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INNOVATIVE AND TRADITIONAL BUILDING MATERIALS – SUSTAINABILITY & COST EFFECTIVENESS – AN ANALYSIS OF EEV

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ABSTRACT

This paper is based on Asian context, more specifically, India. As per current figures India needs to build more than 26.53 million all weather resistant houses of about 25 sqm of plinth area by Year 2012 [1]. Building construction has always been one of the main basic requirements for comfort habitation and there is a huge demand of building materials for the construction of such buildings, which is becoming scarcer day by day, due to heavy exploitation of natural building materials by resource thirsty and large population. Recent studies indicate that at this present rate of consumption, we require a planet FOUR times the present size. It is estimated that about 40% of the energy produced and about 30% of non-saline water and considerable amount of national resources are used to construct buildings in India. There are different types of buildings, which have totally different typologies, functions and are located in different climatic zones, but all the buildings require basic materials like, building blocks/bricks, cement, steel, timber, glass, ceramic tiles, water supply/ sanitation wares and electrical wires/fixtures to some degree. Among these, all buildings primarily require building blocks/bricks in a significant degree. It is also estimated that building blocks/bricks require maximum percentage of resources/energy in any basic building construction, and thus this aspect merits great attention. The absolute total embodied energy values (EEV) of building blocks is very high; as they are required in large quantities and thus define the energy footprint of the Buildings
Traditional building blocks/brick materials used world over, were adobe, stabilized earth blocks, reeds, mud wall with bamboo/wooden members, timber, stone, fired clay bricks/blocks, cement concrete blocks (solid, hollow or hybrid), etc. The Old structures like Great Wall of China, almost all Ancient Forts in India, Egyptian Pyramids, etc. are built with local stone, Earth, local bonding agents (cement, lime etc.), sand, using local construction techniques and have fared very well for centuries. However these cannot be encouraged in the same forms, due to large requirements of the materials and labour intensive construction techniques which are largely outdated. Now, major advancement has taken place in these materials and construction techniques, as stabilization of earthen blocks has become more scientific(resulting in more strength & durability), concrete blocks are custom made (as per design strength and properties), fired clay bricks having made perforated/hollow (to save on materials, weight & provide insulation), aerated concrete blocks have evolved, along with cellular light weight concrete(to reduce dead weight), Fly ash/FaLG/Calcium Silicate or Sand lime bricks/blocks have been developed along with many other products, which are environment friendly, cost effective and structurally sound.
However, in developing countries like India, fired clay bricks are still the main stay of building blocks, although they require lots of natural resources (good soil and bio mass to fire). Efforts are on to go back to improved traditional (stone, stabilized earth blocks) and modern building blocks i.e. cement concrete hollow/perforated with Fly ash, CLC, reconstituted stone blocks, etc. to replace the same to achieve reduced energy footprint & impart more durability of the buildings.

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The use of flyash would actually provide a negative EEV if considered globally ,since its disposal would entail energy consumption and negative influence on biodiversity, but this aspect is currently ignored for simplicity of presentation. Moreover, currently our focus is on absolute values of consumption only.
This paper deals with the advantages of traditional building blocks and with intervention of present scientific knowledge, in developing and using improved traditional & newly developed building blocks to construct sustainable building without compromising on functionality or structural performance of the buildings.

Keywords: *EEV, CLC, Sand lime, Adobe, FaLG*

INTRODUCTION

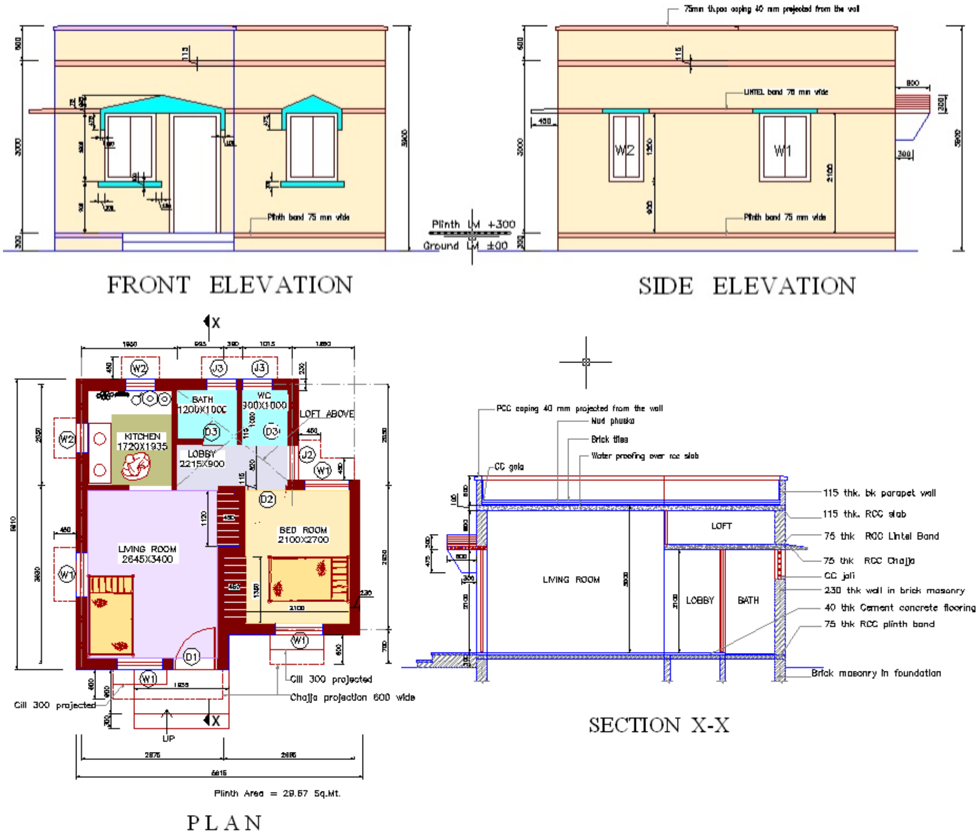
Any Building construction primarily requires building materials comprising of Cement, Steel (Reinforcement), Bricks/Blocks, Sand, Aggregates, Water, Glass, timber, Insulation materials, marble/ /granite/tiles, Plumbing and Electrical wares etc. Out of these, Bricks/Blocks consume major share of cost and Embodied Energy in any building construction and especially in Housing units in those countries, which do not emphasize on HVAC systems, for tropical climatic conditions like India.
To understand the Cost effectiveness and sustainability of housing units up to 25 sqm of plinth area, scores of such houses are analysed in HUDCO (Housing & Urban Development Corporation Limited, New Delhi, India) and a hypothesis is formed. The houses analysed, were cost effective houses conforming to all building bylaws and local climatic and living conditions and are presented in this paper.
The housing typology studied in the present case study is defined in Table 1. The Design of the typical housing typology is given in Fig. 1. In a single, two, three and four storied building, the consumption pattern of basic building materials, is as defined in Table 7. This is derived based on an average Carpet area of housing unit as 21 sqm and wall area in plan is 20%, having a total plinth area of 25 sqm per unit [2].
Different building materials have different physical, structural properties, and different costing parameters, which are also presented in this paper. The Thermal comfort of different building materials have not been analysed in the present case.

Table 1 Brief Specifications of Housing Typology Studied [2]

S. no.	Specifications	
1	Structure	Load Bearing Structure
2	Walls	230/200 mm thick brick masonry in 1:6 (cement: coarse sand) mortar
3	Roof	Flat RCC roof (M25 concrete), 115 mm thick TMT Fe 500 D Steel reinforcement
4	Flooring	40 mm thick cement concrete (1:2:4)
5	Skirting in Rooms/Dado in Toilets & Kitchen	12 mm thick 300/1200 mm high in 1:6 (cement: coarse sand) mortar
6	Plaster/Rendering	12/15mm thick 1:6 (cement: coarse sand) mortar
7	Mud Fuska/Terracing	100 mm thick (average) with brick tiles
8	Parapet	900 mm high 115 mm thick brick masonry in 1:4 (cement coarse sand) mortar
9	Joinery and Doors	MS Frames with steel grill and 4 mm float glass panel in windows, Flush Door Shutters.
10	CC Gola/Khurrah/coping	1:2:4 PCC (Plain cement concrete)
11	Earthquake Resistant Features	RCC Plinth/Lintel Bands for all and Vertical Steel in 3rd and 4th floor buildings only

- Here the Houses are reinforced with horizontal and vertical RCC Bands as per the requirements of seismic provisions given in IS 4326:1993, as per class C Buildings (Seismic Zone III with Importance Factor 1.0) [3].
- The Houses are having same foundation up to two storied Houses (750 × 750 mm continuous spread stepped footing) and in three & four Storied Houses, foundations are slightly increased

to (900 × 900 mm / 1000 × 1000 mm) continuous spread stepped footings) for a soil Bearing Capacity of @ 11 T/sqm (nett.).
- Vertical Steel has been provided from foundation to top RCC slab in Three & Four Storied houses only.



(Source HUDCO JNNURM – Meerut, UP, India)

Fig. 1 Typical Drawings of the Housing Typology Chosen in the Study

Different Building Materials available

Till today there is no alternate for Cement, steel, sand or aggregates for any mass housing Project in India, but there are good options for substitution of Bricks/Blocks. Many of these options have been used in different construction projects and have shown encouraging results. The National Building Code (NBC) of India 2005 and Bureau of Indian standards(BIS) have recognized the specifications of these building materials and have prepared Indian Standards on them. The Compressive stress, Tensile & shear stress, slenderness ratio, weathering effects, water absorption, hardness, dimensional stability, Poisson ratio, etc. have been defined. Some of the commonly used Alternative Bricks/Blocks & their specifications are listed in Table 2.

Table 2 Different Building Bricks/Blocks Available [6]

Building Material	Size	Comp Strength	Weight	Density	EEV (Block)	EEV
	(mm)	(N/Sqmm) MPa	(N)	(KN/Cum)	MJ	(MJ/N)
Fired Clay Brick (conventional)	229 × 114 × 76	7.5	27.5	13.86	4.5	0.164
Hollow Cement concrete block	400 × 200 × 200	4.0	268.8	16.80	11	0.041
AAC/CLC	400 × 200 × 200	4.0	192	12.00	11.5	0.060
Fal G Block	300 × 200 × 150	7.5	180	20.00	7.9	0.044
Solid Concrete Block	300 × 200 × 150	7.5	216	24.00	10.4	0.048
HF SEB (soil-cement block)	230 × 220 × 115	5.0	110	18.90	6.1	0.055
HF (fly ash block)	230 × 220 × 115	7.0	95	16.33	5.3	0.056

Embodied Energy of Building Materials

The embodied energy is the total quantification of energy required in making of the building materials from excavation, handling, transportation, process, and final usages in the buildings. The production process and transportation lead distances of building materials are not uniform in any country; hence there is no consensus on EEV (Embodied Energy Values) of different building materials. However the values assumed in this case are taken from a paper published in the Journal of institution of Engineers (India) as represented in Table 3:

Table 3 EEV of basic construction materials [4]

Items	**EEV (MJ)**	**Units**	**Sizes in mm**
Soil	0	0	0
Cement	0.67	MJ/N	0
Sand	0	0	0
Fly ash	0	0	0
Steel	3.20	MJ/N	0
Standard Burnt Bricks (Fired Clay)	4.50	MJ/Bricks	229 × 114 × 76
Clay Fly ash Bricks	2.32	MJ/Bricks	200 × 100 × 100
Sand Lime Bricks	2.79	MJ/Bricks	200 × 100 × 100
Hollow Cement Concrete Blocks	11.00	MJ/Blocks	400 × 200 × 200
Aerated Blocks	11.50	MJ/Blocks	400 × 200 × 200
Fal G Blocks	7.90	MJ/Blocks	300 × 200 × 150
Solid Concrete Blocks	10.40	MJ/Blocks	300 × 200 × 150

The EEV indicated in Table 3, are without adding for handling/transportation inputs. Apart from these, there are soil stabilized blocks, made by manual press and hydraulic press, with or without fly ash, which can be used in load bearing masonry construction. The proportion & specification of manufacturing process of the soil stabilized blocks manufactured by Hydra Form (HF) machine is given below in Table 4.

Table 4 Properties of Hydraform block (Hydra form India (P) Ltd) [5]

Basic Data:

Block Dimension (mm)	**Length (mm)**	**Width (mm)**	**Height (mm)**
	230	**220**	**115**
Production Capacity of machine by working for 8 hours	2800		
Weight of Soil based block(kg)	11		
Weight of Fly ash based block (kg)	9.5		
Total weight of Soil based mix (kg)	30800		
Total weight of Fly ash base mix(kg)	26600		
Volume of each Block (in cu.m)	0.006		
Total volume of blocks produced (cu.m)	16		
Density of soil base block (per cu.m)	1890		
Density of Fly ash base block (per cu.m)	1633		

The calculations for the EEV of interlocking SEB (stabilized earth block) using Hydra form machine and fly ash interlocking block using Hydra form machine are given below in Table 5 and Table 6 respectively.

Table 5 EEV of SEB block (Hydraform India (P) Ltd) [5]

Raw Material (for 2800 blocks)	**% age**	**Weight (kg)**	**EEV (MJ)**
Soil	62.00	19096	0
C. Sand / St. Dust	30.00	9240	0
Cement	8.00	2464	16509
Total	100.00	30800	16509
Power: 18.5 kWh × 8 h × 3.6 MJ			533
Total EEV per day production			17042
EEV per Hydra form Block (SEB) (size: 230 × 220 × 115) in MJ			**6.09**

Table 6 EEV of fly ash block (Hydra form India (P) Ltd) [5]

Raw Material (for 2800 blocks)	**% age**	**Weight (kg)**	**EEV (MJ)**
Fly Ash	65.00	17290	0.00
C. Sand/ St. Dust	27.00	7182	0.00
Cement	8.00	2128	14258
Total	100.00	26600	14258
Power: 18.5 kWh × 8 h × 3.6 MJ			533
Total EEV per day production			14791
EEV per Hydra form Block (Fly Ash) (size: 230 × 220 × 115) in MJ			**5.28**

Table 7 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with fired clay bricks

S No	**Item**	**Units**	**Single Storied**	**Two Storied**	**Three Storied**	**Four Storied**
1	Fired Clay Bricks	No	460	366	369	345
2	Cement	Bags of 50 Kg	5	4.4	4.3	4.2
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.65	0.56	0.55	0.53
5	Aggregates	Cum	0.45	0.39	0.38	0.36

Table 8 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with Hollow Cement Concrete Blocks

S No	**Item**	**Units**	**Single Storied**	**Two Storied**	**Three Storied**	**Four Storied**
1	Hollow CC Block of 400 × 200 × 200 mm	No	60	47	47	44
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 9 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with AAC Blocks

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	AAC Block of 400 × 200 × 200 mm	No	60	47	47	44
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 10 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with FalG Blocks

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	FalG Block of 300 × 200 × 150 mm	No	105	82	83	77
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 11 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with Solid CC Blocks

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	Solid CC Block of 300 × 200 × 150 mm	No	105	82	83	77
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 12 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with HF SEB Blocks

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	HF SEB Block of 230 × 220 × 115 mm	No	150	117	118	110
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 13 Consolidated statement of Basic Building Materials requirement per sqm of plinth area of a load bearing housing unit up to 25 sqm of Plinth Area, for House constructed with HF Fly ash Blocks

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	HF Fly ash Block of 230 × 220 × 115 mm	No	150	117	118	110
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 7 to 13 above, demonstrates the building materials requirement in different storied building construction and nos of brick/ Blocks required per sqm of plinth area. This also illustrates that Four Storied (G+3) is the most optimum type of Construction of housing units in India in terms of material requirements. There is marginal increase in steel quantities, which is getting off-set by other materials.

Computation of EEV of housing units

The EEV of the Basic building materials and the quantities of the basic building materials is available, which enables us to calculate the EEV of housing units per Sqm of Plinth area. This will give designers a fair idea regarding the energy footprint of the housing units (but without adding for handling, transportation and sundries energy as this aspect has innumerable variations in Indian context). This is explained in Tables 14 & 15.

Table 14 EEV per sqm of Plinth area of Houses

S No	Type of Masonry	Single Storied	Two storied	Three Storied	Four Storied
1	Fired Clay Brick	4257	3597	3677	3516
2	Hollow CC Block	2512	2153	2256	2176
3	AAC Block	2542	2177	2280	2198
4	Fal G Block	2681	2285	2390	2300
5	Soild CC Block	2944	2490	2597	2492
6	HF SEB	2767	2352	2457	2363
7	HF Flyash	2647	2258	2362	2275

Hence from Embodied Energy Values pespective Two Storied (G+1), Load bearing structure is the best model in this situation and Four Storied Housing is also very close to Two Storied Housing in terms of Embodied Energy Values. More options have not been worked upon as Indian Standards IS 1905 do not allow unreinforced Load bearing Construction higher than Four Storied (G+3) in India, due the different loading and wall slenderness combinations.

However this masonry option, although widely practised in India, is not energy & cost efficient, as the EEV of Fired Clay Brick is much higher compared with other building blocks options available and wall thickness is also 230 mm, whereas in other options wall thickness can also be controlled as other blocks can be designed as per requirement.

Table 15 Comparative Chart for EEV with different Masonry option for a Single Storied House per sqm of Plinth Area

S No	Masonry with following	EEV(MJ)/sqm of plinth area	% Saving
1	Fired Clay Brick	4257.00	0
2	Hollow concrete Blocks	2512.00	41
3	AAC/CLC Blocks	2542.00	40
4	HF Flyash Block	2647.00	38
5	FalG Block	2681.00	37
6	HF SEB Block	2767.00	35
7	Solid Concrete Block	2944.00	31

Table 16 Comparative chart for EEV of 1 sq. m. of Masonry with different building materials (Prices in Indian Rupees for the Year 2012)

Building Materials	Sizes (mm)	Wall thickness (mm)	No of Blocks/Bricks required per sqm of Wall Area	Cost/cum (INR*)	Cost/Sqm (INR*)
Standard Burnt Brick (Fired Clay Bricks)	229 × 114 × 76	230	116	4000	920
Hollow cement concrete blocks	400 × 200 × 200	200	13	4000	800
AAC Block	400 × 200 × 200	200	13	5000	1000
FalG	300 × 200 × 150	200	23	5000	1000
Solid CC Block	300 × 200 × 150	200	13	5000	1000
HF SEB(soil cement blocks)	230 × 220 × 115	230	40	5000	1150
HF(fly ash blocks)	230 × 220 × 115	230	40	5000	1150

1 USD is about 50 INR as on April 2012.

Comparison

In this exercise attempt is made to draw a comparison between conventional building blocks (Fired Clay Brick) with other commonly available options and draw a parallel to understand the energy and cost footprint of the building for a chosen housing typology in India, with only one variable i.e. building block.

This gives a broad idea that the correct application of building blocks can influence economies of scale on energy and cost without compromising on functionally and structural performance of the building.

CONCLUSION

The exercise shows that Hollow Cement Concrete Blocks uses least cost (INR 800 per sqm of wall area) and least energy (2512 MJ per sqm of Plinth area) of Housing unit, which is 41 % less than Fired Clay Brick house and have less wall thickness (200 mm compared to 230 mm in case of Clay fired Bricks), resulting in more carpet area.

IMS Journal [11] also reported that thermal performance of brick houses is also much better than that of Timber houses with insulation, giving a boost to Hollow Cement Concrete Blocks as they offer better thermal properties than Fired Clay bricks .Translating the above benefits of inherent thermal properties to Energy Efficiency shall form a separate study.

It is proposed to carry out further exercise for other building materials also up to Four storied, to understand the EEV of the other types of buildings also.

REFERENCES

[1] Report of the Technical Group [11th Five Year plan: 2007-12] on Estimation of Urban Housing Shortage in India.

[2] Bansal Deepak, Affordable houses & Cost Effective Technologies, Hudco Darpan, Issue 4, October 2008, pp. 29-30, www.hudco.org.

[3] IS 4326:1993, Indian Standard on Earthquake Resistant Design and Construction of buildings- Code of Practice (Second Revision) www.bis.org.in.

[4] IE (I) Journal AR, vol. 84, October 2003, Dr P S Chani, Dr Najamuddin, and Dr S K Kaushik) pp. 47-50.

[5] Hydra Form Asia (P) Ltd, New Delhi, India. Website www.hydraformasia.com.

[6] Bansal Deepak, et el, International Conference on Structural Engineering, Construction and Management, Kandy, Sri Lanka, Dec 2011, pp. 3.

[7] Bansal Deepak, Masonry from Stabilized Earth Blocks-sustainable & structurally viable Option, International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Volume 04, No 06 SPL, October 2011, pp. 772-779.
[8] Bansal Deepak et el, Sustainable Urban Development & Bio Diversity, Hudco Shelter, Vol. 13, No 1 & 2, Oct 2011, pp. 15-28.
[9] Bansal Deepak, et el, embodied energy in residential cost effective Housing, International Conference on Sustainable Built Environment, Kandy, Sri Lanka, Dec 2010, pp. D11.
[10] Bansal Deepak,et el, embodied energy in residential cost effective Housing, TERI-BMTPC Conclave, New Delhi, India, Nov 2010.
[11] T H McNeilly, For Energy Conservation in Houses, Construction Mass out-Performs insulation in most Australia. Journal of International Masonry society UK.

This is authors personal research, HUDCO may or may not agree with the same.