EMBODIED ENERGY IN BUILDING MATERIALS AND TECHNOLOGIES FOR GREEN RESIDENTIAL BUILDINGS

Auroville Earth Institute
UNESCO CHAIR EARTHEN ARCHITECTURE

United Nations Educational, Scientific and Cultural Organization
UNESCO Chair Earthern Architecture
National High School of Architecture of Grenoble

ENVIRONMENTAL IMPACT OF THE BUILDING INDUSTRY

- Cities take about 2 % of the land surface but consume 75 % of the world's natural resources.

- The construction sector is responsible for :
- 40% of the consumed resources
- 40% of CO_2 emissions
- 40% of waste (construction and demolition)
  (UNCHS/ Habitat)

- Buildings account for 30 to 40% of total global energy usage
  (United Nations Environmental Programme)

ENVIRONMENTAL IMPACT OF THE CONCRETE INDUSTRY

☛ 1 ton Portland Cement = ~ 0.95 ton CO_2 emissions (ICE)

☛ 1 ton Concrete = ~ 0.107 ton CO_2 emissions (ICE)

☛ Cement production accounts for 5% of global CO_2 emissions. (IPCC)

(Though it is argued by many experts that the Concrete industry is closer to 7 – 9% of global CO_2 emissions.)

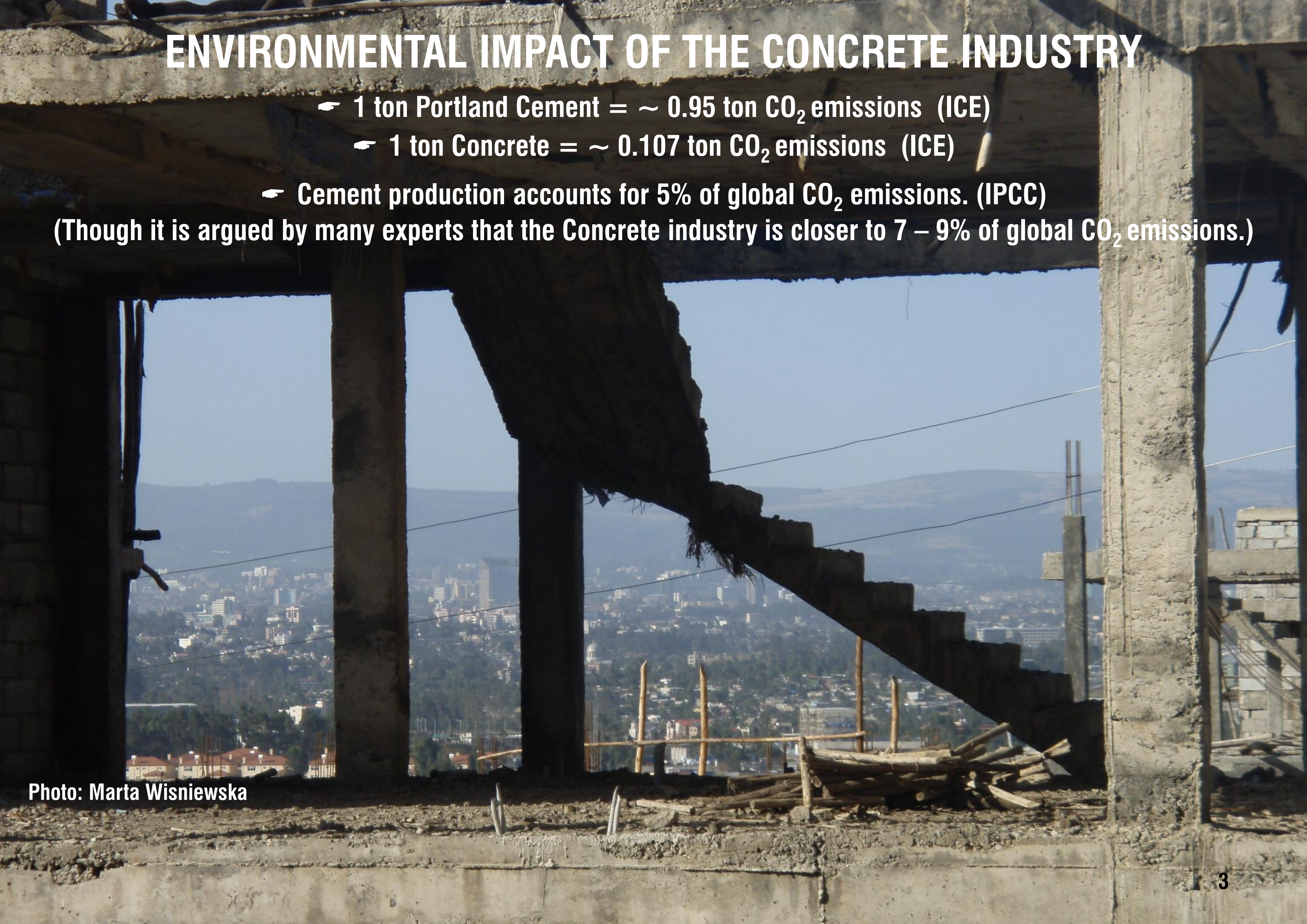


Photo: Marta Wisniewska

CHANGING PARADIGMS

ARE “GREEN MATERIALS” REALLY “GREEN”?

HOW DO WE KNOW THAT “GREEN BUILDINGS” ARE REALLY “GREEN”?

- Can “Green buildings” reduce consumed energy with these materials?
- The initial embodied energy in these materials is very high, with high-tech building systems.
- Designing sustainable buildings requires first an appropriate choice of the building materials.

EMBODIED ENERGY – TERMS & DEFINITIONS

Initial Embodied Energy in Buildings

- The non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction.
- As a rule of thumb, embodied energy is a reasonable indicator of the overall environmental impact of building materials, assemblies or systems.

Recurring Embodied Energy in Buildings

- The non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the lifetime of the building.

Operating Energy

- The recurring energy consumed in buildings for heating, cooling, ventilation, lighting, equipment and appliances.
- Passive energy systems rely on the building envelope to take advantage of natural energy sources such as sunlight, wind, water, and the surrounding soil.
- Active energy systems represent mechanical, electrical and/or chemical processes.

Energy Pay Back Time (EPBT)

- The time required for any energy producing system or device to produce as much energy as was required in its manufacture.

UNITS OF MEASUREMENT

- Standard Unit for Embodied Energy: MJ/ kg material

Functional units:

MJ/ m^3 material

- Standard Unit for Carbon emissions: Kg CO_2/ kg material

Kg CO_2/ m^3 material

BOUNDARY CONDITIONS

EMBODIED ENERGY (CARBON):

"The embodied energy (carbon) of a building material can be taken as the total primary energy consumed (carbon released) over its life cycle. This would normally include (at least) extraction, manufacturing and transportation. Ideally the boundaries would be set from the extraction of raw materials (inc fuels) until the end of the products lifetime (including energy from manufacturing, transport, energy to manufacture capital equipment, heating & lighting of factory, maintenance, disposal… etc.), known as 'Cradle-to-Grave'. It has become common practice to specify the embodied energy as 'Cradle-to-Gate', which includes all energy (in primary form) until the product leaves the factory gate. The final boundary condition is 'Cradle-to-Site', which includes all the energy consumed until the product has reached the point of use (i.e. building site)."

– ICE, University of Bath, 2008

- 'Cradle-to-Gate' : From Material extraction to Manufacturing gate.
- 'Cradle-to-Site' : From Material extraction to Building site.
- 'Cradle-to-Grave' : From Material extraction to End-of-life.

ICE takes as boundary condition only 'Cradle to Gate for general data (not regionally specific).

⇒ We prefer to take 'Cradle-to-Site' as it includes the transportation energy to the site.

EMISSION VARIATION ACCORDING TO FUEL SOURCE

FUEL COMBUSTION				
Items	**Details**	**Country**	**$KgCO_2$ and Energy Quantity / Unit**	
Petrol	Inferior combustion power	France	2.898 $KgCO_2$/ litre	32.20 MJ/litre
Diesel	Inferior combustion power	France	3.222 $KgCO_2$/ litre	35.80 MJ/litre
LPG (Propane or Butane)	Inferior combustion power	France	2.277 $KgCO_2$/ litre	25.30 MJ/litre
Wood combustion	Casuarinas wood at 15 % mh	India	1.584 $KgCO_2$/ Kg	15.00 MJ/Kg
Human energy		India	0.904 $KgCO_2$/day	10.04 MJ/day
Note for human energy: It is normally not counted as it generates livelihood. But if it has to be taken, it would be food value: ~300 Kcal/h				

Conversion Carbon / $CO_2 \Rightarrow C = 0.27273\ CO_2$

Carbon (C) = 12 Gr/molecule	Oxygen (O)= 16 gr/molecule	CO_2 = 12 + (16 x 2) = 44 Gr/molecule

RESOURCE PLANNING: SCARCITY & OVER-QUARRYING

- **Unplanned quarrying**
  - Leads to environmental stress/ material shortage/ scarcity
  - Which leads to rapid inflation of material costs
  - And even more unsustainable quarrying patterns
  - Which impacts livelihoods, affordability and accessibility
- **Demand**
  - For efficient and economical use of local available resources to meet housing demand
  - Strengthening local supply chains from quarry to factory to house




No resource management or rehabilitation plan before extraction (Pondicherry)

Unplanned quarrying contributes to land erosion, loss of soil fertility, garbage dumps, etc.

Country Fired Brick industry in Pondicherry, Tamil Nadu

No management of material and fuel resources (Data: AVEI from Puducherry area)

TRANSPORTATION OF MATERIALS

FUEL COMBUSTION				
Items	**Details**	**Country**	**$KgCO_2$ and Energy Quantity / Unit**	
Human energy		India	0.904 $KgCO_2$/day	10.04 MJ/day
Note for human energy: It is normally not counted as it generates livelihood. But if it has to be taken, it would be food value: ~300 Kcal/h				

Photo: Benjamin Staehli

ENERGY EFFICIENCY OF CSEB

TRANSPORTATION OF MATERIALS				
Items	**Details**	**Country**	**$KgCO_2$**	**Energy Quantity / Unit**
Diesel consumption for truck on site (8 m^3 / 12Tons)	For moving materials on site ~500 m = 15 litres / day 8h	India	4.967 $KgCO_2$/hour	67.13 MJ/h
Diesel consumption for truck on road (8 m^3 / 12Tons)	For road driving with 12 Tons = 3 Km / litre	India	0.883 $KgCO_2$/Km	11.93 MJ/Km
Diesel consumption for excavator	JCB excavator = 6 Litres / hour	India	15.895 $KgCO_2$/hour	214.80 MJ/h

<u>LOCAL/ ON-SITE EXTRACTION & USE</u>:

⇒ **Reduces carbon footprint**

⇒ **Reduces transport costs**

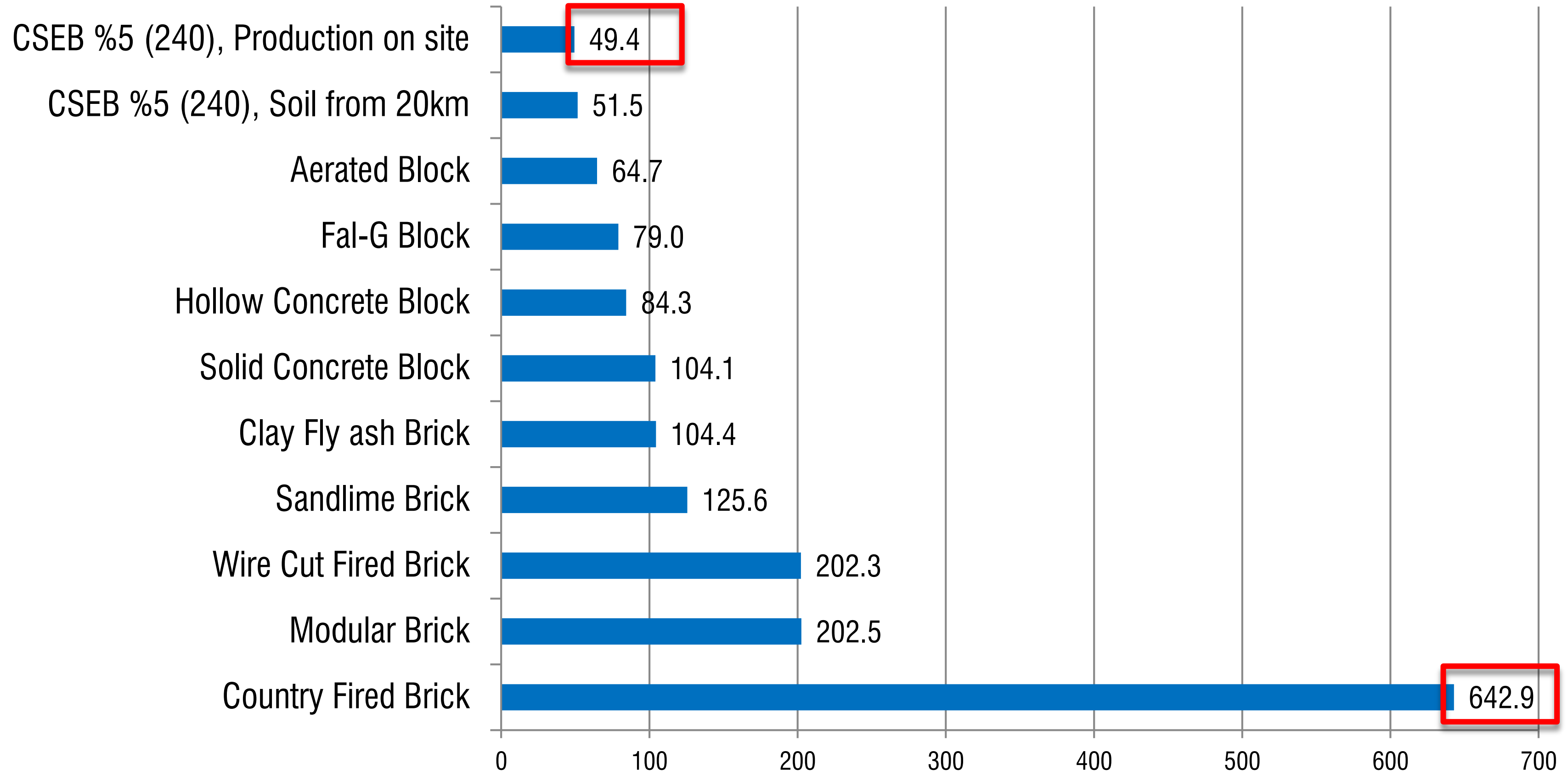
⇒ **Increases accessibility for low income tenants**

⇒ **Invests in local economies and value chains**

⇒ **Produces employment & livelihoods**

ENERGY EFFICIENCY OF CSEB

Emissions kg CO_2 /m³ for the manufacture of Building units



ENERGY EFFICIENCY OF CSEB vs COUNTRY FIRED BRICK

Embodied energy per m^3 material		Carbon emission per m^3 of material	
➢ CSEB	= 572 MJ per m^3	➢ CSEB	= 51.5 Kg CO_2 /m^3
➢ Wire cut bricks	= 2,247 MJ per m^3	➢ Wire cut bricks	= 202 Kg CO_2 /m^3
➢ CFB	= 6,122 MJ per m^3	➢ CFB	= 643 Kg CO_2 /m^3

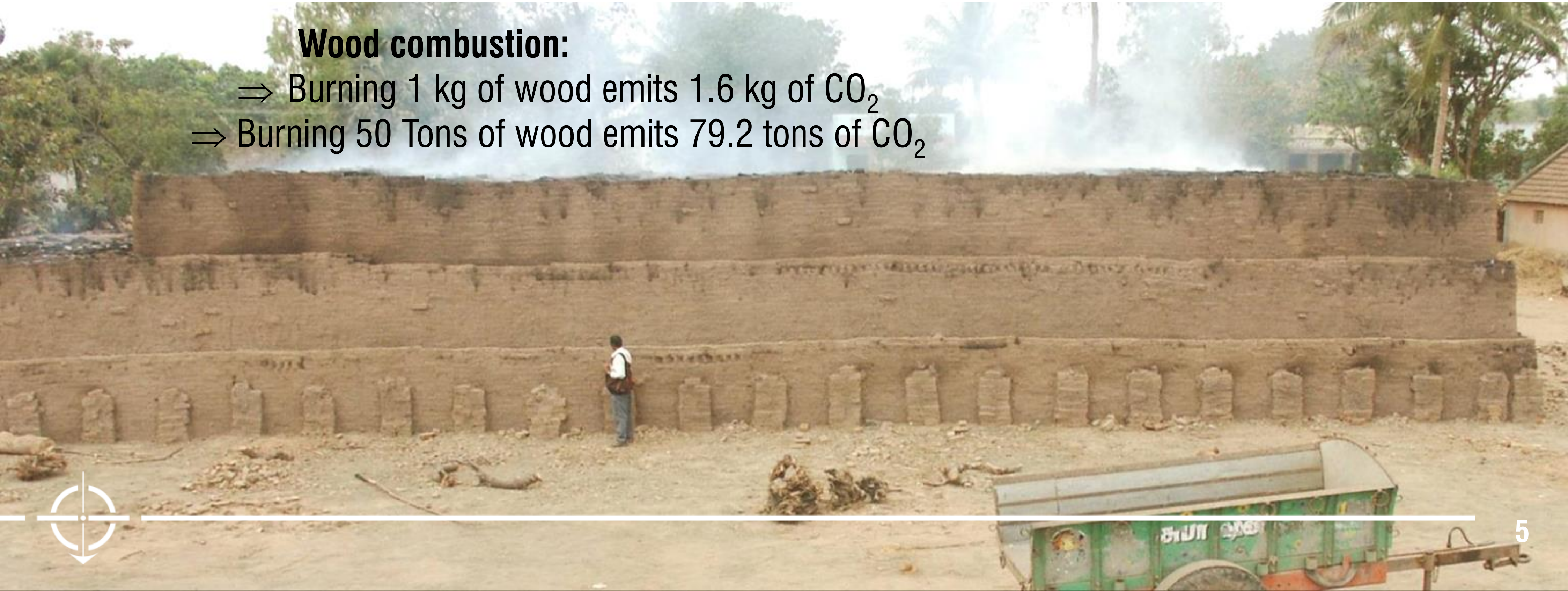
10.7 TIMES LESS EMBODIED ENERGY THAN COUNTRY FIRED BRICKS

12.5 TIMES LESS EMISSIONS THAN COUNTRY FIRED BRICKS

Wood combustion:

⇒ Burning 1 kg of wood emits 1.6 kg of CO_2

⇒ Burning 50 Tons of wood emits 79.2 tons of CO_2



DATA SOURCES: Inventory of Carbon & Energy (ICE)

UNIVERSITY OF BATH

INVENTORY OF CARBON & ENERGY (ICE)

Version 1.6a

Prof. Geoff Hammond & Craig Jones

Sustainable Energy Research Team (SERT)

Department of Mechanical Engineering

University of Bath, UK

This project was joint funded under the Carbon Vision Buildings program by:

CARBON TRUST — Making business sense of climate change

EPSRC

Available from: www.bath.ac.uk/mech-eng/sert/embodied/

Peer Review Source: Hammond, G.P. and C.I. Jones, 2008, 'Embodied energy and carbon in construction materials', *Proc. Instn Civil. Engrs: Energy*, in press.

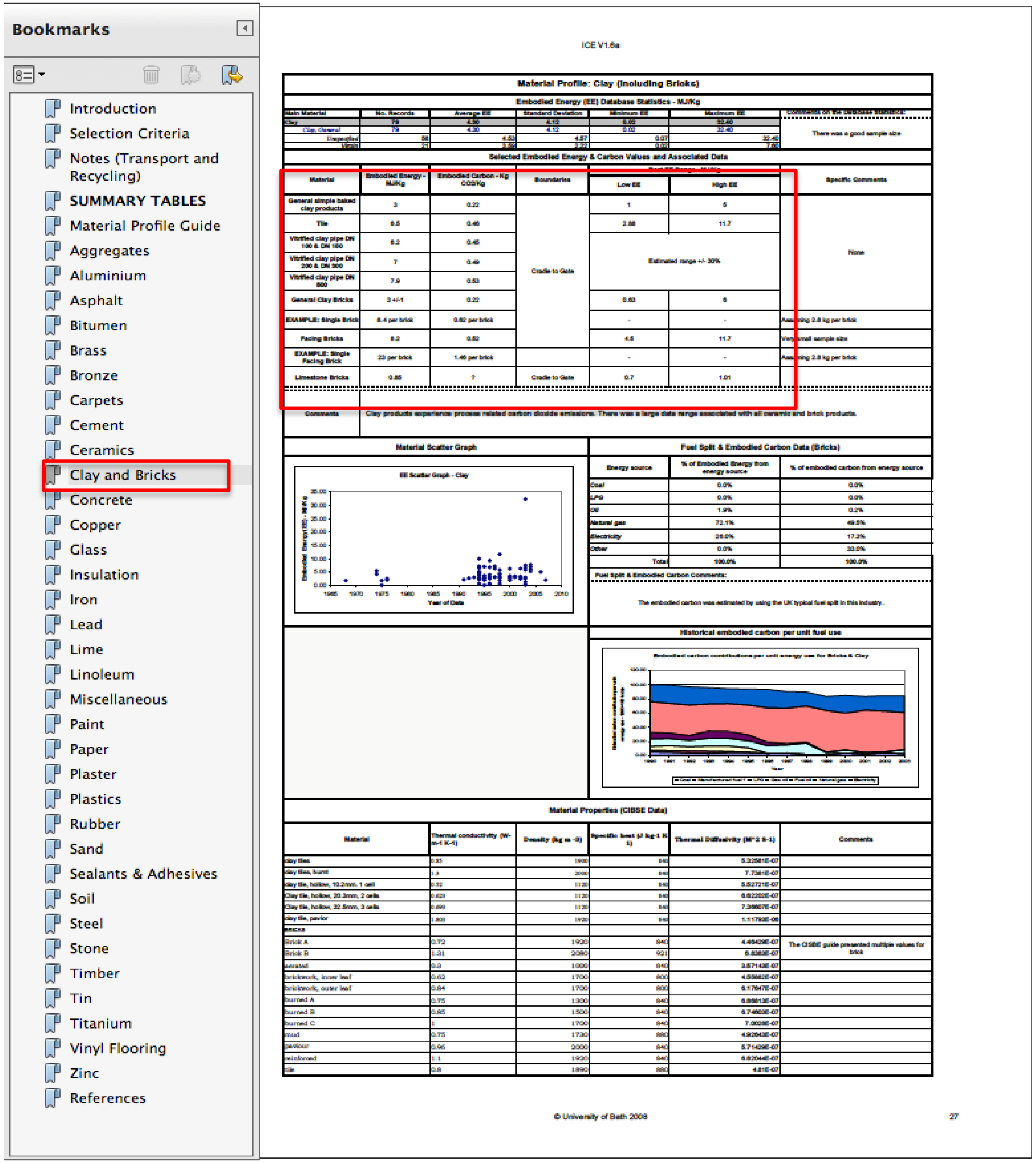
INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

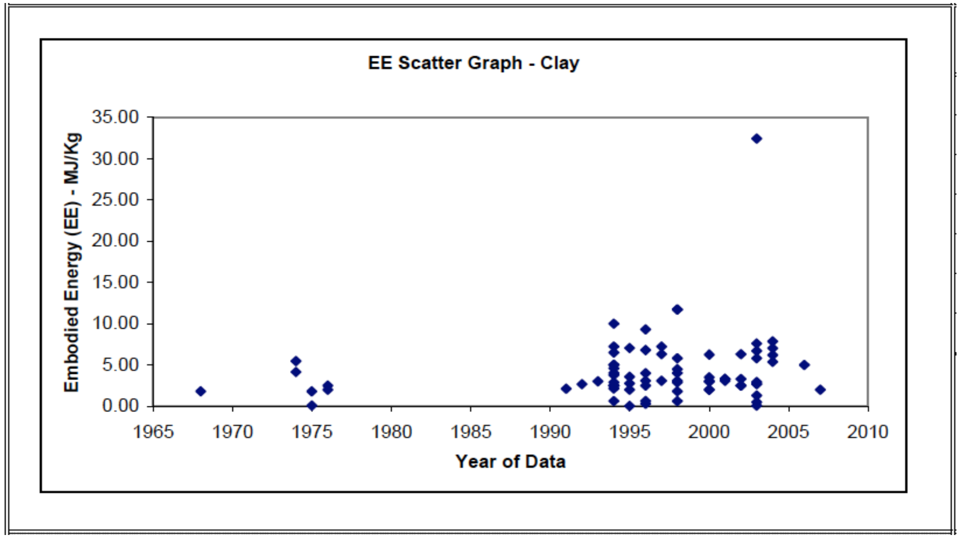
Materials	Embodied Energy & Carbon Data		Comments
	EE - MJ/kg	EC - kgCO2/Kg	EE = Embodied Energy, EC = Embodied Carbon
Aggregate			
General	0.1	0.005	
Aluminium			
General	166	8.24	13.8 MJ/kg Feedstock Energy (Included). Assumes UK ratio of 25.6% extrusions, 55.7% Rolled & 18.7% castings. Worldwide recycled content of 33%.
Virgin	218	11.46	20.7 MJ/kg Feedstock Energy (Included).
Recycled	28.8	1.69	
Cast Products	159	8.28	14.3 MJ/kg Feedstock Energy (Included). Worldwide recycled content of 33%.
Virgin	226	11.70	21.3 MJ/kg Feedstock Energy (Included).
Recycled	24.5	1.35	
Extruded	154	8.16	13.6 MJ/kg Feedstock Energy (Included). Worldwide recycled content of 33%.
Virgin	214	11.20	20.2 MJ/kg Feedstock Energy (Included).
Recycled	34.1	1.98	
Rolled	165	8.26	13.8 MJ/kg Feedstock Energy (Included). Worldwide recycled content of 33%.
Virgin	217	11.50	20.6 MJ/kg Feedstock Energy (Included).
Recycled	27.8	1.67	
Asphalt			
General	2.60	0.045	1.91 MJ/kg Feedstock Energy (Included)
Road & Pavement	2.41	0.14	0.82 MJ/kg Feedstock Energy (Included), reference 123
EXAMPLE: Road	2,672 MJ/Sqm	134 KgCO2/Sqm	906 MJ/Sqm Feedstock Energy (Included)
Bitumen			
General	47	0.48	37.7 (?) MJ/kg Feedstock Energy (Included). Feedstock taken as typical energy content of Bitumen, uncertain carbon dioxide emissions
Brass			
General	44.00	2.42 (?)	poor data availability, largely dependent upon ore grade. Very poor carbon data, uncertain of estimates, which were taken from average quoted emissions per MJ energy
Virgin	80.00	4.39 (?)	
Recycled	20.00	1.1 (?)	
Bricks			
General (Common Brick)	3.00	0.22	
EXAMPLE: Single Brick	8.4 MJ per brick	0.62 kgCO2 per brick	Assuming 2.8 kg per brick
Facing Bricks	8.20	0.52	Very small sample size
EXAMPLE: Single Facing Brick	23 MJ per brick	1.46 kgCO2 per brick	Assuming 2.8 kg per brick
Limestone	0.85	?	
Bronze			
General	77.00	4.1 (?)	Reference 155
Carpet			
General Carpet	74.40	3.89	For per square meter see material profile
Felt (Hair and Jute) Underlay	18.60	0.96	Reference 77
Nylon	67.9 to 148	3.66 to 7.31	Very difficult to select value, few sources, large range, value includes feedstock's
Polyethylterepthalate (PET)	106.50	5.55	Includes feedstock's
Polypropylene	95.40	5.03	Includes feedstock's, for per square meter see material profile
Polyurethane	72.10	3.76	Includes feedstock's
Rubber	67.5 to 140	3.91 to 8.11	
Saturated Felt Underlay (impregnated with Asphalt or tar)	31.70	1.70	Reference 77
Wool	106.00	5.48	For per square meter see material profile, References 57,166 & 234
Cement			
General (Typical)	4.6	0.83	Portland Cement, CEM I
Fibre Cement	10.90	2.11	
Mortar (1:3 cement:sand mix)	1.40	0.213	Values estimated from the ICE Cement, Mortar & Concrete Model
Mortar (1:4)	1.21	0.177	
Mortar (1:6)	0.99	0.136	
Mortar (1:½:4½ Cement:Lime:Sand mix)	1.37	0.196	
Mortar (1:1:6 Cement:Lime:Sand mix)	1.18	0.163	
Mortar (1:2:9 Cement:Lime:Sand mix)	1.09	0.143	
Soil-Cement	0.85	0.14	

% Cementitious Replacement	EE 0%	EE 25%	EE 50%	EC 0%	EC 25%	EC 50%	Note 0% is a 'standard' CEM I cement
General (with Fly Ash Replacement)	4.6	3.52	2.43	0.83	0.62	0.42	Portland Cement
General (with Blast Furnace Slag Replacement)	4.6	3.81	3.01	0.83	0.64	0.45	Portland Cement

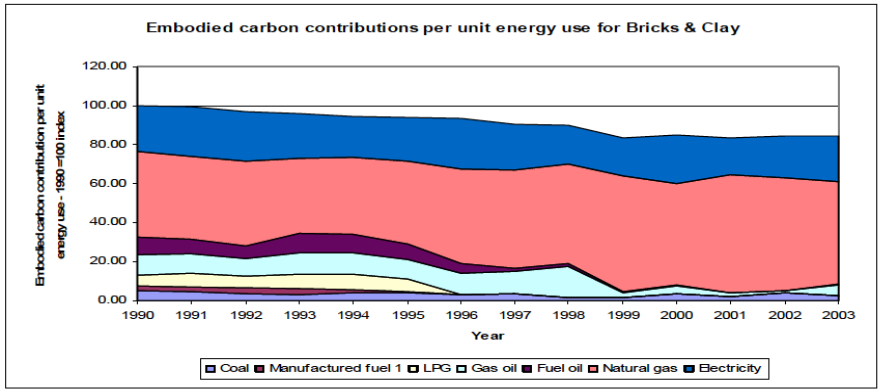
Units are $KgCO_2/Kg$ and MJ/Kg

DATA SOURCES: Inventory of Carbon & Energy (ICE)





Historical embodied carbon per unit fuel use



DATA SOURCES: Embodied Energy Compilation (AVEI)

Auroville Earth Institute
UNESCO CHAIR EARTHEN ARCHITECTURE

EMBODIED ENERGY OF VARIOUS MATERIALS AND TECHNOLOGIES

A DATA COMPILATION
May 2005
Revision November 2013

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2 – PROCESSED MATERIALS

The energy of transportation for cement, steel, sand and aggregates which are integrated in the calculations are based on the distances of the suppliers around Auroville, as indicated in the footnotes of the tables.

BUILDING UNITS					
Items	Details	Country	$KgCO_2/m^3$	Energy Quantity / Unit	
Kiln Fired Brick (Indian average) [10]	22 x 10 x 7cm, Delivered 150 Km	India	202.255	3.457 MJ/unit	2,247.28 MJ/m^3
Country Fired Brick (Indian average) [10]	22 x 10 x 7cm, Delivered 50 Km	India	441.123	7.074 MJ/unit	4,501.25 MJ/m^3
Country Fired Brick (Puducherry area) [5]	23 x 10 x 7cm, Delivered at 50 Km	India	642.866	9.857 MJ/unit	6,122.54 MJ/m^3
Modular Brick [2]	(20 × 10 × 10 cm)	India	202.520	4.500 MJ/unit	2,250.00 MJ/m^3
Clay Fly Ash Brick [2]	(20 × 10 × 10 cm)	India	104.410	2.320 MJ/unit	1,160.00 MJ/m^3
Burnt Roofing Tiles [2]		India		5.100 MJ/unit	
Sand Lime Brick [2]	(20 × 10 × 10 cm)	India	125.562	2.790 MJ/unit	1,395.00 MJ/m^3
Aerated Block [2]	(40 × 20 × 20 cm)	India	64.716	11.500 MJ/unit	719.00 MJ/m^3
Fal-G Block [2]	(30 × 20 × 15 cm)	India	79.027	7.900 MJ/unit	878.00 MJ/m^3
Hollow Concrete Block [1]	7 % cement (40 x 20 x 20 cm)	India	69.307	12.300 MJ/unit	770.00 MJ/m^3
Hollow Concrete Block [1]	10 % cement (40 x 20 x 20 cm)	India	84.338	15.000 MJ/unit	937.00 MJ/m^3
Solid Concrete Block [1]	(30 × 20 × 15 cm)	India	104.050	10.400 MJ/unit	1,156.00 MJ/m^3
4% CSEB, Production on site [5]	Earth by hand with 4% cement (24 x 24 x 9 cm)	India	41.874	2.412 MJ/unit	465.26 MJ/m^3
5% CSEB, Production on site [5]	Earth by hand with 5% cement (24 x 24 x 9 cm)	India	49.366	2.844 MJ/unit	548.52 MJ/m^3
5% CSEB, Production on site/machine [5]	Earth by machine with 5% cement (24 x 24 x 9 cm)	India	51.531	2.968 MJ/unit	572.58 MJ/m^3
6% CSEB, Production on site [5]	Earth by hand with 6% cement (24 x 24 x 9 cm)	India	58.134	3.349 MJ/unit	645.94 MJ/m^3
8% CSEB, Production on site [5]	Earth by hand with 8% cement (24 x 24 x 9 cm)	India	79.837	4.599 MJ/unit	887.09 MJ/m^3
Bitumen Stabilised Earth Block [2]		India		0.790 MJ/Kg	
Steam Cured Earth Block [1]	10 % lime (23 x 19 x10 cm)	India	137.983	6.700 MJ/unit	1,533.00 MJ/m^3
Sand-lime brick [2]		India		0.8 -1.2 MJ/Kg	
Adobe [2]	(22 x 10 x 7 cm)	India	3.472	0.200 MJ/unit	129.87 MJ/m^3

Notes: - CSEB = Compressed Stabilised Earth Blocks
- Energy values for CSEB integrate the energy for transporting materials: 150 Km for cement and 20 Km for sand.

MORTARS AND CONCRETE – 1					
Items	Details	Country	$KgCO_2/Kg$	Energy Quantity / Unit	
Lime Pozzolana (LP) [1]		India	0.228	2.330 MJ/Kg	
Cement Pozzolana Sand Mortar [1]	(0.8: 0.2: 6)	India			918.00 MJ/m^3
Cement Pozzolana Sand Mortar [1]	(0.8: 0.2: 8)	India			736.00 MJ/m^3
Concrete, Fibre reinforced [4]		UK	0.450	7.750 MJ/Kg	
Gypsum Plaster [2]		India	0.098-0.392	1 - 4 MJ/Kg	
Lime Pozzolana Sand Mortar [1]	(0.33: 0.66: 3)	India			732.00 MJ/m^3
Lightweight aerated concrete [2]		India			1,000-2,000 MJ/m^3
Sintered fly ash [2]	Light weight aggregate concrete	India	0.098	1.000 MJ/Kg	1400.00 MJ/m^3

Functional units: $KgCO_2/m^3$, MJ/m^3

DATA SOURCES: Embodied Energy Calculation (AVEI)

DATA AND SUMMARY - 1

Values in the sheet "Data & Summary" with reference [5] were calculated by the Auroville Earth Institute from data of raw materials collected from various realiable sources. The details of these calculations are showed in the other sheets.

STONES AND AGGREGATES

Items	Details	Country	$KgCO_2/m^3$	Energy Quantity / Unit	
River sand [5]	(ρ = 1,450 Kg/m^3) [AVEI]	India	2.899	0.0204 MJ/Kg	29.58 MJ/m^3
Aggregate [1 & 6]	(granite stone ρ = 2,690 Kg/m^3) [13]	India	57.996	0.2200 MJ/Kg	591.80 MJ/m^3
Crushed stone, gravel / chipping [4]	(granite stone ρ = 2,600 Kg/m^3) [AVEI]	UK	41.600	0.3000 MJ/Kg	780.00 MJ/m^3
Lime Stone [4]	(ρ = 2,690 Kg/m^3) [13]	UK	32.280	0.2400 MJ/Kg	645.60 MJ/m^3
Marble [4]	(ρ = 2,560 Kg/m^3) [13]	UK	273.920	2.0000 MJ/Kg	5120.00 MJ/m^3
Granite Stone [4]	(ρ = 2,690 Kg/m^3) [13]	UK	852.730	5.9000 MJ/Kg	15871.00 MJ/m^3
Soil from site, extracted by hand [5]	(ρ = 1,300 Kg/m^3) [AVEI]	India	1.033	0.0081 MJ/Kg	10.54 MJ/m^3
Soil from site, extracted with machine [5]	(ρ = 1,300 Kg/m^3) [AVEI]	India	2.142	0.0223 MJ/Kg	28.95 MJ/m^3
Soil by truck, extracted with machine [5]	(ρ = 1,300 Kg/m^3) [AVEI]	India	2.189	0.0228 MJ/Kg	29.58 MJ/m^3
Note: River sand is considered with the same values as for the soil dug wih a machine and transported over 50 Km.					

BINDERS

Items	Details	Country	$KgCO_2/Kg$	Energy Quantity / Unit	
Cement [4]	Coal Fired Dry process, Bag 50Kg	India	0.830	4.60 MJ/Kg	230.00 MJ/bag
Lime [4]	(Bag 40 Kg)	India	0.740	5.63 MJ/Kg	225.20 MJ/bag
Pozzolana [1]		India			15.00 MJ/m^3

WOOD BASED MATERIALS

Items	Details	Country	$KgCO_2/Kg$	Energy Quantity / Unit	
Timber (sawn) [2]		India	0.490	2.50 MJ/Kg	1,380.00 MJ/m^3
Timber, soft wood air dried (rough sawn) [6]	(ρ = 550 Kg/m^3)	NZ	0.029	0.30 MJ/Kg	165.00 MJ/m^3
Timber, soft wood air dried (dressed) [6]	(ρ = 550 Kg/m^3)	NZ	0.114	1.16 MJ/Kg	638.00 MJ/m^3
Timber, hard wood air dried (rough sawn) [6]	(ρ = 850 Kg/m^3)	NZ	0.049	0.50 MJ/Kg	425.00 MJ/m^3
Timber, hard wood air dried (dressed) [6]	(ρ = 850 Kg/m^3)	NZ	0.176	1.80 MJ/Kg	1,530.00 MJ/m^3
Plywood [7]		Canada	1.019	10.40 MJ/Kg	5,720.00 MJ/m^3
Particle board [7]		Canada	0.784	8.00 MJ/Kg	4,400.00 MJ/m^3

METALS

Items	Details	Country	$KgCO_2/Kg$	Energy Quantity / Unit	
Aluminium [2]	2,600 Kg/m^3	India	25.480	260.00 MJ/Kg	676,000 MJ/m^3
Copper [2]	8,930 Kg/m^3	India	10.976	112.00 MJ/Kg	1,000,160 MJ/m^3
Galvanized Steel (Sheet or Wire) [1]	7,860 Kg/m^3	India	4.978	50.80 MJ/Kg	399,288 MJ/m^3
Steel [12]	7,860 Kg/m^3	India	3.000	33.33 MJ/Kg	262,000 MJ/m^3
Steel Wire [4]	7,860 Kg/m^3	UK	4.195	46.61 MJ/Kg	282,960 MJ/m^3
GI Chicken Mesh [5] (3' wide, ½", 22 gauge)	0.355 Kg/m^2 = 0.323 Kg/m	India	5.390	59.89 MJ/Kg	19.34 MJ/m
GI Chicken Mesh [5] (4' wide, ½", 22 gauge)	0.475 Kg/m^2 = 0.430 Kg/m	India	5.390	59.89 MJ/Kg	25.75 MJ/m

BUILDING UNITS

Items	Details	Country	$KgCO_2/m^3$	Energy Quantity / Unit	
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Country Fired Brick (Puducherry area) [5]	23 x 10 x 7 cm - Delivered at 50 Km	India	642.866	9.857 MJ/unit	6,122.54 MJ/m^3
4% CSEB, Production on site [5]	Earth by hand 4% cement (24x24x9cm)	India	41.874	2.412 MJ/unit	465.26 MJ/m^3
5% CSEB, Production on site [5]	Earth by hand 5% cement (24x24x9cm)	India	49.366	2.844 MJ/unit	548.52 MJ/m^3
5% CSEB, Production on site / machine [5]	Earth machine 5% cement (24x24x9cm)	India	51.531	2.968 MJ/unit	572.58 MJ/m^3
6% CSEB, Production on site [5]	Earth by hand 6% cement (24x24x9cm)	India	58.134	3.349 MJ/unit	645.94 MJ/m^3
8% CSEB, Production on site [5]	Earth by hand 8% cement (24x24x9cm)	India	79.837	4.599 MJ/unit	887.09 MJ/m^3
Adobe [2]	(22 x 10 x 7 cm)	India	3.472	0.200 MJ/unit	129.87 MJ/m^3
Notes: - CSEB = Compressed Stabilised Earth Block					
- Energy values for CSEB integrate the energy for transporting materials: 150 Km for cement and 20 Km for sand.					

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FIRED BRICKS

EMBODIED ENERGY IN COUNTRY FIRED BRICKS - LOCAL CLAMP (PUDUCHERRY)

DATA		COUNTRY FIRED BRICK = CFB	
Brick size (L, W, H) (in cm)		23.0 / 10.0 / 7.0	
Brick weight (average dry)		3.00 Kg = 1,863 Kg/ m^3	
Item	**Energy MJ/unit**	**Detail**	**MJ/unit**
Soil dug by machine (m^3)	28.95	0.0021 m^3	0.061
Casurina burnt /CFB (Kg)	15.00	0.5 Kg / Brick	9.178
Transport (MJ/Km)	11.93	50.0 Km	0.149
	SUB TOTAL		9.39
Miscellaneous	5.0%		0.47
	TOTAL ENERGY MJ/piece		**9.86**
	TOTAL EMISSIONS $KgCO_2/m^3$		**642.87**
	TOTAL ENERGY MJ/M³		**6,122.5**

Notes: - 25 Tons of wood to burnt 50,000 country fired bricks ⇒ 0.5 Kg of wood per country fired brick
- 1 Truck transports 4,000 bricks

EMISSIONS OF COUNTRY FIRED BRICKS AND KILN FIRED BRICKS - (NATIONAL AVERAGES)[10]

	SPECIFIC ENERGY CONSUMPTION		PRODUCTION CAPACITIES		NUMBER OF PLANTS	NUMBER OF BRICKS	% PRODUCED
	MJ/Kg-Brick		Lakh Kg-bricks/year		No.	Crore Bricks / year	Anuual Production
	Range	Average	Range	Average			
BTK-fixed chimney	1.0 – 1.5	1.25	83 -275	179	25000	16,155	83.82
High draft/ zig zag	0.8 – 1.0	0.9	83 -138	110	200	79	0.41
Clamps	2.0 – 3.0	2.5	1.4 – 27.5	14	60,000	3,032	15.73
Vertical Shaft Brick Kiln	0.8 – 1.0	0.9	14 -110	62	30	7	0.03

Notes

Average weight of a brick: size 22 x 10 x 7 cm (L x W x H)	=	2.770	Kg/Brick
Average energy consumption for kiln fired brick (BTK, High draft/ zig zag, Vertical Shaft)	=	3.457	MJ/Brick
Average emissions for kiln fired brick (BTK, High draft/ zig zag, Vertical Shaft)	=	0.339	$KgCO_2$/ Brick
Average energy consumption for country fired brick (Clamp kiln)	=	6.925	MJ/Brick
Average emissions for country fired brick (Clamp kiln)	=	0.679	$KgCO_2$/ Brick

DATA SOURCES: Embodied Energy Compilation (AVEI)

1 - *Embodied energy of common and alternative building materials and technologies* – BV Venkatarama Reddy, KS Jagadish Department of Civil Engineering, Indian Institute of Science, Bangalore, India, 2001.

2 - *Comparative analysis of embodied energy rates for walling elements in India* – PS Chani, Najamuddin, SK Kaushik, 2003.

3 - 50 years *Energy in Building Materials* – Building Materials in India.

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6 - *The Energy embodied in Building Materials – Updated New Zealand coefficients and their significance* Georges Baird, Andrew Alcorn Phil Haslami – 1997.

7 - Recurring Embodied Energy**:** http://www.canadianarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_embodied.htm

8 - Emissions produced as an average: http://www.cmit.csiro.au/brochures/tech/embodied/

9 - *Energy in Building Materials: Final Report* – Development Alternatives & BMTPC, New Delhi – 1995.

10 - *IPCC Certified Methodology* – VSBK Brick Plants India, the PDD.

11 - India's Cement Industry: Productivity, Energy Efficiency and Carbon Emissions - Katja Schumacher and Jayant Sathaye.

12 - *Climate change & steel sector: IPCCC WG III's Dissemination workshop on Fourth Assesment Report -Shashi Bhushan Prasad.*

13 - Density of materials: http://www.simetric.co.uk/si_materials.htm

AVEI – Density of materials measured by the Auroville Earth Institute

EXAMPLE OF EMBODIED ENERGY CALCULATION
REALIZATION APARTMENTS BUILT BY THE AUROVILLE EARTH INSTITUTE

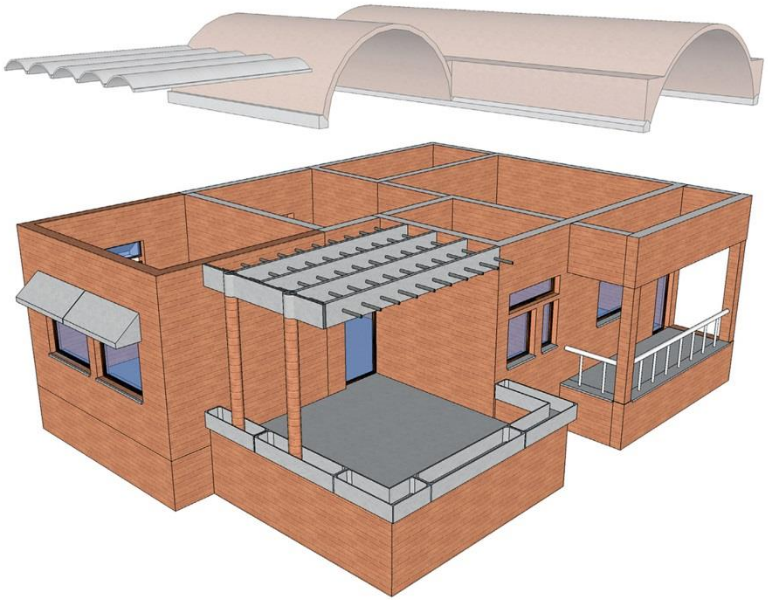
17 apartments built in 3 building blocks

- **Initial embodied energy for Realization is ~4 times less than a conventional building (RCC frame, RCC slab, infill with fired bricks)**
- **Low emission for construction and use**

- CSEB and stabilised earth from foundations to roof
- Wind energy
- Rainwater harvesting
- Wastewater biological system
- Earth tunnel for natural air conditioning

COMPARISON OF MATERIALS AND TECHNIQUES

CSEB MASONRY WALLS



ENVIRONMENTAL IMPACT OF MATERIALS:

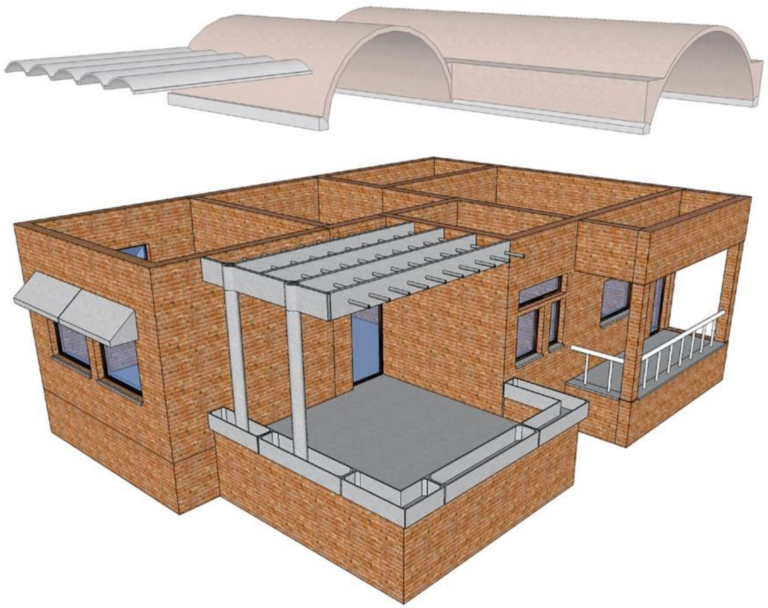
Material:	CO_2 Emission: ($kgCO_2/m^3$)	Embodied Energy: (mJ/m^3)
• Earth Block (5%)	51.531 *	572.58 *
• Earth Mortar 1:4:8 (7.5%)	61.813 *	686.81 *

CSEB MASONRY WALL (24cm):

• Cost/ m^2	1,666 Rs.
Material Cost (16 Rs./block)	25.7%
Labor Cost	74.3%
• Carbon Cost/ m^2	**13.630** $kgCO_2$ *
• Embodied Energy/ m^2	**151.44** mJ *

* Embodied Energy Data Compilation, Auroville Earth Institute, 2013

COMPARISON OF MATERIALS AND TECHNIQUES
CONVENTIONAL COUNTRY FIRED BRICK WALLS



ENVIRONMENTAL IMPACT OF MATERIALS:

Material:	CO_2 Emission: ($kgCO_2/m^3$)	Embodied Energy: (mJ/m^3)
• Country Fired brick	642.866 *	6,122.54 *
• Cement mortar 1:4	178.525 *	1,983.61 *

COUNTRY FIRED BRICK WALL (23cm):

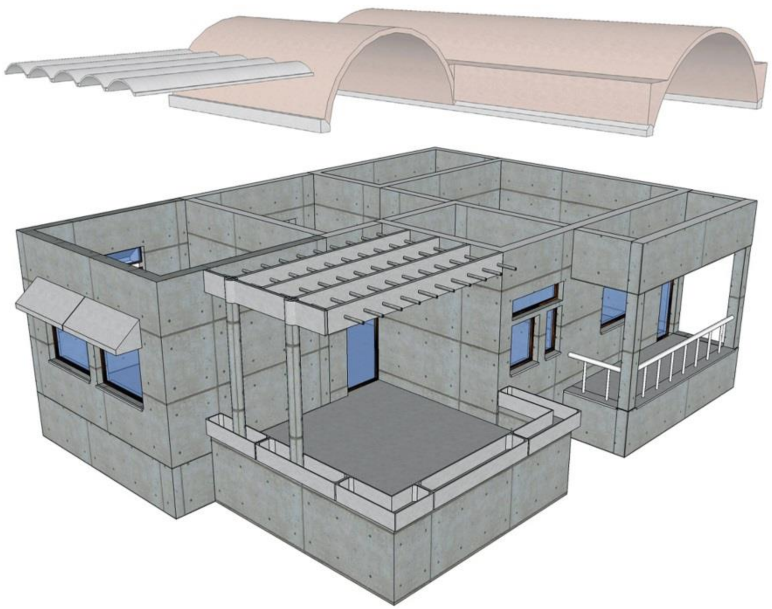
• Cost/ m^2	1,112 Rs.
Material Cost (4.25 Rs./brick)	80.8%
Labor Cost	19.2%
• Carbon Cost/ m^2	**120.807** $kgCO_2$ *
• Embodied Energy/ m^2	**1,342.3** mJ *

Carbon emissions: 8.8 times greater than CSEB blocks

Cost: 37 % less than CSEB blocks

* Embodied Energy Data Compilation, Auroville Earth Institute, 2013

COMPARISON OF MATERIALS AND TECHNIQUES
CONVENTIONAL REINFORCED CONCRETE WALLS



ENVIRONMENTAL IMPACT OF MATERIALS:

Material:	CO_2 Emission: ($kgCO_2/m^3$)	Embodied Energy: (mJ/m^3)
• M20 Concrete (1:1.5:3)	213.062 *	2,367.35 *
• Steel reinforcing	3.000 ($kgCO_2/kg$) *	262,000 *

RCC WALL (20cm):

• Cost/ m^2	2,810 Rs.
Material Cost	80.6 %
Labor Cost	19.4 %
• Carbon Cost/ m^2	108.4 $kgCO_2$ *
• Embodied Energy/ m^2	1,204.2 mJ *

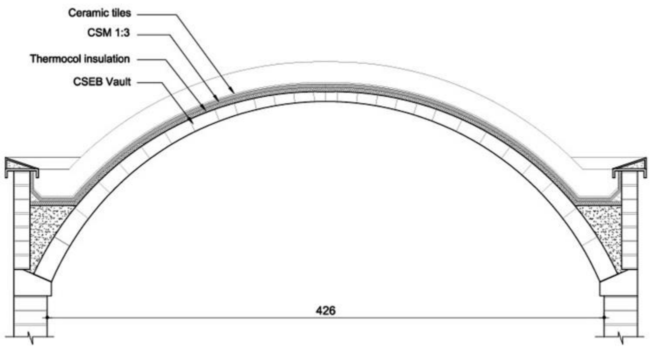
Carbon emissions: 7.9 times greater than CSEB blocks

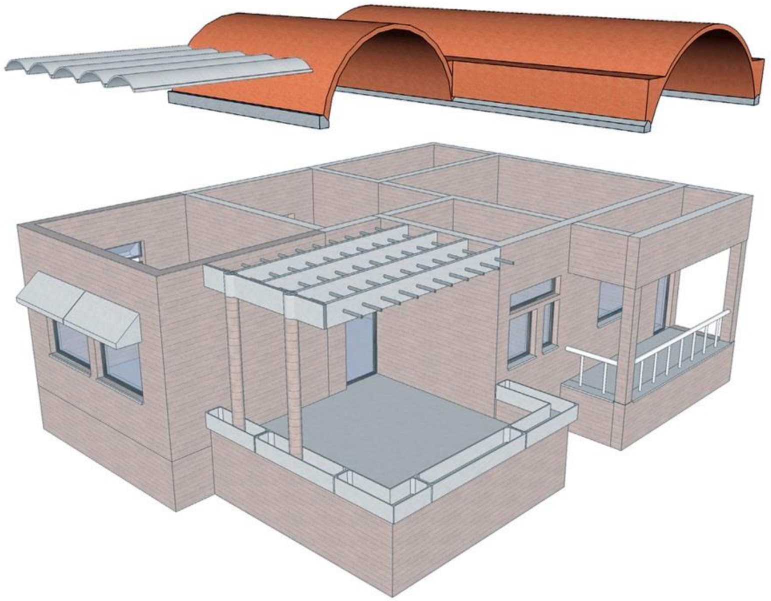
Cost: 102 % greater than CSEB blocks

* Embodied Energy Data Compilation, Auroville Earth Institute, 2013

COMPARISON OF MATERIALS AND TECHNIQUES

CSEB VAULTING





ENVIRONMENTAL IMPACT OF MATERIALS:

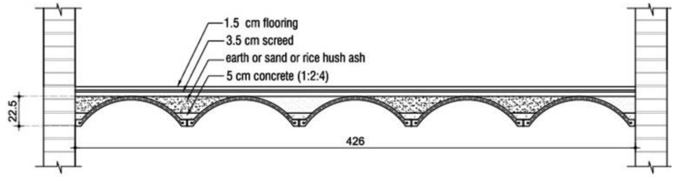
Material:	CO_2 Emission: ($kgCO_2/m^3$)	Embodied Energy: (mJ/m^3)
• Earth Block (5%)	51.531 *	572.58 *
• Earth Mortar 1:4:8 (7.5%)	61.813 *	686.81 *

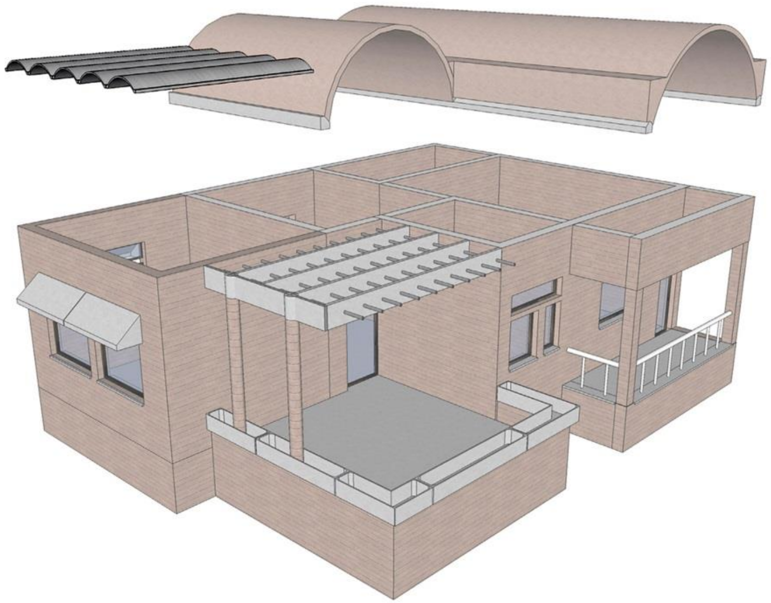
CSEB MASONRY VAULT (11.5 thick shell, projected area):

• Cost/ m^2	2,755 Rs.
Material Cost	39.0 %
Labor Cost	61.0 %
• Carbon Cost/ m^2	**11.627** $kgCO_2$ *
• Embodied Energy/ m^2	**129.19** mJ *

* Embodied Energy Data Compilation, Auroville Earth Institute, 2013

COMPARISON OF MATERIALS AND TECHNIQUES
FERROCEMENT CHANNELS





ENVIRONMENTAL IMPACT OF MATERIALS:

Material:	CO_2 Emission: ($kgCO_2/m^3$)	Embodied Energy: (mJ/m^3)
• Concrete (1:2:4)	185.698 *	2,063.31 *
• Mortar (1:3)	239.112 *	2,656.80 *
• Steel reinforcing	3.000 ($kgCO_2/kg$) *	262,000 *
• Chicken mesh	5.390 ($kgCO_2/kg$) *	59.89 ($kgCO_2/kg$) *
• Sand filling	2.899 *	29.58 *

FC CHANNEL FLOOR/ ROOF (projected area):

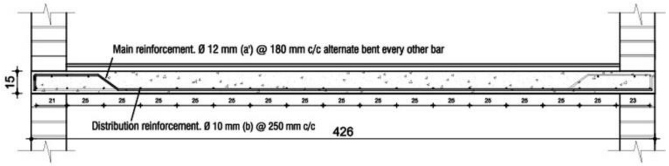
• Cost/ m^2	2,468 Rs.
Material Cost	46.8 %
Labor Cost	53.2 %
• Carbon Cost/ m^2	**47.400** $kgCO_2$ *
• Embodied Energy/ m^2	**526.67** MJ *

Carbon emissions: 4.4 times greater than CSEB vaults

Cost: 12 % less than CSEB vaults

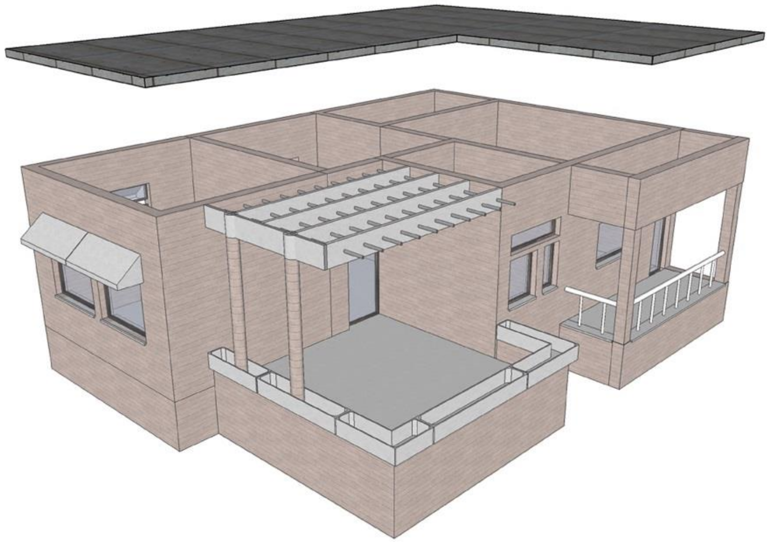
* Embodied Energy Data Compilation, Auroville Earth Institute, 2013

COMPARISON OF MATERIALS AND TECHNIQUES
CONVENTIONAL RCC SLAB



ENVIRONMENTAL IMPACT OF MATERIALS:

Material:	CO_2 Emission: ($kgCO_2/m^3$)	Embodied Energy: (mJ/m^3)
• M20 Concrete (1:1.5:3)	213.062 *	2,367.35 *
• Steel reinforcing	3.000 ($kgCO_2/kg$) *	262,000 *



RCC FLOOR SLAB (15cm thick, projected area):

• Cost/ m^2	2,194 Rs.
Material Cost	75.7 %
Labor Cost	24.3 %
• Carbon Cost/ m^2	**66.333** $kgCO_2$ *
• Embodied Energy / m^2	**737.03** mJ *

Carbon emissions: 5.7 times greater than CSEB vaults

Cost: 7 % greater than CSEB vaults

* Embodied Energy Data Compilation, Auroville Earth Institute, 2013

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1 - *Embodied energy of common and alternative building materials and technologies* – BV Venkatarama Reddy, KS Jagadish Department of Civil Engineering, Indian Institute of Science, Bangalore, India, 2001.

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14 - Density of materials: http://www.simetric.co.uk/si_materials.htm

15 - Net Energy Gain: http://en.wikipedia.org/wiki/Energy_payback_time

16 - Energy Pay Back Time: http://www.ecotopia.com/apollo2/pvepbtne.htm

17 - Life Cycle Assessment: http://en.wikipedia.org/wiki/Life_cycle_analysis

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19 - Mattoo, et al, *Can Global De-Carbonization Inhibit Developing-Country Industrialization?* – 2009.

Thank you for your kind attention!

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