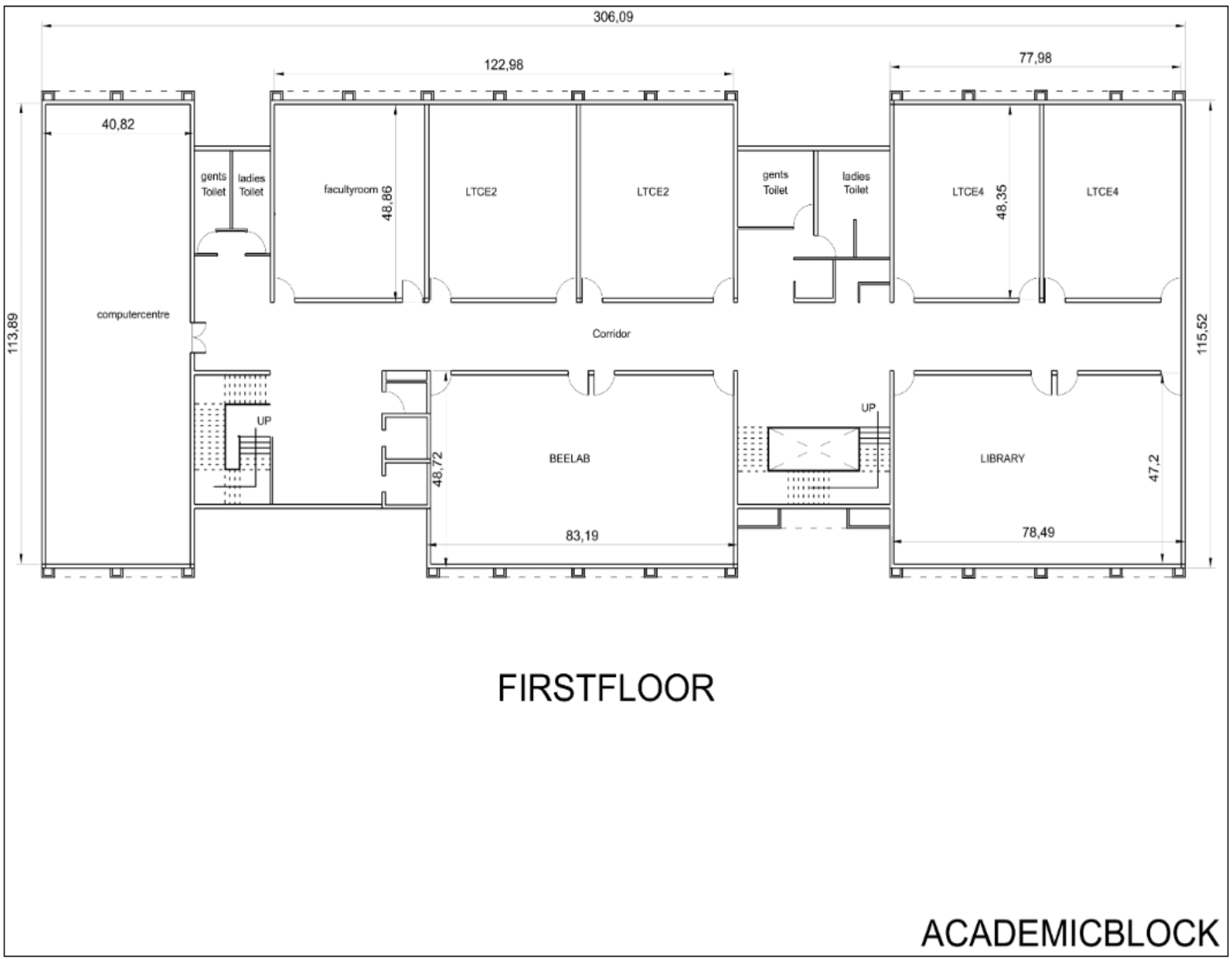


Figure:-13:- First Floor Plan (Proposed)

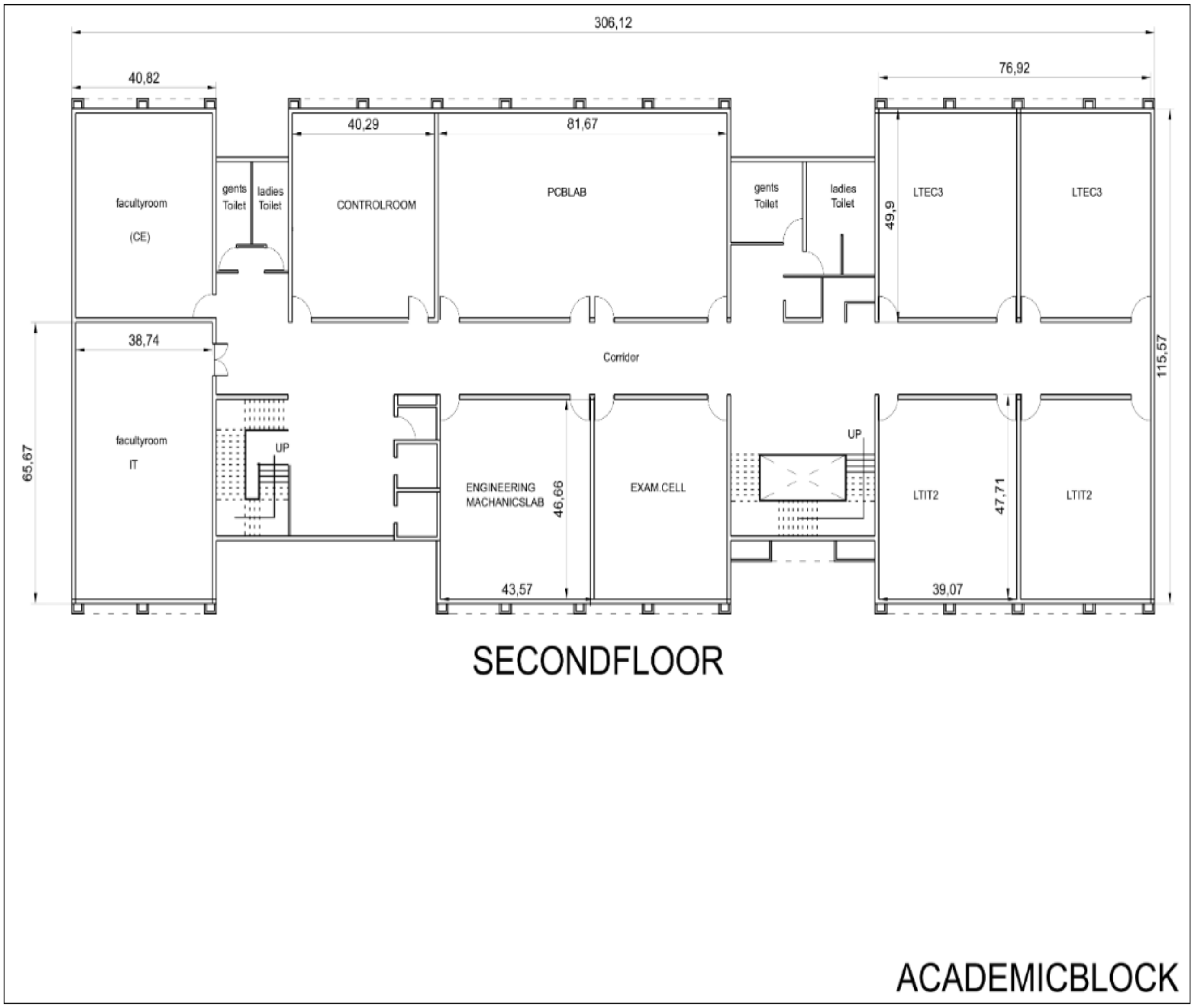


Figure:-14:- Second Floor Plan (Proposed)

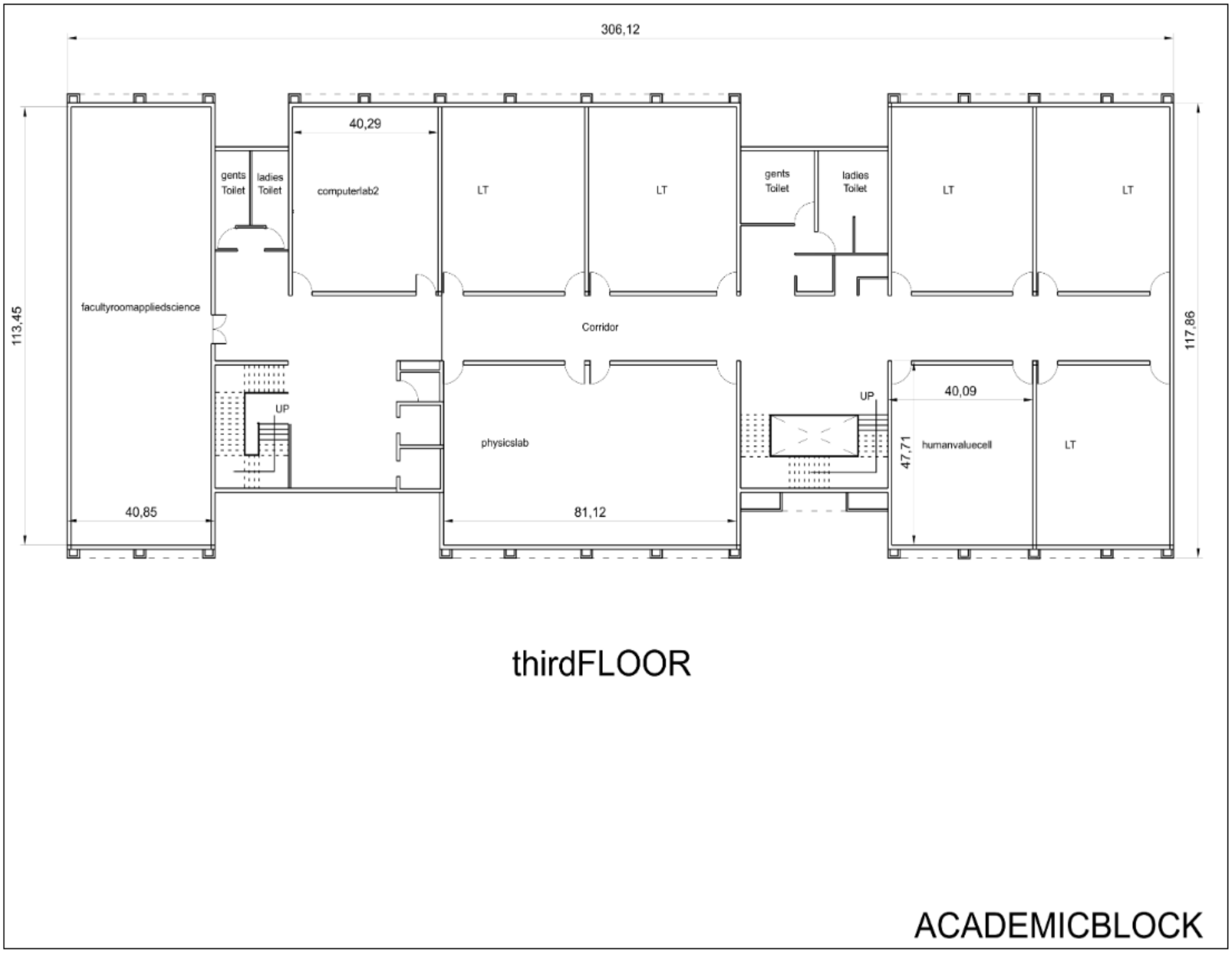


Figure:-15:- Third Floor plan (Proposed)

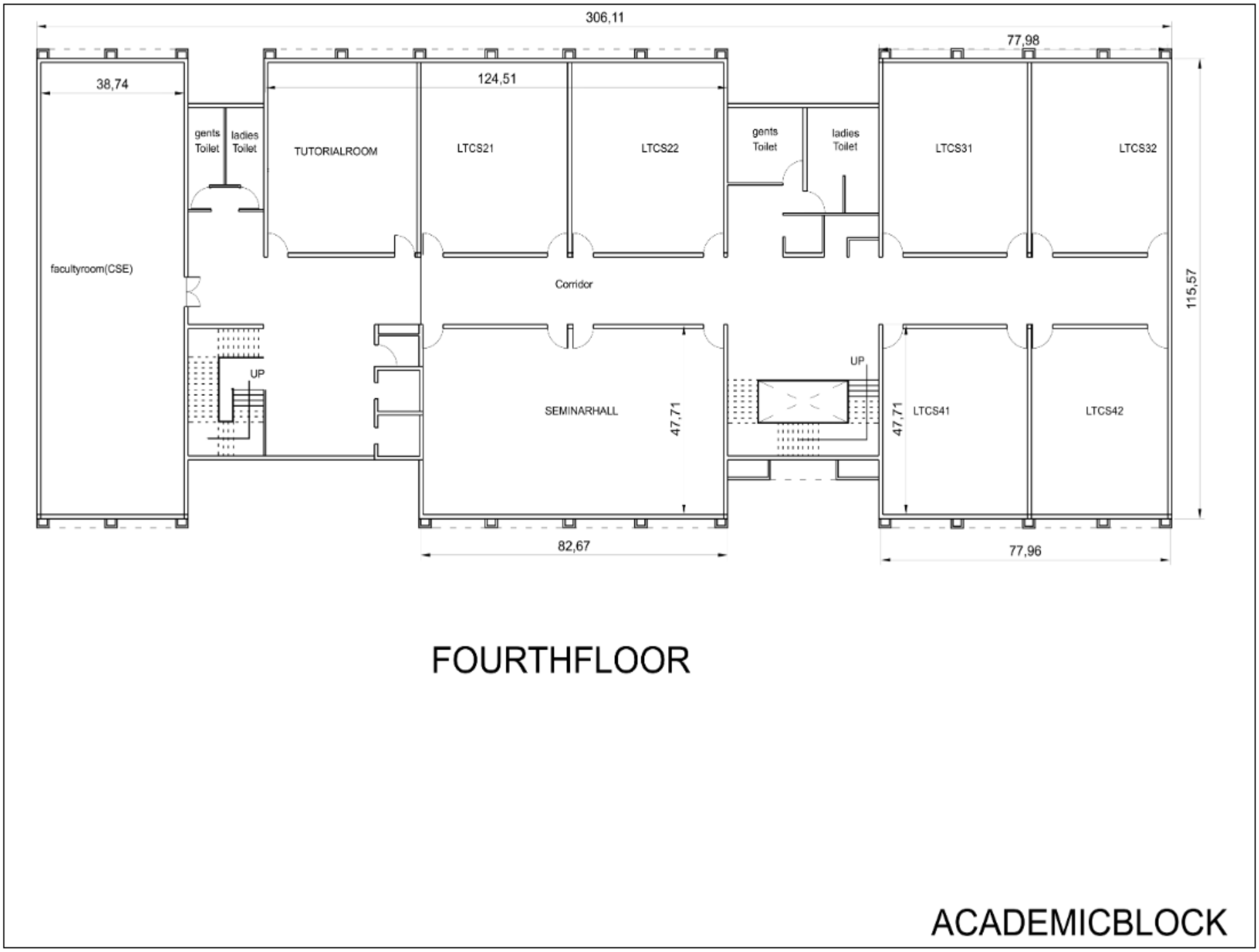


Figure:-16:- Fourth Floor Plan (Proposed)

3.2 Heat load details:-

The heat load calculation is done using hourly analysis program **(HAP) 5.10 software.**

- **Standards used while estimating the heat load are:**

LEED rating system – LEED version 4

Ventilation Standard – ASHRAE Std 62.1-2016 & ISHRAE

Energy Standards – ASHRAE Std 90.1-2013 & ISHRAE

3.3 Building Design Parameters:-

Summer Design Dry-Bulb	**107.0**°F (41.667^0 Celsius)
Summer Design Wet-Bulb	**72.0**°F (22.222^0 Celsius)
Winter Design Dry-Bulb	**44.0**°F (6.667^0 Celsius)
Winter Design Wet-Bulb	**36.9**°F (2.722^0 Celsius)
Outside DBT	48°C
Inside DBT	23^0 C -24^0 C
Glass U VALUE	1.1 W/m2k
SHGC	0.3

Table 1:- Building Design Parameters

*Current Data is as per the standards of **ASHRAE Handbook.**

3.4 Zone Heat Loads:-

- **GROUND FLOOR**

Zone Name / Space Name	UNIT	Cooling Load (MBH)	Time of Peak Sensible Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
FLUID MECHANICS LAB	1	273.8	Aug 1900	6502	20.1	2134.9	3.05
Zone 2							
BANK AREA	1	365.6	Jul 1900	8684	25.7	3067.5	2.83
Zone 3							
Director office	1	88.2	Aug 1900	2096	10.2	643.9	3.26
Zone 4							
PA office	1	51.6	Aug 1900	1224	6.7	338.7	3.61
Zone 5							
Controller office	1	145.8	Jul 1900	3463	14.3	1130.7	3.06

Zone 6							
ME Workshop 1	1	436.4	Jul 1800	10363	22.1	4010.4	2.58
Zone 7							
ME Workshop 2	1	437	Jul 1800	10380	22.1	4010.4	2.59
Zone 8							
Survey lab	1	503.8	Jul 1900	11966	33.3	4449.6	2.69
Zone 9							
BMC LAB	1	504.2	Jul 1900	11972	33.3	4449.6	2.69

Table 2:- ZONE HEAT LOAD (Ground Floor)

- **FIRST FLOOR**

Zone Name / Space Name	UNIT	Cooling Sensible (MBH)	Time of Peak Sensible Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
COMPUTER CENTRE	1	647.8	Jul 1900	15383	40.8	5638.8	2.73
Zone 2							
FACULTY ROOM	1	271.8	Jul 1900	6456	21.6	2392.8	2.70
Zone 3							
LT CE 2	1	271.8	Jul 1900	6456	21.6	2392.8	2.70
Zone 4							
LT CE 2.	1	271.8	Jul 1900	6456	21.6	2392.8	2.70
Zone 5							
BEE LAB	1	509.4	Jul 1900	12097	33.8	4567.3	2.65
Zone 6							
LT CE 4	1	251.4	Jul 1900	5969	20.8	2167.8	2.75
Zone 7							
LT CE 4.	1	251.4	Jul 1900	5969	20.8	2167.8	2.75
Zone 8							
LIBRARY	1	449.6	Jul 1900	10680	32.4	3870.9	2.76

Table 3:- ZONE HEAT LOAD (First Floor)

- **SECOND FLOOR**

Zone Name / Space Name	UNIT	Cooling Sensible (MBH)	Time of Peak Sensible Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
FACULTY ROOM IT	1	347.2	Jul 2000	8245	26.0	3116.8	2.65
Zone 2							
FACULTY ROOM CE	1	263.2	Jul 2000	6249	21.2	2302.6	2.71
Zone 3							
CONTROL ROOM	1	243	Jul 2000	5773	20.1	2109.9	2.74
Zone 4							
PCB	1	484.4	Aug 2000	11504	32.8	4307.3	2.67

Zone 5							
ENGG MECHANICS LAB	1	301	Jul 2000	7150	21.8	2459.1	2.91
Zone 6							
EXAM CELL	1	276.6	Jul 2000	6568	21.8	2459.1	2.67
Zone 7							
LT EC3	1	263.8	Jul 2000	6265	19.8	2081.0	3.01
Zone 8							
LT EC3.	1	263.8	Jul 2000	6265	19.8	2081.0	3.01
Zone 9							
LT IT2	1	266.0	Jul 2000	6316	19.9	2094.2	3.02
Zone 10							
LT IT2.	1	266.0	Jul 2000	6316	19.9	2094.2	3.02

Table 4 :- ZONE HEAT LOAD (Second Floor)

- **THIRD FLOOR**

Zone Name / Space Name	UNIT	Cooling Sensible (MBH)	Time of Peak Sensible Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
Faculty room applied science	1	590.0	Jul 1900	14011	39.9	5496.6	2.55
Zone 2							
Computer lab	1	316.4	Jul 1900	7514	23.3	2632.8	2.85
Zone 3							
LT 1	1	318.8	Jul 1900	7573	23.2	2607.4	2.90
Zone 4							
LT 2	1	318.8	Jul 1900	7573	23.2	2607.4	2.90
Zone 5							
Physics lab	1	487.2	Jul 1900	11573	32.7	4338.6	2.67
Zone 6							
LT 3	1	311.4	Jul 1900	7396	22.8	2529.8	2.92
Zone 7							
LT 4	1	311.4	Jul 1900	7396	22.8	2529.8	2.92
Zone 8							
human value cell	1	248.6	Jul 1900	5902	20.5	2156.1	2.74
Zone 9							
LT5	1	273	Jul 1900	6484	20.5	2156.1	3.01

Table 5:- ZONE HEAT LOAD (Third Floor)

- **FOURTH FLOOR**

Zone Name / Space Name	UNIT	Cooling Sensible (MBH)	Time of Peak Sensible Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
FACULTY ROOM CSE	1	569.4	Jul 1900	13521	38.8	5295.2	2.55
Zone 2							
TUTORIAL ROOM	1	313.8	Jul 1900	7453	22.8	2561.3	2.91
Zone 3							
LTCS21	1	313.8	Jul 1900	7453	22.8	2561.3	2.91

Zone Name / Space Name	UNIT	Cooling Sensible (MBH)	Time of Peak Sensible Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 4							
LTCS22	1	313.8	Jul 1900	7453	22.8	2561.3	2.91
Zone 5							
SEMINAR HALL	1	536.2	Jul 1800	12734	34.5	4634.0	2.75
Zone 6							
LTCS31	1	312.8	Jul 1900	7431	22.8	2551.7	2.91
Zone 7							
LTCS32	1	312.8	Jul 1900	7431	22.8	2551.7	2.91
Zone 8							
LTCS41	1	440.4	Jul 2000	10460	58.0	2248.3	4.65
Zone 9							
LTCS42	1	335.8	Jul 1900	7977	24.1	2798.4	2.85

Table 6:- ZONE HEAT LOAD (Fourth Floor)

Note:-1 MBH(Mega British Thermal Unit per hour)= 0.0833 TR(Ton of Refrigeration)

1 TR = 12000BTU/hr, 1 MBH= 1000 BTU/hr

(BTU (British Thermal Units) is defined as the amount of heat required to raise the temperature of one pound of water (0.45 litres) by one Fahrenheit (-17.22 degree Celsius).)

Heat Load:-

- The net heat load estimated for the entire building is 1297.5 T.R.
- The heat load required for the respective floors from ground floor to fourth floor is:

FLOOR	Heat Load Details
Ground floor	242.36 TR
First floor	255.92 TR
Second floor	251.05 TR
Third floor	270.55 TR
Fourth floor	277.62 TR

Table 7:- Heat Load Required per floor

3.5 LIST OF RESPONDENTS:-

VARIABLE REFRIGERANT VOLUME/ VARIABLE AIR VOLUME	**Krishna Refrigeration** Plot No-5, Sandhyapuri Colony, Opp. New High Court, Gate No.4,Faizabad Road,Lucknow-226016 www.kripl.net
	Amba Solutions Pvt Ltd. A1/3 Sector –B, Aliganj, Opp Aliganj Post Office, Lucknow-226024 www.amba.co.in
CHILLED BEAM	**SWEGON,** Blue Box Private Limited A793,TTC Industrial area, Road No.4, MIDC Khairane, Navi Mumbai- 400709 www.swegon.com
	TROX India Pvt. Ltd. Unit 751, Building No7, 5th floor, Solitaire Corporate Park, Chakala, Andheri (E),Mumbai, 400093 www.trox.in

Table 8 :- List of Respondents

3.6 HEAT LOAD DETAILS AND SYSTEM INSTALLATIONS FOR VRV SYSTEM
(Provided by Krishna Refrigeration Pvt. Ltd.)

Sr. No.	Floor	Area (sqft.)	Required Air (In CFM)	Required Load (In TR)	Required Load (In HP)	Selected Load (In HP)	Qty.	Total Capacity	Selected Outdoor
1	Ground Floor	2,134.86	8,539.44	21.35	25.88	5.00	6	30.00	30 HP
2		3,067.48	12,269.92	30.67	37.18	5.00	8	40.00	40 HP
3		643.85	2,575.40	6.44	7.80	4.00	2	8.00	24 HP
4		338.71	1,354.85	3.39	4.11	4.00	1	4.00	
5		1,130.70	4,522.81	11.31	13.71	4.00	3	12.00	
6		4,010.35	16,041.40	40.10	48.61	5.60	9	50.40	50 HP
7		4,010.35	16,041.40	40.10	48.61	5.60	9	50.40	50 HP
8		4,449.61	17,798.44	44.50	53.93	5.60	10	56.00	56 HP
9		4,449.61	17,798.44	44.50	53.93	5.60	10	56.00	56 HP
10	First Floor	5,638.80	22,555.20	56.39	68.35	5.60	12	67.20	(40+26) HP
11		2,392.84	9,571.36	23.93	29.00	5.00	6	30.00	30 HP
12		2,392.84	9,571.36	23.93	29.00	5.00	6	30.00	30 HP
13		2,392.84	9,571.36	23.93	29.00	5.00	6	30.00	32 HP
14		4,567.32	18,269.28	45.67	55.36	5.60	10	56.00	56 HP
15		2,167.75	8,670.99	21.68	26.28	5.00	6	30.00	30 HP
16		2,167.75	8,670.99	21.68	26.28	5.00	6	30.00	30 HP
17		3,870.89	15,483.57	38.71	46.92	5.00	10	50.00	50 HP
18	Second Floor	3,116.81	12,467.25	31.17	37.78	5.00	8	40.00	40 HP
19		2,302.63	9,210.52	23.03	27.91	5.00	6	30.00	30 HP
20		2,109.90	8,439.59	21.10	25.57	5.00	5	25.00	24 HP
21		4,307.36	17,229.42	43.07	52.21	5.60	10	56.00	56 HP
22		2,459.13	9,836.50	24.59	29.81	5.00	6	30.00	30 HP
23		2,459.13	9,836.50	24.59	29.81	5.00	6	30.00	30 HP
24		2,081.04	8,324.17	20.81	25.22	5.00	5	25.00	24 HP
25		2,081.04	8,324.17	20.81	25.22	5.00	5	25.00	24 HP
26		2,094.18	8,376.71	20.94	25.38	5.00	5	25.00	24 HP
27		2,094.18	8,376.71	20.94	25.38	5.00	5	25.00	24 HP
28		5,496.59	21,986.36	54.97	66.63	5.60	12	67.20	(40+26) HP
29		2,632.81	10,531.25	26.33	31.91	5.60	6	33.60	34 HP

30	Third Floor	2,607.36	10,429.44	26.07	31.60	5.60	6	33.60	34 HP
31		2,607.36	10,429.44	26.07	31.60	5.60	6	33.60	34 HP
32		4,338.62	17,354.48	43.39	52.59	5.60	10	56.00	56 HP
33		2,529.76	10,119.04	25.30	30.66	5.00	6	30.00	30 HP
34		2,529.76	10,119.04	25.30	30.66	5.00	6	30.00	30 HP
35		2,156.08	8,624.33	21.56	26.13	5.00	6	30.00	30 HP
36		2,156.08	8,624.33	21.56	26.13	5.00	6	30.00	30 HP
37	Fourth Floor	5,295.16	21,180.64	52.95	64.18	5.60	12	67.20	(40+26) HP
38		2,561.32	10,245.30	25.61	31.05	5.60	6	33.60	34 HP
39		2,561.32	10,245.30	25.61	31.05	5.60	6	33.60	34 HP
40		2,561.32	10,245.30	25.61	31.05	5.60	6	33.60	34 HP
41		4,634.04	18,536.16	46.34	56.17	5.60	10	56.00	56 HP
42		2,551.74	10,206.96	25.52	30.93	5.60	6	33.60	34 HP
43		2,551.74	10,206.96	25.52	30.93	5.60	6	33.60	34 HP
44		2,248.25	8,993.00	22.48	27.25	5.00	6	30.00	30 HP
45		2,798.41	11,193.64	27.98	33.92	5.60	6	33.60	34 HP
	TOTAL		**5,18,998.73**	**1297.5 TR**					

Table 9:- HEAT LOAD AND CFM DETAILS OF THE BUILDING BY VRV SYSTEM

Formulae used:-

- Required Air (In CFM)= 4 to 5 CFM per square feet.
- Required Load (In TR) = Required Air (In CFM) / 400.
- Required Load (In HP) = Required Load (In TR) 0.825.
- One TR = 0.825 HP.
- CFM = It is a measurement of the velocity at which air flows into or out of a system or space.

3.7 HEAT LOAD DETAILS AND SYSTEM INSTALLATIONS FOR ACB SYSTEM

(Provided by TROX India Pvt. Ltd.)

S. No.	Floor	Required Load (In TR)	Required Latent Load (In BTU) (Air side)	Required Sensible Load (In BTU) (Water - side)	Sensible load Watts	Required Latent CFM	Primary Air/ Beam CFM	Water flow rate/beam USGPM	Total Primary Air CFM Provided	Total chilled Beam (Req.)
1	Ground Floor	21.35	13,500.00	2,42,700.00	71,128	2327	70	1.30	2982	42
2		30.67	13,500.00	3,54,540.00	1,03,905	2327	70	1.29	4402	62
3		6.44	450.00	76,830.00	22,517	78	66	1.24	938	14
4		3.39	1,125.00	39,555.00	11,592	194	68	1.28	483	7
5		11.31	2,250.00	1,33,470.00	39,116	388	67	1.26	1632	24
6		40.10	13,500.00	4,67,700.00	1,37,069	2327	69	1.28	5740	82
7		40.10	13,500.00	4,67,700.00	1,37,069	2327	69	1.28	5740	82
8		44.50	13,500.00	5,20,500.00	1,52,543	2327	68	1.28	6440	92
9		44.50	13,500.00	5,20,500.00	1,52,543	2327	68	1.28	6440	92
10	First Floor	56.39	22,500.00	6,54,180.00	1,91,721	3879	69	1.28	8050	115
11		23.93	2,700.00	2,84,460.00	83,367	465	69	1.28	3500	50
12		23.93	13,500.00	2,73,660.00	80,202	2327	69	1.28	3360	48
13		23.93	13,500.00	2,73,660.00	80,202	2327	69	1.28	3360	48
14		45.67	13,500.00	5,34,540.00	1,56,658	2327	70	1.29	6603	93
15		21.68	13,500.00	2,46,660.00	72,289	2327	70	1.29	3010	43
16		21.68	13,500.00	2,46,660.00	72,289	2327	70	1.29	3010	43
17		38.71	22,500.00	4,42,020.00	1,29,543	3879	68	1.28	5460	78
18	Second Floor	31.17	2,700.00	3,71,340.00	1,08,829	465	69	1.28	4485	65
19		23.03	2,700.00	2,73,660.00	80,202	465	69	1.28	3360	48
20		21.10	2,250.00	2,50,950.00	73,546	388	69	1.28	3080	44
21		43.07	13,500.00	5,03,340.00	1,47,514	2327	70	1.30	6177	87
22		24.59	13,500.00	2,81,580.00	82,523	2327	68	1.27	3450	50
23		24.59	2,250.00	2,92,830.00	85,820	388	68	1.27	3588	52
24		20.81	13,500.00	2,36,220.00	69,229	2327	68	1.27	2898	42
25		20.81	13,500.00	2,36,220.00	69,229	2327	68	1.27	2898	42

26		20.94	13,500.00	2,37,780.00	69,686	2327	68	1.27	2898	42
27		20.94	13,500.00	2,37,780.00	69,686	2327	68	1.27	2898	42
28	**Third Floor**	54.97	2,700.00	6,56,940.00	1,92,530	465	68	1.28	8120	116
29		26.33	11,250.00	3,04,710.00	89,302	1940	68	1.27	3726	54
30		26.07	13,500.00	2,99,340.00	87,728	2327	68	1.28	3657	53
31		26.07	13,500.00	2,99,340.00	87,728	2327	68	1.28	3657	53
32		43.39	13,500.00	5,07,180.00	1,48,640	2327	70	1.30	6248	88
33		25.30	13,500.00	2,90,100.00	85,020	2327	70	1.30	3550	50
34		25.30	13,500.00	2,90,100.00	85,020	2327	70	1.30	3550	50
35		21.56	2,250.00	2,56,470.00	75,164	388	67	1.26	3128	46
36		21.56	13,500.00	2,45,220.00	71,867	2327	67	1.26	2992	44
37	**Fourth Floor**	52.95	2,700.00	6,32,700.00	1,85,426	465	70	1.29	7700	110
38		25.61	13,500.00	2,93,820.00	86,110	2327	66	1.24	3604	53
39		25.61	13,500.00	2,93,820.00	86,110	2327	66	1.24	3604	53
40		25.61	13,500.00	2,93,820.00	86,110	2327	66	1.24	3604	53
41		46.34	22,500.00	5,33,580.00	1,56,377	3879	70	1.29	6603	93
42		25.52	13,500.00	2,92,740.00	85,794	2327	66	1.24	3551	53
43		25.52	13,500.00	2,92,740.00	85,794	2327	66	1.24	3551	53
44		22.48	13,500.00	2,56,260.00	75,102	2327	67	1.26	3128	46
45		27.98	13500.00	3,22,260.00	94,445	2327	70	1.29	3976	56
	TOTAL	1297.5 TR	5,07,825 **42.31875 TR**	1,50,62,175 **1255.1812 5 TR**					**Total CFM** Required **1,84,831**	**2653**

Table 10:- HEAT LOAD AND CFM DETAILS OF THE BUILDING BY ACB SYSTEM

- Required Load (In TR) = Calculated by HAP Software (approx).
- Required Total Load (In BTU) = Required Load (In TR) * 12000.
- 1 MBH= 1000 BTU/hr.
- Required Latent Load (In BTU) = OCCUPANCY * 225.
- Required Sensible Load (In BTU) = Required Load (In BTU) - Required Latent Load (In BTU).
- Sensible load Watts = Required Sensible Load (In BTU) / 3.412141633.
- Latent CFM = Required Latent Load (In BTU) / (0.68*8.53).

- Latent load of the building (Air-Side) - Latent load by primary air.
- Sensible load of the building (Water side) – Sensible load by chilled coil coiling.
- Total Beam Required Numbers = Sensible load Watts / Chilled beam Capacity watts
- Total Primary Air CFM = Total Beam Required Numbers * Primary Air/Beam CFM.
- Total Water Flow Rate USGPM = Total Beam Required Numbers * Water Flow rate/beam l/h.

3.8 COST DETAILS:-VRV/VRF System.(Daikin)

Outdoor units:-

S.NO	OUTDOOR UNITS	QTY	ESTIMATED RATE	TOTAL AMOUNT
1	56 HP cooling only [RXQ56ARY6]	6	9,49,412.00	56,96,472.00
2	50 HP cooling only [RXQ56ARY6]	3	8,56,665.00	25,69,995.00
3	40 HP cooling only [RXQ56ARY6]	5	6,73,465.00	33,67,325.00
4	34 HP cooling only [RXQ56ARY6]	9	5,82,918.00	52,46,262.00
5	32 HP cooling only [RXQ56ARY6]	1	5,49,435.00	5,49,435.00
6	30 HP cooling only [RXQ56ARY6]	13	5,19,835.00	67,57,855.00
7	26 HP cooling only [RXQ56ARY6]	3	4,58,371.00	13,75,113.00
8	24 HP cooling only [RXQ56ARY6]	6	4,28,771.00	25,72,626.00
	TOTAL COST OF OUTDOOR UNITS			**2,81,35,083**

Table 11:- COST OF OUTDOOR UNITS BY VRV SYSTEM

Indoor units:-

S.NO	INDOOR UNITS	QTY	ESTIMATED RATE	TOTAL AMOUNT
1	5.6 HP [FXFSQ140ARV16]	168	47,912.00	80,49,216.00
2	5.0 HP [FXFSQ140ARV16]	135	45,318.00	61,17,930.00
3	4.0 HP [FXFSQ140ARV16]	6	43,888.00	2,63,328.00
	TOTAL COST OF INDOOR UNITS			**1,44,30,474**

Table 12:- COST OF INDOOR UNITS BY VRV SYSTEM

Refrigerant Piping:-

S.NO	Refrigerant Piping	Qty	Estimated rate	Total Amount
1	41.27 mm dia (OD) with 19 mm thick insulation	1250	1,558.00	19,47,500.00
2	34.9 mm dia (OD) with 19 mm thick insulation	1060	1,183.00	12,53,980.00
3	28.58 mm dia (OD) with 19 mm thick insulation	1260	869.00	10,94,940.00
4	22.2 mm dia (OD) with 19 mm thick insulation	1180	706.00	8,33,080.00
5	19 mm dia (OD) with 19 mm thick insulation	1260	620.00	7,81,200.00
6	15.86 mm dia (OD) with 19 mm thick insulation	1350	535.00	7,22,250.00
7	12.7 mm dia (OD) with 19 mm thick insulation	1350	403.00	5,44,050.00
8	9.5 mm dia (OD) with 19 mm thick insulation	1350	330.00	4,45,500.00
	TOTAL COST OF REFRIGERANT PIPING			**76,22,500**

Table 13:- COST OF Refrigerant Piping By VRV SYSTEM

Other Installations:-

S.NO	Other Installations	Qty	Estimated Rate	Total Amount
1	Supply, fixing & commissioning of BHF kit for connecting two outdoor. **Make- Daikin**	55	9,013.00	4,95,715.00
2	Supply, fixing & commissioning of Imported Y-Joint or Refnets. **Make- Daikin**	309	5,331.00	16,47,279.00
3	Supply, fixing & commissioning of Corded/Cordless remote contoller for the indoor unit. **Make- Daikin** [BRC7M632F-6] and [BRC1C62-9]	309	2,169.00	6,70,221.00
4	Supply, installation, testing and commissioning of Centralized Remote Controller as per specification & Complete in all respect. **Make- Daikin [DCS302CA61]**	42	23,488.00	9,86,496.00

				37,99,711

Table 14:- COST OF OTHER INSTALLATIONS BY VRV SYSTEM

TOTAL COST:-Variable Refrigerant Volume (Krishna Refrigeration)

- (Outdoor + Indoor +Refrigerant piping + Installations) Cost:- 5,39,87,768
- Installation cost & other cost will be around 3crores. (Data By the dealer associated)
- Total Amount without GST:- **8,16,35,878.00**
  *(GST will paid at extra 18%).

3.9 COST DETAILS OF ACB (Active Chilled Beam) by (TROX)
Chilled Beam Size (1800*600) DID604 (4 way)

Sr. No.	Floor	Chilled Beam Size (Length X Width)	Chilled beam Capacity watts	Primary Air/Beam CFM	Total Beam Required Numbers	TROX MALAYSIA MODEL
1	Ground Floor	1800X600	1693	71	42	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
2		1800X600	1684	71	62	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
3		1800X600	1609	67	14	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
4		1800X600	1656	69	7	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
5		1800X600	1630	68	24	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
6		1800X600	1672	70	82	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
7		1800X600	1672	70	82	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
8		1800X600	1658	70	92	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
9		1800X600	1658	70	92	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
10	First Floor	1800X600	1667	70	115	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
11		1800X600	1667	70	50	DID604-MY-LR-2-G-HL-

						A1/593x1793/P1/RAL9010/0/0
12		1800X600	1670	70	48	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
13		1800X600	1670	70	48	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
14		1800X600	1684	71	93	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
15		1800X600	1681	70	43	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
16		1800X600	1681	70	43	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
17		1800X600	1660	70	78	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
18	Second Floor	1800X600	1674	69	65	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
19		1800X600	1670	70	48	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
20		1800X600	1670	70	44	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
21		1800X600	1695	71	87	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
22		1800X600	1650	69	50	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
23		1800X600	1650	69	52	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
24		1800X600	1648	69	42	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
25		1800X600	1648	69	42	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
26		1800X600	1648	69	42	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
27		1800X600	1648	69	42	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
28	Third Floor	1800X600	1660	70	116	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
29		1800X600	1654	69	54	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
30		1800X600	1655	69	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
31		1800X600	1655	69	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
32		1800X600	1689	71	88	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
33		1800X600	1700	71	50	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0

34		1800X600	1700	71	50	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
35		1800X600	1634	68	46	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
36		1800X600	1633	68	44	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
37	Fourth Floor	1800X600	1685	70	110	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
38		1800X600	1625	68	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
39		1800X600	1625	68	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
40		1800X600	1625	68	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
41		1800X600	1681	71	93	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
42		1800X600	1619	67	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
43		1800X600	1619	67	53	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
44		1800X600	1632	68	46	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0
45		1800X600	1686	71	56	DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0

Table 15:- NUMBER OF CHILLED BEAM REQUIRED

Total number of chilled beams required:-2653

Cost of ONE Trox Chilled beam :-

TROX Model	Qty.	Unit	Price
DID604-MY-LR-2-G-HL-A1/593x1793/P1/RAL9010/0/0	1	No.	**In USD**
			$740.00

Table 16:- TROX MODEL UNIT COST

ACB:- DID604 (Four discharge), DID632 (Two discharge)

ONE DOLLAR= 75.62 INR, 740 DOLLAR = 55,958.8 INR (as on 20 march 2020)

Total number of chilled beams required:-2653.
So the Price of chilled beam system will be 2653* 55,958.8 = 14,84,58,696 INR.
GST will paid at extra 18%.

Total cost = 14,84,58,696.

Chapter-4 (CONCLUSION)

The movement toward sustainable building designs is being driven largely by environmentally-sensitive building owners and their occupants. It's seen that merely refining the system within the building we'll achieve energy efficiency and overall sustainable structure. A completely effective HVAC system must also solve many other indoor environmental matters that affect occupant comfort, productivity and health like ventilation air, air distribution, humidity control, noise levels, etc. Chilled beam systems are the perfect "**green**" solution for several buildings. There's also an overall comfort and economy for the employment of active chilled beam systems over other of the more conventional systems choices.

4.1 <u>Vital Points leading towards Conclusion:-</u>

- Both systems will generally have the same installed refrigeration and heating and as a result, common chiller and boiler plants.
- **The main differences are in the air handling systems.**
- With the greatly reduced primary airflows and static pressures of Active Chilled Beam systems the fan energy savings over "all air" systems can be dramatic, particularly in buildings with relatively high sensible load densities.
- While this is true for both single duct and fan-powered VAV systems, the savings are even more dramatic in the latter case as all the fans and motors in the VAV terminal units are eliminated.
- With respect to the installed cost of Active Chilled Beam systems, the terminal units normally cost more as typically more of them are required. There are, however, offsetting installed cost savings in the system.
- The size and cost of the central air handlers and ductwork/risers in the Active Chilled Beam system are significantly reduced due to the reduced in primary airflows.
- The cost of the building's overall electrical infrastructure may also be reduced due to much lower fan power requirements.
- Wiring expenses are reduced as there are no main power connections to the Active Chilled Beams. Controls are also often less expensive as the Active Chilled Beams are controlled by simple low voltage zone valves.
- In addition there are also ongoing maintenance cost savings.
- The Active Chilled Beams have no moving parts and do not require regular maintenance (other than infrequent vacuuming of the unit's coil as required).
- Reduces ceiling space

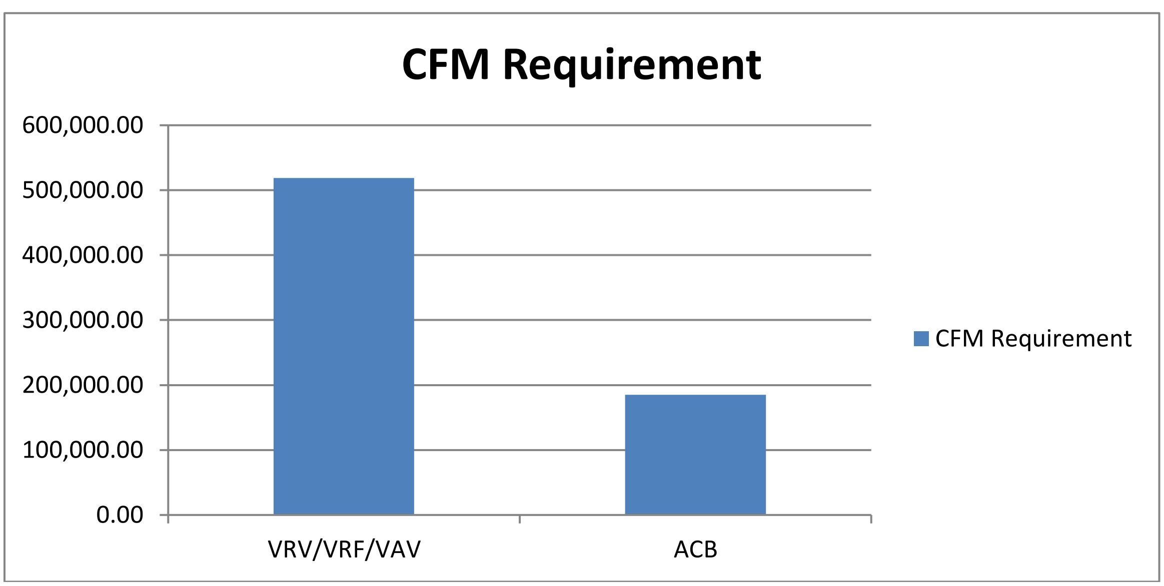
- Compared to large VAV systems 50,000 CFM and greater, a chilled beam system can reduce ceiling space by as much as **18 inches** •Compared to small VAV systems 20,000 CFM and less, a chilled beam system can reduce ceiling space by as much as 12 inches.
- An additional **8 – 10 LEED points** can be achieved. Chilled beams have no moving parts and require no regular maintenance.
- Mostly the maintenance cost involves Filter change, Clean coil and condensate system and fan motor replacement and maintenance.
- Fan coil unit, VAV, VRV are some of the conventional HVAC systems.
- **Operating Costs:-** Although total pump energy is generally somewhat higher, this is more than offset by the reduction in fan energy
- A one inch diameter water pipe can transport the same cooling energy as an 18 inch square air duct.
- Depending on system design, kW/ton is improved by utilizing relatively warmer water temperatures through the chilled beams**.**
- Higher chilled water temperatures used by chilled beams may allow chiller efficiencies to increase by as much as 35%.

The conclusion is in the form of Primary Air Requirement and Cost Analysis:-

4.2 CFM Requirement (Primary air):-

	Conventional System	Chilled Beam System
C.F.M Required Air handling system	5,18,998.73	1,84,831

- **Table 17:- CFM REQUIREMENT COMPARISON**



4.3 Cost of System Comparison(Economic parameter of sustainability):-

- Maintenance cost is 4500 Rupees Per HP Per Year.(By Krishna Refrigeration)
- Required Load in (HP) is 1572.72(By the heat load calculation).
- Maintenance cost is Clean coil and condensate system for chilled beam is 30 dollars for each chilled beam for a period of four years.
- For one year = 30/4= 7.5 dollar for one chilled beam (one dollar =75.90 INR as on date 23 april 2020).
- Operation cost details is given below.

It is to be noted that The Conventional System is costing at around 30000-35000 per Ton.

WHILE

The Chilled Beam System cost around 100000-150000 per Ton.

	Fan Coil Unit	Active Chilled Beam
Filter Changes:		
Frequency:	Twice Yearly	NA
Cost per Change:	$30.00	
Cost over Lifetime (20 Years):	$1,200.00	$0.00
Clean Coil and Condensate System:		
Frequency:	Twice Yearly	Every four Years
Cost per Event:	$30.00	$30.00
Cost Over Lifetime:	$1,200.00	$150.00
Fan Motor Replacement:		
Frequency:	Once during life	NA
Cost per Event:	$400.00	
Cost Over Lifetime:	$400.00	$0.00
Life Cycle (20 years) maintenance cost:	$2,800.00	$150.00

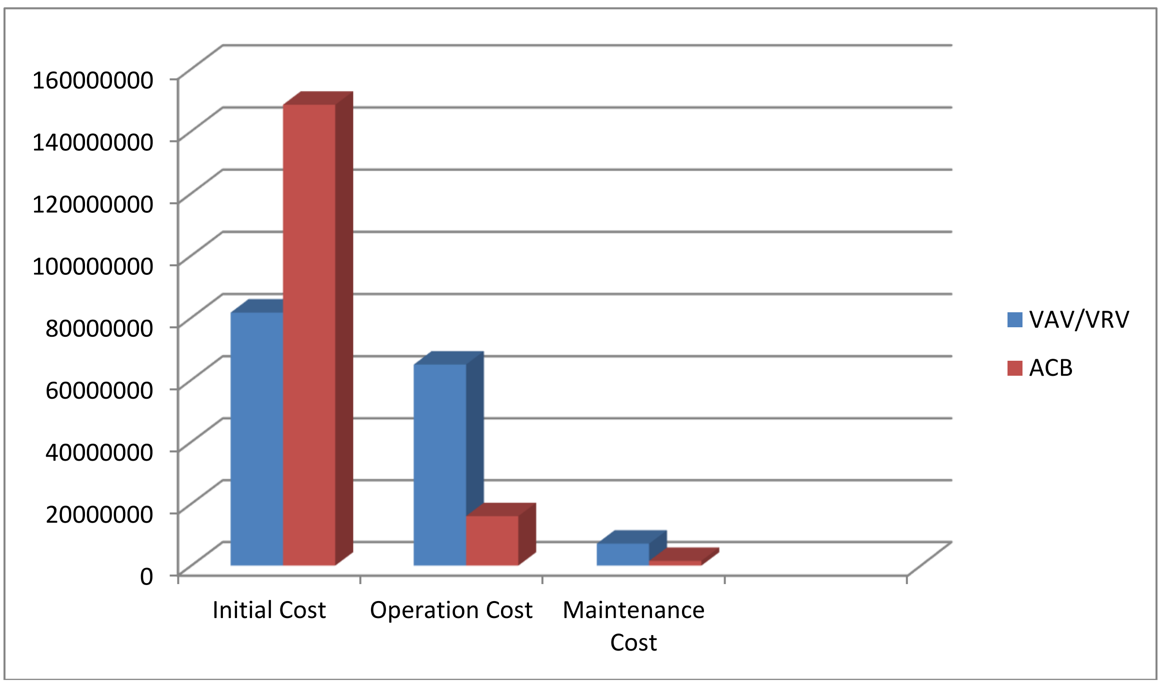
Source: REHVA Chilled Beam Application Guidebook (2004)

Figure:-17:- Maintenance cost comparison

COST COMPARISON:-

Cost	Conventional System	Chilled Beam System
1)Initial cost of the system	**8,16,35,878.00**	**14,84,58,696**
2)Maintenance cost for (1 year)	**70,74,900**	**15,10,220.25**
3)Operation cost for (1 year)	**6,49,06,220**	**1,59,67,705**

- **Table 18:- COST COMPARISON**



4.4 RESULTS:-

4.4.1 VAV/ACB RESULT (ECONOMIC FACTOR)

	VAV /VRV	ACB
Installed Costs		
Central air handlers size	Much Larger	Much Smaller
Ductwork/risers size	Much Larger	Much Smaller
Ceiling space required	Larger	Smaller

Water piping	Slightly Smaller	Slightly Larger
Control system complexity	Higher	Lower
Operating Costs		
Fan energy	Much Higher	Much Lower
Pump energy	Slightly Lower	Slightly Higher
Maintenance	Higher	Lower
Comfort		
Thermal control	Same/Slightly Worse	Same/Slightly Better
Humidity control	Much Worse	Much Better
Noise levels	Higher	Lower
Air Movement	Variable/Worse	Constant/Better
Contribution to LEED credits	Little	Significant

Table 19:- VAV/ACB COMPARISON AND RESULT

4.4.2 Energy Savings Details:-

HVAC System	**VRF**	**ACB**
Total Conditioned Area (sq. feet)	1,29,750	1,29,750
Energy Consumption*	2254	554
Annual Power 8 hour / day	5408852	1330642
Electricity Charge Rupees. 12/-	₹ 6,49,06,220	₹ 1,59,67,705
Each Year Energy Saving		₹ 4,89,38,515
Maintenance Saving		₹ 55,64,679.75
Total Saving / Year		**₹ 5,45,03,194.8**

*Annual Power details= 300days (approx.)*8*Energy consumption *Electricity charge= 12*Annual power details.

- **Table 20:- ENERGY SAVINGS DETAILS COMPARISON AND RESULT**

*Energy Consumption Details:-

Details of Energy load	VRF System	ACB System
Air Load	1298	210
Water load	0	177
System TR	**1298**	**387**
ENERGY SAVINGS DETAILS		
Water Chiller kW/TR@ 35 Deg C	0	193
Air Chiller kW/TR@ 35 Deg C	0	246
VRF Power 1.3 ikW/TR @ 35 ^{0}C & Indoor 23^{0}C	1687	0
DOAS/TFA	139	69
VRF Indoor Fan kW-0.2 kW/TR	260	0
Pump Power kW/TR - 0.12	0	46
IDU to ODU Distance loss power	169	0
Total System Power Consumption	2254	554

Table 21:- ENERGY SAVINGS DETAILS

4.4.3 COMPARISON DATA OF SUSTAINABLE AND CONVENTIONAL BUILDING

LEED was established in 1998 and is presently recognized internationally as a credible green building certification system. To ensure the optimal performance and maximum energy saving, LEED has been applied. LEED is one of the most popular GB certification programs used worldwide.

13 points awarded for this GB design according to the LEED rating system.

%COST SAVINGS	POINTS AWARDED
12%	1
14%	2
16%	3

18%	4
20%	5
22%	6
24%	7
26%	8
28%	9
30%	10
32%	11
34%	12
36%	13

Table 22:- LEED POINTS AWARDED ON THE BASIS OF COST SAVINGS

4.4.4 LIFE-CYCLE COST ANALYSIS :-

- For **Life-Cycling Cost Analysis**, a study period of **20 years** is taken into consideration. In this Initial cost, Energy costs (Operating cost) and costs for Maintenance are calculated separately for their future value.
- For **LCCA**, they are converted to present value with the help of discount factor.
- In India, present discount factor by Reserve Bank of India (RBI) is 8%.
- For calculating **Present Value** following equation is used,

$$\mathbf{(PV) = FV / (1+r)^n}$$

PV= Present Value

FV= Future Value n years hence

R= Discounted rate

N = Number of periods over which the cash flow occurs.

LCC for Conventional HVAC System:-

1) Initial cost of the system = 8,16,35,878.00 (Present value)

2) Maintenance cost for (1 year) = 70,74,900

3) Maintenance cost for (20 years) = 14,14,98,000

- **Present value for Maintenance cost = 30358142.3**

4) Operation cost for (1 year) = 6,49,06,220

5) Operation cost for (20 years) = 64906220*20

- **Present value for Operation cost = 278510263.**

LCC = 8,16,35,878 + 30358142.3 + 278510263 = 39,05,04,283

LCC for ACB HVAC System:-

1) **Initial cost of the system = 14,84,58,696.**
2) **Maintenance cost for (1 year) =** 15,10,220.25
3) **Maintenance cost for (20 years) =** 3,02,04,405

- **Present value for Maintenance cost = 6480300.95**

4) Operation cost for (1 year) =1,59,67,705

5) Operation cost for (20 years) = 31,93,54,100

- **Present value for Operation cost = 68516849.7**

LCC= 14,84,58,696 + **6480300.95 + 68516849.7 = 22,34,55,847.**

4.4.5 CONCLUSION:-

- **LCC == 39,05,04,283** (VRF TECHNOLOGY / TRADITIONAL

TECHNOLOGY/ CONVENTIONAL TECHNOLOGY)

- **LCC == 22,34,55,847** (ACB TECHNOLOGY)

DIFFERENCE BETWEEN THE LCC OF VRF AND ACB TECHNOLOGY IS 16,70,48,436.

- On the basis of cost savings% = (167048436/390504283)*100 = 42.766%
- LEED Rating:- (13 points)
- **Conclusion- From this study it is clear that LCC for ACB is much less than that of VRF technology.**

CHAPTER-5

5.1 ISHRAE GUIDELINES REGARDING USE OF HVAC IN TIMES OF COVID-19 PANDEMIC

On 11th February 2020, the International Committee on Taxonomy of Viruses (ICTV) announced "severe acute respiratory syndrome corona virus 2 (SARS- CoV-2)" as the name of the virus that has caused the new disease COVID-19.

A month later, the World Health Organisation (WHO) made an assessment and announced the disease to be a pandemic. COVID-19 has led to severe global socio-economic disruption impacting millions around the globe.

Commercial and Industrial Facilities:-

Commercial Establishments and Industrial Facilities have multiple occupancy as well as transient visitors. It is this aspect that necessitates precaution in operating their Air conditioning Systems.

For the purpose of Guidance for operation during a Pandemic like COVID-19, Air Conditioning is **Categorized** based on the **types of Indoor Units installed :**

(These indoor Units may be connected via refrigerant or chilled water pipes to DX Outdoor Units, VRF Outdoor Units or a Chiller)

The best action to limit risk of COVID-19 infection by air is to ventilate indoor environments with outdoor air as much as possible. Mechanical ventilation systems and air conditioning systems, which provide ventilation, can perform this function more effectively than simply opening the windows, because they improve the quality of the outdoor air with filtration.

CATEGORIES OF INDOOR UNITS :

i) **Multiple Cassette Units: C**eiling mounted units that can each cool up to 50 sqm and can be controlled individually or as a group.

ii) **Multiple Hi Wall Units:** Used due to ease of installation and low Cost.

iii) **Tower Units:** For larger spaces, where most occupants are not stationary thus allowing for higher drafts.

iv) **Ducted Units :** A mini central Air conditioning system that is easy to operate.

v) **Fan Coil Units :** Installed in guest rooms, individual office spaces or patient wards.

vi) **Air Handling Units:** Can provide better ventilation, filtration and Coil disinfecting.

OPERATING GUIDELINES FOR ALL CATEGORIES

A) **Air Filters must be kept clean as given in the Section -** Operation & Maintenance.

B) **Provide adequate Ventilation** (Fresh Air and Exhaust).

C) **Inspect and clean the indoor unit Coils, as given in the Section -** Operation & Maintenance.

D) **Set Room Temperature between 24°C and 30°C.** Maintain relative humidity between 40% and 70%.

(In humid Climates set temperature closer to 24°C for de-humidification and in Dry Climates closer to or at 30°C Use Fans to increase air movement)

E) **Heat Recovery Wheel (HRW) :** It is advisable to keep this wheel in off mode to reduce cross contamination. Upon restarting, the wheel must first be sanitized.

F) **Toilet and Kitchen Exhaust Fans** must be kept in operating mode.

RECOMMENDATIONS FOR CATEGORY I) , II) AND III) INDOOR UNITS :

If fresh air is not provided, it is advisable to introduce a fresh air duct attached to a central inline fan filter unit and distribute the fresh air by grilles into the space or near the indoor units. For Cassette Units the fresh air duct may be connected to the available port of the Cassette Unit. In case fresh air cannot be provided through a fan it is recommended to actively use operable windows.

A minimum fresh air volume of 8.5 cum/ hour per person and 1.1 cum/ hour per sq m (5 cfm per person and 0.06 cfm per sq ft) is recommended.

A Separate Treated Fresh Air DX Unit may be provided in the case of a multiple unit installation.

RECOMMENDATIONS FOR CATEGORY IV), V) AND VI) INDOOR UNITS :

Fresh air must be provided by an inlet duct and fan. It is advisable to provide a MERV 13 or higher filter fitted on the Air Handling Unit. If a filter of higher filtering capability is retrofitted into an existing system, care shall be taken to ensure that the fan and motor capacities are adequate to handle the higher pressure drop.

A minimum fresh air volume of 8.5 cum/ hour per person and 1.1 cum/ hour per sq m (5 cfm per person and 0.06 cfm per sq ft) is recommended. The recommendation is to maximize supply of outside air within the limits of the system.

In buildings without mechanical ventilation systems it is recommended to actively use operable windows. Add a TFA (treated fresh air) unit if recommended Fresh Air intake impacts cooling performance. Install UVGI (Ultraviolet germicidal irradiation) for larger Ducted Units and AHUs to keep Coils continuously clean and disinfected. It is advisable to inspect the AHUs and ducts for Air tightness and low leakage.

ADDITIONAL RECOMMENDATIONS FOR INDUSTRIAL FACILITIES

1) Minimum air changes of around 10-15 ACHP (Air Changes Per Hour) is advised for good ventilation.

2) The mechanical exhaust air shall be 70% to 80% of fresh air quantity to maintain necessary positive pressure in the space.

3) In cases of evaporative cooling / air washers it is advisable to disinfect the water using UVGI or Ionization or chemical dosing. Run the system in fan only mode for 30-60 minutes every day to dry the cooling pads. Then run only the pumps for water circulation without fans in operation for 30 minutes, to wash out any bacterial growth. Finally flush the water from the tanks and re-start the system with fresh water.

4) In case of **re-circulating system**, it is recommended to limit return air circulation. The return air system could be converted to **an exhaust system.**

The following steps are recommended for the start-up of air conditioning system.

1. The user or the owner should get the area sanitized.

2. Study **the fresh air** and **exhaust system adequacy** as per the guidelines and inform the user to modify the system if found inadequate.

3. Carry the preventive maintenance on all the units as per manufacturer's guidelines. This should include disinfecting and cleaning of :

   a. **Filters, grilles, diffusers & internal surfaces**:- it is recommended to use 5% Cresol solution (containing 50% Cresol and 50% Liquid soap solution). Mix 1 liter of this solution in 9 liters of water. The surface shall be sprayed with this solution, left for 10 minutes and then washed / wiped clean with water / cloth. (the above methodology is only for washable filters)

   b. **Condensate drain pan**:- Disinfecting / treatment of condensate drain pan is suggested using UV treatment or 1% sodium hypochlorite dosing. This will apply only if the HVAC equipment is working on a re-circulatory mode.

   c. **Coils:-** Follow standard recommendations of coil cleaning and then sanitize using the same protocol as that of the filters specified above

4. In case the area has ducted air distribution, it is advisable to clean the ducts by an appropriate method that may include santization.

5. The following process is recommended at start-up :

   a. Open all the doors and windows of the space.
   b. Ensure that all cleaning protocols as advised above are complete

c. Run the fresh air system at the maximum intake of air setting.

d. Start the air conditioning system in fan mode only, without filters and run it for minimum of two to four hours with doors open and exhaust system operational.

e. Install the clean & sanitized filters.

f. **Start the AC in normal mode and run for two hours with doors open and then close the doors and windows.**

6. The fresh air and ventilation system should be kept on throughout the off cycle and on the weekend and holidays in air circulation mode.

REFERENCES:

1. *Peter O. Akadiri 1,*, Ezekiel A. Chinyio 1 and Paul O. Olomolaiye 2 ,"Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector, Buildings 2012, 2, 126-152; doi:10.3390/buildings2020126.*
2. *Mohd. Wira Mohd Shafiei and Hooman Abadi ,Tools"The Importance of Green Technologies and Energy Efficiency for Environmental Protection. International Journal of Applied Environmental Sciences ISSN 0973-6077 Volume 12, Number 5 (2017), pp. 937-951 © Research India Publications http://www.ripublication.com*
3. *Mohammed Ubied Ali1, Mohammed Ishaq2, "To Identify the HVAC Energy Savings through Chilled Beam Cooling Technique, International Journal for Research in Applied Science & Engineering Technology (IJRASET), ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887, Volume 5 Issue XII December 2017- Available at www.ijraset.com.*
4. *Y.H. Yau1,2*, J.H. Tam1,3,"A COMPARISON STUDY FOR ACTIVE CHILLED BEAM AND VARIABLE AIR VOLUME SYSTEMS FOR AN OFFICE BUILDING "1876-6102 Copyright © 2018 Elsevier Ltd. All rights reserved Selection and peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum 2018.*
5. *Syed Moazzam Ali &Dr.Balu Naik Banoth "LOW ENERGY CONSUMPTION HVAC SYSTEMS FOR GREEN BUILDINGS USING CHILLED BEAM TECHNOLOGY",Volume 4, Issue 3, April 2013, pp. 316-324 © IAEME: www.iaeme.com/ijaret.asp Journal Impact Factor (2013): 5.8376 (Calculated by GISI) www.jifactor.com.*
6. *Saeed Reza Mohandes1, (Hossein Omrany2)'STUDY THE ROLE OF CHILLED BEAMS IN IMPROVING COOLING EFFICIENCY OF BUILDINGS: LITERATURE REVIEW.*
7. *Darren Alexander, P.Eng.; and Mike O' Rourke,Design Considerations For Active Chilled Beams ,The following article was published in ASHRAE Journal, September 2008. ©Copyright 2008 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. It is presented for educational purposes only. This article may not be copied and/or distributed electronically or in paper form without permission of ASHRAE.*

8. Kuei-Peng Lee 1, Kuan-Ting Lin 1 and Bo-Huei Wu 1 ,"A Case Study of Energy and Condensation Analysis for Chilled Beam Systems in the Office Building Located in Hot and Humid Climate Zone" 4th International Conference On Building Energy, Environment.,
9. Kenneth Gong, TROX, Malaysia,"CHILLED BEAM SYSTEM –A green energy Solutions for hvac systems.
10. RACHNA DHINGRA*1 AND PUJA GUPTA2, "Green building:" A case study of Indra Paryavaran Bhawan, Delhi",Internat. J. Appl. Home Sci. | Feb., 2018.
11. John Woollett1, Jonas Åkesson2 Swegon AB1,2,"Chilled beam technology overview,CIBSE journal November 2013.
12. Wenhong Yu Hui Li,"Application of the Active Chilled Beam in Air-conditioning Engineering",2018 International Conference on Civil and Hydraulic Engineering (IConCHE 2018).
13. Rohit Upadhyay Rodrigo Mora PH.D.,"Performance Evaluation of Active Chilled Beam in Real Office Conditions in a High-Performance Building in Heating",ASHRAE.
14. Janghyun Kim,James E. Braun,W. Travis Horton,"Performance Evaluation of a Passive Chilled Beam System and Comparison with a Conventional Air System",4th International High Performance Buildings Conference at Purdue, July 11-14, 2016.
15. 1V.Suvarna Kumar, 2 G.Prasanna Kumar, 3G. Bhasker,"Design and Analysis of the Air Conditioning System using Chilled Beam Technology",International Journal on Mechanical Engineering and Robotics (IJMER),ISSN (Print) : 2321-5747, Volume-5, Issue-5, 2017.
16. 1 Saskia Kuliga, 2 Tyler Thrash, 3 Ruth Dalton "Virtual reality as an empirical research tool-Exploring user experience in a real building and a corresponding virtual model",ResearchGate.net/publication, Computers Environment and Urban Systems.
17. 1Marszal, 2 Anna Joanna; 3Heiselberg, 4 Per "A Literature Review of Zero Energy Buildings (ZEB) Definitions".
18. IGBC New Green Building Rating System by Indian Green Building Council, IGBC continuously works to provide tools that facilitate the adoption of green building practices in India.
19. Sustainability in Building Construction: General Principles ISO15392
20. Chilled Beam Application Guidebook by REHVA Federation of European Heating, Ventilation & Air-Conditioning

21. *ISHRAE COVID-19 Guidelines Document for Air-Conditioning and Ventilation by ISHRAE.*

22. *REHVA COVID-19 guidance document, How to operate and use building services in order to prevent the spread of the coronavirus disease (COVID-19) virus (SARS-CoV-2) in workplaces.*

23. *DADANCO ACB Active Chilled Beam Design Book*

24. *Issues arising from the use of chilled beams in energy models by 1Fred Betz Affililated Engineers, 2 James Mcneill Cedar Stack*

25. *Towards Sustainable Development: A Review of Green Technologies by Zaffar Ahmed Shaikh*