SDConference Proceedings 2022 ISBN: 978-86-87043-85-5

# Architecture as a Catalyst in Mitigating Heat Island Effect

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## ABSTRACT

With the increased rate of expansion of urbanization and urban sprawl in the recent years, the environmental issues faced by urban places become ever more concerning. The heat island effect has prejudicious effects on the environment as well as on the dwellers. Urban heat Island effect, which is generally caused due to the replacement of natural land cover with dense concentrations, the research paper will help in understanding whether and how architecture plays a role in mitigating the heat island effect. Architecture has a definite role to play in the mitigation of the urban heat island effect: cities are defined by their buildings and make up a large part of the built environment. The choices that architects and planners make can have a huge impact on the size of a city's urban heat island. (Munro, 2012) Questions of sustainability and environmental consequences pervade most aspects of our lives. In architectural practice, they influence our building regulations and our energy codes. (Thomas, 2015) The research paper is an attempt to review various cases across the world where architecture – both buildings and spaces affect a city's urban heat and also review the factors that help to develop resilient architecture in the context of climate change.

**KEYWORDS:** *Urban heat island, Architecture, Environment, Climate change, Design strategies*

 ISBN: 978-86-87043-85-5

## 1. INTRODUCTION

Due to replacement of natural terrain and land cover with dense accumulation of built mass like pavements, buildings and other surfaces that absorb and retain heat brings up an effect called “urban heat islands”.(Learn About Heat Islands: Environmental Protection Agency, 2022)Urban heat island effect has been consequently associated with additional environmental effects like Urban canyon effect – which occurs as a result of trapped heat on streets due to construction on both sides, and dust dome effect – a phenomenon in which soot, dust, and chemical emissions from human activities and vehicles get trapped in the air above urban spaces.(Munro, 2012)Due to urbanizing trends in society, a greater number of populations is shifting towards urban areas which is eventually increasing the demand of housing and amenities in the urban areas. People expect to seek new opportunities and improve their lifestyle. Even though urban development and infrastructure satiate number of amenities to the people, but it also comes up with long-term ramifications. Though urbanization comes up with its own prospects, but the dark side of the urban development needs to be thrown light upon. The increased prevalence of environmental issues caused due to urbanization cannot be compromised with economic and social stability. Architecture and urban infrastructure being the main cause for the occurrence of these phenomena, we intend to entail architecture as a part of the solution in mitigating the heat island effect.

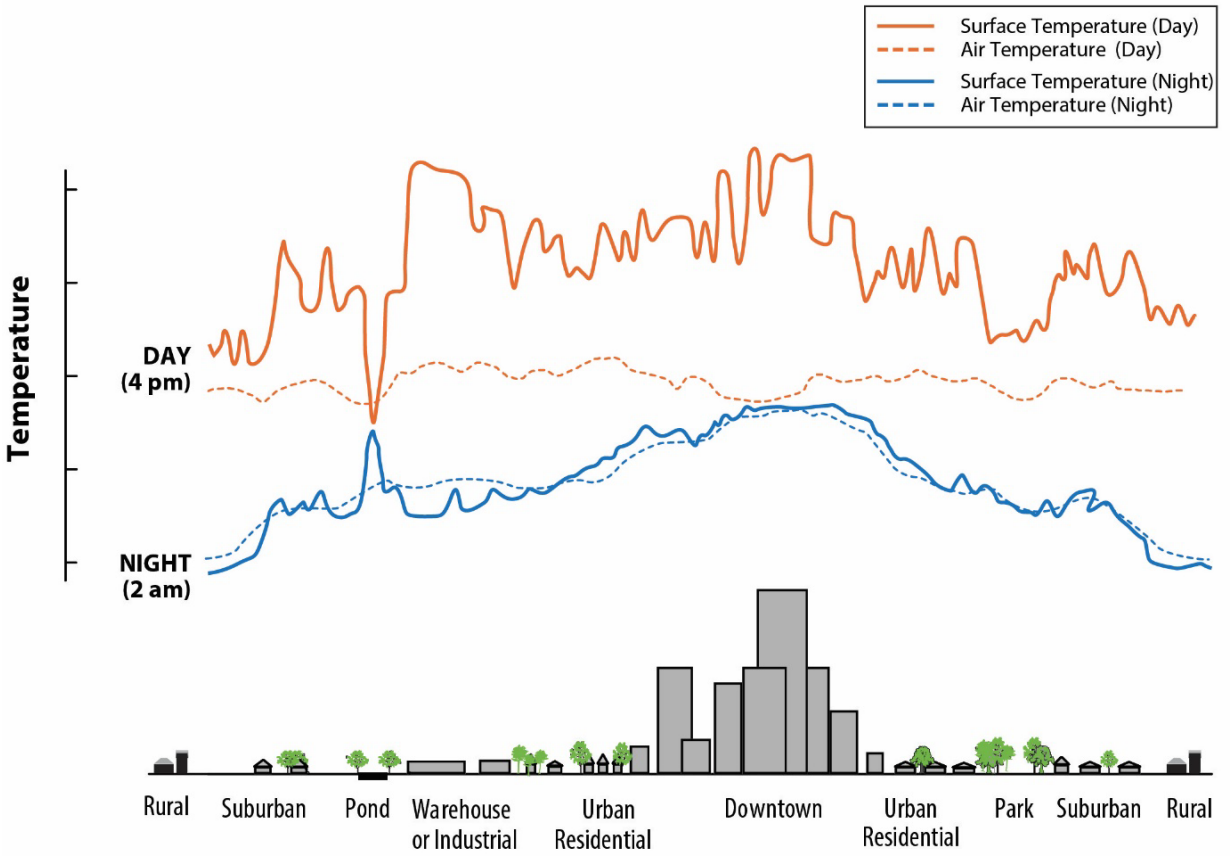


Figure 1: Day and Night-time temperature variations in various regions (Source: US Environmental Protection Agency)

 ISBN: 978-86-87043-85-5

## 2. METHODOLOGIES

2.1 Study through various cases around the world, in which architecture –
- 2.1.1 - affected the urban heat island effect
- 2.1.2 - mitigated the urban heat island effect

2.2 Understanding views of experts in the field regarding role of architecture in mitigating urban heat island effect.

## 3. IMPACT OF URBAN HEAT ISLAND EFFECT

Urban spaces experiencing this effect eventually experience higher daytime temperatures, reduced night-time cooling, and higher air-pollution levels. Due to which the demand for electricity elevates. Electricity which is typically sourced from fossil fuel power plants, lead to increase in air pollutants and greenhouse gas emissions. As the infrastructure gets more complex and denser, the way for the trapped heat and pollutants to escape or dilute becomes too narrow. The increased temperature on ground level eventually leads to ozone layer zone formation usually identified by smog which contributes to complex air quality problems. Sensitive population become vulnerable during such conditions. All humans are physiologically affected in different ways by prolonged exposure to heat, which frequently exacerbates pre-existing illnesses and causes risk of premature death and disability. (WHO, 2018) Heat islands effect cause excessive and abrupt increase in temperature due to which the burden on water, energy, transportation, food, and livelihood security elevates resulting in power shortages or even blackouts. According to WHO, between 2000 and 2016, the number of people exposed to heat waves increased by around 125 million. These heat islands thus become catalysts for it to intensify and have harmful and threatening effect on the environment as well as the people. (Learn About Heat Islands: Environmental Protection Agency, 2022)

## 4. CASE STUDY OF NEW YORK – urban environment where urban heat islands have affected the environment and people.

A heat island effect exists in New York City, with mean temperatures in the NY Central Park (NYCP) Station typically higher than the surrounding stations, ranging from 1.20°C to 3.20°C, according to an analysis of temperature differences over time between the NYCP station and 23 regional weather stations classified according to distance and level of urbanisation.(Rosenthal, Knowlton, Rosenzweig, Goldberg, & Kinney, 2003)NYC experienced heat wave conditions majorly in the month of July which is considered to be the hottest month of the year; the highest air temperature above 32.22 °C (90 °F) on roughly more than half of the month for which the local meteorological office issued heatwave warnings.(Ramamurthy, González, Ortiz, Arend, & Moshary2, 2017)Urban environments are dominated by constructed surfaces, which have a high thermal inertia and a large ability to store heat. After nightfall, the heat that has been stored is released as sensible heat, accelerating the urban-rural thermal gradient. The inner-city areas experience greater UHI

 ISBN: 978-86-87043-85-5

values than the neighbourhoods close to the coastal areas. The UHI intensity is amplified due to the spatial pattern to local dynamics and land cover characteristics. According to study conducted by New York City Community Air Survey (NYCCAS), the most significant predictor of monthly average minimum temperatures was greater level of development, followed by distance to coastline and that it might take a green cover above a baseline level and reduction of impervious surface such as asphalt, tar and building materials that absorb most of the sun's radiation for temperature to drop.

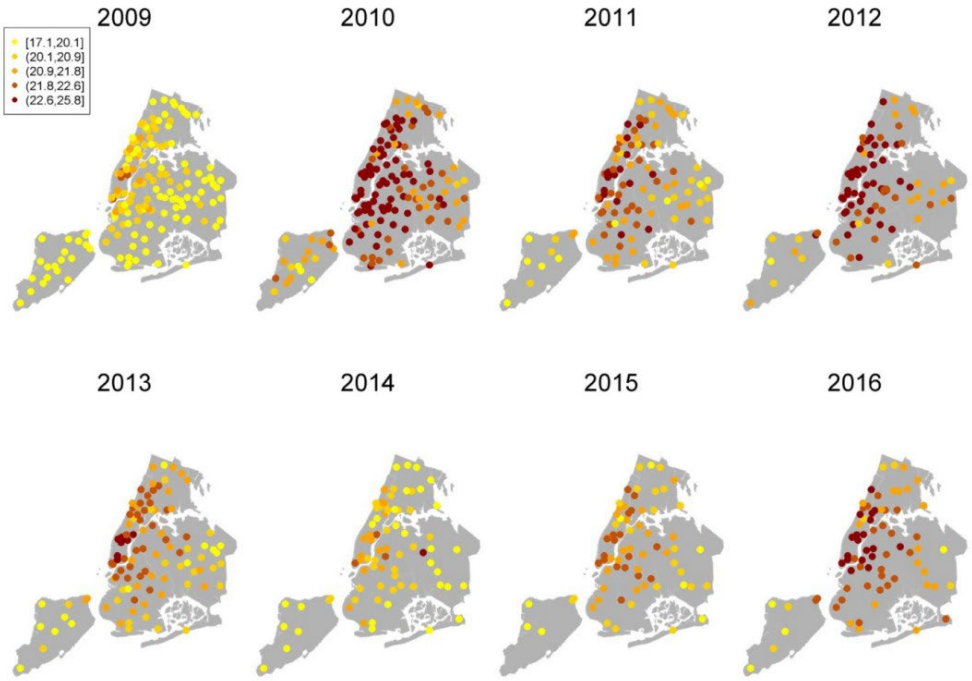


Figure2: New York map of temporally adjusted summer average temperature by year (Johnson, Ross, Kheirbek, & Ito, 2020)

## 5. ARCHITECTURAL FACTORS RESPONSIBLE FOR URBAN HEAT ISLAND EFFECT

**5.1 Impervious surfaces:** Vegetation when replaced by impervious surfaces like asphalt and concrete for roads, buildings, and other structures lead to increase in surface temperatures and ambient temperatures, as a result of materials that absorb heat from the sun rather than reflecting it.(UCAR, 2022)

**5.2 Size and shape of cities:** Cities are significantly different in shape from rural places in terms of aerodynamics. Tall structures serve as barriers and slow down winds.(UCAR, 2022)

**5.3 Reduced natural landscapes in urban areas:** Reduction in the number of trees, plants, and water bodies that would otherwise serve to cool the air by shade, water transpiration from plant leaves, and surface water evaporation, respectively.(Learn About Heat Islands: Environmental Protection Agency, 2022)

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**5.4 Urban Geometry:** Wind flow and the potential of urban materials to both collect and release solar energy are influenced by the size and arrangement of structures inside a city. Surfaces and structures that are blocked by nearby buildings in densely populated places evolve into huge thermal masses that are difficult to dissipate heat from. Cities with plenty of narrow streets and tall structures can turn into urban canyons that can prevent the cooling effects of natural wind flow. (Learn About Heat Islands: Environmental Protection Agency, 2022)

**5.5 Dark Surfaces:** A black material absorbs all light energy and transforms it into heat, which causes the thing to warm up. Dark surfaces, like those used in construction, therefore absorb solar heat, and amplifies urban heat island effect.(Penny, 2019)

**5.6 Air conditioning:** Buildings with dark surfaces heat up more quickly and need more air conditioning to cool them down, which takes more energy from power plants and produces more pollution. Additionally, air conditioners heat the local area by exchanging heat with the outside air. Urban heat islands are therefore growing as a result of a cascading effect.(Marar & Gupta, 2022)

## 6. ROLE OF ARCHITECTURE IN MITIGATING THE HEAT ISLAND EFFECT

The urban heat island effect will only expand as the world becomes more urbanised, and architecture will have a greater challenge—and obligation—to play a substantial role in its mitigation. The decisions that architect, designers, and planners make about these new roads, buildings, and cities will have a significant impact on the quality of life for the people who live there, from the air they inhale to the electricity costs they pay to the climate they experience. This is true throughout the globe as the natural environment keeps making way for the built environment.
Understanding how the structures and spaces that are designed affect a city's urban heat is important for the profession of architecture to mitigate the effect of the urban heat island. Sustainable building design has been primarily focused on the internal environment of the building, whereas designing out urban heat islands will require consideration of the external ramifications of designs, so architecture's response to mitigating urban heat islands needs to be distinct from its environmental response. It is necessary to comprehend how choices in external cladding, construction materials, glazing placement and size, building shape, and geometry affect the urban heat island effect in a region. In the efforts to make each city unique, it is crucial that architects should be aware of the effect of the design on the environment. Their materiality and design, however, is a significant contributor to the urban heat island effect.(Munro, 2012)

**6.1 Use of materials with low thermal mass:** One of the main contributors to the urban heat island effect is concrete, which has a large ability to retain heat and is referred to as a "high thermal mass" material. To help minimize the heat island effect and protect the environment, the use of highly reflective materials like glass or metals should be reduced.(Tiwari, Karmakar, & Sharma, 2021)

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**6.2 Cool Roofs/ Green Roofs:** About 25% of a city's surface area is comprised of roofs, therefore the heat they absorb and release, significantly affects the city's temperature.(Akbari & Levinson, 2008) Replacing the conventional concrete roofs which absorb 90% of the sun's heat energy, with a light-coloured roof/ greener roof which will only absorb 10% or less will significantly impact on the heat transferred inside the building and thus reducing the artificial air conditioning demand.

**6.3 Landscaping:** The urban heat island effect was first brought about by as a result of natural environment being destroyed to make way for the constructed environment. Thus, reintroducing vegetation in horizontal as well as vertical elements effectively spread across the buildings and urban public spaces would help in reducing urban heating. Increased use of green elements could significantly reduce the impact of the urban heat island effect. Vegetation at street level can be employed to mitigate the urban heat island effect where green roofs and living walls are not suitable equally effectively. (Munro, 2012)

**6.4 Street plantations:** Urban heat island effect can be significantly reduced by street level landscaping. Trees that are close to a building may significantly affect the need for air conditioning by affecting both the interior and outside temperatures of the building.(Munro, 2012)

**6.5 Improving the urban geometry:** The streets should be made wider to increase circulation, and they should be supported by vegetation to prevent adjacent buildings from blocking the air in the narrow streets.

**6.6 Reducing dark coloured surfaces:**Some cities are "lightening" their streets to reduce urban heat islands. This is accomplished by applying a highly reflecting grey coating to the dark rooftops, parking lots, and streets made of black asphalt. Urban air temperatures can be drastically lowered by these modifications, particularly in the sweltering summer months. This can lessen the urban heat island effect, which is caused by the black body effect.

**6.7 Vernacular methods of building construction:** Utilizing readily available, environmentally friendly materials along with unique construction methods can improve the area's attractiveness while simultaneously minimising the consequences of urban heat islands.(Tiwari, Karmakar, & Sharma, 2021)

**6.8 Building envelope and shading devices:** This concept, known as "Cool Building Envelopes," describes a building envelope that can decrease the amount of radiant heat that is stored and, as a result, minimise the amount of heat that is emitted into the environment. The Cool Building Envelope concept not only reduces traditional energy use but also protects the environment from pollutants and serves as a strategy to combat urban heat island.(Elhinnawy, 2005) In the urban environment, shading devices block incoming solar radiation from surfaces like the urban floor, seating spaces, building façades, and rooftops and successfully maintain their temperatures lower.(Vartholomaios & Kalogirou, 2020)

**6.9 Effective and efficient electrical appliances:** Utilizing energy-efficient equipment and appliances can lessen the heat island effect by reducing greenhouse gas emissions from electrical appliances. The heat island effect is reduced by the efficient use of energy-saving

 ISBN: 978-86-87043-85-5

appliances, which release lesser greenhouse gases into the atmosphere. (Tiwari, Karmakar, & Sharma, 2021)

**6.10 Rain gardens and swales:** Storm water attenuation benefits majorly from Sustainable Urban Drainage Systems (SUDS). Swales and rain gardens are examples of SUDS that catch storm water and enable it to slowly seep into the ground. They give water extra time to evaporate since they hold onto it for a longer amount of time. By integrating vegetation, rain gardens perform evapotranspiration as well, significantly cooling the air.(Jolma Architects, 2018)

## 7. CASE STUDY OF COPENHAGEN: Urban environment where urban heat islands have been mitigated using architectural strategies.

On the hottest day in Copenhagen in 2010, surface temperatures up to 47 degrees were recorded; nevertheless, the temperature was 12 degrees lower outside the city. As part of the city's comprehensive climate plan, Copenhagen has created its own climate adaptation strategy in response to rising sea levels, more rainfall, and a warmer city centre. By reducing CO2 emissions by more than 20% over the past ten years and ensuring that 30% of its energy supply comes from carbon-neutral sources, Copenhagen has already reduced its environmental footprint. To reduce rainwater run-off, more green spaces, such as "pocket" parks and green walls and roofs, have been added. In addition to capturing 60% of rainfall, green roofs help enhance air quality, plant life, and wildlife habitat while minimising the effects of urban heat islands.(About: ENVIRONMENT Eco-Innovation Action Plan, 2010) Copenhagen seeks to alter its current urban layouts to make better use of energy. Retrofitting is the process of renovating historic structures with an eye towards energy efficiency. Old windows are replaced during renovations, and insulated walls, doors, and roofs are built. Solar panels and green roof gardens are additionally incorporated. Copenhagen not only constructs infrastructure but also protects its green spaces. It is considered a successful method of lowering the city's surface temperatures and helps lessen the impact of the urban heat island. (Sustainability: Urbanlife Copenhagen, n.d.) According to the European Environment Agency, roughly 60% of the Copenhagen region is covered in impermeable materials, which leads to many difficulties during periods of heavy rain. Therefore, all of these green spaces that make up Copenhagen's green infrastructure are storm water management solutions with the primary goal of reducing the strain on the sewage system. Copenhagen's green infrastructure contributes to cooling off the city during heat waves.

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Figure 3: Sustainable strategies to mitigate urban heat islands in Copenhagen (Copenhagen Urban Lab Executive Summary, 2020)

## 8. INNOVATIVE STRATEGIES

A new field of study in the reduction of the urban heat island effect has been evolving. Innovative strategies with subject to materiality, coatings, technologies, planning processes, policies, etc. can be looked up to develop mitigating techniques for urban heat islands.

**8.1 Sponge cities:** A recent AI-based study measures cities' resilience to climate change by comparing the number of trees and lakes they have to how much concrete they contain. Urban areas that include plenty of natural features, such lakes, parks, and trees, as well as other well-designed structures meant to soak up rain and prevent flooding, are known as "sponge cities." In order to promote sponginess and provide additional advantages, such as cleaner air, habitat for wildlife, and places to escape the summer heat, many cities are developing green spaces. The Sponge City theory places a strong emphasis on the fundamental ideas of 'based on nature', 'source control', 'local adaptation', 'protecting nature', 'learning from nature', preserving urban ecological space to the greatest extent possible, regenerating biodiversity, and creating a beautiful landscape environment. (Harrisberg, 2022)

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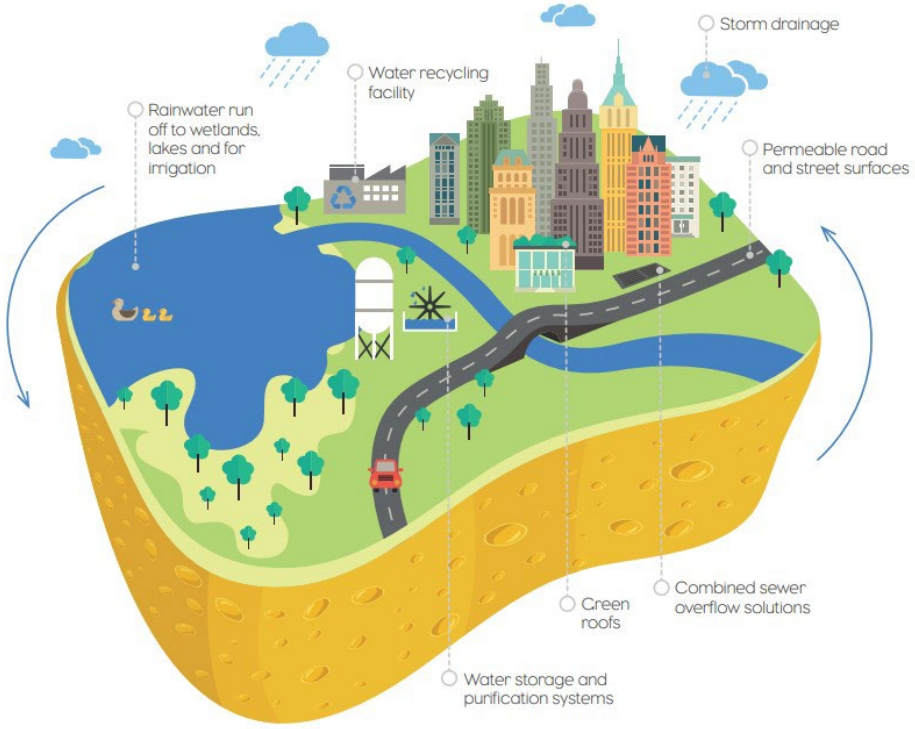


Figure 4: Module of a sponge city (Source: China-Britain Business Focus)

**8.2 Thermo chromic materials and coatings:** A substance that offers a remedy to one city might not make much of a difference to another. Innovative materials like thermo chromic, for example, have the ability to reduce urban heat islands on a scale greater than just one city. The importance of thermochromism and thermo chromic materials in a wide range of applications, including energy-efficient building constructions, the textile industry, thermal or heat storage, maintenance processing, and sensors, makes them of great interest. Buildings would be constantly changing, with all facades having slightly varying colours throughout the day, changing completely from morning to evening.(K, et al., 2022)

**8.3 Retro reflective materials:** Retro reflective materials have been proposed as a creative way to lower the amount of energy needed for cooling while also enhancing urban microclimates. Regardless of the direction of incidence, retro reflective materials have the capacity to reflect incident energy back towards its source.(Pérez, Castro, Melo, & Xamán, 2017)

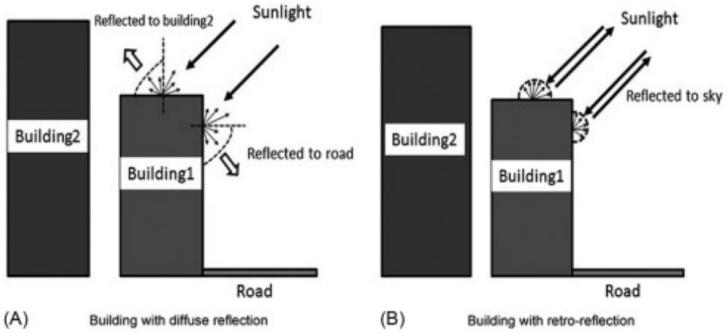


Figure5: Difference between diffuse reflection and retro-reflection (Pérez, Castro, Melo, & Xamán, 2017)

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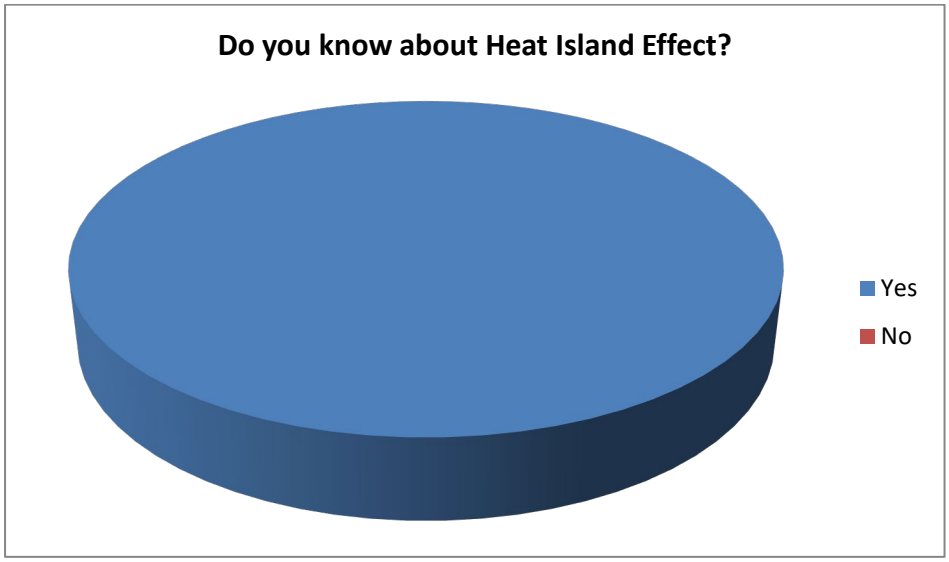
**8.4 Cool roofing strategies:** A cool roof technology system integrates smart sensors with rainwater harvesting systems to reduce attic and roof temperatures for increased occupant comfort. (Yew, 2021) TARC, or temperature-adaptive radiative coating, was created by researchers at the Materials Sciences Division of UC Berkeley with the intention of assisting in the achievement of this objective of zero electricity use and zero emissions.(Sander, 2022)

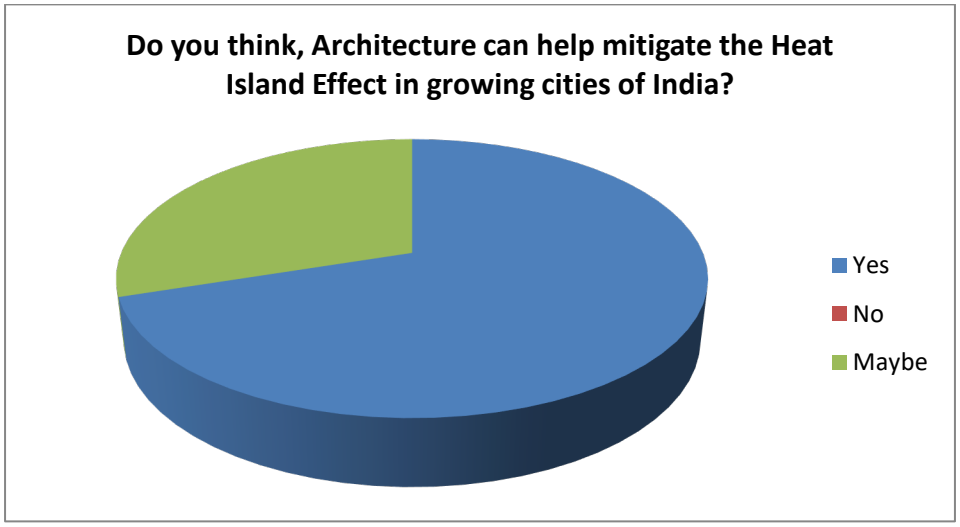
## 9. EXPERT'S OPINIONS, SUGGESTIONS AND VIEWS THROUGH INTERVIEWS AND QUESTIONNAIRE

To understand the expert's perspective about this research, a chosen sample of 10 respondents were identified and interviewed. The respondents are practicing architects, professors with a background of Environmental & sustainable Architecture. The respondents were asked *three* questions for which the following responses were recorded.

Do you know about Heat Island Effect?




Do you think, Architecture can help mitigate the Heat Island Effect in growing cities of India?



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What ways do you think Architecture contributes as a catalyst towards mitigating the Heat Island Effect?

**The responses from the respondents can be summarized as follows:**

For centuries, traditional Architecture has revolved around building in context with response to local climate & context, with focus on using traditional construction methods and materials. In several cases, self-shading blocks, mutual shading, low-rise and high density designs have typically addressed concerns that could create the issue of heat island effect. Architects like Charles Correa (at the Belapur housing, arts and crafts museum), B V Doshi (Madhya Pradesh Electricity Board Housing, Aranya Housing), Achyut Kanvinde (Most of his institutional campuses) and others have carefully created designs which not only have respected the built but also the unbuilt as well. Climate and context responsive architecture are a key towards addressing the growing concerns of heat island effect. Careful planning decisions at city level, implementing urban design guidelines that address the development of the built and the unbuilt, will help mitigate the growing temperatures of city core areas. (Source: responses from respondents)

## 10. FUTURE SCOPE OF RESEARCH

The following research suggests that both, Architecture and the role of Architect, can substantially contribute towards designing of the future built environment, which will have lesser environmental impact and the resultant heat island effect can also be addressed. Detailed studies about preparing guidelines for development can further be carried out as an extension to this research and it shall help evolve a better assessment matrix of the heat island effect.

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