An Approach towards Designing an Energy Efficient Building through Embodied Energy Assessment: A Case of Apartment Building in Composite Climate

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***Abstract*—**In today's world, the growing demand for urban built forms has resulted in the production and consumption of building materials i.e. embodied energy in building construction, leading to pollution and greenhouse gas (GHG) emissions. Therefore, new buildings will offer a unique opportunity to implement more energy efficient building without compromising on building performance of the building. Embodied energy of building materials forms major contribution to embodied energy in buildings. The paper results in an approach towards designing an energy efficient apartment building through embodied energy assessment. This paper discusses the trend of residential development in Rourkela, which includes three case studies of the contemporary houses, followed by architectural elements, number of storeys, predominant material use and plot sizes using primary data. It results in identification of predominant material used and other characteristics in urban area. Further, the embodied energy coefficients of various dominant building materials and alternative materials manufactured in Indian Industry is taken in consideration from secondary source i.e. literature study. The paper analyses the embodied energy by estimating materials and operational energy of proposed building followed by altering the specifications of the materials based on the building components i.e. walls, flooring, windows, insulation and roof through res build India software and comparison of different options is assessed with consideration of sustainable parameters. This paper results that autoclaved aerated concrete block only reaches the energy performance Index benchmark i.e. 69.35 kWh/m^2 yr i.e. by saving 4% of operational energy and as embodied energy has no particular index, out of all materials it has the highest EE 23206202.43 MJ.

***Keywords*—**Energy efficient, embodied energy, energy performance index, building materials.

I. Introduction

INCREASING GHG concentration in the atmosphere has led to cause graves global warming, and Vorsatz et al. estimate that 33% of all global carbon emissions are originated from existing buildings. The main reason for significant percentage increase of country's energy consumption is mostly due to energy used in residential and commercial structures [1]. The factors responsible for this increased percentage are growth in urbanization, area required per capita of building, gradation of electrification, the prevailing climate, as well as national and local policies to promote efficiency [1]. The energy efficiency of a building reflects the per square meter of floor area energy consumed which measures the established energy consumption benchmarks for particular type of building under different climatic zones [1]. As the demand for urban built spaces increased so has the consumption and production of building materials in construction sector [2]. The required energy for production of building material is significantly more contributing to pollutions [2]. More or less the aim should be to reduce energy consumption and pollution which requires quantification of production of building materials [2]. As different building materials have different embodied energy depending upon the location as for in India, rather practically very difficult to calculate embodied energy. According to record of the United Nation's Environment Programme's Sustainable Building and Climate Initiative [3], due to the use of fossil fuels, GHG emissions and energy consumption in the construction field accounted for about 30% and 40% of global, respectively. India is the fourth largest emitter of global GHG emissions contributing about 7 % of total emissions [4]. As global climate change is directly related to GHG emissions, due to demand for urban spaces leading to the production and consumption of building materials in construction and in India the data available for embodied energy of a building material is limited. Already the fourth-largest economy, India is the world's third-largest GHG emitter and fourth-largest electricity consumer [5]. Total Net energy consumption is 1054 million kilowatt-hours by 2015 [5]. Buildings in India already consume over 30% of electricity and its seen that in 2030, 2/3rd of built form is predicted to come in existence [5]. Energy expenditure for manufacture of building materials constitutes 20–25% of India's total energy demand [2]. Bureau of Energy Efficiency predicts that India's constructed floor area will increase by around five times from 2005 to 2030 [6]. CEU data suggest that by 2050, 85% of floor space will be in residential use, while 15% will be used for commercial purposes [7]. Embodied energy, the energy consumed by a building material for a building life cycle, is an index value, which is calculated based on the processes involved in extraction of raw materials, manufacture, assembly, transportation, construction, operation & maintenance and disposal [8]. The assessment of energy consumption related to building are of three phase embodied energy, operating energy and demolition or possible recycling and reuse, as the objective of paper deals with only the calculation of embodied energy and finally how is the energy performance of proposed apartment building.

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II. Methodology

The methodology used in this paper starts with the theoretical background about the energy scenarios in India and the construction industry followed with the initiative taken by government bodies. As one of the objectives of paper is to calculate embodied energy for which data of embodied energy (EE) coefficient is required. The data considered for EE coefficients for building materials used in Indian Industry are taken from secondary source i.e. literature study [2], [9]. Case study includes total three residential houses which are designed according to National Building Code, India, for people under medium income group. Plinth area of the three apartment houses varies between 60 and 160 sqm. These houses are constructed as four storeyed. The bill of quantities of materials is prepared for foundation and super structure. The embodied energy and energy consumption are calculated with help of software; Excel and in IT Toolkit Eneff Res Build India software. For the proposed apartment, the design process comprises with climate analysis using Autodesk FormIt for form generation. Identification of locally available building materials in Rourkela, Odisha considering radius of 400 km is referred from secondary data source. This paper determines the co-relationship between Embodied Energy and energy consumption which defines the threshold of Embodied Energy to per sqm.

III. Area of Study

The project is located in Rourkela at 22.2604° N, 84.8536° in Sundergarh district of Odisha which falls under composite climate. The typology of the project is residential (apartment building). Scale of the project is 2.05 acres.

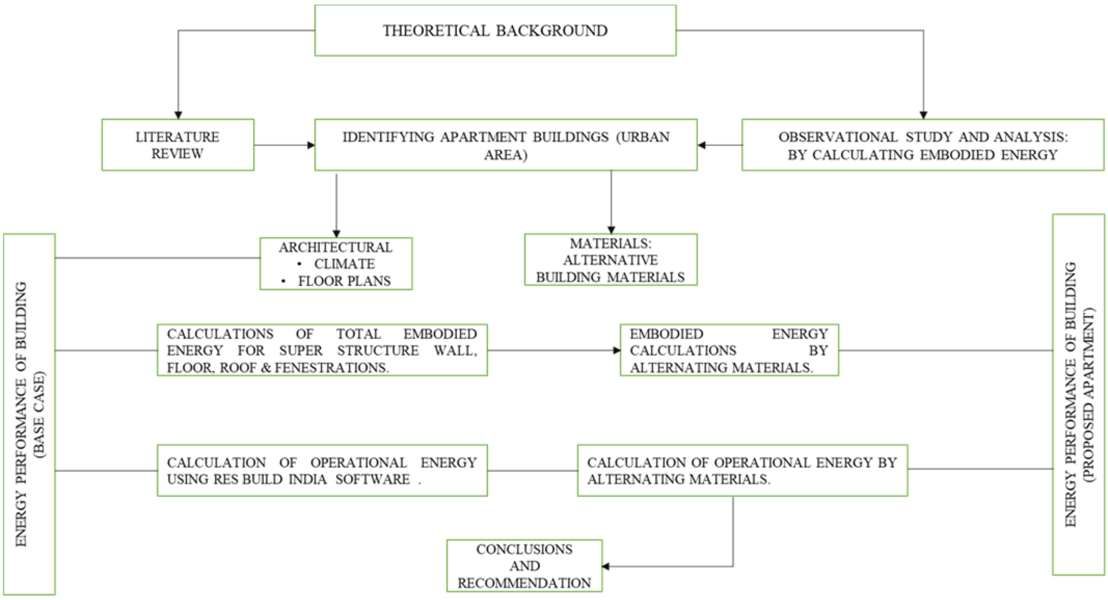

Fig. 1 Methodology adopted for current study

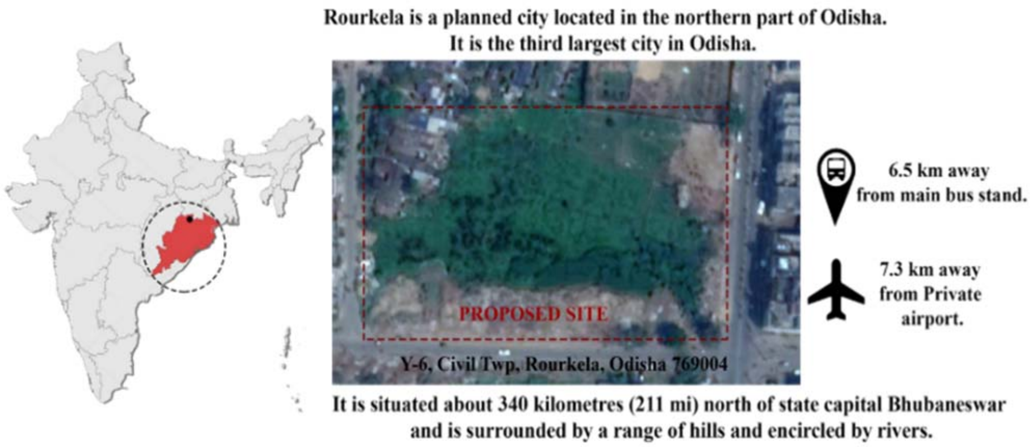

Fig. 2 Location of the proposed site

Fig. 3 Case Studies

IV. Analysis of Case Studies

For the three case studies, the Bill of Quantities is calculated with the regression equation for estimating the quantity of materials published by Central Building Research Institute (CBRI) [9]. The regression equation is used for estimation bill of quantities, with different floor areas for three types of houses i.e. single storey, double storey load bearing wall residential buildings and four storey framed structure residential buildings [9]. These equations are valid for total floor area ranging from 30 to 300 m^2 for single and double storey structures, and from 120 to 400 m^2 for four storeyed structures [9]. In order to establish a relationship between the material requirement and the plinth area of different house types, other factors like the soil condition, floor height, foundation etc. are kept the same [9]. With the help of these regression equations, the quantity of the major material required for the construction of the sub-structure and superstructure has been estimated for all the three case studies. All the three studies are calculated on the basis of parameters taken in consideration for calculating EE sub-structure and super structure i.e. wall, roof window and floor. The paper is limited to just building level; the calculation is only done for initial embodied energy and operational energy. The classification are based on usage, condition, predominant material use, ownership size and number of rooms, number of storey and plot sizes using primary and secondary data. The EE coefficient of every material is important, even if logically if we see we need to reduce the use of steel and cement and the option should be the vernacular materials and techniques. This results in identification of predominant materials and construction technique used and other characteristics in each of urban area. This case study imparts the material used in each case and leads to a base case. The EE depends on the quantity of the material used in a building and also the floor area. Case-I (Site Area: 5467.814 sqm) has the highest EE 7109997.23 MJ, and then Case-II (Site Area: 1471.93 sqm) has the value of EE 3820667.71 MJ, Case-III (Site Area: 1448.969 sqm) has 3769938.90 MJ.

V. Proposal for Residential (Apartment Building)

A. Form Development

The form generation has been analyzed with FormIt software and Autodesk flow design keeping the climatic factors in consideration. The strategies used for developing the form are based on the climate analysis for composite climate.

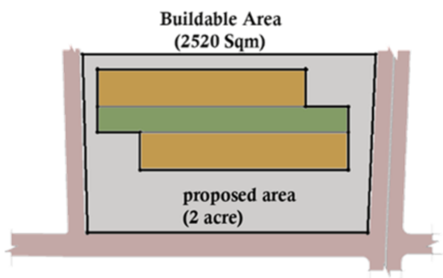

Fig. 4 Site area with buildable area

The value of radiation is found from Autodesk FormIt. The value of the south façade is 937.4 kWh/sqm. In terms of the form, the first rectangle it creates a shading device to the other part in Fig. 5.

In terms of considering the wind flow, the form creates a suction in which there is a continuous movement of air flow through all parts of the site in Fig. 6. The wind flow was analyzed by Autodesk flow design in which the value ranges from 1.2 m/s to 2.6 m/s.

Fig. 5 Radiation of the south facade

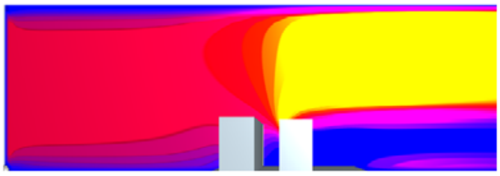

Fig. 6 South facade is directly exposed to wind flow ranging 1.2 m/s to 2.6 m/s

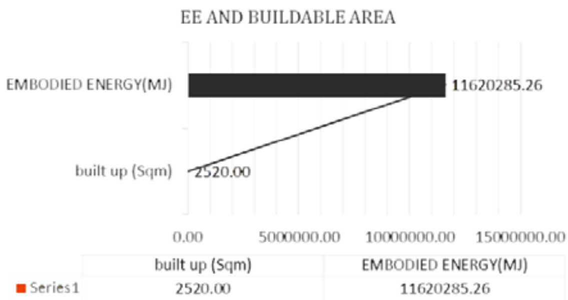

Fig. 7 EE and buildable area

The EE is calculated through the regression equations for estimating the quantity of materials. The buildable area is 2520 sqm in the proposed site of 2 acre and the EE is 11620285.26 MJ. The building form (Fig. 5) is eventually good, but it has issue regarding the privacy and the visual aspects therefore, this form is not applicable. In designing residential project, the requirement of good privacy and view point is necessary.

B. Final Proposed Design (Apartment Building)

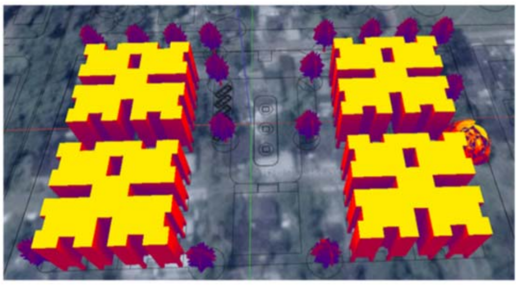

Fig. 8 Radiation of the south facade

The form generation has been analyzed as same as for the form development.

The solar radiation is highest in the western and eastern side of the form in Fig. 8. Hence the placement of fenestrations and balconies are in form of recessed façade and shaded. In this particular form the wind flow is well distributed and there is a continuous movement of air flow through all parts of the site in Fig. 10.

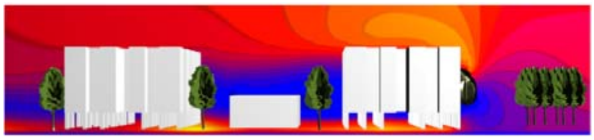

Fig. 9 Wind flow along the z axis

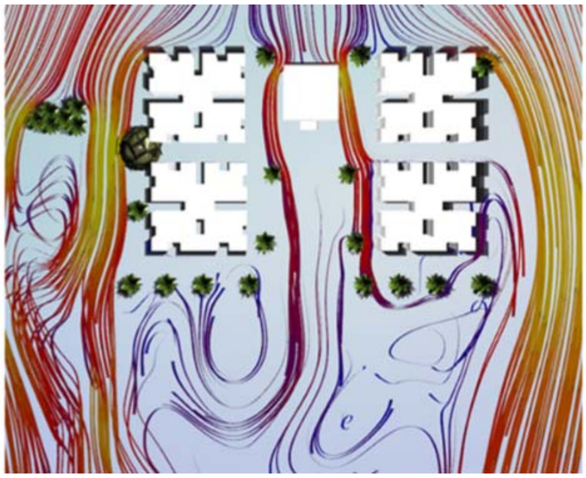

Fig. 10 Wind flow along the site, top view

The wind flow is continuous throughout the site hence 50% of balconies are provided towards the windward side. The selected form (Fig. 8) satisfies climatic characteristics, privacy and visual aspects respectively.

C. Site Plan and Typical Floor Plan (Apartment Building)

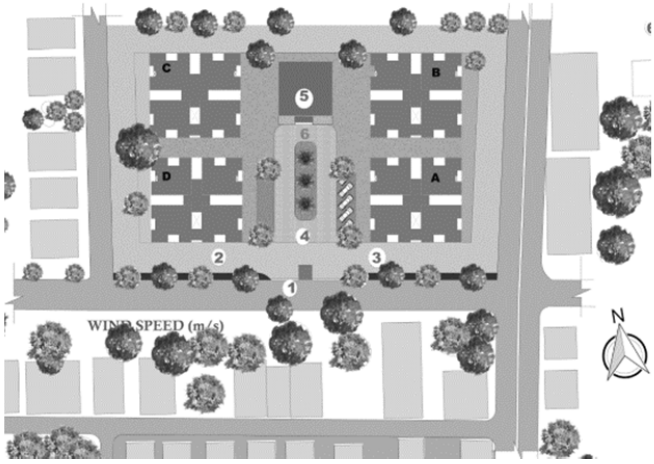

Fig. 11 Site plan

The floor plan is design according to the bye laws of Rourkela Municipal Co-operation. The proposed apartment building is of four storey and a stilt floor. The apartment has total of four blocks A, B, C, & D with a club house i.e. 5 see Fig. 11. The paper is limited in calculating the initial embodied energy (EE) for all four blocks. The first floor of one block is calculated for first floor which resulted in one blocks EE. The final initial EE is attained by multiplying the value of one block to other four block see (Fig.11).

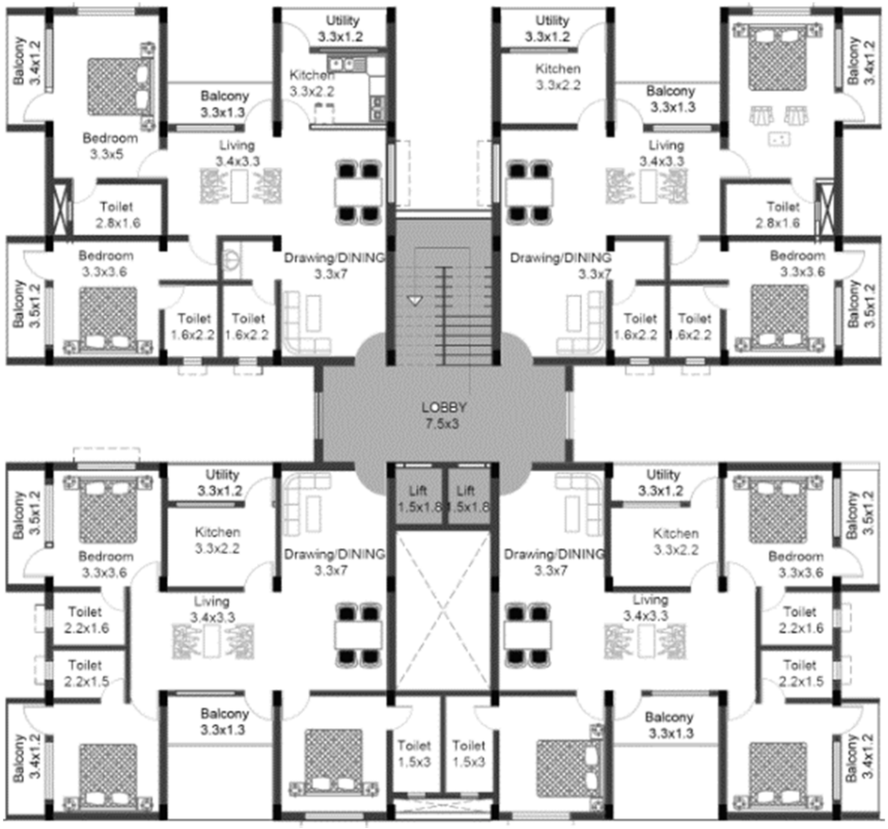

Fig. 12 Typical floor plan of all the blocks

The typical floor plan consists of only 2 BHK and 3 BHK having an area of 119.47 sqm and 124.5 sqm respectively.

D.Calculation of EE (Apartment Building)

The estimation of the total quantity of material required is calculated by long wall short wall method. For analyzing the material of wall is changed, and window and roof component is constant and is limited to the availability of their EE coefficients.

i. Wall
- Fly ash brick
- Autoclaved aerated concrete (ACC) block
- Solid concrete block
- Hollow Cement Concrete (hollow CC) block
- Laterite stone

ii. Window
- Single glazed window
- Double glazed window

iii. Roof (Rcc roof)

E. Inference (Base-Case)

The objective of the paper was to calculate the initial EE and energy consumption. As the paper aims to propose an energy efficient building, the energy performance is calculated and a base case is evolved. Now, in Figs. 14 and 16 it is observed that, normal brick is taken in consideration. Through res build India software, the energy consumption is calculated for the material burnt brick used for wall component. The EE for area 119.47 sqm and 124.47 sqm is 94174.59 MJ and 108116.89 MJ respectively. Therefore, for all four blocks, the total EE is 12099336.83 MJ and the operational energy for burnt brick is 75.71 kWh/m^{2}yr.

VI. Results and Findings (Apartment Building)

EE with Respect to Different Materials

ACC block is recommended in this type of climate in terms of operational energy. ACC block has a reduction of operational energy by 4%. EE per sqm differs due to the EE coefficient of the materials. From the case study it is seen that fly ash is only used as a building material for walls, but to determine the base case, burnt brick is considered as building material. The EE coefficient value of burnt brick is 4.14 MJ/kg, hence the EE per sqm is 6199.966 MJ/m^2 (see Fig. 22). The EE coefficient value of ACC is 11.5 MJ/kg hence the EE per sqm is 11891.34 MJ/m^2 (see Fig. 21). Hence, the EE of a particular building is directly proportional to the EE coefficients of the building material. The value of EE changes with respect to the change in material i.e. the wall component only in this particular case.

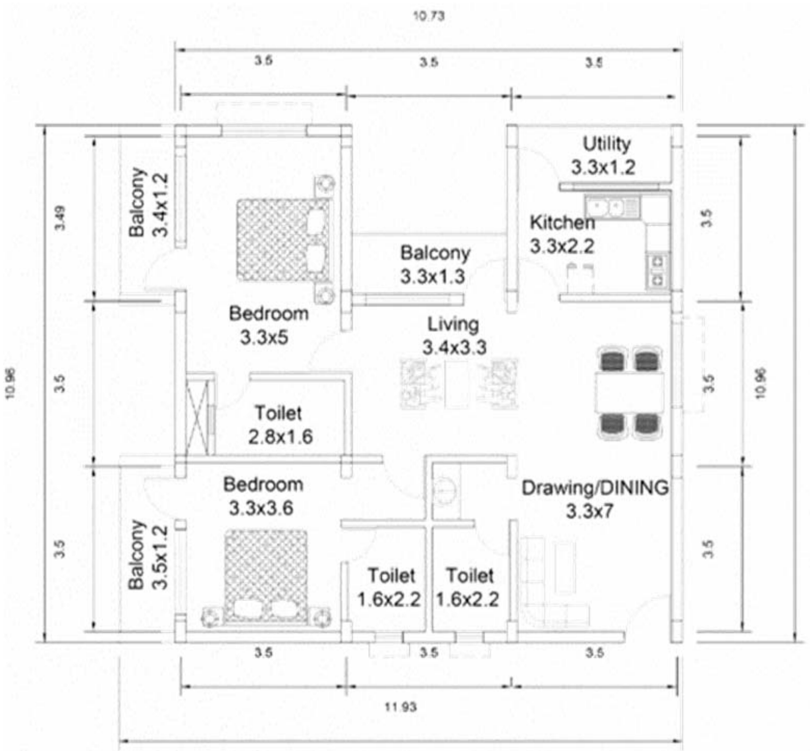

Fig. 13 Typical floor plan of 2 BHK (1 unit)

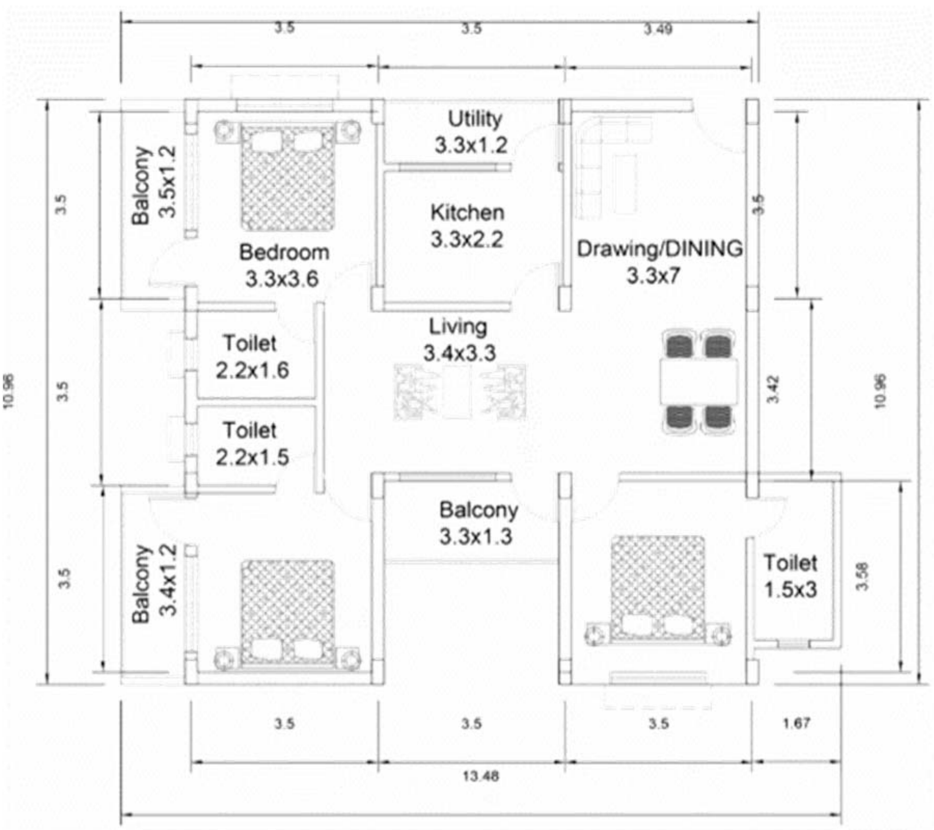

Fig. 14 Typical floor plan for 3 BHK (1 unit)

TABLE I
CALCULATION OF EE FOR 2 BHK (1 UNIT)

2 Bhk (1unit) : Area 119.47 sqm					
Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No	Description of quantities	Unit	Quantity	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1.	Burnt clay brick	Nos.	21915.00	4.14	90728.1
2.	Cement	(bags of 50 kg)	137.10	4.2	575.82
3.	Steel	kg	25.75	34.23	881.42
4.	Sand	Cum	9.48	0.037	0.351
5.	Aggregate	Cum	16.8	0.04	0.67
Roofing					
6.	Roof terracing of R.C.C	Cum	14.34	3.18	45.6
Flooring					
7.	Marble flooring	Sqm	90	2	92
8.	Ceramic flooring	Sqm	11.5	18	207
Joinery (Teak Wood)					
9.	Door shutters	Sqm	20.06	7	27.06
10.	Glass (window glazed shutters)	Sqm	15.66	8.94	140
Finishing					
11.	12mm Plaster in 1:6 cement mortar	Sqm	237.94	4.2	242.14
12.	White wash with lime in three coats	Sqm	251.27	0.58	145.74
13.	Paint	Litre	9.64	13.5	130.14
Total EE					94174.59

TABLE II
CALCULATION OF EE FOR 3 BHK (1 UNIT)

3 Bhk (1unit) : Area 124.5 sqm					
Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No	Description of quantities	Unit	Quantity	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1.	Burnt clay brick	Nos.	25240	4.14	104493.6
2.	Cement	(bags of 50 kg)	139.85	4.2	587.37
3.	Steel	kg	26.11	34.23	893.75
4.	Sand	Cum	9.66	0.037	0.357
5.	Aggregate	Cum	17.16	0.04	0.69
Roofing					
6.	Roof terracing of R.C.C	Cum	14.95	3.18	47.54
Flooring					
7.	Marble flooring	Sqm	93	2	186
8.	Ceramic flooring	Sqm	11.32	18	203.76
Joinery (Teak Wood)					
9.	Door shutters	Sqm	21.95	7	153.65
10.	Glass (window glazed shutters)	Sqm	15.66	8.94	140
Finishing					
11.	12mm Plaster in 1:6 cement mortar	Sqm	263.79	4.2	1107.92
12.	White wash with lime in three coats	Sqm	277.12	0.58	160.73
13.	Paint	Litre	10.48	13.5	141.48
Total EE					108116.89

TABLE III
CALCULATION OF EE FOR 4 BLOCKS (BURNT BRICK)

Apartment (64 units) Base Case (4-BLOCK)					
Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No	Description of quantities	Quantity	Unit	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super Structure					
1	Burnt clay brick	1509085.00	Nos.	4.14 [10]	6247611.90
2	Cement	8830.65	(bags of 50 kg)	4.32	38148.41
3	Steel	164816.00	kg	34.23	5641651.68
4	Sand	614.2	cum	0.062	38.08
5	Aggregate	1226.4	cum	0.04	49.06
Roofing					
6	Roof terracing of R.C.C	937.01	cum	3.18	2979.6918
Flooring					
7	Vinyl flooring	5856	Sqm	2	11712.00
8	Ceramic flooring	730.24	Sqm	18	13144.32
Joinery (Teak Wood)					
9	Door shutters	1344	Sqm	34.1	45830.4
10	Glass (window glazed shutters)	501.12	Sqm	8.94	4480.01
Finishing					
11	12mm Plaster in 1:6 cement mortar	16055.36	Sqm	4.32	69359.16
12	white wash with lime in three coats	16908.28	Sqm	0.58	9806.80
13	Paint	1075.95	Lt	13.5	14525.33
Total EE					12099336.83

TABLE IV
CALCULATION OF EE FOR 4 BLOCKS (FLY ASH BRICK [4])

Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No	Description of quantities	Quantity	Unit	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1	Fly ash brick	1509085	(Nos)	5.3	7998150.50
2	Cement	8830.65	(Bags of 50kg)	4.32	38148.41
3	Steel	164816	kg	34.23	5641651.68
4	Sand	614.2	cum	0.062	38.08
5	Aggregate	1226.4	cum	0.04	49.06
Roofing					
6	Roof terracing of R.C.C	937.01	cum	3.18	2979.6918
Flooring					
7	Marble flooring	5856	Sqm	2	11712.00
8	Ceramic flooring	730.24	Sqm	18	13144.32
Joinery(teak wood)					
9	Door shutters	1344	Sqm	34.1	45830.4
10	Glass (window glazed shutters)	501.12	Sqm	8.94	4480.01
Finishing					
11	12mm Plaster in 1:6 cement mortar	16055.36	Sqm	4.32	69359.16
12	white wash with lime in three coats	16908.28	Sqm	0.58	9806.80
13	Paint	1075.95	Lt	13.5	14525.33
TOTAL EE					13849875.43

TABLE V
CALCULATION OF EE FOR 4 BLOCKS (ACC BLOCK [4])

Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No	Description of quantities	Quantity	Unit	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1	ACC	1509085.00	(Nos)	11.5	17354477.50
2	Cement	8830.65	(Bags of 50kg)	4.32	38148.41
3	Steel	164816.00	kg	34.23	5641651.68
4	Sand	614.2	cum	0.062	38.08
5	Aggregate	1226.4	cum	0.04	49.06
Roofing					
6	Roof terracing of R.C.C	937.01	cum	3.18	2979.6918
Flooring					
7	Marble	5856	Sqm	2	11712.00
8	Ceramic	730.24	Sqm	18	13144.32
Joinery (teak wood)					
9	Door shutters	1344	Sqm	34.1	45830.4
10	Glass(window glazed shutters)	501.12	Sqm	8.94	4480.01
Finishing					
11	12mm Plaster in 1:6 cement mortar	16055.36	Sqm	4.32	69359.16
12	white wash with lime in three coats	16908.28	Sqm	0.58	9806.80
13	Paint	1075.95	Lt	13.5	14525.33
TOTAL EE					23206202.43

TABLE VI
CALCULATION OF EE FOR 4 BLOCKS (HOLLOW CC BLOCKS)

Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No.	Description of quantities	Quantity	Unit	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1	Hollow CC blocks	1509085.00	(Nos)	11	16599935.00
2	Cement	8830.65	(Bags of 50kg)	4.32	38148.41
3	Steel	164816.00	kg	34.23	5641651.68
4	Sand	614.2	cum	0.062	38.08
5	Aggregate	1226.4	cum	0.04	49.06
Roofing					
6	Roof terracing of R.C.C	937.01	cum	3.18	2979.6918
Flooring					
7	Marble	5856	Sqm	2	11712.00
8	Ceramic	730.24	Sqm	18	13144.32
Joinery (teak wood)					
9	Door shutters	1344	Sqm	34.1	45830.4
10	Glass (window glazed shutters)	501.12	Sqm	8.94	4480.01
Finishing					
11	12mm Plaster in 1:6 cement mortar	16055.36	Sqm	4.32	69359.16
12	white wash with lime in three coats	16908.28	Sqm	0.58	9806.80
13	Paint	1075.95	Lt	13.5	14525.33
TOTAL EE					22451659.93

TABLE VII
CALCULATION OF EE FOR 4 BLOCKS (LATERITE STONE)

Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No.	Description of quantities	Quantity	Unit	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1	Laterite stone blocks	1509085.00	(Nos)	0.007	10563.60
2	Cement	8830.65	(Bags of 50kg)	4.32	38148.41
3	Steel	164816.00	Kg	34.23	5641651.68
4	Sand	614.2	Cum	0.062	38.08
5	Aggregate	1226.4	Cum	0.04	49.06
Roofing					
6	Roof terracing of R.C.C	937.01	Cum	3.18	2979.6918
Flooring					
7	Marble	5856	Sqm	2	11712.00
8	Ceramic	730.24	Sqm	18	13144.32
Joinery (teak wood)					
9	Door shutters	1344	Sqm	34.1	45830.4
10	Glass (window glazed shutters)	501.12	Sqm	8.94	4480.01
Finishing					
11	12mm Plaster in 1:6 cement mortar	16055.36	Sqm	4.32	69359.6
12	White wash with lime in three coats	16908.28	Sqm	0.58	9806.80
13	Paint	1075.95	Lt	13.5	14525.33
TOTAL EE					5862288.53

TABLE VIII
CALCULATION OF EE FOR 4 BLOCKS (SOLID CONCRETE BLOCK)

Calculation of EE of the building EE = Quantity of the material x EE coefficient					
S. No	Description of quantities	Quantity	Unit	EE Coefficient (MJ/Kg)	Total EE (MJ)
Super structure					
1	Solid concrete block	1509085.00	(Nos)	10.4	15694484.00
2	Cement	8830.65	(Bags of 50kg)	4.32	38148.41
3	Steel	164816.00	kg	34.23	5641651.68
4	Sand	614.2	cum	0.062	38.08
5	Aggregate	1226.4	cum	0.04	49.06
Roofing					
6	Roof terracing of R.C.C	937.01	cum	3.18	2979.6918
Flooring					
7	Marble flooring	5856	Sqm	2	11712.00
8	Ceramic flooring	730.24	Sqm	18	13144.32
Joinery (teak wood)					
9	Door shutters	1344	Sqm	34.1	45830.4
10	Glass (window glazed shutters)	501.12	Sqm	8.94	4480.01
Finishing					
11	12mm Plaster in 1:6 cement mortar	16055.36	Sqm	4.32	69359.16
12	white wash with lime in three coats	16908.28	Sqm	0.58	9806.80
13	Paint	1075.95	Lt	13.5	14525.33
TOTAL EE					21546208.93

F. Building Performance Index with Respect to Different Materials

From Tables III-VIII the calculation of EE is done with the method of calculating the quantity of materials i.e. long and short wall method. The values of each material taken in consideration are either increasing the value of EE or vice versa. The total value of EE for fly ash brick is 13849875.43 MJ, ACC block is 23206202.43 MJ, laterite stone is 5862288.53 MJ, hollow cc block is 22451659.93 MJ and solid concrete block is 21546208.93 MJ. Figs. 15-20 represent the energy consumption of 4 block with the change in materials of wall component. The total EE of a 4 block is calculated and the wall material is burnt brick and hence the 12099336.83 MJ & operational energy: 75.71 kwh/m^{2}yr. The EE and energy consumption of 4 block is calculated for fly ash brick resulting in the total value of 13849875.43 MJ and energy consumption is 71.74 kwh/m^{2}yr. The EE and energy consumption of 4 block is calculated for ACC block, resulting in the total value of 23206202.43 MJ and energy consumption is 69.35 kWh/m^{2}yr. The EE and energy consumption of 4 block is calculated for solid concrete block, resulting in total value of 21546208.93 MJ and energy consumption is 71.80 kWh/m^{2}yr. The EE and energy consumption of 4 block is calculated for hollow CC block resulting in total value of 22451659.93 MJ and energy consumption 72.55 kWh/m^{2}yr respectively. The EE and energy consumption of 4 block is calculated for laterite stone blocks resulting in total value of 5862288.53 MJ and energy consumption 74.93 kWh/m^{2}yr. From the above analysis, it is observed that energy efficient material i.e. ACC has good operational energy i.e. 69.35 kWh/m^{2}yr. The bench mark or the energy performance index for composite climate is 70 kWh/m^{2}yr (see Fig. 24) but has the highest EE compared to others.

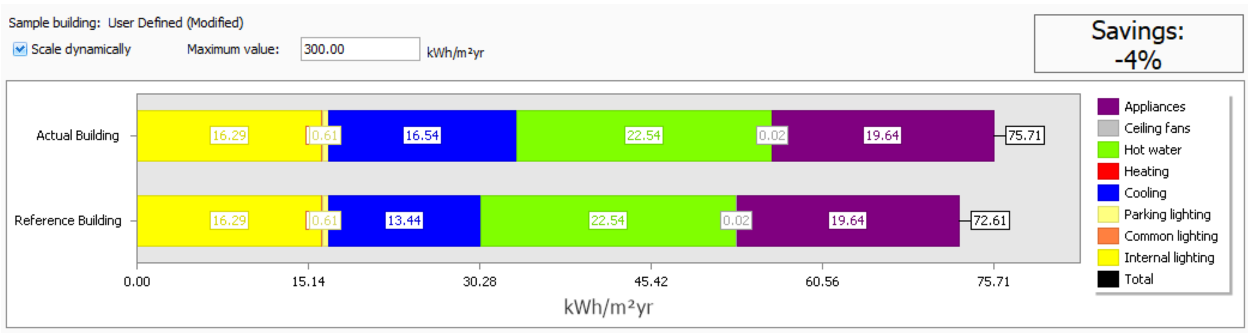

Fig. 15 Energy consumption Burnt Brick (Base Case)

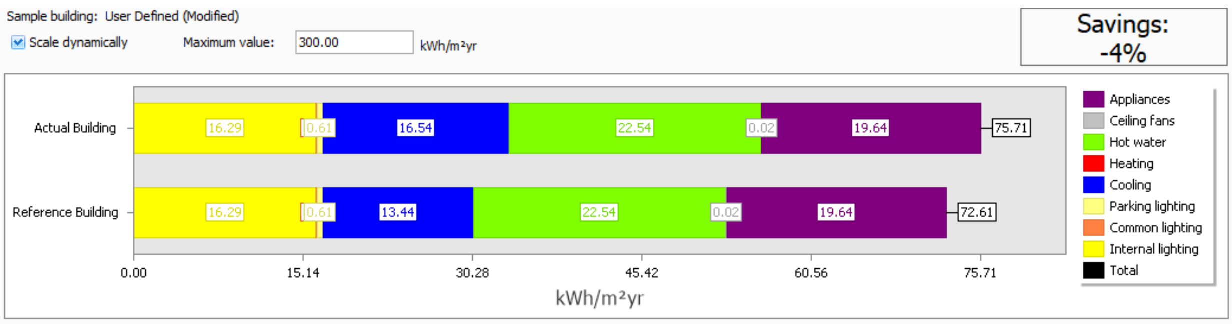

Fig. 16 Energy consumption (Fly Ash bricks)

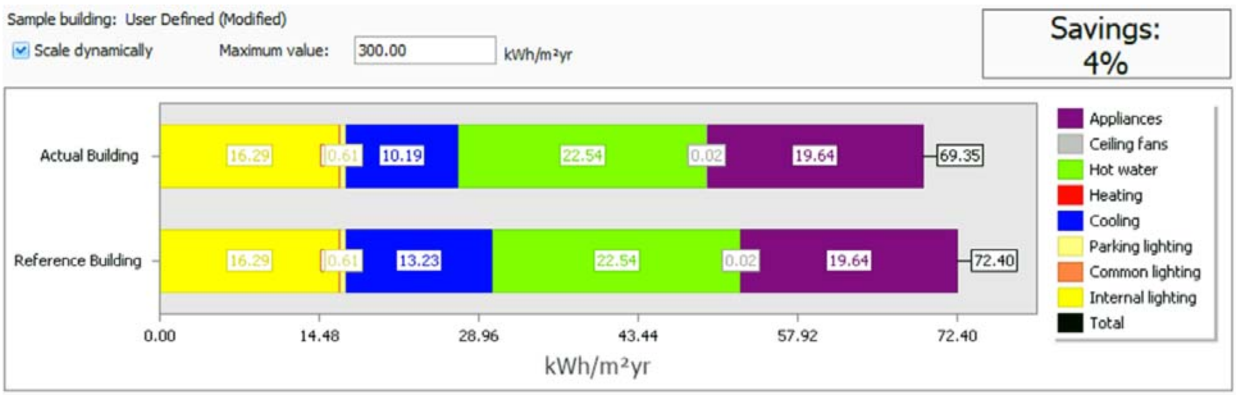

Fig. 17 Energy consumption (ACC blocks)

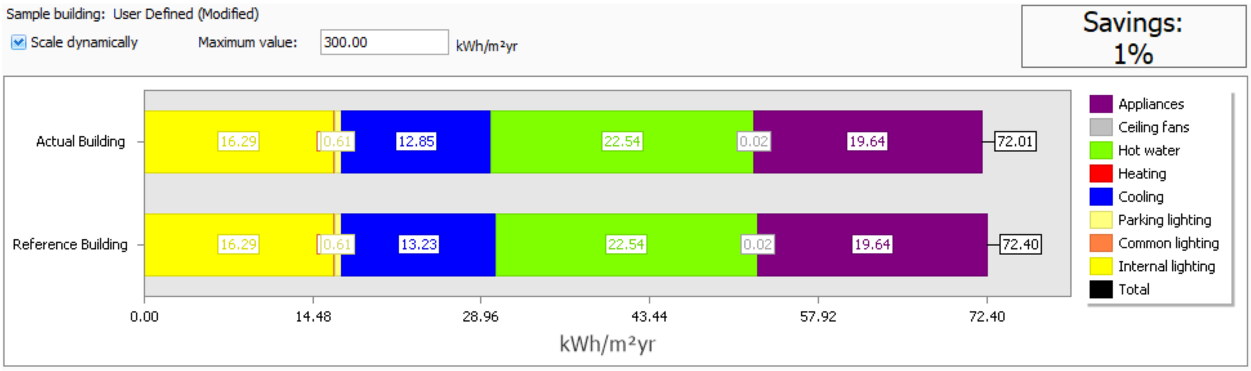

Fig. 18 Energy consumption (solid concrete block)

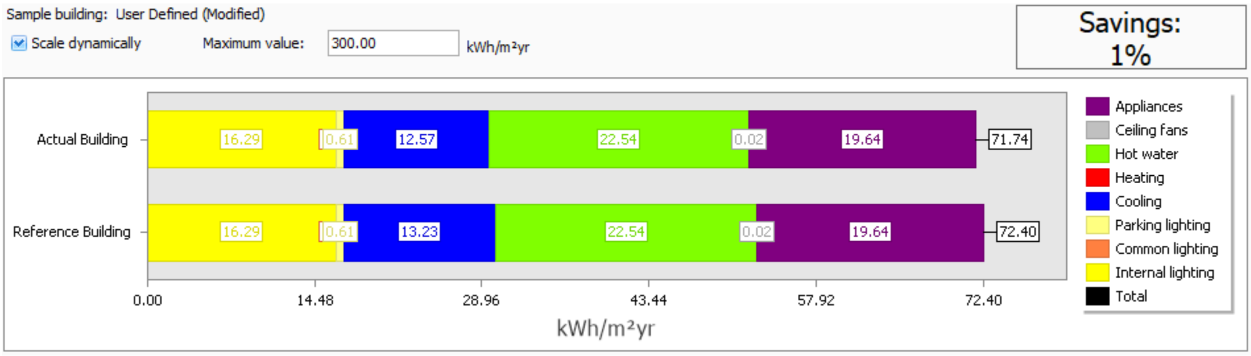

Fig. 19 Energy consumption (hollow CC block)

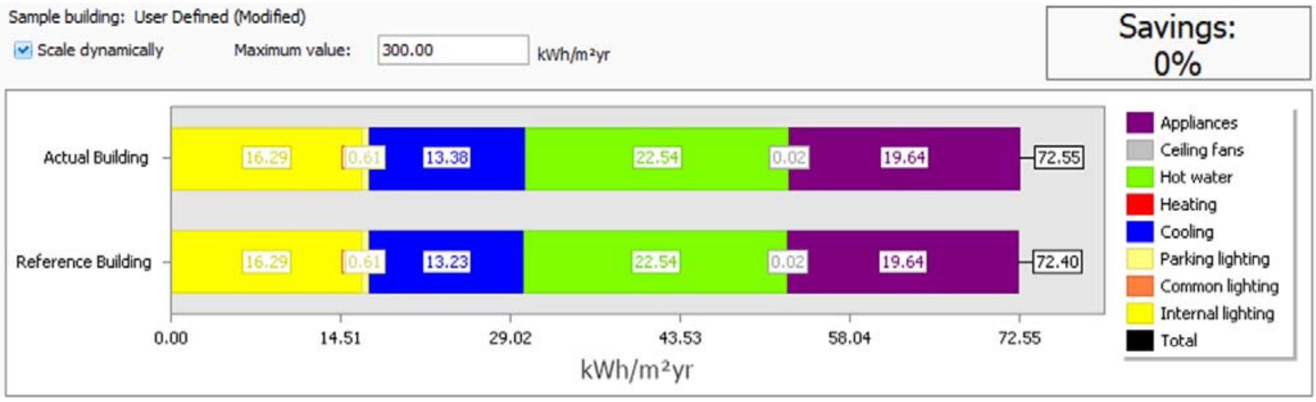

Fig. 20 Energy consumption (laterite stone)

VII. Conclusions

Fig. 23 shows that the six building material has different operational energies. ACC block only reaches the energy performance Index benchmark i.e. 69.35 kWh/m^{2}yr i.e. by saving 4% of energy. As, EE has no particular index or a bench mark, out of all the six materials it has the highest EE 4338260 MJ. The building performance is good in terms of operational energy and not on EE. ACC block is recommended in this type of climate in terms of operational energy. ACC block helps in reduction of operational energy by 4%. EE per sqm differs due to the EE coefficient of the materials. Burnt brick is taken in consideration for the base case and its EE coefficient value of burnt brick is 4.14 MJ/kg hence the EE per sqm is 6199.96 MJ/m^2 (see Fig. 22). Autoclaved Aerated Concrete (ACC) is taken in consideration for the proposed case, and its EE coefficient value is 11.5 MJ/kg hence the EE per sqm is 11891.34 MJ/m^2 (see Fig. 21). The EE of a particular building is directly proportional to the EE coefficients of the building material. ACC block only reaches the energy performance Index benchmark i.e. 69.35 kWh/m^{2}yr by saving 4% of energy. As, EE has no particular index, out of all the six materials it has the highest EE 23206202.43 MJ. The building performance is good in terms of operational energy and not on EE.

For everything there is a standard e.g. the building codes, energy codes etc. which deal with specified dimensions of each component of building to the energy performance index. Certain building energy codes talk about low EE but do not specify the threshold or values of EE that should come within. For this particular case in composite climate, ACC should be preferred as a building material as its energy performance index is less than the bench mark mentioned.

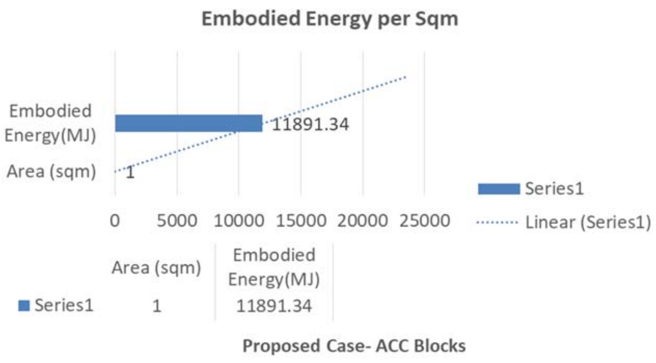

Fig. 21 EE per sqm proposed case

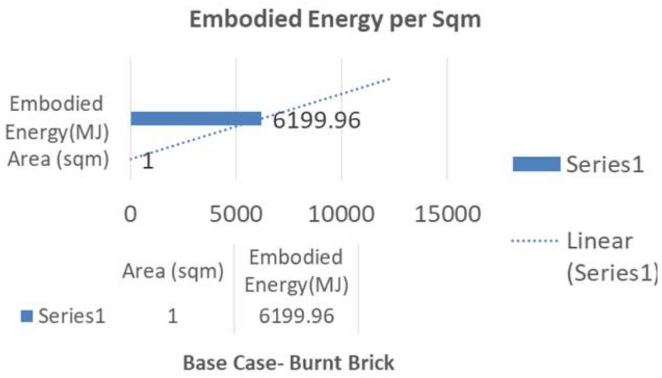

Fig. 22 EE per sqm for Base case

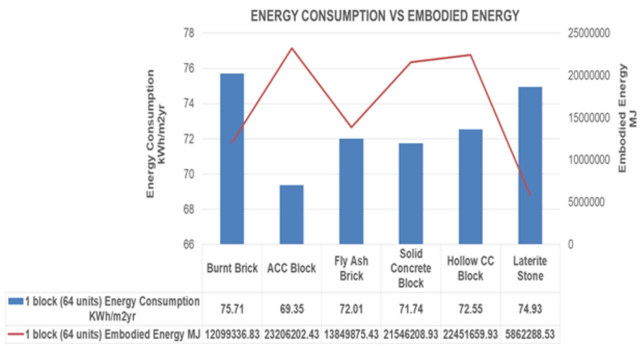

Fig. 23 EE vs Operational Energy

Energy Performance Index Benchmarks (EPI) – (kWh/ m²/year)		
Climate Classification	Day time occupancy	24 hours Occupancy
	5 Days a week	7 Days a week
Commercial/Institutional/Academic/Hospital buildings		
Moderate	75	225
Composite / Warm and humid / hot and dry	90	300
Residential buildings/Hostels		
Moderate	50	
Composite / Warm and humid / hot and dry	70	

Fig. 24 Energy Performance Index [10]

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