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# INVESTIGATION OF EMBODIED ENERGY CONTENT OF MATERIALS IN A BUILDING CONSTRUCTION PROJECT

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***Abstract*: –** In the modern times, due to urbanization, there is a rising demand for energy intensive activities around the globe. Construction Industry itself is accountable for approximately 36% of the total energy consumption. This calls for serious attempts to check, limit and reduce the indiscriminate energy consumption in Construction Projects. Achieving Energy Efficiency in Construction is one of the core concerns around the world. Construction Projects consume energy on a massive scale during Construction as well as Operation Phases in the various construction activities like transportation, manufacturing, labor and machinery. This Energy is termed as Embodied Energy and is a major contributing factor to release of $CO_2$ emissions ultimately leading to Global Climate Change. As Construction Industry has been wholly reliant on Fossil Fuel Consumption with extremely limited possibilities for the use of Renewable Energies, there is a pressing need to understand the sources of energy consumption, identify the types of energy and try to limit or possibly reduce the consumption of the same at various levels of projects.
This paper presents a method to quantify the Embodied Energy Content in four major Building Activities like Concreting, CLC Blockwork, Plastering, and Reinforcement Steel. Another goal of this study is to signify the impact and effect of Embodied Energy on the energy efficiency of a Building Construction Project.

***Index Terms - Energy Consumption, Construction, Embodied Energy*.**

## I. Introduction

The advent of urbanization and modernization have created large scale concerns due to indiscriminate use of energy worldwide. According to the data provided by International Energy Agency (IEA), the world's Total Primary Energy Supply (TPES) for 2017 reached an all-time high at 13651 Million Tones of Coal Equivalent (MTCE), releasing a massive 32,316 Million Tones of energy related $CO_2$ emissions in the atmosphere [1]. Out of this, building and building construction sectors combined accounted for 36% of worldwide final energy consumption and were responsible for 40% of total direct and indirect $CO_2$ emissions [2].

In Residential Buildings, the Embodied Energy may range from 30% to as high as 100% of total Life Cycle Energy Consumption. [6]

Hence, there is a pressing need to work towards quantifying the energy consumption in Building Construction Projects and attempting to reduce the same.

In order to identify, quantify and attempt to control and reduce the huge energy consumption in a construction project, we need to first understand the type of energy consumed and its sources.

Hence, this research aims to study the concept of embodied energy, its effects and impacts on energy efficiency of a construction project. The key objectives of this research study are:

1. Present a method to quantify Embodied Energy of Materials during Construction Phase.
2. Highlight the effects and impacts of Embodied on energy efficiency of a construction project.

## II. Literature Review

Various literature has been referred to for the purpose of this research and have been explained herewith.
IEA, Key World Energy Statistics [1], have compiled the Global Energy Data and published key energy statistics which are updated every year. Their study reveals crucial information about Energy sources, production, consumption and reserves of the world by region. This proves to be very useful for Research Scholars and Governments and policy makers of the world.

IEA, Energy Technology Perspectives, 2017 [2], is a compiled report of current global energy scenario, trends and future recommendations for a cleaner environment for global policy makers.

Jones [3], https://www.igbc.ie/resources/inventory-of-carbon-and-energy/ developed a comprehensive database of embodied energy and embodied carbon of materials. *Inventory of Carbon and Energy (ICE)* is considered to be an international benchmark for all industries. It contains the embodied energy coefficients of various industrial raw materials and encompasses an exhaustive list of over 200 materials.

Co-Funded by the European Union [4], International finance corporation (IFC) have developed a database of environmental impacts of compressive set of materials used in construction within India and compiled a report on the same named as India construction material database of embodied energy and global warming potential methodology report.

Zhang et al., [5] tried to examine the total energy consumption in delivering construction projects with the help of BIM technology and ran several simulation studies for the same. They created a BIM model in *Revit* and also created a *plugin* to link BIM data with external database. Finally, they also used energy simulation software *Simphony* to analyse the potential to reduce energy consumption. They found that embodied energy in construction materials accounts for 90% of the total energy utilization of the building. However, their study used simple simulation models and lacked professional effectiveness.

Richard Haynes[6] detailed the important contribution of Embodied Energy to global greenhouse gas emissions ans also explained a comprehensive and repeatable approach to estimating the embodied energy in new developments with the help of a case study.

Nizam et al. [7] presented a structure to evaluate the embodied energy content inside the native BIM environment. They had deployed *Autodesk Revit 2016* as the BIM authoring tool and developed a *plugin* to integrate the embodied energy data from external database into the model and hence automate the energy estimation process.

Shadram et al. [8] proposed a framework for assessing the embodied energy in a building material supply chain and evaluated the same by the use of a prototype in a case study. The prototype of their proposed framework uses *Autodesk Revit* as the BIM authoring tool, *Feature Manipulation Engine (FME)* as the spatial ETL tool, *Google Maps (GM)* API as the map web service API, and *Power Pivot* – which is an add-in to *Microsoft Excel* – for implementing the rest parts of the proposed framework like setting up the database model and assessment of the embodied energy.

S. Balubaid et al.[9] conducted comparative analysis of the Malaysian Construction systems with the historical literature and also explored the energy efficiency in building construction.

Rock et al. [10] proposed a methodology utilizing BIM to assess an extensive range of construction options and their embodied environmental impact. This will support decision making in the early design phase. They used *Autodesk Revit* to develop the BIM model, *MS Excel* to create an aggregated Life Cycle Analysis (LCA) database and the visual scripting software is *Autodesk Dynamo* for establishing an automated link between the other two.

Davies et al. [11] studied and demonstrated practical difficulties and opportunities for delivering improved initial embodied energy efficiency in a construction project. They found that material phase impacts represented a significant proportion (95.1%) of the total initial embodied energy consumption. They explored the practices followed by contractors on-site and improved them in an attempt to address the initial embodied energy issue.

Autodesk White Paper [12] One of the major industry players in the engineering software domain and pioneering developers of BIM software environment, Autodesk, have published this White Paper on BIM technology, to explain the wonderful features of BIM and how it enables the AEC industry to achieve optimal solution to their existing challenges and also helps the professionals in their endeavour to avoid any future issues
in advance.

Guan et al. [13] proposed a method to analyze the energy preservation of high rise buildings based on BIM technology. They found that BIM technology can be used effectively to optimize building design and hence improve the Green Building performance & decrease building energy consumption. Although they also found that while transferring the BIM data into environmental energy analysis tool, there is loss of some data significant to the analysis process, hence there is a need to solve this issue.

From the literature review conducted herein, it was found that previous researchers have conducted extensive studies on energy consumption in construction during the operational phase, but the main focus of this study lies on presenting a method to determine embodied energy values of materials in construction. The conclusions of the literature review study have been summarized as below:

1. Energy consumption in general and especially in the construction industry is a major challenge faced by global policymakers. Hence, major studies have been conducted by researchers till now in an attempt to reduce the energy usage on construction projects.
2. Most of the studies conducted till now have focused majorly on energy saving during the occupational phase only and very little attention has been paid to reducing the embodied content of materials and construction activities during the construction phase.
3. The existing research developed and used complex methodologies for computing the embodied energy and that too majorly during the operational phases of the buildings only.

Hence, as a complement to the existing research done, there is a need to develop a practically simple to follow process of quantifying embodied energy during the construction phase of a building.

## III. METHODOLOGY

**Flow of the study: -** All in all, the entire process flow will be divided in the following steps:

**Step#1:** The study starts with the review of energy usage pattern in construction.
**Step#2:** The concept of Embodied Energy is explained with its consumption pattern in construction.
**Step#3:** Various stages of Embodied Energy Consumption are listed
**Step#4:** Data collection of the compiled database of Embodied Energies at International & National level
**Step#4:** The effects and impacts of Embodied Energy on Energy Efficiency of a Construction Project are studied.
**Step#5:** A simple method to find the Embodied Energy of Construction materials in a Project is presented.

**ENERGY USAGE IN CONSTRUCTION:**

Construction is a time intensive and resource intensive affair. Large amounts of energy are used in construction projects. Energy in construction is used in many forms at various stages, components of construction. Till date we are dependent on fossil fuels as our major energy source in construction. The total energy consumed in a building project has become a major global concern due to depleting resources as well as due to the negative environmental impacts in the form of GHG (Green House Gases) emissions. This has an adverse effect on the Energy Efficiency of the Buildings.

The energy is not only used during operation of the building but in the pre-construction phases as well. In order to be able to effectively achieve a high Energy Efficiency in building project, we first need to identify the sources, quantify the energy consumption and then attempt to reduce the consumption. For this a holistic approach needs to be adopted, which can be enabled by considering the energy consumed during the entire life cycle of the construction project.

The entire Life cycle of Construction Project comprises of the following stages:

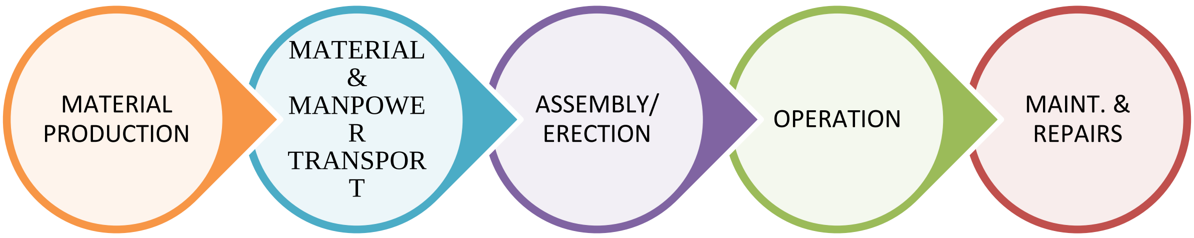


Fig. 1 Life Cycle Energy Consumption of Materials in Construction Project

As shown above, the Life cycle Energy in buildings comprises of two major components namely Embodied Energy (EE) and Operational Energy (OE).

**EMBODIED ENERGY:**

This is the energy consumed or spent in the sequence of extracting, processing, transporting and installing the materials in a construction project.

**OPERATONAL ENERGY:**

Operational Energy is the one spent during the occupational phase of the building and includes the energy consumed in operating, maintaining and repairing of the materials used in the construction project.

Various researchers have developed and used to measure embodied energy of buildings[9] like:

(a.) Input-Output Analysis
(b.) Top-down method
(c.) Hybrid Approaches

**DATA COLLECTION:**

TWO databases were selected for the purpose of acquiring the values of embodied energy coefficients of different construction materials:

(1.) *Inventory of Carbon and Energy (ICE)* is considered to be an international benchmark for all industries. It contains the embodied energy coefficients of various industrial materials. It contains an exhaustive list of over 200 construction materials.

(2.) *India Construction Materials Database for Embodied Energy and Global warming Potential* (*ICMDEEGWP*) which is an embodied energy database prepared by the International Finance Corporation (a World Bank Initiative) with support from the European Union, especially prepared for Indian conditions. This database is used to collect the embodied energy coefficients data in this project.

Out of the above two, the ***India Construction Materials Database of Embodied Energy and Global Warming Potential*** published by International Finance Corporation (IFC) is selected for the purpose of this study, being relevant to Indian conditions. A sample excerpt from the same is presented herewith (with due permission of IFC).

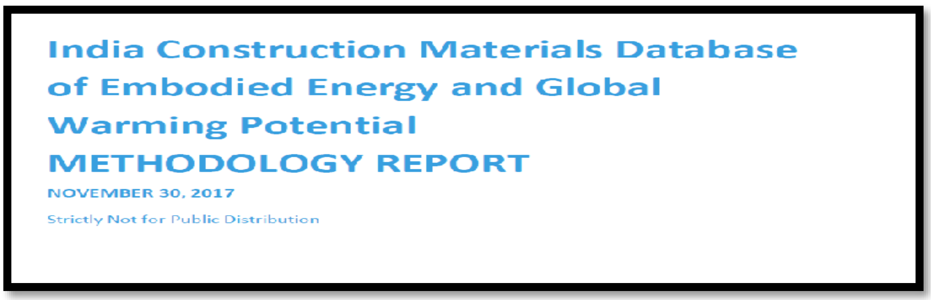
India Construction Materials Database of Embodied Energy and Global Warming Potential
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Figure 2 - IFC screenshot.

ANNEX A: EMBODIED ENERGY AND GLOBAL WARMING POTENTIAL RESULTS

Table 14: below presents the embodied energy and global warming potential results for the materials included in the India Construction Materials Database. Embodied energy results represent the total primary energy demand from renewable and non-renewable resources based on the net calorific value (lower heating value) and excluding any renewable feedstock energy. Global warming potential is calculated using the IPCC AR5 characterization factors over a 100-year time horizon and including biogenic carbon emissions - IPCC AR5 GWP100, including biogenic carbon (IPCC, 2014).

**Table 14: Embodied energy and global warming potential results for India Construction Materials Database**

| Material Name | Embodied Energy (MJ) | GWP (kg $CO_2$ eq.) |
|---|---|---|
| Adhesive for parquet | 130 | 6.7 |
| Aggregate (mixed gravel/crushed stone) | 0.11 | 0.0090 |
| Aircrete (autoclaved aerated concrete) | 3.7 | 0.50 |
| Air-dried sawn timber | 4.1 | -1.3 |
| Aluminum extruded profile | 330 | 33 |
| Aluminum extruded profile (window frame) | 280 | 26 |
| Aluminum ingot | 310 | 31 |
| Aluminum profiled cladding | 360 | 35 |
| Aluminum sheet | 330 | 32 |

Figure 3 - Annex A: Embodied Energy Coefficient

**Case Study:**

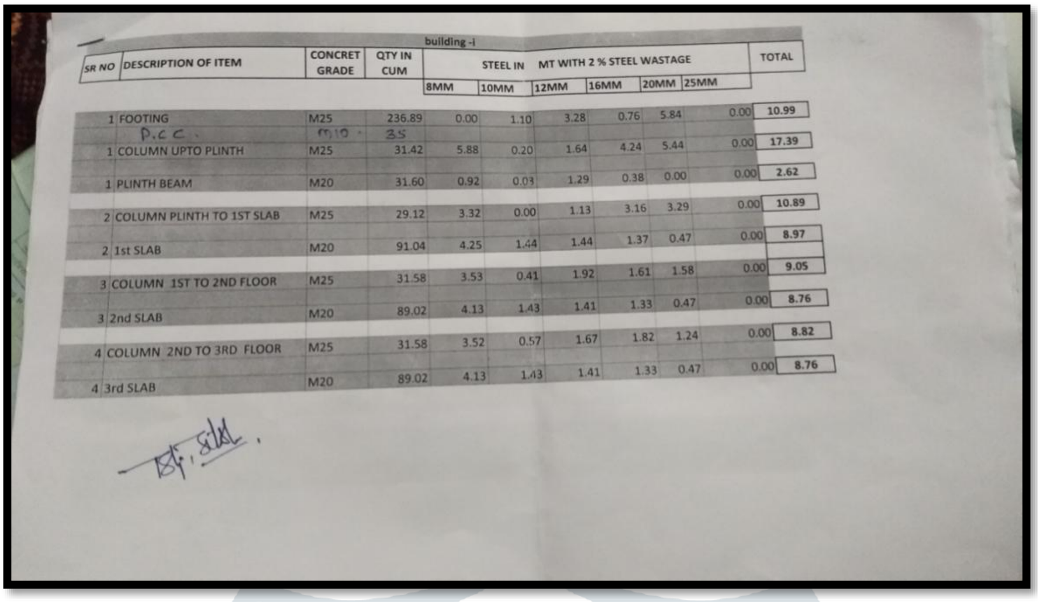
The case study considered for the present work is an ongoing project of Jaikumar Construction, one of the renowned developers in the city of Nasik, M.S. This is a high-rise residential mass-housing project comprising of a total of Five Construction Phases. Out of the total Five Phases, Three Phases have been already handed over. The Fourth phase is about 90 percent complete, while the last phase is under construction. Masonry work is done in Autoclaved Aerated Concrete (AAC)Blocks.

Figure 4 - Under–construction Multi-Storey Building at Parksyde Homes

*Site details:*

1. Name Of Company : Jaikumar Construction LLP. Nasik
2. Project Name : Parksyde Homes
3. Owner : Mr. Gopal Atal and Mr. Manoj Tibriwala
4. Location : Parksyde Homes, Hanuman Nagar, Opp. Rasbihari High School, Adgaon, Nasik.
5. Area Of Site : 25 acres
6. Type of Building : High-Rise Structure
7. Type of Structure : G+ 15 RCC Constructions
8. RCC consultants : J.W. Consultants
9. Architect name : Mr. Umesh Bagul

*Materials Quantities:*



building -I

| SR NO | DESCRIPTION OF ITEM | CONCRET GRADE | QTY IN CUM | STEEL IN MT WITH 2 % STEEL WASTAGE 8MM | 10MM | 12MM | 16MM | 20MM | 25MM | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FOOTING | M25 | 236.89 | 0.00 | 1.10 | 3.28 | 0.76 | 5.84 | | 0.00 | 10.99 |
| | P.C.C. | M10 | 35 | | | | | | | | |
| 1 | COLUMN UPTO PLINTH | M25 | 31.42 | 5.88 | 0.20 | 1.64 | 4.24 | 5.44 | | 0.00 | 17.39 |
| 1 | PLINTH BEAM | M20 | 31.60 | 0.92 | 0.03 | 1.29 | 0.38 | 0.00 | | 0.00 | 2.62 |
| 2 | COLUMN PLINTH TO 1ST SLAB | M25 | 29.12 | 3.32 | 0.00 | 1.13 | 3.16 | 3.29 | | 0.00 | 10.89 |
| 2 | 1st SLAB | M20 | 91.04 | 4.25 | 1.44 | 1.44 | 1.37 | 0.47 | | 0.00 | 8.97 |
| 3 | COLUMN 1ST TO 2ND FLOOR | M25 | 31.58 | 3.53 | 0.41 | 1.92 | 1.61 | 1.58 | | 0.00 | 9.05 |
| 3 | 2nd SLAB | M20 | 89.02 | 4.13 | 1.43 | 1.41 | 1.33 | 0.47 | | 0.00 | 8.76 |
| 4 | COLUMN 2ND TO 3RD FLOOR | M25 | 31.58 | 3.52 | 0.57 | 1.67 | 1.82 | 1.24 | | 0.00 | 8.82 |
| 4 | 3rd SLAB | M20 | 89.02 | 4.13 | 1.43 | 1.41 | 1.33 | 0.47 | | 0.00 | 8.76 |

Figure 5 - Actual Material Consumption Data obtained from Site

The above picture shows actual material consumption data for RCC components for one of the 15 storey Buildings of the project and comprises 3-BHK Flats. On the account of lack of sufficient data, several assumptions had to be made to derive the values of material consumption for the entire building.
The data obtained was in crude form and unsuitable to be used as received for any calculation purpose. Hence, there was a need to convert the same into unified units.
Next, the material consumption data obtained as above was converted in unified unit (Kg) by using suitable conversion factors from their unit weights.

## IV. Analysis, Results and Discussion

### Material Consumption Data Analysis

The raw data about material consumption as obtained from site interviews was very crude and incomplete. The following tables show the raw data first converted into standard metric units and then converted into unified unit of "Kg" by using various standard conversion factors. This was necessary for the calculation of Embodied Energies, since the Embodied energy Coefficients of various materials are notified in the form of MJ per Unit Mass. (MJ/kg)

Table No. 1 Line-Item Quantities Data for single 3 BHK building

| Sr. No. | Work Item | Quantity | Unit |
|---|---|---|---|
| 1. | Concreting | 2497.78 | Cu.M |
| 2. | Plastering | 2772 | Sq.M |
| 3. | Blockwork | 7186.95 | Cu.M |
| 4. | Reinforcement | 348.04 | M.T |

Table No-2 On-site Material Consumption Data (Converted in Metric Units)

| Material Consumption (Converted in Metric Units) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sr. No. | Work Item | Quantity | Unit | Cement | F.A (A.S) | C.A (20 Mm) | R/F Steel | AAC Blocks |
| | | | | (Bags) | (Cum) | (Cum) | (M.T) | (No.) |
| 1. | Concreting (1:2.8:2.94) | 2497.78 | Cum | 17859 | 1423.73 | 1623.56 | | |
| 2. | Plastering | 2772 | Sq.M | 277.2 | 26.65 | | | |
| 3. | Blockwork | | Sq.M | | | | | |
| A. | 110 Mm thick (630 X 230 X 100) | 3052.5 | Sq.M | | | | | 21300 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| B. | 150 Mm thick (630 X 230 X 150) | 4134.45 | Sq.M | | | | | 27900 |
| 4. | Reinforcement | 348.04 | M.T | | | | 351.52 | |
| | Total Quantity | | | 18136 | 1450 | 1624 | | 49200 |

Table No-3 On-site Material Consumption Data (Converted in Kg)

| Material Consumption (Converted in Kg) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sr. No. | Work Item | Quantity | Unit | Cement | F.A (A.S) | C.A (20 Mm) | R/F Steel | AAC Block |
| | | | | (Kg) | (Kg) | (Kg) | (M.T) | (Kg) |
| 1 | Concreting (1:2.8:2.94) | 2497.78 | Cum | 892956 | 2508620 | 2630162 | | |
| 2 | Plastering | 2772 | Sq.M | 13860 | 46957.30 | | | |
| 3 | Blockwork | | Sq.M | | | | | |
| | 110 Mm thick (630 X 230 X 100) | 3052.5 | Sq.M | | | | | 185182.2 |
| | 150 Mm thick (630 X 230 X 150) | 4134.45 | Sq.M | | | | | 363843.9 |
| 4 | Reinforcement | 348.04 | M.T | | | | 351.52 | |
| | Total Quantity | | | 906816 | 2555578 | 2630162 | 352 | 549026 |

## IV. RESULTS AND DISCUSSION

### 4.1 Results

The following results regarding the Embodied Energy Quantification have been compiled from the work done till date. These results show the Embodied Energy consumed for One 15 Storey Building.

Table No-4 Results of Total Energy consumption of material

| EMBODIED ENERGY IN CONCRETE 1 BUILDING - 3 BHK | | | | | |
|---|---|---|---|---|---|
| SR. NO. | MATERIAL | QTY. | UNIT | EE COEFF. (MJ/KG) | EE (MJ) |
| 1 | Cement | 906816 | kg | 6.4 | 5803624.6 |
| 2 | F.A (A.S) | 2555578 | kg | 0.11 | 281113.54 |
| 3 | C.A (20 mm) | 2630162 | kg | 0.11 | 289317.86 |
| 4 | Reinforcement Steel | 351520 | kg | 30 | 10545612 |
| 4 | CLC Blocks | 555251 | kg | 3.6 | 1998901.8 |
| | TOTAL | | | | 1,89,18,570 |

### 4.2 Discussion

Results show the values of Embodied Energy Consumption during Construction Phase of a FIFTEEN STOREY Building having a total plan area of 728 SQ.M. Only the major work activities viz. Concreting, Reinforcement, Plastering and Blockwork were considered in the study, being the volumetrically largest activities during the construction phase.

The results show that the total Embodied Energy consumption of the entire building in just four major activities as mentioned above was 18918570 MJ (Mega Joules) or 18.92 TJ (Tera Joules). This is a massive amount of energy consumed during the construction phase of such a small building project. Considering the power consumption of an average Indian house as (12 Units/ day X 365 days) 4380 Units, it is equivalent to 5255555.55 Units of Electricity and could power 1200 houses for an entire year.

Unfortunately, there is a general lack of awareness about this tremendous amount of energy going into construction activities everywhere and its detrimental environmental impacts.

### 4.3 Conclusion

Construction Projects consume large amounts of Energy. The energy consumed during construction phase is termed as 'Embodied Energy'. In this study, a simple method to derive the Embodied Energy of a fifteen-storey apartment building project is presented. The four major activities viz. Concreting, Reinforcement, Blockwork and Plastering were considered for computing the Embodied Energy by using construction material data and by applying the standard Embodied Energy Coefficients to the respective quantities of different materials consumed during the construction phase. It was found that the Embodied Energy consumed in just one building was 18.92 TJ (Tera Joules). Since construction industry is largely reliant on fossil-based fuels for its energy needs, it highlights the pressing need to attempt to reduce this energy consumption to mitigate the adverse environmental impacts of construction activities. This paper presents a simple method to derive the embodied energy content in the four major construction activities, which can be scaled up to derive a more accurate figure to cover other activities too on any construction project. This could pave a way in improving the energy efficiency of the building project by achieving large energy savings during the construction phase.

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