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Evaluation of the impacts of end-of-life management strategies for deconstruction of a high-rise concrete framed office building

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HIGHLIGHTS

- Energy savings obtained from various EOL management strategies were estimated.
- Recycling aluminum and external walls achieved the highest energy saving.
- Maximum reuse could save up to 38.5% of the total embodied energy of original buildings.
- The best EOL management strategies varied with types of materials and their life spans.

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ABSTRACT

Recently, greater attentions have been started to put on the end-of-life (EoL) phase of buildings. Recycling, reuse and incineration of deconstructed wastes can help relieve the landfill burden and recover some energy from existing building materials in order to reduce environment impacts and/or reduce energy consumption. Life cycle energy assessment (LCEA) was performed for the EoL phase of a high-rise concrete office building in Hong Kong. The amount of energy that could be saved at the EoL phase through implementation of a specific EoL management strategy was evaluated in terms of energy saving potential (ESP), which was defined as the percentage of energy savings from the salvage materials to the total embodied energy of the building during its initial construction. Recycling of aluminum (30.7% ESP) and recycling of external walls (30.6% ESP) contributed to most of the total energy saving. Maximum reuse provided higher energy savings than maximum recycling (38.5% vs 35.9% ESP), while maximum incineration was not able to bring any energy saving (−44.8% ESP). In addition, the best EoL management strategies for different materials and elements were found to vary with time after taking the remaining proportions of embodied energy into considerations. Implementing the best EoL management strategies for different materials gave an ESP of 54.4% for 50-year life span. The life span of a building exerted considerable influences on the amount of energy saving. Highest energy saving was gained by implementing the best EoL strategies for 70-year life span.

1. Introduction

With the growing awareness of sustainability, numerous efforts have been put on buildings with an ultimate objective to reduce their energy and environmental impacts. Since 1990s, Life cycle assessment (LCA) has successfully been applied in building sector to help evaluate the impacts of buildings on the environment and also integrated into decision making tools [1]. Later, life cycle energy analysis (LCEA) was evolved as a variant of LCA method to evaluate the lifecycle energy flows of buildings [2], building elements, materials and/or services throughout their lifecycle phases. In the past and even now, energy consumption during operational phase has always been the major focus for architects and engineers as it contributed to 70–90% of the total life cycle energy consumption of conventional buildings [3,4]. With the advancement in passive and active energy saving and renewable energy technologies, a new breed of low or zero energy buildings emerges [5–9]. The shrinking contribution of the operational energy to the total consumption of these buildings opens up new opportunities for energy savings during end-of-life (EoL) phase [10].

The concept of deconstruction emerges as a response to the need to reduce the environmental impacts of EoL phase by closing the material loops. Deconstruction is a disassembling process in reverse order to building construction with an objective to cause minimum damages to materials and building elements [11].

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Deconstruction can produce many positive environmental impacts. It can reduce the burden of landfill [12,13] by rendering reuse and recycling of dismantled building components possible and easier [13]. Also it can bring energy savings during EoL phase if appropriate waste management strategies are implemented for treating salvage materials [14–16]. In addition, deconstruction was considered more cost-effective than conventional demolition when the costs of landfill disposal and revenues from salvage materials were also included into consideration [11].

Earlier attempts have been made on estimating the savings brought by EoL waste management strategies of building materials with a major focus on exploring the recycling potentials. Recycling building materials saved about 13% of total energy consumption of a light steel building, and 25% of energy consumption could be saved if both reuse and recycling were adopted [17]. By comparing ratio of emergy in a material to emergy used to recycle, it was determined that there were greater advantages to recycle aluminum and steel (44.7 and 17.0) [18]. On the other hand, reuse softwood framing and hardwood flooring could save energy for primary product production by 6467 and 7763 MJ/m^3 respectively [19]. Besides reuse and recycling of materials from deconstruction, incineration of wastes arising from wood and plastics was shown to produce energy for power plants and heat delivery centers [20–24], though the incineration process itself might release toxic wastes and gases [25,26]. Nowadays, landfill is the most commonly adopted management practice [27,28]. However, it has often been considered to be the least preferred option as it incurs wastages in both material and energy and may even lead to contamination of soil, water and air [29]. Conceivably, the practice of reuse, recycling and incineration of salvage materials from buildings should be encouraged since they can lead to energy savings as well as a reduction in use of natural resources and landfill volume [17].

In the meantime, efforts have also been initiated on comparing the amount of savings arising from implementing different EoL management strategies for different types of building structures or materials. For an eight-story building, savings of 32.3%, 69.1% and 81.3% in initial total energy could be attained by reuse materials if the main structure of the building was concrete, timber or steel respectively [30]. Largest exergy savings were gained by reusing roof tiles, bricks and tiles and recycling of broken stones in a dwelling house, while less exergy savings were gained by reusing wood, recycling of metal and glass and incineration of wood [31]. Recycling of steel from a steel frame supporting the roof of an industrial hall was found to provide larger energy saving than recycling or incineration of glulam beam supporting the same roof [32]. For a low energy building, 35% of total embodied energy could be recovered through the combination of recycling and incineration while 39% could be recovered through maximum reuse [33]. Maximum reuse was found to be able to achieve the largest reduction in energy consumption for wood-framed houses [34]. However, all these findings were confined to low-rise buildings with limited application to high-rise concrete framed buildings, whose construction form is more popular in cities.

Furthermore, none of the above studies conducted so far reported on the effect of building life span on the environmental impacts imposed by EoL phase although many earlier embodied energy or operational energy studies suggested that the environmental impacts would become less for a building with a longer life span [35,36]. For example, the sum of initial and recurring embodied energy could be reduced by 29% if the life span of building increased from 50 to 150 years based on a premise that a building would be replaced by an identical one at the end of its life span [37]. Net energy saving for additional insulation of a two-story detached brick veneer house was found to be increasing with the life span after considering both embodied and operational energy for space heating [35]. However, it is doubtful whether similar conclusion can be drawn if EoL phase has also been considered.

Accordingly, this study aims to evaluate the energy savings arising from implementing different EoL management strategies for different building materials and elements in a high-rise concrete framed office building. It also aims to identify the materials and elements that can provide the largest energy savings during deconstruction. Finally, this study also aims to reveal the effect of building life span on the total energy savings gained by implementing different EoL management strategies.

2. Methodology

2.1. System scope and boundaries

Given no consensuses on the scope and boundaries for the EoL study, it is necessary to define them clearly at the outset [38]. This study only focused on the energy impacts associated with reuse and recycling immediately after deconstruction phase of a high-rise concrete frame office building in Hong Kong but excluding those incurred after first reuse or recycling of materials. The scope only embraces the primary energy associated with building deconstruction, material dismantling for replacement and maintenance, transportation from deconstruction site to disposal site and disposed during recycling, reuse, incineration and direct landfill. The building was assumed to be deconstructed at the end of 50th year. The building elements investigated in this study embrace building structure, envelope, and interior partitions and finishes but excluding building services systems and foundations. Fig. 1 defines the system boundaries for this study.

2.2. Background and scenarios

To estimate the energy savings arising from implementing different waste management strategies during EoL phase, information like average construction floor area, and types and average quantities of building materials was extracted from the bills of quantities of thirteen Grade A high-rise concrete framed office buildings in Hong Kong. The total number of stories of the buildings varied between 16 and 62. The extracted information in relation to building materials were also grouped into appropriate building elements according to the classification system proposed by Building Research Establishment (BRE) in the UK [39].

Two hypothetical scenarios were constructed to identify the best waste management strategies for EoL phase. Scenario 1 corresponds to an idealized situation that maximum recycling, maximum reuse, or maximum incineration strategies were implemented for all the salvage building materials and elements. Maximum recycling refers to a scenario that all the salvage materials will be recycled without reuse; and maximum reuse refers to a scenario that all the salvage materials will be reused; maximum incineration refers to a situation that all the salvage materials whose energy can be recovered will be incinerated. Bricks and blocks, stones, tiles and plywood were assumed not to be recycled due to lack of recycling energy data; and metals, concrete, glass were assumed not to be transported to incineration plant because these materials virtually contain no heat value [25,40]. In consequence, all these materials were assumed to be disposed to landfills. Table 1 lists the types of strategies implemented for different types of materials under three different strategies investigated in Scenario 1. Scenario 2 corresponds to a situation that the best EoL management strategies identified from Scenario 1 were implemented for all building materials and elements. In addition, it was assumed that the types of waste management strategies implemented at

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