ASSESSMENT OF EMBODIED ENERGY OF AN EDUCATIONAL BUILDING IN KOLKATA, INDIA

A project report submitted in Partial Fulfillment of the requirements for the Degree of

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Introduction

The singular most important first step towards attaining the three goals of energy policy mainly security of supply, environmental protection and economic growth lies in energy efficiency improvements [1]. Nearly 40% of the world's total energy consumption and one third of related global greenhouse gases (GHG) emissions are related to the building sector as it creates significant economic, environmental and social impacts [2-4]. According to the United Nations Environment Programme, the environmental footprint of the building sector consists of: 40% of energy use, 30% raw materials use, 25% of solid waste, 25% water use and 12% of land use. This trend may seem to be rising as Perez Lombard et al [5] also stated that global GHG emission from buildings continue to rise at an annual rate of 1.5%. There are substantial emission arising from the extractions of various raw materials, processing, manufacturing, transportation, construction, maintenance, renovation and final demolition as well as the activities and processes that contribute to constitute the building. These are collectively known as embodied emissions.

The Climate Change Committee [6] states that a typical new 2 bed home built with traditional materials like brick, concrete foundation etc. embodies around 80 tCO2.

Energy expenditure for the manufacture of building materials constitutes 20-25% of India's total energy demand [7]. An estimated 30% of GHG emissions are contributed by the construction sector in India [7]. Cement and Steel industries represent 7.5% and 6.8% respectively of net GHG emissions from India. Transportation sector has a share of 8.22% of net GHG emissions from the country [8,9].

Embodied energy consists of all energy embedded in a building products and other activities associated with construction, maintenance, replacement and disposal of a building [10,11,12]. LCEE consists of three primary components which are: initial embodied energy (IEE), recurrent embodied energy (REE), and demolition energy (DE) [13]. The EE components are spread over the three major building life cycle stages which are initial construction, operation and maintenance, and end of life/demolition [13-16].

IEE refers to the energy that is utilized directly and indirectly in a building's design and construction process [12]. REE refers to the direct and indirect energy spent on maintenance, repair, replacement and renovation activities, whereas DE is associated with end-of-life activities such as deconstructing a building, recycling/reusing its building systems or disposing them [14,17].

Calculation methods commonly used for EE includes process-based, input output (IO) based and hybrid methods [18-21].

Research carried out by the Commonwealth Scientific and Industrial Research Organization (CSIRO [22]) shows that an average household in Australia contains about 1000 GJ of energy embodied in the materials used in the construction. This is equivalent to about 15 years of normal operational energy use. For a house that lasts for about 100 years, this is over 10% of energy used in its life [23]. The research says that as buildings become more and more energy efficient, their embodied energy will approach half the life time energy consumption. Pullen

[24] also stated that the embodied energy of a building is a very significant portion of the life cycle energy consumption when compared to operational use. Crawford and Treloar [25] suggest that in Australia, the embodied energy contained in a building is 20-50 times the annual operational energy needed for the building. In response to energy crisis and the overwhelming evidence of the effect of climate change, the concept of the Green Building was developed in the 1970s [3].

The desire to minimize building related energy consumption and mitigate environmental problems due to GHG emissions encouraged a wave of green building innovation that has contained till today. Green Buildings which are often known as sustainable buildings or eco-buildings are not easily defined. Definitions may range from ‘a building that is “not as bad” as the average buildings in terms of its impact on the environment or one that is “notably better” than the average building, to one that may even represent a regenerative process where there is actually an improvement and restoration of the site and its surrounding environment” [26].

A green building is therefore “one whose construction and lifetime of operation assure the healthiest possible environment while representing the most efficient and least disruptive use of land, water, energy & resources” [26].

Green Building assessment systems like BREEAM, BEPAC, HQE, VERDE, LEED and Green Globe, have recognized the importance of embodied emissions [27]. This has been included in green building energy assessment framework based on two key performance indicators, namely, reduction in material consumption and use of locally available materials [28]. This recognition will facilitate environmental selection of materials or products with low embodied emissions. This could result in greater energy consumption savings with a corresponding decrease in CO2 emissions due to energy production [27,29]. The building sector accounts for about one-third of the global greenhouse gases into the atmosphere [30,31,32].

The life cycle CO2 emissions (LCCEs) from buildings can be differentiated into two aspects which are the embodied and operational CO2 emissions. The embodied CO2 (ECEs) are defined as the CO2 emitted from the extraction of raw materials, material manufacture, transportation, construction, demolition and disposal as well as all the activities and processes along with the supply chain [33,34,35].

The operational CO_2 emissions (OCEs) are defined as the CO_2 emitted from energy consumed to achieve the building function and for maintaining the comfortable indoor environment in the operating process such as heating and cooling, ventilation and air conditioning, lightning and appliances [36,37].

Buildings are built in various forms using different materials and are used by different occupants. Since various building materials including insulation materials and occupants' behaviour can affect the LCCEs of building, buildings with similar performance levels should be analysed to minimize the effects of these differences on the LCCEs.

Cities take about 2% of the land surface but consume 75% of the world's natural resources. The construction sector is responsible for 40% of the consumed resources, 40% of CO_2 emissions, 40% of waste (construction & demolition), buildings account for 30 to 40% of total global energy use (United Nations Environmental Programme). It is estimated that buildings consume approximately 48% of global energy each year in their construction, operation, maintenance and deconstruction [38,39]. Energy is consumed directly in buildings mostly as delivered energy sources such as electricity and natural gas.

Buildings also use energy sources indirectly through the use of construction materials. Sartori and Hestnes [40] concluded that embodied energy could account for 2–38% of the total life-cycle energy of a conventional building, whereas this range could be 9–46% in the case of a low-energy building. A low-energy building, according to Sartori and Hestnes [40], is designed to minimize its operating energy usage. Thormark [41] also found that the energy embodied in a low-energy house could account for roughly half of total life-cycle energy. Thormark [41] argued that a low-energy building consumes more material and less operating energy (mostly electricity) than a conventional building. Shadram et al. [42] found that the share of embodied energy could be up to 60% of total building energy use.

An important goal for the building sector is to produce buildings with a minimum of environmental impact. Energy use is a central issue as energy is generally one of the most important resources used in buildings over their lifetime. Low energy houses have therefore become an important research field. In the last few years, there has been an increasing interest in the energy use of buildings in a lifetime perspective. The lifetime is mostly divided into production (including all processes from extraction of raw materials up to the time the material is ready to leave the factory and feedstock), erection, operation, maintenance and demolition. Numerous studies show that the operation accounts for the main part of the energy use in the general run of dwellings. The energy for production accounts for only about 10 –15% in most cases [43-49].

The energy required for operation can be considerably decreased by improved insulation of the building envelope, technical solutions, etc. These measures will increase the energy use for the production phase. Studies of low energy houses have shown that the energy for production can account for 40 – 60% of the total energy use [45,47]. However, studies have shown that even if the energy for operation was very low in one building, the total energy use (energy for production, maintenance and operation) in that building over 50 years was higher than in a building which had a higher energy need for operation [50].

The past few decades have experienced a general increase in the patterns of primary energy consumption across the four major end-use sectors including residential, commercial, transportation, and industrial. Despite this increase, the percentile contribution of different sectors to total consumption has significantly changed [51]. For instance, the industry made an approximate 48% contribution to total energy consumption in 1950s, while its contribution drops to 31% in the early 2010s, despite the significant growth of economy. On the other hand, commercial building sector has experienced increased growth in contribution to total primary energy consumption; from 11% in 1949 to 19% in 2011 [51].

Embodied energy needs to become an important consideration in design of buildings due to several reasons. First, construction industry is an energy intensive industry with about 6% [51] contribution to primary energy use. Second, shorter renovation cycles, the use of less durable materials, and some energy-intensive maintenance practices can increase the embodied energy of buildings. Third, many of the operational energy-efficiency strategies that are applied in contemporary buildings, such as thicker envelopes, more insulation, external shading devices, multiple-glazed windows, etc. translate into more embodied energy and can compromise meaningful net life cycle energy savings [52]. Fourth, while operational energy savings are often subject to occupancy phase uncertainties caused by occupant behaviour, climate variations, and facility operations, the initial embodied energy savings are fixed when the building is constructed and therefore, can be considered as reliable short- and long-term savings in energy.

The EE content of buildings varies from building to building and from location to location. It is primarily a function of materials, products, systems, and technologies that are used in construction of building. Geographical location also affects the EE content through unique manufacturing practices, sources of primary energy used in power plants to generate electricity, modes of transportation, and distances from construction site to manufacturers, suppliers, landfills, etc. That is why geographical location often limits the extent to which the results of EE studies can be generalized.

The embodied energy that is estimated for a single building can vary as well, depending on the estimation methodology (i.e., estimation method, system boundary, data quality and inventory databases, estimation assumptions, limitations, cutoff criteria, etc.) that is used to determine EE, and the geographical location in which the building is, or is assumed to be, located at. The effect of geographical location of building occurs due to varying sources of raw material and building products, transport types and distances, manufacturing technologies, electricity generation types, and other factors that would change with building location. For example, the steel that is used to manufacture I-beams for a building in Australia is supplied from a location that might be different than that of a building in Europe or the US. This difference in steel

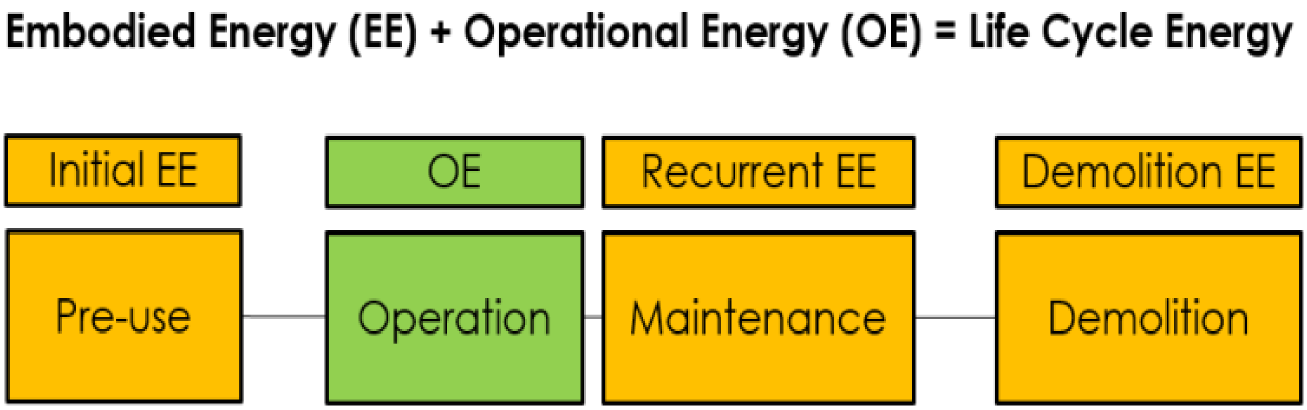


Fig. 1. Life cycle energy analysis

steel source translates into other differences such as difference in steel manufacturing technologies, transportation distances (from mine to smelter to steel production facility to I-beam manufacturing facility to construction site), and transport modes (truck, train, ship, etc.). Other factors that cause variations in EE results include variations in construction, maintenance, reuse and recycle, and demolition practices.

Accelerating globalization allows regions to assimilate into global and domestic supply chains [53]. The resources use and pollutant emissions in the regions are therefore increasingly tied. International trade plays an important role in stimulating global economic integration along with a series of environmentally detrimental transactions between nations [54]. In this regard, a number of studies have examined energy use in the trade-linked analysis [55], which mainly focuses on two aspects. One aspect evaluates holistic characteristics of energy use and captures important relationships (between countries or sectors) within the international trade system [56]. The second aspect focuses on portraying national energy trade performances between specific countries [57].

To achieve environmental sustainability, the reduction of primary energy (PE) use in buildings should be an aim of a design process. For an integrated approach to the energy-efficient design of buildings [58–60], it is crucial that design tools can address energy issues at the earliest stages of a design process. As the major considerations at the early stage of the design process are orientation; configuration; size, location, and distribution of glazing; and shape and size, crucial opportunities for improving a building's energy performance occur at this stage. The natural energy flows brought about by the sun, wind, and temperature differences can be organized so that only the minimum levels of artificial heating, cooling, and lighting need to be provided.

Objective

a. Estimation of an educational building (G+12) by using Estimator 2 software.

b. Calculation of Embodied Energy of the same building using standard EE Co-efficient.

Scope

An educational building was considered for this project and EE of materials like Brick, Cement and Steel etc. were taken into account.

Literature Review

Building life cycle energy:

The amount of energy spent during a building's lifetime consists of EE and OE [4,13]. Conventionally, studies use a life cycle energy analysis (LCEA) approach to measure environmental impacts and estimate net energy savings over the building's lifetime [23,28]. Previous studies have consistently shown that LCEA results vary based on a multitude of factors such as the system boundary definitions, LCI method, and type and form of energy included in EE calculations [29,30]. A system boundary defines processes and energy flows of a product's life cycle that are included in LCEA [30]. Frequently used system boundary definitions used in LCEA include 'cradle to gate', 'cradle to site', and 'cradle to grave' [30]. The cradle-to-gate assessment for a product includes all processes from raw material extraction and main manufacturing through the final product leaving the factory gate. The cradle to site system boundary covers additional activities such as transporting the final product from the factory gate to the construction site, on-site fabrication, administration, disposal of waste, etc. The cradle to grave system boundary includes operation, maintenance, renovation, retrofit, demolition, and other end of life activities, along with the cradle to site processes [4,31]. A system boundary definition also varies based on direct and indirect embodied energy components that are covered in LCEA [11,12,29,30]. Direct energy refers to the energy consumed by the main processes, such as on-site and off-site construction activities, equipment, and material transportation [32]. Indirect energy refers to non-energy inputs such as building materials, assemblies, packaging, equipment, etc., that are installed in a building [33].

Embodied energy:

Embodied energy consists of all energy embedded in building products and other activities associated with the construction, maintenance, replacement, and disposal of a building [2,12,26]. LCEE comprises three primary components: initial embodied energy (IEE), recurrent embodied energy (REE), and demolition energy (DE) [34]. These EE components are spread over the three major building life cycle stages, namely initial construction, operation and maintenance, and end of life/demolition [32–35]. IEE refers to the energy utilized directly and indirectly in a building's design and construction processes [26]. REE pertains to the direct and indirect energy spent on maintenance, repair, replacement, and renovation activities, whereas DE is associated with end-of-life activities such as deconstructing a building, recycling/reusing its building systems, or disposing of them [10,32]. Commonly used calculation methods for EE, include process-based, input-output (IO) based, and hybrid methods [27,36–38]. In a process-based approach, actual energy use data is collected from construction sites and manufacturers and summed to compute the total EE. In an IO-based method, monetary flows between energy and other industry sectors are converted into physical energy flows using energy tariffs. Compared to other LCI methods, the process-based method is relatively more reliable since it uses actual energy use data from manufacturers, whereas IO-based approaches are considered complete but unreliable since the EE is computed for an aggregated industry sector [38–40]. The process-based method includes direct and indirect energy flows and material inputs of each upstream process [29,40,41]. However, tracking the major and minor energy flows for the entire supply chain is difficult and time-consuming [40]. Due to the issue of data unavailability, the system boundary in the process-based approach is incomplete [21,41,42]. This causes ‘truncation error’ leading to under-estimation of EE values [21,43,44]. The IO-based method overcomes the issue of incomplete data by using economic IO data of economic transactions between various industry sectors [40,41,45]. These transactions are converted into energy flows by using the product price and energy intensity of its manufacturing sector [46]. Although the IO-based method has a relatively complete system boundary, it suffers from several methodological issues such as the assumptions of proportionality and homogeneity that make its results unreliable [42]. The IO-based approach uses energy tariffs and product prices for calculations that may over/underestimate EE values; furthermore, the energy intensities are assigned for the entire sector rather than the product level, resulting in ‘aggregation error’ [38–41,47]. A hybrid method was developed to resolve the limitations of both process-based and IO-based methods [9, 48]. This method utilizes process data until the stage where complete information is available; beyond that, IO data is used. Based on the framework used for calculating EE, the hybrid method is either a process-based hybrid or an IO-based hybrid [47]. As the name suggests, the process-based hybrid method uses a process-based framework with IO data, while the IO-based hybrid uses an IO-based framework integrated with process data [41,42]. Since the hybrid method uses reliable process data and the wider system boundary of the IO-based method, the hybrid method is regarded as more accurate and complete [41,42,45].

Trade-offs between operating and embodied energy components:

Conventionally, LCEA studies focus on reducing operating energy since it is considered to constitute a larger proportion of building LCE [13,23,56–58]. However, recent research has shown that improving building design or system efficiency to reduce OE increases the proportion of EE in the total LCE [6,8,59]. This trend of higher EE proportion in building LCE can be profoundly observed in carbon neutral and energy-efficient buildings [26]. For instance, Sartori and Hestnes estimated that the EE proportion in building LCE increases from 2 to 38% in a conventional building to 9–46% in a low energy building. Similarly, Shadram et al. found that EE can account for 60% of the building LCE. Implementing operating energy measures such as increasing the level of insulation, changing the glazing system, or installing energy-efficient equipment utilizes energy-intensive material. As a result, the IEE of the entire building increases, counterproductive to the goal of reducing total building LCE. These trade-offs highlight the need to comprehensively evaluate both EE and OE.

Stephan et al. assessed the LCE impacts for an apartment complex with 87 variations created by changing the design features of the building envelope. Their study revealed that the 40% wall to window ratio, double glazed window system, and heavyweight walls demonstrated the least LCE. Even though these variations used energy-intensive material, the increased IEE was offset by the OE savings. Venkatraj et al. evaluated the impacts of OE reduction measures on EE. Their study modeled 23 variations of an educational building and quantified the EE-OE trade-offs in four climate zones across the United States. The design measures considered in their study to reduce OE included changing the building orientation, wall to window ratio, shading depth, glazing system, and roof and wall insulation. They found that a 10–15% decrease in OE increases EE by 27–33% for the most optimum variation. Several studies focus on increasing the level of insulation in the exterior walls to reduce operating energy [40]. In most of these studies, implementing higher insulation levels results in net LCE savings despite the increase in IEE. For example, Utama and Gheewala studied the LCE implications of changing the exterior wall type of a high-rise residential building located in Indonesia. They found that the wall type with a higher level of insulation held more LCE benefits even with the use of additional material. Stochastic population-based algorithms such as genetic algorithms (GA), particle swarm optimization, and hybrid algorithms have also been applied to building LCE optimization. Multi-objective optimization (MOO) algorithms are used to improve decision making while dealing with conflicting objective functions (e.g., EE vs. OE). Such computational approaches explore the design space by creating several design alternatives based on objective functions. Ultimately, the designer selects the optimum building design from the Pareto-set of solutions that denote some of the most optimized options [25]. Shadram and Mukkarva presented a MOO framework to explore the interdependencies between EE and OE of a low-energy building in Sweden. Their study used a multi-objective genetic algorithm (MOGA) to show that small reductions in OE (140 GJ) resulted in large increases of EE (340 GJ). Similarly, Wang et al. [25] used a MOGA to show that a 5% decrease in OE resulted in a similar EE increase. Azari et al. optimized the LCE performance of building envelope design for a low-rise office building located in Seattle, Washington. The study evaluated combinations of six design features such as window type, wall to window ratio, insulation level, etc., of the building envelope. Typically, these features affect operational energy and environmental indicators (acidification, eutrophication, global warming potential, smog formation, and ozone depletion) differently. Using a hybrid artificial neural network and GA for optimization, the results showed that the triple glazed window with fiberglass frame, R-17 wall insulation, 60% WWR on the south, and 10% WWR on the north provided the optimum solution.

Methodology

Workflow:

Interpretation of plan and elevation of the building

↓

Input the dimensions of each of the rooms

↓

Input the different types of openings and assign them to the floor

↓

Input the dimensions of the walls and calculate the amount of brickwork

↓

Select the option for concrete calculation and choose RCC as the evaluation parameter

↓

Select which materials are to be used for different parts of the building to generate an account of quantity

↓

Generate a report showing the net amount of materials required.

↓

Calculate the embodied energy by multiplying the net amount of quantity of each of the materials with their

Building Description

A commercial building consisting of 13 Floors (G+12) is considered for this project.

The commercial building considered in this project has the following specifications:

Table No. 1: Block B plan specifications

Floor	**Specification**
Ground Floor	The ground floor has a waiting lounge, a pantry, an electrical room, a fire-fighting equipment storage room, a surveillance room, a lift lobby, a service lift lobby, 2 toilets, and 2 staircases. Additionally, it also has a parking area which continues up to the first floor.
1st Floor	This floor has one office, a dining hall, a faculty room, a lift and a service lift lobby, 2 toilets and the parking area continued from below.
2nd to 7th floor	All the floors here have almost the same layout. They have 5 classrooms, 3 tutorial rooms, 2 laboratories, 2 toilets and a faculty room.
8th and 9th floor	Each of these floors have 5 offices, 2 records room, 1 submission room, 1 executive lounge and 1 faculty room.
10th floor	This floor has 2 tutorial rooms, 1 seminar room, 1 e-library, 1 research lab, 1 students' center, 1 drawing hall, 1 computer center and 1 faculty room
11th floor	This floor has 2 terrace gardens, 1 admin office, and 1 reception lounge. The floor has a doubly-heighted multipurpose hall in addition with a backstage area and an ante room along with a wide corridor.
12th floor	This floor accommodates Chancellor's lounge and his main chamber along with a room for Chancellor's Secretary. The floor also has 2 terrace gardens, 1 equipment, maintenance and storage room.

Quantity Estimation:

A detailed quantity estimation has been done by using the Estimator 2.0 software. Estimator 2.0 is an on-premise solution for Windows, designed to help builders, architects, contractors and engineers automate processes related to estimates preparation, tender comparison, work order issuance, purchase request generation and more. Key features include project management, item-wise summary, labour billing, project rate analysis and cost control.

Embodied Energy Calculation:

The EE Co-efficient were collected from standard literatures considering the geographic locations. The EE Co-efficient were multiplied with the amount of materials used to obtain the Embodied Energy.

Calculations

Table No. 2: Brick requirement for Block B

BRICK WORKS CM 1:4	
FLOOR	
GROUND FLOOR	114.99 Cu.M.
FIRST FLOOR	147.26 Cu.M.
SECOND FLOOR	32.89 Cu.M.
THIRD FLOOR	139.14 Cu.M.
FOURTH FLOOR	63.90 Cu.M.
FIFTH FLOOR	65.32 Cu.M.
SIXTH FLOOR	10.18 Cu.M.
SEVENTH FLOOR	25.31 Cu.M.
EIGHTH FLOOR	12.27 Cu.M.
NINTH FLOOR	65.62 Cu.M.
TENTH FLOOR	58.99 Cu.M.
ELEVENTH FLOOR	28.55 Cu.M.
TWELTH FLOOR	41.69 Cu.M.
ROOF FLOOR	155.02 Cu.M.
Total for BRICK WORKS CM 1:4	**961.13 Cu.M.**

Total for Brick Works	**961.13 Cu.M.**

<u>Table No. 3: Cement requirement for Block B</u>

Table No. 3.1

RCC (M20)	
RCC ALL RCCS (M20)	
GROUND FLOOR	267.26 Cu.M.
FIRST FLOOR	332.28 Cu.M.
SECOND FLOOR	360.95 Cu.M.
THIRD FLOOR	360.95 Cu.M.
FOURTH FLOOR	360.95 Cu.M.
FIFTH FLOOR	360.95 Cu.M.
SIXTH FLOOR	360.95 Cu.M.
SEVENTH FLOOR	360.95 Cu.M.
EIGHTH FLOOR	360.95 Cu.M.
NINTH FLOOR	360.95 Cu.M.
TENTH FLOOR	448.47 Cu.M.
ELEVENTH FLOOR	448.47 Cu.M.
TWELTH FLOOR	301.64 Cu.M.
Total for RCC ALL RCCS M20	**4685.72 Cu.M.**

Table No. 3.2

BRICK WORKS CM 1:4	
GROUND FLOOR	114.99 Cu.M.
FIRST FLOOR	147.26 Cu.M.
SECOND FLOOR	32.89 Cu.M.
THIRD FLOOR	139.14 Cu.M.
FOURTH FLOOR	63.90 Cu.M.
FIFTH FLOOR	65.32 Cu.M.
SIXTH FLOOR	10.18 Cu.M.
SEVENTH FLOOR	25.31 Cu.M.
EIGHTH FLOOR	12.27 Cu.M.
NINTH FLOOR	65.62 Cu.M.
TENTH FLOOR	58.99 Cu.M.
ELEVENTH FLOOR	28.55 Cu.M.
TWELTH FLOOR	41.69 Cu.M.
ROOF FLOOR	155.02 Cu.M.
Total for BRICK WORKS CM 1:4	**961.13 Cu.M.**

Table No. 3.3

FLOOR AND WALL FINISHES		15mm thickness
GROUND FLOOR	287.83 Sq.M.	4.32 Cu.M.
FIRST FLOOR	213.66 Sq.M.	3.20 Cu.M.
SECOND FLOOR	673.17 Sq.M.	10.10 Cu.M.
THIRD FLOOR	770.43 Sq.M.	11.56 Cu.M.
FOURTH FLOOR	705.47 Sq.M.	10.58 Cu.M.
FIFTH FLOOR	665.60 Sq.M.	9.98 Cu.M.
SIXTH FLOOR	57.74 Sq.M.	0.87 Cu.M.
SEVENTH FLOOR	771.96 Sq.M.	11.58 Cu.M.
EIGHTH FLOOR	771.96 Sq.M.	11.58 Cu.M.
NINTH FLOOR	771.96 Sq.M.	11.58 Cu.M.
TENTH FLOOR	771.96 Sq.M.	11.58 Cu.M.
ELEVENTH FLOOR	771.96 Sq.M.	11.58 Cu.M.
TWELTH FLOOR	771.96 Sq.M.	11.58 Cu.M.
ROOF FLOOR	771.96 Sq.M.	11.58 Cu.M.
Total for FLOOR FINISHING MARBLE TILES	**8,777.62 Sq.M.**	**131.67 Cu.M.**

Table No. 3.4

DOORS AND WINDOWS	
GROUND FLOOR	1.65 Cu.M.
FIRST FLOOR	1.64 Cu.M.
SECOND FLOOR	3.48 Cu.M.
THIRD FLOOR	2.08 Cu.M.
FOURTH FLOOR	3.00 Cu.M.
FIFTH FLOOR	3.23 Cu.M.
SIXTH FLOOR	4.18 Cu.M.
SEVENTH FLOOR	4.05 Cu.M.
EIGHTH FLOOR	4.09 Cu.M.
NINTH FLOOR	4.54 Cu.M.
TENTH FLOOR	3.16 Cu.M.
ELEVENTH FLOOR	2.86 Cu.M.
TWELTH FLOOR	3.20 Cu.M.
ROOF FLOOR	0.41 Cu.M.
Total for FRAMES CONCRETE	**41.57 Cu.M.**

Table No. 3.5

PLASTERING AND POINTING		**12mm thickness**
PLASTERING WALLS CM 1:2 12 MM		
GROUND FLOOR	1,633.50 Sq.M.	19.60 Cu.M.
FIRST FLOOR	2,201.70 Sq.M.	26.42 Cu.M.
SECOND FLOOR	2,217.96 Sq.M.	26.62 Cu.M.
THIRD FLOOR	2,407.83 Sq.M.	28.89 Cu.M.
FOURTH FLOOR	2,356.54 Sq.M.	28.28 Cu.M.
FIFTH FLOOR	2,335.58 Sq.M.	28.03 Cu.M.
SIXTH FLOOR	2,280.43 Sq.M.	27.37 Cu.M.
SEVENTH FLOOR	2,292.11 Sq.M.	27.51 Cu.M.
EIGHTH FLOOR	2,289.82 Sq.M.	27.48 Cu.M.
NINTH FLOOR	2,964.04 Sq.M.	35.57 Cu.M.
TENTH FLOOR	2,970.48 Sq.M.	35.65 Cu.M.
ELEVENTH FLOOR	2,979.82 Sq.M.	35.76 Cu.M.
TWELTH FLOOR	1,799.74 Sq.M.	21.60 Cu.M.
ROOF FLOOR	361.60 Sq.M.	4.34 Cu.M.
Total for PLASTERING WALLS CM 1:2 12 MM	**31,091.15 Sq.M.**	**373.12 Cu.M.**

Total for Cement	**6193.21 Cu.M.**

Table No. 4: Glass requirement for Block B

Table No. 4.1

Doors and Windows		
Shutters Wood Glazed		
GROUND FLOOR	118.20 SqM	0.3546 Cu.M.
FIRST FLOOR	137.42 SqM	0.41226 Cu.M.
SECOND FLOOR	248.84 SqM	0.74652 Cu.M.
THIRD FLOOR	156.09 SqM	0.46827 Cu.M.
FOURTH FLOOR	200.10 SqM	0.6003 Cu.M.
FIFTH FLOOR	217.14 SqM	0.65142 Cu.M.
SIXTH FLOOR	266.58 SqM	0.79974 Cu.M.
SEVENTH FLOOR	254.56 SqM	0.76368 Cu.M.
EIGHTH FLOOR	255.53 SqM	0.76659 Cu.M.
NINTH FLOOR	257.94 SqM	0.77382 Cu.M.
TENTH FLOOR	287.48 SqM	0.86244 Cu.M.
ELEVENTH FLOOR	282.42 SqM	0.84726 Cu.M.
TWELTH FLOOR	287.61 SqM	0.86283 Cu.M.
ROOF FLOOR	32.33 SqM	0.09699 Cu.M.
Total for Shutters Wood Glazed	**3004.65 SqM**	**8.24013 Cu.M.**

Table No. 4.2

Windows		
GROUND FLOOR	49.01 Sq.M.	0.14703 Cu.M.
FIRST FLOOR	73.08 Sq.M.	0.21924 Cu.M.
SECOND FLOOR	153.12 Sq.M.	0.45936 Cu.M.
THIRD FLOOR	98.6 Sq.M.	0.2958 Cu.M.
FOURTH FLOOR	148.19 Sq.M.	0.44457 Cu.M.
FIFTH FLOOR	136.3 Sq.M.	0.4089 Cu.M.
SIXTH FLOOR	163.85 Sq.M.	0.49155 Cu.M.
SEVENTH FLOOR	154.57 Sq.M.	0.46371 Cu.M.
EIGHTH FLOOR	166.46 Sq.M.	0.49938 Cu.M.
NINTH FLOOR	187.64 Sq.M.	0.56292 Cu.M.
TENTH FLOOR	197.49 Sq.M.	0.59247 Cu.M.
ELEVENTH FLOOR	232.58 Sq.M.	0.69774 Cu.M.
TWELTH FLOOR	219.01 Sq.M.	0.65703 Cu.M.
ROOF FLOOR	7.44 Sq.M.	0.02232 Cu.M.
Total for Windows	**1987.34 SqM**	**5.96202 Cu.M.**

Total amount of Glass used	**14.202 Cu.M.**

Table No. 5: Wood requirement for Block B

Table No. 5.1

SHUTTERS WOOD GLAZED		12mm thickness
GROUND FLOOR	118.20 Sq.M.	1.4184 Cu.M.
FIRST FLOOR	137.42 Sq.M.	1.6490 Cu.M.
SECOND FLOOR	248.84 Sq.M.	2.9860 Cu.M.
THIRD FLOOR	156.09 Sq.M.	1.873 Cu.M.
FOURTH FLOOR	200.10 Sq.M.	2.4012 Cu.M.
FIFTH FLOOR	217.14 Sq.M.	2.6057 Cu.M.
SIXTH FLOOR	266.58 Sq.M.	3.1990 Cu.M.
SEVENTH FLOOR	254.56 Sq.M.	3.0547 Cu.M.
EIGHTH FLOOR	257.94 Sq.M.	3.0953 Cu.M.
TENTH FLOOR	287.48 Sq.M.	3.450 Cu.M.
ELEVENTH FLOOR	282.42 Sq.M.	3.389 Cu.M.
TWELTH FLOOR	287.61 Sq.M.	3.4513 Cu.M.
ROOF FLOOR	32.33 Sq.M.	0.3880 Cu.M.
Total for SHUTTERS WOOD GLAZED	**2,746.71 Sq.M.**	**32.9606 Cu.M.**

Table No. 5.2

DOORS		30mm thickness
GROUND FLOOR	79.76 Sq.M.	2.3928 Cu.M.
FIRST FLOOR	73.28 Sq.M.	2.1984 Cu.M.
SECOND FLOOR	119.04 Sq.M.	3.5712 Cu.M.
THIRD FLOOR	70.09 Sq.M.	2.1027 Cu.M.
FOURTH FLOOR	71.79 Sq.M.	2.1537 Cu.M.
FIFTH FLOOR	104.64 Sq.M.	3.1392 Cu.M.
SIXTH FLOOR	132.24 Sq.M.	3.9672 Cu.M.
SEVENTH FLOOR	129.84 Sq.M.	3.8952 Cu.M.
EIGHTH FLOOR	120.24 Sq.M.	3.6072 Cu.M.
NINTH FLOOR	125.04 Sq.M.	3.7512 Cu.M.
TENTH FLOOR	108.75 Sq.M.	3.2616 Cu.M.
ELEVENTH FLOOR	64.32 Sq.M.	1.9296 Cu.M.
TWELTH FLOOR	83.29 Sq.M.	2.4987 Cu.M.
ROOF FLOOR	27.00 Sq.M.	0.81 Cu.M.
Total for DOORS	**1,309.32 Sq.M.**	**39.2833 Cu.M.**

Table No. 5.3

WINDOWS		10 mm thickness
GROUND FLOOR	49.01 Sq.M.	0.4901 Cu.M.
FIRST FLOOR	73.08 Sq.M.	0.7308 Cu.M.
SECOND FLOOR	153.12 Sq.M.	1.5312 Cu.M.
THIRD FLOOR	98.60 Sq.M.	0.9860 Cu.M.
FOURTH FLOOR	148.19 Sq.M.	1.4819 Cu.M.
FIFTH FLOOR	136.30 Sq.M.	1.3630 Cu.M.
SIXTH FLOOR	163.85 Sq.M.	1.6385 Cu.M.
SEVENTH FLOOR	154.57 Sq.M.	1.5457 Cu.M.
EIGHTH FLOOR	166.46 Sq.M.	1.6646 Cu.M.
NINTH FLOOR	187.64 Sq.M.	1.8764 Cu.M.
TENTH FLOOR	197.49 Sq.M.	1.9749 Cu.M.
ELEVENTH FLOOR	232.58 Sq.M.	2.3258 Cu.M.
TWELTH FLOOR	219.01 Sq.M.	2.1901 Cu.M.
ROOF FLOOR	7.44 Sq.M.	0.0744 Cu.M.
Total for WINDOWS	**1,987.34 Sq.M**	**19.8734 Cu.M.**

Total Amount of Wood used	**92.1173 Cu.M.**

Table No. 6: Ceramic Tiles requirement for Block B

FLOOR FINISHING		10mm thickness
GROUND FLOOR	287.83 Sq.M.	2.8783 Cu.M.
FIRST FLOOR	213.66 Sq.M.	2.1366 Cu.M.
SECOND FLOOR	673.17 Sq.M.	6.7317 Cu.M.
THIRD FLOOR	770.43 Sq.M.	7.7043 Cu.M.
FOURTH FLOOR	705.47 Sq.M.	7.0547 Cu.M.
FIFTH FLOOR	665.60 Sq.M.	6.6560 Cu.M.
SIXTH FLOOR	57.74 Sq.M.	0.5774 Cu.M.
SEVENTH FLOOR	771.96 Sq.M.	7.7196 Cu.M
EIGHTH FLOOR	771.96 Sq.M.	7.7196 Cu.M
NINTH FLOOR	771.96 Sq.M.	7.7196 Cu.M
TENTH FLOOR	771.96 Sq.M.	7.7196 Cu.M
ELEVENTH FLOOR	771.96 Sq.M.	7.7196 Cu.M
TWELTH FLOOR	771.96 Sq.M.	7.7196 Cu.M
ROOF FLOOR	771.96 Sq.M.	7.7196 Cu.M
Total for Ceramic Tiles	**8777.62 Sq.M.**	**87.7762 Cu.M.**

Total Amount of Ceramic Tiles Used	**87.7762 Cu.M.**

<u>Table No. 7: Stone Ballast requirement for Block B</u>

Table No. 7.1

RCC ALL RCCS M20	
GROUND FLOOR	267.26 Cu.M.
FIRST FLOOR	332.28 Cu.M.
SECOND FLOOR	360.95 Cu.M.
THIRD FLOOR	360.95 Cu.M.
FOURTH FLOOR	360.95 Cu.M.
FIFTH FLOOR	360.95 Cu.M.
SIXTH FLOOR	360.95 Cu.M.
SEVENTH FLOOR	360.95 Cu.M.
EIGHTH FLOOR	360.95 Cu.M.
NINTH FLOOR	360.95 Cu.M.
TENTH FLOOR	448.47 Cu.M.
ELEVENTH FLOOR	448.47 Cu.M.
TWELTH FLOOR	301.64 Cu.M.
Total for RCC ALL RCCS M20	**4,685.72 Cu.M.**

Table No. 7.2

DOORS AND WINDOWS	
FRAMES CONCRETE	
GROUND FLOOR	1.65 Cu.M.
FIRST FLOOR	1.64 Cu.M.
SECOND FLOOR	3.48 Cu.M.
THIRD FLOOR	2.08 Cu.M.
FOURTH FLOOR	3.00 Cu.M.
FIFTH FLOOR	3.23 Cu.M.
SIXTH FLOOR	4.18 Cu.M.
SEVENTH FLOOR	4.05 Cu.M.
EIGHTH FLOOR	4.09 Cu.M.
NINTH FLOOR	4.54 Cu.M.
TENTH FLOOR	3.16 Cu.M.
ELEVENTH FLOOR	2.86 Cu.M.
TWELTH FLOOR	3.20 Cu.M.
ROOF FLOOR	0.41 Cu.M.
Total for FRAMES CONCRETE	**41.57 Cu.M.**
Total Amount of Stone	**4727.29 Cu.M.**

Table No. 8: Sand requirement for Block B

Table No. 8.1

RCC		12mm aggregate
GROUND FLOOR	267.26 Sq.M.	3.20712 Cu.M
FIRST FLOOR	332.28 Sq.M.	3.98736 Cu.M
SECOND FLOOR	360.95 Sq.M.	4.3314 Cu.M
THIRD FLOOR	360.95 Sq.M.	4.3314 Cu.M
FOURTH FLOOR	360.95 Sq.M.	4.3314 Cu.M
FIFTH FLOOR	360.95 Sq.M.	4.3314 Cu.M
SIXTH FLOOR	360.95 Sq.M.	4.3314 Cu.M
SEVENTH FLOOR	360.95 Sq.M.	4.3314 Cu.M
EIGHTH FLOOR	360.95 Sq.M.	4.3314 Cu.M
NINTH FLOOR	360.95 Sq.M.	4.3314 Cu.M
TENTH FLOOR	448.47 Sq.M.	5.38164 Cu.M
ELEVENTH FLOOR	448.47 Sq.M.	5.38164 Cu.M
TWELTH FLOOR	301.64 Sq.M.	3.61968 Cu.M
ROOF FLOOR	178.22 Sq.M.	2.13864 Cu.M
Total for RCC ALL RCCS M20	**4685.72 Sq.M.**	**58.36728 Cu.M.**

Table No. 8.2

BRICKWORKS	
BRICK WORKS CM 1:4 GROUND FLOOR	
FIRST FLOOR	147.26 Cu.M.
SECOND FLOOR	32.89 Cu.M.
THIRD FLOOR	139.14 Cu.M.
FOURTH FLOOR	63.90 Cu.M.
FIFTH FLOOR	65.32 Cu.M.
SIXTH FLOOR	10.18 Cu.M.
SEVENTH FLOOR	25.31 Cu.M.
EIGHTH FLOOR	12.27 Cu.M.
NINTH FLOOR	65.62 Cu.M.
TENTH FLOOR	58.99 Cu.M.
ELEVENTH FLOOR	28.55 Cu.M.
TWELTH FLOOR	41.69 Cu.M.
ROOF FLOOR	155.02 Cu.M.
Total for BRICK WORKS CM 1:4	**961.13 Cu.M.**

Table No. 8.3

DOORS AND WINDOWS	
FRAMES CONCRETE	
GROUND FLOOR	1.65 Cu.M.
FIRST FLOOR	1.64 Cu.M.
SECOND FLOOR	3.48 Cu.M.
THIRD FLOOR	2.08 Cu.M.
FOURTH FLOOR	3.00 Cu.M.
FIFTH FLOOR	3.23 Cu.M.
SIXTH FLOOR	4.18 Cu.M.
SEVENTH FLOOR	4.05 Cu.M.
EIGHTH FLOOR	4.09 Cu.M.
NINTH FLOOR	4.54 Cu.M.
TENTH FLOOR	3.16 Cu.M.
ELEVENTH FLOOR	2.86 Cu.M.
TWELTH FLOOR	3.20 Cu.M.
ROOF FLOOR	0.41 Cu.M.
Total for FRAMES CONCRETE	**41.57 Cu.M.**

Table No. 8.4

PLASTERING WALLS CM 1:2 12 MM		
GROUND FLOOR	1,633.50 Sq.M.	19.6 Cu.M.
FIRST FLOOR	2,201.70 Sq.M.	26.42 Cu.M.
SECOND FLOOR	2,217.96 Sq.M.	26.62 Cu.M.
THIRD FLOOR	2,407.83 Sq.M.	28.89 Cu.M.
FOURTH FLOOR	2,356.54 Sq.M.	28.28 Cu.M.
FIFTH FLOOR	2,335.58 Sq.M.	28.03 Cu.M.
SIXTH FLOOR	2,280.43 Sq.M.	27.37 Cu.M.
SEVENTH FLOOR	2,292.11 Sq.M.	27.51 Cu.M.
EIGHTH FLOOR	2,289.82 Sq.M.	27.48 Cu.M.
NINTH FLOOR	2,964.04 Sq.M.	35.57 Cu.M.
TENTH FLOOR	2,970.48 Sq.M.	35.65 Cu.M.
ELEVENTH FLOOR	2,979.82 Sq.M.	35.76 Cu.M.
TWELTH FLOOR	1,799.74 Sq.M.	21.60 Cu.M.
ROOF FLOOR	361.60 Sq.M.	4.34 Cu.M.
Total for PLASTERING WALLS CM 1:2 12 MM	**31,091.15 Sq.M.**	**373.12 Cu.M.**

Total Amount of Sand used	**1434.277 Cu.M.**

Table No. 9: Steel requirement for Block B

STEEL REQUIREMENTS		
GROUND FLOOR		20,979.91 Kg
FIRST FLOOR		26,083.98 Kg
SECOND FLOOR		28,334.58 Kg
THIRD FLOOR		28,334.58 Kg
FOURTH FLOOR		28,334.58 Kg
FIFTH FLOOR		28,334.58 Kg
SIXTH FLOOR		28,334.58 Kg
SEVENTH FLOOR		28,334.58 Kg
EIGHTH FLOOR		28,334.58 Kg
NINTH FLOOR		28,334.58 Kg
TENTH FLOOR		35,204.90 Kg
ELEVENTH FLOOR		35,204.90 Kg
TWELTH FLOOR		23,678.74 Kg
ROOF FLOOR		13,990.27 Kg
Total for Steel Requirements		**381,819.34 Kg**

Total Amount of Steel Used	**381,819.34 Kg**

Results and Discussion

Embodied Energy Calculations

Embodied Energy of a material = (Amount of the material) * (Embodied Energy coefficient) Total Embodied Energy = Sum of Embodied Energy of all the materials

Table No. 10: - EE Energy calculation

Material Used	Amount (with unit)	Embodied Energy Coefficient	Embodied Energy
Ceramic Bricks	961.13 m^3	5170 MJ/m^3	**4969042.1 MJ**
Cement	6193.21 m^3	3200 MJ/m^3	**19818272 MJ**
Glass	14.202 m^3	40060 MJ/m^3	**568932 MJ**
Wood	92.113 m^3	388 MJ/m^3	**35739.844 MJ**
Ceramic Tiles	87.7762 m^3	5250 MJ/m^3	**460825.05 MJ**
Stone Ballast	4727.29 m^3	1890 MJ/m^3	**8934578 MJ**
Sand	1434.277 m^3	232 MJ/m^3	**332752.264 MJ**
Steel	381819.34 kg	34.8 MJ/kg	**13287313.032 MJ**

Total Embodied Energy of the building = 43934454.29 MJ

Fig. 2. Embodied Energy Proportion

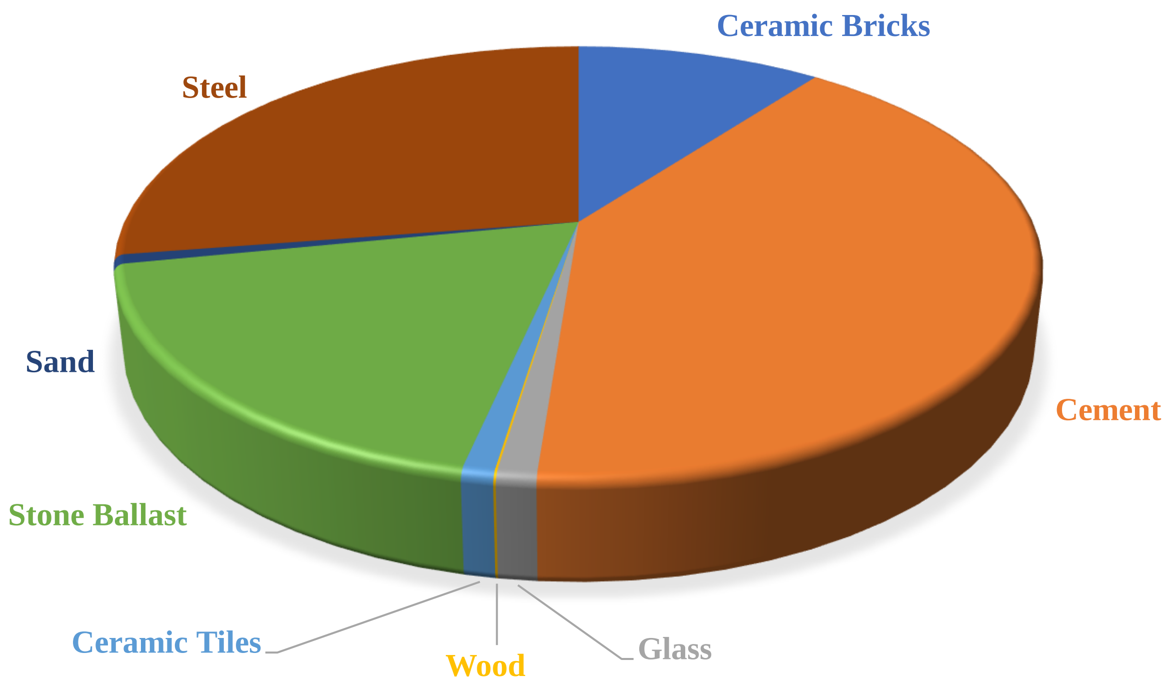


Fig 3. Material Proportion

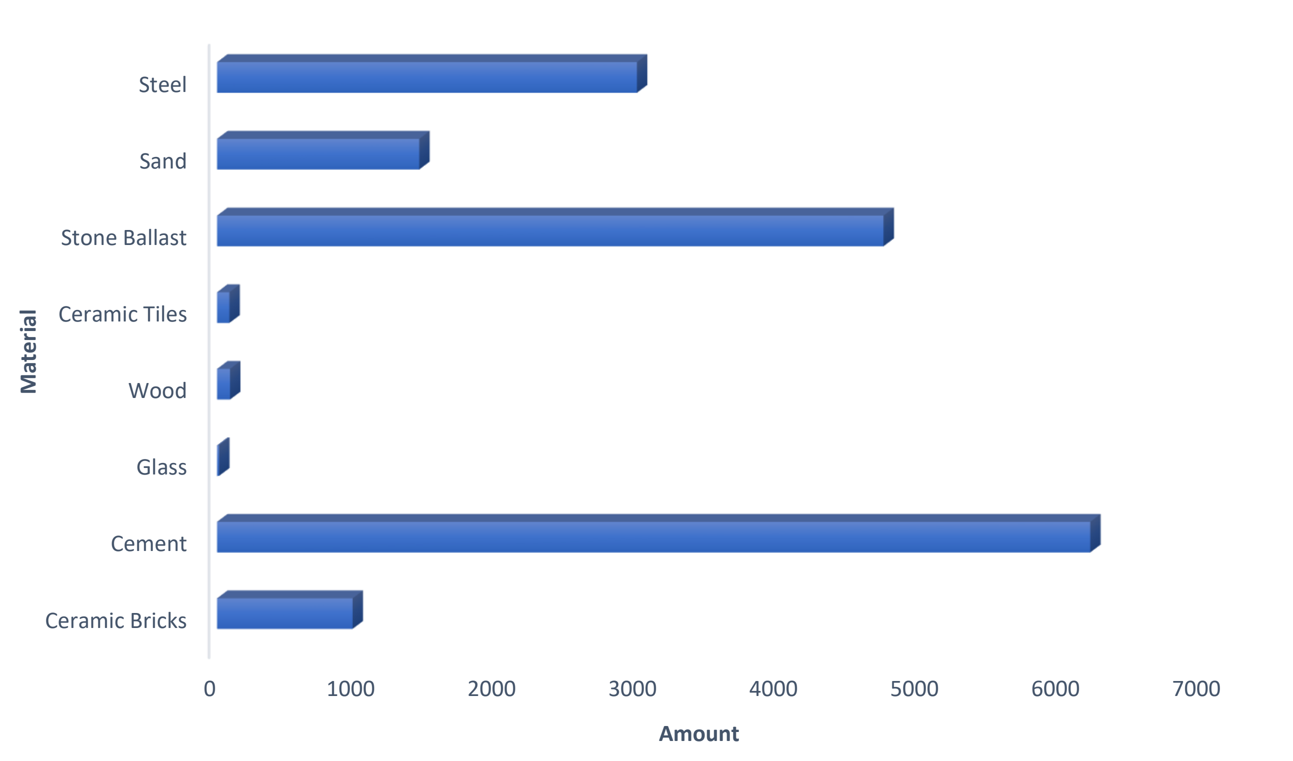
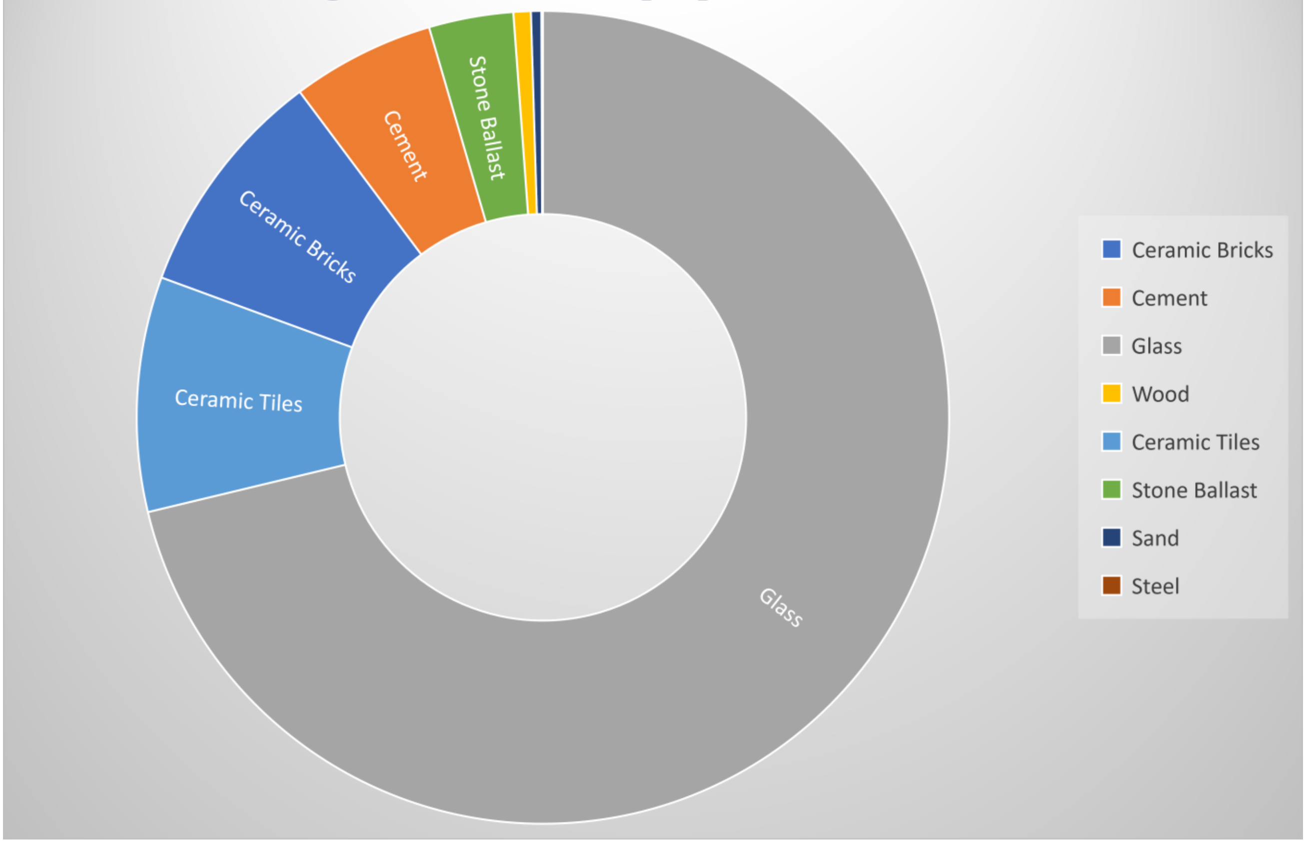


Fig. 4. EE Coefficient proportion of materials



Conclusion

This study aimed to determine the overall energy required to construct an educational building in Kolkata. With the proper estimation methodology, we were successfully able to calculate the total energy requirements of various materials required in our building design plan using the EE factor. We have also been successful in determining the amount of material required for the construction.

The total embodied energy of the building was found out to be 43934454.29 MJ. In this total energy the major components were of Steel (13287313.032 MJ), Cement (19818272 MJ) and Stone Ballast (8934578 MJ). While the minor components were Ceramic Bricks (496042.1 MJ), Glass (568932 MJ), Wood (35739.844 MJ), Ceramic Tiles (460825.05 MJ) and Sand (332752.264 MJ). In case of the EE coefficient of glass is having the maximum EE value of 40060 MJ/m3 while Steel having the lowest i.e., 34.8 MJ/kg.

With extensive review of existing literature, we have been able to find out the embodied energy coefficient for various materials. Further analysis will help us to understand how we can use more eco-friendly materials or alternative materials to minimise the energy requirements. But with the present data of estimation, we can calculate the difference in expenditure for alternate materials. We can also calculate the operational energy of the building and compare how an increase or decrease in EE tends to affect the operational energy of any material.

The materials used in this construction are conventional and easily available, however it requires a huge amount of energy. If we replace it with eco-friendly alternatives, the EE will decrease at the same time increasing overall cost.

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