Bureau of Energy Efficiency

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ANGAN
Augmenting Nature by Green Affordable New-habitat

A Courtyard for Revolutionary Change in Building Energy Efficiency

An International Conference on Building Energy Efficiency

9th-11th September, 2019 | Hotel The LaLiT, New Delhi

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THIS PRESENTATION WAS SHARED BY

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FOR THE SESSION:

"Embodied Energy and the Life Cycle Approach"

DURING ANGAN 2019

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International Conference on

Building Energy Efficiency

Augmenting Nature by Green Affordable New – Habitat (ANGAN)

Life Cycle Energy Assessment of the Building Stock in India: Current Practices & the Way Forward

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September 11, 2019

Sequence of the Presentation

CSIR - CBRI

01 **Background**

CSIR-CBRI & Domains of Research

02 **Life Cycle Energy Analysis (LCEA)**

State - of - the – Art Current Practices

03 **Examples**

Computing EE, LCE & the Way Forward

CSIR - CBRI

Established : 1947

The Institute has been helping the Government and Building Material industries in finding appropriate and economical solutions to the problems of:

- Rural & Urban Housing
- Energy Efficient Buildings & Conservation
- Building Materials: Waste - to - Wealth
- Fire Hazards
- Structural & Foundation
- Disaster Mitigation etc.

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Domains of Research

	Building Materials & Housing	Energy (Renewable)	Vernacular and Heritage	Smart Cities & Infrastructure
Build Energy Effici. + Sust.	Building Materials & Housing	Energy (Renewable)	Vernacular and Heritage	Smart Cities & Infrastructure
Research Areas	Climate adaptive designs, day lighting energy-efficient & advance materials & technologies, comfort Sustainability	Solar Thermal Applications for Heating & Cooling, Energy Storage	Interventions in Traditional Building Systems & Blending Traditional with Alternatives	Intelligent buildings Sensors & Controls, Green retrofitting, Structural Health Monitoring & Life Extn., Waste management
Relevant GoI Initiatives	Housing for All -2022 Waste - to - Wealth	Energy Security E.E. Buildings Solar Mission	Rural Housing	Energy Security Smart Cities & Villages IoT, AI

Recent Research Outcomes:

- App for Integrating Daylight with Artificial Lighting for India & United Kingdom – Relevant to ANGAN;
- App for Determining the Appropriate Thickness of Glass used in buildings in different regions – WZs of the country;
- Standardized / Typology EWS Designs for different climatic regions – Confined Masonry Technique, Modular Coordination;
- Pahal – A Compendium of Rural Housing Typologies for different regions of the country –Designs, Materials & Tech. , Costing etc.
- New Classification of Climates – (Under Progress)

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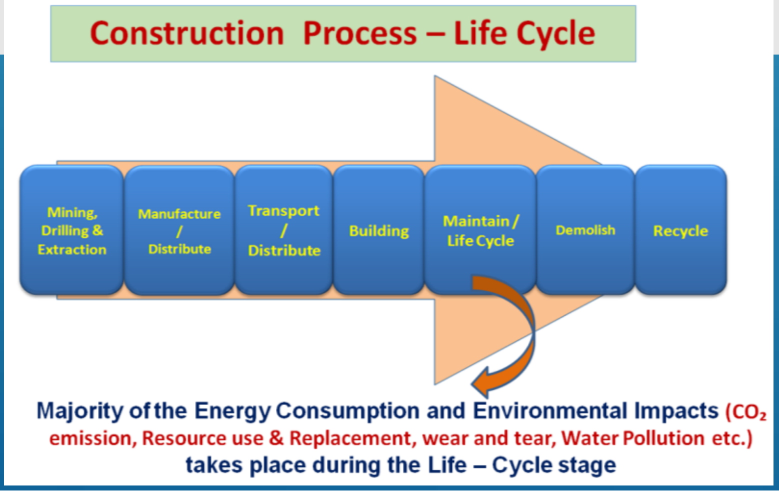
Relevance:

LCA, & LCEA are the environmental indicators of construction industry leading to sustainability in construction.

Life Cycle Energy Analysis (LCEA)

State - of - the - Art Current Practices

- Traditionally, local building materials with low energy costs and low environmental impact were used.
- At present, materials such as cement, steel, aluminium, concrete , glass, and PVC etc. are used, increasing the Embodied Energy and Environmental Impacts.



Life Cycle Energy Analysis (LCEA)

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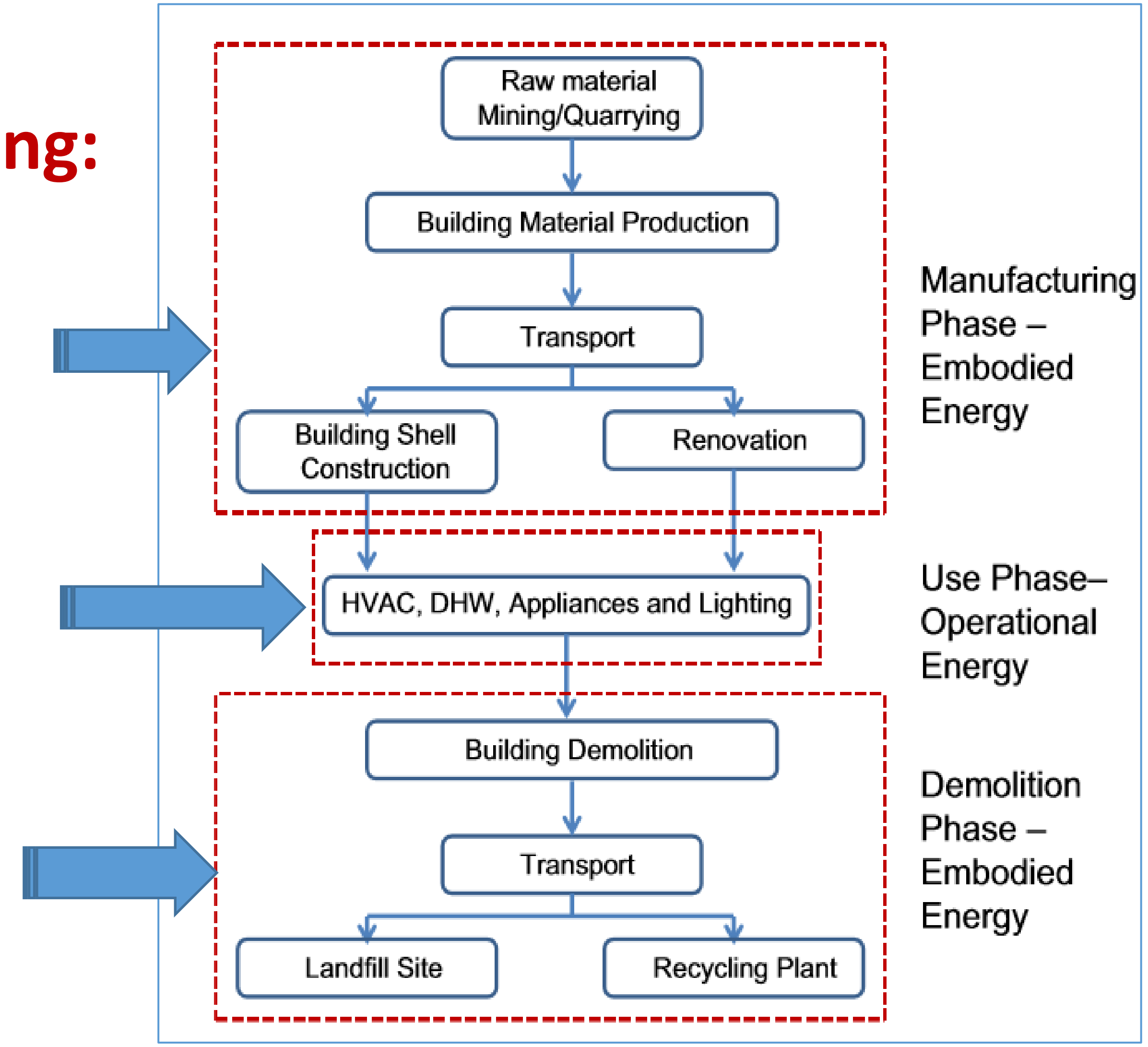
Life cycle energy (LCE) of a building is the sum of all the energies incurred in its life cycle. It is thus expressed as:

$$LCE = EE_i + EE_r + (OE_{\text{Building Life}}) + DE$$

Analysis that accounts for all energy inputs to a building in its life cycle & energy use of the following:

- **Manufacture, and Renovation.** Manufacture phase includes manufacturing and transportation of building materials and technical installations used in erection and renovation of the buildings.
- **Operation Phase -** Activities related to the use of the buildings, over its life span, including maintaining comfort condition inside buildings, water use and powering appliances etc.
- **Demolition Phase -** destruction of a building and transportation of dismantled materials to landfill sites and/or recycling plants.



Life Cycle Energy (LCE)

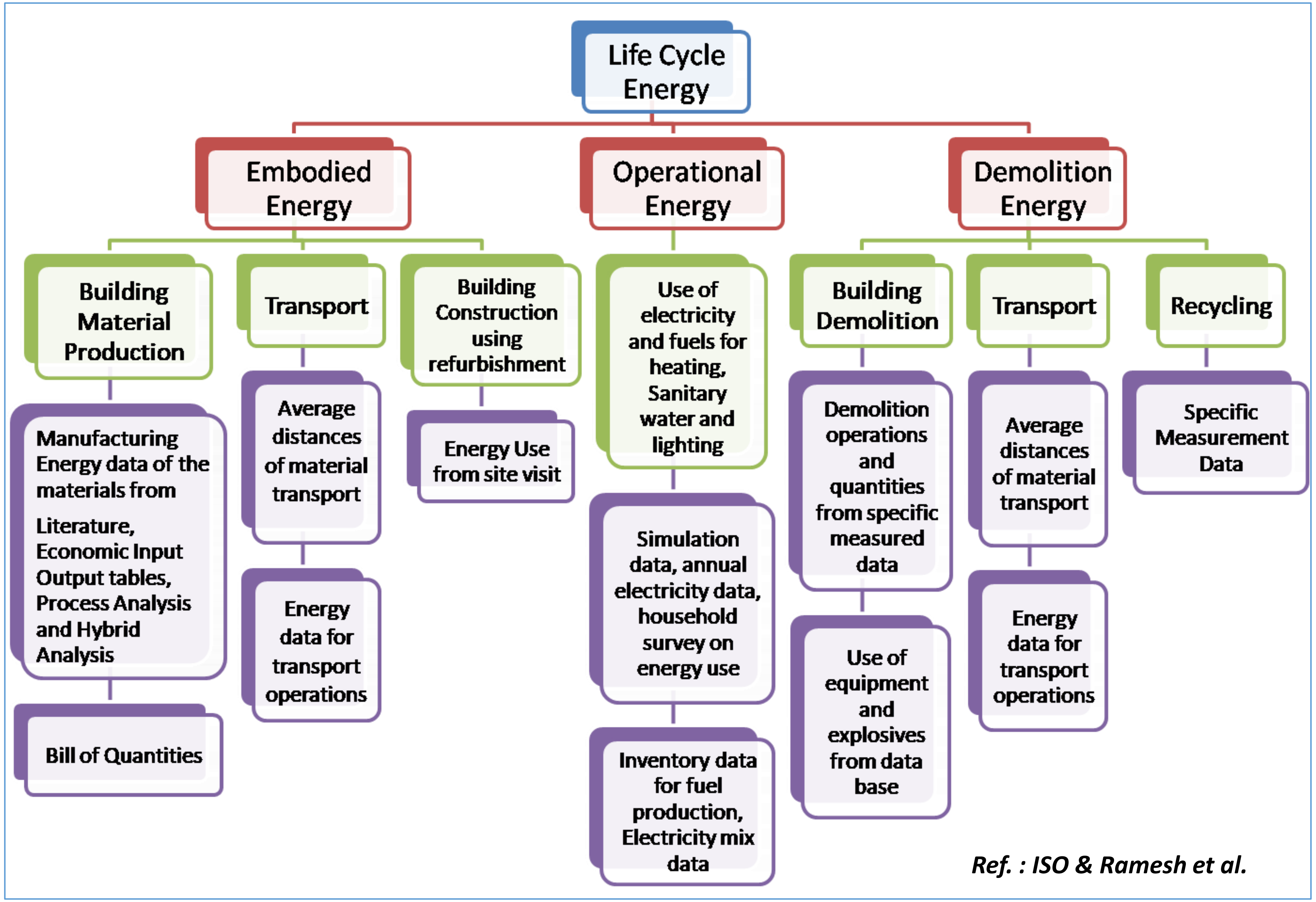
$$LCE = EE_i + EE_r + (OE_{Building\ Life}) + DE$$

CSIR - CBRI

LCE components:

- Embodied Energy
- Operating Energy
- Demolition Energy

Building Life: 20-100years or more



Life Cycle Energy Analysis (LCEA)

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State -of -the- Art:

Sr. No.	Studies	Country	Year	Findings
1.	Life Cycle Assessment of German Energy Scenarios Journal : Progress in Life Cycle Assessment	Germany (Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT)	2018	➢ LCA results are often sensitive to the impact of electricity mix. ➢ Further research is needed to investigate & analyze the impact of future energy scenarios within additional impact categories. ➢ Also the current LCA models work with background data representing the present technology of power generation systems. ➢ The compliance with future limit values for emissions and the environmental impact of future energy carriers are only partly taking into account. The consideration of technological developments of power generation systems for estimating the impact of future energy scenarios is not yet adequately reflected. ➢ Future research - focus on the deviations of the LCA results and how to build a LCA model with smaller uncertainties.

Life Cycle Energy Analysis (LCEA)

CSIR - CBRI

State -of -the- Art :

Sr. No.	Studies	Country	Year	Findings
2.	**Life cycle energy analysis of buildings: An overview** Journal : Energy and Buildings	India	2010	➢ Building's LCE demand can be reduced by reducing its 'OE' significantly through use of Passive and Active Technologies, even if it leads to a slight increase in embodied energy.

Life Cycle Energy Analysis (LCEA)

CSIR - CBRI

$LCE = EE_i + EE_r + (OE_{Building\ Life}) + DE$

LCE analyses - Residential and Office buildings indicate:
'OE' (≈ 80 – 85%) and 'EE' (≈ 15 - 20%)
significant contributors to building's LCE use.
'DE' & other process energy has negligible / little share, but in case of C&D waste utilization, may be (≈ 2- 3%)

- LCE (primary) requirements:
  - Conventional Res. Buildings : 150 – 400kWh/m^2 per year
  - Office Buildings : 250 – 550kWh/m^2 per year

  (Survey by CBRI – about 500 R & O buildings - Urban)

BLCE demand can be reduced by :

- Reducing its 'OE' significantly through use of 'Passive' and 'Active' technologies, even if it leads to a slight increase in Embodied Energy.

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Life Cycle Energy (LCE)

$$LCE = EE_i + EEr + (OE_{Building\ Life}) + DE$$

Building's Initial Embodied Energy (EE_i):

The energy incurred for initial construction of the building, expressed as:

$$EE_i = \sum m_i M_i + E_c$$

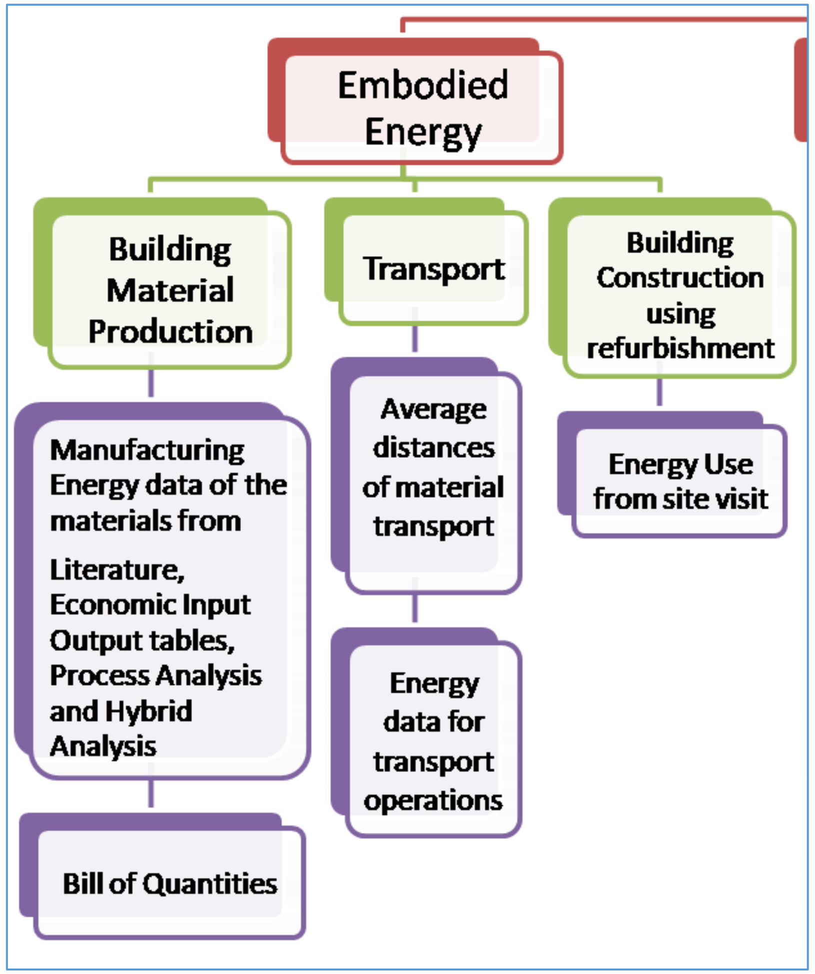
Where,

EE_i = Initial embodied energy of a building;

m_i = Quantity of building material;

M_i = Energy content of material per unit quantity;

E_c = Energy used at site for erection/construction of the building.



EE largely depends on the type of materials used, primary energy sources, and efficiency of conversion processes in making building materials and products

Life Cycle Energy (LCE)

$LCE = EE_i + EE_r + (OE_{\text{Building Life}}) + DE$

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Recurring Embodied Energy (EE_r)

- large variety of materials used in building construction – Some may have life span less than that of a building & replaced to rehabilitate the building.
- Buildings also require regular annual maintenance. The energy incurred for such repair and replacement (rehabilitation) needs to be accounted during the entire life of the buildings.

The sum of the energy embodied in the material used for the rehabilitation and maintenance – EE_r can be expressed as:

$$EE_r = \sum m_i M_i[(L_b/L_{mi}) - 1]$$

Where,

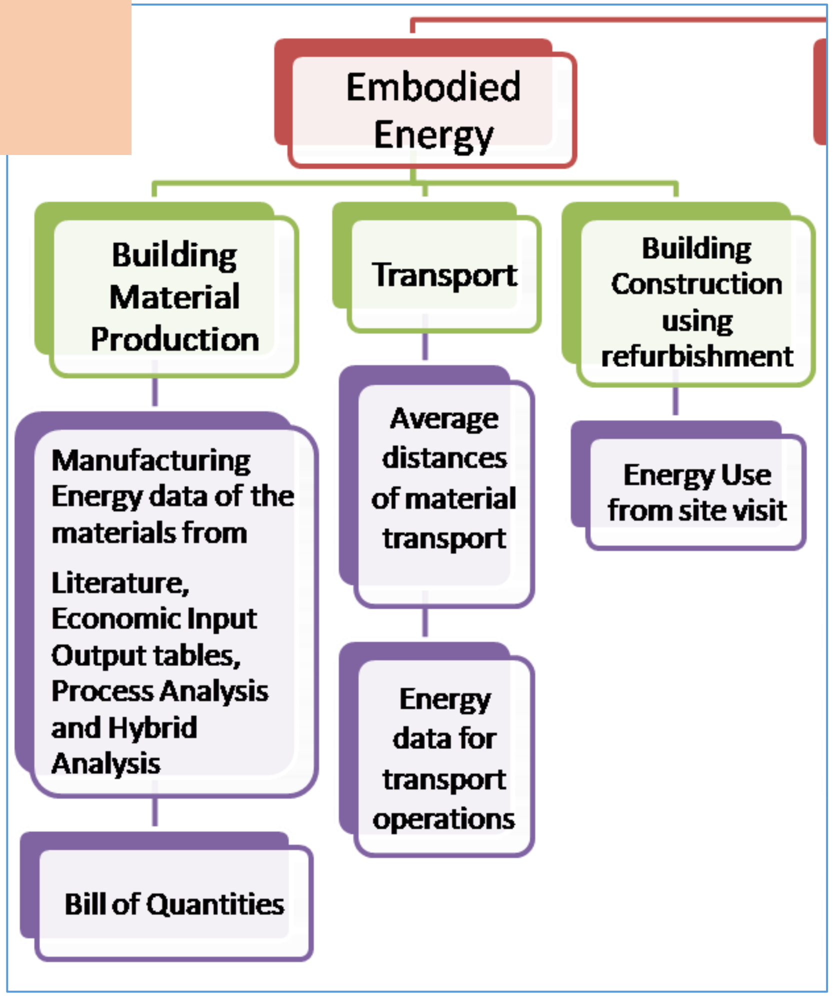
EE_r = Recurring embodied energy of the building;

m_i = Quantity of building material;

M_i = Energy content of material per unit quantity;

L_b = Life span of the building;

L_{mi} = Life span of the material.



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Life Cycle Energy (LCE)

$$LCE = EE_i + EEr + (OE_{\text{Building Life}}) + DE$$

Operating Energy (OE) - The energy required for maintaining comfort conditions and day-to-day maintenance of the buildings –

- The energy for HVAC, domestic hot water, lighting, & for running other appliances.

OE – Varies as per climatic conditions, on the level of comfort required, and operating schedules. Operating energy in the life span of the building is expressed as:

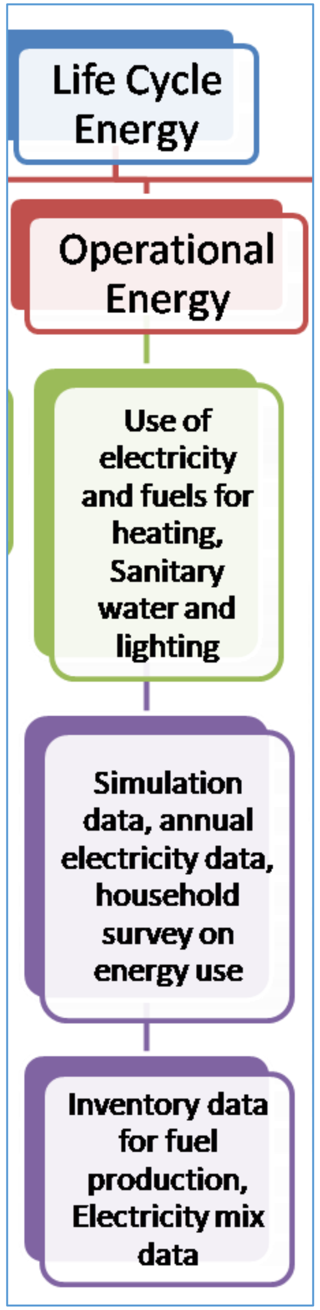
$$OE = E_{OA} L_b$$

Where,

OE = Operating energy in the life span of the building;

E_{OA} = Annual operating energy;

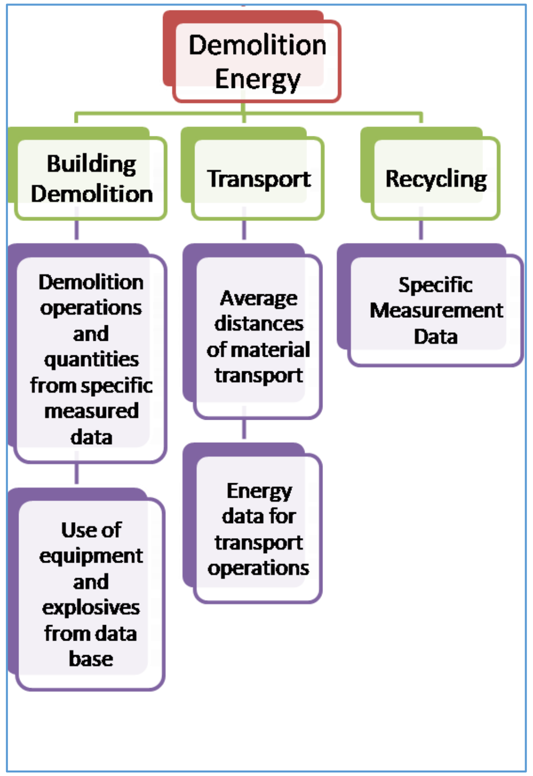
L_b = Life span



Life Cycle Energy (LCE)

$LCE = EE_i + EEr + (OE_{\text{Building Life}}) + DE$

Demolition Energy (DE) – At the end of Buildings' Service Life, energy is required to demolish the building and transporting the waste material to landfill sites and/or recycling plants.



'DE' is expressed as:

$$DE = E_D + E_T$$

Where,

DE = Demolition energy of the building;

E_D = Energy incurred for destruction / demolishing the building;

E_T = Energy used for transporting the waste materials.

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01

Background

CSIR-CBRI & Domains of Research

02

Life Cycle Energy Analysis (LCEA)

Define & State - of - the - Art

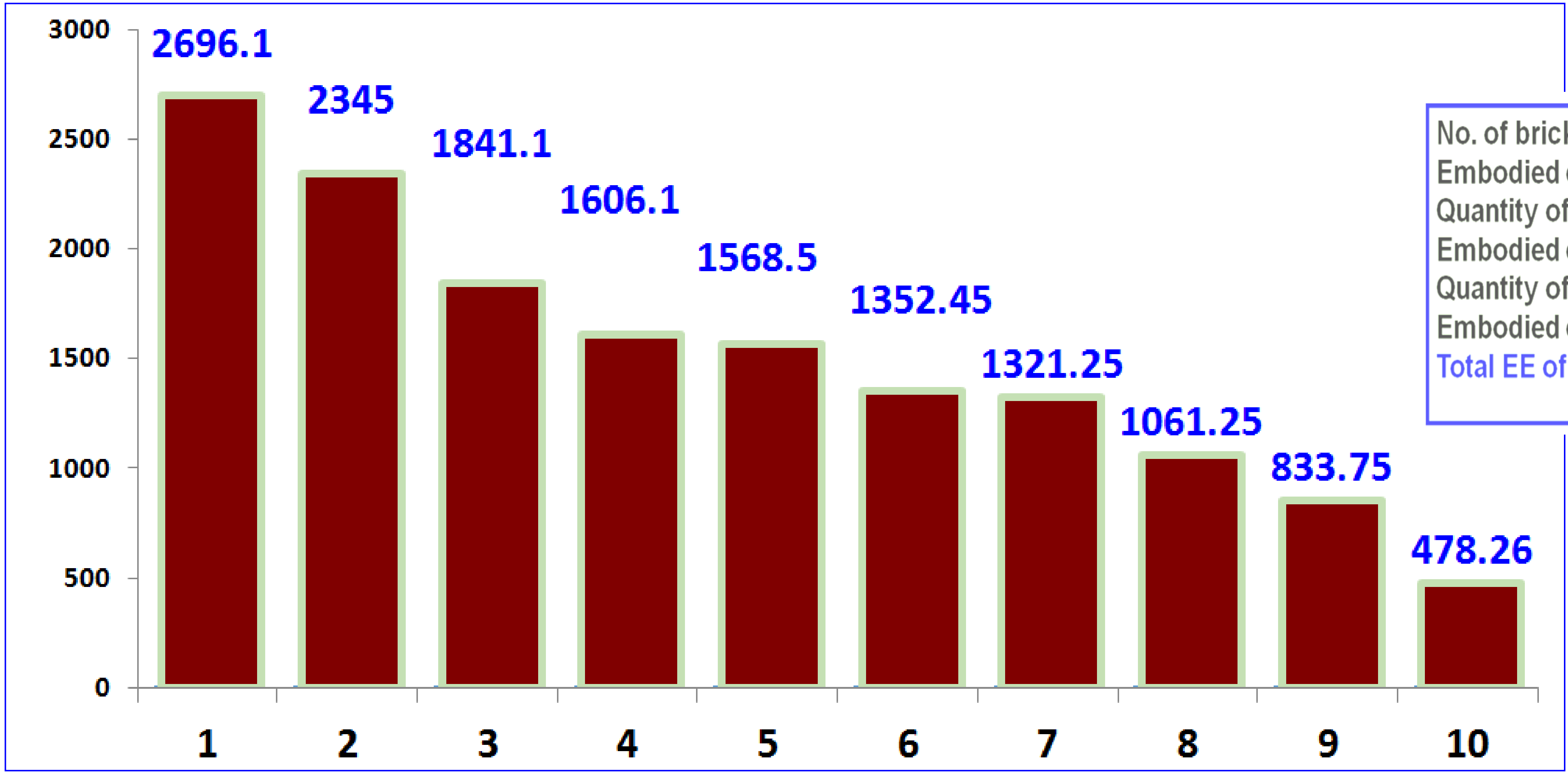
03

Examples

Computing EE, LCE & the Way Forward

EE of Different Types of Walls (MJ)

CSIR - CBRI



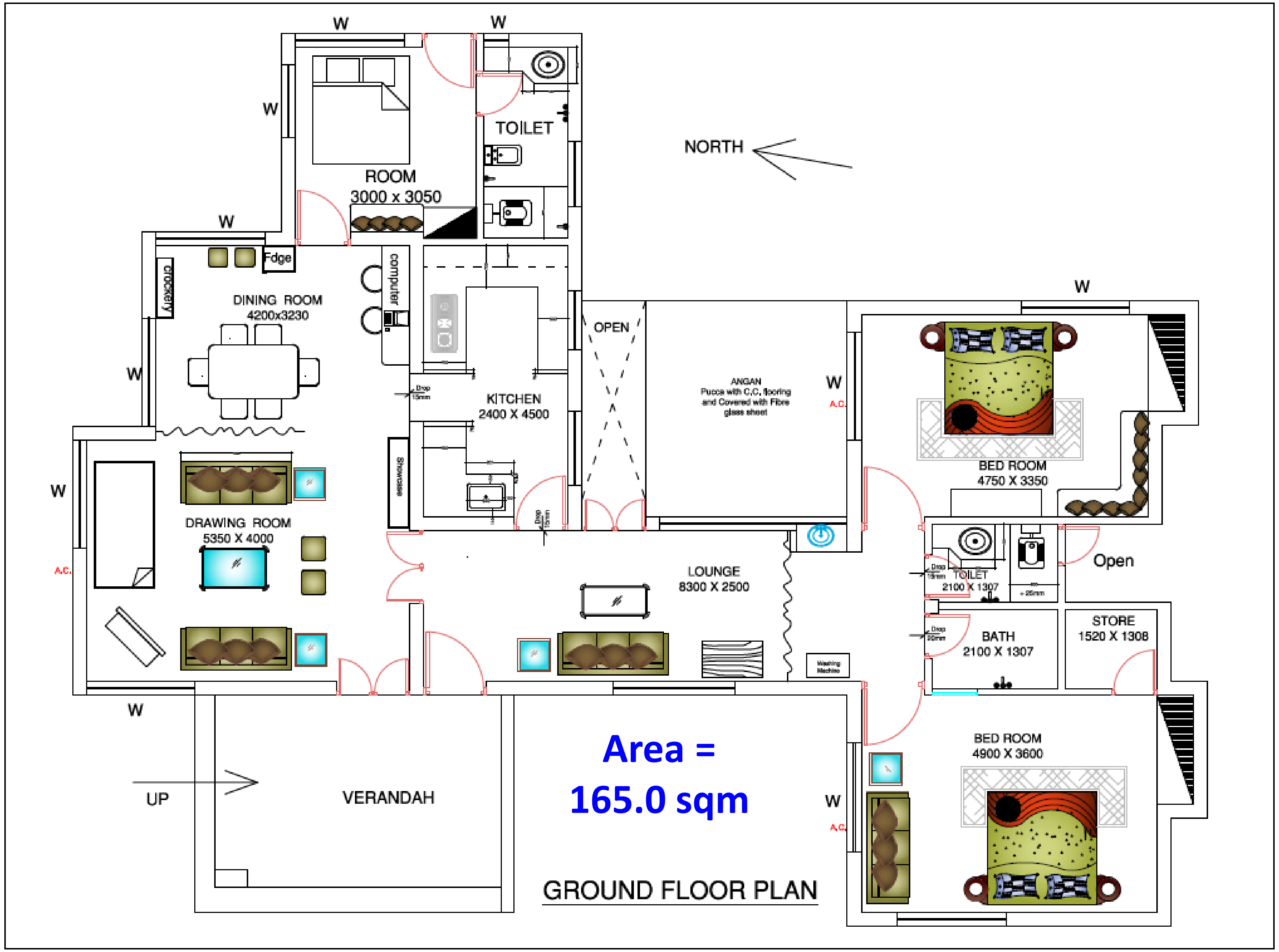
No. of bricks for per cu.m.		= 500 (approx.)
Embodied energy of brick	2.32 x 500	= 1160 MJ
Quantity of cement for per cu.m.		= 60 kg
Embodied energy of cement	= 60 x6.7	= 402 MJ
Quantity of sand for per cu.m.		= 0.252 cu.m.
Embodied energy of sand	= 0.252 x 175	= 44.1 MJ
Total EE of Clay Fly Ash Brick Masonry		= 1606.1 MJ

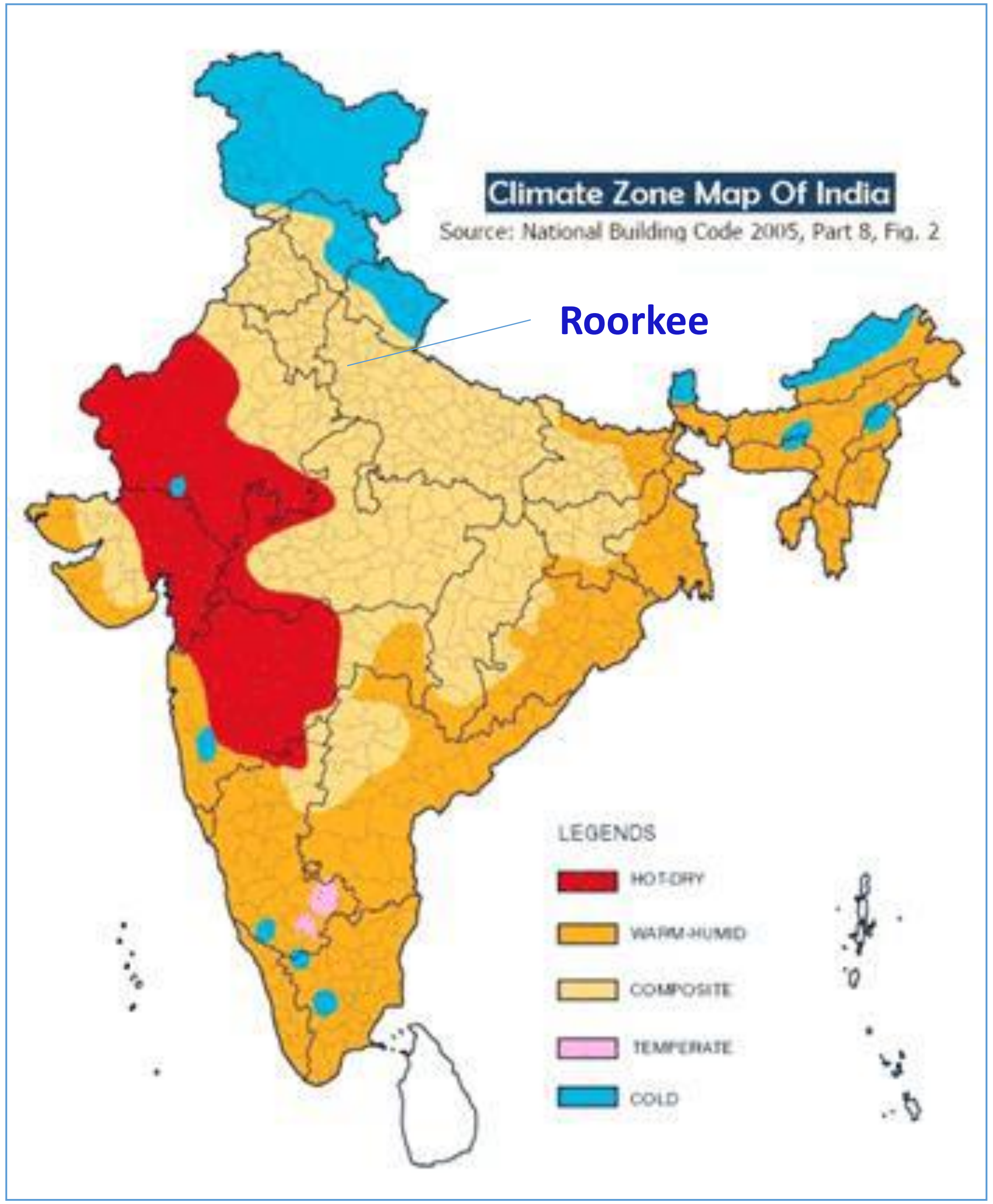
Android App : LCE (Under Progress)

1. Burnt clay brick wall	2. Wire cut brick wall	3. Sand lime brick wall (CSIR – CBRI)	4. Clay fly ash brick wall (CSIR – CBRI)	5. Cement concrete hollow block wall (CSIR – CBRI)
6. Course Rubble stone wall	7. Concrete block Wall (CSIR – CBRI)	8. Fal – G – block wall	9. Aerated concrete block wall (CSIR – CBRI)	10. Compressed stabilized earth block wall

Life Cycle Energy of a House: Case Study Roorkee

CSIR - CBRI





BoQ of the House - Civil

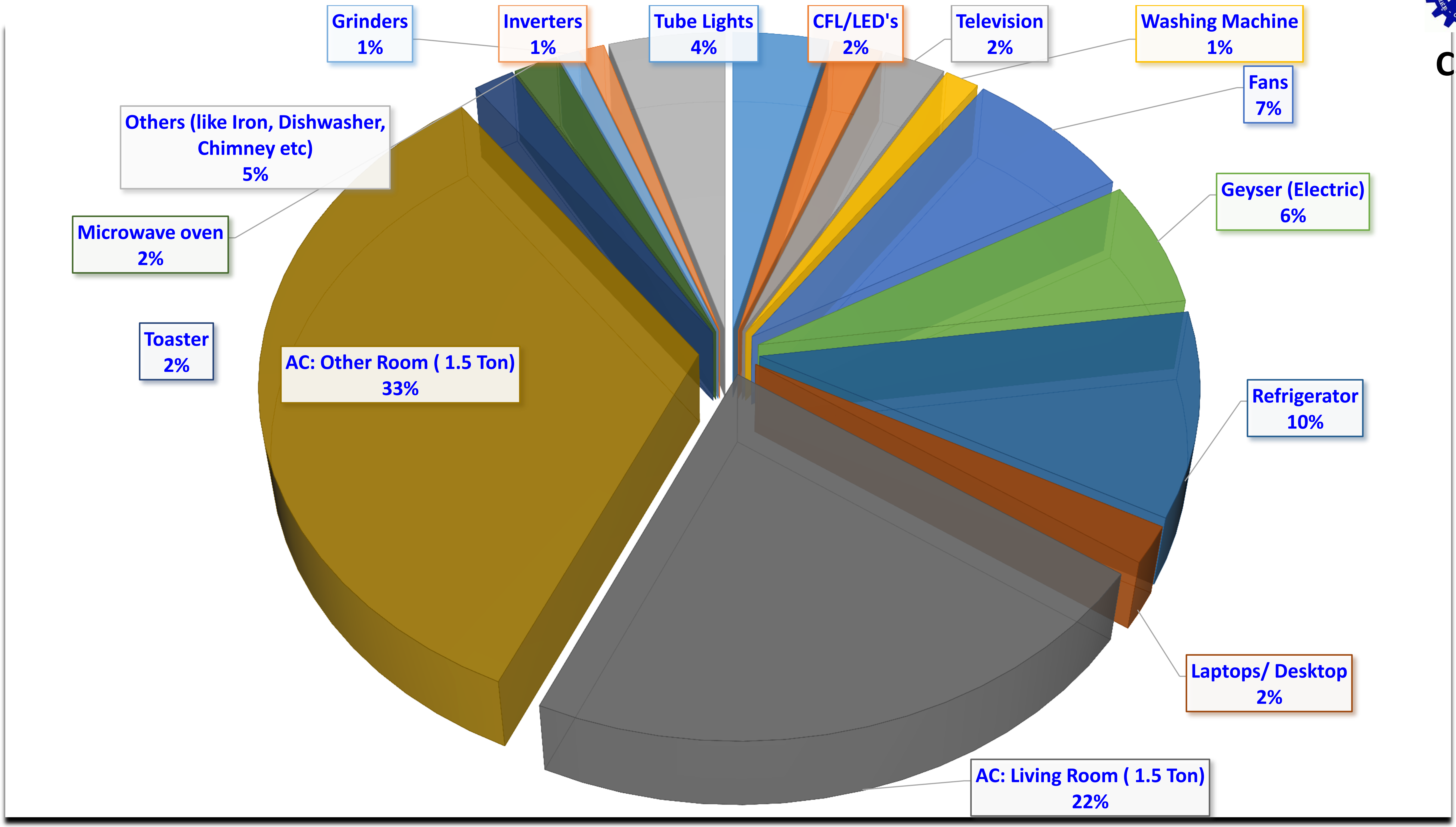
Material	Embodied Energy of Material	Life Span of Material	Life Span of Building*	EE_i (MJ)	EE_r (MJ)	OE (MJ)
P.C.C in foundation (1:5:10)	1561.38	100 Years	100 Years	14748	-	1941975
R.C.C work (1:1.5:3)	543.36	100 Years	100 Years	7301.7	-	
Mild steel Reinforcement in R.C.C	32	100 Years	100 Years	6944.355	-	
Brick work in plinth	1606.1	100 Years	100 Years	31948.97	-	
12 mm Internal Plaster work (1:6)	24.75	60 Years	100 Years	6944.355	4629.57	
15mm Outer plaster work (1:4)	30.94	40 Years	100 Years	6419.741	6419.7406	
6 mm Ceiling plaster work (1:4)	20.6	60 Years	100 Years	3528.78	2352.52	
Flooring C.C.	65	30 Years	100 Years	9421.5	16107.91	
Flooring Vitrified Tiles	40.3	50 Years	100 Years	-	4629.57	
Wood frames (100×60)	34650	50 Years	100 Years	21240.45	-	
Window shutter (Glazed)	41340	50 Years	100 Years	261200	-	
Total				397409.5	29509.7406	1941975

*Note: Building Life ≈ 100 Years (may vary)
Materials Life = > 5 years

S.No.	Appliance	Daily Usage (Hrs.)	Electricity Consumption (watt/hour)	Daily Consumption of one count in (watt/hour)	Count	Total Energy Consumed Daily (watt/hour)	Total Energy kWh/day	Percentage Share
1	Tube Lights	2	35	70	10	700	0.7	3.877042371
2	CFL/LED's	2	15	30	12	360	0.36	1.993907505
3	Television	3	150	450	1	450	0.45	2.492384381
4	Washing Machine	0.5	500	250	1	250	0.25	1.384657989
5	Fans	3	60	180	7	1260	1.26	6.978676267
6	Geyser (Electric)	1	1100	1100	1	1100	1.1	6.092495154
7	Refrigerator	18	100	1800	1	1800	1.8	9.969537524
8	Laptops/ Desktop	1.5	110	165	2	330	0.33	1.827748546
9	AC: Living Room (1.5 Ton)	2.5	1600	4000	1	4000	4	22.15452783
10	AC: Other Room (1.5 Ton)	2	1500	3000	2	6000	6	33.23179175
11	Toaster	0.5	600	300	1	300	0.3	1.661589587
12	Microwave oven	0.5	650	325	1	325	0.325	1.800055386
13	Grinders	0.25	600	150	1	150	0.15	0.830794794
14	Inverters	18	10	180	1	180	0.18	0.996953752
15	Others (like Iron, Dishwasher, Chimney etc)	1	850	850	1	850	0.85	4.707837164
	Total						18.055	100%

Operational Energy of a House: Case Study Roorkee

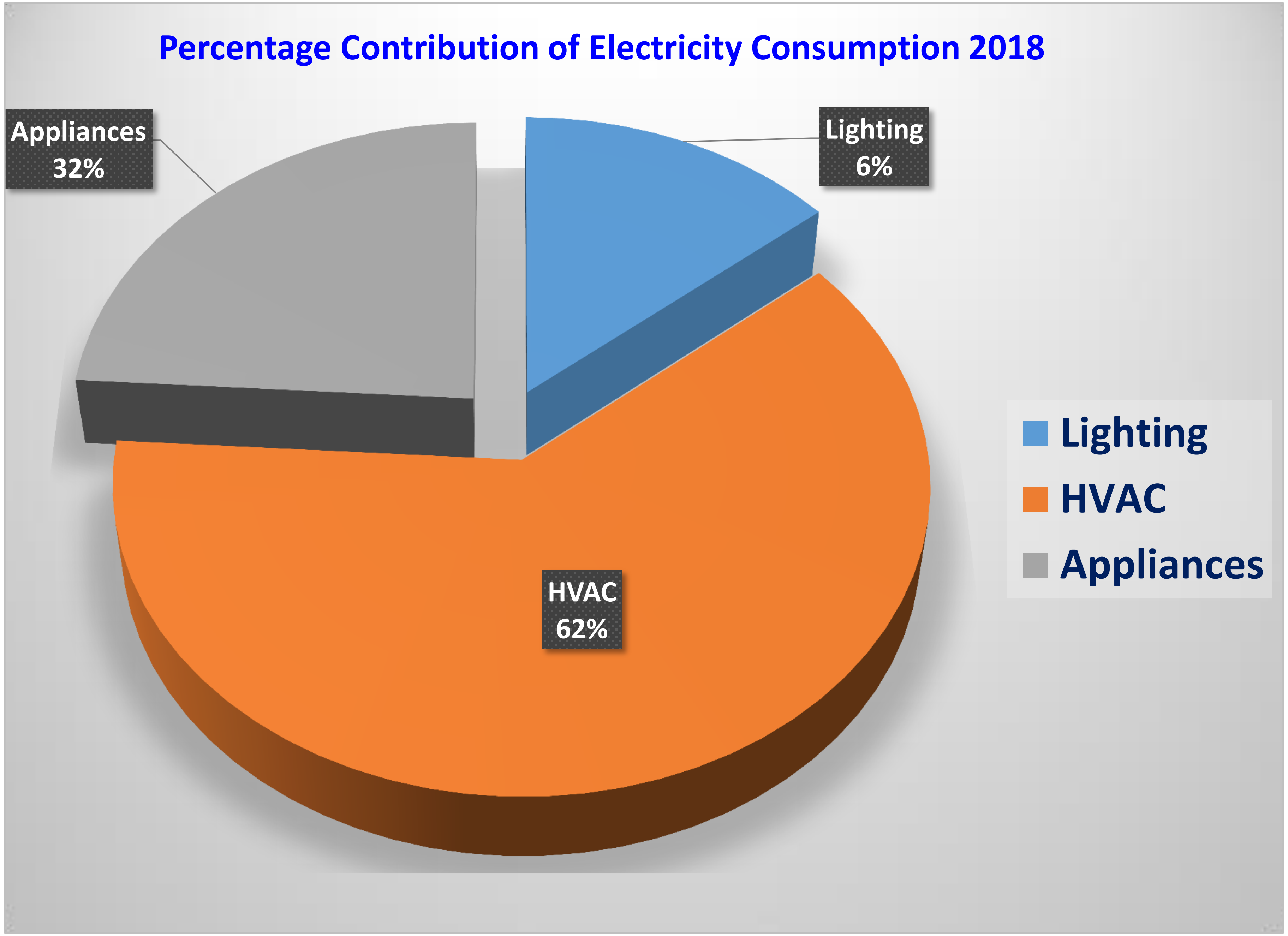
CSIR - CBRI



Percentage Contribution of Electricity Consumption in a House

Operational Energy of a House: Case Study Roorkee

CSIR - CBRI



18.05 kWh/day

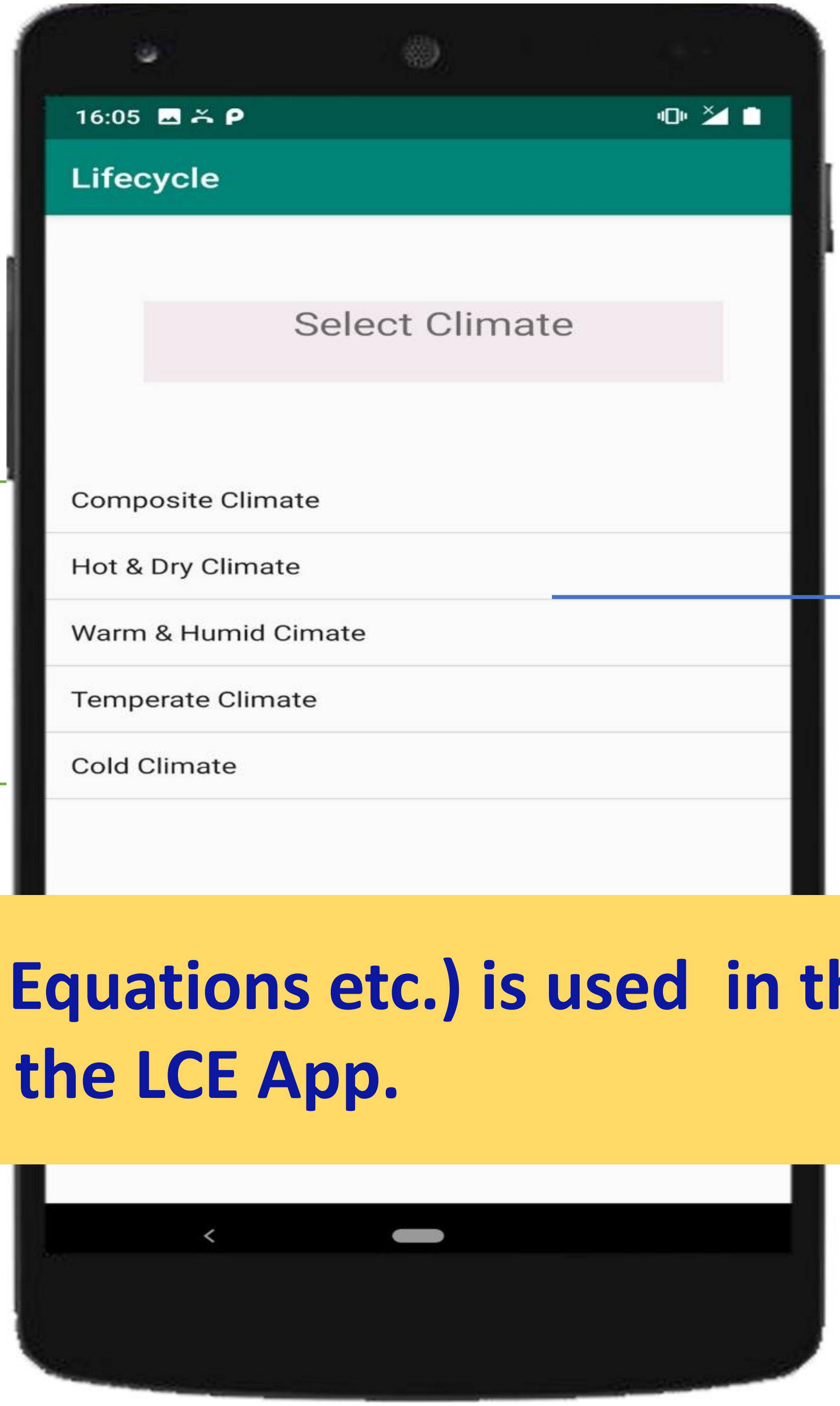
18.05x3.6= 64.98MJ

64.98x365=23,717.70 MJ/year

Screen Shots of the App (Under Progress)

CSIR - CBRI

Select Life Cycle Energy to enter in the App

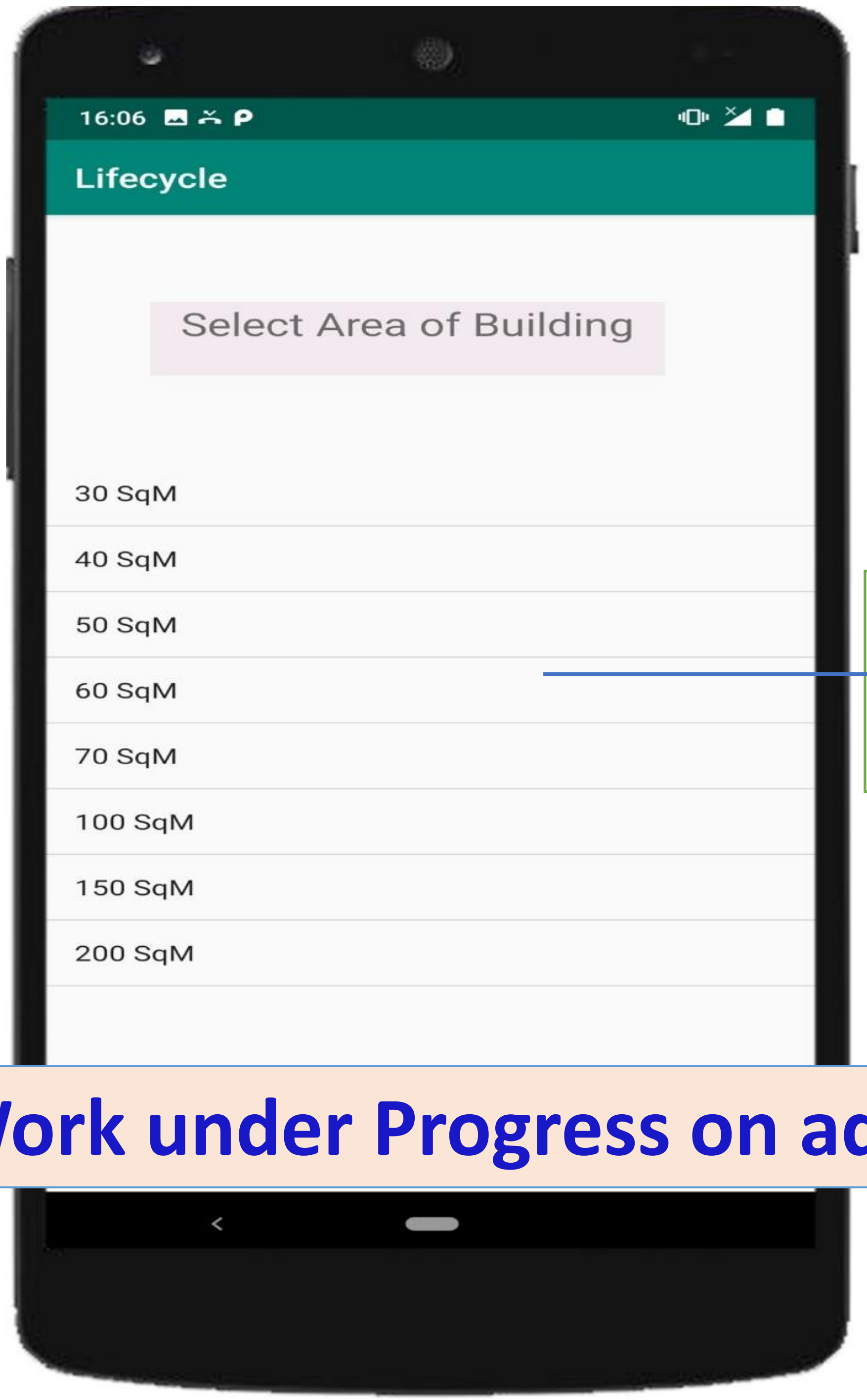


Select Climate Type

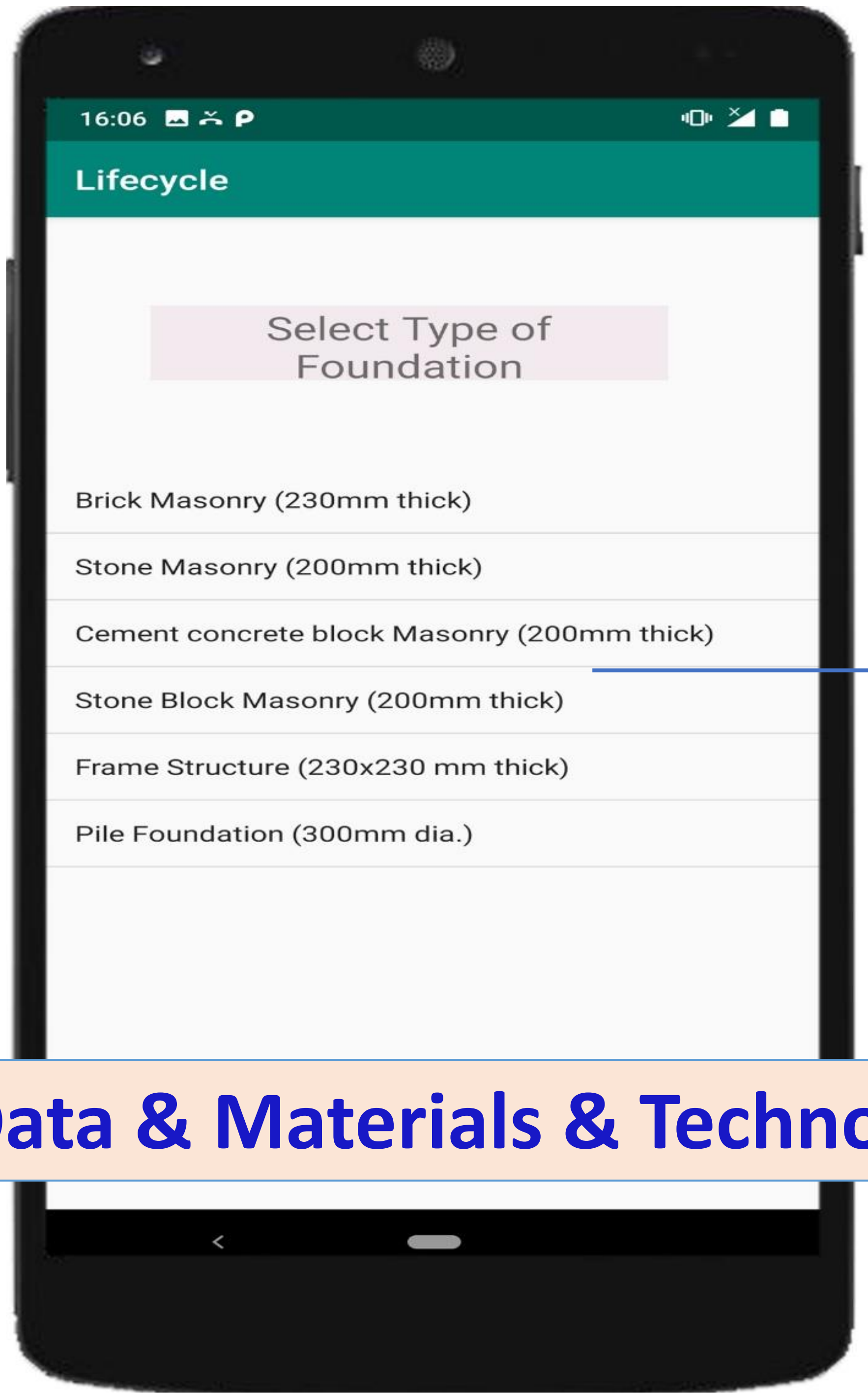
Data available in the literature (DSR, EE, Equations etc.) is used in the Database of Developing the LCE App.

Screen Shots of the App (Under Progress)

CSIR - CBRI



Select Area of the Building - Residential

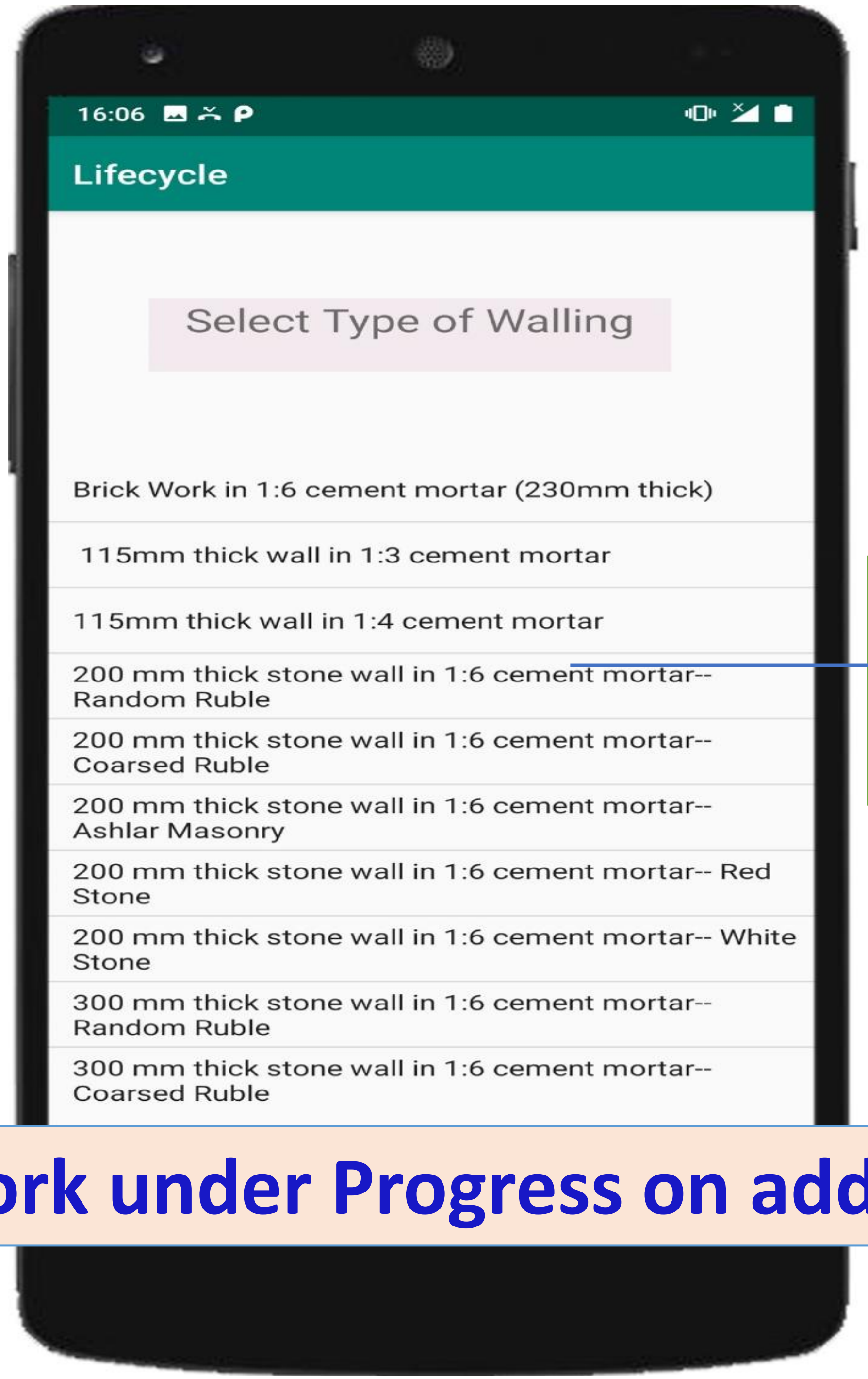


Select Foundation Type

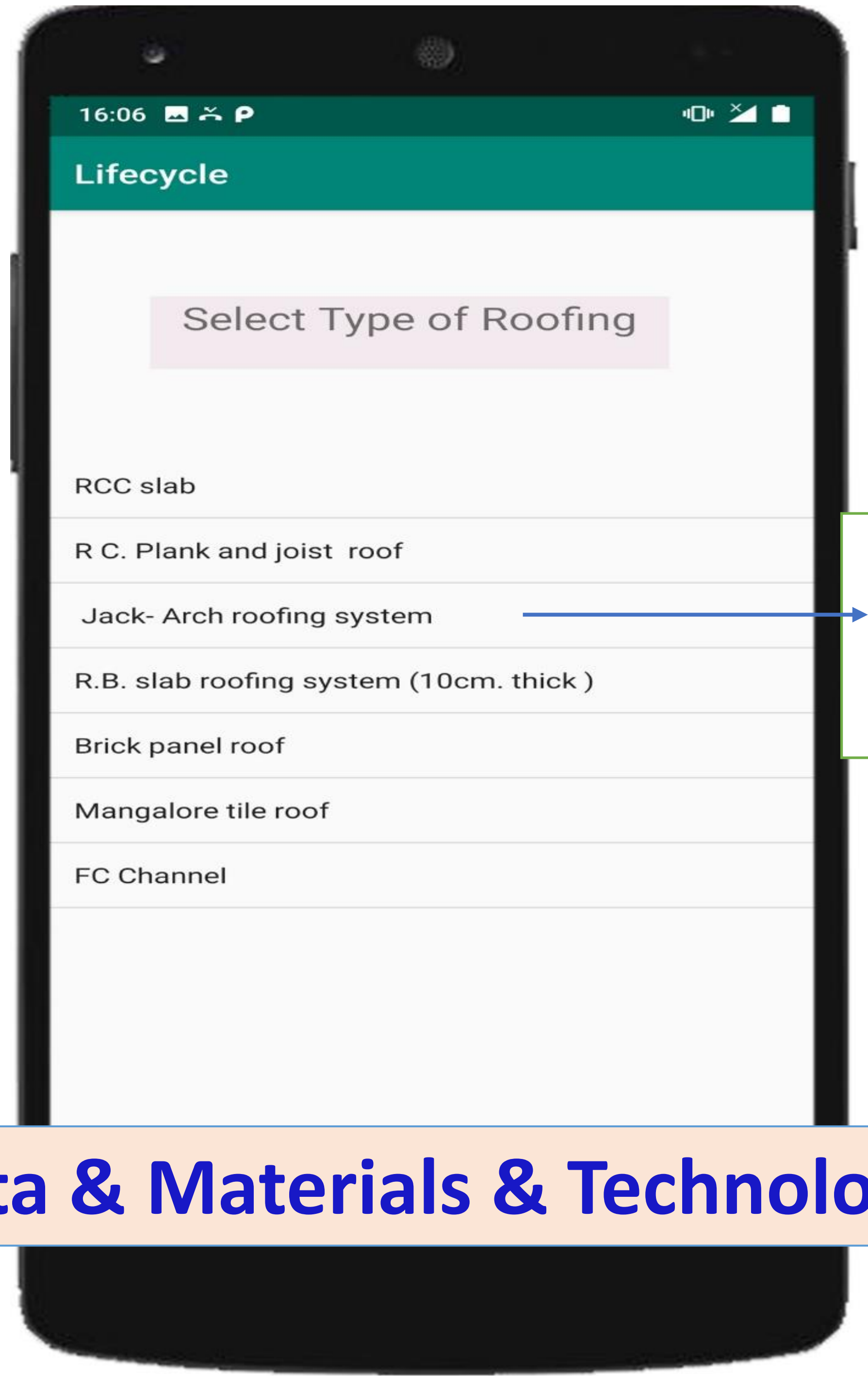
Work under Progress on adding more Data & Materials & Technology Options

Screen Shots of the App (Under Progress)

CSIR - CBRI



Select Walling Material

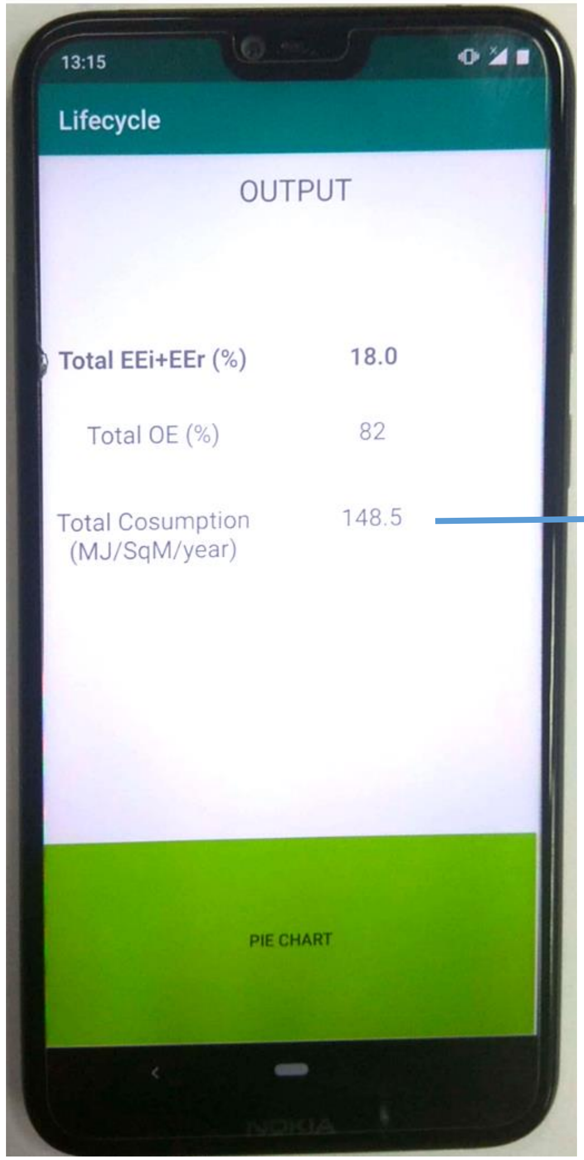


Select Roofing Material

Work under Progress on adding more Data & Materials & Technology Options

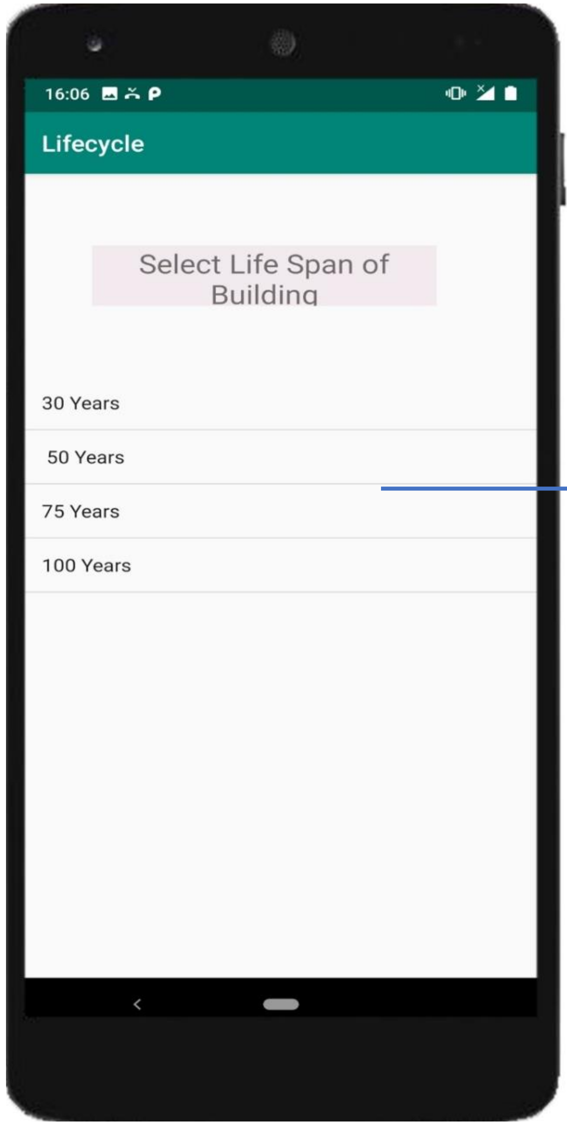
Screen Shots of the App (Under Progress)

CSIR - CBRI

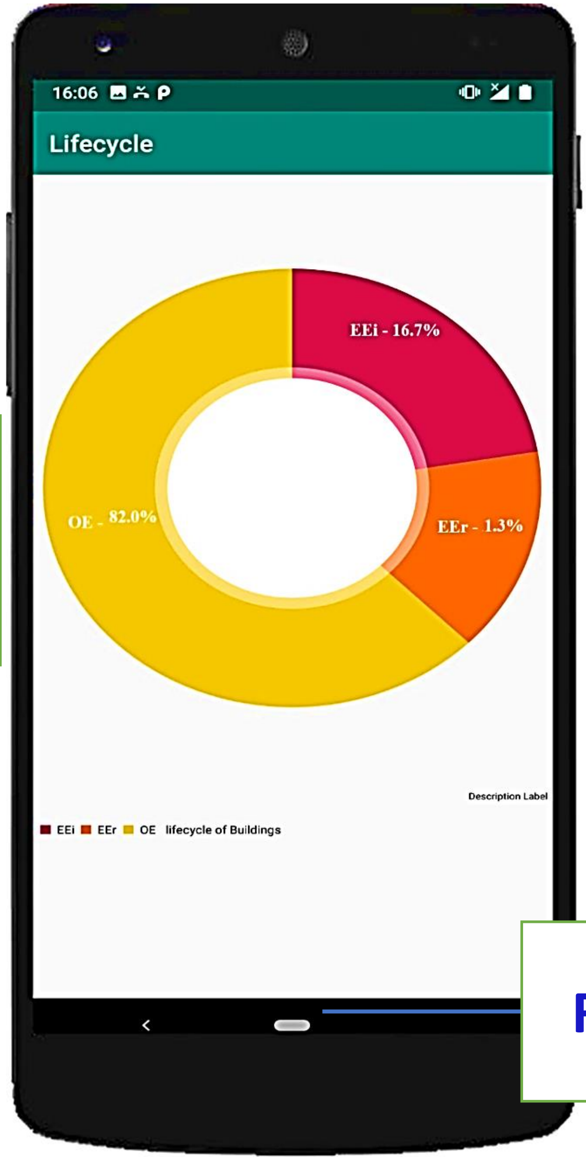


Total Consumption = 148.5 MJ/m²/year

OE = 82.00%
EE_i = 16.70%
EE_r = 01.30%



Life Span of Building



Results

Regression Equations for Estimating the Quantity of Materials

CSIR - CBRI

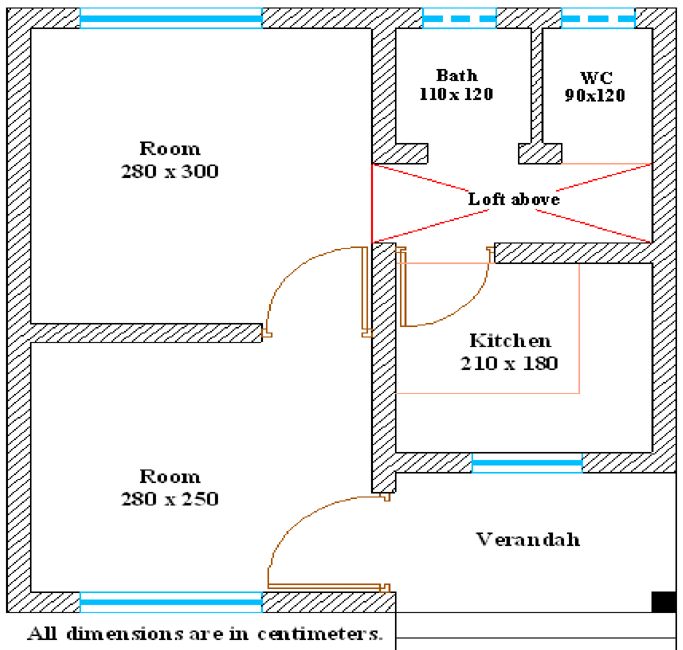
- **CSIR- CBRI has developed equations for estimating major building material requirements with different floor areas for three types of houses i.e. single storey, double storey load bearing wall residential buildings and four storey framed structure residential buildings.**

Regression Equations for Estimating the Quantity of Materials in Residential Buildings (A is the floor area in m^2)

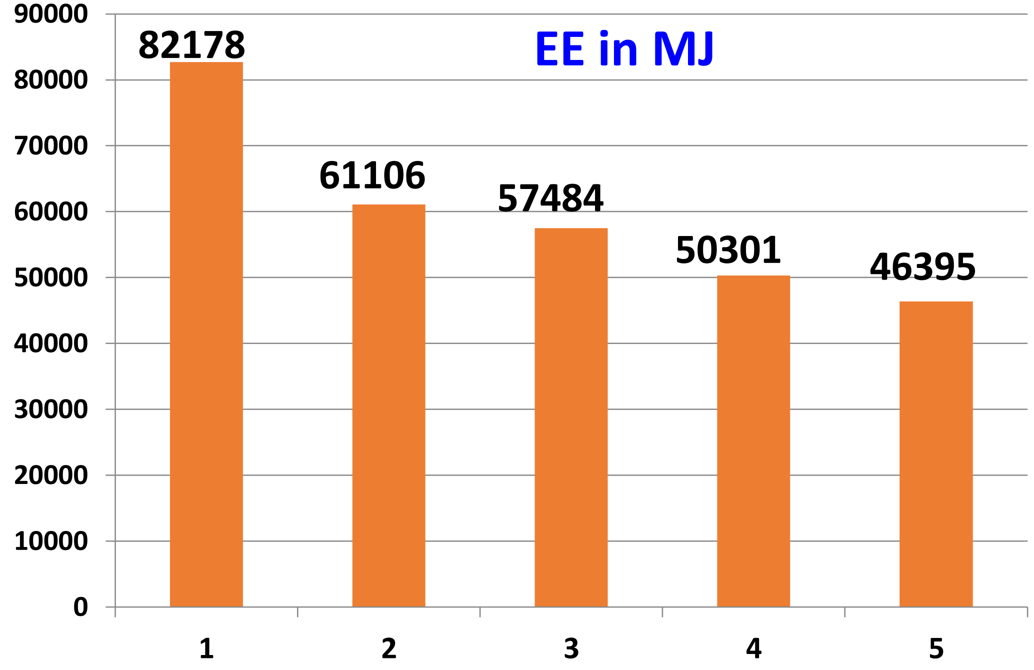
Materials	Single Storey	Double Storey
Bricks (1000 nos)	2.26A + 66.8	2.15A + 63
Cement (tonne)	0.153A + 0.57	0.145A + 0.54
Steel (kg)	21.3A - 314	21.97A - 305
Coarse Aggregate (m^3) (all sizes)	0.176A - 0.21 + 0.145A + 1.5	0.178A - 0.21 + 0.075A + 0.78
Brick Aggregate (m^3)	0.113A - 0.83	0.056A - 0.42
Timber (m^3)	0.019A + 0.23	0.019A + 0.23
Glass (m^2)	0.064A - 0.73	0.064A - 0.73
Primer (l)	0.068A	0.068 A
Paint (l)	0.108A + 0.27	0.108A + 0.27

Note: The quantity of materials required for the installation of electrical, mechanical, plumbing, sewage and drainage systems is not included.

The equations are valid for total floor area ranging from 30 to 300 m^2 for single and double storey structures, and 120 to 400 m^2 for four storeyed structures.



Ground Floor Plan



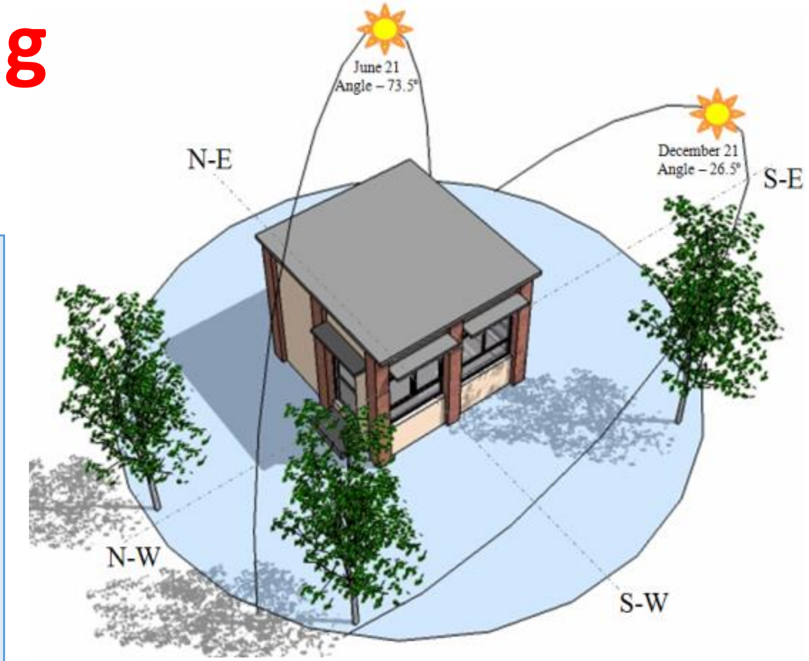
Computation of EE - Case of Lowering Embodied Energy of Five Types of Single Storey Houses

Sr. No.	Description of materials used in the House
1.	Single Storey House using conventional materials such as brick masonry in foundation & in walls and R.C.C. in roof, (Wall thickness: 230mm).
2.	Single storey house using stone masonry block in foundation, brick masonry in walls and R.C. Planks and Joists in roof, (Wall thickness: 230mm).
3.	Single storey house using stone masonry block in foundation, Clay fly ash brick masonry in walls, and Brick panel, R.C. Planks and Joists in roof, (Wall thickness: 230mm).
4.	Single storey house using stone masonry block in foundation, stone block masonry in walls and Brick panel, R.C. Planks and Joists in roof. (Thickness of walls 300mm).
5.	Single storey house using stone masonry block in foundation, concrete block masonry in walls and Brick panel, R.C. Planks and Joists in roof. (Thickness of walls 200mm).

Full – scale Experimental Study – Reducing Operational Energy

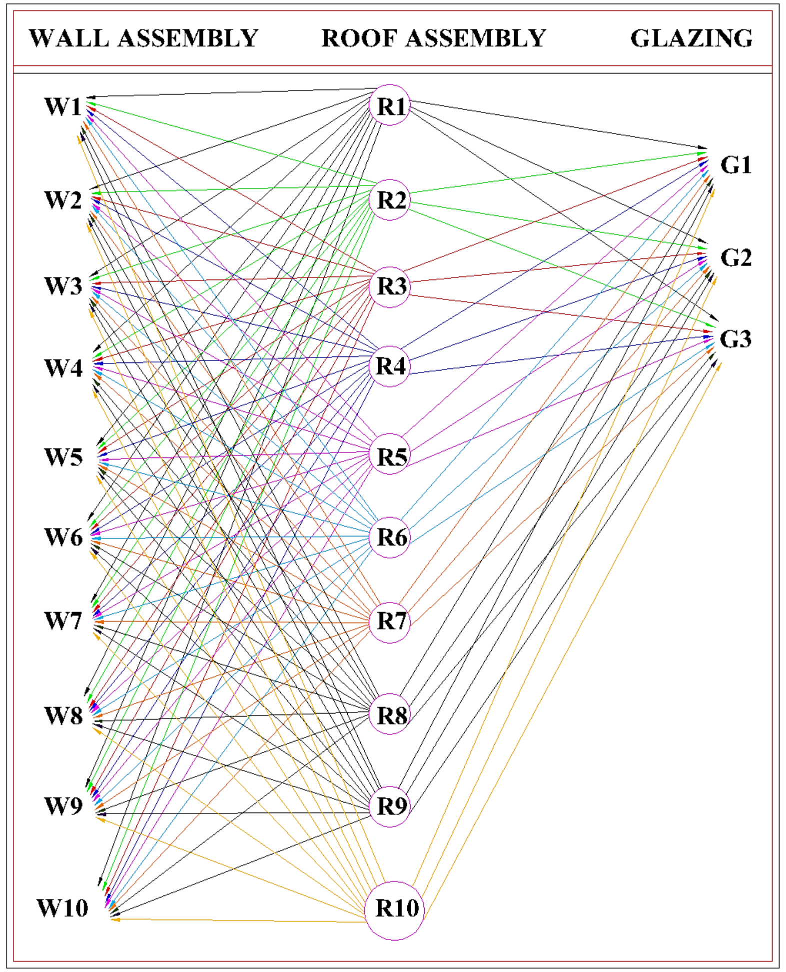
CSIR - CBRI

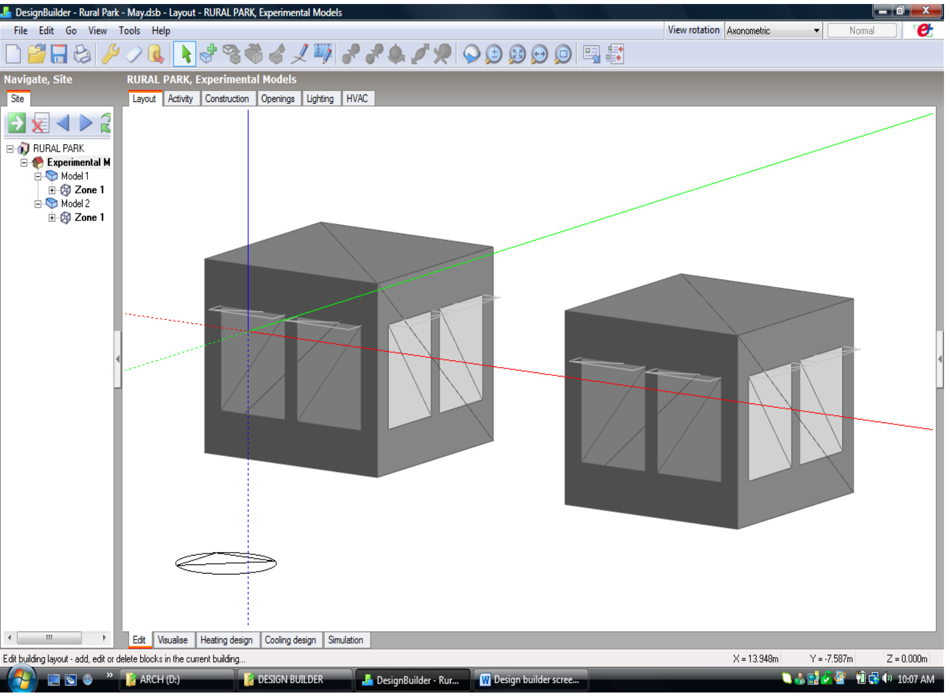
- **Two identical experimental models of size (3620mm x 3620mm) with 3.0 m ceiling height.**
- **Model-1 Constructed with Precast RC Planks & Joists Roof.**
- **Both have 229 mm thick brick masonry walls on all the sides.**
- **WWR – 50%**



300 combinations

10 Types of Walls
10 Types of Roofs
3 Type of Glass

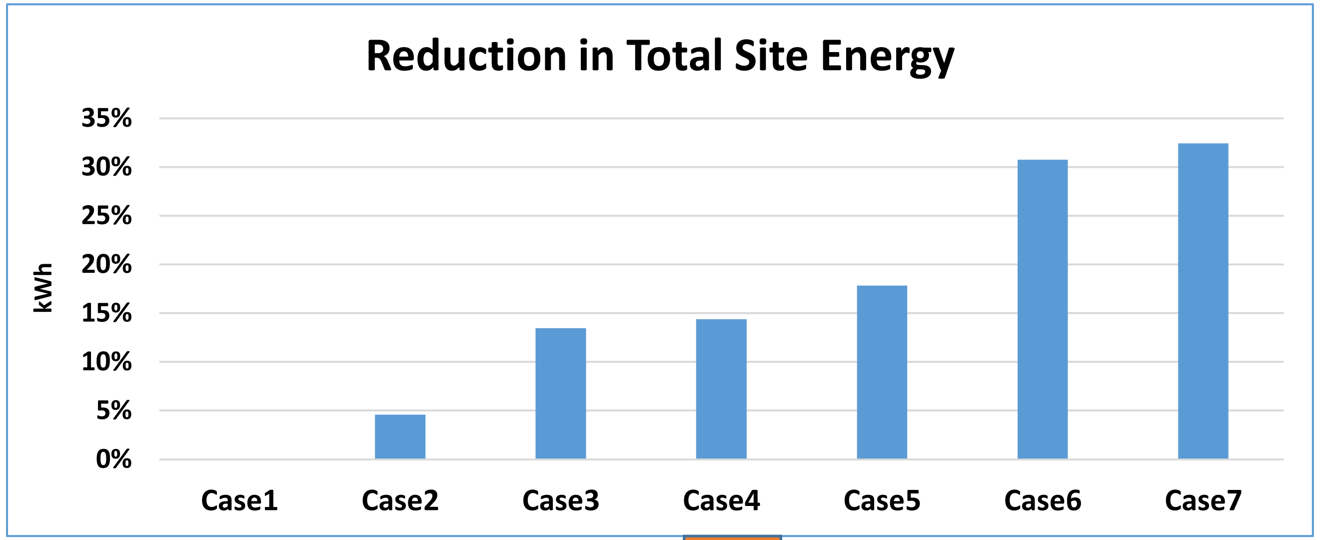




W9 R9 G3	Building Assembly	U-value (W/m² K)
W9	229 mm Clay Flyash Brick + 50mm PUF Insulation	0.403
R9	76mm Brick Panel / RC Planks & Joists + 35mm cement concrete + 15mm cement plaster + 125 mm PUF Insulation	0.212
G3	Double Glazing:- Shading Coefficient - 0.244,Visible Transmittance - 0.30	1.80

Full – scale Experimental Study – Reducing Operational Energy

CSIR - CBRI



Approx. 34% reduction in Energy by applying Six Retrofitting Interventions.

Quantification of Interventions (Invasive):

Case 1 : No Interventions (Baseline)
Case 2: Film on Glazing (4%)
Case 3: C2+ Over deck Roof Insulation for ECBC compliance (12%)
Case4: C3+ Vermiculite Tiles and White Reflective Coating Finish (13%)
Case5: C4+ External Wall Insulation with 20mm air gap finished with cement mortar and white reflective paint (18%)
Case6: C5 + Double glazing (30.6%)
Case7: C6+ Night –Time Ventilation (34%)

Current Research at CSIR-CBRI

- **To parametrically analyze life cycle energy of the residential building typologies based on various prefab technologies for various geo-climatic regions of India.**

Possible Research Collaboration with FIBP, GIZ, & BEE

Waste - to – Wealth (Circular Economy

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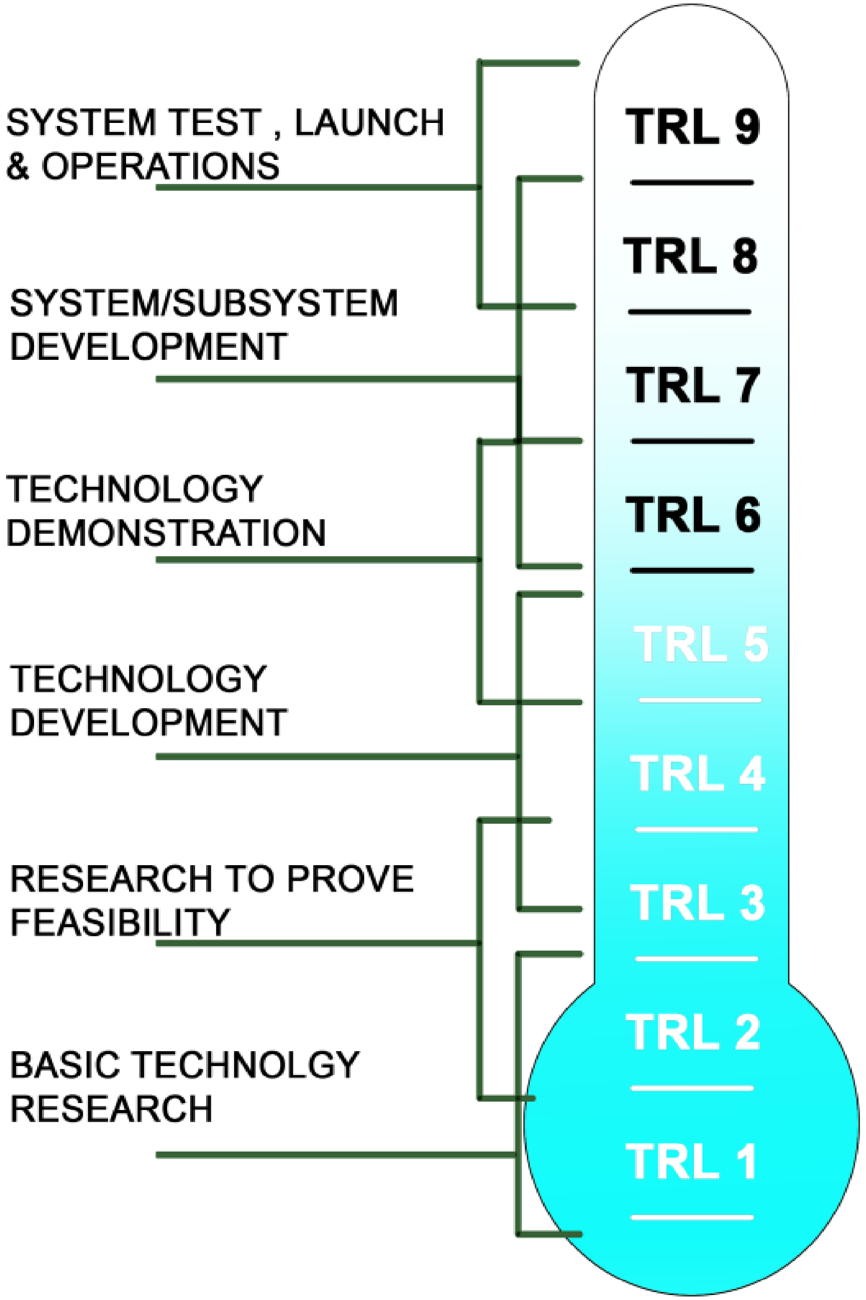
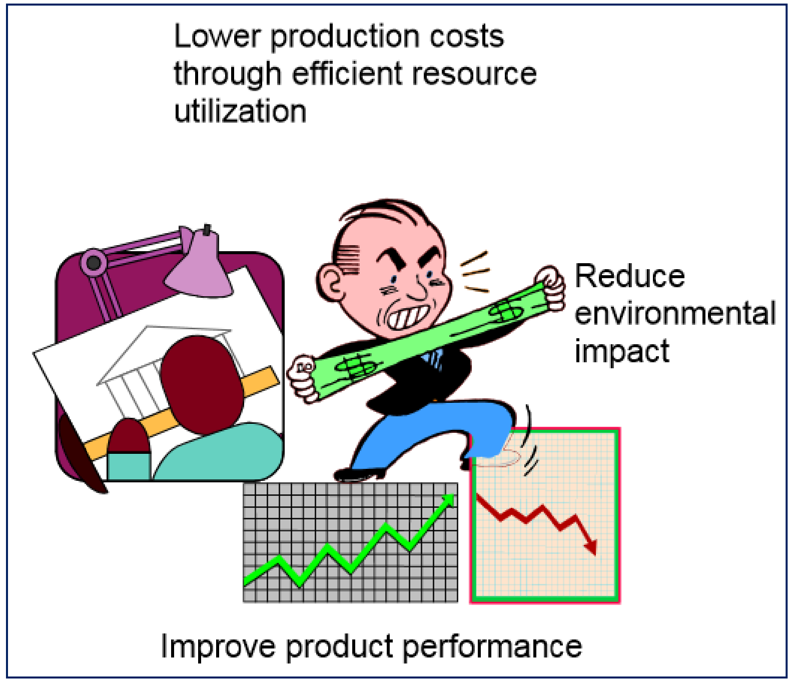
Building Materials Studies at CSIR (CBRI, NML, AMPRI, IMMT, SERC etc.)

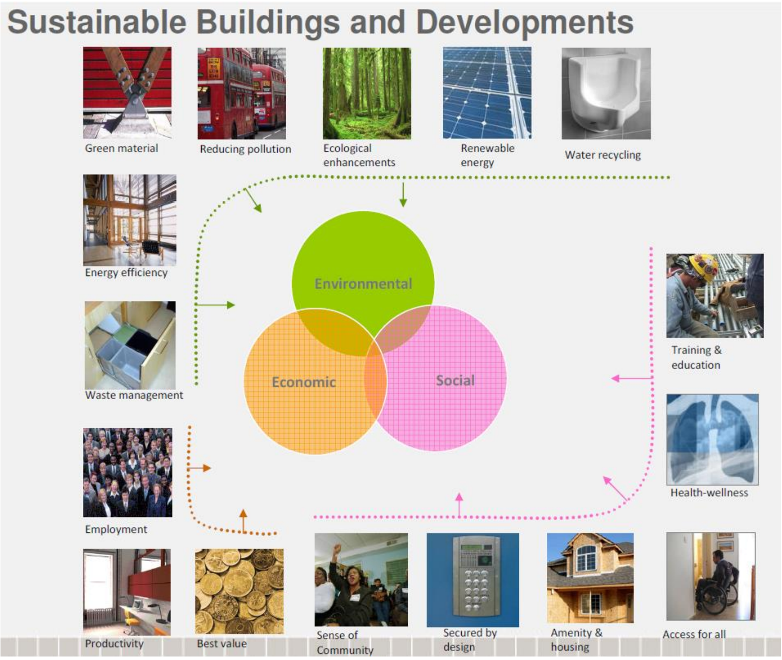
- Construction & Demolition Waste
- Granulated Blast Furnace Slag
- Fly ash & Bottom Ash
- Manufactured Sand
- Lime Sludge
- Red Mud
- LD Slag
- Zinc Smelter Slag
- Copper Smelter Slag
- Induction Furnace Slag
- Foundry Sand
- Kota & marble stone waste
- Other wastes

Environmentally Compatible Products

CSIR - CBRI







4R- Concept

Reduce

Recycle

Reuse

Recover

Building Products Developed at CSIR - CBRI using C&D waste

CSIR - CBRI

Flooring tiles

Bricks

Paver blocks

Paver blocks

Hollow blocks

Semi prefabricated RCC plank

Semi prefabricated RCC Joist

The Way Forward…

Life Cycle Ecological Footprint of a Building Project ($LCEF_{total}$)

$LCEF_{total}$	Life cycle ecological footprint
$LCEF_{e\&m}$	Life cycle ecological footprint of energy and material consumption
$LCEF_{w}$	Life cycle ecological footprint of water consumption
$LCEF_{t}$	Life cycle ecological footprint of transportation
$LCEF_{we}$	Life cycle ecological footprint of C&D waste disposal
$LCEF_{m}$	Life cycle ecological footprint of manpower
$LCEF_{built-up}$	Life cycle ecological footprint of built-up land consumption

$LCEF_{total}$ is used to effectively examine the overall impact of the building project on the environment.

$LCEF_{total}$ contains all phases of the building's life:

- **Implementation and construction phase,**
- **Operation and maintenance phase, and**
- **Demolition phase.**

The principle of evaluating the $LCEF_{total}$ of a building:

$$LCEF_{total} = LCEF_{e\&m} + LCEF_{w} + LCEF_{t} + LCEF_{we} + LCEF_{m} + LCEF_{built-up}$$

Where,

$LCEF_{e\&m}$, $LCEF_{w}$, $LCEF_{t}$, $LCEF_{we}$, $LCEF_{m}$ and $LCEF_{built-up}$

Represent the Life Cycle Ecological Footprint of :

- **Energy and material consumption;**
- **Water consumption;**
- **Transportation;**
- **C&D waste disposal;**
- **Manpower; and**
- **Built –up land consumption of the building.**

Conclusions:

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LCE analyses - Residential and Office buildings indicate:
'OE' (≈ 80 – 85%) and 'EE' (≈ 15 - 20%)
significant contributors to building's LCE demand.

BLCE demand can be reduced by :

- Reducing its 'OE' significantly through use of 'Passive' and 'Active' Technologies, even if it leads to a slight increase in Embodied Energy : Daylight App & Other by CSIR-CBRI

- Balance in Operating and Embodied energy of housing stock needs to be struck to optimize the energy consumption of building. Low energy buildings perform better in life cycle context.

Conclusions:

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- Integration of LCEA with BIM and compare the results with Simapro or other programs. Focus on deviations of LCA results, & build LCA model with smaller uncertainties.

- Various new processes and materials & technologies are emerging without any scientific data – PC properties, no information about embodied energy – Materials / Technologies must be labeled.

- Further LCEA research is needed to update, investigate and analyze the impact of future energy scenarios – Prefab Housing / Building Technologies & New Materials : CSIR

Further research is needed to reduce GHG emissions' – alternatives – Low Carbon Cement, Cement – free Concrete, Solar Thermal Acs, Solar – Tree (small size) etc. : CSIR.

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AUGMENTING NATURE BY

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GREEN AFFORDABLE NEW-HABITAT

Thank You!