Embodied Energy of Rural Houses in Uganda
Nkozi Village Survey

Roberta Mutschler
Introduction

• In East Africa 95% of the population use solid fuels for heating and cooking

• Deforestation in Uganda
  o 44 million tones of wood per annum (equals to 12 toe)
  o Expected to increase up to 135 tones by 2020 in a BAU projection.
  o Burned brick industry accounts of around 6 million tones per annum
Introduction: ELITH Project

• Energy and Low Income Tropical Housing (ELITH) project
  • Seeks to identify, and then propagate, methods of reducing the energy consumption of low-income houses.

• Partners:

  UK
  • University of Warwick
  • University of Cambridge

  China
  • University of Nottingham

  Thailand
  • King Mongkut’s University of Technology Thonburi (KMUTT)

  Tanzania
  • National Housing and Building Research Agency (NHBRA)

  Uganda
  • Uganda Martyrs University
Introduction: Aims and Objectives

- **Mission to Uganda:**
  - Visit partners and collaborate in dissemination report.

- **Objectives:**
  - Identify embodied and operational energy in low-income houses
  - Identify a low-cost architectural design to minimise energy use
  - Provide support writing the dissemination report
Methodology: Flow chart

1. Route & survey template design
2. Data collection
3. Material’s volume & area calculations
4. Gathering Embodied Energy factors

Embodied Energy of the house
Methodology: Route and Survey Template

Nkozi Village

Uganda Martyrs University

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Group 1
Group 2
Group 3
Group 4
Methodology: Data Collection

**House measures:**
- Length, width, height and thicknesses
- Record of materials used: doors, windows, masonry, floor, roof structure
- Presence of mortar, plaster, paint, roughcast and ring beam.

**Household interview:**
- Ownership
- Aspirations of refurbishment
- Energy consumption: wood, charcoal and kerosene
- Income range

Total sample size = 79 houses
Methodology: Materials’ Volume and Area

• Variables
  o Volume of bricks [m$^3$]
  o Volume of mortar [m$^3$]
  o Volume of plaster [m$^3$]
  o Area painted [m$^2$]
  o Area roughcast [m$^2$]
  o Volume of ring beam [m$^3$]
  o Volume of roof structure [m$^3$]
  o Area roof covering [m$^2$]
  o Volume of floor [m$^3$]
  o Foundation [m$^3$]
  o Number and type of doors and windows
Methodology: Embodied Energy Factors

- Embodied Energy of Burned Bricks
- Produced locally

<table>
<thead>
<tr>
<th></th>
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<td>2</td>
<td>41%</td>
<td>10,2</td>
<td>8116,2</td>
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<td>3869,2</td>
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<td>8,70</td>
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<td>16000</td>
<td>9,08</td>
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<tr>
<td>5</td>
<td>1</td>
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<td>4916,3</td>
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Average 6,95 2765

Benchmarks

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<tr>
<th>Embodied Energy [MJ/brick]</th>
<th>Source</th>
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<tr>
<td>Source 1</td>
<td>39</td>
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<tr>
<td>Source 2</td>
<td>16</td>
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<td>Source 3</td>
<td>6,95</td>
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<tr>
<td>Source 4</td>
<td>4,25</td>
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Methodology: Embodied Energy Factors

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<tr>
<th>Material</th>
<th>Description</th>
<th>Material</th>
<th>Energy Factor</th>
<th>Unit</th>
<th>Source</th>
<th>Density</th>
<th>Density units</th>
<th>Embodied Energy</th>
<th>Embodied Energy Units</th>
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<td>Bricks/Blocks</td>
<td>Concrete Blocks</td>
<td>Block</td>
<td>0.243</td>
<td>MJ/kg</td>
<td>Praseeda et al. (2015)</td>
<td>2320</td>
<td>kg/m3</td>
<td>564</td>
<td>MJ/m3</td>
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<tr>
<td></td>
<td>Half Clay bricks</td>
<td>Half brick</td>
<td>1.270</td>
<td>MJ/kg</td>
<td>Praseeda et al. (2015)</td>
<td>1435</td>
<td>kg/m3</td>
<td>1822</td>
<td>MJ/m3</td>
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<td>Steel reinforced concrete</td>
<td>Concrete</td>
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<td>MJ/kg</td>
<td>Praseeda et al. (2015)</td>
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<td>kg/m3</td>
<td>564</td>
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<td>Steel</td>
<td>25.3</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>7800</td>
<td>kg/m3</td>
<td>197340</td>
<td>MJ/m3</td>
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<td>Burned Clay Brick</td>
<td>Clay Brick</td>
<td>2765</td>
<td>MJ/m2</td>
<td>Own research</td>
<td>1441</td>
<td>kg/m3</td>
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<td>MJ/m3</td>
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<td>5:1 volumetric, sand and cement</td>
<td>Sand</td>
<td>0.0081</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>411</td>
<td>MJ/m3</td>
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<tr>
<td></td>
<td></td>
<td>Cement CEM II/B-V</td>
<td>4.065</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1506</td>
<td>kg/m3</td>
<td>613</td>
<td>MJ/m3</td>
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<tr>
<td>Plaster</td>
<td>3:1 volumetric, sand and cement</td>
<td>Sand</td>
<td>0.0081</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>409</td>
<td>MJ/m3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cement CEM II/B-V</td>
<td>4.065</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1506</td>
<td>kg/m3</td>
<td>10.5</td>
<td>MJ/m2</td>
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<td>Paint</td>
<td>Single coat paint</td>
<td>General Paint</td>
<td>10.5</td>
<td>MJ/m2</td>
<td>ICE 2.1</td>
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<td>kg/m3</td>
<td>613</td>
<td>MJ/m3</td>
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<tr>
<td>Roughtcast</td>
<td>2:1 volumetric, sand and cement</td>
<td>Sand</td>
<td>0.083</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>444</td>
<td>MJ/m3</td>
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<td>Ring beam</td>
<td>2:4:1 volumetric. Sand, aggregates and cement</td>
<td>Aggregates</td>
<td>0.083</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>444</td>
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<td>Cement CEM II/B-V</td>
<td>4.065</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
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<td>kg/m3</td>
<td>3574</td>
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<td>Roof timber</td>
<td>Swan softwood</td>
<td>Sawn Softwood</td>
<td>7.4</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>483</td>
<td>kg/m3</td>
<td>3574</td>
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<td>Roof steel sheet</td>
<td>Galvanised corrugated steel sheets</td>
<td>Steel Sheet</td>
<td>28.5</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>3.13</td>
<td>kg/m2</td>
<td>89</td>
<td>MJ/m2</td>
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<td>Foundation concrete</td>
<td>3:4:1 volumetric. Sand, aggregate and cement</td>
<td>Sand</td>
<td>0.0081</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>108</td>
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<tr>
<td></td>
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<td>Aggregates</td>
<td>0.083</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>108</td>
<td>MJ/m3</td>
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<td></td>
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<td>Cement CEM II/B-V</td>
<td>0.7</td>
<td>MJ/kg</td>
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<td>kg/m3</td>
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<td>MJ/m3</td>
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<td>Foundation wall</td>
<td>3:1 volumetric mortar and bricks. Sand and cement.</td>
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<td>4.065</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1506</td>
<td>kg/m3</td>
<td>409</td>
<td>MJ/m3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brick</td>
<td>2765</td>
<td>MJ/m2</td>
<td>Own research</td>
<td>2765</td>
<td>MJ/m3</td>
<td>2765</td>
<td>MJ/m3</td>
</tr>
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<td>Floor</td>
<td>4:1 volumetric, sand and cement</td>
<td>Sand</td>
<td>0.0081</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1602</td>
<td>kg/m3</td>
<td>410</td>
<td>MJ/m3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cement CEM II/B-V</td>
<td>4.065</td>
<td>MJ/kg</td>
<td>ICE 2.0</td>
<td>1506</td>
<td>kg/m3</td>
<td>410</td>
<td>MJ/m3</td>
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<tr>
<td>Door Timber</td>
<td></td>
<td>Sawn Softwood</td>
<td>154</td>
<td>Door</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>154</td>
<td>MJ/door</td>
<td>154</td>
<td>MJ/door</td>
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<tr>
<td>Door Steel</td>
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<td>Steel</td>
<td>3755</td>
<td>Door</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>3755</td>
<td>MJ/door</td>
<td>3755</td>
<td>MJ/door</td>
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<td>Door Timber+Glass</td>
<td></td>
<td>Timber</td>
<td>103</td>
<td>Door</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>103</td>
<td>MJ/door</td>
<td>103</td>
<td>MJ/door</td>
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<td></td>
<td></td>
<td>Glass</td>
<td>46.8</td>
<td>Door</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>46.8</td>
<td>MJ/door</td>
<td>46.8</td>
<td>MJ/door</td>
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<td>Door Steel+Glass</td>
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<td>Steel</td>
<td>25.24</td>
<td>Door</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>25.24</td>
<td>MJ/door</td>
<td>2570</td>
<td>MJ/door</td>
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<tr>
<td></td>
<td></td>
<td>Glass</td>
<td>46.8</td>
<td>Door</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>46.8</td>
<td>MJ/door</td>
<td>2570</td>
<td>MJ/door</td>
</tr>
<tr>
<td>Window Timber</td>
<td></td>
<td>Timber</td>
<td>81.4</td>
<td>Window</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>81</td>
<td>MJ/window</td>
<td>81</td>
<td>MJ/window</td>
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<tr>
<td>Window Timber+Glass</td>
<td></td>
<td>Window</td>
<td>199</td>
<td>Window</td>
<td>ICE 2.0 (or 77.1MJ own R.)</td>
<td>199</td>
<td>MJ/window</td>
<td>199</td>
<td>MJ/window</td>
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<tr>
<td>Window Steel+Glass</td>
<td></td>
<td>Steel</td>
<td>631</td>
<td>Window</td>
<td>ICE 2.0 &amp; Own R.</td>
<td>682</td>
<td>MJ/window</td>
<td>682</td>
<td>MJ/window</td>
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Results

Average Embodied Energy Materials of Rural Houses in Uganda

- Bricks/blocks
- Foundation
- Roof (galvanised sheets)
- Doors
- Roof Structure (timber)
- Mortar
- Plaster
- Windows
- Paint
- Floor (cement/concrete)
- Ring beam
- Clay half bricks
- Roughcast
Results: Embodied Energy Material Category

<table>
<thead>
<tr>
<th>Material Category</th>
<th>Percentage</th>
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<tr>
<td>Burned Bricks</td>
<td>90%</td>
</tr>
<tr>
<td>Concrete</td>
<td>5%</td>
</tr>
<tr>
<td>Mud &amp; wattle</td>
<td>5%</td>
</tr>
</tbody>
</table>

Average Embodied Energy per material category

- **Burned Bricks**
- **Concrete**
- **Mud & wattle**
Results: Embodied Energy Burned Bricks

Average, minimum and maximum of burned bricks houses

Max: House 310b

Average Burned Bricks

Min: House 412

Embodied Energy [MJ/m²]

Bricks/blocks
Foundation
Roof (galvanised sheets)
Doors
Roof Structure (timber)
Mortar
Windows
Plaster
Paint
Floor (cement/concrete)
Clay half bricks
Ring beam
Roughtcast
Results: Embodied Energy Burned Bricks

House 310b

House 412
Results: Statistics

Embodied Energy of houses per material category

Total House EE [MJ/m²]

Burned B
Concrete
Mud & wa

Bricks Categories
Results: Burned Bricks Statistics

Tests of Normality

<table>
<thead>
<tr>
<th></th>
<th>Kolmogorov–Smirnov&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Shapiro–Wilk</th>
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<tbody>
<tr>
<td></td>
<td>Statistic</td>
<td>df</td>
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<tr>
<td>Total House EE</td>
<td>0.074</td>
<td>70</td>
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</table>

<sup>a</sup>. This is a lower bound of the true significance.

<sup>*</sup>. The Lilliefors Significance Correction
Results: Burned Bricks Statistics

<table>
<thead>
<tr>
<th>House 412</th>
<th>House 310b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor Area [m²]</td>
<td>149</td>
</tr>
</tbody>
</table>

Boxplot percentiles of houses embodied energy vs floor Area
Results: Burned Bricks Statistics

- Total EE vs Burned Bricks
- Total EE vs Foundation
- Total EE vs Doors
- Total EE vs Roof Covering
- Total EE vs Roof Structure
- Total EE vs Mortar
## Interlocking Stabilised Soil Blocks (ISSB)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>ISSB</th>
<th>Burned Bricks</th>
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</thead>
<tbody>
<tr>
<td>Size [mm]</td>
<td>266x140x95¹</td>
<td>221x121x94**</td>
</tr>
<tr>
<td>Compression Strength [N/mm²]</td>
<td>2.5 – 6.7²</td>
<td>5.9 – 7**</td>
</tr>
<tr>
<td>Price [UGX]</td>
<td>300¹</td>
<td>120**</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>1700¹</td>
<td>1441**</td>
</tr>
</tbody>
</table>

¹ This research
² Perez-Peña (2009)
² Walker (2007) and Odongo (2008)

Source: M. M. Nambatya (2015)
Results: Evaluating ISSB vs Burned Bricks

Embodied energy savings changing Burned Bricks by ISSB

- BB+Mortar [MJ/m²]
- ISSB + Mortar [MJ/m²]
Results: Evaluating ISSB vs Burned Bricks

- Material costs

£1 = UGX 4,798
Limitations

- No permission to enter to houses:
  - Estimation of roof structure
  - Estimation of interior layout
- Lack of embodied energy factors for African/Ugandan building materials
- Errors on measures taken
- Foundations cannot be seen
Conclusions

• Change burned bricks by ISSB means high energy savings per slightly higher investment. However, by using ISSB plaster, paint and roughcast are not necessary.

• As expected, correlation was found between Burned Bricks and the total embodied energy of houses, but no clear correlation was shown for the other variables.

• Deeper statistic analysis is needed to know the influence of each variable on embodied energy results
Acknowledgements

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• Alex Ndibwami (Uganda Martyrs University)
• Thomas More (Uganda Martyrs University)
References


Thank you!!