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Sustainable design guidelines for detached housing in the Lebanese inland region

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Abstract

Developed through a holistic approach, this study aims at setting new applicable sustainable design guidelines for single-family detached residences in the Lebanese inland region, and any other region with similar climate. This paper is an evaluation of the effects of using passive building design strategies on the energy consumption of a housing unit in the Lebanese inland region, and any other location of similar climate. The paper, also, examines the possibility of saving energy through using low embodied energy building construction materials, and investigates the viability of integrating renewable energy sources. The application of the passive design strategies proved to save up to 78% of the annual heating and cooling electric energy consumption. The total annual operational energy of the best case is 63% less than that of the base case. Using the construction materials' cost variation, a range of 26–45% of the overall annual energy needs could be produced using renewable energy systems. Furthermore, using local low-embodied energy construction materials in the developed model is found to save approximately 80% of the embodied energy compared to the insulated base case model.

Keywords: Dry climate; Passive building design; Operational energy, Embodied energy; Renewable energy system

1. Introduction

Lebanon is a country that depends on imported fossil fuels to run its power generation utilities. The power production of utilities fails to match the growing demand of the market due to the fact that their capacities are less than needed, and their production processes are inefficient (Karaki et al., 2005). Given that residential sector accounts for 47% of the produced energy, any possible savings in the sector's consumption are a factor in the growth of the national economy, and an improvement in the environmental conditions (Ghaddar and Bsat, 1998). Also, saving energy lowers the operational costs which, in turn, offers the residents a better quality of life. Accordingly, the development of a low-energy residence is vital.

A low-energy house is a house which designs accounts for its energy performance at the early stage of its design process, during its construction phase, throughout its operation period, and when it is demolished. Most available studies have focused on multifamily multistory residential buildings located in Beirut, however, 93.1% of the residences in the inland region are 1–2 floors (Chedid and Ghajar, 2004). Thus, studying this category of buildings in the inland region that has a different climatic conditions compared to Beirut is essential.

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At the design stage of any building many factors come into play; accordingly, understanding the impact of each factor would facilitate the development of a holistic approach with optimized factors. To begin with, factors such as building proportions, geometries, and envelopes are examined for their impact on the building's energy consumption. Bostancioglu (2010) studied the effect of building shape, orientation, and envelope proportions on the energy, construction, and life cycle costs. The paper evaluated a multistory residential building of various floor plans, envelopes, and orientations. The results indicated that the construction cost, the energy cost, and the LCC increase as the external wall area/floor area ratio increases. The increase in the change of shape causes the biggest increase in energy costs, 26.9%; whereas the increase in cost due to change in orientation is 0.86% only. The results also indicated that the increase in EWA/FA ratio also increases the construction cost and LCC.

Furthermore, Tuhus-Dubrow and Krarti (2010) developed a simulation optimization tool that evaluates the building envelopes to minimize energy use, taking into consideration the plan shape of the building. The tool was used to optimize many envelope related parameters in five different climates in the USA. The results indicated that the rectangular and trapezoidal plan shapes are optimal, compared to H, U, cross, L, and T shapes. The results also indicated that when using optimal building envelope materials, realized using the tool, the building plan shape represents a variation of only 0.5% in LCC values in the five different climates investigated. Also, Hatamipour et al. (2007) investigated the cooling load power consumption for different building types in Iran. It is found that 60% of total consumption during peak load is accounted for cooling systems. Simulations were done to examine measures that would reduce this load. The results showed that using an insulated light-colored envelope with low window-to-floor ratio could save up to 40% of the cooling load. Moreover, Hirano et al. (2006) examined the impact of using building-scale voids, double-skin walls and roof, and Predicted Mean Vote (PMV) Control System on the cooling loads in the hot humid climate of Japan. The paper also investigated the amount of reduction in CO_2 emissions when PV modules and solar water heating are used along with efficient lighting and appliances. The results showed that cooling loads are reduced by 40%, and CO_2 emissions are reduced by 15%.

Consequently, it can be clearly seen that the geometry, proportions, and envelope of the building can contribute to cutting the energy demand for cooling and heating. Using a rectangular floor plan, along with a low wall-to-floor area ratio, contributes to reducing both the cooling and heating loads, as well as the LCC of the building. In addition, using an optimized building envelope with light colors contributes to further reducing the energy demand. These findings serve as design guidelines when developing an optimized building design, using passive design principles.

Nonetheless, building ventilation also contributes to energy savings in buildings; thus, assessing its impact is necessary. Shaviv et al. (2001) studied the effectiveness of using night ventilation and thermal mass as a passive cooling strategy. They examined three main parameters involved; T-swing, thermal mass, and air change rate. They concluded that for this strategy to be effective, T-swing must be greater than 6 °C while using heavy building mass, and a rate of 20 Air Change per Hour (ACH) to achieve a reduction of 3C in T-max. As T-swing increases the effectiveness of this passive strategy increases, this can be deduced from the simple design tool developed through this study to predict the effectiveness of this strategy given the three examined parameters. In addition, Kubota et al. (2009) studied the effectiveness of different natural ventilation modes in Malaysia. They examined four different cases, including full day ventilation, day ventilation, night ventilation, and no ventilation. The results showed that night ventilation achieved best temperature reduction, 2.5 °C. Nevertheless, due to the high level of humidity, night ventilation was not able to meet the occupants' thermal comfort needs; thus, unless a dehumidification system is used, night ventilation would not be applicable in such climate. These findings highlight the effectiveness of using natural ventilation, as a form of passive design strategy to reduce the mechanical ventilation energy demand; especially that the level of humidity within the Lebanese inland region is very low compared to that of coastal cities.

As building materials and their embodied energy constitute an integral part of any sustainable construction, and contribute to the total energy consumption of the building, it is vital to assess this impact, and examine what construction materials have the least possible impact. Morel et al. (2001) studied the performance of selected local building materials in southern France. Soil mortar, rammed earth, stone, and timber were the materials used to construct a series of small residential units. The strength of the materials was examined; cement was used to strengthen the performance of soil mortar, however, organic fibers could also be used to improve the rammed earth properties, according to Morel et al. Also, the embedded energy of each material was evaluated, and the results indicated a reduction of up to 215% in the energy consumed in the building.

Additionally, Huberman and Pearlmutter (2008) conducted a life-cycle energy analysis through the analysis of the embodied and operational energy of the building materials currently in use as well as alternative materials such as stabilized soil blocks. It was found that the embodied energy of the building accounts for some 60% of the overall life-cycle energy consumption, which could be reduced significantly by using alternative building materials. It was also found that the cumulative energy saved over a 50-year life cycle by the alternative material substitution is in the order of 20%.

Besides, a significant potential for using local building materials in Lebanon is verified by Hamad et al. (2010)