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Building a Heat-Resilient Community in Richmond, Virginia

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Introduction

A total of 739 people died over seven days, all for the same exact reason. Can you take a guess why? Could it be a deadly virus outbreak? No. Was it just excessive violence in the community? Again, no. Was it a natural disaster, such as an earthquake or a series of tornadoes? Not that either. “It was a natural disaster, that revealed an unnatural one,” as Judith Helfand coins it.[1] In July of 1995, the most traumatic heatwave in the history of the United States came knocking on the doors of Chicago, Illinois. The daily average temperature for that week: 104°F, a devastating 20°F above the average temperature for July.[2] All tolled, 739 people perished tragically, dying of heat-related deaths.

According to Dr. Steve Whitman, the Director of Epidemiology of Chicago from 1990-2000, people die from the heat for 2 reasons. “If you have a pre-existing condition, so it’s already weakened your body, then clearly it’s going to be easier for the heat to kill you. The second, and intimately related factor, is that people aren’t able to defend themselves against the heat. That defense can be in terms of opening their windows, and in poor vulnerable communities people don’t want to open their windows. It could be by turning on the air conditioner, and in vulnerable communities people don’t have air conditioning. It could also be going outside their house and going to an institution where there is air conditioning. For example, a public library might have air conditioning, or even the lobby of an apartment house might have air conditioning. Vulnerable communities tend not to have those as well.[3] ” Chicago, a city like many other cities across the country that suffers from the Urban Heat Island (UHI) effect, had an African-American population in 1995 that was affected at an alarmingly disproportionate rate. African Americans (.3 per 100,000) and Native/Indigenous Peoples (.6 per 100,000) are dying from heat-related illnesses at a higher rate than their White (.2 per 100,000) counterparts.[4] This rings true in many communities in America, due to a long-history of racially discriminatory government practices, including my students’ city of Richmond, Virginia.

Rationale

The students who I teach at John B. Cary Elementary School in Richmond, Virginia are no strangers to excessive heat in their own neighborhoods. John B. Cary Elementary School is an open-enrollment and Title I school, residing in Richmond, Virginia. Our students are a mix of families who are zoned for our school, and a portion of students who are zoned for other elementary schools. So long as they can be provided adequate transportation, students from across the entire city are welcome. Albeit, 98% of our students qualify for free or reduced lunch. Most of the students who enroll at John B. Cary through open enrollment reside on the east or south side of the city, two of the typically lower-income living areas.

I have been teaching 4th and 5th grade special education at John B. Cary for two years now, with three years of total experience. I push into various general education classrooms to service and support my students with disabilities. My students have disabilities such as Autism Spectrum Disorder, Specific Learning Disability, Attention Deficit Hyperactivity Disorder, or Emotional Disabilities. I support them as a case manager who modifies their educational programming, and a classroom co-teacher, primarily in math and reading, but also in science and social studies. The demographics of the 300 students at John B Cary is 84% African American, 8% White, 4% Hispanic, 2% Multiple Races, 1% Asian, and 1% Native American, with about 18% of the student population having one or more disabilities. This unit will be taught primarily in the 5th grade Science for classroom with possible extensions in writing and math. There is one hour allocated towards science daily in 5th grade. For the upcoming 2020-2021 school year, the state of Virginia has new and revised Science standards. I will incorporate the seminar teachings of Dr. Jordan Peccia, Professor of Environmental Engineering at Yale University.

Learning Objectives

The students who I teach are living in an urban heat island, along with 80% of other Americans. The term urban heat island simply describes built up urban areas that are hotter than nearby rural areas.[5] The annual mean air temperature of a city with one million or more people can be 1.8 to 5.4°F (1 to 3°C) warmer than its surroundings during the day, and on a clear, calm night, this temperature difference can be as much as 22°F (12°C).[6] Cities smaller than one million people total, such as Richmond (220,000), are still considered urban heat islands, however in smaller cities it is likely that the effects are not as severe. So, why does this happen?

As cities are built with impervious materials, such as brick, steel, and asphalt “we change the balance that natural unaltered landscapes have with the sun.” In addition, paving green spaces into water-resistant surfaces, such as roads and parking lots, eliminates cooling effect of evaporating water after a rainstorm.. Instead, that water is directly diverted into local bodies of water, such as streams, lakes, and rivers. In addition, buildings that are made out of impervious materials can “absorb and hold onto the sun’s energy during the day, and then turn around and emit that heat back into the air at night.[7] When compared with natural vegetative areas, built up areas with more buildings containing materials such as concrete and asphalt contribute to the urban heat island effect because the darker materials absorb more light and have a higher heat capacity, thus holding a lot of heat from hotter days.

Why should we care about this? There is a major strain on our energy resources, leading to rising energy bill costs. There is also a disproportionate effect on people who can't afford to cool their homes, such as the massive 1995 heatwave in Chicago. After teaching my unit, my goal for my students is to be exposed to ways that they can positively affect change in their own communities as it relates to the improving the environment. My students will design their own response to mitigate excessive heat in their own communities. To summarize what they have learned, my students will document their findings by writing to their city council representatives to encourage and advocate for change.

Background

There are two main types of urban heat islands: surface and atmospheric. A surface urban heat island refers to the difference in temperatures that is measured from dark areas, such as pavement and roofing, or right above them. An atmospheric urban heat island relates to measuring the ambient air in and around the tree canopy and above.[8] For the purposes and teachings of my unit, I will solely focus on the characteristics and mitigation strategies for surface urban heat islands as there are more practical and grade appropriate activities for my students to engage in.

In addition to added impervious surfaces replacing naturally green areas, there are other qualities of cities that contribute to the Urban Heat Island effect such as the color of impervious surface materials, the shape of cities, and unique weather and geographic implications.[9]

Darker surfaces

Roofing, pavement, and parking lots tend to have lower solar reflectance values than lighter surfaces. Therefore, these surfaces absorb more radiation from the sun and heat the areas around them more through convection. Radiation from the sun is felt by city inhabitants in various forms: long-wave/infrared radiation, latent heat from evapotranspiration (evaporation + transpiration), heat that we feel as traditional temperature, and anthropogenic heat, referring to any excess heat created by human processes. This can include heat discharged by running AC window units during the day, driving a car back and forth to work or cooking.

Darker surfaces contain specific characteristics that makeup how much they contribute to the extra heating of their surrounding areas:

Albedo: an object's ability to reflect solar radiation back into the atmosphere and fully to outer space, thus not contributing to the greenhouse gas effect and warming the surrounding areas and Earth as a whole. Solar reflectance is correlated with the color of its material, and 43% of the sun's energy is attributed to visible wavelengths. As the sun's energy increases, darker materials with lower wavelengths are less effective in reflecting heat.

Thermal emissivity: a material's ability to shed heat away from the object. Most building materials, such as those used to produce cool roofing, have high thermal emittance values to keep their structures cool.

Heat Capacity: an object's ability to store heat. Objects with low heat capacities that are able to displace heat effectively such as soil and sand, are found in rural areas more often. Higher heat capacities are found in materials such as steel or stone, which are more abundant in urbanized areas.

The Shape of Urban Spaces

The dimensions and spacing of various buildings and structures encompassed in the built up, urban, area can contribute to excessive warming as well. Obstructions, such as tall buildings and skyscrapers, can easily impact a building's overall albedo. The effects of this can be felt through excess temperatures during the afternoon, as well as in the evening to night time. When there are copious amounts of skyscrapers or tall buildings on narrow streets, this is known known as an *urban canyon*.

Increased Energy Consumption associated with heat island effect

As our cities are getting hotter and temperatures continue to rise a result of the Urban Heat Island effect, there is an increase in overall energy consumption in communities within these localities. There is an increased demand for cooling in all settings, whether it be commercial or residential. As cooling increases, there is also an added demand on local electricity grids. During the later afternoon and into the evening, electricity grids are often working at full demand to cool homes, power lights, and run household appliances. At this peak, for every 1°F increase the electrical urban electrical demand increases between 1.5 to 2%. Adding additional surge puts an excessive strain on the overall capacity of the system. In worst cases, this can lead to brownouts and blackouts across cities, leaving residents in temporary health crises.

Elevated air pollutants and Greenhouse Gases

Higher temperatures and increased energy used across electricity grids only begin to scratch the surface of problems that the Urban Heat Island effect can cause localities. Pollutants that can be harmful to overall human health are produced as fossil fuels, which are combusted. Currently, fossil fuel combustion accounts for most electricity production in the United States. Fossil fueled power plants produce CO_2, the leading greenhouse gas which contributes to climate change. In addition, many other pollutants are produced in power plants including Mercury (Hg), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Particulate Matter 2.5 (PM), and Nitrogen Oxide (NOx). When Nitrogen Oxide reacts with sunlight, it yields the ground level formation of Volatile Organic Compounds (VOCs) such as Ozone, another greenhouse gas contributing significantly to climate change.

Compromised human health and comfort

Certain populations, especially those primarily made up of people living in low-income areas, can be made uncomfortable and even develop serious life-threatening conditions due to elevated temperatures. Factors such as higher daytime surface temperatures, higher evening temperatures without the reprieve of cooling, and added air pollution with dangerous pollutants greatly exacerbate this issue**.** This can lead to difficulty breathing, heat exhaustion, non-fatal heat strokes, and ultimately heat-related deaths. As heat waves roll across the country, which have become more regular as a result of climate change, the Urban Heat Island effect perpetuates these symptoms and can cause more sickness and deaths overall.

Water Quality of Surrounding Ecosystems

Rooftop and pavement surfaces are up to 50°F hotter as a result of surface urban heat islands, will residually heat excess runoff water and storm water as it moves through a collection system and into a body of water such as creek or stream that flows into a lake or river. This excess water can be heated on average up to 4°F more than normal. These rapid temperature changes can affect species' metabolic rates and ability to reproduce.

Strategies for Building Heat-Resilient Communities

To limit these effects, there are research-based strategies that city residents should consider when it comes to their homes and land they own. On a larger scale, local governments should also take into account the following strategies with any urban planning. I will go into detail on research-based strategies examining the use of trees and vegetation, green roofing, cool roofing, cool pavements, and local community and policy efforts.

Trees and Vegetation

Strategic placement of trees, vines, and other plants in urban areas around various structures can have significant benefits overall in mitigating the aforementioned adverse outcomes due to the Urban Heat Island effect.[10] There are two specific processes that support the use of trees and vegetation in this way.

Shading

When trees are placed near areas that radiate heat, such as roads, buildings, and parking lots, up to 90% of the sun's energy is captured by the leaves of the tree before it can reach the ground below, and subsequently heat the surface. The light is both absorbed by leaves for photosynthesis, and reflected back into the atmosphere. This creates a more suitable temperature for people or materials below the tree.

Evapotranspiration

Evaporation + transpiration. This cools the air by using heat from the air to evaoprate water. This is essentially how a plant "sweats".

Transpiration: as precipitation makes its way into soil and nutrients, the roots from trees and vegetation will absorb water, move the water through the stem, and eventually emit the water through their leaves. Evaporation: the chemical change of state in water from a liquid to a gas. The evaporation occurs in water that has been transpired from the plant, and from rainfall around trees as it collects water. As water evaporates, the surrounding air cools. Rural areas with natural landscapes that are able to retain more moisture have more evapotranspiration than urban areas. As a result, impervious infrastructure reaches very high temperatures as heat is unable to be transferred. This leads to higher air temperatures.

Shading and evapotranspiration in conjunction can help address high temperatures during the day in the summer (see Figure 1). This can reduce temperatures up to 9°F of tree covered areas versus open terrain. Suburban living areas with trees can reduce the temperatures up to 6°F when compared to similar areas without trees. Open sports fields that are lined with trees can reduce bordering areas up to 4°F.

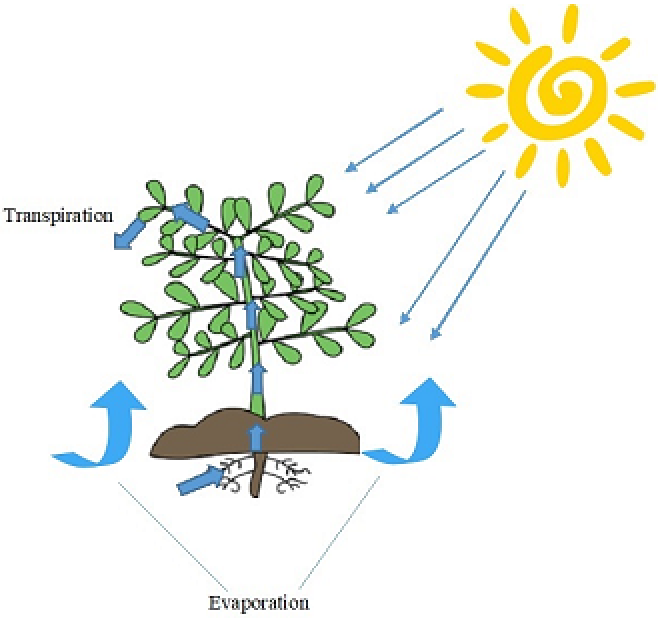


Figure 1: Demonstration of Evapotranspiration in a plant[11]

Green Roofing

In most cities, rooftops account for about 20-25% of total land cover. Similar to how shading and evapotranspiration help cool ground layer surface temperatures, trees and vegetation can reduce temperatures when planned or retrofitted on buildings and homes. Conventional rooftop surfaces can exceed ambient air temperatures by up to 90°F. Growing a vegetative layer on a rooftop will mitigate these temperatures, and can reduce associated energy costs.[12]

The sun's energy will be limited as specially engineered soils and plants on top of roofing blocks a portion of the sunlight that reaches the roof membrane. Through photosynthesis of leaves, heat and light energy is reflected back into the atmosphere. As a result, less heat is transmitted onto buildings that would excessively heat its surroundings, effectively keeping the area cooler. In addition, buildings are protected from ultraviolet radiation. There are two types of green roofing that can help buildings and homes stay cool, and use less energy.

Extensive Green Roofing

A low profile design system containing sedum plants, such as succulent and hardy plants that would tend to be suitable for an alpine environment (Figure 2). With a simple rugged design, little maintenance and upkeep is required over time. This type is perfect for retrofitting roofs, as little to no added structural support is required to house the added system. This system can be applied to diverse existing roof designs, such as roofs that feature a slope.

Figure 2: Virginia Commonwealth University Arts Pollak Building Rooftop Garden, Richmond, VA.[13]

Intensive Green Roofing

A high profile design considered to mirror a conventional garden or park, where people can utilize the space. These systems include a more diverse grouping of plants, such as small to medium size trees and shrubs. Intensive roofs will require more maintenance over time to upkeep the vegetation. Intensive roofs are more beneficial when they are planned into the original construction of a building. Larger vegetation and public use will require more structural support, which does not lend itself to being retrofitted onto an existing building. This will also often require a built in irrigation system.

Both intensive and extensive green roofing systems have a wide-range of benefits, while the negatives are mostly cost related. Vegetative roofing allows the building to reduce its overall energy consumption. When green roofs are wet following a precipitation event or routine irrigation, they’re able to store large amounts of heat due to evaporative cooling. Buildings are also cooled and protected when vegetative roofing layers are dry, as they act as an insulating barrier.

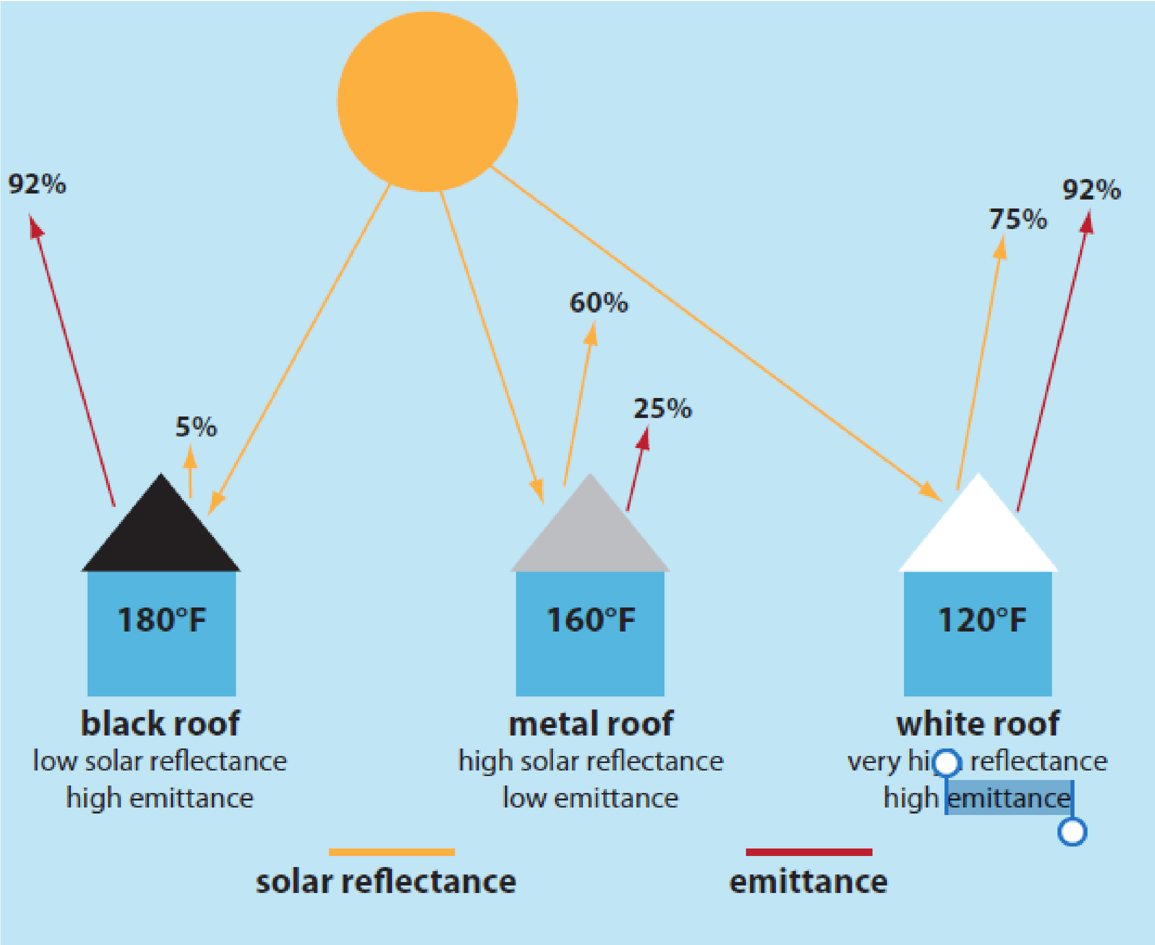
Cool Roofing

In the United States, traditional roofing can reach peak temperatures up to 185°F, which severely heats surface temperatures of suburban roofing and creates warmer ambient air temperatures in neighborhoods. Cool roofing materials, which have emerged in the last 30 years, can keep surfaces between 50-60°F cooler than traditional roofing. Cool roofing products are able to reflect and emit solar energy more effectively, thus keeping the surrounding areas cooler.[14]

Solar energy that reaches the Earth’s surface and roofing is comprised of 5% Ultraviolet rays, 43% visible light, and 52% infrared light. Ultraviolet rays are what we associate with getting a sunburn. Visible light solar energy accounts for colors from violet to red. Infrared light is felt as traditional heat to people. How do we keep all of these different types of damaging heat from penetrating our roofs? Simply, energy must be redirected. In this case, all three types of solar energies will be reflected away from Earth's surface.

The solar reflectance of a surface material, also known as albedo, is the percentage of solar energy that is able to be reflected away from the surface. Solar reflectance is the most important property in determining how a material contributes to urban heat islands. The higher the percentage of albedo, the more effective cool roofing is able to be and keep ambient air temperatures lower. Scientists have devised many ways of calculating a material's albedo by using specially designed equipment such as spectrophotometers, solar reflectometers, or pyranometers in both laboratories and in the field. Traditional roofing is able to reflect only about 5-15% of solar energy, while newer cool roofing materials are able to reflect up to 65%.

Another part of the equation in determining how materials, specifically roofing, contribute to urban heat islands is its thermal emittance. This term refers to a material's ability to release any radiated heat that is absorbed back into the environment and atmosphere. Any surface exposed to radiated energy from the sun will get hotter until reaching thermal equilibrium, when a material releases as much heat as it absorbs. A surface with a higher, more efficient thermal emittance value reaches an equilibrium level at a lower temperature, thus releasing less heat into the surrounding environment. Below (Figure 3) is an image illustrating the combined effects of both solar reflectance and thermal emittance on roofing materials as it relates to their overall temperature. On a hot, sunny summer day, a black roof that reflects 5% of the sun's energy and emits more than 90 percent of the heat it absorbs can reach 180°F (82°C). A metal roof will reflect the majority of the sun's energy while releasing about a fourth of the heat that it absorbs and can warm to 160°F (71°C). A cool roof will reflect and emit the majority of the sun's energy and reach a peak temperature of 120°F (49°C), see Figure 3.



Lisa Gartland

Figure 3: Example of Combined Effects of Solar Reflectance and Thermal Emittance on Roof Surface Temperature[15]

The ASTM (the American Society for Testing and Materials) has devised a calculation to determine the solar reflectance index (SRI), a value that represents a material's temperature in the sun.[16] The calculation takes in to account both solar reflectance and thermal emittance of a material. The SRI is calculated as follows:

$$SRI = \frac{(Tblack - Tsurface)}{(Tblack - Twhite)} \times 100$$

Tblack= Temperature of a completely black surface

Tsurface: Temperature of the surface being tested

Twhite: Temperature of a completely white surface

This calculation compares how hot a material would get if you placed a completely black and a completely white one next to the material being tested, under radiant heat. The final value will be calculated as a percentage between 0 and 1. The higher the number, the higher the overall SRI, and more efficient it is in mitigating its contribution to urban heat islands.

Low-sloped commercial cool roofing

An essentially flat roof, with a minimal amount of slope to provide drainage. These roofs are defined as having more than 2 inches of vertical rise, over 12 inches of vertical run (a ratio of 2:12). These are often found on larger buildings such as commercial, industrial, warehouse, office, and multifamily housing.

As a heat mitigation strategy, large low-sloped roofs generally use two approaches: thick coatings or single-ply membranes. Roof coatings mimic the thickness of paint, with a few additives to make the layer more durable for a variety of temperatures and weather events. There are two types of coatings that are generally used: cementations and elastomeric.

Coatings

Cementitious coating contains particles of cement that are partially pervious, while relying on the underlying roof materials for water displacement and proofing. Elastomeric coatings use polymers for adhesion thus providing a waterproof membrane. Both cementitious and elastomeric coating have at least a 65% solar reflectance and 80-90% thermal emittance to keep the surrounding areas as cool as possible.

Single-ply membranes

This type of low-sloped cool roofing approach initially costs more, and is used when a roof is deemed as needing to be fully repaired for a variety of reasons. The system implores pre-fabricated sheets made with a cool surface and are placed together, connected, and fastened down to create a low sloping roof.

Steep-sloped residential roofing

While most cool roofing is focused on mitigating effects from low-sloped roofing, steep-sloped cool roofing options are becoming more readily available in the last 10 years. Asphalt tiles are most commonly used. Other materials that are used include metal roofing, tiles, and shakes. Generally, low-sloped roofing solar reflectance outcomes are more effective than steep-sloped, as they account for more area and conserve more energy proportionally. Traditional housing tiles only have about 10-30% of solar reflectance. Cool colored metal roofing has a wide variation of solar reflectance as different colors have quite different values from 20-90%. Regular asphalt tiles that are used on single family homes have 25-65% solar reflectance.

Cool Pavements

When compared with conventional paved surfaces, cool pavement solutions tend to store less heat and have lower surface temperatures than conventional pavement. Conventional pavements in the United States include impervious concrete and asphalt, which can reach summer temperatures of 120-150°F.[17] Conventional pavements have two detrimental contributing factors to the formation of urban heat islands: (1) Heat that is trapped below the subsurface of pavements, and re-released during the nighttime; and (2) Heated storm water runoff into local waterways impairs water quality.

Cool pavements resemble the process in which cool roofing uses to keep surrounding areas cooler. Understanding how solar energy is transmitted to Earth, solar reflectance, and thermal emittance are key to develop knowledge of cool pavements. For the purpose of not being repetitive, I will not reiterate these concepts again as they relate specifically to cool pavements.

Similar to cool roofing characteristics, reflective (increased solar reflectance) pavements tend to be the most widely used cool pavement. Conventional concrete typically has a high solar reflectance, but as time goes on and it is used more, the surface becomes dirty and is able to reflect less energy. Darker materials with lower albedo also leads to higher temperatures and the formation of Volatile Organic Compounds (VOCs) as air pollution. In general, the type of pavement used is based on the function it will serve such as roads, parking, sidewalks, etc. There is extensive research on new types of cool pavements by modeling parking lots, as all types can be used due to low impact nature and ability to maintain these spaces.

Cool Pavement Type	Description
Conventional asphalt pavements	Used for decades as parking lots and highways. Consists of an asphalt binder mixed with aggregate, and the possibility of higher albedo materials to increase solar reflectance. This can also be treated with newer materials to update outdated solar reflectance properties.
Conventional concrete pavements	Used in trails, roads, and parking lots. Made by mixing cement, water, and aggregate.
Reflective pavements	Used in low traffic residential areas such as sidewalks, trails, and parking lots. There are two types: Resin based: uses tree resin instead of petroleum based ingredients. Colored asphalt and concrete: uses added pigments to increase solar reflectance.
Non-vegetated permeable pavements	Employs the same structural integrity as conventional pavement, while allowing water to drain through voids into the subsurface and below. This includes porous asphalt, rubberized asphalt, pervious concrete, and brick and block pavers.
Vegetated permeable pavements	Uses plastic, metal, or concrete lattices to support and allow vegetative growth in the interstices. More commonly used in alleys, parking lots, and trails, although it can support weight sufficient for vehicles.
Chip Seals	Used to resurface low volume asphalt roads and highways by using aggregate bound in liquid asphalt.
Whitetopping	Used to resurface roads, intersections and parking lots. A layer of concrete greater than 4 inches. Ultra-thin whitetopping is 2-4 inches thick.

There are mixed results in cooling performance for permeable pavements. Originally developed for storm water management, permeable pavement allows air, water, and water vapor into the voids of the pavement. Various permeable pavements are being implemented in cities, when suitable for various structural requirements. These options include porous asphalt, pervious concrete, and grid pavements.

Similar to how evapotranspiration cools ambient air with trees, vegetation, and green roofing, so does permeable pavement when wet through evaporative cooling. Water passes down through openings into the soil and supporting material sub-surface. As the surface heats, water is drawn out of the pavement, thus drawing heat out as well and the ambient air. Although, when permeable pavement is dry, the effect is not nearly as efficient as temperatures of dry permeable pavements are on average about 9°F hotter.[18]

Local efforts and policy

From governments and citizens, to the scope of large corporations, many stakeholders can benefit from heat island mitigation across the United States. While heat island mitigation is typically focused on increasing sustainability and energy consumption, local communities can get involved at both a voluntary level and a policy level.[19] The Environmental Protection Agency (EPA) lists many practices and initiatives for communities to engage in to help improve outcomes for their own communities.

Voluntary Efforts	Description with example
Demonstration Projects by local organizations.	Groundwork RVA has used projects to demonstrate specific heat island mitigation strategies by quantifying heat effects in the community. Groundwork RVA directly teaches local students mitigation strategies to improve positive environmental outcomes in their neighborhoods.[20]
Incentive Programs	Encourages individuals to engage in heat island reduction strategies with a financial benefit. The Homeowner Trees Project in Richmond provides up to three free shading trees through the forestry department.[21]
Urban Forestry programs	Serves local communities with planting and maintenance needs. The Urban Forestry Division in Richmond is responsible for planting approximately 2,000 new and replacement trees during each planting season.[22]
Weatherization programs	Involves making homes more energy efficient. These programs are generally reserved for low-income families at no extra cost. Funds for these non-profit organizations are disbursed from the U.S. Department of Energy's Weatherization Assistance Program. Project HOMES in Richmond has been able to "improve safety, accessibility, and energy efficiency of existing houses, and build high quality affordable housing through Central Virginia.[23] "
Awards	Recognizes exemplary work through innovative responses to mitigating urban heat island effects in both private and public sectors. Over the last 25 years, the city of Richmond has earned the award of "Tree City USA," by the National Arbor Day Foundation for exemplary tree management programs.[24]

Policy

Some state and local governments adopt and include urban heat island mitigation strategies in their own regulations and policies. This both provides wider access and incentives for implementing strategies.

Policy efforts	Description with example
Procurement	Acquiring cool technologies for municipal buildings sets an example for the community of a government's intention of committing to mitigating urban heat islands. Richmond's Wastewater Treatment Facility has intensive green roofing to limit the urban heat island effect.[25]
Tree and Landscape Ordinances	Designed to ensure public safety, protect trees, and provide shade. In 1992, the Richmond City Council established a full commission for shade trees to examine the overall benefits, and soon implemented ordinances.[26]
Comprehensive Plans and Design Guidelines	Policies, goals, and objectives adopted by local government bodies set forth to development and conservation. "Richmond 300: A Guide for Growth," is Richmond's plan to "create a more equitable, sustainable, and beautiful future for all Richmonders.[27] "
Resolutions	Demonstrate localities' awareness and specific intentions regarding policies related to urban heat island mitigation.
Zoning Codes	Implementation of goals and objectives formally from a comprehensive plan.
Green Building Programs and Standards	Human health, environmental health, and conservation is prioritized over the life cycle of buildings, which can contain hazardous materials.

Building Codes	Establish construction, modification, and repair standards for buildings and other structures.
Air Quality Requirements	Enact emissions control strategies from local governments to limit Volatile Organic Compounds (VOCs) such as smog and ozone formation.

Segregation and Heat Vulnerability

In 1933, the midst of the Great Depression in the United States, the federal government found themselves up against a national housing shortage. As a way to stabilize and encourage home ownership during this tumultuous financial time for families, the Home Owners’ Loan Corporation (HOLC) was established as a program under the New Deal. This program was instrumental because long-term federally backed mortgages were an option for homebuyers for the first time. According to Richard Rothstein, author of the book *The Color of Law,* this program was designed explicitly to not only increase, but segregate, the availability of equitable housing in America.

To further segregate housing in America, the HOLC examined and mapped cities across the country designating which neighborhoods were considered safe or risky to grant loans. Private lenders were provided with this information to increase the amount of white middle and lower class families moving into newer suburban areas. As African Americans were denied time and again the opportunity live in these areas, they were systemically pushed into urban housing projects in separate parts of their communities (Figure 4).

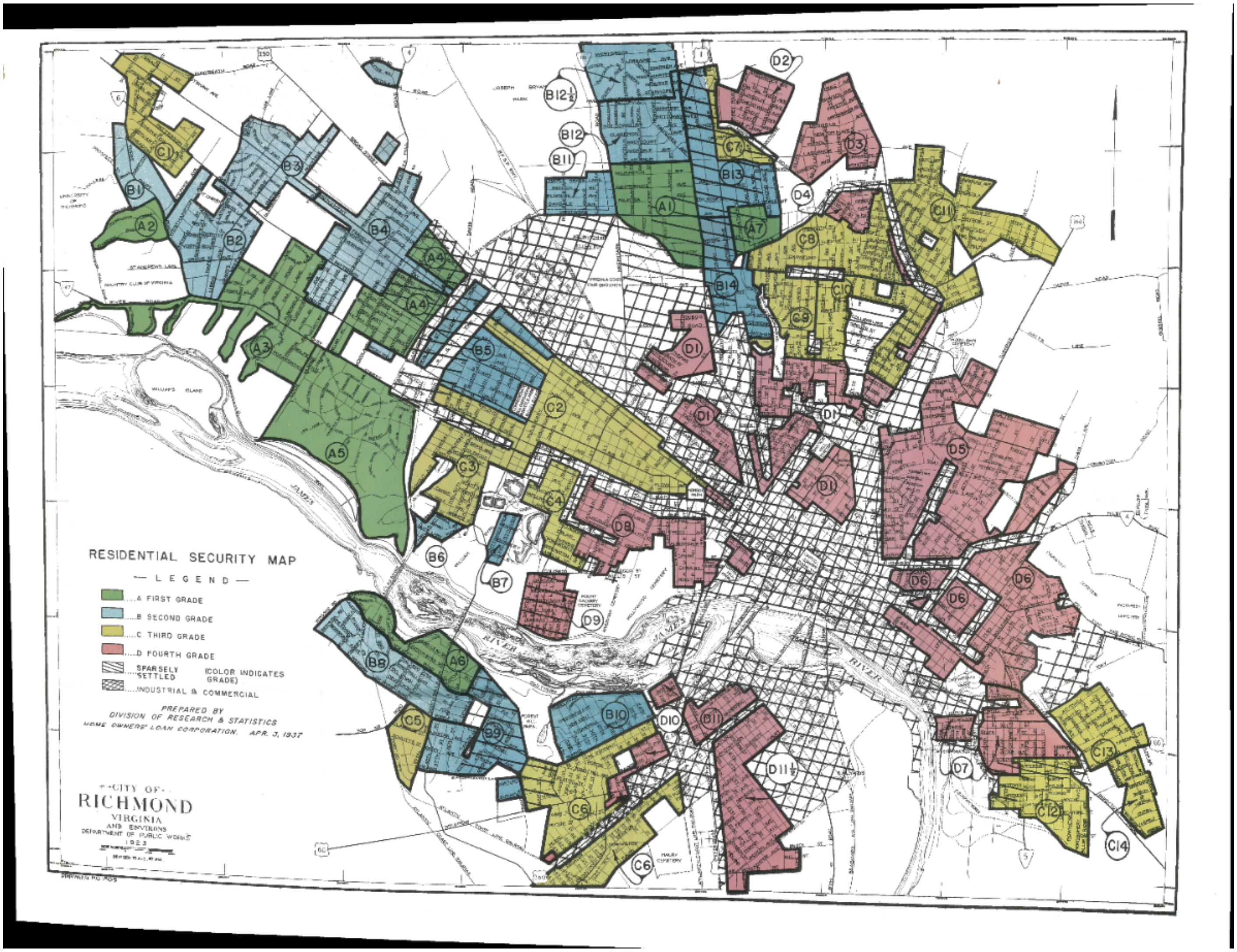


Figure 4: Geocorrectified image of the Residential Security “Redlined” map[28]

In 1934, the Federal Housing Administration furthered segregation efforts by refusing to insure mortgages in and around these newly designated African American neighborhoods. While the Federal Housing Administration was subsidizing builders to produce suburban neighborhoods for whites only, the private security companies began quantitatively grading residential areas according to their lending risk. This discriminatory practice is known as *redlining*. The lending risk factors were assessed by the quality of the housing, race, and ethnicity. Neighborhoods were graded from A – D, an A rating consisting of the green lined, safest, whitest, high quality neighborhoods, and a D rating made up of risky, redlined, people of color, with lesser quality of homes.[29] "The segregation of our metropolitan areas today leads to stagnant inequality, because families are much less able to be upwardly mobile when they're living in segregated neighborhoods where opportunity is absent. If we want greater equality in this society, if we want a lowering of the hostility between police and young African-American men, we need to take steps to desegregate.”[30]

While there have been lasting financial and social equity implications for African Americans across the United States as a result of these redlining practices, there have also been implications for the environmental quality in these neighborhoods. It is no coincidence that the historically redlined neighborhoods lack access to green spaces, green roofing, cool roofing, and cool pavements to mitigate excessive heat in their communities. Today, excessive heat disproportionally affects people who can’t afford to cool their homes and live in predominantly low income areas as a result of government instituted segregation. 74% of the neighborhoods that the HOLC deemed as hazardous over 80 years ago are still considered to be low to moderate income today. In addition, 64% of neighborhoods that were deemed hazardous are home to minorities.[31]

The bar graph below (Figure 5) represents the overall environmental risk in correlation with original HOLC neighborhood grades. As the neighborhood grade decreases, the average land surface temperature increases, the tree canopy cover decreases, and the amount of impervious surfaces increase as well. As it relates to the Urban Heat Island effect, these three factors are the main determinants in how much hotter these areas will get. There is a significant relationship between the practice of redlining, community segregation, and overall environmental risk in many cities today, including Richmond, Virginia. A neighborhood that was rated "D" over 80 years ago, will be on average 4°F hotter than a neighborhood designated "A." This leaves certain neighborhoods and communities more intensely impacted by urban heat and more vulnerable to excessive heat events as a result.

Figure 5: HOLC Neighborhood Grades in Richmond, Virginia[32]

Calculating Heat Vulnerability

Teaching Strategies

Before I teach any new concepts, I usually begin by adminstering a pre-test, which can be conducted in a variety of ways. A KWL chart is an effective way of assessing the knowledge in a whole group format informally. Students are given time to contemplate what they know about the subject, any background knowledge they know about the concept, what they want to know including any questions they might have, and then what they learned about the topic after engaging with it. This is also a great time to clear up any misconceptions as I am able to engage in a class dialogue as we collabratively write on our KWL charts. Another informal way of assessing any pre-knowledge that a student might have is by using technology as a brief assessment. An example of this is Plickers. Students are able to manipulate a physical QR code to give a letter response to a multiple-choice question. After the content is completed, students are able to take the same Plickers assessment to observe what they have learned. My students are given the opportunity to graph their scores, from pre-test to post-test, to observe their learning.

As an introduction to new learning material, I begin by making a connection to the real world. Many times in the classroom I hear students as the same question: “Why do we have to learn this?” When I am able to relate a concept to my students’ background knowledge and actually engage in them in their learning, students will be able to apply their learning outside of the classroom. This can be achieved by having a class discussion, showing a short video clip, or doing a demonstration to explain a natural phenomena.

After answering the question of why they are learning about specific concepts, I will engage students with the content in interactive note taking. The information being learned can be presented in different forms such as a video, a teacher-made powerpoint, or any other type of media. Close notes, traditionally known as fill in the blank, is the first step in exposing students to new vocabulary. Any new vocabulary terms will be presented on a strategically placed word wall so students are constantly reminded of new vocabulary. Word wall words can be reviewed each day in the form of an exit ticket. By using the word in a meaningful sentence, or drawing a picture to demonstrate the concept, students can make further connections with initially unfamiliar words.

Demonstrations of scientific concepts can be done in both the introductory phase of the unit, and the interactive note taking phase as well. Tangible and visual demonstrations give students hands-on experiences to connect with their learning. Demonstrations for this unit inlcude: creating a teacher powerpoint with close notes, demonstrating evaporation with boiling water, measuring the temperature differences between the blacktop and grassy areas, measuring the temperature difference of areas with a tree canopy and areas with a tree covering, measuring the temperature difference of light colored surfaces and dark colored surfaces, and measuring the temperature differences of an area that has been cooled due to evaporation (which can be done by spraying a fine mist into the ambient air) compared to an area that has not been.

When engaging in the Scientific Method students are able model experiments as a scientist may in the real world. Another key benefit of this is exposing students to a grwoth mindset approach to learning. Often following an incorrect hypothesis, many young students will get frustrated and upset simply because they aren’t correct. The scientific method assists students in correctly engaging in a process and working hard to prove an answer, without regard to the correctness of their answer. This shift from a fixed to a growth mindset will help to dissect why they were wrong, and will propel students in solving questions that they don’t initially understand. For this unit, students will conduct scientific investigations into temperature differences. To model research-based strategies to mitigate urban heat islands, investigations will be done by measuring temperature differences of light and dark colored materials, differences of temperatures with tree canopy and without tree canopy, and differences in a permeable surface such as soil compared to an impermeable surface such as a blacktop containing asphalt. Materials for measuring these differences can be high-tech by utilizing a Temperature Gun. Other low-tech measuring tools can be done with a classroom thermometer placed on various surfaces, or even placing thermometers in beakers of water on different surfaces.

My students are often subject to multiple-choice based assessments to demonstrate their growth and learning. While this is necessary to achieve statewide testing goals, there are a wide variety of more engaing and authentic summative assessments. A great way to do this is for students to engage in Project Based Learning. Students are able to create and solve a real world problem for multiple class periods, in this case as it relates to urban heat islands. A final product will be created by individual students or small groups.

Student-led station learning is an effective way to utilize students who quickly absorb new information and present for leadership opportunities in the classroom. Students may receive specific directions from a teacher to either faciliate conversation and/or materials so that the rest of the group meets their learning outcome.

For this unit, students will engage in the iterative writing process to convey what they have learned to local leaders, such as city councilors. This includes, but is not limited to, brainstorming, writing a rough draft, editing for spelling and grammar, and synthesizing a final draft. A final draft can be hand-written or typed depending on students typing abilties and time constraints.

Classroom Activities

Prior to teaching this unit in the 5th grade science class, students will have been exposed to the iterative process of the scientifc method and it’s steps: observation (question, predict), hypothesis (educated guess), experiment (test it), results (collect data), and conclusion (summarize). Throughout the lesson students will be able to access what they learned about the scientific method in their interactive notebooks. Each lesson will be between 45 minutes and one hour long.

Lesson 1: Students will begin by investigating how light energy does work to cause change into another energy form, such as thermal and radiant energy. Students will go outside near the playground and measure temperatures at three different stations. Station 1 will be measuring the temperatures of a white and black material, such as a roof shingle, a flooring tile. Station 2 will measure temperatures of an area under a tree canopy and an area unprotected from a tree canopy. Station 3 will measure temperatures of pavement and a grassy area. While students are reading thermometers, they will have to record observations about why they think there is a difference in temperatures at each station. After roughly 5 minutes at each station totaling 15 minutes, we will come back to the classsroom to share our findings and make conclusions as a group. Time permitting, students can calculate the SRI (Solar Reflectance Index) during the investigation mentioned in the Cool Roofing section. The concept of energy conservation as it relates to the warming of our Earth’s surface will be discussed and related to the light energy from the sun. As an exit ticket, students will write a pargraph about how they currently conserve enrgy at home and school, and what more they can do to conserve energy more efficiently.

Lesson 2: The lesson will begin by summarizing the findings from observations about temperature differences and conserving energy the day before. Students will share out on their ideas about how they currently conserve energy and how they can continue to conserve energy more efficiently. Students will be informally assessed about what they already know about renewable and nonrenewable energy using a short assessment containing picture examples of various types of energies, such as fossil fuels, biomass, solar, wind, geothermal, etc. Following this, students will receive close notes to fill in during a powerpoint dicsussion on renewable energy and as it relates to heat island solutions. Maps presenting hotter areas in Richmond communities with more poverty will be presented and discussed. Students will be asked to critically think and journal. The guiding question will be “Is it fair for people who have less money and resources to have less renewable resources as they relate to urban heat? Why?” After writing, students will share out and classroom conclusions will be made.

Lesson 3: We will begin be reviewing lesson 1 and 2 and our class conlcusions about environemntal equity and the fairness of less resources in areas of Richmond where it is hotter. We will watch the video *Mayah’s Lot* as a class with comprehension questions as the video progresses. Following a discussion of the video and key takeaways we will play the *Limited Resources Game*. In small student-led groups, students will be tasked with making the biggest tower out of daily recyclable materials. The catch is the there are inequitable resources among the groups, demonstrating heat vulnerability and segregation in Richmond. As the teacher monitors and observes how each of the groups are working together, I will pay close attention how students realize the difference in their resources. After about 10 minutes of building, I will bring the class back together for initial comments making sure each group is heard and portraying the activity as social inequities in our neighborhood environments. After a group discussion, students will write and reflect for 5-10 minutes on their experiences. Guiding questions can include “What actions did you take? What could you have done differently?” I will record student responses so reflections can be continued and built upon later.

Lesson 4&5: Continuing the theme of renewable energy and conservation of energy, we will start to look at urban heat island mitigation strategies in a powerpoint, while students follow along filling in close notes and drawing their own models and representations of these research based strategies. Key concepts provided will be trees and vegetation, green roofing, cool roofing, and cool pavements. Following an introduction to these strategies, students will be grouped into collabortive teams of four. Each group will be provided a local Richmond case study of an area where urban heat is excessive. Students will then brainstorm utilizing notes in their journals, and initially develop responses for their specific case studies. Different scenarios will require different responses, with scaffolding from teachers to develop critical thinking in their responses. A second class period will be fully devoted to creating a 3-D model with various construction and coloring materials to represent their solutions to excessive urban heat in Richmond communities. Students will adhere to a formal rubric for grading. For the last 10 minutes, students will reflect in their interactive journals why they chose their designs and why it’s important to implement their responses, especially in underserved communities.

Lesson 6&7: For the final two lessons, students will go through the iterative writing process to complete a persuasive essay. These will besent to the corresponding city councilpersons for each case scenario. On the first day, students will complete a graphic organizer to collect their thoughts such as a flow chart or an idea map. Following successful completion and a teacher check of a graphic organizer, the student may begin individually writing their rough draft. On the second day of writing, students will receive comments from the teacher for revision. Students will begin to edit their rough drafts for capitalization, punctuation, and any other grammatical issues. Once a final draft is complete and approved by the teacher, the student will have the option to type their paper based on their skill level and time remaining.

Appendix: Implementing District Standards

This unit was designed to directly correlate with the following Standards of Learning for Science, adopted in 2018 by the Virginia Department of Education.

5.1 The student will demonstrate an understanding of scientific and engineering practices by:

Asking questions and defining problems.

Planning and carrying out investigations.

Interpreting, evaluating, and analyzing data.

Constructing and critiquing conclusions and explanations.

Developing and using models.

Obtaining, evaluating, and communicating information.

5.2b The student will investigate and understand that energy can take many forms. Key ideas include energy is the ability to do work or cause change.

5.9a,b The student will investigate and understand that the conservation of energy resources is important. Key ideas include some sources of energy are considered renewable and others are not; individuals and communities have means of conserving both energy and matter.

Teaching Resources

Interactive Notebooks

Close Notes

Glue

Scissors

Clipboards

Calculators

Thermometers

Temperature Gun (optional)

Beakers filled with water

Chart paper

Lab sheets to fill in data and observations

Plickers for assessment

Cardstock

Laminator

Teacher created powerpoints

Mayah's Lot video with comprehension questions

Limited Resources Game

Job descriptor cards for student leaders

Building materials for *Limited Resources Game*: Recyclables, tape, kids' scissors, etc.

Local city case studies

Rubric for 3-D model

Materials to construct 3-D model: glue, scissors, popsicle sticks, construction paper, markers, string

Rubric for persuasive essay

Graphic organizer for writing

Computers for typing (optional)

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