Low Carbon Materials, Environment & Sustainable Constructions

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Outline of the presentation

- **Some issues on sustainability of construction sector**
- **Energy & Low Embodied Carbon Materials**
- **Alternative building technologies: Some examples & technical details**

Sustainability?

Sustainable Society
is the one which manages its economic growth in such a way as to do no irreparable damage to its environment

It satisfies the needs of its people without jeopardizing the prospects of future generations

Source:
Dr. JC Kumarappa (1930), Concept of "Economy of Permanence"

Sustainability is associated with……

- **Earth's capacity to sustain a large human population (~7 billion & still rising)**
- **Pollution causing climate change (GHG emissions & global warming)**
- **Managing the material resources in a sustainable fashion**
- **Development with minimum or no damage to environment**

Energy consumption & Developments in building materials

Prior to 4000 BC	4000 BC – 1800 AD	1800 AD – To-date
Mud, stones, reeds/thatch Sun dried bricks/adobe	Burnt bricks Lime, Iron products Pozz. cements	Aluminium Portland Cement Steel, Plastics, composites, Smart materials, etc
Zero energy materials	Medium energy materials	High energy materials

Construction materials

Raw materials

(Depends on type of product/material)

Energy

Construction materials

Materials resources
Soil
Aggregates
Minerals/chemicals
Timber, Biomass, etc

- **Limited,**
- **Mining resources is un-sustainable**
- **Indiscriminate use causes environmental damage**

Energy expenditure:

Causes
- **Pollution**
- **GHG emissions**

Energy Resources
Electricity
Coal
Oil
Biomass
Renewable energy, etc

Too much Emphasis on → **GHG emission reduction**

↓

Attempt to link the concept of Green buildings to Sustainable Construction

Very little or less Emphasis on

- **Conservation of dwindling basic Material resources**
- **Scarcity due to mining of raw material resources**
- **Competition to Agriculture**
- **Damage to Environment due to indiscriminate mining of raw materials**

Materials consumed in bulk quantities

Type of material	Annual consumption
1. Burnt Clay Bricks	150×10^9
2. Cement	220×10^6 t
3. Steel	45×10^6 t
4. Coarse aggregates	300×10^6 m^3
5. Fine Aggregates	350×10^6 m^3

Vol. of materials produced & consumed: ~1.60 billion t/year

Type of material	Annual per capita consumption
Steel	50 kg
Cement	200 kg
Burnt bricks	400 kg
Aggregates	900 kg
---------------	-----------
Food grains	200 kg

~30% of GHG emissions from Construction sector

Case of
Cement & Burnt clay bricks

… Carbon emissions &

… Pressure on natural resources

Cement production & CO_2 emissions (MMT/Y)

	1990	2005	2010
Global			
Cement Production (t)	1040	2270	~2800
CO_2 Released (t)	900	2040	2520

China			
Cement Production (t)	~300	1000	~1600

India			
Cement Production (t)	45	127	~240

During 20 years, the CO_2 emissions from cement/clinker production
--- has more than doubled (globally)
--- has gone up by >4 – 5 times (India & China)

Cement production & consumption

CO_2 Released: 0.70 - 0.9 ton/ton of cement

Materials required to utilise 1 ton of cement

5 – 6 tons aggregates

Aggregates:

like natural river sand & crushed stone are becoming scarce commodities & come with a heavy environmental price

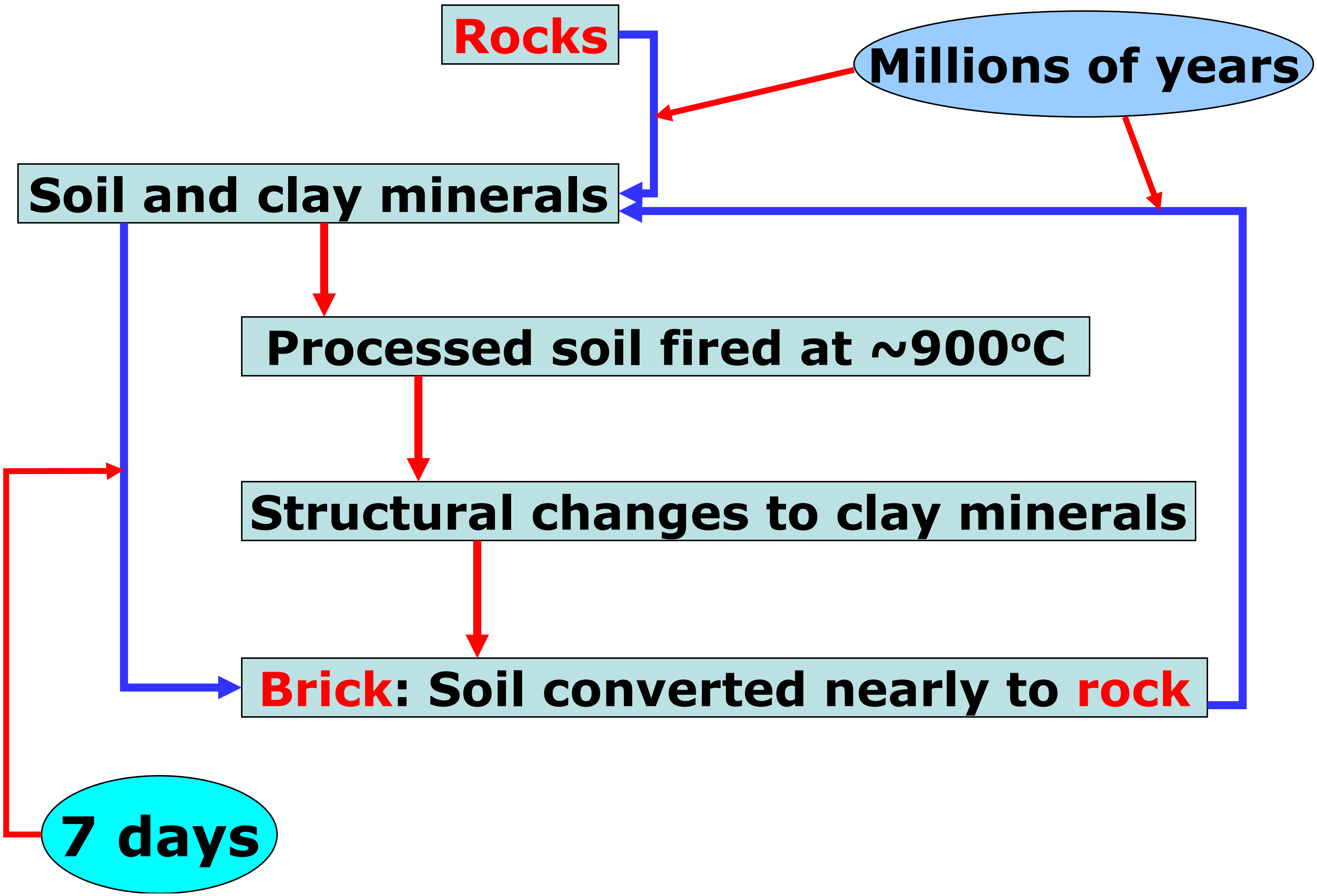
Efforts to reduce CO_2 emissions and improving energy efficiency will not lead cement industry becoming sustainable?

Burnt clay bricks

- 6000 years old technology
- Annual global brick production:
  *1100×10^9
- Fertile top soil is consumed
- Clay minerals: permanently changed

*Ellen Baum, Black carbon from brick kilns, 2010

Life cycle of burnt clay brick



Need for easily recyclable materials

- Effect minimum changes to natural materials during production processes
- Discarded manufactured materials should go back to their native state with minimum environmental costs
- Produce environmentally benign construction materials

There are questions on

- Sustainability of existing construction practices with reference to mining of resources?

Are there options or alternatives?

Possible options

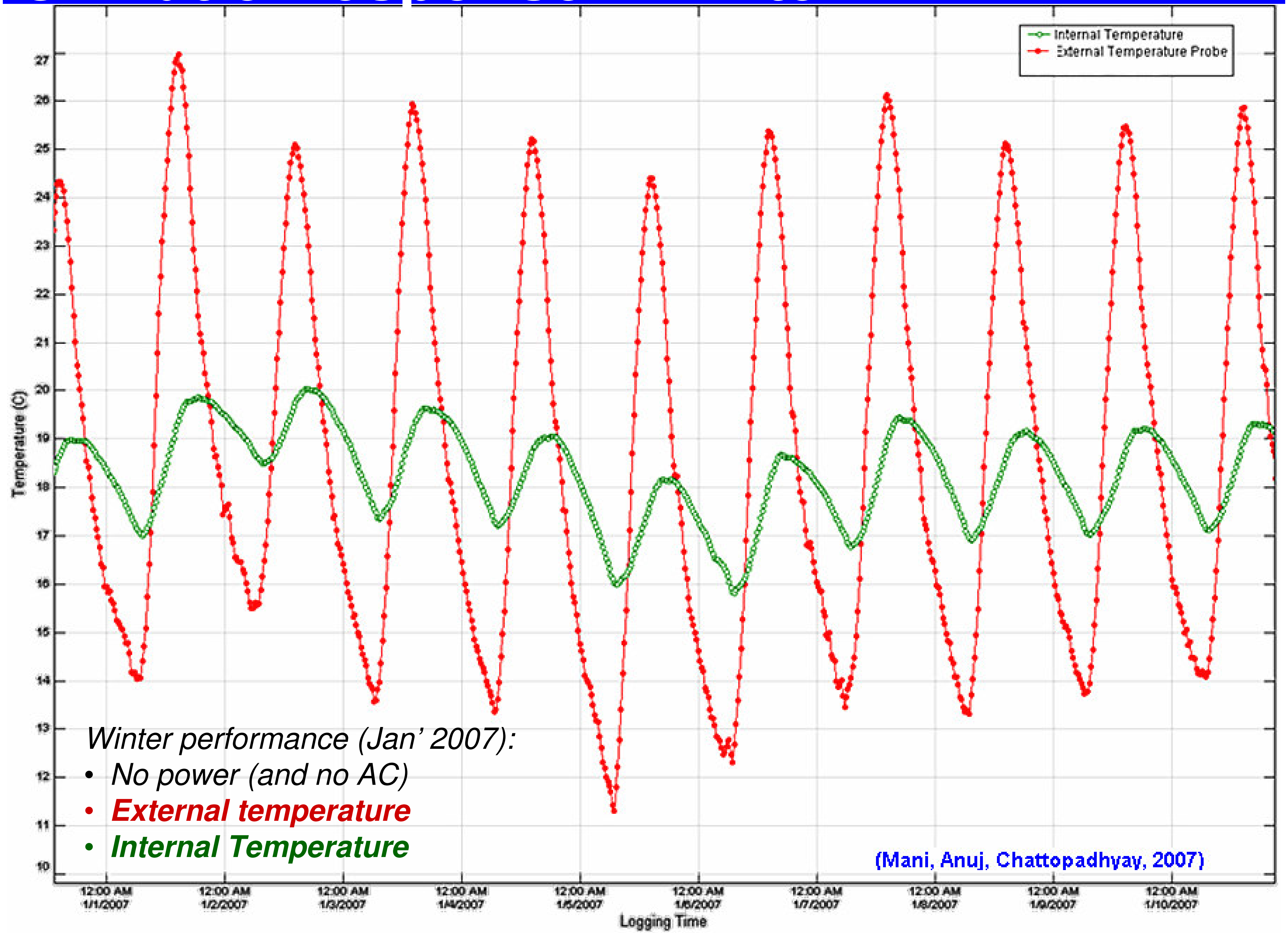
- Develop recyclable & reusable alternative construction materials
- Utilise solid wastes for the production of construction materials
- Use structurally & functionally efficient construction systems
- Develop building products from renewable materials like bio-mass, bamboo, timber, etc.

  & maximise their use

...zero energy building!

...we have a lot to learn from vernacular (Palaces in Jaipur India, Earthen structures in Iran, etc) !

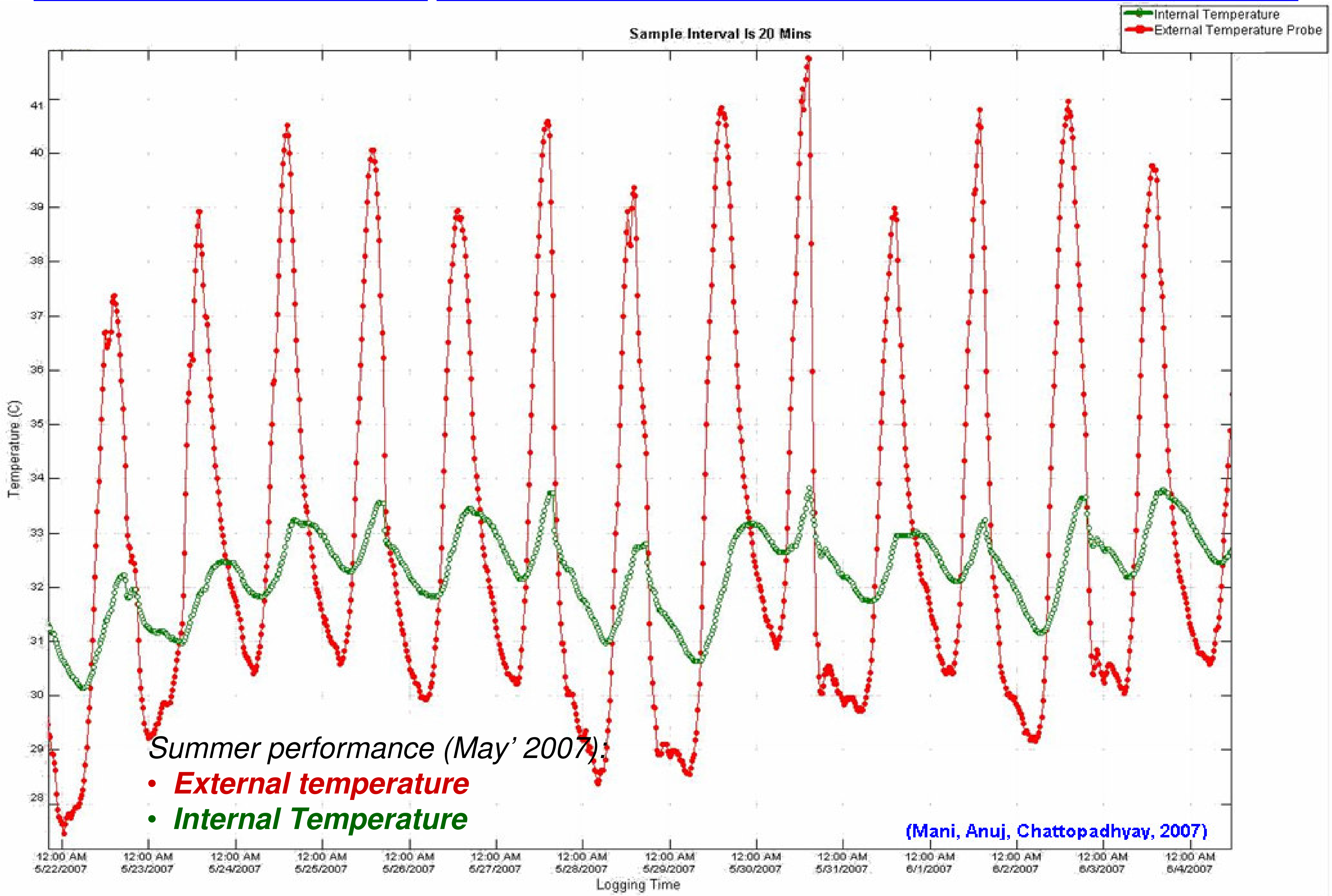
Climatic Response – winter!



Winter performance (Jan' 2007):
- *No power (and no AC)*
- ***External temperature***
- ***Internal Temperature***

(Mani, Anuj, Chattopadhyay, 2007)

Climatic Response



Summer performance (May' 2007):

- ***External temperature***
- ***Internal Temperature***

No (Ecological) footprint

…modern transformations


NATION THE TIMES OF INDIA, BANGALORE SATURDAY, FEBRUARY 2, 2008 17

Rural India matches urban spending pattern: survey

Mahendra Kumar Singh | TNN

New Delhi: Rural India is matching the promise it has shown with the elusive market showing consumption patterns similar to urban areas.

While an average city-dweller may be spending almost twice than his counterpart in rural areas but in terms of allocation of his budget to key segments, the villager has sprung a few surprises. According to latest data on household consumption expenditure, rural India is allocating alomst 10% of the monthly household budget for fuel and lighting, while an average urban houshold spends 9% under the head.

ALL FOR A BETTER LIFE

…transition-I

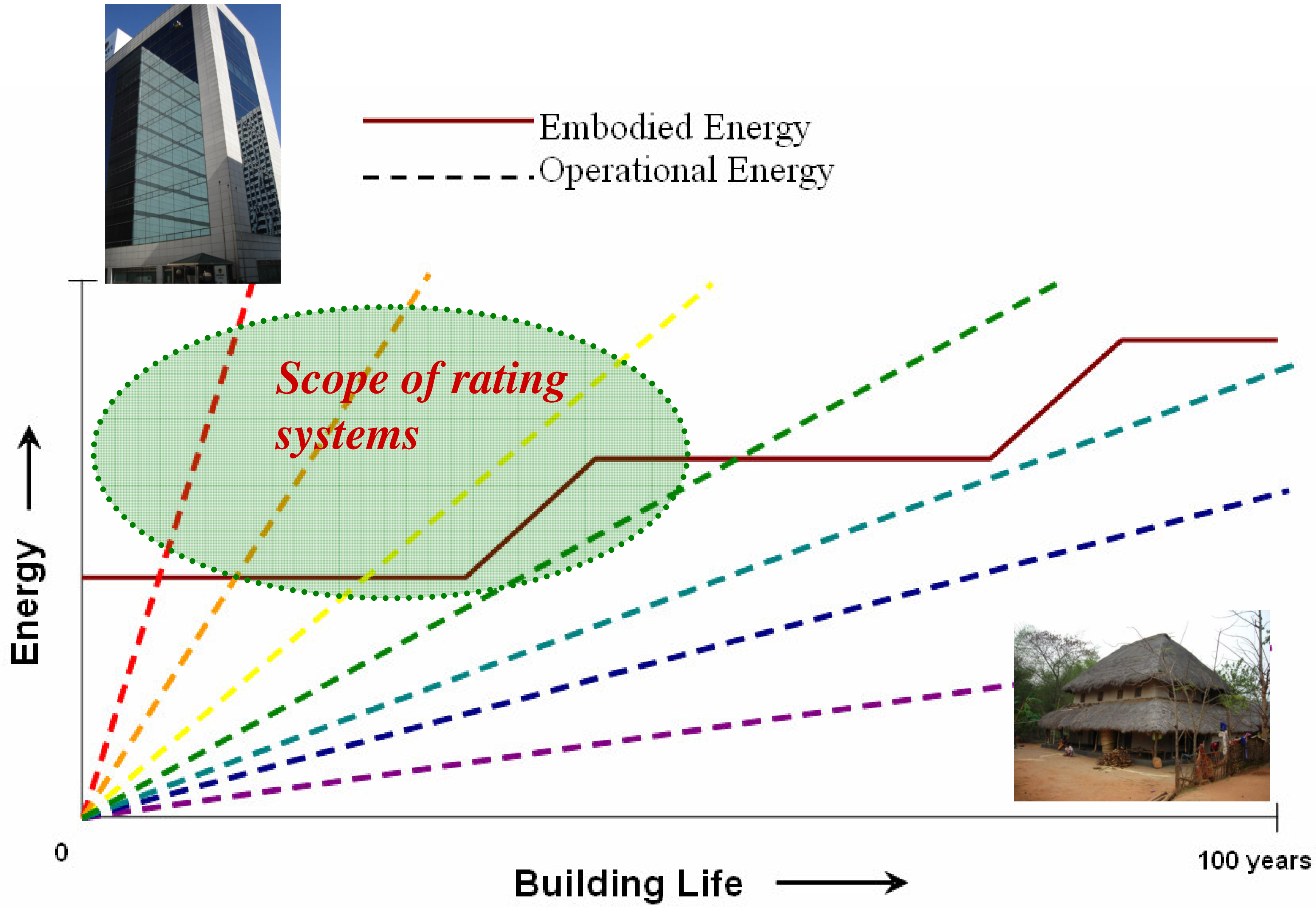
…transition-II

…transition-III

…transition-IV

...consider this!

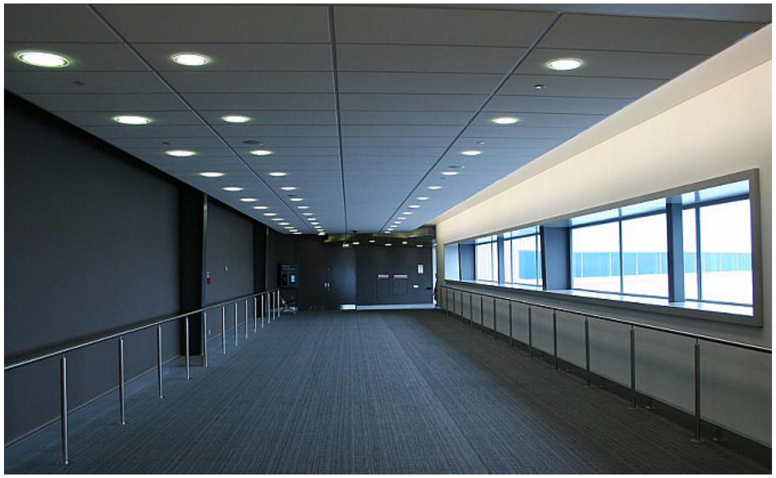
...transition-V, VI, VII...



Embodied Energy
Operational Energy
Scope of rating systems
Energy
0
100 years
Building Life

…modern pursuits

…modern pursuits



Mining resources
without jeopardizing
the prospects of
future generations ???....

Construction sector

Is surviving on
mined material resources

Anything mined: Un-Sustainable

Sustainable Construction ???

Green buildings need not be sustainable constructions

Sustainability of construction sector?

- Energy conservation
- GHG emission reduction

Possible

Mining resources for materials production

Sustainability ???

- **Devise techniques to recycle solid wastes into building products**
- **Essential to recycle & reuse materials**
- **Maximise use of renewable materials like biomass, bamboo, timber based products**

Affordable Housing Solutions?

- **Economic considerations: cost & affordability?**
- **Affordable solutions & damage to environment**
- **Affordability, environment, green solutions: Conflicts**

Possible options to develop affordable & eco-friendly housing technologies

- Maximum use of local materials
- Minimise transportation

- Develop low embodied carbon materials & technologies

- Decentralised production systems
- Scope for self-help

- Develop technologies from solid wastes
- Develop technologies from renewable materials like bio-mass, bamboo, etc.

Low carbon Building Materials & Technologies

- Cement Stabilised Soil Blocks (CSSB)
- Cement stabilised rammed earth (CSRE)
- Fly ash blocks
- Straw-Bale Construction
- GluBam – Glue-laminated Bamboo
- Alternative Roofing Systems

Cement Stabilised Soil Blocks (CSSB)

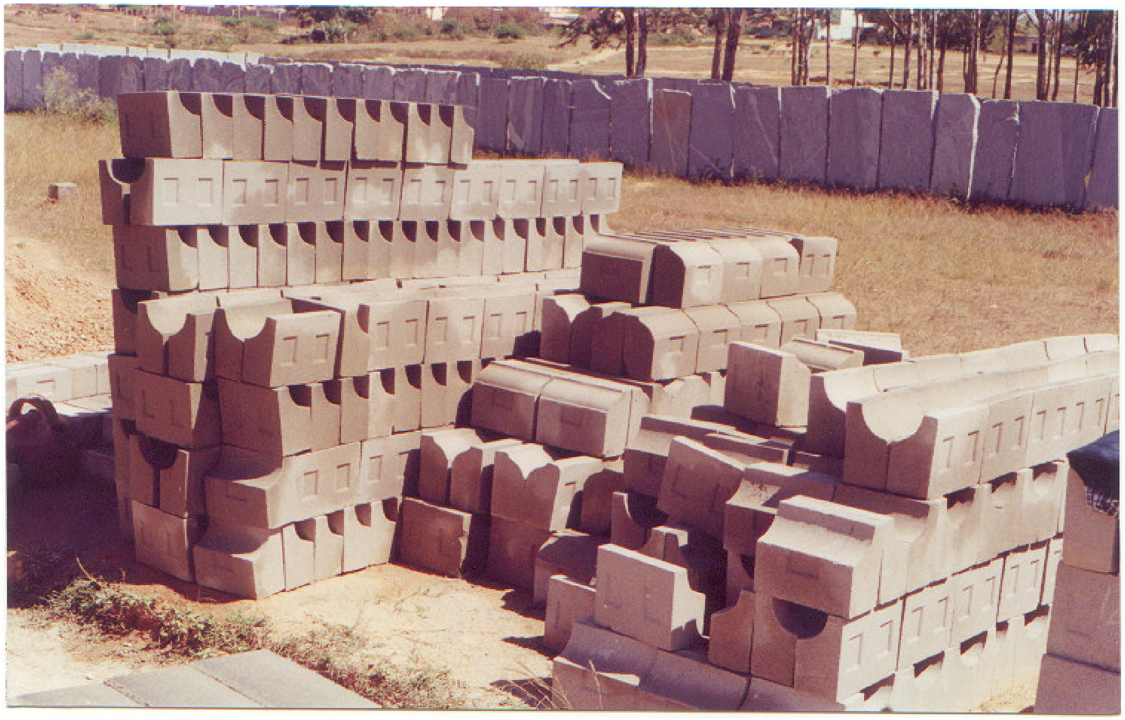
Weighing the Mix

Filling the mould

Block Production (manual process)

Curing: sprinkling water for 4 weeks


Courtesy: Development Alternatives
DST Project
DST Project
Mechanised Operation



Blocks of different shapes & sizes

CST Office, IISc 1985, B'lore

Residential building, 2004, Bangalore

Apartment complex load bearing walls, 2000

CSSB load bearing masonry walls

Courtesy: Dr. M. R. Yogananda

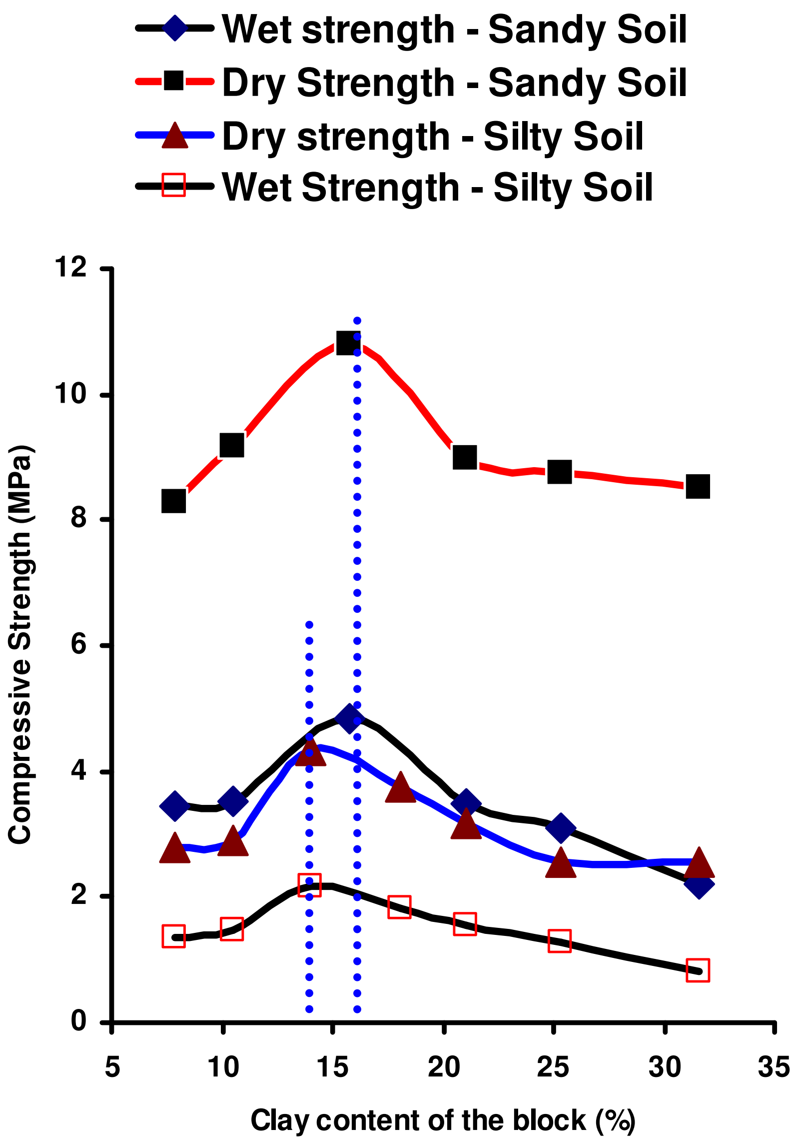
CST seminar hall complex IISc, Bangalore

CST seminar hall complex
IISc, Bangalore, 2004

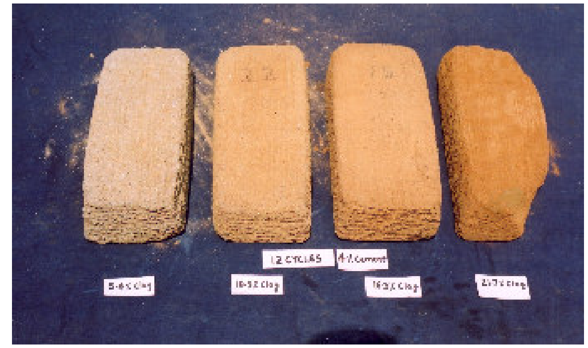
Bhunga house, Gujarat, India, 2003
Bhuj earthquake rehabilitation

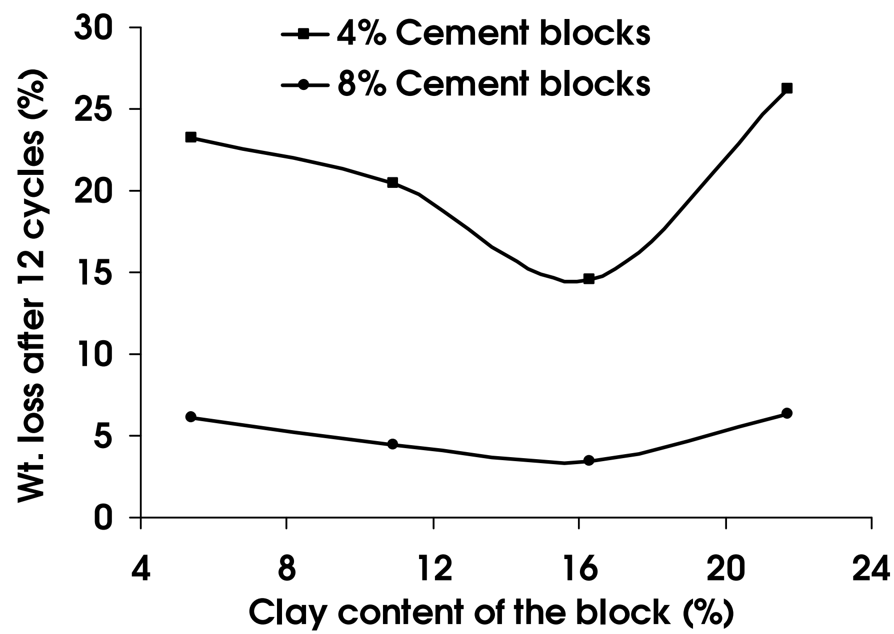
Courtesy:
Kiran Vaghela and Sandeep Virmani
Kutch Nav Nirman Abhiyan
Gujarat

Optimum soil grading limits maximising strength, dimensional stability and durability of stabilised soil blocks



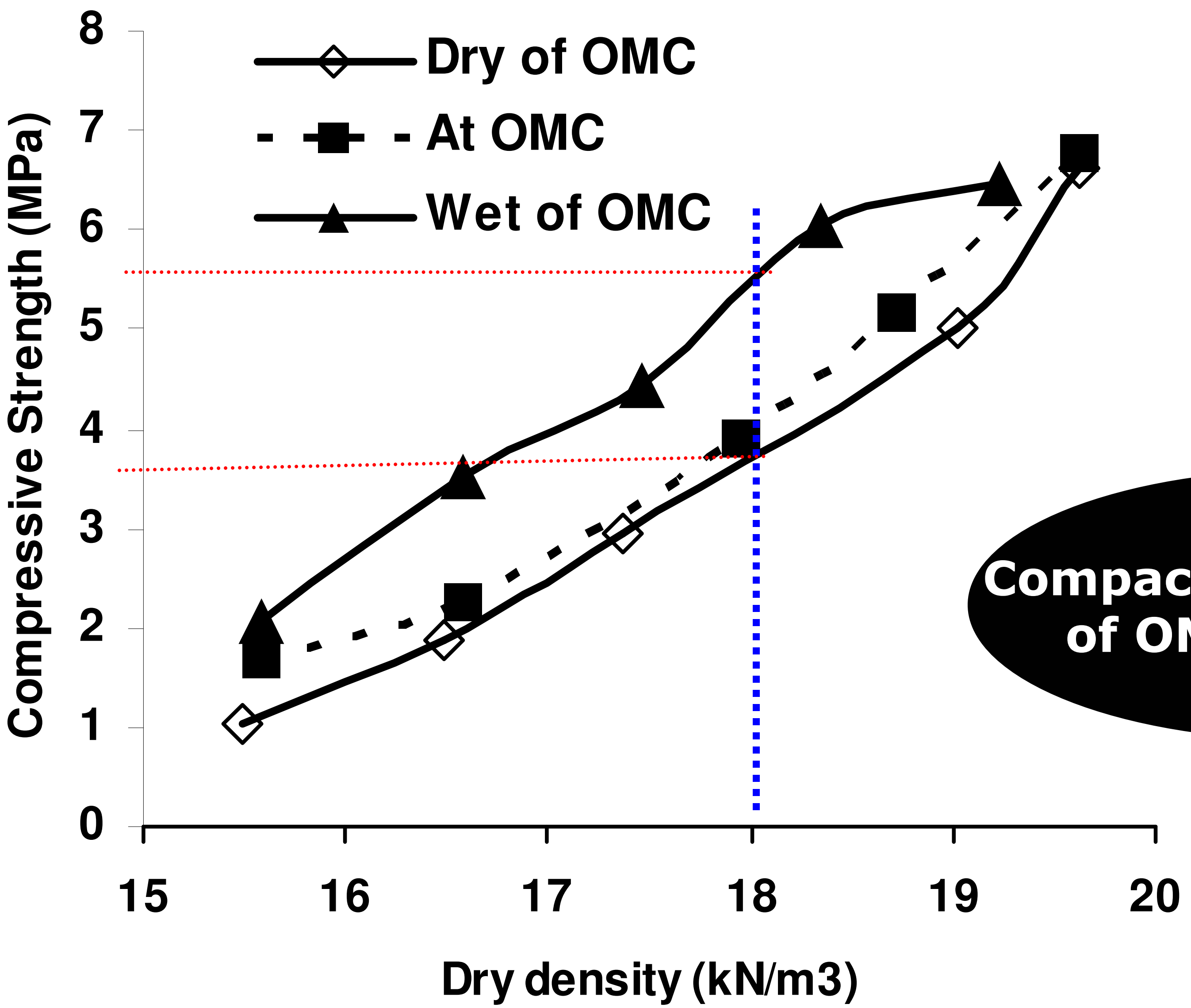
Strength versus clay fraction





Weight loss versus clay content of the block

Reddy et al, J Mat. in Civil Engg. 2007



Compaction on wet side of OMC is superior

Source: Reddy & Kumar, Materials & Structures 2010

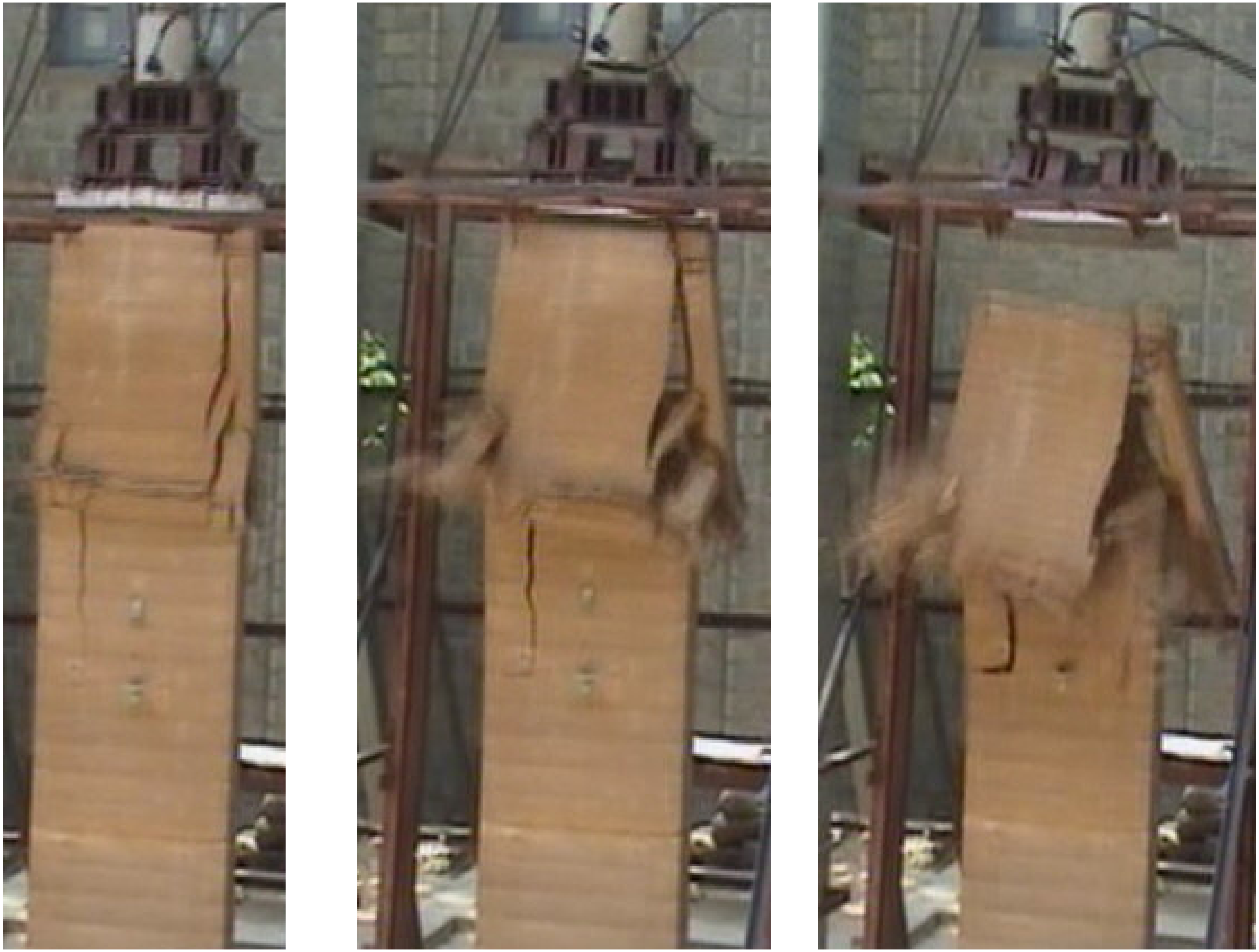
Specifications	Limiting values
Material composition a) Clay fraction (<0.002mm) b) Sand &silt fraction (0.002 – 4.75mm)	 10 – 15% 85% – 90%
c) Block thickness (machines using static compaction process) d) Dry density of the block e) Weight loss (ASTM D559 test) f) Linear expansion on saturation Stabiliser to Clay ratio: (a) Soils with non-expansive clay minerals (b) Soils with expansive clay minerals	<100 mm > 1.80 gm/cc < 3% < 0.05% ≥ 0.50 ≥ 0.75

Cement stabilised rammed earth (CSRE) construction

Mix

Small metal formwork

Wooden formwork (longer dimension)



Reddy & Kumar, J Mat. In Civil Engg. 2010

Strength of rammed earth (CSRE) & masonry

Rammed earth wallette

Masonry wallette

	CSRE	Masonry with CSRE bricks
Compressive strength (MPa)	6.0	4.0

Source: Reddy & Kumar, Masonry International 2009

Cement stabilised Rammed earth

Courtesy: Kiran Vaghela and Sandeep Virmani
Kutch Nav Nirman Abhiyan, Gujarat


11 12 2008
Source: Dr. Schroeder
Bauhaus University Germany

Rammed earth house, Gujarat

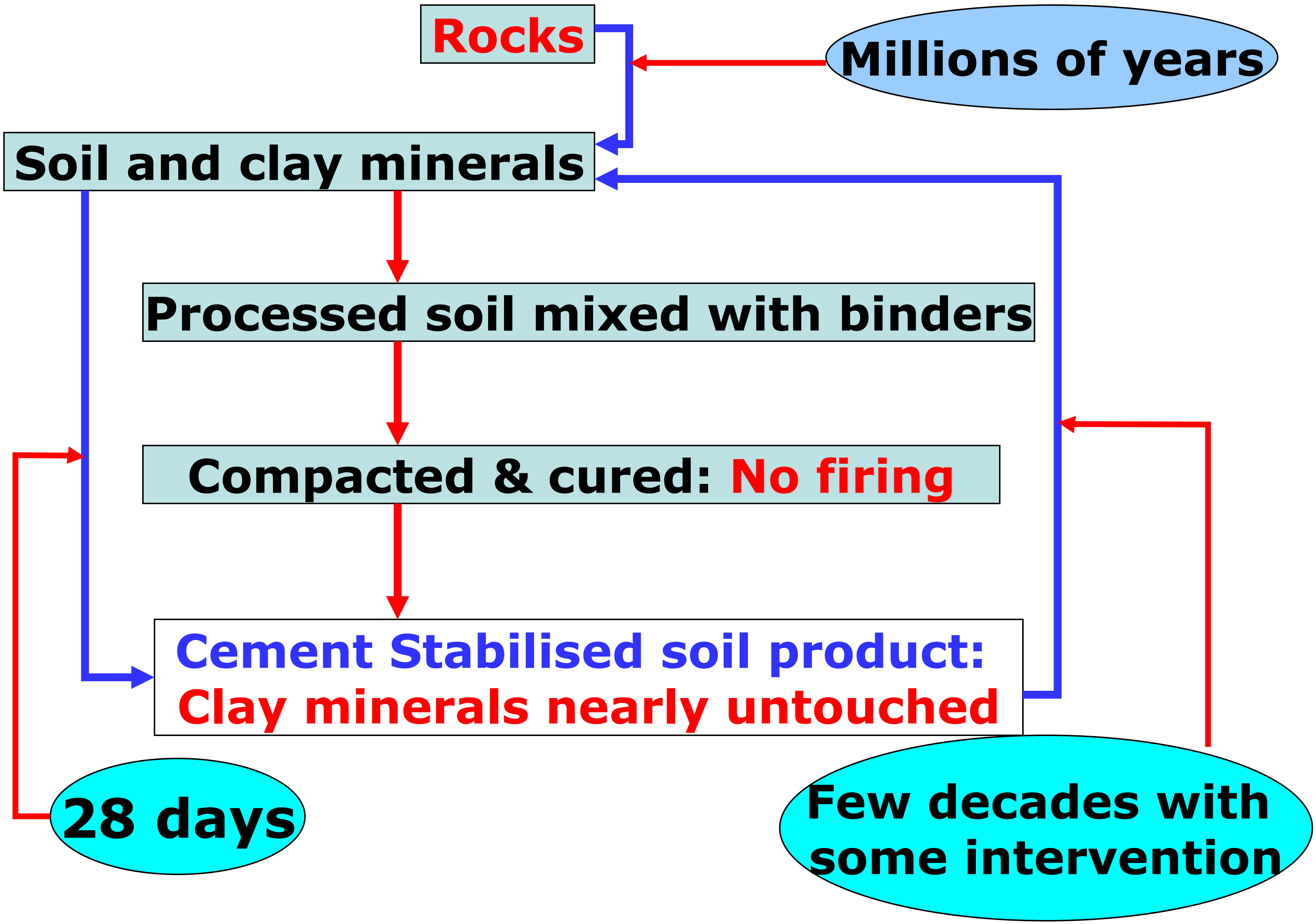
Source:
Kiran Vaghela and
Sandeep Virmani
Kutch Nav Nirman Abhiyan,
Gujarat

Source:
Kiran Vaghela and
Sandeep Virmani
Kutch Nav Nirman Abhiyan
Gujarat

CSRE walls under construction – 3 storey buildings


3 Storey Rammed earth school building

Life cycle of cement stabilsed earth product



Burnt clay bricks: Clay is destroyed
....re-cycling as soil not possible

Cement Stabilised Soil block:
Clay intact, aggregation of silt & sand particles
.... Recycling as soil possible

Fly ash blocks

Fly ash blocks/bricks for masonry

- **Basic ingredients**:

  Fly ash, sand, lime or lime & cement
- **Cementation is due to lime-fly ash reactions**
- **Lime-fly ash reactions are slow & hence need longer curing periods under ambient curing conditions**
- **Need for accelerating lime-fly ash reactions**

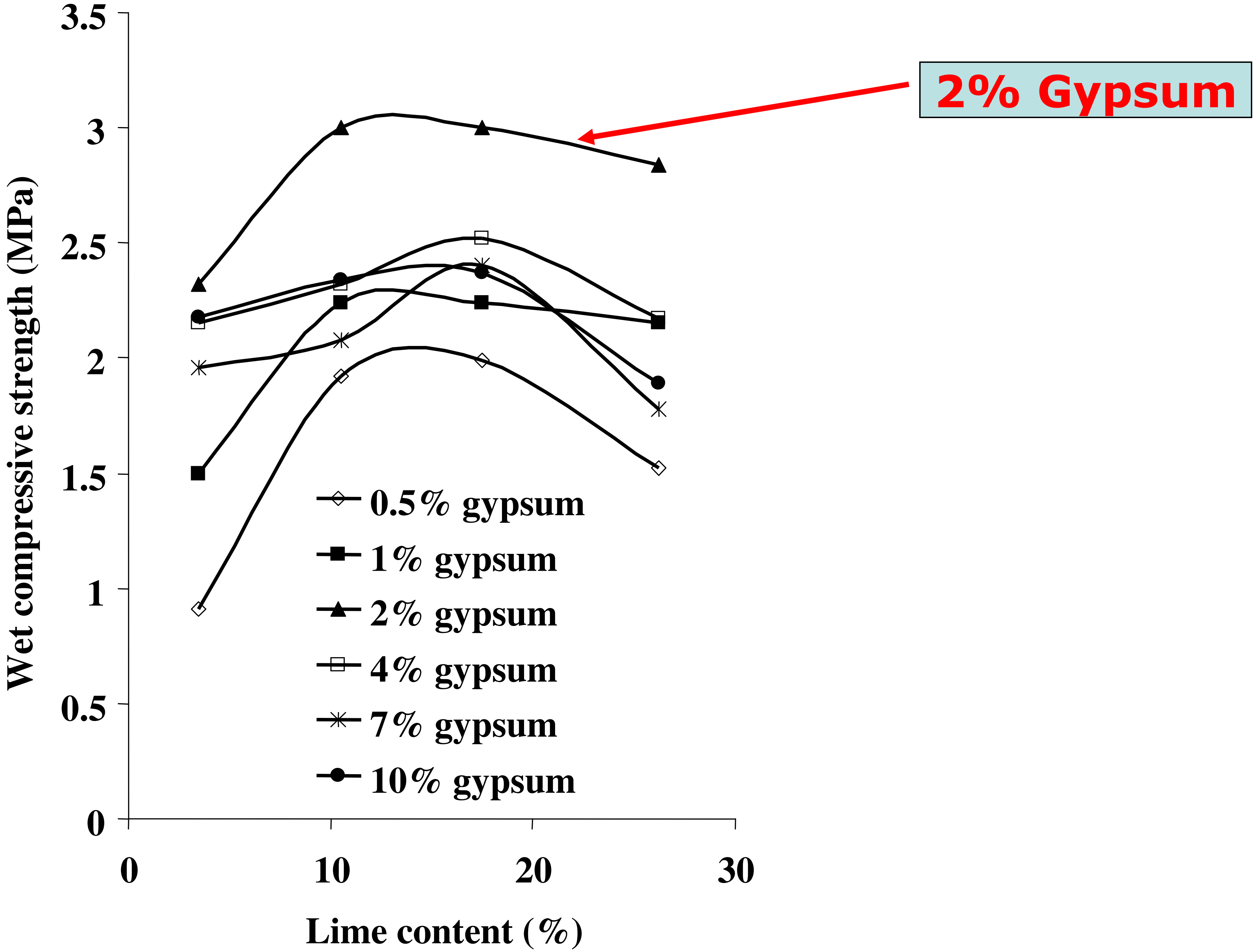
How to accelerate lime-fly ash reactions or rate of strength gain?

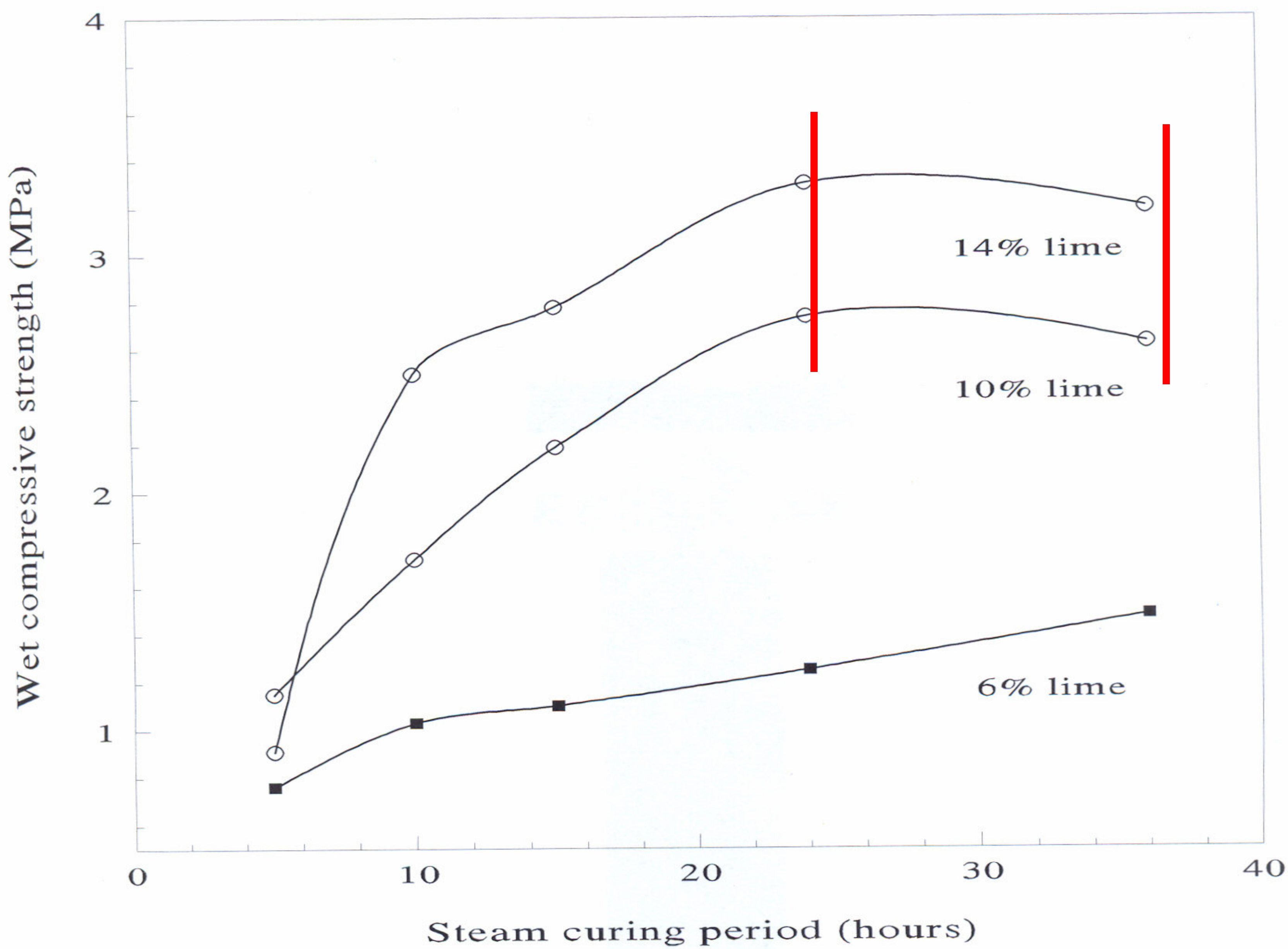
Use of additives like gypsum

Optimum dosage of additives?

Steam curing

Period & tempr. of steam curing, Production systems?


2% Gypsum
Wet compressive strength (MPa)
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
Lime content (%)
0.5% gypsum
1% gypsum
2% gypsum
4% gypsum
7% gypsum
10% gypsum



Wet compressive strength (MPa)
Steam curing period (hours)
14% lime
10% lime
6% lime
4
3
2
1
0
10
20
30
40

Strength of steam cured & moist cured specimens

Details	Wet Comp. Strength (MPa)			
Lime (%)	6	10	14	18
24 hour steam curing at 80^{o}C	1.84	2.65	2.92	3.10
28 days wet burlap curing	0.29	1.05	0.95	1.00

- 3 to 6 times difference in strength between steam curing & 28 day water curing
- Block is ready within 2 days after casting

Steam cured fly ash blocks

Lime-pozzolana reactions are slow at ambient temperatures & can be accelerated by steam curing at 80^{O}C

Mixing raw Materials → **Pressing into dense block** → **Steam curing**

Mixing raw Materials ↑
- Sand
- Fly ash
- Lime/cement

Pressing into dense block ↑
Using a machine

Steam curing ↑
At 80^{O}C
Efficient
Steam chamber

Steam cured fly ash block unit

Compressive strength (wet) of blocks:
8 – 11MPa

Fly ash block load bearing building

Steam cured block building at IISc Bangalore 1998

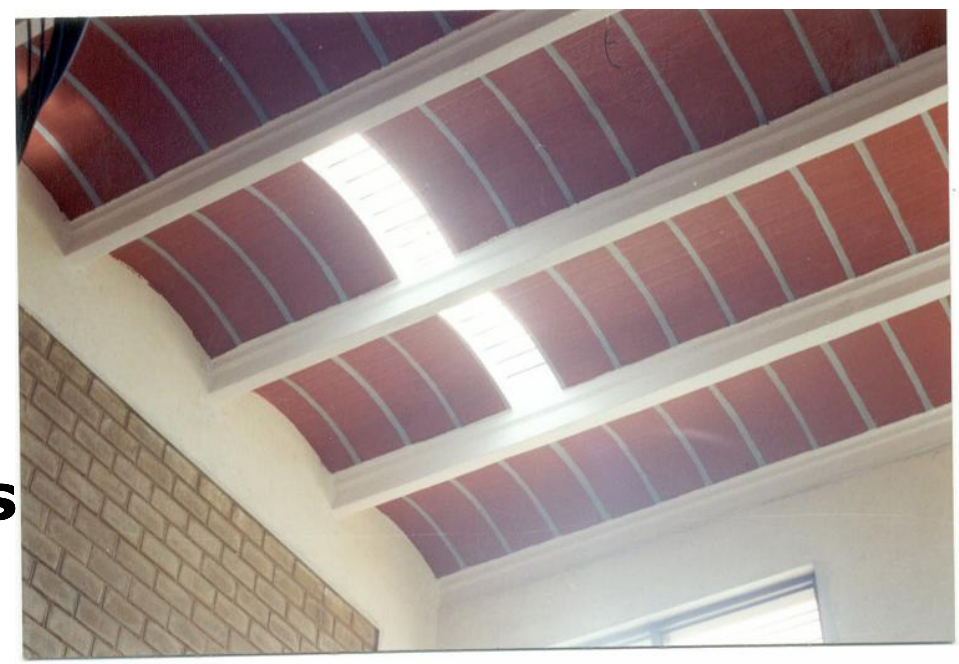
Fly ash block houses

Tsunami rehabilitation housing, T. N.

Examples of Roofing Systems

CSSB Block
Filler Slab Roof

Composite jack-arch roofs



Masonry vaults

Masonry domes

Straw-Bales, France

Straw-Bale Construction

Source: www.StrawBale.com

Straw-Bale Construction process

Source:
www.celebratebig.com/.../index.htm

Straw-Bale House

Source: www.StrawBale.com

Source:
www.glubam.com/content/products

Bridge girders
using GluBam

House using GluBam

House using GluBam, China

Source: www.glubam.com/content/products

Utilise solid wastes for construction materials

Type of solid waste	… X 10^6 t/year
Fly ash	112
Coal mine wastes	60
Lime stone waste	18
Construction waste	15
Blast furnace slag	11
Iron ore tailings	11
Copper mine tailings	4
Marble dust	6
Red mud, lime sludge, phospho-gypsum, zinc tailings, kiln dust, gold mine tailings etc + Organic wastes, MSW, etc …………………………	20
Inorganic industrial/mine wastes (total)	~300 X 10^6 t/year

Source: Gupta (1998), Ramachandra & Saira (2004), Asokan Pappu et al (2007)

- 200×10^6 tons of iron ore tailings stored in dams
- Iron ore Tailings: Potential sand substitute for constructions
- Can meet sand requirement of Karnataka state for several decades

Non-organic solid wastes

- **Annual production: ~300 x 10^6 t (India)**
- **Accumulated solid wastes (approx. estimates)**

  Fly ash & Bottom ash: 2000 x 10^6 t

  Coal mine wastes: 3000 x 10^6 t

  Mine tailings & others: ???

Energy in masonry/walls

Type of masonry / wall	Energy (GJ)	
	per tonne	per m^3
1. Burnt clay brick	1.25 – 2.40	2.00 – 3.40
2. Stabilised mud block	0.25 – 0.35	0.50 – 0.60
3. Hollow concrete block	0.80 – 1.00	1.30 – 1.60
4. Fly ash brick	0.60 – 0.85	1.00 – 1.35
5. Stabilised rammed earth wall	0.25 – 0.35	0.45 – 0.60
6. Laterite, natural stone	0.00 – 0.10	0.15 – 0.30
7. unstabilised rammed earth,	0.00 – 0.10	0.00 – 0.18
8. Adobe, cob, pure mud walls	0.00 – 0.00	0.00 – 0.10

Embodied energy

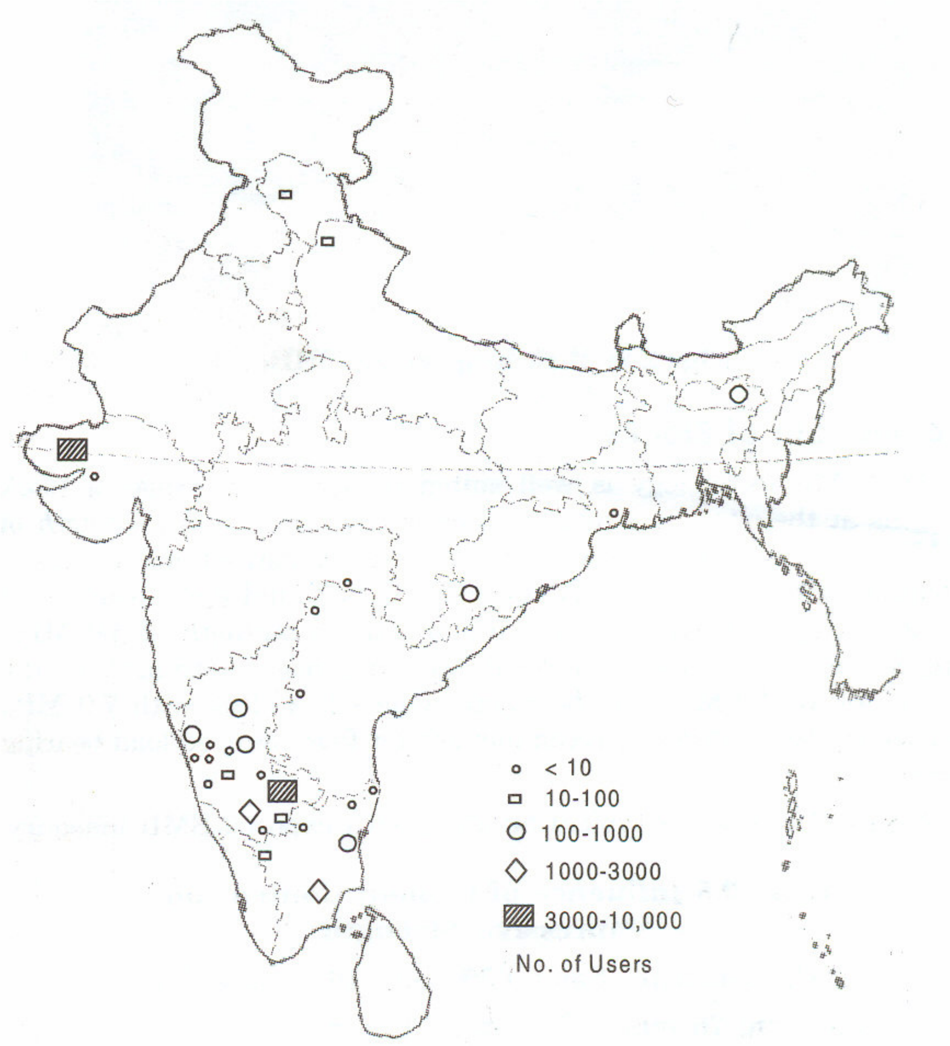
load bearing masonry 2 storey residential building (India)

Total built-up area = 150 m^2

Specifications of the building	Total embodied energy of masonry walls (GJ/m^2)		
	Burnt clay brick masonry	CSSB masonry	
Spread footing foundation, load bearing walls, R. C. floor & roof slab, concrete tile floor	3.00	1.6	

R. C. Framed structure:

- Embodied energy: 4.5 – 9 MJ/m^2



Spread of low carbon building technologies in INDIA

>50,000 users of these technologies

>5,000 houses in the Bangalore City

Technology outreach to large sections of society:

~ 700 x 10^6 US$ invested by public

~ 1.5 x 10^6 t carbon emissions saved (worth ~20 x 10^6 US$)

Thank you

How is CSSB different from Burnt Clay Brick?

Details	SSB	Burnt Brick
Raw material	Soil	Soil
Binding mechanism	Cement, Lime etc.	Firing clay (>800ºC)
Clay mineral	Nearly intact in Cement SSB	Destroyed
Getting back clay	Possible	Not possible
Energy consumption	0.25 – 0.30 MJ/kg	1.0 – 1.60 MJ/kg
Size & shape	Perfect	warped
Strength	Can be designed	Fixed

Type of stabilization	Atterberg's Limits		Soil Composition		
	Liquid Limit (%)	Plasticity Index	Sand	Silt	Clay
Soil: No Stabilization	33.3	25.6	44	36.4	19.6
7% Cement	30	19.6	57.7	33.6	8.7
7% Lime	23	13.6	71	26.3	2.7
15% Lime	15	3.1	80.7	18.9	0.4