EMBODIED ENERGY OF VARIOUS MATERIALS AND TECHNOLOGIES

COMPILATION AND CALCULATIONS
May 2005
Revision November 2013

Satprem Maïni
Varun Thautam

Auroshilpam, Auroville 605 101 Auroville TN India Tel. +91 (0) 413 - 262 3064 / 262 3330 Fax: +91 (0) 413 - 262 2886
Email: earthinstitute@auroville.org.in Web: http://www.earth-auroville.com

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AUROVILLE EARTH INSTITUTE

CONTENT

SUMMARY - 1

The boundary condition for all values is "Cradle to site".

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	
Kiln Fired Brick (Indian average) [10]	22 x 10 x 7 cm - Delivered at 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 7 cm - Delivered at 50 Km	India	441.123	10.006 MJ/unit	4,501.25 MJ/m^3
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	59.547	3.430 MJ/unit	661.64 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.					

SUMMARY - 2

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.

MORTARS AND CONCRETE					
Items	Details	Country	$KgCO_2/m^3$	Energy Quantity & Unit	
Cement sand mortar (CSM 1: 2) [5]	1 cement: 2 sand	India	340.091		3,778.79 MJ/m^3
Cement sand mortar (CSM 1: 2.5) [5]	1 cement: 2.5 sand	India	283.992		3,155.46 MJ/m^3
Cement sand mortar (CSM 1: 3) [5]	1 cement: 3 sand	India	239.112		2,656.80 MJ/m^3
Cement sand mortar (CSM 1: 4) [5]	1 cement: 4 sand	India	178.525		1,983.61 MJ/m^3
Cement sand mortar(CSM 1: 5) [5]	1 cement: 5 sand	India	144.865		1,609.61 MJ/m^3
Cement sand mortar (CSM 1: 6) [5]	1 cement: 6 sand	India	120.181		1,335.35 MJ/m^3
Cement sand mortar (CSM 1: 8) [5]	1 cement: 8 sand	India	91.009		1,011.21 MJ/m^3
Cement sand mortar (CSM 1: 10) [5]	1 cement: 10 sand	India	73.731		819.23 MJ/m^3
Cement sand mortar (CSM 1: 12) [5]	1 cement: 12 sand	India	61.838		687.08 MJ/m^3
Cement sand mortar (CSM 1: 16) [5]	1 cement: 16 sand	India	47.252		525.02 MJ/m^3
Stabilised earth sand mortar(SEM 1:1:3)[5]	1 cement: 1 soil: 3 sand	India	178.506		1,983.40 MJ/m^3
Stabilised earth sand mortar(SEM 1: 6: 3)[5]	1 cement: 6 soil: 3 sand	India	81.984		910.93 MJ/m^3
Stabilised earth sand mortar(SEM 1:3:6)[5]	1 cement: 3 soil: 6 sand	India	82.009		911.21 MJ/m^3
Stabilised earth sand mortar(SEM 1: 4: 8)[5]	1 cement: 4 soil: 8 sand	India	61.813		686.81 MJ/m^3
Stabilised earth sand mortar(SEM 1:6:6) [5]	1 cement: 6 soil: 6 sand	India	61.801		686.67 MJ/m^3
Plain cement concrete (PCC 1: 1.5: 3)[5]	1 cement:1.5 sand: 3 Chips or 1/2"	India	213.062		2,367.35 MJ/m^3
Plain cement concrete (PCC 1: 2: 4)[5]	1 cement: 2 sand: 4 gravel 1/2"	India	185.698		2,063.31 MJ/m^3
Plain cement concrete (PCC 1: 3: 6)[5]	1 cement: 3 sand: 6 gravel 1/2"	India	147.101		1,634.46 MJ/m^3
Plain cement concrete (PCC 1: 4: 8)[5]	1 cement: 4 sand: 8 gravel 1/2"	India	119.601		1,328.90 MJ/m^3
Plain earth concrete (PEC 1: 2: 3: 4)[5]	1 cement: 2 soil: 3 sand: 4 gravel 1/2"	India	117.281		1,303.12 MJ/m^3
Plain earth concrete (PEC 1: 2: 4: 8 (1")[5]	1 cement: 2 soil: 4 sand: 8 gravel 1"	India	109.167		1,212.97 MJ/m^3
Plain earth concrete (PEC 1:2:4:8 (1.5")[5]	1 cement: 2 soil: 4 sand: 8 gravel 1.5"	India	109.167		1,212.97 MJ/m^3
Notes: Densities of materials = ρ Mortars (CSM & SEM) = 2,000 Kg/m^3 - ρ Concrete (PCC & PEC) = 2,200 Kg/m^3					
All energy values for mortars & concrete integrate the energy for transporting materials: cement = 150Km, sand = 20Km, gravel = 40Km					

VARIOUS TYPES OF WALLS					
Items	Details	Country	$KgCO_2/m^3$	Energy Quantity & Unit	
CSEB wall (Production on site) [5]	24 cm thick with 5% cement CSEB	India	56.790	151.4 MJ/m^2	631.00 MJ/m^3
Klin Fired Bricks (average)[10]	22 cm thick (22 x 10 x 7 cm)	India	234.375	572.9 MJ/m^2	2,604.17 MJ/m^3
Country fired bricks wall (Puducherry) [5]	23 cm thick (23 x 10 x 7 cm)	India	525.248	1,342.3 MJ/m^2	5,836.08 MJ/m^3
Concrete blocks wall [2]	15 cm thick	India	179.700	299.5 MJ/m^2	1,996.67 MJ/m^3

OTHER MATERIALS					
Items	Details	Country	$KgCO_2/Kg$	Energy Quantity / Unit	
Asphalt road [4]		UK	134.000	Kg CO_2/m^2	2,672.00 MJ/m^2
Bitumen [4]		UK	4.380	44.70 MJ/Kg	
Ceramic Tiles [1]	(ρ = 1,750 Kg/m^3)	India	0.245	2.50 MJ/Kg	4,375.00 MJ/m^3
Toughened glass [6]	(ρ = 2,600 Kg/m^3)	NZ	2.567	26.20 MJ/Kg	68,120.00 MJ/m^3
Float glass [6]	(ρ = 2,600 Kg/m^3)	NZ	1.558	15.90 MJ/Kg	41,340.00 MJ/m^3
Paint [4]		UK	6.100	80.00 MJ/Kg	
Plastics, General [2]		India	7.350	75.00 MJ/Kg	
Plastics, Polystyrene [4]	(Thermoformed expanded)	UK	3.400	109.20 MJ/Kg	3,518.00 MJ/m^3
Plastics, Nylon [7]		UK	5.500	120.50 MJ/Kg	
Powered fired brick (Surkhi) [2]		India	0.157	1.60 MJ/Kg	
PVC [2]		India	11.270	115.00 MJ/Kg	
Rubber [4]	(Synthetic)	UK	4.250	120.00 MJ/Kg	
Sanitary ware [2]		India	3.714	37.90 MJ/Kg	
Stoneware [2]		India	1.636	16.70 MJ/Kg	
Straw [4]		UK	0.010	0.24 MJ/Kg	31.00 MJ/m^3

SUMMARY - 3

BUILDING COMPONENTS

Items	Details	Country	$KgCO_2/m^2$	Energy Quantity & Unit	
Stabilised Mud Brick Filler Slab [1]	Span 3.6 m	India	53.100	590.00 MJ/m^2	
Mangalore Tile Roof [1]	Span 3.6 m	India	20.430	227.00 MJ/m^2	
Micro concrete Tile Roof [1]	Span 3.6 m	India	14.220	158.00 MJ/m^2	
Country Fired Brick Wall 23cm(Puducherry)[5]	Mortar and pointing with CSM 1: 4	India	120.807	1,342.3 MJ/m^2	5,836.08 MJ/m^3
Wire Cut Brick Wall 22 cm (Average) [5]	Mortar and pointing with CSM 1: 4	India	51.562	572.92 MJ/m^2	2,604.17 MJ/m^3
Stabilised Rammed Earth Foundations [5]	5% cement (500 l soil: 200 l sand, 1 bag)	India	53.423 Kg CO_2/m^3		593.59 MJ/m^3
CSEB Masonry Wall 24 cm (B 240) [5]	Mortar and pointing with SEM 1: 4: 8	India	13.630	151.44 MJ/m^2	631.00 MJ/m^3
CSEB Masonry Wall 11.5 cm (1/2 B 240)[5]	Mortar and pointing with SEM 1: 4: 8	India	6.861	76.23 MJ/m^2	662.91 MJ/m^3
CSEB Masonry Vault for roof 1 + ring beam[5] (For the projected area of the room)	5m span, 2m rise, 5m long, 11.5 cm thick with RCC ring beams in FC shuttering	India	27.006	300.06 MJ/m^2	2,609.24 MJ/m^3
CSEB Masonry Vault for roof 2 + ring beam[5] (For the projected area of the room)	5m span, 1.5m rise, 5m long, 9 cm thick with RCC ring beams in FC shuttering	India	21.749	241.65 MJ/m^2	2,685.03 MJ/m^3
CSEB Masonry Vault for floor 1 + ring beam[5] (For the projected area of the room)	5m span, 0.6m rise, 5m long, 7 cm thick with RCC ring beams in FC shuttering	India	18.069	200.77 MJ/m^2	2,868.16 MJ/m^3
CSEB Masonry Vault for floor 2 + ring beam[5] (For the projected area of the room)	4m span, 0.4m rise, 5m long, 7 cm thick with RCC ring beams in FC shuttering	India	17.542	194.91 MJ/m^2	2,784.37 MJ/m^3
RCC Slab (PCC 1: 2: 4) [5]	6 x 6 m, 15 cm thick, PCC 1: 2: 4, top mat Φ10@ 20cm, bot mat Φ12@ 20cm	India	64.977	721.96 MJ/m^2	4,813.09 MJ/m^3
RCC Slab (PCC 1: 1.5: 3) [5]	6 x 6 m, 15 cm thick, PCC 1: 1.5: 3, top mat Φ10@ 20cm, bot mat Φ12@ 20 cm	India	69.492	772.13 MJ/m^2	5,147.54 MJ/m^3
RCC Beam 23 x 20 cm (PCC 1: 2: 4) [5]	2Φ10TS top, 2Φ12TS bot, stirrups 6@25	India	20.627 Kg CO_2/m		229.19 MJ/m
RCC Column Φ 20 (PCC 1: 2: 4) [5]	5 Φ 12 TS, stirrups Φ 6 @ 20 c/c	India	23.730 Kg CO_2/m		263.67 MJ/m
RCC Wall 15 cm thick [5]	2 mats Φ10TS@25 + Stirrups Φ6@25	India	77.908	865.65 MJ/m^2	5,770.97 MJ/m^3
RCC Wall 20 cm thick [5]	2 mats Φ12TS@25 + Stirrups Φ6@25	India	108.381	1,204.24 MJ/m^2	4,816.95 MJ/m^3
Composite ring beam 240, 4/4 size blocks[5]	2 Φ 8 TS + stirrups Φ 6 MS @ 25 c/c	India	5.265 Kg CO_2/m		58.50 MJ/m
Composite ring beam 240, 1/2 size blocks[5]	1 Φ 12 TS	India	3.780 Kg CO_2/m		42.01 MJ/m
Composite beam 240 single height 4/4 B.[5]	2 Φ 12 TS + stirrups Φ 6 MS @ 25 c/c	India	7.770 Kg CO_2/m		86.34 MJ/m
Composite beam 240 single height 1/2 B.[5]	1 Φ 16 TS	India	5.692 Kg CO_2/m		63.25 MJ/m
Composite beam 240 double height 4/4 B.[5]	top 2Φ8TS bot 2Φ12TS, stirrupsΦ6@25	India	13.160 Kg CO_2/m		146.23 MJ/m
Composite beam 240 double height 4/4 B.[5]	top 2Φ12TS bot 2Φ12TS stirrupsΦ6@25	India	16.324 Kg CO_2/m		181.38 MJ/m
Composite beam 240 triple height 4/4 B.[5]	top 2Φ10TS bot 2Φ12TS stirrupsΦ6@25	India	16.033 Kg CO_2/m		178.15 MJ/m
Composite beam 240 triple height 4/4 B.[5]	top 2Φ12TS bot 2Φ12TS stirrupsΦ6@25	India	17.774 Kg CO_2/m		197.48 MJ/m
Composite Column 240 [5]	3 Φ 12 TS, stirrups Φ 6 @ 20 c/c	India	14.168 Kg CO_2/m		157.42 MJ/m
Composite Column 290 [5]	4 Φ 12 TS, stirrups Φ 6 @ 20 c/c	India	20.031 Kg CO_2/m		222.56 MJ/m
FC door (12 mm thick, 1: 2 - 3 layers)[5]	1 cement: 2 sand, 3 layers	India	13.387	148.75 MJ/m^2	
FC door (12 mm thick, 1: 2.5 - 3 layers)[5]	1 cement: 2.5 sand, 3 layers	India	12.386	137.62 MJ/m^2	
FC door (12 mm thick, 1: 2 - 4 layers) [5]	1 cement: 2 sand, 4 layers	India	15.203	168.92 MJ/m^2	
FC door (12 mm thick, 1: 2.5 - 4 layers)[5]	1 cement: 2.5 sand, 4 layers	India	14.201	157.79 MJ/m^2	
FC panel (25 mm thick, 1: 2 - 2 layers)[5]	1 cement: 2 sand, 2 layers	India	16.733	185.92 MJ/m^2	
FC panel (25 mm thick,1: 2.5 - 2 layers)[5]	1 cement: 2.5 sand, 2 layers	India	14.848	164.98 MJ/m^2	
FC panel (25 mm thick, 1: 2.5 - 3 layers)[5]	1 cement: 2.5 sand, 3 layers	India	17.041	189.35 MJ/m^2	
FC panel (25 mm thick, 1: 3 - 2 layers)[5]	1 cement: 3 sand, 2 layers	India	13.340	148.22 MJ/m^2	
FC gutter (15mm CSM 1: 3 - 1 layer) [5]	U shape 24 x 10 / 10 cm	India	3.563 Kg CO_2/m		39.58 MJ/m
FC gutter (15mm CSM 1: 3 - 1 layer)[5]	U shape 27 x 20 / 10 cm	India	4.040 Kg CO_2/m		44.88 MJ/m
FC gutter (15mm CSM 1: 3 - 1 layer) [5]	U shape 27 x 20 / 20 cm	India	4.416 Kg CO_2/m		49.07 MJ/m
FC gutter (15mm CSM 1: 3 - 1 layer) [5]	U shape 36.5 x 10 / 10 cm	India	4.027 Kg CO_2/m		44.74 MJ/m
FC channel semicircular(62.5/30 round)[5]	1cement: 2.5 sand, top 1Φ8, bot 2Φ12	India	36.816	409.07 MJ/m^2	255.67 MJ/m
FC channel semicircular (62.5/30 flat) [5]	1cement: 2.5 sand, top 2Φ8, bot 2Φ12	India	40.192	446.57 MJ/m^2	279.11 MJ/m
FC channel, Interlocking (75/35 cm) [5]	1Ce: 2.5 Sa, top 2Φ8, bot 2Φ12	India	37.448	416.09 MJ/m^2	312.07 MJ/m
FC channel, U shape (75/35 cm) [5] +	1 Ce: 2.5 Sa, top 2Φ10TS, bot 2Φ12	India	68.614	762.38 MJ/m^2	571.79 MJ/m
FC channel roof not filled (6m span)[5]	Semicircular top round, CSM 1: 2.5	India	40.217	446.85 MJ/m^2	279.28 MJ/m
FC channel floor/roof filled flat (6m span)[5]	Semicircular top round, CSM 1: 2.5	India	47.400	526.67 MJ/m^2	329.17 MJ/m
FC channel roof not filled (6m span)[5]	Semicircular top flat, CSM 1: 2.5	India	43.761	486.23 MJ/m^2	303.90 MJ/m
FC channel floor /roof filled flat (6m span)[5]	Semicircular top flat, CSM 1: 2.5	India	50.869	565.21 MJ/m^2	353.26 MJ/m

Notes: - FC = Ferrocement – Chicken mesh = 1/2", 22 gauge – X layers = Nos. layers of chicken mesh – Ce = cement – Sa = sand

- All energy values for building components integrate the energy for transporting materials: cement and steel = 150 Km, sand = 20Km, Gravel = 40Km

NOTES

TRANSPORTATION OF MATERIALS

Items	Details	Country	Energy Quantity / Unit	
Diesel consumption (8 m^3/12 T. truck on road)[5]	Moving materials 500m on site = 15 litres / 8h	India	4.967 $KgCO_2$/hour	67.13 MJ/h
Diesel consumption (8 m^3/12 T. truck on road)[5]	On road driving with 12Tons = 3 Km / litre	India	0.883 $KgCO_2$/Km	11.93 MJ/Km
Diesel consumption for excavator [5]	JCB excavator = 6 Litres / hour	India	15.895 $KgCO_2$/hour	214.80 MJ/h

FUEL COMBUSTION

Items	Details	Country	$KgCO_2$ and Energy Quantity / Unit	
Petrol [5]	Inferior combustion power	France	2.898 $KgCO_2$/litre	32.20 MJ/litre
Diesel [5]	Inferior combustion power	France	3.222 $KgCO_2$/litre	35.80 MJ/litre
GPL [5]	Inferior combustion power	France	2.277 $KgCO_2$/litre	25.30 MJ/litre
Wood combustion [5]	Casuarinas wood at 15 % mh	India	1.584 $KgCO_2$/Kg	15.00 MJ/Kg
Human energy [5]		India	0.904 $KgCO_2$/day	10.04 MJ/day

Note of 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.

CARBON EMISSIONS

CO_2 Emissions produced as an average [8] =	0.098	Kg of CO^2 per MJ of embodied energy
CO_2 Emissions produced by burning coal [11] =	0.090	Kg of CO^2 per MJ of embodied energy
CO_2 Emissions produced by burning petroleum products [11] =	0.074	Kg of CO^2 per MJ of embodied energy
CO_2 Emissions produced by thermal electricity [11] =	0.316	Kg of CO^2 per MJ of embodied energy
CO_2 Emissions produced by burning wood [5]	0.105	Kg of CO^2 per MJ of embodied energy

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

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

Wood combustion [5]: 1 Kg of wood contains ~440 gr. of carbon – 1 Kg of carbon burnt emits 3.6 Kg of CO_2

$\Rightarrow$ 1 Kg of wood burnt emits 1.584 Kg of CO_2 [5]

UNITS

- The Joule (J) is the SI unit of energy measuring heat, electricity and mechanical work. It was named after English physicist James Prescott Joule.
- The kilowatt hour (KWh) is a unit of energy. Energy delivered by electric utilities is usually expressed and charged for in kWh.
  Note that the KWh is the product of power in kilowatts multiplied by time in hours. It is not kW/h.
- The British thermal unit (BTU or Btu) is a unit of energy used in the power, steam generation, heating and air conditioning industries.

- 1 Joule = 1Newton Metre = 1Watt second
- 1 Joule = 2.7778 $\times 10^{-4}$ Watt Hour
- 1 Joule = 2.7778 $\times 10^{-7}$ KWh
- 1 Joule = 9.4782 $\times 10^{-4}$ BTU
- 1 Joule = 6.2415 $\times 10^{18}$ eV (electronvolts)
- 1 Joule = 0.239 Calories
- 1 Calorie = 4.184 Joules
- 1 Kilowatt Hour (KWh) = 3.6 MJ
- MJ = Mega Joule
- GJ = Giga Joule
- Mega = 1 million = 10^6
- Giga = thousand million = 10^9

WEIGHT OF STEEL (Kg / m)

4 MS = 0.099 - 6 MS = 0.222 - 8 TS= 0.395 - 10 TS = 0.617 - 12 TS = 0.888 - 16 TS = 1.579 - 20 TS = 2.468

SOURCES

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DEFINITIONS

Initial Embodied Energy [7]
This energy in buildings represents 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 [7]
This energy in buildings represents the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life time of the building.

Operating Energy [7]
It is the recurring energy consumed in buildings for heating, cooling, ventilation, lighting, equipment and appliances. Passive energy systems rely on the building enclosure or 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.

Carbon footprint [18]
A carbon footprint is a measure of the amount of greenhouse gas (GHG) emissions that are released within the boundaries of study. A carbon footprint is often measured in the units of kg or tonnes of CO2e. A true carbon footprint starts at the cradle and measures the release of GHG emissions throughout a supply chain or life-cycle.

Embodied carbon [18]
Embodied carbon may be defined as the carbon footprint of a material. It considers the amount of greenhouse gas emissions (GHGs) that are released throughout a production supply chain to produce a material or product

Boundary conditions [18]
Boundary conditions are used to define what a study includes. The common boundary conditions are cradle to gate, cradle to site and cradle to grave. Full boundaries should also define what was excluded (i.e. due to lack of data, or inputs that were assumed negligible).

Net Energy Gain (NEG) [14]
It is a concept important in energy economics, referring to a surplus condition in the difference between the energy required to harvest an energy source and the energy provided by that same source. By the above definition, a net energy gain is achieved by expending less energy acquiring a source of energy than is contained in the source to be consumed: NEG = Energy Consumable – Energy Expended

Energy Pay Back Time [15]
The Energy Pay Back Time is defined by EPBT = Einput/Esaved, where Einput is the energy input during the module life cycle (which includes the energy requirement for manufacturing, installation, energy use during operation, and energy needed for decommissioning) and Esaved the annual energy savings due to electricity generated by the Photovoltaic module.

Life Cycle Assessment [16]
A life cycle assessment (LCA, also known as life cycle analysis, eco-balance, and cradle-to-grave analysis) is the investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its existence.

Energy Returned on Energy Invested [17]
In physics, energy economics and ecological energetics, Energy Returned on Energy Invested (EROEI), or less frequently called eMergy, is the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource. When the EROEI of a resource is equal to or lower than 1, that energy source becomes an "energy sink", and can no longer be used as a primary source of energy.
EROEI and Net energy (gain) measure the same quality of an energy source or sink in numerically different ways. Net energy describes the amounts, while EROEI measures the ratio or efficiency of the process. They are related simply by:
[(Net Energy + Energy Expended) □ Energy Expended = EROEI] or [(Net Energy □ Energy Expended) +1 = EROEI]

Cradle-to-grave [16]
Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave').

Cradle-to-gate [16]
Cradle-to-gate is an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (i.e., before it is transported to the consumer). The use phase and disposal phase of the product are omitted in this case.

Cradle to site [18]
Cradle to site is a boundary condition associated with embodied carbon, carbon footprint and LCA studies. A study to these boundaries includes the cradle to gate results and the transportation of the material or product to its site of use.

CALCULATION - MORTARS

Notes: B/m^3 = Bag per m^3 - m^3/D= m^3 per day

EMBODIED ENERGY PER M^3 OF STABILISED EARTH MORTAR (SEM)

DATA		SEM 1: 6: 6 (± 7%)		SEM 1: 4: 8 (± 7%)		SEM 1: 3: 6 (± 9%)		SEM 1: 6: 3 (± 9%)		SEM 1: 1: 3 (± 17.5%)	
Item	Energy MJ/unit	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/unit
Cement (Bag)	230.0	2.6 B/m^3	598.00	2.6 B/m^3	598.0	3.5 B/m^3	805.0	3.5 B/m^3	805.0	7.8 B/m^3	1794.0
Soil # 10mm (m^3)	29.0	0.625 m^3	18.10	0.415 m^3	12.02	0.415 m^3	12.02	0.835 m^3	24.18	0.312 m^3	9.03
Sand # 4mm (m^3)	29.6	0.625 m^3	18.49	0.835 m^3	24.70	0.835 m^3	24.70	0.415 m^3	12.28	0.938 m^3	27.75
Transport cement MJ/Km	11.93	150 Km	19.39	150 Km	19.39	150 Km	26.10	150 Km	26.10	150 Km	58.18
SUB TOTAL			654		654.1		867.8		867.6		1889.0
Miscellaneous	5.0%		32.7		32.7		43.4		43.4		94.4
TOTAL ENERGY MJ/M^3			686.7		686.8		911.2		910.9		1,983.4

EMBODIED ENERGY PER M^3 OF CEMENT SAND MORTAR (CSM)

DATA		CSM 1: 2 (± 29.3%)		CSM 1: 2.5 (± 25.6%)		CSM 1: 3 (± 22.5%)		CSM 1: 4 (± 17.7%)		CSM 1: 5 (± 14.8 %)	
Item	Energy MJ/unit	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/unit
Cement (bag)	230.0	15 B/m^3	3450.0	12.5 B/m^3	2875.0	10.5 B/m^3	2415.0	7.8 B/m^3	1794.0	6.3 B/m^3	1449.0
Sand # 2mm (m^3)	29.6	1.25 m^3	36.97	1.25 m^3	36.97						
Sand # 4mm (m^3)	29.6					1.25 m^3	36.97	1.25 m^3	36.97	1.25 m^3	36.97
Transport cement MJ/Km	11.93	150 Km	111.88	150 Km	93.23	150 Km	78.31	150 Km	58.18	150 Km	46.99
SUB TOTAL			3598.8		3005.2		2530.3		1889.1		1533.0
Miscellaneous	5.0%		179.9		150.3		126.5		94.5		76.6
TOTAL ENERGY MJ/M^3			3,778.8		3,155.5		2,656.8		1,983.6		1,609.6

EMBODIED ENERGY PER M^3 OF CEMENT SAND MORTAR (CSM)

DATA		CSM 1: 6 (± 12.5%)		CSM 1: 8 (± 9.7%)		CSM 1: 10 (± 7.9%)		CSM 1: 12 (± 6.7%)		CSM 1: 16 (± 5.1%)	
Item	Energy MJ/unit	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/m^3	Detail	MJ/unit
Cement (bag)	230.0	5.2 B/m^3	1196.0	3.9 B/m^3	897.0	3.13 B/m^3	719.9	2.6 B/m^3	598.0	1.95 B/m^3	448.5
Sand # 4mm (m^3)	29.6	1.25 m^3	36.97	1.25 m^3	36.97	1.25 m^3	36.97	1.25 m^3	36.97	1.25 m^3	36.97
Transport cement MJ/Km	11.93	150 Km	38.78	150 Km	29.09	150 Km	23.34	150 Km	19.39	150 Km	14.54
SUB TOTAL			1271.8		963.1		780.2		654.4		500.0
Miscellaneous	5.0%		63.6		48.2		39.0		32.7		25.0
TOTAL ENERGY MJ/M^3			1,335.3		1,011.2		819.2		687.1		525.0

NOTE FOR MIXES OF MORTAR

SEM 1: 6: 6 = 1 cement: 6 soil: 6 sand = 1 Bag: 240 Litres soil: 240 Litres sand	CSM 1: 4 = 1 cement: 4 sand = 1 Bag: 160 Litres sand
SEM 1: 4: 8 = 1 cement: 4 soil: 8 sand = 1 Bag: 160 Litres soil: 320 Litres sand	CSM 1: 5 = 1 cement: 5 sand = 1 Bag: 200 Litres sand
SEM 1: 3: 6 = 1 cement: 3 soil: 6 sand = 1 Bag: 120 Litres soil: 240 Litres sand	CSM 1: 6 = 1 cement: 6 sand = 1 Bag: 240 Litres sand
SEM 1: 6: 3 = 1 cement: 6 soil: 3 sand = 1 Bag: 240 Litres soil: 120 Litres sand	CSM 1: 8 = 1 cement: 8 sand = 1 Bag: 320 Litres sand
SEM 1: 1: 3 = 1 cement: 1 soil: 3 sand = 1 Bag: 40 Litres soil: 120 Litres sand	CSM 1: 10 = 1 cement: 10 sand = 1 Bag: 400 Litres sand
CSM 1: 2 = 1 cement: 2 sand = 1 Bag: 80 Litres sand	CSM 1: 12 = 1 cement: 12 sand = 1 Bag: 480 Litres sand
CSM 1: 2.5 = 1 cement: 2.5 sand = 1 Bag: 100 Litres sand	CSM 1: 16 = 1 cement: 16 sand = 1 Bag: 640 Litres sand
CSM 1: 3 = 1 cement: 3 sand = 1 Bag: 120 Litres sand	

CALCULATION - PLAIN CEMENT CONCRETE (PCC) - PLAIN EARTH CONCRETE (PEC) REINFORCED CEMENT CONCRETE (RCC)

NOTES : B/m^3 = Bag per m^3 - m^3/D= m^3 per day

EMBODIED ENERGY PER M^3 OF PCC

DATA		PCC 1: 1.5: 3 Chips		PCC 1: 1.5: 1.5: 1.5		PCC 1: 1.5: 3 (1/2")		PCC 1: 2: 2: 2		PCC 1: 2: 4 (1/2")	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Cement (bag)	230.0	6.9 B/m^3	1587.0	6.9 B/m^3	1587.0	6.9 B/m^3	1587.0	5.2 B/m^3	1196.0	5.2 B/m^3	1196.0
Sand # 4mm (m^3)	29.6	0.42 m^3	12.42	0.42 m^3	12.42	0.42 m^3	12.42	0.42 m^3	12.42	0.42 m^3	12.42
Gravel chips (m^3)	780.0	0.84 m^3	655.20	0.42 m^3	327.60			0.42 m^3	327.60		
Gravel 1/2" (m^3)	780.0			0.42 m^3	327.60	0.84 m^3	655.20	0.42 m^3	327.60	0.84 m^3	655.20
Transport cement	11.93	150 Km	51.46	150 Km	51.46			150 Km	38.78	150 Km	38.78
Transport aggregates	11.93	20&40 Km	62.65	20&40 Km	62.65			20&40 Km	62.65	20&40 Km	62.65
SUB TOTAL			2368.7		2368.7		2254.6		1965.1		1965.1
Miscellaneous	5.0%		118.4		118.4		112.7		98.3		98.3
TOTAL ENERGY MJ/M^3			**2,487.2**		**2,487.2**		**2,367.4**		**2,063.3**		**2,063.3**

PCC 1: 2: 2: 2= 1 cement: 2 sand: 2 chips: 2 (1/2" gravel) **PCC 1: 1.5: 1.5: 1.5**= 1 cement: 1.5 sand: 1.5 chips: 1.5 (1/2" gravel)

EMBODIED ENERGY PER M^3 OF PCC

DATA		PCC 1: 3: 6 (1/2")		PCC 1: 3: 6 (3/4")		PCC 1: 4: 8 (1/2")		PCC 1: 4: 8 (3/4")		PCC 1: 4: 8 (1")	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Cement (bag)	230.0	3.48 B/m^3	800.4	3.48 B/m^3	800.4	2.6 B/m^3	598.0	2.6 B/m^3	598.0	2.6 B/m^3	598.0
Sand # 4mm (m^3)	29.6	0.42 m^3	12.4	0.42 m^3	12.4	0.42 m^3	12.4	0.42 m^3	12.4	0.42 m^3	12.4
Gravel chips (m^3)	780.0										
Gravel 1/2" (m^3)	780.0	0.84 m^3	655.2			0.84 m^3	655.2				
Gravel 3/4" (m^3)	780.0			0.84 m^3	655.2			0.84 m^3	655.2		
Gravel 1" (m^3)	780.0									0.84 m^3	655.2
Transport cement	11.93	150 Km	25.96	150 Km	25.96			150 Km	19.39	150 Km	19.39
Transport aggregates	11.93	20&40 Km	62.65	20&40 Km	62.65			20&40 Km	62.65	20&40 Km	62.65
SUB TOTAL			1556.6		1556.6		1265.6		1347.7		1347.7
Miscellaneous	5.0%		77.8		77.8		63.3		67.4		67.4
TOTAL ENERGY MJ/M^3			**1,634.5**		**1,634.5**		**1,328.9**		**1,415.0**		**1,415.0**

EMBODIED ENERGY PER M^3 OF PEC

DATA		PEC 1: 2: 3: 4 (1/2")		PEC 1: 2: 3: 4 (1")				PEC 1: 2: 4: 8 (1")		PEC 1: 2: 4: 8 (1.5")	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit			Detail	MJ/unit	Detail	MJ/unit
Cement (bag)	230.0	3.125 B/m^3	718.8	3.125 B/m^3	718.8			2.23 B/m^3	512.9	2.23 B/m^3	512.9
Sand # 4mm (m^3)	29.6	0.28 m^3	8.3	0.28 m^3	8.3			0.18 m^3	5.3	0.18 m^3	5.3
Soil sieved #10 (m^3)	29.0	0.42 m^3	12.2	0.42 m^3	12.2			0.36 m^3	10.4	0.36 m^3	10.4
Soil sieved #10 (m^3)	29.0										
Gravel chips (m^3)	780.0									m^3	
Gravel 1/2" (m^3)	780.0	0.56 m^3	436.8							m^3	
Gravel 3/4" (m^3)	780.0									m^3	
Gravel 1" (m^3)	780.0			0.56	436.8			0.72 m^3	561.6	m^3	
Blue metal 1.5" (m^3)	780.0									0.72 m^3	561.6
Transport cement	11.93	150 Km	23.31	150 Km	23.31			150 Km	16.63	150 Km	16.63
Transport aggregates	11.93	20&40 Km	41.77	20&40 Km	41.77			20&40 Km	48.33	20&40 Km	48.33
SUB TOTAL			1241.1		1241.1				1155.2		1155.2
Miscellaneous	5.0%		62.1		62.1				57.8		57.8
TOTAL ENERGY MJ/M^3			**1,303.1**		**1,303.1**				**1,213.0**		**1,213.0**

EMBODIED ENERGY PER M^2 OF RCC SLAB, 6 x 6 M, 15 CM THICK											
DATA		PCC 1: 2: 4 (1/2") 15 cm thick		PCC 1: 1.5: 3 (1/2") 15 cm thick							
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit						
PCC 1: 2: 4 (m^3)	2,063	5.4 m^3	11,142								
PCC 1: 1.5: 3 (m^3)	2,367			5.4 m^3	12,783.7						
Binding wire (Kg)	36.00	24 Kg	864.0	24 Kg	864.0						
Top Φ10TS @ 20	33.33	142 Kg	4,733.3	142 Kg	4,733.3						
Bot.Φ12TS @ 20	33.33	205 Kg	6,833.3	205 Kg	6,833.3						
Transport steel MJ/Km	11.93	150 Km	55.341	150 Km	55.341						
SUB TOTAL PER M^2			656.3		701.9						
Formwork	5.0%		32.8		35.1						
Miscellaneous	5.0%		32.8		35.1						
TOTAL ENERGY MJ/M^2			**722.0**		**772.1**						
TOTAL ENERGY MJ/M^3			**4,813.1**		**5,147.5**						

EMBODIED ENERGY PER M OF RCC BEAM (23 x 20 CM) & COLUMN (Φ 20 CM)							
DATA		BEAM (23 x 20 CM) 2 Φ10TS top, 2Φ12TS bot, stirrups @ 25 c/c				COLUMN (Φ 20 CM) 5 Φ 12 TS, stirrups @ 20 c/c	
Item	Energy MJ/unit	Detail	MJ/unit			Detail	MJ/unit
PCC 1: 2: 4 (m^3)	2,063	0.04 m^3	82.5			0.03 m^3	64.8
Binding wire (Kg)	36.00	0.1 Kg per m of beam	3.6			0.05 Kg per m high of column	1.8
Stirrups Φ 6 MS (Kg)	33.33	0.6 Kg per m (spacing 25 c/c)	20.0			0.67 Kg per m (spacing 20 c/c)	22.3
Top 2 Φ10TS (Kg)	33.33	1.25 Kg per m of beam	41.7				
Bottom 2 Φ12TS (Kg)	33.33	1.80 Kg per m of beam	60.0			4.5 Kg per m high of column	150.0
Transport steel MJ/Km	11.93	150 Km	0.559			150 Km	0.779
SUB TOTAL PER M^2			208.4				239.7
Formwork	5.0%		10.4				12.0
Miscellaneous	5.0%		10.4				12.0
TOTAL ENERGY MJ/M			**229.2**				**263.7**

EMBODIED ENERGY PER M^2 OF RCC WALLS							
DATA		WALL 15 CM THICK Inner & outer mat: Φ10TS @ 25 c/c Stirrups between mats: Φ6MS @ 25 c/c				WALL 20 CM THICK Inner & outer mat: Φ12TS @ 25 c/c Stirrups between mats: Φ6MS @ 25 c/c	
Item	Energy MJ/unit	Detail	MJ/unit			Detail	MJ/unit
PCC 1: 2: 4 (m^3)	2,063	0.15 m^3	309.5			0.2 m^3	412.7
Binding wire (Kg)	36.00	0.5 Kg per m^2 of wall	18.0			0.5 Kg per m^2 of wall	18.0
Stirrups Φ 6 MS (Kg)	33.33	1.38 Kg per m^2 (25 cm @ 25 c/c)	46.0			1.93 Kg per m^2 (35 cm @ 25 c/c)	64.4
Φ10TS (Kg)	33.33	12.34 Kg per m^2 of wall (20 Nos.)	411.3				
Φ12TS (Kg)	33.33					17.90 Kg per m^2 of wall (20 Nos.)	596.7
Transport steel MJ/Km	11.93	150 Km	2.121			150 Km	3.033
SUB TOTAL PER M^2			787.0				1,094.8
Formwork	5.0%		39.3				54.7
Miscellaneous	5.0%		39.3				54.7
TOTAL ENERGY MJ/M^2			**865.6**				**1,204.2**

NOTE FOR MIXES OF PCC & PEC
PCC 1: 1.5: 3 Chips = 1 cement: 1.5 sand: 3 gravel chips ⇒ 1 Bag: 60 Litres sand: 120 Litres gravel chips
PCC 1: 1.5: 1.5: 1.5 = 1 cement: 1.5 sand: 1.5 gravel chips: 1.5 gravel 1/2" ⇒ 1 Bag: 60 Litres sand: 60 Litres gravel 1/2": 60 Litres chips
PCC 1: 1.5: 3 (1/2") = 1 cement: 1.5 sand: 3 gravel 1/2" ⇒ 1 Bag: 60 Litres sand: 120 Litres gravel 1/2"
PCC 1: 2: 2: 2 = 1 cement: 2 sand: 2 gravel chips: 2 gravel 1/2" ⇒ 1 Bag: 80 Litres sand: 80 Lts gravel chips: 80 Lts gravel 1/2"
PCC 1: 2: 4 (1/2") = 1 cement: 2 sand: 4 gravel 1/2" ⇒ 1 Bag: 80 Litres sand: 160 Litres gravel 1/2"
PCC 1: 3: 6 (1/2") = 1 cement: 3 sand: 6 gravel 1/2" ⇒ 1 Bag: 120 Litres sand: 240 Litres gravel 1/2"
PCC 1: 3: 6 (3/4") = 1 cement: 3 sand: 6 gravel 3/4" ⇒ 1 Bag: 120 Litres sand: 240 Litres gravel 3/4"
PCC 1: 4: 8 (1/2") = 1 cement: 4 sand: 8 gravel 1/2" ⇒ 1 Bag: 160 Litres sand: 320 Litres gravel 1/2"
PCC 1: 4: 8 (3/4") = 1 cement: 4 sand: 8 gravel 3/4" ⇒ 1 Bag: 160 Litres sand: 320 Litres gravel 3/4"
PCC 1: 4: 8 (1") = 1 cement: 4 sand: 8 gravel 1" ⇒ 1 Bag: 160 Litres sand: 320 Litres gravel 1"
PEC 1: 2: 3: 4 (1/2") = 1 cement: 2 sand: 3 soil: 4 gravel 1/2" ⇒ 1 Bag: 90 Litres sand: 135 Litres soil: 180 Litres gravel 1/2"
PEC 1: 2: 3: 4 (1") = 1 cement: 2 sand: 3 soil: 4 gravel 1" ⇒ 1 Bag: 90 Litres sand: 135 Litres soil: 180 Litres gravel 1"
PEC 1: 2: 4: 8 (1") = 1 cement: 2 sand: 4 soil: 8 gravel 1" ⇒ 1 Bag: 80 Litres sand: 160 Litres soil: 320 Litres gravel 1"

CALCULATION - FERROCEMENT

EMBODIED ENERGY PER M^2 OF FERROCEMENT DOOR

DATA		12 mm thick 1: 2 Mix 3 Coat - 3 ' Mesh		12 mm thick 1: 2.5 Mix 3 Coat - 3 ' Mesh		12 mm thick 1: 2 Mix 4 Coat - 4 ' Mesh		12 mm thick 1: 2.5 Mix 4 Coat - 4 ' Mesh	
Item	**Energy MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**
Mortar 1: 2 (m^3)	3,779	0.017 m^3	64.24			0.017 m^3	64.24		
Mortar 1: 2.5 (m^3)	3,155			0.017 m^3	53.64			0.017 m^3	53.64
Binding wire (Kg)	46.61	0.25 Kg	11.65	0.25 Kg	11.65	0.25 Kg	11.65	0.25 Kg	11.65
Chicken mesh 3 ' (m)	19.34	3.4 m	65.77	3.4 m	65.77				
Chicken mesh 4 ' (m)	25.75					3.3 m	84.98	3.3 m	84.98
SUB TOTAL			141.66		131.07		160.87		150.28
Miscellaneous	5.0%		7.08		6.55		8.04		7.51
TOTAL ENERGY MJ/M^2			**148.75**		**137.62**		**168.92**		**157.79**

Notes: Areas are calculated either for mesh of 3 ' or 4 ' wide - Labour time is calculated for door of 2 m^2

EMBODIED ENERGY PER M^2 OF FERROCEMENT PANEL

DATA		2.5 cm thick 1: 2 Mix 2 Coat - 3 ' Mesh		2.5 cm thick 1: 2.5 Mix 2 Coat - 3 ' Mesh		2.5 cm thick 1: 3 Mix 2 Coat - 3 ' Mesh		2.5 cm thick 1: 2.5 Mix 3 Coat - 3 ' Mesh	
Item	**Energy MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**
Mortar 1: 2 (m^3)	3,779	0.032 m^3	120.92						
Mortar 1: 2.5 (m^3)	3,155			0.032 m^3	100.97			0.032 m^3	100.97
Mortar 1: 3 (m^3)	2,657					0.032 m^3	85.02		
Binding wire (Kg)	46.61	0.25 Kg	11.65	0.25 Kg	11.65	0.25 Kg	11.65	0.25 Kg	11.65
Chicken mesh 3 ' (m)	19.34	2.3 m	44.49	2.3 m	44.49	2.3 m	44.49	3.5 m	67.70
SUB TOTAL			177.07		157.12		141.16		180.33
Miscellaneous	5.0%		8.85		7.86		7.06		9.02
TOTAL ENERGY MJ/M^2			**185.92**		**164.98**		**148.22**		**189.35**

Notes: Areas are calculated for mesh of 3 ' wide - Labour time is calculated for panel of 2 m^2

EMBODIED ENERGY PER M OF FERROCEMENT GUTTER

DATA		1.5 cm thick 24 x 10 / 10 cm 1: 3 Mix 1 Coat - 3 ' Mesh		1.5 cm thick 27 x 20 / 10 cm 1: 3 Mix 2 Coat - 3 ' Mesh		1.5 cm thick 27 x 20 / 20 cm 1: 3 Mix 1 Coat - 3 ' Mesh		1.5 cm thick 36.5 x 10 / 10 cm 1: 3 Mix 1 Coat - 3 ' Mesh	
Item	**Energy MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**
Mortar 1: 3 (m^3)	2,657	0.007 m^3	17.53	0.009 m^3	22.58	0.01 m^3	26.57	0.008 m^3	22.45
Binding wire (Kg)	46.61	0.25 Kg	11.65	0.25 Kg	11.65	0.25 Kg	11.65	0.25 Kg	11.65
Chicken mesh 3 ' (m)	19.34	0.44 m^2	8.51	0.44 m^2	8.51	0.44 m^2	8.51	0.44 m^2	8.51
SUB TOTAL			37.70		42.75		46.73		42.61
Miscellaneous	5.0%		1.88		2.14		2.34		2.13
TOTAL ENERGY MJ/M			**39.58**		**44.88**		**49.07**		**44.74**

Notes: Areas are calculated for mesh of 3 ' wide - Labour time is calculated for gutter of 2 m^2

EMBODIED ENERGY PER M OF FERROCEMENT SEMICIRCULAR CHANNEL (Top round 62.5x30cm)									
DATA		1: 2 Mix		1: 2.5 Mix		1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0281	1Φ6 top +2Φ10 bot		1Φ6 top +2Φ10 bot		1Φ8 top +2Φ12 bot		1Φ8 top +2Φ12 bot	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Mortar 1: 2 (m^3)	3,779	0.037 m^3	138.04			0.037 m^3	138.04		
Mortar 1: 2.5 (m^3)	3,155			0.037 m^3	115.27			0.037 m^3	115.27
Binding wire (Kg)	46.61	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31
Steel Φ 6 MS (Kg)	33.33	0.222 Kg	7.40	0.222 Kg	7.40				
Steel Φ 8 TS (Kg)	33.33					0.395 Kg	13.17	0.395 Kg	13.17
Steel Φ 10 TS (Kg)	33.33	1.234 Kg	41.13	1.234 Kg	41.13				
Steel Φ 12 TS (Kg)	33.33					1.776 Kg	59.20	1.776 Kg	59.20
Transport steel MJ/Km	11.93	150 Km	0.217	150 Km	0.607	150 Km	0.324	150 Km	0.324
Chicken mesh 3 ' (m)	19.34	1.666 m	32.23	1.666 m	32.23	1.666 m	32.23	1.666 m	32.23
SUB TOTAL			242.32		219.94		266.26		243.49
Miscellaneous	5.0%		12.12		11.00		13.31		12.17
TOTAL ENERGY MJ/M			**254.44**		**230.94**		**279.58**		**255.67**

NOTES

The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)

Labour time are calculated for 6 m long channels Steel bars = 2 at bottom + 1 on top

Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M OF FERROCEMENT SEMICIRCULAR CHANNEL (Top flat 62.5x30cm)									
DATA		1: 2 Mix		1: 2.5 Mix		1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0303	2Φ6 top +2Φ10 bot		2Φ6 top +2Φ10 bot		2Φ8 top +2Φ12 bot		2Φ8 top +2Φ12 bot	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Mortar 1: 2 (m^3)	3,779	0.039 m^3	148.85			0.039 m^3	148.85		
Mortar 1: 2.5 (m^3)	3,155			0.039 m^3	124.29			0.039 m^3	124.29
Binding wire (Kg)	46.61	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31
Steel Φ 6 MS (Kg)	33.33	0.444 Kg	14.80	0.444 Kg	14.80				
Steel Φ 8 TS (Kg)	33.33					0.790 Kg	26.33	0.790 Kg	26.33
Steel Φ 10 TS (Kg)	33.33	1.234 Kg	41.13	1.234 Kg	41.13				
Steel Φ 12 TS (Kg)	33.33					1.776 Kg	59.20	1.776 Kg	59.20
Transport steel MJ/Km	11.93	150 Km	0.325	150 Km	0.325	150 Km	0.457	150 Km	0.457
Chicken mesh 3 ' (m)	19.34	1.666 m	32.23	1.666 m	32.23	1.666 m	32.23	1.666 m	32.23
SUB TOTAL			260.64		236.08		290.37		265.82
Miscellaneous	5.0%		13.03		11.80		14.52		13.29
TOTAL ENERGY MJ/M			**273.67**		**247.89**		**304.89**		**279.11**

NOTES

The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)

Labour time are calculated for 6 m long channels Steel bars = 2 at bottom + 2 on top

Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M OF FERROCEMENT INTERLOCKING CHANNEL (75 x 23cm)									
DATA		1: 2 Mix		1: 2.5 Mix		1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.03535	2Φ6 top +2Φ10 bot		2Φ6 top +2Φ10 bot		2Φ8 top +2Φ12 bot		2Φ8 top +2Φ12 bot	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Mortar 1: 2 (m^3)	3,779	0.046 m^3	173.65			0.046 m^3	173.65		
Mortar 1: 2.5 (m^3)	3,155			0.046 m^3	145.01			0.046 m^3	145.01
Binding wire (Kg)	46.61	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31
Steel Φ 6 MS (Kg)	33.33	0.444 Kg	14.80	0.444 Kg	14.80				
Steel Φ 8 TS (Kg)	33.33					0.790 Kg	26.33	0.790 Kg	26.33
Steel Φ 10 TS (Kg)	33.33	1.234 Kg	41.13	1.234 Kg	41.13				
Steel Φ 12 TS (Kg)	33.33					1.776 Kg	59.20	1.776 Kg	59.20
Transport steel MJ/Km	11.93	150 Km	0.325	150 Km	0.908	150 Km	0.457	150 Km	0.457
Chicken mesh 4 ' (m)	25.75	1.666 m	42.90	1.666 m	42.90	1.666 m	42.90	1.666 m	42.90
SUB TOTAL			296.12		268.06		325.85		297.21
Miscellaneous	5.0%		14.81		13.40		16.29		14.86
TOTAL ENERGY MJ/M			310.93		281.46		342.15		312.07

NOTES

The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)

Labour time are calculated for 6 m long channels

Steel bars = 2 at bottom + 2 on top

Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M OF FERROCEMENT U CHANNEL WITH TOP COVER (75 x 35cm)									
DATA		1: 2 Mix		1: 2.5 Mix		1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0943	2Φ10 top +2Φ10 bot		2Φ10 top +2Φ10 bot		2Φ10 top +2Φ12 bot		2Φ10 top +2Φ12 bot	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Mortar 1: 2 (m^3)	3,779	0.123 m^3	463.24			0.123 m^3	463.24		
Mortar 1: 2.5 (m^3)	3,155			0.123 m^3	386.83			0.123 m^3	386.83
Binding wire (Kg)	46.61	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31	0.5 Kg	23.31
Steel Φ 6 MS (Kg)	33.33								
Steel Φ 8 TS (Kg)	33.33								
Steel Φ 10 TS (Kg)	33.33	2.50 Kg	83.33	2.50 Kg	83.33	1.25 Kg	41.67	1.25 Kg	41.67
Steel Φ 12 TS (Kg)	33.33					1.80 Kg	60.00	1.80 Kg	60.00
Transport steel MJ/Km	11.93	150 Km	0.448	150 Km	1.250	150 Km	0.530	150 Km	0.530
Chicken mesh 3 ' (m)	19.34	1.666 m	32.23	1.666 m	32.23	1.666 m	32.23	1.666 m	32.23
SUB TOTAL			602.56		526.94		620.97		544.56
Miscellaneous	5.0%		30.13		26.35		31.05		27.23
TOTAL ENERGY MJ/M			632.68		553.29		652.02		571.79

NOTES

The mesh length is calculated for 1 m of channel

Labour time are calculated for 6 m long channels

Steel bars = 2 at bottom + 2 on top

Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M^2 OF FERROCEMENT ROOF - 6 M SPAN (SEMICIRCULAR CHANNEL 62.5 cm, TOP ROUND - ROOF NOT FILLED)

DATA						1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0281					1Φ8 top +2Φ12 bot		1Φ8 top +2Φ12 bot	
Item	Energy MJ/unit					Detail	MJ/unit	Detail	MJ/unit
Channel, Mortar 1: 2 (m)	279.58					1 m	279.58		
Channel, Mortar 1: 2.5 (m)	255.67							1 m	255.67
PCC 1: 2: 4 (valley m^3)	2,063					0.005 m^3/m	10.32	0.005 m^3/m	10.32
SUB TOTAL							289.89		265.98
Miscellaneous	5.0%						14.49		13.30
TOTAL ENERGY MJ/M							**304.39**		**279.28**
TOTAL ENERGY MJ/M^2							**487.02**		**446.85**

NOTES: The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)
Labour time are calculated for 6 m long channels Steel bars = 2 at bottom + 1 on top
Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M^2 OF FERROCEMENT FLOOR OR ROOF - 6 M SPAN (SEMICIRCULAR CHANNEL 62.5 cm, TOP ROUND - ROOF FILLED FLAT)

DATA						1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0281					1Φ8 top +2Φ12 bot		1Φ8 top +2Φ12 bot	
Item	Energy MJ/unit					Detail	MJ/unit	Detail	MJ/unit
Channel, Mortar 1: 2 (m)	279.58					1 m	279.58		
Channel, Mortar 1: 2.5 (m)	255.67							1 m	255.67
PCC 1: 2: 4 (valley m^3)	2,063					0.005 m^3/m	10.32	0.005 m^3/m	10.32
Sand filling (m^3)	100					0.05 m^3/m	5.00	0.05 m^3/m	5.00
CSM 1: 3, 2.5 cm (m^3)	2,657					0.016 m^3/m	42.51	0.016 m^3/m	42.51
SUB TOTAL							337.40		313.49
Miscellaneous	5.0%						16.87		15.67
TOTAL ENERGY MJ/M							**354.27**		**329.17**
TOTAL ENERGY MJ/M^2							**566.83**		**526.67**

NOTES: The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)
Labour time are calculated for 6 m long channels Steel bars = 2 at bottom + 1 on top
Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M^2 OF FERROCEMENT ROOF - 6 M SPAN (SEMICIRCULAR CHANNEL 62.5 cm, TOP FLAT - ROOF NOT FILLED)

DATA						1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0303					2Φ8 top +2Φ12 bot		2Φ8 top +2Φ12 bot	
Item	Energy MJ/unit					Detail	MJ/unit	Detail	MJ/unit
Channel, Mortar 1: 2 (m)	304.89					1 m	304.89		
Channel, Mortar 1: 2.5 (m)	279.11							1 m	279.11
PCC 1: 2: 4 (valley m^3)	2,063					0.005 m^3/m	10.32	0.005 m^3/m	10.32
SUB TOTAL							315.21		289.42
Miscellaneous	5.0%						15.76		14.47
TOTAL ENERGY MJ/M							**330.97**		**303.90**
TOTAL ENERGY MJ/M^2							**529.54**		**486.23**

NOTES: The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)
Labour time are calculated for 6 m long channels Steel bars = 2 at bottom + 2 on top
Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

EMBODIED ENERGY PER M^2 OF FERROCEMENT FLOOR OR ROOF - 6 M SPAN (SEMICIRCULAR CHANNEL 62.5 cm, TOP FLAT - ROOF FILLED FLAT)

DATA						1: 2 Mix		1: 2.5 Mix	
Section area (m^2)	0.0303					2Φ8 top +2Φ12 bot		2Φ8 top +2Φ12 bot	
Item	Energy MJ/unit					Detail	MJ/unit	Detail	MJ/unit
Channel, Mortar 1: 2 (m)	304.89					1 m	304.89		
Channel, Mortar 1: 2.5 (m)	279.11							1 m	279.11
PCC 1: 2: 4 (valley m^3)	2,063					0.005 m^3/m	10.32	0.005 m^3/m	10.32
Sand filling (m^3)	100					0.045 m^3/m	4.50	0.045 m^3/m	4.50
CSM 1: 3, 2.5 cm (m^3)	2,657					0.016 m^3/m	42.51	0.016 m^3/m	42.51
SUB TOTAL							362.21		336.43
Miscellaneous	5.0%						18.11		16.82
TOTAL ENERGY MJ/M							**380.32**		**353.26**
TOTAL ENERGY MJ/M^2							**608.52**		**565.21**

NOTES

The mesh length is calculated for 5 /3 of the length of the channel (double mesh at both extremities for 1/3 of the length)

Labour time are calculated for 6 m long channels Steel bars = 2 at bottom + 2 on top

Weight steel (Kg/m): 4MS = 0.099 / 6MS = 0.222 / 8TS= 0.395 / 10TS = 0.617 / 12TS = 0.888 / 16TS = 1.579 / 20TS = 2.468

CALCULATION - EARTH, STABILISED RAMMED EARTH AND CSEB

NOTES : B/m^3 = Bag per m^3 - m^3/D= m^3 per day

EMBODIED ENERGY PER M^3 OF EARTH DUG AND SIEVED

DATA		DUG BY HAND TRANSPORT BY HAND ON SITE		DUG BY MACHINE TRANSPORT ON SITE IN TRUCK		DUG BY MACHINE TRANSPORT ON ROAD IN TRUCK					
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit				
People digging(Man/day)	10.04	1 Man	10.0								
People sieving(Man/day)	10.04	1 Man	10.0	50 Man	502.0	50 Man	502.0				
JCB excavator (hour)	214.80			8 Hour	1,718	8 Hour	1,718				
Truck on site (hour)	67.13			8 Hour	537.0						
Truck on road (Km)	11.93					50 Km	596.67				
Number of m^3 per day extracted		2 m^3		100 m^3		100 m^3					
SUB TOTAL			10.0		27.6		28.2				
Miscellaneous	5.0%		0.5		1.4		1.4				
TOTAL ENERGY MJ/M^3			10.54		28.95		29.58				

Notes: 1 JCB = 100 m^3 per day + transport ~ 500 m on site - Truck on road = transport on ~ 50 Km for 8 m^3

EMBODIED ENERGY PER M^3 OF STABILISED RAMMED EARTH WALLS OR FOUNDATION

DATA		SRE (1: 700: 300) (± 3.6%)		SRE (1: 600: 250) (± 4.2%)		SRE (1: 500: 200) (± 5.1%)		SRE (1: 400: 200) (± 5.8%)		SRE (1: 300: 150) (± 7.6%)	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Cement (bag)	230.00	1 Bag	230.0	1 Bag	230.0	1 Bag	230.0	1 Bag	230.0	1 Bag	230.0
Sieved soil / hand (m^3)	28.95	0.7 m^3	20.267	0.6 m^3	17.372	0.5 m^3	14.476	0.4 m^3	11.581	0.3 m^3	8.6858
Sand # 4mm (m^3)	29.58	0.3 m^3	8.8738	0.25 m^3	7.3948	0.2 m^3	5.9158	0.2 m^3	5.9158	0.15 m^3	4.4369
Transport cement MJ/Km	11.93	150 Km	7.458	150 Km	7.458	150 Km	7.458	150 Km	7.458	150 Km	7.458
Transport sand MJ/Km	11.93	20 Km	8.950	20 Km	7.458	20 Km	5.967	20 Km	5.967	20 Km	4.475
Volume rammed in situ		0.667 m^3		0.567 m^3		0.467 m^3		0.4 m^3		0.3 m^3	
SUB TOTAL			413.3		475.9		565.3		652.3		850.2
Miscellaneous	5.0%		20.7		23.8		28.3		32.6		42.5
TOTAL ENERGY MJ/M^3			434.0		499.7		593.6		684.9		892.7

EMBODIED ENERGY PER CSEB 240 (24 x 24 x 9 cm)

DATA		CSEB ~ 4 % soil dug by hand / site		CSEB ~ 5 % soil dug by hand / site		CSEB ~ 5 % soil dug machine/ site		CSEB ~ 6 % soil dug by hand / site		CSEB ~ 8 % soil dug by hand / site	
Item	Energy MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit	Detail	MJ/unit
Cement (Kg)	4.60	13.5 Kg	62.1	16.67 Kg	76.7	16.67 Kg	76.7	21 Kg	96.6	28.5 Kg	131.1
Sieved soil / hand (m^3)	10.54	0.200 m^3	2.1	0.200 m^3	2.1			0.200 m^3	2.1	0.200 m^3	2.1
Sieved soil/machine (m^3)	28.95					0.200 m^3	5.7905				
Sand # 4mm (m^3)	29.58	0.045 m^3	1.3311	0.045 m^3	1.3311	0.045 m^3	1.3311	0.045 m^3	1.3311	0.045 m^3	1.3311
Transport cement MJ/Km	11.93	150 Km	2.014	150 Km	2.486	150 Km	2.486	150 Km	3.133	150 Km	4.251
Transport sand MJ/Km	11.93	20 Km	1.343	20 Km	1.343	20 Km	1.343	20 Km	1.343	20 Km	1.343
Steel press (Kg)	33.33	500 Kg	0.0167	500 Kg	0.0167	500 Kg	0.0167	500 Kg	0.0167	500 Kg	0.0167
No. of blocks per mix		30 B.		31 B.		31 B.		32 B.		32 B.	
SUB TOTAL			68.9		84.0		87.6		104.5		140.1
Miscellaneous	5.0%		3.4		4.2		4.4		5.2		7.0
TOTAL ENERGY MJ/Block			2.41		2.84		2.97		3.43		4.60

Notes: - Auram Press 3000 = ~ 500 Kg with a lifespan of 1,000,000 blocks
- Transport of cement = trucks of 12 tons on 150 Km - Soil is from the site, extracted by machine or by hand.

CALCULATION - CSEB MASONRY

EMBODIED ENERGY OF CSEB MASONRY WALLS WITH PLAIN BLOCK 240

DATA		CSEB WALL WITH 4/4 SIZE BLOCKS 240				CSEB WALL WITH 1/2 SIZE BLOCKS 240				
Block size (L, W, H) (in cm)		24.0	24.0	9.0		24.0	11.5	9.0		
Block weight (average dry)		9.85 Kg =		1,900 Kg/ m^3		4.72 Kg =		1900 Kg/ m^3		
Wall thickness		24.0 cm				11.5 cm				
Mortar thickness		1.0 cm				1.0 cm				
Item	**Energy MJ/unit**	**Detail**			**MJ/unit**	**Detail**				**MJ/unit**
Full blocks	2.97	40 Full blocks per m^2			118.7					
1/2 blocks	1.48					40 Half blocks per m^2				59.4
Mortar SEM 1: 4: 8	687	34.3 Litres per m^2 of wall			23.5	16.4 Litres per m^2 of wall				11.3
Mortar 1: 6: 6 (pointing)	687	2.9 Litres per m^2 of wall			2.0	2.9 Litres per m^2 of wall				2.0
SUB TOTAL PER M^2					144.2					72.6
Miscellaneous	5.0%				7.2					3.6
TOTAL ENERGY MJ/M^2					**151.4**					**76.2**
TOTAL ENERGY MJ/M^3					**631.0**					**662.9**

EMBODIED ENERGY PER M^2 OF CSEB MASONRY VAULTS FOR ROOFS (1 & 2)

DATA		CSEB VAULT FOR ROOF 1 (5m span - 2m rise - 5m long - 11.5cm thick)					CSEB VAULT ROOF 2 (5m span - 1.5m rise - 5m long - 9cm thick)				
Block size (L,W, H) - Mortar thickness		24.0	11.5	5.0	0.2	cm	19.0	9.0	5.0	0.2	cm
Block weight (average dry)		2.62 Kg =			1900 Kg/ m^3		1.62 Kg =			1900 Kg/ m^3	
Vault thickness - Vault length		11.5 cm			500 cm		9.0 cm			500 cm	
Vault span - Vault rise		500 cm			200 cm		500 cm			150 cm	
Item	**Energy MJ/unit**	**Detail**				**MJ/unit**	**Detail**				**MJ/unit**
1/2 block 240 (24 x 11.5 x 5cm)	0.79	79 Blocks per m^2 of shell				62.8					
Block 190 (19 x 9 x 5 cm)	0.49						100 Blocks per m^2 of shell				49.0
Mortar SEM 1: 6: 3 (m^3)	911	3.9 Litres per m^2 of vault				3.5	3.8 Litres per m^2 of vault				3.5
FC shuttering 1: 3 27/20/10 (m)	44.9	10.0 m gutter for 2 side beams 6m				12.5	10.0 m gutter for 2 side beams 6m				12.5
Springer beam PCC 1: 2: 4 (m^3)	2,063	0.63 m^3 (2 side beams+C. beam 6m				36.3	0.63 m^3 (2 side beams+C. beam 6m				36.3
Binding wire (Kg)	46.61	7.5 Kg for 2 side beams 6m				9.7	7.5 Kg for 2 side beams 6m				9.7
Steel Φ 8 TS stirrups @ 20 cm	33.33	19.5 Kg for 2 side beams 6m				18.0	19.5 Kg for 2 side beams 6m				18.0
Steel Φ 8 TS (Kg)	33.33	4.0 Kg (2 side beams 6m, 1Φ8TS)				3.7	11.9 Kg (2 side beams 6m, 3Φ8TS)				11.0
Steel Φ 10 TS (Kg)	33.33	12.3 Kg (2 side beams 6m, 2Φ10TS				11.4					
Steel Φ 12 TS (Kg)	33.33	26.9 Kg (2 side beams 6m, 3Φ12TS				24.9	26.9 Kg (2 side beams 6m, 3Φ12TS				24.9
Steel Φ 10 TS truss rod (Kg)	33.33						12.3 Kg (2 sides truss rods, 2Φ10TS				11.4
Steel Φ 12 TS truss rod (Kg)	33.33	17.9 Kg (2 sides truss rods, 2Φ12TS				16.6					
Transport steel MJ/Km	11.93	150 Km				13.1	150 Km				11.6
SUB TOTAL PER M^2						212.5					188.0
Miscellaneous	5.0%					10.6					9.4
TOTAL ENERGY MJ/M^2 + Ring Beam						**300.1**					**241.7**
TOTAL ENERGY MJ/M^3 + Ring Beam						**2,609.2**					**2,685.0**
TOTAL ENERGY MJ/M^2 (Only shell)						**69.7**					**55.1**
TOTAL ENERGY MJ/M^3 (Only shell)						**605.7**					**612.7**

Notes: - MJ/M^2 and MJ/M^3 + Ring Beam for the masonry vault includes the curvature of the vault + 2 springer beams + 2 sides truss rods

⇒ These values should be taken for the flat area (projected area) of the room = 36 m^2 here.

- MJ/M^2 and MJ/M^3 (Only shell) for the masonry vault are the exact values for the shell for the vault, without ring beam.

⇒ These values should be used for the exact quanitites (area or volume) of the vault shell.

EMBODIED ENERGY PER M^2 OF CSEB MASONRY VAULTS FOR FLOORS (1 & 2												
DATA		**CSEB VAULT FOR FLOOR 1 (5m span - 0.60m rise - 5m long - 7cm thick)**						**CSEB VAULT FOR FLOOR 2 (4m span - 0.4m rise - 5m long - 7cm thick)**				
Block size (L,W, H) - Mortar thickness		14.0	7.0	5.0	0.2	cm		14.0	7.0	5.0	0.2	cm
Block weight (average dry)		0.93 Kg =			1900 Kg/ m^3			0.93 Kg =			1900 Kg/ m^3	
Vault thickness - Vault length		7.0 cm			500 cm			7.0 cm			500 cm	
Vault span - Vault rise		500 cm			60 cm			400 cm			40 cm	
Item	**Energy MJ/unit**	**Detail**				**MJ/unit**		**Detail**				**MJ/unit**
Block Mini (14 x 7 x 5 cm)	0.28	135 Blocks per m^2 of shell				38.0						
Block Mini (14 x 7 x 5 cm)	0.28							135 Blocks per m^2 of shell				38.0
Mortar SEM 1: 6: 3 (m^3)	911	4.0 Litres per m^2 of vault				3.6		4.0 Litres per m^2 of vault				3.6
FC shuttering 1: 3 27/20/10 (m)	44.9	10.0 m gutter for 2 side beams 5m				12.5		10.0 m gutter for 2 side beams 5m				12.5
Springer beam PCC 1: 2: 4 (m^3	2,063	0.63 m^3 (2 side beams+C. beam 5m				36.3		0.61 m^3 (2 side beams+C. beam 4m				35.2
Binding wire (Kg)	46.61	7.5 Kg for 2 side beams 5m				9.7		7.5 Kg for 2 side beams 5m				9.7
Steel Φ 8 TS stirrups @ 20 cm	33.33	19.5 Kg for 2 side beams 5m				18.0		19.5 Kg for 2 side beams 5m				18.0
Steel Φ 8 TS (Kg)	33.33	11.9 Kg (2 side beams 5m, 3Φ8TS)				11.0		11.9 Kg (2 side beams 5m, 3Φ8TS)				11.0
Steel Φ 10 TS (Kg)	33.33											
Steel Φ 12 TS (Kg)	33.33	26.9 Kg (2 side beams 5m, 3Φ12TS				24.9		26.9 Kg (2 side beams 5m, 3Φ12TS				24.9
Steel Φ 10 TS truss rod (Kg)	33.33	12.3 Kg (2 sides truss rods, 2Φ10TS				11.4		9.9 Kg (2 sides truss rods, 2Φ10TS				9.1
Steel Φ 12 TS truss rod (Kg)	33.33											
Transport steel MJ/Km	11.93	150 Km				11.6		150 Km				11.3
SUB TOTAL PER M^2						177.1						173.4
Miscellaneous	5.0%					8.9						8.7
TOTAL ENERGY MJ/M^2 + Ring Beam						**200.8**						**194.9**
TOTAL ENERGY MJ/M^3 + Ring Beam						**2,868.2**						**2,784.4**
TOTAL ENERGY MJ/M^2 (Only shell)						**43.7**						**43.7**
TOTAL ENERGY MJ/M^3 (Only shell)						**624.6**						**624.6**

Notes: - MJ/M^2 and MJ/M^3 + Ring Beam for the masonry vault includes the curvature of the vault + 2 springer beams + 2 sides truss rods

⇒ These values should be taken for the flat area (projected area) of the room = 36 m^2 here.

- MJ/M^2 and MJ/M^3 (Only shell) for the masonry vault are the exact values for the shell for the vault, without ring beam.

⇒ These values should be used for the exact quanitites (area or volume) of the vault shell.

EMBODIED ENERGY PER M OF COMPOSITE RING BEAMS 240													
DATA		**COMPOSITE RING BEAM 240 - 4/4 BLOCKS 2 bars Φ 8 TS + stirrups Φ 6 MS @ 25 c/c**							**COMPOSITE RING BEAM 240 - 1/2 BLOCKS 1 bar Φ 12 TS**				
Block size (L, W, H) (in cm)			24.0	24.0	9.0					24.0	11.5	5.0	
Ring beam width		24.0 cm							11.5 cm				
Void U shape		43%							29%				
Block weight (average dry)		5.61 Kg =				1900 Kg/ m^3			1.86 Kg =			1900 Kg/ m^3	
CSEB 240 plain (MJ/Unit)	2.97												
CSEB 240 1/2 (MJ/Unit)	1.48												
Item	**Energy MJ/unit**	**Detail**					**MJ/unit**		**Detail**				**MJ/unit**
U shape 4/4 blocks (Unit)	1.69	4 U blocks per m					6.8						
U shape 1/2 blocks (Unit)	1.05								4 U blocks per m				4.2
Mortar CSM 1: 3 (m^3)	2,657	0.50 Litres per m of ring beam					1.3		0.30 Litres per m of ring beam				0.8
PCC 1: 2: 4 (m^3)	2,063	2.34 Litres per m of ring beam					4.8		0.80 Litres per m of ring beam				1.7
Binding wire (Kg)	46.61	0.05 Kg per m of ring beam					2.3						
Steel stirrups Φ 6 MS @ 25 c/c	33.33	0.20 Kg per m of ring beam					6.7						
Steel Φ 8 TS (Kg)	33.33	0.80 Kg per m of ring beam					26.7						
Steel Φ 12 TS (Kg)	33.33								0.90 Kg per m of ring beam				30.0
Transport steel MJ/Km	11.93	150 Km					0.2		150 Km				0.1
DPC Mortar CSM 1: 3 (m^3)	2,790	2.50 Litres per m of ring beam					7.0		1.15 Litres per m of ring beam				3.2
SUB TOTAL PER M							55.7						40.0
Miscellaneous	5.0%						2.8						2.0
TOTAL ENERGY MJ/M							**58.5**						**42.0**

EMBODIED ENERGY PER M OF COMPOSITE BEAMS 240, SINGLE HEIGHT													
DATA		**COMP. BEAM SINGLE HEIGHT 240 - 4/4 B 2 bars Φ 12 TS + stirrups Φ 6 MS @ 25 c/c**							**COMP. BEAM SINGLE HEIGHT 240 - 1/2 B 1 bar Φ 16 TS**				
Block size (L, W, H) (in cm)			24.0	24.0	9.0					24.0	11.5	5.0	
Ring beam width		24.0 cm							11.5 cm				
Void U shape		43%							29%				
Block weight (average dry)		2.80 Kg =				1900 Kg/ m^3			3.10 Kg =			1900 Kg/ m^3	
CSEB 240 plain (MJ/Unit)	2.97												
CSEB 240 1/2 (MJ/Unit)	1.48												
Item	**Energy MJ/unit**	**Detail**					**MJ/unit**		**Detail**				**MJ/unit**
U shape 4/4 blocks (Unit)	1.69	4 U blocks per m					6.8						
U shape 1/2 blocks (Unit)	1.05								4 U blocks per m				4.2
Mortar CSM 1: 3 (m^3)	2,657	0.50 Litres per m of ring beam					1.3		0.30 Litres per m of ring beam				0.8
PCC 1: 2: 4 (m^3)	2,063	2.34 Litres per m of ring beam					4.8		0.80 Litres per m of ring beam				1.7
Binding wire (Kg)	46.61	0.05 Kg per m of ring beam					2.3						
Steel stirrups Φ 6 MS @ 25 c/c	33.33	0.20 Kg per m of ring beam					6.7						
Steel Φ 12 TS (Kg)	33.33	1.80 Kg per m of ring beam					60.0						
Steel Φ 16TS (Kg)	33.33								1.60 Kg per m of ring beam				53.3
Transport steel MJ/Km	11.93	150 Km					0.3		150 Km				0.2
SUB TOTAL PER M							82.2						60.2
Miscellaneous	5.0%						4.1						3.0
TOTAL ENERGY MJ/M							**86.3**						**63.2**

EMBODIED ENERGY PER M OF COMPOSITE BEAMS 240, DOUBLE HEIGH			
DATA		**COMPOSITE BEAM DOUBLE HEIGHT 240 2 Φ8TS top, 2Φ12TS bot, stirrups @ 25 c/c**	**COMPOSITE BEAM DOUBLE HEIGHT 240 2 Φ12TS top, 2Φ12TS bot, stirrups @ 25 c/c**
Block size (L, W, H) (in cm)		24.0 24.0 9.0	24.0 11.5 5.0
Ring beam width		24.0 cm	24.0 cm
Void U shape		43%	43%
CSEB 240 plain (MJ/Unit)	2.97		
Item	**Energy MJ/unit**	**Detail** / **MJ/unit**	**Detail** / **MJ/unit**
U shape 4/4 blocks (Unit)	1.69	8 U blocks per m / 13.5	8 U blocks per m / 13.5
Mortar CSM 1: 3 (m^3)	2,657	1.60 Litres per m of ring beam / 4.3	1.60 Litres per m of ring beam / 4.3
PCC 1: 2: 4 (m^3)	2,063	4.68 Litres per m of ring beam / 9.7	4.68 Litres per m of ring beam / 9.7
Binding wire (Kg)	46.61	0.10 Kg per m of ring beam / 4.7	0.10 Kg per m of ring beam / 4.7
Steel stirrups Φ 6 MS @ 25 c/c	33.33	0.60 Kg per m of ring beam / 20.0	0.60 Kg per m of ring beam / 20.0
Steel Φ 8 TS (Kg)	33.33	0.80 Kg per m of ring beam / 26.7	
Steel Φ 12 TS (Kg)	33.33	1.80 Kg per m of ring beam / 60.0	3.60 Kg per m of ring beam / 120.0
Transport steel MJ/Km	11.93	150 Km / 0.5	150 Km / 0.6
SUB TOTAL PER M		139.3	172.7
Miscellaneous	5.0%	7.0	8.6
TOTAL ENERGY MJ/M		**146.2**	**181.4**

EMBODIED ENERGY PER M OF COMPOSITE BEAMS 240, TRIPLE HEIGHT			
DATA		**COMPOSITE BEAM TRIPLE HEIGHT 240 2 Φ10TS top, 2Φ12TS bot, stirrups @ 25 c/c**	**COMPOSITE BEAM TRIPLE HEIGHT 240 2 Φ12TS top, 2Φ12TS bot, stirrups @ 25 c/c**
Block size (L, W, H) (in cm)		24.0 24.0 9.0	24.0 11.5 5.0
Ring beam width		24.0 cm	24.0 cm
Void U shape		43%	43%
Item	**Energy MJ/unit**	**Detail** / **MJ/unit**	**Detail** / **MJ/unit**
CSEB 240 plain (Unit)	2.97	4 U blocks per m / 11.9	4 U blocks per m / 11.9
U shape 4/4 blocks (Unit)	1.69	8 U blocks per m / 13.5	8 U blocks per m / 13.5
Mortar CSM 1: 3 (m^3)	2,657	2.20 Litres per m of ring beam / 5.8	2.20 Litres per m of ring beam / 5.8
PCC 1: 2: 4 (m^3)	2,063	2.34 Litres per m of ring beam / 4.8	2.34 Litres per m of ring beam / 4.8
Binding wire (Kg)	46.61	0.10 Kg per m of ring beam / 4.7	0.10 Kg per m of ring beam / 4.7
Steel stirrups Φ 6 MS @ 25 c/c	33.33	0.80 Kg per m of ring beam / 26.7	0.80 Kg per m of ring beam / 26.7
Steel Φ 10 TS (Kg)	33.33	1.25 Kg per m of ring beam / 41.7	
Steel Φ 12 TS (Kg)	33.33	1.80 Kg per m of ring beam / 60.0	3.60 Kg per m of ring beam / 120.0
Transport steel MJ/Km	11.93	150 Km / 0.6	150 Km / 0.7
SUB TOTAL PER M		169.7	188.1
Miscellaneous	5.0%	8.5	9.4
TOTAL ENERGY MJ/M		**178.1**	**197.5**

EMBODIED ENERGY PER M HIGH OF COMPOSITE COLUMNS 240 & 290					
DATA		**COMPOSITE COLUMN 240 3 Φ 12 TS, stirrups @ 20 c/c**		**COMPOSITE COLUMN 290 4 Φ 12 TS, stirrups @ 20 c/c**	
CSEB 240 plain (MJ/Unit)	2.97				
Volume plain block 240 (litres)	5.184				
Volume round block 240 (litres)	3.500				
Volume round block 290 (litres)	5.446				
Item	**Energy MJ/unit**	**Detail**	**MJ/unit**	**Detail**	**MJ/unit**
Round block 240 (Unit)	2.00	10 U blocks per m high	20.0		
Round block 290 (Unit)	3.12			10 U blocks per m high	31.2
Mortar CSM 1: 3 (m^3)	2,657	4.75 Litres per m high of column	12.6	7.20 Litres per m high of column	19.1
PCC 1: 2: 4 (m^3)	2,063	5.72 Litres per m high of column	11.8	5.00 Litres per m high of column	10.3
Binding wire (Kg)	46.61	0.05 Kg per m high of column	2.3	0.05 Kg per m high of column	2.3
Steel stirrups Φ 6 MS @ 20 c/c	33.33	0.38 Kg per m high of column	12.7	0.85 Kg per m high of column	28.3
Steel Φ 12 TS (Kg)	33.33	2.70 Kg per m high of column	90.0	3.60 Kg per m high of column	120.0
Transport steel MJ/Km	11.93	150 Km	0.5	150 Km	0.7
SUB TOTAL PER M			149.9		212.0
Miscellaneous	5.0%		7.5		10.6
TOTAL ENERGY MJ/M			**157.4**		**222.6**

CALCULATION - FIRED BRICKS

EMBODIED ENERGY IN COUNTRY FIRED BRICKS UNIT - 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/M^3						6,122.5					

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

EMISSIONS OF COUNTRY FIRED BRICKS AND KILN FIRED BRICKS UNIT - (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 kiln 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

EMBODIED ENERGY OF FIRED BRICKS MASONRY

DATA		COUNTRY FIRED BRICK PUDUCHERRY = CFB					KILN FIRED BRICK AVERAGE = KFB				
Brick size (L, W, H) (in cm)			23.0	10.0	7.0			22.0	10.0	7.0	
Brick weight (average dry)		2.80 Kg = 1739 Kg/ m^3					2.77 Kg = 1799 Kg/ m^3				
Wall thickness		23.0 cm					22.0 cm				
Mortar thickness		1.5 cm					1.5 cm				
Item	Energy MJ/unit	Detail				MJ/unit	Detail				MJ/unit
CFB Bricks delivered (50 Km)	10.006	102 bricks per m^2 x 1.10 waste				1,122.7					
Kiln fired bricks (150 Km)	3.905						102 bricks per m^2				398.3
Mortar CSM 1: 4	1,984	69.7 Litres per m^2 of wall				138.3	65.8 Litres per m^2 of wall				130.6
Mortar 1: 4 (pointing)	1,984	8.7 Litres per m^2 of wall				17.3	8.5 Litres per m^2 of wall				16.8
SUB TOTAL						1,278.4					545.6
Miscellaneous	5.0%					63.9					27.3
TOTAL ENERGY MJ/M^2						1,342.3					572.9
TOTAL ENERGY MJ/M^3						5,836.1					2,604.2