Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 75 (2015) 2884 – 2891

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

New life of the building materials- recycle, reuse and recovery

W.Y. Ng[a] , C. K. Chau[a]*

[a] *Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong*

Abstract

Bulk of construction wastes generated through the dismantling process in a building redevelopment project creates many environment problems. Greater efforts are needed to put on the End-Of-Life (EOL) of building materials. Recycling, reusing and recovering of demolished wastes can either help relieve the landfill capacity or 'regain' some energy from existing building materials in order to reduce the embodied energy use for in the next new built building. This paper proposes to use 'energy saving potential' to quantify the amount of energy at the EOL phase that can be made usable in the building new life. Life cycle energy assessment was performed for the end-of-life phase of a high rise concrete commercial building. The energy associated with different waste management strategies was calculated to identify the options that can produce the highest energy saving in embodied energy. Recycling was found to have the highest energy saving potential of 53% while the energy saving potential of reusing was 6.2% and that of incineration was only 0.4%. Recycling strategy should be implemented for the building elements containing large amount of concrete (e.g. upper floor construction). Reusing instead of recycling should be adopted for the building parts with high aluminium content (e.g. windows).

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords : Embodied energy; End-of-life; LCA; high-rise commerical buildings;

1. Introduction

Life cycle assessment (LCA) of buildings has been successfully applied to evaluate the impacts of buildings on the environment and also extended to become decision making tools [1]. Within this

* Corresponding author. Tel.: +852 2766 7780;
E-mail address: chi-kwan.chau@polyu.edu.hk

Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.581

framework, life cycle energy analysis (LCEA) was applied to evaluate all energy uses by a building over its life cycle which mainly consists of manufacturing phase, operation phase and demolition phase [2,3]. In the past and even now, architects and engineers have been highly concerned of the energy consumption during operational phase as it contributed most to the life cycle impacts of conventional buildings [4]. With the advance in low energy or low environmental impact building designs, the environmental impacts or energy consumption of the operating phase becomes substantially reduced. The proportion of energy consumed during manufacturing and demolition phase becomes more significant for the low energy buildings. Thus, focuses have been shifted towards the end-of-life phase of building materials. Recycling of building materials [5,6] could reduce the environmental burden associated with the materials in the building and could reduce the total life cycle energy by 30% [7]. Recycling of steel or aluminium could provide savings in embodied energy by more than 50% [8]. In addition, recycling or reusing of building wastes could reduce the landfill demands. Using recycling concrete could reduce the total quantity of the wastes by 12-15%. Non-inert wastes (e.g. timber, bamboo and packaging waste), which are mainly disposed at landfills, accounted for about 15-18% of all the construction wastes.

Nevertheless, the energy associated with the end-of-life phase was rarely included in most of the LCA studies [4,7,9] as it may only account for a small proportion within building life cycle. It should not be neglected as the real 'life cycle' of a product included loops between several life phases [10]. It is vital to apply this concept to buildings, in particular, those redevelopment projects in old urban areas. Boundary of life cycle energy assessment can be extended to the second or later life of new buildings as recycling, reusing or recovering of the demolished building is associated with the full benefit of recycling at end of life. The life cycle energy analysis (LCEA) conducted for the end-of-life phase is intended to identify waste management strategies that cover most energy, and to provide information for architects on which parts of existing buildings that need to be preserved or reused in lieu of being demolished. Up to now, most of the previous studies only focused on determining the recycling potentials for low rise buildings [7,11,12] and there is a lack of studies focusing on high rise concrete frame buildings. Accordingly, two major objectives were formulated for this paper. First of all, it is intended to examine the potential energy savings by recycling, reusing and recovering the demolition waste of a high-rise commercial building. Second, it is intended to identify the building parts that have highest energy saving potentials and the most appropriate EOL management strategies.

2. Methodology

2.1. Scope and system boundaries

The scope of this study covers the energy associated with different waste management strategies at the End-of-life phase of a building. LCEA was performed to estimate the energy saving potential by recycling, reusing or combusting the construction debris and compare their potentials with those associated with the option of transporting to landfill sites. The studied scenario was a commercial building in Hong Kong with a lifespan of 60 years and would be redeveloped after 20 years of operation. The new embodied energy content in the redeveloped building can actually be reduced by recovering the construction wastes produced during the demolition process. Fig. 1 presents the life cycle phases of a building and the LCEA boundary in this study.

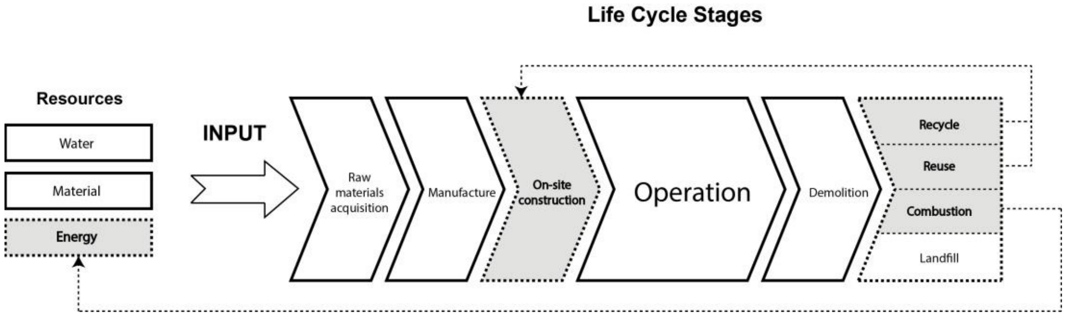


Fig. 1 The life cycle stages and boundary

2.2. Energy saving potential

Energy saving potential of individual building element can be briefly described as the amount of the embodied energy of the redeveloped building that can be recovered by implementing different EOL measures. It is expressed in the form shown in Eq (1).

$$Energy\ potential_i = 1 - \frac{EE_{0,i} - E'_i}{EE_{0,i}} \times 100\% \quad (1)$$

where EE_0 is the original embodied energy [13], EE'_i is the energy associated with different EOL measures: disposing the i building parts to landfill (E_L) and recycling the wastes ($E_{r,i}$), reusing ($E_{u,i}$) and wastes incineration ($E_{c,i}$). All the energy associated with the building parts are equal to the multiples of energy intensities (MJ/kg) of the corresponding process of each building material and the mass (m_i) of the i^{th} type of building material (kg).

2.2.1. Waste disposal to landfill

Energy associated with disposal to landfill can be estimated by Eq (2) [14].

$$-EE_{L,i} = E_{T1} \quad (2)$$

where E_{T1} represents the energy consumed due to transport of the wastes from the site to landfill. Negative sign represents the embodied energy of the redeveloped building that cannot be recovered due to disposal of all materials.

2.2.2. Recycling waste

Feedstock recycling process was assumed in this study. It refers to a process that disassembled material is processed into the feedstock and acted as the substitute for the original natural resources to produce another building material. One of the most common examples for the aggregate from recycled concrete [15]. Most of the building materials, such as concrete, asphalt, bricks, ferrous metal, glass, non-ferrous metal, are recyclable [7,12,16,17].

$$EE_{r,i} = [EE_{0,i} \times (1 - R_i) + (1 - r) * E_{D,i} + (R * E_{proc,i}) + E_{T2i}] \quad (3)$$

Where R_i refers to the recycled content of material to the remaining lifespan of the material, E_{T2} represents the energy consumed during transporting the wastes from the site to recycle factory, $E_{proc,i}$ is the energy associated with the recycling process with the values being shown in Table 1. During recycling process, only a percentage of the recycled materials can be used to replace the raw materials. Thus, the total amount of energy should be multiplied by a percentage of recycled material.

Table 1 Energy intensities associated with the recycling process of different building materials

Building materials	Recycled content [16,18]	Production energy unit for recycle process (MJ/kg) [14,19]
Aluminium	81%	108.6
Asphalt	30%	7.32
Concrete	30%	0.805
Glass	100%	11.9
Reinforcing bar	100%	21.6
Stainless steel	100%	11
Galvanized steel	100%	32.75

2.2.3. Waste reuse (product recycle)

Reusing the building wastes can also be regarded as one of the recycling method - product recycling [14,20]. Some of the building materials (e.g. beams, bricks, glass, etc.) can be reused again without changing their forms or nature. This scenario only consumes a small amount of energy [14]. Here, bricks & blocks, glass, stainless steel, reinforcing bars, plywood and tiles were assumed to be reused.

2.2.4. Waste incineration (waste to energy)

Materials can generate electricity through combustion process. Combustible materials like plywood has a heat value of 16 MJ/Kg [21] .

2.3. Transportation energy

Energy for transport was included in the calculation. It was assumed that the mode of transportation was by medium trucks for land and by general cargo ships for sea. And the energy consumption by different transport modes was extracted from the report prepared by Cambridge systematics [22].

Table 2 Energy intensities associated with transportation

Process	Transport distance (km)
Landfill sites, sites for inert waste	50
Incineration plant in China	150
Reuse/recycling plant	150

2.4. Data acquisition

Thirteen Grade A high-rise concrete framed commercial buildings in Hong Kong were selected to be a base for this evaluation. Information like construction floor areas, and types and quantities of building materials used was extracted from previous records. The units for comparison were based on different building elements and the classification of building elements followed the proposal made by Building Research Establishment (BRE) in the UK. The input datasets for estimating the energy saving potentials was an average value obtained from the generated probabilistic distribution in one of our previous studies [13].

3. Results and discussion

3.1. Energy saving potential of a high rise commercial building in Hong Kong

The average embodied energy of a high rise commercial building was found to 9.4 GJ/m^2 which lies within the range reported in previous studies [23]. Table 3 shows the percentages of embodied energy of materials that could be saved in their second life. Recycling building materials, which could save more than half of the embodied energy, yielded the highest saving among the four strategies. The saving by the other two options was reported to be less than 10%. This implied that structure with high content of concrete should adopt recycling option. Our results further agreed with the previous findings that recycling the building wastes could exert a significant impact on embodied energy [12,17,21].

Table 3 Energy saving potentials of different material end of life management strategy

	Energy saving potential (%)
Landfill	-0.00144
Recycling waste (feedstock recycle)	+ 53.27
Reusing waste (material recycle)	+ 6.22
Waste to energy (incineration)	+ 0.44

3.2. Energy saving potentials for different building elements

Fig. 2 compares the energy potential that can be saved by recycling, reusing and incinerating of the building wastes for different building elements. As shown in Figure 1, recycling the demolition wastes was the most preferred strategy for the three concrete based elements i.e. upper floor construction, external wall and suspended ceiling & finishes. The recycling potential of upper floor construction was found to be even more than 80%. Doors and windows should be reused rather than recycled as more energy could be saved (door: 50% vs 8%; windows: 48% vs 26%). Besides, it is not preferable to recycle windows as they contain a large content of aluminum of high reproducing energy [24,25]. In addition, combustion was found to be another efficient waste management strategy as it can be used as the resources for producing primary energy. The potential was even higher than that of recycling. For the remaining building elements (e.g. floor surfacing & finishes, roof construction, wall finishes internal wall & partitions), recycling and reusing can also be valuable strategies.

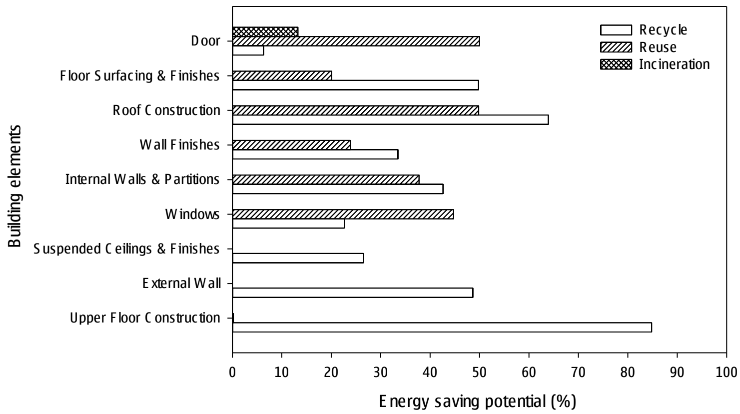


Fig. 2. The energy saving potentials of implementing different strategies in different building elements

4. Conclusion

This study has successfully demonstrated the application of life cycle energy analysis on the end-of-life phase for high rise concrete framed commercial buildings and evaluated the relative impacts of different EOL management strategies on embodied energy. Four different end-of-life management strategies were compared. Recycling of demolished wastes was found to be able to produce the largest amount of savings on the embodied energy of the next new building. Recycling of 'doors' or 'windows' was not considered to be the most favorable option. Our findings could provide more insights for architects or civil engineers to determine the appropriate wastes management option to reduce the environment burden of the new building designs by adopting some recycled/ reused building materials.

5. Copyright

References

[1] Miettinen P, Hämäläinen RP. How to benefit from decision analysis in environmental life cycle assessment (LCA). European Journal of Operational Research 1997;102:279–94.

[2] Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: An overview. Energy and Buildings 2010;42:1592–600.

[3] Cabeza LF, Rincón L, Vilariño V, Pérez G, Castell A. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and Sustainable Energy Reviews 2014;29:394–416.

[4] Adalberth K, Almgren A, Holleris Petersen E. Life-cycle assessment of four multi-family buildings. International Journal of Low Energy and Sustainable Buildings 2001;2:1–21.

[5] Thormark C. A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential. Building and Environment 2002;37:429–35.

[6] Zabalza Bribián I, Aranda Usón A, Scarpellini S. Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. Building and Environment 2009;44:2510–20.

[7] Blengini G. Life cycle of buildings, demolition and recycling potential: a case study in Turin, Italy. Building and Environment 2009;44:319–30.

[8] Chen TY, Burnett J, Chau CK. Analysis of embodied energy use in the residential building of Hong Kong 2001;26:323–40.

[9] Blengini GA, Di Carlo T. The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. Energy and Buildings 2010;42:869–80.

[10] Rebitzer G, Ekvall T, Frischknecht R, Hunkeler D, Norris G, Rydberg T, et al. Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications. Environment International 2004;30:701–20.

[11] Thormark C. Energy and resources , material choice and recycling potential in low energy buildings 2007:1–6.

[12] Vefago LHM, Avellaneda J. Resources , Conservation and Recycling Recycling concepts and the index of recyclability for building materials. "Resources, Conservation & Recycling" 2013;72:127–35.

[13] Chau CK, Hui WK, Ng WY, Powell G. Assessment of CO2 emissions reduction in high-rise concrete office buildings using different material use options. Resources, Conservation and Recycling 2012;61:22–34.

[14] Gao W, Ariyama T, Ojima T, Meier A. Energy impacts of recycling disassembly material in residential buildings. Energy and Buildings 2001;33:553–62.

[15] Topçu İB, Şengel S. Properties of concretes produced with waste concrete aggregate. Cement and Concrete Research 2004;34:1307–12.

[16] Tam VWY, Tam CM. A review on the viable technology for construction waste recycling. Resources, Conservation and Recycling 2006;47:209–21.

[17] Brown MT, Buranakarn V. Emergy indices and ratios for sustainable material cycles and recycle options 2003;38.

[18] Hendriks CF, Pietersen HS. Report 22: Sustainable Raw Materials: Construction and Demolition Waste. RILEM Publication, Cachan Cedex, France; 2000.

[19] Hammond G, Jones C. Inventory of Carbon & Energy: ICE. University of Bath 2011; 2008.

[20] Saghafi MD, Hosseini Teshnizi ZS. Recycling value of building materials in building assessment systems. Energy and Buildings 2011;43:3181–8.

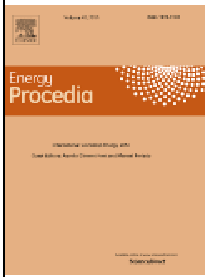
[21] Thormark C. Conservation of energy and natural resources by recycling building waste. Resources, Conservation and Recycling 2001;33:113–30.

[22] Grenzeback LR, Brown A, Fischer MJ, Hutson N, Lamm CR, Pei YL, et al. Freight Transportation Demand: Energy-Efficient Scenarios for a Low-Carbon Future. Transportation Energy Futures Series. Prepared by Cambridge Systematics, Inc., and the National Renewable Energy Laboratory (Golden, CO) for the U.S. Department of Energy, Washington, DC.: 2013.

[23] Yohanis YG, Norton B. Life-cycle operational and embodied energy for a generic single-storey office building in the UK. Energy 2002;27:77–92.

[24] Tyskeng S, Finnveden G. Comparing Energy Use and Environmental Impacts of Recycling and Waste Incineration. Journal of Environmental Engineering 2010;136:744–8.

[25] Edwards DW, Schelling J. Municipal waste life cycle assessment part 1, and aluminium case study. Process Safety and Environmental Protection 1996;74:205–22.



Biography

The biography of the corresponding author. (50 words)

Dr. C.K. Chau is currently an Associate Professor in the Department of Building Services Engineering in the Hong Kong Polytechnic University in Hong Kong. He has been actively involved in studies related to sustainable built environment and green buildings. Besides revealing human preferences for sustainable development, he has conducted many lifecycle assessment studies aiming at reducing the embodied energy and lifecycle environmental impacts of buildings and their constituting elements and components.