A Review on Life Cycle Energy Analysis of Buildings- Methods and Scenario

AyeratharasuRajasekharan. K
Research Scholar, School of Civil Engineering,
VIT University, Vellore, India

Porchelvan.P
Senior Professor in Environmental Engineering Division
School of Civil Engineering,
VIT University, Vellore, India

Abstract- Construction industry is one of the major industries which consume large amount of energy. Life cycle energy analysis (LCEA) of a building includes its initial embodied energy, operational energy and recurrent embodied energy. Embodied energy comprises direct need of energy to manufacture a product and indirect energy of the materials used in the process. When the service life of the buildings is more, there may be a considerable increase in recurrent embodied energy. Process Analysis, Input-Output Analysis and Hybrid Analysis are the major methods of measuring the embodied energy of the building. In construction industry, residential sector are the major contributors of carbon emission. Operational energy use is the major consumer of life cycle energy of the residential building. Embodied energy based retrofit techniques may have a significant benefit in environmental as well as economic aspects. The literature finding shows that energy efficiency practices will reduce the overall life cycle energy demand of the building. It also enhances the sustainability and reduction of Greenhouse gas emissions. Thus the study on life cycle energy analysis of building proves to be vital in the development aspect of the nation.

Keywords: Life Cycle Energy Analysis, Greenhouse Gas Emission, Embodied Energy, Residential Building

I. INTRODUCTION

The world is full of energy. Each and every product in the universe will consume some sort of energy directly or indirectly. Construction industry is one of the major sectors which consume more energy, with infrastructure development taking place all over the world, projects such as high rise buildings, metro rails and other construction projects were highlighted and more energy shall be consumed. Globally 30 – 40% of all primary energy is used in buildings of which residential sectors alone can be over 90%. The type of building and the climatic zone where it is located determines the energy use pattern in buildings. Current scenario of energy consumption in buildings is more during its operational phase for heating, cooling and lighting purposes which paved the way for more energy-efficient buildings and rehabilitate the existing structure to suit for sustainability [1] and also due to usage high embodied energy materials for construction. The generation of energy to fulfill these requirements shall emit more GHGs. The 2014 IPCC assessment report, AR5 (Intergovernmental Panel on Climate Change 2014), estimates that global GHG emissions need to be reduced between 41% and 72% from 2010 levels by 2050 to be likely to keep warming under 2 degrees Celsius [2] and emissions need to be virtually eliminated by the end of the century. Key risks with large magnitude, high probability and/or irreversible impacts include: mortality and morbidity from extreme heat, breakdown of production systems and subsequent food insecurity, decreasing availability of water, loss of marine ecosystem services and inland flooding with severe risks to human health and livelihoods [3], among other risks.

II. LIFE CYCLE ENERGY ANALYSIS

Life cycle energy analysis (LCEA) is a perspective way of quantifying the energy demand of a building across its life time. LCEA of a building typically includes energy demand for manufacturing of materials associated in building, construction technique, operation, maintenance and end-of-life phase of the building. It includes initial embodied energy, recurring embodied energy and operational energy[4] as highlighted in Fig.1. Embodied is the energy embodied in a product comprises the energy to extract, transport and refine the raw materials and then to manufacture components and assemble the product.

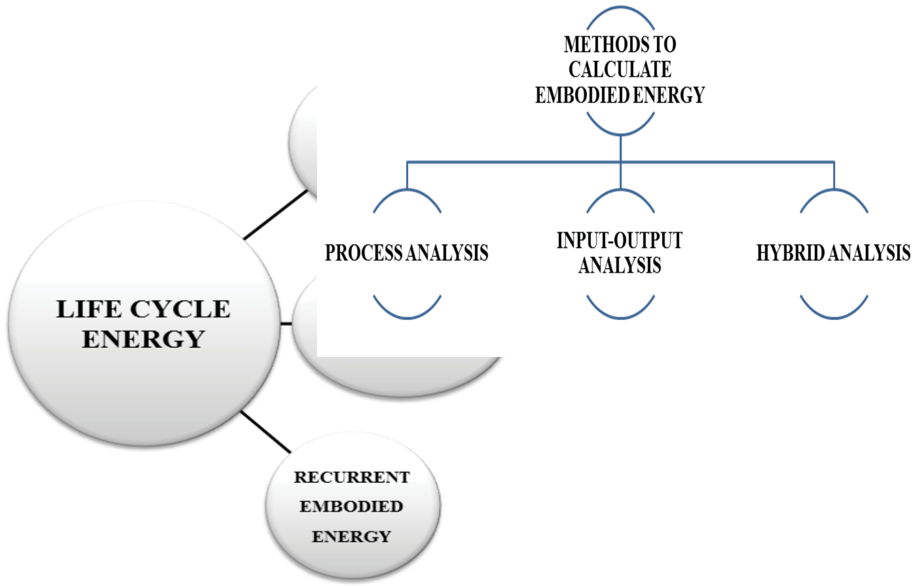

Fig.1. Components of life cycle energy

The total embodied energy comprises the direct energy purchased to support the process under consideration plus the indirect energy embodied inputs to the process. During a building's life the embodied energy is added through goods and services used in maintenance and renovation. These additional provision and replacement materials and works are quantified and valued and is known as the recurrent embodied energy. The operational energy is used for space heating and cooling , hot water heating, lighting, refrigeration[5].

III. MEASUREMENT OF EMBODIED ENERGY OF A BUILDING

Embodied energy analysis of a building may be calculated based on any one of the following methods: Process Analysis, Input-Output Analysis or Hybrid Analysis as in Fig.2. The choice of method is based on accuracy and extent of embodied energy analysis [6].

A. Process Analysis

In process analysis, embodied energy is calculated based on the direct energy required for manufacturing process and the indirect energy embodied in the materials which are used in the manufacturing process (i.e., direct energy of burning the clay bricks in kiln and indirect energy embodied in the clay).

The derivation of embodied energy figures for each individual product of a process generally is not feasible, due to the onerous requirements for record keeping [7]. Some degree of data aggregation is therefore necessary. However, the derivation of different embodied energy figures for short batch runs may be subject to large variations, due to, for example, production run efficiency, raw material source and quality, and conditions requirement of the process[8]. Process analysis excludes large number of small inputs and hence it is incomplete and also very difficult to find all the process involved in manufacturing a product [9].

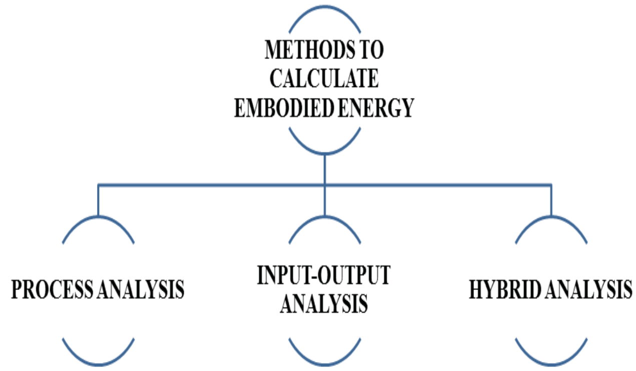

Fig.2. Methods to calculate embodied energy

B. Input-Output Analysis:

Input-Output Analysis (IOA) is an alternative method which depends on nation's economic data which includes most of the sectors which contribute to economy. IOA is based on the original work by Leontief [10] which paved the way for approach to the analysis of economic inter-relationships. Later many researches [11][12][13], developed IOA based on their requirements. Lenzen and Trelor [14] provide a more complete analysis by extending the application of IOA to include capital input to products. Australian Bureau of Statistics [15] developed an Input-Output tables for the Australian economy in the form of 106x106 matrix. The total direct and indirect energy inputs were included in the matrix. This approach provides the total energy requirements for every dollar output of industrial sector.

The direct and indirect energy intensities for the appropriate sector for the product is done in the following ways: (i). Price of the product or estimate of the building is obtained, (ii). Input-Output tables from Australian Bureau of Statistics, (iii). Energy data from Australian Bureau of Agricultural and Resource Economics (ABARE), (iv).Both (ii) and (iii) are combined to develop an energy – based input-output model of the economy, (v).The input-output tables are divided into the sectors of Australian economy. Each one of the economic sector has a respective direct energy intensity and total energy intensity, both quantified in GJ/$100 of product [16]. This Input Output Analysis is more complete system than process analysis. Pullen [17] estimated that the Embodied energy co-efficient derived from IOA may be around ± 20%.

C. Hybrid Analysis

Bullard et al [18] proposed combination of process analysis and input-output analysis by overcoming many disadvantages of both analysis techniques. Many advanced research have been going in Australia and two types of hybrid analysis have been defined by Trelor et.al [19] and later by Crawford [16] namely input-output hybrid analysis and process hybrid analysis. In process based hybrid analysis, hybrid energy intensity (GJ/unit) figure was calculated based on Bullard et al [18] and quantities of materials were from obtained from process analysis or from BOQ. In input-output based hybrid analysis, relevant sector of economy of a product is determined and its energy intensity is calculated from the input-output model developed by Trelor [6].

IV. SCENARIO OF LIFE CYCLE ENERGY ANALYSIS (LCEA)

Considering the construction sector, residential buildings are the major contributors of carbon emission [20]. In residential buildings, operational energy use is the largest consumers of life cycle energy than embodied energy of materials used in the building [21]. Based on a study in India, Embodied energy of a building is about 11% of operational energy and this embodied energy is equivalent to about 9 years of operational energy requirement.

Considering the materials used for construction, steel is accounted for maximum initial embodied energy followed by cement and brick. Also most of the operational energy is used for space cooling and lighting [22].

In Spain a study on energy consumption of building before and after refurbishment of different rehabilitation strategies shows nearly 91% of embodied energy consumption can be decreased by adopting a strategy and type of finish of the ventilated façade [23]. Based on the LCEA of residential apartment in china shows a change in orientation of a building to a particular direction may have a life cycle energy savings of around 267.1 MWh and the reduction in life cycle CO2 emission may be of 297 ton [24].

An energy efficient based retrofit technique shows a significant benefit in environmental as well as economic aspects [25]. Construction of walls in a building plays a major role in contributing overall embodied energy of the building. When comparing the Insulated concrete form (ICF) wall system and cavity wall system, the mean electricity consumption of cavity walls are 16 % more than the ICF wall system during the use phase of the building. Also, Greenhouse gas emission for the entire life cycle of the building for cavity wall system is 11% more than the ICF wall system [26]. Wooden wall cladding with straw bales between I- joists will enhance a significant energy efficient practice [27].

A study in South Africa, insisted that straw bale construction has more striking advantages in environmental and embodied energy perspective [28]. Cork flooring with straw bales insulation proves to be environmental friendly and optimum for green building concepts. Also straw bales insulation for roof construction may be more sustainable alternative to conventional way of construction and it enhance reduction in CO2 emission and embodied energy as in fig.3, preferable physical and thermal parameter which indirectly reduce operational energy use [27]. The increase in service life of buildings will significantly lower the overall life cycle energy demand despite increase in recurrent embodied energy [4].

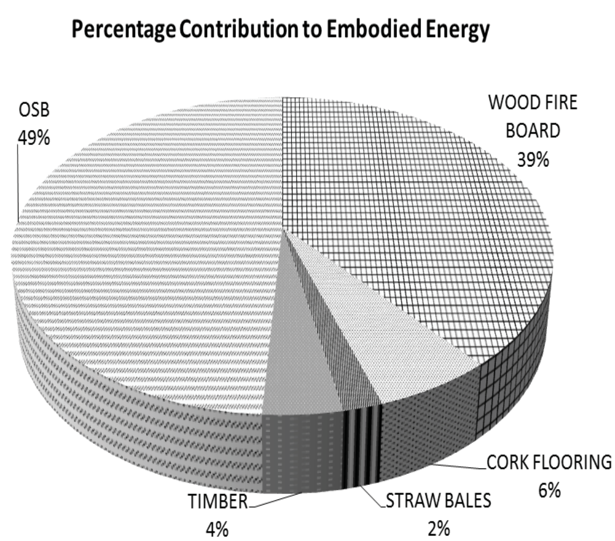

Fig.3. Comparison of embodied energy by different materials

V. CONCLUSION

The literature finding shows that energy efficiency practices will reduce the overall life cycle energy demand of the building. It also enhances the sustainability and reduction of Greenhouse gas emissions. Thus the study on life cycle energy analysis of building proves to be vital in the development aspect of the nation.

REFERENCES

[1] Buildings and climate change-Status, Challenges and Opportunities, United Nations Environment Programme, 2007, ISBN: 978-92-807-2795-1

[2] Edenhofer et al., "IPCC,2014:Summary for Policymakers, In Climate Change 2014, Mitigation of Climate Change Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change".

[3] Field et al. "Climate Change 2014: Impacts, Adaptation and Vulnerability: Summary for policymakers".https://ipcc-wg2.gov /AR5 /images/uploads/IPCC_WG2AR5_SPM_Approved. pdf, November 23,2014

[4] Abdul Rauf, Robert H. Crawford, Building service life and its effect on the life cycle embodied energy of buildings, Elsevier, Energy 79 (2015) 140-148

[5] Roger Fay, Graham Treloar and Usha Iyer-Raniga, Life-cycle energy analysis of buildings: a case study, Building Research & Information (2000) 28(1), 31-41

[6] Treloar, G.J. Extracting Embodied Energy paths from Input-Output Tables: Towards an Inuput-Output Based Hybrid Energy Analysis Method, Economic Systems Research, 9(4), 375-391, 1997.

[7] Boustead, I. and Hancock, G.F., Handbook of Industrial Energy Analysis, Ellis Horwood Limited, Chichester,1979.

[8] Sinclair, T., Energy Management in the Brick and Ceramics Industry, Report No. 646, Commonwealth of Australia National Energy Research, Development and Demonstration Program, Department of Resources and Energy, Canberra, 1896

[9] Lave, L.B., Cobas-Flores, E., Hendrickson, C.T., and McMichael. F., Life-Cycle Assessment: Using Input-Output Analysis to Estimate Economy-Wide Discharges, Environmental Science and Technology, Vol. 29, No. 9, pp. 420A-426A, 1995

[10] Leontif.W., The Structure of the American Economy, 1919-1939, Oxford University Press, U.K., 1941.

[11] Bullard.C, Herendeen.R.,The Energy cost of goods and services, Energy Policy 3(4) 268-278, 1975

[12] James.D, The Energy Content of Australian Production, Research paper no.208, School of Economic and Financial Studies, Macquaine University,April 1980, ISBN No. 0858374137.

[13] Lenzen M, Environmentally Imp. Paths, Linkages and Key sectors in the Australian Economy. Structural Change and Economic Dynamics, Vol.14(1), pp 1-34. 2003

[14] Lenzen and Treloar G, Endogenising Capital: A Comparison of Two Methods, Journal of Applied Input-Output Analysis, Vol.10,pp.1-11,2004

[15] Australian Bureau of Statistics, 1996, Australian National Accounts, InputOutput tables 1992-93,Table 9,Direct Requirements co-efficients, Australian Bureau of Statitics, Cat.No.5209.0AGPS,Canberra.

[16] Robert.H.Crawford, Graham.J.Treloar, Validation of The Use of Australian Input-Output Data For Building Embodied Energy Simulation, Eighth International IBPSA Conferenece, Eindhoven, Netherlands, 2003

[17] Pullen S, Data Quality of Embodied Energy Methods, Proceedings of Embodied Energy: The current state of play seminar, Deakin University, 28/29 November.

[18] Bullard C, Penner P and Pilati D, Net energy analysis: Handbook for combining process and input-output analysis, Resource and Energy.1,267-313,1978

[19] Treloar G, Lave P, Holt G, Using Input-Output Data for Embodied Energy Analysis of Individual Residential Buildings, Construction Management and Economics 19, pp.49-61,2001a.

[20] Jukka Heinonen , Antti Säynäjoki, Seppo Junnila, A Longitudinal Study on the Carbon Emissions of a New Residential Development, Sustainability 2011, 3, 1170-1189; doi:10.3390/su3081170

[21] Nathaniel Aden, Yining Qin, David Fridley, Lifecycle Assessment of Beijing-Area Building Energy Use and Emissions: Summary Findings and Policy Applications, Ernest Orlando Lawrence Berkeley National Laboratory, September 2010.

[22] Talakonukula Ramesh, Ravi Prakash, Karunesh Kumar Shukl, Life Cycle Energy Analysis of a Multifamily Residential House: A Case Study in Indian Context, Open Journal of Energy Efficiency, 2013, 2, 34-41, March 2013.

[23] Xabat Oregi Isasi, Patxi Hernandez Inarra, Cristina Gazulla Santos, Eneko Arrizabalaga Uriarte, Optimization of the Refurbishment of the envelope throughout its life cycle, Central Europe towards Sustainable Building 2013

[24] Jian Yao, A Multi-Objective (Energy, Economic and Environmental Performance) Life Cycle Analysis for Better Building Design, Sustainability 2014, 6, 602-614; doi:10.3390/su6020602

[25] Moncef Krarti, Case study on analysis of economical and environmental benefits of promoting energy efficiency in buildings, Economic and Social Commission for Western Asia, United Nations Development Account Project

[26] Reza Broun , Hamed Babaizadeh, Abolfazl Zakersalehi , Gillian F. Menzies, Integrated Life Cycle Energy and Greenhouse Gas Analysis of Exterior Wall Systems for Residential Buildings, Sustainability 2014, 6, 8592-8603; doi:10.3390/su6128592

[27] Monika Čuláková, Ingrid Šenitková, Optimization of Construction Compositions for Design of GreenBuilding, Sustainability 2011, 3, 1-x manuscripts; doi:10.3390/su30x000x

[28] Marcel Bruelisauer, Sustainable construction in South Africa –Theoretical and practical analysis of sustainable infrastructures in the case study of the Hawequas Straw Bale Accommodation, Diploma thesis in Civil Engineering, June 2007