# Scaling Behavior of the Life Cycle Energy of Residential Buildings and Impacts on Greenhouse Gas Emissions

**Stephane Frijia, Eric Williams, Subhrajit Guhathakurta, and Ariane Middel**

GLOBAL INSTITUTE of SUSTAINABILITY
ARIZONA STATE UNIVERSITY

## INTRODUCTION

The specter of man-made climate change triggered by greenhouse gas (GHG) emissions from fossil fuels has signaled an urgent need to reduce global petroleum-based energy use. Among the strategies to achieve the reduction targets, transportation, housing and land use sectors have received the most attention. In this study, we take up the question of energy use in the housing sector and its relationship to size and characteristics of housing units and to neighborhood urban form.

Specifically, **we address the variation in embedded energy use by size of housing unit and, by extension, density of residential land use patterns**.

## CASE STUDY

Ten case studies are developed and analyzed including five single story and five two-story single family detached homes of various sizes ranging from 1,500 to 3,500 square feet of livable space. The cases represent a low-density subdivision development typically found in the Phoenix metropolitan area described as follows:

- average construction quality;
- no basement;
- cement slab foundation;
- basic architectural components;
- exterior wall of stucco on a wood frame; and
- cement tiled roof.

## DATA

- Construction materials, quantities, and cost for each case study are estimated using RS Means – a commercially available construction estimating tool.
- On-site energy used during construction includes the use of gasoline, diesel fuel, lubricants, and electric energy purchases (DOC 2005).
- Life cycle operational energy use is estimated using the EIA 2005 Residential Energy Consumption Survey.

## METHOD

The energy profiles of different sizes of housing units are estimated from
1) the embedded energy in construction and materials required for building the structure; and
2) the operational energy required for habitation in that structure.

We calculated the construction material embedded energy and GHG emissions using a disaggregated hybrid Economic Input Output Life Cycle Assessment (LCA) model (CMU 2008).

## RESULTS: ENERGY

Table A shows the total materials life cycle embedded energy plus the on-site energy required to assemble the single-family detached homes analyzed.

**Table A**

| Size (ft²) | Construction Energy (GJ) | Increases in Energy | %Δ Total Energy |
|---|---|---|---|
| **1 Story Single-Family Detached** | | | |
| 1,500 | 898.9 | - | - |
| 2,000 | 1,118.9 | 24.5% | 24.5% |
| 2,450 | 1,315.5 | 46.3% | 17.6% |
| 3,000 | 1,543.1 | 71.7% | 17.3% |
| 3,500 | 1,734.8 | 93.0% | 12.4% |
| **2 Stories Single-Family Detached** | | | |
| 1,500 | 808.3 | - | - |
| 2,000 | 961.7 | 19.0% | 19.0% |
| 2,450 | 1,131.2 | 40.0% | 17.6% |
| 3,000 | 1,422.5 | 76.0% | 25.7% |
| 3,500 | 1,476.5 | 82.7% | 3.8% |

Figure A shows that the energy used on-site during the construction phase of a single story 1,500 ft² home corresponds to **5.10%** the total energy used in the life of the building. Additionally, the embedded energy in material manufacturing corresponds to **18.15%** of the total energy used for space heating and cooling during the life of the building. Similar ratios are found for homes of larger size (see Table B).

**Figure A**

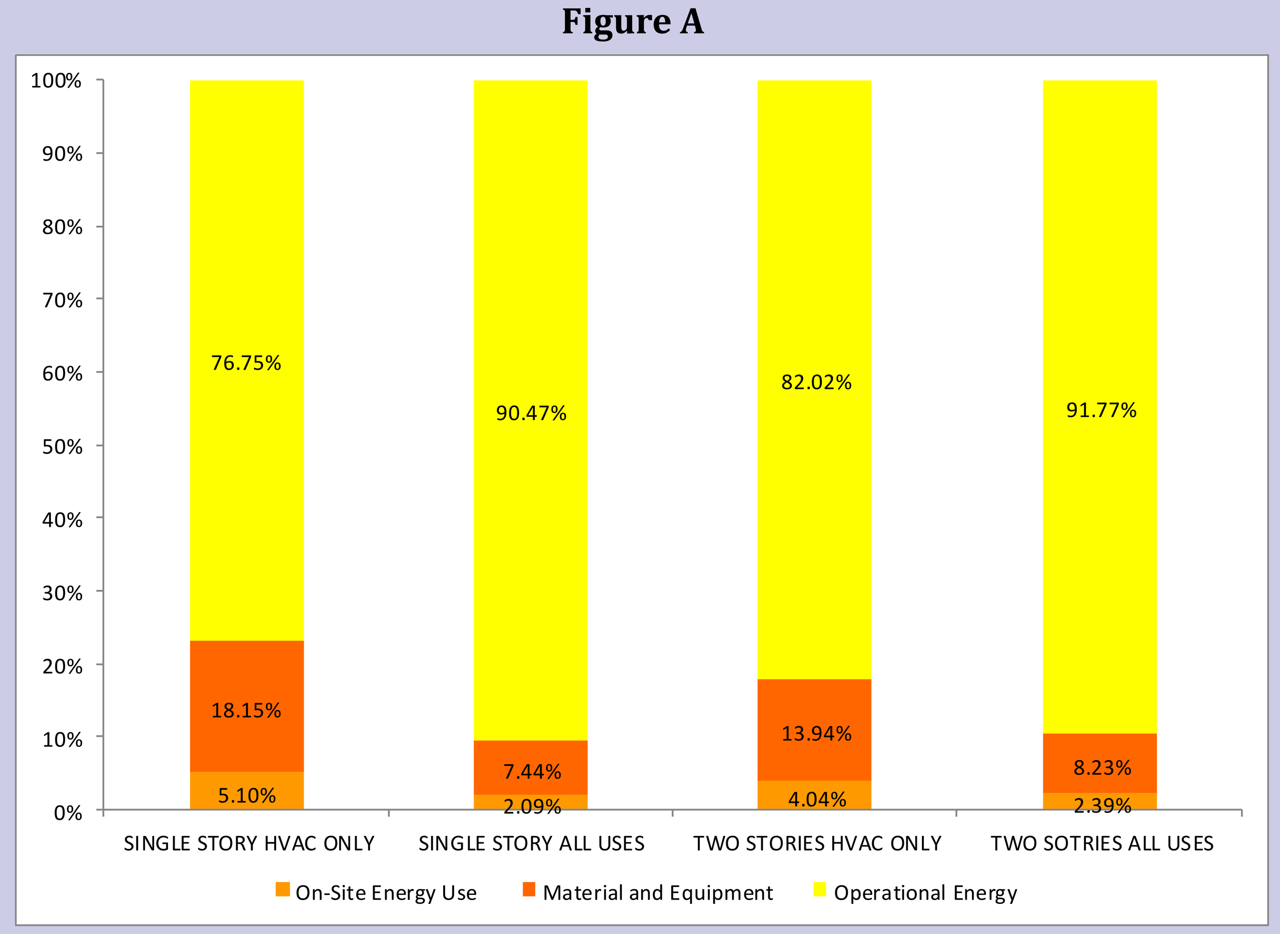


**Table B**

| Size (ft²) | On-Site Construction Energy Use | Construction Material and Equip. Energy | Total Construction Energy | Total Operational HVAC Energy Use |
|---|---|---|---|---|
| **1 Story Single-Family Detached** | | | | |
| 1,500 | 5.10% | 18.15% | 23.25% | 76.75% |
| 2,000 | 4.05% | 14.79% | 18.85% | 81.15% |
| 2,450 | 5.01% | 18.22% | 23.23% | 76.77% |
| 3,000 | 5.27% | 19.37% | 24.64% | 75.36% |
| 3,500 | 5.91% | 22.08% | 27.99% | 72.01% |
| **2 Stories Single-Family Detached** | | | | |
| 1,500 | 4.04% | 13.94% | 17.98% | 82.02% |
| 2,000 | 4.60% | 16.08% | 20.68% | 79.32% |
| 2,450 | 4.24% | 14.88% | 19.11% | 80.89% |
| 3,000 | 5.04% | 17.70% | 22.74% | 77.26% |
| 3,500 | 4.76% | 17.24% | 22.00% | 78.00% |

## RESULTS: GHG EMISSIONS

Total GHG emissions are shown in Figure B - for the single story homes, and in Figure C - for the two-story homes.

**Figure B**

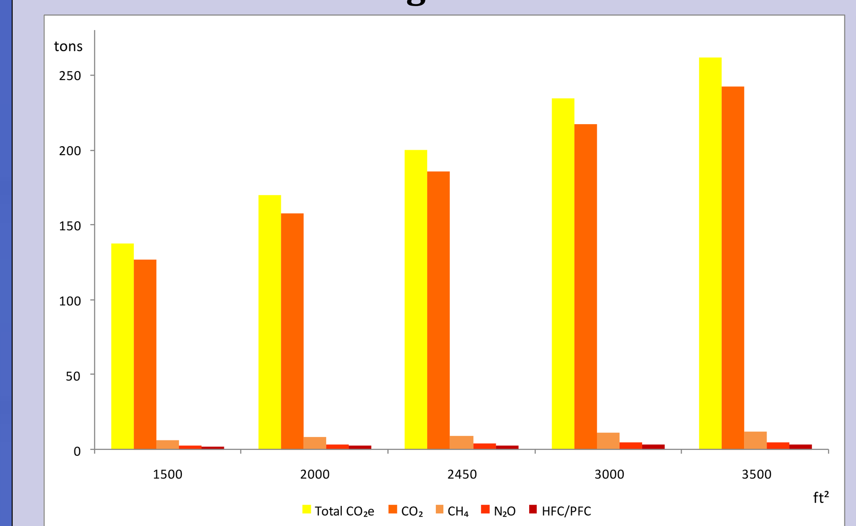

**Figure C**

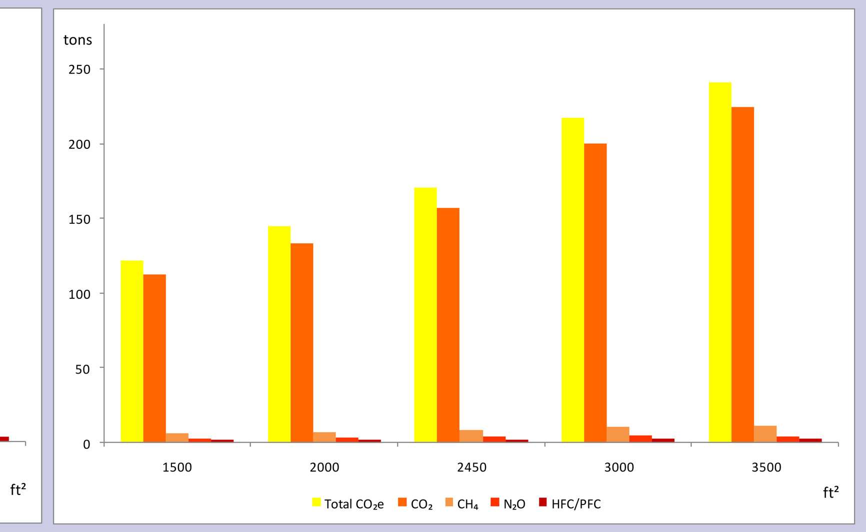

Table C shows the total GHG emissions (tons) produced during the materials manufacturing and on-site energy construction processes.

**Table C**

| Size (ft²) | Total $CO_2e$ | $CO_2$ | $CH_4$ | $N_2O$ | HFC/PFC |
|---|---|---|---|---|---|
| **1 Story Single-Family Detached** | | | | | |
| 1,500 | 137.33 | 127.17 | 6.50 | 2.69 | 1.94 |
| 2,000 | 170.18 | 157.75 | 7.97 | 3.30 | 2.31 |
| 2,450 | 200.31 | 185.69 | 9.36 | 3.89 | 2.64 |
| 3,000 | 234.47 | 217.45 | 10.90 | 4.53 | 2.96 |
| 3,500 | 261.85 | 242.85 | 12.16 | 5.06 | 3.23 |
| **2 Stories Single-Family Detached** | | | | | |
| 1,500 | 121.95 | 112.29 | 6.07 | 2.70 | 1.61 |
| 2,000 | 144.88 | 133.46 | 7.15 | 3.23 | 1.87 |
| 2,450 | 170.40 | 157.04 | 8.38 | 3.77 | 2.13 |
| 3,000 | 217.43 | 200.43 | 10.61 | 4.82 | 2.63 |
| 3,500 | 241.37 | 224.52 | 10.88 | 4.16 | 2.92 |

## CONCLUSION

There is not a linear relationship between the size of a housing unit and the life cycle embedded energy in construction and materials. The type of construction, number of stories, and material used affects the total life cycle energy and GHG emissions. Certain materials (e.g., cement used for foundations) are scaled proportionally to the overall size of the building, while others are scaled as a function of perimeter and volume (e.g., drywalls, paint, wood, stucco). The construction phase accounts for almost a quarter of the total LCA, when controlling for appliances and lighting energy consumption. This indicates that it should be further evaluated when considering energy and GHG reduction strategies.

Future work will investigate the LCA of additional building envelope materials and additional building typologies (e.g., multi family) to create a more complete neighborhood energy profile.

**Acknowledgements**

This material is based upon work supported by the National Science Foundation under Grant SES-0951366, Decision Center for a Desert City II: Urban Climate Adaptation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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