Scope of Cool Roofs in India

An Analysis on the

Changes in Residential Roof Construction in India

(2001 to 2011)

For

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1. Background

The Indian construction industry is an integral part of the economy and is poised for solid growth due to industrialisation, urbanisation and economic development together with people's expectations of improved living standards. The construction sector employs approximately 31 million people, accounting for some 6-8% of GDP and, after agriculture, is the largest employment sector in the country.

The construction industry in general has been growing at 9-11% year on year, primarily due to the strength of increased domestic and international manufacturing activities and industrial growth. There have also been increased levels of investment - especially by the Government - in infrastructure and real estate projects (EC Harris Research. 2011).

According to the final figures of Census 2011, known as the House Listing and Housing Census, the number of households increased from 191 million to 246 million, registering growth of 28.5% since 2001. The population of India increased from 1.02 billion to 1.21 billion, registering growth of 17.7% in its 35 States and Union Territories since 2001.

As per above mentioned census, there is a substantial improvement in the quality of housing both in rural and urban areas. Thus, there is an improvement in the construction material used for roofs, walls and floors. This report reviews the trends in the Indian housing market with a focus on construction practices, building codes (Energy Conservation Building Code - ECBC) that improve the thermal comfort of occupants and energy efficiency in buildings.

Though conditions vary by region, India's climates and building types make roofs the most important building envelope component for achieving energy efficiency and thermal comfort. In the light of this, this study was limited to the analysis of data on roofs alone. The other building envelops like wall and floor would be dealt with separately.

The decadal percentage change in households, by construction material of roofs under 5 categories separately under rural and urban set ups, was also linked to decadal percentage change in respective population figures.

2. Study Data Analysis

2.1 Procurement of Study Data

For the analysis, data for the two base years, 2001 and 2011, were procured from the website of the "Census of India", Ministry of Home Affairs, Government of India (http://www.devinfolive.info/censusinfodashboard/website/index.php/pages/construction_roof/total/HouseHolds/IND). It includes the following roof parameters and variables (Table 1):

Table 1: Variables and Indices of Study of Change in Households by material of roof

S. N.	Variable	Indices Available/Selected
1.	Year	a) 2001 b) 2011

2.	Construction materials of roof (5 categories)	a) Grass/Thatch/Bamboo/Wood/Mud/Plastic/Polythene b) Tiles (Hand and Machine made) c) G.I./Metal/Asbestos sheets , d) Concrete e) Any other material (Burnt Brick, Stone/Slate, Other materials)
3.	Set up	a) Rural b) Urban c) Total
4.	Climatic Zone (ECBC)	a) Hot and dry b) Cold c) Warm & Humid d) Composite e) Temperate
5.	Total Population	a) Rural b) Urban c) Total

The national level scenario of decadal change in the number of households along with comparative population figures is given in Table 2 below:

Table 2: National Level Change in Households by construction material of roof

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	3,88,60,909	41,42,619	4,30,03,528	3,45,39,160	41,41,638	3,86,80,798	-11.12	-0.02	-10.05
Tiles	5,19,58,331	1,05,47,545	6,25,05,876	4,82,19,995	1,04,23,368	5,86,43,363	-7.19	-1.18	-6.18
G.I./Metal/Asbestos	1,36,36,699	86,29,015	2,22,65,714	2,67,33,862	1,25,39,390	3,92,73,252	96.04	45.32	76.38
Concrete	1,52,74,215	2,27,10,486	3,79,84,701	3,07,46,938	4,09,12,361	7,16,59,299	101.30	80.15	88.65
Any Other	1,86,96,315	75,07,801	2,62,04,116	2,75,86,775	1,08,49,180	3,84,35,955	47.55	44.51	46.68
Total Households	13,84,26,469	5,35,37,466	19,19,63,935	16,78,26,730	7,88,65,937	24,66,92,667	21.24	47.31	28.51
Total Population	74,24,90,639	28,61,19,689	1,02,86,10,328	83,34,63,448	37,71,06,125	1,21,05,69,573	12.25	31.80	17.69

2.2 Discrepancy in the Data

The national level scenario of decadal change in households, when presented as the SUM of all 35 States and Union Territories, it shows negligible discrepancy owing to some wrong clubbing of 2001 data in rural set up instead of urban set up, as show in Tables 3-4 below:

Table 3: National Level Change in Households shown as Sum of Individual States

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	3,88,49,720	41,53,808	4,30,03,528	3,45,39,160	41,41,638	3,86,80,798	-11.1	-0.29	-10.05
Tiles	5,19,32,746	1,05,73,130	6,25,05,876	4,82,19,995	1,04,23,368	5,86,43,363	-7.15	-1.42	-6.18
G.I./Metal/Asbestos	1,36,09,736	86,55,978	2,22,65,714	2,67,33,862	1,25,39,390	3,92,73,252	96.43	44.86	76.38
Concrete	1,51,92,513	2,27,92,188	3,79,84,701	3,07,46,938	4,09,12,361	7,16,59,299	102.38	79.50	88.65
Any Other	1,86,86,844	75,17,272	2,62,04,116	2,75,86,775	1,08,49,180	3,84,35,955	47.63	44.32	46.68
Total Households	13,82,71,559	5,36,92,376	19,19,63,935	16,78,26,730	7,88,65,937	24,66,92,667	21.37	46.88	28.51
Total Population	74,24,90,639	28,61,19,689	1,02,86,10,328	83,34,63,448	37,71,06,125	1,21,05,69,573	12.25	31.80	17.69

Table 4: Difference of Table 2 and Table 3 Showing discrepancy in Data

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	11,189	-11,189	0	0	0	0	0	0	0

Tiles	**25,585**	**-25,585**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
G.I./Metal/Asbestos	**26,963**	**-26,963**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Concrete	**81,702**	**-81,702**	**0**	**0**	**0**	**0**	**-1**	**1**	**0**
Any Other	**9,471**	**-9,471**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total Households	**1,54,910**	**-1,54,910**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 4 shows that discrepancy in the overall data is nil (as significant to two decimal digits) but it only slightly offsets the interpretations of rural and urban set ups. For all the purposes of analysis of study data, therefore Table 3 would be considered as the base-table.

2.3 Inferences Drawn on the Data

The following general inferences could be drawn from Table 3:

- The housing deficit gap in India has closed to some extent. While population has increased by 17.7%, the number of households has gone up 28.5%. This relationship is more apparent in rural areas, where population is up 12.25% and the number of households is up 21.24%). Greater growth in households indicates landless or homeless people have now access to their own houses and earnings of rural people have increased.

- As regards the construction material of roofs, under two categories namely *Grass/Thatch/ Bamboo/Wood/Mud/Plastic/Polythene* and *Tiles* (Hand and Machine made), percentage change in both rural and urban set ups is negative. This means these roof materials are being increasingly replaced, which is amply reflected by nearly 100% increase in rural set up in roof categories *G.I./Metal/Asbestos sheets* and *Concrete* with handsome increases in urban set up as well.

- Under Urban set up also, there are handsome increases in the roof categories of *G.I./Metal/Asbestos sheets* and *Concrete*.

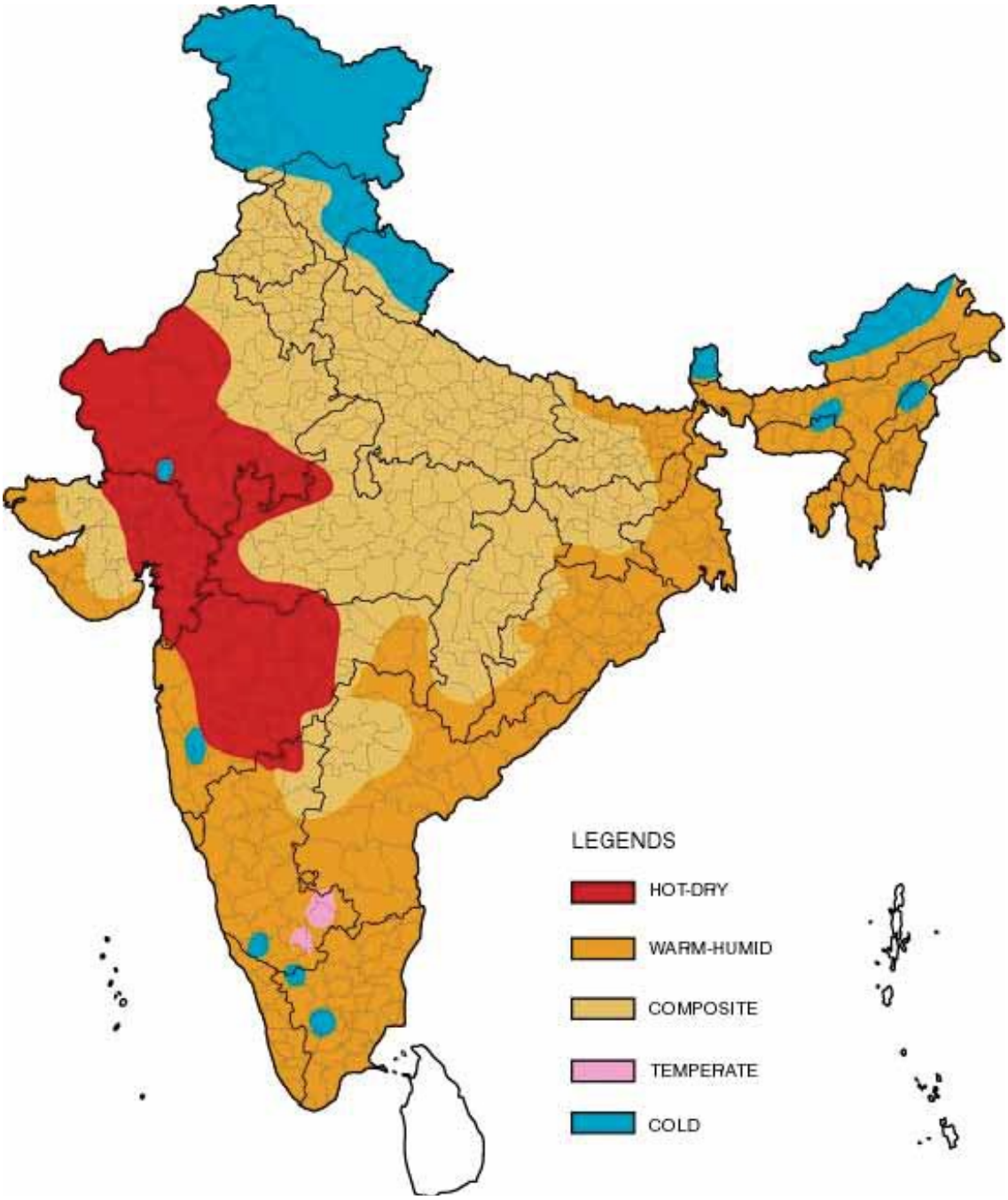
- The roof material under *Any other category (Burnt Brick, Stone/Slate, Other materials)* is rather evenly hiked by over 45%.

3. Climate Zone Analysis

3.1 Climate Zones In India - ECBC Guide

The Energy Conservation Building Code (ECBC) User Guide (July 2009, Reprinted April 2011) of the Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India is the building code and agency covering energy efficiency in buildings in India.

The ECBC classifies India into 5 climate zones as depicted on the Map 1 below and its corresponding climatic variables, as shown in Table 5, taken from their website: (http://eco3.org/wp-content/plugins/downloads-manager/upload/ECBC%20User%20Guide%20V-0.2%20(Public).pdf).



Map 1: Climate Zone Map of India (BEE)

Table 5: Classifications of Different Climate Zones in India (BEE)

Climate Zone	**Description**	**Mean Temperature (o C)**					Places (States/ districts)
		Summer Midday (High)	Summer Night (Low)	Winter Midday (High)	Winter Night (Low)	Diurnal Variation	
Hot and Dry	High temperature, Low humidity and rainfall, Intense solar radiation and a generally clear sky, Hot winds during the day and cool winds at night,	40 to 45	20 to 30	5 to 25	0 to 10	15 to 20	Rajasthan Gujarat Western Madhya

	Sandy or rocky ground with little vegetation, Low underground water table and few sources of surface water.						Pradesh Central Maharashtra etc.
Warm and Humid	Temperature is moderately high during day and night, Very high humidity and rainfall , Diffused solar radiation if cloud cover is high and intense if sky is clear, Calm to very high winds from prevailing wind directions, Abundant vegetation, Provision for drainage of water is required	30 to 35	25 to 30	25 to 30	20 to 25	5 to 8	Kerela Tamilnadu Costal parts of Orissa Andhra Pradesh etc.
Temperate	Moderate temperature, Moderate humidity and Rainfall. Solar radiation same throughout the year and sky is generally clear, High winds during summer depending on topography, Hilly or high plateau region with abundant vegetation	30 to 34	17 to 24	27 to 33	16 to 18	8 to 13	Bangalore Goa Parts of the Deccan
Cold (Sunny/ Cloudy)	Moderate summer temperatures and very low in Winter, Low humidity in cold/sunny and high humidity in cold/cloudy, Low precipitation in cold/sunny and high in cold/cloudy, High solar radiation in cold/sunny and low in cold/cloudy, Cold winds in winter, Very little vegetation in cold/sunny and abundant vegetation in cold/cloudy	17 to 24 / 20 to 30	4 to 11 / 17 to 21	(-7) to 8 / 4 to 8	(-14) to 0 / (-3) to 4	25 to 25 / 5 to 15	Jammu & Kashmir including Ladakh Himachal Pradesh Uttaranchal Sikkim Arunachal Pradesh
Composite	This applies when 6 months or more do not fall within any of the above categories, High temperature in summer and cold in winter, Low humidity in summer and high in monsoons, High direct solar radiation in all seasons except monsoons high diffused radiation, Occasional hazy sky Hot winds in summer, cold winds in winter and strong wind in monsoons, Variable landscape and seasonal vegetation	32 to 43	27 to 32	10 to 25	4 to 10	35 to 22	Uttar Pradesh Haryana Punjab Bihar Jharkhand Chattisgarh Madhya Pradesh etc.

Sources: Bansal and Minke (1988) Climatic zones and rural housing in India
Krishan et al. (2001). Climate responsive architecture: A design handbook for Energy-Efficient Buildings

3.2 Constraints to Fitting Data in Climate Zones

There is a constraint with the ECBC map of climatic zones because, as ideally required, this map is not made by allotting respective districts to their zones though the background of the map shows contours of all districts. The BEE scientist handling ECBC was contacted but, he informed that BEE has followed ISI map in enlisting districts whereas the final work on the inclusion or exclusion of any district or part thereof in a zone is the responsibility of respective State, as and when they achieve that sought-after feature.

Also, there were some anomalies like Goa which was included in Temperate zone with Bangalore, but Goa is typically a coastal zone entity falling under Warm and Humid zone. Also, some clusters like Deccan were clubbed as such and all states were not listed in Table 5. Under such a situation, the district could not be made the basic unit for fixing the households as per ECBC climate zones.

Thus, an approximation was made to by making States as the basic unit, and not districts, as retrievable index. This is based on the criterion that if more than 50% of the state area comes under a given climate zone then the entire state would be taken into that zone. For example, inclusion of entire states of Jammu & Kashmir and Uttrakhand (blue colour with light brown in the northernmost part of Map 1) will not deviate the actual scene a great deal especially in the extreme cold and hot weather months. Accordingly, the following spectrum was chosen to represent states vis-a-vis climate zones (Table 6):

Table 6: Modified Criteria for Fitting Different States in Climate Zones

S. N.	Climate Zone (ECBC map)	Constraints	States/UTs
1-3	**Hot and dry (Red)**	**Quite many districts of other zones included from 3 states (small loss on accounts of coastal parts of 2 states)**	**> Rajasthan > Gujarat > Maharashtra**
4-8	**Cold (Blue)**	**Not much of a departure in first 3 states but other 2 states overlapped (overall stable criteria)**	**> Jammu & Kashmir > Uttarakhand > Himachal Pradesh > Sikkim > Arunachal Pradesh**
9-26	**Warm & Humid (Orange)**	**Not much of a departure**	**Karnataka/Kerala/ Tamil Nadu/ Andhra Pradesh/ Orissa/ West Bengal/ Assam/ Manipur/ Meghalaya/ Mizoram/ Nagaland /Tripura/ Goa/ Andaman & Nicobar/ Dadra & Nagar Haveli/ Daman and Diu/ Lakshadweep/ Pondicherry**
27-35	**Composite (Brown)**	**Not much of a departure (Barring inclusion in Rajasthan)**	**Punjab/ Haryana /Uttar Pradesh/ Madhya Pradesh/ Chhattisgarh/ Jharkhand/ Bihar/ Chandigarh/ Delhi**
	Temperate (Pink)	**These represented district level entities for which data is neither available nor feasible.**	**Not represented**

3.3 Presentation of Data by Climate Zone

The overall scenario of decadal percentage change in households under stated categories of roof material is shown above in Table 3. As outlined in Section 3.2, climate zone wise details of decadal percentage change in households is presented below in Tables 7-8 whereas change in household by category roof material in different zones are shown in Tables (Tables 9-12) except the Temperate zone for which there is no data.

Table 7: Percentage Change in Households by Climate Zones

Climate Zone	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Hot and Dry	2,40,36,287	1,40,13,145	3,80,49,432	2,92,72,418	1,93,21,183	4,85,93,601	21.78	37.88	27.71
Cold	37,11,258	9,84,817	46,96,075	45,01,396	13,77,086	58,78,482	21.29	39.83	25.18
Warm and Humid	5,65,66,893	2,24,26,758	7,89,93,651	6,50,90,860	3,47,89,523	9,98,80,383	15.07	55.13	26.44
Composite	5,39,57,121	1,62,67,656	7,02,24,777	6,89,62,056	2,33,78,145	9,23,40,201	27.81	43.71	31.49
Temperate									
Total Households	13,82,71,559	5,36,92,376	19,19,63,935	16,78,26,730	7,88,65,937	24,66,92,667	21.37	46.88	28.51
Total Population	74,24,90,639	28,61,19,689	1,02,86,10,328	83,34,63,448	37,71,06,125	1,21,05,69,573	12.25	31.80	17.69

Table 8 shows decadal percentage change in households vis-à-vis population in each climate zone. It makes amply clear that the gap between people having their own houses and homeless people has reduced by some extent. Also, more homeless people have now access to their own houses especially in the rural set up on account of their enhanced earnings and thus better social status.

Table 8: Climate Zone Wise Percentage Decadal Change: Households Vs. Population

Climate Zone	% Decadal Change (2001 vs. 2011)					
	Rural Households	Rural Population	Urban Households	Urban Population	Total Households	Total Population
Hot-Dry	21.78	12.95	37.88	27.80	27.71	18.28
Cold	21.29	14.80	39.83	36.98	25.18	19.49
Warm & Humid	15.07	4.39	55.13	35.68	26.44	13.42
Composite	27.81	18.45	43.71	30.13	31.49	21.18
Temperate						
Total	21.37	12.25	46.88	31.80	28.51	17.69

3.3.1 Data under "Hot and Dry" Climate Zone

Out of 35 States and Union Territories, the hot and dry climate zone entails three major States of western India namely Rajasthan, Gujarat and Maharashtra. The data is presented in Table 9 below:

Table 9: Percentage Change in Households by construction material of roof (Hot and Dry Climate Zone)

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	35,08,766	4,46,541	39,55,307	31,55,072	4,80,616	36,35,688	-10.08	7.63	-8.08
Tiles	99,59,860	18,67,793	1,18,27,653	93,10,987	14,75,440	1,07,86,427	-6.51	-21.01	-8.80

G.I./Metal/Asbestos	46,67,907	39,79,752	86,47,659	72,84,732	45,47,423	1,18,32,155	56.06	14.26	36.82
Concrete	20,54,702	59,33,697	79,88,399	37,64,981	1,01,65,528	1,39,30,509	83.24	71.32	74.38
Any Other	38,45,052	17,85,362	56,30,414	57,56,646	26,52,176	84,08,822	49.72	48.55	49.35
Total Households	2,40,36,287	1,40,13,145	3,80,49,432	2,92,72,418	1,93,21,183	4,85,93,601	21.78	37.88	27.71
Total Population	13,08,11,227	7,32,45,605	20,40,56,832	14,77,51,035	9,36,11,427	24,13,62,462	12.95	27.80	18.28

In the Hot and Dry Climatic zone, both roof categories viz ***Grass/Thatch/Bamboo*** and ***Tiles*** have gone down marginally (- 8%) whereas there is a handsome increase in roof categories viz ***G.I./Metal/Asbestos*** and ***Concrete*** especially in rural set up. This indicates the improved economic status of the people in the rural set up and need for sturdier house to cope up with harsh climate.

3.3.2 Data under "Cold" Climate Zone

Out of 35 States and Union Territories, the cold climate zone entails five States (4 major and one minor) in the North and NE parts of India as mentioned in Table 6. The data is presented in Table 10 below:

Table 10: Percentage Change in Households by construction material of roof (Cold Climate Zone)

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	8,61,039	79,104	9,40,143	7,54,359	66,518	8,20,877	-12.39	-15.91	-12.69
Tiles	31,499	4,946	36,445	37,856	11,111	48,967	20.18	124.65	34.36
G.I./Metal/Asbestos	7,53,893	3,16,745	10,70,638	10,51,124	4,30,656	14,81,780	39.43	35.96	38.40
Concrete	7,31,492	4,41,411	11,72,903	13,75,146	6,81,212	20,56,358	87.99	54.33	75.32
Any Other	13,33,335	1,42,611	14,75,946	12,82,911	1,87,589	14,70,500	-3.78	31.54	-0.37
Total Households	37,11,258	9,84,817	46,96,075	45,01,396	13,77,086	58,78,482	21.29	39.83	25.18
Total Population	2,07,70,724	55,79,044	2,63,49,768	2,38,44,421	76,42,079	3,14,86,500	14.80	36.98	19.49

In the Cold Climatic zone, obviously the most susceptible roof category viz ***Grass/Thatch/Bamboo*** has shown a decline by (- 12%) whereas all roof categories including ***Tiles, G.I./Metal/Asbestos*** and ***Concrete*** have shown increase. The people still preferred roof category of ***Tiles*** in urban set up. The increasing trend in roof categories viz ***G.I./Metal/Asbestos*** and ***Concrete*** is almost similar to the Hot and Dry Zone.

3.3.3 Data under "Warm and Humid" Climate Zone

Out of 35 States and Union Territories, the warm and humid climate zone entails 18 States (Southern, East coastal, North-East and Union Territories) of India as mentioned in Table 6. The data is presented in Table 11 below:

Table 11: Percentage Change in Households by construction material of roof (Warm and Humid Climate Zone)

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	2,05,09,206	23,73,626	2,28,82,832	1,41,65,396	19,20,314	1,60,85,710	-30.93	-19.10	-29.70
Tiles	1,93,92,110	62,93,301	2,56,85,411	1,86,68,842	68,99,668	2,55,68,510	-3.73	9.64	-0.46
G.I./Metal/Asbestos	71,04,775	33,24,989	1,04,29,764	1,46,80,597	58,51,827	2,05,32,424	106.63	76.00	96.86
Concrete	74,86,533	96,53,712	1,71,40,245	1,49,22,626	1,88,55,466	3,37,78,092	99.33	95.32	97.07
Any Other	20,74,269	7,81,130	28,55,399	26,53,399	12,62,248	39,15,647	27.92	61.59	37.13
Total Households	5,65,66,893	2,24,26,758	7,89,93,651	6,50,90,860	3,47,89,523	9,98,80,383	15.07	55.13	26.44
Total Population	27,07,90,023	10,98,34,915	38,06,24,938	28,26,87,256	14,90,23,230	43,17,10,486	4.39	35.68	13.42

In the Warm and Humid climate zone, covering many States, both roof categories viz ***Grass/Thatch/Bamboo*** and ***Tiles*** have gone down sizeably whereas nearly 100% increase is seen in roof categories viz ***G.I./Metal/Asbestos*** and ***Concrete*** in general but especially in rural set up showing an improvement in the economic status of people in general.

3.3.4 Data under "Composite" Climate Zone

Out of 35 States and Union Territories, the composite climate zone entails 9 States (5 major, 4 minor) mainly in the central part of India as mentioned in Table 6. The data is presented in Table 12 below:

Table 12: Percentage Change in Households by construction material of roof (Composite Climate Zone)

Households under Roof Material	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Grass/Thatch/Bamboo	1,39,70,709	12,54,537	1,52,25,246	1,64,64,333	16,74,190	1,81,38,523	17.85	33.45	19.13
Tiles	2,25,49,277	24,07,090	2,49,56,367	2,02,02,310	20,37,149	2,22,39,459	-10.41	-15.37	-10.89
G.I./Metal/Asbestos	10,83,161	10,34,492	21,17,653	37,17,409	17,09,484	54,26,893	243.20	65.25	156.27
Concrete	49,19,786	67,63,368	1,16,83,154	1,06,84,185	1,12,10,155	2,18,94,340	117.17	65.75	87.40
Any Other	1,14,34,188	48,08,169	1,62,42,357	1,78,93,819	67,47,167	2,46,40,986	56.49	40.33	51.71
Total Households	5,39,57,121	1,62,67,656	7,02,24,777	6,89,62,056	2,33,78,145	9,23,40,201	27.81	43.71	31.49
Total Population	32,01,18,665	9,74,60,125	41,75,78,790	37,91,80,736	12,68,29,389	50,60,10,125	18.45	30.13	21.18

In the Composite climate zone, as a marked departure, roof category ***Grass/Thatch/Bamboo*** has shown quite an increase in both rural and urban set ups may be as these areas supported good forests, whereas roof category ***Tiles*** as usual showed a decrease. There is more 200% increase under roof category ***G.I./Metal/Asbestos*** and more than 100% increase under roof category ***Concrete*** under the rural set up with about 65% increase in both under the urban set up.

4. Scope for Cool Roofs

4.1 Types of Cool Roofs

Cool roofs fall into one of three categories: roofs made from cool roofing materials, roofs made of materials that have been coated with a solar reflective coating, or green roofs.

Membrane cool roofs

White thermoplastic membrane roofs, are inherently reflective, achieving some of the highest reflectance and emittance measurements of which roofing materials are capable. A roof made of white thermoplastic, for example, can reflect 80 percent or more of the sun's rays and emit at least 70% of the solar radiation that the roof absorbs. An asphalt roof only reflects between 6 and 26% of solar radiation.

Coated cool roofs

An existing (or new) roof can be made reflective by applying a solar reflective coating to its surface. The reflectivity and emissivity ratings for over 500 reflective coatings can be found in the Cool Roofs Rating Council.

Green cool roofs

Green roofs provide a thermal mass layer which helps reduce the flow of heat into a building. The solar reflectance of green roofs varies depending on the plant types (generally 0.3-0.5). Green roofs may not reflect as much as other cool roofs but do have other benefits such as evapo-transpiration which cools the plants and the immediate area around the plants, aiding in lowering rooftop temperatures, naturally.

4.2 Relative Thermal Advantages of Materials of Roofs Used

S. N.	Construction Materials of Roof in Households	Relative Thermal Advantage of roof category
1.	Grass/Thatch/Bamboo/Wood/ Mud/Plastic/Polythene	These materials do not as such qualify to be useful for any additional thermal advantages of any of 3 cool roof categories. In practice, such roofs are also devoid of any evapo-transpiration advantage of green roofs.
2.	Tiles (Hand and Machine made)	The kind of tiles used in rural set up are both hard to work on with coatings. If used somehow, the maintenance would be costly and advantage feeble. Thus, Tiles as roof material also do not as such qualify to be useful for any additional thermal advantages of any of 3 cool roof categories.
3.	G.I./Metal/Asbestos sheets	Readily qualify to be useful for coated cool roof category.
4.	Concrete	Readily qualify to be useful for cool roofs.
5.	Any other material (Burnt Brick, Stone/Slate, Other materials)	Some of these materials qualify to be useful for cool roofs.

4.3 Scope of Cool Roofs in Current Household Scenario

In order to drive home the scope of cool roofs, for their technologically possible relative thermal advantages, various construction materials of roof used in the above household scenario were grouped. As presented in section 4.2, households data of first two categories viz ***Grass/Thatch/Bamboo*** and ***Tiles*** was categorized as a Non-Cool Roof and next two

categories (***G.I./Metal/Asbestos*** and ***Concrete)*** were categorized as a Cool Roof. "Any Other Material" was termed as Miscellaneous category as shown in Table 13 below:

Table 13: Scope of Cool Roofs - Change in Households by construction material of roof

Scope for Cool Roofs [Combined Roof Material Categories]	2001 Households (Number)			2011 Households (Number)			% Change		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Non-Cool Roof Category 1.Grass/Thatch/Bamboo 2. Tiles	9,07,82,466	1,47,26,938	10,55,09,404	8,27,59,155	1,45,65,006	9,73,24,161	-8.84	-1.10	-7.76
Cool Roof Category 3. G.I./Metal/Asbestos 4. Concrete	2,88,02,249	3,14,48,166	6,02,50,415	5,74,80,800	5,34,51,751	11,09,32,551	99.57	69.97	84.12
Misc. Category 5. Any Other	1,86,86,844	75,17,272	2,62,04,116	2,75,86,775	1,08,49,180	3,84,35,955	47.63	44.32	46.68
Total Households	13,82,71,559	5,36,92,376	19,19,63,935	16,78,26,730	7,88,65,937	24,66,92,667	21.37	46.88	28.51

Table 13 clearly shows that the potential for cool roofs has substantially increased in India as reflected by about 100% increase in the rural set up and 70% in the urban set up under the cool-roof category. If the government of India makes suitable changes in the guidelines for housing sector to adopt green technologies by all operators, as recently done by the Ministry of Rural Development in their housing scheme for weaker sections (Indira Aawas Yojna), energy efficiency in households will get a desirable kick to address urban heat-island effect (UHI) which is fast gripping the rural set up around mega-cities and well-known towns.

In fact, some of the households from Misc. Category (Burnt Brick, Stone/Slate, Other materials) also qualify to be treated using reflective or cool roof surfaces thus adding to to the potential for cool roofs in India.

5. Thermal Comfort in Households in Different Climate Zones

For India, roofs are one of the most important building envelop components for setting the thermal comfort and cost and cooling or heating in buildings.

5.1 Thermal Comfort in Households with Untreated Roof

Thermal comfort is the condition of mind that expresses satisfaction with the **thermal** environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55).

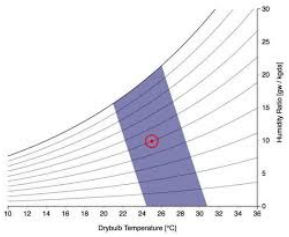


Fig. 1 shows the energy flow into a household through an *untreated* roof of thickness (d).

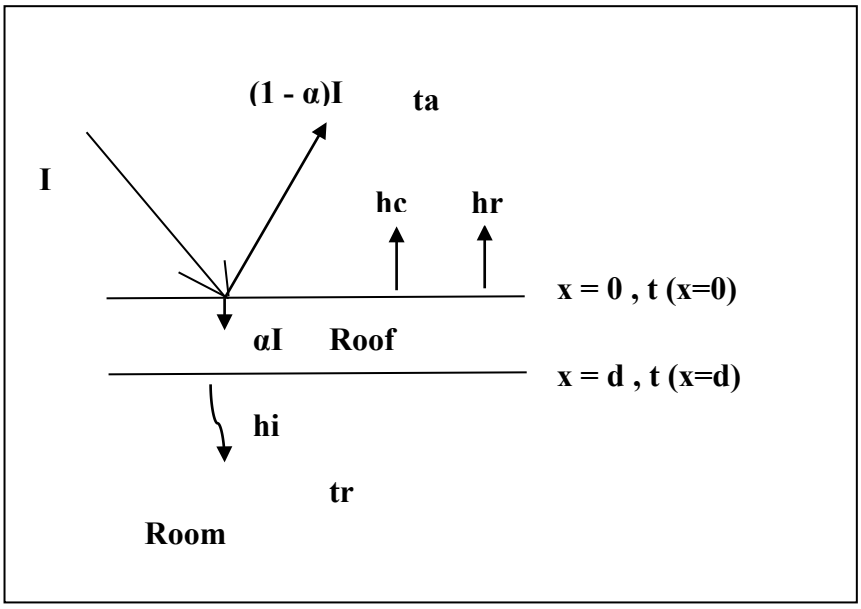


Fig 1: Energy Flow into a Household through an *Untreated* Roof

The rate of heat gain (q watt/m^2) at the top of the roof surface could be written as,

q = αI - (hr + hc) [t(x=0) - ta]

hr = σ ϵ $[T(x=0)^2 + Ta^2][T(x=0) + Ta]$
σ = Stefan-Boltzmann constant, ϵ = Emissivity of roof surface, ho = (hr + hc)

The above energy balance equation at the top of roof along with energy balance equations through the roof and into the household yield:

q = αI - ho [t(x=0) - ta] …….…… (1)
q = (k/d) [t(x=0) - t(x=d)] …….…… (2)
q = hi [t(x=d) - tr] …….…… (3)
(1/U) = [(1/ho) + (d/k) + (1/hi)]
q = (αU/ho) I - U [tr - ta] ……..…… (4)

Where:
q = Rate of heat gain or loss (W/m^2), I = Solar Intensity (W/m^2), α = Absorptivity of roof material, hr = Radiative heat transfer coefficient to ambient (W/m^2.K), hc = Convective heat transfer coefficient to ambient (W/m^2.K), ho = Overall heat transfer coefficient to ambient, t(x=0) = Temperature at the top of roof (Deg C), t(x=d) = Temperature at the internal surface of roof (Deg C), ta = Ambient temperature (Deg C), T(x=0) = t(x=0) + 273, Ta = ta + 273, k = Thermal conductivity of the roof material (W/m. K), d = Thickness of roof (m), hi = Convective heat transfer coefficient inside the room (W/m^2.K), U = U-Value or reciprocal of thermal resistance of the building envelop i.e. roof (W/m^2. K), and tr = Inside room temperature (Deg C).

5.2 Thermal Comfort in Households with Treated Roof

When the roof of thickness (d) is treated with cool roof material (say reflective paint, tile or plastic sheet) of thickness (do), conductivity (ko), emissivity (ϵo) and absorptivity (αo), the modified rate of heat gain (q') equations at various boundaries could be written as,
hro = σ ϵo $[T(x=0)^2 + Ta^2][T(x=0) + Ta]$
σ = Stefan-Boltzmann constant, ϵo = Emissivity of reflective surface

ho' = (hro + hc)

q' = αo. I - ho' [t(x=0) - ta] …….…… (1')
q' = (ko/do) [t(x=0) - t(x=do)] ……..…..… (2')
q' = (k/d) [t(x=do) - t(x=do+d)] …….……... (2'')
q' = hi [t(x=do+d) - tr] …….……..… (3')

(1/U') = [(1/ho') + (do/ko) + (d/k) + (1/hi)]

q' = (αo. U' /ho') I - U' [tr - ta] ……...… (4')

Where:
q' = Modified rate of heat gain or loss (W/m^2), αo = Absorptivity of reflective material, hro = Modified radiative heat transfer coefficient to ambient (W/m^2.K), ho' = Modified overall heat transfer coefficient to ambient (W/m^2.K), ko = Thermal conductivity of the reflective material (W/m. K), do = Thickness of reflective material on roof (m), U = Modified U-Value or reciprocal of thermal resistance of the treated building envelop (W/m^2. K), and tr = Inside room temperature (Deg C).

***Note**: The value of Radiative heat transfer coefficient (hr) depends on the Roof-top temperature [t(x =0)], which is an unknown variable that could be found be iteration by equating equations (1) and (4) which gives:*

t(x=0) = ta + (Iα/ho)[1 - (U/ho)] + (U/ho) [tr - ta]
or
t(x=0) = {(Iα/ho) + ta}[1 - (U/ho)] + (U/ho) [tr]

For a given climate zone, on the basis of data provided in Table 5 of ECBC code for India, rate of heat gain or loss (q) could be calculated for various construction materials of roofs under 5 categories using a uniform roof thickness (d) using equation (4). Due to the constraints, as mentioned in Section 3.2, head gain or loss for climatic zones would be calculated in a separate study when district-wise zonation of climate zones is achieved by all States.