Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

SUSTAINABILITY ASSESSMENT OF THE REPLACEMENT OF CLAY BRICK WALLS WITH IN-SITU COMPOSITE SANDWICH WALLS

KRISHNA LAWANIA[1], NATALIE LLOYD[2], and WAHIDUL K. BISWAS[1]

[1]*Sustainable Engineering Group, Curtin University, Australia*
[2]*Dept of Civil Engineering, Curtin University, Australia*

Clay bricks are used for house construction in Western Australia. Clay bricks produce large amounts of construction and demolition waste, and have a large carbon footprint. In order to achieve energy savings and greenhouse gas (GHG) reduction targets, there is a need to use an alternative wall system. The objective of this paper is to undertake a sustainability assessment of the replacement of clay brick walls with in-situ composite sandwich walls (CSW). A Life Cycle Assessment (LCA) tool has been applied to assess the carbon footprint and embodied energy consumption for non-insulated and insulated brick and CSW. The LCA analysis identified the stages or inputs/process causing the most significant impacts for determining further improvement opportunities. The findings indicate that a significant GHG reduction and energy saving can be achieved.

Keywords: In-situ sandwich wall, greenhouse gas, embodied energy, LCA.

1 INTRODUCTION

Australia is one nation with a significantly high per capita carbon and ecological footprint (Garnaut 2008). The densely-populated urban area (87%) not only has caused an unsustainable built environment (SOE 2011), but also has increased the ecological footprint. A majority of Australians live in detached houses made of clay bricks (SOE 2011) which are labor intensive. They account for almost 16% of the annual construction and demolition (C&D) waste (DCCEE 2010), with fairly high embodied energy consumption at 2.5 MJ/kg (Milne 2013). To achieve Australia's 60% greenhouse gas (GHG) reduction target by 2050, and also 30-35% energy savings from the building sector (ASBEC 2007), suitable replacements for brick wall houses require further investigation. The alternative wall systems are slowly gaining acceptance (DCCEE 2010) While composite sandwich wall (CSW) systems are being extensively used in Europe, in the Middle East and Asia there were few trials in the eastern states (QUESTECH 2013). There seems to have been no initiatives undertaken in Western Australia (WA) to build CSW houses.

CSW systems consist of a welded wire space frame integrated with an expanded polystyrene (EPS) insulation core, with thin layers of concrete sprayed on either side through a shotcrete process after being placed in position. This system provides a combination of both lightweight and thermal mass, built-in insulation, resistance to earthquake and fire, low moisture absorption, and constructibility (Rezaifar 2008a).

Most published literature focused mainly on the structural efficacy of these walls. Structural, non-linear dynamic, vertical in-plane forces, and flexural behaviors of sandwich walls have been investigated to confirm that they can perform the same as conventional pre-cast concrete walls (Mousa 2012, Kabir 2004, Carbonari 2012, Gara 2012, Mashal 2012). Experimental and finite-element analyses have confirmed the suitability of this system for slab application (Bajracharya 2010). Results of pseudo-static tests, with horizontal loads and dynamic energy absorption and dissipation behaviors, have been found promising for this sandwich wall system (Ricci 2013, Rezaifar 2008a). Seismic performance testing, for single and three-story full-scaled buildings and four-story scaled building models, have revealed that a considerable resistance to earthquake vibrations could be attained by these sandwich walls (Rezaifar 2008b, Ricci 2012, Rezaifar 2008a). To date, no studies on environmental impacts of the CSW system for construction of houses has been conducted. Hence the main aim of this paper is to present the environmental benefits of replacing brick walls with CSW in WA houses.

2 METHODS AND MATERIALS

In this study, the environmental impacts (in particular GHG emissions and energy use) of brick and CSW house walls were assessed using a Life Cycle Assessment (LCA) tool, following the four steps of ISO14040-2006 guidelines (ISO 2006). A building's life cycle in this analysis includes pre-construction, construction, and use stages. The heating and cooling loads were obtained from the Australian Energy Efficient Building Consultant's report and through BERS Pro 4.2 software. The environmental impacts associated with the demolition of buildings and its end-of-life activities (e.g., disposal, recycling) were excluded from this analysis.

The goal is to compare the carbon footprint and embodied energy of brick walls in houses with and without wall insulation and/or CSW. The functional unit, a basis for developing a life-cycle inventory, is a typical 4-bedroom, 2-bath, and 2-garage detached house of 156m^2 conditioned floor area, with standard features and finishes in WA (DCCEE 2010). The walls have been constructed on reinforced concrete slab over compacted sand. For the brick wall house, the external cavity walls consist of 110mm face brick, 50mm air gap, and 90mm utility brick; internal walls are made of 90mm utility bricks with 10mm cement sand rendering on internal faces. Walls with insulation are also considered for comparison. The CSW consists of 50mm insulation core sandwiched within two layers of 50mm-thick concrete on either face throughout the house. All other finishes and features are considered as identical in both cases, except that separate wall insulation is considered for cavity brick walls, and rendering is not required for CSW. The operational life time of a house has been assumed to be 50 years for both clay brick and CSW systems (TBA 2010). Life cycle inventory (LCI) was developed to determine the amount of inputs in the form of energy and material for pre-construction, construction, and use stages for both bricks and CSW houses, respectively. Data was validated by performing mass and energy balance for the functional unit.

Input data from LCI were entered into Simapro 7.33 (PRé-Consultants 2012) LCA software. Each input was linked to relevant emission database in the LCA software. A cut-off for material or energy and their associated environmental impacts was applied when these variables were smaller than 1% for some inputs.

One of the main objectives of this LCA study is to understand how the brick wall and CSW perform over their entire life cycle. Therefore more attention has been given to cumulative-energy demand (in GJ) and GHG emissions (in tons of CO_2-e). The embodied energy consumption associated with the operational lifetime of houses was calculated using the cumulative energy demand method in the Simapro. The Australian GHG method was used to calculate the carbon footprints of the buildings. Process-flow charts were developed to determine the breakdown of the GHG emissions, to determine the embodied energy consumption of all processes during the operational life time of the houses, and to identify the "hotspot" causing the highest GHG emissions and embodied energy consumption. Toxicity and resource consumption are also important impacts, but they are outside the scope of this LCA. Hence this study is to facilitate decision-making in developing GHG-mitigation strategies.

3 RESULTS AND DISCUSSION

The study calculated cumulative energy demand or embodied energy in GJ (Figure 1) and GHG emissions in kilotons of CO_2-e (Figure 2) for houses constructed with brick walls, with and without wall insulation and/or CSW.

Figure 1 shows the total embodied energy of brick wall house without wall insulation, brick wall house with wall insulation, and CSW house. About 51.6% and 41.9% of the total embodied energy consumption could be avoided due to the use of CSW as a replacement for non-insulated and insulated brick walls, respectively.

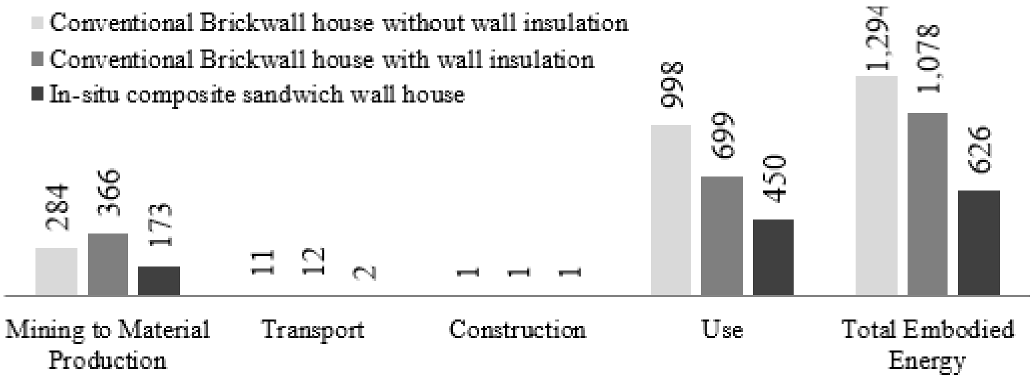

Figure 1. Embodied Energy Saving Benefits in GJ.

The embodied energy during use stage has been found to be highest, and varies between 65-77% of total embodied energy, for these wall options. Similar results were found in other studies (e.g., Biswas and Rosano 2011), where the "usage stage" accounts for major portion (i.e., 87%) of the embodied energy. The energy saving in the use stage accounts for 81% and 55% of the embodied energy saving associated with the use of sandwich walls, as a replacement for non-insulated and insulated clay brick walls, respectively, indicating that the sandwich wall could also offer energy-cost-saving opportunities to the dwellers of these houses. Fay et al. (2000) and this current study confirmed that the incorporation of insulation to conventional walls could achieve an energy saving potential of 6% to 16%, but this saving could be significantly increased (i.e., to 51.6%) by replacing brick walls with CSW. The embodied energy during transportation and construction stages in all cases is insignificant, but there is a comparable difference in embodied energy during the mining-to-material production stage of these wall options. The energy saving during the mining to material production stage accounts for 17% and 42% of the embodied energy associated with the replacement of non-insulated and insulated walls with CSW, respectively. The embodied energy consumption of the insulating materials in insulated clay brick houses has in fact increased the energy-saving opportunity during the mining-to-material production stage.

Figure 2 shows the total GHG emissions of brick wall houses without wall insulation, brick wall houses with wall insulation, and CSW houses. The data indicates that saving potentials of 53.2% and 37.99% respectively can be achieved from GHG emissions by replacing brick walls with CSW. The GHG emission during use stage has been found to be the highest, varying between 55.15 and 35.76% of total GHG emissions for these wall options.

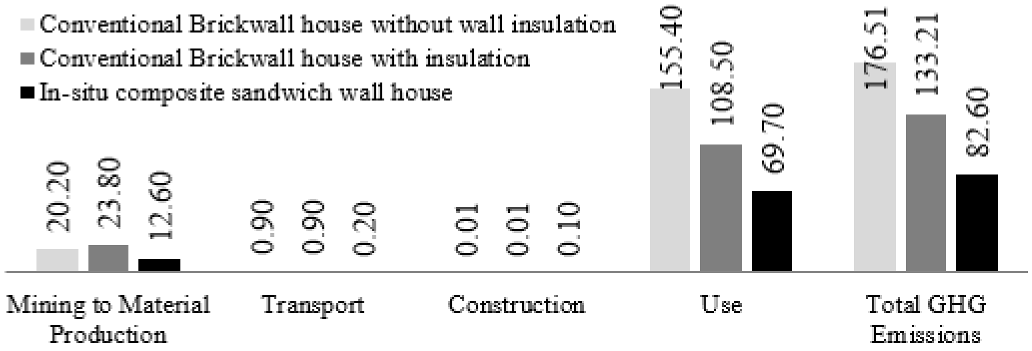

Figure 2: GHG-saving benefits.

Similar to the embodied energy analysis, GHG emissions during the transportation and construction stages are insignificant, but there is comparable difference in GHG emissions during the mining-to-material production stage. The sandwich wall provides an opportunity of saving of GHG emission by 37.62% and 47.06% respectively during this stage, which is substantial. There is an almost 43%-reduction of dead-weight construction material due to replacement.

4 CONCLUSION

Though the most significant GHG emissions and embodied-energy consumption are during the use stage, due to electricity consumption for heating and cooling, the replacement will help mitigate the impacts of high-embodied energy and GHG emission during the mining-to-material production and use stages. A substantial amount of energy required for heating and cooling is lost through the walls. The reduction in embodied-energy consumption and GHG emissions will have associated economic and social benefits as well. The replacement may reduce the cost and time of construction, thus increasing affordability and meet growing demand. The resource saving will be beneficial for future generations.

There are a few limitations with this study, which include probable errors and variations associated with heating and cooling loads. These are guided by a number of factors, such as the exclusion of other components of the house such as foundations, roofs, doors, windows, and finishes from the scope of this study. In all wall options, however, these building components are considered as having the same embodied energy and GHG emissions, and their contribution for comparison is nullified.

Acknowledgement

The authors wish to acknowledge anonymous reviewers for their valuable comments and information.

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