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Evaluating the sustainability impact of improved building insulation: A case study in the Dubai residential built environment

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ABSTRACT

Environmental sustainability considerations are slowly being integrated into governing criteria and regulations in industrial and urban development worldwide. A "cradle to grave" analysis increases understanding the implications of specific design options in the context of creating an environmentally sustainable product, however in commercial real estate the focus is generally on reducing cost, while long term operational and end-of-service considerations remain on a second plane of importance. The balance between initial costs and operational costs (environmental, economic and energetic) is directly reflected in the building energy use which, while requiring a higher initial investment, constitutes the principal driver in reducing the carbon footprint of the dwelling. But constructive measures that decrease operational energy use and thus also decrease operational greenhouse gas emissions require the use of more insulation materials. The embodied energy and GHG emissions associated with the full lifecycle of these additional materials needs to be included in the overall sustainability balance sheet of the development. This study shows that, in the particular case of the residential built environment of Dubai and the prevailing local electric power source generation mechanisms, the environmental sustainability cost of adding the insulation levels required to significantly mitigate transmission losses is small in comparison to the operational GHG emissions saved by their application. However, and in part due to typically short building lifetime and lack of comprehensive waste management strategies, the overall impact of using these materials within the full lifecycle of the Dubai built environment requires special consideration to end-of-service treatment.

1. Introduction

According to International Energy Agency (IEA) [1] residential buildings are responsible for 6% of the total worldwide CO_2 production. These emissions can be attributed to different life phases of a residential building, and consist primarily of embodied CO_2 and CO_2 generated during production of the materials and assembly of the home, CO_2 produced during its operational life (this is directly related to the energy efficiency of the home and the site dependent energy generation method applied), and the CO_2 generated during disassembly and disposal. In this work we examine the influence of improved home efficiency on the overall environmental sustainability balance sheet by comparing the reduction in operational emissions to the increase in embodied CO_2 due to improved constructive thermal efficiency. The emissions attributed to the operational phase of the building are inversely proportional to the thermal quality of the constituent materials, which dictate the heating or cooling requirements of the dwelling. In order to frame the environmental sustainability analysis presented here, and to quantify the operational savings, an overview of the specific local climatic circumstances and energy generation emissions is required.

Dubai has a harsh environment with an average maximum temperature of 42 °C in summer and minimum temperature of 16 °C in winter and an average annual relative humidity of 60% [2]. Explosive development, increasing number of tourists, high rate of population growth, hot and humid climate, and low fuel and electricity prices all have placed United Arab Emirates (UAE) and at its core Dubai among top ten highest CO_2 emission producers per capita globally [3]. According to Dubai Statistics Center, the population of Dubai has increased from 862,387 in 2000 to 1,321,453 in 2005 and to 2,003,170 in 2011 [2]. According to IEA [1], there has been a 15.1% increase in the rate of CO_2 production per capita in the UAE from 9.20 tons of CO_2/capita in 1971 to 31.97 tons of CO_2/capita

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in 2009. While the electricity consumption per capita shows a decreasing trend since 2005 (Fig. 1), the rapid rate of population growth in combination with Dubai's extreme climate continuously increases the demand for electricity generation which leads to further CO_2 production. According to DEWA, in 2011 the residential sector was responsible for 27.78% of the overall electricity consumption [4]. The electricity consumed by this sector has doubled from 4691 GWh in 2003 to 9307 GWh in 2011 [4]. This means that the CO_2 emission to the atmosphere by the residential sector has been escalated from 3.26 million tons of CO_2 to 6.46 million tons of CO_2 during the same period. This rapid growth is commensurate with the population increase and new construction, and required mostly to provide adequate indoor comfort levels in the harsh climate.

1.1. *Environmental sustainability implications of Dubai power generation mechanisms*

According to the International Energy Agency (IEA) for each kWh electricity produced in the UAE 0.694 kg of CO_2 enters to the atmosphere [1]. Thus the amount of CO_2 emission entering the atmosphere, as the result of electrical power generation only (source CO_2), has increased by about 244% from 9.84 million tons of CO_2 in 2002 to 24.02 million tons of CO_2 in 2011.

The power plants deployed in the UAE, and due to the rapid growth of the country and infrastructure expansion, are of recent construction and thus of good efficiency. The technology employed is that of combined cycle electricity production cogenerating with the desalination process, typically co-located at the power plant. Due to the use of fossil fuels (natural gas) to run these power plants, the embodied CO_2 of electricity generation is very high. While the UAE is ranked seventh in natural gas reservoirs worldwide, these reserves are still not developed, and thus the UAE depends on imports to supply all its gas requirements [6]. The UAE uses LNG imported from Qatar via the Dolphin pipeline to supply the natural gas required to feed the power plants. Power and desalination plants owned or operated by DEWA include Jebel Ali Power and Desalination plant (Stations 'D', 'E', 'G', 'K', 'L' in Phase I, Station 'L' & 'M' in Phase II), Aweer Power Station 'H' in three phases and gas turbines in Satwa Power Station and Hatta Power Station which are kept as emergency standby [7]. Most of the electricity consumed in Dubai is produced at the Jebel Ali Power and Desalination plant [7]. Station 'D' phase 1 of this plant was built between 1976 and 1980. Phase 2 of this station was built between 1981 and 1984 [8]. This plant has undergone continuous expansion since then. The latest station that became fully operational in 2009 is Station 'L' phase 2. Station 'M' phase 2 is completed partially. The electric power generation in the UAE is dominated by gas turbines that indeed give the advantage of having abundant waste heat to be utilized for multi-stage flash distillation (MSF). According to DEWA, out of 8721 MW installed capacity in 2011, 6637 MW utilizes gas turbines and 2084 MW utilizes steam turbines [8].

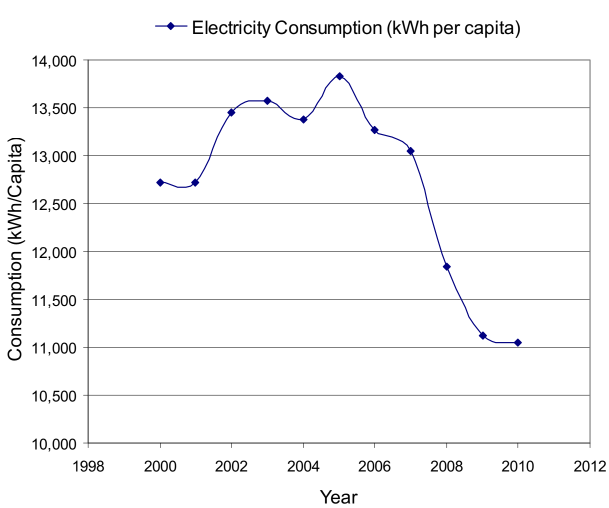

Fig. 1. Electricity consumption in UAE (kWh/capita) [5].

UAE is the second largest producer and consumer of desalinated water, with 14% of the worldwide production or around 8,743,000 m^3 desalinated water per day [9]. Multi-stage flash distillation (MSF) is the principal process (63%) through which desalinated water is produced [9]. Other techniques through which water is desalinated are multiple-effect distillation (MED) (6%), reverse osmosis (RO) (12%) & vapor compression distillation (VC) and other technologies (19%) [9]. All the UAE desalinated water is produced in co-generation plants generating electricity and water at the same time using the low pressure/temperature steam from the power plant as the heating source [6,9]. Water desalination is highly GHG and energy intensive. This energy, depending on the technology used for water desalination, is of heat type or electric type. For each cubic meter of desalinated water through MSF 2.5–3.5 kWh electric energy is required. This figure is 2.0 kWh for MED, 7.0–15.0 kWh for VC & 2.5–8.0 kWh for RO [10]. This means that for water desalination only, between 26 GWh and 49 GWh electrical energy per day is consumed in the UAE which leads to the emission of about 18 million tons of CO_2 to 31.8 million tons of CO_2 to the atmosphere per day. That is why in Dubai, for instance in 2011, desalination at the power plants consumes about 9% of the total electricity that they produced [4].

1.2. *Dubai regulatory environment*

In addition to the climatic and power generation parameters, the socio-economic context of the location often has a strong influence, as developing nations with high growth rates often place lower emphasis on environmental sustainability considerations than highly developed nations with consolidated growth. Dubai, the location for this study, represents a vivid example of rapid growth and highest emphasis on economies of scale over operational environmental sustainability.

To address the high CO_2 footprint of the UAE, Dubai authorities have introduced a series of prescriptive building codes which focuses on the heat losses/gains through external walls, windows and roof (AD77 in 2001, AR66 in 2003 & Green Building Regulations in 2011). However, based on a recent study it is observed that most of the buildings, while following the requirements of these codes, exhibit significant heat loss through the non-insulated reinforced concrete (RC) frame of the buildings [11]. By analyzing the effect of the thermal bridges (TB) on the building electricity consumption it was concluded that by applying insulation on the full perimeter of the building the energy losses as well as CO_2 emission would decrease [11].

Addressing the high CO_2 and energy footprint of the buildings through additional full perimeter insulation has multiple implications; the ones considered in the context of this study are:

- An increase in the embodied energy and CO_2 produced during insulation production, transportation and disposal.
- Due to the high volume and low density of the typical insulation material employed (EPS), and the short operational lifetime of UAE residential construction [12,13], an important end-of-service consideration is the waste management and/or recycling.