# Strategies for Cleaner Walling Materials in India

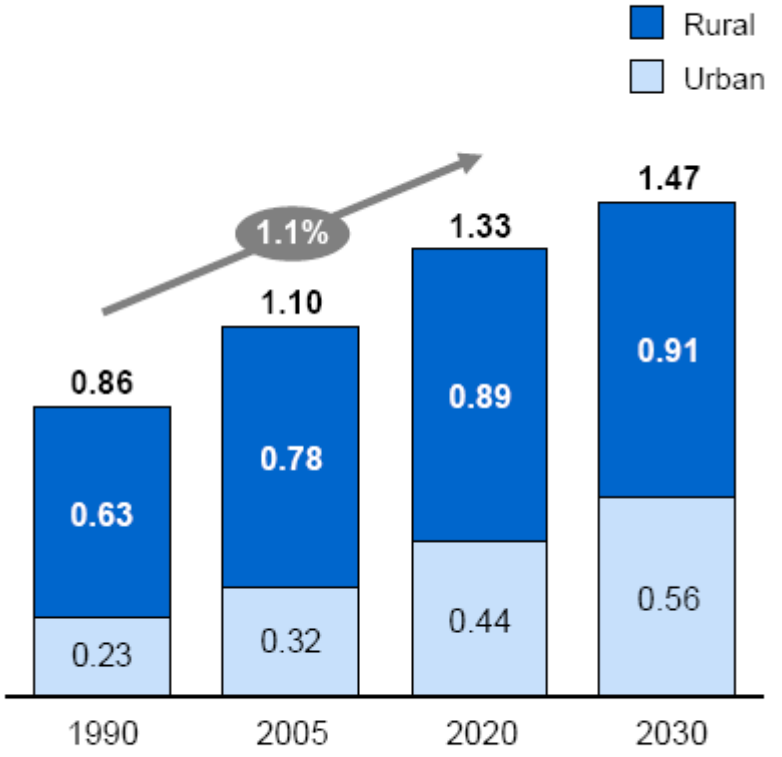
GREENTECH knowledge solutions

CLEAN AIR TASK FORCE

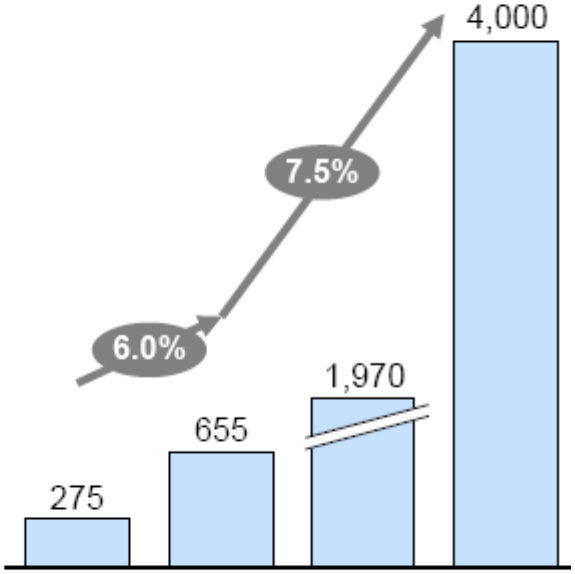
enzen™

# Drivers of building construction in India

**India population**
Billion



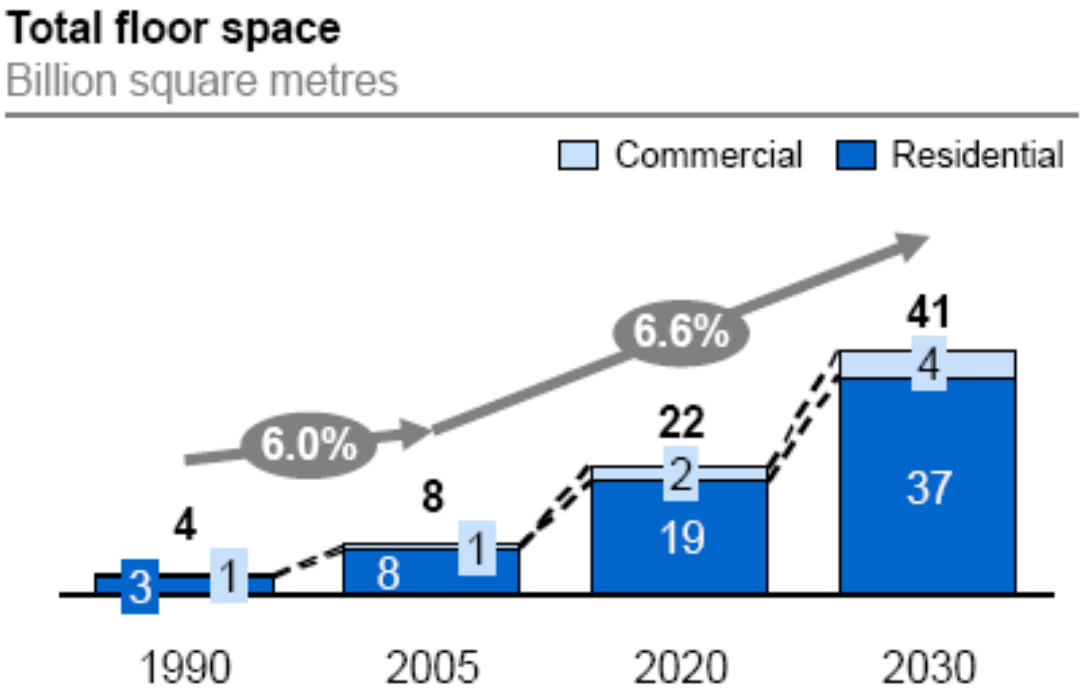

**India GDP**
USD billion, 2000, real




| | 1990 | 2005 | 2020 | 2030 |
|---|---|---|---|---|
| **Per capita GDP,** USD (Real) | 320 | 595 | 1,495 | 2,720 |

SOURCE: MGI – Oxford Economic Model; National Commission on Population, Office of Registrar General for Census of India; WMM Global Insight; McKinsey analysis

# Building construction and power demand




SOURCE: MGI – Oxford Economic Model; National Commission on Population, Office of Registrar General for Census of India; WMM Global Insight; McKinsey analysis

80% of building stock in 2030 would have been constructed in the period between 2005 and 2030

Housing shortage estimated at 24.7 million units at the end of the 10$^{th}$ five year plan of which about 70% is in rural areas (Government of India, 2007)

# Building construction in India

## Present status

### Building materials for walls

- Fired clay bricks
- Cement based blocks
- Fly-ash based products
- Earth based blocks


### Fired clay bricks

- 150-200 billion bricks produced annually in over 100,000 units
- Annual coal consumption of 25 million tons
- Majority production in small-scale unorganized units

# Building construction in India

## Consequences related to growth of Building Sector

Natural resource use:

Large environmental footprint in manufacture of building material products

Clay

Limestone

Sand

# Building construction in India

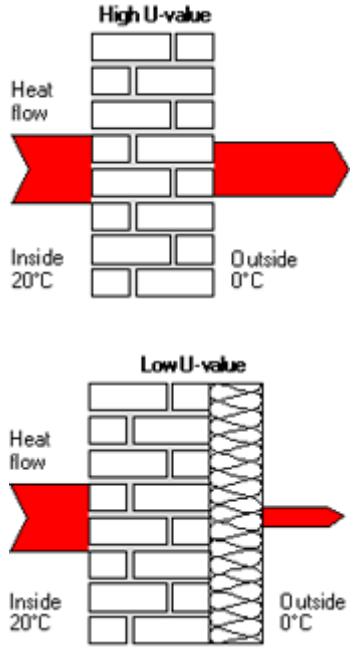
## Consequences related to growth of Building Sector

Energy use:

- Embodied energy
- Operational energy over life of a building

Coal for firing bricks

Biomass for firing bricks




Insulation properties

# Building construction in India

## Consequences related to growth of Building Sector

Environmental emissions:

- Regional pollutants – PM, $SO_2$, NOx, BC
- Global pollutants – $CO_2$

# Building construction in India

## Consequences related to growth of Building Sector

Socio-economic:

- Employment generation potential
- Occupational health risks

# Assessment of Walling Materials

## Study objectives

Comprehensive assessment of walling materials encompassing:

- Consumption of resources and raw materials including water
- Consumption of energy for production and transportation (embodied energy)
- Operational energy of buildings resulting from material (thermal) properties
- Productivity or efficiency
- Emissions of greenhouse gas (GHG) emissions – $CO_2$
- Regional air pollutant emissions – Particulates, $SO_2$, NOx, BC
- Socio-economics (costs; occupational health and safety)

# Walling materials selected for the study

## Masonry walls

- Fired clay bricks

- Concrete blocks (solid / hollow)
- Autoclaved Aerated Concrete blocks

- Fly ash concrete blocks (solid)
- Fly ash-Lime-Gypsum (FAL-G) blocks
- Fired fly ash clay bricks

- Stabilised Mud blocks

# Analysis framework
## Systems

**Unit of Analysis:** 1.0 square meter of wall area

### Load bearing wall (> 8” thick, G+1)

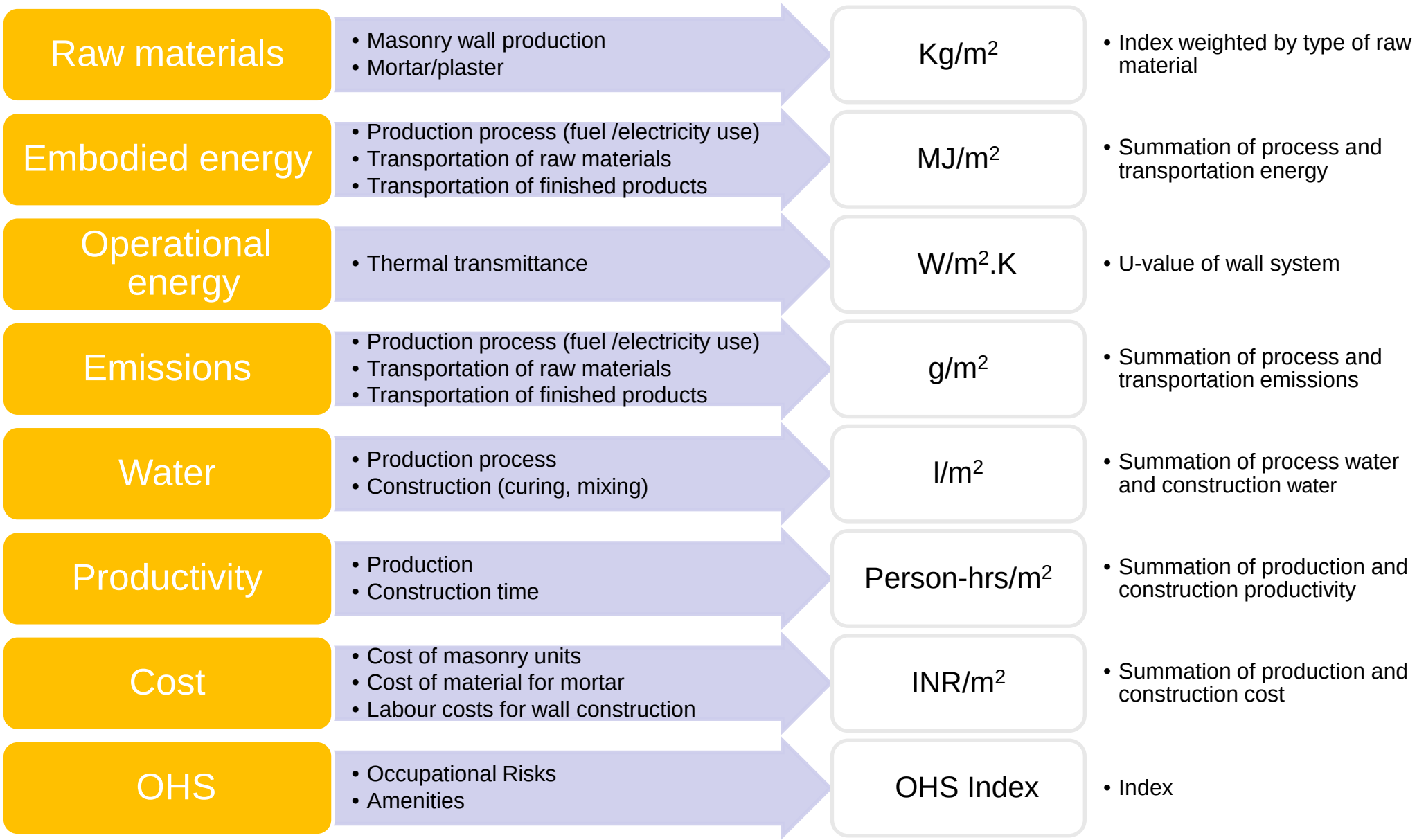
- English bond
- Rat-trap bond (for bricks / blocks of standard brick size)

Min. compressive strength of 3.5 MPa and design life of 50 years - wall design criteria

### Partition wall (< 6” thick)

# Analysis framework

## Study approach



# Cement Concrete Blocks

## Case study - Bangalore

**Raw materials, embodied energy, productivity**

| | Solid concrete block | Hollow concrete block |
|---|---|---|
| Weight of block (kg) | 23.20 | 17.79 |
| Size of block (mm) | 400 x 200 x 200 | 400 x 200 x 200 |
| Raw materials | | |
| Sand (%) | 25 | 20 |
| Cement (%) | 15 | 20 |
| Stone dust (%) | 60 | 60 |
| Water (including curing) (l/block) | 33.0 | 33.0 |
| Embodied Energy[1] | | |
| Total (MJ/block) | 28.15 | 27.83 |
| Excluding raw material transportation (MJ/block) | 21.17 | 21.79 |
| Production productivity (person-hours/block) | 0.15 | 0.18 |

**Wall assembly**

| | Load bearing | Non-load bearing |
|---|---|---|
| Block size (mm) | 400 x 200 x 200 | 400 x 200 x 100 |
| Wall thickness (mm)[1] | 200 | 100 |
| Blocks/m$^2$ | 11.6 | 11.6 |

# Fly ash Concrete Blocks

## Case study - Nagpur



**Raw materials, embodied energy, productivity**

| | Fly ash concrete block |
|---|---|
| Weight of block (kg) | 3.50 |
| Size of block (mm) | 230 x 115 x 75 |
| Raw materials | |
| Fly ash (%) | 24 |
| Cement (%) | 4 |
| Stone dust (%) | 72 |
| Water (including curing) (l/block) | 15.3 |
| Embodied Energy[1] | |
| Total (MJ/block) | 1.72 |
| Excluding transportation (MJ/block) | 0.86 |
| Production productivity (person-hours/block) | 0.003 |

**Wall assembly**

| | Load bearing (English bond) | Load bearing (Rat-Trap bond) | Non-load bearing |
|---|---|---|---|
| Block size (mm) | 230 x 115 x 75 | 230 x 115 x 75 | 230 x 115 x 75 |
| Wall thickness (mm)[1] | 230 | 230 | 115 |
| Blocks/$m^2$ | 98.0 | 68.6 | 49.0 |

# Fly ash-Lime-Gypsum (FaL-G) Blocks

## Case study - Nagpur



**Raw materials, embodied energy, productivity**

| | FaL-G block |
|---|---|
| Weight of block (kg) | 2.80 |
| Size of block (mm) | 230 x 115 x 75 |
| Raw materials | |
| Fly ash (%) | 33 |
| Sand (%) | 50 |
| Lime (%) | 17 |
| Water (including curing) (l/block) | 15.5 |
| Embodied Energy[1] | |
| Total (MJ/block) | 3.15 |
| Excluding transportation (MJ/block) | 3.92 |
| Production productivity (person-hours/block) | 0.02 |

**Wall assembly**

| | Load bearing (English bond) | Load bearing (Rat-Trap bond) | Non-load bearing |
|---|---|---|---|
| Block size (mm) | 230 x 115 x 75 | 230 x 115 x 75 | 230 x 115 x 75 |
| Wall thickness (mm)[1] | 230 | 230 | 115 |
| Blocks/$m^2$ | 98.0 | 68.6 | 49.0 |

# Autoclaved Aerated Concrete (AAC) blocks

## Case study - Pune

**Raw materials, embodied energy, productivity**

| | AAC block |
|---|---|
| Weight of block (kg) | 15.60 |
| Size of block (mm) | 650 x 240 x 200 |
| Raw materials | |
| Fly ash (%) | 61 |
| Cement (%) | 31 |
| Sand (%) | 8 |
| Water (including curing) (l/block) | 8.0 |
| Embodied Energy[1] | |
| Total (MJ/block) | 70.17 |
| Excluding transportation (MJ/block) | 45.51 |
| Production productivity (person-hours/block) | 0.058 |

**Wall assembly**

| | Load bearing | Non-load bearing |
|---|---|---|
| Block size (mm) | 650 x 240 x 200 | 650 x 240 x 100 |
| Wall thickness (mm)[1] | 200 | 100 |
| Blocks/$m^2$ | 6.1 | 6.1 |

# Stabilized Mud Blocks (SMB)

## From literature


**Raw materials, embodied energy, productivity**

| | SMB |
|---|---|
| Weight of block (kg) | 8.94 |
| Size of block (mm) | 305 x 143 x 100 |
| Raw materials | |
| Sand (%) | 65 |
| Silt (%) | 12 |
| Clay (%) | 17 |
| Cement (%) | 6 |
| Water (including curing) (l/block) | 6.0 |
| Embodied Energy[1] | |
| Total (MJ/block) | 4.62 |
| Excluding transportation (MJ/block) | 3.14 |
| Production productivity (person-hours/block) | 0.206 |

**Wall assembly**

| | Load bearing | Non-load bearing |
|---|---|---|
| Block size (mm) | 230 x 190 x 100 | 305 x 143 x 100 |
| Wall thickness (mm)[1] | 230 | 100 |
| Blocks/m$^2$ | 45.9 | 20.8 |

# Fired clay bricks

## 7 kilns across India + 1 in Vietnam

**Raw materials, embodied energy, productivity**

| | K1 | K2 | K3 | K4 | K5 | K6 | K7 | K8 |
|---|---|---|---|---|---|---|---|---|
| Weight of brick (kg) | 2.79 | 2.74 | 2.81 | 2.91 | 3.67 | 3.34 | 3.21 | 1.66 |
| Size of brick (mm) | 230 x 115 x 75 | 230 x 115 x 75 | 230 x 115 x 75 | 230 x 115 x 75 | 255 x 125 x 75 | 242 x 120 x 75 | 230 x 115 x 75 | 210 x 95 x 54 |
| Annual production (million) | 5.0 | 8.8 | 4.5 | 5.7 | 1.0 | 3.0 | 2.5 | 25.0 |
| Water (l/brick) | 0.30 | 0.27 | 0.28 | 0.18 | 0.37 | 0.14 | 0.18 | 0.35 |
| Kiln type | BTK | Zig-zag | Fixed Draft | BTK | VSBK | BTK | Down draft | Tunnel |
| Location | Hapur | Varanasi | Varanasi | Ludhiana | Arah | Arah | Malur | Vietnam |
| Fuel used | Mixed | Coal | Coal | Coal | Coal | Coal | Biomass | Coal |
| Embodied Energy | | | | | | | | |
| Total (MJ/brick) | 5.32 | 4.54 | 4.15 | 4.56 | 5.13 | 5.17 | 10.82 | 2.72 |
| Excluding transportation (MJ/brick) | 4.07 | 3.32 | 2.89 | 3.26 | 3.49 | 3.67 | 9.34 | 2.47 |
| Production productivity (person-hours/brick) | 0.042 | 0.040 | 0.046 | 0.037 | 0.096 | 0.058 | 0.060 | 0.012 |

# Fired clay fly ash bricks

## Case study - Akola


**Raw materials, embodied energy, productivity**

| | Fired clay fly ash brick |
|---|---|
| Weight of block (kg) | 2.60 |
| Size of block (mm) | 230 x 115 x 75 |
| Raw materials | |
| Fly ash (%) | 30 |
| Clay (%) | 70 |
| Water (l/block) | 0.65 |
| Embodied Energy[1] | |
| Total (MJ/block) | 5.01 |
| Excluding transportation (MJ/block) | 3.09 |
| Production productivity (person-hours/block) | 0.037 |

# Comparative assessment of walling materials
## Emissions

Emissions related to wall assemblies (g/m$^2$)

| | Production emissions | | | | | | | | Transportation emissions[1] | | | | | | Regional Emissions Index[2] (Plastered wall) | Normalised REI | $CO_2$ Emissions (Plastered wall) | Normalised $CO_2$ emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plastered wall | | | | Unplastered wall | | | | Plastered wall | | | Unplastered wall | | | | | | |
| | PM | $CO_2$ | $SO_2$ | NOx | PM | $CO_2$ | $SO_2$ | NOx | PM | $CO_2$ | NOx | PM | $CO_2$ | NOx | | | | |
| **Non-load bearing walls** | | | | | | | | | | | | | | | | | | |
| Solid Concrete Block | 43.3 | 30277.0 | 149.6 | 137.1 | 34.4 | 22801.2 | 113.0 | 103.9 | 7.8 | 4808.8 | 58.7 | 6.1 | 3765.9 | 45.9 | 396.6 | 0.31 | 35,085.8 | 0.46 |
| Fly Ash Concrete Blocks | 37.8 | 19647.8 | 99.5 | 88.0 | 28.9 | 12172.0 | 62.8 | 54.7 | 8.8 | 5385.9 | 65.7 | 7.1 | 4343.0 | 53.0 | 299.8 | -0.66 | 25,033.7 | -0.68 |
| FaL-G | 26.6 | 50051.0 | 128.8 | 100.0 | 17.6 | 42575.2 | 92.2 | 66.7 | 8.2 | 5040.9 | 61.5 | 6.5 | 3998.0 | 48.8 | 325.0 | -0.40 | 55,091.9 | 2.73 |
| AAC Blocks | 62.5 | 28137.4 | 136.9 | 120.1 | 46.6 | 11217.6 | 41.4 | 24.6 | 12.7 | 7785.3 | 95.0 | 14.3 | 8787.9 | 107.2 | 427.2 | 0.62 | 35,922.7 | 0.56 |
| Stabilized Mud Blocks | 25.9 | 21544.1 | 105.6 | 95.9 | 52.5 | 19727.1 | 95.7 | 82.7 | 6.6 | 4071.7 | 49.7 | 10.8 | 6612.1 | 80.7 | 283.6 | -0.82 | 25,615.8 | -0.61 |
| Fly Ash Clay Bricks | 55.5 | 18693.4 | 78.0 | 57.9 | 16.9 | 14068.3 | 68.9 | 62.6 | 16.0 | 9830.7 | 119.9 | 4.9 | 3028.8 | 36.9 | 327.3 | -0.38 | 28,524.1 | -0.28 |
| K1_Clay Bricks_BTK_Mixed fuel | 261.8 | 19379.6 | 132.1 | 57.9 | 252.8 | 11903.8 | 95.5 | 24.6 | 11.4 | 7027.8 | 85.7 | 9.7 | 5985.0 | 73.0 | 548.9 | 1.84 | 26,407.5 | -0.52 |
| K2_Clay Bricks_NDZZ_Coal | 22.3 | 18448.3 | 77.2 | 57.9 | 13.4 | 10972.5 | 40.5 | 24.6 | 11.3 | 6934.4 | 84.6 | 9.6 | 5891.6 | 71.9 | 253.2 | -1.12 | 25,382.7 | -0.64 |
| K3_Clay Bricks_FD_Coal | 87.2 | 18693.4 | 118.8 | 57.9 | 78.3 | 11217.6 | 82.2 | 24.6 | 11.5 | 7065.2 | 86.2 | 9.8 | 6022.4 | 73.5 | 361.6 | -0.04 | 25,758.6 | -0.60 |
| K4_Clay Bricks_BTK_Coal | 55.5 | 18693.4 | 78.0 | 57.9 | 46.6 | 11217.6 | 41.4 | 24.6 | 11.8 | 7252.1 | 88.5 | 10.1 | 6209.2 | 75.7 | 291.7 | -0.74 | 25,945.4 | -0.57 |
| K5_Clay Bricks_VSBK_Coal | 19.6 | 16371.9 | 69.7 | 59.4 | 10.6 | 8896.1 | 33.0 | 26.2 | 13.1 | 8073.5 | 98.5 | 11.4 | 7030.7 | 85.8 | 260.3 | -1.05 | 24,445.4 | -0.74 |
| K6_Clay Bricks_BTK_Coal | 116.4 | 18698.5 | 158.2 | 58.7 | 107.5 | 11222.7 | 121.5 | 25.4 | 12.7 | 7831.8 | 95.5 | 11.0 | 6789.0 | 82.8 | 441.6 | 0.76 | 26,530.3 | -0.51 |
| K7_Clay Bricks_DD_Biomass | 335.0 | 35262.0 | 63.7 | 57.9 | 326.1 | 27786.2 | 27.1 | 24.6 | 13.0 | 8012.6 | 97.7 | 11.3 | 6969.7 | 85.0 | 567.4 | 2.03 | 43,274.6 | 1.39 |
| K8_Clay Bricks_Tunnel_Coal | 46.5 | 24811.1 | 136.8 | 58.9 | 37.6 | 17335.3 | 100.1 | 25.6 | 10.3 | 6340.4 | 77.3 | 8.6 | 5297.5 | 64.6 | 329.8 | -0.36 | 31,151.5 | 0.02 |

[1] $SO_2$ emission factors are negligible

[2] REI = PM emissions + $SO_2$ emissions + NOx emissions

# Ranking of wall assemblies

## Load bearing walls

| | Normalized Scores | | | | | | | | | Composite Environmental Index | RANKING |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | RMI | Water | Embodied Energy | Operational Energy | REI | $CO_2$ Emissions | OHS Index | Productivity Index | Cost | | |
| Solid Concrete Block | -1.17 | 0.24 | -0.47 | 1.02 | 0.68 | 0.80 | -1.19 | -0.82 | -0.48 | -2.13 | 8 |
| Hollow Concrete Block | -1.28 | 0.24 | -0.49 | 0.29 | 0.69 | 0.80 | -1.19 | -0.35 | -0.90 | -2.92 | 6 |
| Fly Ash Concrete Blocks | -1.43 | 2.60 | -0.78 | 0.55 | -0.15 | -0.17 | -0.72 | -1.14 | 0.34 | -0.73 | 14 |
| FaL-G | -0.68 | 2.64 | 0.20 | -1.67 | 0.08 | 2.89 | -0.96 | -0.20 | 0.05 | 0.88 | 16 |
| AAC Blocks | -1.55 | -0.46 | -0.09 | -3.13 | 0.85 | 0.77 | -2.11 | -1.49 | 2.80 | -5.23 | 3 |
| Stabilized Mud Blocks | 0.33 | 0.02 | -0.70 | 0.46 | 0.03 | 0.22 | -0.49 | 0.19 | -0.95 | -1.02 | 13 |
| Fly Ash Clay Bricks | 0.11 | -0.42 | 0.69 | -0.16 | 0.10 | 0.19 | 0.44 | 0.02 | 0.34 | 1.16 | 18 |
| K1_Clay Bricks_Hapur_BTK_Mixed fuel | 0.96 | -0.50 | 0.83 | 0.72 | 2.13 | -0.03 | 0.44 | 0.19 | 0.93 | 4.63 | 21 |
| K2_Clay Bricks_Varanasi_NDZZ_Coal | 0.92 | -0.50 | 0.48 | 0.72 | -0.58 | -0.13 | 0.44 | -0.53 | 0.93 | 2.10 | 19 |
| K3_Clay Bricks_Varanasi_FD_Coal | 0.98 | -0.50 | 0.31 | 0.72 | 0.42 | -0.09 | 1.36 | 1.11 | 0.93 | 5.08 | 22 |
| K4_Clay Bricks_Ludhiana_BTK_Coal | 1.07 | -0.52 | 0.49 | 0.72 | -0.22 | -0.07 | 1.13 | 0.02 | 0.93 | 3.69 | 20 |
| K5_Clay Bricks_Arah_VSBK_Coal | 1.53 | -0.49 | 0.63 | 0.72 | -0.47 | -0.19 | -0.03 | 3.18 | 0.78 | 6.00 | 24 |
| K6_Clay Bricks_Arah_BTK_Coal | 1.35 | -0.53 | 0.69 | 0.72 | 1.15 | -0.01 | 1.13 | 0.64 | 0.84 | 5.41 | 23 |
| K7_Clay Bricks_Malur_DD_Biomass | 1.34 | -0.52 | 3.29 | 0.72 | 2.30 | 1.69 | 0.20 | 0.79 | 0.93 | 8.75 | 25 |
| K8_Clay Bricks_Vietnam_Tunnel_Coal | 0.91 | -0.44 | 0.86 | 0.72 | 0.37 | 0.71 | -1.88 | -0.88 | 0.94 | 0.77 | 15 |
| Fly Ash Concrete Blocks_RTB | -1.77 | 1.65 | -1.62 | -0.16 | -1.17 | -1.14 | -0.72 | -1.16 | -1.08 | -6.01 | 1 |
| FaL-G_RTB | -1.24 | 1.68 | -0.93 | -2.20 | -1.01 | 1.01 | -0.96 | -0.50 | -1.29 | -5.44 | 2 |
| Fly Ash Clay Bricks_RTB | -0.69 | -0.47 | -0.59 | -0.83 | -0.99 | -0.89 | 0.44 | -0.35 | -1.08 | -4.51 | 4 |
| K1_Clay Bricks_Hapur_BTK_Mixed fuel_RTB | -0.09 | -0.52 | -0.49 | 0.01 | 0.43 | -1.04 | 0.44 | -0.23 | -0.67 | -1.87 | 9 |
| K2_Clay Bricks_Varanasi_NDZZ_Coal_RTB | -0.12 | -0.53 | -0.73 | 0.01 | -1.47 | -1.11 | 0.44 | -0.73 | -0.67 | -3.63 | 5 |
| K3_Clay Bricks_Varanasi_FD_Coal_RTB | -0.08 | -0.53 | -0.86 | 0.01 | -0.77 | -1.08 | 1.36 | 0.42 | -0.67 | -1.27 | 10 |
| K4_Clay Bricks_Ludhiana_BTK_Coal_RTB | -0.02 | -0.54 | -0.73 | 0.01 | -1.22 | -1.07 | 1.13 | -0.34 | -0.67 | -2.31 | 7 |
| K5_Clay Bricks_Arah_VSBK_Coal_RTB | 0.29 | -0.52 | -0.66 | 0.01 | -1.43 | -1.19 | -0.03 | 1.87 | -0.82 | -1.17 | 11 |
| K6_Clay Bricks_Arah_BTK_Coal_RTB | 0.17 | -0.55 | -0.60 | 0.01 | -0.27 | -1.04 | 1.13 | 0.09 | -0.75 | -1.16 | 12 |
| K7_Clay Bricks_Malur_DD_Biomass_RTB | 0.17 | -0.54 | 1.23 | 0.01 | 0.54 | 0.16 | 0.20 | 0.20 | -0.67 | 0.95 | 17 |

# Ranking of wall assemblies

## Non-load bearing walls

| | Normalized Scores | | | | | | | | | Composite Environmental Index | RANKING |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | RMI | Water | Embodied Energy | Operational Energy | REI | $CO_2$ Emissions | OHS Index | Productivity Index | Cost | | |
| Solid Concrete Block | -1.37 | 0.55 | -0.86 | 0.61 | 0.31 | 0.46 | -0.93 | -0.32 | -1.21 | -3.15 | 3 |
| Fly Ash Concrete Blocks | -1.61 | 2.24 | -1.21 | 0.28 | -0.66 | -0.68 | -0.51 | -1.05 | -0.28 | -2.81 | 4 |
| FaL-G | -0.91 | 2.28 | -0.23 | -1.50 | -0.40 | 2.73 | -0.72 | -0.24 | -0.60 | -0.75 | 6 |
| AAC Blocks | -1.66 | -0.47 | -0.37 | -2.93 | 0.62 | 0.56 | -1.77 | -1.54 | 2.38 | -5.78 | 1 |
| Stabilized Mud Blocks | -0.24 | -0.10 | -1.40 | 0.55 | -0.82 | -0.61 | -0.30 | -0.10 | -2.15 | -4.46 | 2 |
| Fly Ash Clay Bricks | -0.17 | -0.44 | 0.27 | -0.25 | -0.38 | -0.28 | 0.54 | -0.05 | -0.28 | -0.71 | 7 |
| K1_Clay Bricks_Hapur_BTK_Mixed fuel | 0.63 | -0.50 | 0.40 | 0.40 | 1.84 | -0.52 | 0.54 | 0.10 | 0.36 | 2.59 | 10 |
| K2_Clay Bricks_Varanasi_NDZZ_Coal | 0.59 | -0.51 | 0.05 | 0.40 | -1.12 | -0.64 | 0.54 | -0.53 | 0.36 | 0.03 | 8 |
| K3_Clay Bricks_Varanasi_FD_Coal | 0.64 | -0.51 | -0.12 | 0.40 | -0.04 | -0.60 | 1.38 | 0.90 | 0.36 | 2.74 | 11 |
| K4_Clay Bricks_Ludhiana_BTK_Coal | 0.73 | -0.52 | 0.06 | 0.40 | -0.74 | -0.57 | 1.17 | -0.05 | 0.36 | 1.49 | 9 |
| K5_Clay Bricks_Arah_VSBK_Coal | 1.09 | -0.50 | 0.14 | 0.40 | -1.05 | -0.74 | 0.12 | 2.62 | 0.11 | 3.10 | 12 |
| K6_Clay Bricks_Arah_BTK_Coal | 0.98 | -0.53 | 0.26 | 0.40 | 0.76 | -0.51 | 1.17 | 0.49 | 0.26 | 3.17 | 13 |
| K7_Clay Bricks_Malur_DD_Biomass | 0.97 | -0.52 | 2.88 | 0.40 | 2.03 | 1.39 | 0.33 | 0.62 | 0.36 | 6.75 | 14 |
| K8_Clay Bricks_Vietnam_Tunnel_Coal | 0.32 | -0.46 | 0.13 | 0.40 | -0.36 | 0.02 | -1.56 | -0.86 | -0.02 | -2.22 | 5 |

# Summary
## Raw materials and Water

- Clay fired bricks have the maximum impact on natural resources
  - High clay content from top soil

- Higher density materials have correspondingly higher impact on natural resource consumption
  - Mechanization for extrusion increases density but this can be offset by creating voids (hollow bricks)

- Fly ash content and alternative construction practices (Rat-trap bond) can reduce this impact significantly

- Water consumption is lowest for clay fired bricks (production as well as construction)

# Summary

## Embodied energy, operational energy and emissions

- Clay fired bricks have the highest embodied energy compared to non-fired materials irrespective of kiln efficiency
- Thermal performance of non-fired materials are also generally superior to fired bricks but only marginally
- On average, emissions are also lower for non-fired materials compared to fired clay bricks for same category of wall although variations within these two groups are very high.

# Summary
## OHS, productivity and cost

- Poor conditions for labour at kiln sites result in a lower OHS index compared to other materials
    - Units producing non-fired materials are generally located close to large urban areas and do not require labour to live on site during the production period as in the case of fired clay materials

- Labour intensive brick making results in lower production productivity compared to non-fired materials
    - Mechanization in moulding can significantly improve productivity (e.g., fly ash clay blocks and AAC blocks)

- Cost of walls with non-fired materials are generally lower than fired products (except for AAC block walls)

# Recommendations

## Strategies

- Promoting the use of non-fired masonry materials
- Promoting the production and use of larger sized low-density masonry units
- Promoting further use of fly ash in masonry material production
- Encouraging alternative construction practices
- Promoting mechanization in production units and year round production
  - Block density to be reduced through cavities/perforations where mechanization is adopted

# Action Plan

## National Level – Facilitating non-fired masonry material development and production

- Identification of regional level strategies based on demand and resources available in that geographical context
- Providing incentives to entrepreneurs for establishment of non-fired masonry materials, e.g., tax benefits for equipment and machinery, financing options, etc.; financing units with proposals for year-round production
- Setting up of entrepreneurship training and technical support centres for establishment of non-fired masonry industries (and fly ash based masonry block industries) in major demand centres; providing guidance on choosing appropriate machinery and equipment for mechanization; skill upgradation for masons on alternative construction techniques (rat-trap bond construction)
- Mandating fly ash processing facility at thermal power plants so that graded fly ash can be made available to end user
- Development of low density, larger sized masonry; Development of other waste material based masonry blocks of low density and larger size

*Possible actors:*
*Ministry of Urban Development and Poverty Alleviation (including HUDCO), Department of Industries, Ministry of Environment and Forests, Ministry of Power, Thermal Power Plants, Research Institutes*

# Recommendations

## National Level – Facilitating non-fired masonry material development and production

*Quality control of masonry products*

- Establishment of a quality control mechanism for masonry unit manufacturers to ensure products adhere to IS

*Creating demand for alternative materials and practices*

- Specification of non-fired masonry material (and other proven alternative masonry blocks with low environmental impact) in large building construction projects
- Specification of unplastered walls for large building projects using better / appropriate quality masonry material.
- Specification of alternative construction techniques (rat-trap bond) in large building projects

*Possible actors:*
*Bureau of Indian Standards, Central Public Works Department*

# Recommendations

## State and local Level

- Provide incentives to entrepreneurs for establishment of non-fired masonry materials, e.g., tax benefits for equipment and machinery, financing options, land approvals, etc.
- Ensuring continuous power supply for (semi) mechanized masonry industries
- Providing incentives for biomass based power generation for (semi) mechanized masonry industries

- Specification of non-fired masonry material (and other proven alternative masonry blocks with low environmental impact) in large building construction projects
- Specification of unplastered walls for large building projects using better / appropriate quality masonry material.
- Specification of alternative construction techniques (rat-trap bond) in large building projects

- Modifying building byelaws to encourage non-fired masonry materials
- Awareness creation on benefits of non-fired masonry use among developers and other individual building construction proposers; on exposed masonry using better quality masonry units; and on alternative construction techniques (rat-trap bond construction)

*Possible actors:*
*Urban Development Departments, Departments of Industries, State Public Works Departments, Housing Boards, Urban Development agencies, Urban Local Bodies*

Thank you!