# COOL ROOFS FOR A WARMING WORLD

## Why We Need Cool Roofs and What to Consider When Planning to Install Them

By Kurt Shickman

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Rising temperatures are fast becoming the key challenge for our cities and urbanized areas. The effects of heat have negative outcomes for people's health and well-being, social equity, energy use and peak demand, resilience of health, transportation and electrical infrastructure, crime, education outcomes, and productivity.[1] A study of nearly 1,700 cities found that these combined effects would cost a city that does nothing to address heat approximately 1.7% of its annual economic output by 2050 and 5.6% by 2100.[2] Think of it as a tax for inaction on rising temperatures that we can measure in the billions of dollars.

When it comes to high temperatures, there is a lot stacked against cities. Cities tend to be hotter than surrounding less-developed areas because they absorb more solar radiation, have less vegetation, release built-up heat more slowly, and generate more waste heat from vehicles and mechanical (or active) cooling. These factors contribute to a phenomenon called the urban heat island (UHI), wherein the annual mean air temperature of a city with 1 million people or more can be 2–5°F warmer than its surroundings. On a clear, calm night, however, the temperature difference can be as much as 22°F.[3] This rise in average ambient temperatures is affecting cities in all climates (**Figure 1**) and increases the frequency, duration, and intensity of extreme heat waves.

Cities are not just heating up, they are heating up fast. Since the 1980s, the number of days of extreme heat in the United States has nearly doubled (**Figure 2**).

The intensity and speed of these changes to urban environments require immediate action, particularly in our built environments where we live, learn, and work. Transforming our building design and materials choices to focus on improving the ability of building occupants and communities to mitigate and manage the effects of rising temperature, often referred to as heat resilience, has started, but has not reached anywhere near the scale needed to offset the effects of UHIs.

### BUILDING ENCLOSURE SOLUTIONS TO IMPROVE HEAT RESILIENCE

The good news is that there are solutions that minimize heat gain which building experts can adopt today to reduce temperatures in buildings, in cities, and on the planet. These solutions can generally be considered in three basic categories:

1. Passive, non-mechanical cooling solutions, such as:

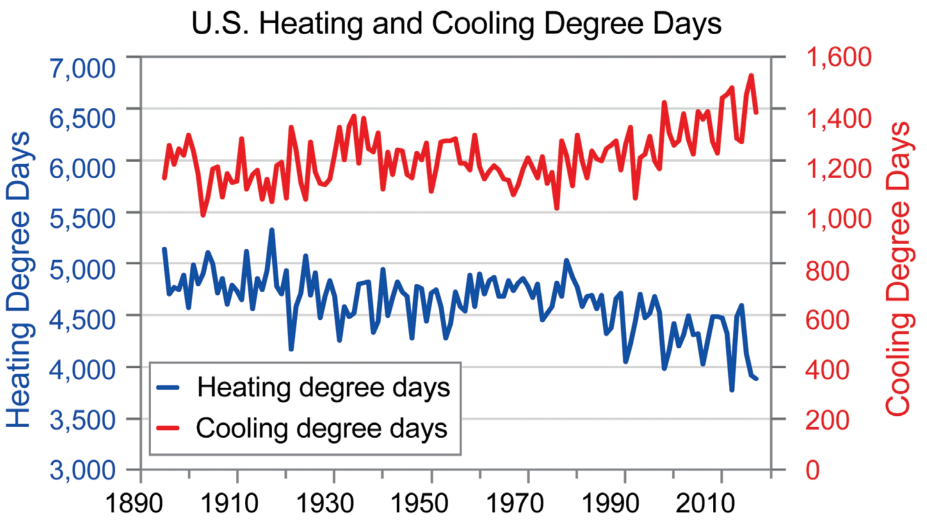


*Figure 1. Heating and cooling degree days by decade. Source: 4th National Climate Assessment. 2018. https://nca2018.globalchange.gov/chapter/1/.*

    - Roof, wall, and pavement materials that reflect a greater portion of solar radiation than traditional materials (highly reflective surfaces),
    - Expanded vegetated areas and tree canopies (shading, green roofs/walls, and permeable surfaces).
2. Heat-resilience planning, such as:
    - Natural and human-made water features including lakes, rivers, or fountains (water infrastructure),
    - Urban planning that minimizes heat buildup and retention (urban design),
    - Passive cooling designs for buildings, such as increased thermal insulation (passive building design).
3. Energy-efficient cooling solutions, such as:
    - Energy-efficient cooling technologies and climate-friendly centralized cooling applications, including district cooling,[4]
    - Technologies that reduce waste heat exhaust, including electric vehicles.

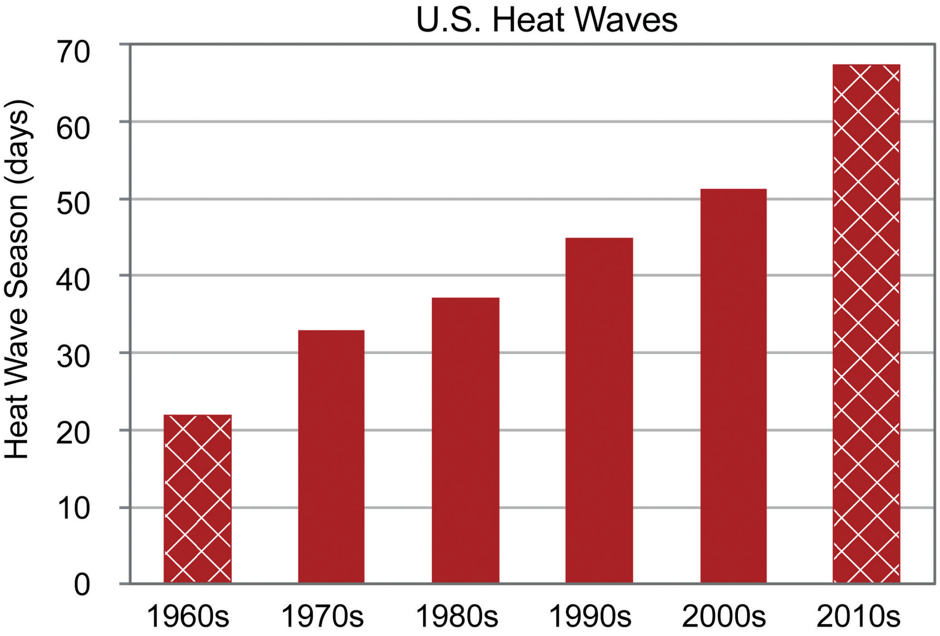


*Figure 2. Average extreme heat days by decade. Source: 4th National Climate Assessment 2018. https://nca2018.globalchange.gov/chapter/1/.*

Each of these solutions is an important part of an integrated strategy to build heat resilience. That said, this article will mainly focus on cool roofs and walls because cool materials are widely available in North America and can cover nearly every type of roof and wall structure. Cool roof and wall solutions can be applied at a variety of times, including when a building is retrofitted, when a roof is being repaired or replaced, or simply over an existing functional roof or wall. Importantly, for most roof and wall types, there is a cost-comparable cool version that can be specified with minimal maintenance costs.

## COOL ROOFS AND WALLS

Cool surfaces work by reflecting solar energy rather than absorbing it. The reflected solar energy mostly passes out of the earth's atmosphere and into space, creating a net cooling effect at the building scale and, when deployed widely, at the community, city, and even global scales. **Figure 3** summarizes the impact of shifting to a light-colored cool roof. At the building scale, solar-reflective roofs can reduce cooling energy demand by 10–40%. In winter, heating penalty may range between 5% and 10% as a function of local climate and building characteristics (for example, the amount of roof and wall insulation, window-to-wall ratio, and the like).[5] In unconditioned structures, cool roofs result in 5–6°F reductions in temperatures on the floor below the roof.[6] Cool walls provide similar benefits, at about 80% of the level generated by cool roofs.[7] At the building scale, cool roofs and cool walls can contribute to cool air temperature. A comprehensive literature review has found that a 0.1 increase in

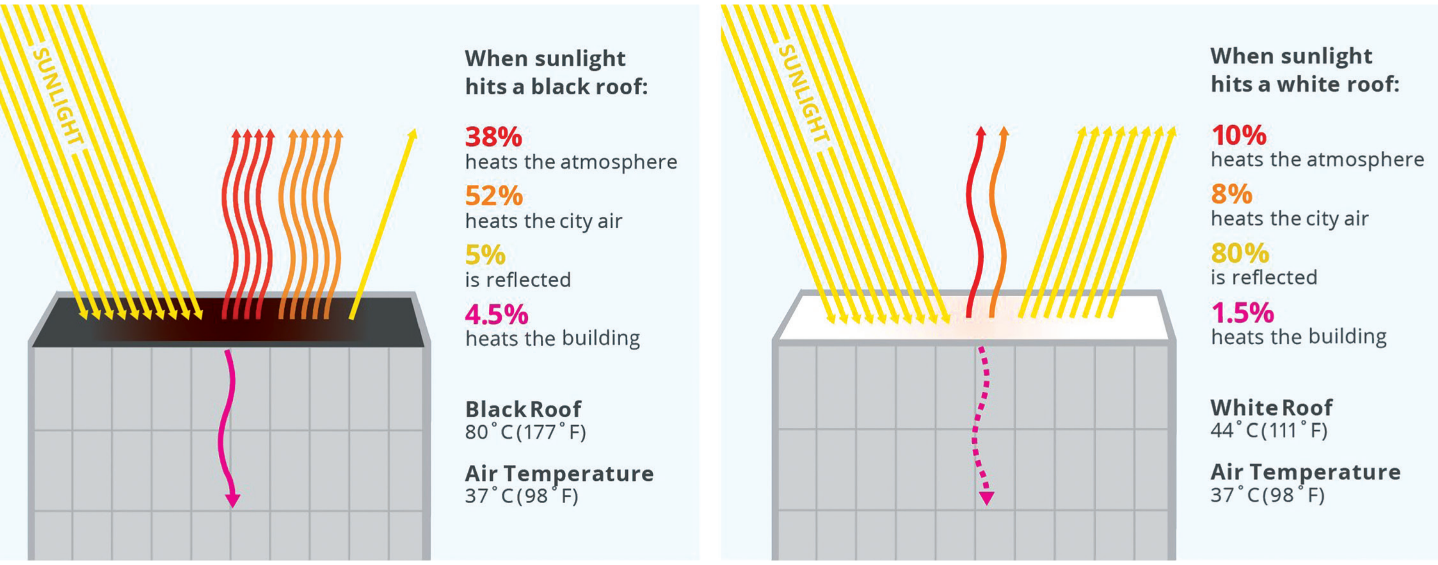


*Figure 3. Effects of a cool roof versus a dark roof. Source: Global Cool Cities Alliance (2012), with data from Lawrence Berkeley National Laboratory.*

*Figure 4. Almeria region of Spain. Source: Google Earth.*

solar reflectance (solar reflectance is measured on a scale from 0 to 1, so a 0.1 increase is similar to shifting from a dark- to a medium-grey color) results in a 0.5°F reduction in average outdoor air temperatures and a 1.5°F reduction in peak temperatures.[8]

These potential effects on air temperature can influence the formation of ozone. A decrease in air temperatures tends to correlate with a reduction in the amount of ozone formed and thus an overall improvement in air quality.[9] The relationship between air temperature and air quality is a complex one. Some of the air-quality improvements from reduced ozone formation may be offset because reduced air temperatures near the urban surface may slow wind speeds and vertical mixing of air with higher air levels, leaving some pollutants near the ground.[10] That said, the amount of air-temperature reduction needed to trigger this effect at a significant level is not practically achievable by simply adopting cool roofs.

A recent analysis of the potential benefits of passive cooling in Los Angeles highlights just how important even small changes in average air temperature can be. Researchers studying the potential impact of passive cooling on mortality during historic heat waves found that the indoor and outdoor cooling resulting from highly reflective roofs and vegetation areas could have saved one out of four lives lost during the heat waves studied and would delay climate change-induced warming by 25 to 60 years.[11]

A real-world case of the effect of large-scale deployment of cool surfaces comes from Almeria, Spain (shown in **Figure 4**), which has a unique tradition of whitewashing its greenhouses in preparation for summer weather. Almeria has over 67,000 acres of land area covered by greenhouses, making it one of the largest concentrations of greenhouses in the world. The region reflects substantially more sunlight than neighboring regions that have fewer whitewashed greenhouses. A 20-year longitudinal study comparing weather-station data in Almeria to similar surrounding climatic regions found that average air temperatures in Almeria have cooled 0.7°F compared to an air temperature increase of 0.5°F in the surrounding regions lacking whitewashed greenhouses—a 1.2°F difference.[12]

Cooling buildings and cities directly addresses the many negative effects of rising temperatures noted earlier in this article. Valuing those many benefits shows that every $1 invested in cool surfaces generates $12 in net economic gains.[13] Beyond the economics, the negative effects of heat are overwhelmingly borne by low-income communities of color. Thus, a concerted effort to deploy cool roofs (and other passive measures) will meaningfully contribute to efforts to improve social and racial equity.[14,15]

## WHAT TO CONSIDER WHEN PLANNING TO INSTALL COOL ROOFS

While cool roofs are applicable and deliver benefits in all but the coldest climates, there are a few issues, all relatively minor, to consider when determining the type of roof to install.

### Winter heating penalty

While a cool roof reduces cooling energy demand in the summer, it can increase heating energy demand in winter when installed in some cold climates. This is known as the "winter heating penalty" and, though it is an issue to be factored into energy savings determinations, its effects are often greatly exaggerated for a number of reasons. In winter, the sun is generally at a lower angle and days are shorter than in summer months. In fact, in northern locations winter solar irradiance is only 20% to 35% of what is experienced in summer months, which means that the sun has a reduced impact on roof surface temperature during the winter.[16] Heating loads and expenditures are typically more pronounced in evenings, whereas the benefit of a darker roof in winter is mostly realized during daylight hours. Further, many commercial buildings require space cooling all year due to human activity or equipment usage, thereby negating what little, if any, heating benefit would be achieved by a dark roof.

Snow cover on roofs also affects the winter heating penalty. Snow has two impacts on the roof that are relevant to understanding the true impact of roof surface reflectivity on energy consumption. First, snow helps insulate the roof. As a porous medium with high air content, snow conducts less heat than soil. This effect generally increases with snow density and thickness. Second, at a thickness of about 4 in., snow will transform any roof into a highly reflective (approximately 0.6 to 0.9 solar reflectance) surface. Researchers evaluated the impact of reflective roofs on new and older-vintage commercial buildings in Anchorage, Milwaukee, Montreal, and Toronto when snow cover is factored in.[17,18] The study finds that

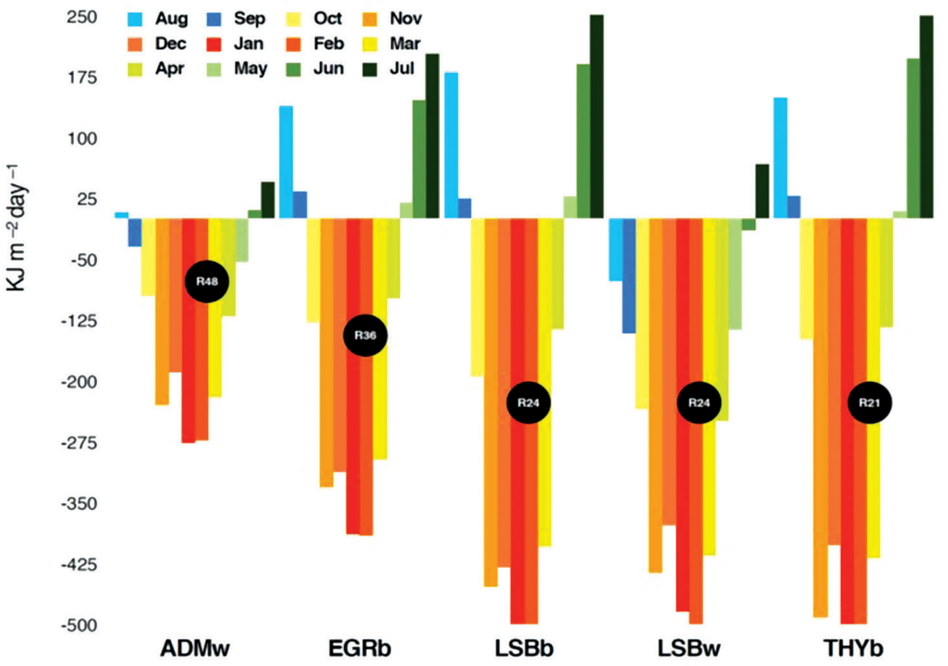


*Figure 5. Heat flux results from Princeton field tests. Source: Ramamurthy et al., 2015.*

"cool roofs for the simulated buildings resulted in annual energy expenditure savings in all cold climates." The study also identified peak energy savings in addition to the base energy efficiency gains.

## Insulation

Another argument often heard against reflective roofing in cold climates is that buildings in northern climates tend to have higher levels of roof insulation that reduce or negate the energy-saving impact of roof surface color. A field study and model analysis of black and white roof membranes over various levels of insulation by City University of New York, Princeton University, and Princeton Plasma Physics Lab showed that the relationship between roof reflectivity and insulation is symbiotic, not a tradeoff.[19] The Princeton papers highlight the interconnected role of reflectivity and insulation in roofing systems and find that reflectivity is the variable that minimizes heat flux during the summer, and that insulation levels are the driving variable during winter. In other words, to have a high-performance roofing system that minimizes heat gain in the summer and heat loss in the winter, you need both insulation and a highly reflective roof surface.

The researchers deployed high-resolution heat-flux sensors over and through various roofs on buildings inside the Princeton University campus. The buildings were very similar in design and usage, with the exception of different roof membranes (black or white) and thicknesses of polymer-based insulation (R-21 up to R-48).

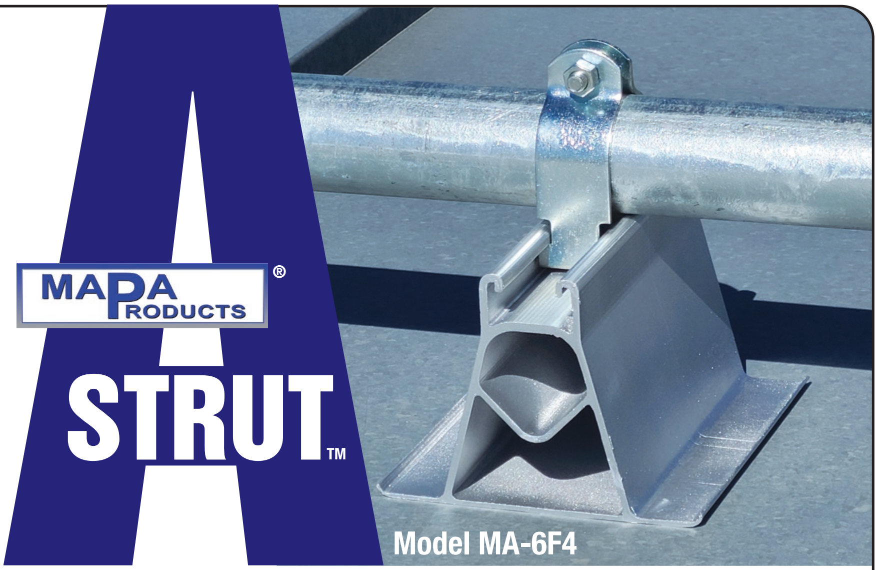
This study, which gathered measurements for one year, is one of the first to directly observe heat fluxes entering and leaving the building. It is the first study that paired a field test with an evaluation of the same buildings using a finely resolved model to validate and more deeply understand the interaction between insulation levels and surface reflectivity.

**Figure 5** shows the net heat entering (positive values) or leaving (negative values) the building by month for each roof. The findings are better observed on the two buildings with R-24 insulation levels but different membrane colors (LSBb is black and LSBw is white). These two roofs were installed at the same time on buildings that are close to one another. During the cold months, both the white and black roofs allow roughly the same amount of heat to escape from the building. In the summer months, however, the white roof has substantially less heat gain than the black roof and even maintains a negative heat flux in August and September. The benefits of cool roofs are still evident in the building with R-48 insulation (ADMw). There is a net reduction in heat flux in the roof with the highly reflective surface.

## Moisture/Condensation

Another consideration when installing highly reflective roofs in cold climates is the potential for moisture damage from condensation. It is important to note that a properly installed code-compliant roof system should not have any issues with moisture damage. Most of the cases of damage described in the literature can be explained by installation error and do not indicate a systemic problem with the use of cool roofs.

Over the course of a year in seasonal climates, moisture can build up in roof systems during cool periods and dry out during warm periods.[20] This process occurs regardless of roof color. Research indicates that although cool roofs may take a little longer to dry out than dark roofs, they also fully dry out, resulting in no net moisture build-up over yearly weather cycles.[21] As the US Department of Energy has noted in reference to the potential for



> Knowing the radiative performance of roofing products is important for understanding the roof's impact on building energy use, occupant comfort, and the surrounding environment.

condensation in cold climates, "while this issue has been observed in both cool and dark roofs in cold climates, the authors are not aware of any data that clearly demonstrates [sic] a higher occurrence in cool roofs." This finding is borne out by field tests of a large number of buildings and model-based research.

Target and Sika Sarnafil undertook a field performance evaluation of single-ply white roofs in service for between 10 and 14 years on 26 Target stores located in cold climates.[22] Two test cuts were made on each roof (and three test cuts on one roof) for a total of 53 samples, and moisture was present in two of them. One was determined to be the result of leakage from a nearby HVAC unit, and the other showed no signs of staining, mold, or deterioration that would indicate a long-term moisture problem.

In another case, researchers simulated the performance of several roofing systems—including typical, smart, and self-drying roofs for residential and commercial buildings in very cold climate regions—and found that office buildings did not experience moisture accumulation problems during the simulation period (five years) using WUFI modeling.[23] The "smart roof" features related to venting and vapor retardation are covered in IgCC/ASHRAE 189.1.

In a paper presented at the 2011 NRCA International Roofing Symposium, the Single Ply Roofing Industry (SPRI) reported on a field survey and modeling studies to verify whether cool roofs were, in fact, susceptible to condensation issues.[24] The study was designed to achieve the greatest likelihood of observing condensation within the roofs. The roofs studied all consisted of a white roof membrane (aged 2 to 12 years) mechanically fastened over a single layer of insulation on a steel deck without a vapor retarder. The roofs were surveyed during the months of February and March of 2010, and were located in ASHRAE Climate Zone 5. Two test cuts were done on each of the roofs. All cuts were done in the morning to minimize the impact of any heating of the roof surface that might occur under the afternoon sun. In seven of the roofs there was no evidence whatsoever of any moisture in the assembly. Though moisture was observed on the top face of the insulation and/or the underside of the membrane on three roofs, researchers noted no detrimental effects due to moisture in any of the roofs. WUFI modeling was performed for the 10 roofs included in the study, with simulations conducted for both a black and a white surface in each case. Although the modeling results showed that all of the roofs would be subjected to condensation in the winter months, it predicted higher levels of condensation below a cool white membrane than below a black sheet. However, in all cases, for both white and black membranes, the modeling showed that the resulting moisture would dry out completely in the summer months.

## COOL ROOFS FOR THE FUTURE

While there is ample bad news and dire predictions about our present and future climate, we do have solutions available to meet these challenges. An abundance of cool roofing materials is readily available on the market, and at little to no incremental cost depending on the product type. Building enclosure consultants, architects, specifiers, contractors, and builders can use the free, online CRRC Rated Products Directory (https://coolroofs.org/directory) to identify roofing products that meet a variety of needs, including:

- Complying with local energy code requirements and/or green building certifications;
- Qualifying for financial incentives (for example, rebates, tax incentives, PACE financing);
- Decreasing indoor air temperature and increasing occupant comfort;
- Lowering the building's cooling demand and utility bills;
- Reducing energy peak demand; and
- Helping to mitigate the UHI effect by lowering ambient and surface temperatures.

Each of the products on the Rated Products Directory has a CRRC product rating that indicates the radiative performance (solar reflectance, thermal emittance, and solar reflective index [SRI]) of the roofing product. Knowing the radiative performance of roofing products is important for understanding the roof's impact on building energy use, occupant comfort, and the surrounding environment.

## REFERENCES

1. World Bank Energy Sector Management Assistance Program. 2020. "Primer for Cool Cities: Reducing Excessive Urban Heat." Knowledge Series 031/20. Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/605601595393390081/Primer-for-Cool-Cities-Reducing-Excessive-Urban-Heat-With-a-Focus-on-Passive-Measures.
2. Estrada, F., W. Botzen, and R. Tol. 2017. "A Global Economic Assessment of City Policies to Reduce Climate Change Impacts." *Nature Climate Change*. https://doi.org/10.1038/NCLIMATE3301.
3. Oke, T.R. 1997. "Urban Climates and Global Environmental Change." In *Applied Climatology: Principles & Practices*, edited by Thompson, R.D., and A. Perry, pp. 273–287. New York, NY: Routledge.
4. District cooling refers to the use of highly efficient central cooling plants to supply cold water to multiple buildings to provide air conditioning. Cold supply water enters the building and flows through a heat exchanger, absorbing the heat from the building space before recirculating back to the central plant. International District Energy

Association. https://www.districtenergy.org/topics/district-cooling.

5. Salamanca et al. 2014. "Anthropogenic Heating of the Urban Environment Due to Air Conditioning." *Journal of Geophysical Research: Atmospheres.* Volume 119, Issue 10.
6. Blasnik, M. 2004. "Impact Evaluation of the Energy Coordinating Agency of Philadelphia's Cool Homes Pilot Project." https://coolrooftoolkit.org/knowledgebase/impact-evaluation-of-the-energy-coordinating-agency-of-philadelphias-cool-roof-program/.
7. Levinson, R. et al. 2019. "Solar-Reflective "Cool" Walls: Benefits, Technologies and Implementation." https://doi.org/10.20357/B7SP4H.
8. Santamouris, M. 2014. "Cooling the Cities—a Review of Reflective and Green Roof Mitigation Technologies to Fight Heat Island and Improve Comfort in Urban Environments." *Solar Energy* 103: 682–703.
9. Kenwood, A. 2014. "Summer in the City: Hot and Getting Hotter." *Climate Central*. https://climatecentral.org/news/urban-heat-islands-threaten-us-health-17919.
10. Sharma et al. 2016. "Green and Cool Roofs to Mitigate Urban Heat Island Effects in the Chicago Metropolitan Area: Evaluation with a Regional Climate Model." *Environmental Research Letters* 11, No. 6.
11. De Guzman et al. 2020. "Rx for Hot Cities." Los Angeles Urban Cooling Collaborative. https://www.fs.fed.us/research/docs/webinars/urban-forests/rx-hot-cities/UFCJul2020_deGuzmanEisenmanKalksteinSides.pdf.
12. Campra, P. 2011. "Global and Local Effect of Increasing Land Surface Albedo as a Geo-Engineering Adaptation/Mitigation Option: A Study Case of Mediterranean Greenhouse Farming." *Climate Change-Research and Technology for Adaptation and Mitigation*.
13. Estrada et al. 2017. *Nature Climate Change*. https://doi.org/10.1038/NCLIMATE3301.
14. Hoffman et al. 2020. "The Effects of Historical Housing Policies on Resident Exposure to Intra-Urban Heat: A Study of 108 US Urban Areas." *Climate* 8, no. 1: 12. https://doi.org/10.3390/cli8010012.
15. Jesdale et al. 2013. "The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation." *Environmental Health Perspectives*: 121, no. 7 (July): 811-817.
16. US Department of Energy website, "Solar Radiation Basics." https://www.energy.gov/eere/solar/solar-radiation-basics.
17. Hosseini, M. et al. 2016. "Effect of Cool Roofs on Commercial Building Energy Use in Cold Climates." *Energy and Buildings* 114: 143-155. https://www.researchgate.net/publication/279216326_Effect_of_Cool_Roofs_on_Commercial_Buildings_Energy_Use_in_Cold_Climates.
18. Ranamurthy, P., T. Sun, K. Rule, and E. Bou-Zeid. 2015. "The Joint Influence of Albedo and Insulation on Roof Performance: An Observational Study." *Energy and Buildings* 93: 249-258. https://doi.org/10.1016/j.enbuild.2015.02.040.
19. Ranamurthy, P., T. Sun, K. Rule, and E. Bou-Zeid. 2015. "The Joint Influence of Albedo and Insulation

on Roof Performance: A Modeling Study," *Energy and Buildings* 102: 317-327. https://doi.org/10.1016/j.enbuild.2015.06.005.

20. Boyer, R. 2020. "Theory of a Self-Drying Roof." *Construction Canada*. (January). https://www.constructioncanada.net/theory-of-a-self-drying-roof/.
21. Taylor, T. 2016. "Cool Roofs in the North: Some Studies Suggest Condensation Under White Membranes in the North is Rare." *Interface*. (August). http://iibec.org/wp-content/uploads/2016-08-taylor.pdf.
22. DiPietro, Michael, Michael Fenner, and Stanley P. Graveline. 2014. "Study Targets Cool Roofs—Assessing the Performance of Cool Roofs in Northern Climates." *Roofing Contractor*. (October). http://www.roofingcontractor.com/articles/90602-study-targets-cool-roofs.
23. Moghaddaszadeh, M. et al. 2013. "Hygrothermal Behavior of Flat Roof and Standard Roofs on Residential and commercial roofs in North America." *Building and Environment* 60, (February): 1-11.
24. Kehrer, M. and S. Pallin. 2013. "Condensation Risk of Mechanically Attached Roof Systems in Cold-Climate Zones." *Proceedings of the 28th RCI International Convention and Trade Show*. http://iibec.org/wp-content/uploads/2013-CTS-kehrer-pallin.pdf.

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## Amazon's Arlington Headquarters to Highlight Helix

Plans designed by architecture firm NBBJ have been submitted for Amazon's new headquarters in Arlington, Virginia, near the United States Capitol. One of the four buildings will be shaped like a double helix and offer two walkable paths of landscaped terrain. The 350-ft.-tall tower, dubbed "The Helix," will be the centerpiece of the PenPlace campus, which will also include three 22-story office buildings (for a total of 2.8 million sq. ft.), a 250-seat outdoor amphitheater, and public green space.

The featured building's shape is a reference to the prevalence of said form in nature, such as in the double-helix shape of DNA. Much of the shared space, including 2.5 acres of open spaces, will be open to the public in an effort to foster a bond with the community rather than merely creating one within the culture of the company itself. The $2.5 billion Arlington HQ2 will feature native plant species incorporated into alternative workspaces within The Helix to "prioritize areas for collaboration, natural light, and a constant interaction with nature."[1] All vehicle access will be planned for underground, further creating a pedestrian-friendly environment.

The new buildings are designed to LEED Platinum standards, the highest certification available from the United States Green Building Council. The project will also incorporate an all-electric HVAC system which will draw its power from a solar power farm in Pittsylvania County, in southern Virginia.

***Rendering of The Helix. Image courtesy of NBBJ/Amazon.***

**— *Archinect*, Amazon, CNN**

1. Schoettler, John. 2021. "The next chapter for HQ2: sustainable buildings surrounded by nature." https://www.aboutamazon.com/news/amazon-offices/the-next-chapter-for-hq2-sustainable-buildings-surrounded-by-nature. Accessed Feb. 4, 2021.