ISSN 0973-2284

INDIAN JOURNAL OF OCCUPATIONAL & ENVIRONMENTAL MEDICINE

VOL.24 NO.1 January-April 2020

PubMed Included

IAOH

Official Publication of
Indian Association of Occupational Health

Wolters Kluwer

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Original Article

Combating Climate Change-induced Heat Stress: Assessing Cool Roofs and Its Impact on the Indoor Ambient Temperature of the Households in the Urban Slums of Ahmedabad

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Abstract

Background: The rising global temperature and frequent heatwaves are the adverse effects of climate change. The causalities and ill impacts of the heat stress were higher among the slum dwellers because of the vulnerable household structures, which were made by heat-trapping materials like tin sheets, cement sheet (asbestos), plastic, and tarpaulin. The houses are not only dwellings but also a source of livelihood for many slum dwellers as they are involved in home-based work. The increase in the temperature of more than 40°C severely affects health and increases energy expenditures. **Objective:** The present study conducted to identify the efficient cool roof technologies that reduce indoor temperature of the households and improve the heat resilience of dwellings located in the urban slums of Ahmedabad. **Methodology:** The performances of cool roof interventions were compared with the nonintervention - roof types, namely, tin, asbestos/cement sheet, and concrete. Relative humidity/temperature data loggers (Lascar EL-USB-2-LCD, Sweden) were used to measure the indoor ambient temperature and humidity. The questionnaire-based survey also has been conducted to understand the socioeconomic status and the perceptions related to roofing and health. **Results:** The results revealed that selected cool roof technologies including Thermocol insulation, solar reflective white paint on the outer surface of the roof, and Modroof are effectively reducing the indoor temperature as compared to the nonintervention roofing. **Conclusion:** Cool roof technologies have a wider scope as number of informal settlements are increasing across the cities in India and other developing countries. The governments may not able to provide proper housing to all these inhabitants due to various reasons including the land tenure of the habitats. Validated cool roof technologies can be promoted as these structures are not requires legal sanctions and easily dismantled and installed in multiple places and safeguards the investment of urban poor.

Keywords: Climate change, cool roofs, heat stress, slum, urban poor

Introduction

Climate-induced heat stress and heat waves are being frequently observed around the world. In urban areas, reduced greenery and lapses in land use planning instigate the heat island effect.[1] The elevated temperatures severely impact the vulnerable groups, such as infants, children, women, and the elderly, as well as poor income groups, by discomfort and heat-related mortality.[2] The heatwave of 2015 claimed about 2,300 deaths across India, making it globally the fifth-worst wave in terms of number of deaths.[3]

Within the city boundaries, the urban poor living in informal settlements are highly susceptible to heat stress due to their housing structures. Lack of property rights and financial loan products, low household incomes, nonidentification as a slum by the governments, inadequate awareness on heat and its correlation with health are primarily preventing the urban poor investing in heat resilient roofing. Further, the economic viability, ease in installation process and reusable characteristics of heat trapping roofing materials attracts

Submitted: 27-May-2019 **Accepted:** 28-Nov-2019 **Published:** 18-Mar-2020

Access this article online

Quick Response Code:

Website: www.ijoem.com

DOI: 10.4103/ijoem.IJOEM_120_19

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How to cite this article: Vellingiri S, Dutta P, Singh S, Sathish LM, Pingle S, Brahmbhatt B. Combating climate change-induced heat stress: Assessing cool roofs and its impact on the indoor ambient temperature of the households in the Urban slums of Ahmedabad. Indian J Occup Environ Med 2020;24:25-9.

and motivates to adopt it.[4] Most of the houses in slum are roofed with materials like corrugated tin sheets,[5] cement sheet (Asbestos),[6] plastic, and tarpaulin[7] without sufficient ventilation facilities. The inhabitant dwellings are used as the workplace of gender-inclusive livelihoods where women involved in home-based works other than merely living.[8] Every degree rise above 25°C (77°F) results in 2% loss in productivity and pushes the poor into poverty trap by income loss and rise in expenditure on energy.[9-11] Reducing the indoor temperature by adopting active cooling systems could work better; however, it costs the resource-deprived communities in terms of increased energy bills, as well as add up to climatic change in a larger context. On the other hand, the passive cooling techniques reduce the heat transfer by adding the insulation material on/under the roofs.[12]

This study evaluates the passive cool roofing interventions implemented in the slum communities of Ahmedabad by Mahila Housing SEWA Trust (MHT), the women-led nongovernmental organization (NGO).[13] The study hypothesized that intervention households (Modroof, Solar reflective white paint on tin roof, Airlite ventilation on the tin roof, and Thermocol sheet insulation beneath asbestos) provide better thermal insulation than the non-intervention households roofed with regular Tin, Asbestos or cement sheets and Reinforced Cement Concrete (RCC).

Methodology

This cross-sectional study was conducted in 16 selected slum households across the city of Ahmedabad during October 4, 2017 and October 10, 2017, a post-monsoon heat season. Each day we compared one intervention roof—modroof, solar-reflective white painted tin roof, Airlite ventilation installed on tin roof, and false Thermocol ceiling beneath the asbestos—against three control households roofed with tin, asbestos/cement sheet, and concrete. Figure 1 shows the intervention roof type (Thermocol ceiling; Modroof; Solar reflective white paint and Airlite ventilation) of the study areas across Ahmedabad, India.

The characteristics of study roofs

Intervention households: Roofing types and characteristics

Solar reflective white paint on tin

Painting the external surfaces and roofs with white paint reduces indoor temperature of the buildings. However, the solar reflective white paint made with specialized pigments have more solar reflectance and higher thermal emittance [Figure 1d].

Modular roofing (Modroof) system

Modroof is a modular roofing system manufactured by an Indian startup 'Re-Materials'. Panels are the primary components of the system which are water proof in nature and manufactured from packaging and agriculture waste. The ease in shipment, installation, and replacement of individual panels and the aesthetics of the roofing is increasing its adoption multiple cities India [Figure 1b].[14]

Airlite ventilation sheet on the tin

Airlite ventilation sheets are installed on the roof, they have a passage to allow daylight and airflow into the house. These sheets are often used in households that do not have any windows. The sheet is made of fiber, and it has a dome-shaped structure in the middle with a small opening that ensures the circulation of air in the house [Figure 1a].

Thermocol insulation beneath the asbestos

Thermocol ceiling is a kind of dropping roof or false ceiling where the Thermocol is used as a secondary ceiling, which is hung beneath the main (structural) ceiling [Figure 1d].

Control households: Roofing and attributes

Tin roof

Corrugated steel sheets were widely used as roofing material among the poor income groups residing in the slums across India because of their pocket-friendliness and easy accessibility. Lighter weight, flexibility (bendable), and reusability are the major structural characteristics of this material, which attracts the buyers. This sheet is popularly identified as a tin sheet or tin roof by the Indian users.[5]

Asbestos sheet

The asbestos sheet is made up of cement as the base material. The asbestos fiber acts as a reinforcing material to strengthen this sheet. Like the tin roof, the asbestos sheet is also corrugated to add structural value to the roof. According to health researchers, asbestos causes many life-threating diseases, such as asbestosis, pleural mesothelioma (lung), and peritoneal mesothelioma (abdomen).[15]

Reinforced cement concrete (RCC)/concrete

Generally, concrete-roofed houses are categorized as *pucca* (solid/permanent) house structures. The concrete is reinforced by steel because of the high-tensile power of steel and the strong 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.

Data collection

The questionnaire was translated into Gujarati, the local language of Ahmedabad. The questionnaire mainly focused on the socioeconomic conditions, heat stress vulnerability, housing type, ventilation, and strategies to confront heat as well as health problems in the family. The questions were asked to the head female of the household who volunteered to participate in the study. All responses were self-reported.

Environmental parameters

A relative humidity/temperature data logger (Lascar EL-USB-2-LCD, Sweden) was used to measure the indoor ambient temperature and humidity at an interval of 1 min from each household. The indoor temperature of the interventional households was recorded continuously



Figure 1: Four intervention type roofs: (clockwise) (a) Thermocol ceiling, (b) Modroof, (c) Solar reflective white paint, (d) Airlite ventilation

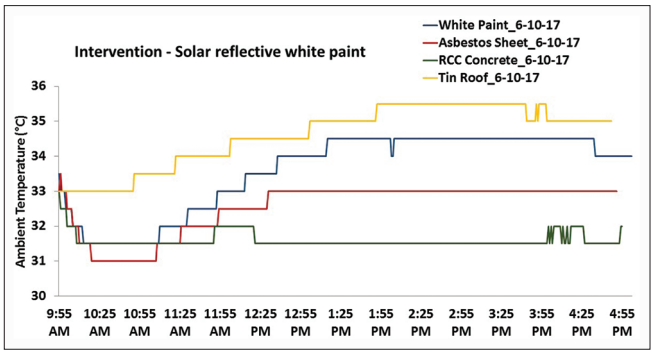


Figure 2: Plot of ambient temperature (°C) of solar reflective white paint and nonintervention roofs

for 7 h during the day, from 10 am to 5 pm. Each day we surveyed four households, of which three were control and one was an intervention household. The data loggers were installed with a tag in a well-lit space within the household, generally hanging on the wall and away from direct sunlight or any cooling structure.

Statistics

One-way analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) for *post hoc* analysis were applied to validate the mean difference in the mean ambient temperature of the roof types statistically. Microsoft Excel and R software packages were used for analyzing the data.

Results

The women from each of the 16 households (4 interventions and 12 controls) participated in the survey. Around 45% of the women had completed their primary schooling and 15% never enrolled themselves in formal education. Only 7% of the surveyed population received professional degrees.

All the surveyed households had legal electricity connections. 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 had an electrical fan in their living rooms. None of the houses had cooler or air conditioner (AC) facilities. About 50% of the houses did not have cross ventilation and further the windows opened in closed spaces. However, unanimously all of them answered winter as their most comfortable season and about 80% of them reported summer as their least favorite. Around 45% of the female responded to heat-related illnesses during the summer.

Solar-reflective white paint on the tin roof

The mean ambient temperature of solar reflective paint-coated tin roof was 33.5 ± 1.12°C. This was higher as than the asbestos sheet and RCC/concrete roof with mean ambient temperatures 32.5 ± 0.7°C and 31.6 ± 0.21°C respectively. However, the mean temperature of the solar reflective paint-coated roof was 1°C lower than the uncoated tin roof with mean temperature 34.6 ± 0.87°C [Figure 2]. The results of one-way ANOVA show that the mean difference in the indoor ambient temperatures is statistically significant at $P < 0.05$ level (F [3, 1604] =1621.35, $P = 0.000$).

Modular roofing system (Modroof)

The modroof system and the control households from Viswas Nagar were compared with an asbestos sheet, RCC/concrete, and tin roof. The data show that the indoor ambient temperature gradually starts rising from 10 am, reaching a peak around 12 pm, and remains at the peak until 4 pm, and then gradually decreases. The mean ambient temperature of modroof (33.8 ± 1.03°C) was lesser compared with the asbestos sheet (36.83 ± 2.08°C), RCC/concrete (33.75 ± 0.76°C), and tin roof (35.8 ± 1.02°C). At 1 pm, the ambient temperature of the modroof was around 4.5°C, which was lesser than the other control roofs [Figure 3].

Airlite ventilation on the tin roof

We observed that the Airlite ventilation roof's indoor temperature was more than the other three control roofs [Figure 4]. During the daytime, the temperature reached 39.5°C, which was approximately 3°C higher than the tin and asbestos roofs and 6°C higher than the concrete roof. The mean ambient temperature of Airlite (37.8 ± 2.03°C) was higher than the asbestos sheet (35.3 ± 1.01°C), RCC/concrete (33.06 ± 1.01°C), and tin roof (35.14 ± 0.64°C). The mean difference in the ambient temperatures is statistically significant based on the results of the one-way ANOVA at $P < 0.05$ level (F [3, 1604] = 995.96, $P = 0.000$).

Thermocol ceiling beneath the asbestos roofing

Generally, a Thermocol ceiling is used as a false ceiling in commercial buildings, but it is less commonly used in households. MHT has executed this intervention to understand its suitability to reduce the temperature in the slum households. The results [Figure 5] have exhibited a good decrease in ambient temperature since the beginning of time compared with the tin and asbestos sheet. It reached a maximum of 34°C. The mean ambient temperature of the Thermocol-insulated asbestos roof (33.50 ± 0.73°C) is about 2.5°C lesser than the asbestos sheet (35.88 ± 1.72°C) and uncoated tin roof (35.44 ± 0.71°C). Interestingly, the RCC/

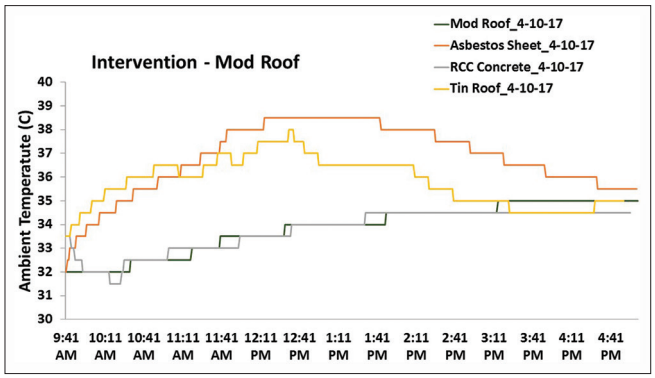


Figure 3: Plot of ambient temperature (°C) of modroof and nonintervention roofs

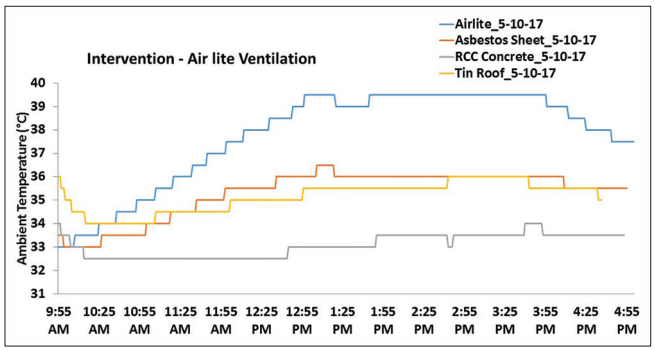


Figure 4: Plot of ambient temperature (°C) of different roof types with intervention as Airlite ventilation

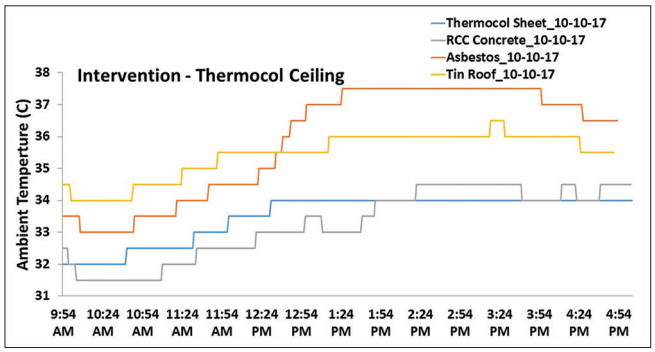


Figure 5: Plot of ambient temperature (°C) of different roof types with intervention as Thermocol ceiling

concrete roof's mean ambient temperature (33.25 ± 1.09°C) is closer to the mean temperature of Thermocol-insulated household [Figure 5]. The results of the one-way ANOVA shows that the mean difference in the indoor ambient temperatures is statistically significant at $P < 0.05$ level (F [3, 1664] = 579.42, $P = 0.000$).

Discussion

The cities within low-income countries of Asia and Africa are growing faster than ever. By 2050, 6.5 billion people will live in urban centers, which is two-thirds of the projected world population.[16] The lack of access to land and increased cost of food, water, electricity, and housing contribute to urban poverty that divides the cities further.[17] The estimates show that approximately 880 million people worldwide lived in urban slums in 2014, and these numbers are tend to rise to 3 billion by 2050.[18] The lack of durable housing structures makes the slum dwellers susceptible to extreme weather and aggravates the health risks.[19] In Ahmedabad, about 2 million slum dwellers have greater exposure to extreme heat because of their poorly ventilated dwellings, which also serves as workplaces to them.

The study compared four cool roof interventions against the nonintervention roofs. It was believed that Airlite ventilation reduces the energy expenditure of the households by allowing the daylight through the roof. Although this system is effective in bringing light, it heats up the house. The indoor temperature of the Airlite roof houses was approximately 3°C higher than the tin and asbestos roof houses and 6°C higher than the concrete roof houses. Thus, Airlite may not be an effective solution to reduce indoor heat stress.

On the other hand, modroof is 4.5°C less hot than asbestos, tin, and RCC/concrete roofs. Thus, asbestos and tin sheets produce more heat than modroof and RCC/concrete and are comparatively hotter. However, aesthetically-pleasant Modroof requires a complete dismantle of the existing roof and much more financial investment, which further distances the community from opting such roofs. Availability as well as accessibility of financial assistance for such roofs is also very limited. The solar reflective painted tin roof reduces the heat transfer better than the noncoated tin sheet. The efficiency of the solar reflective coated roof depends on the quality of paint and its resistance to dirt pick-up, rust formation, and corrosion in rains during high humidity.

Thermocol-insulated asbestos houses reported a lower indoor temperature than houses with asbestos roof which were neither coated nor insulated. However, the difference in mean indoor temperature of Thermocol-insulated households and RCC/concrete households is minimal. The woman who owned a Thermocol-insulated house said that the cost-effective roof does not just reduce the heat transmission but also brings an aesthetic look to the house.

Psychologists and sociologists have studied that increasing global temperature increase violent behaviors and crime and conflict rate among individuals. People staying in hot temperatures for prolonged periods have increased feelings of anger and hostility, decreased alertness and energy, as well as increased aggression and violence.[20,21] Thus, hot temperatures may affect their mental health and behavioral aspects.

The slum population has little access to ACs and air cooler to reduce the indoor temperature. They usually prefer sleeping outside during the night, but this technique might not be effective in many parts of the country. During daytime, women and children mainly stay at home. The study also shows that around 45% of the females have reported heat-related illness during the summers. Hence, a cost-effective passive cooling system, such as Thermocol insulation, may be promoted.

Conclusion

The slums or informal settlements in cities mostly have issues of land tenure. This majorly excludes the urban poor from accessibility of government housing schemes which require secure land titles in order to benefit them. Threats of eviction further prevents the slum dwellers from investing in improvement of their households with *pucca* materials. This complexity along with the poor economic status forces the slum dwellers to opt for household materials like tin sheets and asbestos (cement) sheets, which are pocket-friendly and reusable in case of eviction. Hence, technologies like cool roofs are a boon to the slum dwellers that fulfill their expectations in terms of cooling without much alteration in the existing structures and with less investment as compared to the RCC roofs. Within the methodological limitations of the present study, Thermocol false ceiling, solar reflective paint, and modroof have emerged as promising solutions to reduce the heat stress in the slum communities. Further, the Airlite ventilation works well to lighten the house in the daytime by allowing the light inside the home but heats up the house. To understand the dynamics in the performance of cool roofs, future studies on cool roofs must be conducted with larger sample size and improved research designs.

Acknowledgment

The authors wish to acknowledge the Indian Institute of Public Health Gandhinagar (IIPHG) for providing the data loggers and other instruments, and Ms.Bhavna Mehariya, Programme manager (Energy) from Mahila Housing Trust (MHT) for field level coordination. Authors also extending the sincere thanks to the Natural Resources Defense Council (NRDC),USA for helping in conceptualizing the research design.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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