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Building Heat-Resilient Communities: A Collaborative Approach to Beat the Heat

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Abstract

As urbanization and climate change progress, cities face rising temperatures, worsening the urban heat island (UHI) effect. This creates localized heat pockets, posing health risks to vulnerable populations, particularly in informal settlements. In 2023, 78% of the global population endured extreme heat for 31 days. Vulnerable groups such as low-income communities, women, and children, are disproportionately affected, and indoor heat, driven by poor housing and limited cooling access, remains an underexplored hazard. Resilience AI, a Tech4Impact start-up, focuses on digitizing climate risk, assessed urban heat risks in Vivekananda Camp, Delhi, India using a technology-driven and community-focused intervention. Leveraging ResSolv™, a novel risk assessment tool, utilizes AI and ML to asses hyperlocal heat risks using geoclimatic data, building typology and community input. These building-level heat risk scores provided deeper insights into heat risks distribution, identifying highly vulnerable pockets enabling targeted, evidence-based decision-making for interventions such as cool roofs, street shading, and water station revitalization. Additionally, community-driven initiatives, including heatwave advisories and early warning systems, were implemented. This comprehensive strategy highlights the importance of combining technological and community-based solutions to address heat risks, thereby enhancing resilience and adaptive capacity.

Keywords: Heatwave; Artificial Intelligence; Early Warning Systems; Risk Assessment; Community; Climate Change

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1. Our cities are heating up, and we can feel it

As climate change accelerates, urban areas are experiencing rising temperatures. The Intergovernmental Panel on Climate Change (IPCC) projected in 2007 that shifting climatic conditions would persist for decades, with increased variability and more frequent extreme weather events [9]. Additionally, regional weather patterns are expected to become increasingly unpredictable [7]. Urbanization further intensifies these challenges, contributing to global temperature rise and increasing both the frequency and severity of heatwaves. A report by Climate Central and the Red Cross Red Crescent Climate Centre indicates that in 2023, 78% of the global population experienced 31 days of extreme heat, while 76 days of heatwaves were recorded across 90 countries [5]. Historically, heatwaves that occurred once every decade in the pre-industrial era now take place 8 times per century and are 1.2°C hotter. If global temperatures rise by 2°C, heatwaves could occur 5.6 times per decade and intensify by 2.6°C, largely due to fossil fuel emissions [3]. IPCC report from August 2021 highlights the alarming rise in India's temperatures, warning that Delhi could become the country's "heat capital" by the end of the century, with an expected temperature increase of at least 2°C—even under the most optimistic emission scenarios [1]. The urban heat island (UHI) effect exacerbates these extreme temperatures by reducing air circulation, leading to localized "heat pockets" where some city areas become significantly hotter than others [6]. During heatwaves, this uneven temperature distribution can further amplify heat stress in vulnerable neighborhoods. The consequences of rising urban heat extend beyond discomfort as it adversely impacts health and psychosocial wellbeing. Crucially, not all urban residents experience these impacts equally. Identifying heat-vulnerable zones before extreme heat events occur is essential for mitigating health risks and improving urban resilience.

1.1. Everyone experiences heat differently

The impacts of extreme heat are not uniform across populations. Vulnerability to heatwaves is shaped by three key factors: exposure, sensitivity, and adaptive capacity [11]. Low-income communities, particularly those in overcrowded informal settlements, face disproportionate risks due to inadequate access to essential cooling resources such as water and ventilation. Housing in these areas is often constructed with low-cost, heat-absorbing materials, while cramped living conditions further intensify heat exposure and sensitivity. Limited financial resources restrict access to cooling appliances like air conditioners or fans, while barriers to healthcare further reduce the capacity to adapt. Women bear additional burdens, managing caregiving and household responsibilities—including securing water and fuel—while also coping with the effects of extreme heat [12]. Similarly, individuals with disabilities and chronic illnesses face heightened risks, as heat exposure can exacerbate existing health conditions and limit mobility during extreme weather events [13].

1.2. The Problem of Indoor Heat- The Invisible Hazard

Heatwaves are the leading cause of weather-related deaths globally [8]. While their effects are widely recognized in outdoor environments, indoor heat remains an often overlooked danger. Buildings absorb, store, and radiate heat, causing indoor temperatures to rise significantly at times exceeding outdoor temperatures. Given that heat vulnerability is determined by exposure, sensitivity, and adaptive capacity [11], it is crucial to recognize how differences in indoor and outdoor exposure shape overall risk. Indoor heat disproportionately affects specific demographic groups. Women, children, and the elderly particularly pregnant, menstruating, or menopausal women, as well as older adults with underlying health conditions, experience greater heat sensitivity. For low-income households, urban heat acts as a "poverty trap" [4], forcing residents to allocate a significant portion of their income to counter heat effects, whether by purchasing cooling devices or increasing water consumption. However, financial constraints often limit these options, leaving many to rely on passive cooling methods. Paradoxically, staying indoors as a protective measure can backfire when indoor temperatures become dangerously high. For vulnerable populations with limited access to cooling, indoor heat presents an insidious and often underestimated health risk during heatwaves. Addressing these hidden vulnerabilities requires targeted interventions that go beyond outdoor heat mitigation, ensuring that both indoor and outdoor thermal risks are considered in adaptation strategies.

2. Building Community Resilience: People experience heat in different ways

Understanding built form, livelihood patterns, and community sentiment is key to assessing heatwave risks. Vivekananda Camp in Delhi, India, covering approximately 0.5 square kilometers, is a densely populated low-income settlement with minimal rooftop protection, where temperatures often exceed city averages. This study focused on vulnerable groups residing in the camp, including women, children, the elderly, and informal/unorganized sector workers—populations highly exposed to heatwave impacts due to both their socio-economic conditions and the nature of their work. A technology-driven, community-owned intervention was deployed to assess and mitigate these risks. (See Fig.1). Resilience AI is developing a climate risk and sustainability compass to address climate threats heatwaves, cyclones, earthquakes, floods, and landslides—throughout their lifecycle. The proprietary software, Resilience360, enables (i) hyperlocal, area-level, and organizational risk assessments, (ii) risk diagnosis and root cause analysis, (iii) automated climate action planning and disaster risk management, and (iv) in-house scaling of climate risk management through learning and skilling. ResSolv™, a tool within Resilience360, was used to assess heatwave risks in Vivekananda Camp, leveraging a proprietary algorithm and machine learning. By integrating high-resolution satellite imagery and open-source data, ResSolv™ identified heat risk at a hyperlocal level down to individual buildings and areas as small as 100 sq.m.

Fig. 1. ResSolv heatwave risk analysis of Vivekananda Camp, Delhi

2.1.Mapping granular heat risk using ResSolv

Resilience360™, is a climate risk management software designed at the intersection of city planning, built-form architecture, heatwave vulnerability metrices and advanced software intelligence technologies such as AI/ML. The software is aimed at providing hypoerlocal preparedness and crisis response reliably, scalably and actionably to the eco-system comprising govermnents, small and microenterprises, businesses, relief providers and grassroot.

Our approach blends technical precision of large language model (LLM) with ground-truthed built-environment database, leveraging AI models such as UNet and Inception v3, to identify high-risk areas and uniquely label building footprints into graded severity of risk due to extreme heat exposure. Machine learning processes over 14 geo-climatic, geo-spatial and built-form parameters, including land surface temperature, roof typology, sensor data for indoor temperatures, and climatic conditions, to pinpoint heat "hotspots". The final severity of risk is available as an API (plug-and-play) and software, which can integrate seamlessly with existing government disaster systems and disaster management plans, GIS and custom-map interface, as well as deploy as an independent system, providing ease of adoption. Combining the heat risk building data records with community input, the software produces automated-targeted advisories for households, public infrastructure operators (railways, airports, healthcare centres, institutions) facilitating a coordinated and planned crisis response. Governments and businesses use the granularized intelligence with >90% accuracy towards redevelopment of structures, strengthening of infrastructure using frugal architecture designs and capacity-building workshop to engage communities in tackling heat risks.

3. Combating heat using frugal interventions

3.1. Frugal-architecture and structural interventions

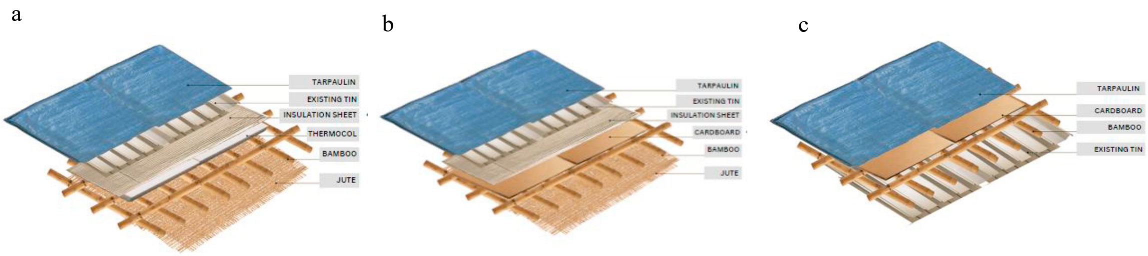

Fig. 2. (a) Cool roof model 1; (b) Cool roof model 2; (c) Cool roof model 3.

a) Cool Roofs: Three cool roof models incorporating locally sourced and recycled materials were developed and deployed in various buildings located within the site. The three cool roof model prototypes were developed post-material research that consisted of jute, bamboo, cardboard, insulation sheet, tarpaulin sheet, and existing tin. Here, Model 1 is durable with good thermal efficiency (See *Fig.2*), Model 2 had similar thermal efficiency as 1 when deployed, and Model 3 was the cheapest, easy to install, and had comparatively lesser thermal efficiency (See *Fig.2*). In this scenario, a building's thermal efficiency determines how quickly it regulates its indoor temperatures [14]. Data loggers placed within these models then showed 26% and 28% temperature reductions for Models 1 and 2, respectively (See *Fig.3*). At the same time, the cost-effective Model 3 exhibited a promising 19% decrease in temperature from the highest recorded peak temperature on the hottest day.

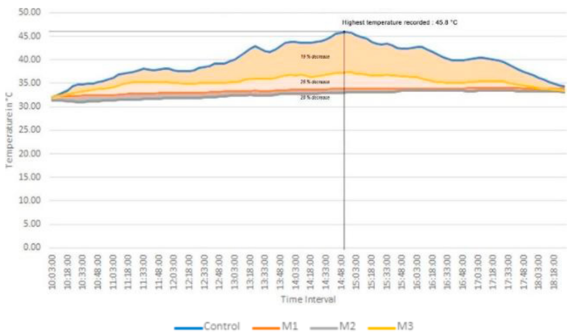

Fig. 3. Temperate variations recorded across roofing without intervention & cool roof model deployed

Here, the control roofing structure without the cool roof intervention had retained heat, with a maximum temperature recorded at 45.8°C. On the other hand, the other models with the alternate roofing structures recorded interesting results. Model 2 recorded the lowest temperature at 33.1°C, followed by roofing model 1, which recorded a temperature of 33.8°C. Lastly, model 3 yielded less effective results, resulting in a temperature of 37.3°C. As observed, the cool roof Model 2 had brought down indoor temperatures by a remarkable 12°C variation from the control building and retained humidity at less than 50%. Through these cost-effective interventions, we explored different methods of mitigating indoor heat and achieving ambient and more people-friendly indoor conditions.

b) Street shading: The community-driven street shading initiatives were developed by strategically placing green nets in high-traffic areas. These interventions utilised recycled fabrics like out-of-use scarves and traditional attires to provide adequate shading (See *Fig.4*). The community also built creatively crafted shelters by tying discarded plastic bottles to an overhead net.

Fig. 4. Public Placemaking- Street shading intervention.

c) *Revitalising Safe Drinking Water Stations*: To improve drinking water infrastructure, collaborative and community-led efforts helped revitalise neglected and deteriorating water stations within the study area by systematically addressing structural and water quality issues. This initiative played a vital role in helping restore the stations as reliable hubs for access to clean water, with ongoing maintenance commitments for sustained effectiveness.

3.2. Behavioural interventions

a) *Heat Waves Advisory and Community Engagement*: Amidst the rising frequency of heat waves, a comprehensive advisory has been formulated to protect community well-being. This advisory includes essential measures like staying indoors, seeking shade, maintaining hydration, and adjusting dietary habits to alleviate the impact of extreme temperatures. Integral to this initiative is a community-led dissemination approach, led by local leaders and organisations, fostering broad awareness and adherence to guidelines. Through information dissemination, workshops, and a preparedness culture, the effort aims to empower communities, enhancing resilience against heat waves, particularly among vulnerable populations, emphasizing the significance of collective action in establishing a heat-resilient community.
b) *Developing Early Warning Systems (EWS):* There is a growing need for effective Early Warning Systems (EWS) that could potentially tackle heatwaves by empowering various sections of the community. Recognising the crucial role of community-led volunteers, the activities were focused on equipping the community with the knowledge and tools to participate actively in heat wave preparedness. Training programs were tailored to respond to the diversity within the community and provided clear instructions on operating Early Warning System (EWS) equipment. This included data loggers, portable devices that record environmental data over time, and Automatic Weather Stations (AWS), which are more sophisticated units that provide real-time data on various parameters. The data logger units deployed indoors revealed a significant increase in indoor humidity beyond liveable conditions at over 70% when compared to ambient retained humidity at less than 50% (See *Fig.5*).

Fig. 5. Data loggers set up in the community

The volunteers learned to measure essential environmental factors like indoor and outdoor temperature, humidity, atmospheric pressure, and wind speed and direction. This data collection process established a baseline for understanding the local heat stress levels. Following the temperature and humidity readings recorded by the volunteers, the heat stress warnings were disseminated to the communities based on the heat stress chart, which translated environmental data into actionable information. Informative banners (heat stress charts) were strategically placed at various locations, displaying "Do's and Don'ts" for each heat stress level (See *Fig. 6*). These user-friendly instructions guided residents on appropriate behaviours during different heatwave intensities, empowering them to take preventive measures to safeguard their health. However, the series of activities and data collection yielded crucial results. This highlighted the need for a more comprehensive approach to heatwave mitigation and a need for strategies that create comfortable and healthy indoor environments during heatwaves.

Relative Humidity %	Air temperature °C										
	21	24	27	29	32	35	38	41	43	46	49
0	18	21	23	26	28	31	33	35	37	39	42
10	18	21	24	27	29	32	35	38	41	44	47
20	19	22	25	28	31	34	37	41	44	49	54
30	19	23	26	29	32	36	40	45	51	57	64
40	20	23	26	30	34	38	43	51	58	66	
50	21	24	27	31	36	42	49	57	66		
60	21	24	28	32	38	46	56	65			
70	21	25	29	34	41	51	62				
80	22	26	30	36	45	58					
90	22	26	31	39	50						
100	22	27	33	42							

Serious risk to health - heatstroke imminent

Prolonged exposure and activity could lead to heatstroke

Prolonged exposure and activity may lead to fatigue

Fig. 6. Heat stress chart *(Source: Enviraj-Beyond Temperature: Humidity's Hidden Impact on Heatwaves)*

c) *Building Community Preparedness through Early Warning Systems:* People-centred early warning systems are designed to empower individuals and communities threatened by hazards to act promptly and effectively, minimizing risks to life, property, and the environment. Using the International Strategy for Disaster Reduction (ISDR) checklist, our study focused on key elements of these systems:
   i. *Risk knowledge:* By systematically collecting data and performing risk assessments, we gained an understanding of hazards and vulnerabilities. This helped drive community prioritization of early warnings. In Vivekananda Camp, the ResSolv™ AI model generated a heat risk map, supplemented by surveys, community walks, questionnaires, and training workshops.
   ii. *Monitoring and warning service:* This element focuses on developing hazard monitoring systems. Using Automatic Weather Stations (AWS) for metrics like temperature and humidity, a community-centred warning service was managed by local volunteers.
   iii. *Dissemination and communication:* Custom hyperlocal heat risk alerts and pre-emptive notifications were crafted with community input, ensuring clarity and practical understanding.
   iv. *Response capability:* To strengthen response capabilities, community volunteers participated in training, and educational materials were created using adult learning principles.

4. Reimagining Heat Action

Reimagining heat action demands a comprehensive approach that resonates with the realities on the ground, where communities bear the brunt of rising temperatures. It is not just about forecasting heat waves; it is about anticipating hyper-local risks that affect neighbourhoods differently. To effectively address the challenges posed by extreme heat, a comprehensive set of initiatives and policies is recommended for federal actors. Such initiatives may be classified as short, medium and long-term measures, depending on their respective time requirements, and as follows:

4.1. Short-term measures

a) *Releasing actionable guidelines for heatwave emergencies:* When extreme heat is predicted, targeted advisories based on risk classification (low, medium, high) can help communities take preventive action. While staying indoors is recommended, indoor heat risks must also be addressed. Actionable measures should guide individuals, communities, and responders in adapting to urban heat impacts.
b) *Deploying frugal cooling interventions:* Immediate interventions include providing materials for makeshift cooling infrastructure, such as street shading and heat shelters using locally sourced materials. While effective short-term, these are not long-term solutions. Additional efforts include distributing cooling kits, collaborating with aid agencies, and developing community-driven resilience strategies.

4.2. Medium-term measures

a) *Prioritising natural cooling methods***:** Leveraging natural elements and ecosystems mitigates heatwave impacts affordably and sustainably. Strategies like increasing vegetation and tree cover reduce temperatures via evapotranspiration. Integrating Professor Konijnendijk's 3-30-300 rule—ensuring 3 trees per resident, 30% green cover, and a park within 300 meters—links this index to urban strategies, reducing heat exposure and strengthening community resilience.
b) *Institutionalising heat action in green building guidelines:* Urban structures can intensify heatwave effects. Using ResSolv™ AI/ML-based heat risk assessments, decision-makers can prioritize retrofitting high-risk buildings. For heat-prone areas, green building guidelines should include targeted recommendations to mitigate heat impacts.

4.3. Long-term measures

a) *Statutory provisions to mandate climate vulnerability assessments:* Statutory assessments can identify high-risk communities by mapping inadequate housing and cooling access. ResSolv™ accelerates this process, reducing planning time by nine months, digitizing impact monitoring, and providing hyperlocal risk insights (100m² zones in <72 hours). This enables authorities to prioritize high-risk areas, plan emergency responses, and cut recovery costs.
b) *Developing an index to measure indoor heat:* Poorly ventilated buildings can trap heat, exceeding outdoor temperatures. A specialized index assessing ventilation, insulation, and heat-absorbing materials would enhance understanding of indoor thermal risks and based on local knowledge, further empower residents to take action.

5. Conclusion

Reimagining heat action demands a comprehensive, community-centred approach that addresses hyper-local heat risks, especially in densely populated and socio-economically vulnerable areas like Vivekananda Camp, Delhi. Traditional forecasting isn't enough; the focus must include engaging local stakeholders—community leaders, health workers, and local government- who can drive practical solutions such as cooling systems, heat shelters, and safety education. This approach centres inclusivity and empowers communities to act, yet recognizes that localized actions need broader strategies for a larger impact. A modern heat action plan, exemplified by Delhi's 2023 plan, incorporates Artificial Intelligence to assess climate and health impacts, fostering informed, resilient communities. ResSolv ™ enables precise risk assessments, identifying vulnerable households and targeting retrofitting in high-risk areas using recycled materials for sustainable temperature control. This model showcases the effectiveness of integrating technology with local resources to combat urban heat offering a scalable solution for widespread resilience. By combining technology, community engagement, and frugal innovation, this strategy creates a blueprint for enduring climate resilience, emphasizing the importance of collective action and technological interventions in mitigating the impacts of climate change on urban populations.

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