

# **ENERGY SUSTAINABILITY STUDIES ON UNDER-CONSTRUCTION BUILDINGS: BASELINE FOR TOMORROW'S POLICY**

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## **Abstract**

In the past decade, building research in Asia has been found to have diverged into a relatively less treaded subject of embodied energy (EE) assessment of buildings across their size and construction types as has been reported by several studies. As buildings are complex entities and known to be highly energy intensive, EE contributes a major share in energy use and carbon emission over their life-cycle. While the focus of most policies remains on operational energy of buildings, the energy embodied in the building fabric has, so far, escaped critical scrutiny. However, demand of housing coupled with the pace and scale of urbanization in Asian countries have triggered an unprecedented real estate surge, which translates into accelerated energy consumption during the making of the buildings itself. Thus, the cumulative effect of the embodied energy no longer remains a benign issue in the broader context of energy sustainability and optimization in the building sector. With this in view, this paper presents a base-line study of embodied energy assessment of some real estate case-studies, comprising of multi-storied residential apartments of steel reinforced cement concrete frame structure in and around the city of Calcutta (now Kolkata) in India. The buildings selected are at different life-cycle stages and the results thus obtained appear to be potential inputs for future policy actions.

**Key words:** Urban buildings, materials, construction, embodied energy, sustainability

# 1. Introduction

The Confederation of Indian Industry (CII) acknowledges that the “*construction industry is one of the largest economic activities contributing to India's development. India has been witnessing tremendous growth in building and construction sector for the past 5 years. With the increase in income levels, there are also changes in the life styles of various sections of the society. While this provides ample opportunities, it is also putting enormous pressure on resources - like energy, water, materials etc. The stakeholders of the industry have a vital role to play in preserving the environment.*” While India ranks eleventh among the top fifteen countries in construction spending (billion US dollars), the construction growth rate is substantial and has a positive effect on the economy.

Forecasts prepared by World Construction Review/Output (2011) predicts China to grow 9.2% annually in 2012 and India to grow at 7.9% (with Brazil not far behind), while the global average annual growth, including the U.S., was forecast at 4.8%, with Western Europe (3.9%) anticipated to lag behind worldwide average growth. In addition, much of this developing world construction work is expected to be new construction rather than the more demanding and often less productive upgrading and maintenance work that characterize a large share of the construction market in the U.S., Canada, Western Europe and Japan.

Interestingly, the same construction sector is known to be having highly adverse effect on the environment, with 40% global energy use and one-third of global greenhouse gas emissions in both developed and developing nations. Currently India is rated as the 6th largest contributor of CO<sub>2</sub> emissions and the energy sector is its largest contributor standing at 55%. Again, 52% of this energy is expended in the building sector with an estimated 85% as operational while 15% as embodied.

UNEP's Buildings and Climate Change document (UNEP DTIE 2009) stresses the need of prioritizing the building sector by the Governments in their climate change strategies and design appropriate policy instruments for reducing emissions from new and existing buildings. Since the developed countries already have matured building stock as opposed to the rapidly urbanizing nations characterized by new upcoming constructions, policy approach for these two reverse phenomena is also fundamentally different. In the latter case, UNEP recommends policies to incorporate energy and greenhouse gas emission considerations into the feasibility and design stages of buildings. However, since buildings have long life-span, the operational energy had been the focus of all deliberations, strategies and policies so far. In this backdrop, this paper investigates the energy realities of the contemporary urban multi-storied residential buildings in the warm-humid climatic zone of eastern India, with a particular focus on the embodied energy of the building and argues in favour of formulating specific energy strategies towards this from energy sustainability perspectives.

## 1.1 Framework and methodology

Studies in built environment can be very complex as a building, in general, is a product of multi-criteria process. It needs to respond to the terrain as well as local site conditions, to address the essentialities of intended usage & users, takes full shape though a time-energy-money involving process and like living beings, has different life-cycle stages. In India, with

five different climatic zones (hot-dry, warm-humid, composite, temperate and cold), the climatic conditions are varied. The following table outlines the broad gamut of different factors affecting the building-energy relationship in the context of the above discussions:

*Table 1: Factors influencing energy consumption in buildings*

<i>Climate types</i>	<i>Building types (based on use)</i>	<i>Construction types</i>	<i>Building life-cycle stages</i>	<i>Life-cycle energy involvement</i>
<i>Hot-dry</i>	<i>Residential</i>	<i>Load-bearing masonry</i>	<i>Construction at site</i>	<i>Energy embedded in building materials</i>
<i>Warm-humid</i>	<i>Commercial</i>	<i>RCC frame structure</i>		<i>Energy expended in transporting these materials from production point to site (or grey energy)</i>
<i>Composite</i>	<i>Institutional</i>	<i>Structural Steel</i>		<i>Energy expended in actual construction (or induced energy)</i>
<i>Temperate</i>	<i>Industrial</i>	<i>Others</i>	<i>Operation</i>	<i>Collectively: Embodied Energy of the building</i>
<i>Cold</i>	<i>Others</i>		<i>Demolition and recycling</i>	<i>Energy used by occupants for comfortable living</i>
				<i>Energy expended to pull down a building after its useful life span</i>

The sum of the energy components at the initial life-cycle stage of the building, i.e. before the building turns operational, will give a measure of the energy that has already been locked or embedded within the building's fabric. This may be expressed in terms of electrical energy and can be translated into its corresponding carbon emission based on the consumption of fossil fuel. This result, when divided by the total built-up area of the building, gives a measure of the Embodied Energy (EE) per unit area of the building as well as the Capital Carbon Foot-print (CCF) i.e. emission per unit area of the building. Embodied energy foot-prints assessed for multiple case studies can give an idea of the constructional energy consumption pattern of urban multi-storied residential buildings.

In this particular research, energy consumed in construction has been assessed for three similar case studies, which are located in and around the city of Kolkata in eastern India and are at different stages of development. Thus, the main objective of this paper is to map the EE of high-rise urban residential buildings in the hot-humid climatic zone of the Indian sub-continent and explore the rationale for policy intervention in this particular building-energy sub-sector.

The study followed the Life-Cycle (LCA) approach to buildings and applied a simple methodology: i. Identification of an appropriate case-study fitting the criteria of scale, height, built-up area and type of construction ii. Data collection covering quantity survey of major materials used in the building and the energy bills during the construction period iii. Assessment of energy embedded in the body of the building in the form of materials from the quantity survey and iv. Assessment of electrical energy used during construction from the energy bills.

Field visit and data collection from the site office was carried out though it was observed that record keeping and documentation by building industry is still inadequate and difficult to access. The data presented in this research report has been supplied by the respective project offices in a prescribed format prepared by the author. It is to be noted that the estimate and assessments based on these data would be a conservative one.

## 1.2 Selection of Case-studies

Three case studies were selected in the city and surroundings of Kolkata based on the rationale followed by State Expert Appraisal Committee (SAEC) constituted by Ministry of Environment and Forests (MoEF) for preparing its Guidelines for Rain Water Harvesting for ‘*large construction projects with built up area equal to or more than 20,000 SQM*’, in which it has further categorized buildings based on their number of storeys as: 10 to 15 storied buildings & above, six to ten storey, three to five storey and less than 3-storied.

Hence, the selection criteria for the case studies were:

- i. Built up area more than 20,000 Sq m
- ii. Number of storey more than ten
- iii. Preferably comprising of more than one tower block
- iv. No. of flats more than 100
- v. Located in and around Kolkata city

A brief comprehensive profile of selected case studies is presented in Table 2 for easy comprehension.

*Table 2: Comprehensive profile of selected Case Studies*

<i>Sl. No.</i>	<i>Criteria</i>	<i>Case Study 01</i>	<i>Case Study 02</i>	<i>Case Study 03</i>
1.	<i>Built-up area (Sq m)</i>	310173.22	20368	37967.4
2.	<i>No. of storeys</i>	<i>Basement + Ground + Thirty five</i>	<i>Ground + Twelve</i>	<i>Basement + Ground + Eighteen</i>
3.	<i>No. of towers</i>	<i>Four</i>	<i>Three</i>	<i>Three</i>
4.	<i>Total number of apartments</i>	<i>1600 (12 flats/floor)</i>	<i>210 (6 flats/floor)</i>	<i>216 (4 flats/floor)</i>
5.	<i>Location</i>	<i>South of Kolkata</i>	<i>Hooghly District, North-West Kolkata</i>	<i>East of Kolkata</i>
6.	<i>Construction type</i>	<i>R.C.C. frame &amp; R.C.C. shear walls</i>	<i>R.C.C. frame &amp; brick walls</i>	<i>R.C.C. frame &amp; brick walls</i>

### 1.3 Boundary conditions of the study

In this study, however, out of the myriad materials normally used in a building, the evaluation has been kept limited to those having the largest stake in its construction. Since the embodied energy of building materials varies from one country to another, depending on the sources of energy used for manufacturing and climatic condition of that country, availability of data on embodied energy of building materials in the Indian context is also limited. This is another reason for keeping the list of materials restricted to a major few. A previous study on embodied energy of smaller buildings with about 300- 400 Sq m built area in eastern India (Bardhan *et al*, 2010) had earlier estimated the energy consumed in transportation of building materials to be only 1.85 % of the embodied energy of the materials while that consumed during actual construction is lesser - a mere 0.06 % of the same. Together, these account for only 1.91% of the embodied energy of the materials. For a larger building, the figures lowered to 0.52 % and 0.02 % respectively. However, since the said study was conducted for buildings located 140 Km from the nearest metropolis of Kolkata, the energy expended under transportation head (grey energy) was much more than that for erection (induced energy). In contrary to this, urban buildings require more induced energy than grey energy, since built areas are not only considerably higher but also have greater electro-mechanical dependence. Hence the energy involved in transporting the building materials from supply source to site was not considered in this particular investigation as the case studies are located within the city and the materials are already in stock with the building material suppliers irrespective of any particular construction. Reddy *et al* (2003) had estimated that when transportation energy is compared with respective production energy, it is negligible for high energy materials like cement and steel, though it is 4-8% in case of bricks and 400-800% in case of aggregates. Thus, while acknowledging that the grey energy component may have significant contribution in many cases, it was believed that this would be negligible with respect to the present study. The embodied energy coefficients of different materials used to calculate the material energy were based on recent studies in India and New Zealand (2010). The induced energy component has been considered here by way of energy bills paid by the project site during the actual construction, which was for a substantial period and access to these bills were also fairly easy.

## 2. Discussions and Results

The study was conducted over a period of two and a half years and as mentioned earlier, data was collected in a simple prescribed format by actual field visits. In case of the first and the third case study, relevant facts and figures had to be extracted from the project documents provided by the project office, which were mainly energy bills, certain bills of quantities and quantity survey of materials. Floor plans, material specifications, site photographs and basic statistics were obtained from the respective web-sites that are in the public domain. Information for the second case study was supplied by the project site in the format and relatively more accurate as data collection was documented along-side actual progress of construction work at site.

## 2.1 Case-study- 01

This project is a mixed-use development led by residential use and is popular for being one of the tallest residential building projects in and around Kolkata. Its four nos. 35-storey (above ground) residential tower blocks are set in a site of more than 30 acres in a residential neighbourhood of the city. The tower blocks comprise of 1600 nos. of flats and a total built-up area of 310173.22 Sq m. This project was constructed during the period 2002 - 2009 and is primarily reinforced cement concrete construction with other materials used being glass, steel, Aluminium, timber/plywood, natural stones like granite/ marble and ceramic/vitrified tiles. Ancillary materials include those needed for engineering services like PVC - electrical switch boxes and cable-covers, Copper cables, other metals like plumbing fittings, hardware, nails etc. The structure is primarily consisted of:

- Pile Foundation
- R.C.C. Frame structure
- Brick work
  - External 200 mm
  - Internal 100 mm

The detailed calculations revealed that the material energy of all the residential blocks by virtue of the major materials is in the range of  $2.9 \times 10^6$  Giga Joules (GJ), which comes to around 9.36 GJ/ Sq m of built-up area with an emission component of 684 x 1000 ton of CO<sub>2</sub>. The energy spent for building erection was found to be 0.2 GJ/Sq m and thus, the total embodied energy per unit area of this project works out to be around 9.56 GJ/Sq m. It is important to repeat here that this is, by all means, a conservative estimate approach and represents a much lower figure than the actual. Further investigation was made to understand the contribution of individual construction materials to their collective energy head and quite understandably, steel (46.9%) and cement (41.6%) topped the list, together contributing to 88.5% of the material energy. It is interesting to note that the multi-family steel reinforced concrete (SRC) houses studied by Suzuki *et al* (1995) found the embodied energy to be 8-10 GJ, which is at par to the findings of the current study.

## 2.2 Case-study- 02

The second case study is located in the Hooghly district of West Bengal in a site of 12.3 acres and comprising of 12 tower blocks, each of Ground and twelve floors, out of which three towers are coming up in the first phase. The number of dwelling units for the first phase is 210, with super built up area of apartments ranging between 77- 109 Sq m (i.e. 826-1173 sq ft). The area of a typical floor of each tower block is 536 Sq m. The total typical area of a set of three towers is, therefore, 1608 Sq m. This area is also the total plinth area of the three towers considered collectively. The construction comprises of RCC frame structure with brickwork for walls. Finishing materials include vitrified tiles for habitable rooms while anti-skid ceramic tiles and glazed tiles for kitchen and toilet floors and walls respectively. Wall finish is proposed to be Plaster of Paris. Sal wood frames and flush doors for all rooms other than toilet and PVC door for toilet have been proposed while windows will be Aluminium or UPVC. Granite and

Stainless Steel are other materials that are to be used in the interiors. The pile foundation work (with a 26.0 M depth from cut-off level) for three towers began in the first quarter of 2011 and was already been completed in five months time. This paper has assessed the embodied energy for the foundation work only.

With the detailed quantity survey of materials obtained for this case study, it was interesting to find possibilities of applying both top-down and bottom-up approaches for calculating the EE attributed by materials. The top-down approach involves using the concrete volume data while the bottom-up approach uses the break-up quantities of its constituent materials i.e. cement, sand and stone chips separately, while brick and steel remain common for both. Since concrete quantity was available in volume, it was translated in to mass by multiplying with its normal density, considered 2300 Kg/Cu m. The result is 4.83 GJ/Sq m. In contrast, the bottom-up approach with the constituent material break-up results in 1.36 GJ/Sq m. Interestingly, it was not only the total EE that decreased substantially, the share of the materials also undergo changed proportions. In the former approach, concrete has around 85% share, while the latter approach records around 46% share covering the combined EE of cement, sand and stone chips. The disparity of the results in the EE value for the two approaches (4.83 GJ/Sq m and 1.35 GJ/Sq m) is presumably due to the contribution of machine energy in converting the constituent materials into concrete. Since energy consumed by machines were separately considered, the lower value obtained through the bottom-up approach is being considered for the purpose of this research. Notably, the steel and cement share remain almost same as the first case study at 47% and 42% respectively. The other materials, too, retain similar share.

The two alternative approaches were also applied for assessing the induced energy. Both the methods are primarily concerned with the electrical energy used during the site construction work. The top-down approach considered the connected electrical load, which in this case was one no. 43.75 KVA meter and it was considered that 90% of this electric load was used during the construction period. The bottom-up approach takes account of the energy bills of the site and were analyzed to obtain the actual power consumption over the entire construction period. Both the approaches yielded approximately the same result - 0.01 GJ/Sq m of building area.

Thus, total embodied energy of the case study 02 for its pile foundation stage is 1.37 GJ/Sq m, out of which 99% is attributed by materials and the rest 1% being the induced energy.

### **2.3 Case-study- 03**

This project consists of three categories of housing meant for three types of income groups viz. High Income Group or HIG (188 tenements), Middle Income Group or MIG (152 tenements) and Low Income Group or LIG (58 tenements). The mixed housing is spread over a five acre site.

Site sources mention that a batching plant with concrete pump and transit mixer of 40 kVA power rating and a builder's hoist were used for 2.5 hours/day and 3 hours per day respectively, with the former in use for 15 days a month. The batching plant worked for a total of 1900 hours

producing 12 Cum. of concrete per hour. The power for running this batching plant was supplied by the Diesel Generator of 62.5 kVA and in the process, contributed to 70% of the electrical energy used for the construction of the HIG section. Thus, the following inferences have been directly drawn from the above data:

- Total concrete volume used through batching plant is (12 Cum/hr x 1900 hrs) or 22800 Cum and
- Electrical energy required for producing this volume is  $62.5 \times 1900 = 118750$  kWh. However, it is to be noted that this qualifies to be part of the construction period energy.

Fortunately for the current research, this project was found to be more methodical in maintaining resource database and materials used for the project was found to have been recorded separately for the pile foundation as well as for the rest of the structure covering basement, ground and superstructure. Embodied Energy of the materials per unit built-up area of the building for foundation stage was found to be 2.41GJ/Sq m.

Material energy for the superstructure was assessed to be 6.62 GJ/Sq m. Considering the pile foundation stage along-with the above, the material energy of this case study works out to be (2.41 + 6.62) or 9.03 GJ/Sq m with steel (61.66 %) and cement concrete (34.9 %) being the bulk contributors.

Induced energy was calculated on the basis of construction period energy bills and energy consumed by the Diesel Generator in producing the required volume of concrete and together, the energy consumed during building erection was found to be 0.05 GJ/Sq m. The total EE of the case study 03 as a sum of EE of materials and induced energy is 9.08 GJ/Sq m, out of which 99.4 % is attributed by materials and the rest 0.6 % incurred during construction.

### **3. Conclusions**

Overall, it is interesting to note that the findings are not too different and present a reasonably cognizable pattern of energy consumption for a particular size and scale of buildings similar in use (in this case, residential), construction type (in this case, RCC frame structure) and for a particular climatic zone (in this case, warm-humid). To conclude, the embodied energy estimates were found to be comparable for urban multi-storeyed residential buildings in Kolkata with height above ten storeys and built-up area more than 20,000 Sq m, as evident from table 3 as well as figure 1, showing a comprehensive and comparative EE profile of the three case studies. However, further studies with similar case-study criteria across geographical boundaries and climatic zones are required to establish these findings as actual facts to base policy decisions on. In addition, the scope of study as depicted in table 1 need to be expanded to cover the entire gamut of parameters and include varying typologies of buildings to understand the environmental implications of the choices that architects, builders and engineers make during the design and construction of buildings.



Table 3: Comprehensive EE profile of the Case Studies

Sl. No.	Criteria	Case Study 01	Case Study 02	Case Study 03
1.	Built-up area (Sq m)	310173.22	20368	37967.4
2.	Construction type	R.C.C. frame & R.C.C. shear walls	R.C.C. frame & brick walls	R.C.C. frame & brick walls
3.	Embodied Energy	9.56 GJ/Sq m	1.37 GJ/Sq m (for foundation stage only)	2.41 GJ/Sq m (foundation stage) & 9.08 GJ/Sq m total.

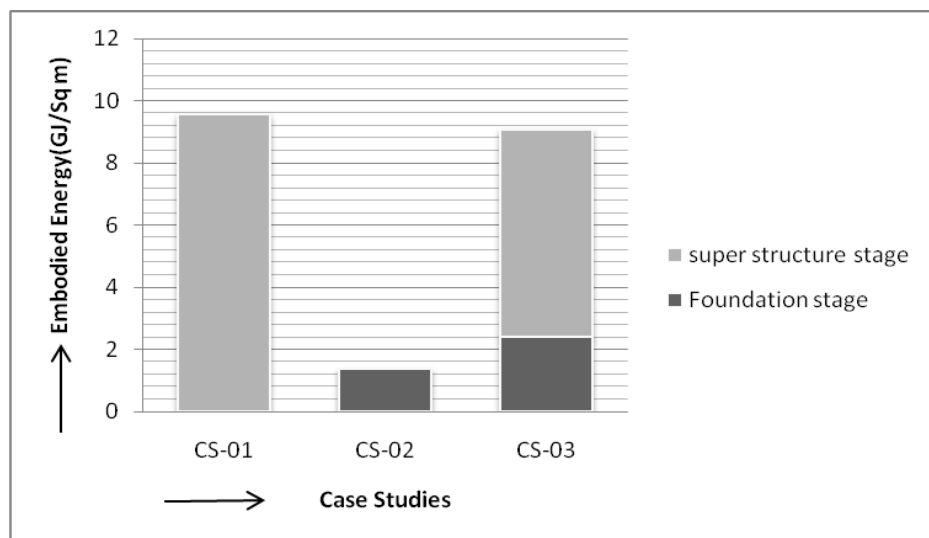
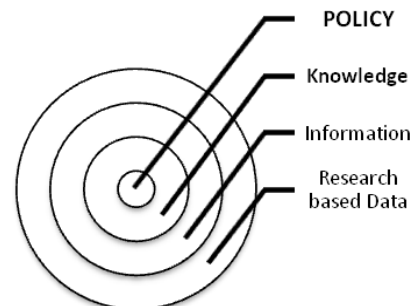


Figure 1: Comparative Embodied Energy foot-prints of the case studies

It is expected that this investigation backed with field data has been able to shed light on the energy implications of contemporary constructions and form a knowledge base on pre-operational and under construction building-energy connection. Further research involving more case studies across different climatic zones and building typologies need to be undertaken to consolidate this sector specific knowledge, based on which the current energy consumption practice adopted by construction industries can be regulated by appropriate policy decisions.



It has been projected that by 2030 building sector in India will grow nearly by five times and residential sub-sector more than four times (Anand 2012). Residential buildings are expected to

occupy about 70% of the total building stock estimated at 69283 million Sq ft of built-up area. Thus, the embodied energy and the captive emission contributed by this huge upcoming building stock shall no longer remain ignorable from energy sustainability perspectives. UNEP DTIE (2009) has observed that if no action is taken at present, green house gas emissions from building sector will double in the next twenty years. It also notes that proven policies, technologies and knowledge already exist to achieve such reduction. Hence, if climate action strategies are to look into mitigating GHG emission from building sector, it has to take the embodied energy and captive emissions into account as well. With a focus on the building operational energy, it has identified five main policy targets to meet the low carbon growth targets. Of these, one that promotes substitution of fossil fuels with renewable sources of energy should also be oriented towards the pre-operational emission mitigation needs in under-construction buildings, which has high potential in most part of India. With availability of adequate technology and knowledge, it is only a wait for appropriate policy tools that can drive mass-scale regional implementation.

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