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Environmental assessment of popular single-family house construction alternatives in Jordan

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ABSTRACT

The building and construction sector is vital in Jordan. Over the past decade it witnessed rapid growth. Single-family housing is a popular option in Jordan. The construction sector consumes large amounts of energy and resources. Green and energy efficient buildings are growing in popularity and there are policies adopted to encourage energy efficient buildings. These buildings are often justified based on energy saving during the operation phase. Nevertheless, up to date, there is no study that analyses the efficiency of these buildings in Jordan from a life cycle perspective. In this study, the six most popular construction configurations for a single family house in Jordan are assessed using "cradle to grave" life cycle methodology. The alternatives included: single hollow concrete block (Economic), double layer hollow concrete blocks (improved economic), double layer hollow concrete blocks with insulation layer (insulated economic), typical limestone cladding, insulated limestone wall and multi-layer with limestone cladding and insulation (luxury). The results show that using the typical Jordanian family thermal comfort level and heating and cooling patterns, the economic house is the option that performs best in terms of energy resources (5050 UBP), climate change (727.85 Mg $CO_{2\ eq}$), acidification (2.91 Mg $SO_{2\ eq}$) and particulate matter formation (1.14 Mg $PM_{10\ eq}$). Limestone cladded houses show better results in terms of human toxicity and water depletion impact. The results further suggest that energy resource and water depletion impacts may be used as proxy indicators for the overall performance of the building.

1. Introduction

The building and construction sector is a rapidly growing economic sector in Jordan. The sector is expected to expand at a rate of 20% over the next five years with the residential sector contributing 75% of the growth due to natural population growth and migration [1]. Building and construction is a material intensive activity that accounts for 40% of the world material and energy flows [2]. Jordan is a small country with limited resources. It imports 97% of its energy needs. Furthermore, Jordan is one of the most water-scarce countries in the world [3].

Efficient use of available resources and reduction of waste in residential buildings can contribute significantly to the sustainability of the sector. Over the last two decades, the building and construction sector in Jordan has seen a dramatic shift away from traditional construction methods and materials towards modern construction technology. Nevertheless, green buildings design has witnessed renewed interest in recent years. For example, guidelines and regulations to reduce energy consumption during the operational period of the building are developed. In many cases, these guidelines do not take into account energy use during the full life cycle of the building [4]; neither do they consider other potential environmental impacts such as water use, acidification and human health. Life cycle assessment (LCA) is a standardised methodology which offers comprehensive assessment of the environmental performance of a building throughout its life cycle.

Based on LCA results, Adalberth [5] concluded that 85% of the energy consumed throughout the life cycle of a building is attributed to the use (operational) phase. A literature review concluded that 62–98% of the environmental impacts of a building may be attributed to the operational phase [6]. However, Monteiro and Freire [4] noted that while many LCA studies tend to confirm Adalberth's conclusion, most of the studies were conducted in cold climate regions. Nevertheless, Radhi and Sharples [7] found that 80–90% of the environmental impacts of a building may be attributed to the operational phase after conducting an LCA study

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on residential buildings in Bahrain. The high impacts during the operation phase can be attributed to high energy use. In fact, when considering the Portuguese reduced HVAC levels, material production is the process which is responsible for the most environmental impacts of a single-family house [4].

The design of the building façade and exterior walls play an important role in the thermal performance and lighting conditions of the building [6,8]. In turn, exterior wall construction affects the energy consumption during the use phase of the building. Therefore, it is not surprising that current practices in Jordan focus on exterior wall construction and windows to alter the energy requirements of the house; with the aim to reduce the heating and cooling demand. The Jordanian energy efficient building code recommends thermal transfer values for various components of the building [9]. These values were derived from simulating the thermal comfort levels for an active and passive model apartment in Amman during the operation phase of the building [10]. Ali and Al Nsairat [11] developed SABA as a tool to evaluate green buildings in Jordan. It uses AHP multi-criteria evaluation to assign a score based on developed criteria which includes site, material, cost, water and energy efficiency as well as indoor air quality. However, no LCA study of the housing sector in Jordan was conducted. Jordan has comparable climate conditions and HVAC levels to Portugal. Excessive use of material may be counter effective if the energy savings during the operation phase are not sufficient to offset the impacts incurred due to the extra use of material.

Irbid is the governorate with the highest population density in Jordan and the second largest in terms of population numbers after the capital Amman [12]. According to official statistics, Irbid had 164,733 housing units as of 2004. Nearly one third of which are classified as single-family housing [13]. However, the housing sector in Irbid has seen dramatic growth over the past few years due to natural population increase and migration from neighbouring countries as a result of political instability in the region.

To the best of the author's knowledge, there has been no study conducted to assess the overall environmental impacts of a single-family home construction in Jordan. In this study, LCA is used to evaluate and compare the efficiency of the most common methods for the construction of external walls of a single family home in Irbid, Jordan. Although, this study uses a single-family house in Irbid in the analysis, the results are relevant to the other parts of Jordan as well as other countries in the region as the climate conditions, construction methods, cultural and operation of buildings are similar.

2. Methods

Life cycle assessment (LCA) is a standardised method (ISO 14040:2006). It consists of four phases: scope and goal definition; life cycle inventory (LCI); life cycle impact assessment (LCIA); and interpretation [14]. The modelling was carried out in openLCA v1.4 [15]. The life cycle inventory (LCI) was collected from published literature. The ReCiPe Midpoint (H) LCIA method was used to assess the environmental impacts.

2.1. Goal and scope definition

The goal of this study is to evaluate the environmental impacts of a single-family house in Jordan over its life time assuming typical HVAC levels of a Jordanian family-house. The aim is to evaluate the efficiency of different exterior wall construction on the overall environmental performance of the house throughout its life span. The life span of a house depends on many factors. Nevertheless, several LCA studies used 50 years as the practical life span of a house [4,16]. This study is directed towards architects, engineers and policy makers who are directly involved in the design and construction of buildings in Jordan.

2.2. System boundary and functional unit

The study uses an example three bedroom single-family house with a floor area of 144 m^2 (Fig. 1) located in Irbid, Jordan to analyse material and energy requirements. The study follows LCA 'cradle to grave' methodology. It covers the material, construction, use, demolition and disposal stages of a single-family house.

The system definition includes material production, acquisition, transportation to construction site, installation, operation phase, maintenance and demolition and disposal. The functional unit chosen for this study is the whole unit as shown in Fig. 1 over the entire life span of the building.

2.3. System description and life cycle inventory

Material and energy consumption throughout the life span of the building, shown in Fig. 1, are calculated based on the six most common exterior wall construction configurations in Jordan. Heating and cooling requirements are calculated using the Jordanian common HVAC levels rather than the entire house. Window areas are calculated based on the Jordan energy efficient buildings code [9].

Exterior wall construction: six (6) exterior wall configurations that are most common in the Jordan housing market are considered in this study: economical; improved economical; insulated; limestone façade; insulated limestone façade and luxurious exterior wall. Walls in Jordan are typically non-load bearing. The load is usually carried by frame constructed on site using reinforced concrete columns and beams. Therefore, exterior walls are usually non-structural elements of the house and can be altered easily without affecting the structural integrity of the building. Furthermore, as exterior walls are non-structural elements, the need for allocation of impacts is eliminated.

Economical exterior wall configuration, wall type *a*, (Fig. 2a) was widely used in the older building stock in Jordan. It is still a popular wall configuration for a single-family house and multi-unit flats of the lower middle economic class. It typically consists of a single layer of 150 mm hollow concrete blocks with 25 mm cement plaster on both sides. Cement mortar with a typical joint thickness of 10 mm is used to fix blocks in place.

In the Improved economical exterior wall, wall type *b*, the configuration is the most commonly used configuration of the economic single-family house and multi-unit flats. It typically consists of two layers of hollow concrete blocks with a 50 mm gap. The wall is cladded on both sides with 25 mm cement plaster as shown in Fig. 2b.

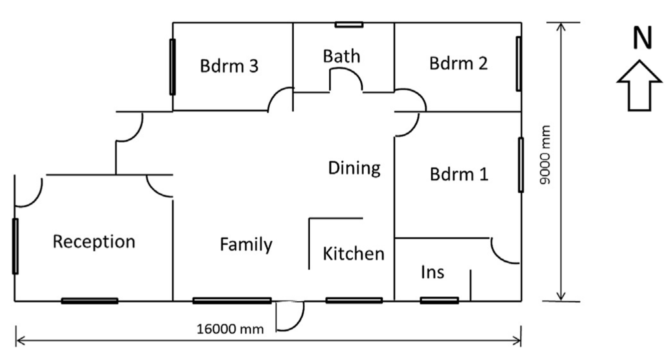

Fig. 1. Floor plan of modelled house/apartment.