Supplementary material

Content

1. Distribution of household size in India

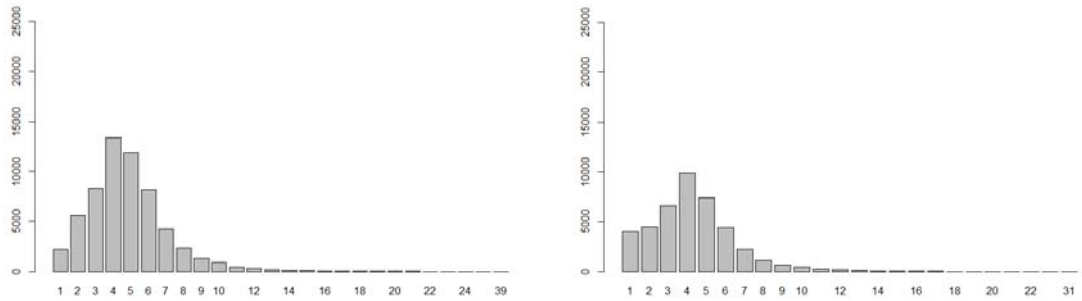

Figure SM1 - Distribution of household size in India: rural areas (left) and urban areas (right).

Note: Data elaborated from: IHSN - International Household Survey Network, India - National Sample Survey 2011-2012 (68th round), (2013). http://catalog.ihsn.org/index.php/catalog/3281

2. Weather data

Table SM1 - Climatic zones and monthly statistics for daily average air temperature and relative humidity.

Climatic zone	Location	Parameter	Monthly statistics*											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Warm-humid	Chennai	T_{air} (°C)	24.2	25.8	28.2	30.1	31.5	31.1	30.3	29.4	29.2	27.7	25.7	24.9
		RH (%)	*77*	*73*	*80*	*73*	*69*	*68*	*71*	*71*	*75*	*83*	*84*	*77*
Composite	Allahabad	T_{air} (°C)	14.7	18.9	24.0	30.9	33.0	33.1	29.5	29.3	28.2	25.7	21.3	16.6
		RH (%)	*67*	*70*	*51*	*37*	*51*	*57*	*80*	*81*	*86*	*67*	*61*	*78*
Hot-dry	Jodhpur	T_{air} (°C)	16.9	17.1	24.6	30.9	31.2	33.9	30.5	28.9	30.2	27.4	22.8	17.7
		RH (%)	*54*	*35*	*32*	*30*	*48*	*50*	*66*	*70*	*51*	*43*	*52*	*47*
Temperate	Bangalore	T_{air} (°C)	20.8	23.4	26.0	27.6	26.8	23.8	23.4	22.7	23.3	22.9	21.8	20.5
		RH (%)	*66*	*45*	*52*	*49*	*68*	*77*	*75*	*85*	*78*	*80*	*72*	*71*
Cold	Dehradun	T_{air} (°C)	11.2	14.0	18.9	24.2	27.3	28.8	26.1	25.9	25.0	20.7	16.7	13.5
		RH (%)	*66*	*69*	*58*	*56*	*54*	*61*	*88*	*86*	*78*	*78*	*63*	*63*

*Source: Indian Society of Heating Refrigerating and Air-Conditioning Engineers (ISHRAE), Indian Weather Data, (2005). https://energyplus.net/weather.

3. Life Cycle Energy (LCE) of housing archetypes in different climatic zones

Table SM2 reports the complete LCE results for the three archetypes in the reference case under different climatic conditions and highlights the contribution of embodied energy (EE) and operational energy (OE).

Table SM2 - LCE results for different archetypes – climatic zones in India.

Archetype	Climate	LCE (GJ/m^{2}y)					Contribution (%)	
		Embodied	Cooling	Heating	Lighting	Total	EE	OE
Single-storey	Warm-Humid	0.105	0.321	0.000	0.024	0.450	23	77
	Composite	0.105	0.256	0.014	0.024	0.399	27	73
	Hot-dry	0.105	0.223	0.001	0.024	0.352	30	70
	Temperate	0.105	0.156	0.000	0.024	0.284	37	63
	Cold	0.105	0.144	0.055	0.024	0.327	32	68
Two-storey	Warm-Humid	0.096	0.223	0.000	0.024	0.343	29	71
	Composite	0.096	0.173	0.012	0.024	0.304	33	67
	Hot-dry	0.096	0.153	0.001	0.024	0.274	36	64
	Temperate	0.096	0.103	0.000	0.024	0.223	45	55
	Cold	0.096	0.095	0.055	0.024	0.270	36	64
Multi-storey	Warm-Humid	0.086	0.136	0.000	0.018	0.240	36	64
	Composite	0.086	0.222	0.009	0.018	0.222	39	61
	Hot-dry	0.086	0.208	0.001	0.018	0.208	42	58
	Temperate	0.086	0.164	0.000	0.018	0.164	53	47
	Cold	0.086	0.199	0.054	0.018	0.212	43	57

4. Parametric analysis: Additional results

The results of the LCE for different household sizes of the three archetypes under composite climate conditions are reported in Table SM3.

Table SM3 - LCE results for different archetypes by changing the household size (composite climate).

Archetype	Dwelling size (m^2)	LCE (GJ/m^{2}y)			Difference with reference (%)
		Embodied	Operational	Total	
Single-storey	30	0.111	0.406	0.517	43
	40*	0.105	0.256	0.361	0
	50	0.101	0.331	0.432	20
	60	0.099	0.380	0.479	33
Two-storey	30	0.108	0.314	0.422	58
	40*	0.096	0.171	0.267	0
	50	0.092	0.212	0.303	14
	60	0.089	0.220	0.310	16
Multi-storey	30	0.104	0.233	0.337	67
	40*	0.093	0.109	0.202	0
	50	0.089	0.135	0.224	11
	60	0.086	0.141	0.227	12

Note: *Reference case.

Table SM4 shows the results of the energy savings calculation for the following building envelope measures: P1 – masonry of hollow concrete blocks; P2 – masonry of aerated concrete blocks; P3 – insulation of external walls with EPS (5 cm); P4 – Roof insulation with EPS (5 cm). Results are reported for single energy savings measures and for the combination of measures P1-P3-P4 for different archetypes in a composite climate

Table SM4 – Results of the parametric analysis on building envelope measures (composite climate).

Archetype	Building envelope energy savings measures	Difference with reference (%) EE	OE	LCE
Single-storey	P1	-29%	-3%	-13%
	P2	-24%	-7%	-14%
	P3	3%	-8%	-4%
	P4	0%	-27%	-16%
	P1-P3-P4	**-26%**	**-37%**	**-33%**
Two-storey	P1	-33%	-3%	-15%
	P2	-27%	-12%	-18%
	P3	4%	-15%	-7%
	P4	0%	-21%	-12%
	P1-P3-P4	**-29%**	**-20%**	**-24%**
Multi-storey	P1	-20%	-4%	-11%
	P2	-16%	-17%	-17%
	P3	2%	-20%	-11%
	P4	0%	-16%	-9%
	P1-P3-P4	**-18%**	**-16%**	**-17%**

Figure SM2Figure SM4 show detailed LCE results for the three archetypes under different climates for both the reference (Ref) and energy savings (Min) cases.

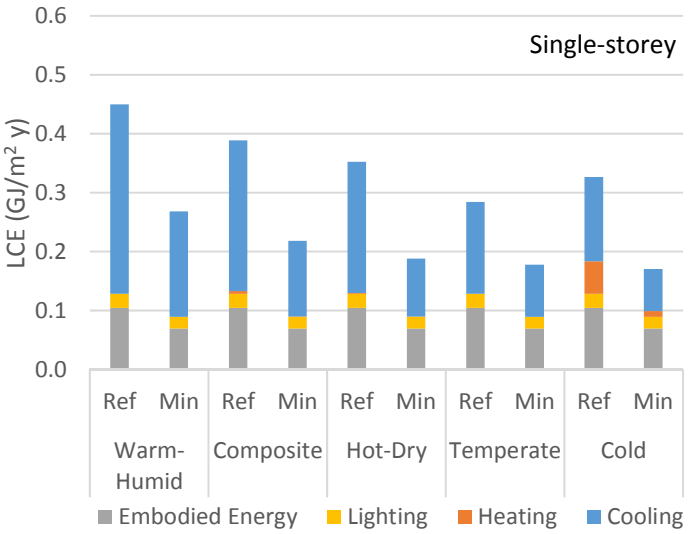

Figure SM2 - LCE results for the single-storey archetype in the reference case (Ref) and after applying the energy savings measures (Min) for different climatic zones.

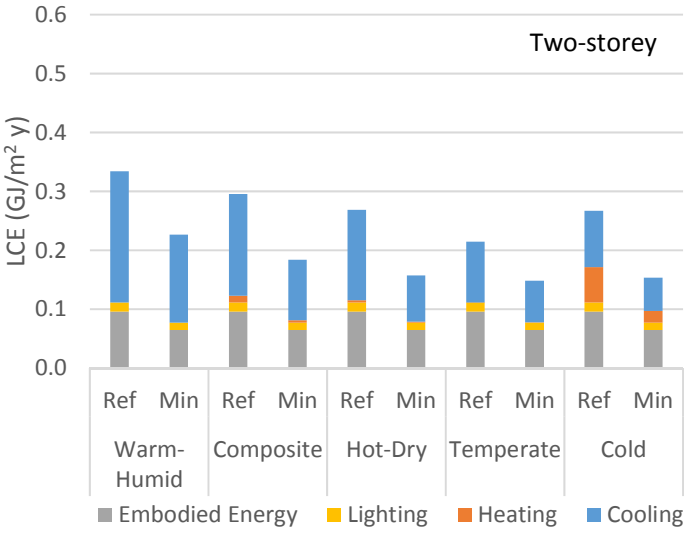

Figure SM3 - LCE results for the two-storey archetype in the reference case (Ref) and after applying the energy savings measures (Min) for different climatic zones.

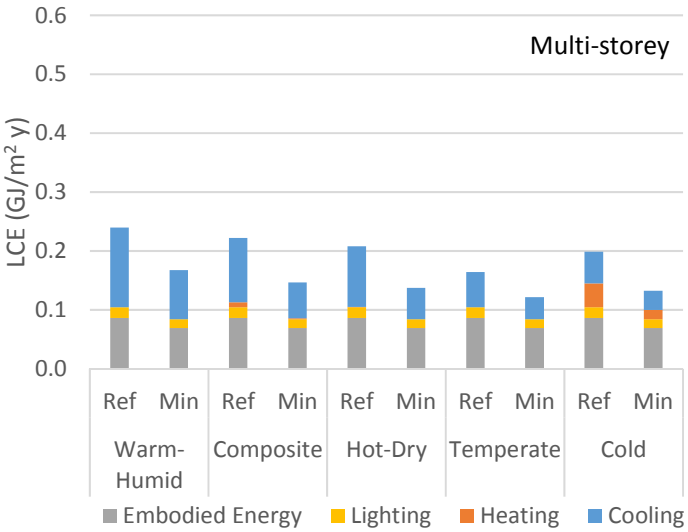

Figure SM4 - LCE results for the multi-storey archetype in the reference case (Ref) and after applying the energy savings measures (Min) for different climatic zones.

5. Life Cycle Cost (LCC): comparison between affordable and conventional rural archetypes

This section describes the method and results of the LCC calculation in order to compare the affordable and conventional rural archetypes. We used the following equation to calculate global costs in line with similar studies (cited in the paper) and technical standards[1]:

$$C_G(t) = C_I + \sum_j \left[\sum_{i=1}^{t} \left(C_{a,i}(j) \cdot R_d(i) \right) - V_{f,t}(j) \right]$$

where $C_G(t)$ is the global cost, C_I the initial investment cost, $C_{a,i}$ the annual cost for the component j, R_d the discount rate for the year i and $V_{f,t}$ the final value of component j at the end of the calculation. The discounting factor is calculated with the following equation:

$$R_d(i) = \left(\frac{1}{1 + R_r} \right)^i$$

where R_d is the discounting factor for the year i and R_r is the discount rate. Two discount rates were assumed: 4% (collective perspective) and 10% (private perspective).

We included in the calculation the construction and operational phase. For the construction phase, the cost of construction works and building materials were identified based on the Delhi Schedule of Rates[2] for 2014 and are reported in Table SM5. Technological systems, piping and cabling are not included in the assessment. Unitary costs were then multiplied by the estimated quantity of material in the building. For the operational phase, we calculated the cost for electricity by multiplying the final energy for different end-uses by the unitary cost of 0.08 €/kWh assumed for 2014. The calculation included the case of reference and extended cooling schedules.

Table SM5 – Unitary cost of construction works.

Material	Unit	Unitary cost* *(€/unit)*
Fired brick masonry (with cement mortar)	m^3	68.67
Cast concrete	m^3	79.66
Gravel (Crushed stones)	m^3	12.97
Reinforced concrete (2% Steel included)	m^3	83.71
Plaster (Cement-sand)	m^2	2.55
Rammed earth masonry**	m^3	1.54
Floor tiles	m^2	7.78
Roof tiles (pitched roof)	m^2	3.75
Roof tiles (flat roof)	m^2	14.00
Bitumen	m^2	1.75
Wood (Roof structure)	m^3	575.18
Wood (Door and window framing)	m^2	17.09
Glass (Single Glazing)	m^2	26.83
Earth excavation	100 m^2	62.30

Notes: *Based on the Delhi Schedule of Rates 2014; currency exchange rate conversion Rupee-Euro for 2014 assumed at 0.01235. **Rammed earth calculated on the basis of the raw material cost, increased to include the construction cost.

[1] European Committee For Standardization (CEN), Energy performance of buildings - Economic evaluation procedure for energy systems in buildings - European Standard EN 15459 (2007).
[2] Government of India - Central Public Works Department, Delhi Schedule Of Rates, (2014) 442.

Table SM6 reports the results of the construction and annual operation cost calculation. Regarding construction costs, the affordable construction has costs 25% lower than conventional construction. Table SM7 shows the results of the LCC calculation assuming a service life equal to 50 years for both archetypes and varying interest rates and cooling schedules. In Table SM8, a reduced service life of 40 years was assumed for the affordable construction and the calculation was carried out for a time horizon of 40 years, taking into consideration a residual value for the conventional option in order to account for the extra service life.

Table SM6 – Construction cost and annual operational cost per floor surface unit.

Case	Construction cost	Operational cost (Cooling schedule*)
	(€/m²)	*(€/m²y)*
Affordable construction	121.93	5.73 (R)
		9.15 (E)
Conventional construction	162.57	6.32 (R)
		8.56 (E)

Note: * Code for cooling schedules: R: reference schedule; E: Extended schedule.

Table SM7 – LCC per floor surface unit. Time horizon and service life of buildings assumed as 50 years.

Case	Construction cost	Operational cost (Cooling schedule*)	LCC	Difference with conventional construction
	(€/m²)	*(€/m²)*	*(€/m²)*	*(%)*
Discount rate: 4%				
Affordable construction	121.93	123.10 (R)	245.02	-18%
		196.51 (E)	318.44	-8%
Conventional construction	162.57	135.72 (R)	298.29	-
		183.93 (E)	346.50	-
Discount rate: 10%				
Affordable construction	121.93	56.81 (R)	178.74	-21%
		90.70 (E)	212.63	-14%
Conventional construction	162.57	62.64 (R)	225.21	-
		84.89 (E)	247.46	-

Note: * Code for cooling schedules: R: reference schedule; E: Extended schedule.

Table SM8 – LCC per floor surface unit. Service life of buildings assumed as 50 year for the conventional construction and 40 years for the affordable construction; time horizon for calculation assumed as 40 years.

Case	Construction cost	Residual value	Operational cost (Cooling schedule*)	LCC	Difference with conventional construction
	(€/m²)	*(€/m²)*	*(€/m²)*	*(€/m²)*	*(%)*
Discount rate: 4%					
Affordable construction	121.93	0.00	113.41 (R)	235.34	-7%
			181.06 (E)	302.99	+2%
Conventional construction	162.57	34.75	125.05 (R)	253.76	-
			169.46 (E)	298.17	-
Discount rate: 10%					
Affordable construction	121.93	0.00	56.04 (R)	177.96	-19%
			89.46 (E)	211.38	-13%
Conventional construction	162.57	3.69	61.78 (R)	220.76	-
			83.73 (E)	242.71	-

Note: * Code for cooling schedules: R: reference schedule; E: Extended schedule.