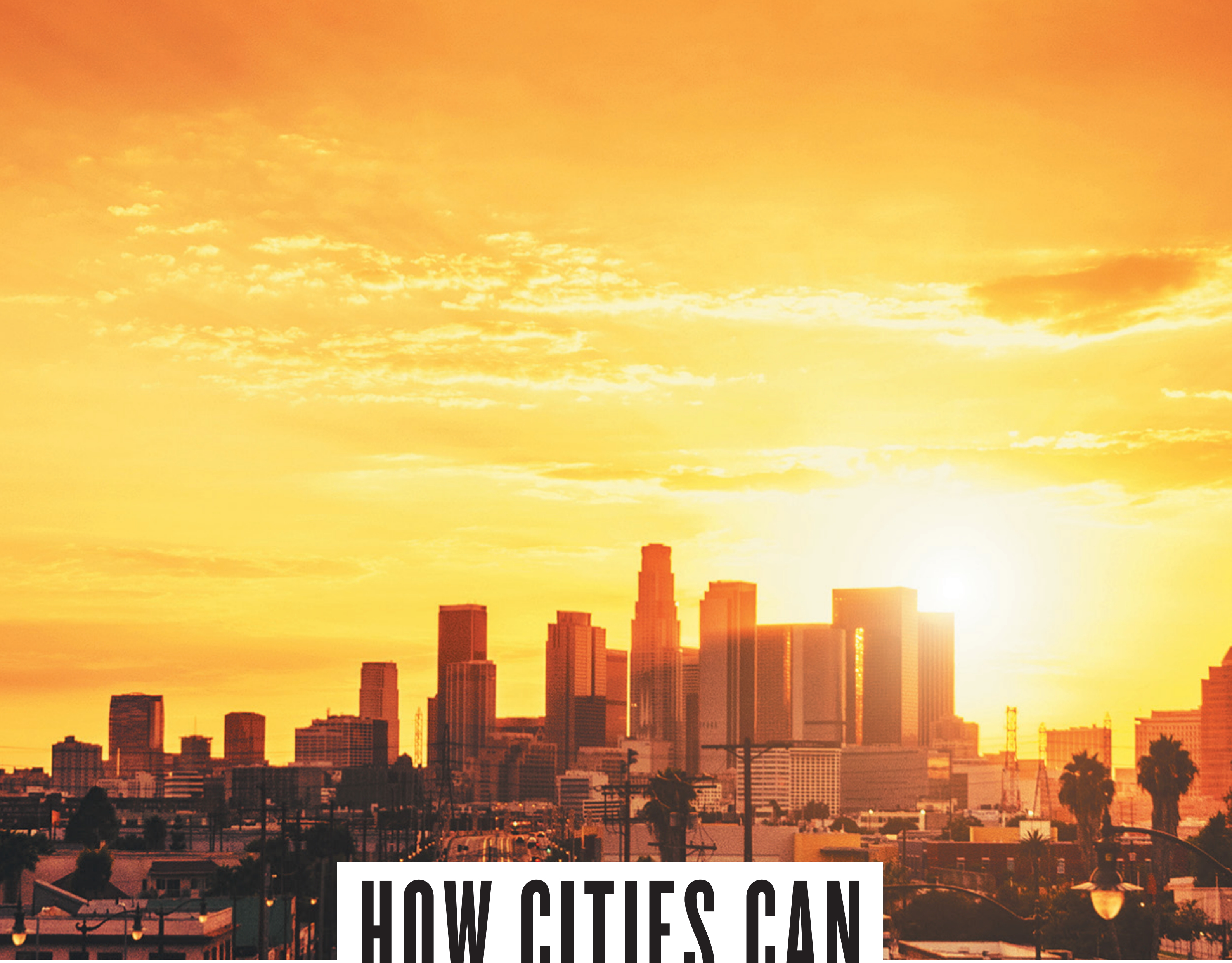

HOW CITIES CAN BEAT THE HEAT

Rising temperatures are threatening urban areas, but efforts to cool them may not work as planned.

BY HANNAH HOAG

Last year, Los Angeles ruled that new and renovated homes must have 'cool roofs'.

The greenhouses that sprawl across the coastline of southeastern Spain are so bright that they gleam in satellite photos. Since the 1970s, farmers have been expanding this patchwork of buildings in Almería province to grow produce such as tomatoes, peppers and watermelons for export. To keep the plants from overheating in the summer, they paint the roofs with white lime to reflect the sunlight.

That does more than just cool the crops. Over the past 30 years, the surrounding region has warmed by 1 °C, but the average air temperature in the greenhouse area has dropped by 0.7 °C (ref. 1).

It's an effect that cities around the world would like to mimic. As Earth's climate changes over the coming decades, global warming will hit metropolitan areas especially hard because their buildings and pavements readily absorb sunlight and raise local temperatures, a phenomenon known as the urban heat island effect. Cities, as a result, stand a greater chance of extreme hot spells that can kill. "Heat-related deaths in the United States outpace — over the last

FRANCKREPORTER/GETTY

30 years — all other types of mortality from extreme weather causes," says Kim Knowlton, a health scientist at Columbia University in New York. "This is not an issue that is going away."

Some cities hope to stave off that sizzling future. Many are planting trees and building parks, but they have focused the most attention on rooftops — vast areas of unused space that absorb heat from the Sun. In 2009, Toronto, Canada, became the first city in North America to adopt a green-roof policy. It requires new buildings above a certain size to be topped with plants in the hope that they will retain storm water and keep temperatures down. Los Angeles, California, mandated in 2014 that new and renovated homes install 'cool roofs' made of light-coloured materials that reflect sunlight. A French law approved in March calls for the rooftops of new buildings in commercial zones to be partially covered in plants or solar panels.

But the rush to act is speeding ahead of the science. Although cool roofs and green roofs can strongly curb temperatures at the tops of buildings, they do not always yield benefits at the street level, and they may trigger unwanted effects, such as reducing rainfall in some places. "There was a notion that the community had reached a conclusion and there was a one-size-fits-all solution," says Matei Georgescu, a sustainability scientist at Arizona State University in Tempe. "But that is not the case."

On top of that, it is unclear whether the limited programmes currently in place will have a measurable effect on temperature — and citizen health — and whether cities will expand their efforts enough to produce results. "If you're just putting green roofs on city hall and schools, it's not going to move the needle," says Brian Stone Jr, an urban scientist at the Georgia Institute of Technology in Atlanta.

HOT TIME IN THE CITY

For ten days in August 2003, an unprecedented heatwave stifled Western Europe, breaking records reaching back five centuries (see *Nature* http://doi.org/fvgkt4; 2004). Daytime temperatures in Paris shot up to 40 °C and nights remained torrid. By the end of August, the death toll from dehydration, hyperthermia, heat stroke and respiratory problems for all of Europe surpassed 70,000, with many fatalities in the urbanized areas around Paris and Moscow.

This is just a taste of conditions to come. Regional climate models indicate that by 2050, week-long heat spells on par with the August 2003 event may strike once a decade in Eastern Europe and every 15 years in Western Europe[2]. Across the globe, the number, duration and frequency of heatwaves is projected to increase. "This is one of the few extreme events where all of the models agree with each other," says Dan Li, a climate modeller at Princeton University in New Jersey.

And when temperatures rise, cities suffer disproportionately because of the way they are built. Dark roofs, roads and other construction materials absorb incoming short-wave radiation from the Sun and re-radiate it as long-wave energy, warming the atmosphere nearby. Air conditioning adds to the problem by pulling heat from inside buildings and vehicles and dumping it outside, further driving up urban temperatures.

In the absence of interventions, heat islands will only grow: by 2050, urban surface area in the United States is expected to expand by one-third. At the same time, the global population is projected to grow to 9.6 billion, with two-thirds living in urban areas, compared with just over half today. It all adds up to more heat-trapping potential and more people affected by extreme heat. And yet despite the risks, few cities have plans in place to address urban heat directly. In the United States, says Stone, "most cities are ignoring the climate issue".

Los Angeles is not. The city has seen its annual average temperature rise by more than 2 °C since 1878. By mid-century, its downtown area could face 22 days of extreme heat annually (temperatures exceeding 35 °C), nearly four times the long-term average[3]. To counter the warming, the city aims to convert 10,000 dark-coloured roofs to cool roofs by 2017. By pairing this effort with street plantings and reflective pavements, it intends to shave 1.65 °C off the urban heat island effect by 2035.

Chicago, Illinois, has also become a leader on this issue: it hopes to prevent the kind of mass deaths seen during the city's 5-day heatwave in 1995, when 700 people died. Since that disaster, it has added cool roofs, green roofs and street plantings — and transformed black-top playgrounds into grass fields. Incentives have helped to trigger the construction of more than 516,000 square metres of green roofs on 509 buildings.

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Toronto is rapidly catching up. It requires new buildings taller than six storeys and with more than 2,000 m^2 of roof space to cover 20–60% of that with plants. Since 2010, the city has added 260 green roofs covering 196,000 m^2.

Some forms of cool roofs can be comparable in price to regular ones, but green roofs are more expensive to install, and they have higher maintenance costs. They offer other benefits, however, such as slowing storm-water run-off, providing habitat for pollinating insects and making cities more beautiful.

SEEING GREEN

On the roof of the University of Toronto's architecture building, bumblebees flit from one yellow flower to another. Located in the city's downtown, the building is topped by a patchwork of 33 rectangular, raised garden beds planted with native grasses, flowers or non-native sedums — plants with waxy, water-storing leaves. Each bed has a different combination of plants, soil and irrigation techniques — all of which are monitored by 270 sensors measuring air temperature, soil temperature, soil moisture and rainwater run-off. The garden beds are part of the Green Roof Innovation Technology Laboratory (GRIT Lab), the only facility of its kind in Canada to test the performance of green roofs and other strategies to mitigate climate change.

Green roofs reflect more sunlight than conventional tar or gravel roofs, but they get much of their cooling power from moisture in the plants and soil. As water in leaves and soil evaporates, it carries heat to the atmosphere and lowers air temperature nearby, just as athletes cool off when their sweat evaporates. Compared with a black roof, a green roof can be 40 °C cooler on a hot summer day. Green roofs also act as insulators and reduce energy costs associated with cooling.

The coolest test bed on the GRIT Lab roof is irrigated and contains organic soil and a thick mat of sedum that flows over the box edges. Its neighbour has a patchy lawn of meadow grasses growing in an unirrigated box lined with a porous rocky medium that is widely used on green roofs. At its surface, the sedum box is 4 °C cooler than the air temperature, but the sparsely planted meadow-grass box can be 14 °C hotter, notes Liat Margolis, GRIT Lab's director. "You might as well not have it on the roof," she says. Experiments such as this show how difficult it can be to find the right combination of substrate, vegetation and irrigation to have an impact on the temperature of one rooftop, Margolis adds.

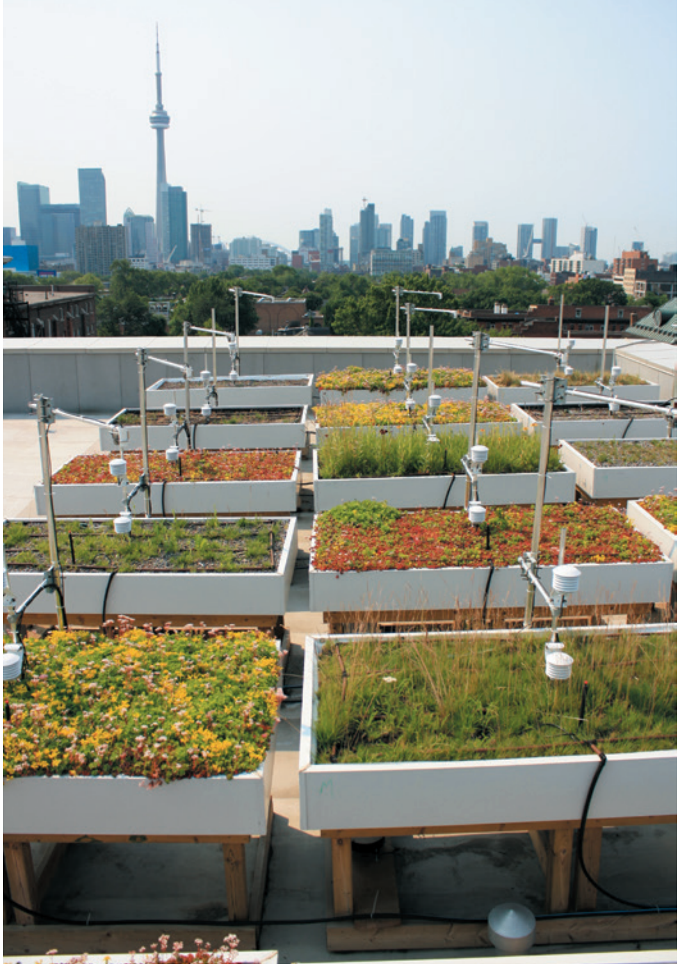
And even with the best green roofs, no one knows how much this approach can cool a whole city. Only a few simulations have evaluated green roofs at that scale. A decade-old report prepared for the city of Toronto suggests that if the city's entire 50 square kilometres of available rooftop were converted to green roofs, the ambient air temperature would reduce by 0.5–2 °C. But the area of green roofs added since the by-law came into effect amounts to less than 0.5% of the city's available roof space.

In the Baltimore–Washington metropolitan area, a 2014 study projected that 90% of the rooftops had to be planted to decrease the daily maximum air temperature by 0.5 °C during a 3-day heatwave[4].

Because there is less evaporation when the Sun goes down, green roofs do not cool as well at night — a deadly time during heatwaves. And rooftop plantings release stored heat after the Sun goes down. "If you try to mitigate the urban heat by putting up green roofs, it will do some good for reducing temperatures during the day, but it might increase at night," says David Sailor, an urban climate scientist at Portland State University in Oregon.

It's also unclear how well green roofs many storeys up offer relief to people below. A modelling study[5] that replicated a day during the 2003 European heatwave found that planting 25% of the roof area along a street in the centre of Arnhem in the Netherlands had no effect on street-level temperatures because the wind blew away the cooler air before it could reach the ground.

Observations of green roofs in Chicago have also raised questions about their benefits. Comparing satellite images from 1995 and 2009, researchers checked how surface temperatures had changed at spots within the city where dark roofs and pavement had been replaced by vegetation or brighter coatings.



GRIT LAB

Researchers test different types of vegetation in Toronto, Canada.

The green roofs did not alter temperatures significantly, but cool roofs did[6]. They increased the city's reflectivity, or albedo, by 1.6% — equivalent to the cooling power of 65,000 large, window-sized air conditioning units operating at full capacity over the summer. Planting trees and converting paved areas to grass were also more effective than green roofs.

DOWNSIDES OF COOL

The effects in Almería are even bigger. Each summer, after farmers whitewash the greenhouse roofs with slaked lime, they reflect 35% of the incident sunlight. The pastures nearby reflect just 15%, on par with most cities.

Simulations show that by whitening roads and roofs, cities could cool down considerably. Doubling the rooftop albedo of Los Angeles, which is on average 17%, could trim temperatures by 0.5 °C in some areas and by as much as 2 °C in others, says Haider Taha, an urban atmospheric modeller and president of Altostratus, a meteorological company in Martinez, California. "One degree Celsius isn't too much to ask for, and according to the models, it's doable," he says.

But cool roofs could also produce some unfavourable effects, depending on the location. If the albedo is increased too much, it could slow local sea breezes, reduce air quality or warm downwind areas, says Taha. "Each city has a threshold, and if you go beyond that, some things start looking bad."

And cool roofs could also inhibit rain. In many regions, heating of the ground during the day causes moist air to rise, driving cloud formation and precipitation. "If we don't have that, then we don't have precipitation," says Georgescu. In a modelling study[7], he found that if cool roofs were widely implemented in urban areas from Florida to the north-eastern United States, daily summertime precipitation could decrease by 2–4 millimetres by 2100.

Despite the uncertainties, many scientists say that cities are not pursuing cooling strategies quickly enough, given the pace of climate change and urban growth. Proponents say that both green roofs and cool roofs have helped in some situations and that careful implementation could improve their efficiency. Stuart Gaffin, an urban-climate scientist at Columbia University in New York, warns against placing too much stock in modelling studies that forecast unwanted side effects such as reduced cloud cover and rainfall. Clouds are among the most complex things to model, and cities already enhance rainfall because of the particulates they produce, he says.

Despite all of the heat-related risks that cities face in the future, few have put heat-management plans in place. Louisville in Kentucky is one: it will soon become the first major US city to develop an urban heat-adaptation plan, says Stone, who is leading the project. The effort is driven by necessity. Louisville has the fastest warming urban heat island in the United States, and temperatures there have climbed by more than 4 °C since 1961. Part of the problem is that the city has lost 54,000 trees per year to insects, ice storms and lack of care.

Stone is now collecting the baseline data that most cities lacked before embracing cooling steps. He is travelling around Louisville measuring tree cover, finding hot spots and identifying areas with vulnerable residents. The next step is to create a blueprint that combines cool roofs, green roofs, tree plantings and cool paving materials that could change the fate of the city's most at-risk residents. Stone is starting with modest but realistic assumptions in his modelling: the conversion of just 100 buildings to green roofs, for example. At the same time, the city hopes to increase its number of trees.

If Louisville implements the strategies that Stone recommends, it could become a testing ground that will reveal how changes to a city's physical surface alter the urban heat island — and its pioneering programme could point the way for other cities to follow. "We're already crossing thresholds that are pretty sensitive," says Stone. "Cities are going to be contemplating more aggressive action. But cities can measurably slow the rate at which they're warming over a decade or two." And that's pretty quick, he adds, because even if we eliminated greenhouse-gas emissions tomorrow, "we're still going to warm for a couple of hundred years". ■

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