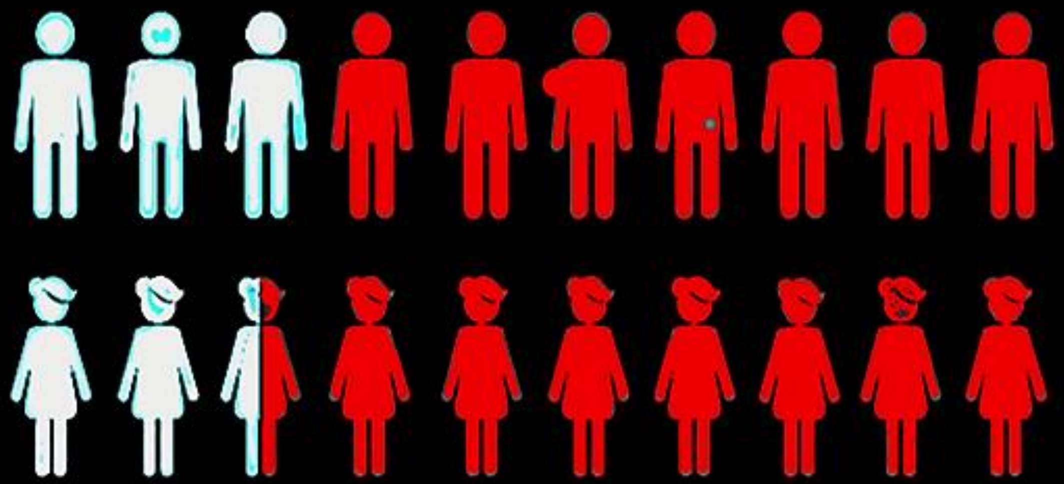
Urban Climate and its Impact – Paving the way for Sustainable and Resilient Cities

On the magnitude of Urban Climate Change, Its impact on Energy, Health, Productivity, Vulnerable Population, Economy and Environmental Quality. Heat Mitigation and Adaptation Potential and Proposals to Counterbalance Urban Heat

M. Santamouris, UNSW, Sydney, Australia



13,000 OVERHEATED CITIES

1.7 BILLION PEOPLE UNDER SEVERE OVERHEATING

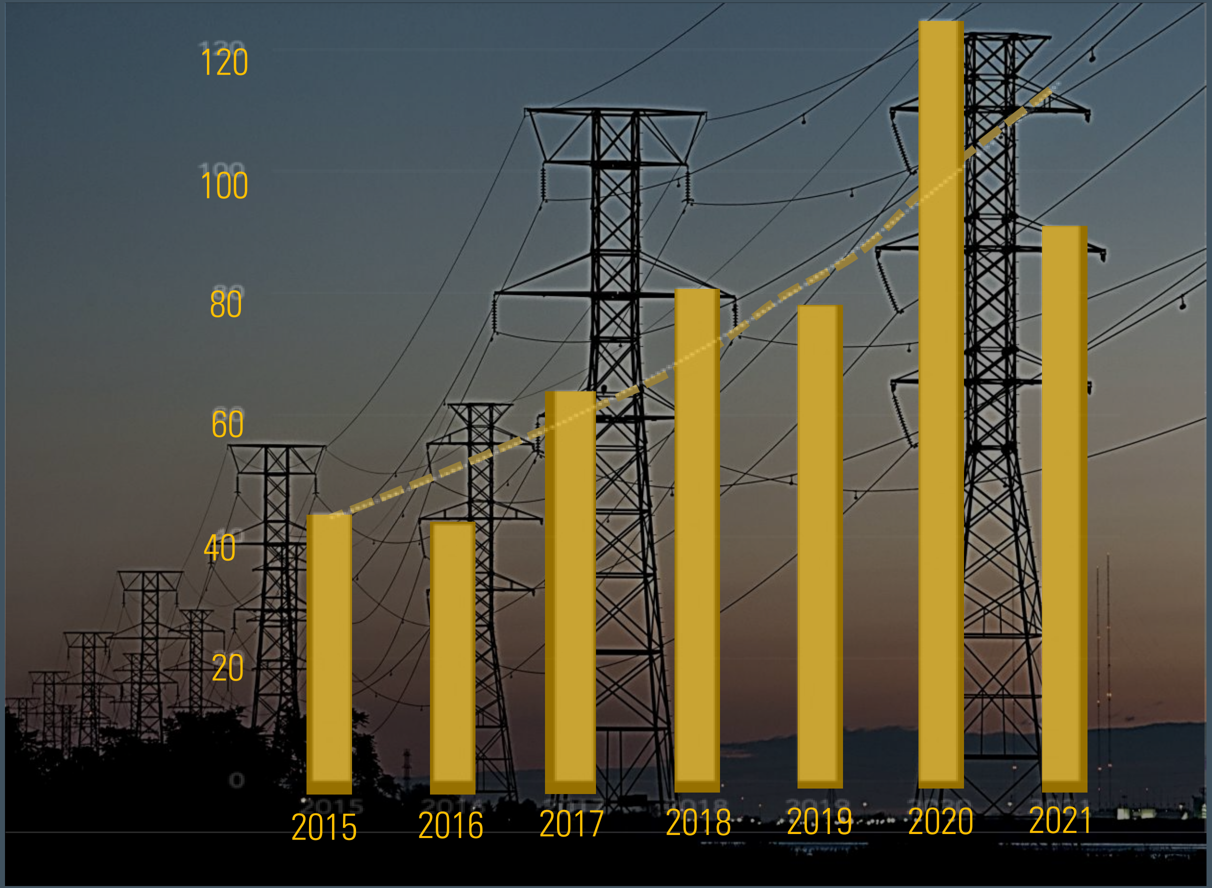
THREE TIMES MORE OVERHEATING HOURS SINCE 1980

118 BILLION OVERHEATING MAN HOURS

IN CHINA AND INDIA HEATWAVE EXPOSURE INCREASED BY 508 MILLION PERSON DAYS PER YEAR THE LAST DECADE

CLIMATE CHANGE HAS PUT 9 % OF THE POPULATION, (600 MILLION) OUTSIDE THE CLIMATE CONDITIONS THAT HAVE SUSTAINED HUMAN LIFE AND ACTIVITIES

C. Tuholske *et al.*, "Global urban population exposure to extreme heat," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 118, no. 41, pp. 1–9, 2021, doi: 10.1073/pnas.2024792118.



M. Santamouris, "Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change," *Energy Build.*, , 2020,

How Blackouts during Heat Waves Amplify Mortality and Morbidity Risk Brian Stone, Jr.,* Carina J. Gronlund, Evan Mallen, David Hondula, Marie S. O'Neill, Mayuri Rajput, Santiago Grijalva, Kevin Lanza, Sharon Harlan, Larissa Larsen, Godfried Augenbroe, E. Scott Krayenhoff, Ashley Broadbent, and Matei Georgescu, Env Research and Technology, 2023

Increases the Cooling Energy Consumption: Urban overheating is inducing an additional energy penalty at the city scale close to 0.74 kWh/m2 /°C, while the average energy penalty per person, is close to 237 (± 130) kWh/p

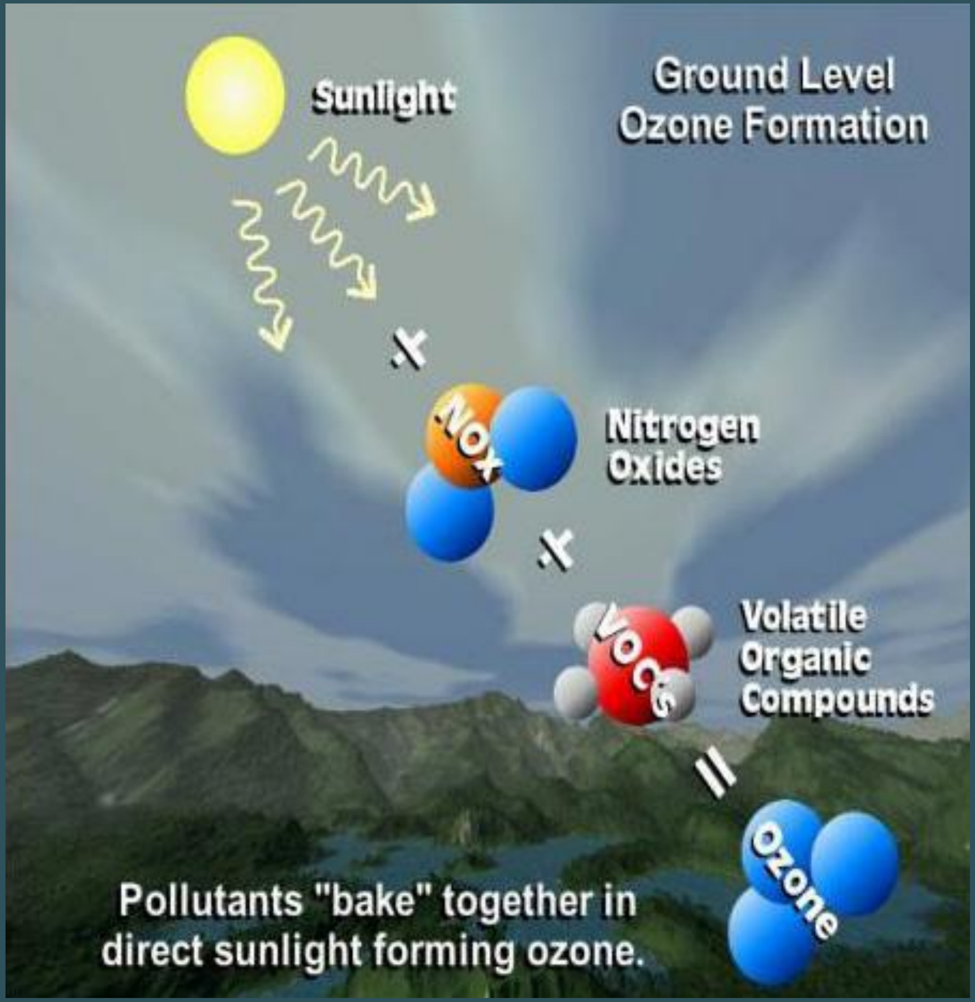
Increases the Peak Electricity Demand : The peak electricity rise per degree of temperature increase varies between 0.45% and 4.6%, corresponding to an additional electricity penalty close to 21Watts (± 10.4) per degree of temperature increase and per person

Decreases the Efficiency of Power Plants : 1 °C rise of the ambient temperature reduces the power output of thermal and nuclear power stations by 0.6%

Increases Grid Failures and Blackouts : In USA, since 2015, the number of such events nationwide has more than doubled, increasing by 151% between 2015—16 and 2020—21

In June of 2021,electrical grid failures because of a very high intensity heat wave in in the Pacific Northwest zone of USA resulted in at least:

600 excess deaths, 3500 emergency hospital visits, and Loss of electricity to tens of thousands of citizens in the area



Overheating affects the urban environmental quality increasing the concentration of toxic and oxidant ozone affecting the human respiratory and cardiovascular systems.

According to WHO, ozone causes 423100 additional deaths per year

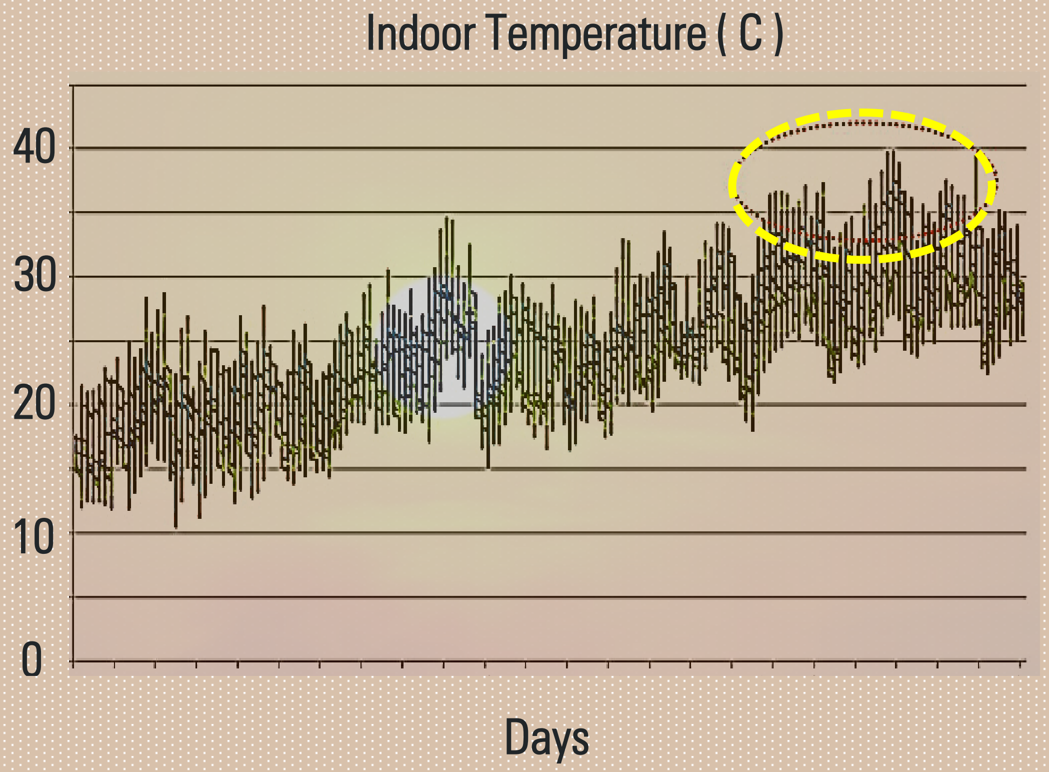
About 96 % of the world cities, 12500, present much higher levels of ozone than the threshold.

Urban overheating obliges utilities to operate power plants for an extended period to satisfy the peak electricity demand

Each degree of temperature rise in the Eastern United States during the period between 2007-2012, resulted in a rise by:

3.35%/°C ±0.50%/°C of the SO_2 emissions,
3.32%/°C ±0.36%/ °C rise in CO_2 emissions, and a
3.60%/°C ±0.49%/°C increase in NO_X emissions.

M. Santamouris, “Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change,” *Energy Build.*, vol. 207, 2020



Shamila Haddad, Riccardo Paolini, Afroditi Synnefa, Lilian De Torres, Deo Prasad, Mattheos Santamouris : Integrated assessment of the extreme climatic conditions, thermal performance, vulnerability, and well-being in low-income housing in the subtropical climate of Australia, Energy and Buildings, 272, 112349, 2022

Low-income population lives in deprived urban zones with high overheating. Urban Overheating results in high mortality, energy cost and discomfort.

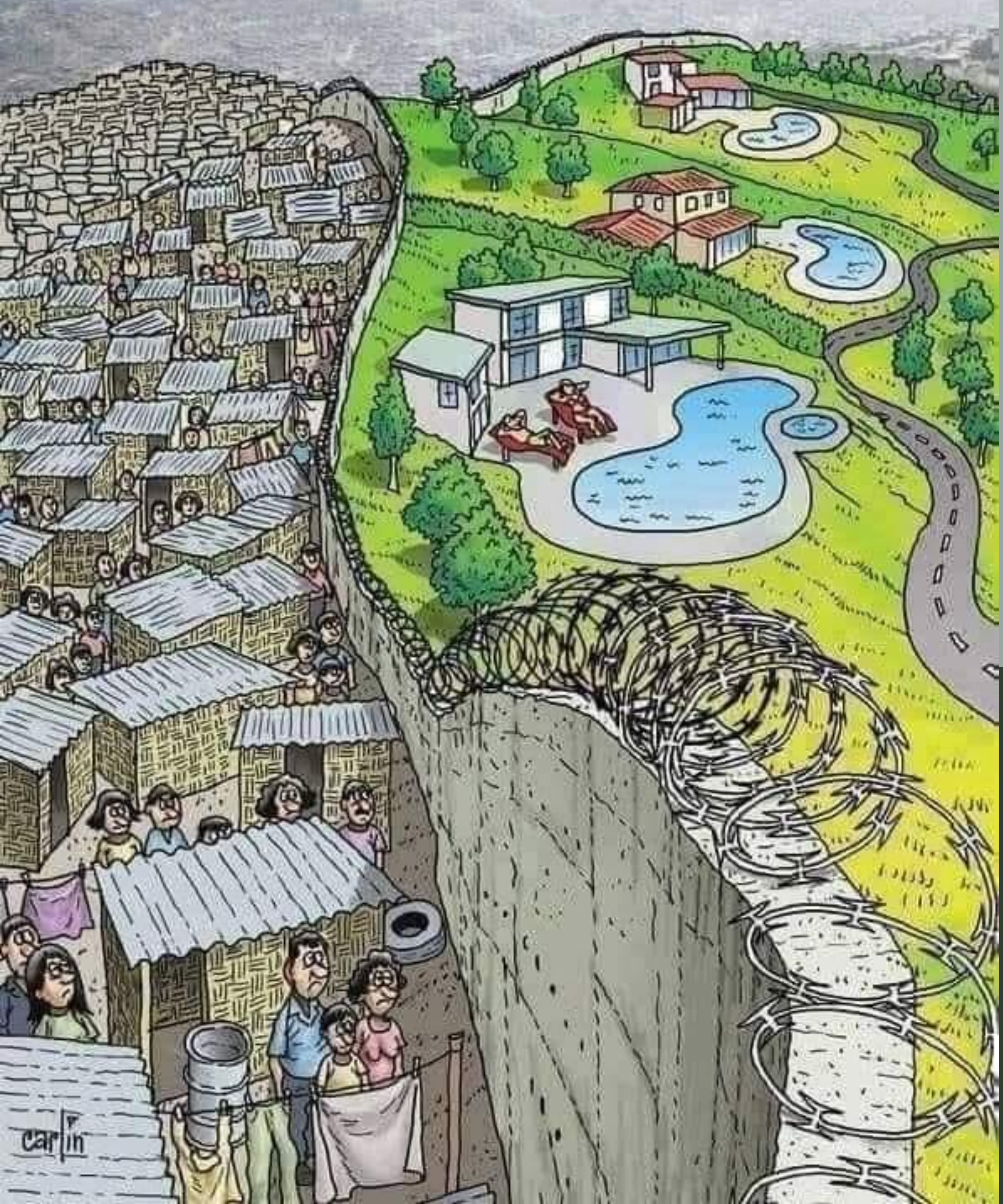
Overheating affects the urban socioeconomic and biophysical vulnerability and has a serious impact on low-income population.

Vulnerable population lives in districts of disproportionately high UHI intensity, excess heat stress, higher risk of heat related mortality and significant socioeconomic vulnerability

A significant correlation between exposure to extreme heat and the socioeconomic vulnerability exists for several cities resulting in almost twice the mortality risk in the deprived districts.

Vulnerable population lives in buildings of considerably lower thermal quality. Extreme indoor temperatures, 35-40°C, are recorded during extreme events in low-income houses.

Only 2% of the necessary cooling load is covered by low-income population in Portugal, while in Greece the cooling cost for low-income households is approximately double the average cost.

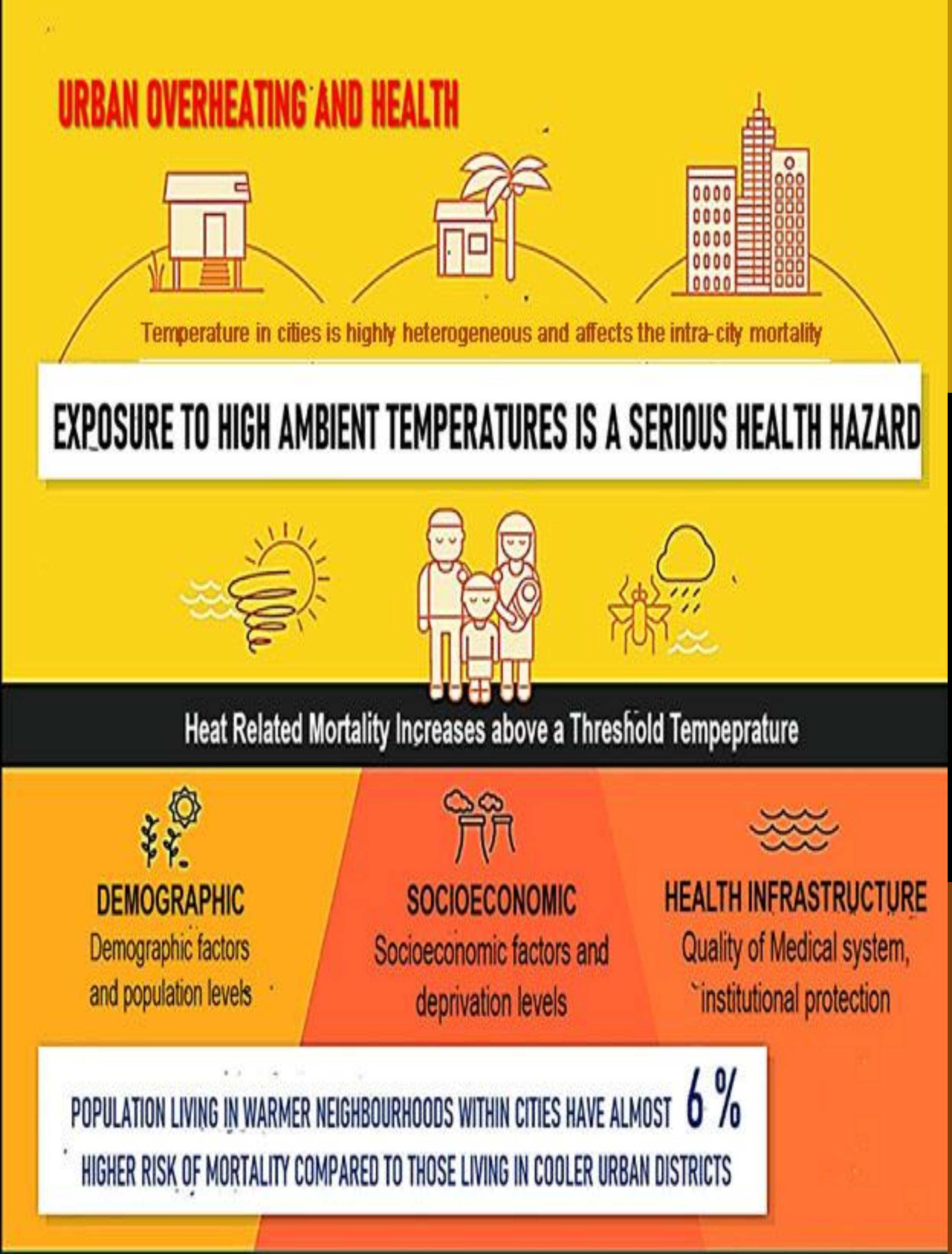


Results from 175 cities in USA correlating the magnitude of the surface Urban Heat Island against social and demographic characteristics, shown that immigrants, black and Hispanic population and vulnerable groups live in urban zones presenting a much higher UHI Intensity

Heat Related Mortality in the low income population below 22 years old is 3.72 % while in the high income population is 2.07 %

In New York, heat related mortality of the black population is almost the double than for the white people.

In USA, the mortality risk of high-income population, during heat waves, is almost by 220 % higher for the low than for the high income population.



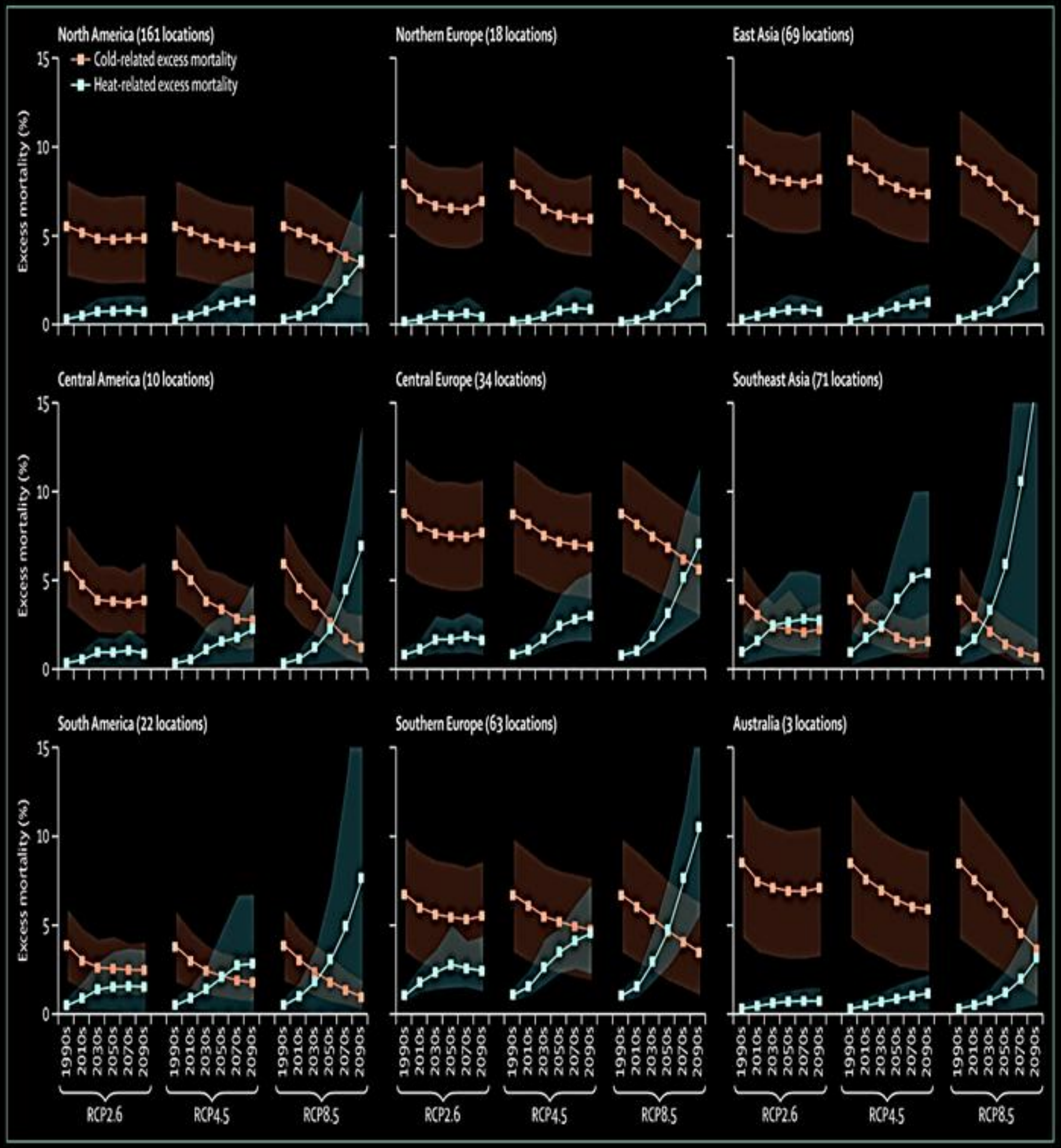
When exposed to temperature beyond a certain threshold, the human thermoregulation system cannot offset the impact of extreme heat resulting in increased global mortality and morbidity

Heat related morbidity and mortality caused by the local climate change, is highly alarming, and it seems to be one of the current and future peak scientific topics .

Elderly is the most vulnerable population group
Those with preexisting health problems like respiratory, cardiovascular, or mental health problems
Those using medication that affects thermoregulation, and
Those ‘lacking in economic assets and access to public support systems, with diminished physical or cognitive capacities to respond to warnings and missing strong and enduring social support systems like social isolated people, and those living in hazardous places’

In Europe, Heat related mortality for aged population, > 65 years, has increased by 85 % between 2004 and 2021

According to the WHO, the magnitude of the heat related mortality in the world is close to 500000 persons per year.



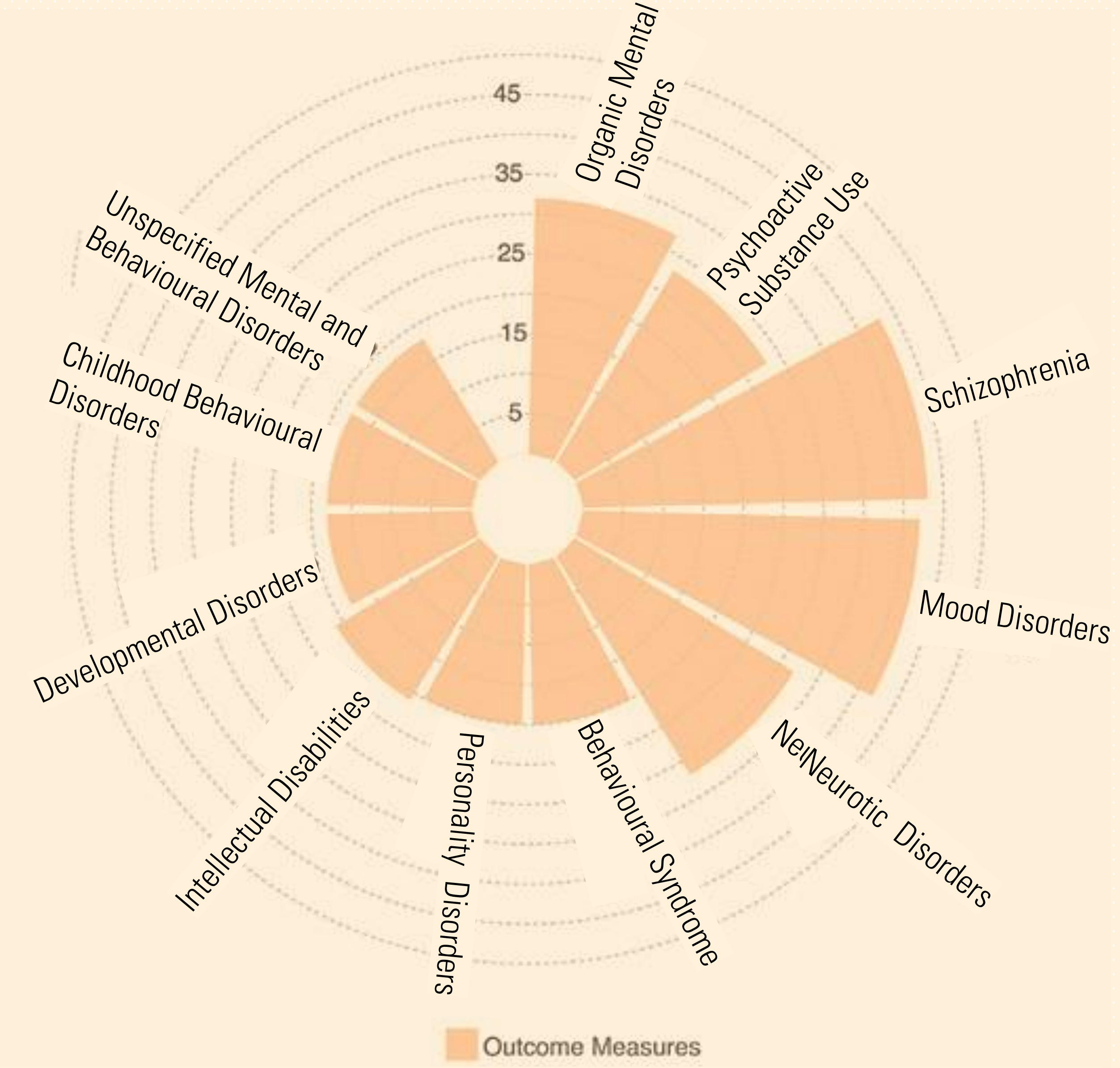
Lancet has published an extended epidemiological investigation on the potential health effects of higher ambient temperatures under various climate change scenarios, socioeconomic and demographic conditions , public health status and levels of economic development.   services.

'The study indicates that, in high-emission scenarios, most regions are projected to experience a steep rise in heat-related mortality that will not be equaled by a reduction in cold-related deaths, resulting in a substantial positive net increase in mortality.

However, the potential impact varies across areas, and populations living in warmer and potentially poorer regions are expected to sustain an increased burden.

Furthermore, the increase in temperature-related excess mortality would be substantially reduced in scenarios involving mitigation strategies to limit greenhouse gas emissions and further warming of the planet, and stricter mitigation approaches are associated with larger benefits'.

www.thelancet.com/planetary-health Vol 1 December 2017



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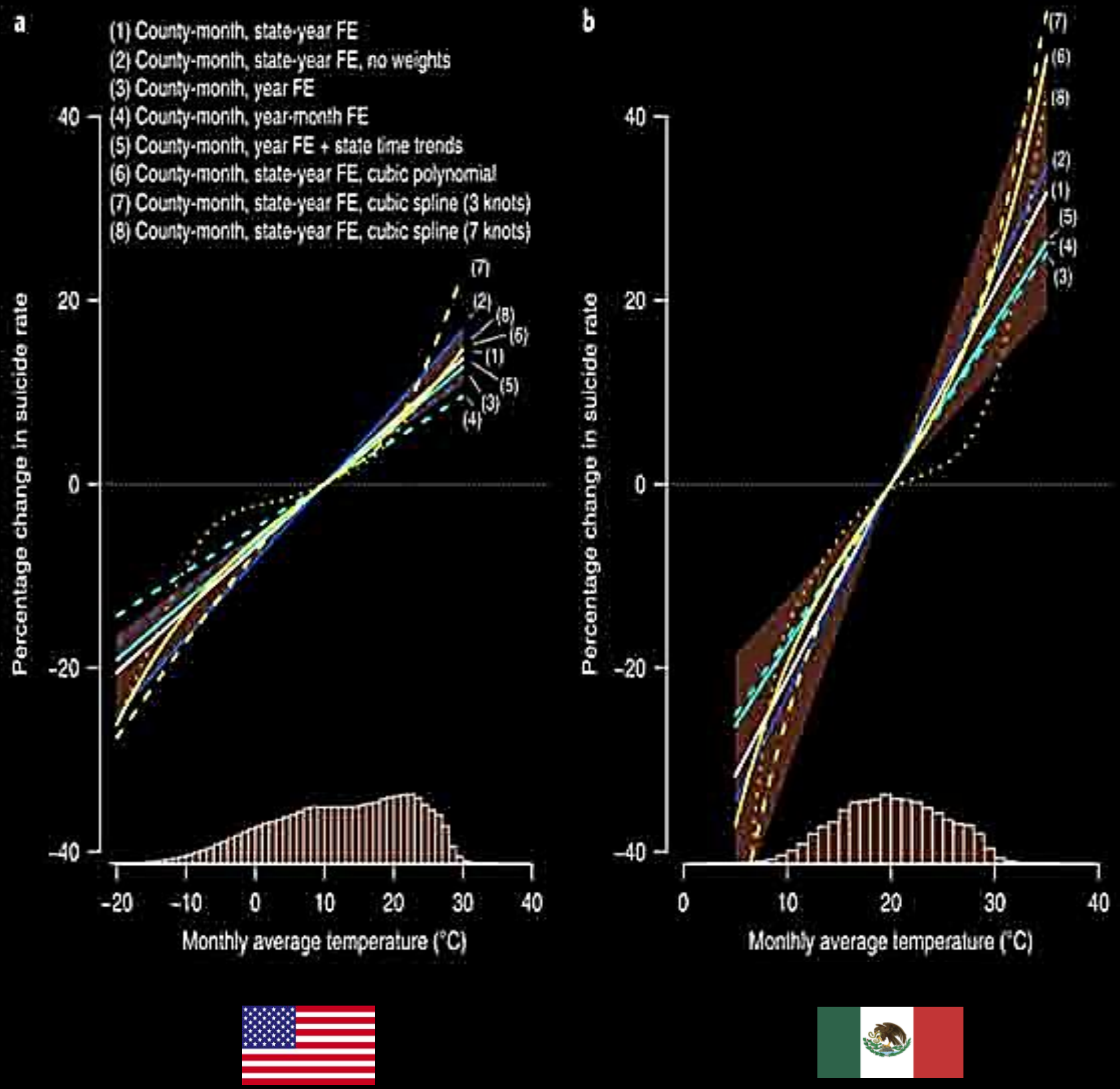
Numerous studies have revealed critical associations between temperature extremes, and mental illness
Three types of climate-related events (acute, subacute, and long-lasting changes) on mental health are identified. Extreme heat events that occur in summer could pose a serious risk to human mental conditions.

Meta-analysis showed that heatwaves and extreme high temperatures were associated with higher risk of schizophrenia, mood disorders, neurotic disorders.

A strong association between increases apparent temperature and elevated risk of Mental Behavioral Disorders.
A 99th percentile high temperature was associated with increased schizophrenia risk

D.Li et al: Climatic and Meteorological Exposure and Mental and Behavioural Health. A systematic Review and Metanalysis. Science of the Total Environment, 2023.



Using comprehensive data from multiple decades for both the United States and Mexico, it is found that suicide rates rise 0.7% in US counties and 2.1% in Mexican municipalities for a 1 °C increase in monthly average temperature.

This effect is similar in hotter versus cooler regions and has not diminished over time, indicating limited historical adaptation.

In contrast to all-cause mortality, suicide increases at hot temperatures and decreases at cold temperatures; also unlike all-cause mortality, the effect of temperature on suicide has not decreased over time and does not appear to decrease with rising income or the adoption of air conditioning.

Burke et al : High Temperatures Increase Suicide Rates in the USA and Mexico, Nature Climatic Change 2018

‘The impact of prior year heat on black and Hispanic students is three times larger than the impact on white students. The impact of prior year heat on students in lower income ZIP codes is twice as large as on those from higher income ZIP codes

Experiencing 1_F hotter school years over the past four years has a nearly 80 percent larger impact on black and Hispanic students than on white students.

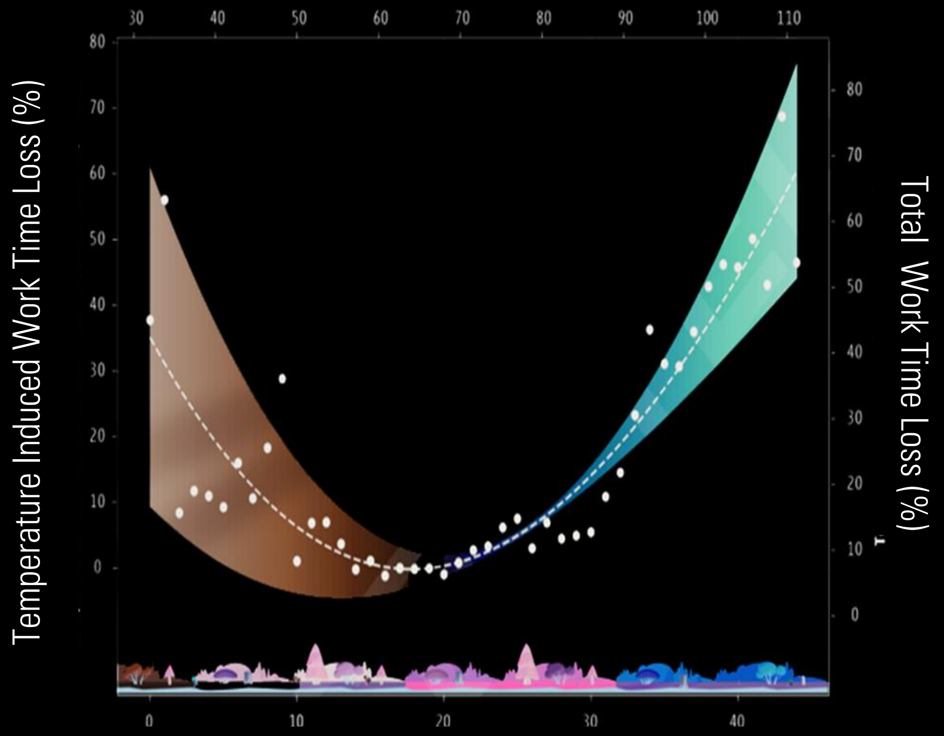
The impact of one additional day above 90_F , (32.2 C), in each of the preceding four school years has a 40 percent larger impact on black and Hispanic students than on white students’

Total exposure to days above 32.2 C lowers black and Hispanic students’ achievement by 0.043 standard deviations

For white students, the comparable effect is 0.021 standard deviations

This means that extremely hot days widen the racial achievement gap by approximately three percent of the 0.8 standard deviation gap in PSAT performance between black and Hispanic students and white students.

Excess heat accounts for about seven percent of the racial achievement gap.



Journal of Occupational and Environmental Medicine, The impact of workplace heat and cold on work time loss

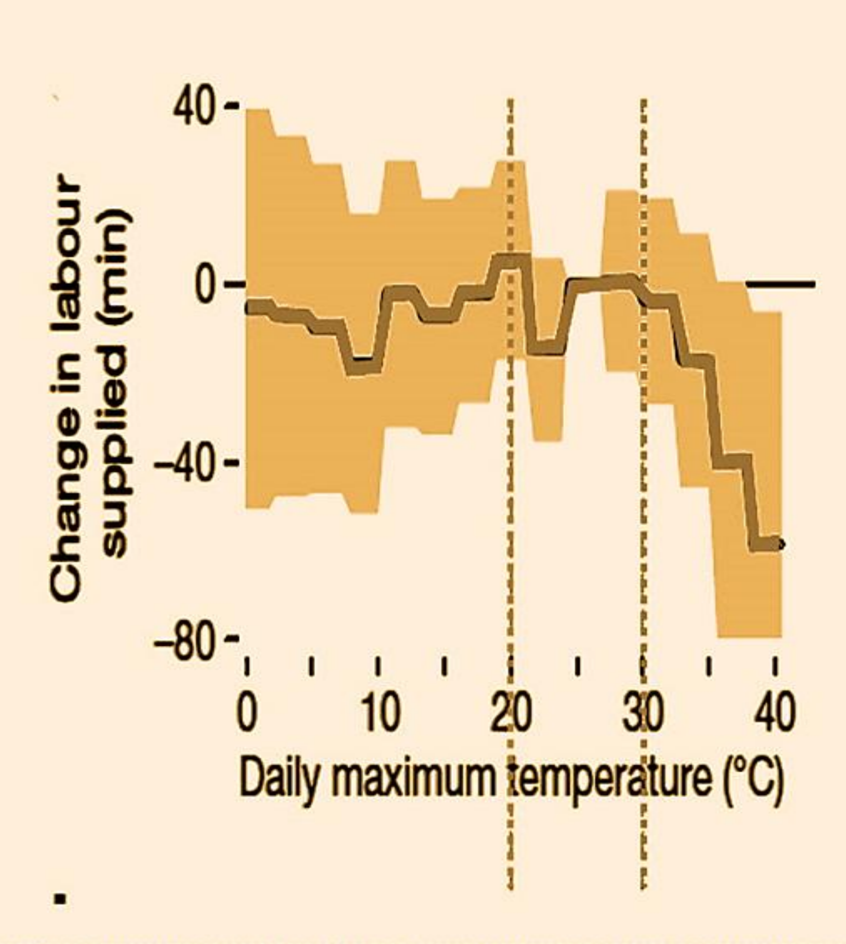
United States lose approximately $100 billion annually from heat-induced loss in labor productivity.

Economy in U.S. grows at a slower pace during hot summers. The annual growth falls 0.15 to 0.25% for every 1 F increase of the average summer temperature.

Warming is expected to reshape the global economy by reducing average global incomes by roughly 23% by 2100 and widening global income inequality, relative to scenarios without overheating.

About 1 Million work life-years are projected to be lost by 2030 due to operational heat stroke fatalities with 70 million work life-years lost because of reduced labour productivity.

Global non-linear effect of temperature on economic production, Marshall Burke, Solomon M. Hsiang*& Edward Miguel, 1 2 N O V E M B E R 2 0 1 5 | VO L 5 2 7 | N AT U R E | 2 3 5



Recent research found that labour supply and human productivity may decrease up to 60% when ambient temperature exceeds 30-35 C

Financial Losses caused by the decreased human productivity is close to 311 billion dollars and it is expected to increase up to 2.3 trillion by 2010, or 1 % of the world GDP.

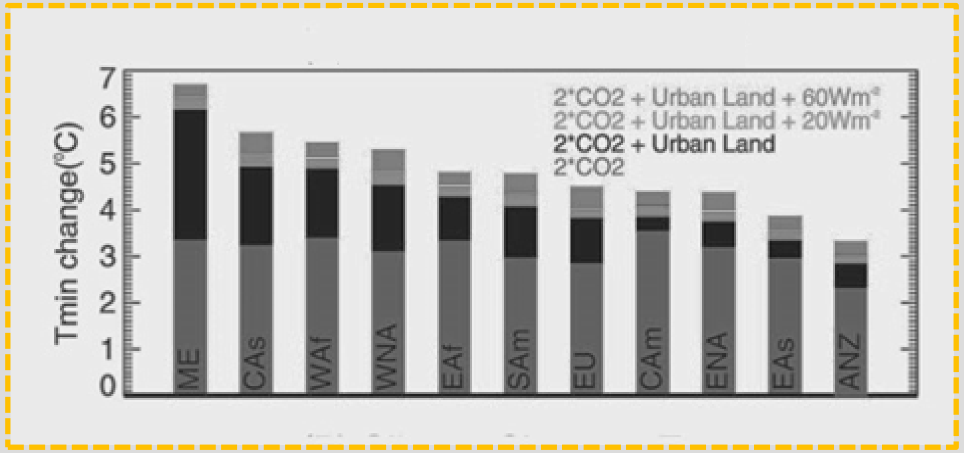
The economy of USA delays between 0.15 to 0.25 % for each degree of temperature increase during the summer period

Human-caused increases in heat waves have depressed economic output most in the poor tropical regions least culpable for warming.

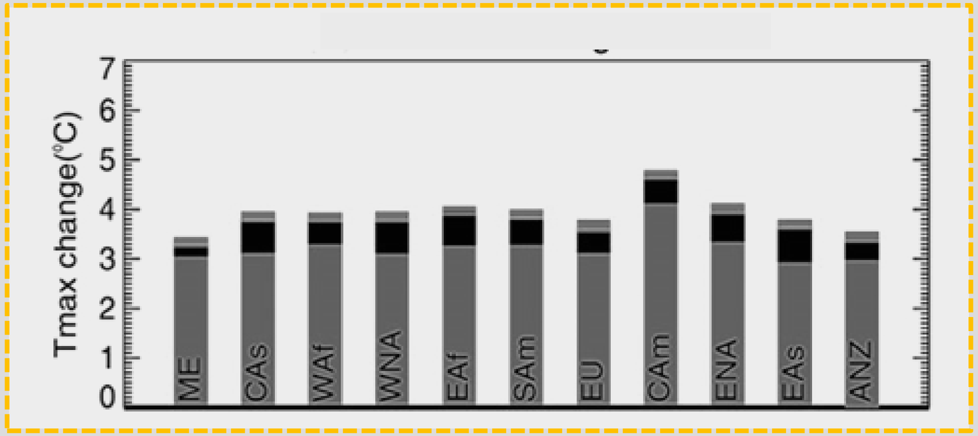
Cumulative 1992–2013 losses from anthropogenic extreme heat likely fall between $16 trillion and $50 trillion globally. Losses amount to 8% of Gross Domestic Product per capita per year for regions in the bottom income decile, but only 3.5% for regions in the top income decile.

Graff Zivin, J. & Neidell, M. Temperature and the allocation of time: Implications for climate change. J. Labor Econ. 13, 1–26 (2014).

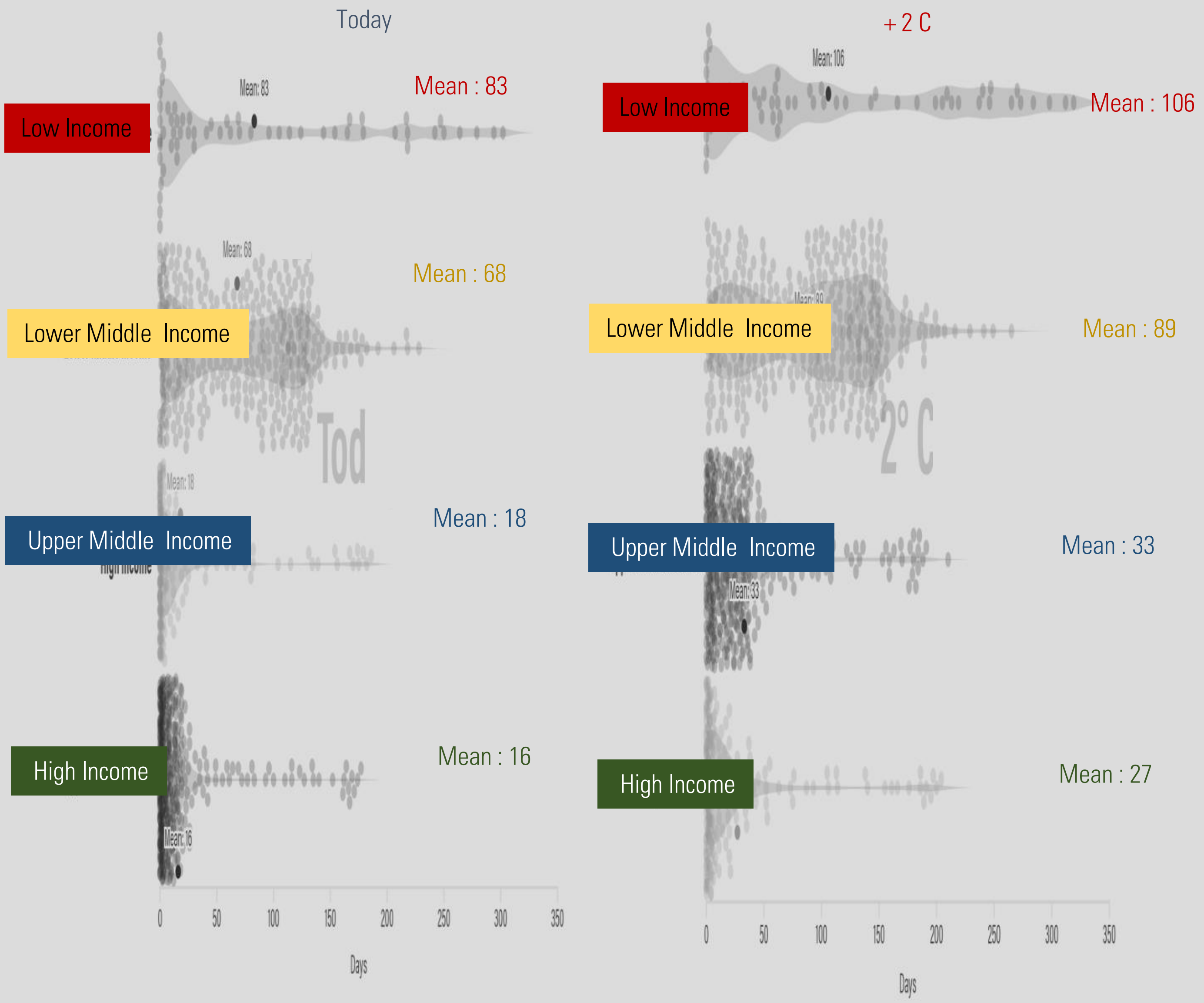
Potential Increase of Min Nighttime Temperature (C)



Potential Increase of Max Daytime Temperature (C)

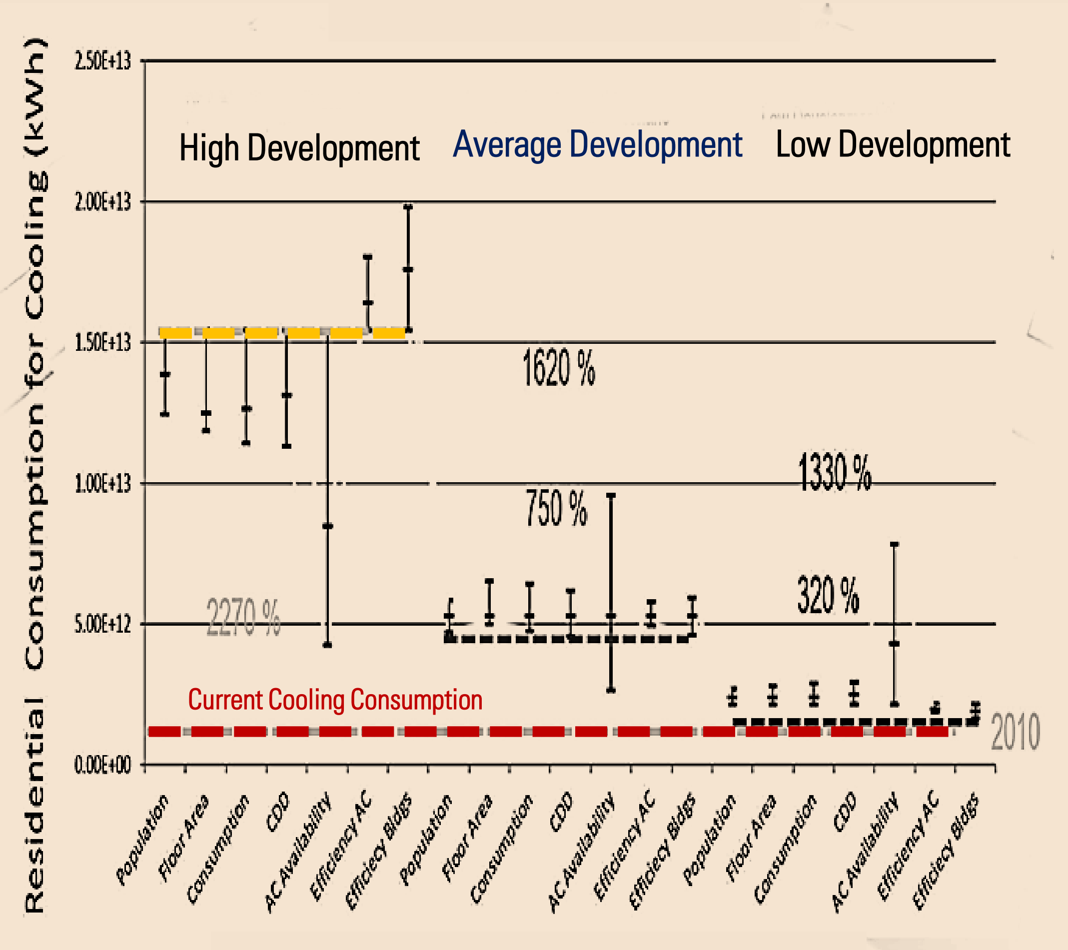


Days per Year that Max Temperature Exceeds 35 C by City



Source: WRI analysis from IPCC Interactive Atlas, Bias Adjusted TX35 from CMIP6.

WORLD RESOURCES INSTITUTE



Cooling Energy Consumption of Buildings by 2050

There currently is a shortfall of about 330 million homes in the world and is expected to increase up to 440 million by 2025.

By 2030 the additional housing needs will grow by more than 77 billion square meters of floor space, equivalent or greater than the actual area of China

We add a total floor area equal to the city of Paris per week.

Cooling energy consumption in buildings may rise by 200% and up to 2,000% by 2050, depending on the evolution of the main economic and climatic drivers.

By 2050, one single Indian city, Mumbai will present a comparative electrical energy consumption for cooling than the whole USA

.

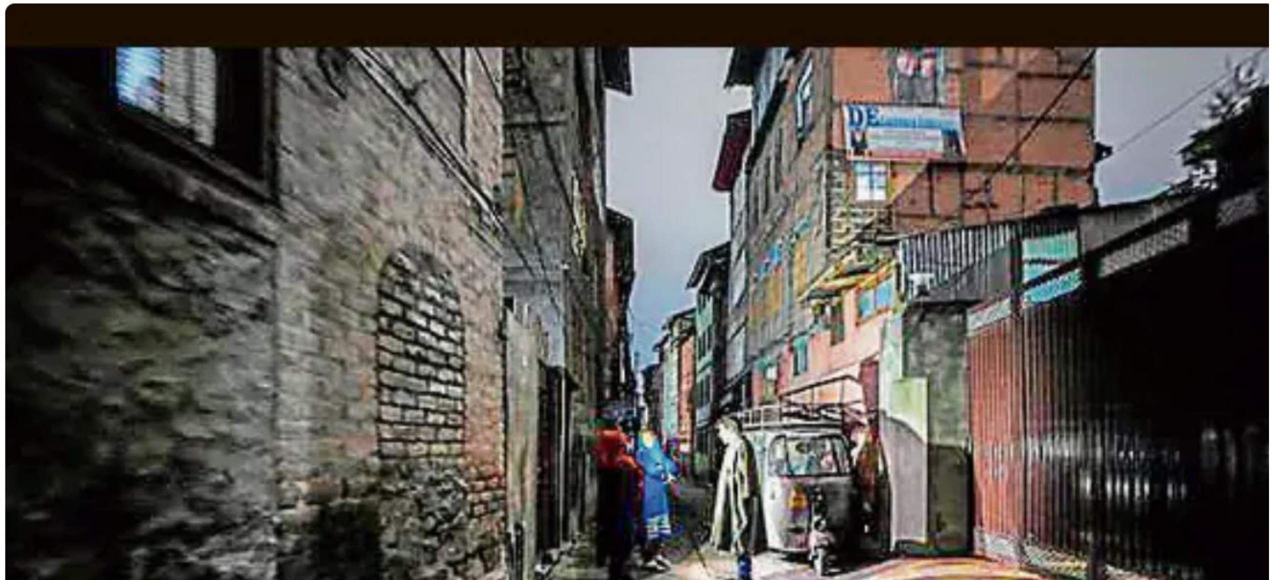
M. Santamouris : Minimizing Energy Consumption, Energy Poverty and Global and Local Climate Change in the Built Environment: Innovating to Zero, Causalities and Impacts in a Zero Concept World, Elsevier, 2019

Valley plunges into darkness amid 10 to 15-hour power cuts

By Ashiq Hussain, Srinagar

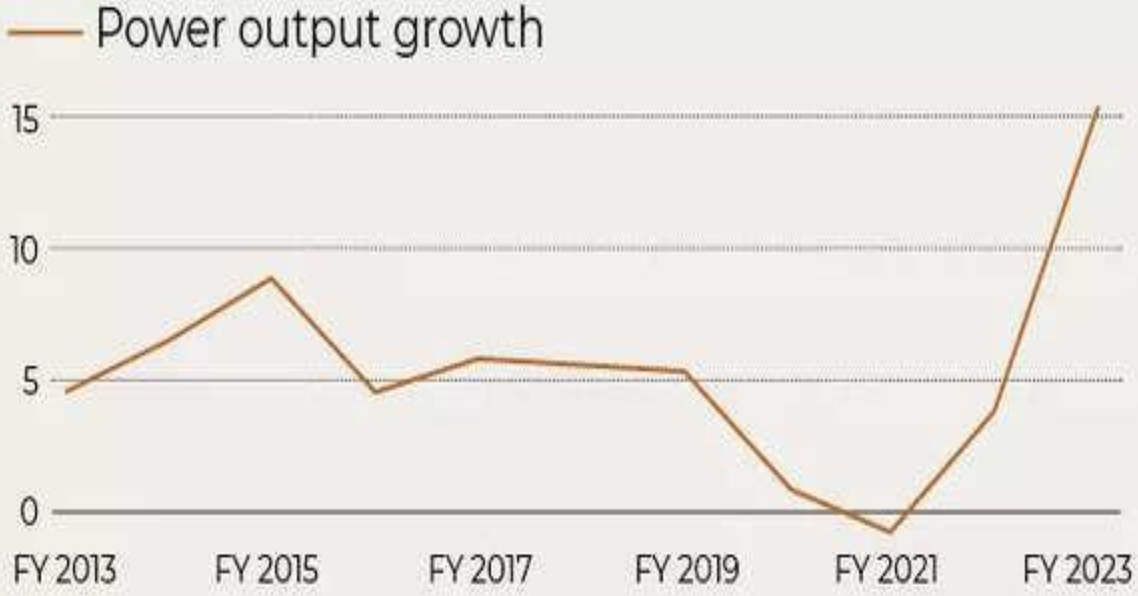
Feb 27, 2024 06:48 AM IST

For the past few days, people across the valley are reeling under 10-15 hours of power cuts every day, up from 4.5 to 8 hours curtailments earlier in both metered and non-metered areas

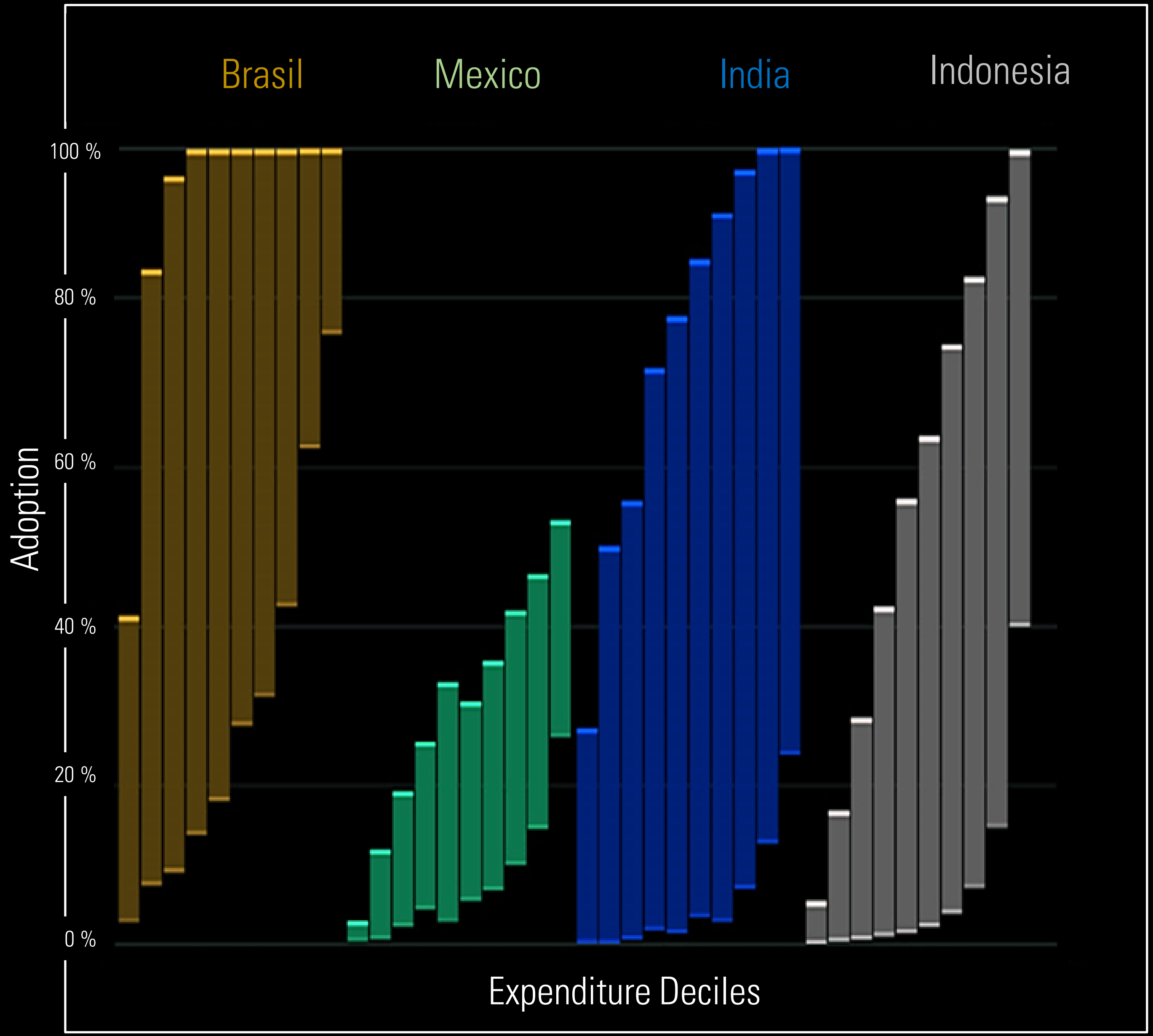


Unprecedented growth in power demand seen in FY23

Overall power generation is seen surging 15.2% to to 1,644 billion killowatt hours (kWh) during the year ended March 2023, a power ministry note showed, with demand set to rise at the fastest pace in at least 38 years.



Note: All figures in %, FY23 figure is an internal government estimate
Source: Central Electricity Authority, internal government note/Reuters

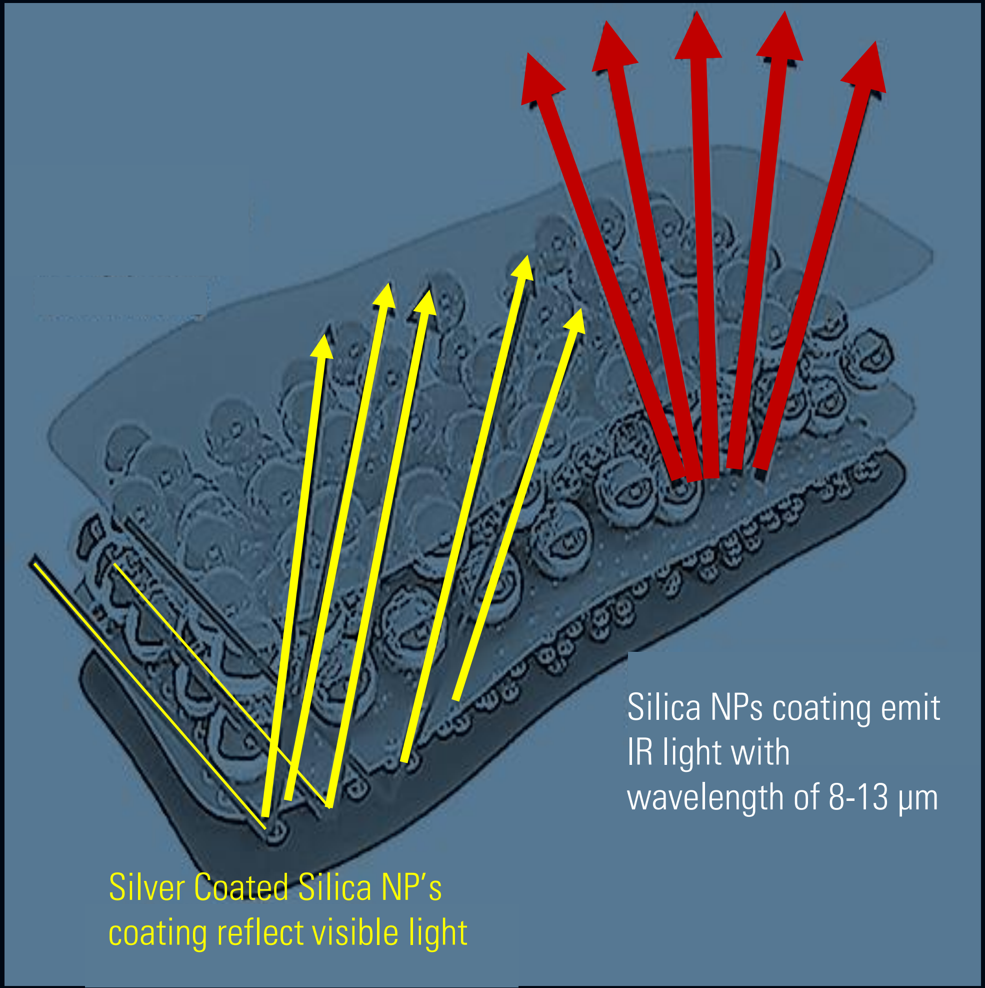


The Current and Future Penetration of A/C in Emerging Economies per Income Group demonstrates that low income population will not have access to air conditioning.

By 2040, a nonnegligible fraction of the population will be left behind.

On 2040, between 64 and 100 million households out of the total number of households living in the four countries considered in the latest waves of 343 million will face an adaptation cooling deficit

NATURE COMMUNICATIONS | (2021) 12:6460 | https://doi.org/10.1038/s41467-021-26592-2 | www.nature.com/naturecommunications



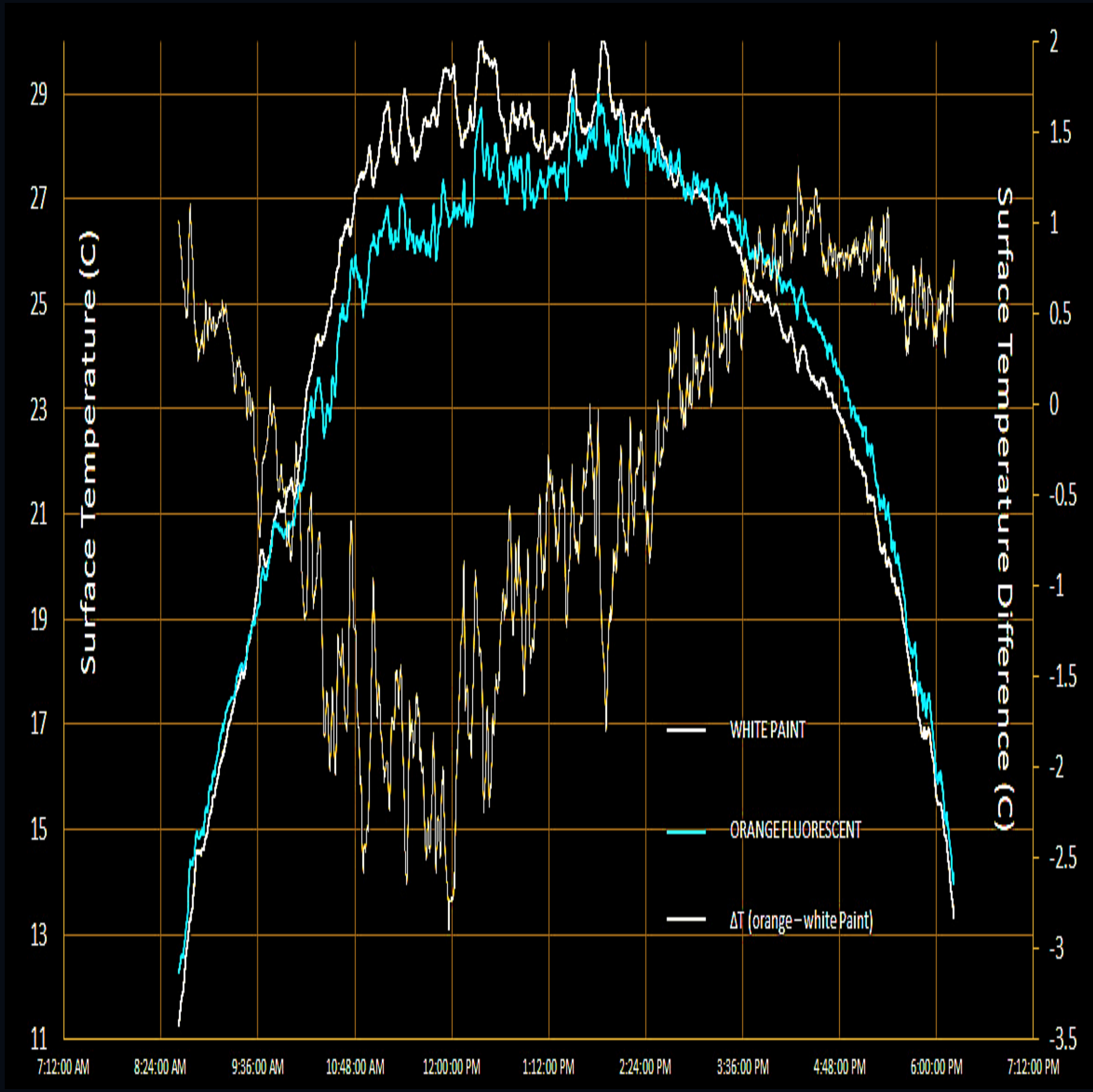
Passive Radiative Coolers, or Super Cool Materials, present a very high solar absorptance combined with a high emissivity in the atmospheric window, 7-13 μm.

The recent development of

Super Cool Materials

like the photonic and fluorescent materials, permits the decrease of the surface temperature of buildings and urban structures up to 15 C below the ambient temperature under the summer sun

The implementation of SCM in cities can reduce the peak ambient temperature up to 4-5 C and provide very significant energy and health benefits.



25/5/2023 – Alice Springs- Orange Fluorescent SC Material against conventional white paint.

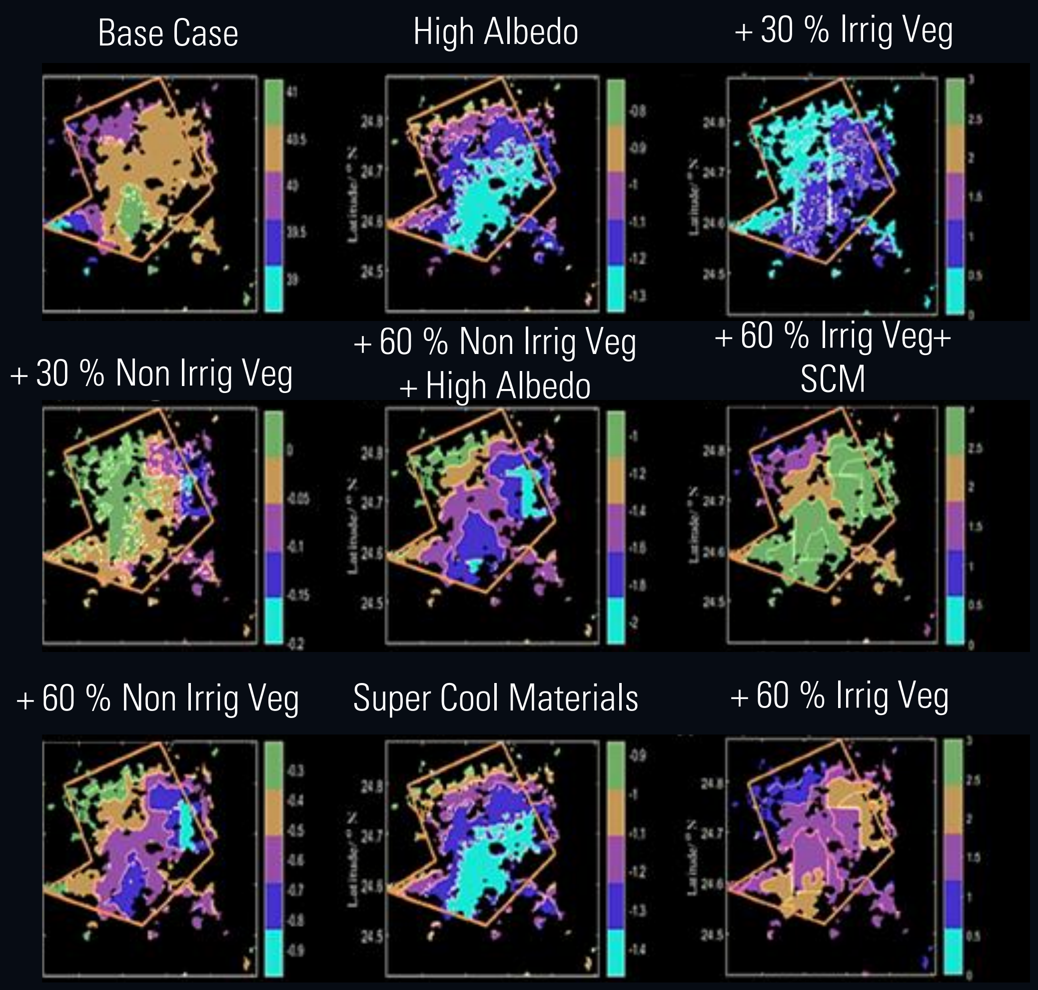
Max Amb. Temp : 27.4 C
Max SR : 740 W/m2
RH (noon) : 20 %,
Max Atm Rad : 370 W/m2

Comparison of the Colored against Conventional White Paint

During day time the average temperature of the white paint was 24.6 C

while of the Orange SCM was 24.1 C

During noon time the orange Super Cool material was almost 3 C of lower surface temperature than the white paint.



The developed Super Cool Materials have been considered as the primary heat mitigation strategy to decrease the ambient temperature and reduce the energy consumption of buildings in numerous cities.

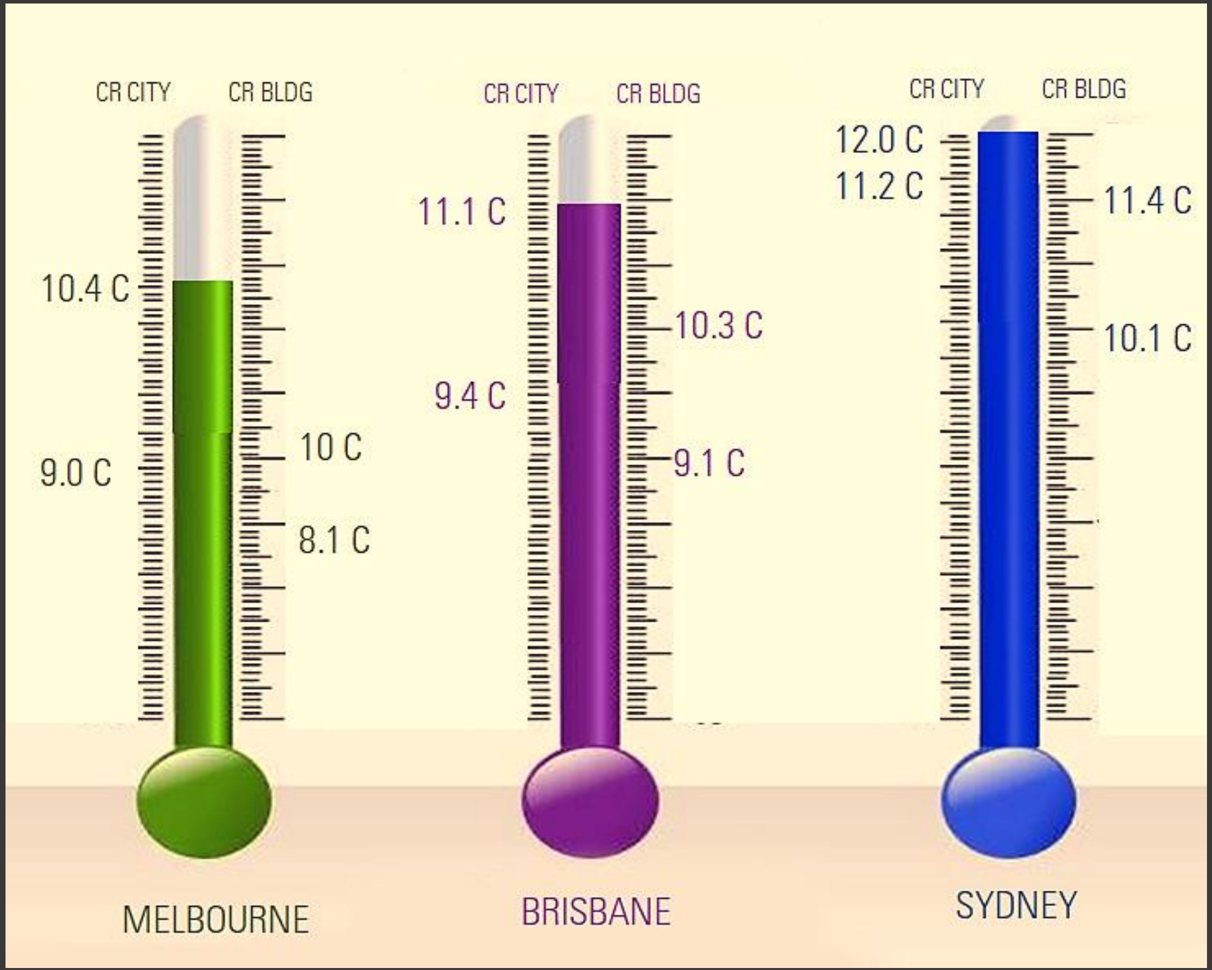
Results from the Heat Mitigation Study in Riyadh, KSA

- Use of white super cool materials in the roofs of the city, can reduce the peak daytime summer temperature up to 2.8 C

- Combined use of white SCM on the roof of buildings, with well irrigated greenery, can reduce the peak day summer ambient temperature up to 4.6 C

- Increase of the albedo in the city by 0.4 can reduce the peak daytime ambient temperature up to 1.5 C.

S. Haddad et al : **Quantifying the Energy Impact of Heat Mitigation Technologies at the Urban Scale,** Nature-Cities, 2024



A study has been performed by the Department of Industry in Australia to assess the impact of cool roofs in the major Australian cities has concluded that:

Main Results of the Study

The implementation of cool roofs in low income houses in Australia, not insulated buildings can decrease the peak indoor summer temperature up to 12 C.

Cool Roofs can improve tremendously thermal comfort during the warm period of the year and decrease substantially heat related mortality and morbidity

S. Garshasbi, Jie Feng, Riccardo Paolini, Jean Jonathan Duverge ,Carlos Bartesaghi-Koc, Samaneh Arasteh, Ansar Khan, M. Santamouris : On the energy impact of cool roofs in Australia, Energy and Buildings, Volume 278, 1 January 2023, 112577

A personal take on science and society

World view

By Gavin Schmidt

Why 2023's heat anomaly is worrying scientists

Climate models struggle to explain why planetary temperatures spiked suddenly. More and better data are urgently needed.

When I took over as the director of NASA's Goddard Institute for Space Studies, I inherited a project that tracks temperature changes since 1880. Using this trove of data, I've made climate predictions at the start of every year since 2016. It's humbling, and a bit worrying, to admit that no year has confounded climate scientists' predictive capabilities more than 2023 has.

For the past nine months, mean land and sea surface temperatures have overshot previous records each month by up to 0.2 °C — a huge margin at the planetary scale. A general warming trend is expected because of rising greenhouse-gas emissions, but this sudden heat spike greatly exceeds predictions made by statistical climate models that rely on past observations. Many reasons for this discrepancy have been proposed but, as yet, no combination of them has been able to reconcile our theories with what has happened.

For a start, prevalent global climate conditions one year ago would have suggested that a spell of record-setting warmth was unlikely. Early last year, the tropical Pacific Ocean was coming out of a three-year period of La Niña, a climate phenomenon associated with the relative cooling of the central and eastern Pacific Ocean. Drawing on precedents when similar conditions prevailed at the beginning of a year, several climate scientists, including me, put the odds of 2023 turning out to be a record warm year at just one in five.

El Niño — the inverse of La Niña — causes the eastern tropical Pacific Ocean to warm up. This weather pattern set in only in the second half of the year, and the current spell is milder than similar events in 1997–98 and 2015–16.

However, starting last March, sea surface temperatures in the North Atlantic Ocean began to shoot up. By June, the extent of sea ice around Antarctica was by far the lowest on record. Compared with the average ice cover between 1981 and 2010, a patch of sea ice roughly the size of Alaska was missing. The observed temperature anomaly has not only been much larger than expected, but also started showing up several months before the onset of El Niño.

So, what might have caused this heat spike? Atmospheric greenhouse-gas levels have continued to rise, but the extra load since 2022 can account for further warming of only about 0.02 °C. Other theories put forward by climate scientists include fallout from the January 2022 Hunga Tonga–Hunga Ha'apai volcanic eruption in Tonga, which had both cooling effects from aerosols and warming ones

> **"If the anomaly does not stabilize by August, then the world will be in uncharted territory."**

Gavin Schmidt is a climatologist and director of NASA's Goddard Institute for Space Studies in New York City.
e-mail: gavin.a.schmidt@nasa.gov

from stratospheric water vapour, and the ramping up of solar activity in the run-up to a predicted solar maximum. But these factors explain, at most, a few hundredths of a degree in warming (Schoeberl, M. R. *et al. Geophys. Res. Lett.* **50**, e2023GL104634; 2023). Even after taking all plausible explanations into account, the divergence between expected and observed annual mean temperatures in 2023 remains about 0.2 °C — roughly the gap between the previous and current annual record.

There is one more factor that could be playing a part. In 2020, new regulations required the shipping industry to use cleaner fuels that reduce sulfur emissions. Sulfur compounds in the atmosphere are reflective and influence several properties of clouds, thereby having an overall cooling effect. Preliminary estimates of the impact of these rules show a negligible effect on global mean temperatures — a change of only a few hundredths of a degree. But reliable assessments of aerosol emissions rely on networks of mostly volunteer-driven efforts, and it could be a year or more before the full data from 2023 are available.

This is too long a wait. Better, more nimble data-collection systems are clearly needed. NASA's PACE mission, which launched in February, is a step in the right direction. In a few months, the satellite should start providing a global assessment of the composition of various aerosol particles in the atmosphere. The data will be invaluable for reducing the substantial aerosol-related uncertainty in climate models. Hindcasts, informed by new data, could also provide insights into last year's climate events.

But it seems unlikely that aerosol effects provide anything close to a full answer. In general, the 2023 temperature anomaly has come out of the blue, revealing an unprecedented knowledge gap perhaps for the first time since about 40 years ago, when satellite data began offering modellers an unparalleled, real-time view of Earth's climate system. If the anomaly does not stabilize by August — a reasonable expectation based on previous El Niño events — then the world will be in uncharted territory. It could imply that a warming planet is already fundamentally altering how the climate system operates, much sooner than scientists had anticipated. It could also mean that statistical inferences based on past events are less reliable than we thought, adding more uncertainty to seasonal predictions of droughts and rainfall patterns.

Much of the world's climate is driven by intricate, long-distance links — known as teleconnections — fuelled by sea and atmospheric currents. If their behaviour is in flux or markedly diverging from previous observations, we need to know about such changes in real time. We need answers for why 2023 turned out to be the warmest year in possibly the past 100,000 years. And we need them quickly.

WILLIAM D. HRYBYK

Establishment of Urban Warming Markets

Setting as a goal a minimum urban overheating and pollution involves limiting the strength of warming and polluting sources and increasing the strength of urban heat sinks to balance the urban heat budget.

Achieving a Zero Urban Thermal and Pollution budget requires to:

Change the way we design, build and operate urban buildings, spaces and infrastructures and transition to less warming and polluting patterns and policies

Put a value on the urban mitigation and adaptation capital that limits the strength of local climate change and environmental quality

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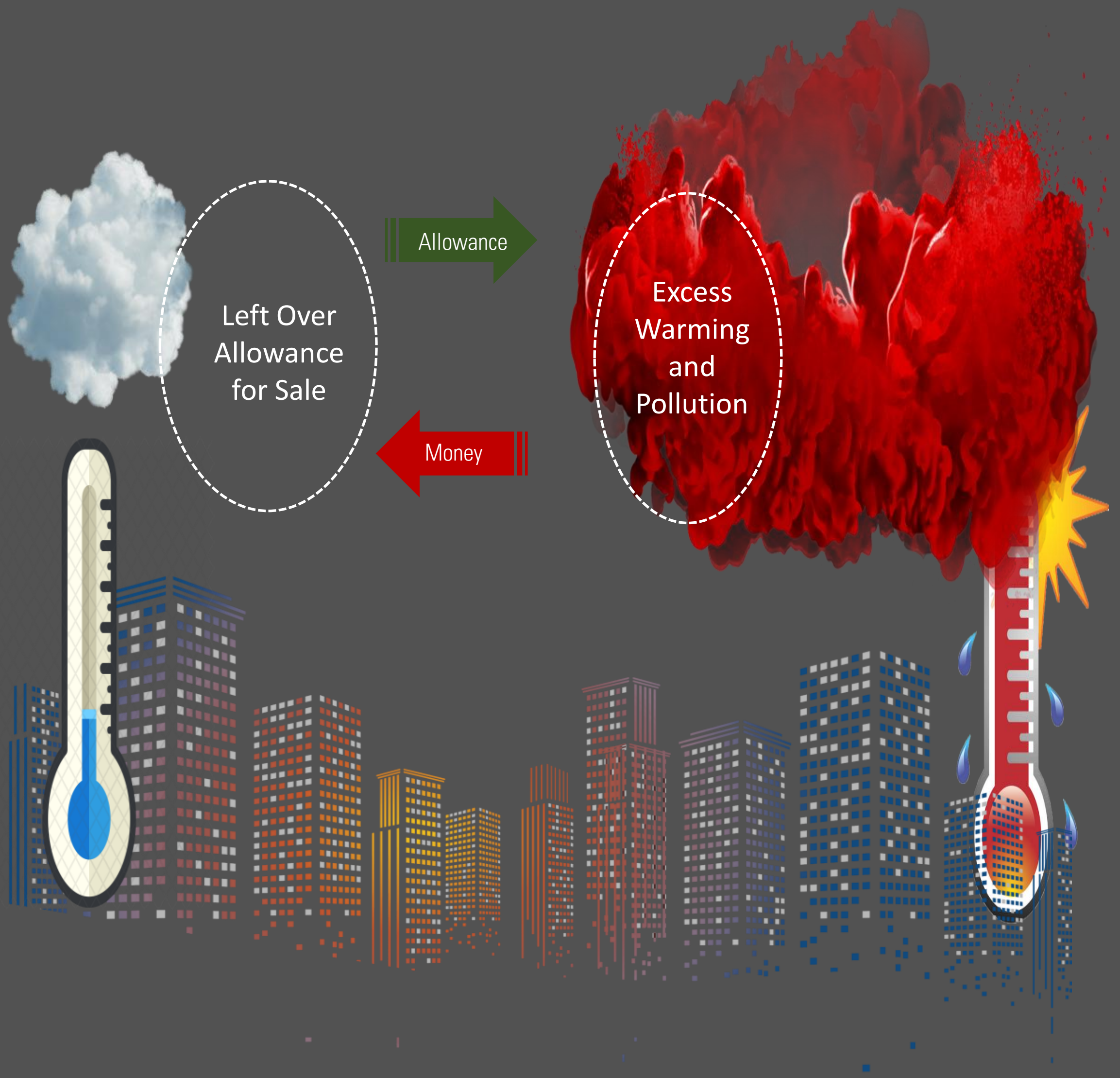


Putting a Price on Urban Warming

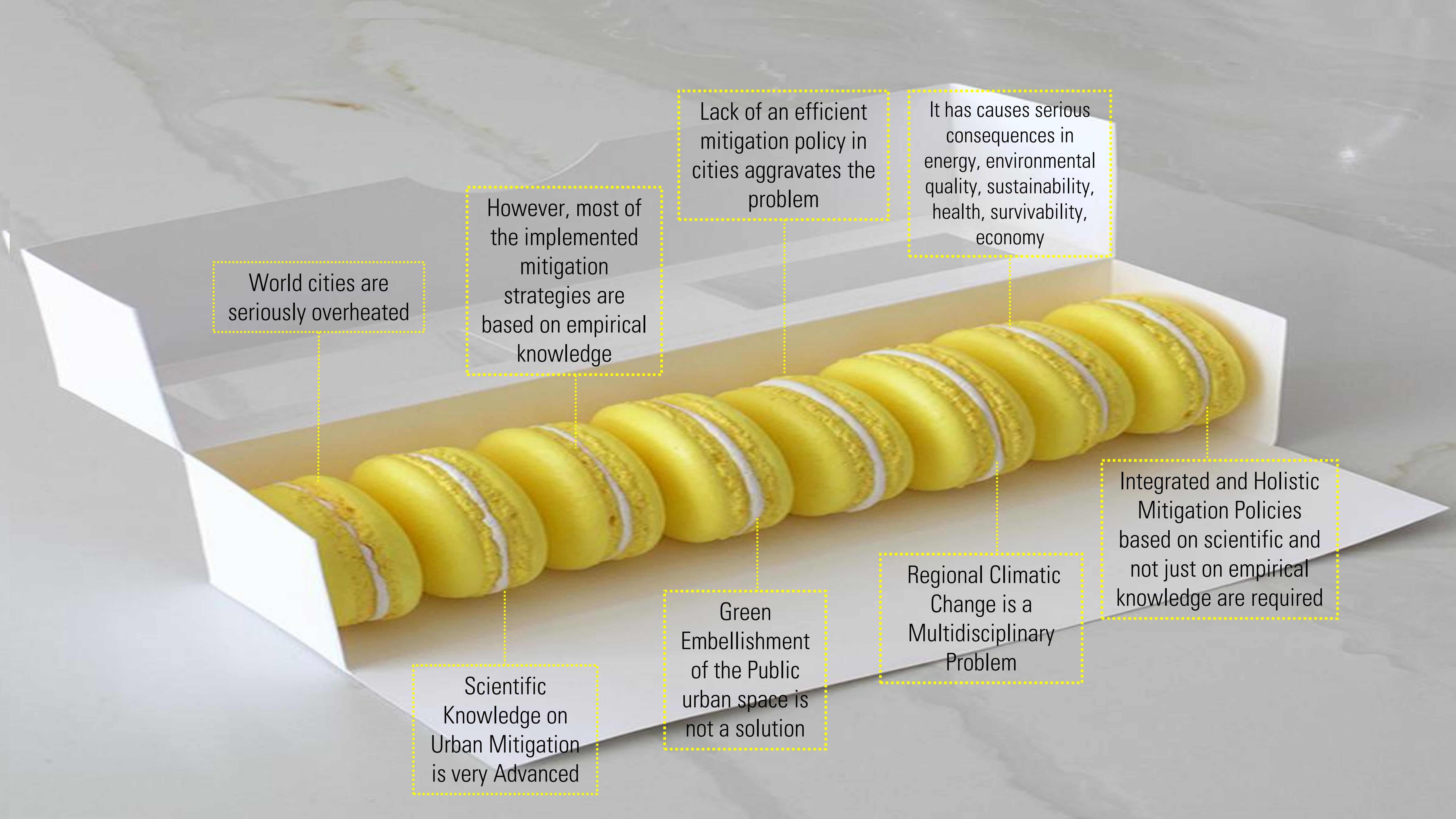
The magnitude of overheating and pollution caused by selected major urban activities has to be assessed and controlled.

Liable entities exceeding the threshold and causing urban warming must pay a price for every warming or pollution unit, shortfall cost, or to surrender the appropriate number of allocated units.

Boosting Sustainable Urban Investments

To accelerate urban cooling and finance urban heat mitigation and adaptation it is critical to value urban overheating with liquidity.

The development of a voluntary Urban Warming Market could bring urban mitigation and adaptation investments sooner to the market and make them more affordable.


World cities are seriously overheated
However, most of the implemented mitigation strategies are based on empirical knowledge
Lack of an efficient mitigation policy in cities aggravates the problem
It has causes serious consequences in energy, environmental quality, sustainability, health, survivability, economy
Integrated and Holistic Mitigation Policies based on scientific and not just on empirical knowledge are required
Scientific Knowledge on Urban Mitigation is very Advanced
Green Embellishment of the Public urban space is not a solution
Regional Climatic Change is a Multidisciplinary Problem