Applied Energy 171 (2016) 429–443

Contents lists available at ScienceDirect

Applied Energy

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

Comparative life cycle energy and cost analysis of post-disaster temporary housings

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HIGHLIGHTS

- Life cycle energy and cost analysis of post disaster housings have been studied.
- Life cycle energy use of PH70 and CH20 are calculated to be 18.5 and 24.7 GJ/m^2.
- The life cycle costs of PH70 and CH20 are calculated to be 919 and 1308 \$/m^2.
- PH have 25.1 and 29.7% lower life cycle energy and cost requirements respectively.

ARTICLE INFO

Article history:
Received 13 January 2016
Received in revised form 9 March 2016
Accepted 16 March 2016

Keywords:
Post-disaster housings
Prefabricated
Container
Life cycle cost assessment
Life cycle energy assessment

ABSTRACT

Temporary housings play an important role by providing people a habitable environment while the effects of a disaster are being fixed. In this paper, life cycle energy and cost analysis of two common types of post-disaster temporary housings constructed in Turkey has been studied. The aim of this study was to identify whether it is more convenient to use prefabricated (PH) or container housings (CH) in post-disaster reconstruction projects. Construction and operational energy requirements are calculated over 15 years using a comprehensive approach. The energy and financial requirements of the housings have been evaluated by considering four different base areas. The life cycle investment, operation, maintenance, service and end of life costs have been investigated by using the net present value technique. Life cycle primary energy consumption values of the most widely used prefabricated (PH70) and container (CH20) housings are calculated to be 18.5 and 24.7 GJ/m^2, respectively. The results show that operational phase was dominant over the housings 15-year lifetime. The life cycle cost of PH70 and CH20 are calculated to be 919 and 1308 \$/m^2, respectively. It is found that increasing the total base area of the housings is an important cost-effective energy reduction measure. The results expressed that prefabricated housings have 25.1 and 29.7% lower life cycle energy and cost requirements respectively.

1. Introduction

Natural disasters still affect a significant number of people. Since 1980, 21,700 loss events registered, killing more than 1.7 million people and affecting over 2.9 billion people all around the world. The disaster housing projects have been one of the most challenging and controversial responsibilities faced by the impacted countries. Sheltering after an emergency situation is the first step used in post-disaster construction activities. The needs of disaster victims or migrants for temporary shelters and houses should be met very fast. The aim of disaster housing is to provide survivors of affected place with shelter and support services when their homes and communities have been destroyed. Temporary housings are the places where the survivors can reside temporarily, usually planned for six months to five years, returning to their normal daily activities. The works of permanent constructions or reconstructions may be delayed and people have to stay in temporary units longer than it was planned [1]. Turkey, like many countries in the World, is always under the threat of earthquakes and many other disasters and immigration risks. Nowadays, the country is struggling with the sudden and large immigration problems from neighboring countries such as Iraq and Syria due to the civil war since March 2011 [2]. Turkey is currently hosting more than half million refugees in twenty temporary accommodation centers which have been established in ten cities [3].

Construction sector plays an important role in the consumption of energy resources. About 40% of all primary energy is used in

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http://dx.doi.org/10.1016/j.apenergy.2016.03.058

buildings all over the world [4]. Thus, construction sector represents a major opportunity for reducing energy requirements [5]. In 2011, natural gas made up 30% of the total energy consumption in Turkey households; followed by solid fuels (26%), electrical energy (16%) and oil products (5%) [6]. Final electricity consumption per capita in Turkey grew continuously between 2001 and 2011 (from 1404 kW h to 2493 kW h). The building sector has remarkable effects on the emissions released and total natural resource consumption [7]. The construction of housing is one of the most resource intensive and economically significant decisions made by designers. A detailed analysis of the resource intensity of a building requires a life cycle perspective which includes production, construction, operation, and demolition phases [8].

Life cycle assessment (LCA) methods have been used for energy and environmental evaluation in many industries. This method has been increasingly used by researchers to assist with decision-making for environment-related strategies. Life cycle energy analysis (LCEA) is used to assess the environmental impact of buildings. In this method, all energy inputs required to produce components, materials, and services needed for the manufacturing process are calculated. This methodology is applied to several studies found in the literature.

Life cycle cost assessment (LCCA) of the buildings is used to assess financial benefits of energy efficiency measures of a housing and to optimize the house design [9–11]. It is commonly used to estimate total investment costs [12,13].

Due to the large immigration and natural disasters affecting a significant number of people, the construction and use of post-disaster housings have been growing rapidly in the last decades and expected to increase in the future. Thus, post-disaster temporary housings are an important area to represent a major opportunity for reducing energy and cost requirements.

There are very few studies combining the life cycle energy and cost analyzes of buildings. The studies about temporary post-disaster housings are limited in number and scope in literature. This paper is the first study evaluating the energy consumption and related cost requirements of post-disaster housings using process-based methods. The study addresses the primary life cycle energy consumption and the cost requirements of the investment, operation, maintenance, service and end of life phases of two typical post-disaster housings. The main aim of this study was to identify whether it is more appropriate to use PH or CH in post-disaster reconstruction projects.

The analysis includes the entire set of housing subsystems and components, including wall systems, flooring, roof and ceiling systems, foundation and basement, doors, windows, and appliances. The methodology for such a detailed analysis is provided including the quantity of each construction element in terms unit costs, mass, and process based embodied energy intensity values. The developed methodology is applied to existing PH and CH located in Gaziantep City. The results and the information obtained from this study will be very valuable for improving the design and operational conditions of post-disaster housings.

This study is presented in 10 Sections. In Section 2, a comprehensive and timely review of the literature on the subject is presented; Section 3 gives a detailed description of the post-disaster housings; in Sections 4 and 5 the methodologies about the life cycle energy and cost analysis are presented; the effects of base area on energy consumption and related costs of the housings are presented in Section 6; in Section 7, assumptions & uncertainties about the analysis are specified; results are presented in Section 8; Section 9 discusses the results of the study and conclusions are presented in Section 10. The actual operational and material data have been considered during the study.

2. Literature review

LCA methods have been increasingly used by researchers to reduce life cycle energy consumption of buildings for the last 25 years [14].

Leckner and Zmeureanu [15] are studied in an energy efficient house which uses solar technologies to generate primary energy. The operating and embodied energy of the house have been considered. In terms of the life cycle energy use the energy payback time is calculated to be 8.4–8.7 years. By converting solar energy, the combi-system supplies at least 3.5 times more energy than the energy invested in manufacturing and shipping the system. The life cycle cost analysis of the energy efficient house shows that due to the high cost of the solar technologies and the low cost of electricity in Montreal, financial payback is never achieved.

Bromilow and Pawsey [16] performed a cost analysis for a 30-year-old building at the University of Melbourne, Australia. The average annual cost of maintenance and rehabilitation is calculated to be 2.0% of the cost of the building. They indicated that the demolition and replacement of the building studied is not an economic proposition.

Adalberth [17] has focused on the life cycle energy use of three dwellings in Sweden. He analyzed the construction, use and end-of-life phases of a residential building. Total energy consumption of the building is calculated to be 7.6–8.8 MW h/m^2 in 50 years of life span. From the case studies presented in Adalberth [18], it is concluded that in LCEA, operation energy has a major share (80–90%), followed by embodied energy (10–20%), whereas demolition and process energy has negligible or little share.

Dodoo et al. [19] analyzed the effect of thermal mass on space heating energy use and life cycle primary energy balances of a concrete- and a wood-frame building. They found that a concrete-frame building has slightly lower space heating demand than a wood-frame alternative, due to the high thermal mass of concrete-based materials. Even so, a wood-frame building has a lower life cycle primary energy balance than a concrete-frame alternative.

In another study, Dodoo and Gustavsson [20] have analyzed the primary energy use and carbon footprint over the life cycle of a wood-frame apartment building designed either conventionally or to the passive house standard. The results showed that the operation of the building accounts for the largest share of life cycle primary energy use. The passive house design reduces the primary energy use and CO_2 emission for heating, and the significance of this reduction depends on the type of heating and energy supply systems. A biomass-based system with cogeneration of district heat and electricity gives low primary energy use and low carbon footprint, even with a conventional design.

Fay et al. [21] made a study on the primary energy use of a detached house in Melbourne, Australia and offered alternative designs with additional insulation. It was found that the addition of higher levels of insulation in Australia paid back its initial embodied energy in life-cycle energy terms in around 12 years. LCEA over lifetimes of 0, 25, 50, 75 and 100 years were carried out for the base case and then with added insulation. Total energy consumption of the building is calculated to be 76 GJ/m^2 in 50 years of life span. The additional insulation decreased the total energy of the house by 3.4 GJ/m^2 of floor area.

Keoleian et al. [22] calculated life cycle energy and greenhouse gas emissions of a standard house and an energy efficient house, both in Michigan, USA. The life cycle energy and emissions were roughly 1.4 GJ/(m^2 year) and 89 kg CO_2eq/(m^2 year) for the standard house, and 0.56 GJ/m^2 year and 32 kg CO_2eq/(m^2 year), for energy efficient house. The discounted (4%) life-cycle cost, consisting of mortgage, energy, maintenance, and improvement payments