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Assessment of Embodied Energy for an Institutional Building

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ABSTRACT: ***Today, developing nations are witnessing an unprecedented pace of urbanization in the wake of industrialization and globalization. This is giving rise to an ever increasing demand for housing and infrastructure to support the growing population and its activities. Embodied energy is the energy in total needed in manufacturing and extracting the raw materials, energy consumed for transportation and the external energy applied to raw materials in producing or assembling the final product. In this project, Energy accounted in different material used for construction of this building is calculated. All the material used for construction is accounted and Embodied energies of different materials has been worked out. The Embodied energy calculation arrived based on energy consumed for production and Transportation. With the estimated total quantity of all the materials and the energy, an analysis about the major contributors of embodied energy has been studied and comparisons have been made across different materials between the production and transportation energies. The values have been normalized and a tool has been made on a platform called Spyder to generate the embodied energy calculation for the provided inputs. Suitable alternative material, which consumes less Embodied energy is suggested.***

KEY WORDS: ***Embodied energy; Production energy; Transportation energy; Alternative.***

I. INTRODUCTION

Over the last decades the term sustainable development has been one of the most discussed topics in our society. In one hand, there is a demanding concern with environmental issues in order to preserving the Earth for the present generation, but also for the next ones. On the other hand, the population growth is expected to increase rapidly in the near future. Between 2011 and 2050 it is estimated an increase of 2,3 billion people (United Nations, 2014). In consequence, the social and economic activities will become more competitive. Associated with the population growth is associated a larger consumption of water, food, energy, and materials and higher values of waste production and CO2 emissions. Currently, more than half of world's population is living in cities and more and more people are expected to migrate from the rural areas to the urban areas.

Buildings are essential for the major socio-economic development of any nation, however they have serious negative environmental impacts in our planet. It is indeed necessary to promote the life quality of the populations without compromising the life quality on Earth. This goal can be achieved by implementing sustainable construction. With sustainable construction it is intended to achieve sustainable development within building industry. To reach this goal, policies that promote sustainability are being implemented all over the world. In fact, recently new standards and methodologies that use a life cycle approach to evaluate buildings environmental impact have emerged. According to the United Nations Environment Programme (UNEP), the use of these methodologies can reduce the energy consumption in buildings from 80 to 30%.

This project assesses the embodied energy of an institutional building by accounting for its production and transportation energy and is used to identify the major contributors of embodied energy in the process and suggest alternative material that helps towards a sustainable environment.

II. SCOPE OF THE PROJECT

The embodied energy emitted from the buildings is an emerging concern with respect to environmental sustainability. There are several practices that could be adopted to minimize this energy, either with respect to the production energy or with that of the transportation energy. In this project, the materials involved in the construction are listed out and their quantities are determined. Assessment of quantities is an important step in the evaluation of embodied energy. The standard production energy coefficients of these materials are calculated and referred. The coefficients are multiplied with the quantity of that material to calculate the production energy of that material. Next by, the energy emitted by the burning of fuels while transporting the materials from the manufacturing plant to the site of construction is measured by taking the mileage of the vehicle that is used for construction, the number of trips made and the distance into consideration. Several comparisons have been made between the production and transportation energy to study about the major contributors of embodied energy.

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Also a tool is developed on a platform called "SPYDER" to assess the embodied energy for any building by providing a few inputs. This would be useful to take precautionary measures. Also the major contributor is replaced with a suitable alternative material with their embodied energy calculation proving to be more efficient than its former.

III. EXPERIMENTAL PROCEDURES

OBJECTIVES

- Analyze and list the materials that are used in the construction of an institutional building and those contribute to embodied energy.
- Compute the production and transportation energies of those materials.
- Based on the results of analysis, alternate material is suggested and a tool for evaluation of embodied energy is established.

Formulae

- Embodied energy = Production energy + Transportation energy
- Production energy = Production energy per unit x Total quantity
- Transportation energy (1) = Total distance/3 X 45.5

EMBODIED ENERGY

Calculation for brick

Material – Brick

Uses in building– Used in construction of wall

Quantity estimation

Weight of 1 brick - 3.5 kg
Total number of brick - 793136
Total Quantity - 2775976 kg

Production process:

Production Energy Calculation

- No of bricks fired in one batch = 20,000 Bricks
- Average of weight of fired brick = 3.21 kg
- Total weight of fired batch = 64,200 kg
- Type of fuel = Wood
- Weight of fuel used in one batch = 12,000 kg
- Calorific value of fuel = 15.54 MJ/kg
- Total energy input = Calorific value of fuel * Weight of fuel used = 186,516 MJ
- Specific Energy consumption = Total energy input/weight of fired batch
- Specific energy consumption = **2.91** MJ/kg fired brick

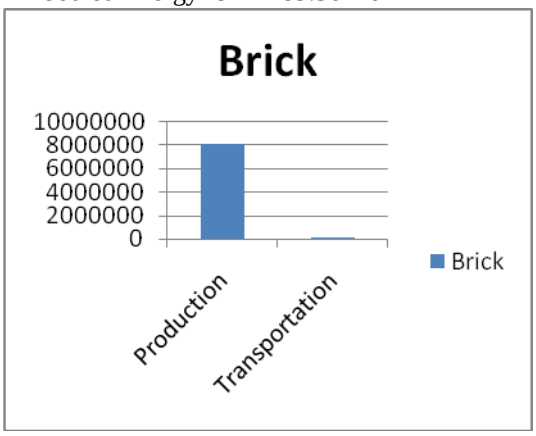
Transportation energy

Place of acquiring: Thirukaatupalli

Distance = 20.2 kms ~ 22 kms
Transportation energy = 333.6 MJ/Kg
= 333.6/13000
= 0.025 MJ/Kg for each trip
Total transportation energy = Quantity x Transportation energy per unit
= 2775976 x 0.025
= 69399.4 MJ

Embodied energy calculation

Production Energy - 2.91 MJ/kg
Transportation Energy- 0.025 MJ/kg
Energy per brick - 2.935 MJ/kg
Weight of 1 brick - 3.5 kg
Total number of bricks- 793136
Total Quantity - 2775976 kg
Total Embodied Energy -8147489.56 MJ



Calculation for cement

Material - Cement

Uses in building – It is used in mortar for plastering, masonry work, pointing etc. It is used in concrete for laying floors, roofs and construction lintels, beams, stairs etc…

Quantity estimation

BEAM

Beam size = 0.3x 0.6 m
Beam volume = 661.072 m3
Total quantity of cement= 403.21 x 661.072 = 266544.23 kg

COLUMN

Column 1 size = 0.3 x 0.45 m
Column 2 size = 0.23 x 0.3 m
Volume of column=176.175 m^3
Total quantity of cement = 403.2 x 176.175= 71033.76 kg

SLAB

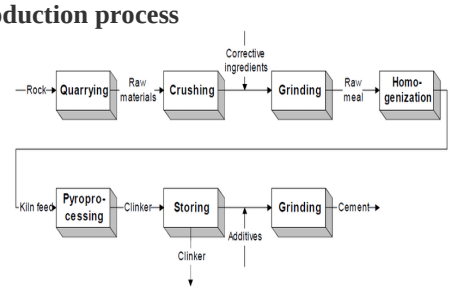
Slab thickness = 0.15 m
Slab volume = 2836.58 m3
Total quantity of cement =403.2x2836.58=1143709.04 kg

WALL

Wall thickness = 0.23 m
Volume of wall= 1788.76 m3
Volume of openings= 202.489 m3

Total volume of wall= 1586.271 m3
For masonry wall taking ratio as 1:5
Volume of cement = 133200 kg
Total quantity of cement
=1481379.53kg

Production process



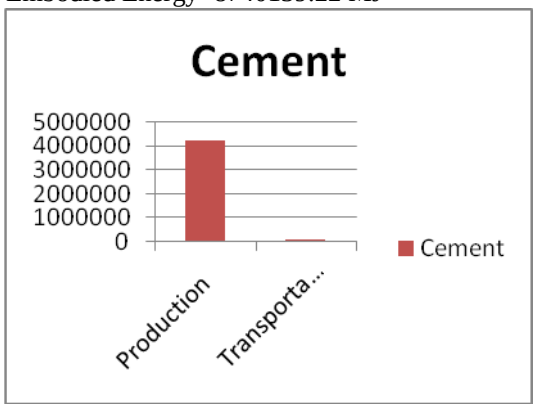
Production energy of cement = 2.85 MJ/kg

Transportation energy calculation

Place of acquiring: Ariyalur
Distance: 49.2 ~ 50 kms (approx.)
Transportation energy = 50/3 x 45.5 = 758.3 MJ/Kg = 758.3/13,000
= 0.0583 MJ/Kg for each trip
Total transportation energy = Quantity x Transportation energy per unit
= 266544.23 x 0.0583
= 15539.5 MJ

Embodied energy calculation

Production Energy - 5.85 MJ/kg
Transportation Energy - 0.0583 MJ/kg
Energy per kg of cement - 5.90 MJ/kg
Total Quantity -1481379.53 kg
Total Embodied Energy -8740139.22 MJ



Calculation for coarse aggregate

Material –Coarse aggregate

Uses in Building: It is used in concrete for laying floors, roofs and construction lintels, beams, stairs etc.

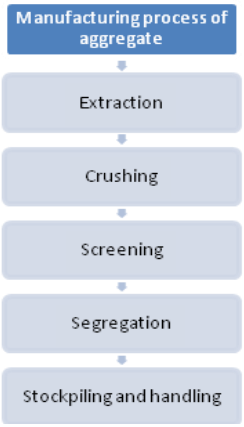
Quantity estimation

BEAM
Beam size = 0.3 x 0.6 m
Beam volume = 661.072 m^3
Quantity of coarse aggregate = 661.072x1310= 866004.32 kg
COLUMN
Column 1 size =0.3 x 0.45 m
Column 2 size =0.23 x 0.3 m
Volume of column =176.175 m^3
Quantity of coarse aggregate= 176.175x 1310= 230789.25 kg
SLAB

- Slab thickness = 0.15 m
- Slab volume = 2836.58 m^3
- Quantity of coarse aggregate = 2836.58 x 1310 = 3715919.8 kg

Total quantity of coarse aggregate = 4812713.37 kg

Production process

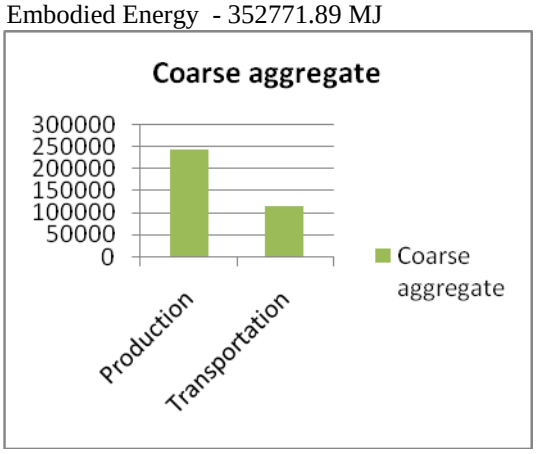


Transportation energy calculation

Place to be acquired: Thanjavur
Distance: 17.8 kms ~ 20 kms
Transportation energy = 20/3 x 45.5 = 0.0233 MJ/Kg for each trip
Total transportation energy = Quantity x Transportation energy per unit= 4812713.37 x 0.0233= 112136.22 MJ

Embodied energy calculation

Production Energy - 0.05 MJ/kg
Transportation Energy - 0.0233 MJ/kg
Energy per kg of CA - 0.0733 MJ/kg
Total Quantity - 4812713.37 kg
Total Embodied Energy - 352771.89 MJ



Calculation for fine aggregate

Material – Fine aggregate

Uses in building: It is used in concrete for laying floors, roofs and construction lintels, beams, stairs etc.

Quantity calculation

BEAM

- Beam size = 0.3 * 0.6 m
- Beam volume = 661.072 m^3
- Total quantity of sand = 661.072 * 672 = 444240.38 kg

COLUMN

- Column 1 size =0.3*0.45 m
- Column 2 size =0.23*0.3 m
- Volume of column=176.175 m^3
- Total quantity of sand = 176.175 * 672

= 118389.6 kg

SLAB

- Slab thickness = 0.15 m
- Slab volume = 2836.58 m^3
- Total quantity of sand = 2836.58 * 672
  = 1906181.76 kg

Production energy= 0 MJ/Kg

Transportation energy calculation

Place to be acquired: Trichy

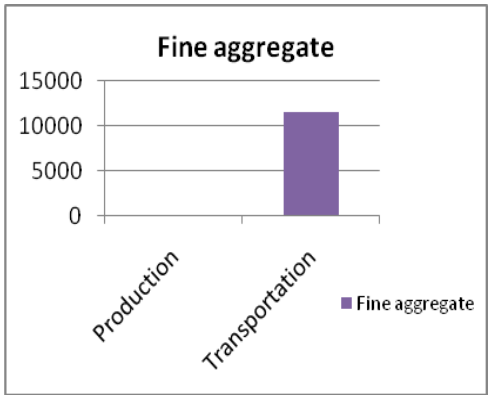
Distance: 39.3 kms ~ 40 kms

Transportation energy = 606.6/13000= 0.0466 MJ/Kg for each trip

Total transportation energy = Quantity x Transportation energy per unit= 11501.42 MJ

Embodied energy calculation

Production Energy - 0 MJ/kg
Transportation Energy - 0.0466 MJ/kg
Energy per kg of FA - 0.0466 MJ/kg
Total Quantity - 246811.74 kg
Total Embodied Energy -11501.427 MJ



Calculation for steel

Material - Steel

Uses in building: It is used in reinforcements of beams, columns, slab.

Quantity Estimation

BEAM

Total quantity of steel = 661.072 * 120
=79328.64 kg

COLUMN

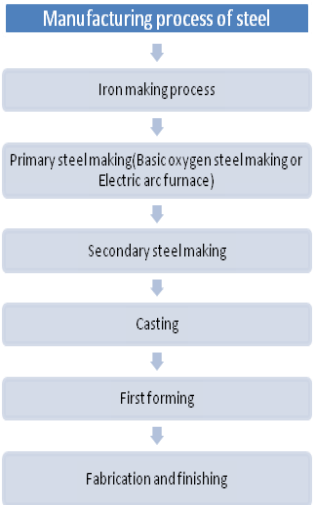
Total quantity of steel = 176.175 * 120
=21141 kg

SLAB

Total quantity of steel = 2836.58 * 100
= 283658 kg

Total quantity of steel = 384127.64 kg

Production process



Production energy = 42 MJ/kg

Transportation energy calculation

Place of acquiring: Salem

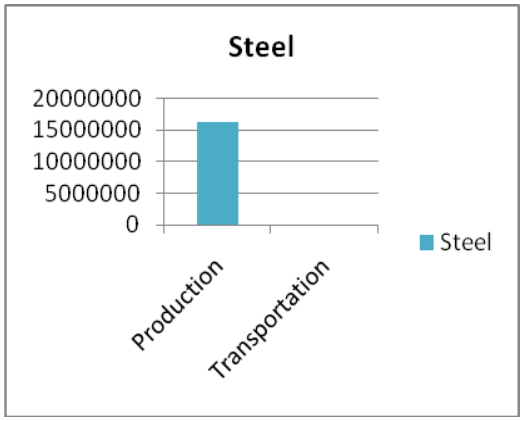
Distance: 185.4 ~ 190 kms

Total transportation energy = Quantity x Transportation energy per unit

= 384127.64 x 0.221 = 84892.2 MJ

Embodied energy calculation

Production Energy - 42 MJ/kg
Total Quantity - 384127.64kg
Total Embodied Energy-16218253.09 MJ



Calculation for Glass

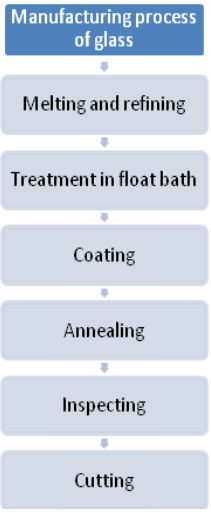
Material - Glass

Uses in building: It is used in windows of the building.

Quantity estimation

Total weight of glass = 3184 kg

Production process



Production energy = 25.8 MJ/kg

Transportation process

Place of acquiring: Chennai

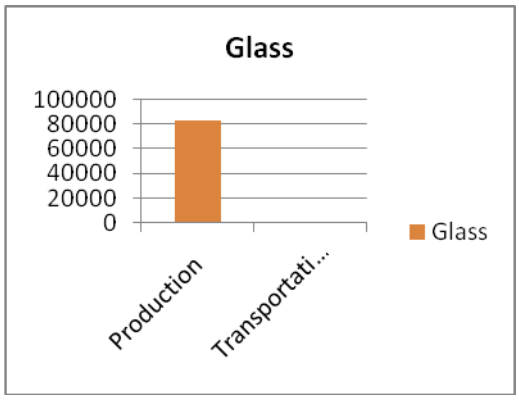
Distance = 364 kms ~ 370 kms

Total transportation energy = Quantity x Transportation energy per unit= 3184 x 0.4316 = 1374.2 MJ

Embodied energy calculation

Total Quantity -3184kg

Total Embodied Energy -83521.414 MJ



Calculation for Aluminum

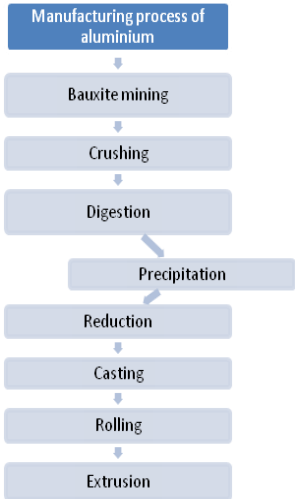
Material- Aluminum

Uses in building: Partitions for segmentation

Quantity assessment: Aluminum partitions (5kg/sq.m)

Total Weight of Aluminum = 1450 kg

Production process



Production energy = 236.8 MJ/kg

Transportation energy

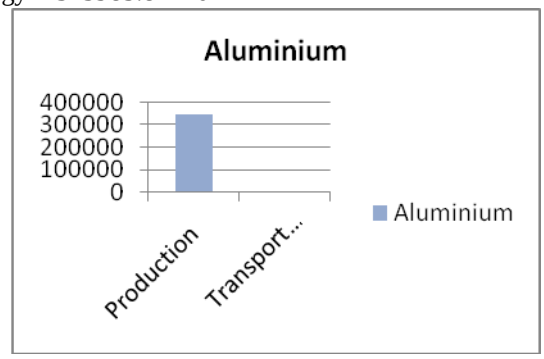
Place of acquiring: Madhavaram

Distance = 365.5 kms ~ 370 km

Total transportation energy = Quantity x Transportation energy per unit= 1450 x 0.4316= 625.82 MJ

Embodied energy calculation

Total Quantity = 1450 kg Total Embodied Energy = 343985.82 MJ



Calculation for Galvanized iron

Material – Galvanized iron

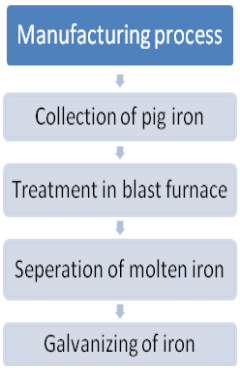
Uses in building: Used in exhaust pipe fittings and in vents

Quantity estimation

Exhaust in restrooms

Total weight = 3750 kg

Production process



Transportation energy

Place of acquiring: Dharapuram

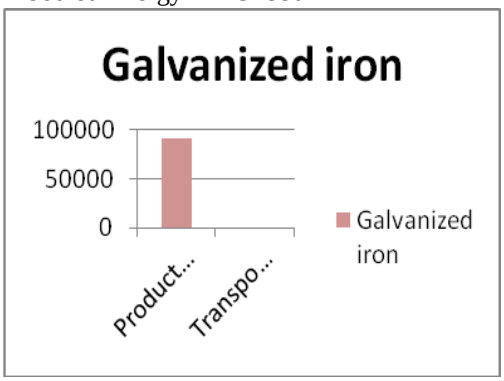
Distance = 222 kms ~ 230 kms

Total transportation energy = Quantity x Transportation energy per unit= 1005 MJ

Embodied energy calculation

Total Quantity = 3750 kg

Total Embodied Energy = 92880



Calculation for Timber

Material - Timber

Uses in building: It is used in windows and doors of the building

Quantity estimation

Dimension of pane of window= 1.82 x 0.52 m

Total volume of timber for windows = 27.7 m^3

Doors

Total volume of timber = 31 m^3

Total weight of timber = 22,000 kg

Production process

Production energy = 3 MJ/kg

Transportation energy calculation

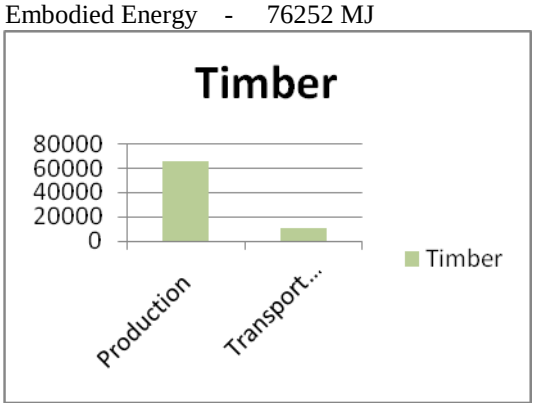
Place of acquiring: Chittoor

Distance = 387 ~ 400 kms

Total transportation energy = Quantity x Transportation energy per unit = 22000 x 0.466= 10252 MJ

Embodied energy calculation

Total Embodied Energy - 76252 MJ

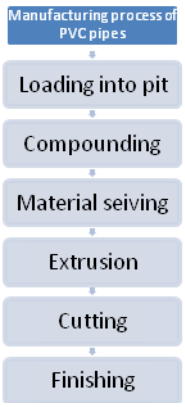


Calculation for PVC Pipes

Material – PVC

Use in building: Piping and plumbing works.

Production process



Quantity estimation

Gent's restroom

Total weight of pipe in Gent's restroom = 4680.315 Kg

Ladies restroom

Total weight of pipe in Gent's restroom =3762.04 Kg

Total weight of PVC pipe = 8441.34 Kg ~8700 Kg (with miscellaneous additions)

Production energy = 67.95 MJ/Kg

Transportation energy calculation

Place of acquiring: Tirunelveli

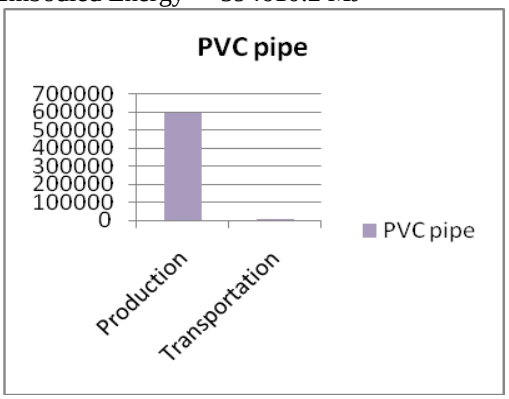
Distance = 337 kms ~ 340 kms

Total transportation energy = Quantity x Transportation energy per unit=8700 x 0.396= 3445.2 MJ

Embodied energy calculation

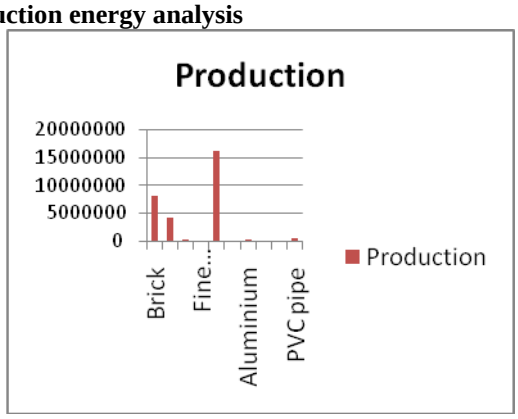
Total Quantity - 8700 Kg

Total Embodied Energy - 594610.2 MJ

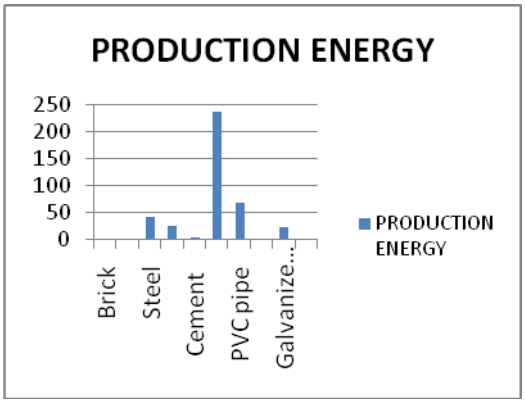


RESULTS AND DISCUSSIONS

Production energy analysis

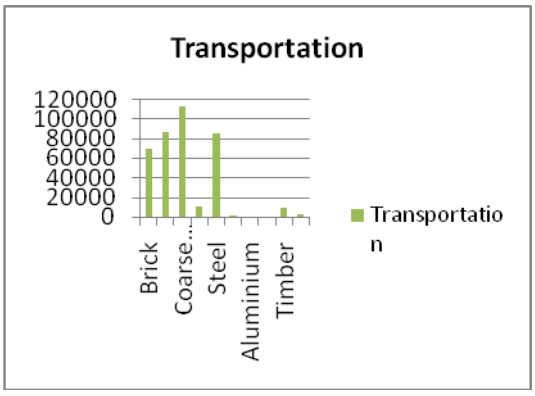


Total Production energy analysis



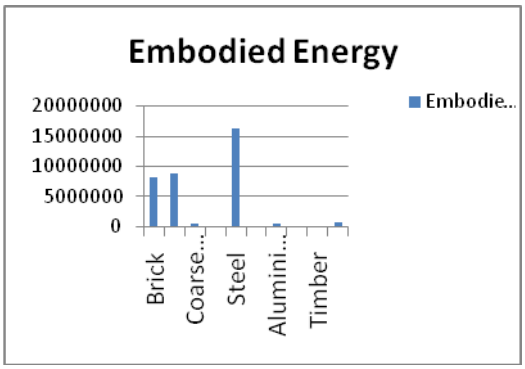
Production energy analysis

Transportation energy analysis



Total Transportation energy analysis

Embodied energy analysis



Embodied energy analysis

- Despite the fact that the production energy of Aluminium is comparatively higher than that of others, on mass analysis it does not majorly contribute to energy released.
- On the similar pattern, due to the quantity of coarse aggregate that is used, the transportation energy is more. But due to the very less production energy it is counter balanced.
- With that the major contributor of energy to the surroundings is from Steel, while suggesting replacement for materials that are major contributors, there is no viable replacement for steel.
- Thereby next significant contributor brick can be replaced by fly ash bricks.

Calculation of embodied energy for fly ash bricks

Size of fly ash brick = 0.23 x 0.11 x 0.07 m

Total Quantity =2.6x689413 = 1792473.8 kg

Production energy = 0.89 MJ/kg

Transportation energy calculation

Place of acquiring: Trichy

Distance = 45 kms

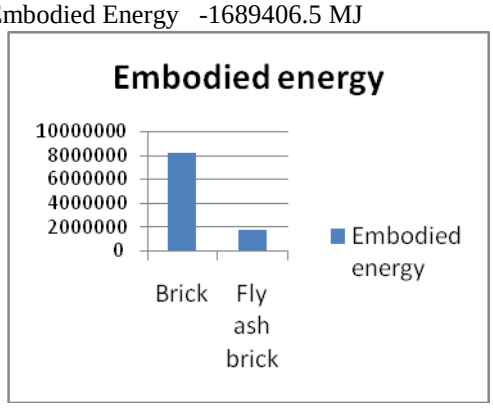
Total transportation energy = Quantity x Transportation energy per unit

=1792473.8 x 0.0525= 94104.8 MJ

Embodied energy calculation

Total Quantity - 1792473.8 Kg

Total Embodied Energy -1689406.5 MJ



Energy comparison between brick and fly ash brick

IV. CONCLUSION

In this project an extensive quantity analysis and embodied energy analysis has been done for all the materials involved in the construction of an institutional building. The results showed us the major contributors of energy. Taking that into consideration and in the aim to reduce the embodied energy alternative material to a major contributor has been suggested without impacting the structural strength too. Thereby, conventional bricks are replaced by fly ash bricks which have considerably reduced the embodied energy to about 79.26%.Also a custom embodied energy calculator has been designed based on the results obtained, using a tool named "SPYDER". This can be used as a tool to calculate the embodied energy involved in the construction prior to the commissioning of the work.

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