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Tiny house, tiny footprint? The potential for tiny houses to reduce residential greenhouse gas emissions

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Abstract. While considerable improvements to the energy efficiency of housing have been achieved over recent decades, the residential sector still represents a significant and increasing proportion of global greenhouse gas emissions. This is exacerbated by an increasing global population and living standards, demand for larger houses, and smaller household size. Tiny houses have emerged as a potential solution to this issue. While research exists on the environmental benefits of smaller housing, there is little on that of tiny houses. This study quantifies the life cycle GHG emissions of a tiny house, and their potential to reduce residential GHG emissions. A hybrid analysis and a dynamic energy modelling tool were used to quantify embodied and operational GHG emissions, respectively, for a tiny house located in Australia. The study shows that a tiny house may result in a 70% reduction in per capita GHG emissions over its life compared to a traditional Australian house. This indicates the potential of tiny houses to be a useful option for reducing GHG emissions in the building sector.

1. Introduction

Buildings account for over a third of global energy use, and nearly 40 percent of energy-related greenhouse gas (GHG) emissions [1]. Residential buildings alone were responsible for more than 70% of total building energy demand across the globe in 2017, and while there have been considerable energy efficiency gains over recent decades, an increasing population (expected to increase by a further 29% to 9.8 billion by 2050) and residential floor area have resulted in an overall increase in energy demand [1]. Australia, for example, has the second largest houses in the world, behind the US, with the average new freestanding house measuring 231m^2 [2].

Multiple studies have shown there is a direct relationship between house size and operational energy use [3, 4], while some studies, such as [5], have found house size is also a dominant factor in determining life cycle energy use. Therefore, with house size being shown to strongly influence energy use, smaller houses represent an opportunity to reduce global energy use and GHG emissions.

The Tiny House Movement, which began in the US, has been expanding particularly in industrialised economies. Tiny houses are defined as less than 400 square feet (37m^2) and primarily a full-time dwelling that is either permanent or mobile, on wheels or a skid [6]. Tiny houses are argued to result in lower environmental effects compared to a standard house by using less resources for construction, less energy for heating, cooling and lighting, and encouraging lower consumption [7, 8].

While many studies highlight tiny house affordability [6], broad environmental benefits [8] and the motivation of inhabitants to reduce their environmental footprint [6, 9, 10], limited research has been conducted on the specific environmental benefits of a tiny house. Carlin [7] argues tiny houses reduce energy use by requiring less heating and cooling, along with decreasing resource demands for material possessions. However, the study lacks quantification of the extent of these benefits. Eberle [11] completed a tiny house life cycle assessment and found that on a per square metre basis, tiny houses were comparable or had a higher global warming potential compared to a standard house, with operational energy accounting for 80% of the tiny house GHG emissions. Beyond this, knowledge of the potential for a tiny house to reduce energy use and GHG emissions is limited, especially including a comprehensive understanding of their embodied GHG emissions. This addresses SDG 11 and 12 in our attempt to create cities and communities that are more environmentally sustainable, considering resource efficiency and minimising non-essential resource consumption.

1.1. Aim and scope
The aim of this study was to determine the potential for tiny houses to reduce the greenhouse gas emissions associated with housing. The scope of the analysis includes stages A1-3 (production of materials), A4-5 (construction process), and B5-6 (use stage) as per EN 15978 [12]. The end of life stage (C1-4) was excluded.

2. Research method
A case study approach was used to evaluate the potential of tiny houses to reduce GHG emissions associated with housing. Drawings for a typical tiny house were sourced from a tiny house builder in Melbourne, Australia. The tiny house is 6m × 2.4m × 3.6m (12.2m^2 NCFA) and is built on a steel-framed trailer, with softwood timber framed walls and roof, corrugated steel roofing, painted plasterboard internal linings, particleboard and laminated timber flooring, timber weatherboard cladding, aluminium single glazed windows, cabinetry, kitchen and bathroom fittings.

Figure 1. Tiny house case study floorplan [13]

2.1. Quantifying embodied greenhouse gas emissions
A bill of materials was developed from the tiny house drawings. A Path Exchange hybrid technique [14] was used to quantify the embodied GHG emissions of the initial construction of the tiny house (A1-3). The material quantities were multiplied by hybrid embodied GHG emissions coefficients from the EPiC Database [15]. Emissions associated with the construction process (A4-5) were quantified with the use of national average construction data for Australia, as per [15]. The recurrent embodied GHG emissions associated with material replacement (B5) were calculated as per [16].

2.2. Quantifying operational greenhouse gas emissions
Operational energy was calculated for two distinctive locations (temperate Melbourne and humid subtropical Brisbane). FirstRate5 was used to estimate the heating and cooling-related energy for the tiny house. The comfort range assumed was 20-26.5°C. Constraint factors of 0.45 for heating and 0.15 for cooling were used to adjust for predicted overestimation of energy use through simulation.

Operational energy associated with appliances, cooking and hot water were calculated based on average per capita usage from [17]. Hot water usage of 70L/capita/day and an average annual temperature difference between mains water and final hot water of 38.8°C for Melbourne and 34°C for Brisbane was assumed. Operational GHG emissions were calculated by multiplying the energy demand for each use and fuel type by relevant GHG emissions factors from [18, Table 2 and 41].

2.3. Potential to reduce greenhouse gas emissions of housing
To determine the potential of tiny houses to reduce residential GHG emissions, the tiny house life cycle GHG emissions were compared to those of a more traditional house. A hypothetical house of

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were based on [16] and [19]. To correct for household size, the comparison was made on a per capita basis, assuming two occupants for the tiny house and three occupants for the traditional house.

3. Results

On a per capita basis, the total life cycle GHG emissions of the tiny house were found to be 73 tCO_2-e for Melbourne and 62 tCO_2-e for Brisbane (Figure 2). The initial and recurrent embodied GHG emissions represent 7-8% and 4-5% of these values, respectively. Thus, the operational energy-related GHG emissions for the tiny house represent at least 87-89% of its life cycle GHG emissions.

The total life cycle GHG emissions of the traditional house were found to be 275 tCO_2-e for Melbourne and 201 tCO_2-e for Brisbane, on a per capita basis. The initial and recurrent embodied GHG emissions represent 26-35% and 15-21% of these values, respectively. Embodied GHG emissions thus represent at least 41% of the life cycle GHG emissions of the traditional house.

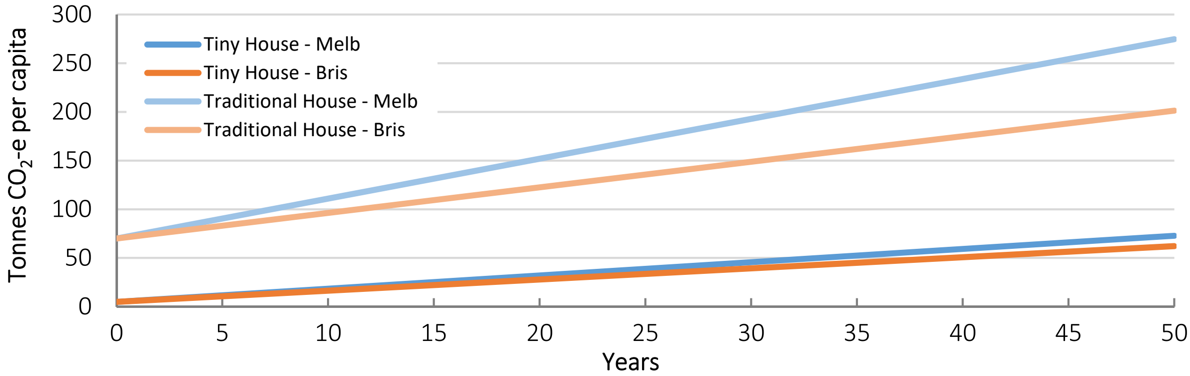

Figure 2. Life cycle GHG emissions of tiny house and traditional house for Melbourne and Brisbane

4. Discussion and conclusions

Due to the small volume of the tiny house, there is very little difference between the heating and cooling-related GHG emissions of both locations. For this same reason, the contribution of these emissions to total operational GHG emissions is less than 2%, with appliance-related emissions contributing over 80% of operational GHG emissions. This contrasts with the traditional house, where a greater difference in operational GHG emissions between locations is evident, due in most part to the significant difference in heating needs between the two locations. For the traditional house, heating and cooling-related emissions account for a much higher proportion of operational GHG emissions.

The operational and embodied GHG emissions for the traditional house were found to be much higher than for the tiny house. This was to be expected on a whole-of-house basis, due to the much larger footprint of the traditional house, as demonstrated by [20]. However, this also held true on a per capita basis. The reason for this is due to the average volume of space per capita, which was seven times greater in the traditional house, based on the assumed household size. This contributed to at least a 70% reduction in per capita life cycle GHG emissions for the tiny house. While the traditional house has the capacity to house many more people, it would require at least 10 occupants for the per capita life cycle GHG emissions to be lower than those of the tiny house. This is extremely rare in Australia, as in many developed economies, with a current average household size of 2.6 [21].

While the operational GHG emissions for the traditional house are based on actual survey data, the equivalent data for the tiny house is based on simulations (heating and cooling) and regional average data. As tiny houses tend to be at one extreme end of the scale of what would be considered typical housing in Australia, these values are likely to be limited in their representativeness of the GHG emissions associated with running a tiny house. This is particularly likely to be the case for the non-thermal-related GHG emissions, such as appliances. Inevitably, these values are likely to overestimate the emissions for a tiny house, and as such, actual emissions are most likely to be even lower.

The findings may be affected by any number of variables, including: climate, house size, location, occupant behavior, material choice and source, energy types and number of occupants. In addition, a

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number of variables were assumed constant over the 50-year study period (household size, operational energy demand, fuel types, emissions factors). Variations in any of these may also alter the results.

In conclusion, on a per capita basis, the tiny house analysed in this study leads to at least a 70% reduction in life cycle GHG emissions compared to a traditional house. This provides additional evidence of the potential significant benefits of smaller housing and impetus for industry and owners to consider it during housing design. While further research on the social and other implications of tiny houses is needed, this study shows that they may be able to make a significant contribution to achieving the rapid emissions reductions that are urgently needed in the housing sector.

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