A Study on Embodied Energy of Various Building Blocks in the Construction Industry

* *Geena George*
** *Bhoomika Suresh*
*** *M. G. Priuthvishree*

Abstract

Due to the rapid growth of construction activity there is a huge demand of building materials. A large quantity of construction materials are used which consume a huge amount of energy in their manufacturing process. The energy efficiency of an entire building can be gained by selecting low embodied energy materials. The zero-energy building is an ambitious yet increasingly achievable goal that is gaining importance across the world. In this paper, an attempt has been made to calculate the embodied energy values of various building blocks and to suggest a sustainable building block based on the comparison of their embodied energy and economic performance.

Keywords : **Embodied energy, renewable energy, zero energy concept**

I. INTRODUCTION

In India construction industry is one of the fastest growing industries which consumes large amounts of energy. The energy consumed mainly in the manufacturing process of various construction materials [1]. India was the fourth highest emitter of Carbon Dioxide in the world, accounting for 7% of global emission in 2017. Its emission was set to continue strong growth by an average of 6.3% in 2018. The construction sector in India emits about 22% of total annual emission of CO_2 resulting from the Indian economy. Of the emission from the construction sector, 80% is mainly from products or industrial processes of four energy intensive building materials, and these are steel, cement, brick, and lime. As the housing stock consumes 30 to 40% of all energy resources, energy efficiency improvement becomes very important [4]. The energy efficiency in a building can be achieved by following four major aspects.

The first one among them is designing zero energy buildings before actual construction, second is to use building materials with low energy during construction, third is usage of energy efficient equipments, and finally incorporating renewable energy technologies for various applications [5].

A concept of life cycle assessment also contributes to identifying the material that has major impact on the environment. Life-cycle assessment (LCA), also known as life-cycle analysis, eco-balance, and cradle-to-grave analysis is a technique to assess environmental impact associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance,

Manuscript Received : October 20, 2020, Revised : November 10, 2020, Accepted : November 16, 2020. Date of Publication : December 5, 2020.

* *G. George* is Associate Professor with Department of Civil Engineering, East Point College of Engineering & Technology, Bengaluru - 560 049, Karnataka, India. (Email : id-geenasajith@gmail.com)
** *B. Suresh* is B. E. Student at Department of Civil Engineering, East Point College of Engineering & Technology, Bengaluru-560 049, Karnataka, India. (Email : bhoomikasuresh98@gmail.com)
*** *M. G. Priuthvishree* is B.E. Student at Department of Civil Engineering East Point College of Engineering & Technology, Bengaluru - 560 049, Karnataka, India.(Email : ggeethasrg09@gmail.com)

DOI : https://doi.org/10.17010/ijce/2020/v3i2/156366

and disposal or recycling. Designers use this process to help critique their products. LCAs can help avoid a narrow outlook on environmental concerns by :

- Compiling an inventory of relevant energy and material inputs and environmental releases ;
- Evaluating the potential impacts associated with identified inputs and releases ;
- Interpreting the results to help make a more informed decision.

Ideally, the boundaries would be set from the extraction of raw materials (including fuels) until the end of the products lifetime (including energy from manufacturing, transport, energy to manufacture capital equipment, heating & lighting of factory, maintenance, disposal, etc.), known as 'Cradle-to-Grave'. 'Cradle-to-Gate', includes all energy (in primary form) until the product leaves the factory gate. The final boundary condition is 'Cradle-to-Site', which includes all the energy consumed until the product has reached the point of use (i.e. building site) [10].

During last few years, the concept of zero energy building (ZEB) has gained worldwide attention and is now the future target for the design of buildings [5]. The term *zero-energy building* is most often defined as a building that produces as much energy on-site as it consumes on an annual basis. Energies in buildings are classified into four types that are maintenance energy, embodied energy, operational energy, and demolition energy.

- **Maintenance energy :** Energy used for servicing and maintenance of building during its life cycle.
- **Embodied energy :** Energy used for production of building materials.
- **Operational energy :** Energy required by the building during its life span to serve its purpose and to create a healthy atmosphere.
- **Demolition energy :** Energy required to deconstruct, demolish, and dispose off building components at the end of its effective life span.

Lot of efforts are being made for the assessment of embodied energy since the last few decades and to find solutions. As a result, many methods have been developed and adopted. Energy analysis is one method which can be used to estimate and evaluate the impacts of different activities [3]. Most of the time the energy analysis of a building is restricted only to the operational energy, and the impact of embodied energy to construct the building is ignored. In this paper, an attempt is made to showcase the importance of embodied energy of building materials for sustainable living.

II. EMBODIED ENERGY

Embodied energy is termed as all the energy inputs required from production of building materials to construction of a building [5, 6]. It can also be defined as the energy consumed by all of the processes associated

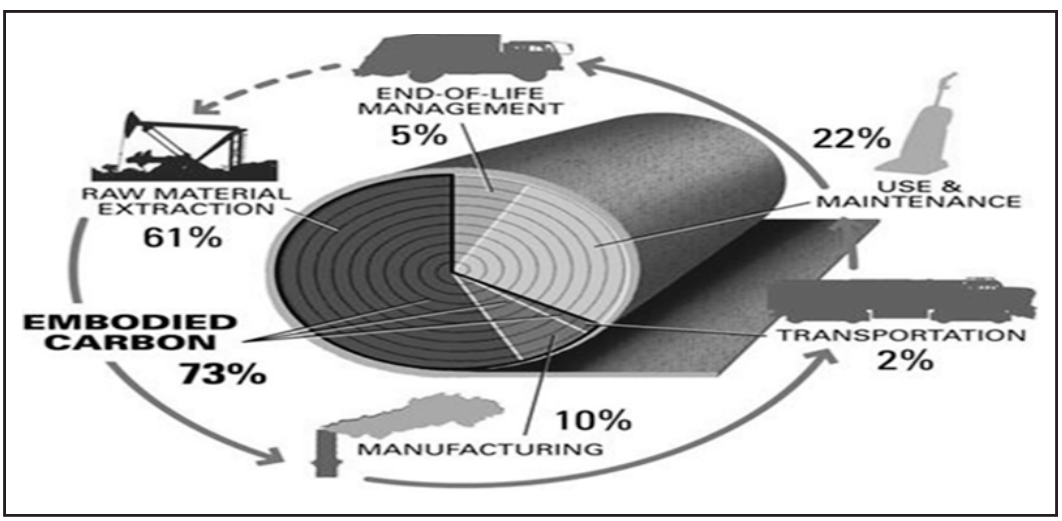

Fig. 1. Lifecycle Chart

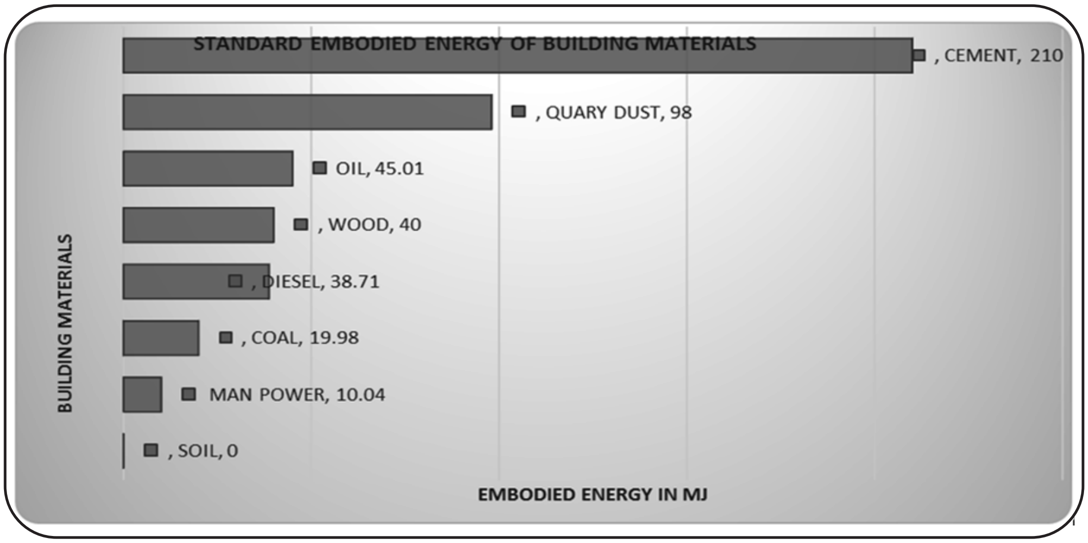

Fig. 2. Embodied Energy of Building Materials in Mega Joule/Kg (MJ/Kg)

with building construction, from the acquisition of raw materials to product delivery, which includes mining, manufacturing of materials, and equipment, transport, and administrative functions [12]. According to life cycle assessment, it has become common practice to specify the embodied energy as 'Cradle-to-Gate', which includes all energy (in primary form) until the product leaves the factory gate.

Buildings are constructed using various building materials and each of these materials requires energy throughout its phases of manufacture/production, use, deconstruction, and disposal [8]. This involves procurement of natural resources for manufacturing of construction materials (mining, manufacturing of materials, equipment and transportation) and using them in a building.

The embodied energy of a building from the extraction of raw materials to the end of its life is represented through a life cycle chart in Fig. 1. There is a standard embodied energy for most of the building materials, raw materials, man power, and other forms of resources that are used during manufacturing and construction of a building [2]. Soil has the least embodied energy value while cement is topping the chart. This is because soil is a raw material that doesn't involve any manufacturing process whereas, cement is the largest producer of CO_2 that consumes 50% of the energy in chemical composition alone. Cement manufacturing is a complex process that begins with mining and then grinding raw materials that include limestone and clay to a fine powder, which is then heated and further powdered. This entire process consumes more energy than rest of the materials. Hence, soil has least embodied energy and cement has greater embodied energy comparatively. Fig.2 shows the embodied energy of various resources used in construction such as cement, quarry dust, wood, man power, oil, coal, diesel, and soil.

A. Embodied Energy Modeling

Embodied energy right from extraction of virgin materials till deconstruction and disposal in a building can be modeled and shown in a flowchart (Fig. 3).

Generally, a building blocks life cycle can be organized in three stages. These are : pre-building, building, and post-building [9]. Pre-building phase generally creates more environmental destruction. By knowing the environmental impact in this phase, wise selection of building block can be made. There is an environmental impact right from raw materials collecting methods, the manufacturing process, and the distance from the manufacturing location to the building site.

A pre building phase can be explained using embodied energy modeling. This phase consists of energy used during raw materials extraction, manufacturing, packing and transportation to a building site. This energy is classified as indirect and direct energy.

➢ **Indirect energy :** It is a type of non-renewable energy consumed in operations like extraction of raw materials, transportation of raw materials, factory set up, and associated works.

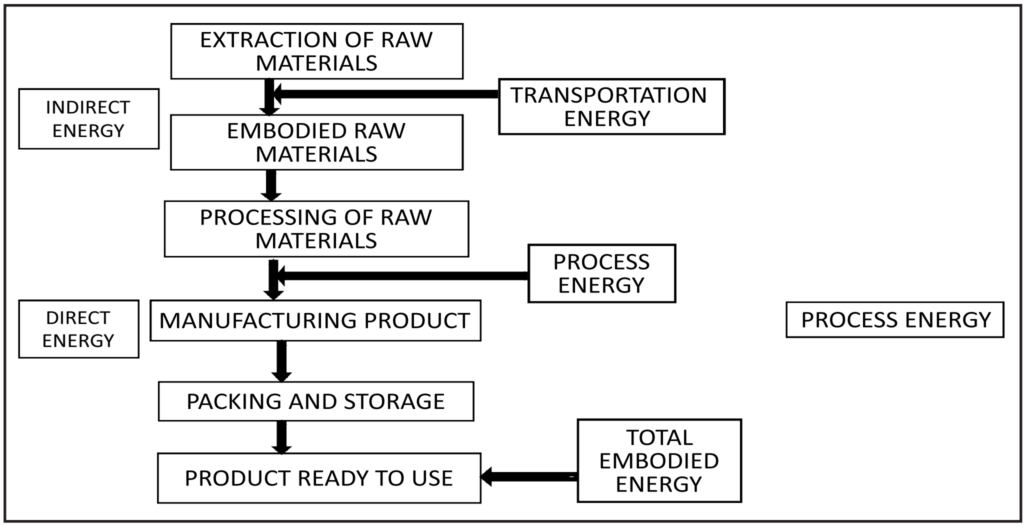

Fig. 3. Embodied Energy Modelling

➯ **Direct energy :** The energy consumed directly in on-site and offsite operations like manufacturing, construction, and transportation.

III. METHODOLOGY

On the basis of data collected for raw materials, electricity consumption if it was used, man power, diesel usage in the manufacturing process of various building blocks, the embodied energy that each building block consumed was calculated. Four different building blocks such as stabilized mud blocks, concrete blocks, wire cut bricks, and table mould bricks were considered for the study. A comparative study has been conducted on the embodied energy of these varying building blocks for cradle to site as the study parameter. A 2 BHK house of 1200 sq.ft. area was considered for the energy consumption, quantity estimation, and economic performance of building blocks. The total embodied energy of building blocks was calculated using the various parameters considered in manufacturing [7]. From the values obtained, the embodied energy was compared and the most suitable building block based on energy consumption and economic performance was selected for further study.

A. Study on Various Building Blocks

(1) Stabilized mud blocks : Stabilized mud blocks are considered to be one of the most environmentally friendly building materials by building professionals as these are very good insulators and suitable for areas with high temperature because heat from the sun during the day is not stored for a long time after sunset. As these can be produced onsite, don't require transportation. This indirectly contributes to reducing carbon footprints. They are energy efficient; 60% of the energy is saved compared to the burnt bricks.

(2) Concrete blocks : Concrete blocks are commonly made from concrete. Cement is the main content in producing concrete blocks but cement industry is one of the largest producers of CO_2, creating upto 5% of world-wide man-made emissions of this gas, of which 40% is from burning fuel and 50% from chemical processes [5]. Hence, concrete is unfortunately not an environmentally friendly material as much energy and water are required to get the raw materials and produce the product, that is, concrete blocks. It causes environmental destruction and pollution while quarrying for sand and other aggregates.

(3) Wire cut bricks : Wire cut bricks are made of fired clay in the factory. Hence, wire cut bricks have uniform properties, higher strength and regular surface but it is costlier than table moulded bricks. Wire cut usually has rough edges created by the wire that gives better appearance compared to table mould bricks. It is more porous and fragile than table mould bricks.

(4) Table mould bricks : Raw materials required for table moulded bricks are easily available and economical. They are hard, durable, and highly fire resistant. The required

TABLE I.

EMBODIED ENERGY (EE) FOR CONCRETE BLOCKS (CB)

Material	Quantity			Unit EE	Total EE for Concrete Blocks(CB)		
	4'8'16'	6'8'16'	8'8'16'	required MJ	CB(4'8'16')	CB(6'8'16')	CB(8'8'16')
Cement (Bags)	2661.12	1995.84	1330.5	210	558835.2	419126.4	279405
Dust grit(MT)	415.8	311.85	207.9	98	40748.4	30561.3	20374.2
Jelly(MT)	831.6	623.7	415.8	68	56548.8	42411.6	28274.4
Man power	250	250	250	10.4	2600	2600	2600
Diesel (L)	180	180	180	38.71	6967.8	6967.8	6967.8
Electricity (Kwh)	500	500	500	16.3	8150	8150	8150
Total EE					673850.2	509817.1	337621.4
Total MJ per block					17.96	13.59	9.22

maintenance cost is very less. The time consumed during construction is more but it is easy to demolish. The brick structures and are reusable and recyclable.

IV. RESULTS AND DISCUSSION

Various building blocks such as concrete blocks, table mould bricks, wire cut bricks, and stabilized mud blocks are considered to compare energy efficient building blocks. Embodied energy per building block varies on the basis of energy used for the production of their building materials and the embodied energy differs for the same building material with different sizes. The embodied energy calculation for various building materials is given in Tables I to IV. From the results it is observed that concrete block has the highest embodied energy as it is composed mainly from cement whereas, stabilized mud block has the least embodied energy as the production includes soil as a major composition that has zero embodied energy. Fig. 4 gives the variation of embodied energy of different building blocks considered for the study.

The embodied energy per building block of concrete is 76.18%, wire cut brick is 183.36%, and table mould brick is 269.3% greater than stabilized mud block. This variation is mainly due to the materials used for the

TABLE II.

EMBODIED ENERGY FOR WIRE CUT BRICK (WCB)

Materials	Quantity	EE in MJ	Total EE for WCB
Soil (trucks)	125	0	0
Wood(Kg)	13330	40	533200
Diesel(L)	40000	38.71	1548400
Man power	1333	10.04	13386.63
Oil (L)	5000	45.01	225050
Total in MJ			2320036.63
MJ/brick			3.86

TABLE III.

EMBODIED ENERGY FOR STABILIZED MUD BLOCKS (SMB)

Materials	Quantity		EE in	Total EE of SMB	
	9'x 6'x 4 '	12'x 6'x 4'	MJ	9'x 6'x 4'	12'x 6'x 4'
Soil (trucks)	166	166	0	0	0
Cement (Kg)	833	1000	210	174930	210000
Quarry Dust(Kg)	4998	6000	98	489804	588000
Man Power	250	250	10.04	2510	2510
Total in MJ				667244	800510
MJ/ block				2.1	2.5

TABLE IV.

EMBODIED ENERGY FOR TABLE MOULD BRICKS (TMB)

Materials	Quantity	EE in MJ	Total EE of TMB
Soil (Trucks)	13	0	0
Coal(Kg)	10,000	19.98	199800
Diesel(Litres)	150	38.71	5806.5
Man power	500	10.04	5020
Total in MJ			211830.5
MJ/brick			3.53

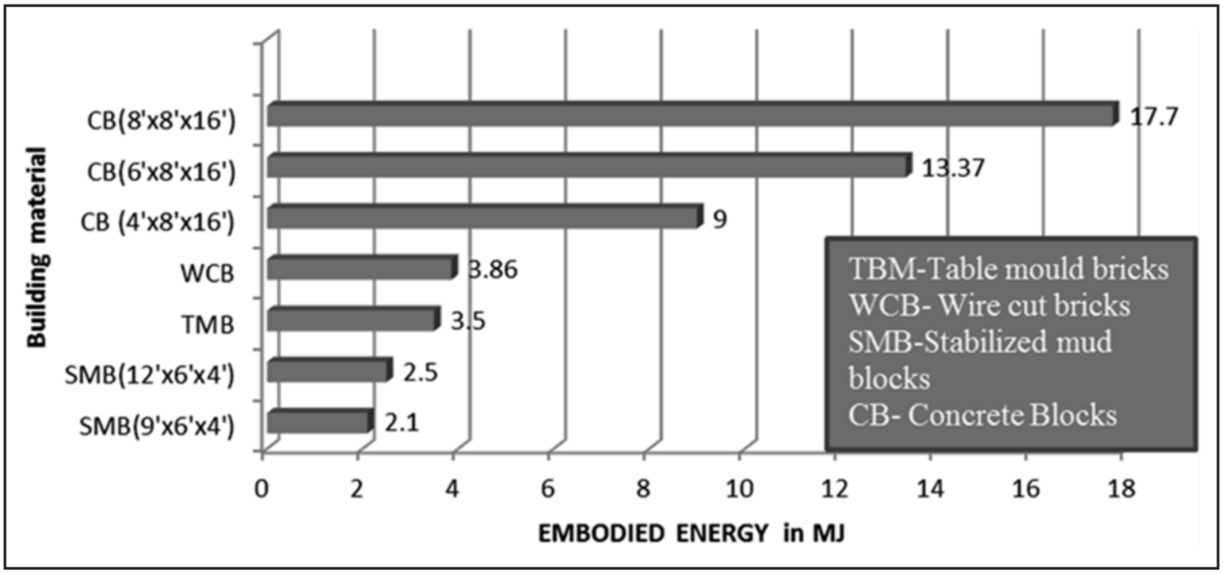

Fig. 4. Embodied Energy in Various Building Blocks

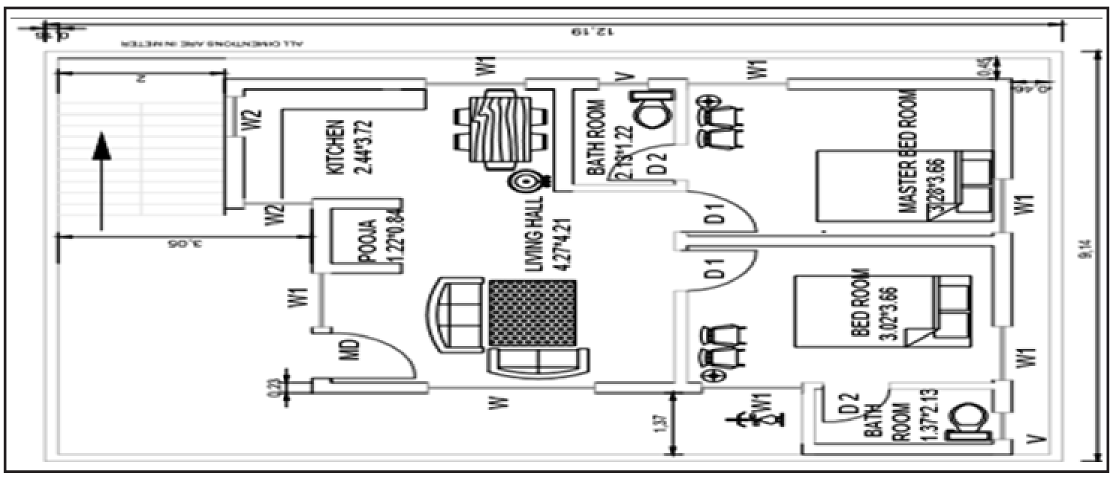

Fig. 5. Plan of a 2BHK Residential Building

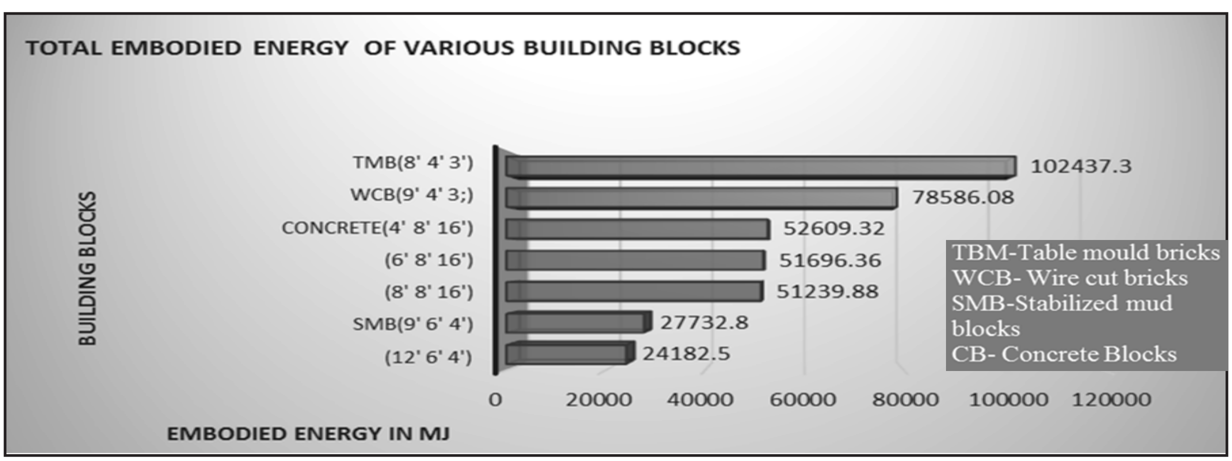

Fig. 6. Total Embodied Energy of Different Building Blocks

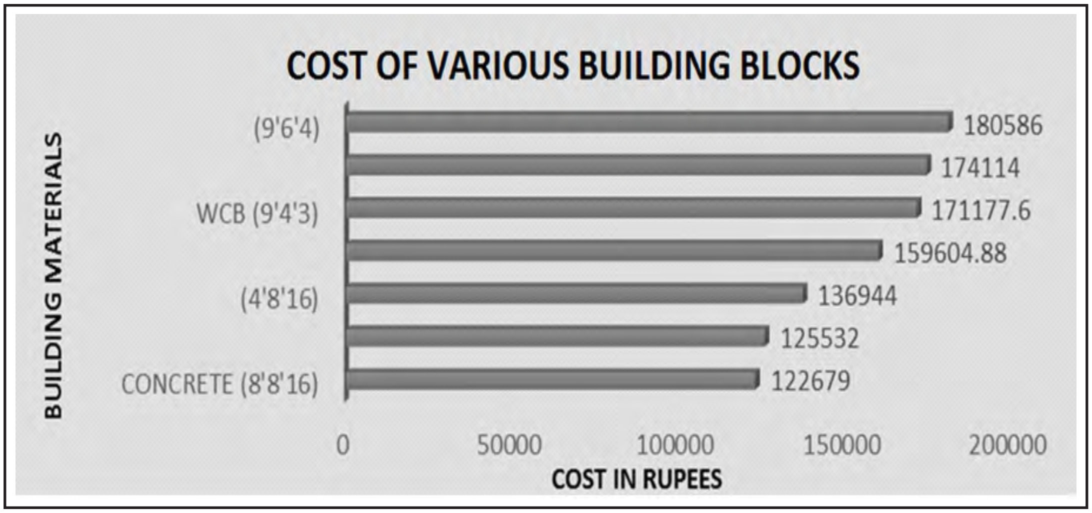

Fig. 7. Cost Comparison of Various Building Blocks

manufacturing.

To conduct further study on Zero Energy concept of buildings, a residential building of 1200 sq .ft. is considered (Fig. 5). The quantity estimation of the different building blocks required for the construction is done. Fig. 6 shows the variation of the total embodied energy of each building block. When the embodied energy of different blocks is considered, it can be concluded that SMB has lower embodied energy as compared to concrete block.

A. Cost Comparision

The cost of various building blocks required for the construction is compared in Fig. 7. From the cost analysis it can be stated that concrete blocks have the least cost when compared with other blocks. The cost of table mould brick is 30.09%, wire cut brick is 39.53%, and stabilized mud block is 47.20% more than the cost of concrete blocks.

V. CONCLUSION

From the studies conducted, it can be concluded that stabilized mud blocks has lower embodied energy compared to remaining building blocks which makes them energy efficient. Concrete blocks are economical, because of higher embodied energy can't be considered as environmental friendly building material. The stabilized mud blocks are found to be less economical, and contribute more towards the concept of zero energy building which has a positive impact on environment. The selection of building material considering their embodied energy reduces the CO_2 emission and results in energy efficient buildings. The concept of zero energy building in construction plays a major role in sustainable global environment.

REFERENCES

[1] R. Kassim and M. H. Santhi, "Basic studies on embodied energy in construction materials," *Int. J. of Earth Sciences and Eng.,* vol. *9,* no. *6*, pp. 2452–2456, 2016.

[2] Rakesh, S. and M. Keshava, "A study on embodied energy of recycled aggregates obtained from processed demolition waste," presented at the *Nat.Conf. Recent Trends in Architecture & Civil Engineering Towards Energy Efficient and Sustainable Develop.,* NIT Tiruchirapalli, January 2019.

[3]. K. Peterson et al., *"A common definition for zero energy buildings," U.S. Dept. of Energy*, September 2015.

[4] E. Perlova, M. Platonova, A. Gorshkov, and X. Rakova, "Concept project of zero energy building," *Procedia Eng.,* pp. 1505-1514, vol. *100*, pp. 1505–1514, 2015 December. doi: https://doi.org/10.1016/j.proeng.2015.01.522

[5] A. Chel and G. Kaushik, "Renewable energy technologies for sustainable development of energy

efficient building," *Alexandria Eng. J.,* vol. *57*, no. *2*, pp. 655–669, 2018. Doi: 10.1016/j.aej.2017.02.027

[6] M. K. Dixit, J. L. Fernandez-Soli, S. Lavy, and C. H. Culp, "Identification of parameters for embodied energy measurement: A literature review," 2010, *Energy and Buildings,* vol. *42*, no. *8*, pp. 1238–1247. doi: https://doi.org/10.1016/j.enbuild.2010.02.016

[7] A. J. Marszal, P. Heiselberg, J. S. Bourrelle, E. Musall, K. Voss, I. Sartori, and A. Napolitano, "Zero energy building – A review of definitions and calculation methodologies," *Energy and Buildings,* vol. *43*, no *.4*, pp. 971–979, 2011.

[8] A. Hashemi, H. Cruickshank, and A. Cheshmehzangi, "Environmental impacts and embodied energy of construction methods and materials in low-income tropical housing," *Sustainability,* pp. 7866–7883, 2015. https://doi.org/10.3390/su7067866

[9] A. Stephan, R. H. Crawford, and K. Myttenaere, "Towards a comprehensive life cycle energy analysis framework for residential buildings," *Energy and Buildings,* vol. *55*, pp. 592–600, 2012.

[10] A. Stephan, R. H. Crawford, and K. Myttenaere, "Towards a more holistic approach to reducing the energy demand of dwellings," *Procedia Eng.,* vol. *21*, pp. 1033–1041, 2011. Doi: https://doi.org/10.1016/j.proeng.2011.11.2109

About the Authors

Geena George has completed B. Tech. (Civil Engineering) and M.Tech. (Environmental Engineering), and is currently pursuing Ph.D. at Visvesvaraya Technical University. She has 15 years of teaching experience and has published 14 papers in international journals and conferences. Her areas of interest include waste management, recycling of waste materials in concrete, and green buildings.

Bhoomika Suresh is B.E. student at Department of Civil Engineering, East Point College of Engineering & Technology, Bangalore.

M. G. Priuthvishree is B.E. student at Department of Civil Engineering, East Point College of Engineering & Technology, Bangalore.