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Solving the Heat Island Effect with Modern Transportation Systems

At the turn of the 21st century it became clear to the scientific community that there was a growing list of environmental issues affecting the planet. Further research indicated that certain travel modalities were root causes underneath the umbrella of climate change. This in turn sparked the global trend to study emboldened issues such as traffic congestion and greenhouse gas emissions. These valid obstacles are well documented as primary concerns, but other nondescript environmental problems are often not given the technical attention they deserve. Specifically, the Urban Heat Island effect (UHI) is a unique environmental issue in growing metropolises related to unmanageable heat retention. The Urban Heat Island effect directly impacts the health of millions for its harmful effects on peak energy demand, air pollution, heat-related mortality, water quality, and serious threats to life expectancy. Therefore, data driven research on the topic should strategize initiatives that mitigate its harm on the economy as well as public and natural health. Ideally, technology and policy decision making would work together, although in reality that is rarely the case. The crux of this study is to shed light on what policies can be derived from technological applications in order to address the UHI. This paper seeks to analyze the correlation between the Urban Heat Island effect and current transportation systems in order to determine what technological methods could enlist policy initiatives designed to install an equitable framework to improve city health. This paper will accomplish this explanatory review by evaluating the interrelationship between the UHI and modern transportation, continue by recommending novel engineering answers, and issue a realistic policy agenda relevant to the goals and objectives of the infrastructure bill (IIJA) passed in 2021.

Although cities suffer from a wide variety of environmental problems, the Urban Heat Island effect is one of growing concern (Figure 1). The UHI is a phenomenon sparked by "higher temperatures experienced in urban areas [because of an] increased use of manmade materials and increased anthropogenic heat production that has enormous consequences for the health and wellbeing of people living in cities" (Mohajerani, 2017). Asphalt concrete is a primary component in roadways and one of the biggest contributors to the negative impacts associated with the UHI because of its "low albedo and high volumetric heat capacity" (Mohajerani, 2017). The low albedo refers to asphalts inability to reflect energy while the high heat capacity dictates there is an increased number of heat units required for the asphalt body to increase one unit of temperature (Figure 2). Extrapolating this information, low albedo means more energy absorption in the form of heat. On the other hand, volumetric heat capacity is responsible for longer cool down times, and the direct relationship with volume means the greater the use of asphalt the more drastic the cool down time. Beside the design choice to use traditional asphalt concrete, urban sprawl bears even more responsibility for the impacts of the phenomenon. "The most significant cause of the UHI is urbanization. The constant increase in hard and heat absorbing surfaces, the density of our cities, and the reduction of natural vegetation are the main contributors to the heat island effect […]. The changes in our cities mean that the amount of vegetation is decreasing, and pavements now cover an increasingly high proportion of our cities." (Mohajerani, 2017). As post-pandemic behaviors begin to motivate urban sprawl again, the ultimate result is the increased manufacturing of engineered materials that have properties similar to the ones previously mentioned. A byproduct of increased temperatures is the consequence that urban heat islands increase electricity consumption for air conditioning (Haddad, 2015). Thermal discomfort is responsible for increased peak energy demands that have a negative impact on our energy grid and resource use. Besides inefficient energy usage, "Today there are more than 3 billion urban dwellers and, by 2025, there could be three quarters of the population or even 80% of the world living in urban cities" (Haddad, 2015). These worrisome statistics are motivating numbers to put forth solutions to make cities more habitable for all demographics. Otherwise, the UHI will continue to cause cities to "experience 0.5-4.0 degrees Celsius higher daytime temperatures and 1.0-2.5 degrees Celsius higher night-time temperatures than the nearby rural areas" (Aram, 2019). Additionally, modern transportation systems are heavily reliant on personal vehicles, so a combination of extreme car use and a lack of vegetation compounds the release of greenhouse gas emissions and its entrapment. The exponential relationship with car traffic and the urban heat island effect is best exemplified by studying the plumes of gas emissions from cars and how they form heat islands by forming a "vortex [that] traps many particles leading to an accumulation" (Haddad, 2015). A visualization of this vortex (Figure 4) depicts the situation that pollutants and heat are retained at high concentrations, but low heights with no room for escape. The particulates and heat do not dissipate vertically and are entrapped in a recirculation pattern. Ultimately, the UHI is a dangerous phenomenon that is exacerbated by engineering decisions that abet heat absorption, modern urban planning practices that reduce heat escape, and private transit as a primary modality. The ramifications of these civil engineering decisions have a tremendous impact on public and natural health and are reason enough to begin research and development on alternative methodologies to city engineering/planning.

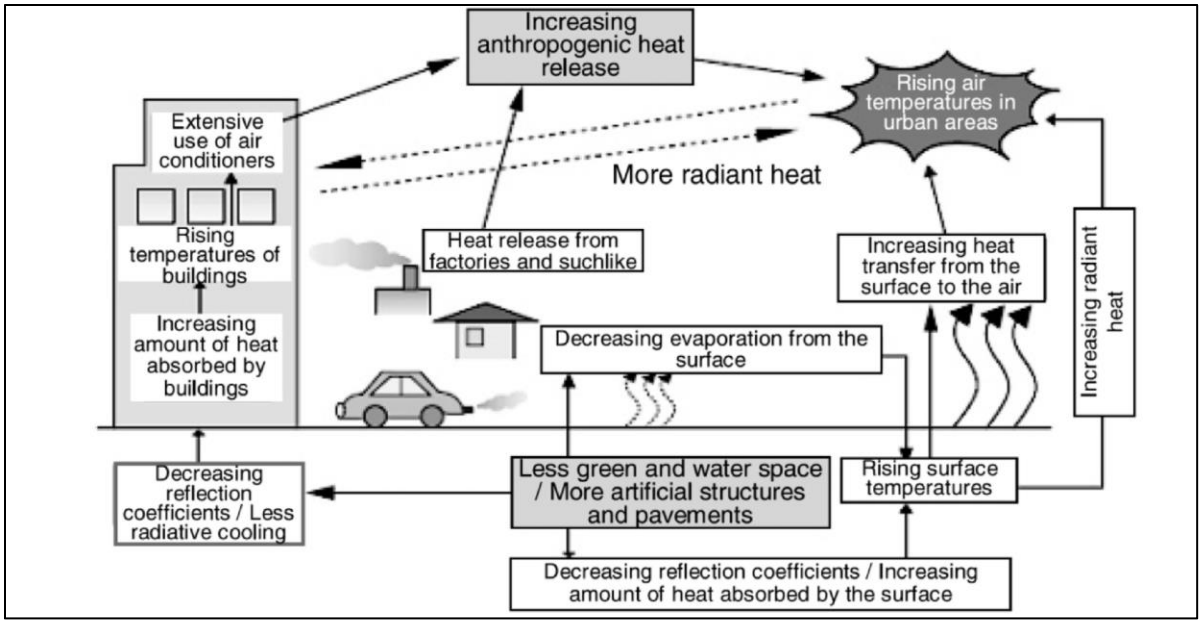

Figure 1. How the Urban Heat Island Effect Occurs [1]

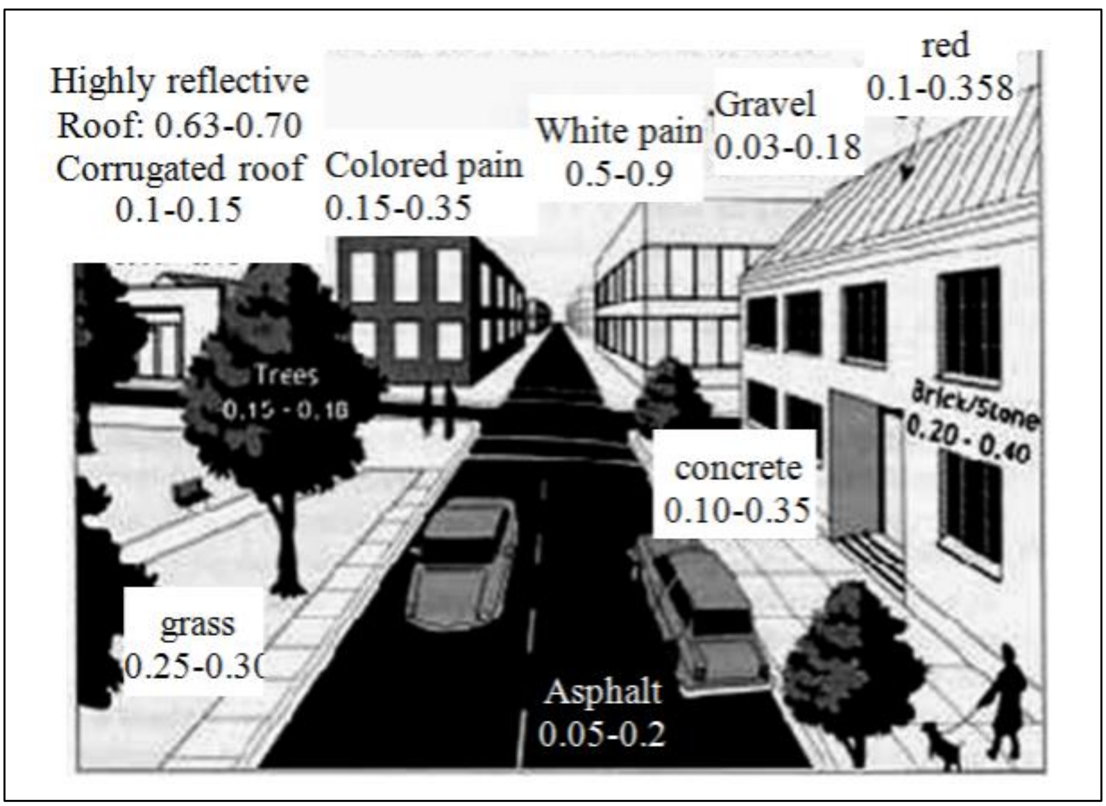

Figure 2. Albedo values of an Urban Area [2]

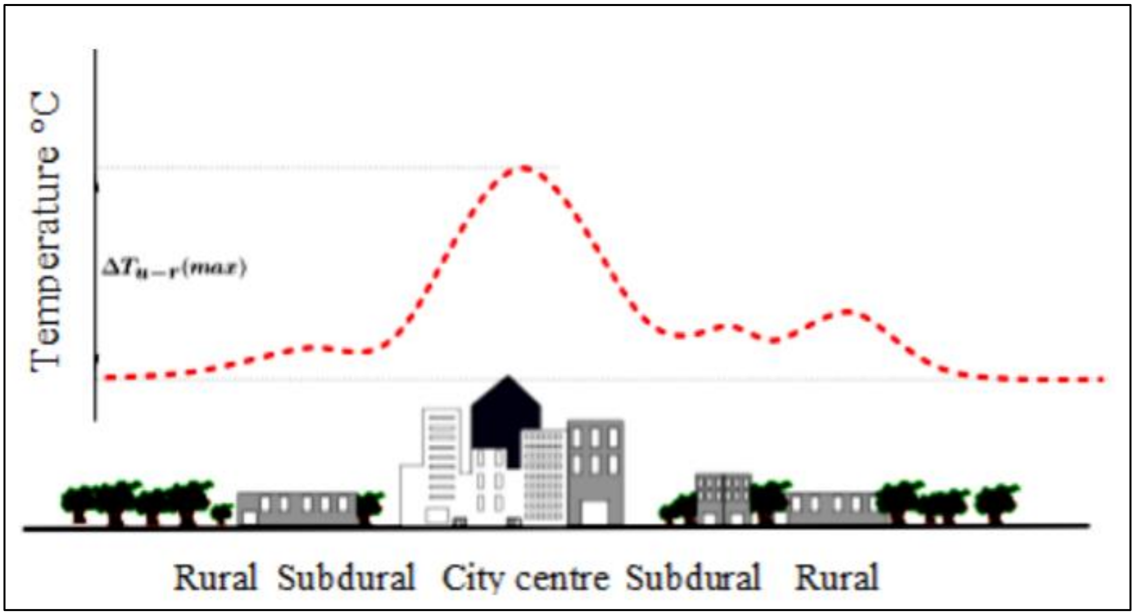

Figure 3. Thermal Profile of Urban Heat Island [2]

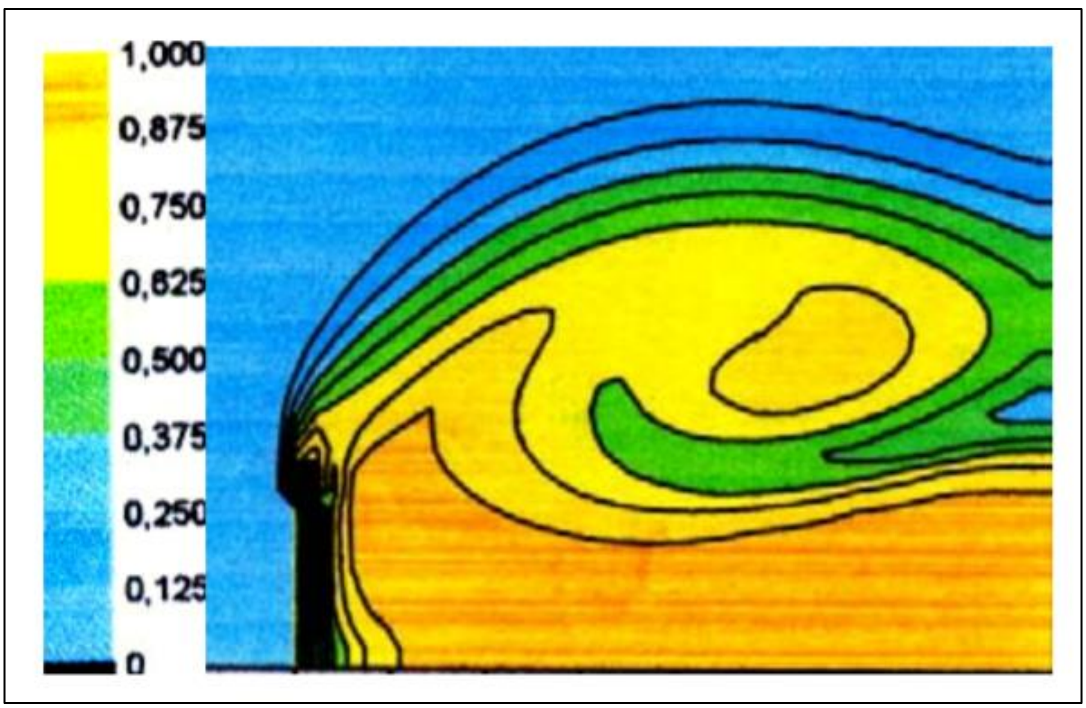

Figure 4. Turbulent Viscosity of Particulates and Energy [2]

The aforementioned causes of the UHI effect can be solved by utilizing new engineering materials, incorporating green spaces to modernize urban planning, and investing in mass transit. As previously mentioned, the UHI effect is exacerbated by engineering materials such as black asphalt concrete whose chemical and physical properties entrap heat and forms of energy within a city space. The first step to address material heat capture would be to completely revamp the approach to pavement design methodologies. New inventions such as *Cool Pavements* have recently been developed to "increase albedo, increase permeability […] to decrease surface temperatures through evaporation processes, increased thermal storage capacities, usage of external mechanical systems in order to reduce the surface temperature, and provide efficient shading of paved areas using natural or artificial solar control devices" (Santamouris, 2013). Increasing the permeability of pavement designs would allow water to flow through materials and cool down roadways through natural processes. These cool pavements also increase thermal storage capacity, resulting in a large latent heat storage value: an ability to store heat energy with little temperature gradients. External mechanical systems could also be installed to use fluid circulation, just as water would flow in permeable pavements, during non-rainy seasons. Concerns about the lifetime of cool pavements can be put to rest as an increase in albedo can also "increase the durability of pavements […] by either an appropriate surface coating, or aggregates of light color or proper binder or a combination of the above" (Santamouris, 2013). Although changing roadway materials would allow for better energy dissipation, it does nothing for the number of cars and vehicle miles travelled (VMT). Investing in mass transit systems with concepts such as Bus Rapid Transit (BRT) would reduce private vehicle ownership. Public transportation networks of various modalities already exist and have abundant ridership and environmental data that prove their energy efficient methods of travel. Research in Brisbane, Australia supports that "intensifying land use in compact development in close proximity to public transport interchanges […] were the most productive forms of land use to maximize compact development within the bounds of the UHI" (Degirmenci, 2021). If mass transit systems were vast and accessible, the insistence to use private transit would decrease rapidly if the networks connected housing, central business districts, and locations of leisure. An added benefit is the decrease in greenhouse gas emissions, especially if public transit modalities ran on alternative fuels. Haddad's projections for increased population density in urban settings also makes public transit investment an obvious priority for its potential to solve multiple environmental concerns. Besides changing the engineering fundamentals of a city, modernizing urban planning practices with vegetation would solve both circulation and heat transfer issues. Design principles that implement cool pavements and public transportation would actually increase the general area that could be used for green spaces (Figure 5). By taking advantage of the increased area, vegetation could help "improve local air circulation through installation of street trees, city parks, and rooftop gardens and could be further enhanced in conjunction with water and wind sources" (Mohajerani, 2017). Rooftops (Figure 6) are often underutilized, and by converting the numerous metropolitan rooftops to greenscapes the UHI could be massively alleviated. Green spaces work by "providing solar protection and cooling of the ambient air through evapotranspiration […] and mask noise, prevent erosion, stabilize soil, filter the ambient pollutants, increase property values, and make cities more attractive" (Santamouris, 2013). Green canopies should become a standard priority in developing new cities and should also be retrofitted into existing ones to help moderate the UHI, and their nice aesthetics are only an added bonus. In order to reduce the UHI effect from an engineering perspective we must combine modern efforts in R&D to change the standards of pavement design, expand mass transit modalities, and create greenspaces in as many avenues as possible. By applying these principles, politicians and city planners could leverage proven techniques to establish a policy-built agenda that protects these projects and to install them in an equitable fashion that benefits all city dwellers regardless of demographic or socioeconomic status.

Figure 5. Urban Green Space Example [6]

Figure 6. Green Rooftop Example [7]

In order to implement the engineering and planning principles mentioned before, city planners and politicians must work together to use data driven decisions to create policy frameworks that incentivize the protection of public and natural health. Without policy, the innovative ideas just presented could not be implemented in an equitable fashion and are destined to falter without proper guidance and accountability for operation. In the face of the newly passed Infrastructure Investment and Jobs Act (IIJA) passed in November 2021, important decisions need to be made cohesively with advanced technical solutions to bring the country back to the gold standard of civil engineering and city planning on a global scale. The US currently sits at a C- level according to the infrastructure report card, worsened by its specific grades in bridges: C, in roads: D, and in transit: D- (Figure 7). Cities like Phoenix, Arizona have kickstarted programs to reduce UHI intensities through a multi-pronged approach that can be scaled to other locations. For example, municipal governments in Arizona (an arid climate already susceptible to heat related issues) “implemented a popular rebate policy in 2007 that offered $500 for homeowners to convert at least 46.5 m^2 (500 square feet) of existing mesic landscaping to xeriscape yards” (Chow, 2012). Xeriscaping means to convert existing land conditions to low-water demand vegetation, as part of a wider sustainability initiative. Xeriscaping addresses the issue of low albedo and can provide larger green canopies in order to recycle energy dissipation. By involving the community, awareness is spread in an incentivized manner. Although landscape measures are a part of the equation, automobile use still is the largest factor in determining how far the impact of the UHI effect can reach. Electrified mass transit, or even alternative fuel mass transit is the key to mitigating the impact of the UHI. The strictest method to increase ridership would be to install “Driving restrictions and governmental taxes [that] can help to increase the number of people that use public transportation” (Kolbe, 2019). The issue remains that public transportation systems cannot be overhauled overnight, and it is expensive to change entrenched travel behaviors. The IIJA promises six hundred billion dollars dedicated to surface transportation investments over the next 5 years, so there is a massive opportunity to revitalize mobility in this country. Important considerations involve accessibility given that “persons differ in how they value the many dimensions related to transport, ranging from travel costs, and travel time up to safety, as well as the destinations themselves, which in turn may translate into quite distinct travel and activity patterns between and within population groups, even when they live in the same area and have access to comparable transportation modes” (Martens and Golub 2018). Public transportation is already serviced at a loss, so by subsidizing the modality for low-income demographics, ridership could drastically increase and have an overall net benefit. Another idea to reduce the number of cars on the road is curb space and roadway allocation (Figure 8). Currently, urban roadways “divide neighborhoods, destroy local businesses in established communities and create sterile, inhospitable streetscapes (Laplante and McCann 2008). Establishing pedestrian safety and walking communities alongside public transit by using the principles of complete streets would spur natural greenscape architecture and also disincentivize private travel. A buildings footprint also has a significant role on the UHI “since HVAC systems are energy-intensive and create anthropogenic heat” (Degirmenci, 2021). Therefore, policy frameworks like the one installed in California for *cool communities* can help reduce utility bills, improve air quality, and enhance urban livability (Degirmenci, 2021). Cool community strategies are voluntary measures that when aggregated together can have a profound impact on an area’s climate. The emphasis on combatting the UHI requires a collective effort from multiple sectors and industries and cannot be solved from one side. There are different perspectives on what efforts need to be taken and prioritized to begin the process. Across my studies it became clear that some believe revolutionizing mass transit is the best answer, although the initial costs are heavy, as is the same for overhauling engineering materials, while others believe small scale green space investment is the proper first step. “Fix it first, expand second, reward third” (Kahn & Levinson 2011), is a famous adage that refers to a framework that encapsulates the mission to solve policy issues. In reference to the UHI, revenue from gas taxes can be used to begin installing cool pavements as part of maintenance and rehabilitation, help create a new federal highway bank for new expansions to existing public transit infrastructure, and thirdly finance new green space models using the revenues of the newly created federal highway bank. There needs to be a multidisciplinary effort to make sure strategic policies host a feasible and fortuitous return on mitigating the overall impacts of climate change with opportunities such as "an integrated policy mix […] as having both cohesiveness across policy goals (for example, GHG mitigation as well as other desirable co-benefits) and consistency across specific policies" (Axsen, Plotz, Wolineatz, 2020). This cooperation is necessary to merge the benefits of multiple policies rather than the lesser sum of them as independents. The purpose of policy mixing is to enact a set of standards and bylaws that are palatable to different but large bodies of society. Although "Announced goals to date are not enough to move the market quickly" (Brown 2020), the economics for public health behind these decisions gives credence to the fact that it is possible to use policy mixing, regulations, and incentives in order to mitigate the effects of the Urban Heat Island.

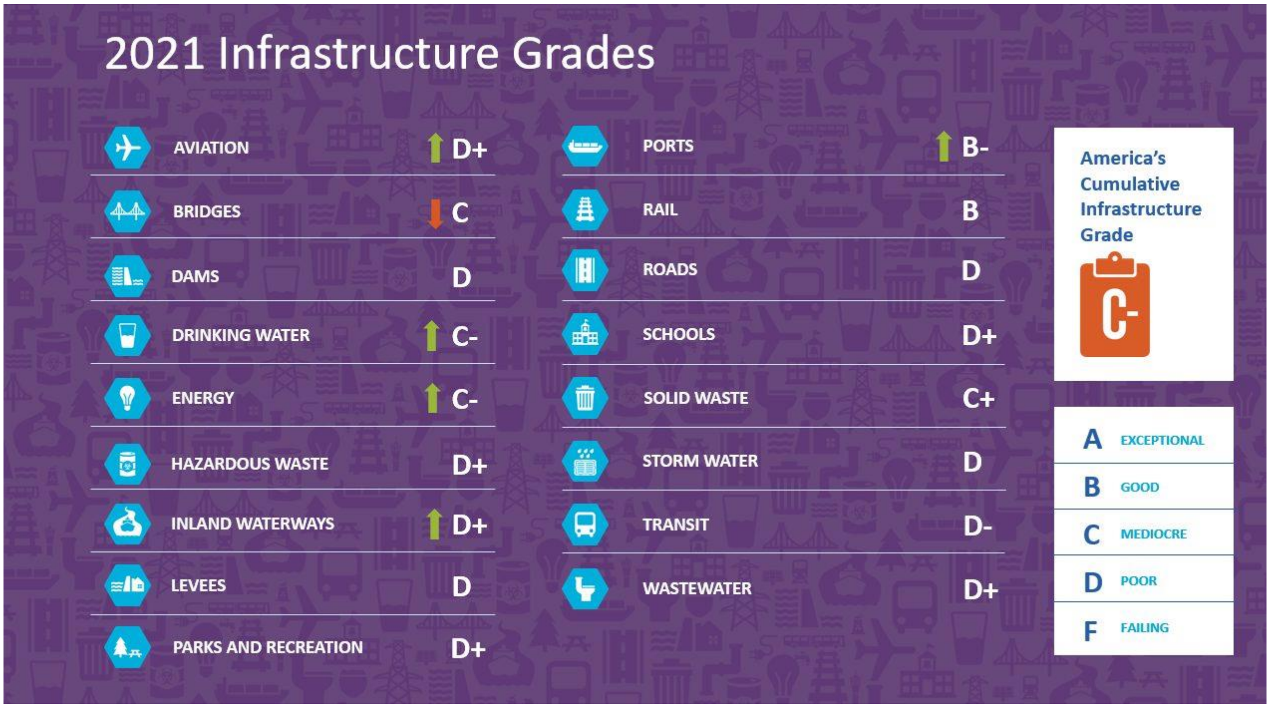

Figure 7. USA Infrastructure Report Card [8]

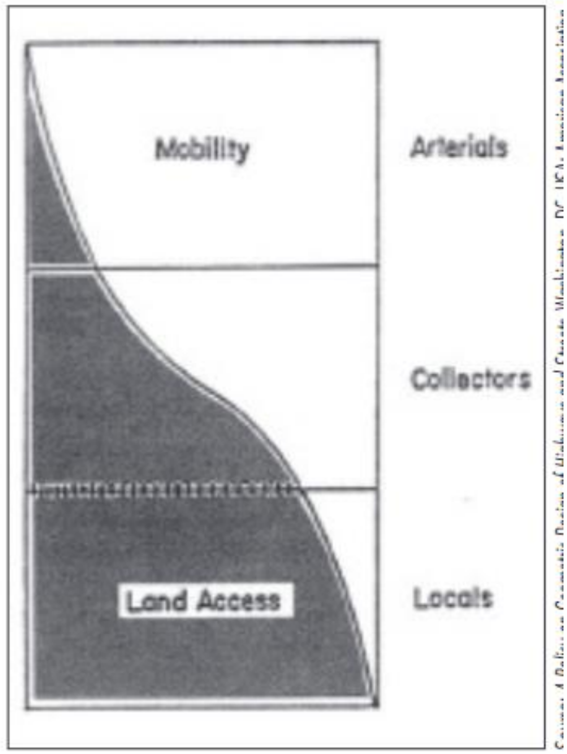

Figure 8. Roadway Breakdown [15]

Overall, the UHI can managed by understanding the root causes of the phenomenon, analyzing the engineering solutions to the aforementioned issues, and working with policy strategies that sustain a proper shift in city planning. Considering the UHI effect, there are only two ways to install policy-based frameworks given the context of the information available. Newly developed cities should install subsidized mass-transit systems, utilize cool pavements wherever possible, and prioritize green spaces as much as they can. On the other hand, cities already suffering from tough climate change conditions should begin by educating the community about the negative impacts and begin a voting process over which initiatives best serve their urban area with initiative-taking efforts. Regardless, it is clear that providing mass transit options has the most significant impact on reducing the UHI and should be prioritized as the idea that best serves the interest of the community. By informing the public on the harmful impacts the UHI can have on cities, government authorities should be more inclined to solve the problem given the ongoing research and development for sustainable engineering practices. Important policy decisions will have to utilize the IIJA as the perfect outlet to implement a multi-faceted approach that can be spearheaded by research institutions, city planners, and politicians to guarantee public health and safety from the destructive impacts of the Urban Heat Island effect.

References

1. Mohajerani, Abbas, et al. "The Urban Heat Island Effect, Its Causes, and Mitigation, with Reference to the Thermal Properties of Asphalt Concrete." *Journal of Environmental Management*, vol. 197, 15 July 2017, pp. 522–538., https://doi.org/10.1016/j.jenvman.2017.03.095.
2. Louiza, Haddad, et al. "Impact of the Transport on the Urban Heat Island." *INTERNATIONAL JOURNAL FOR TRAFFIC AND TRANSPORT ENGINEERING*, vol. 5, no. 3, 2015, pp. 252–263., https://doi.org/10.7708/ijtte.2015.5(3).03.
3. Aram, Farshid, et al. "Urban Green Space Cooling Effect in Cities." *Heliyon*, vol. 5, no. 4, 8 Apr. 2019, https://doi.org/10.1016/j.heliyon.2019.e01339.
4. Santamouris, M. "Using Cool Pavements as a Mitigation Strategy to Fight Urban Heat Island—a Review of the Actual Developments." *Renewable and Sustainable Energy Reviews*, vol. 26, Oct. 2013, pp. 224–240., https://doi.org/10.1016/j.rser.2013.05.047.
5. Degirmenci, Kenan, et al. "Understanding Policy and Technology Responses in Mitigating Urban Heat Islands: A Literature Review and Directions for Future Research." *Sustainable Cities and Society*, vol. 70, 2021, p. 102873., https://doi.org/10.1016/j.scs.2021.102873.
6. "Do You Really Know All the Benefits of Green Roofs?" *Urbanscape*, 19 Oct. 2018, https://www.urbanscape-architecture.com/do-you-really-know-all-the-benefits-of-green-roofs/.
7. Constantino, Sherry. "The Benefits of Urban Green Spaces." *NewPro Containers*, 27 May 2019, https://www.newprocontainers.com/blog/benefits-urban-green-spaces/.
8. *America's Infrastructure Report Card 2021 | GPA: C-*. https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf.
9. Chow, Winston T., et al. "Urban Heat Island Research in Phoenix, Arizona: Theoretical Contributions and Policy Applications." *Bulletin of the American Meteorological Society*, vol. 93, no. 4, 2012, pp. 517–530., https://doi.org/10.1175/bams-d-11-00011.1.
10. Kolbe, Karin. "Mitigating Urban Heat Island Effect and Carbon Dioxide Emissions through Different Mobility Concepts: Comparison of Conventional Vehicles with Electric Vehicles, Hydrogen Vehicles and Public Transportation." *Transport Policy*, vol. 80, 2019, pp. 1–11., https://doi.org/10.1016/j.tranpol.2019.05.007.
11. Martens, Karel, and Aaron Golub. "A Fair Distribution of Accessibility: Interpreting Civil Rights Regulations for Regional Transportation Plans." *Journal of Planning Education and Research*, vol. 41, no. 4, 2018, pp. 425–444., https://doi.org/10.1177/0739456x18791014. **Δ**
12. Kahn, Matthew E., and David M. Levinson. *Fix It First, Expand It Second, Reward It Third: A New Strategy for America's Highways*. Hamilton Project, 2011. **Δ**
13. Axsen, Jonn, et al. "Crafting Strong, Integrated Policy Mixes for Deep CO2 Mitigation in Road Transport." *Nature Climate Change*, vol. 10, no. 9, 2020, pp. 809–818., https://doi.org/10.1038/s41558-020-0877-y. **Δ**
14. Brown, Austin L., et al. "Driving California's Transportation Emissions to Zero." *EScholarship, University of California*, 22 Apr. 2021, https://doi.org/10.7922/G2MC8X9X. **Δ**
15. LaPlante, John, McCann, Barbara. "Complete Streets: We Can Get There from Here." *ITE Journal*, vol. 78, no. 5, 2008, pp. 24-28. **Δ**

Δ Refers to five source materials obtained from CIVENG 250N