Gujarat Mahila Housing Sewa Trust

Research Report

Combating climate - change induced Heat stress: Assessing cool roofs and its impact on the indoor ambient temperature of the households across slums of Ahmedabad

701-702, 7th Floor, Sakar-4, Opp. M.J. Library, Ashram Road,
Ellis bridge, Ahmedabad-380006.
www.mahilahousingtrust.org | info@mahilahsg.org
Ph: +91-79-2658 7725, 2658 7726, 65446208

Contents

INTRODUCTION

The adverse effect of climate change, a result of rapid industrialization, urbanization and other anthropogenic activities, have led to the rise of global temperatures and frequent heat waves. The consequent land use causes a change in the physical characteristic of surface flow and air temperature thus contributing to urban heat Island effect. The magnitude or intensity of heat island depends on various factors such as, heat storage by buildings and pavements, heat generated by industrial processes, transportation, logarithm of the population, city size, air conditioning and also as a result of reduced evaporation cooling from vegetation(Santamouris , 2014; Santamouris, 2015; Arnfield, 2003; Anniballe et. al., 2014). Their combined effect, however, results in the formation of the 'heat island', which varies in intensity from city to city and from season to season. Studies have found that the heat island effects causes human discomfort and high mortality in urban populations (Steeneveld et. al., 2011; Lowe 2016; Molenaar et al., 2015).

In India, 4620 people have lost their lives due to extreme heat or heatwaves in the past four years, which mostly comprises of the poor and the aged. The causalities and ill impacts of the heat stress were higher among the slum dwellers due to the vulnerable infrastructures made of heat-trapping materials such as Tin sheets, Cement sheet (Asbestos), Plastic and Tarpaulin without proper ventilation facilities. Those houses are not merely dwellings but a livelihood source for many as they are mostly involved in home-based work. The increase in the temperature over 40° Celsius (°C) (104° Fahrenheit) (°F) severely affects the health and thereby affects their productivity. Multiple studies have reported that during summers the urban heat islands increase the average air temperature by 5 to 6 °C, which is higher than the surrounding rural areas(Oke, 1973). The financial burden owing to the rise in the expenditure for energy also increases making the low-income families more vulnerable. In 2018, India's total Slum population is expected to be 104 million and it's crucial to develop the technologies, which are sustainable, packet friendly and scalable for the poor. The cool roofs are one such solution, which provides a combination of modern and ancient technologies to reduce the indoor temperatures in the existing built structures. Slum housing is very congested; the dwellers reside in close built houses that have almost no ventilation facilities. There are many types of cool roof techniques available in the market some techniques are expensive and other are not. Studies have found that the available cool materials for roof and walls like reflective paints, mod roof, reflective tiles, cool single ply membranes or traditional architecture can reduce the building thermal load (Bansal et al. 1992;). Synnefa et al (2006) have found that the use of reflective coatings can reduce the surface temperature of white concrete tiles under hot summer conditions by 4 °C and during the night by 2 °C. The results also show that choosing appropriate coating for building can contribute to the mitigation of the heat island effect as well as the reduction of cooling loads and electricity consumption of buildings. Hence, a better roof design alone is the way to reduce cooling loads or discomfort hour.

MHT AND HEAT RESILIENT ROOF TECHNOLOGIES

Mahila Housing Trust (MHT) has been working to enable access to basic services and better habitats for the poor in urban slums in India.MHT do this by mobilizing and empowering communities to create a demand for better services, while simultaneously working with local governments and service providers for strengthening the supply side. MHT strongly believes that access to light, ventilation, affordable, & efficient energy is critical to improving the quality of life & productivity of the poor, especially women who spend the majority of their time indoors, working on household chores, or engaged in livelihood activities.

The study conducted by MHT revealed that increased indoor temperatures in the households severely affects the productivity of women home-based workers, who mostly work in afternoons could also go down sometimes up to 50% in summers resulting in reduced household incomes and increased financial burden. In this context, MHT has been promoting pro-poor sustainable technology solutions by enabling a series of process innovations that help the solutions to be tested, validated and customized as per the need of the poor communities, especially women. We are striving to Identify, pilot and validate the cool roof solutions and better ventilation facilities for the poor to build resilience to increasing heat stress in India. The heat resilient roofing technologies are reducing the indoor temperatures and resulting in the lower energy needs and improve the health status of the residents. Further, the reduced energy expenses positively impact the economic status of the households in the slums.

The present study is an effort to validate some of the cool roof and ventilation solutions implemented by MHT in Ahmedabad by collaborating with Indian Institute of Public Health, Gandhi Nagar with the support of National Resources Defense Council (NRDC), USA.

METHODOLOGY

The present study aimed to identify suitable cool roofs to combat heat stress in slum communities.

Research Hypothesis

The cool roofing interventions: Mod-roof, solar reflective white paint on the tin roof, Air lite ventilation on the tin roof and Thermocol sheet insulation beneath the Asbestos reduce the indoor ambient temperatures of the households compared to the non – intervention households roofed with Tin, Asbestos/Cement sheet, and RCC/Concrete.

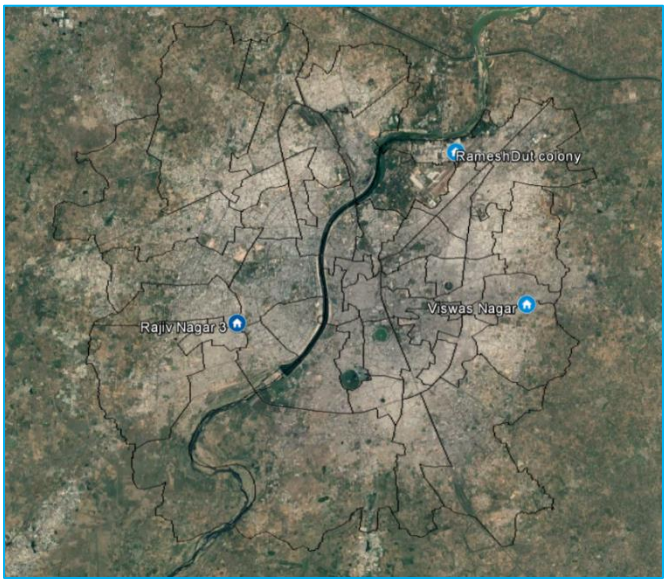


Figure 1: Study sites across Ahmedabad

The study compared the indoor ambient temperature of the households that implemented the cool roof technologies with the support of Mahila Housing Trust (MHT) against the controls. Modular roofing system, solar reflective white paint on tin roof, Air lite ventilation on tin roof and Thermocol sheet insulation beneath the Asbestos have been compared against roofing of control households: Tin, Asbestos/Cement sheet and Concrete in the slums across Ahmedabad. The study was conducted in 16 households during September 2017.The performance of cool roof interventions was compared with the non-intervention roof types namely, Tin, Asbestos/Cement sheet and Concrete.

The four-day long study comprised of the research team measuring indoor ambient temperatures and humidity of one of the interventions against three controls each day by deploying Relative Humidity/Temperature data loggers (Lascar EL-USB-2-LCD, Sweden).The data was recorded indoor for seven continuous hours, from 10:00 AM to 5:00 PM in each household with a per minute logging system. The infrared thermography camera (ThermoCAM, FLIR system, Sweden) was used for temperature profiling of the roof and the walls at three-time intervals in a day. ThermoCAM, FLIR system used automated calibration systems to adjust for ambient conditions, diurnal variations in temperature and thermal drift. The measurements were repeated thrice a day, at around 10:00 AM, 1:00 PM and 5:00 PM at an interval of about 3 hours across all the four selected households. A short survey was also used to capture the participants' socio economic conditions, household characteristics, coping mechanism against the summer heat stress and their perception about impact of heat on health. Further, statistical analysis like One –Way ANOVA and Post-Hoc Analysis – Tukey's HSD were applied to validate the mean difference in mean Ambient Temperature of the roof types. Microsoft Excel and R software packages were used to analyze the collected data. Table-1 explains the detailed plan of the study and Figure-1 gives the locational information of the study areas across Ahmedabad, India.

Table 1: Study location and Roofing

Day	Date	Slum Name	Cool roof intervention	Roofing of Control group		
1	04-10-2017	Vishwasnagar	Modular roof	Concrete roof	Tin roof	Asbestos/ Cement sheet
2	05-10-2017	Vishwasnagar	Airlite ventilation on Tin Roof	Concrete roof	Tin roof	Asbestos/ Cement sheet
3	06-10-2017	Rajivnagar	Solar reflective white paint on Tin Roof	Concrete roof	Tin roof	Asbestos/ Cement sheet

4	10-10-2017	Rameshdutt Colony	Thermocol Insulation ceiling (Inside the Asbestos roof)	Concrete roof	Tin roof	Asbestos/ Cement sheet

CHARACTERISTICS OF THE COMMUNITIES

The study was conducted in the three slums of Ahmedabad, Rajiv Nagar, Vishwas Nagar and Rameshdutt colony.

Rajiv Nagar

Rajiv Nagar (23° 0'40.64"N, 72°32'4.57"E) is an outgrowth of Rajivnagar II and I, established around 1980. This slum is located off the Ma Anandmayi Marg, which connects the 120 feet Ring Road and the 132 feet Ring Road at Shyamal crossroads. About 192 families are residing in the slum; family size was varying from four to ten. The ownership of the land in which the settlement had built changed from private to the government, which help recognize the residents by the state government. Further, the settlement does not have a proper sewerage system and paved roads. The slum has less open space within its boundary; hence, planting saplings/Trees may not feasible within the community.

Vishwas Nagar

Seventy years old, notified slum Vishwasnagar (23° 1'9.39"N, 72°40'7.89"E) situated in the periphery of the Ahmedabad. The settlement has access to legal electricity, municipal water supply and sewer connections. The slum has more than 175 pukka concrete houses and about 60 semi – pukka houses that roofed with tin sheets or Asbestos.

Rameshdutt Colony

Rameshdutt colony (23° 5'2.91"N, 72°38'9.55"E) is located in the Sardar Nagar ward of Ahmedabad, the outskirts of the city. Around 1000 families are residing in the slum and majority of them are daily wage laborers. The slum has access to legal electricity, municipal water supply and sewer connection. The houses are mostly semi-pukka or pukka in nature. Asbestos sheets or Tin Sheets are the major roofing types and very less houses have concrete/RCC roofs. The walls are made up of bricks and plastered with cement. The researchers have observed that most of the families are using electrical fans even during the daytime due to high indoor temperatures.

Modular Roofing System (Mod Roof)

The modular roofing system (Mod Roof) is a waterproof roofing, made of paper waste & coconut husk. It is an environment-friendly alternative to the RCC roofing system. It is also easily dismantable, and could be reinstalled after adding additional floors, or taken to new locations. The roof proves to be a boon for slum dwellers with uncertain land tenures owing to its reinstallation property.

Figure 2 : Four Intervention roof types: Clockwise 1.Solar reflective white paint, 2. Modular Roof, 3.Air-lite Ventilation and 4.Thermocol Ceiling

Air-lite Ventilation Sheet

Ventilation sheets are the sheets installed on the roof that has a passage to allow daylight and airflow into the house. It is often used in the households that do not have windows and are compelled to use external light sources even during the daytime. The sheet is made up of fibre with a dome-shaped structure in the middle with small opening that ensures circulation of air inside the house. The fiber sheet enables better daytime lighting of homes, thereby reducing electricity consumption (of fans and tube lights). Households which installed the Air-lite Ventilation Sheet

usually expressed positive experiences in terms of significant reduction of electricity bills (by almost half) and little amount of cooling.

Solar reflective white paint

Studies on the effect of external surface colour on the thermal behaviour of buildings shows that light colour reflects the heat from the surface and helps in reduction of indoor temperature. On the other hand, solar reflective paints made with specialized pigments have high solar reflectance and high thermal emittance. Following the literature, the roofs of the households are painted on the top side of the roof.

Thermocol Ceiling

Thermocol ceiling comes from a kind of dropping roof or false ceiling concept where the thermocol sheet I used as a secondary ceiling that is hung beneath the main (structural) ceiling. The literature shows that these roofs have thermal insulating qualities and improves the sustainability by reducing expenditure on energy. MHT have installed this technology in the slum communities as part of its climate resilience and adaptive capacity building initiative.

CONTROL HOUSEHOLDS: ROOFING AND ATTRIBUTES

Tin Roof

Packet friendliness and easy accessibility has made the corrugated steel sheet as a widely used roofing material among the poor income groups in slums across India. Lighter weight, flexibility (Bendable) and reusability are the major structural characteristics of material, which attracts the buyers. The Indian users popularly identify this sheet as Tin sheet or Tin roof. It observes more heat and make the indoors hotter than other roofing materials. Further, the chances of rust formation and corrosion is high due to heavy rains and change in the humidity.

Asbestos Sheet

Asbestos sheet is made up of cement as a base material. The asbestos fibre is a reinforce material to strengthen this sheet. As tin roof, asbestos sheet is also corrugated to add the structural value to the roof. When exposed to weather and erosion elements, such as tin roofs, the surface corrosion of asbestos cement can be a source of airborne toxic fibers. The health researchers have reported that Asbestos as roofing material could cause the life threating diseases such as asbestosis, pleural mesothelioma (lung) and peritoneal mesothelioma (abdomen).

Reinforced Cement Concrete (RCC)/ Concrete

Concrete roofed houses are generally categorized as pucca house structures. The concrete is reinforced by the steel due to its high tensile power and the high bond between steel and concrete. Mild steel or ribbed steel bars ranging from 6 mm to 32 mm diameter are used to reinforce the concrete.

Figure 3: Control roof types - Right to Left 1.Tin Roof, 2.Asbestos Sheet and 3.RCC Concrete roof

RESULTS AND DISCUSSION

Modular Roofing System (Modroof)

The Modular roofing system and the control households from the Viswas nagar were compared for the difference in the average indoor ambient temperature. The data shows that the indoor ambient temperature starts gradually rising by 10:00 AM, reaches the peak around 12:00 PM, remains in the peak for that day till around 4:00 PM and gradually decreases. The mean ambient temperature of mod roof (M = 33.82, SD =1.03) is lesser than the Asbestos sheet (M = 36.83, SD =2.08), RCC/Concrete M = 33.75, SD =0.76) and indoor ambient temperature of Tin Roof (M = 35.80, SD =1.02). The data points of mid-day (around 1:00 PM) shows that ambient temperature of mod roof is about 4.5ºC lesser than other control roofs (Figure -4).Further, Asbestos and Tin Sheets are producing more heat and the subgroup variation among these two groups are less but significant. However, both of these roofs are comparatively hotter than Mod roof and RCC/concrete.

Tukey's Multiple Comparison of Means	Difference (ºC)	Lower (ºC)	Upper (ºC)	P-Adj
Mod Roof-Asbestos Sheet	-3.01508121	-3.20919	-2.82097	0.00000
RCC Concrete-Asbestos Sheet	-3.08932715	-3.28344	-2.89522	0.00000
Tin Roof-Asbestos Sheet	-1.03480278	-1.22891	-0.84069	0.00000
RC Concrete-Mod Roof	-0.07424594	-0.26836	0.119865	0.75884
Tin Roof-Mod Roof	1.98027842	1.786167	2.17439	0.00000
Tin Roof-RCC Concrete	2.05452436	1.860413	2.248636	0.00000

Table 2 Tukey HSD result for Study day-1 Ambient Temperature (Cº) of different roof types with intervention as Mod Roof

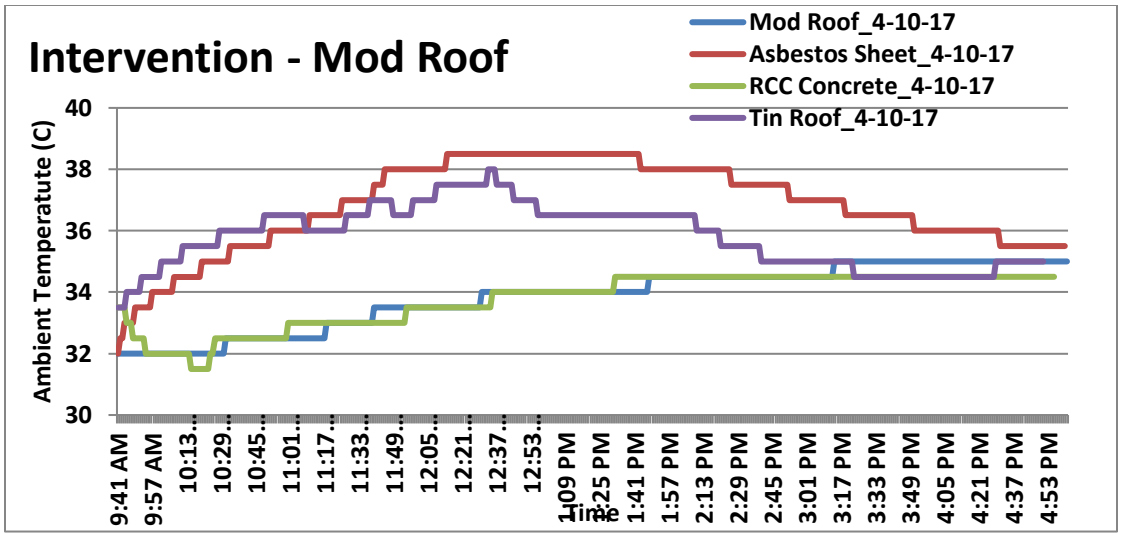


Figure 4 Plot of Ambient Temperature (C°) of different roof types on Study Day -1 with intervention as Mod Roof

The One –Way ANOVA confirms the mean difference in the ambient temperature among these roofs at $p<0.05$ level [$F(3, 1720) = 3.793$, $p= 0.000$]. Post hoc comparison test Tukey HSD indicates that except the mean difference of concrete and Mod Roof, rest of them statistically differs in its mean difference (Table-2)

The Air lite ventilation

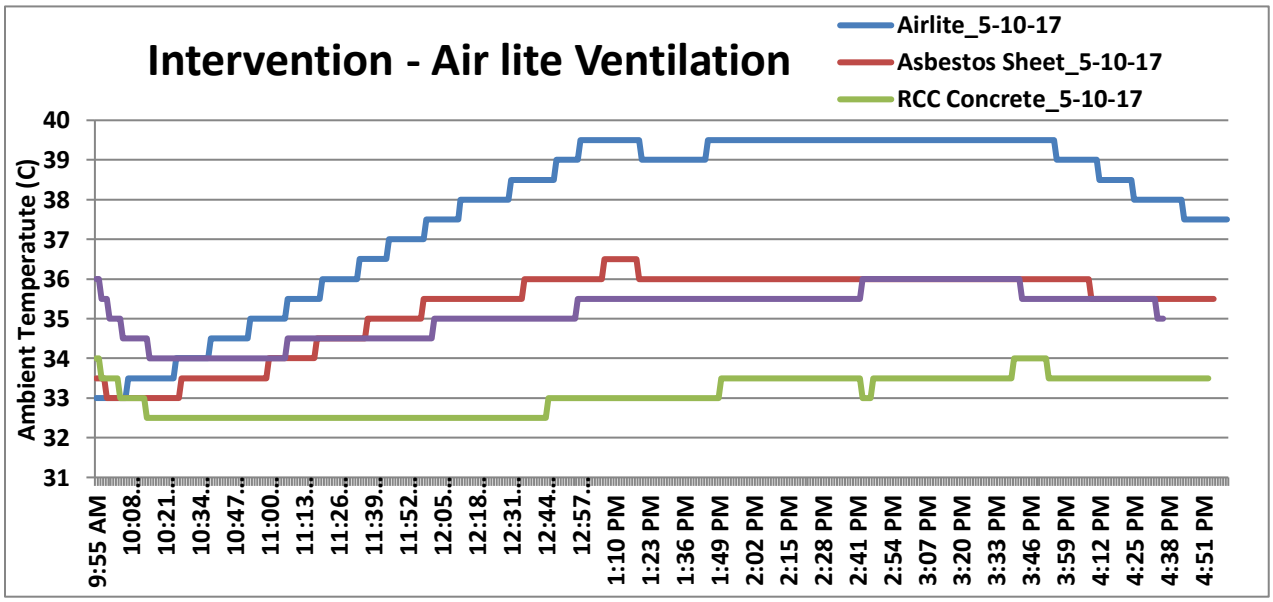


Figure 5 Plot of Ambient Temperature (C°) of different roof types on Study Day -2 with intervention as Air lite ventilation

The Air lite ventilation heats up more than the non-interventional roof types (Figure -5). It reaches 39.5(ºC) during daytime which is at least three degree Celsius (ºC) higher than the Tin and Asbestos roofs and 6(ºC) more than the concrete roof. The design of Air lite allows more light inside the house that makes the house warmer than other roof types. The mean ambient temperature of Air lite (M = 37.77, SD =2.03) is higher than the Asbestos sheet (M = 35.29, SD =1.01), RCC/Concrete M = 33.06, SD =1.01) and Tin Roof (M = 35.14, SD =0.64). Hence, Air lite may not be an effective solution to reduce the indoor heat stress. The mean difference in the ambient temperatures are statistically significant based on the results of One –Way ANOVA at $p<0.05$ level [$F (3, 1604) = 995.96$, $p= 0.000$]

Solar reflective white paint on Tin Roof

The mean ambient temperature of Solar reflective paint coated tin roof (M = 33.5, SD = 1.12) higher than the Asbestos sheet (M = 32.54, SD = 0.71) and RCC/Concrete M = 31.59, SD = 0.21) but was consistently found around one (ºC) lower than the tin roof which was not coated (M = 34.59, SD = 0.87). (Figure-6).The results of One –Way ANOVA shows that the mean difference in the indoor ambient temperatures are statistically significant at $p<0.05$ level [$F (3, 1604) =1621.35$, $p= 0.000$].

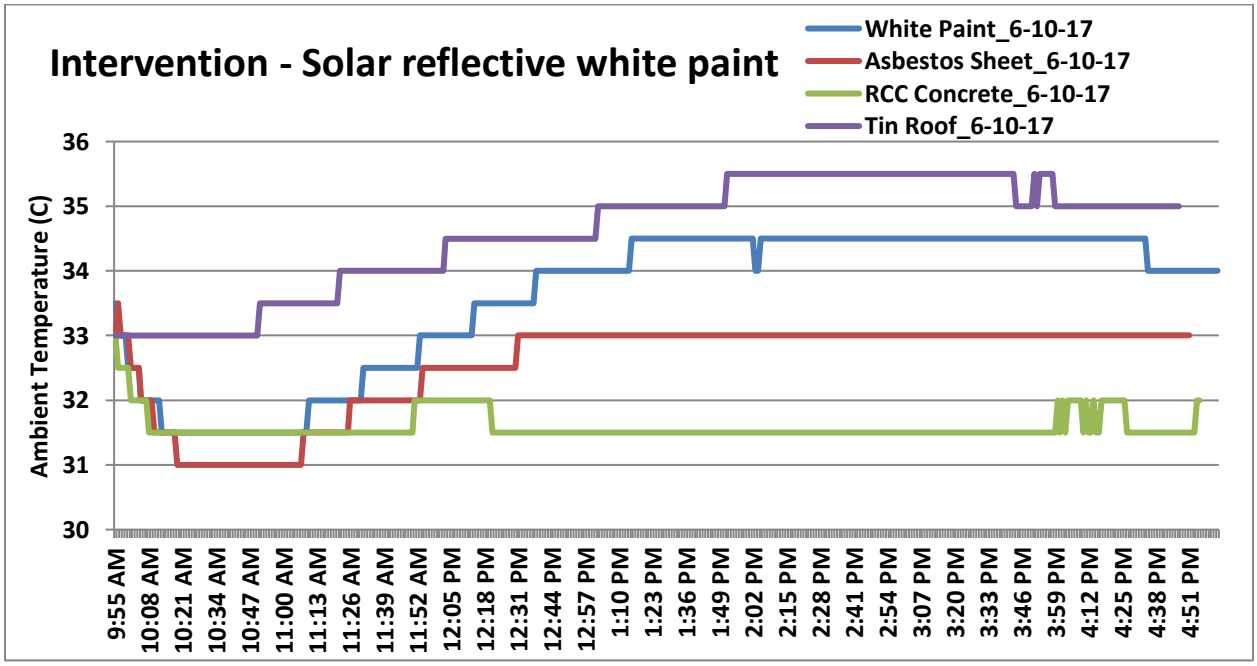


Figure 6 Plot of Ambient Temperature (Cº) of different roof types on Study Day -3 with intervention as solar reflective white paint

Thermocol Ceiling beneath the Asbestos roofing

Thermocol ceiling is generally used as the false ceiling in the commercial buildings but less in the households.MHT has executed this intervention to understand its suitability to reduce the temperature in the slum households. The results (Figure -7) have exhibited a good decrease in ambient temperature since the beginning of time compared to tin and asbestos sheet. It reached

maximum of 34(ºC). The mean ambient temperature of Thermocol insulated Asbestos roof (M = 33.50, SD = 0.73) is about 2.5 degree Celsius lesser than the Asbestos sheet (M = 35.88, SD = 1.72) and tin roof which are not coated (M = 35.44 SD = 0.71). Interestingly, RCC/Concrete roof's mean ambient temperature (M = 33.25, SD = 1.09) is very close to the mean temperature of Thermocol insulated household. (Figure-7).The results of One –Way ANOVA shows that the mean difference in the indoor ambient temperatures are statistically significant at $p<0.05$ level [$F(3, 1664) = 579.42$, $p = 0.000$].

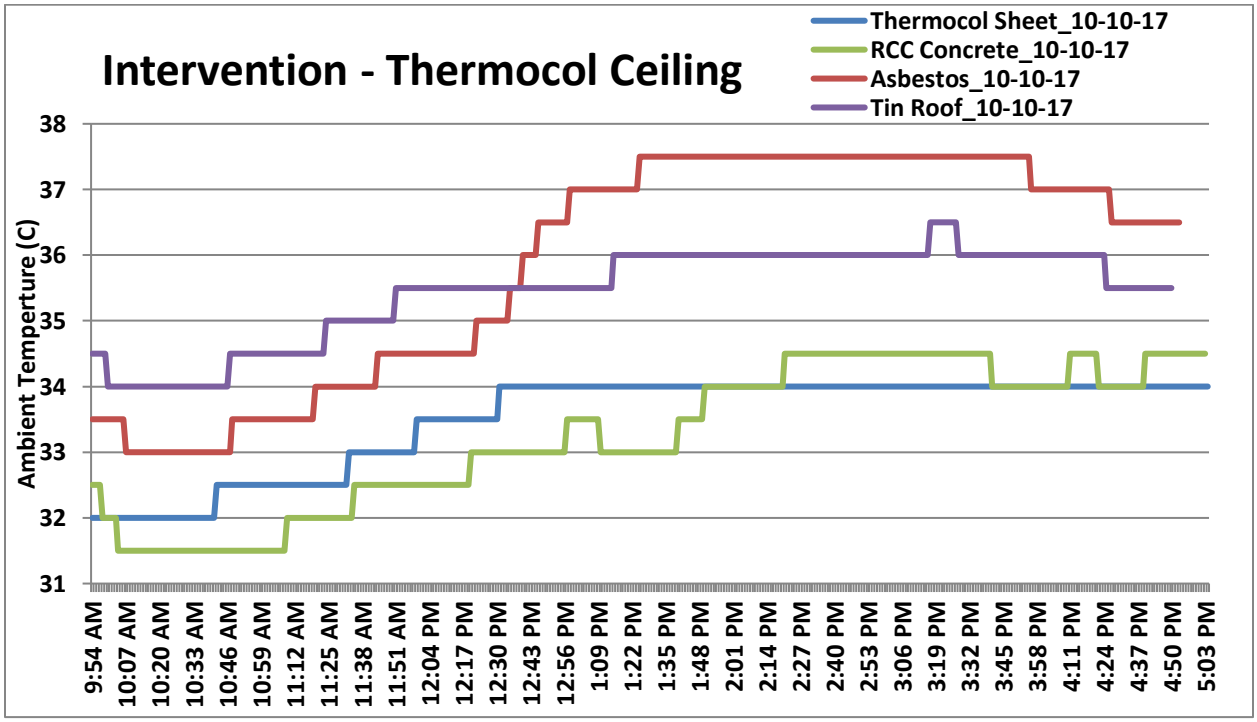


Figure 7 Plot of Ambient Temperature (Cº) of different roof types on Study Day -4 with intervention as Thermocol ceiling

The mean of nonintervention houses was calculated out of the temperature data of three days. Since we had measured, each intervention measured for only one day, the average was used to compute the mean and it compared against the non-intervention (Figure 8.)The results show that Solar reflective paint coated tin sheet(M=37.78, SD =2.09) cooler than the non-coated Tin sheets(M=35.39,SD=0.48). Further, Thermocol insulated Asbestos roofs (M =33.47,SD=0.75) also significantly reducing the indoor temperatures compared non-insulated Asbestos households(M=34.91,SD=0.99). Among the controls, except the RCC Concrete roof (M =32.78, SD=0.44), all the others are warmer than the interventions: Modular roof (M=33.74,SD=1.00), Solar reflective paint(M=37.78, SD =2.09) and thermocol insulated household(M =33.47,SD=0.75).

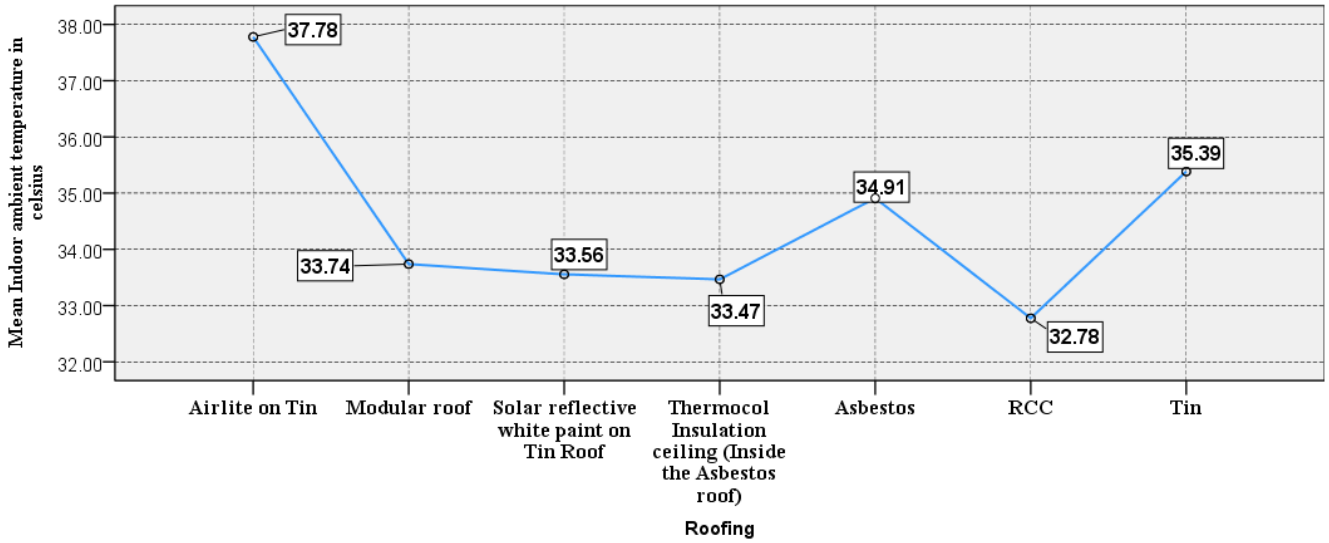


Figure 8 Plot of the mean ambient temperature of the Intervention and nonintervention households. ***(*Mean of Nonintervention household (Asbestos, RCC and Tin): Calculated out of its three-day data. Mean of Intervention Household: Calculated out of one-day data.)***

OBSERVATIONS FROM THE THERMAL IMAGES

Thermal images used to measure the surface temperature of the various roofing systems. To visualize the change in surface temperatures on the roofs, the researchers have used a reference point in the roof and shoot the thermal picture of the same surface at regular time intervals at around 10:00 AM, 1:00 PM and 4:00 PM. The figure -8 depicts the thermal pictures of four intervention roofs at regular time intervals. The scale on the right-hand side of the picture informs the range of temperature in the given region at that particular point in time. It clearly shows that the mid-day (around 1:00 PM) has a maximum range in the scale and a similar trend had been noticed in the time series plot of the ambient temperature.

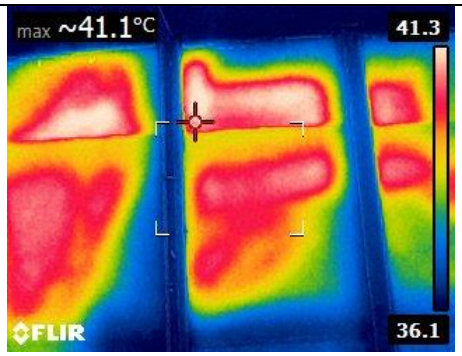
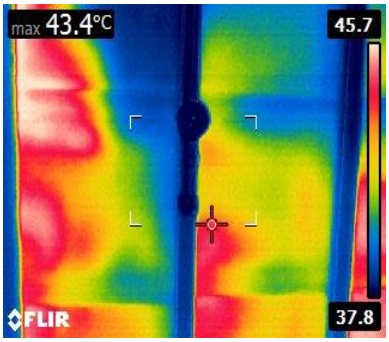
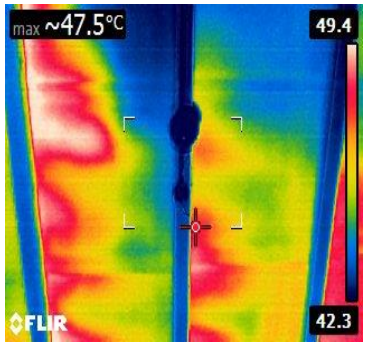
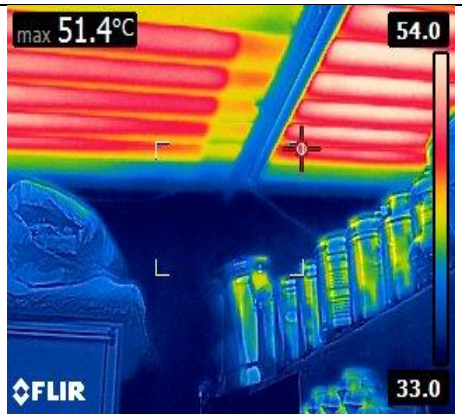
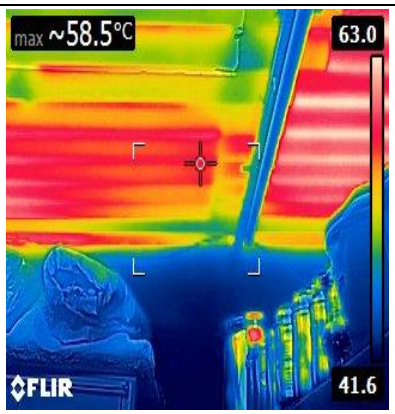
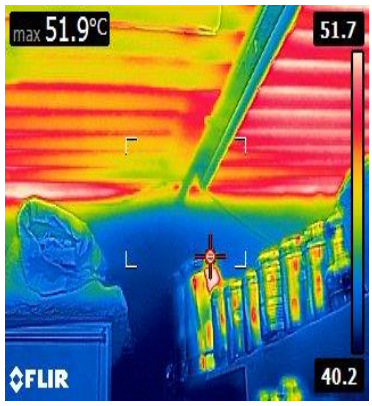
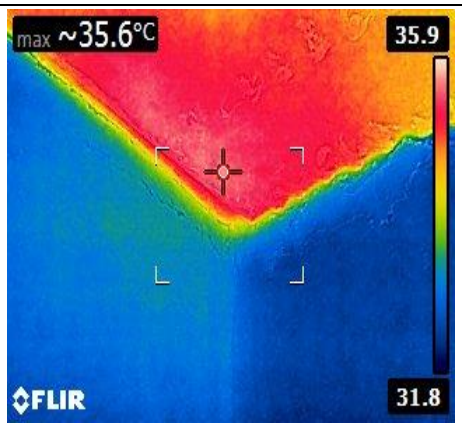
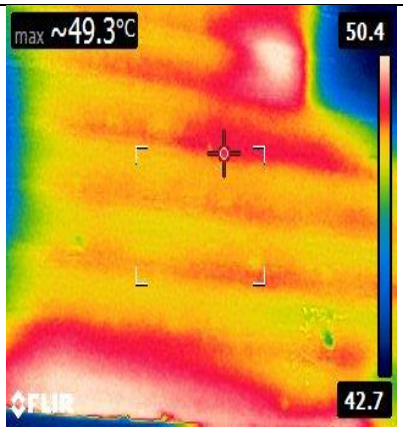
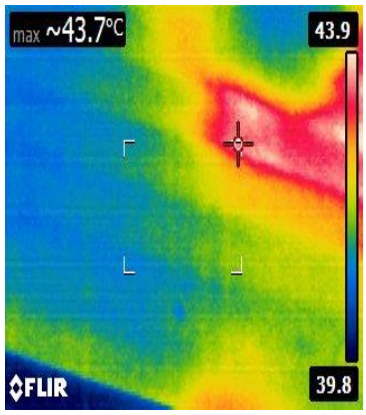
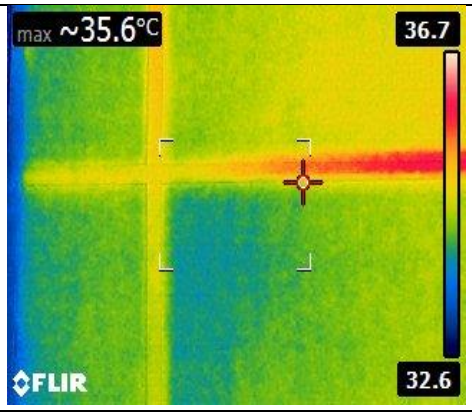
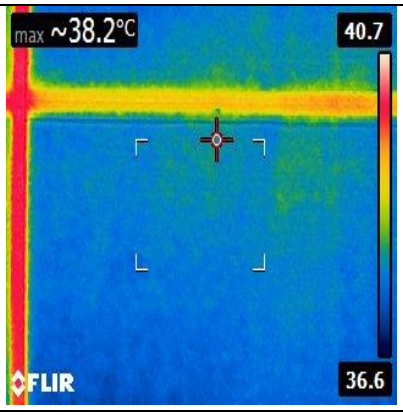
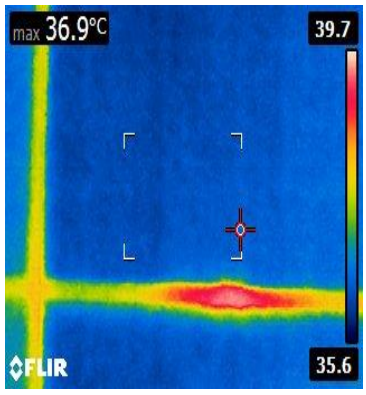
	10:00 AM	1:00 PM	4:00 PM
Mod Roof			
Air lite			
White Paint			
Thermocol Ceiling			

Figure -9: Thermal images of roofs of Intervention Roofing

Among the four cool roof types, thermocol insulated roof recorded the lowest surface temperature. Whereas, the Air lite ventilation heats up and emits more heat. It is observable that over a period, the utensils that have been placed near the roof are also getting gradually heated. This may create the effect similar to the heat island effect within the home.

Socio –economic status & Perception on Heat and Its Impact on Health

The women from the 16 households have participated and answered for the short survey. Among the respondents, more than 45 percent of them have completed their primary schooling and 15 percent have never enrolled themselves in formal education. Only 7% of the surveyed population got professional degrees. Considerably 21% of family members are at home mainly females and 21% are unskilled; this situation forces them to take the unskilled lower level jobs. Only 9% of the surveyed family members are going to the professional jobs, which may pay them well (Fig.10).

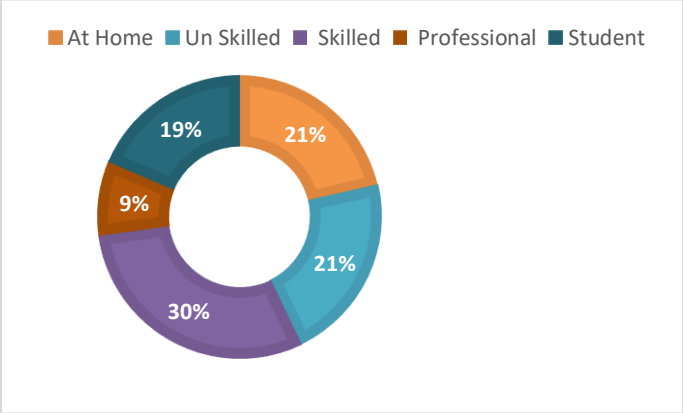


Figure 10 Occupational Information on the surveyed family members

Further, all the surveyed households had a valid meter connection to access electricity. The walls were built with cement and bricks. Few houses had tiled flooring whereas most of them were made of cement and sand. All the families have been cooking inside the house and using efficient LPG/Bio Gas as a fuel. All the families have been using electrical fans in their living rooms. About 50% of the houses do not allow for cross ventilation due to the positioning of the doors and windows. Further, the number of windows opening in the closed areas also found to be high in numbers.

When the respondents were asked for their favorable seasons, unanimously all of them answered winter as their most comfortable season and about 80% of them reported summer as their least favorite. Few women recorded the monsoon as their least comfortable season. This may be due to the structure of the households and poor drainage system in slums, which brings more discomfort during the monsoon in the form of inland flooding/ water logging. Further, most of the respondents reported that using electrical fan, Air conditioner, Air cooler and sleeping outside during the night times are the effective measures, which limit the heat exposure. Very few of them shared that the wearing loose clothes helps them to protect from extreme heat. As per the responses, the heat

related illnesses affects 45% of the surveyed households during the summer as many other studies have reported.(Figure -10)

The awareness about the Ahmedabad Heat Action Plan (HAP) was low and about two third of the households were not aware of Ahmedabad Heat Action Plan (HAP) an initiative of Ahmedabad Municipal corporation. About 60% of the respondents have never seen Information, Education and Information (IEC) materials that were distributed to create awareness on heat stress during summers, which leads to lack of understanding about the heat impact on health. Interestingly, In spite of not having any access to awareness materials, 75% reported of them were aware about the rise in temperature and among them 50% have reported MHT as their prime source of information and 25% get information from TV and print media. When asked for the effective preventive measures to combat the heat stress, many have reported tree plantation as the effective measure whereas few reported using Air conditioner and coolers.

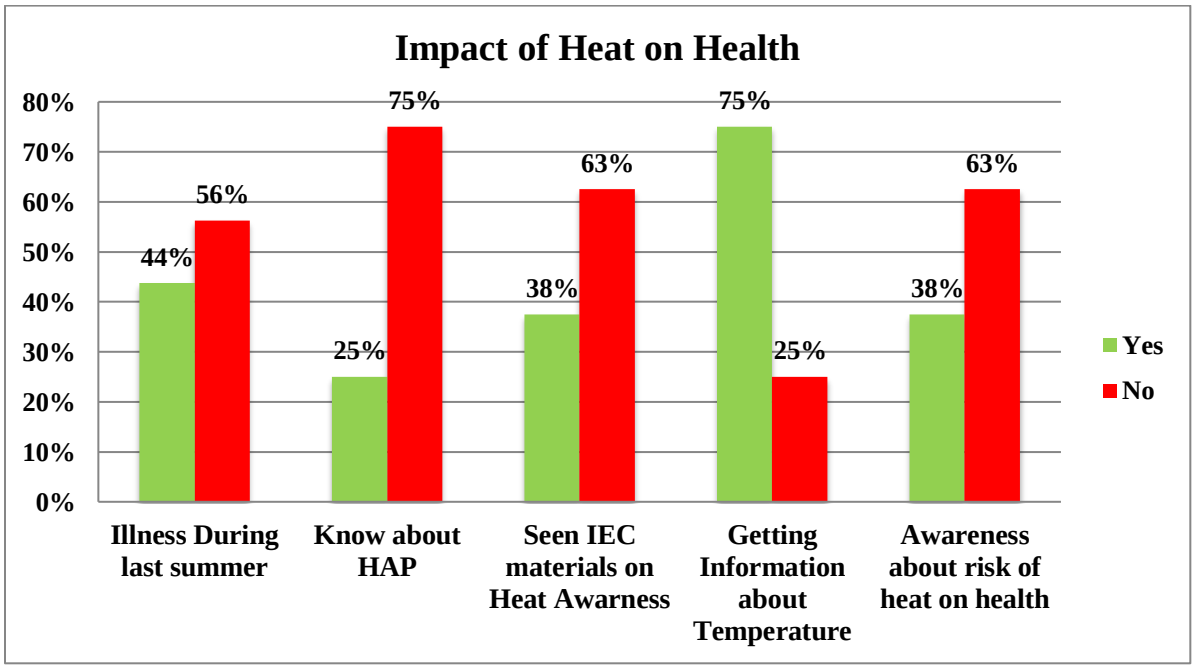


Figure 11 Binary responses of Impact of heat on health

CONCLUSION

The slums or informal settlements are mostly present on land with insecure land tenure. This causes the urban poor slum dwellers to have lower accessibility to government housing schemes. Further, the eviction threats are another challenge that may prevent slum dwellers to invest in improving the houses with pukka materials. This complexity along with the poor economic status forces the slum dwellers to opt for the household materials such as tin sheets and Asbestos (Cement Sheet) which are pocket friendly and reusable in case of eviction. Hence, Technologies like cool roofs are a savior to the slum dwellers that fulfills their expectations in terms of cooling without much alteration in the existing structures and with less investment as compared to RCC/Concrete roofs. Within the methodological limitations of the present study, Thermocol false ceiling and solar reflective paint and mod roof have emerged as promising solutions to reduce the heat stress in the slum communities. Further, the Air lite ventilation works well to lighten the house in the daytime by allowing the light inside the home but ultimately heats up the house. To understand the dynamics in the performance of cool roofs, future studies on cool roofs may be conducted with a larger sample size and improved research designs.

ACKNOWLEDGEMENT:

This research was supported by National Resources Defense Council (NRDC), USA. We sincerely thank Indian Institute of Public Health, Gandhi Nagar, Gujarat for providing their insights and expertise to conduct this research study. We also thank them for providing the study instruments and overall support in analysis and research design.

RESEARCH TEAM

Bijal Brahmbhatt: Director, Mahila Housing Sewa Trust
Sathish LM : Research Associate, Indian Institute of Public Health, Gandhi Nagar, Gujarat
V.Selvakumar : Development Associate, Mahila Housing Sewa Trust, Ahmedabad, Gujarat
Email: selva@mahilahsg.org Mobile: 08056694687
Srishti Singh : Coordinator, Mahila Housing Sewa Trust, Ahmedabad, Gujarat
Priya Dutta : Research Associate, Indian Institute of Public Health, Gandhi Nagar, Gujarat

REFERENCES:

Azhar, G. S., Mavalankar, D., Nori-Sarma, A., Rajiva, A., Dutta, P., Jaiswal, A., … Hess, J. J. (2014). Heat-related mortality in India: Excess all-cause mortality associated with the 2010 Ahmedabad heat wave. *PLoS One*, 9(3), e91831.

Garrison, N., Horowitz, C., & Lunghino, C. A. (2012). *Looking up: how green roofs and cool roofs can reduce energy use, address climate change, and protect water resources in Southern California*. Natural Resources Defence Council.

Steeneveld, G. J., Koopmans, S., Heusinkveld, B. G., van Hove, L. W. A., & Holtslag, A. a. M. (2011). Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. *Journal of Geophysical Research: Atmospheres*, 116(D20), D20129. https://doi.org/10/fcdj8f.

Oke, T. R. (1973). City size and the urban heat island. *Atmospheric Environment (1967)*, *7*(8), 769–779. https://doi.org/10.1016/0004-6981(73)90140-6.