Life cycle Assessment of different walling materials and their comparative analysis

Ar. Rahul C. Shrikhande , Ar. Pranjali Desale

Abstract

Energy use of a building can be derived from five sources: Embodied Energy from mining and manufacturing of materials, Energy from transportation of materials, Energy from construction of the building, Energy use during operation of the building, and Energy used in the disposal of the building at the end of its life. Buildings use many materials with a high Embodied Energy, and it is estimated that, 10% of its total energy use comes from Embodied Energy in materials. Thus, the use of low Embodied Energy Materials for the sustainable development is preferred. Life cycle assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of buildings materials, buildings and its products through all of its life stages.

The paper will aimed to compare nine types of structures using various kinds of walling materials. Where material's life cycle, maintenance cost & operation costs will be compared. Wall and roof are the most significant building component in any building. The walling materials can determine the cost of the building as well as the total life cycle cost of a building and it will also impacts conditioning systems in buildings. Resulting wall materials will helps in conserving energy and lowering it's environmental impact.

Keywords :
Building Construction, Embodied energy, Energy Conservation Life cycle cost, Walling materials, Construction cost, Maintenance cost and operation cost.

1. INTRODUCTION

1.1 Building Construction Industry current scenario :

The building construction industry is a major contributor of environmental pollution, with high levels of energy consumption and greenhouse gas emissions, all of which contribute to climate change. 30%-40% primary energy is consumed by worldwide building sector by means of construction - maintenance and operation activity . It further emits global warming gases. In India, building stock are likely to grow five times, taking total floor space from 8 billion square meters in 2005 to 41 billion square meter by 2030 (McKinsey & company, inc., August 2009). This will increase the total demand of building materials in India. The bulk of building materials is presently derived from locally available clay, soil, sand, and gravel. The most common walling material used in India is fired clay bricks which account 92.2% of 151.83 cu. billion brick equivalent masonry unit produced annually in the country, followed by concrete blocks, AAC and Fal-G blocks 5.9%, 0.2% and 1.6% respectively. The annual demand for walling material will increase to 511.38 cu. billion brick equivalent masonry unit in 2030 at the growth rate of 6.6% annually. (Enzen & Greentech). Apart from having a large environmental foot print in terms of raw material use, the production of building materials also requires an enormous amount of energy. The amount of energy consumed in the extraction of raw materials, the manufacturing process, the associated transportation energy as well as the energy for construction and demolition, accounts for 10-20% of a building's life cycle energy which is known as embodied energy of a materials. For different materials its I different depending upon its process, while 80-90% of the energy a building uses during its entire life cycle is consumed for heating, cooling, lighting and other appliances. (Enzen & Greentech). Since the energy consumption of a building is totally dependents on the typology of building materials used, so there is a a need to analyse it in the Life Cycle Analysis (LCA) perspective to understand its impact on environment and its performance to reduce cooling demand.

2. Objective of Study

2.1 Study Objective :

The paper is aimed to compare the environmental impacts by calculating the life cycle energies of different wall assemblies which are referred in INTEGRATED GREEN DESIGN booklet by CPWD and in GRIHA MANUAL VOLUME 4 [1]. The final objective of the paper is to evaluate the materials or the assemblies on the basis of Life Cycle Energy Assessment impact a category which includes: Fossil Fuel Consumption, Global Warming Potential, Acidification Potential, Human health Criteria, Eutrophication Potential, Ozone Depletion Potential, and Smog Potential thereby targeting the most energy efficient wall assembly design of a common office building. The system studied included the manufacture of building materials, construction, operation, maintenance, and refurbishment and demolition phases.

2.2 Description of building :

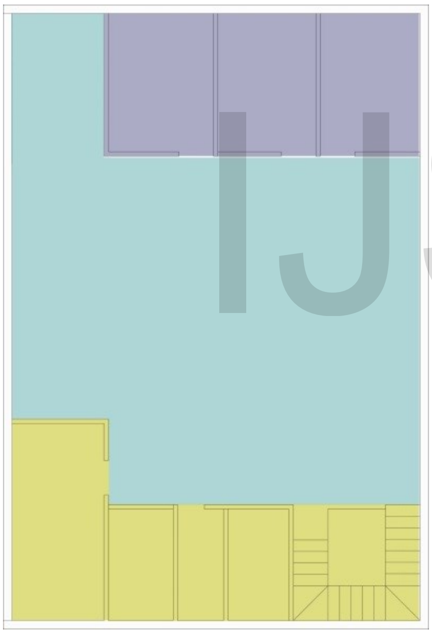

Fig. 1 : Office Building Plan

An existing office building at Defence Colony in New Delhi has served as a base case for the analysis. It lies in 28.575806 ° N latitude and 77.229676° E longitude in a composite climatic zone, with temperature ranging from −2.2 °C to 48.4 °C. It is a 3 storied building with a stilt floor and a basement. Building is oriented along West Axis.

Floor to Floor height is 3000 mm. The plinth area of the building is 1916 m².

Each floor has occupancy of approximately 25 members.

The plan of a building is in such a way that it can be divided in three zones.

2.2 Description of building :

The plan of a building is in such a way that it can be divided in three zones.

- 1st Zone - Comprises of open office plan which has 25 Workstations on each floor and 4 split AC's
- 2nd Zone - Consists of three cabins each having separate split AC's
- 3rd Zone - It is unconditioned area having pantry and washrooms.
- The North Side wall is a common wall with the adjutant building and as the building is located at the corner of the street thereby South West and South east getting direct
- sunlight and having maximum glazed area on these faces.

3. Methodology

This study is based on the evaluation of life Cycle Energy of a three storied office building. Firstly, nine cases having different wall assembly designs are carefully chosen by referring the INTEGRATED GREEN DESIGN booklet by CPWD [1][2][3] and in GRIHA MANUAL VOLUME 4. Secondly, different types of basic building materials used in this office building for the construction are enumerated such as cement, sand, aggregate, steel, brick on per m² of plinth area and the Embodied Energy of each and every material used in the building is evaluated by manual estimation approach. The main information on the types and quantities of materials as well as components of the building is obtained from the detailed estimates of the building, technical specifications and other relevant documents from the building consultant. The Embodied Energy for all the nine cases are quantified for this paper are calculated by referring the Embodied energy MJ per unit as mentioned in the GRIHA MANUAL 4 W(Criteria 16).

The energy used for running the electrical fixtures which is widely known as Operational energy is estimated by two parallel approaches. In the first one, manual estimation approach similar to the Conditional Demand Analysis is followed in second approach E-QUEST is employed to generate the simulation results or the operational energy for all the nine cases by keeping other components constant and changing the external wall assembly of the building, the energy consumption by the base-case model is then compared with the result of both the approaches. The demolition energy considered in this case is the sum of energy required to demolish the building and the energy required in the transportation of the material from the site to the nearest landfill. Finally, the Life Cycle Energy is calculated by adding the three Energies together which are supported by various comparison charts.

4. Analysis

4.1 : Description of Cases Analysed :

Case 1 (Base Case) - Fire Kiln Brick

This wall assembly is constructed by traditional bricks of size 230mm and plastered on both the sides (12mm).This is the present condition of the building; it does not have any insulation material or cavity.

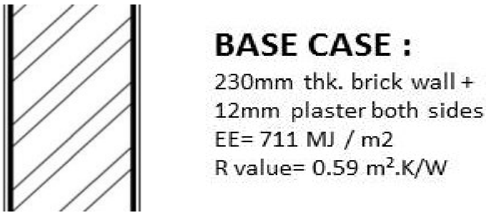

Fig. 2 : Fire Kiln Brick

Case 2 - Hollow Concrete Block

The hollow bricks are lighter in weight than the normal bricks. The raw material used in the construction of such bricks are basically fly ash, cement, lime, gypsum, stone dust etc.

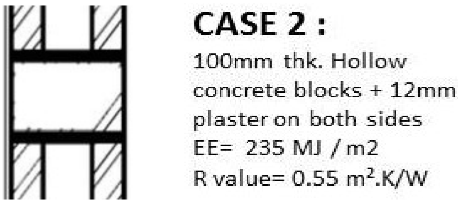

Fig. 3 : Hollow Concrete Block

Case 3 - ACC Block

AAC is lightweight, precast building material that simultaneously provides structure, insulations, and fire & mould resistance. Main ingredients include fly ash, water, quicklime, cement, aluminium powder & gypsum.

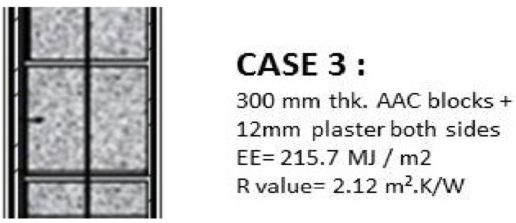

Fig. 4 : ACC Block

Case 4 - CSEB Bricks

Compressed earth block (CEB) or pressed earth block is a building material made primarily from damp soil compressed at high pressure to form blocks. If the blocks are stabilized with a chemical binder such as Portland cement they are called compressed stabilized earth block (CSEB) or stabilized earth block (SEB).

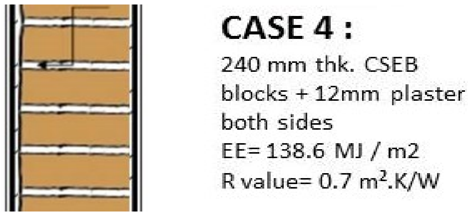

Fig. 5 : CSEB Brick

Case 5 - Fly Ash Block

It is a building material, containing class C fly-ash and water. Manufacturing method saves more energy, reduces mercury pollution, and costs 20% less than traditional clay brick manufacturing.

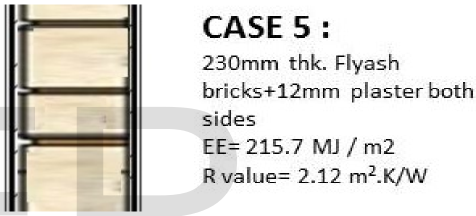

Fig. 6 : Fly Ash Block

Case 6 - 230 Brick + 70 Air cavity + 115 Brick

This wall assembly consists of 70mm cavity finished with 230 brick on one side and 115 mm brick on the other. The cost of the bricks is low but the u-value is quite low ,their thermal conducting and it increases the cooling load of the space but by giving an air-cavity in between the overall u-value of the assembly reduces.

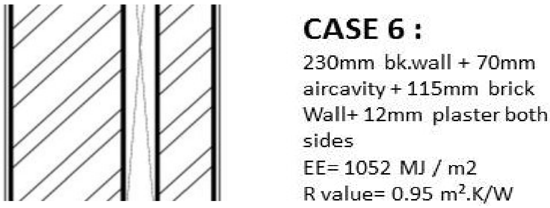

Fig. 7 : Brick + Air Cavity + Brick

Case 7 - 230 mm FALG + 70mm Air cavity + 115 FALG

These blocks require less mortar, plastering can be avoided, are cost effective and environment-friendly as it avoids use of fertile top soil.

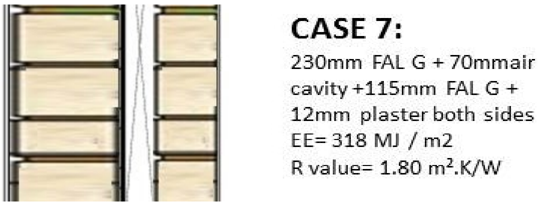

Fig. 8 : FALG + Air cavity + FALG

Case 8 - 230 mm Brick + 50 XPS + 115 Brick

50mm XPS panel is finished by 230mm brick wall on one side and 115 mm brick wall on the other side. The insulating material which is used in this assembly will reduce the operational energy.

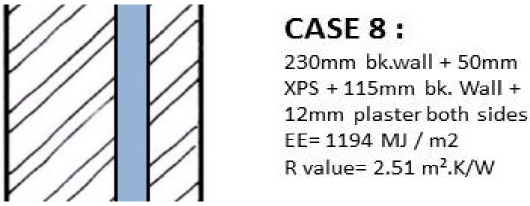

Fig. 9 : Brick + XPS + Brick

Case 9 - ECO Wall

This wall assembly consists of a 100mm EPS panel finished with 50mm shotcrete on both sides, reinforced by wire mesh. The 200 mm thk. Panel saves space and provides excellent insulation. Shortcrete is a concrete conveyed through a hose and pneumatically projected at high velocity onto a surface, as a construction technique.

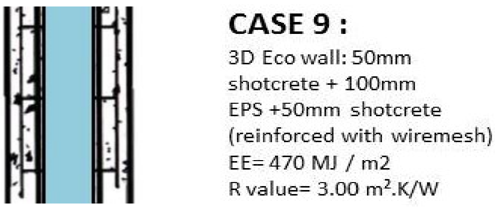

Fig. 10 : ECO Wall

5. LIFE CYCLE ENERGY

A Life Cycle Assessment (LCA) evaluates the environmental load of each activity. The life cycle of a product means that it is assessed from its "cradle" where raw materials are extracted from natural resources through production and use to its "grave", the disposal. It also provides a mechanism for systematically evaluating the inputs, outputs and the potential environmental impacts linked to a product or process throughout its life cycle (ISO 14040) . LCA addresses the impacts of a product through all of its life stages. The transportation for each life cycle stage is also included.

5.1 : Embodied Energy :

Although many assessment methods and databases have been developed for Embodied Energy across the globe for different building materials, but the actual EE for a given material is highly dependent on local technologies, local manufacturing process and transportation distance. The Embodied energy coefficients of building materials are taken in Indian context which is referred in GRIHA MANUAL 4 [1][2], which gives a complete detail of different type of basic building materials, walling materials with their Embodied Energy (MJ/unit). The transportation energy is also included in this document which includes all modes of transportation. All the materials are manufactured in India.

The initial Embodied energy of the building materials are obtained by summing up the product of quantity of materials multiplied by their embodied energy coefficients which is then again summed up with the transportation energy, maintenance energy and refurbishment energy. The transportation energy which is considered in all the cases is computed by measuring the distances of various manufacturers of building material from the site most of them are established near Delhi itself.

Construction energy is additionally included within the initial embodied energy which incorporates electricity used for lighting, water lifting and diesel oil employed by construction equipment at the location. These are subsequently aggregated with energy consumption for the transportation of artifact to the development site.

BASE CASE		
MATERIALS	VOLUME IN TON	ENERGY MJ
FOUNDATION		
CEMENT	12.93	86.68
SAND	24.25	420.33
AGGREGATE	48.5	16.06
STEEL	12.47	351.77
SLAB	56.44	87696
WALL (BRICK IN CEMENT MORTAR 230MM)	249.3	292923.9
CEMENT SAND PLASTER	18.34	31813.2
FLOORS (RCC)	282.24	438480
ROOF(RCC)	56.4	87696
INTERNAL WALLS (SOLID BRICKS, 115mm, Plastered on both sides)	5.37	29869.52
WINDOW (GLASS)	4.6	105.8
CERAMIC TILE	3.97	13.22
FLUSH DOORS	1.42	18.31
PAINT	0.43	62.20
INITIAL EMBODIED ENERGY	**969553.03**	
TRANSPORTATION ENERGY (MJ)	**221331**	
REFURBISHMENT ENERGY (MJ)	**87259.77**	
TOTAL EMBODIED ENERGY	**1278143.8**	

Fig. 11 : Total Embodied Energy of Base case

5.1 : Embodied Energy :

The most building elements are building frames (beams, columns), slabs, floors, staircases, foundation, walls, windows, and finishes. Items like fitments, sanitary fixtures, appliances, electrical and external items are excluded from the study thanks to the problem related to obtaining their embodied energy data. All data relevant to construction machines and equipment used on site and transportation distances of construction materials to the development site are obtained from the available records.

6. Building Maintenance

Energy consumption valuation for the future maintenance (recurring embodied energy) is calculated based on the estimated life span of the building materials and components. To calculate the maintenance energy same procedure as explained in evaluation of initial embodied energy is followed.

6.1 : Building Refurbishment :

It is very difficult to anticipate future alterations to building use as a result of changes in techniques. The embodied energy associated with refurbishment can be predicted to some extent as far as general advancement is concerned.

An approximate value of refurbishment energy can be evaluated by summing proportions of the elements comprising the fit-out and external features of the buildings.

Hence, three quarters of the initial embodied energy for the original services/fixtures/ external features/internal walls/ external which is almost 36% of the initial embodied energy.

CASE NO	INITIAL EMBODIED ENERGY (MJ)	TRANSPORTATION ENERGY (MJ)	REFURBISHMENT ENERGY (MJ)	TOTAL EMBODIED ENERGY (MJ)
CASE 1	969553	221331	87260	1278144
CASE 2	801231	212256	72111	1085598
CASE 3	790998	106500	71190	968688
CASE 4	761464	103824	68532	933820
CASE 5	815515	209385	73396	1098296
CASE 6	1234421	308209	111098	1653727
CASE 7	845239	373851	76072	1295162
CASE 8	1309712	308542	117874	1736128
CASE 9	925833	93208	83325	1102365

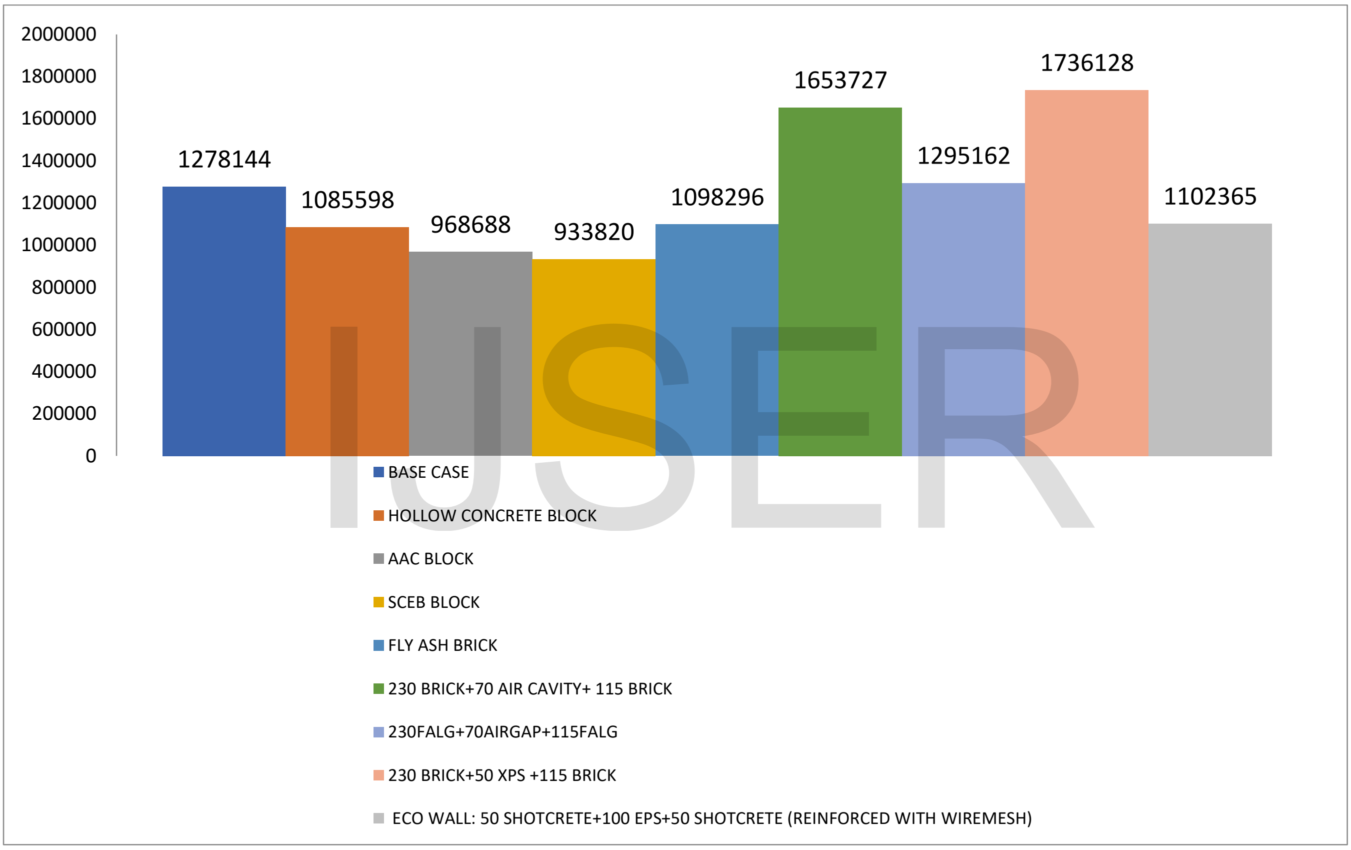

Fig. 12 : Comparative Analysis Of Embodied Energy

6.2 : Operational Energy :

Operating energy of the building includes electricity used for cooling, heating, ventilation, lighting (6 W/m2 for 100 lux), miscellaneous equipment operation and water system. this is often calculated by simulation through e-Quest energy simulation software. Annual operating energy of the building is assumed to be constant throughout its lifetime. The calculated R-values (includes outside air film for exterior surfaces) for all the above mentioned cases is used in e-Quest simulation software to assess the operational energy or the energy consumption.

Zone 1 and Zone 2 of the building are air conditioned using split air conditioner. The indoor operating set point temperature is around 25°C and all lighting controls of the building are manual but they are in operation in office hours from 8 A.M to 6 P.M.

The building is occupied during day time between 8.00 am to 6.00 pm and not operated during weekend i.e., Saturday, Sun- day and other public holidays. Comfort indoor air temperature is set as 25°C for cooling and 18°C for heating.

The EER of split air conditioner is taken as 3. Each floor consists of 7 air conditioners. Thus, calculated annual electrical energy demand of the building for its operation is then converted to primary energy using primary energy conversion factor.

A primary energy conversion factor of 3.6 is adapted for electricity from national grid as in India 70% of electricity is derived from coal, oil and gas, 25% hydro and remaining from renewable energy resources.

To verify the results obtained by energy simulation; annual electricity meter readings (actual electrical energy consumption) are compared with the simulated value. As difference between the two values is small (1% - 8%); results of the simulation can be taken as reliable.

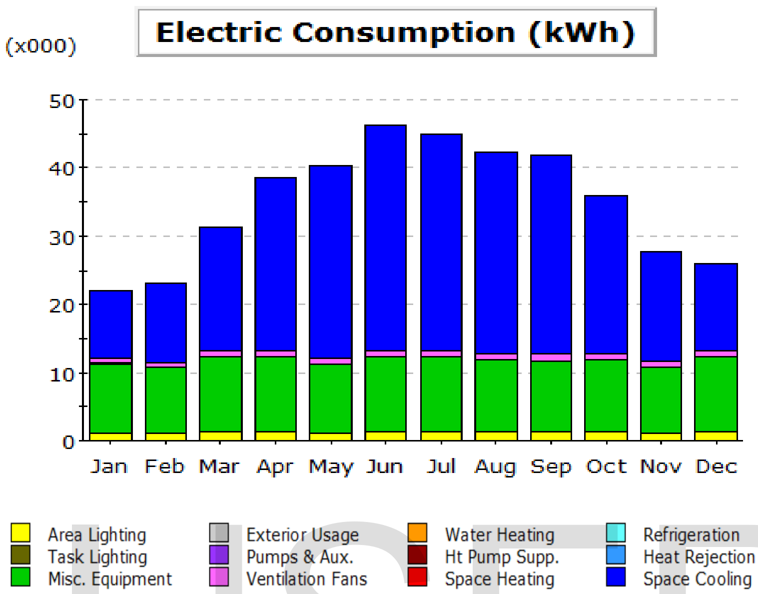

Fig. 13 : Total Embodied Energy of wall assemblies

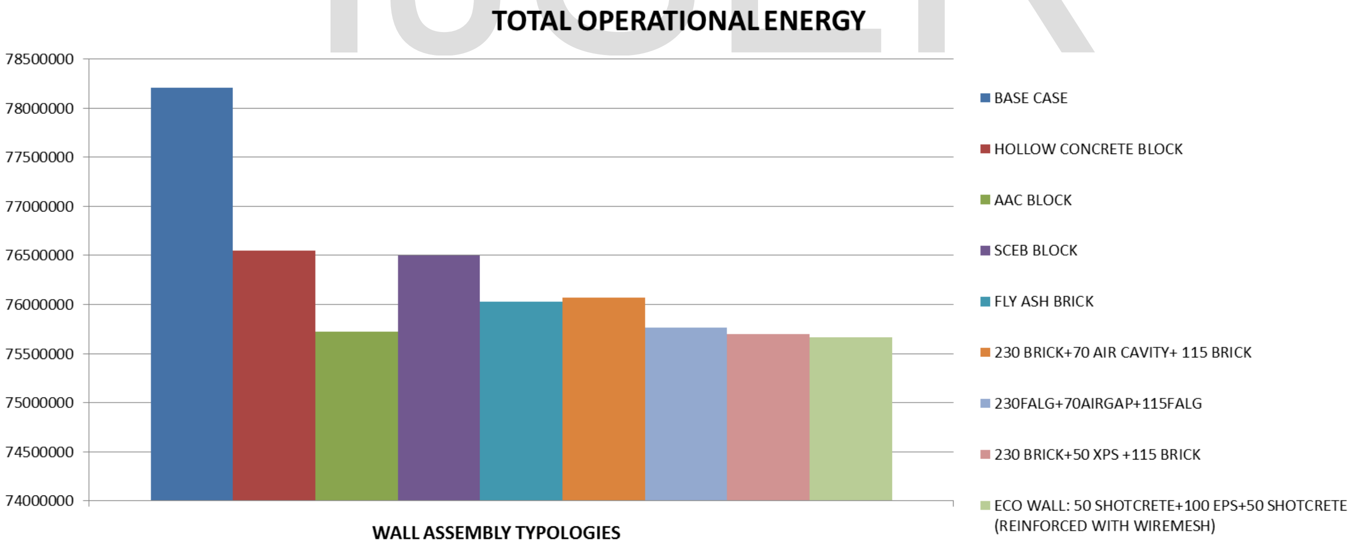

Fig. 15 : Comparative analysis of operational energy

6.3 : Demolition Energy :

The End of life cycle analysis is usually referred to as Demolition phase. Two methods for calculation are used; the primary one is that the Conventional Demolition method which frequently leads to landfill disposal of majority of the materials. Energy consumption at this phase is mainly due to the operation of demolition machinery and transportation of waste materials to land-fill site. Due to lack of data on the energy requirement of actual demolition process in India, it is assumed that 51.5 MJ/m2 of energy as diesel fuel is required to demolish the building . (This is considered by consulting various consultants and contractors).

In the second case the construction and demolition waste is separated to different fractions to be recycled and avoid deposit. The methods of how these buildings are demolished vary like using an excavator or crane. Some of the materials are primarily chosen which have a commercial resale value.

A demolition for optimal re-use of construction and demolition materials begins with selective demolition where material that may be re-used is selectively dismantled. Materials consisting of steel, wood and inert material are separated into respective fraction to be recycled, recovered to utilize energy, or landfilled.

For both the above methods, the Volume of waste materials generated is converted to mass in ton by material density .

To estimate the energy required for transportation of waste material, it is considered that waste material is transported from the site via a diesel powered dump truck. Truck requires 2.85 MJ energy per ton of material for one km travel.The transportation distance for this study is assumed to be the distance from the site where the building under study is located to the landfill site at the city outskirts at about 15 km.

The primary energy balances of the end-of-life phase of the buildings. Recovery of wood to be used as bio-fuel gives the best end-of-life primary energy benefit, followed by recycling steels to exchange ore-based steel.Recycling of concrete as crushed aggregate gives a minor end-of-life primary energy benefit.

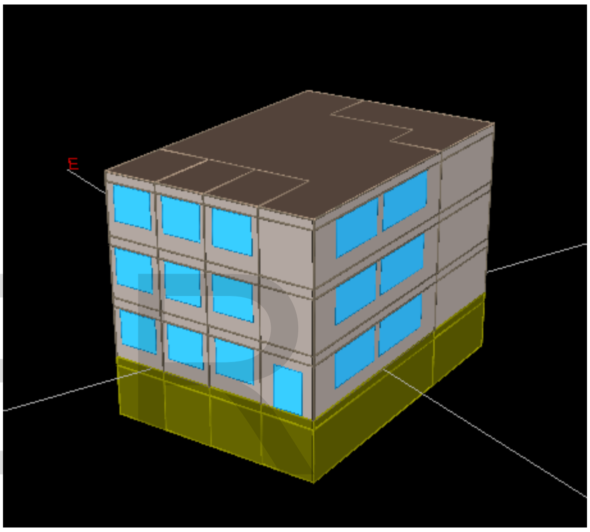

Fig. 16 : 3D model of building on E-QUEST

		WEIGHT IN TON	DEMOLITION ENERGY (MJ)	TRANSPORTATION ENERGY (MJ)	TOTAL DEMOLITION ENERGY (MJ)
CASE 1	BASE CASE	776.6686	394696	66405.1653	461101.1653
CASE 2	HOLLOW CONCRETE BLOCK (100 mm)	744.7588	394696	63676.8774	458372.8774
CASE 3	AAC BLOCK (300mm)	622.8082	394696	53250.1011	447946.1011
CASE 4	CSEB BLOCK(240mm)	728.58709	394696	62294.1962	456990.1962
CASE 5	FLY ASH BRICK (230mm)	734.68462	394696	62815.53501	457511.535
CASE 6	230mm BRICK+70mm AIR CAVITY+ 115mm BRICK	901.1946	394696	77052.1383	471748.1383
CASE 7	230 mm FALG+70mm AIRGAP+115mm FALG	819.8486	394696	70097.0553	464793.0553
CASE 8	230mm BRICK+50mm XPS +115mm BRICK	902.1686	394696	77135.4153	471831.4153
CASE 9	ECO WALL: 50mm SHOTCRETE+ 100mm EPS+50mm SHOTCRETE	654.0886	394696	55924.5753	450620.5753

Fig. 17 : Total Embodied Energy of wall assemblies

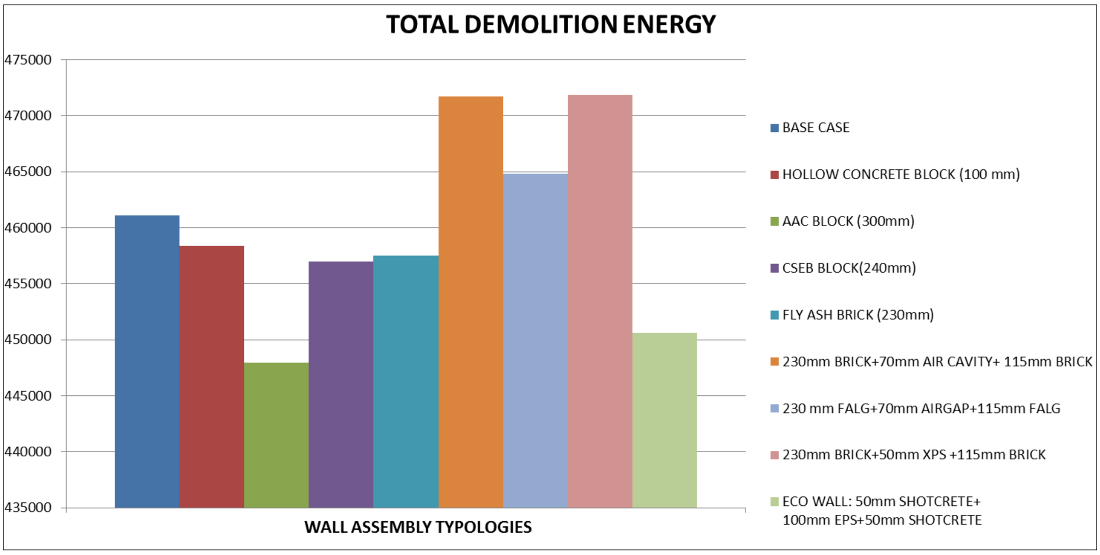

Fig. 18 : Comparative analysis of demolition energy

6.4 : Life Cycle Energy :

Life cycle energy of the building is estimated by summing up the energy incurred for construction (initial embodied), operation, maintenance (recurring embodied) and finally demolition of the building at the end of its life. The life cycle energy data is summarised in Table 4 and indicates that the entire embodied energy amounts to just about 1 / 4 of the operational energy over the lifetime considered. Alternatively expressed, 13 years of operational energy is like the entire embodied energy of the buildings. The life cycle energy of the chosen building is evaluated supported an assumed service lifetime of 75 years.

		TOTAL EMBODIED ENERGY (MJ)	TOTAL OPERATIONAL ENERGY (MJ)	TOTAL DEMOLITION ENERGY (MJ)	TOTAL LIFE CYCLE ENERGY(MJ)
CASE 1	BASE CASE	1278143.798	78204600	461101.1653	79943844.96
CASE 2	HOLLOW CONCRETE BLOCK (100 mm)	1085597.858	76548600	458372.8774	78092570.74
CASE 3	AAC BLOCK (300mm)	968687.5645	75726000	447946.1011	77142633.67
CASE 4	CSEB BLOCK(240mm)	933819.7758	76500000	456990.1962	77890809.97
CASE 5	FLY ASH BRICK (230mm)	1098296.415	76032000	457511.535	77587807.95
CASE 6	230mm BRICK+70mm AIR CAVITY+ 115mm BRIC	1653726.97	76071600	471748.1383	78197075.11
CASE 7	230 mm FALG+70mm AIRGAP+115mm FALG	1295161.565	75769200	464793.0553	77529154.62
CASE 8	230mm BRICK+50mm XPS +115mm BRICK	1736127.53	75699000	471831.4153	77906958.95
CASE 9	ECO WALL: 50mm SHOTCRETE+ 100mm EPS+50mm SHOTCRETE	1102365.079	75666600	450620.5753	77219585.65

Fig. 19 : Total energy use for the life cycle of 50 years

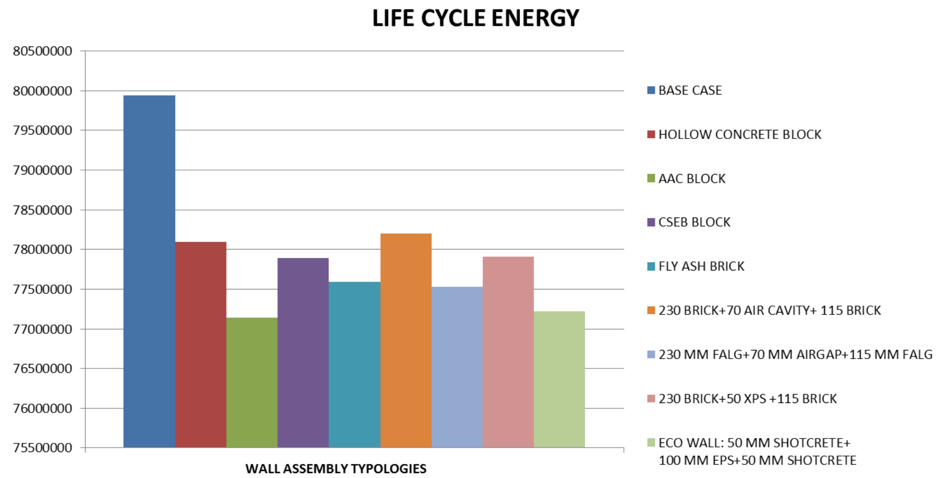

Fig. 20 : Comparative analysis of Life cycle energy

7. Results & Discussion

The results of the life cycle energy analysis are discussed in this section. Also, a comparison of the embodied energy and operating energy of the building over its life span indicated that embodied energy is about 8% of the operating energy. This is considerable and is equivalent to about nine years of the building's operating energy requirement. Further analysis of the initial embodied energy profile reveals that steel, cement, and bricks are the most dominant materials and they play a vital role in changing the embodied energy of a material.

The analysis of the LCE profile of the building revealed that the use of Eco-Wall will have the least life cycle energy on the other hand ACC is also having quite low LCE as well as it has lower embodied energy as compared to the Eco wall, while the hollow concrete block is having the highest life cycle energy after the base case.

The initial embodied energy results reveal that the Stabilized Compressed Earth block is having the lowest embodied energy due to the composition of these blocks which primarily consists of damp soil and cement. The energy consumption during manufacturing is quite low and in this case the materials are being manufactured 18 km away from the site which drastically reduces the energy consumption.

AAC Blocks are also having low embodied energy as it is mainly composed of fly-ash and locally available while on the other hand the wall assemblies which are having a cavity or an insulation in between have higher embodied energy.

The operational phase of the building dominates the other life cycle phases. Operational energy results reveal that the major part of the energy consumption is due to space cooling and the energy requirements for this building are considered for the life span of around 50 years. The most energy saving wall assembly is the ECO-WALL as the thermal conductance of this wall is quite low while on the other hand case 7 and 8 in which Brick with insulation material in between and Fly-ash bricks with an air cavity in between also have considerably low operational energies.

Case 6 (Bricks with the cavity), AAC brick wall and Fly ash brick is almost having same operational energy which is quite low as compared to the base case. The key finding of the results are that the space cooling is directly proportional to the cooling load of the space and this is generally altered by changing the Walling materials and Roofing materials as the U-value of the different materials will affect both the embodied energy as well as the operational energy which can decrease the life cycle energy. Lesser the U-value more is the efficiency of the building.

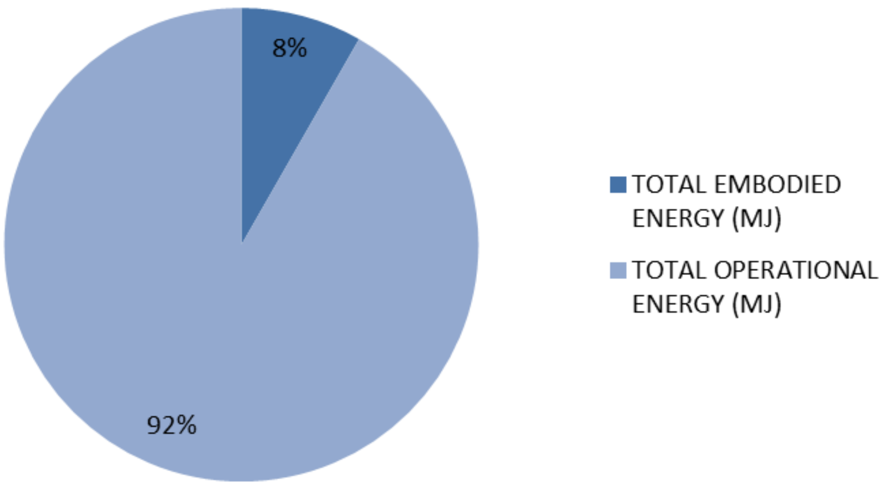

Fig. 21 : Breakdown of avg. embodied energy & operational energy

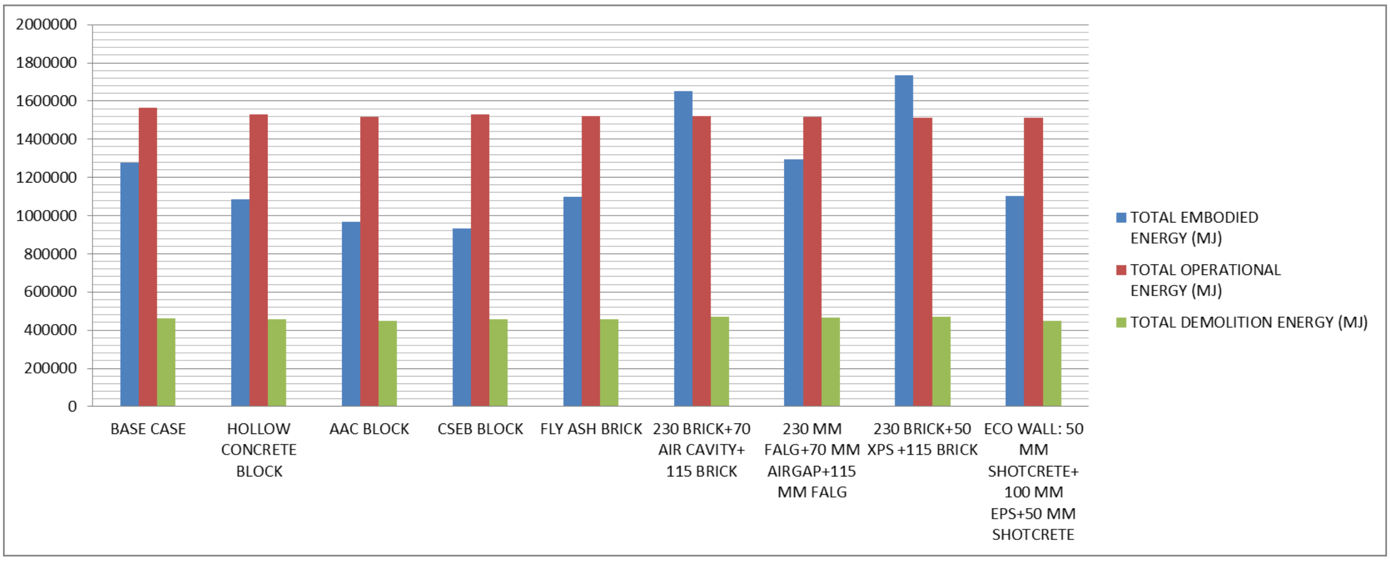

Fig. 22 : Comparison chart of all energies of wall assemblies

8. CONCLUSIONS

The Life Cycle energy has been discussed in this paper for a given building. The paper focuses upon comparison of nine types of structures using various kinds of walling materials. Though the cases which are mentioned in this paper can be costlier then the base case but the use of such structures has considerably reduced the size of air conditioning system, total life cycle energy.

Hence, use of walling assemblies like Eco wall, AAC, Fly-ash brick will help in conserving the natural resources, energy and environment. Despite the difficulty in calculating embodied energy, as the database is not available in Indian context , the analysed data confirms that the green materials which are described in CPWD manual, decreases the operational and embodied energy noticeably while insulation should be judiciously used and chosen as it increases 5% of the embodied energy of the building .

9. References

[1] - https://www.scirp.org/html/6-2650020_29012.htm

[2] - GRIHA MANUAL 4

[3]- INTEGRATED GREEN DESIGN booklet by CPWD