Sustainable cooling and heat adaptation: 
*Cool roofs as a potential strategy for Dhaka, Bangladesh*

Fall 2018 - Spring 2019
EE Practicum Report

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ACKNOWLEDGEMENTS

This practicum project has been as much a personal journey for us as it has been an academic exercise. It is with great pleasure and gratitude that we would like to acknowledge individuals as well as institutions, of whom without their support, this project would not have come to fruition.

Our deepest thanks go to:

Our faculty advisors, Professor Wolfram Schlenker and Elora Ditton for being our sounding boards and unfailing cheerleaders as we navigated our way through this project.

Hannah Nissan, our project advisor whose research was a guiding influence for this project and who was a critical source of ideas and provider of suggestions.

Julie Arrighi for her valuable advice and constructive insights especially when we were designing our survey questions.

Huraera Jabeen for welcoming us to BRAC University so warmly and for her enthusiastic support and practical advice for working in Korail.

Upoma Alam and S.J.M Shourov, our research assistants, translators and all-round Dhaka guides during our time there.

Malabika Sarker and Sayema Akter from the BRAC James P. Grant School of Public Health for their help arranging fieldwork logistics and assistance applying for our Bangladesh visas.

Mr Khokan Miah, our fixer during our time in Dhaka, without whom navigating the streets of Dhaka would have been impossible.

We are also very grateful to the Energy and Environment concentration at SIPA, the Center on Global Energy Policy (CGEP) at Columbia University, the Women in Energy program at CGEP and the Earth Institute for providing us with the funding needed to travel to Dhaka to conduct our fieldwork. We would also like to thank our friends and family who contributed to our GoFundMe fundraising campaign.

We would also like to express our deepest gratitude to the residents living in Korail Basti, those who opened up their homes to welcome us. Thank you for agreeing to speak with us, this research would have been impossible without their participation.
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Executive Summary

Human exposure to heat extremes is at unprecedented levels in many parts of the world. With rising global temperatures due to climate change, heat exposure is likely to increase. In countries where wide access to cooling is not available, the population faces several risks including heat-related illness, uncertain food and nutrition security, impaired human productivity and in extreme cases, even death.

Dhaka, the capital and largest city in Bangladesh regularly experiences weather related disasters, with flooding being the most common. However, rising average ambient temperatures coupled with the Urban Island Heat (UHI) effect as a result of rapid urbanization now threaten the city and its residents. Cool roofs offer a potential sustainable cooling strategy that allow residents to adapt and mitigate the negative impacts of heat. The objectives of this project were twofold: (i) To understand the current coping strategies for heat adaptation used by residents in the Korail slum, and (ii) to assess whether cool roofs are an appropriate sustainable cooling solution for the community.

Korail Basti situated in the heart of New Dhaka it is the largest slum in the city, with more than 100,000 residents from all over Bangladesh. These urban migrants come to Dhaka in search of better economic prospects due to limited opportunities in their village and/or natural climate disasters. Korail has been the subject of several climate change adaptation research projects and has a close relationship with BRAC and BRAC University.

In March 2019, the research team travelled to Dhaka to conduct an ethnographic study comprising of two components. The first being a semi-structured survey covering socioeconomic demographics, heat perceptions, heat-coping strategies and the willingness to implement cool roofs. The second part was an observational checklist focusing on the housing structure and roof characteristics. A total of 19 coping strategies were identified among the 32 households interviewed.

Our main conclusions are as follows:

- Heat is considered a relevant issue by the community and residents are negatively impacted by it.

- While many of the households use heat coping strategies, 72% did not feel that their current strategies were sufficient to deal with heat. The most oft-cited barrier to expanding heat coping strategies was money.

- Current housing structures and materials in Korail do not present a technical impediment to implementation of cool roofs; at least one of the three types of cool roofs we looked at could be implemented in every household we surveyed.

- White paint is the most feasible type of cool roof to implement in Korail.
• Uncertainties remain regarding how effective cool roofs can be in mitigating heat stress caused by increased humidity in conjunction with increased temperatures.

• The most important challenges for implementation of cool roofs in Korail are financing, the physical labor required for installation and maintenance, the priorities and mindset of Korail residents, and uncertainties around the values of indoor temperatures and the difference in temperatures between day and night.

Based on our analysis and remaining information gaps, we propose three possible next steps: a cool roofs pilot project in residences, a cool roofs pilot project in schools, or a non-cool roofs community-level coping strategy (e.g., cooling centers, more shaded public spaces) coupled with an awareness campaign to increase people’s knowledge of effective household coping strategies. Each of these recommendations will require funding, most likely through a grant given to a non-governmental development organization. As such, we do not make a definitive statement as to which of these three solutions is the best, but rather highlight the pros and cons of each so that any organization interested in taking this further can make an informed decision as to what cool roofs pilot or community-level strategy best fits their organizational capacity.
I. Project Justification

A. Heat and Sustainable Cooling

*Rising temperatures and climate change: the urgency of addressing heat in cities*

Today, nearly one-third of the world's population is exposed to life-threatening heat extremes for 20 days a year or more. In 2018, the Special Report by the Intergovernmental Panel on Climate Change (IPCC) reported that anthropogenic induced climate change has resulted in a 1°C increase above pre-industrial levels. The report also projected that if global greenhouse gas (GHGs) emissions continue to increase under a business-as-usual scenario, it is highly likely that average global temperatures will exceed the moderate 1.5°C limit countries agreed upon under the Paris Climate Agreement within the next decade. This difference of 0.5°C will significantly worsen the impacts of climate change, one of which is exposure to extreme heat. Under a 1.5°C scenario, it is estimated that 14% of the global population will be exposed to severe heat at least once every five years and an increase of 2°C will result in 37% of the global population impacted by extreme heat.

Rapid urbanization coupled with rising average global temperatures put cities and their urban dwellers at higher risk. Today, an estimated 14% of the global urban population or two-hundred million people live under high heat conditions. This number is going to increase significantly as climate change is expected to bring both a rise in average temperature and an increase in the intensity and frequency of heat waves in the future. A study predicts that if carbon emissions continue their current path, by 2050, 45% of the global urban population will be living with extreme summer temperatures. This will be particularly harmful if high night time temperatures prevent the body from readjusting internal feedback loops to decrease body temperature.

Cities are at greater risk due to the Urban Island Heat effect (UHI), a phenomenon where cities tend to be warmer than surrounding areas as a result of the built environment. UHI affects urban communities by increasing the surface temperature of building envelopes and infrastructures; intensifying thermal discomfort; increasing energy use for cooling and peak energy demand; compounding air pollution; and elevating the risks in heat related illness such as heat strokes.

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1 Camilo Mora, Benedicte Doussset, Iain Caldwell and Clay Trauernicht. *Global risk of deadly heat* (Nature Climate Change, June 2017)
2 The intergovernmental Panel on Climate Change (IPCC) *Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments.* (2018)
3 Kelly Levin, *8 Things You Need to Know About the IPCC 1.5°C Report.* (WRI Blog, October, 2018)
5 idem
6 Tengfang Xu, Jayant Sathaye, Hashem Akbari, Vishal Garg and Surekha Tetali. *Quantifying the direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse gas emissions.* (Building and Environment, February 2012) 1-6
kidney diseases, dehydration, and even death. UHI effect is set to intensify with climate change, potentially increasing urban temperatures by up to 7°C.

When heat is combined with other environmental stressors such as air and water pollution, the consequences on human health and well-being can be even more alarming. This additional stress has the capacity to induce heart attacks, reduce lung function and aggravate asthma. The most vulnerable populations, the elderly, the sick, children, women and the poor, tend to be less able to adapt and resist and as a result are more vulnerable.

Sustainable cooling: why is it important?

Sustainable cooling refers to climate-friendly, energy-efficient and economically-viable solutions that satisfy the increasing demand for cooling needs whilst minimizing energy usage and limiting environmental impacts. Examples of sustainable cooling solutions include Minimum Energy Performance Standards for appliances, Heat Action Plans, requirements for vegetative cover, renewable sources for cooling purposes and cool roofs or cool coatings for buildings.

Equitable access to sustainable cooling is critical to achieving the Sustainable Development Goals (SDGs) adopted by all UN member states in 2015. First, cooling has direct impacts on mortality. Heat waves already kill approximately 12,000 people annually and the World Health Organization (WHO) forecasts that, by 2050, deaths from more extreme heat waves could reach 255,000 annually. Cooling is also related to food security and health. With efficient and sustainable cooling solutions, global food loss could be reduced by 50%, allowing an additional 1 billion people to be fed. Incidences of food poisoning could also be reduced. A 2015 WHO report, estimated that 600 million people fall in per year after eating contaminated food and 420,000 die. This can be mitigated with efficient and sustainable cold value chains. Cooling is related to health through vaccines as well, which need to be kept in carefully controlled temperatures. Today, approximately 1.5 million children under 5 die annually from vaccine preventable diseases.

Moreover, as stated before, sustainable cooling is also related to SDG 11, that targets sustainable cities and communities. An additional effect of heat in cities is for example, the transmission of certain diseases such as the mosquito-borne dengue fever.

Since cooling brings benefits to human development, health, well-being and economic productivity, wider access to cooling is essential for both developed and developing countries.

Whilst, air-conditioning is one solution to cooling, it is a myopic strategy that is both a major contributor to climate change, as well as a consequence. Cooling by means of an air-conditioner

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7 Kim Knowlton, TRACKING “THE SILENT KILLER”: EXPERTS TRACK EFFECTS OF HEAT ON HUMAN HEALTH AS TEMPERATURES RISE (NRDC Fact Sheet, May 2016)
8 Ian Johnston. Urban 'heat island' effect could intensify climate change, making cities up to 7C warmer. (The Independent, May 2017)
10 Keith Oleson, A. Monaghan and Olga V. Wilhelmi. Interactions between urbanization, heat stress, and climate change (Climatic Change, 2013) 3-4
12 Sustainable energy for All (SEforALL). “Chilling Prospects: Providing Sustainable Energy for All” (July, 2018)
13 idem
requires evacuation of hot air to the outside of the buildings. It is estimated that this can raise temperatures by more than 1°C overnight in some cities. Additionally, the generation of the electricity needed to power these air-conditions contributes to sizable GHG emissions, except in the case of pure renewable-based cooling systems. The usage of ACs also represents an equity issue, while 1.1 billion people in 52 countries face cooling access risks, developed countries continue to increase their energy demand for cooling purposes even with energy efficiency measures in place. The United States, with approximately 330 million people, uses the same amount of electricity for air conditioning alone than 1.1 billion Africans use all electricity needs.

Faced with this challenge, there is an urgent need to find sustainable, efficient and affordable cooling solutions that allow equitable access to cover our basic cooling needs whilst limiting the burden on climate change. Motivated by this we decided it was relevant to assess and understand heat in a particular community but also to propose a feasible and sustainable solution. Because urban environments are at greater risk, we decided to take a city-focused approach, considering as well that cities also make possible economies of scale, and replication of the suggested solution might be easier.

B. Bangladesh and Dhaka

Globally, Bangladesh has been identified as one of the most vulnerable nations to climate change. The country ranked sixth in the Long-Term Climate Risk Index (CRI) published by Germanwatch. This index lists the top 10 countries most affected by climate events from 1998 to 2017. In this 20-year period, Bangladesh has suffered from a multitude of extreme weather events. The lower-middle income country is also listed as the second most disaster-prone country in the Asia-Pacific region according to a 2015 risk analysis Global Focus Model report released by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). In the last ten years droughts, floods, landslides and storms have affected more than 45 million people and caused around 6,900 deaths together with heavy damage to property and development. Because Bangladesh has a high population density, disaster management is more complex and recovery often difficult and slow.

Climate change adaptation efforts in the country have primarily focused on flooding, river erosion and sea level rise. Recently however, awareness of heat and its impacts has started to emerge as an imminent health stressor for the nation as Bangladesh has experienced 39 heat waves from 1989 to 2011. Several studies have also demonstrated that ambient temperatures have increased since 1960 for all three seasons (hot season -March to May-, monsoon season -June

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16 OCHA. Bangladesh Country Profile. (January, 2017)
17 idem
to September-, and cool season -December to February-). Furthermore, the number of warm nights has also increased over the last 40 years.\textsuperscript{20}

Dhaka, the capital and economic powerhouse of Bangladesh, is extremely vulnerable to the impacts of climate change. It is also the most densely populated city in the world and the rapid urbanization it is undergoing makes it more susceptible to overcrowding as well as UHI effect and heat. Over the last five years, the city has experienced an overall temperature increase of 0.11ºC.\textsuperscript{21} A 2014 paper that analyzed the temperature patterns of Dhaka from 1995 to 2010 concluded that the minimum average monthly temperatures is showing a significant increase most prevalent in the winter. Worryingly, the trend indicates an increase of 13ºC in 100 years.\textsuperscript{22}

In Dhaka, more than 37% of the population lives in informal settlements.\textsuperscript{23} Residents of these settlements are even more vulnerable to climate change stressors and shocks due to the limited resources to adapt. They live well below the poverty line with the constant threat of eviction. Korail is mainly constructed by heat trapping materials, insufficient open space, limited vegetation and lack of ventilation which increases the exposure to heat.

\section*{II. Project Objectives}

Our project aims to contribute to the growing dialogue surrounding vulnerability and coping responses to climate change-derived extreme heat events by exploring the current perceptions of heat and coping strategies used by the residents of Korail in Dhaka; and the feasibility of cool roofs as a potential sustainable cooling measure for the community. Our objectives are twofold:

1) Understand the current coping strategies for heat adaptation in the Korail slum in Dhaka, Bangladesh.

2) Assess whether cool roofs are an appropriate sustainable cooling strategy to mitigate the adverse impacts of rising temperatures due to climate change and rapid urbanization.

\subsection*{A. Introduction of Objectives}

\textit{Why heat coping strategies?}

Adaptation measures in urban informal settlements in Bangladesh can increase resilience to extreme heat events and decrease the health effects associated with higher temperatures. However, measures that are effective and technically feasible need to be consistent with the

\begin{footnotesize}
\begin{itemize}
\item Met Office, The University of Nottingham, Walker Institute, Centre of Ecology and Hydrology, University of Leeds and Tyndall Center. Climate: Observations projections and impacts: Bangladesh (UK Government Department of Energy and Climate Change, 2011)
\item Sifat Sharmin, Kathryn Glass, Elvina Viennet and David Harley. \textit{Interaction of Mean Temperature and Daily Fluctuation Influences Dengue Incidence in Dhaka, Bangladesh}. (PloS Negl Trop Dis, July, 2015)
\item Md Musfiqur Rahman Bhuiya and Hossain Mohiuddin. \textit{An analysis of the temperature change of Dhaka city}. (ICEAB 2014)
\item Nicola Banks, Manoj Roy and David Hulme. \textit{Neglecting the urban poor in Bangladesh: research, policy and action in the context of climate change}. (Environment & Urbanization, International Institute for Environment and Development (IIED, 2011).
\end{itemize}
\end{footnotesize}
culture, expertise, knowledge, and institutions already present in those communities.\textsuperscript{24} An understanding of how the urban poor perceive heat and the actions they take in response to or in anticipation of heat hazards can help assess their vulnerabilities and inform the development and implementation of more comprehensive adaptation measures, such as cool roofs.

Despite the importance of coping strategies to understanding and mitigating vulnerability, there has been limited research on heat coping strategies used in urban informal settlements in Bangladesh. This may be due to a low perceived risk from increased heat relative to other climate change impacts in Bangladesh. A substantial body of literature and international development programs support Bangladesh’s status as being extremely climate vulnerable however, there is little information or focus on extreme heat events.\textsuperscript{26} \textsuperscript{27} Heat has only recently been recognized as an additional public health concern exacerbated by climate change with serious potential impacts for Bangladesh, sparked in part by health modeling of heat-related mortality in Bangladesh by the World Health Organization that was published in 2015\textsuperscript{28} and deadly heat waves which significantly affected multiple countries in South Asia in 2015\textsuperscript{29}. The first South Asian Climate Services Forum for Health (CSF-Health) in 2016, focusing on managing extreme heat events, was a significant step forward towards acknowledging and addressing the heat hazard. The forum recommended increased research on extreme heat exposure vulnerability, exposures, impacts, and effectiveness of preventative measures, among other actions.\textsuperscript{30} Increased knowledge of the heat coping strategies currently used by the urban poor in Bangladesh can contribute to closing the knowledge gap and guiding future heat actions.

\textit{Why cool roofs?}

Roofs have a significant role in regulating internal building temperatures and are capable of providing indoor thermal comfort. Low-rise buildings, such as those found commonly in Korail, can absorb up to one-fifth of a building’s heat via the roof.\textsuperscript{31} This number can be higher if heat-trapping materials, such as tin or PVC are used.

A cool roof is a sustainable cooling solution that stays cooler than a regular roof because their surfaces are prepared, covered or coated with materials that have special characteristics that reflect solar radiation back into the atmosphere and emit thermal radiation preventing heat build-

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\textsuperscript{24} Interviews with Kurt Shickman, Executive Director of the Global Cool Cities Alliance and Mofizur Rahman, co-investigator at the International Center for Diarrheal Disease Research.
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\textsuperscript{26} Shannon Rutherford, Mohammad Zahirul Islam, & Cordia Chu, supra, pp. 62, 81
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\textsuperscript{31} idem
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up from migrating inside.\textsuperscript{32} Through the modification of roofs, specific characteristics such as the albedo and infrared emittance of the roof can be altered, improving indoor temperatures substantially.\textsuperscript{33} Cool roofs are a sustainable alternative to air conditioning. This technology does not require the use of electricity and requires minimal/little maintenance and depending on the insulation.\textsuperscript{34}

Cool roofs offer a simple and cost-effective solution to urbanization challenges and have been implemented successfully in a number of cities including New York, Houston, Tokyo, Mumbai, Hyderabad and Ahmedabad in India. A study in Hyderabad found that cool roofs can reduce cooling energy use by 10 - 26\% depending on the roof area. The study also found that cool roofs potentially reduced citywide air temperature by 2°C. Scaling up cool roofs across the country has the potential to save over 700 KWh of energy use, avoid 0.60-0.65 Mt CO2-e, and save five billion rupees over 10 years.\textsuperscript{35}

This project focuses on three different types of cool roofs: white paint, membranes such as PVC and ModRoofs. The first two methods are the most common type of cool roofs\textsuperscript{36} and the third one, ModRoof is a modular roof made of coconut husk and paper waste which has been implemented locally in India\textsuperscript{37}.

Besides the reduction of indoor air temperature, the use of cool roofs has other benefits like:

- Energy savings of approximately 1000 kWh/year\textsuperscript{38} for very hot climates, by reducing the need for fans and air conditioners
- The increase of a roof’s lifetime\textsuperscript{39}
- The reduction of cooling costs
- In the long run, the mitigation of the heat island effect and the reduction of air pollution.

Even though the use of cool roofs has several benefits, there are also challenges that come with the application of this technology. Some of the challenges include:

- Increase of heating-needs during the winter
- Dirt and weathering conditions reduce solar reflectance
- Increase of roof-maintenance costs

\textsuperscript{32} Natural Resources Defense Council. Cool Roofs: Protecting Local Communities and Saving Energy. (2018) 7-10
\textsuperscript{33}Konopack, S., Gartland, L., Akbari, H., Ranier, L., Demonstration of Energy Savings of Cool Roofs. (Ernest Orlando Lawrence, 1998) 1-6
\textsuperscript{34} Natural Resources Defense Council. Cool Roofs: Protecting Local Communities and Saving Energy. (2018) 7-10
\textsuperscript{35} Tengfang Xu, Jayant Sathaye, Hashem Akbari, Vishal Garg and Surekha Tetali. Quantifying the direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse gas emissions. (Building and Environment, February 2012) 1-6
\textsuperscript{36} idem
\textsuperscript{37} idem
\textsuperscript{38} Konopack, S., Gartland, L., Akbari, H., Ranier, L., Demonstration of Energy Savings of Cool Roofs. (Ernest Orlando Lawrence, 1998) 1-6
\textsuperscript{39} idem
Because of its reduction of indoor air temperature, energy savings, the use of approachable low-cost materials and its feasible implementation, cool roofs offer a simple and effective cooling alternative for vulnerable communities in low-income housing.

III. Methodology

The project had two distinct phases; a diagnostic phase where data and information was collected and the assessment phase, in which the information was analyzed to solve our research questions.

In the first phase, data was collected through four key methods: (1) Initial calls with stakeholders to choose the community, (2) Literature review of Bangladesh, coping strategies and cool roofs; (3) Data collected from semi-structured interviews with Korail slum dwellers and Observational Checklists.; (4) Interviews with key stakeholders and experts on urban slums, sustainable development and climate change adaptation. All the interviews with slum dwellers and in-country interviews with experts were recorded, with consent. Ethnographic observations and the answers to the semi-structured interview were written in field journals and on the printed questionnaires.

**STEP 1: Selection of community: Korail**

The selection of our study community, Korail was based on desktop research and in-depth interviews with key stakeholders.

To select this community we considered the following indicators:
(1) Feasibility

We wanted to work in a community that was accessible and relatively easy for us to conduct surveys during the field research trip. We also needed a community that had at least some building owners, which makes it more feasible to implement housing adaptation strategies such as cool roofs.

Korail has close working relationships with several local non-profit organizations and particularly with BRAC University which is located next to the settlement. Korail has been featured regularly on climate change research papers and has attracted researchers from all over the world. This not only proved that it was feasible to conduct research in the community, but that there was a sufficient literature body to review.

(2) Physical characteristics

We wanted to work in a community with diverse physical conditions: different building structures and distinct materials. We wanted to focus mainly on residential buildings where owners and tenants were implementing heat adaptation strategies. Certain specific housing characteristics were needed to make sure cool roofs could be installed, supported and maintained.

(3) Socioeconomic indicators

The objective of the research was to target a vulnerable community, in terms of socioeconomic indicators. Our literature review showed that in addition to climate variability residents of Korail are vulnerable to: unsecured livelihoods, increased health risk, constrained economic activities, and limited access to services.

(4) Exposure to heat

Korail is mainly built with heat trapping materials which increases the exposure to heat for slum dwellers.

After consultations with different organizations including BRAC University, the Global Cool Cities Alliance, and the International Centre for Climate Change and Development, we determined that Korail, complied with all the selected indicators.

About Korail. Korail is the largest and oldest slum in the city. The informal settlement started in 1961, under Pakistani governance and it sits at the junction of two very affluent neighborhoods, Banani and Gulshan. An estimated 100,000 people live in Korail spreading over 90 acres, creating a highly concentrated population. The majority of Korail’s inhabitants are living below the poverty line and working in low-income, unskilled jobs such as rickshaw driving or day labor. Many women are also involved in the garment industry. The average monthly income is between 2000 to 4500 BDT.

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The population suffers regularly from weather variability. Korail’s population is particularly vulnerable to flooding and water-loggng because of its low-lying topography, its proximity to the lake, the lack of a city-wide sewage and insufficient storm water management system.

Some of the challenges of working with this community are: risk of eviction based on the precarious tenure situation, language, government relationship with the slum, and the varying priorities within the slum. Given the precarious tenure situation, researchers have found that inhabitants are unwilling to invest in improving living conditions despite having lived in Korail for more than twenty years.\footnote{Jabeen, H., Cassidy Johnson, and Adriana Allen. “Built-in resilience: learning from grassroots coping strategies for climate variability.” \textit{Environment and Urbanization} 22.2 (2010): 415-431.}

**STEP 2: Research**

**A. Design and implementation of questionnaire and observational checklist**

\textit{Design of the Survey and Observational Checklist}

In order to address objective one (heat coping strategies), the team designed a semi-structured interview with four components - Socio-demographic statistics, Perceptions of heat, Heat coping strategies and Willingness to adopt Cool roofs (Appendix). The purpose of this was to better understand the needs of the community in relation to heat. The survey questions were benchmarked against a compiled list of questions obtained from similar research projects. The survey was then translated into the local language, Bangla by a team of two research assistants that were hired to participate in the project.

To address objective two (cool roofs), the team designed an observational checklist of housing characteristics (Appendix III). The purpose of this was to better understand our study environment, the community of slum dwellers, and to assess if the building structures and materials would be suitable for cool roof implementation.

\textit{Implementation of the Survey and Observational Checklist}

The team entered Korail on five separate occasions, one of which was to conduct a transect walk to understand the spatial topography and surroundings. The remaining four visits were to conduct interviews with the residents of Korail.

The survey was conducted in 35 households. They were chosen based primarily on their willingness to participate, housing structure, location and ownership status.

From the 35 surveys, 32 were finally documented and used. None were situated next to Banani Lake (water’s edge). At least one family member was interviewed although it was common for other family members and community to observe the conversation and chime in. In order to get a more inclusive sample population, interviews were conducted in the morning as well as in the afternoon until 6:00pm. Interviews at night were not conducted due to safety and logistical
reasons. A total of approximately 16 hours (4 hours x 4 days) were spent conducting interviews and observational studies.

Members of the team were split into two groups with each group having one local research assistant who was in charge of carrying out the interviews in Bangla. The team members were to take observational notes on the housing characteristics as well as living conditions of each household surveyed. An internal pilot with Version 1 of the survey was conducted on 12 households on the first day to ensure the appropriateness of the questions to the target population. After obtaining these initial results, the two local research assistants were consulted and asked for their feedback regarding the format and structure of the questionnaire and to troubleshoot any logistical and technical issues. The survey was revised based on their input and Version 2 was used on the remaining households.

Each survey took approximately 30 - 40 minutes to complete and each interview was recorded with permission from the respondents.

B. Interviews with key experts in Dhaka

Prior to arriving in Dhaka, several key experts were identified with whom we conducted interviews while on the ground. Methodologically the experts were chosen based on the relevance of their work and their connections within Dhaka. See Appendix for a complete list of interviews.

STEP 3: Data Analysis

The responses from the completed questionnaires and from the observational checklists were compiled and analyzed using Microsoft Excel and Google Sheets. Notes and photographs were used to provide additional documentation and to corroborate findings. The transcripts from the surveys were translated from Bangla to English by the team of local researchers.

IV. Findings: Heat and coping strategies

The following section presents the most important findings related to the surveyed population, heat perceptions in the community and current coping strategies in place.

The information presented here was gathered through 32 surveys and 32 observational checklists.

Due to the size of the sample is not possible to draw conclusive and general findings, but rather to expose some of the most important patterns found during the field research.

A. General findings of our population

Population. 69% of the surveyed individuals were female. This was primarily due to the fact that we were in the settlement during the day which meant mainly women were home and older males who were no longer working. Roughly half of the respondents were informal owners, with 53% tenants and 47% owners. Fifteen of the individuals were between 18-33 years old. On average, each room housed three to four family members.
### Table 1- Main population findings

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<table>
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<th>Age of interviewee</th>
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<td>48-60</td>
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<td>60-older</td>
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<table>
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<tr>
<th>Family status</th>
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<tbody>
<tr>
<td>Average number of family members in room</td>
<td>3.5</td>
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<tr>
<td>Average sex of family head</td>
<td>73% male</td>
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<table>
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<tr>
<th>Living status</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Informal owner</td>
<td>47%</td>
</tr>
<tr>
<td>Rented</td>
<td>53%</td>
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<tr>
<td>One income source</td>
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<td>27%</td>
</tr>
<tr>
<td>Three income sources</td>
<td>3%</td>
</tr>
<tr>
<td>No income</td>
<td>13%</td>
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</tbody>
</table>

**Economic activities.** Of the 32 homes, 81 percent have a male head of the household, who were also the primary income source of the family. Most homes had one source of income *(57%)* and 27 percent of homes had two sources of income. With a wide variation in income sources across Korail, the majority of earnings came from rickshaw pullers, security guards, and drivers. Six percent of households had female sources of income, with 16 percent of household income coming from both female and male members of the house.

**Tenancy and migration.** Fifteen of the 32 individuals surveyed were owners and landlords, with 86.6 percent of owners living on the ground floor, which is considered cooler than the first floor.
Twenty-seven percent of homeowners were female, of these all were head of the household. Households migrated to Korail for a variety of reasons, with 68.7 percent moving for economic reasons and 18.7 percent due to environmental disasters such as river erosion. Fifty-six percent of residents surveyed had lived in Korail for more than 20 years, with 28 percent having lived in Korail for 20 to 25 years and only 12.5 percent of residents having moved to the slum in the last five years.

B. General findings related to heat and coping strategies in Korail

1. **All the interviewees expressed that heat impacts negatively their families.**

A key finding from the surveys is that heat is a persistent problem for all of the 32 respondents interviewed, that negatively impacts their livelihoods. The most frequent effects were related to health. Interviewees also mentioned loss of time and decrease in income as negative consequences of extreme heat. 47% of the interviewees mentioned that kids are particularly impacted through the feeling of fatigue, loss of concentration or loss of appetite.

During the surveys, 59% of the interviewees expressed that they wanted the weather to be cooler. It’s important to point out that from the 14 respondents that wanted the weather to stay the same, 9 were surveyed the same day. That day only 2 of the 12 interviewees said they wanted the weather to be cooler.

2. **The majority of the interviewees want to increase their strategies to better face heat and 63% mentioned that money is the main barrier for them to conduct better-coping strategies.**

72% of the respondents mentioned that the strategies that they currently implement to cope with heat are not enough. The most important obstacle to better cope is money, 63% of respondents mentioned that they do not conduct further and better activities because they lack the financial resources to do so. Other reasons are density and lack of open space (31%), tenancy status (31%) and risk of tenure (6%).

![Figure 2 - Barriers to better cope with heat](image-url)
3. **94% of the respondents identified at least one health impact caused by heat.**

As mentioned, health impacts were the most common identified negative effects caused by heat. 69% said that they suffered from sleep disorders, which is independent from the location of the room; this is an impact perceived by 22 of the 32 surveyed people regardless if they sleep in the ground or first floor. For the 10 dwellers that didn’t mention sleeping disorders, 4 of them sleep in the ground floor while the rest sleeps in the first and second floor.

59% mentioned that either their chronic diseases get worse or they suffer from illness caused by heat as diarrhea and fever. 56% said that they feel fatigued when is hot and 44% identified eating disorders, particularly loss of appetite.

The two respondents that didn’t identified any type of health impacts were men.

![Figure 3 - Identified health impacts](image)

4. **There is a strong notion in the community about the relationship between materials and housing structure with heat.**

There is a strong sense in the community regarding how materials and housing structure affect temperature. 63% of the respondents knew that their houses were warm because of tin and that cement had stronger cooling effects. 28% of the respondents knew that the first floor is warmer than the ground floor. Two owners expressed difficulty in renting out rooms on the first floor during summer and how tenants complaint because of high temperatures.

During the surveys, four respondents, only one of them an owner, mentioned the difference in prices between the ground and first floor. Rooms in the first floor, warmer rooms, cost between 2,500 and 3,000 taka, while costs of rooms in the ground floor range from 3,000 to 4,000 taka.
From the nine respondents living in the first floor, four said that they would prefer to live in the ground floor but they cannot because of higher costs.

5. **There is high interest in roofs-cooling techniques.**

56% of the respondents mentioned they knew roof-related cooling techniques, most of them mentioned cement roofs and hardboard. 72% of the interviewees were interested in learning about new cool roofs techniques, but only 9% (3 persons) said that they were willing to actually implement the strategy. Money was the strongest impediment: 53% of them mentioned that money was the main constraint. Being a tenant was the second most important determinant.

5. **Conclusions show mixed results in terms of access to weather information.**

Through an interview with the Meteorological Department we learned that they have several initiatives in place to communicate weather alerts through mobile phones. During the surveys we identified 19 households with TVs, that is almost 60% of the interviewees, and 15 with cell phones. This last figure is not complete since it was taken only as part of our observational checklist.

Even 60% of the population has a TV only 53% get weather information. This percentage is combined between, getting the information from the neighbors, through the cellphone and by watching the news. The latter is the most frequent way to access weather information. From the surveys we learned that getting this information is not a priority for the households.

6. **Gender plays an important role in heat perception and heat coping strategies**

While analyzing the perception and impacts of heat on households in Korail, gender appears as an important determinant. First, women appear to be the most impacted members of the households, since they spend most of the day inside the room. In some cases, women are not even allowed to go out of their rooms, which decreases their coping ability. On the other hand, men have jobs outside the house, in many cases even outside Korail. Men not only return to the room at night when it is cooler, but also have more options to cope simply getting off their clothes.

Additionally, women are the ones in charge of cooking which is directly related to heat stress, since they are exposed to fire which increases the temperature sensation.
Figure 4 - Gender and perception of heat and health impacts

From the graphs above we can see than 60\% of men wanted the weather to stay the same. Four men replied that they wanted the weather to be cooler, from those one was 84 years old, the other 60 years old and the third one 95 years old. In general men felt comfortable with the weather but when gender is combined with age this changed. The oldest surveyed men wanted the weather to be cooler, while the rest of the men, with only one exception felt comfortable.

In terms of the health impacts, the majority of men perceives that heat causes 2 or less health impacts while women perceive that heat causes 2 or more impacts. While two men didn’t identify any heat related health impact, all surveyed women mentioned at least one.
### C. Types of heat coping strategies identified in Korail

A total of 19 coping strategies were identified among the 32 respondents interviewed (Table 2).

**Table 2: Identified coping strategies in Korail**

<table>
<thead>
<tr>
<th>Physical modification</th>
<th>Social Support Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn on the ceiling fan</td>
<td>Change location physically to a cooler area</td>
</tr>
<tr>
<td>Turn off the ceiling fan</td>
<td></td>
</tr>
<tr>
<td>Use of a hand fan</td>
<td></td>
</tr>
<tr>
<td>Open/Close window and/or door</td>
<td></td>
</tr>
<tr>
<td>Draw the curtains</td>
<td></td>
</tr>
<tr>
<td>Modify housing structure including roof</td>
<td></td>
</tr>
<tr>
<td>- Use of chandina/cloth, hardboard, ventilation holes, paint</td>
<td></td>
</tr>
<tr>
<td>Increase fluid intake</td>
<td></td>
</tr>
<tr>
<td>- Includes (cold) water, fruit juice (e.g. lemon, coconut), saline water.</td>
<td></td>
</tr>
<tr>
<td>Apply wet cloths and/or water to the head/body</td>
<td></td>
</tr>
<tr>
<td>Sweeping the floor with water</td>
<td></td>
</tr>
<tr>
<td>Removing clothes and/or dressing in lighter clothes</td>
<td></td>
</tr>
<tr>
<td>Increase frequency of shower/baths</td>
<td></td>
</tr>
<tr>
<td>Increase utilization of electric cooling devices (table fan, standing fan, additional lines of electricity)</td>
<td></td>
</tr>
<tr>
<td>Plant trees</td>
<td></td>
</tr>
<tr>
<td>Eat different foods for different seasons for nourishment</td>
<td></td>
</tr>
</tbody>
</table>
On average, respondents had 5.53 different heat-coping strategies, with a maximum of eight (8) and a minimum of two (2) coping strategies. Females on average had 5.57 coping strategies compared to males having 5.3 coping strategies.

Most of the coping strategies took place inside the room and were individual actions, in terms of social networks, few respondents mentioned that they ask their families for help. The team didn't identify any community level coping strategy. When two male respondents were asked if they go to the mosque when they felt hot, they replied that they only go to the mosque to pray.

The five most common coping strategies identified amongst the respondents were (Figure 5):

1. Change physical location to a cooler area
2. Increase frequency of shower/bath
3. Open or closing the windows and/or door
4. Increasing fluid intake
5. Changing activities to avoid the hottest part of the day

![Figure 5 - The five most common coping strategies identified](image)
1. Change physical location to a cooler area

30 out of the 32 (93.75%) respondents interviewed changed their location physically to seek cooler areas if they feel hot. This included moving within a house, sitting outside their rooms, seeking shade under a tree, going outside to the street, shop or a more open space.

“If the tenants on the 1st floor feel more heat, they come down from the top and sit at certain places to have cool air “

“I cannot sit inside the room because it is made of tin and it also has a tin roof. So it remains hotter than outside during hot weather. I just sit out the house in the open yard”

Respondents frequently mentioned that they would sit, rest, lay, roll or sleep on the floor as it was cooler. This was a common technique in the community, since 90% of the floors are constructed with cement, even if the walls and roofs are made of tin. This makes the floor the coolest surface in the house.

2. Increase the frequency of shower/bathing

65.63% of respondents increased the frequency of showering and/or bathing from once daily to two to three times daily. One respondent also mentioned that they bathe specifically before sleeping in the summer.

“While it's so hot and if the tap has water, then one can take shower 2-3 times”

3. Open/Close the window and/or door

20.2% of those interviewed opened their windows and/or doors when they felt hot. It is important to take into consideration that from the surveyed houses, 20 up to 27 had windows. However, some of them always kept the windows closed. Particularly in the ground floor opened windows are not common because of security and privacy issues. Ventilation is insufficient and opening a window is a coping strategy limited to certain houses.

“We open our windows during the day only (safety). But when the power goes off at night, we open the window”

“I try to keep the window open during the daytime but when the sunlight gets too hot, I close the windows”

4. Increasing fluid intake

17 participants increased their fluid intake as part of their coping strategy. Fluids included juice (lemon, coconut, other fruit), cold water, saline water and plain water. Interestingly, two female respondents did not increase their fluid intake during periods of high heat and suffered Urinary Tract infections as a result of this.
5. Changing activities to avoid the hottest part of the day

Approximately half (46.8%) of the interviewees responded that they and/or their family members changed their daily activities to avoid the hottest parts of the day. These activities are mainly related to domestic tasks such as cooking and eating. The majority of the respondents weren't able to change their income generating activities because of heat. In some cases, they changed the hours in which they worked, but maintaining the income source was a priority.

“No, I can’t change my daily activities. I have to do many household chores. I have to take care of my niece; I have to cook for everyone. So, I cannot change the routine I have to do all the things in a timely manner. Although I feel lazy sometimes, I try to do all the work in a timely manner “

The most changed daily activity was cooking, many of the women said that they change the times that they cook and that they need to change their cooking patterns because food easily rots when it is warmer.

Other coping strategies

It was interesting to note that while all of the respondents had the ceiling fan on during the interviews, only 34.38% of them identified the ceiling fan as one of their coping strategies to deal with heat. However, four (4) respondents actually preferred to turn off the ceiling fan when it was hot.

“Turning on the fan while its too hot creates warm waves of air. This makes it feel hotter. Only when there is no heat from the sun, we turn on the fan”

21.88% of those interviewed modified their house specifically to deal with heat. The majority of the residents used hardboard and/or chandina (a large cloth). One interviewee used tarpaulin and another one installed large window in each of the room together with ventilation gaps and had painted the rooms orange.

“Every room of this house has one or two big windows for air passing purposes. I have also made some holes in the walls for the passing of cool air. (Walls painted orange) because it keeps the room cooler. You will feel less hot here. This colour prevents the heat from coming inside. It is durable and is not easily damage”

Conclusions

Drawing general conclusions about coping strategies in Korail is not possible since the size sample is not large enough, however there are certain insights that can be concluded from the observations: (a) households are currently implementing coping strategies that are mainly related to individual actions, (b) there is an information gap, households do not have enough knowledge to better cope with heat, (c) there isn't enough clarity about the costs of the current coping strategies in place; what is known is that in many cases households utilize more water, cook more
food for it not to get rotten, use more time to rest and buy cold consumable goods such as carbonated drinks and ice-creams.

Even if fans could be considered as a heat coping strategy, it is important to notice that not only some household’s turn-off the fan when it is too hot but also that 90% said that the face power shortages at least once a day, with increased shortages during hot days.

In general, although all the interviewees performed multiple activities to cope with heat, the majority of them expressed dissatisfaction with the adequacy of these coping mechanisms, citing money as the main barrier to them feeling cool. Coping strategies are not enough and heat is still negatively impacting families in Korail.

V. Cool Roofs Assessment

The following section assesses if cool roofs are an appropriate sustainable cooling solution for households in Korail. The indicators analyzed to answer this question were:

A. Climatic conditions
B. Housing structures
C. Price and availability of materials
D. Willingness of Korail’s residents to implement cool roofs techniques.
E. Challenges for cool roofs

A. Climatic conditions

1. Humidity

The Heat Index (HI) is a measure of discomfort caused by both ambient temperature and humidity on the human body. High humidity combined with high temperatures increases the level of heat stress on a person and can have a serious impact on a person’s well-being and health. An environment with high humidity impairs the body’s response to regulate internal temperatures through sweating, making high temperatures more dangerous. Periods of very high Heat Index have been associated with adverse human health consequences. An example of this, is the death of 62 persons in 2013 in Bangladesh due to extreme heat.

Dhaka is wet and humid with annual average rainfall between 2000 mm and 3000 mm\textsuperscript{47} and a mean annual relative humidity of 75 percent\textsuperscript{48} that can rise to 82 percent\textsuperscript{49} depending on the ambient temperature. During early monsoon season, relative humidity peaks at approximately 90 percent\textsuperscript{50}. The Meteorological Department of Bangladesh does not measure the levels of relative humidity; the absence of verified observations constrains the proper calculation of heat index in Dhaka.

Humidity not only negatively impacts the human body it can also be damaging to certain building structures. Due to Dhaka's high humidity, condensation may present as an unintended consequence to the use of cool roofs. While the trapped moisture can help to decrease room temperature, it erodes building material leading to decreased longevity of the roof.\textsuperscript{51} For the purpose of this research, humidity is not only relevant as a feature to factor in for cool roofs maintenance but also to have in consideration when thinking about the benefits of cool roofs. Cool roofs can decrease temperatures but cannot affect humidity, taking this into consideration, is not very clear the impact that cool roofs can have in heat stress.

2. Average maximum temperatures day and night

The mean annual temperature in Dhaka is 30.58ºC, with an annual range between 8.2ºC to 39.4ºC.\textsuperscript{52} Dhaka's night temperatures fluctuate depending on the season, averaging 13ºC in the winter and 26ºC during the monsoon. Over the last five years, the city has experienced an overall increase of 0.11ºC.\textsuperscript{53} A 2014 paper that analyzed the temperature patterns of Dhaka from 1995 to 2010 concluded that the minimum average monthly temperatures is showing a significant increase most prevalent in the winter.

Given these circumstances, cool roofs offer an attractive solution to increasing adverse climatic conditions. However, it is also important to assess how cool roofs might impact night temperatures. If during the night people have enough time to recover, they can reduce heat stress. There isn't enough information to draw a conclusion about how cool roofs might alter night temperatures.

\textsuperscript{47} Sharmin, T., Steemers, K., Matzarakis, A. *Analysis of Microclimatic Diversity and Outdoor Thermal Comfort Perceptions in the Tropical Megacity Dhaka, Bangladesh.* (Building and Environment, 2015). 734-750
\textsuperscript{48} Shourav, S., Alamgir, M. *Historical Trends and Future Projection of Climate at Dhaka City of Bangladesh.* (Jurnal Teknologi, 2016). 69-75
\textsuperscript{49} Sharmin, T., Steemers, K., Matzarakis, A. *Analysis of Microclimatic Diversity and Outdoor Thermal Comfort Perceptions in the Tropical Megacity Dhaka, Bangladesh.* (Building and Environment, 2015). 734-750
\textsuperscript{52} Sharmin, T., Steemers, K., Matzarakis, A. *Analysis of Microclimatic Diversity and Outdoor Thermal Comfort Perceptions in the Tropical Megacity Dhaka, Bangladesh.* (Building and Environment, 2015). Pp. 734-750
\textsuperscript{53} idem
3. Dust

In 2019, Dhaka ranked the second worst capital in an air quality report by Greenpeace averaging a PM2.5 concentration of 97.1 μg/m³\textsuperscript{54}, which rises during the dry season between November and March. PM2.5, or fine particulate matter, is an indicator of air pollution and poses the greatest health threat amongst all other air pollutants. Long-term exposure results in to heart disease, lung cancer and other cardiovascular and respiratory conditions.\textsuperscript{55}

Dhaka’s street dust is particularly toxic and has been found to contain highly carcinogenic metals such as arsenic, chromium and cadmium.\textsuperscript{56} In 2008, a governmental report revealed that Dhaka’s residents suffered high rates of air pollution 197 out of 365 days.

This high rate of air pollution can be detrimental to the effectiveness of cool roofs. The high initial solar reflectance of a white roof membrane can decrease from 0.8, on a scale of 0 to 1, to 0.6 with the accumulation of dust and soot.\textsuperscript{57} Dust becomes a criterion to factor in when analyzing the feasibility of cool roofs. Given the pollution levels in Dhaka, regular maintenance of cool roofs would be crucial if they were to remain effective.

4. Lack of data for internal temperatures

In order to properly assess the effectiveness of cool roofs, it is imperative to have baseline data about indoor temperatures. However, given the timeframe and cost constraints for this project, indoor temperature data hasn’t been collected and the team hasn’t found any available dataset with this information.

B. Current structures and materials

The following table analyses the technical feasibility of implementing and installing three cool roofs techniques: white paint, membranes and ModRoofs, taking into consideration the housing characteristics found during the field research.

\textsuperscript{54}Khan, M. *The Dust-laden Air of Dhaka.* (The Daily Star, 2019)
\textsuperscript{55} idem
\textsuperscript{56} idem
\textsuperscript{57} Santamouris, M., Synnefa, A., Karfessi, T. *Using Advanced Cool Material in the Urban Built Environment to Mitigate Heat Islands and Improve Thermal Comfort Conditions.* (ScienceDirect, 2011), Pp.3085-3102
<table>
<thead>
<tr>
<th>Indicators</th>
<th>Type of Cool Roof</th>
<th>White Paint</th>
<th>Membranes</th>
<th>ModRoof</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Korail</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Roof Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71.8% tin</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>12.5% cement</td>
<td>✔</td>
<td>✔</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>15.6% wood</td>
<td>×</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Inclination</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65% steep</td>
<td>✔</td>
<td>✔</td>
<td>~[2]</td>
<td></td>
</tr>
<tr>
<td>34% flat</td>
<td>✔</td>
<td>✔</td>
<td>~[3]</td>
<td></td>
</tr>
<tr>
<td>Walls Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65.7% tin</td>
<td>✔</td>
<td>✔</td>
<td>~[4]</td>
<td></td>
</tr>
<tr>
<td>34.3% cement</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Internal Structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>47% wood [5]</td>
<td>✔</td>
<td>~</td>
<td>~</td>
<td></td>
</tr>
<tr>
<td>25% bamboo [6]</td>
<td>✔</td>
<td>~</td>
<td>~</td>
<td></td>
</tr>
<tr>
<td>28% cement</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Internal Structure for Installation &amp; Maintenance</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>47% wood</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>25% bamboo</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Analysis of indicators and feasibility of three assessed cool roofs technologies
Roof Material and inclination. Of the 32 homes surveyed, more than 70 percent use tin as the main material to build their roofs with the remaining 12.7 percent and 15.9 percent using cement and wood respectively. Tin roofs work for the implementation of any of the three technologies. ModRoofs won't work in cement roofs and white paint will not work in wood roofs, since white paint in that material does not increase reflectivity.

87 percent of all the tin roofs were inclined and 13 percent, flat. The inclination itself do not represent a major issue for the implementation of any technology.

---

<table>
<thead>
<tr>
<th>Building stories</th>
<th>28% cement</th>
<th>✔</th>
<th>✔</th>
<th>✔</th>
</tr>
</thead>
<tbody>
<tr>
<td>53% One-Story</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>43.75% Two-Stories</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td></td>
</tr>
<tr>
<td>3.1% Three-Stories</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td></td>
</tr>
</tbody>
</table>
Wall materials and internal structures. More than 65 percent of the families use the tin to build most part of the walls of their houses, and 34.3 use a combination of brick and cement. In general, almost 72 percent use bamboo or wood for the internal structure and the remaining 28 percent, cement. When the walls are made of tin, which is the majority of the houses, the structure is always made of wood or bamboo, with a greater predominance of wood.

The wall material itself does not represent an issue for the implementation of any technology. The three technologies can work in any type of wall, however, the internal structure is a significant determinant to define which type of cool roof could be implemented given the weights of the technologies and the needed support for its installation and maintenance.

White paint and membranes are lighter than ModRoofs. In theory it doesn't matter what material is used, wood, bamboo or cement, for the internal structure, however it needs to be strong enough not only to support the technology but also to install and maintain it. Just by observations we can conclude that the current internal structures of the houses in Korail, when made out of wood and bamboo, may not be resistant enough to support the installation and maintenance of these technologies.

Therefore, further research should be done to determine the amount of extra weight the roofs and internal structures can support. If needed, specific structures would have to be installed in the walls prior to the implementation of these technologies. The price of these extra structures should be included in the cost-benefit analysis.

Floor Materials and number of stories. 90 percent of the households interviewed had cement flooring, 6 percent wood, and in just one home, tiling was used their main flooring material. All the
households surveyed with wooden flooring were found on the second story of the building. The type of floor does not affect the type of cool roof that could be implement.

53% of the houses surveyed, were one-story buildings, 43.75% had two stories and 3.1% three stories. The number of stories is an indicator to take into consideration when analyzing the efficiency of the technologies. The three of them would have a direct and most beneficial effect on the floor on the top of the building. However, to a lesser extent, in multi-stories cool roofs will have effect as well.\(^{58}\)

**Conclusions**

The most important indicator to choose which technology might work in Korail is the material of the roof and the internal structure, which needs to be strong enough to support the weight of the technology but also the installation and maintenance process, in which at least one person needs to climb to the roof to install the technology and clean the surface.

In terms of the general indicators and the current conditions of the houses in the community, the implementation of white paint and/or membranes in the roofs are more feasible than the complete replacement of the roof with the installation of ModRoofs.

**C. Price and availability analysis**

In addition to the technical feasibility of modifying roofs in Korail with either white paint, membranes, or the ModRoof system, the price and availability of the materials must be considered. This analysis is important because of two main reasons; first because the majority of the residents surveyed identified monetary costs as the major barrier for cool roofs implementation ,and second because for a cool roof technology to be sustainable, the roofing technology must become part of the local economy, ideally both in terms of materials sourcing and application of the technology.\(^{59}\) Below, we present a summary table and brief discussion of the three materials we looked at – white paint, membranes, and the ModRoof system. We compare prices between the different materials and the price differentials under different scenarios. Further research is needed to confirm our material cost and relative price estimates and to quantify additional costs related to application, roof/structure prep, and shipping.

---


\(^{59}\) Interview with Kurt Shickman, Executive Director of the Global Cool Cities Alliance
Table 4 - Price comparison of white paint, membranes, and the ModRoof

<table>
<thead>
<tr>
<th></th>
<th>White lime-based paint (USD/sq ft)</th>
<th>White enamel paint (USD/sq ft)</th>
<th>Semi-transparent blue membrane (USD/sq ft)</th>
<th>Transparent white membrane (USD/sq ft)</th>
<th>ModRoof (USD/sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>0.02-0.03</td>
<td>0.03-0.04</td>
<td>0.30</td>
<td>0.83</td>
<td>2.95-3.54</td>
</tr>
<tr>
<td>Costs not included</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Application, roof prep</td>
<td>Application, roof prep</td>
<td>Shipping, structure prep</td>
</tr>
<tr>
<td>Relative to electricity (cost of 1 line/month)</td>
<td>3-4 months</td>
<td>4-6 months</td>
<td>3.5 years</td>
<td>9.7 years</td>
<td>34.5 years</td>
</tr>
<tr>
<td>Relative to extra rent charged (per month)</td>
<td>2 weeks</td>
<td>3 weeks</td>
<td>6 months</td>
<td>1.5 years</td>
<td>5 years</td>
</tr>
<tr>
<td>Relative to monthly non-food expenditure</td>
<td>~1 week</td>
<td>~2 weeks</td>
<td>3.6 months</td>
<td>10 months</td>
<td>3 years</td>
</tr>
<tr>
<td>Relative to monthly food expenditure</td>
<td>~1 week</td>
<td>~2 weeks</td>
<td>4 months</td>
<td>10.7 months</td>
<td>3.2 years</td>
</tr>
<tr>
<td>Relative to average per capita monthly income</td>
<td>~3-5 days</td>
<td>~5-6 days</td>
<td>1.5 months</td>
<td>4 months</td>
<td>1.25 years</td>
</tr>
</tbody>
</table>
37.5% of the residents we surveyed (12 out of 32) had painted the interior or exterior walls of their homes. Given this, we do not expect there to be a substantive additional cost associated with paying for paint application (residents are able to paint their homes themselves without needing specialized training, assuming they have the physical fitness and ability to climb onto the roof). The above price estimates for a white lime-based paint and a white enamel paint are thus considered to be representative of the total financial cost of painting a roof white.

The above prices for membranes do not include the cost of application or of any precursor work that needs to be performed on the roof to prepare the surface for membrane application (e.g., removal of scaling rust). If the membrane is permanently applied, technical skills requiring the hiring of an outside expert will likely be needed. Even if the membrane is simply weighed down with ropes or bricks, there may still be a cost associated with hiring the manpower to do the job.

The above price for the ModRoof represents the cost of the material and installation and does not include the cost of shipping the ModRoof from India to Dhaka or any precursor work that needs to be performed on the structure of the house to make sure it can support the ModRoof system.

**Conclusions**

From our price comparison in the above table, we conclude that white paint, either lime-based or enamel, is by far the cheapest option for Korail residents. The cost of painting a roof in Korail is estimated to be roughly equivalent to the cost of one line of electricity for a few months; 2-3 weeks of extra rent charged; 1-2 weeks of monthly food or non-food expenditure; and less than one week’s income. In contrast, the cost of enough membrane material to cover a roof in Korail is estimated to be approximately equivalent to at least 1.5-4 months of income and the cost of the ModRoof system is estimated to be approximately equivalent to at least 1.25 years of income. While the latter technologies may be financially feasible if Korail residents received loans to pay for them or support with house preparation and purchase and installation of the membranes/ModRoof from an NGO, white paint is the only cool roof technology that Korail residents can implement themselves.

The lime-based paint and the enamel paint are similar in price. The enamel paint is more appropriate for tin roofs, the most common roof among the residents surveyed. As such, we conclude that a white enamel paint is the most financially and technically appropriate cool roof technology for residents of Korail when considering both the price analysis in this section and the materials analysis in the preceding one.

**Assumptions made in calculating relative prices:**

We used the local prices of a white lime-based paint, a white enamel paint, a semi-transparent blue membrane, and a transparent white membrane that are commercially available in Dhaka and the price of the ModRoof as it retails in India\(^6\). We assumed an average roof size of 250 square feet.

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From our interviews with Korail residents, we gathered that electricity prices in Korail are relatively standardized and residents pay ~$1.78 per month for each line of electricity.

Additionally, we gathered that although rent prices are also relatively standardized, house owners in Korail are able to charge up to ~$11.84 more for renting out a ground-floor room as opposed to renting out a first-floor room. In our calculations, we assume that the entire price differential is due to the ground floor being cooler than the first floor.

While there may be other factors that contribute to the higher price of the ground floor, most other non-monetary considerations that influence renters’ choice of which floor to live on within Korail tend to be in favor of the first floor. For example, the first floor is generally a better choice for renters concerned about property damage from flooding, theft, or privacy. The latter is particularly relevant to women, who are under societal pressure to not seem as though they are on display. As such, cooler temperatures are likely a major driver of why renters are willing to pay more for the ground floor even in the face of other benefits associated with the first floor. Owners surveyed said that they preferred to sleep on the ground floor for a variety of reasons, including to maintain better control of the building and because the ground floor is cooler. ~87% of owners slept on the ground floor. If owners are able to cool down the first-floor room, they may be able to charge a higher rent for the first floor and thereby increase their income while still sleeping on their preferred, relatively cool ground floor.

The average monthly food and non-food expenditures and average per capita income for slum residents in Dhaka was taken from a 2018 study mapping the urban slums of Bangladesh conducted by the Research and Evaluation Division of BRAC. We assume that income and expenditures within Korail do not differ significantly from the average for slums in Dhaka.

D. Willingness and priorities

When analyzing if cool roofs are an appropriate sustainable cooling solution in Korail, it is important to take into consideration the willingness of the slum dwellers as well as their priorities when making choices about housing structures and materials. The following information has been gathered through the 32 surveys and observational checklists.

**Interest to implement cool roofs.** As mentioned before, 72% of the surveyed households were interested in knowing more about cool roofs techniques but only 9% of the respondents were willing to actually implement apply a technology that would make their houses cooler. Not being an owner of the building was a substantial factor towards the willingness to apply cool roofs, but cost was the most important barrier.

**Priorities: cost, fire protection and security.** The main barrier for respondents to implement cool roofs or any other heat coping strategy are costs. 22% of the respondents said they were willing to move to a ground floor or a room made of cement but couldn’t do it because of money constraints. Owners also mentioned that implementing a cool roof technique would increase rent prices and they weren’t sure if they would be able to find renters willing to pay more money,

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however two owners also mentioned that during hotter months they find it difficult to find someone willing to rent a room in the first floor. Respondents knew that tin is associated with heat, but they still prefer to buy tin because of lower costs.

Tin sheets are also chosen because are less flammable in case of a fire, in comparison to wood and bamboo mats which are more combustible materials. Fire prevention and protection is definitely a priority in the community, not only mentioned during the surveys but also in our meeting with Selina Begum, President of the Community Based Organization.

When thinking about housing structures and materials, security is also a concern. Previous research has shown that residents believe that tin offers them more protection towards intrusion or theft.\(^{62}\)

**Temporal mindset and risk of eviction.** Even if the majority of the surveyed households have been in Korail for more than 20 years, we sensed in our surveys that some still view living in the slum as temporary. That idea coupled with a constant risk of eviction may make slum dwellers reluctant to implement any permanent solution.

### E. Challenges of cool roofs in Korail

Based on our analysis of climatic conditions, current building materials used, price and availability of cool roof materials, and willingness and priorities of Korail residents, we identified four main types of challenges that must be acknowledged and addressed as part of any effort to implement cool roofs in Korail: a) finance, b) installation and maintenance, c) behavioral challenges, and d) uncertainties.

- **Finance:** Residents cited money as the biggest barrier to implementation of cool roofs. The lack of willingness on the part of residents to pay for cool roof materials, as seen in the responses of residents to our surveys, is one part of this barrier. Another part is lack of access to housing credit. Microfinance programs operating in Korail are reluctant to give credit to residents to make structural changes to their homes given the illegal nature of their residency on government-owned land.\(^{63}\) The limited finance mechanisms and willingness to pay are notable challenges to cool roof implementation.

- **Installation and maintenance:** All types of cool roofs that we considered require some degree of physical labor and technical skill during initial installation and, in the case of white paint and membranes, ongoing maintenance. White paint is the simplest to apply; ModRoofs are the simplest to maintain. In all cases, though, a household must have at least one person, preferably multiple people, who are physically active enough to climb onto the roof to perform installation and maintenance. Additionally, in the case of paint and membranes, a household must have someone who is willing and able to periodically climb onto the roof to remove dust and other contaminants that might decrease the effectiveness of cool roofs and, if needed, touch up the paint or membrane coating. More

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\(^{63}\) Interview with the BRAC Urban Development Programme.
research needs to be done to determine the degree to which households in Korail are willing and able to put in the physical effort needed for installation and maintenance.

As mentioned in the feasibility analysis, another challenge is the needed internal structure for the maintenance of the cool roofs.

- **Behavioral challenges:** The temporary mindset of Korail residents may keep them from being willing to spend money on a structural change to their homes. Additionally, residents generally prioritize other issues over increased heat, for example, fire and security.

- **Uncertainties:** A lack of information on indoor temperatures in Korail and how they change with day and night limits our ability to assess the efficacy of cool roofs in general and how the different technologies we focus on - white paint, membranes, and ModRoofs - compare. For example, if the tin roofs currently used by many Korail residents cool down significantly at night, it may be more effective to apply a coating to the tin roof to make it more reflective and less heat-trapping during the day rather than replacing the entire roof with a ModRoof.

**VI. Conclusions and Recommendations**

**A. Conclusions**

Before listing the final conclusions of this research project, it is important to note that we worked with a small number of households which may not be representative of the large, diverse and dynamic Korail population. Not all types of houses were assessed, and more surveys need to be conducted in other areas of the slum, for example in houses that are built in the river with elevated structure since the housing characteristics and the levels of vulnerability vary significantly. Taking this into consideration, the most relevant conclusions related to the two project objectives are listed below:

1. **Heat is a relevant issue and the community is being negatively impacted by it.**

Both in the surveys and in the interviews with key stakeholders, heat was considered a relevant issue in the community. The President of the Korail Community Based Organization, Selena Begum, ranked heat as a seven on a 1 to 10 scale in priority. The most common negative impacts of heat are related to health with sleeping disorders being the most frequently mentioned.

It is important to consider that heat is not a standalone issue but is related with other priorities that the households have such as access to green space, ventilation, security and affordability, and that there are other issues that have greater relevance for the households.

2. **Households have coping strategies but 72% believe these strategies are not enough.**
Although all the interviewees performed multiple activities to cope with heat, the majority of them expressed dissatisfaction with the adequacy of these coping mechanisms, citing money as the main barrier to them feeling cool.

3. **With the current housing conditions, the three cool roofs technologies could work.**

As shown in the cool roof’s assessment, current housing conditions do not represent an impediment to implement cooling technologies. At least one technology can be implemented given the housing conditions of the houses assessed. However not all technologies can be implemented in all houses. For example, for houses with cement roofs it would be impossible to install a ModRoof.

The most important determinant in terms of housing conditions is the internal structure, which is needed both to install and give maintenance to the cool roof. In most cases the current internal structures were sufficient to support white paint and membranes, not to support ModRoof and not enough to climb to the roof and stand on it to implement or maintain any of these technologies.

4. **White paint is the most feasible technology to implement in houses in Korail.**

Given that affordability is one of the most important priorities for households in Korail and that cost is the main barrier when trying to implement a cooling strategy, white paint is the most feasible solution for Korail. We know that paint is accessible and that at least, 37.5% of the households have the technical capacity to install it. Periodic removal of dust will play a critical role in the maintenance of this technology.

5. **Uncertainty about impact of cool roofs in heat stress**

Cool roofs can decrease indoor temperature, however humidity in Dhaka plays a significant role when thinking about heat stress, and this element cannot be altered through cool roofs. Without information of maximum temperatures during night and day and indoor measurements, is challenging to conclude a final recommendation.

6. **There are certain challenges for the implementation of cool roofs in Korail**

The most important challenges are: financing (willingness to pay and limited finance mechanisms); the physical effort required for installation and maintenance; the priorities and temporal mindset of Korail residents; and a lack of information on indoor temperature values and the temperature change between day and night in Korail.

**B. Recommendations**

When this project was initially formulated, the idea was to assess whether cool roofs were an appropriate solution and define a roadmap for its implementation.

After conducting extensive research through literature review, surveys and interviews with key stakeholders, we concluded that we cannot make a conclusive recommendation without doing more research and closing some of the information gaps we mentioned in the challenges section.
It is fundamental to resolve some of the uncertainties, particularly the ones about the temperature impacts of cool roofs in Korail and the effect on heat stress, before proposing a large-scale project.

Based on this, we suggest three recommendations. Two of them include cool roofs and the third one is a community level solution without necessarily implementing a cool roof technology but instead tackling other issues mentioned by the community such as insufficient open space, and lack of green and shaded areas.

The first two recommendations are pilot projects. We consider that a pilot is the best way to close the information gap and mitigate uncertainties. One is focused on residences which will be more difficult to implement and monitor and the second one is in schools, which is not only make it easier to implement, finance and monitor but also targets a particularly vulnerable population: kids, which are in schools during the warmest moments of the day. We observed during our field visit that schools financed by international non-profit organizations or foundations already have structure-related heat coping strategies in place, such as foam insulation, while local schools are mainly made of tin.

One of the challenges of implementing cool roofs in residences is that we are not sure whether the three technologies we looked at may decrease cooling during the night and thereby negatively affect the recovery of the residents. Implementing cool roofs in schools mitigates this challenge. However, implementing cool roofs in residences might be a more effective option for helping women to better cope with heat.

The third option is not related to cool roofs and avoids many of the challenges related to housing structure modifications such as maintenance, risk of eviction and land rights issues.

The three recommendations need to be implemented by a local non-profit organization with the support of Korail’s Community-Based Organization. For the first two, since we are proposing a pilot it should be financed with a grant. If the pilots are successful, there are financial mechanisms that could be used to scale up to full implementation, such as microcredits or, in the case of schools, including the cost in the tuition. Microcredits make sense particularly for the owners that might be able to increase their rents if they have cooler rooms, but this mechanism will only be available for households with the proper land rights. The amount of rent increase is also an uncertainty that needs to be verified in a residential cool roofs pilot. For the third option, the ideal would be to have a grant to implement the project. A subsidized membership fee could also be considered but won’t be very attractive to households if it represents additional costs.

Besides these three recommendations there are other solutions that could be assessed in other research projects such as ventilation and indoor insulation materials, already implemented in private schools in Korail.
<table>
<thead>
<tr>
<th></th>
<th>Pilots in residences</th>
<th>Pilot in schools</th>
<th>Community level solution and awareness campaign</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Implement a pilot project with white paint and membrane in houses across Korail with different housing structures and materials.</td>
<td>Implement a pilot in public schools in Korail, considering that kids are inside the classroom during the hottest times of the day. 47% of the interviewees mentioned that kids experience particular negative impacts.</td>
<td>Implement a community level solution such as cooling centers or shading areas coupled with an awareness campaign to share information about impactful coping strategies.</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td>Solve the current uncertainties: 1- Measure temperature differences 2- Assess the internal structure needed and the costs. 3- Assess heat stress impacts. 4- Assess the skills needed to implement and maintain the technology. Introduce the technology to the families and present benefits. Can help women that stay most of the day inside the room.</td>
<td>Costs can be incurred by schools as well as maintenance Easily accepted by the community. Easy to monitor and measure. Some schools are already implementing this in the slum. Doesn´t affect heat stress and recovery during the night.</td>
<td>Doesn´t represent any cost for the households. Avoids land tenure challenges. Easier to implement, since it doesn´t modify any housing structure. Can provide local jobs.</td>
</tr>
<tr>
<td><strong>Challenges</strong></td>
<td>The project would need to be funded and implemented by an NGO with a grant. Risk of eviction Land rights</td>
<td>Costs of tuition will increase. Only targets kids and leaves behind women and the elderly.</td>
<td>Needs to be funded and implemented by a NGO. Some women are not allowed to leave their houses. For the population that is outside Korail or working during the day</td>
</tr>
<tr>
<td>Behavioral challenges</td>
<td>this won't be a feasible solution. Can be more costly since there isn't a established way to recoup the costs and the solution needs to take in consideration other costs such as food</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix

I- List of calls and interviews

Calls during desktop research:
1. Kurt Shickman, Executive Director, Global Cool Cities Alliance
2. Hassan Ahmadul, Technical Adviser, Red Cross Red Crescent Climate Center
3. Julie Arrighi, Climate Advisor, International Services Department, American Red Cross
4. Saleemul Huq, Director, International Centre for Climate Change and Development
5. Mofizur Rahman, Researcher, International Health Research Institute, Bangladesh
6. Malabika Sarker, Dean, Brac University, Public Health School
7. Huraera Jabeen, Associate Professor, BRAC University, Architecture Department
8. Hannah Nissan, Advisor, Earth Institute, Columbia University
10. John Armstrong, National Director, Habitat for Humanity
11. Bijal Brahmbhatt, Director, Mahila Housing Trust
12. Cassie Landers, Assistant Professor, Columbia Mailman School of Public Health
13. Christian Siderius, Research Fellow, London School of Economics and Political Science
14. Mushtaque Chowdhury, Professor, BRAC University and Columbia Mailman School of Public Health
15. Joseph Graziano, Professor, Columbia Mailman School of Public Health

Interviews in Dhaka:
1. Hassan Ahmadul, Technical Adviser, Red Cross Red Crescent Center
2. Hafiza Katum, Professor, University of Dhaka
3. Sardar Alam, Senior Research Coordinator, International Centre for Climate Change and Development
4. Selina Begum, President, Community Council of Korail
5. Zainab Ali, Professor, BRAC University, Architecture Department
6. Huraera Jabeen, Associate Professor, BRAC University, Architecture Department
7. Mojibul Huq, Associate Director, BRAC Urban Development
8. Shanawez Hossain, Associate Professor, BRAC Institute of Governance and Development
9. Abdul Mannan, Director, Meteorological Department of Bangladesh
## II- Survey

### Questionnaire

<table>
<thead>
<tr>
<th>Survey number:</th>
<th></th>
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<tbody>
<tr>
<td>Date:</td>
<td></td>
</tr>
<tr>
<td>Time start:</td>
<td></td>
</tr>
<tr>
<td>Time end:</td>
<td></td>
</tr>
<tr>
<td>Interviewer:</td>
<td></td>
</tr>
</tbody>
</table>

### SECTION 1- Socio-demographic indicators

<table>
<thead>
<tr>
<th>1. Sex</th>
<th>Options</th>
<th>Other/ Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/Female</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Age</th>
<th>#:</th>
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</table>

<table>
<thead>
<tr>
<th>3. Are you the head of the household?</th>
<th>Sex of household head:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes/No</td>
<td>Male/Female</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Are you a tenant or an owner?</th>
<th>Tenant/Owner</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>5. If owner, how many rooms do you have and how many rooms do you rent?</th>
<th># owned:</th>
<th># renting:</th>
</tr>
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<tbody>
<tr>
<td></td>
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<tr>
<th>6. Total number of people living in the house (Family &amp; Non-Family)</th>
<th>#:</th>
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<tr>
<th>7. The number of family members living in each room.</th>
<th>#:</th>
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<thead>
<tr>
<th>8. Highest level of education of the family within the household</th>
<th>a. None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b. Primary</td>
</tr>
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<td></td>
<td>c. Secondary</td>
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<tr>
<td></td>
<td>d. Tertiary (Technical, University)</td>
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<table>
<thead>
<tr>
<th>9. Occupation/Source of income</th>
<th></th>
</tr>
</thead>
</table>
10. How long have you been living in Korail?  

11. Why did you come to Korail?  
   a. Family  
   b. Better economic opportunities  
   c. Environmental/Natural Disasters  
   d. Security  
   e. Other  

12. Have you or any members of your family been diagnosed from any of these chronic diseases?  
   a. Cardiovascular disease  
   b. Diabetes  
   c. Respiratory diseases  
   d. Tuberculosis  
   e. Other chronic diseases  

13. What does your rent include?  
   * To ask about utilities - electricity, gas, water and to ask about cost  

14. Do you always have electricity?  
   Yes/No  

15. If you experience load shedding, how often does this happen?  

SECTIONS 2 - Perceptions and information  

16. What do you think about today’s weather?  

   Elaboration  

17. How do you feel right now?  

   Cool  
   Neutral  
   Hot  

18. Would you like the option of feeling cooler?  

   Elaboration
19. Do you remember a time when you felt very hot? When was this and what did you do about it?

Elaboration

20. When this happened, did you or your family members experience any of these negative consequences?

a. Sleep disorders
b. Income
c. Food and water poisoning
d. Impacts on health
e. Impacts on education (Too hot for kids to focus or study)
f. Others
g. None

Elaboration *If they say health ask what diseases*

21. Do you know when an extreme heat wave is going to happen? And how do you hear about it and is it always accurate?

Elaboration

SECTION 3 - Coping strategies

22. Do you change your daily activities when it is hot?

Yes/No/I don't know

23. What do you do when it is hot? *Let them respond and then give examples if necessary*

| Physical modifications | a. Turn on fan  
b. Open/close window or door.  
c. Drawing curtains  
d. Modify your roof/house  
e. Drink more water |
|------------------------|----------------|----------------|----------------|----------------|----------------|

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24. Do you think that these activities are enough to make you feel cooler?

Yes/No/I don't know

25. If 24=no, what prevents you from feeling cooler?
   a. Money
   b. Space
   c. Information
   d. People to help me

SECTION 4-The willingness of cool roofs

26. Have you heard of any materials or techniques that you can add to your house that would make it cooler?

Elaboration

27. Would you be interested in learning more about these techniques? Show the pictures

Yes/No
28. Would you want to put it in your house?

   Yes/No
### III- Observational Checklist

**Observation Checklist**

Survey number:

<table>
<thead>
<tr>
<th>Indoor/Outdoor</th>
<th></th>
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<tbody>
<tr>
<td>Temperature during the survey</td>
<td></td>
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<tr>
<td>Sun/Shade</td>
<td></td>
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<tr>
<td>General weather description</td>
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</thead>
<tbody>
<tr>
<td>2. Roof characteristics</td>
<td>f. Flat roof</td>
<td>g. Low Sloped Roof</td>
<td>h. Steeped Sloped Roof</td>
<td>i. Low and Steeped sloped roof</td>
<td></td>
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<tr>
<td>4. Roof conditions and general notes</td>
<td></td>
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<tr>
<td></td>
<td>Housing structure</td>
<td></td>
<td>Flooring</td>
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<td>Facilities</td>
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