Energy and Buildings 140 (2017) 131–139

Contents lists available at ScienceDirect

Energy and Buildings

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

Balance between energy conservation and environmental impact: Life-cycle energy analysis and life-cycle environmental impact analysis

Ming Hu *

School of Architecture, Planning and Preservation, University of Maryland, ARC 12-7, 3835 Campus Drive, College Park, MD 20742, USA

ARTICLE INFO

Article history:
Received 28 August 2016
Received in revised form 21 January 2017
Accepted 24 January 2017
Available online 4 February 2017

Keywords:
Embodied energy
Operational energy
Adaptive reuse
Environmental impact

ABSTRACT

A comprehensive case study life-cycle analysis(LCA) was conducted on a four-story National Register historic building with a projected 75-year life span located in Medina, New York. Three adaptive reuse options were compared: historic preservation, renovation, and new construction; six different energy performance targets were constructed and compared as well. The study comprises two parts: a life-cycle energy analysis and a life-cycle environmental impact analysis. In this life-cycle analysis, the building assembly group that consumes the most embodied energy was identified, related suitable renovation options were analyzed, and conclusions were drawn based on the results. The aim of the research was to address the balance between energy and environmental benefits and drawbacks for different adaptive reuse options. Four impact categories (global warming potential, ozone depletion potential, human health particulate potential, and smog potential) were measured and their correlation with primary energy demand was analyzed.

1. Background

Every year, buildings in the United States totaling approximately 1 billion square feet [1] are demolished and replaced with new construction. The Brookings Institution projects that some 82 billion square feet of existing space will be demolished and replaced between 2005 and 2030—roughly one-quarter of today's existing building stock [1]. However, few studies to date have sought to examine the balance between the environmental impacts of razing old buildings and erecting new structures in their place, and the energy saved by building new buildings with advanced materials and efficient building systems. Globally, a number of studies have examined the relationship between the embodied energy (i.e., the energy utilized for the creation of the building [8]) and the operating energy of buildings within the buildings' entire life cycle. Buildings consume energy directly or indirectly in all phases of their life cycle, from the cradle to the grave so to speak, and there is interplay between phases of energy use (both embodied and operating energy). Embodied energy is the total energy required for the extraction, processing, manufacture, and delivery of building materials to the building site. Hence, all of these components need to be analyzed from a life-cycle perspective. Bekker [2] highlighted that in the building sector, a life-cycle approach is an appropriate method for analyzing the use of energy and other natural resources as well as the impact on the environment. Subsequently, Adalberth [3] presented a method for describing the calculation of energy use during the life cycle of a building. In a companion paper [4], he applied the method to gain insight into the total energy use of dwellings during their life cycle. In particular, that paper presented case studies of the total energy use of three single-unit dwellings built in Sweden. Adalberth found that 85% of the total energy usage occurred during the operation phase, while the energy used in manufacturing all the construction materials employed in construction, along with the construction itself and renovation, amounted to approximately 15% of the total energy use. The transportation and process energy used during construction and demolition of the dwellings comprised approximately 1% of the total energy requirement. Several other similar studies of residential buildings [5–8] and office buildings [9–11] are reported in the literature. Table 1). shows the range of life-cycle energy analysis (LCEA) and life-cycle environmental impact analysis (LCEIA) research conducted in the past 20 years globally.

Various researchers (e.g., [12–17]) have studied final energy use in the entire life cycle of buildings and have shown that the operation phase contributes significantly to the life-cycle final energy use of buildings. Ramesh et al. [8] conducted a literature review study of

* Corresponding author.
E-mail address: Mhu200@umd.edu

http://dx.doi.org/10.1016/j.enbuild.2017.01.076
0378-7788/

Table 1
Literature Review Summary.

Reference	Case Study no.	Date	Country	Embodied energy only (EE)	Life-cycle energy (LCE)	Life-cycle Impact Assessment (LCIA)	Type of building	Building size	Life span
Adlberth	1–13	1997	Sweden		7600–8800 kWh/m2	Y	Res	–	50
Keoleian et al. [12]	1	2001	USA	Y	Y	Y	Res	2450 sq ft	50
Treloar et al. [13]	4	2001	Australia	10.7 GJ/m2 for 3-stories	Y	–	Res		40
Johansson and Öberg [14]		2001	Sweden		Y	Y	Res		60
Peuportier [15]		2001	France	Account for 10–15%	Y	–	Res		80
Adlberth et al .[16]	4	2001	Sweden	10–30% of LCE	6100–9100 kWh/m^2	Y	–		50
Morrissey and Home [17]		2001	Australia	Y	Y	Y	–		30–75
Marceau and Gajda [18]		2002	USA	Y	Y	Y	–		100
Thomark [19]	4	2002	Sweden	9.7% of LCE	14,913 GJ	–	–		50
Zacharia [20]		2003	Canada	–	–	–	–		35
Norman et al. [21]		2006	Canada		92–109 MJ/m^2/year	–	Res		50
Sartori [22]	60	2006	9 Countries	Y	Y	Y	Res		–
Citherlet and Defaux [23]	3	2007	Switzerland		40–580 MJ/m^2/year	–	Res		–
Xing et al. [24]		2008	China		–	–	Res		50
Huberman and Pear [25]		2008	Israel	60% of LCE	Y	–	–		50
Utama and Gheewala [26]		2009	Israel	–	–	–	Res		40
Shukla et al. [27]		2009	India	–	–	–	Res		40
Blengini[28]		2009	Italy	7% of LCE	999 MJ/m^2/year	–	Res		40
Belusko and O'Leary[29]		2010	Australia	–	–	–	Res		–
Ortiz-Rodrigue. Et al. [30]		2008	Colombia and Spain		–	–	Res		50
Gustavsson and Joelsson [31]		2010	Sweden	45–60% of LCE	7500–11500 KWh/m^2/year	–	Res		50
Carre		2011	Australia	–	–	Y	–		–
Leckner and Zmerureanu [32]		2011	Canada	–	–	–	Res (NZEH)		–
Lyer and Wong	8	2012	Australia	–	–	–	Res		50–100
Aye et al. [33]	1	2012	Australia	–	–	–	Res		50
Gong et al. [34]		2012	China			–	Res		50
Monteiro and Feire [35]		2012	Portugal		800–1600 GJ/m^2/year	–	Res		50
Säynäjoki et al. [36]		2012	Finland		800–1600 GJ/m^2/year	Y	Res		50
Stephan et al. [37]		2013	Belgium	23% of LCE	800–1600 GJ/m^2/year	–	Res		100
Stephan et al. [38]		2014	Lebanon	18% of LCE	800–1600 GJ/m^2/year	–	Res		50
Ji et al. [39]		2014	Korea	–	–	Y	Res		50
Islam et al. [40]		2015	–	–	–	–	–	–	–