2009-04-01

Embodied Energy Analysis: a Sustainable Construction Design Assessment Tool

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Recommended Citation

Acquaye, A., Duffy, A., Basu, B. (2009). Embodied energy analysis: a sustainable construction design assessment tool. *Engineering Sustainability: Innovations that spans boundaries; Conference Proceedings*, Pittsburgh, USA, April 19-21.

Engineering Sustainability 2009
Pittsburgh, PA
April 19-21, 2009

Extended Abstract

EMBODIED ENERGY ANALYSIS: A SUSTAINABLE CONSTRUCTION DESIGN ASSESSMENT TOOL

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Abstract:
Embodied energy analysis can be used as a construction design assessment tool in a sustainable matrix for a building. Its implementation however remains challenging mainly because of data measurement errors. A comparison between the deterministic embodied energy (EE) of a building and the stochastic EE of the same building undertaken using Monte Carlo simulation showed a wide variation in results. It is recommended that the specification of EE intensity of building materials in the construction industry can assist in producing accurate and more credible EE values of building.

Introduction and Background:
The Irish government published the energy white paper in 2007 entitled ‘’Delivering a Sustainable Energy Future for Ireland’’. The energy white paper describes the actions and targets of the national energy policy framework up to 2020. The energy policy was driven by three key objectives namely; improving security of supply, ensuring international competitiveness and delivering environmental sustainability. The building and construction sector has been identified as one of the key areas where energy use needs to be tackled in order to achieve the objectives set out in the white paper.

Historically, the construction industry has played a significant role in the Irish economy. A United Nations Economic Commission for Europe reported that between 2004 and 2007, Ireland had the highest rate of construction activity of all OECD countries. It is therefore apparent that to achieve the goals set out in the national energy white paper, energy use in the construction sector must be reduced especially since a strong link has been established between energy use and global warming. Energy use in the construction sector can be classified as operational energy or embodied energy. Embodied energy (EE) is the energy consumed by all the process associated with the production of a building. The energy embodied in building materials and buildings can be quiet significant but have been neglected in most energy assessments of buildings mostly because of the difficulty and complexity in calculations (Mumma, 1995). Historically, its been held that the embodied energy typically comprised about 10% of a buildings total life cycle energy use (Hellingsworth et al, 2002) although contemporary research has shown that this can be higher. Research carried out by the Commonwealth Scientific and Industrial Research Organisation, CSIRO (2006) also showed that as buildings become more energy efficient in their operations, the EE approaches half the lifetime energy consumption. By effectively measuring and analysing the energy embodied in buildings and the energy intensity of activities in the construction sector, policymakers can design effective initiatives to combat impacts on the construction sector.

This research is motivated by the following:
i. Methodological and statistical analysis of the energy embodied in buildings could provide an effective way of quantifying the effects of construction activities on the environment
ii. Evaluating energy use in the construction sector and energy embodied in buildings can provide a useful measure when formulating policies and regulatory standards.

In this paper;
i. A systematic analysis of quantifying the energy embodied in a residential building in Dublin, Ireland is presented.
ii. The energy intensity distribution of the building which accounts for energy intensity measurement error is derived
iii. Initiatives needed to accurately specify EE of buildings and measures to reduce energy embodied in buildings are suggested

Approach / Experimental:
A hybrid EE assessment used to calculate the energy embodied in buildings is presented. This hybrid EE technique is used to calculate the energy embodied in a typical residential building in Ireland. The hybrid EE assessment combines process analysis and input-output analysis which also employs construction sub-sector direct energy analysis.

A Monte Carlo simulation is carried out on the EE intensity of the buildings. The stochastic model used in the Monte Carlo simulation is given by:

$$\text{HEEI} = \frac{\left[\sum_{x=1}^{n} M_x e_x\right] + \left[i_{i-o}\sum_{j=1}^{5} S_j + \sum_{j=1}^{5} i_{dj} S_j\right]}{\sum_{s=1}^{5} S_i + C_p}$$

Where:

M = Mass of the main building materials, x to n
e = process energy intensity of the building materials
$i_{i\text{-}o}$ = Input-output indirect energy intensity of construction
S = Expenditure of each construction sub-sector, j of activities associated with the construction of the building
C_p = Cost of main building materials analysed using process energy intensity inventory
i_{dj} = direct energy intensity of sub-sector j

The results of the 2500 iterations of the stochastic hybrid EE model were used to derive a distribution of the EE intensities of the building. The mean, standard deviation and other statistical parameters of the energy embodied in the building were derived from the distribution.

Measures which when implemented can help to improve the accuracy of calculated embodied energy values of buildings are suggested. Policy measure which can help mitigate potential energy related environment impacts are also recommended.

Results and Discussion:

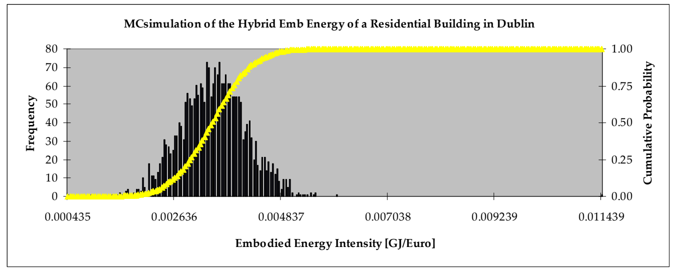
The construction sector in Ireland was sub-divided into sub-sector 1-5 and the direct energy intensities were derived using input-output based approach. The direct energy intensities of these sub-sectors ranged from 0.000374 GJ/€ for sub-sector 3 representing building and electrical installations, plumbing, etc to 0.004487GJ/€ for sub-sector 5 representing use of construction machinery and equipments. The most dominant sub-sector however was sub-sector 2 which has a direct energy intensity of 0.000889GJ/€ representing civil, structural and construction works, etc.

In the hybrid EE analysis, process analysis was used to calculate the energy intensities of the main building materials used in the construction of the building while an input-output approach was used to calculate energy intensities of other cost associated with the construction of the building.

The hybrid energy intensity of the case study building was calculated to be 0.006225GJ/€.

On analysing the output of the stochastic EE model using Monte Carlo simulation, it was determined that the EE distribution for the residential building was normally distributed and the EE intensities ranged from 0.001052GJ/€ to 0.009379J/€. The mean EE was calculated to be 0.003425GJ/€ with a standard deviation of 0.000692GJ/€. It was observed that the EE intensity of the case study building in Dublin fell within four standard deviations of the mean of the EE distribution.

Figure: The diagram below shows the EE profile of residential buildings in Ireland generated using Monte Carlo simulation.



While the deterministic EE of the building fell within the range of the stochastic EE intensities of the building, the variation poses questions about measurement errors in quantifying the energy embodied in buildings. The Inventory for Carbon and Energy, version 1.6a (SERT, 2008) which is one of the most comprehensive energy intensity database (RICS, 2008) available for instance quotes an embodied energy range of +/-30% for two of the most commonly used building materials; steel and concrete. It is expected that when EE intensity of building materials is known to a higher degree of accuracy, the deterministic EE of the building will fall within a smaller stochastic range.

Summary and Conclusions:

By using Monte Carlo analysis to simulation EE values of a building, it was observed that measurement errors in EE intensities of building materials and input-output data remains a big hindrance in accurately quantifying the energy embodied in buildings. It is recommended that specification of the energy intensity of building materials should become an industry requirement if it is to be an effective sustainable construction design assessment tool. In this way, material selection can play an important role in reducing the EE of buildings. Sustainable building design and energy efficiency initiatives targeted at specific construction sub-sector can assist to reduce overall energy use in the construction sector.

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