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Comparison of energy use and environmental impact of alternative exterior opaque walls of hotel construction in Greece

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Abstract: This was a comparative, partial, life-cycle assessment of the energy and environmental impact of four exterior walls, with same thermal transmittance and thickness, in a hotel model placed in Athens, Greece. The assessed energy indicator was the sum of primary energy used in the construction and operation phases of the corresponding model scenarios. The environmental impact indicator was the carbon dioxide air emissions in the same life-cycle phases. The exterior opaque wall variants included: (a) a double leaf brick wall with cavity insulation, (b) a single leaf brick wall with external insulation, (c) a lightweight steel drywall with cavity insulation, and (d) a lightweight steel drywall with external insulation. Results indicated that the lightweight steel drywall with external insulation would be the optimum design choice. Both its energy use and carbon emissions resulted in 1.1% and 1.8% lower life-cycle values respectively than the average values among the four wall variants.

Keywords: Hotels, Embodied, Energy, Carbon, Walls

1. Introduction

Hotels rely on the conservation of natural resources to attract and keep customers. At the same time, they deplete these resources through unsustainable operations. Carbon-intensive accommodation, as attested by researchers (Farrou et al, 2012; Dascalaki and Balaras, 2004), is responsible for afflicting the environment. Particularly in Greece, the hospitality sector is considered a sizable energy consumer and air polluter (Farrou et al, 2012), even though it represents just 0.26% of the building stock (Gaglia et al, 2007). Its Global Warming Potential (GWP), expressed in Carbon Dioxide (CO_2) air emissions, exceeds the European average of 160 to 200kg/m^2 room floor area (Hotel Energy Solutions, 2011). Same research attests that energy in Greek hotels is mostly consumed for space heating and cooling. Competitive operational costs related to thermal conditioning and an increasing trend for erecting new facilities in the coastal areas of Greece have incentivised the ~~urge for~~ investigation~~g~~ of energy and carbon efficient construction choices.

In order to make environmentally sound decisions, several product alternatives and construction methods need to be assessed for that matter. To systematically organise and quantify such work under a common scheme, a Life Cycle Assessment (LCA) methodology has been developed and employed in recent years. Among the building components that have been systematically compared in LCA studies are the Exterior Opaque Walls (EOW). High shares of CO_2 emissions have been credited to wall construction compared to the rest of fabric elements (Rosselló-Batle et al, 2010; Dimoudi and Tompa, 2008). At the same time, differences in mass and insulation level of EOW seem to play an important role in the overall energy and environmental profile of buildings in different parts of the world (Ortiz et al, 2010; Kahhat et al, 2009). Meanwhile, the impact of the Embodied Energy (EE) and Embodied Carbon (EC) of construction products are becoming substantial indicators in life-cycle assessments of new, low energy buildings (Ortiz et al, 2010; Kahhat et al, 2009).

From such a perspective, the present paper was a comparative study of the EE and EC of alternative EOW scaled against the Operational Energy (OE) and Operational Carbon (OC) in an annually operated, hotel model. The five-story, generic model was placed in the coastal suburb of Helliniko, in Athens, Greece, with a temperate Mediterranean climate. This is an area expecting to see high touristic activity from future development and with many existing hotels nearby. The compared EOW were of same thickness and equal steady-state thermal transmittance value, complying with the highest allowable value required by the Greek regulation for the energy efficiency of buildings (KENAK, 2010), but of significantly different mass expressed in kg per m^2 of wall area and location of insulation layer. It quantitively compared and evaluated two traditional brick walls with two newly introduced Lightweight Steel Drywalls (LSD), described here: (a) Double leaf brick wall with cavity insulation (Bcav), (b) Lightweight steel drywall with cavity insulation (LSDcav), (c) Single leaf brick wall with exterior insulation (Betics), and (d) Lightweight steel drywall with exterior insulation (LSDetics). These two types of construction were selected as resilient to ground seismicity, which is the main environmental factor affecting building construction in Greece.

The goal of this paper was to define an optimal EOW for Greek hotels by associating the least EE and EC at pre-use stage with the least primary energy and carbon emissions related to the model's heating and cooling fuel consumption during its occupancy.

2. Literature review

~~A literature review was performed to identify key issues related to the goal of this paper. Its~~ An initial ~~main~~ objective of the literature review was to find and compare quantitative data from past LCA studies performed on EOW of year-round operated hotels. LCA reports on EOW scenarios resembling the two types of construction compared in this paper were prioritised.

A first step was to determine benchmarks of the annual Operational Energy (OE) of existing hotels in a similar Mediterranean, temperate climate whose fabrics were built according to traditional masonry construction. Results from two surveys that covered an extensive sample of Greek units (Farrou et al, 2012; Gaglia et al, 2007) and a Spanish study of annually operated hotels on the Balearic Islands (Rosselló-Batle et al, 2010) reported equal average OE of approximately 180kWh/m^2 of usable floor area per year. The Spanish study was based on LCA methodology and provided additional information on the EE and EC of materials at construction stage. However, a drawback was identified regarding the scope of the present paper. Products were adjusted to basic material categories with a percentile distribution over the total mass of the building and not according to specific components, such as the EOW. A similar approach is common among other LCA reports as well (Dimoudi and Tompa, 2008). Nevertheless, an interesting finding was that the contribution of the installation process was negligible. Considering that the transport of products from the plant gate to the building site was excluded, a share between 95% to 99% of total EE at pre-use stage and 87% to 98% of EC were due to the initial energy content of the cradle-to-gate, product stage (Rosselló-Batle et al, 2010).

A second step was to discover comparable results from existing literature on the EE & EC of EOW assemblies resembling the compared systems of this paper. Recent LCA studies on dwellings were drawn upon for this step (Macias et al, 2017; Ortiz et al, 2010). A common conclusion of these papers was that the low proportionate share of the EOW energy content becomes pertinent when their insulation level is enhanced. This was demonstrated by the relative decrease of the OE share during the lifespans of the examined buildings.

Another LCA study conducted on six single-story dwellings in Phoenix, USA, was closer approximated to the objective of this paper given that the buildings were identical apart from their EOW (Kahhat et al, 2009). EOW scenarios included three massive concrete walls, as well as three light wooden frame and LSD systems. All variants complied with the minimum thermal resistance values set by local codes. However, these values were not equal as they referred to different wall thicknesses based on their individual structural characteristics. Final balanced results indicated that heavier concrete walls performed better in terms of primary energy use and CO_2 emissions in the hot and dry climate of Arizona. Although the EE and EC of EOW at pre-use stage were favourable to lighter construction, the 50-year occupancy phase played a significantly more important role and counterbalanced the results. LSD carried the highest overall share of Operational Thermal Energy (OTE) and resulted in the worst life-cycle performance. Again, like the study conducted by (Rosselló-Batle et al, 2010), the highest percentage up to 92% of EE and EC at pre-use stage was due to the energy content of the EOW at the cradle-to-gate, product stage.

Contrary to existing research, this paper proceeded with a comparative energy and environmental assessment between traditional brick EOW and LSD of same thickness, as commonly applied in Greek construction. EOW were analysed and compared at their constituent product level and not according to overall building mass. Based on literature findings, the installation process was excluded from the EE and EC analysis assuming its detrimental contribution at pre-use stage. For the same reason, use stage was restricted to an OTE analysis which carried the highest weight in past life-cycle assessments.

3. Methodology

The system boundary of the present study is illustrated in Figure 1.

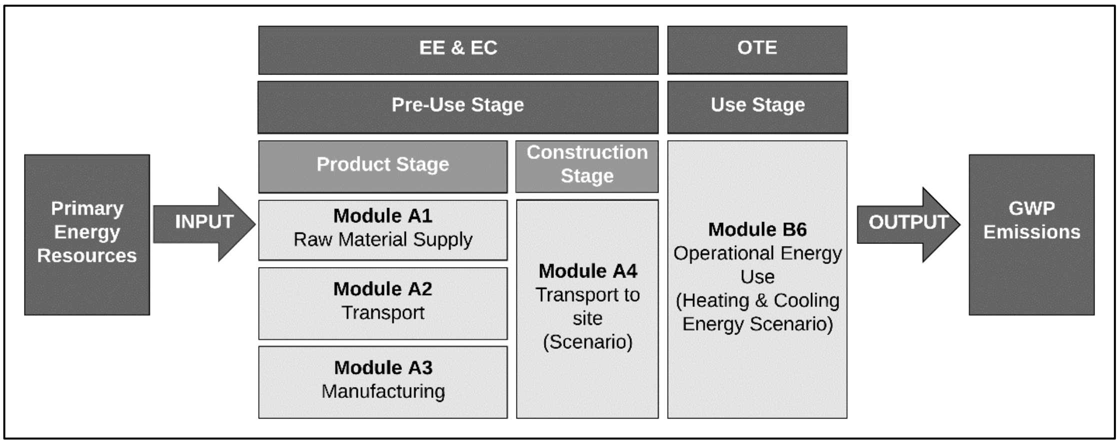

Figure 1: System boundary

The functional unit was set to $1m^2$ of net floor area for a design life of 35 years. It was selected for normalising both primary energy and GWP indicators because it is the reference unit commonly used for comparing OE in buildings. The lifespan of the construction was set to 35 years in order to exclude any maintenance related processes, based on the Environmental Product Declarations (EPD) of the constituent products. The boundary for modules A1 to A3 (Figure 1) covered the raw material supply, transport and manufacturing of the products specified in the construction of the EOW variants. The boundary for module A4 (Figure 1) included a transport scenario of products delivered from each factory gate to the specified building site. The transport scenario was adopted from The Inventory of Carbon &

Energy (ICE, 2011) database of Bath University. The boundary for evaluating module B6 (Figure 1) included the thermal energy used by building-integrated technical systems during the 35-year lifespan of the hotel model externally cladded with each of the EOW variants. Identical fabric elements besides the EOW, as well as identical ventilation, lighting and auxiliary energy requirements were admitted in the annual OTE calculations. The examined indicators were the following: The sum of primary energy use in MJ/m^2 net floor area and the sum of GWP in kgCO_2eq/m^2 net floor area. The sum combined the Operational Primary Energy (OPE) and Operational Carbon (OC) of the hotel model over the 35-year lifespan for each EOW scenario with total EE and EC of each EOW assembly respectively. To quantify these indicators, the methodology was organized in two flows of analysis: (a) OPE and OC analysis, and (b) EE and EC analysis.

The OPE and OC analysis included the model design and annual OTE calculations performed with DesignBuilder software using the EnergyPlus dynamic energy simulator. The model design (Figure 2) followed the morphology of existing three-star hotels in the area with four identical stacked guestroom floors over an entry space floor. A single loaded slab configuration of guestrooms with same southwest orientation of openings was selected for allowing similar solar gains in all guestrooms. Conventional fossil fuels of natural gas and electricity were used in its thermal conditioning. Secondary data for the OTE analysis were adopted by Greek regulations, European standards and calculation methodologies, as well as recent product literature. Normalised OPE and OC calculations for each EOW scenario were based on the following parameters: (a) the annual fuel breakdown calculated for each EOW scenario, (b) the design life of 35 years, and (c) the conversion factors for each fuel as defined by the Greek energy legislation for buildings (T.O.TE.E., 2012).

The EE and EC analysis included an inventory of the EOW variants at product stage and the specification of the transport scenario of their constituent products from factory gate to site location. The inventory was based on EPD from European manufacturers, Environmental System Declarations from European associations of same product manufacturers and ICE, (2011) database. The EE and EC primary data were calculated based on a matrix calculation routine which is defined in (BS EN 15978:2011). BS EN 15978:2011 defines the calculation procedure for the assessment of the environmental performance of new and existing buildings based on the LCA methodology.

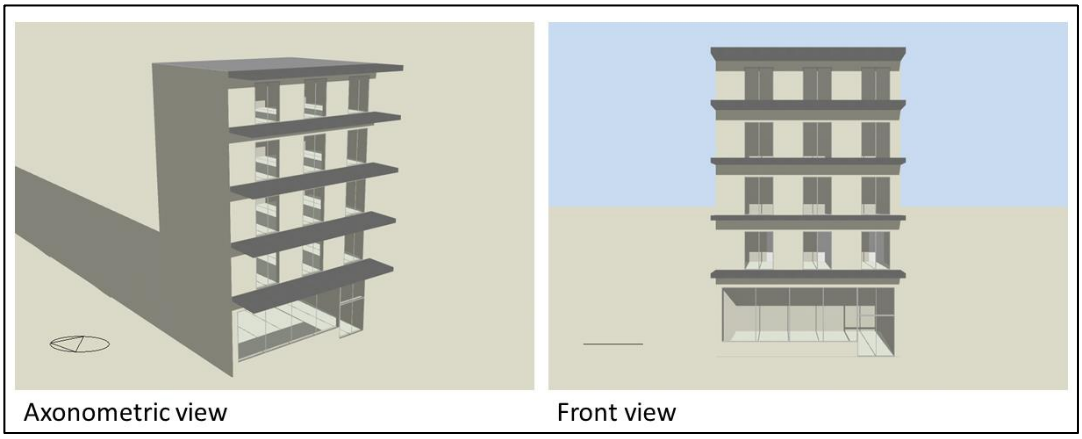

Figure 2: Exterior views of the hotel model (DesignBuilder)

4. Results and Discussion

Results indicated that total fuel consumption in all the EOW scenarios was lower than the average value of 180kWh/m^2/year recorded in Spanish and Greek hotels (Rosselló-Batle et al, 2010; Gaglia et al, 2007). Betics resulted in 1.3% lower annual fuel consumption than the average value among the EOW, marginally followed by Bcav. LSDcav resulted in the slightly highest thermal energy demand year-round. As expected by their analogous relationship, a similar trend with annual OTE was revealed in OPE and OC over the 35-year lifespan of the model. Differences between the EOW variants in each pair of construction methods were almost negligible. On the other hand, comparing the two pairs of masonry and LSD construction with each other, differences were detectable.

Contrary to OPE and OC at use stage, brick walls resulted in considerably higher EE and EC values than LSD at pre-use stage. The construction of an exterior enclosure with Betics resulted in 83% higher primary energy use than the average among the four scenarios. Equally higher percentage than average, at 85%, was also determined for its EC. The highest share up to 80% of the above outcome was due to brickwork. Given that the transport of products resulted in just 6% of total EE and 8% of total EC on average, it could be deduced that the initial EE and EC of brickwork was the main contributor to high total embodied values of brick walls at pre-use stage.

Finally, the operational and embodied values of primary energy and GWP of the four EOW variants were combined in the sum of their life-cycle values over the 35-year lifespan, as illustrated in Figure 3.

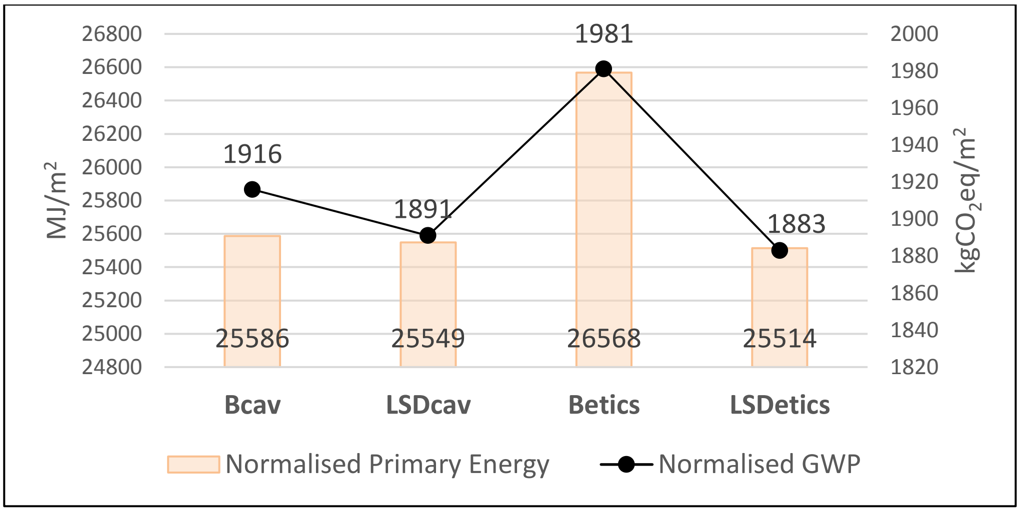

Figure 3: Life-cycle primary energy and carbon

Even though EE and EC represented a small percentage between 2.7% to 9.6% and between 2.5% to 10.6% of the life-cycle primary energy and carbon values respectively, they inverted the operational results. If choosing was based solely on OPE or OC, Betics would have been selected as the optimum wall. However, Betics had the highest EE and EC of 9.6% and 10.6% respectively and resulted in the worst life-cycle performance. When considering over the life cycle, LSDetics proved the best option resulting in 1.1% lower primary energy use and 1.8% lower mass of CO_2eq emissions than the average values. By this conclusive finding, we could state that LSDetics would be the optimum EOW alternative in the specified context of this paper, closely followed by LSDcav and Bcav in this order.

Results justified the claim of existing literature that, despite their low proportionate share, the energy and carbon content of construction are significant parameters in the life-cycle profile of buildings. By switching to an EOW with lower initial EE and EC, results of primary energy use and CO_2 emissions during the operation phase were reversed. Considering that the EOW is only one component among many in building construction, the above claim was quantitively validated by the present paper.

To put this finding in its proper frame, a certain point needs to be highlighted. It is important to acknowledge that the present research was set within the framework of a generic hotel model and not an existing building. Hotels are, after all, among the most complex commercial buildings. The assumed common framework did not affect the comparative results, but it would impact on possible building performance. In this sense, the life-cycle primary energy and carbon values of this paper could be used as benchmarks at design stage for comparative purposes, as initially intended.

5. Conclusion

This was a partial, comparative LCA of four alternative EOW tested in the fabric of a Greek hotel model. Conventional brick walls of higher mass were compared against lightweight drywall construction. The aim was to define an optimum EOW for Greek hotels among the four alternatives with the least life-cycle primary energy use and mass of CO_2eq air emissions. Among the four EOW alternatives, the exterior insulated LSDetics wall resulted in the slightly lowest overall energy and carbon footprint.

Results verified the significance of pre-use stage in life-cycle hotel performance. Although it represented only 5% of the life-cycle indicators on average, it reversed operational results at use-stage. In this sense, the specification of individual products with lighter mass proved more energy and carbon efficient in the examined context.

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