



# Heat impacts on informal settlements

## Participatory heat data collection in Kenya, Tanzania and Zimbabwe

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Issue Paper

March 2026

**Urban; Climate change**

*Keywords:*

Informal settlements, extreme heat, health, urban climate justice

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## Acknowledgements

This project would not have been possible without the support of community members and SDI Federation leaders in Dar es Salaam, Kariba and Nairobi. The authors thank participants for sharing their time, energy and knowledge.

The authors would also like to thank Frank Annor, Gilbert Mwangi and their team at TAHMO for their support and for providing access to their city data in Dar es Salaam and Nairobi. Their input has been important to enable comparisons of indoor and outdoor temperature and humidity in two cities.

Finally, the authors thank the reviewers at IIED, the World Resources Institute, Red Cross and Red Crescent Climate Centre, Geres and IIED-América Latina for their helpful and constructive comments on a working draft of this report. Their input has been particularly helpful as we have developed our thinking on community-led data collection and the analysis of information collected by project partners.

Published by IIED, March 2026

Shand, W, Mardon, M, Schoonman, N, Koyaro, M, Njoroge, N, Raido, M, Banana, E, Nyamangara, T and Muganyi, S (2026) Heat impacts on informal settlements. Participatory heat data collection in Kenya, Tanzania and Zimbabwe. IIED, London.

[iied.org/22697iied](https://www.iied.org/22697iied)

ISBN: 978-1-83759-184-8

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Cover photo: community researchers in Dar es Salaam, Tanzania, preparing for heat data collection. Credit: CCI Tanzania



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There is a growing crisis of overheating cities, with people in urban informal settlements most at risk. Rising temperatures create life-threatening conditions for more than one billion people living in unplanned communities across the global South. While the overall threats to cities are recognised, there are major gaps in data coverage that obscure the risks of extreme and prolonged exposure to heat and humidity in informal dwellings. This issue paper reports the findings of pilot participatory heat data collection in Kenya, Tanzania and Zimbabwe. It reveals indoor temperatures up to 9°C hotter than outside, and the impacts extreme conditions have on the health and wellbeing of people in informal settlements. The paper underlines the urgent need for inclusive data collection and action planning to protect vulnerable urban residents.

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# Abbreviations

<b>COPD</b>	Chronic obstructive pulmonary disease
<b>DARAJA</b>	Developing risk awareness through joint action
<b>HI</b>	Heat index
<b>LP Gas</b>	Liquid petroleum gas
<b>NbS</b>	Nature-based solution
<b>NGO</b>	Nongovernmental organisation
<b>RH</b>	Relative humidity
<b>SDI</b>	Slum Dwellers International
<b>SMS</b>	Short message service (text message)
<b>TAHMO</b>	Trans-African Hydro-Meteorological Observatory

# Summary

The growing populations of global South cities face a major threat from rising temperatures. With urban populations expected to increase by around 2.2 billion people over the next 25 years and most of this growth taking place in climate-threatened cities, there is an urgent need to focus adaptation on places and communities at highest risk.

While there is increasing understanding of how heat concentrates in cities — the urban heat island effect — there is a significant gap in data and knowledge on heat exposure in informal settlements. These areas provide homes for a majority of people in many global South cities, but the unplanned character and use of poor-quality building materials put informal settlement residents at high risk from rising temperatures. This problem will only get worse with climate change. Forecasts estimate that global warming will lead to a seven-fold increase in the number of urban poor people living in extreme heat conditions worldwide by 2050.

Closing the data gap is vital to planning and delivering effective heat adaptation measures for people that are most at risk, but are least able to adapt their environments or behaviours to worsening climate conditions. Improving the granularity of data collection in cities, and understanding heat impacts and coping strategies in informal settlements, are key to reducing the vulnerability of communities already overlooked by much climate policy.

To address the information gap, IIED and SDI piloted participatory data collection in informal settlements in Dar es Salaam (Tanzania), Kariba (Zimbabwe) and Nairobi (Kenya) in March and April 2025. A mixed methods approach was used to investigate exposure to and impacts of heat — recording indoor temperature and humidity data alongside settlement-level surveys and focus groups. With data collected outside of the peak hot seasons, the research provides new insights into chronic exposure to indoor heat and persistent impacts on health, wellbeing and the suitability of informal dwellings to hot and humid conditions.

## Key findings

- This pilot study found that indoor temperatures (inside informal settlement dwellings) could be 9°C higher than external temperatures, with heat and humidity highest at night, disrupting sleep and causing ill health and stress.
- There are patterns of chronic exposure to heat and humidity, with temperatures in dwellings in Mathare (Nairobi) and Kombo (Dar es Salaam) higher for 70% of the day than outside temperatures. Prolonged heat stress, during the day and night, is a major risk to health.
- Nearly three quarters of residents experienced health issues due to heat, with heat exhaustion, skin rashes and dehydration widely reported. Infants, older people and those with chronic illness and disability are particularly at risk from rising temperatures and a lack of access to affordable clean water.
- Extreme and chronic heat has hidden financial and social consequences for women who bear caring responsibilities. Heat leads to increased expenditure on personal hygiene and managing irregular menstruation. Women are socially restricted from wearing lighter clothes and have increased exposure to heat due to gendered roles, such as cooking, in the home. For men and women, heat can significantly reduce earnings and productivity.
- The research underlines the many compromises the urban poor make to cope with extreme temperatures. During periods of extreme heat, households can spend around one sixth of their income on recurring costs to manage high temperatures, causing difficult trade-offs in household expenditure.
- People have limited means of coping with high temperatures in the home, and rely on fans, hydration and light clothing to manage. These strategies offer short-term remedies, but do not reduce future risks from heat exposure. Homes are supposed to provide respite from searing outside temperatures, but 80% of households say their dwellings are uncomfortably hot.
- Humidity is at dangerous levels for people in Kombo and Mathare, averaging relative humidity (RH) levels of 77% and 70%, respectively, during the study period. These conditions not only substantially increase the risks of heat exhaustion, but also contribute to the growth of mould in the home, the risk of respiratory

disease and high humidity also degrades the physical integrity of dwellings.

- Building typology and materials are key determinants of heat exposure. Homes in Kariba made from cement blocks, with little ventilation and corrugated iron roofs, can have indoor temperatures of above 45°C during a relatively cool season.
- Communities have limited knowledge of the risks of heat and the types of adaptations possible to reduce exposure. These, alongside a lack of finance, skills and secure tenure, discourage people from adapting their homes — despite the significant benefits that could be gained from low-cost improvements to roofing, ventilation, insulation and shade.

## Recommendations

The study has shown the risks and the impacts of extreme heat on the residents of informal settlements in Dar es Salaam, Kariba and Nairobi. It has also demonstrated the added value of community-led data collection, and opportunities for household- and settlement-level adaptation to heat. Recommendations are:

- Improve the coverage of heat data collection — extend data collection and the use of community-led research to understand conditions and build evidence for responses to extreme heat.
- Build stronger partnerships between meteorological offices, local government and organised communities — improving information flows and joint working to raise awareness of heat risks through early warning systems.
- Support affordable and incremental housing adaptation — enabling household- and settlement-level improvements that reduce exposure to extreme heat and increase the resilience of homes.
- Reinstate nature — through integration of green space and tree planting to create environments that reduce heat levels and provide natural shade for dwellings and public spaces.

# Introduction

# 1

There is a global crisis of overheating cities. In the context of rising urban populations, and dense residential and commercial development, cities are heating up at twice the global average rate.<sup>1</sup> Projections indicate that there will be an additional 2.2 billion people living in cities by 2050, with 90% of this growth taking place in Asian and African regions<sup>2</sup> that are also highly exposed to rising temperatures. To inform climate-resilient urban development and design, better evidence is urgently needed on how the hidden dangers of heat affect the most vulnerable urban residents, to guide effective adaptation measures.

Intense development, the loss of green space and the effects of human activity (such as industry and traffic) have contributed to rising temperatures in cities. Urban heat islands<sup>3</sup> are formed where the built environment traps heat, reducing natural cooling processes, making cities hotter on average than surrounding countryside areas.<sup>4</sup> The increasing size and levels of overcrowding within cities are likely to exacerbate heat levels.

Overheating is particularly problematic in urban informal settlements, where the high density of unplanned development, lack of tree cover and use of low-quality building materials concentrate heat to create intolerably hot living spaces within homes. With limited financial means and a lack of access to energy, the urban poor are those most exposed to rising temperatures, but are least able to adapt their environments or behaviours to reduce the risks of heat.

This problem will only get worse with climate change. Forecasts estimate that with global warming there will be a 700% increase in the number of urban poor people living in extreme heat conditions worldwide by 2050.<sup>5</sup> Not only will average temperatures continue to rise, but the frequency and length of heatwaves will also increase, with a growing number of cities experiencing 150 or more days per year of temperatures above 35°C.<sup>6</sup>

There is a fundamental need to orientate urban development policy and action to the new reality of overheating cities. This needs to start with accurate and disaggregated climate data that include all urban communities. While advances in mapping and modelling climate conditions at city level are providing new insights into urban heat islands, there remains a major gap in directly recorded and consistent data on residents of informal settlements' exposure to heat.<sup>7</sup> Meteorological stations, often located outside urban areas (to avoid local interference and maintain long-term, standardised observations), fail to record city-specific microclimates and often underestimate urban heat exposure, especially in informal settlements.<sup>8</sup>

The location, organisation, construction, lack of infrastructure, and use of dwellings as homes and workplaces make informal settlements substantively different from the 'formal' city. This difference heightens

the impacts of extreme heat on vulnerable groups, such as infants, older people, pregnant women, women with caring responsibilities and people in the informal economy — all groups already overlooked by much climate policy. The result of this data gap is poorly targeted interventions and rising exposure to risks.

Co-producing climate data with communities not only helps to fill gaps in the coverage of official statistics, but also provides a platform for awareness raising and local ownership of information on climate change. There is significant capacity among organised communities to share information on heat and how risks can be avoided, shift behaviours to reduce exposure to extreme temperatures, and design low-cost actions to adapt housing and environments.

# Method statement



This pilot project aimed to test the viability of community-led research to fill gaps in city-level heat data collection. The project was based on the principles that organised communities are capable, and have unique knowledge and insights into the impacts of climate change in informal settlements. To build inclusive and effective climate adaptation, city plans need to involve those people living in the most vulnerable locations in designing policy and interventions.

The approach recognised that heat is different from other climate threats, such as crisis events of storms and flooding. Heat is a sustained and pervasive risk, where prolonged exposure to high temperatures and humidity in the home and wider environment have long-term impacts on health. But heat is also more manageable at a household and settlement level, through small-scale adaptations and behaviour changes, being less reliant on major infrastructure improvements than other climate risks.

The method was jointly designed by IIED and the SDI affiliate organisations in Kenya, Tanzania and Zimbabwe to enable community-led data collection (see example approach in Box 1), and to engage communities in discussions about heat risks and possible adaptations. The mixed methods approach built on the existing good practice of community-led enumerations, developed by SDI, and introduced the use of temperature and humidity measurement devices, known as iButtons, in informal dwellings (see Appendix 1).

The research, undertaken during March and April 2025, outside of peak hot seasonal conditions, was intended to provide new insights into the chronic exposure of informal settlement residents to high temperatures and humidity. The combination of heat data collection alongside qualitative insights from settlement-level surveys, focus groups and stakeholder interviews, underpinned by a literature review of existing knowledge, was intended to provide a rounded view of exposure and impact. It was also intended to create a platform for engagement of city authorities and meteorological offices, and to inform household and community adaptation actions.

Each stage of the method was documented to allow learning to be shared across the SDI network. The aim is for data collection to be replicated in different urban contexts and adopted by authorities to include in city-level heat action plans. To fully address urban heat risks requires capability and action at different scales: to collect granular data on the experience and impact of heat; to plan for adaptations to homes and communities; and to target adaptation measures at city level. The method is intended to add value to the work of meteorological offices, as well as enabling communities to contribute to delivering transformative adaptation.

## BOX 1. YOUTH RESEARCHERS (ZIMBABWE)

Young members of the SDI 'Know Your City' team in Kariba were trained to engage residents, collect iButton data and undertake household surveys. The team form part of KYC TV — an international collective of young people using film and social media for positive social impact.

<https://sdinet.org/explore-our-data>

# Findings

# 3

## 3.1 Tracking heat levels

### 3.1.1 Temperature and humidity

Data was collected on indoor temperature and humidity in informal dwellings, to assess exposure to, and the likely impacts of, heat on health and wellbeing. The pilot data collection period (March and April 2025) was outside the hot seasons in each country, with temperatures lower than at their seasonal peak. The project generated granular data on heat and humidity in each home, throughout the day. A summary of the average maximum and minimum temperatures and relative humidities for the pilot data collection period are shown in Table 1.

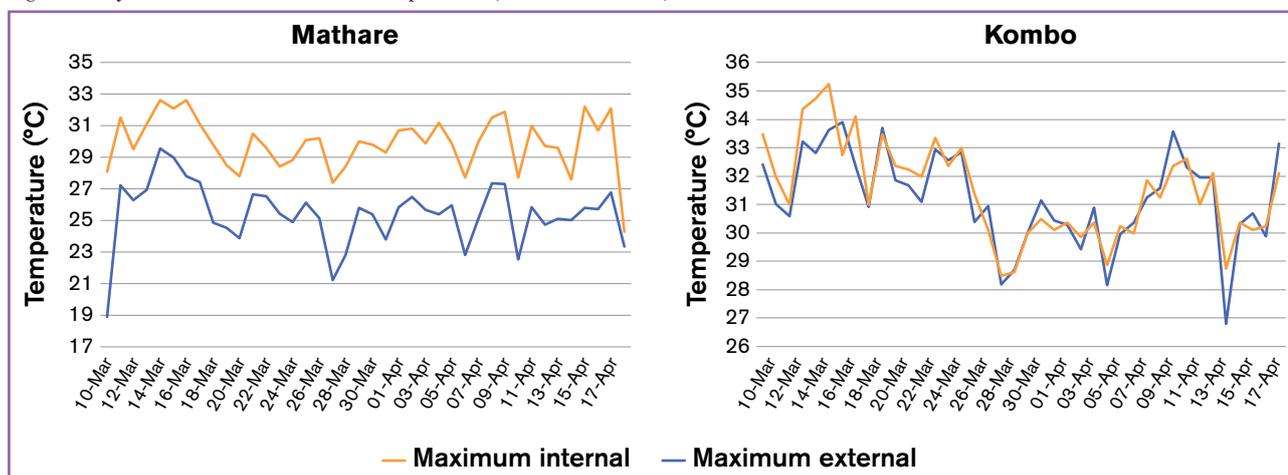
In two settlements (Kombo and Mathare), external heat and humidity data was provided by the Trans-African Hydro-Meteorological Observatory (TAHMO), from their local automated weather stations, to provide a point of comparison between indoor and outdoor readings (see full methodology in Appendix 1). Our evidence shows that indoor temperatures are, on average for the dwellings looked at in each settlement, higher than outdoor temperatures.

Comparing maximum daily indoor and outdoor temperatures (Figure 1), Mathare (Nairobi) homes are on average 4.5°C hotter than the external environment, but reached a maximum difference of 9.2°C during the pilot period. In Mathare, overheating forms a pattern

Table 1. Maximum and minimum average indoor temperatures and humidities over the data collection period

	Temperature average (°C)		RH average (%)	
	Max	Min	Max	Min
Kariba	40.8	23.8	87.0	24.5
Kombo	35.2	25.9	87.8	54.6
Mathare	32.6	20.3	84.2	38.4

Figure 1. Daily indoor and outdoor maximum temperatures (Mathare and Kombo)



of sustained exposure to high heat and humidity that is harmful for health and wellbeing. In Kombo (Dar es Salaam), indoor maximum temperatures more closely followed outdoor temperatures, with an average daily difference of +1.3°C and a maximum difference of 2°C, over the period.

The data reveals notable differences in the ranges of indoor and outdoors temperatures, as illustrated in Kombo (Figure 2). Over the project period, average indoor temperatures stayed hotter and had a more limited range than outdoor recorded temperatures. This is most notable when looking at minimum temperature levels where indoor readings for Kombo were nearly 3°C warmer than the external minimum temperatures. In hot conditions informal dwellings do not cool down, even during the night, before heating to their peak, thereby offering little respite for residents.

On close examination, a one-week extract from Mathare (Figure 3) reveals a pattern of heating, with a lag of two to four hours in peak indoor temperature, as external temperatures rise. This suggests heat accumulates and is retained within the dwelling, with indoor spaces remaining hot throughout the day and night.

While the indoor and outdoor rates of cooling appear to be similar, the lag and retained heat within dwellings result in homes being hotter than outside during the evening and night, when families are most likely to be at home.

Around **one third (38.6%)** of respondents in Kombo and **one in six (15.1%)** in Mathare use electric fans to cool their homes. With limited access to energy and the unaffordability of air conditioning, residents struggle to control indoor heat levels. As discussed in section 3.2, due to the types of construction materials and the absence of good ventilation, indoor spaces cool slower than the external environment. This aligns with feedback from community members who comment on the effects of high temperatures at night on health and sleep patterns (Box 2).

Figure 2. External and average indoor hourly temperatures during the pilot period in Kombo

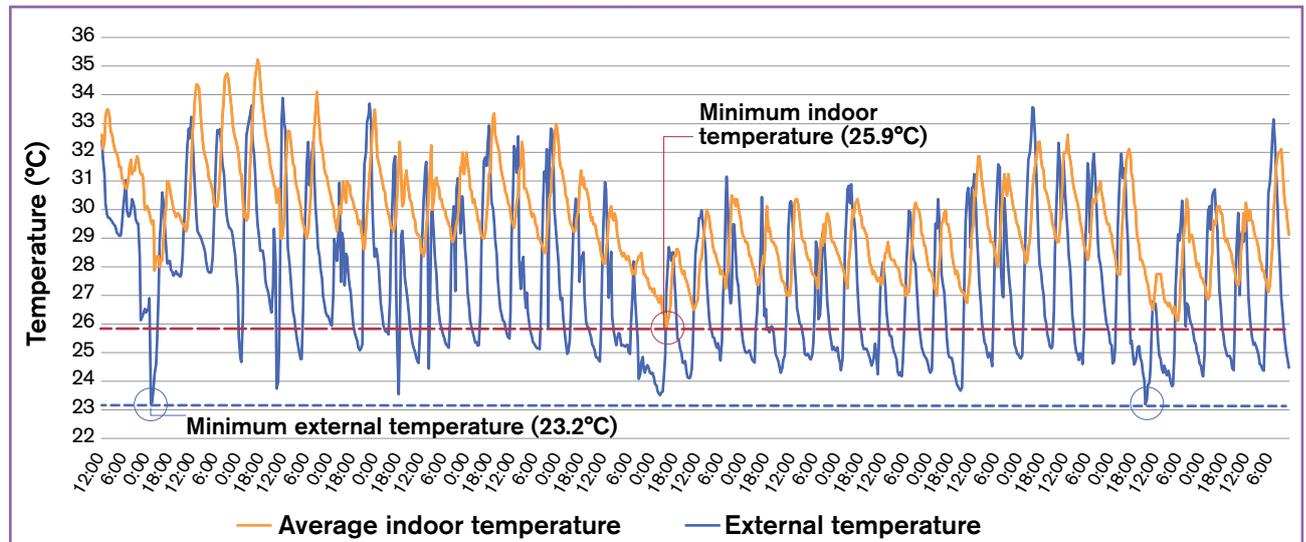
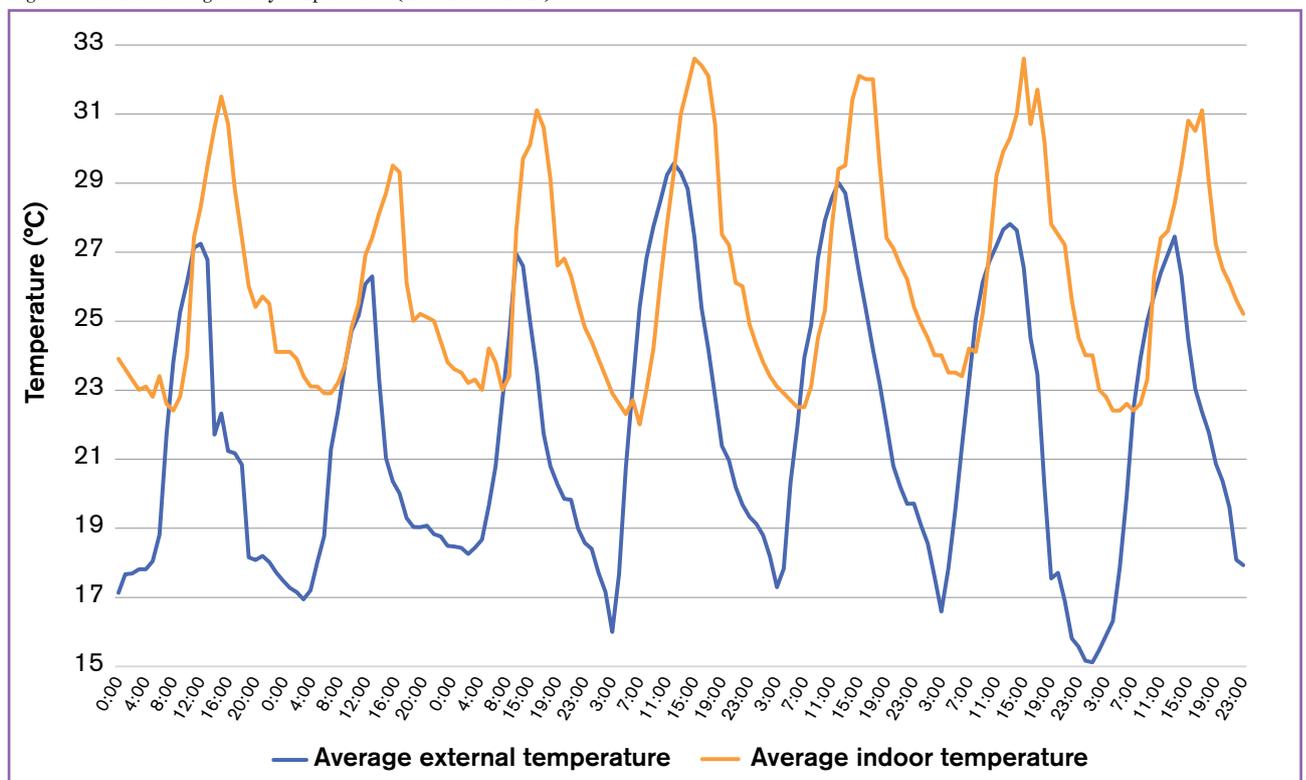


Figure 3. Mathare average hourly temperatures (11–17 March 2025)



## BOX 2. NIGHTTIME HEAT (MATHARE)

“When there is a lot of heat, I get sleepless nights. I usually take time and go outside to get some fresh air. For the kids, they do sweat so much while sleeping and they get skin rashes all over the skin and we rush them to the hospital for medication. The rashes become itchy and when scratched, they become wounds.”

**Mathare focus group member**

The maximum differences between indoor and outdoor spaces can be significant. When viewed over 24 hours, with each hour of the day averaged for the whole data collection period, the lag in cooling and the overheating of homes during the evening and night is clear. External temperatures rise to a maximum level at around midday,

with indoor temperatures instead peaking at around 4pm. At this point of the day, the internal temperatures in Kombo dwellings are more than 5°C higher than outside temperatures, and nearly 8°C higher in Mathare. **Dwellings in Kombo and Mathare are hotter than the external environment for more than 70% of a**

**24-hour period**, with indoor temperatures falling by around 0.5°C per hour from the peak levels.

Humidity levels are also a key issue for communities in the three settlements. Humidity is the concentration of water vapour in the air and is measured as a percentage, indicating how close the air is to holding its maximum amount of water (RH percentage). When the air has a high saturation (above 60%), conditions can feel muggy and uncomfortable. More importantly, high humidity can affect the body’s ability to cool down through sweating (see section 3.3).

Humidity levels are affected by the prevailing weather systems and geography (such as altitude above sea level). The three settlements are influenced by different climate factors and geographical conditions (Table 2).

Recommended RH levels are between 40% and 60%<sup>9</sup> for comfort and the maintenance of core body temperature. Levels outside this range can have significant impacts on people and environments, and increase the transmission of infectious disease. Humidity levels above 60% can contribute to heatstroke and dehydration, and below 40% can lead to skin complaints and respiratory problems. Humidity outside

the recommended range can also affect building materials, creating the conditions for mould and the gradual degrading of wood, concrete and metal.

Levels of humidity during the pilot data collection period show that **Kombo and Mathare had humidity levels significantly above the recommended range** (Figure 4), while the drier environment of Kariba experienced humidity below 60% for almost the entire period. During the evening and nighttime, when the air is cooler, RH increases, making the environment feel more uncomfortable. Cooler air has a lower capacity to hold vapour, so even if the amount of water stays the same, the air is more saturated than when temperatures are higher. Humid air in the evening and night can affect sleep patterns. Data shows that humidity levels are highest between 9pm and 7am, when people are likely to be at home and resting.

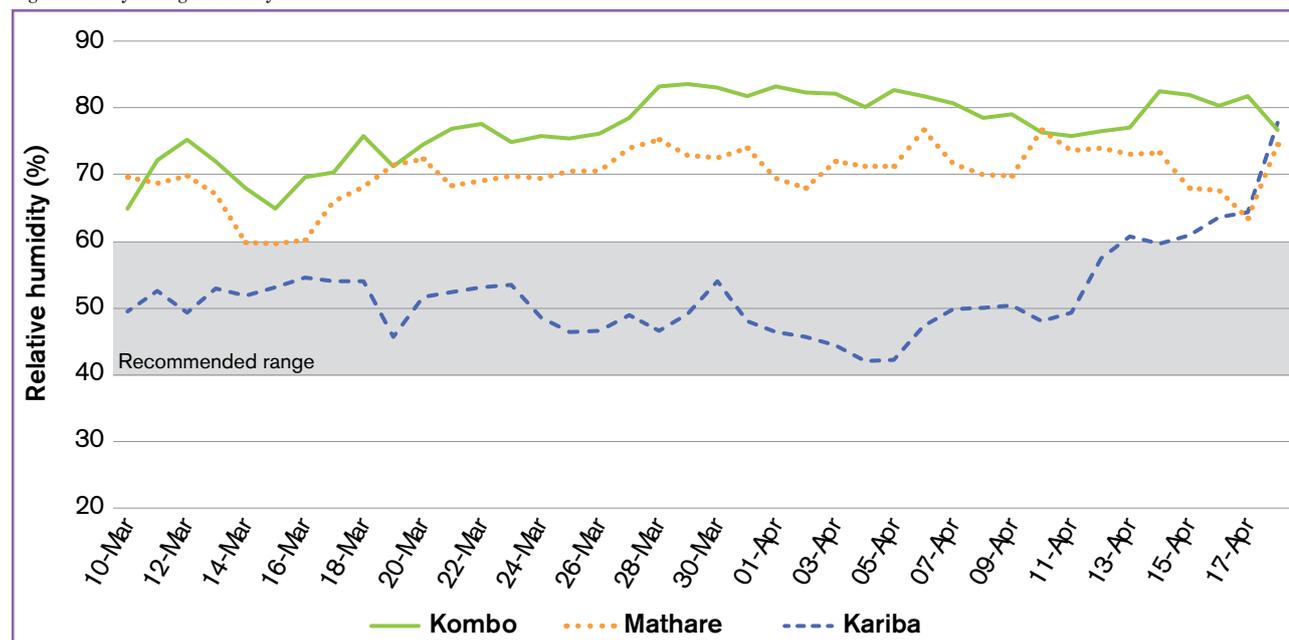
### 3.1.2 Thermal comfort

Data from the three cities show that people are largely dissatisfied with the temperature in their homes. Around **80% of respondents** in all three settlements say they are uncomfortable or very uncomfortable in

Table 2. Average indoor humidity (three settlements)

Settlement	Average RH (%)	Climate context
Kariba	52.0	Tropical savanna climate with warm temperatures year-round and with humidity most significant during the rainy season (November to February)
Kombo	77.3	Tropical savanna climate, but strongly influenced by its coastal position on the Indian Ocean. The ocean contributes to high humidity year-round.
Mathare	70.1	Subtropical highland climate with mild temperatures and cooler evenings, due to its elevation. Influenced by the Indian Ocean, humidity is high year-round.

Figure 4. Daily average humidity



their homes during periods of high heat (Figure 5). The thermal comfort of homes is a key aspect of inclusive development,<sup>10</sup> reflecting inequalities in income, dysfunction of housing markets and land rights, a lack of access to and high costs of energy, and vulnerability to ill health. Positioning thermal comfort within a framework of ‘ambient vulnerability’,<sup>11</sup> helps to explain both the specific impacts of extreme temperatures on wellbeing and the cumulative effects of heat as part of a pattern of exposure to risks.

The focus here on indoor environments allows for consideration of less visible vulnerabilities among people who are tied to home for reasons of age and health, as well as social and gendered roles — particularly for women in domestic and caring roles. Focusing on indoor spaces helps reveal vulnerabilities linked to economic roles, given that **home is also a place of work for around one in five people across the three settlements**. For these groups, considering thermal comfort creates awareness of the sustained periods of heat risk they experience, and prompts discussion about the adaptations needed in contexts of urban poverty.

While the methods for measurement of thermal comfort are well established,<sup>12</sup> these are largely based on global North standards used to assess the thermal performance of buildings. To date there has been more limited study of thermal comfort issues in global South contexts<sup>13</sup> and less still on urban informal settlements. Based on previous studies of thermal comfort in sub-Saharan Africa<sup>14</sup> and drawing on the standards of the Kenya Meteorological Office,<sup>15</sup> Figure 6 shows

comfort ranges alongside average indoor temperatures for day and night for the three settlements.

Homes in Kariba and Kombo spend most of the 24-hour period outside of the thermal comfort range, with just a small part of the day with tolerable temperatures (Table 3). The average temperature in Kariba is 7–8°C above the maximum comfort level (29°C) in the early afternoon. In Kombo, there are just four hours in the morning that are below this comfort level, and only two hours in Kariba. Even in Mathare, which is within the comfort zone much of the time, 79% of people said that they felt uncomfortable or very uncomfortable in their homes — underscoring the need for further analysis of comfort and activity levels in informal dwellings.

In Kariba and Kombo, temperatures are above the recommended range during the night, which affects health and sleep patterns, as discussed more in section 3.3. During the night, households attempt to manage high heat by using fans and cool water to reduce the worst effects of overheating.

### 3.1.3 Heat index

To assess the risks of hot and humid conditions on health, a heat index (HI) can be used. This is a calculation that combines temperature and RH to provide an indication of what temperature ambient conditions ‘feel like’. It is used to identify heightened risks of heat exhaustion.

Here, thresholds produced by the Tanzania Meteorological Agency<sup>16</sup> have been used as a regionally determined benchmark (Table 4). These boundaries provide an approximate indication of risk and are

Figure 5. Feeling ‘uncomfortable’ and ‘very uncomfortable’ at home

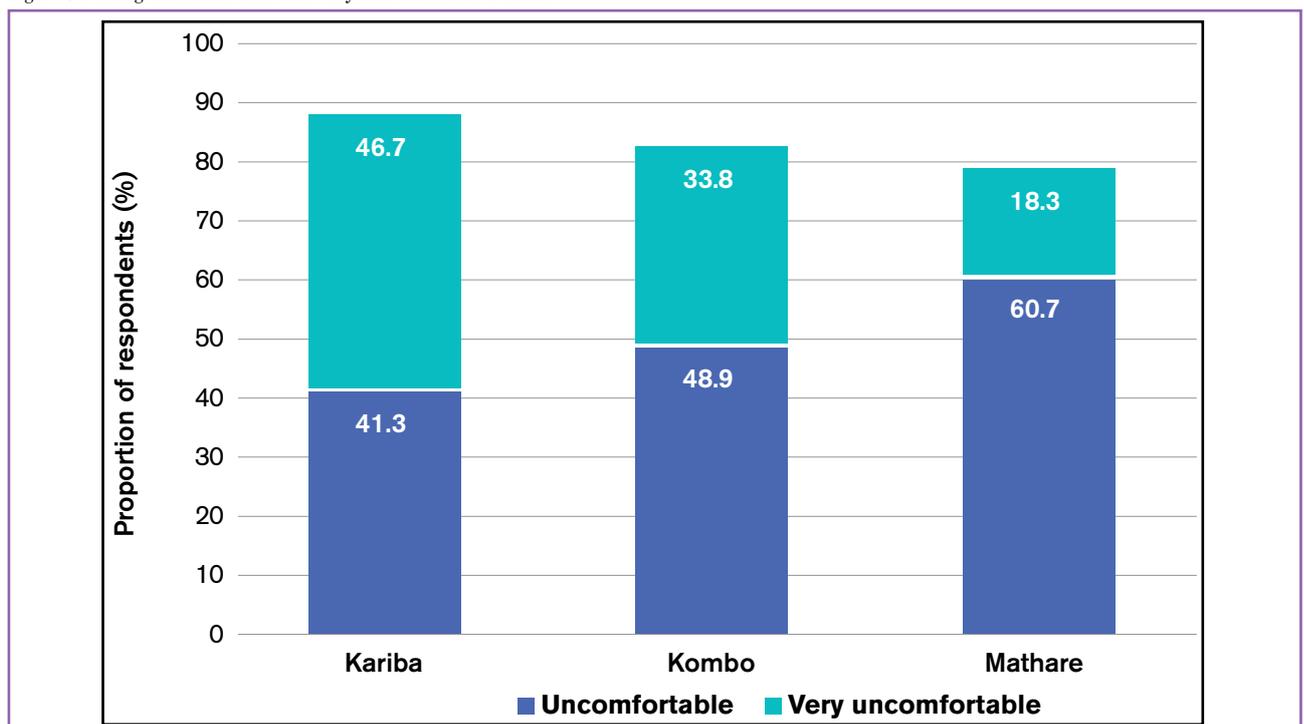


Figure 6. Thermal comfort ranges and average indoor temperatures over 24 hours

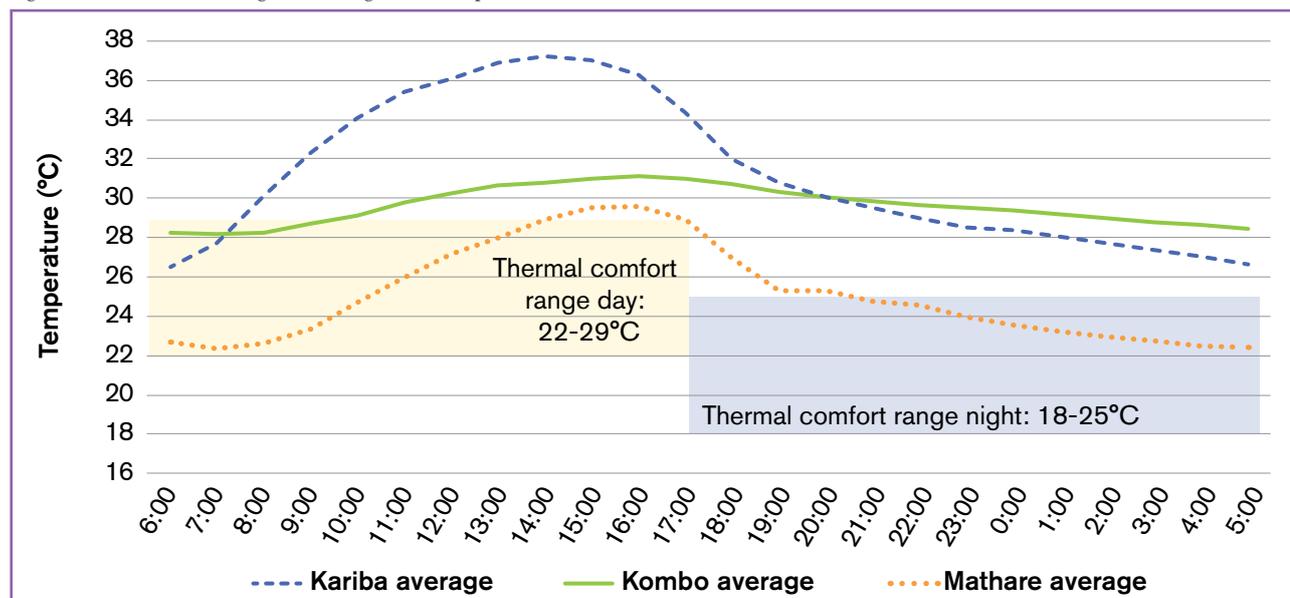


Table 3. Time within thermal comfort range

	Hours within comfort range	Percentage of 24 hours	Times of day
Kariba	2	8.3	Early morning, 6–7am
Kombo	4	16.7	Morning, 6–9am
Mathare	20	83.3	All day other than 3–5pm

Table 4. Heat index thresholds

Heat index (°C)	Threshold	Recommended actions
38+	Danger	Take baths (wet your body), take breaks when working in outdoor workplaces, seek medical attention if needed
32–37	Extreme caution	Reduce working on heavy tasks, avoid sunshine, stay in shade
27–31	Caution	Drink enough water, wear light clothes, have enough rest

Source: Tanzania Meteorological Authority

intended to raise awareness and inform behaviours, but do not account for individual tolerances or differentiate levels of risk for more vulnerable groups.

Figure 7 provides a daily analysis of the maximum heat index levels recorded for all three settlements during the pilot period. As can be seen, maximum indoor temperatures in Kariba are below the danger zone for just one of the 40 days of the pilot data collection. Of the other two settlements, Kombo is in the danger and extreme caution zones, with Mathare showing cautionary heat levels.

The data shows that heat index levels in individual dwellings can rise to above 60°C in Kariba, creating high levels of risk for residents. It is important to understand how the pattern of heat exposure varies

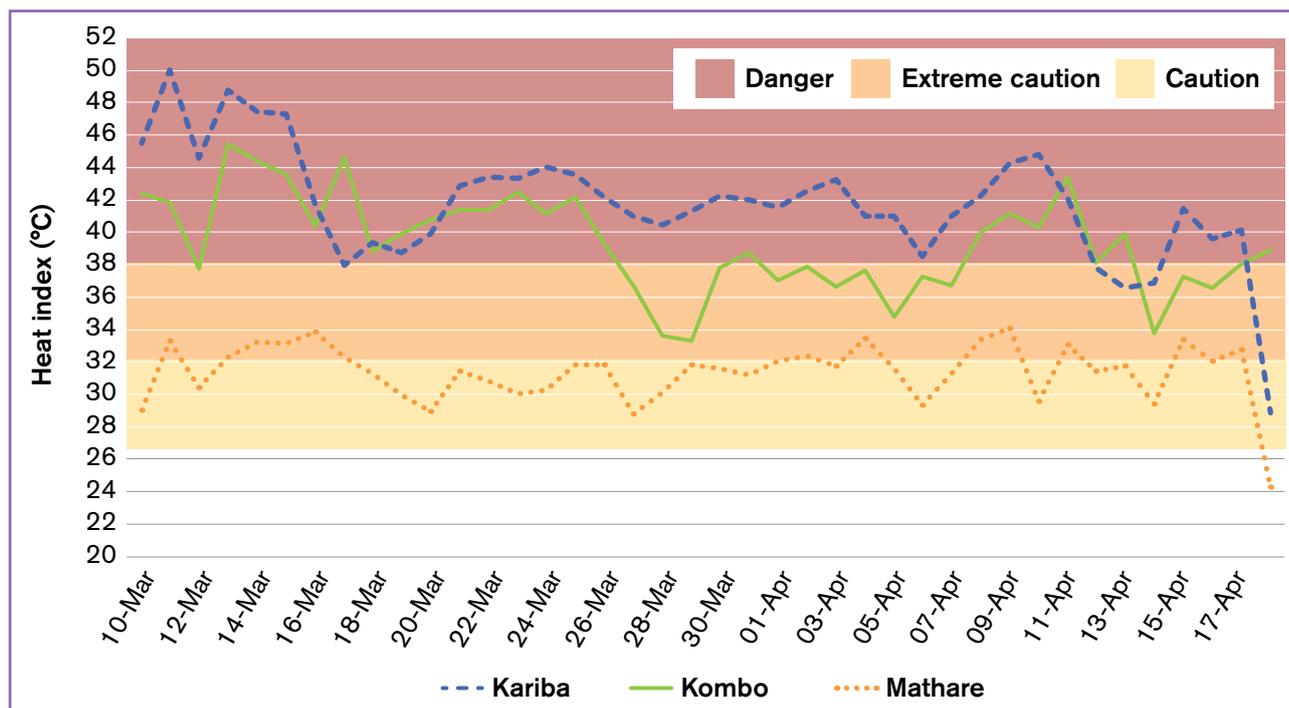
during the day, to identify when people are most at risk and define the actions that can be taken. For example, average and maximum scores for Kombo settlement, over a 24 hour period indicate peak danger in late afternoon and evening. This information can be used to educate settlement residents about risk, undertake adaptive actions to improve housing and counter the normalisation of heat.

## 3.2 Building characteristics and heat

### 3.2.1 Heat patterns

The building envelope (roof, walls and floor) of a dwelling has a key role in determining internal temperatures

Figure 7. Daily maximum heat index



and the liveability of homes. With widespread use of thermally inefficient construction materials, and a lack of shading and adequate ventilation,<sup>17</sup> houses in informal settlements typically offer little protection from extreme heat. While informal settlements share many common characteristics, they are not homogeneous, with important variations in the building materials and their quality, level of insulation, orientation, room height and construction methods, as well as external factors such as the density of buildings and availability of shade to reduce direct sunlight (Table 5).

Temperature and humidity data analysed alongside information from household surveys on the construction materials used to build homes provide

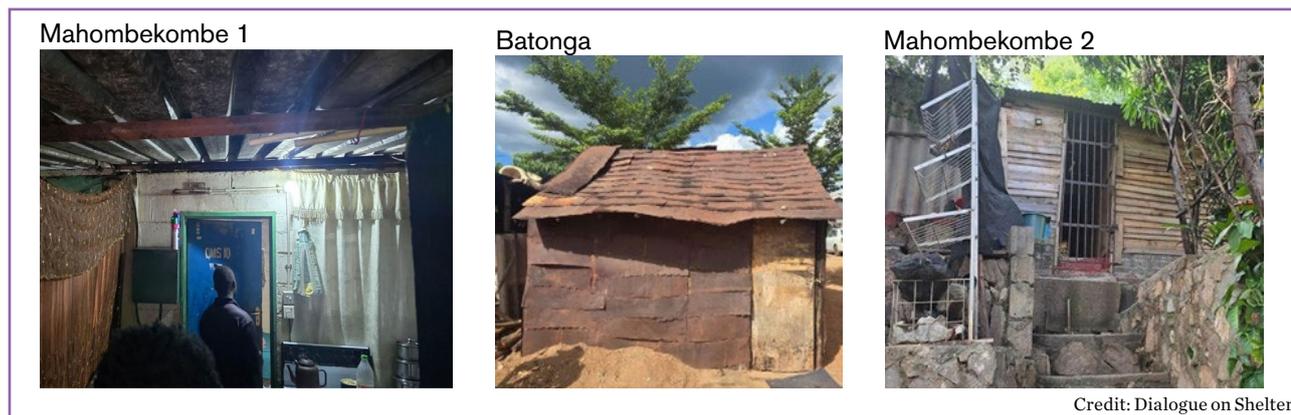
an indication of how building characteristics affect indoor heat levels. The combined use of iButtons and surveys indicate that **housing design and materials effect indoor temperature levels**. However, the limitations of this study (Appendix 1) underline the **pressing need to undertake larger-scale data collection** to inform property-level adaptations to heat in informal settlements.

In Kariba, the form of housing construction and materials used is broadly similar within the settlement, comprising cement brick walls and corrugated iron roofs. Figure 8 shows examples of the properties included in the pilot study. All dwellings experience **very high temperature levels**, with an average of 40.8°C

Table 5. Settlement characteristics

Settlement	Description
<b>Kariba</b>	<ul style="list-style-type: none"> <li>▪ A peri-urban settlement on the bank of Lake Kariba, with a mix of self-built homes, constructed primarily of cement blocks and iron sheet roofing</li> <li>▪ 75% of dwellings have two useable rooms</li> <li>▪ 43% of homes have trees providing shade around the property</li> </ul>
<b>Kombo</b>	<ul style="list-style-type: none"> <li>▪ A mix of Swahili multiple-occupancy buildings, with shared cooking spaces and families typically occupying one room</li> <li>▪ Much of the settlement is low-lying, making it susceptible to flooding, which undermines the stability of the housing</li> <li>▪ Only 25% of dwellings have trees around the property</li> </ul>
<b>Mathare</b>	<ul style="list-style-type: none"> <li>▪ A dense mix of unplanned housing developments, the majority self-built with wood frames and corrugated metal sheets</li> <li>▪ 83% of dwellings have just one useable room</li> <li>▪ 95% have no permanent trees around the property</li> </ul>

Figure 8. Example dwellings in Kariba



and a high of 45.6°C. The range of temperatures is largely consistent, with only the Mahombekombe 1 property showing a notable variation (Figure 9).

In Kombo settlement, the temperatures are also relatively consistent across the four dwellings (Figure 10), with just TZ05 showing notable variation in temperatures over the period. The range in temperature for each property is shown in Figure 11. The TZ05 property has a thermal range of 14.5°C, with a maximum temperature 6°C higher than the lowest maximum in TZ02. The property also has a lower minimum temperature than the other dwellings in this settlement sample, indicating poor insulation.

As the building typologies of the properties in Kombo are similar across the settlement, the variation shown by TZ05 is difficult to isolate, but might be partially explained by the rusty and ill-fitting roofing materials, the lack of an internal ceiling and indoor cooking activities. The condition of the dwelling and its overcrowded spaces are likely to affect internal heat levels, but **further comparative data collection and**

**analysis is needed to identify the specific factors that influence the thermal performance of the building,** and inform adaptations that would make the dwelling more liveable.

The data in Mathare tells a different story, with a stark difference in heat levels recorded in the five properties (Figure 12). The dwellings can be grouped into two types: those built of wood and corrugated iron (HH1–3) and those more formally built from concrete (HH4–5). Not only are the maximum temperatures in the iron shack dwellings higher on average than the concrete dwellings by around 10°C, but the range of temperature change is larger than recorded in the stone and concrete dwellings (Table 6).

As seen in Figure 13, the range of temperature change is much narrower in HH4 and HH5 than the shack buildings, suggesting very different thermal performance linked to the mass of the building material. This is underlined in Figure 14, which shows the average daily temperature change over the data collection period. **The stone and concrete dwellings have a more stable**

Figure 9. Temperature ranges by dwelling (Kariba)

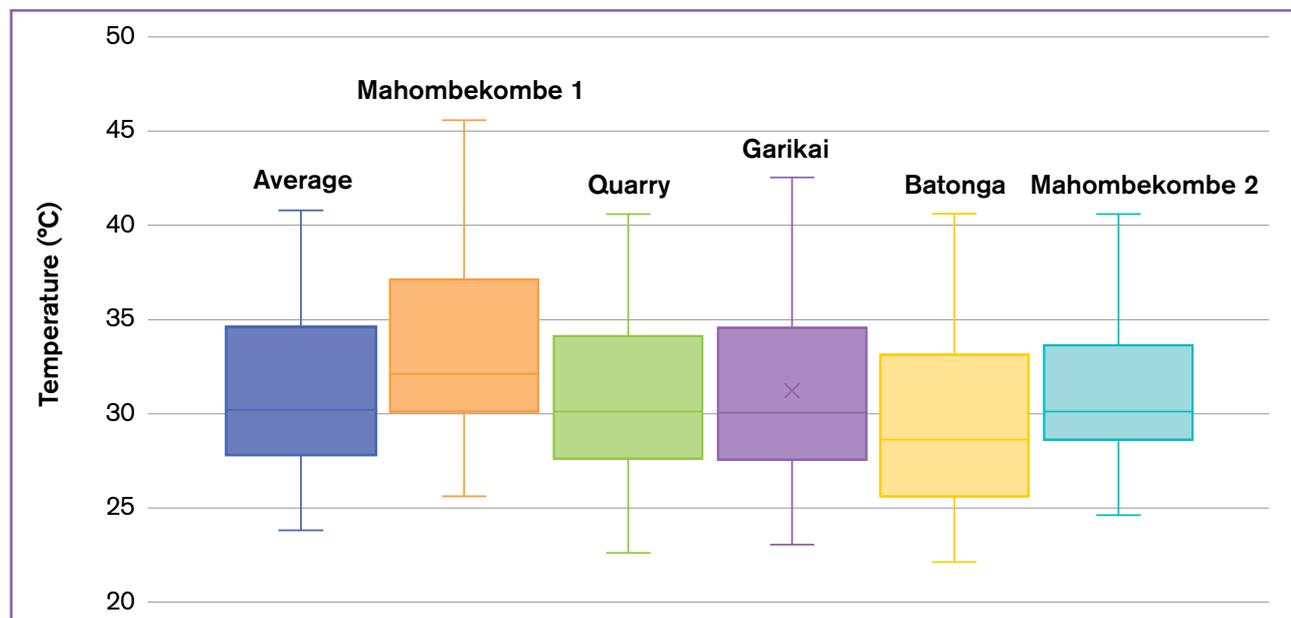


Figure 10. Example dwellings in Kombo

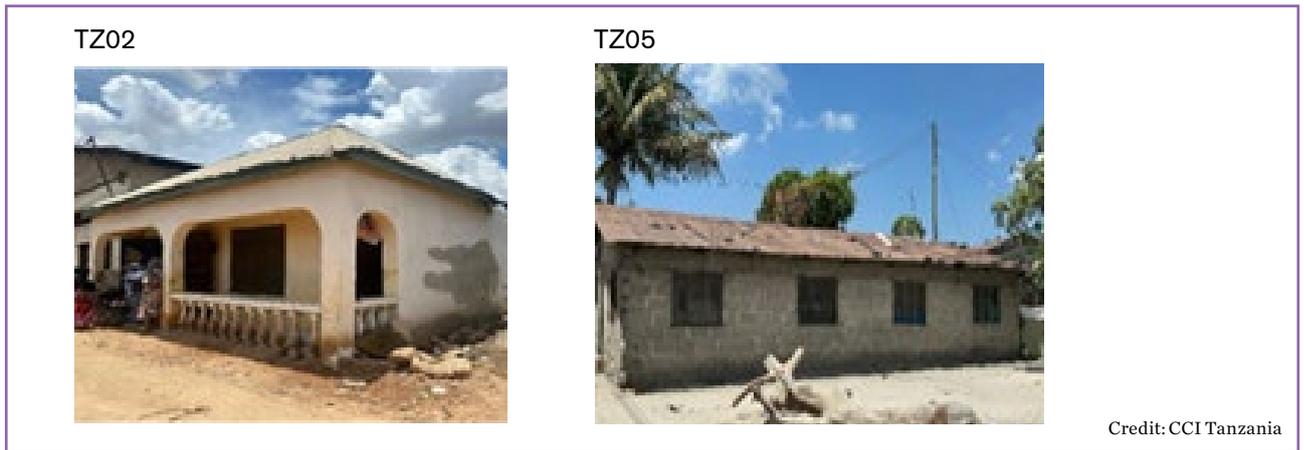
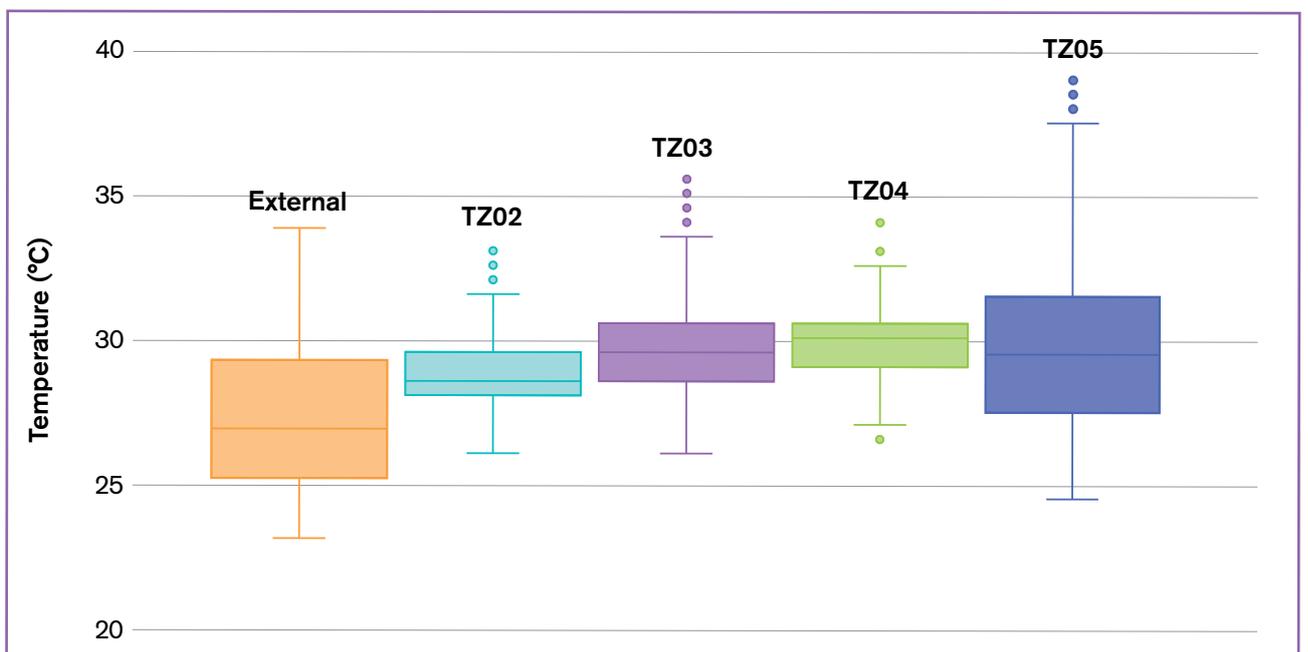


Figure 11. Temperature ranges by dwelling (Kombo)



temperature with over half the range of the shack dwellings, at 8.3°C compared to 20.7°C between maximum and minimum across the pilot period.

The patterns of change can be seen over a 24-hour period (Figure 15), with the concrete dwelling temperatures staying within a 2°C range, whereas the shack dwellings experience a range of 11.9°C. The peak temperature of 32.7°C in the shack dwellings occurs at 4pm; in the concrete dwellings the temperature is more stable over the day. It is notable, however, that temperatures in the shack dwellings continue to fall during the night to a low of 20.8°C at 7am, significantly below 24.1°C in the brick buildings with greater thermal mass.

The homes in Mathare also showed variation in humidity (Table 7). While the maximum levels are comparable between dwellings, the **concrete buildings have a significantly higher minimum level of RH**, which is nearly double that of the shack dwellings. While iron

shack dwellings have extreme temperature swings, the concrete dwellings have **persistent dampness problems that lead to mould and respiratory problems**. The high humidity makes crowded rooms feel damp and uncomfortable when RH is above 60%. While the elevated level may result from the lower average temperature and capacity of the air to hold water vapour, the feel and effect of humidity will have a significant impact on both the health of the residents and the long-term decay of the concrete structure.

Over 24 hours, averaged for the data collection period, the concrete buildings had a constant RH of between 70% and 80%, with the highest levels recorded during the nighttime hours. This is significantly above the recommended level and indicates an unhealthy living environment for residents. For the iron shacks (HH1–3), humidity falls during the day but rises at night to be outside the recommended range, again indicating a risk for residents at times when they are most likely to be at home.

Figure 12. Example dwellings in Mathare



Credit: KYCTV Kenya

Table 6. Maximum and minimum temperatures, and temperature ranges, for dwellings in Mathare

Dwelling	Dwelling type	Temperature (°C)		
		Max	Min	Range
HH1	Corrugated iron shack dwellings	39.1	18.1	21.0
HH2		38.6	15.6	23.0
HH3		36.6	18.6	18.0
HH4	Stone and concrete dwellings	28.6	19.6	9.0
HH5		29.1	21.6	7.5

Figure 13. Temperature ranges by dwelling (Mathare)

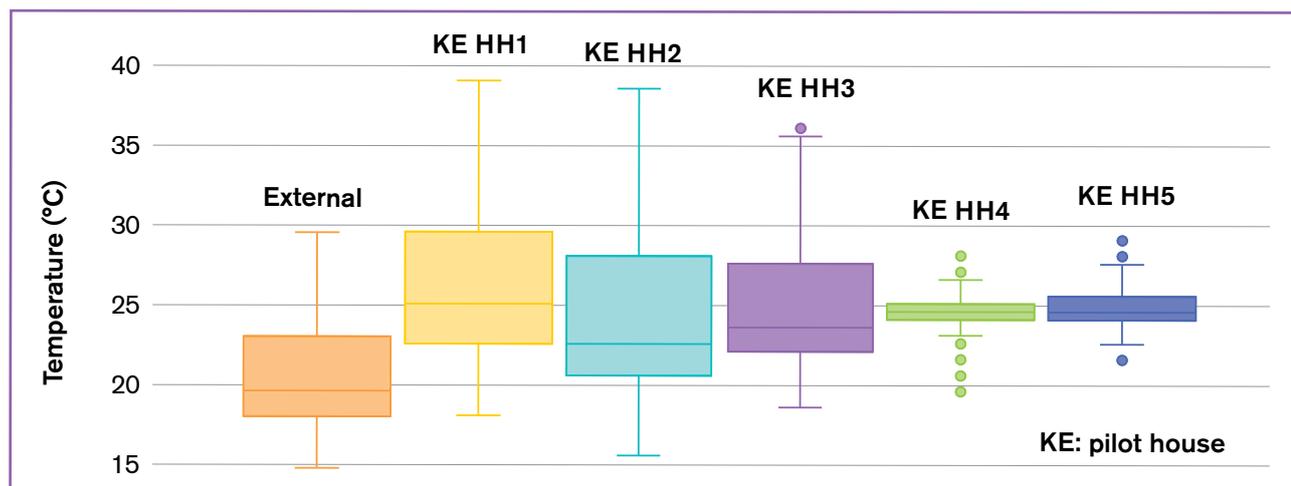


Figure 14. Average daily change in temperature in Mathare

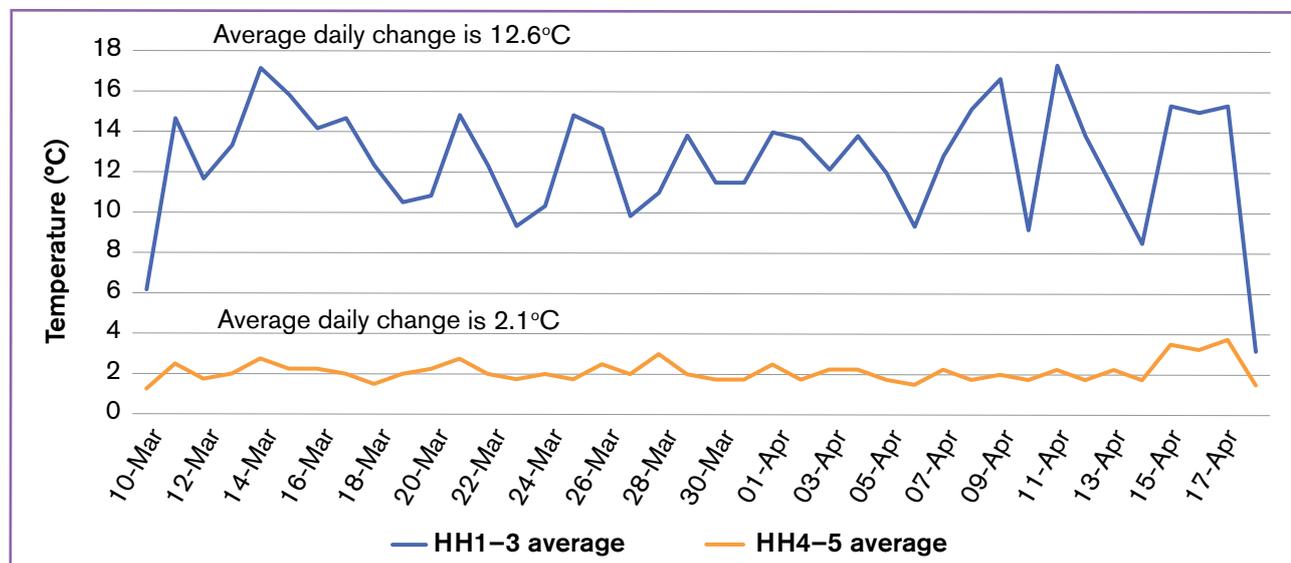


Figure 15. Average temperature change over a 24-hour period in Mathare

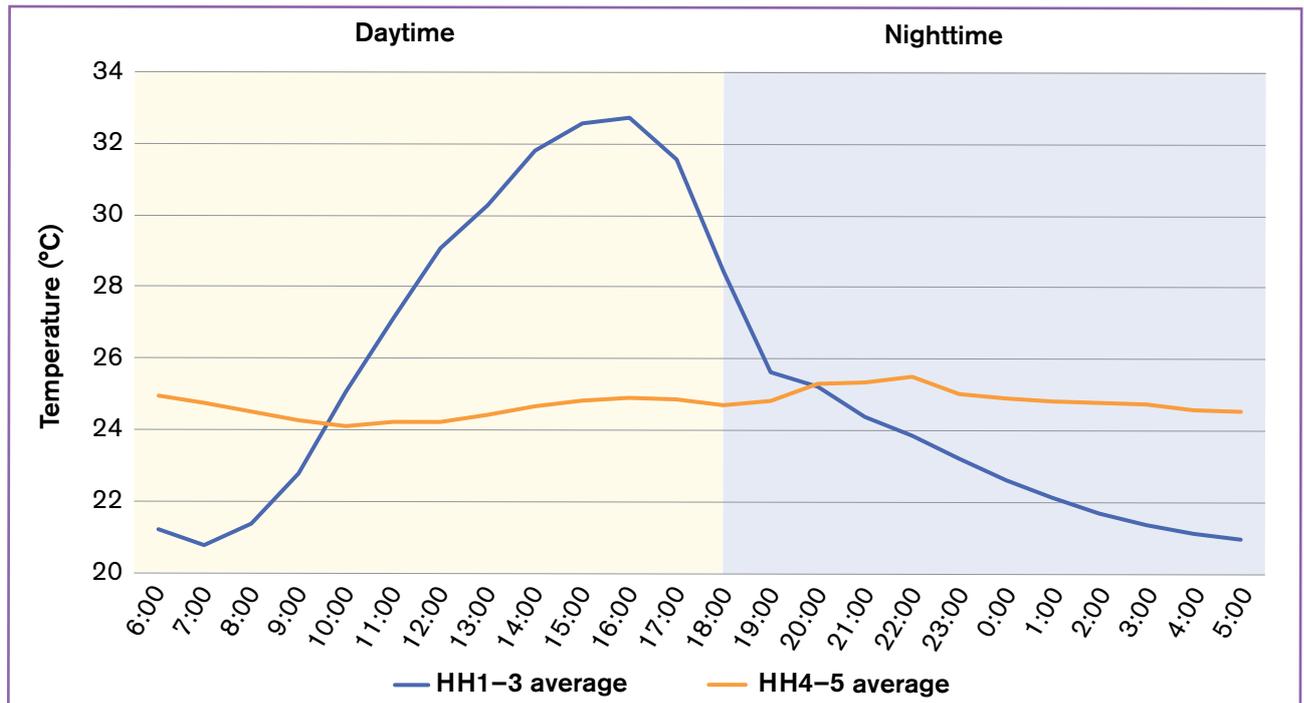


Table 7. Humidity and range for dwellings over the pilot period (Mathare)

Housing type		RH (%)		
		Max	Min	Range
HH1	Corrugated iron shack dwellings	84.8	21.4	63.4
HH2		96.3	25.1	71.1
HH3		84.2	25.4	58.9
HH4	Stone and concrete dwellings	90.7	53.7	37.0
HH5		92.7	37.1	55.6

### 3.2.2 Building materials

Looking further at the type of building material and construction present in the three settlements provides some explanation of exposure to heat. Materials used are shown in Table 8.

The primary form of roofing material in all three settlements is corrugated metal sheets (Table 8) in various states of repair. Corrugated metal roofing is widely used as a readily available, lightweight and durable material that can be easily installed on informal dwellings. However, while commonplace, corrugated metal roofing provides little protection from solar radiation, with heat transmitted through metal roofs into living spaces at around **10 times the rate** of concrete or clay roof tiles.<sup>18</sup>

Metal roofing sheets have been found to be less effective in tropical regions<sup>19</sup> compared to more natural materials (such as bamboo or sugar palm tree fibres in Indonesia)<sup>20</sup> that either reflect or conduct heat at a

lower rate into internal spaces. The design of informal dwellings is unlikely to include roof overhangs to form a veranda or to shade windows from direct sunlight.

Ceilings can provide a thermal barrier to the transfer of heat into living spaces and are particularly effective where the roof is ventilated (by roof eaves) to allow the heat to escape. The benefit can be significant, with case studies suggesting that **ceilings can reduce indoor temperatures by around 3°C in metal-roofed homes.**<sup>21</sup> But most dwellings in the three settlements do not have ceilings (Table 8). Instead, as in Mathare, some residents use empty sacks, newspaper, plywood or cardboard to line the inside of roofs to insulate metal sheets and reduce heat transfer. This may have some insulating effects, but also increases fire risk, where there is no air-gap between the ceiling and the roof.

While not currently used in the three settlements, there are a number of initiatives globally that are testing the effectiveness of 'cool roofs', which increase the radiant reflectivity of surfaces to reduce the amount of heat

Table 8. Housing construction materials and occupation levels

	Kariba	Kombo	Mathare
<b>Roofing</b>	<ul style="list-style-type: none"> <li>56% of roofing is corrugated metal sheets</li> <li>27% use asbestos sheets and 7% grass thatch</li> </ul>	<ul style="list-style-type: none"> <li>All properties have corrugated metal roofs, many are rusty and in poor states of repair</li> </ul>	<ul style="list-style-type: none"> <li>89% of properties have corrugated metal sheet roofs</li> <li>4.5% have concrete roofs</li> </ul>
<b>Internal ceiling</b>	<ul style="list-style-type: none"> <li>Just 9% of dwellings have internal ceilings</li> </ul>	<ul style="list-style-type: none"> <li>41% have had ceilings installed</li> </ul>	<ul style="list-style-type: none"> <li>46% have permanent or temporary ceilings</li> </ul>
<b>Walls</b>	<ul style="list-style-type: none"> <li>58% of walls are made from cement bricks</li> <li>10% use stones and 7% use mud blocks</li> </ul>	<ul style="list-style-type: none"> <li>99% of properties have walls made from cement bricks</li> </ul>	<ul style="list-style-type: none"> <li>69% of properties have walls made from metal sheets</li> <li>10% use stones and 7% cement blocks</li> </ul>
<b>Floor</b>	<ul style="list-style-type: none"> <li>68% of floors are cement</li> <li>16% of floors are soil</li> </ul>	<ul style="list-style-type: none"> <li>80% have floors of cement</li> <li>19% have tiled floors laid on cement</li> </ul>	<ul style="list-style-type: none"> <li>63% of floors are cement</li> <li>25% of floors are soil</li> </ul>
<b>Windows</b>	<ul style="list-style-type: none"> <li>22% have one functional window</li> <li>43% have two functional windows</li> </ul>	<ul style="list-style-type: none"> <li>All dwellings have at least one functional window</li> </ul>	<ul style="list-style-type: none"> <li>36% of dwellings have no functional windows</li> <li>51% have just one functional window</li> </ul>
<b>Median household size</b>	<ul style="list-style-type: none"> <li>Five people</li> </ul>	<ul style="list-style-type: none"> <li>Four people</li> </ul>	<ul style="list-style-type: none"> <li>Three people</li> </ul>

transferred into dwellings. Some early findings in South Africa indicate that metal roofs painted in reflective paint can reduce internal temperatures by 4°C and reduce the incidence of internal temperatures above 40°C.<sup>22</sup> Green roofs (roofs covered in plants) are also shown to reduce the transfer of heat into dwellings<sup>23</sup> in tropical regions.

The efficacy of these measures varies, and their suitability and affordability for low-income households will need to be assessed. Costs such as buying specialist paint and upgrading the structures of dwellings to support the weight of green roofs, alongside ongoing maintenance, may be too much for people with low and irregular incomes. Tenants will also need permission from landlords to make adaptations and homeowners may be reluctant to invest in improvements without security of tenure. **Addressing affordability and tenure security issues are key, enabling communities to invest more in heat adaptation measures.**

The walls and flooring of dwellings also have a significant impact on indoor temperatures and residents' exposure to heat stress. The choice of materials and the construction method (for example, single or double layer concrete blocks) can make a significant difference to the transfer of heat to indoor spaces. As shown in Table 8, the primary materials used for the construction of dwellings in the three settlements are concrete blocks and corrugated iron sheets, which are far less thermally efficient than house bricks (by seven and

13 times, respectively).<sup>24</sup> While house bricks might be unaffordable wall material, replacing corrugated iron sheets with concrete building blocks could **reduce heat transfer by around 46%**.

With most homes in sub-Saharan Africa naturally ventilated,<sup>25</sup> using passive cooling within structures, such as windows, doors, roof eaves and high-level air vents, to circulate air and reduce internal temperatures is vital. These methods are particularly important in low-income contexts, where there is limited electricity connection or cooling equipment is unaffordable. Effective ventilation of living spaces can make a significant difference to indoor comfort levels,<sup>26</sup> particularly venting rooms during the evening and night when trapped warm and moist air is most uncomfortable. While few studies have tested improved ventilation on indoor temperatures in informal dwellings, using ventilation screens and slat windows/doors has been shown to result in 2°C cooling in an African context.<sup>27</sup>

As shown in Table 8, dwellings in the three settlements have limited ventilation. For example, more than one third of dwellings in Mathare have no functional window and more than half have only one window. The cooling function of air circulation is most effective where there is a cross-breeze, which prevents warm air and humidity from stagnating in the dwelling.

A lack of air flow is exacerbated by overcrowding of homes, where people and possessions limit the

circulation of air in rooms, and doorways and windows may be blocked. Survey data shows a median occupancy of 3–5 people per dwelling, where all household functions take place in one or two usable rooms (Table 8).

The research also identified a reluctance to open windows and doors to improve air circulation due to **risks of theft or animal incursion** into homes. In Mathare, residents noted that even where windows were included in the design of the dwelling, these may be blocked to improve security (Box 3). Evidence indicates people in informal settlements have a trade-off between actions to reduce heat exposure and concerns about safety.

### 3.2.3 Contributing factors

Alongside the physical fabric of homes, human activity within dwellings and the availability of external shade can make an important contribution to indoor heat levels, humidity and liveability.

Cooking food is a routine domestic task, but also a contributor to indoor heat and humidity levels. Most cooking takes place indoors, with a mix of burnt fuels, such as charcoal and wood (Table 9). While most available studies on cooking in informal housing have looked at increased air pollution rather than heat,

open cooking units add to already high temperatures. Stoves also lose their heat slowly, prolonging raised indoor temperatures. Within the confined space of a single room dwelling, the compound effects of heat, humidity and air pollution not only reduce comfort, but add significantly to health risks.<sup>28</sup> As women undertake most of the cooking — and for long periods of the day if food is being cooked for sale — they are particularly vulnerable.

Homes are the principal asset for people in informal settlements, and dwellings often have multiple uses. In addition to providing living space for families, they are places for small enterprise activity. In Kariba, 11% use their home as a base for enterprise activity, and this rises to 27% in Mathare and 41% in Kombo. Activities include hairdressing and other personal services, and small-scale manufacturing of goods sold on streets and in markets — including ‘food bites’ and clothing (Box 4). Homes are also used to store goods for sale. These types of enterprise activity are likely to generate direct heat outputs, such as from cooking and machinery use — or add to the overcrowding of space, restricting air flow and effective ventilation of heat. Poverty requires people to leverage their assets to increase earnings. This means a trade-off between income and the effects on health and wellbeing of additional heat being created.

External shade from the natural environment or shade built into window frames or roof overhangs can also make a difference to the level of insolation and resulting indoor temperatures. Demand for land within settlements significantly reduces green space and is a

#### BOX 3. LIMITS ON NATURAL VENTILATION

“For us to get free air in the houses, we just open the door. Assume you have fallen asleep at the time when the door is open and someone comes into your house — he/she takes your property and goes away.”

##### Mathare focus group member

People sleeping outside in Kariba have experienced attacks by hyenas during the night. Drought conditions are drawing elephants, lions, snakes and baboons into settlements in search of food and water, bringing animals into conflict with people. This is a physical threat to people and a deterrent to opening windows and doors. It also has financial consequences, as crops are eaten or trampled by animals.

##### Notes from Kariba focus group

#### BOX 4. HOME ENTERPRISES

In Kombo, nearly half of residents (41%) undertake some form of enterprise or income-generating activity from their dwelling. The main activity (49%) is food vending, where food is prepared, cooked or sold from the property.

“As a businesswoman, when the heat is high, I usually feel dizziness when cooking. Some of us don’t have umbrellas and we usually cook with charcoal, so it affects us. At these times, the work morale goes down.”

##### Mathare focus group member

Table 9. Home cooking fuels and location

	Cooking fuel (%)				Cooking location (%)	
	Charcoal	LP gas	Wood	Other	Inside	Outside
Kariba	1.7	23.0	56.7	18.6	46.6	53.4
Kombo	80.1	17.6	1.8	0.5	59.8	40.2
Mathare	6.7	60.9	1.0	31.4	96.6	3.4

barrier to re-establishing natural environments that may help to reduce temperatures within settlements. Looking across the three settlements, the dense settlement of Mathare has the fewest trees, with the most in the peri-urban context of Kariba (Table 10).

Table 10. Trees providing shade

Settlement	Percentage of dwellings with trees providing shade
Kariba	42.7
Kombo	25.0
Mathare	4.5

### 3.3 Heat and health

Exposure to indoor temperatures above 26°C has been found to negatively impact respiration, blood pressure, core temperature, blood glucose levels, mental health and cognition, and physical functions such as balance.<sup>29</sup> With most existing studies undertaken in global North contexts, there is a significant gap in understanding the specific implications of high and prolonged heat on people in informal settlements in the global South. For the vulnerable urban poor, underlying health conditions and limited access to affordable medical care may exacerbate vulnerabilities<sup>30</sup> during sustained periods of high temperatures. At particular risk are pregnant women, infants and the elderly, who spend more time in the home, as well as the carers — typically women — who look after them. Older adults, with lower sweat capacity, are particularly at risk of heat stroke when temperatures are above 35°C.

The physiological effect of extreme heat is significant where there is also high humidity. The saturation of

Table 11. Main heat health issues

Heat health issue	Kariba (%)	Kombo (%)	Mathare (%)
<b>Experienced health issues</b>	<b>74.7</b>	<b>71.0</b>	<b>64.7</b>
Heat stress/exhaustion	21.1	8.9	28.8
Skin rashes	19.2	52.6	15.3
Dehydration	17.3	11.1	18.9
Respiration	4.8	11.6	12.5
Urinary infection	1.4	3.2	1.3
Fatigue and dizziness	21.8	6.9	18.8

Table 12. Main heat effects on wellbeing

Heat health issue	Kariba (%)	Kombo (%)	Mathare (%)
Disturbed sleep pattern	52.1	38.8	28.0
Anxiety	31.6	49.3	20.5

water in the air reduces the effectiveness of sweating and respiratory heat loss to cool the body, which can lead to overheating and cardiac strain.<sup>31</sup> Long-term exposure to these conditions can have chronic effects on health, with constant heat stress leading to organ damage. Hot and humid conditions encourage the growth of harmful mould, bacteria and mites, which thrive at humidity levels of 70% and above and contribute to respiratory conditions, such as chronic obstructive pulmonary disease (COPD) and bronchitis,<sup>32</sup> and the transmission of vector diseases.

Evidence from the three settlements show that exposure to hot and humid conditions have a major impact on physical health and the wellbeing of residents. **More than two thirds of respondents had experienced health issues due to exposure to extreme heat.** Health impacts vary, but suggest that the cumulative effects of chronic heat stress has a major impact on health and wellbeing (Table 11). Health issues are particularly significant for people with pre-existing heart conditions, hypertension and diabetes, who are vulnerable to additional stress caused by overheating.

In addition to the physical effects of extreme heat, adverse conditions also impact on the psychological wellbeing of residents in informal settlements. Residents of all three settlements reported difficulty sleeping during hot and humid conditions, which contributes to fatigue and, more broadly, increased anxiety (Table 12). These factors can lead to ill health, but also cause tensions within the home and an increase in domestic violence.<sup>33</sup>

The effects of ill health caused by heat can also have a financial effect on struggling households: **20% of respondents in Mathare, 41% in Kariba and 46% in Kombo had sought medical help due to heat effects.**

The impacts of heat stress are felt unevenly by community members, with infants, older people, pregnant and breastfeeding women, and those with disabilities and chronic illnesses most at risk from extreme heat.<sup>34</sup> Global evidence shows rising mortality rates during heatwaves, with additional deaths caused by heat effects on pre-existing health conditions or vulnerabilities.<sup>35</sup> Underlying issues of poverty and inequality are exacerbated by extreme conditions, with vulnerable people less able to tolerate or adapt to high temperatures and more susceptible to ill health.

Some vulnerabilities and impacts of extreme temperatures are hidden due to social norms and fear of stigma. As shown in Box 5, this affects the health and wellbeing of women, but also people with conditions such as albinism, who have low tolerance to direct sunlight. The effects of heat are compounded by poverty and an inability to meet the additional costs of coping with high temperatures, or to be able to vary their caring or work activities to avoid exposure to it.

### BOX 5. WOMEN'S HEALTH (MATHARE)

High temperatures affect the reproductive health of women. Focus group discussions highlight that exposure to extreme heat can disrupt menstrual cycles and require women to change their sanitary towels more frequently, to maintain hygiene and reduce itching and rashes. This creates an additional cost burden for women, but also has social effects and causes stress when they are not able to wash to cope with excess sweating. Women are socially restricted from wearing fewer or lighter clothes in public spaces. For larger women, heat can make moving around very uncomfortable. With temperatures inside homes even higher than outdoors, there is little respite from hot conditions.

## 3.4 Hidden costs of heat

Coping with heat leads to financial pressure on households, which can have significant impacts on families already struggling with insecure incomes. Households face additional costs coping with heat, and those working in the informal economy may experience loss of earnings.

**In all three settlements, more than one third of respondents indicated that coping with heat results in extra expenditure,** which can cause financial hardship (Figure 16). Precarious incomes mean that even small additional costs can have substantial effects on the ability of households to meet basic needs. Although the additional costs of coping are typically small, they are recurring and impact on household budgets. Expenditure on everyday items during periods of extreme heat can cumulatively amount to **more than one sixth of household income on coping with heat** (Tables 13 and 14). The impacts of these additional costs force families to make difficult trade-offs in how they use their income.

Financial hardship can also be caused by loss of employment and earnings during periods of extreme heat. Across the three settlements, around one quarter of respondents indicated that they lost workdays due to high heat conditions (Figure 17). Lost workdays were typically experienced by self-employed people in the informal economy — those engaged as street traders, day-labourers and casual workers, or working from kiosks selling goods or providing personal services, such as hairdressing. The results showed similar impacts for male and female self-employed workers, albeit men vulnerable working in day-labour and casual worker roles, and women working as vendors.

Impacts can be significant for those affected. For example, a median of six workdays were lost per month in Mathare, and in Kariba a median of seven workdays were lost per month during the last hot period. For

Figure 16. Proportion of respondents spending extra on coping with heat

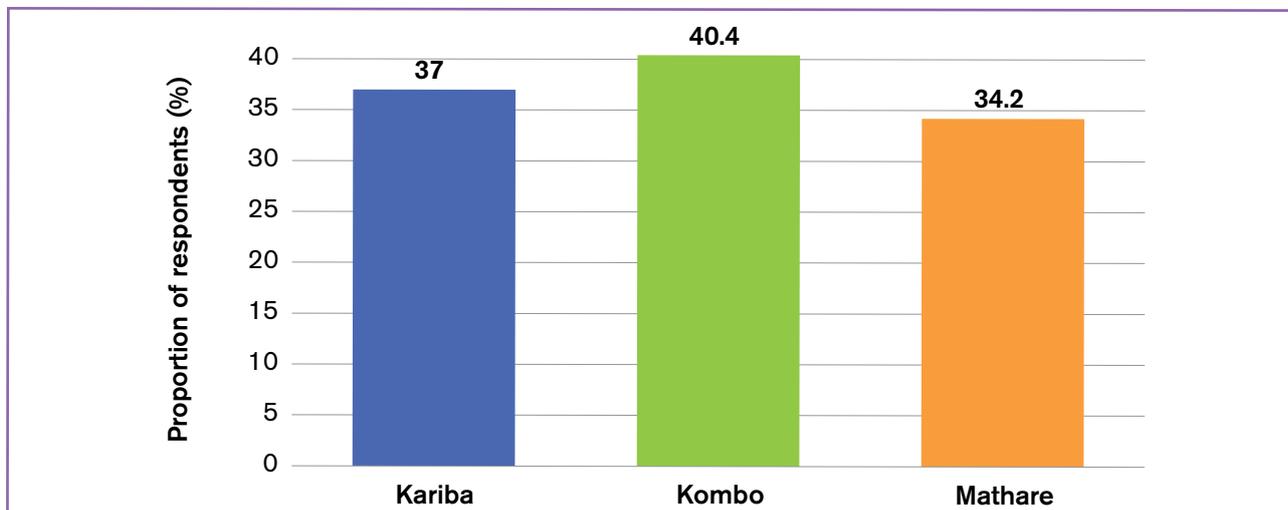


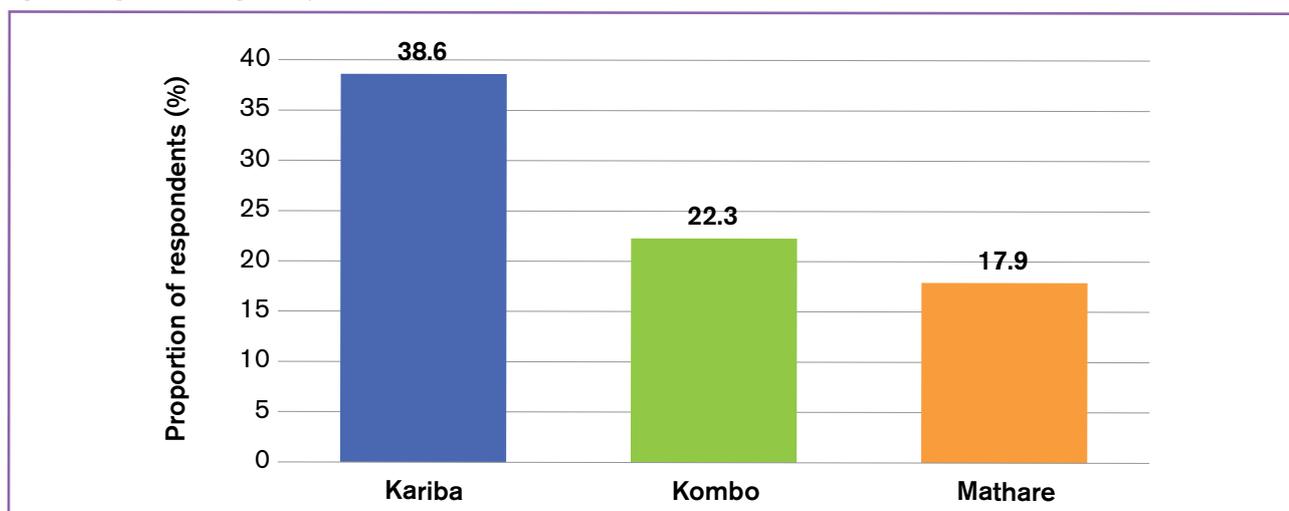
Table 13. Additional costs of coping with heat

Item	Examples of costs
Electricity	Added use of electricity to run fans to improve the air circulation — in Kombo it was reported that this can increase monthly energy costs by around 20%
Water	Purchase of extra clean water to wash, hydrate and cool down can cost around 5% of monthly earnings in Mathare
Medical	With few people in Kombo and Kariba (10% and 5%, respectively) covered by health insurance, medical treatment can be costly
Food	A lack of refrigeration means that food spoils quickly and needs to be replaced
Menstrual products	Extreme heat effects the regularity and duration of periods, causing increased costs of purchasing pads. In Mathare this can be 5–10% of monthly income

Table 14. Estimated extra spending on coping with heat each month

Settlement	Additional amount per month	Percentage of monthly income
Kariba	US\$17	25%
Kombo	US\$7	14%
Mathare	US\$8	12%

Figure 17. Respondents losing workdays due to heat



people involved in vending and personal services, heat has a variety of impacts (Box 6).

For example, heat is disrupting traditional livelihoods of fishers in Kariba. High temperatures have made catching fish more difficult and expensive. Hot conditions have driven fish to deeper waters, making them harder to catch, and fishers spend more time on the water, exposing them to the risk of heatstroke.

Some have started to fish at night, but this increases the risk of accidents in the dark and wildlife conflict with hippos and crocodiles.

In markets without shade or electricity for refrigeration, there are fewer customers during the hottest parts of

the day, resulting in the spoiling of fish and reduced income for households living in poverty.

Where traders are able to shift their activity to take advantage of hot conditions, they can maintain income levels. In Kombo for example, focus group members discussed how vendors of 'food bites' change to selling water or fruit juices. This flexibility can help mitigate changes in customer demand to maintain earnings. However, such changes are not possible in all circumstances, where people have perishable stock or fixed assets that are more difficult to adapt to climate conditions.

## BOX 6. HEAT CAUSES A LOSS OF INCOME (MATHARE)

Comments from focus group members:

- “The heat mostly spoils our food for sale and customers can’t buy spoiled food.”
- “The heat weakens the markets for some foods, like tea.”
- “The heat limits our movement from one place to another.”
- “When there is a lot of heat, it lowers the performance of some businesses, for example blow-dry salons.”
- Heat “forces us to sell at very low prices and/or disposing of them [fruit], making losses when there is a lot of heat.”

reported **variable access to heat alerts**. More than half of people have access to heat alerts in Kariba, but this falls to below one in five in Mathare (Figure 18). In Kombo, there is an established programme of weather early warning information through the UK Met Office’s Daraja project,<sup>36</sup> where more than three quarters of people were able to access weather updates.

Sources of weather alert information differ across settlements. SMS (text) alert systems, where information is circulated by community members through their social networks, is a key source in Kariba and Mathare (Table 15). Information via radio and TV stations are key in Kariba and Kombo, with school children an important source in Mathare. The public information system used in Kombo disseminates information from the Tanzania Meteorological Agency through local media and local gathering points within communities, encouraging word of mouth warnings through families and community networks.

Despite variable access to information, people in informal settlements cope with the extreme temperatures and humidity in the best ways they can. Low and unstable incomes, a lack of technical knowledge and limited skills to adapt housing, along with restrictions on changes to rented homes, limit potential responses to heat. **Without the financial means or skills to adapt homes,**

## 3.5 Coping with extreme heat

### 3.5.1 Coping strategies

Accurate weather information to prepare for or avoid extreme heat is vital to underpin effective coping strategies. However, residents of the three settlements

Figure 18. Proportion of respondents with access to heat alert information

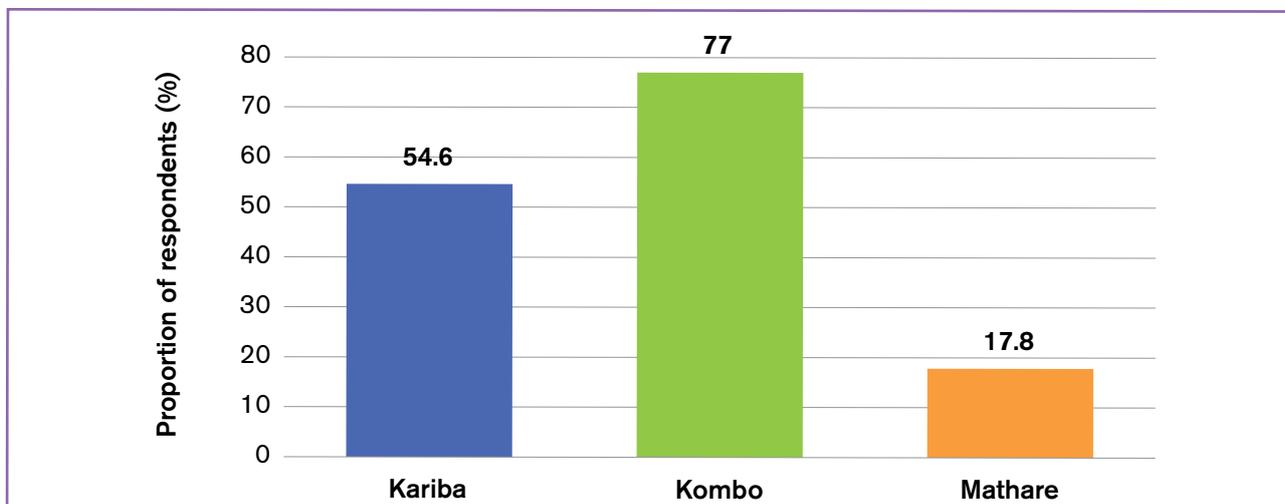


Table 15. Main sources of information on extreme heat

	Kariba (%)	Kombo (%)	Mathare (%)
SMS/text alerts	27.7	4.2	23.8
Radio and TV stations	58.6	57.2	9.5
Social networks	9.2	12.0	17.9
Word of mouth	2.4	26.6	19.1
School children	1.8	-	22.6
Local clinic	-	-	7.1

**people rely on small behavioural changes to cope with extreme heat.**

The primary ways of staying cool are using cooling devices (usually electric fans), remaining hydrated and wearing lighter clothes (Figure 19). These types of responses are sustainable and affordable in low-income contexts and can be used to reduce physiological heat strain,<sup>37</sup> but are not a substitute for longer-term reduced exposure to heat and humidity. Global guidance cautions against the use of fans at air temperatures above 35°C, as they can accelerate body heat gain and are ineffective when there is high humidity.<sup>38</sup>

Beyond efforts to cool body temperature, there is limited action to adapt housing to reduce heat levels within dwellings. There are some examples of small-scale efforts; for example, in Mathare some 8.8% of responses were installing makeshift roof insulation, using sacks, wood or plastic bags, to reduce heat penetration through iron roofing.

According to residents of the three informal settlements, **financial costs, limited technical understanding of the types of adaptations that work, limited building skills to make changes and lack of engagement of landlords, are cited as the most significant barriers to adapting homes to heat.** Additionally, uncertain tenure was also identified as a significant barrier.

Coping with extreme heat can have hidden consequences for households. These vary in relation to the specific contexts of each settlement, but can be a significant additional burden and a deterrent to, for example, opening windows to improve air flow. When householders open doors and windows or sleep outside in Kariba and Mathare, they are susceptible to mosquito bites, leading to cases of malaria (Figure 20). Improving ventilation also creates risk in the peri-urban context of Kariba, where wildlife is attracted into settlements for food or shade (Box 3). Opening windows and doors to improve ventilation also increases risks of theft and assault,

Figure 19. Main ways of staying cool in Kombo and Mathare

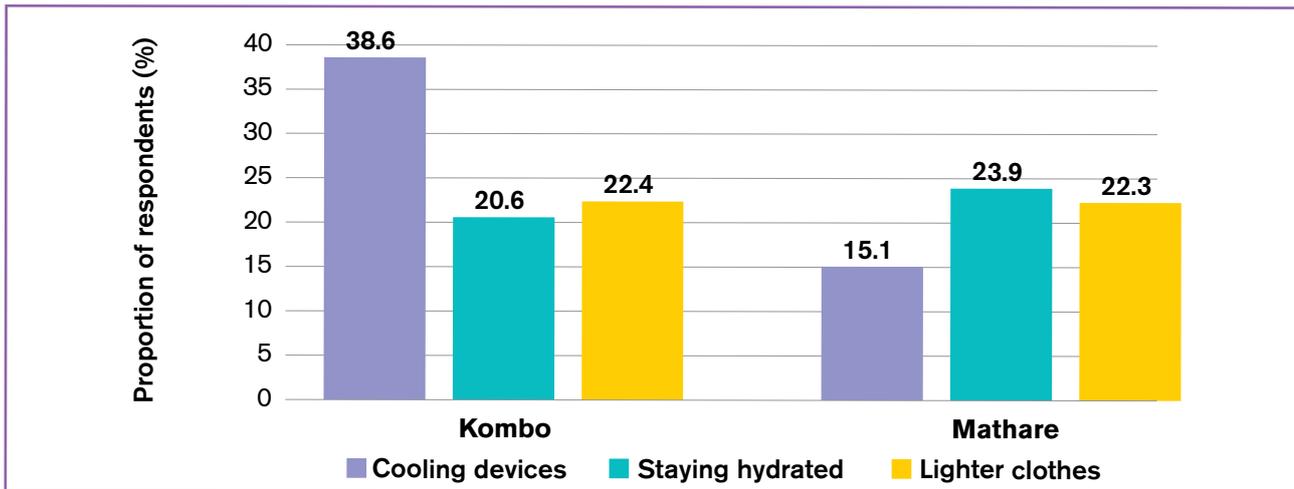


Figure 20. Additional challenges created by coping measures in Kariba and Mathare

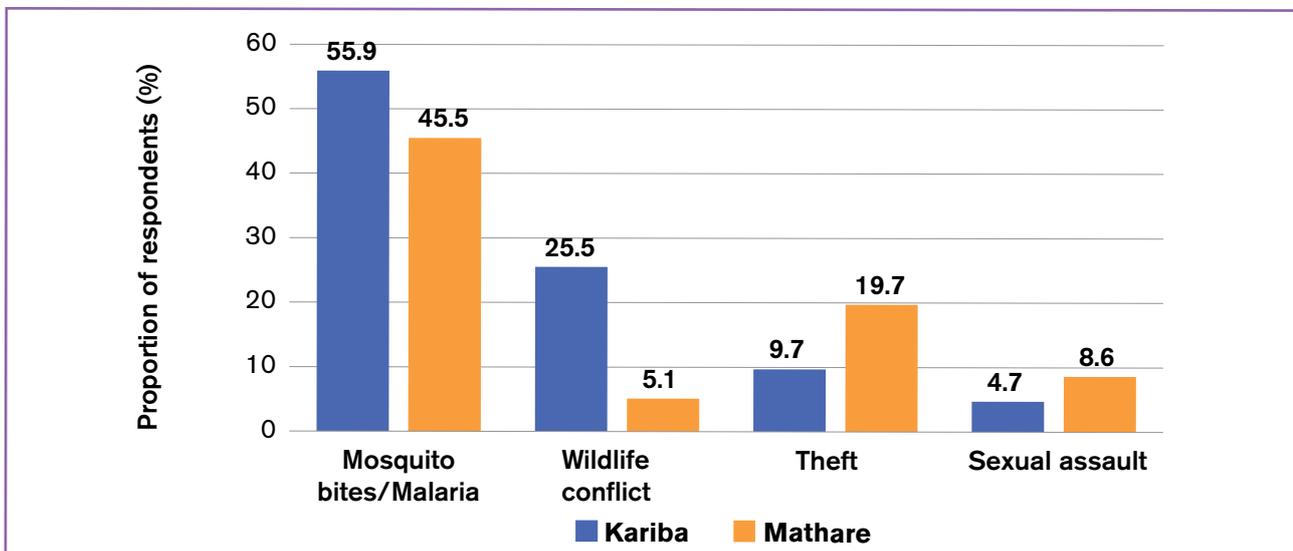
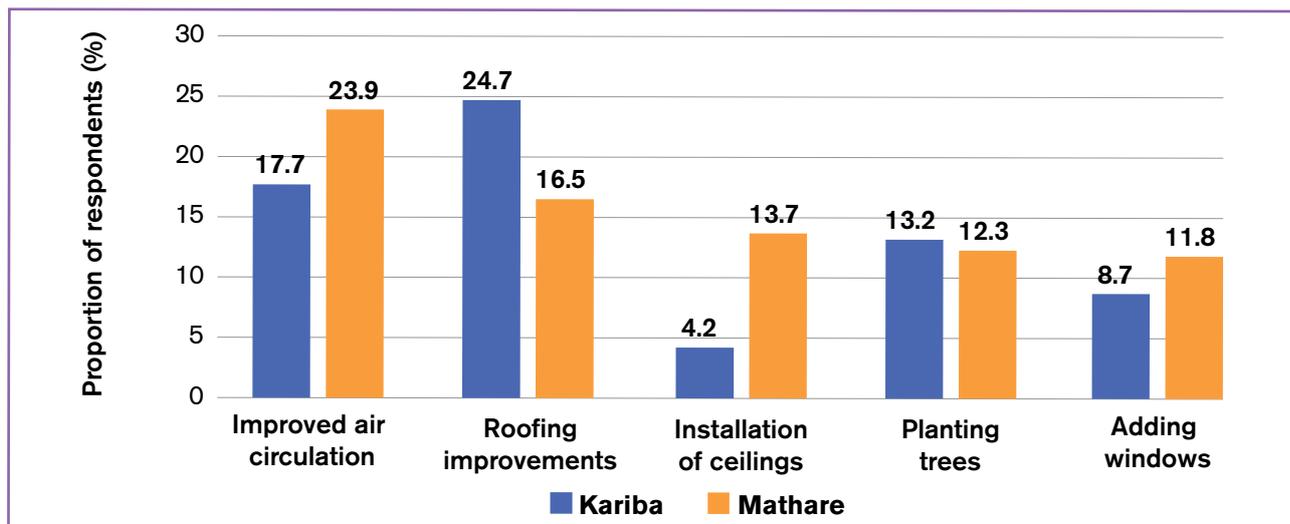


Figure 21. What changes would reduce indoor heat levels in Kariba and Mathare?



creating a disincentive to increase use of natural ventilation methods.

### 3.5.2 Coping better

Residents recognise the limitations of behavioural changes to avoid extreme temperatures. While constrained by lack of finance and construction skills, they identify improved air circulation within dwellings (through use of fans), better insulated roofs and ceilings, and improved shade from trees as ways to improve the comfort of their homes (Figure 21).

While a lack of finance and knowledge are barriers to adaptation, improvements are possible with the support of local government and through organised community action. **Communities are looking to local government** to create the conditions for settlement upgrading, with improved planning processes and initiatives to reinstate natural environments through greening and tree planting. **Collective community action** could provide a vital pillar for housing improvement and upgrading, and retrofitting of homes to reduce heat levels. Underpinning local action is a need for better information on heat to inform behaviours and decisions.

# Looking forward



## 4.1 Conclusions

Overheating cities pose a major risk to low-income populations living in informal settlements. This pilot study found that indoor temperatures are up to 9°C hotter than outside and there are oppressive conditions through the night, leading around 80% of people in the three pilot settlements to find their home uncomfortable. Extreme temperatures and humidity are a cause of ill health for more than two thirds of residents. The pervasive effects of heat have a wider impact on economic and social wellbeing, creating an additional cost burden that deepens poverty. Heat has disproportionate consequences for women, the very young and elderly, and people with disabilities or health conditions who need to spend more time in the home.

While there is growing policy attention on cities, there remains a major gap in climate data on informal settlements. Despite housing a majority of people in many global South cities, these communities are largely excluded from data collection and climate policy. Unplanned settlements lack of green space and have a high density of buildings constructed with low-quality building materials, which makes them substantively different from the 'formal' city and increases their residents' vulnerability to rising temperatures.

Heat is a silent killer, and adaptation to extreme temperatures must be given greater priority in climate policy and planning. But it is important to recognise that heat adaptation differs from adaptation to other climate risks. There is less reliance on major infrastructure investment and greater opportunity to reduce risks through affordable adaptations to housing and environments, within a framework of settlement upgrading. Relatively low-cost improvements can make a major difference to indoor temperatures, reducing risks and making homes more comfortable. While evaluation of such measures is sparse, what evidence there is suggests that a scaled, community-led approach, using local savings schemes and skills support, can be effective.

Similarly, organised communities can play a key role in filling data gaps by working alongside meteorological agencies and local government to extend coverage

of heat monitoring in underserved settlements. This research has demonstrated the efficacy of community-led data collection and how a mixed methods approach can generate new insights. When integrated into city planning, co-produced heat data provides a key resource to both target interventions, and shape local understanding and behaviour change.

## 4.2 Recommendations

Based on the pilot study and the analysis undertaken by project partners, four interlinked actions are recommended to increase the impact of and scale local-level activity to tackle heat (Tables 16–19).

### 4.2.1 Better data

Extend heat data collection and the use of community-led research to understand the conditions and build evidence for responses to extreme heat in informal settlements.

### 4.2.2 Stronger partnerships

Build stronger partnerships between meteorological offices, local government and organised communities to improve information flows and joint working, and to raise awareness of heat risks through early warning systems.

### 4.2.3 Improve homes

Support affordable and incremental housing adaptation, enabling household- and settlement-level improvements that reduce exposure to extreme heat and increase the resilience of homes.

### 4.2.4 Deliver nature-based solutions

Reinstate nature to reduce the risks of extreme temperatures, by integrating green space and tree planting to create environments that reduce heat levels and provide natural shade for dwellings and public spaces.

These recommendations are founded on community-led actions, but require ongoing engagement with city government and national meteorological agencies to build resilient urban environments.

Table 16. Recommendation 1: better data

Priority	Recommended actions
Fill data gaps in urban heat island analysis	<ul style="list-style-type: none"> <li>Scale and support community-led collection of indoor heat data</li> <li>Extend the placement of weather stations into informal settlements</li> </ul>
Develop fuller understanding of heat conditions in informal settlements	<ul style="list-style-type: none"> <li>Use drone technology to map thermal conditions</li> <li>Test standards of thermal comfort</li> </ul>
Understand intersectional impacts of heat on women and vulnerable groups	<ul style="list-style-type: none"> <li>Sponsor women-led research with vulnerable groups on the experience and effects of extreme heat</li> </ul>

Table 17. Recommendation 2: stronger partnerships

Priority	Recommended actions
Integrate community-generated heat data into official data	<ul style="list-style-type: none"> <li>▪ Pilot joint data collection by a meteorological agency and organised community group to test methods of data integration</li> <li>▪ Use integrated datasets to inform the production of heat action plans</li> </ul>
Increased emphasis on heat reduction within major city development programmes	<ul style="list-style-type: none"> <li>▪ Use data to identify priority locations for heat-reducing urban design in public spaces (such as creating shade in markets)</li> <li>▪ Engage urban planners to co-design and implement cooling stations with community groups</li> </ul>
Improve access to early heat warning information and action	<ul style="list-style-type: none"> <li>▪ Extend accessible alert systems to inform residents about heatwaves</li> <li>▪ Enable partnerships between communities and health agencies to better understand the effects of prolonged heat on health</li> </ul>
Community-led action to raise awareness of heat	<ul style="list-style-type: none"> <li>▪ Use community health networks to disseminate information on avoiding and responding to heat</li> <li>▪ Establish women-led support networks (via savings groups) to better cope with heat</li> </ul>

Table 18. Recommendation 3: improve homes

Priority	Recommended actions
Better evidence on the thermal performance of dwellings	<ul style="list-style-type: none"> <li>▪ Conduct research into the thermal performance of building materials used in informal settlements to inform adaptation interventions</li> <li>▪ Model housing typologies to support settlement upgrading</li> </ul>
Removing barriers to housing adaptations	<ul style="list-style-type: none"> <li>▪ Work with local authorities to improve security of tenure as an incentive to adapt housing</li> <li>▪ Engage private landlords to promote tenant-friendly adaptation agreements</li> </ul>
Support for household- and settlement-level heat adaptation	<ul style="list-style-type: none"> <li>▪ Define toolkit of adaptations to extreme heat</li> <li>▪ Transfer of local skills to train residents in low-cost heat adaptation methods</li> <li>▪ Model clean energy and heat-efficient cooking practices within communities</li> <li>▪ Systematically evaluate adaptations to show what works</li> </ul>
Address finance gaps	<ul style="list-style-type: none"> <li>▪ Develop microfinance models, through community savings, to support investment in housing adaptations</li> </ul>

Table 19. Recommendation 4: deliver nature-based solutions (NbS)

Priority	Recommended actions
Integrate NbS into settlement upgrading plans, specifically considering heat reduction	<ul style="list-style-type: none"> <li>▪ Model how NbS can be integrated into settlement upgrading and identify specific heat benefits</li> <li>▪ Support joint work by local government planners, NGOs and communities to make space for nature</li> </ul>
Support community-led tree planting and re-greening of settlements	<ul style="list-style-type: none"> <li>▪ Use community networks to share information on the benefits and methods of tree planting for heat reduction</li> <li>▪ Evaluate the impact of tree planting/shade on indoor temperatures in informal housing</li> </ul>

# Appendix 1. Methodology

The pilot project aimed to address gaps in the collection of heat data at settlement level, and to stimulate local discussion and action by communities to reduce exposure to extreme temperatures. The project sought to localise data collection, building the knowledge and skills of community groups to engage meteorological agencies and local government on adaptation to heat. The following section provides an outline of the research approach and methods used during this project.

## Objectives

The project had the following objectives:

- Better understand the effects of rising heat levels on the residents of urban low-income settlements, drawing out gender differences and how communities are adapting to changing climate conditions
- Develop a participatory method and measures to track heat levels in urban areas that show differences between indoor and outdoor spaces
- Produce data and analysis that can be used to influence policy change and inform actions to reduce the vulnerability of communities to heat
- Bring residents of informal settlements into participatory climate planning.

## Research approach

The project had two complementary strands of data collection that generated information on temperature

and humidity levels. The project collected temperature and humidity readings from inside informal dwellings, and undertook settlement surveys and focus groups. This multi-method approach enabled a better understanding of the experiences and impacts of extreme heat and the coping strategies adopted by households. A combined approach was important to provide a nuanced view of not only exposure to high temperatures, but the implications and effects of heat on the everyday lives of informal settlement residents.

The participatory process of data collection and interpretation of the data were designed to show the value of a community-led approach and how locally generated data could augment meteorological office data, while providing new insights that were meaningful to communities. Design of the pilot process, the methods and the research tools used (Figure A) was undertaken jointly with community leaders to maximise opportunities to embed skills locally.

## Project locations

The project was undertaken jointly with SDI affiliate and federation groups in Kenya, Tanzania and Zimbabwe. These countries were targeted as they had already started, or had an interest in, collecting data on heat in informal settlements. They provided a cross section of locational 'types' (Table A), which were expected to produce differing results in relation to the prevailing climate conditions and the characteristics of the settlement.

Figure A. Research structure and process

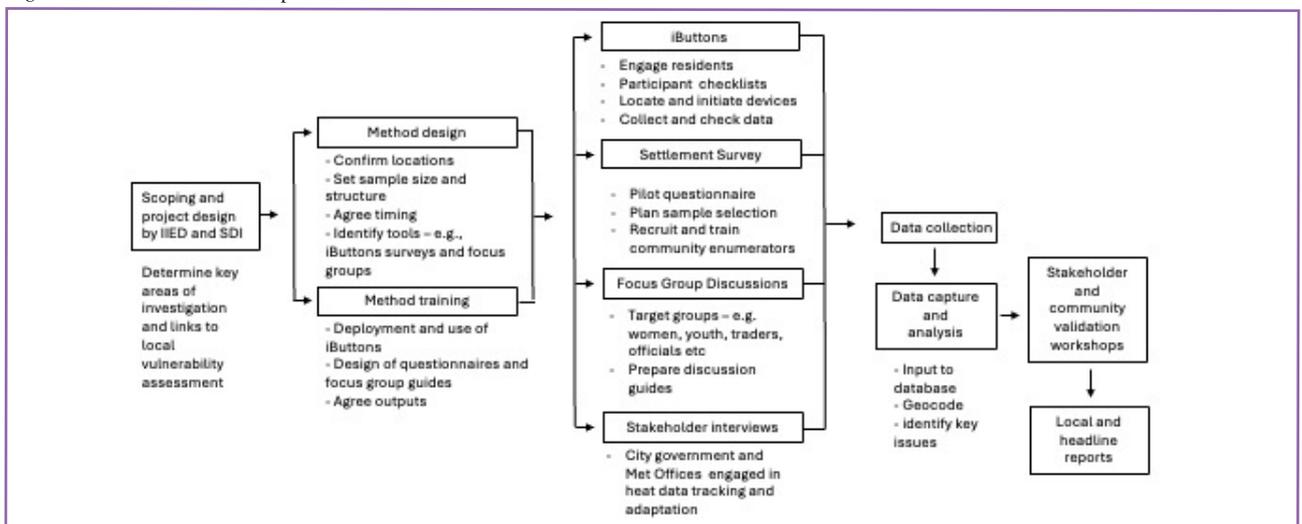


Table A. Project locations and settlement type

Country	City/ settlement	Type	Prevailing climate conditions	Estimated population
Kenya	Nairobi/Mathare	Inland city — high density urban settlement	Sub-tropical climate, with primary hot season January to March	245,468
Tanzania	Dar es Salaam/ Kombo	Coastal city — medium density urban settlement	Tropical savanna climate, with primary hot season December to March	19,358
Zimbabwe	Kariba	Peri-urban — low density settlement	Tropical savanna climate, with primary hot season September to November	27,600

In conjunction with the SDI partners in each city, the geographical targeting of the research was linked into existing community-led research (that is, vulnerability assessments) or existing local-level action. The chosen settlement was required to have the experience and capacity to participate in the research activity and the local leadership to explore issues of heat adaptation. Additional criteria were used to assess the suitability of the settlement for the research and to inform the locations of the iButton devices (Table B).

### Collecting temperature and humidity data

To collect heat and humidity data, Hygrochron (DS 1923) sensors, known as iButtons, were selected as

suitable for recording data within informal settlement dwellings. These have been used in similar studies<sup>39</sup> and have been found to be robust, produce reliable data, and operate within a temperature range of 20°C and 85°C and record RH from 1 to 100%. Devices were procured from a UK supplier and shipped to SDI to distribute among the participating affiliate groups (Figure B). Calibration of the devices was checked at source. However partners also tested the devices in situ for a week before commencing data recording, to identify any problems.

Indoor data was recorded in order to understand heat exposure within the home environment. The importance of indoor temperatures is often overlooked in heat studies,<sup>40</sup> despite the significance of the home

Table B. Selection criteria

Criteria	Issues considered
Settlement characteristics	<ul style="list-style-type: none"> <li>Size of the settlement and distribution of iButtons and surveys</li> <li>Factors of interest such as bodies of water, open space, tree cover, wildlife contact, and proximity of waste dumps or livestock</li> <li>Density of settlement and how density may affect heat levels</li> <li>Sources of heat, such as industry, dump site or traffic</li> <li>Presence of at-risk populations, such as older people, infants and people with disabilities</li> </ul>
Selection of housing for iButtons	<ul style="list-style-type: none"> <li>Variation in form of housing, construction materials and insulation to observe thermal efficiency</li> <li>Space and occupancy levels of housing</li> <li>Windows allowing ventilation and use of cooling devices</li> <li>Location of cooking activities and types of fuels used</li> </ul>
Practicalities and safety	<ul style="list-style-type: none"> <li>Accessibility of the selected locations to place and retrieve data from the iButtons and undertake surveys</li> <li>Safety for community participants and the affiliate staff undertaking the research</li> <li>Strength of federation membership and leaders' support for the project</li> <li>Security of the iButton devices placed in residents' homes</li> </ul>

Figure B. Installation of iButton in Mathare



Credit: KYCTV Kenya

as a place of respite from high external temperatures. In dwellings, the iButtons were located in the main living space, but away from sources of direct heat or cold, and in positions that would not be disturbed while data was being collected. In two cities (Dar es Salaam and Nairobi) outdoor temperature and humidity readings were provided by TAHMO<sup>41</sup> from their weather stations located nearby (Figure C). While the use of data recorded outside of the settlement has limitations, it provided an important point of comparison to assess exposure to extreme conditions as discussed in section 3.

Training was provided to the affiliate groups on how to install and use the iButtons, and a protocol was agreed to govern the collection of the data. Each affiliate was issued with five iButtons together with readers and software and, following a short period of practice and local sensitisation, the devices were installed in dwellings for a period of six weeks (10 March to 18 April 2025). All three settlements were at the end of their respective hot seasons, with average temperatures falling as the rainy seasons approached. The timing of the data collection meant that seasonal extreme temperatures were not reached, so results provided an indication of conditions outside of the hottest times of the year.

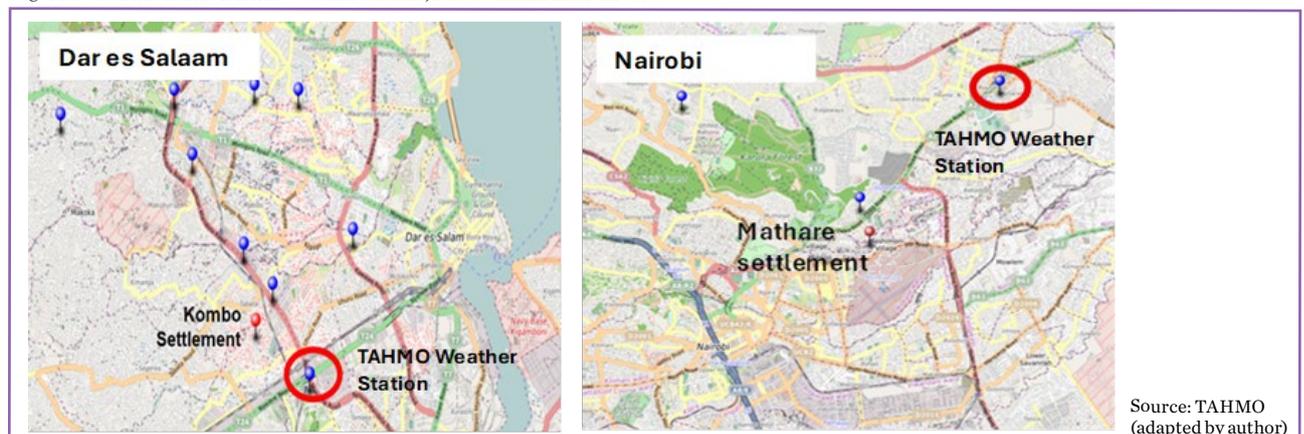
The iButtons were set up to record temperature (°C) and RH (%) every 60 minutes continuously over the data recording period. While the iButtons had sufficient memory to record the data for the pilot period without interruption, data was downloaded and checked every week. Downloading data required researchers to return to each dwelling to connect the device to a laptop and capture the readings. This weekly task allowed the researchers to meet participants, identify any problems and record any changes in the home or external factors that might affect readings.

### Surveys and focus groups

To get a deeper understanding of heat for residents of informal settlements, beyond the recorded data, household surveys and focus groups were undertaken. These were structured to explore the experience and impacts of heat, and how people coped with extreme temperatures and humidity. The survey design and collection of data were undertaken in line with SDI practice of settlement enumerations, with a representative sample from across the settlements (Table C). The research was community-led with SDI federation members in each settlement trained to conduct the survey, using a structured questionnaire designed jointly by the project partners. The affiliate organisations oversaw quality control and the use of online survey platforms to aid gathering and analysis of the data.

The surveys were complemented with semi-structured focus group discussions with residents. Focus group meetings were held in community settings and facilitated by a member of the SDI affiliate team. The groups brought together (as shown in Table C) women, youth and businesspeople to share experiences and explore coping strategies. These peer groupings were selected to investigate and compare experiences in depth, drawing on shared local knowledge that may not have been evident in more mixed groups. These meetings provided

Figure C. Settlement and TAHMO weather stations, Dar es Salaam and Nairobi



Source: TAHMO (adapted by author)

Table C. Summary of data collected

City/ settlement	iButton	Surveys	Focus groups	Stakeholders
Nairobi/Mathare	Five located	486 respondents	Four groups — youth, women, street vendors and a mixed age group	Local government, University of Nairobi, Kenya Met Office
Dar es Salaam/ Kombo	Five located, one lost	272 respondents	Six groups — mixed age group, local leaders, youth, women, traders	Local government, service providers, Ardhi University, Tanzania Met Office
Kariba	Five located	300 respondents	Nine groups — women, youth, vendors and fishers	Local government, health officials, Zimbabwe Parks, Zimbabwe Met Office, Zambezi River Authority

an important opportunity to gather and validate survey information and encourage community-level discussions on adaptation actions.

### Stakeholder interviews

The research also included a small selection of semi-structured interviews with key stakeholder organisations. These were focused on local government and service providers, meteorological offices and universities who were engaged in policy development or research on climate risks. The stakeholder interviews helped to position the research within the public policy agenda and identify ways to strengthen connections between organised communities and public agencies.

### Limitations of the methods

The scale of this project was limited by budget, but was also kept intentionally small to focus on the co-design and co-production of a participatory method of heat data collection. The approach emphasised community ownership of the process and the generation of data that was meaningful to local residents, reflected lived experiences, and could be used to inform behaviours and adaptations to heat. While the small scale of the project enabled a nimble approach, it restricted generalisation of the iButton data.

Each country team had five iButtons to be deployed in the chosen settlement. It was recognised from the outset that this number of devices was insufficient to make confident generalisations of the conditions in all homes within the settlement. As outlined above (Table B), criteria were developed to distribute the iButtons within settlements and among different building typologies to test the method and generate indicative results from settlement dwellings. The analysis was also limited because TAHMO data was only available for Dar es Salaam and Nairobi. Ideally, future data collection activity will have access to, and be aligned with, meteorological agency data. While the outdoor readings provided by TAHMO were not

in the settlements and therefore the readings could be influenced by different environmental conditions to those in the settlements, the close proximity of the weather stations should provide a good indication of local conditions.

Despite these limitations, the data does provide important insights into the conditions in informal dwellings, not elsewhere available. The method of data collection has been shown to work and a representative coverage of data collection points can be defined. There has also been significant learning among the partners that can be used to continue to develop the participatory method. The data collection process and sharing of the results has generated interest in the community for more information on heat and further support to develop adaptation solutions. As set out in the conclusion, it is recommended that the work undertaken in the project continues and is expanded to increase community-led collection.

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There is a growing crisis of overheating cities, with people in urban informal settlements most at risk. Rising temperatures create life-threatening conditions for more than one billion people living in unplanned communities across the global South. While the overall threats to cities are recognised, there are major gaps in data coverage that obscure the risks of extreme and prolonged exposure to heat and humidity in informal dwellings. This issue paper reports the findings of pilot participatory heat data collection in Kenya, Tanzania and Zimbabwe. It reveals indoor temperatures up to 9°C hotter than outside, and the impacts extreme conditions have on the health and wellbeing of people in informal settlements. The paper underlines the urgent need for inclusive data collection and action planning to protect vulnerable urban residents.

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IIED appreciates the contributions of Irish Aid, Danish MFA and Quadrature Climate Foundation in supporting our research and publications. Any views expressed do not necessarily reflect the views of these donors.



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