Thermal Stress and Cool Roofs

Housing Production Research Fellows
Summer 2021 Cohort

EXECUTIVE SUMMARY

Heatwaves, hot seasons, and general thermal stress have been shown to have countless negative effects on corresponding communities. Not only does extreme heat lead to decreases in mental and physical health, but also increases in violence, crime, and mortality rates and decreases in educational performance, work performance, productivity, and agricultural stability.

Mexican families who live in self-produced homes and receive informal income have been shown to be especially vulnerable to extreme temperatures. Research shows that cool roof technology may be a favorable mechanism through which New Story can mitigate these extreme interior temperatures within rural Mexican communities.

SYNTHESIZE

Studies have indicated that high levels of thermal stress lead to negative effects on the physical health of affected communities. Thermal stress is the result of higher than comfortable or extreme temperatures (Simister & Cooper, 2005). A report by the Institute of Medicine (2011) found that human physiologic compensation mechanisms can be overwhelmed when exposed to high environmental temperatures. It can also result in decreased organ function, isolation, and overall poor health status. A study on heatwaves in Mexico revealed negative consequences on adult height when exposed to high temperatures early in life (Agüero, 2014).

Thermal stress can result in life-threatening consequences as well. Extreme heat has been shown to increase mortality rates in Mexico, with a more acute impact on rural communities (Compean, 2013). Heatstroke is an example of a potentially deadly consequence of thermal stress, with the mortality rate sitting around 80% (Joubert & Bates, 2007). Changes in biochemistry, kidney failure, and heat cramps can all result from water and electrolyte loss during periods of intense thermal stress as well.

Negative psychological consequences of thermal stress include increasing rates of mental and behavioral disorders. Hansen et al. (2008) found that during heat waves, hospitalizations for mental and behavioral disorders increased by 7.3%. In addition, mental and behavioral disorder mortalities increased in the 65-74 age group. This data is consistent with the Page et al. (2007) study which found that with every 1° C increase after 18° C, the probability of suicide increased by 3.8%.

There has also been a correlation between thermal stress and aggression and violence. A study by Simister & Cooper (2005) found this correlation and attribute adrenaline stress from thermal stress to be the reason for the increase in aggression. This has led to higher crime rates, strikes, and job resignations. Simister (2021) also explains that extreme temperatures lead to hormones linked to aggression, such as adrenaline and noradrenaline. Another study on heat and violence explains that a 2° F increase in temperature leads to an average of an additional 9 murders or assaults per 100,000 people (Anderson, 2001). Police calls have also been shown to increase during hot weather (Auliciems & DiBartolo, 1995), as well as the number of rapes (Nance, 1995).

Finally, thermal stress has been shown to have negative effects on school, work, and economic performance. A study by Wyon (1970) found that students in higher environmental temperatures showed reduced oral performance, multiplication performance, reading speed, and reading comprehension. Hanna et al. (2010)

found that with a 2° C increase in Wet Bulb Globe temperature (which considers humidity), economic performance decreases by 50%. From an agricultural perspective, hot temperatures lead to increases in mortality and crop prices (Compean, 2013). Agricultural income and productivity then decrease, leaving the rural Mexican communities that depend on agricultural success vulnerable.

PROPOSED SOLUTION STRATEGY

Mexican families who live in self-produced homes and receive informal income tend to have higher interior thermal sensations with an average difference in temperature of 1.35° C and an average difference of 6% humidity (Garcia Gomez et al., 2011). This research shows that consistent differences in environmental temperature can eventually result in negative and even detrimental effects. In order to mitigate thermal stress and its subsequent effects, we need to search for design solutions.

Cool roofs reflect sunlight and absorb less heat than alternative roofing systems, resulting in lower indoor temperatures by about 2-5° C (Bhagavatula et al., 2018). They have the ability to even reach 28-33° C cooler than temperatures within a dark roof on a hot summer day (Garrison & Horowitz, 2012). On a city-wide scale, cool roofs can increase community resilience to heatwaves as well, reducing the urban island heat effect. They are cost-effective, require minimal maintenance, and can be constructed with locally sourced materials (Rao, n.d.).

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RESEARCH LITERATURE REVIEW: CLASSIFICATION OF DOCUMENTED HEAT STRESS EFFECTS

CATEGORY	EFFECT	RISK LEVEL	CONDITIONS	THERMAL THRESHOLD	TIME TOLERANCE	LOCATION	REMARKS/ADDITIONAL NOTES	REFERENCE
Health - Psychological	Above 18C, each increase of 1C was found in **increasing likelihood of suicide and violent suicide** by 3.8% and 5% respectively in the UK. This is troubling because of mental health implications and also that there is possible indication of increase of aggression and impulsivenes	Deadly	hot	18C				Page (2018) Relationship between daily suicide counts and temperature in England and Wales
Health - Physical	Reduce deaths during heatwaves: This research found that cool roofs, which reduce the urban heat island effect and air temperature 0.5C on average and 3C maximum in the city, "may reduce total heat-related deaths by up to 8%, and reduce those attributable to the UHI by up to 25% during heatwave periods." The article measures the temperature difference between urban and rural areas and normalizes it with the population density. Given that the New Story developments might not be big or dense enough to be 'urban', this is a stretch. UHI = Urban heat index	Deadly	hot	Study was conducted in city with 17.7 °C average temperature	n/a			Macintyre (2019) Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European City
Economic	Economic work performance decreases 50% with a 2C rise of Wet Bulb Globe Temperature (takes humdity into effect) when already at 100% work capacity	Low	humid-hot	Above 26 Degrees C. If at 100% capacity at 26, then 28C will be 50% performance and 34C is 0%	Most cases, people wil self adapt by reducing their physical output, impacting productivity or accuracy of the task, before becoming a death threat or passing out. However, there are health effects if someone chronically exerts or dehydrates themselves as they would in these situations (pg 175-176)		See figure 2 for a helpful graph.	Hanna et al (2011) Climate Change and Rising Heat
Social	Thermal stress (existing in higher than comfortable environmental temperatures) creates **an adrenaline stress response in the body, which researchers think have the side effect of aggression**. They find this aggression expresses itself in **higher crime rates and strikes and quitting jobs**. They create this assumption off of finding seasonal pattterns in workers in the USA, correlating higher temperatures with aggressive behavior.	Moderate	hot	Depends on the city - believe that people adapt to the range of temperatures in their city. Believe below 11C is too low to assume adrenaline causes aggression.	N/A wont become deadly			Simister (2005) Thermal Stress in the USA
Health- Psychological	Researchers believe that multiple natural disasters, including **heat waves can negatively impact mental health** of individuals.	Moderate	hot	Hard to quantify	Repeated natural disaster events			Fritze (2008) Hope, despair, and transformation: Climate change and the promotion of mental health and wellbeing
Economic	The single white roof configuration can reduce the interior surface temperature up to 28 °C at midday in comparison to a roof with the original gray color of concrete. On the other hand, the reflective coating keeps the roof close to the inside air temperature in the case of the compound roof; just 3 °C above the set point during the hours with solar radiation.	Low	Hot	The compound roof with the reflective coating is the best configuration in cities with hot climates like Hermosillo and Merida because the highest reductions in heat flux provided by this roof during the day	NA	Mexico		Hernández-Péreza (2014) Thermal Performance of a concrete cool roof under different climatic conditions of Mexico
			Temperate	In Mexico City and Guadalajara, the use of the white compound roof is the most suitable, because this reduces the gains and losses of heat.				

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Health Physical	Healthy people can physically adapt to changes in ambient temperature within some limits. However, when temperatures push the upper end of those limits or are combined with other factors—such as high humidity, strenuous activity, or prolonged exposure—physiologic compensation mechanisms can be overwhelmed. As people age, their ability to cope with external environmental stressors decreases. That is based on both physiologic and social factors: decreased organ function, interactions between medications and heat-compensation mechanisms, overall poor health status, isolation, and decreased access to support services. Thermal stress has well-documented adverse health effects, and is responsible for excess mortality among exposed persons. Temperate indoor conditions (70–72°F or 21–22°C) are associated with higher office and school productivity than colder or warmer environments.					USA	Several technologies and building-design and -siting approaches can provide control of the indoor environment with lower energy costs and greater health benefits than systems typically in use today. No approach will work in all circumstances; the best strategies will depend on building use and on local and occupant circumstances.	Thermal Stress
Social	The study involved comparison of two types of green roofs: sedum covered green roofs and white gravel. Under normal conditions, the sedum-covered green roof exhibits a slight warming effect on its surrounding during the day, and cools down the immediate environment at night. The nighttime cooling effect is, however, weaker than daytime warming, which resulted in a net warming effect of the green. The cooling effect of green roofs on the surrounding environment is mostly evident at night.	Low	Cool and Humid		NA	The Netherlands	This case study discusses the effects of cool roofs at community/urban scale. It points out along with the green roofs, other factors that need to be taken into consideration to reduce the thermal stress is the soil typology, ground water availability, air quality and the vegetation.	Solcerovaa (2017). Do green roofs cool the air
Economic	A cool roof can be 50° to 60°F (28 to 33°C) cooler than a dark, conventional roof on a hot summer day. Cool roofs help reduce energy use and GHG emissions, save money on air-conditioning costs, and improve air quality. When enough are installed on a citywide scale, cool roofs an also reduce the urban heat island effect—helping to lower temperatures across whole urban communities.	Low	Temperate		NA	South California	This study identifies the following points as cons in comparison with other types of sustainable roofing technologies such as green roofs and cool roofs. 1. Unlike green roofs, cool roofs do not reduce surface water pollution or stormwater runoff 2. Cool roofs may result in a "winter heat penalty," as they may require higher heating costs during colder weather due to their ability to transmit heat from the building interior through the roof surface	How Green Roofs and Cool Roofs Can Reduce Energy Use, Address Climate Change, and Protect Water Resources in Southern California
Economic	Urban greenery reduces the annual cooling load of residential buildings by 11.6 kWh m−2 (2.6%); cool roofs and pavements by 25.8 kWh m−2 (5.8%); and the combination of greenery, cool roofs and pavements and urban shading by 31.9 kWh m−2 (7.2%). Cooling load savings in the wet season are higher (by 22–28%) than those in the dry weather regime, consistent with the higher air temperature reduction observed during the wet season. For office buildings, the calculated annual total cooling load is 585 kWh m−2 in the unmitigated condition. Urban greenery can reduce the annual cooling load of office buildings by 8.3 kWh m−2 (1.4%); cool roofs and pavements by 24.3 kWh m−2 (4.1%); and the combined scenario by 30 kWh m−2 (5.1%). Te cooling load savings in the wet season are higher (by 37–67%) than those in the dry season.		Hot and Dry		NA	Australia		Holistic approach to assess co-benefits of local climate mitigation in a hot humid region of Australia

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Economic	Solar control: 1. Minimising the surface areas exposed to direct sunlight/solar geometry/shading effects 2. Heat gain control - fixed or permanent insulation in the roofs 3. Natural Ventilation 4. Evaporative cooling: Roof pond with movable insulation, roof spray, roof covered with a wet pad				NA	India	The paper discussed in detail about the alternative cool roof techniques.	Passive solar energy technologies for energy efficient building designs
Social	Cool roofs programs can have great benefits citywide, and should be tailored to a city's needs and resources. Three emerging models exist: 1) pilot programs; 2) municipal, voluntary, and corporate social responsibility (CSR) programs; and 3) building code programs. These models for cool roof programs enable cities to steadily make progress while building community awareness and support. These three models allow city cool roofs program to grow from a single neighborhood to a city-wide effort.				NA	India		India: Keeping it cool – models for city cool roof programs
Social	-**Hot temperatures increase aggression** by directly increasing feelings of hostility and indirectly increasing aggressive thoughts. - there are about 2.6% more murders and assaults in the United States during the summer than other seasons of the year. -a 2 °F increase in average temperature predicts an increase of about 9 more murders or assaults per 100,000 people. -Aggression—as measured by assault rates, spontaneous riots, spouse batterings, and batters being hit by pitched baseballs—is higher during hotter days, months, seasons, and years.	deadly	hot	N/A	N/A	Multiple- concludes that in many settings hot temperatures cause increases in aggression.		Anderson (2001). Heat and Violence
Health-Physical & Psychological	-Heat stress can increase the heart rate and systolic blood pressure and decrease diastolic blood pressure -**Exposure to excessive high temperatures can reduce attention and consequently decrease cognitive performance.**	Moderate	hot	35 C	N/A	Tehran Province, Iran		Bidel (2020). Evaluation of the effect of heat stress on cognitive performance and physiological parameters of the students
Health-Physical	-Internal heat in the peripheral circulation is lost to the environment by way of active sweating in an attempt to maintain thermal homeostasis, which leads to progressive water and electrolyte loss over time. -The mortality rate of heat stroke is approximately 80%, as the body attains a temperature that causes tissue damage and the brain, liver and kidneys -Prickly heat is a term used to describe skin inflammation, especially following profuse sweating. - fluid/electrolyte loss/imbalance is involved in Heat cramps: painful uncontrolled muscle contractions. -Severe dehydration can lead to changes in the body's biochemistry, kidney failure, and may become life-threatening.	deadly	humid-hot	N/A	N/A		A worker exercising in heat can sweat in excess of 1.5 L/hr14 and over a 12 hour shift may lose over 10 L of fl uid.	Bates (2007). Occupational Heat Exposure
Health-Physical	-**high temperatures can lead to lower productivity**, higher rates of chronic kidney disease, heat exhaustion and heat stroke.	deadly	hot	Serious heat stroke and even death occurs after 42 C (Body temp)	N/A	multiple	-If core body temperature exceeds 38°C over several hours, heat exhaustion and reduced psychometric and motor capacity will occur. Above 39°C, more serious heat stroke and unconsciousness may occur.	Kjellstrom 2009. Climate change, direct heat exposure, health and well-being in low and middle-income countries
Health-Physical Economic	-extreme heat increases mortality -Extreme heat effect on death is significantly more acute in rural regions, leading to increases of up to 0.2 percentage points vis-à-vis a 0.07-point increase in urban areas. **-extremely hot temperatures increase** mortality and **crop prices**, while they at the same time **decrease agricultural income, agricultural productivity, and yields of critical crops such as corn,** which a large number of poor households in rural Mexico depend upon for their subsistence.	deadly	hot-humid	30 C	N/A	Mexico	-exchanging one day with a temperature of 16-18 °C for one day with temperatures higher than 30 ° C increases the crude mortality rate by 0.15 percentage points -extreme heat is the most lethal mechanism through which weather affects human physiology, and this impact is considerably stronger in rural regions	Compean (2013). Weather and Welfare: Health and Agricultural Impacts of Climate Extremes, Evidence from Mexico

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Health-Physical	**-Exposure to higher temperatures early in life has negative consequences on adult height.** -Effects are more negative for individuals growing up in poorer districts	moderate	hot-humid	N/A	N/A	Mexico		Aguero (2014). Long-term effect of climate change on health: Evidence from heat waves in Mexico
Health-Psychological	A positive association between ambient temperature and **hospital admissions for mental and behavioral disorders** was found above 26.7C; hospital admissions **increased by 73% during heat waves** (21.3% increase in hospitalizations for organic mental disorders; 17.4% for dementia; 9.1% for mood/affective disroders; 9.7% for neurotic disorders like anxiety, panic, agoraphobia and ptsd). **Mortalities attributed to mental and behavioral disorders increase**d during heat waves in the 65-to 74-year age group. * heat wave: 3 consecutive days when the daily maximum temperature reached or exceeded 35 C	deadly (for people suffering mental disorders)	hot-dry	35 C	NA	Adelaide, South Australia	mentally ill people may be sensitive to exposure to high ambient temperature and should be considered at risk population. At least 17% of the Mexican population present a Mental/Behavioral disorder.	Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The Effect of Heat Waves on Mental Health in a Temperate Australian City. Environmental health perspectives. 2008;116(10):1369-1375. doi:10.1289/ehp.11339
Health-Psychological	**Scholar performance negatively impacted by heat**. In children students, oral performance significantly deteriorated at an air temperature of 27°C (in comparison to 20 C). A simple multiplication test was performed less well at air temperatures of 25° and 27° than at 20° and 23°. Reading speed and reading comprehension deteriorated by 30% at 30° as opposed to 20°c.	low	NA	27 C	NA	Sweden		Wyon, D. P. (1970). Studies of children under imposed noise and heat stress. Ergonomics, 13(5), 598–612.
Economic/Social	When comparing similar income brackets, **Mexican families with an informal income living in self-produced homes experience higher interior thermal sensations** (+1.35C and +6% humidity) than those with formal incomes living in homes produced by developers. Families living in self-built homes are 30% less likely to have access to climate control devices (fans).	low	humid-hot	NA	NA	Merida, Mexico	Almost 70% of all homes in Mexico were self-produced; dwellers would benefit from affordable cool-roof solutions	Perceived thermal sensation in low cost and self-produced dwellings, in warm periods, in a warm humid climate
Social	Survival in **hostile temperatures requires strong biological reactions**, liberating strees hormones (adrenaline and noradrenaline).	Moderate	NA	Air temperature near or above 37°C Violence increase from above 12°C , and reachs its peak at 23°-25°C	NA	India & Pakistan	There are strong link between stress and violence. Murder rates rise in extreme temperatures	Simister, J. (Forthcoming). Thermal stress, violence, and female autonomy:
Social	Seasonal association between warmth and telephone police calls and violence. **Police calls increase in number during unsettled hot summer and calm warm winter weather**. Calls decrease with the coming of cool season and has a upward blip with gradual return of warmer conditions.	Moderate	NA	The increase of calls comes every uprise in warm temperatures even during coldest months. Temperatures above 25°C tends to enhace effects of thermal stress.	NA	Australia	The frequency of calls may not be only in function of simple responses to heat stress.	Auliciems A, DiBartolo L. Domestic violence in a subtropical environment
Social	Relationshio between long hot summers and outbursts of collective violence, such as racial conflicts in American cities. **Uncomfortably hot conditions facilitated aggression by non-angrey persons**. The summer seasson marks an increase in reapes.	Moderate	high humidity-long hot summer	NA	NA	USA	Warmer climates are positively associated with rape rates.	Nance, 1995. The structural determinants of rape in the United States