# "Urban heat island mitigation in a tropical climate through building design employing passive design strategies"

Ar. Uvapriya. C[1], Ar. Vinodh. S[2], Ar. Emiline Madonna[3]

[1]Student, Masters of Architecture (M.Arch) School of Planning Architecture and Design Excellence – SPADE, Hindustan Institute of Technology and Science -Chennai
[2]Professor, School of Planning Architecture and Design Excellence – SPADE, Hindustan Institute of Technology and Science -Chennai
[3]Associate Professor, School of Planning Architecture and Design Excellence – SPADE, Hindustan Institute of Technology and Science -Chennai

## ABSTRACT

**The instinct of urban heat islands has got worse as a result of urbanization, and population increase, particularly in cities that have tropical climates. Due to urbanization most of the land is being turned into cities, and the cities are expanding getting hotter and hotter every day as a result of the UHI effect. The land surface temperature rise brought on by the urban heat island influences the urban climates, urban hydrologic conditions, soil properties, atmospheric environment, biological habits, material cycles, energy metabolism, residents' health, and mainly on the thermal performance of the buildings. The heat produced by the absorption of solar and infrared energy by urban materials is then released into the atmosphere, further increasing the air's temperature. Based on the review, early planning and building based on local weather information can minimize the UHI effect and reduce energy consumption. This paper is focusedon a healthy built environment with a passive, sustainable design that maximizes building efficiency in the future for the people and surroundings.**

**Keywords: Urban heat island (UHI); tropical climate; UHI mitigation; impact of building; passive design;**

## INTRODUCTION

Urban heat islands (UHI) are a worldwide problem for global environmental quality which is significantly impacted by urban development, including air quality, temperature rise, and traffic congestion. In many developing tropical nations, open space has been replaced by rapidly developing infrastructure due to urbanization and resulting in climate change which causes hotter summersand altered rainfall patterns influencing the buildings and surroundings. The application of heat island mitigation strategies is becoming more and more crucial in order to reduce energy consumption and enhance the quality of life due to the expected rapid and enormous population growth in the near future.

Population and UHI intensity are directly correlated and result in the highest energy consumption for heating and cooling buildings. Higherpopulation increases density and urban temperature in urban areas.The increase in UV-induced heatstress intensity can cause both indoor and outdoor heat stress to significantly increase, eventually experience uncomfortable living conditions. The World Meteorological Organization (WMO) commissioned a number of bibliographies on the subject in 1993 and 1996 because it has long recognized the value of researching tropical urban climates.

### Aim

This paper aims to investigate the origin, effects, and mitigation of UHI through passive design as well asto provide guidance for low thermal impact building design for reducing UHI in thefuture.

### Objective

a. Toexamine how passive design approachesaid in UHI mitigation from a building perspective.
b. To investigate the role that building materials have in thermal comfort (UHI) in tropical regions.
c. To examine how the emissivity and thermal characteristics of paved surfaces and roofs affect the amount of

UHI.

d. To increase the use of green strategies, such as green technologies and vegetation, to combat the urban heat island (UHI) issue.
e. To describe the idea, the forming factors, and the influencing factors of UHI.
f. To suggest ways to reduce building energy use in order to mitigate UHI.

## CAUSES AND EFFECTS OF URBAN HEAT ISLAND

***Causes:***

Tropical cities are perpetually warm and sunny, and heat islands can exacerbate thediscomfort of crowded cities. The following causes of urban heat Islands are

***Albedo-Low Materials*** -The albedo-low materials absorb heat (solar energy) and increase urban temperature.

***Anthropogenic gathering*** -An increase in population leads to the consumption of more energy which causes CO2 emissions,and rapidly increases the urban temperature to a great extent.

***Usage of Air Conditioners*** -Air conditioners keep the building cool inside and release the heat outside causing the atmospheric temperature to increase.

***Destruction of Trees*** -Trees are cut down(deforestation) to develop infrastructures in urban areas. Trees absorb heat and Co2 by photosynthesis and make the environment cool, the destruction of trees causes a rise in urban temperature.

***Urban Canopy*** - In cities, the heat reflected by the building is trapped by taller buildings forming a heat canopy which rises temperature causing UHI.

***Wind blocking*** - The fine-grain urban fabric in cities blocks the wind flow, and as a result cooling effect is reduced and not leaving space for the trapped heat to escape.

***Air Pollutants*** - The exhaust and emissions from the industries and vehicles produce greenhouse emissions and rise the temperature.

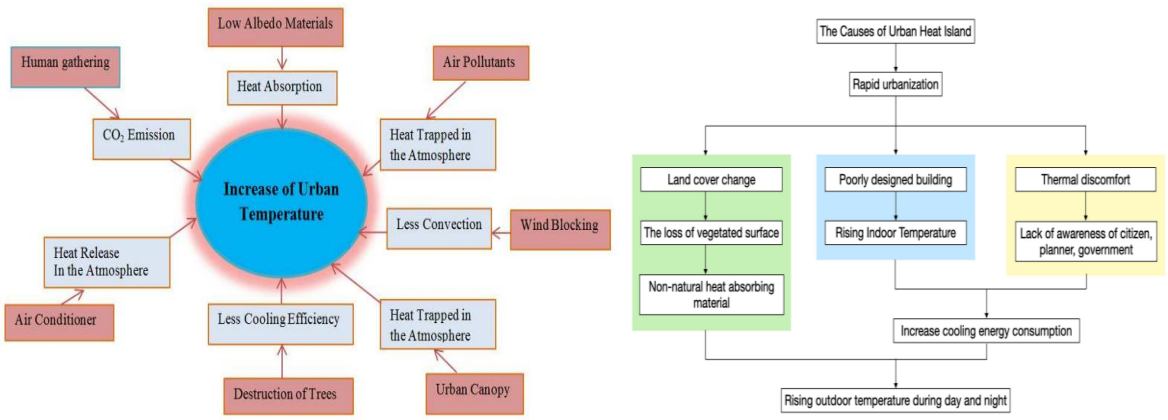


**Fig.1:a)& b) Causes of Urban Heat Island (UHI) Formation**

*Source:*

a) *https://www.wits.ac.za/media/witsuniversity/conferences/documents/UrbanHeatIslandCausesEffectsandMitigation.pdf*
b) *https://www.mdpi.com/26734834/2/3/38#:~:text=In%20this%20paper%2C%20the%20author,and%20minimize%20the%20UHI%20effect.*

**Effects**

Intropical areas during summer, the consequences are more severe living in the center of the metropolis which makes the individuals uncomfortable, the energy required will be more to cool the buildings in order to keep people comfortable when the temperature rises. Both the people's and the government's expenditures will increase as the energy requirement increase by 2–4% in the summer for every 10°C increase in temperature. More fossil fuel is consumed as the demand for electricity rises, resulting in large emissions of greenhouse gases and more frequent usage of air conditioners makes the effect much worse.As the need for electricity grows, more fossil fuels are being consumed, resulting in increased emissions of greenhouse gases that worsen the situation and change the climate[4].

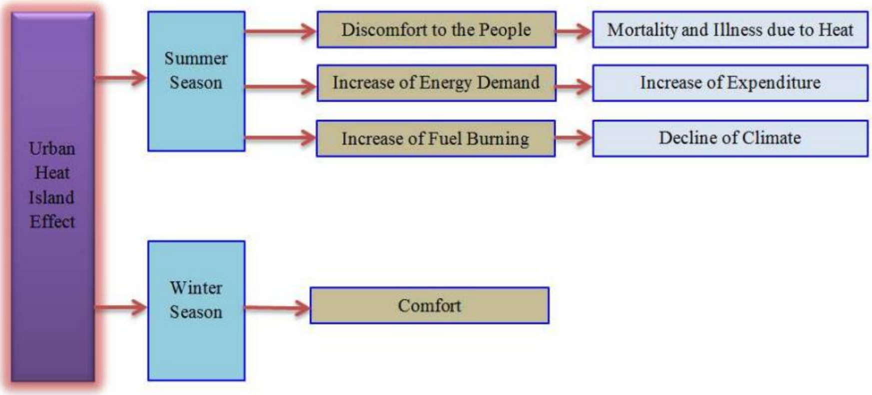


**Figure 2. Effects of Urban Heat Island Formation**

*Source:https://www.wits.ac.za/media/wits-university/conferences/documents/UrbanHeatIslandCausesEffectsandMitigation.pdf*

## MITIGATION OFURBAN HEAT ISLAND

***High albedo materials –*** Dark surface absorbs heat from the sun and makes the environment hot. The light colors which have a high albedo (0.60 -1) reflect the solar light and heat back and make the place cool and comfortable.

***Green Vegetation –*** Trees reduce the UHI effect by its evapotranspiration which absorbs CO2 and reduces temperature. The temperature usually decreases by 0.6k for 10% vegetation added, according to Theuwes.

***Shade Trees –*** Trees absorb heat and release cool breeze. The shade provided by the trees in the pavement and houses cut down the temperature and keep the place cool.

***Pervious Pavements –*** Pervious pavement allows water to pass through and makes the surface cool and reduces the temperature.

***Water Bodies –*** Water bodies placed along the wind direction make the hot air into a cool breeze by its humidity and creatinga cooling effect.

***Urban Planning –*** Planning according to the wind path and sun path traps the air inside the city. The Land breeze and sea breeze plays a major role in the city located near the rivers and sea and planning accordingly reduces the UHI effect.

***Green Roofs –*** Roof represents 21% - 26% of the city area according to Wong (2005) .Green roof filters the air and keeps the place cool by lowering the temperature and energy demand.

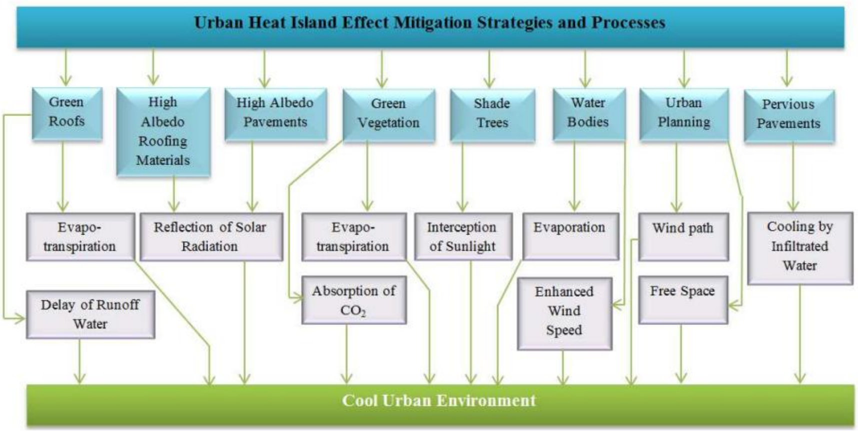


**Figure 3. Urban heat Island mitigation process.**

*Source: https://www.wits.ac.za/media/wits-university/conferences/documents/UrbanHeatIslandCausesEffectsand Mitigation.pdf*

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## UHI IMPACTS ON BUILDING ENERGY CONSUMPTION

Urban heat islands (UHI) significantly have animpact on building energy consumption by raising the demand for space cooling while lowering the need for space heating, the impact of UHI on building energy use has been understudied due to the challenges in defining UHI-induced temperature change and evaluating building energy consumption. A widely used software application has been employed to access the impact of various climatic boundary conditions on a building's energy performance, particularly on its heating and cooling demand.The UHI phenomenon is assessed using the following measure metrological variables: relative humidity, dry bulb temperature, wind speed, and direction. Dry bulb temperatures are compared between urban and rural areas to assess the prevalence of the UHI phenomena. In comparison to the baseline, simulation findings show an increase in cooling energy demand of around 30% and a decrease in heating energy demand of about 11%.

### *Building Simulation using Weather Data:*

The Regional meteorological information should be made available inside large cities which can be used to create more precise and consistent climatic data for improving building simulation model predictions, as well as for better energy cost estimation, internal environmental conditions, and making more logical assessments of energy conservation measures affecting existing buildings[6].

### *User Behaviour:*

Using Surveys and questionnaires the data of human behaviour may frequently be comprehended.Semi-structured interviews with subject-matter specialists were used in the study to examine the effects of urban sustainability, user behaviour, and activities. According to the findings of an interview, it is necessary to increase public awareness through media campaigns, more education, and the presentation of best practices.Despite the greater need of adopting climate adaptation strategies, urban climatic phenomena are comparatively poorly studied in less developed countries. Education and communication are the most efficient means of raising people's awareness[6].

### *Experiment Tools and Calculation:*

In the tropical city of Chennai through the use of temperature isopleths derived from in-situ field measurements, the Urban Heat Island (UHI) in the CMA is studied. 30 fixed locations within and around CMA used a HOBO data logger (HOBO U10 Temp/ RH) to measure the air temperature and relative humidity at hourly intervals[1]. The daytime temperature isopleths at 14.00 hrs revealed that a cool island exists in the urban core of CMA with a temperature difference of 10.4 °Cin the summer monthsand 3.7°C in the winter months.The temperature differences are greatest on still, clear nights and increase over time after sunset; in the CMA, the lowest temperatures were measured at 6:00 a.m[1].The temperature isopleths at 06.00 hrs reveal a significantpositive CLUHI ranging from 3.6°Cin summer to 4.1°Cin winter months[1].The density of urban built form, built geometry, and vegetation were also found to be significantly correlated with urban-rural differences in the study, demonstrating the importance of building codes that define urban built geometry in creating a comfortable urban environment.

## UHI REDUCTION THROUGH BUILDING:

Urban surfaces created by humans are the primary contributor to UHI because they absorb, reflect, and emit heat radiation. A city's radiative budget is affected by its urban shape, surface materials, direct solar radiation and incidence angle, and air diffusion, hence communities and buildings should be planned and designed in a way that increases their resilience to climate change.

### *UHI Mitigation Using Passive Building Design Techniques:*

Buildings can reduce UHI by incorporating passive design strategies, which include seven architectural elements such as orientation, ventilation, thermal zoning, building form and typology, building envelope design, material choice, and landscaping. According to Amira Mersal (2017), the passive design approach consists of various climate-responsive strategies, primarily aimed at preventing heat transfer through the building envelope, promoting natural cross ventilation from the prevailing wind, and ensuring daylight ample inside the building[3].


1. **Orientation:** Toreduce the amount of solar radiation that reaches the building envelope.
2. **Ventilation:** To Release heat and humidity by using airflow.
3. **Thermal zoning:** To allocate resources for time-of-use and solar gain functions.
4. **Building form and typology**: To Reduce solar radiation on the building envelope as much as possible, and make the most of daylight and heavy rain.

5. **Building envelope design:** The very minimum of necessary daylight access, low heat gain, and maximum exterior reflection.
6. **Materials selection:** To order to reduce heat transfer into the interior space.
7. **Landscaping:** to create a comfortable outdoor environment by shading the building to reduce heat gain.

***Building Orientation and Site Context***

To optimize the cooling system, and reduce shading and high sun temperature, a building must be designedand positioned so that it faces the wind. Therefore, earlyplanning is necessary for future buildings to reduce solar heat gain.If the site location cannot be changed, sufficient shading devices can be installed inside the building. Additionally, constructing surfaces above the ground can help to minimize environmental and land impact[3].

***Ventilation Design***

To increase natural ventilation, utilizing the prevailing wind direction is essentialand effective. It is advised that buildings in tropical climates be constructed with raised stilts to reduce the need for walls and other partitions and to create open areas with cross-ventilation potential[3].For maximum cross ventilation, buildings in tropical climates need to have a lot of large openings. In tropical countries, passive cooling is essential for lowering energy usage while a building is in use. Through airflow or air pressure differences, a natural ventilation system can also cool the building, and achieve comfort in the hot environment[3].

***Thermal Zoning***

The building gains external heat from solar radiation and internal sources like occupants, actively used electric lights and equipment. Through conduction and convection from the building envelopes, the exterior heat enters the structure. Prior to designing a building, one should understand how climate response can affect the performance of the facade.While cold countries would prefer to keep the building warm, tropical climate buildings would need a facade that can keep the building cool[3]. The interface between the interior and the exterior is maximized by semi-permeable walls that are lightweight.It also provides immediate and direct contact with the surroundings, rather than blocking out the weather and isolating the occupants from the exterior environment[3].

***Green Façade***

Green facades can effectively reduce indoor temperature by providing shade.The window size has a greater impact than the thermal effect when window areas are not shaded by external shading devices[3].In order to reduce solar irradiation and enhance natural ventilation, buildings and streets should be properly oriented, taking height considerations into account in relation to shading of south- and west-facing facades through facade greeningand trees, shading of rooftop extensions, and shading of south- and west-facing facades. It's essential to ensure that buildings can provide indoor comfortable summer climates, it is crucial to take into account shading, greening, ventilation, and densification during this planning process[3].

***Green Roof and Cool Roof***

UHI has a significant impact on a building's thermal energy performance because, urban materials absorb solar and infrared energy, releasing stored heat into the environment and increasing the ambient temperature. In particular, roofs are envelope components that, by adopting cutting-edge techniques like cool roofs and green roofs, can lower internal temperatures and provide significant energy savings in air-conditioned buildings. Building roofs cover roughly 20–25% of the metropolitan surface area. Buildings with green roofs have been found to enhance the environment successfully, offering advantages such as reduced solar absorption and increased plant evapotranspiration resulting in lower energy usage inside the building[2].

In Indian cities, higher urban densities perform better for cool roofs than in sparsely populated areas. In Singapore, cool roofs have been effective in reducing cooling loads and anthropocentric air pollution with a heat index reduction of appx. 2–5 ◦C[2].

A simulation was used to review Singapore's cool roof and green roof systems. Cool roofs are more effective at reducing heat gains compared to green roofs in a climate, where vegetation can increase the latent heat flux created by evapotranspiration [2].

***Figure 4. The green roof and green wall.***

## CASE STUDY

***Kampung Admiralty – Singapore***

Kampung Admiralty, a public housing development for elderly residents dynamically combines healthcare, public facilities, community space, and commercial amenities. Integrated vegetation serves as a demonstration of the building's biophilia and vegetation forms the part of the roof garden and the rainwater collection system.

***Sun Path***

The Studio apartments are designed taller than the community park, since their height shade the users from the heat and glare of the rising sun in the morning.

***Wind Direction***

The windrose shows that wind has a high frequency of coming from the northwest direction. The wind passing through the vegetation in the Northwest direction freshens and cools the air[10].

***Roof Garden***

The oxygen produced by the green plants contributes to improvingthe air quality by reducing and filtering polluted air particles and gasesand alsoacts as a great acoustic insulator. Green roofs may also help reduce the distribution of dust in the air, which leads to decreasing greenhouse emissions. The roof garden with integrated vegetation shades building from excessive heat and harmful ultraviolet (UV) rays sourced from sunlight and cools down the surrounding temperature to an optimum level.

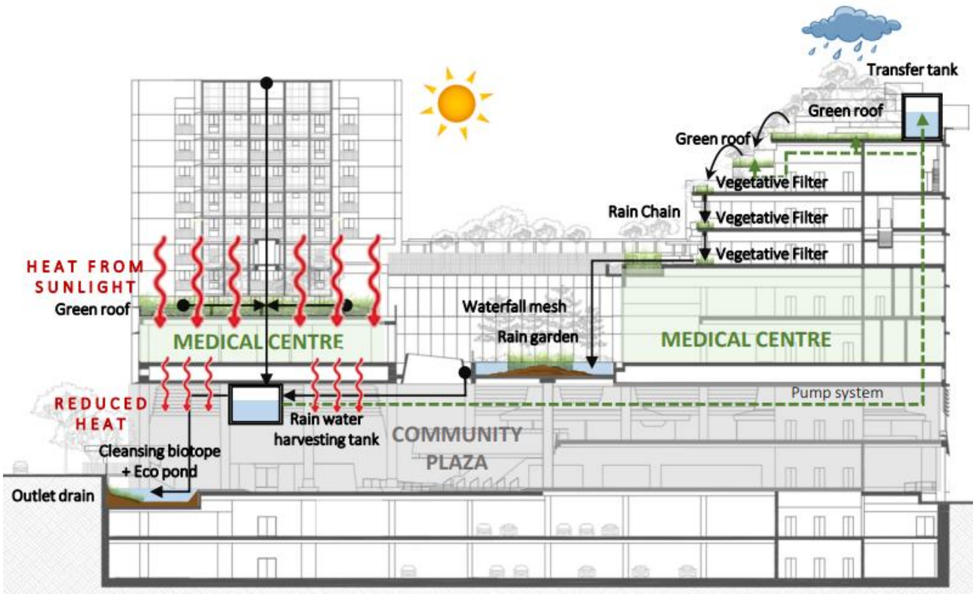


***Figure 5. Passive strategies – Kampung admiralty***
***Source: https://cstan0920.wixsite.com/portfolio/a-e-project-1***

***Environmental Responsive – Thermal***

The integrated vegetation which acts as a heat absorber and an insulator, also shades and protects the building structure in Kampung Admiralty; contributing to the creation of a cool and comfortable environment. The shading devices such as Egg crate shading devices, Perforated shading devices, etc., are effectively designed according to the sun's angle to reduce the heat radiation penetrating into the building by 60% by leaving the spaces well-ventilated. all of which contribute to the creation of a cool environment.The high ceiling facilitates natural convection to control the heatthat is created inside the building[10].

***Environmental Responsive – Ventilation***

Singapore experiences the majority of its wind from the North/ North-Northeast direction.The design of a high ceiling is provided tomaintain natural wind speed from the external environment and the opened skylight allows the hot air to escape which is re-directed from the louvred Windows. Hot air which passes through the garden; is cooled down before exiting through the openings and thesurrounding plants release excess moisture into the air to lower the temperature. The building form which is divided at 4 vertices of the squared plan is designed to reduce the distance between openings, which will effectively promote the prevailing airflow[10].

***Environmental Responsive Light And Sun Shading***

The deep overhangs which are constructed at the north-east, east-west, and south-west facades provide shade and protect the users from glare. The medical center's glass windows, which encircle the central courtyard, are set at full height to maximize passive daylighting when the area is heavily shaded and light intensity is low.The glass windows are properly tinted to reduce heat and glare when the space is largely exposed to sunlight[10].

The skylight is made up of a transparent glass panel to allow the full intensity of daylight to enter the community plaza when the central courtyard has lower exposure to sunlight. Some of the glass panels were made semi-transparent to reduce glare while allowing a certain amount of light to enter. The skylight isopened to air when there is no direct sunlight which will cause glare and excessive heat.The building's exterior is painted in a light color to reflect more light into openings. Light color surfaces in the interior of the building diffuse light and reduce glare[10].

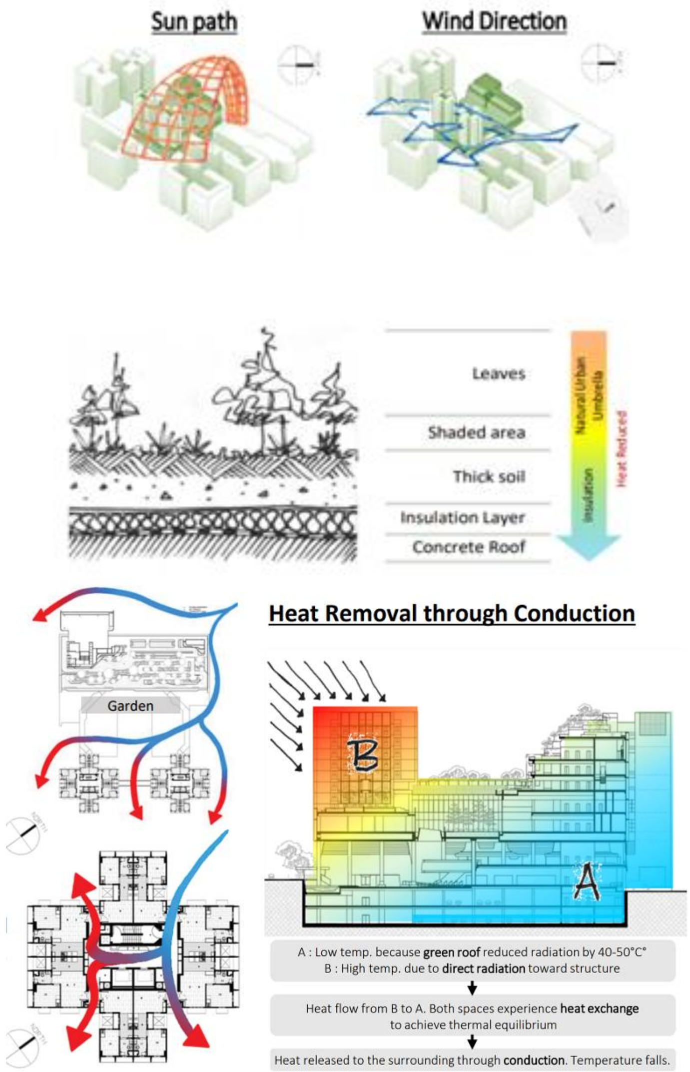


***Figure 6. Passive strategies – Kampung Admiralty***
***Source: https://cstan0920.wixsite.com/portfolio/a-e-project-1***

## CONCLUSION

Building energy efficiency as well as occupant comfort have been impacted by urbanization and landscape changes, among the expansion of urban areas.UHI has grown in densely populated areas of cities over the past two decades, where temperatures are higher than in rural areas. There have been fewer studies on UHI in tropical climates, and the study of how to thoroughly analyze weather data has not been done much in tropical regions. It is necessary to study significant variations in humidity, air movement, and terrain in order to comprehend how buildings must adapt to UHI. Passive design techniques must be used in today's buildings if we are to lessen the effects of urban heat islands and slow down climate change.

In summary, heat regulation, natural lighting, and response to tropical context are the three main categories into which passive design strategies in the tropics are divided. When it comes to controlling the temperature, architects can use natural ventilation by maximizing openings such as louvers, casement, and awning windows as well as vegetation, green roofs, and jack roofs. The use of air wells, openings, clerestory windows, an inner courtyard, and the orientation of the building can all help to maximize natural lighting while also promoting energy efficiency. The use of lightweight materials, locally obtainable materials, materials with low u-Values, an abundance of tropical vegetation, and leveling of floors are other indications that designers were sensitive to the tropical environment. Actually, we can learn all of these techniques from the architecture of our native people. Last but not least, we should draw lessons from the past to improve our energy-consumption habits in tropical sustainable architecture so that we can meet the green building requirements.

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