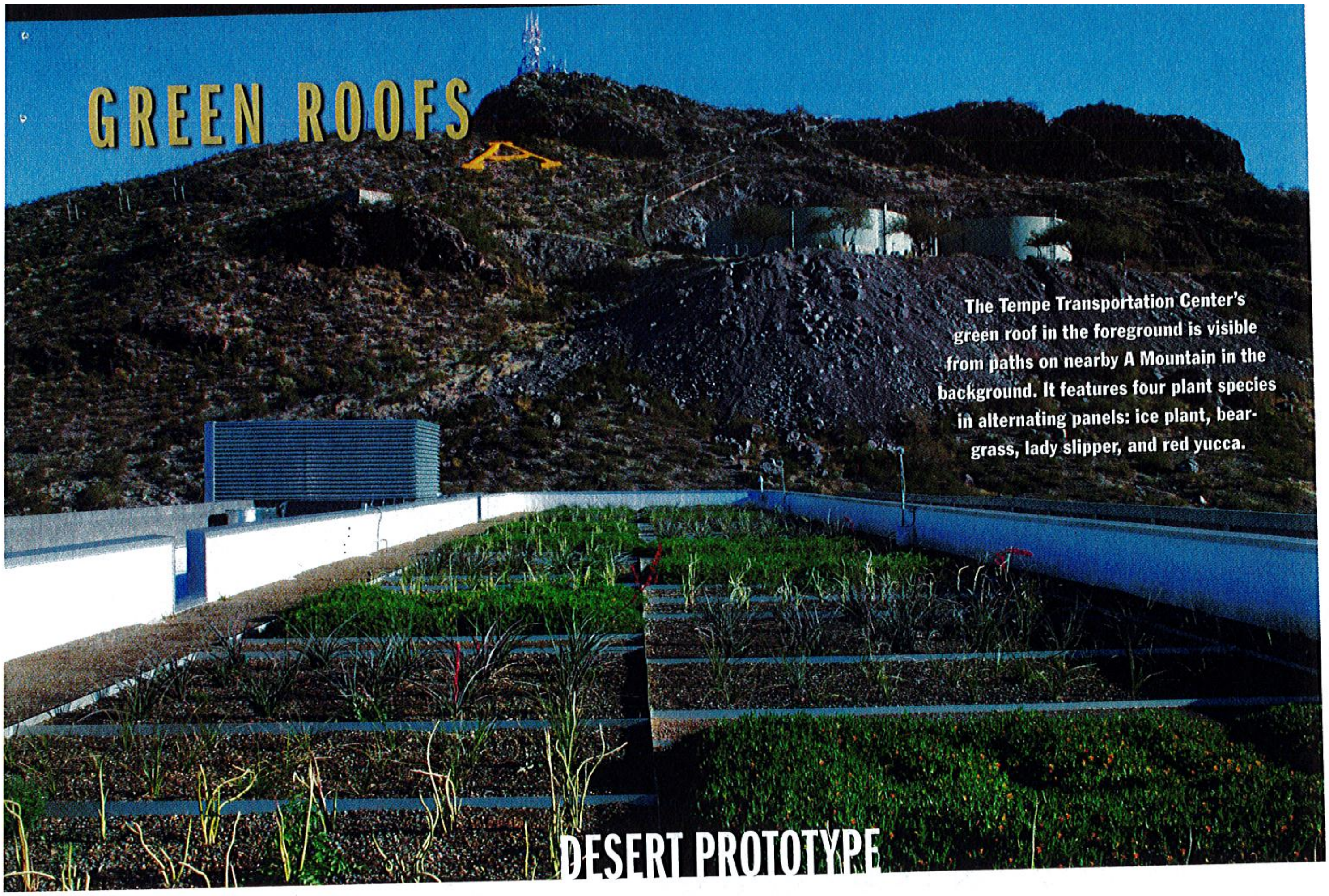


The Tempe Transportation Center's green roof in the foreground is visible from paths on nearby A Mountain in the background. It features four plant species in alternating panels: ice plant, beargrass, lady slipper, and red yucca.

COURTESY A DYE DESIGN

DESERT PROTOTYPE

Is it worth the extra cost—in dollars and water—to build green roofs in Arizona? One project suggests some answers.

By Melanie Lenart

GREEN ROOF CASE STUDY

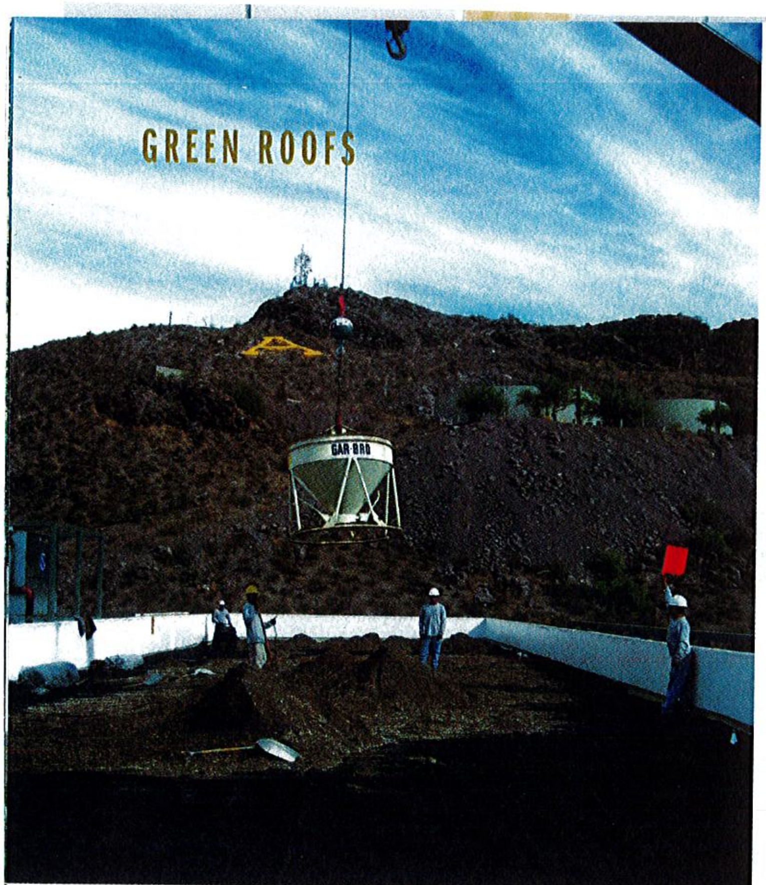
ARIZONA IS NOT the friendliest place for green roofs. Even springtime in much of the U.S. Southwest features glaring sunshine that bakes buildings, ignites forests, and withers plants. Meanwhile, rainfall mostly bypasses the desert, then arrives in sporadic summer torrents that flood the streets.

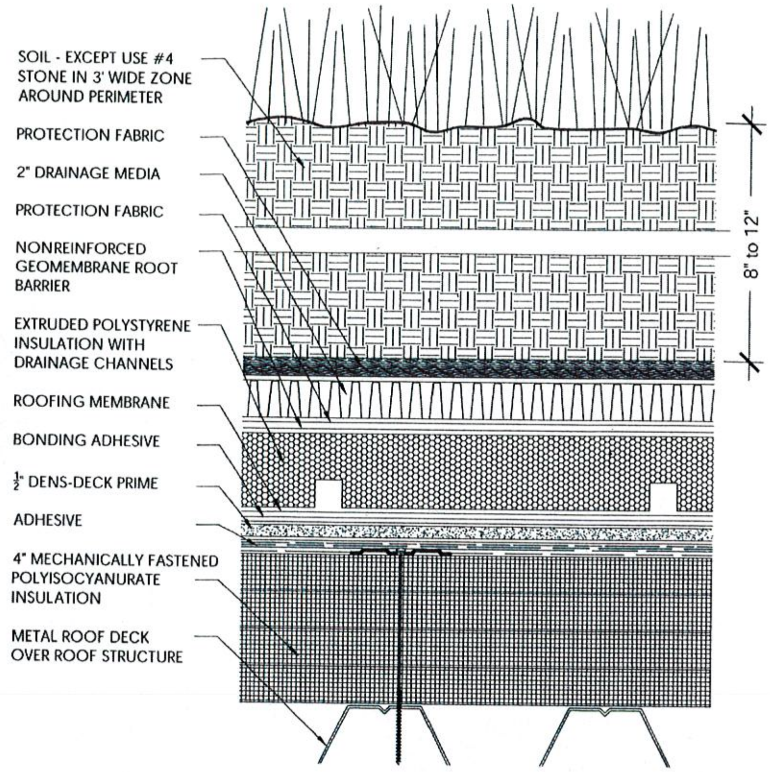
Despite the extreme environment, plants were thriving during an early June visit to the green roof crowning the Phoenix-area Tempe Transportation Center, which opened its doors in late 2008. But those who worked on the project are the first to acknowledge that green roofs in the desert remain experimental. "We were pretty much flying on our own for a public building," says Angela Dye, FASLA, principal of A Dye Design. She had proposed adding a green roof in about 2004, once the city of Tempe decided to pursue LEED certification for the center. Soon afterward, Dye joined the design team working with lead architect John Kane of Architekton.

Dye's green roof proposal initially met with resistance. It took months to convince some of her fellow design team members. Bonnie Richardson, principal planner for Tempe's transportation division, said she liked the idea from the get-go. Still, she knew the rooftop plants might find it challenging to survive in the dry heat. "We're in a pretty harsh climate here—especially when you've got an urban desert where you've got a lot of retained and reflected heat from hard surfaces," Richardson says. "That even complicates it more than if we were out in pure desert."

Once the design team supported the concept, Richardson had the job of selling it to the City Council. It was a tough sell that she says required detailed explanation to city engineers and county officials. But it wasn't until about the time of the building's groundbreaking in 2006, after a two-year research effort by nearby Arizona State University (ASU) showed evidence the green roof could work, that the team got the final go-ahead for this crowning feature. It was in place when the center opened its doors in December 2008.

Ideas vary about where a green roof ends and a roof garden begins. The Tempe Transportation Center's greenery doesn't fit into garden status, in part because security and safety issues keep the roof off-limits to visitors, with exceptions made for special events such as planned tours during the Greenbuild Conference. At the same time, the rooftop plants can't sustain themselves





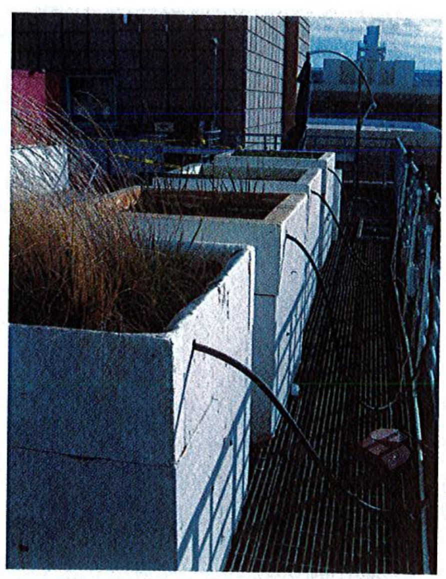
on rainfall alone, a traditional indicator of sustainability when it comes to green roofs. The standard green roof of temperate cities—sedum in a couple inches of soil—simply won't work in the Phoenix area. The Tempe plants need both extra soil and irrigation to survive the desert heat.

Proponents hail the Tempe experiment as a success, pointing to its contribution to energy savings, stormwater capture, and roof longevity as well as its potential to help offset some of the extra heat plaguing cities. Yet debate continues over how such desert-hardy designs fit into the evolving concept of green roofs. Some question the extra cost—in dollars and water—of building green roofs in the desert. They even raise questions about its value for cooling urban heat.

Greening the Roof

On a June morning with temperatures only a few degrees short of their eventual 103-degree high, landscape architect Michele Shelor, ASLA, who led the roof design effort while working for A Dye Design, was excited to see how the 5,880 square feet of planted roof were faring. The green roof had succumbed to killing heat once during its short life, during the summer of 2008, before the drip irrigation system was fully operational. During the June visit,

A lightweight soil designed by a local manufacturer for water retention serves as the substrate for the green roof. During the initial establishment, *above left,* it is lifted by crane onto the roof and laid atop the irrigation system. Underneath the layer of soil on the green roof are layers to promote drainage and to protect the underlying structure from root penetration, *above right,* with a protective membrane and insulation directly above the roof structure. Earlier research, *below,* helped identify which plants could succeed on local rooftops with limited water rations.



Shelor marveled at how the ice plant *(Malephora lutea)* had expanded its territory since she had last visited a few months earlier.

The ice plant covered much of its rectangular shares of the patchwork design atop the roof, with yucca plants *(Hesperaloe parviflora)* filling in their designated squares more sparsely. The spindly yucca waved long red flowers, while the ice plant, a succulent, retained a few small yellow flowers from an earlier bloom.

The design team made an effort to carry down the color theme from a nearby hillside, A Mountain, where hikers can glimpse the inaccessible rooftop. Earlier designs called for carrying some of the natural vegetation down from the butte, with the thought of making wildlife habitat a focus of the roof's functions. But lead architect John Kane and other members of the design team rejected the concept in favor of a more structured design. "As lead designer, I was trying to create a cohesive composition," Kane explains. "I thought it was really important to conceive of the roof as a fifth facade."

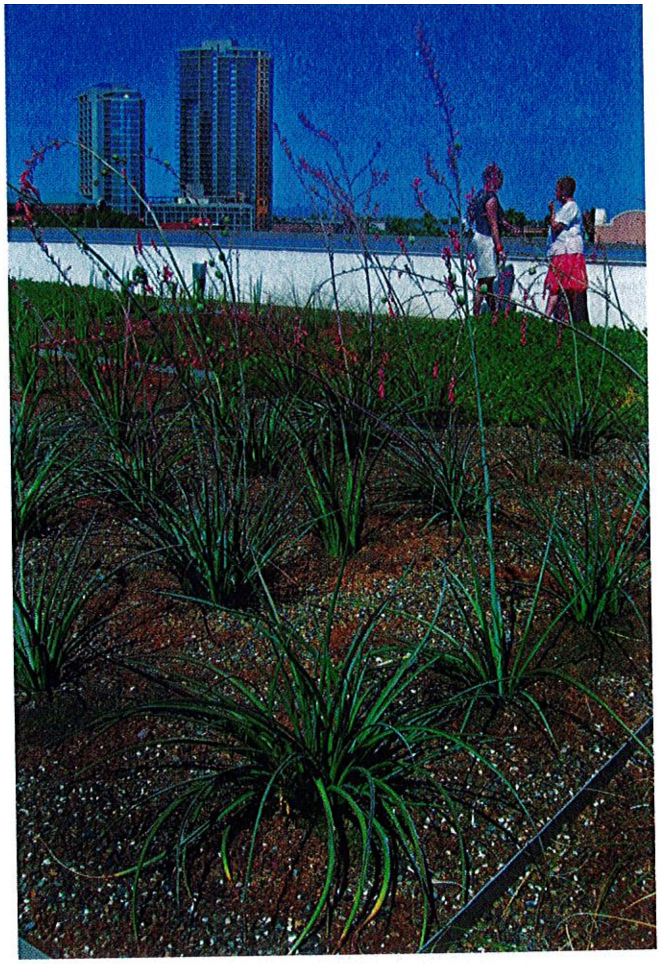
In the end, the team agreed on a design incorporating a series of rectangles reflecting the same pattern as the facades of the building. Although Dye hopes to have future opportunities to pursue her vision of

A DYE DESIGN, TOP LEFT AND BOTTOM; OTAK/ARCHITEKTON, TOP RIGHT a green roof featuring wildlife habitat, she is philosophical about the need to adapt when working as a collaborative team. Being part of a design team had advantages that outweighed the disadvantages, she says. For instance, the design team ran with her suggestion on where to locate the building at the site.

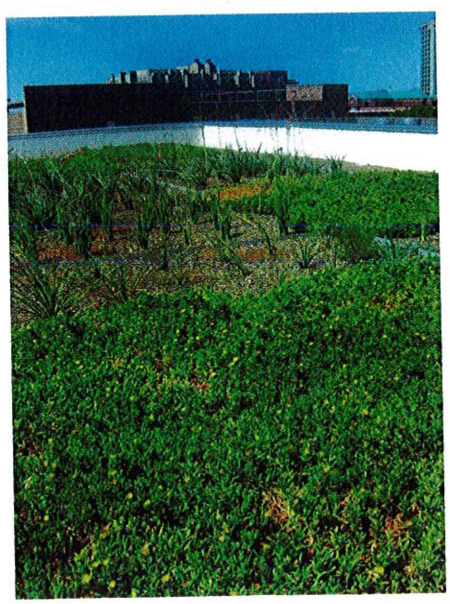
The vision for the green roof called for adjacent rectangles alternating with four segregated species: Rocky Point ice plant, red yucca, beargrass *(Nolina microcarpa),* and lady slipper *(Pedilanthus macrocarpus),* another succulent. In keeping with the team's decision, Shelor took her opportunity during the June visit to pluck out a desertbroom plant *(Baccharis sarothroides)* and a tree seedling that had settled into the design. The variety of textures among the four species suited the design team, but a prime concern was their ability to weather the desert environment.

In earlier experiments, the Rocky Point ice plant flourished on rations of about two gallons of water per week in the three-foot-square containers situated on a rooftop laboratory set up by ASU researchers. The ice plant is a native of the Sonoran Desert where it extends into Mexico, but it doesn't typically grow in the desert's northern edge where Phoenix sits. Tests found the beargrass did fine with about three gallons of water a week. The other two species, red yucca and lady slipper, faced a different kind of testing. "Two of the plants I chose because they do so well in my yard, and I don't water very much," Shelor explained. Though only beargrass is native to Arizona, all four plants thrive in the sandy soils found in the world's deserts.

Phoenix receives about eight inches of rainfall a year. Meanwhile, the desert heat could evaporate about 10 times as much, based on data from the University of Arizona's cooperative extension service. Native greenery exists despite this overall moisture deficit because winter storms soak in while temperatures run low, while summer storms typically come in deluges that temporarily overwhelm evaporation rates. City vegetation thrives on irrigation. Between storms and waterings, summer's high evaporation rates can desiccate topsoil in a matter of hours. The transit center's designers responded by adding extra soil and an irrigation system to help keep the roof green.



Landscape architect Michele Shelor, ASLA, left, and Tempe Transportation Center project manager Bonnie Richardson visit the green roof on a June day, *above.* The red yucca, foreground, and other species live in a soil medium that ranges from eight to 12 inches deep on the Sarnafil roof. The yellow-blossomed Rocky Mountain ice plant, *below,* has been the most successful of four rooftop species for providing cover.



Soil and Water

ASU experiments found using the conventional green roof layer of two to four inches of soil quickly left Phoenix-area plant roots overheated. With this input, the design team settled on a soil depth of eight inches on the eastern side, deepening to 12 inches on the western side, which receives the focus of the setting sun at the hottest time of day. "Additional soil helps protect the roots and keep the plants happy. It dries out so much quicker with less soil," Richardson explains. Another two inches of decomposed granite sits atop the soil to help protect it from desiccation.

Shelor chose a lightweight blend of overstructure soil created by Phoenix-based Western Organics, now going by the name Gro-Well. The blend consists of 40 percent pumice, 40 percent fine sand, 10 percent Omni mulch, and 10 percent Phoenix black-bottom mulch. The porous pumice and black-bottom mulch with its lava sands help retain water, as do the bark and manure in the mulches. "Organics give you your nutrients plus water retention," says Jim Beuerlein, in charge of commercial sales for Gro-Well. "Working in the desert, that's the number one thing, trying to keep the moisture around those root balls."

Though lighter than natural soils, when fully saturated the custom-blend mixture weighs about 110 pounds per cubic foot—or per square foot in areas where soil depth reaches 12 inches. Adding in the weight of an extra two inches of decomposed granite and other loads led architects to design the roof to support 130 pounds per square

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foot. The extra structure needed to support this weight increased the cost of the roof's structural system by about 30 percent, Kane says. "Because we don't have snow, usually our systems can be designed lighter," he says. In meeting the requirement of supporting saturated soil, architects added enough extra structure to hold another floor. They also designed the roof to slant so that extra water will drain off during the desert's other extreme—heavy local rainfall from thunderstorms during a summer monsoon.

Meanwhile, keeping the soil moist enough for plants between monsoon storms requires an elaborate system of drip irrigation. Each of the 990 rooftop plants is slated to receive three gallons of water a week via individual drip irrigation emitters located near their roots, Shelor explains. Providing the water underground, and under a layer of decomposed granite, helps protect it from the area's high evaporation rates. The amount of irrigation translates to about one and a half inches of rainfall a month in summer. Based on published information from the University of Arizona's cooperative extension service, that's about a quarter of the amount used to keep high-quality golf course turf growing in Phoenix.

> Each of the 990 rooftop plants is slated to receive three gallons of water a week via individual drip irrigation emitters located near their roots.

The green roof system is designed so that water use can be cut by a third during winter, Shelor notes. In practice, however, the shifts between winter and summer regimes have not been smooth. In a July 22 phone conversation, Shelor indicated she had just returned from a troubleshooting trip to the roof to investigate why plants were dying. It turned out they hadn't been receiving their weekly rations; instead of getting a gallon of water three times a week, they were getting it only twice a week. Not all of the plants were expected to survive the mishap. "It's basically a giant pot because of the shallowness of the soil," she said of the roof. "And if you don't water your (potted) plants, they're going to die."

The original design plan called for irrigating the rooftop plants with a water harvesting system, saving the water from a rainy day to spend on the many other days of unremitting sunshine. However, health codes blocked plans to irrigate the roof with graywater harvested from the complimentary showers, installed to encourage cyclists to commute to work at the transit center. Instead, that water goes to flush toilets. Plans to use water from the city's stormwater system—which Richardson says can hold 46,000 gallons in underground pipes at the site—failed in the face of Maricopa County regulations that force the release of any water stored in pipes within 36 hours of the storm. Because the rules trace back to concerns about flood control and mosquito infestation, landscape crews can't even use it on plants.

Water funneled into a 12,000-gallon cistern constructed beneath the adjacent plaza helps, but it only adds up to four weeks of rooftop plant watering in summer, based on Shelor's figures. Sharing the water with trees, vines, and other plants featured in the center planting likely would cut that time frame down to a week. That's not enough in a city that can go a month or more without rain during the 100-degree-plus temperatures that characterize May and June.

The expectation that a green roof should be able to sustain itself without any additional water irks Richardson, an architect who chairs the Arizona chapter of the U.S. Green Building Council. "In this harsh climate, that's really unreasonable," she says. "If you don't keep the greenery up and it goes brown, it then increases the heat load of the building."

As long as the roof remains green, the plant cover helps shade the building below, while moist soil promotes evaporative cooling. A study commissioned by the

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Tempe Transportation Center group found a cover of ice plants kept surface temperatures on the experimental roof right around 80 degrees. This compared to surface temperature daytime highs of 120 degrees for white roofs measured in this study, and up to 165 degrees for conventional roofs as found in other studies. This heat load reduction adds up to air-conditioning savings.

Long-term Savings vs. Up-front Cost

The transportation center's electricity costs were projected to run about half of a typical building of its size and location, Kane notes, thanks in part to the savings in air-conditioning. But the transit center has other features that keep offices cool such as natural lighting paired with outside shade cloths that keep direct sunlight from warming the interior. The natural lighting, in turn, also keeps down electricity costs even as it reduces the amount of interior heat generated by lights.

> The potential to cool the urban environment offers one of the reasons for these pioneering efforts in desert green roofs.

Richardson says she and other team members are still in the process of sorting out the costs and savings of the green roof, as they are intertwined with various other aspects of the project. None of the designers interviewed had details on the cost and savings specifically related to the roof. "We've really just finished it and we're still doing some work here," Richardson said in early June, noting the building had been open for less than six months.

Harvey Bryan, a professor in ASU's School of Architecture and Landscape Architecture, questions how much the energy savings should count toward offsetting the cost of constructing and maintaining a green roof in the desert. "A couple of inches of insulation under the roof membrane is always better than anything you do on top of it," he maintains.

Proponents point out that potential savings extend beyond reductions in cooling costs and stormwater handling. Namely, the underlying roof is expected to last longer because the protective layers shield it from the elements. The Tempe Transportation Center boasts a Sarnafil roof, with a gelatinous orange membrane underlying other layered elements that protect the roof from potentially damaging ultraviolet rays. "There are some of these roofs in Europe that have a 50-year history," Richardson says. "Dirt and plants are protecting the membrane that's underneath." In contrast, she says, a conventional flat roof typically requires maintenance every decade or so to keep leaks from springing and expanding.

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Green Roofs and Heat Islands

On that June morning atop the green roof, air temperatures already were creeping toward that day's high of 103 degrees in the city of Tempe. And this was during a relatively cool June, with the heat moderated by several unexpected storm systems. In 2007, Phoenix set a record of daily highs, with the entire month of August hitting 110 degrees or more.

Over the next century, global warming is expected to make it even worse. ASU research indicates air temperatures in metropolitan Phoenix already rose by seven or eight degrees during the course of this past century. About a third of the blame goes to global warming. But researchers attribute most of the increase to the urban heat island effect—the local warming from high-rises, concrete, and asphalt that cooks cities.

The potential for green roofs to cool the urban environment offers one of the most valuable reasons for forging ahead with these pioneering efforts in desert green roofs, Dye says. As in Phoenix, cities overall are heating up much faster than the world as a whole. "You just can't sustain that upward trajectory of heat," Dye says. "So green roofs are a strategy, part of a combination of strategies, that will help over time. Of course, there's a critical mass—you need more of them."

> The transit center's green roof pales in comparison to the many trees sprouting throughout the neighborhood.

In comparison to white roofs, though, ASU researchers found that a covering of ice plants kept surface temperatures of a green roof stable at about 80 degrees day or night, while a nearby white roof fluctuated from about 120 degrees during the day to 60 to 65 degrees at night. The extra nighttime warming of the green versus the white roof worries ASU's Bryan, who has been raising this issue among Tempe designers.

"Much of the (Phoenix) urban heat island is a nighttime problem. So we're very concerned with nighttime radiation," Bryan says. The thicker-soiled desert green roofs contain more mass than traditional thin-soiled sedum roofs, he notes, so they store more daytime heat that can radiate at night. Researchers detect the urban heat island effect by comparing the ongoing temperature rise over cities to that over nearby rural or natural areas.

On the other hand, local vegetation appears crucial in keeping desert cities like Phoenix cooler during the day than nearby natural desert. This makes desert cities unusual when it comes to the urban heat island effect. While Chicago's daytime temperatures may register some 10 degrees higher within the city than in nearby forests, virtually all the extra urban heating in Tempe registers at night. This twist initially took ASU researchers by surprise. Further analysis indicated daytime

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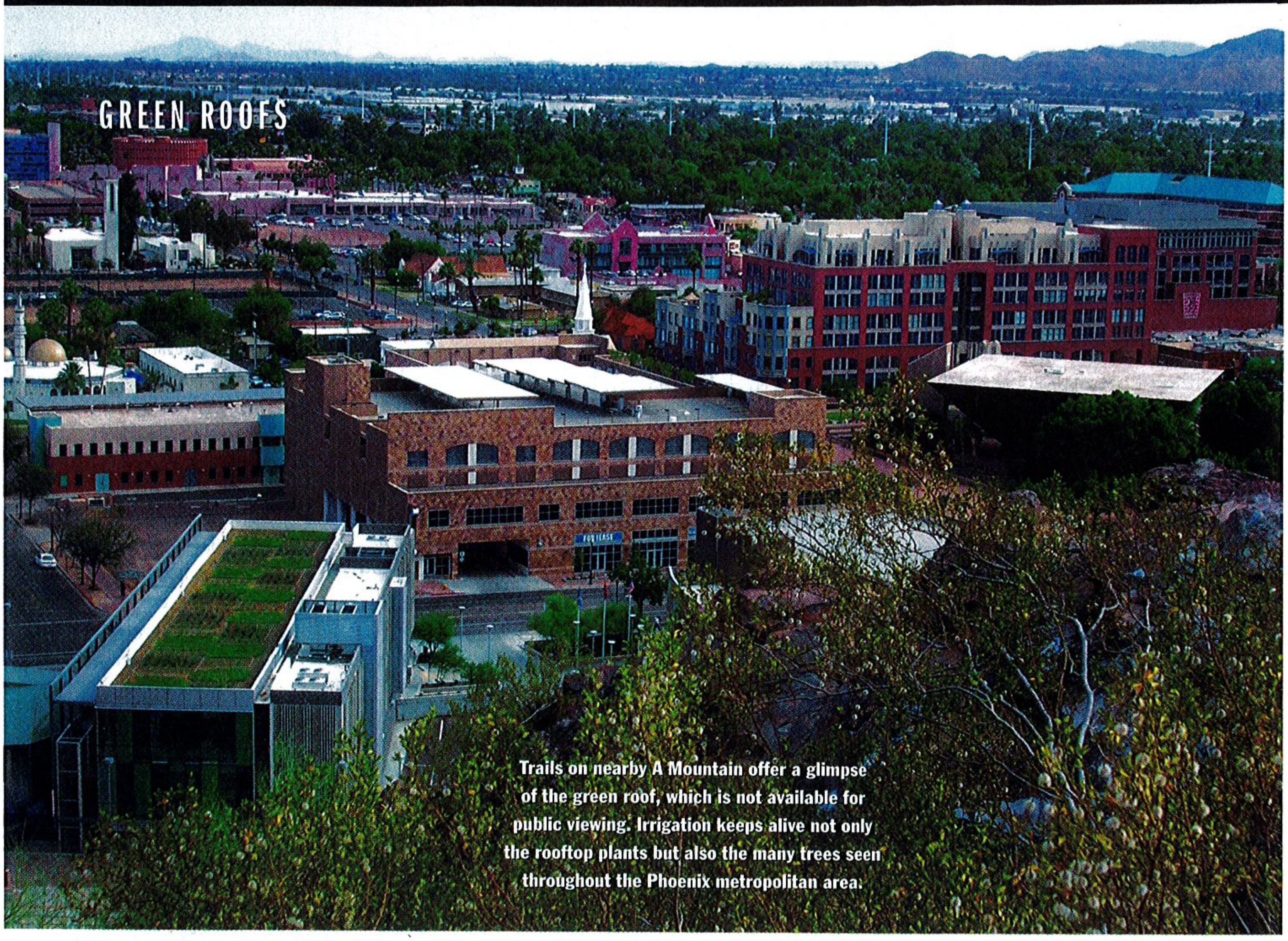

Trails on nearby A Mountain offer a glimpse of the green roof, which is not available for public viewing. Irrigation keeps alive not only the rooftop plants but also the many trees seen throughout the Phoenix metropolitan area.

MELANIE LENART

temperatures were cooler overall thanks to evaporative cooling from swimming pools and swamp coolers (fan-based cooling systems that cool the air by releasing water), as well as local planting.

Research at ASU found daytime temperatures in a Tempe neighborhood with shade trees and abundant plant cover stayed up to 10 degrees cooler than a nearby but relatively barren neighborhood. The temperature difference reached its peak during the hottest afternoons, keeping people walking or working in the treed area at a much lower risk from heat-related illnesses even during a 2005 heat wave. Chicago's 1995 heat wave helped launch its innovative green roof program (see "Chicago's Green Crown," *Landscape Architecture,* November 2004) when officials estimate more than 700 people died from heat-related illnesses and complications. The event helped jar Mayor Richard M. Daley into becoming a major proponent for green roofs. Chicago's City Hall roof garden served as a pilot project under the U.S. Environmental Protection Agency's Urban Heat Island Initiative.

The question remains, how much nighttime heat retention from vegetation can prime the city for even hotter daytime temperatures versus how much daytime cooling traces back to the local greenery. Plants, especially trees, provide daytime shading from direct sunlight along with cooling from evapotranspiration. They emit heat at night, though, and also can help trap heat and block cooling winds. The cooling they do during the day, however, may well offset their contribution to nighttime heating, something Bryan agrees would be worth exploring. In a city with limited water resources, though, another question arises: How do green roofs fit into other efforts to reduce urban heating with vegetation?

From the hillside perspective of A Mountain on a June afternoon, the transit center's green roof pales in comparison to the many trees sprouting enthusiastically throughout the commercial and university neighborhood. If all the water were collected from the city's hardscape to irrigate plants, these trees might well be a sustainable feature on the landscape. As it is, they, like the green roof, stay alive thanks to irrigation. If it came down to a competition for water between rooftop vegetation and streetside trees shading asphalt, shading at the level where people walk would add up to more local cooling than high-in-the-sky green roofs.

It's possible that both might be needed to curb rising temperatures in the densely populated Phoenix metropolitan area, especially with global warming adding an additional heat load. Census reports indicate population increased by about a million people in the decade through 2000 and, as of 2007, was on track to do so again. With the extra pavement and structure that comes with such explosive population growth, a landscape of green roofs arguably could exert a cooling influence in the urban environment. Vines and other types of green walls also could help given the low angle of the setting sun. In a city like Tempe, the intangible savings from more vegetation could include medical bills, health, even lives. But at what cost in water and dollars? More research is needed to address these questions.

In the meantime, vegetated roofs in the desert are growing in popularity, judging from sales of Gro-Well's overstructure soil. Sales of the lightweight soil blend for green roofs and other vegetated overstructure for commercial buildings have skyrocketed in recent years, Beuerlein says. He estimates that the company has sold about 30,000 cubic yards for commercial ventures since 2005—roughly 300 times the amount used on the Tempe Transportation Center. "I think it's just a trend coming this way," says Beuerlein. Perhaps future research will answer some of the questions on exactly what this ongoing greening means for the desert city. LAM

Melanie Lenart is an environmental writer and scientist and author of the upcoming Life in the Hothouse *(University of Arizona Press, 2010).*

Resources

- *Global Warming in the Southwest: Projections, Observations, and Impacts,* by M. Lenart, G. Garfin, B. Colby, T. Swetnam, B. J. Morehouse, S. Doster, and H. Hartmann, 2007. Published by the University of Arizona Climate Assessment for the Southwest and available online at *www.climas.arizona.edu/pubs/pdfs/GWSouthwest.pdf.*
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- "Redefining the Green Roof," by L. M. Cavanaugh; *Journal of Architectural Engineering,* March 2008.

PROJECT CREDITS Tempe Transportation Center Project Team **Owner:** City of Tempe, Arizona (Bonnie Richardson, project manager/architect). **Landscape architecture (plaza, courtyard, roof, LRT Station):** A Dye Design, Phoenix (Angela Dye, FASLA, principal; Michele Shelor, ASLA, project manager [no longer with ADD]). **Irrigation design subconsultant:** Coates Irrigation, Phoenix (Allen George, irrigation designer). **Architects:** (Design) Architekton, Tempe, Arizona (John Kane, principal); (Architect of Record) Otak, Lake Oswego, Oregon (Dennis Haden, architect [no longer with the firm]). **Civil engineering:** Michael Baker Jr. Inc. Civil Engineers, Phoenix (Ann Eisentraut). **Public artists:** Courtyard: Lorna Jordan, Seattle. LRT Station and Plaza: Tad Savinar, Portland, Oregon. **Environmental graphics:** Thinking Caps, Phoenix (Julie Henson, designer). **Structural engineer:** Brickey Design Associates (firm retired) (Levi Gallegos—now with Struktur Studio, Phoenix). **Mechanical/electrical:** LSW, Phoenix. **Lighting:** Akali Lighting Design, Scottsdale, Arizona (Miho Mizukami Schoettker, designer). **LEED consultants:** Natural Logic Inc., Seattle; Natural Systems, Santa Fe, New Mexico. **Construction manager at risk:** Adolfson & Peterson Construction, Tempe, Arizona (John Tomasson, owner).

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