Study of Human Embodied Energy for Masonry Work during Building Construction

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Embodied Energy

- Indirect embodied energy
  - Manufacturing of construction materials

- Direct Embodied Energy
  - On-site construction processes

- Recurring embodied energy
  - Maintenance, repair, renovation
Construction Energy

Embodied Energy

- Indirect embodied energy
- Direct Embodied Energy

Construction Energy

<= 20% of life cycle energy for Air-conditioned buildings
Construction Energy

Embodied Energy

Indirect embodied energy

Direct Embodied Energy

Construction Energy

@ 40-50% of life cycle energy for naturally ventilated buildings
Construction Energy

Embodied Energy

Indirect embodied energy

Direct Embodied Energy

Extraction Processing
Transport Manufacturing

Natural gas
Coal
Fuel
Electricity

Transportation Equipment use
Site office
Site lighting
Construction Energy

Indirect embodied energy

Embodied Energy

Direct Embodied Energy

Extraction Processing Transport Manufacturing

Transportation Equipment use Site office Site lighting
Construction Energy

Embodied Energy

Indirect embodied energy

Direct Embodied Energy

Non-renewable energy versus Human energy

Transportation
Equipment use
Site office
Site lighting
Manpower

Non-renewable energy versus Human energy
Objectives and Scope

• To determine the energy use by human workforce during construction.

• To determine the relation between human energy and non-renewable energy used for construction processes.

• The scope is limited to masonry work of high-rise residential building construction.
Case Study: Masonry work

• Duration of data collection: 16 months

• Project type: high-rise residential building construction

• No of blocks(buildings): 5

• Material hoist: One per block

• Total quantity of work: 4441 cu.m.
Quantity of masonry work completed

Total quantity of work: 4441 cu.m.

Average: 278 cu.m.
### Schedule of manpower (human workforce)

<table>
<thead>
<tr>
<th>Months</th>
<th>Number of Masons</th>
<th>Number of male helpers</th>
<th>Number of female helpers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89</td>
<td>135</td>
<td>119</td>
</tr>
<tr>
<td>2</td>
<td>252</td>
<td>384</td>
<td>327</td>
</tr>
<tr>
<td>3</td>
<td>321</td>
<td>487</td>
<td>418</td>
</tr>
<tr>
<td>4</td>
<td>259</td>
<td>399</td>
<td>338</td>
</tr>
<tr>
<td>5</td>
<td>233</td>
<td>355</td>
<td>303</td>
</tr>
<tr>
<td>6</td>
<td>319</td>
<td>484</td>
<td>417</td>
</tr>
<tr>
<td>7</td>
<td>317</td>
<td>479</td>
<td>416</td>
</tr>
<tr>
<td>8</td>
<td>401</td>
<td>610</td>
<td>527</td>
</tr>
<tr>
<td>9</td>
<td>457</td>
<td>695</td>
<td>600</td>
</tr>
<tr>
<td>10</td>
<td>451</td>
<td>682</td>
<td>592</td>
</tr>
<tr>
<td>11</td>
<td>541</td>
<td>817</td>
<td>701</td>
</tr>
<tr>
<td>12</td>
<td>359</td>
<td>541</td>
<td>471</td>
</tr>
<tr>
<td>13</td>
<td>302</td>
<td>459</td>
<td>397</td>
</tr>
<tr>
<td>14</td>
<td>162</td>
<td>250</td>
<td>215</td>
</tr>
<tr>
<td>15</td>
<td>229</td>
<td>350</td>
<td>292</td>
</tr>
<tr>
<td>16</td>
<td>230</td>
<td>350</td>
<td>294</td>
</tr>
<tr>
<td>Total</td>
<td>4922</td>
<td>7477</td>
<td>6427</td>
</tr>
</tbody>
</table>
Methodology

Embodied human energy (MJ) =
{ (PAR * BMR) – BMR (MJ/hr) } x (Number of work hours)
Methodology

Non renewable energy used for lifting (material hoist)

\[ \text{= No. of lift cycles} \times \text{kWh/lift cycle} \]

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>BMR (MJ/day)</th>
<th>Avg. weight (kg)</th>
<th>BMR (MJ/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>18-30</td>
<td>0.063 W + 2.896</td>
<td>62.5</td>
<td>6.83</td>
</tr>
<tr>
<td>Female</td>
<td>18-30</td>
<td>0.062 W + 2.036</td>
<td>57.5</td>
<td>5.60</td>
</tr>
</tbody>
</table>

Food and Agriculture Organization, 2001
## Methodology

<table>
<thead>
<tr>
<th>Construction Activity</th>
<th>PAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pour Concrete (Foundation)</td>
<td>4.81</td>
</tr>
<tr>
<td>Brick Laying</td>
<td>4.81</td>
</tr>
<tr>
<td>Transport (Walk with 25-30 kg)</td>
<td>3.9</td>
</tr>
<tr>
<td>Place cement mortar</td>
<td>3.3</td>
</tr>
<tr>
<td>Rebar cutting and bending</td>
<td>3.3</td>
</tr>
<tr>
<td>Making Bricks</td>
<td>3</td>
</tr>
</tbody>
</table>

Food and Agriculture Organization, 2001
Energy Use: Manufacturing and Transport

**Manufacturing**
- Cement: 53%
- Block: 42%
- Sand: 5%

**Transportation to site**
- Sand: 10%
- Block: 50%
- Cement: 40%

Material flow: 1.82 tons/cu.m.
Energy: 1.41 GJ/cu.m.
Energy: 67.1 MJ/cu.m.
## Energy use for construction equipment (material hoist)

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Energy use (kWh/cu.m.)</th>
<th>Energy use (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry Block Quantity (75%)</td>
<td>3330.7</td>
<td>0.05</td>
<td>2038</td>
</tr>
<tr>
<td>Cement Mortar Quantity (25%)</td>
<td>1110.3</td>
<td>0.15</td>
<td>2038</td>
</tr>
<tr>
<td>Total Lifting Energy</td>
<td></td>
<td></td>
<td>4076</td>
</tr>
</tbody>
</table>

Energy: 0.92 MJ/cu.m.
Energy use (human workforce)

- Mason Male: 34%
- Helper Male: 39%
- Helper Female: 27%

Human Energy: 29 MJ/cu.m.
Comparison of energy use: Material hoist and human workforce

Material Hoist: 0.92 MJ/cu.m. [3%]

Human workforce: 29 MJ/cu.m. [97%]
Comparison of energy use: Material hoist and human workforce

<table>
<thead>
<tr>
<th>Months</th>
<th>Lifting (Mechanical energy)</th>
<th>Laying (Human energy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>97.3%</td>
<td>2.7%</td>
</tr>
<tr>
<td>2</td>
<td>97.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>3</td>
<td>96.9%</td>
<td>3.1%</td>
</tr>
<tr>
<td>4</td>
<td>97.1%</td>
<td>2.9%</td>
</tr>
<tr>
<td>5</td>
<td>97.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>6</td>
<td>96.8%</td>
<td>3.2%</td>
</tr>
<tr>
<td>7</td>
<td>96.8%</td>
<td>3.3%</td>
</tr>
<tr>
<td>8</td>
<td>96.7%</td>
<td>3.3%</td>
</tr>
<tr>
<td>9</td>
<td>96.7%</td>
<td>3.4%</td>
</tr>
<tr>
<td>10</td>
<td>96.7%</td>
<td>3.0%</td>
</tr>
<tr>
<td>11</td>
<td>97.0%</td>
<td>2.9%</td>
</tr>
<tr>
<td>12</td>
<td>97.1%</td>
<td>2.6%</td>
</tr>
<tr>
<td>13</td>
<td>97.4%</td>
<td>2.8%</td>
</tr>
<tr>
<td>14</td>
<td>97.2%</td>
<td>2.9%</td>
</tr>
<tr>
<td>15</td>
<td>97.1%</td>
<td>2.8%</td>
</tr>
<tr>
<td>16</td>
<td>97.1%</td>
<td>2.9%</td>
</tr>
</tbody>
</table>
Comparison of energy use for transport, lifting (material hoist) and human resources

- Human energy: 30%
- Lifting using hoist: 1%
- Transport: 69%
Summary and Conclusions

Construction energy
(Total initial embodied energy)

- Manufacturing of materials
  - Transportation to site: 67 MJ/cu.m. [69%]
- On-site construction
  - Construction equipment: 0.92 MJ/cu.m. [1%]
  - Manpower (Human Energy): 29 MJ/cu.m. [30%]
Summary and Conclusions

• Human energy is about $1/3$ of the total energy used for on-site construction for masonry work.

• The relation between human energy and on-site construction energy is influenced by the degree of mechanization and manpower used.
Summary and Conclusions

Case-I

LESS mechanization

Irrigation projects rural areas

HIGH manpower use

Case-II

SEMI mechanization

High-rise residential buildings urban areas

Case-III

HIGH mechanization

Major infrastructure projects of national importance

LESS manpower use
Summary and Conclusions

- Limitation: Human energy calculation is based upon the published BMR and PAR in literature. These parameters may vary for construction workforce in India.
Thank you