Energy and Buildings 110 (2016) 211–219

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Embodied and operational energy of urban residential buildings in India

K.I. Praseeda[a], B.V. Venkatarama Reddy[a], M. Mani[b,*]

[a] Department of Civil Engineering, Indian Institute of Science, Bangalore, India
[b] Center for Sustainable Technologies, Indian Institute of Science, Bangalore, India

ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form
24 September 2015
Accepted 30 September 2015
Available online 22 October 2015

Keywords:
Embodied energy
Building materials
Process analysis
Input–output method

ABSTRACT

Globally, buildings consume nearly half of the total energy produced, and consequently responsible for a large share of CO_2 emissions. A building's life cycle energy (LCE) comprises its embodied energy (EE) and operational energy (OE). The building design, prevalent climatic conditions and occupant behaviour primarily determines its LCE. Thus, for the identification of appropriate emission–reduction strategies, studies into building LCE are crucial. While OE reflects the energy utilized in operating a, EE comprises the initial capital energy involved in its construction (material and burden associated with material consumption in buildings. Assessment of EE and OE in buildings is crucial towards identifying appropriate design and operational strategies for reduction of the building's life cycle energy. This paper discusses EE and OE assessment of a few residential buildings in different climatic locations in India. The study shows that share of OE and EE in LCE greatly depends upon the types of materials used in construction and extent of space conditioning adopted. In some cases EE can exceed life cycle OE. Buildings with reinforced concrete frame and monolithic reinforced concrete walls have very high EE.

1. Introduction

Buildings are major consumers of energy. Types of energy use during a building's life cycle comprise embodied energy, operational and maintenance energy, demolition and disposal energy. Embodied energy (EE) represents the total energy consumption for a building construction, i.e., sum of embodied energy of building materials, transportation energy of materials and building construction energy. Embodied energy of building materials represents major contribution to embodied energy in buildings. Appropriate selection of building materials with regard to their embodied energy is crucial for limiting embodied energy of buildings. Use of energy intensive materials such as brick, cement, steel, glass, etc. results in high embodied energy in buildings.

Operational energy (OE) in buildings, resulting mainly from space conditioning and lighting requirements, depends on the climatic conditions of the region and comfort requirements of the occupants. Buildings located in regions experiencing extreme climatic conditions require more operational energy to meet the heating and cooling energy demands. The use of electro-mechanical and/or electric systems for space conditioning and artificial lighting in conventional buildings contributes to high operational energy. Electro-mechanical space conditioners include compressor–chiller based mechanical systems driven by electric motors/pumps. Electric space conditioners primarily include heaters and fans driven entirely by electric power.

A comprehensive analysis of energy consumption in buildings requires estimation of embodied and operational energy. Such an analysis facilitates study of building's life cycle energy to identify appropriate energy conservation measures. Also, the study focused on comparison of embodied and operational energy of typical urban dwellings in different climate zones, to examine the relative significance of these energy components with respect to the dwelling's life cycle energy for a life span of 50 years. Though there is little logical relationship between OE and EE, the current study examines any possible inter-relationships.

2. Earlier investigations

There are several investigations pertaining to life cycle energy of buildings. While a few studies partly focus on aspects of embodied energy in buildings, majority of the studies focus on operational energy, its attributes and measures for conservation. Demolition and disposal energy is rarely addressed in various studies since they

* Corresponding author.
E-mail addresses: monto@astra.iisc.ernet.in, monto@cpdm.iisc.ernet.in (M. Mani).

http://dx.doi.org/10.1016/j.enbuild.2015.09.072
0378-7788/

Table 1
Previous studies on EE of buildings.

Sl. no.	Ref.	Building characteristics	Embodied energy (GJ/m^2)	Salient observations
1	Buchanan and Honey [3]	For a 94 m^2 house	2.32–5.53	Greater use of wood in building construction reduce EE and CO_2 emissions
2	Debnath et al. [16]	For load bearing house with 1 and 2 storeys and a 4 storey RC frame structure (area ranging from 50 to 200 m^2)	3–5	
3	Suzuki et al. [17]	For different types of house constructions in Japan	2.7–10.4	Wooden house has lower environmental impact when compared to steel and RC structure
4	Morel et al. [5]	Small housing project	239 GJ	EE of the studied house is 246% and 240% more than that of a stone masonry house and a rammed house, respectively.
5	Thormark [18]	Initial + recurring EE for 50 years for three different designs of 20 apartments	6.1–7.6	
6	Nässén et al. [15]	Independent building and multi-dwelling building, using I/O analysis	6.2 and 5.8 respectively	
7	Huberman and Pearlmutter [14]	Dormitory complex	3.28–4.91	EE accounted for 60% of LCE for 50 years
8	Monahan and Powell [19]	For three construction types of a low energy house	5.7–8.2	Timber with low EE resulted in low EE of building

Table 2
Previous studies on LCE of buildings.

Sl. No.	Reference	Building characteristics	LCE for 50 years (GJ/m^2)	% Share of different energy components
1	Adalberth [10]	For three prefabricated single-unit dwellings	27.4–31.7	EE – 11 to 12%, Recurring EE – 4 to 5%, OE – 84% and Demolition energy – 0.3 to 0.5%
2	Thormark [20]	Housing complex of 20 apartments	15.24	EE - 46%
3	Mithraratne and Vale [21]	Three residential buildings with light, concrete and super insulation types	17.02, 16.24 and 11.83 GJ/m^2 for 100 years	OE – 74%, 71% and 57% respectively
4	Citherlet and Defaux [22]	Individual house for three different designs	200–580 MJ/m^2/year	
5	Sartori and Hestnes [1]	Residential and non-residential low energy buildings		EE for conventional dwellings – 2 to 38% of LCE, EE for low operational energy buildings – 9 to 46%
6	Utama and Gheewala [23]	Houses with clay brick and concrete based envelopes	12.56 and 13.24 GJ/m^2 respectively for 40 years	EE – 6.7% and 6.2% respectively
7	Utama and Gheewala [24]	High rise residential apartment of 85 m^2 floor area, double wall and single wall envelopes	282.6 GJ and 460 GJ	EE – 28% and 16% of LCE, respectively
8	Ramesh et al. [2]	Residential and office buildings	33–390 kWh/m^2	EE – 7 to 107 kWh/m^2, OE – 0 to 330 kWh/m^2 (80–90% of LCE)
9	Gustavsson et al. [25]	8 storey wooden framed apartment	8074 kWh/m^2	EE – 975 kWh/m^2, OE – 8843 kWh/m^2, Demolition energy – 10 kWh/m^2 and a energy recovery of 1753 kWh/m^2
10	Gustavsson and Joelsson [26]	11 residential buildings	500–1020 kWh/m^2	EE – 45 to 60% of LCE

together form less than 1% of life cycle energy [1,2]. Tables 1 and 2 summarize the earlier investigations on EE and LCE of buildings.

Literature review reveals a wide range of values for EE (1–8.35 GJ/m^2) and OE (0.08–1.19 GJ/m^2/year) for residential buildings. This is attributed to (1) variations in types of materials and building envelope and (2) discrepancies associated with the system boundaries adopted to assess EE of materials. A few studies highlight that wood based constructions and the use of soil based low energy materials lead to significant reduction in embodied energy [3,4]. Also, some studies advocate optimum use of materials/resources and the use of locally available materials as means of conserving embodied energy [5,6]. With regard to