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MORALITY BEFORE KNOWLEDGE

Assessing the vulnerability of urban areas to the urban heat island phenomenon: Strategies for effective mitigation and sustainable urban planning

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ABSTRACT
Background: Urban Heat Island (UHI) is a phenomenon that causes significant temperature differences between urban areas and surrounding suburban or rural areas. This phenomenon can be found even in medium to small-sized cities and is measured based on the temperature difference between urban and rural areas. **Methods:** This study employs a systematic literature review to analyze research on urban heat islands and applied mitigation strategies. The review follows a structured process, including selection criteria based on albedo, vegetation area, and anthropogenic factors, to identify and classify relevant case studies. The analysis focuses on three mitigation approaches: reducing urban albedo, increasing vegetation, and reducing anthropogenic heat emissions. **Findings:** In cities, urban heat islands are influenced by factors such as building density, the nature of roads and building surface materials that store heat, lack of green land, and activities carried out in urban areas. With high activity and population density, urban heat islands can cause temperature increases both locally and globally. The increase in temperature in the microclimate in urban areas triggers an increase in death rates due to heat waves, causes discomfort in human activities, and greatly impacts vulnerable groups. This phenomenon will become increasingly widespread due to urbanization which results in urban sprawl which expands urban areas. **Conclusion:** Urban vulnerability to urban heat islands requires interdisciplinary studies to analyse and develop effective mitigation. The mitigation carried out aims to reduce the negative impact of the urban heat island phenomenon. **Novelty/Originality of this article:** Three mitigation solutions that can be implemented are reducing urban albedo because albedo can reflect solar radiation, increasing urban vegetation to reduce heat in the surrounding area, and reducing anthropogenic heat emissions by reducing heat emissions from daily activities.

KEYWORDS: anthropogenic emissions; low vegetation; mitigation; surface albedo; urban heat islands; urbanization.

1. Introduction

Urban Heat Island (UHI) is a phenomenon where there is a significant temperature difference observed between a city and its suburbs and/or surrounding rural areas (Kolokotroni & Giridharan, 2008). Urban heat islands are urban areas with lower albedo that absorb more than 80% of solar energy, thereby increasing air temperature compared to rural areas (Touchaei & Wang, 2015). Urban heat islands can be found even in medium to small-sized cities (Busato et al., 2014). Urban Heat Island is measured as the temperature difference between urban and rural areas. The average intensity of an urban heat island ranges from 1–2 degrees Celsius but can reach up to 12 degrees Celsius (Ulpiani, 2021). The

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intensity of urban heat islands varies seasonally and with day or night conditions. Variations in the intensity of the urban heat island between day and night depending on the climate zone. In summer, the urban heat island intensity during the day is higher than at night in all climate zones. In winter, there are different patterns between subtropical or tropical climate zones and temperate or high mountain climate zones (Yue et al., 2019).

There is a strong relationship between the urban heat island effect and the composition of urban areas, solar radiation heating is the main factor that influences air temperature and surface temperature in areas, roads, and industrial areas (Hsieh & Huang, 2016). The urban heat island effect is a result of the phenomenon of urbanization or growth of urban areas, changes in land structure and cover, and industrialization (Rizwan et al., 2008) which is caused by changes in surfaces that absorb more heat, producing anthropogenic heat, and there are special air circulation patterns, as well as several other factors (Stewart & Oke, 2012). Cities that experience intensive urbanization tend to show greater urban heat island impacts (Balany et al., 2020). Anthropogenic heat is generated from human activities such as emissions from vehicle exhaust, it makes a building heating phenomenon from cooling equipment (Piracha & Chaudhary, 2022). In cities, factors that influence urban heat islands include the density of buildings and buildings, the orientation and distance between buildings, the nature of road and building surface materials that can store heat, and the cover of green land (Irfeey et al., 2023). Another factor that can cause urban heat islands is a reduction in wind speed due to increased surface vulnerability and increased absorption of solar radiation from surfaces that have low albedo (de Almeida et al., 2021). Urban heat island events can also be exacerbated during heat waves, resulting in synergy between heat waves and urban heat island events. The amplification of urban heat islands during heat waves varies spatially and temporally depending on the local conditions of each region (He et al., 2021).

The negative consequences resulting from the urban heat island phenomenon are an increase in temperature in urban areas, especially the emergence of the risk of heat waves in urban areas which triggers an increase in death rates due to heat waves, the emergence of discomfort in activities, increased energy consumption during the summer, and a decrease in air quality and water quality (Gartland, 2011). The increase in energy consumption during summer is caused by energy use for air conditioning (Balany et al., 2020). Damage to infrastructure due to hot air temperatures is also an impact of UHI (Kim & Brown, 2021). Urban Heat Island can affect human thermal comfort. The human discomfort index increases in urban areas due to the Urban Heat Island effect. The thermal comfort map shows the increasing area experiencing heat and human discomfort due to urban development and the Urban Heat Island effect, the proportion of which reaches more than 50% (Yin et al., 2023).

UHI is associated with improved human health because it increases heat stress, injury, and mortality. This is even worse for vulnerable groups such as children, the elderly, and people with certain medical conditions, as it can cause heat-related deaths. UHI has a direct impact on human health. The impact of UHI on human health can be explained by the beginning that the human body reacts to high temperatures by increasing blood supply to the skin to remove excess heat and producing sweat to cool the skin. This places a heavy burden on the heart to meet oxygen needs. The cardiovascular burden of meeting oxygen needs can cause heart failure which can cause death. It can also cause lung stress and failure of other organs. The rate of heat-related deaths is much higher in urban areas than in rural areas. This illustrates the impact of urban and UHI levels on human health (Piracha & Chaudhary, 2022).

1.1 Climate vulnerability in urban areas

According to Turner et al., (2003), vulnerability is a description of something prone to experiencing danger due to exposure to a danger, disturbance, or stress. According to Técher et al., (2023), vulnerability is something that reflects fragility and resistance to danger, disturbance, or stress caused by exposure to threats. The vulnerability factor is a factor in the lack of preparedness to face an impact, by measuring the level of vulnerability and adaptive capacity of a community (Melis et al., 2023). Vulnerability plays an important role in determining impact. Assessment of a level of vulnerability needs to involve various characteristics and processes which are often defined and evaluated differently in various scientific fields. By using an indicator-based approach, human vulnerability can be understood from various aspects, such as social aspects, environmental aspects, economic aspects, and political aspects (Iqbal et al., 2022). Vulnerability in urban areas can be the biggest impetus in assessing climate change both at a micro and global scale and seeing how humans interact and reciprocate with their environment (Apreda et al., 2019). In the UN Framework for Disaster Risk Reduction in 2015, overcoming vulnerabilities is a starting point for organizing risk reduction measures (Schneiderbauer et al., 2017). The vulnerability of one urban element related to climate will provide a tendency towards worse impacts. Vulnerability depends not only on the intensity of environmental threats but also on demographic conditions, socio-economic conditions, and public health, as well as social networks, resources, governance, behaviour, attitudes, and perceptions of the population (Cresswell et al., 2023).

The urban heat island phenomenon also opens possibilities for various research developments to identify areas that are vulnerable to the urban heat island phenomenon (Técher et al., 2023). Therefore, the vulnerability of urban areas to the urban heat island phenomenon requires studies from various branches of science to analyse the vulnerability of an area and its mitigation (Cheng et al., 2021). Vulnerability is described as an important component in measuring the risk of extreme heat in urban environments. Vulnerability includes sensitivity and adaptive capacity to exposure to extreme heat (Li et al., 2022). Many things are parameters for the level of vulnerability, such as urban climate change, urban landscape (Apreda et al., 2019), population density (Muñoz-Pizza et al., 2023), age, gender, health conditions, source of income (Alonso & Renard, 2020), education level, and household size (Iqbal et al., 2022). Socioeconomic factors such as level of education and employment also influence vulnerability, with groups with lower education and outdoor workers being more vulnerable to the impacts of urban heat islands (Ramly et al., n.d.). Vulnerable groups that are assumed to be affected by this phenomenon are young age groups or children, the elderly (Cresswell et al., 2023), people with health problems, people who live in isolation, and people with low economic conditions (Sidiqui et al., 2022). Population density is very sensitive to temperature and can increase risk factors. This is motivated by a decrease in comfort in carrying out mobility. Locations that are vulnerable to rising temperatures due to exposure to intense sunlight and minimal vegetation will help reduce the comfort of activities for residents (Rinner et al., 2010).

Effectively, urbanization in urban areas responds to and influences the existence of climate change (McCarthy & Sanderson, 2011). Cities contribute 60-85% of world energy consumption and cannot accommodate all activities that consume large amounts of energy (Kamal-chaoui et al., 2009). With high activity and population density, this can cause an increase in temperature locally and globally (O'Malley et al., 2015). Urbanization and climate change are both caused by human activities, especially unsustainable economic development, and growth. This activity results in greenhouse gas emissions which cause global warming and climate change (Wang et al., 2023). Urbanization contributes to carbon dioxide emissions globally. Cities are the main contributor to 70% of the world's total carbon dioxide emissions, and it will be more dangerous if there is a massive expansion of urban areas which can be identified by the existence of urban sprawl. This has an impact on global warming and climate change (Kisvarga et al., 2023).

Urban sprawl is a phenomenon that occurs in cities where there is excessive expansion of urban space compared to urban population growth (Han, 2020). Urban sprawl causes the takeover of urban green land for development. The increasing area of the city due to urban sprawl will weaken the regulatory function of the ecosystem and increase the urban heat island effect. The urban heat island effect caused by urban sprawl can increase energy demand for air conditioning, thereby increasing energy consumption (Wu et al., 2022). Transportation in urban areas, especially motorized vehicles, also increases energy consumption due to urban sprawl. This directly contributes to greenhouse gas emissions (Sarkodie et al., 2020). Urban planning and excessive heat conditions in urban areas at the micro scale have a high relationship (Técher et al., 2023). In this case, urban area expansion is also included and opens the possibility for stakeholders to determine adaptive solutions to be put into practice in urban area planning. It is necessary to determine vulnerable and densely populated areas to be the main asset in carrying out city planning to reduce the impact of the urban heat island phenomenon (Mills, 2006).

1.2 Urban heat island mitigation

Future city resilience is urgently needed as an important step for a sustainable future city. This can be used as a response to environmental disturbances, so that habitats and ecosystems can be reorganized, or as a phenomenon's vulnerability to irreversible change (Dieleman, 2013). Urban resilience refers to the ability of a city to withstand and recover from various challenges, including climate change impacts such as UHI. Urban resilience includes aspects such as infrastructure, public services, environmental sustainability, and adaptive capacity to climate change (Iqbal et al., 2022). The concept of urban resilience to UHI vulnerability can be interpreted as the ability of a city to reduce the risks and negative impacts of UHI on the urban population and environment (Li et al., 2022). Understanding vulnerability to UHI can help in designing effective mitigation solutions in the context of sustainable urban planning (Técher et al., 2023).

Mitigation is an action or strategy to reduce the negative impact of a particular phenomenon or problem. In the context of the Urban Heat Island, mitigation refers to efforts to reduce the effects of excessive warming in urban areas (Battista et al., 2023). Mitigation of UHI needs to be carried out because UHI can have a significant impact on public health, air quality, energy consumption, and thermal comfort in urban environments (Almashhour et al., 2024). High temperatures in urban areas can cause an increased risk of heat-related illnesses, and increased energy consumption for space cooling which in turn increases greenhouse gas emissions and air pollution decreases air quality (Semenzato & Bortolini, 2023), and affects local weather patterns and microclimate cities, which in turn can exacerbate the effects of global warming (C. Wang et al., 2021a). If there is vulnerability in an area, especially in urban areas, the main problem needs to be identified, and mitigation needs to be carried out with solutions based on the triggers of the problem (Kalisch et al., 2014). To reduce the undesirable impacts of UHI, scientists have proposed viable mitigation strategies; such as, (1) decreasing urban albedo, (2) increasing urban vegetation, and (3) reducing anthropogenic heat emissions (Touchaei & Wang, 2015).

2. Methods

2.1 Paper selection

A literature review is generally one of the first steps in a survey that helps researchers to understand and analyse material that presents findings, methods, ways of working, and information related to research questions (Nishida & Braga, 2015). Studies that support a literature review are called primary studies. This research provides knowledge based on published papers and articles. One method to conduct a literature review and gain a basic understanding is to conduct a systematic review, also known as a systematic research synthesis, integrated search review, and integrative review (Biochini et al., 2012). This research is based on qualitative and quantitative analysis based on existing literature. The procedures carried out were to review case studies using several predetermined criteria to identify case studies in this research. First, this research must be related to the topic of urban heat islands. Second, this research investigates urban areas as a case study presented in the article. Third, literature related to efforts made to overcome the urban heat island phenomenon. This is because the research limitations in this study are urban areas. Thus, the papers that appear will have similarities regarding approaches to management, and mitigation carried out more specifically for the urban heat island phenomenon in urban areas. However, this research focuses on applied solutions and focuses on methods that can be used to overcome urban heat island problems which are more relevant for further analysis. Table 1 provides a comprehensive description of the review procedure.

Table 1. Overview of the review procedure

No	Review Steps	Review Procedure
1	Establishing Selection Criteria and Collecting Data	Transforming the research purpose into a search based on keywords to define the study's focus and extracting the bibliographic data.
2	Screening and Clearing Data	Screening from Abstract and Keywords guided by 3 criteria's: 1. Albedo 2. Vegetation Area 3. Anthropogenic
3	Data Scoping	Download the relevant papers
4	Paper Classification	Review of the full text of the selected articles was conducted to assess their relevance to the study's objectives based on the specified criteria
5	Reviewing Paper	Gather information from each paper according to 3 specific categories

(Hintz et al., 2018)

2.2 Content analysis

Three approaches can be distinguished as mitigation solution options, namely 'reducing urban albedo', 'increasing urban vegetation', and 'reducing anthropogenic heat emissions'. Each approach focuses on its structure and benefits for mitigating the impact of urban heat islands. First, decreasing urban albedo allows these surfaces to reduce most of the reflection of incoming solar radiation (Morini et al., 2016). By implementing innovative solutions including reflective materials for roofs, sidewalks, and walls, it is considered possible to reduce the urban heat island effect in cities (Santamouris, 2014). Second, increasing the vegetation area in urban areas is an effective solution, because dense vegetation can allow heat to escape and can provide green space to reduce surrounding temperatures (Peng et al., 2012). Third, reducing anthropogenic heat emissions, which come from human activities that have an impact on the environment by emitting heat into the urban canopy layer.

3. Results and Discussion

3.1 Community involvement in the animal trade

Mitigating and adapting the urban heat island phenomenon with planning in urban areas, can be an alternative solution to reduce the negative impacts of climate change from the urban sprawl phenomenon (Gartland, 2011). Several studies have various methods to provide mitigation options for the urban heat island phenomenon. Table 2 summarizes the methods discussed in more detail.

Table 2 shows that various cities around the world have attempted to mitigate the UHI phenomenon. Almost all these research articles show that mitigation of the UHI phenomenon can be done by increasing albedo to lower temperatures and reduce heat absorption. The essence of increasing albedo is to use materials that are highly reflective, water permeable and retentive to reduce heat absorption. Examples of what can be done to increase albedo include the use of cool roofs or white roofs, which are roofs with a high level of solar reflectivity, the use of cool pavements, the use of high-reflectance paving, the use of light-coloured paints, the use of colour-changing materials, and the use of fluorescent materials. All the research articles also mention another mitigation strategy is to increase the area of vegetation.

Table 2. Summary of literature review on urban heat island vulnerability with 3 types of scope mitigation

City	Mitigation by Decreasing Albedo	Mitigation by Increasing the Vegetation Area	Mitigation by Reducing the Anthropogenic Heat Emissions	Reference	Tools
Cairo, Egypt	Reducing the intensity of thermal fluctuations from impermeable surfaces by using land with green cover	Create recommended vegetation scenarios in built areas with low urban density, namely 30%, 50%, and 75% vegetation	Reduces energy use to cool the air inside the building, thanks to the help of lush vegetation	Aboelata & Sodoudi, 2020	ENVI-met micro scale model
Tainan City	The increase in land temperature on the road is influenced by the width of the road, especially on roads that are more than 20 meters wide, which shows the potential for a more intensive increase in temperature.	Water areas and vegetation are assumed to be things that can reduce temperature	Processing data related to potential areas experiencing rising temperatures and being affected by heat	Hsieh & Huang, 2016	Wind Perfect software and computational fluid dynamics (CFD) simulation software
Not Specified	Use of cool roofs or roofs with a high level of sunlight reflectivity	Development of green infrastructure in cities	Increasing energy efficiency in buildings and city infrastructure to reduce heat generated from cooling and heating systems	Almashhour et al., 2024	-
Urbanism in Canada	Use of Increased Surface Reflectivity (ISR) to increase surface albedo and reduce heat absorption	Use of Increased Surface Greenery/Vegetation (ISG) to provide cooling through shade, evapotranspiration, and wind barriers	Use of Increased Surface Reflectivity (ISR) and efforts to reduce greenhouse gas emissions	(Hayes et al., 2022)	-
Padlova, Italy	The importance of using period-specific orthophotos in the model to ensure the most realistic albedo	Planting trees and increasing vegetation cover	Developing UHI mitigation strategies is important for blocks with high anthropogenic heat emissions	Semenzato & Bortolini, 2023	

7 cities in America (Boston, Charlotte, Chicago, Washington, Durham, San Diego, and San Jose	Use of white roofs as an albedo manipulation strategy	Urban greening, use of grass cover, and selection of appropriate vegetation	Encouraging the use of sustainable transportation, such as public transportation, bicycles, and walking, can reduce greenhouse gas emissions and heat produced by motorized vehicles	Smith et al., 2023	High-resolution landcover datasets in spatial regression analysis and long-term remote sensing data
Melbourne, Australia	Use of light-coloured paint, colour-changing materials, and fluorescent materials to increase surface albedo	Design roads and sidewalks that integrate vegetation to reduce solar energy absorption and increase water infiltration	Innovative design of roads and sidewalks (use of reflective materials) which can reduce solar energy absorption and heat emissions from the surface	Irfeey et al., 2023	-
Mancini Square, Roma, Italia	Use of cool floor materials (cool pavements) with high albedo and permeability values	Expansion of vegetation with species that are compatible with existing ones and the use of green roofs	Using grass pavers as an alternative to conventional asphalt	Battista et al., 2023	ENVI met
Harbin, People's Republic of China	Use of highly reflective, permeable, and water-retentive materials to reduce heat absorption	Planting trees on the streets and building green walls and roofs	Use of modern cooling materials and development of new high-performance cooling materials	Han et al., 2023	-
Functional Urban Areas in Europe	-	Implementation of nature-based solutions increases the percentage of tree cover to a minimum of 16%	Reduces energy requirements for the cooling system, thereby reducing heat emissions produced by the cooling system	Marando et al., 2022	ENVI-met, Weather Research and Forecasting, and Computational Fluid Dynamics
Several Locations in the World, such as Toronto, Los Angeles, Phoenix, and California	The use of materials with high albedo is more efficient in reducing the maximum and average air temperature compared to the use of cold roofs	Green infrastructure such as trees and grass	Water-related strategies such as irrigation and blue infrastructure such as lakes and ponds	C. Wang et al., 2021b	-
Kolkata, Mumbai, Chennai, and New Delhi (India)	Use of high-reflectance roof and paving	Installation of vegetation modules on concrete surfaces, PVC, or other materials that	Use of shading structure technology with energy generation/architectural devices	(Khare et al., 2021)	Cool Roof Calculator

		allow plant growth.			
Singapore	Increase the albedo of artificial materials by using a light-coloured layer or replacing the same material with a light-colour	Planting plants, especially those with high evapotranspiration rates, can replace artificial materials that do not provide shade	Consider interactions between local surface types, plant planting, and shading when planning and implementing UHI mitigation strategies in urban environments	Tan et al., 2021	-

Planting trees and increasing vegetation cover are key urban greening strategies that can reduce urban temperatures. Planting plants, especially those with high evapotranspiration rates, is very useful for heat release and reduction. The use of green infrastructure, the construction of green walls and roofs, the design of vegetation planting on roads or sidewalks, urban greening, and planting vegetation on concrete or PVC surfaces that allow plant growth are examples of what can be done. Increasing the area of vegetation can also have the added benefit of increasing water infiltration, which can also help reduce surface temperatures. The final mitigation strategy is through reducing anthropogenic heat emissions. From the research articles summarized in the table, this mitigation is quite varied in each research area, but the point is an effort to reduce greenhouse gas emissions that can increase temperatures. An example is to reduce energy use, such as for air conditioning, to reduce heat emissions resulting from energy use. Another example is encouraging the use of sustainable transportation, such as public transportation, bicycles, and walking, to reduce greenhouse gas emissions and heat generated by motor vehicles.

3.1 Urban albedo reduction

An increase in albedo causes a decrease in air temperature and an increase in evapotranspiration (Filho et al., 2018). Albedo is a measure of a surface's ability to reflect solar radiation. The higher the albedo value, the greater the reflected radiation, so the heat absorbed by the surface will be reduced. Dark-coloured surfaces such as asphalt usually have a low albedo, so they tend to absorb heat. On the other hand, bright surfaces such as white paint have a high albedo, so they tend to reflect heat. Strategies to increase urban surface albedo can be carried out by choosing light-coloured building materials and road surfaces (Degirmenci et al., 2021).

The materials used in urban structures have an important role in maintaining urban heat balance (Akbari et al., 2016). As in Fig. 1, in the northeast and southwest and several other hot spots were detected by infrared cameras. The image shows a dark roof with low reflective levels, some trees, and a road intersection. Land surface temperature has results that are in line with theory, that the roof surface will generate heat, as will the road surface. Meanwhile, water and plants show much lower temperature levels. Several types of materials can absorb solar radiation and reduce the amount of heat absorbed through convection and radiation processes in the atmosphere, which can then increase environmental temperature (Baldinelli et al., 2015). The increase in albedo of urban surfaces allows these surfaces to reflect most of the incoming solar radiation (Castellani et al., 2014). The increase in albedo causes a decrease in urban temperatures of up to 2.5oC during the day and at night, especially in areas located in industrial locations. Changes in albedo can affect the surrounding temperature, allowing temperatures to decrease over a wider area. Thus, the option of reducing albedo in urban areas is an effective treatment that can be developed to combat the urban heat island phenomenon (Morini et al., 2016).

One strategy for increasing surface albedo to reduce urban heat islands is the nature-based solutions (NBS) strategy using Increased Surface Reflectivity (ISR). ISR can be implemented by using building materials that have a high albedo, such as reflective paint, light-coloured roofs, or other surface materials that can reflect sunlight. In this way, the surface will absorb less heat energy and reduce the heat radiated back to the surrounding environment. One example of applying Increased Surface Reflectivity (ISR) is changing the building roof material from dark materials such as asphalt to light-coloured concrete. A study by Hayes et al., 2022 showed that switching from asphalt to concrete in residential and urban areas in Toronto, Canada, could reduce ground surface temperatures by up to 7.9°C at noon. This shows that changing surface materials to be more reflective can provide significant benefits in reducing environmental temperatures.

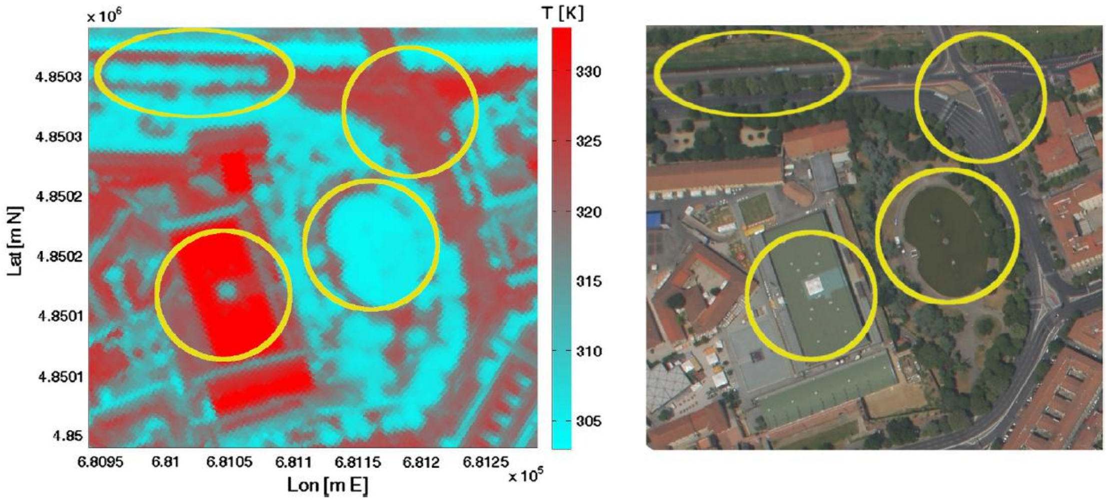

Fig. 1. Land surface temperature from infrared thermography and visible image to detect a dark roof, a crossroad, a fountain, and trees (Baldinelli, 2015)

Rosenfeld et al. (1995), have proposed the use of highly reflective materials for roofs, sidewalks, and walls as a solution to reduce urban microclimate temperatures. The use of materials on the exterior of buildings that are environmentally friendly and reflective is also considered to have a positive effect on this phenomenon (Akbari et al., 2012). Several solutions that are considered effective include thermochromic materials (Doulos et al., 2004), materials with directional reactivity (Hooshangi et al., 2016), and retro-reflective materials (Rossi et al., 2015). These materials can reduce surface albedo and emissivity, thereby changing the energy balance in cities by reducing reflected solar radiation (Synnefa & Santamouris, 2013). Apart from that, reducing the intensity of thermal fluctuations by substituting an impermeable surface for a permeable material (Aboelata & Sodoudi, 2020). However, green cover is a cheap and easy-to-apply land cover.

Thus, based on research that has been carried out, reducing the intensity of thermal fluctuations of impervious surfaces by using land with green cover can help solve heat problems in cities. An increase in land temperature originating from the road is influenced by the width of the road, especially on roads that are more than 20 meters wide. Because the width of the road can indicate the potential for a more intensive increase in temperature. One effective solution is to use a cool roof or a roof with a high level of sunlight reflectivity. Additionally, the use of Increased Surface Reflectivity (ISR) to increase surface albedo and reduce heat absorption is highly recommended. The use of period-specific orthophotos in the model is essential to ensure the most realistic albedo. The use of white roofs as an albedo manipulation strategy can also be very effective. the use of bright-coloured paint, colour-changing materials, and fluorescent materials to increase surface albedo, as well as cool floor materials (cool pavements) with high albedo and permeability values, can help reduce heat. The use of highly reflective, permeable, and waterproof materials to reduce heat absorption is also important. The use of materials with high albedo is more efficient in reducing the maximum and average air temperature compared to the use of cold roofs. Therefore, the use of roofs and paving with high reflectivity, as well as increasing the albedo of artificial materials by using light-coloured coatings or replacing the same materials with light colours, are steps that can be taken to create a more thermally comfortable urban environment.

3.2 Increasing urban vegetation

Reducing the urban heat island effect can be done by increasing evapotranspiration levels because vegetation cover can release heat, and the presence of green space to reduce heat in the surrounding area (Peng et al., 2012). Planting vegetation is the most widely implemented mitigation measure because it can achieve enormous energy savings through reducing temperatures in an area (Kikegawa et al., 2006). This is in research by Spronken-Smith et al., (2000) which found that green open space can help control temperature by as much as 300% compared to the surrounding environment. Trees have an important cooling impact by reducing the urban heat island phenomenon and improving thermal performance. In addition, the use of grass as a substitute for asphalt on more than 60% of parking lot surfaces can reduce air temperature by up to 1 degree Kelvin (Takebayashi & Moriyama, 2009). Building density and street design can contribute to the rise of the Urban Heat Island.

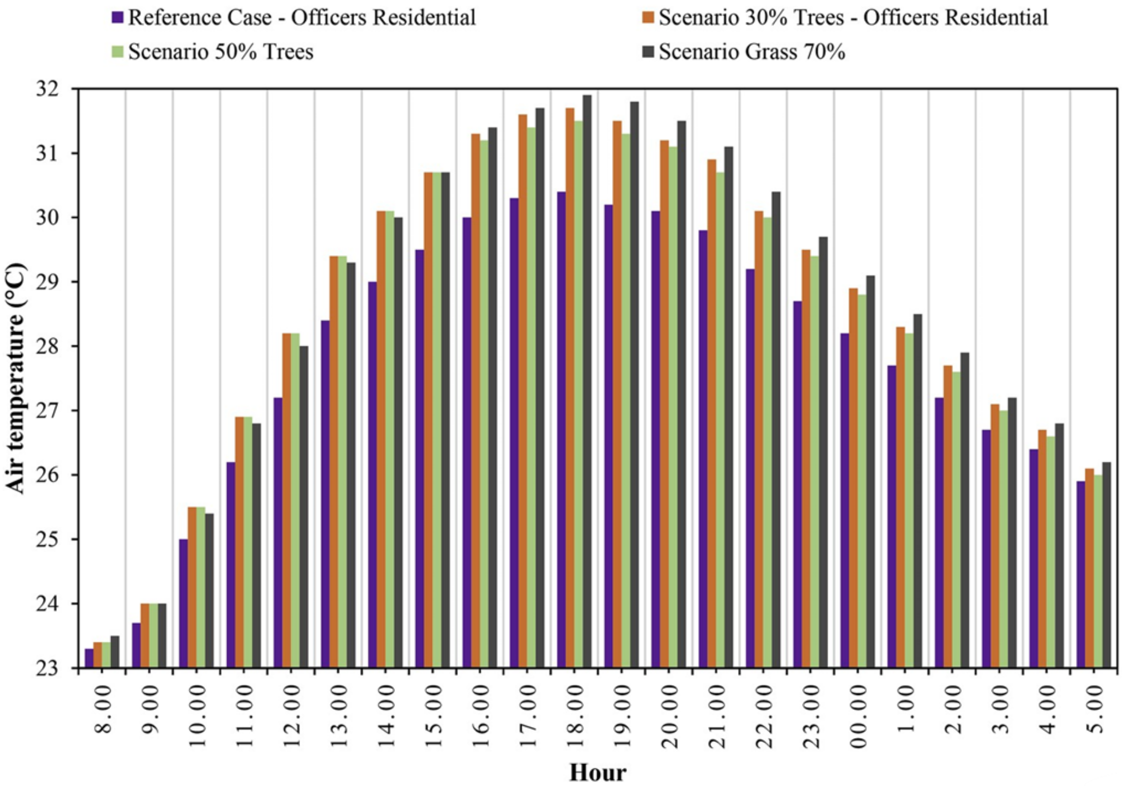

Fig. 2. Comparison the air temperature in 30% trees, 50% trees and 70% grass scenario in Officers Residential (Aboleta et al, 2020)

A study by Alobaydi et al. (2016) shows that the use of trees in areas with medium density results in a decrease in air temperature of 0.4 degrees Kelvin and trees with tall trunks are recommended for built-up areas with low density. Also, in the study provided by Aboleta et al. (2020), recommended vegetation cover of 50% in a landscape of high density-built areas. This is considered effective in reducing air temperature by 0.5 K. In addition, it can reduce evaporation. Urban planners can use more than 50% of trees in built-up areas with the aim of reducing sun exposure, reducing evaporation in water bodies, increasing shade and humidity, and lowering air temperature. It explained in Fig. 2.

Green infrastructure is one of the main strategies for increasing the vegetation area which aims to reduce the impact of urban heat islands. The implementation of green infrastructure (GI) includes increasing various types of green vegetation such as trees, grass, bushes, green roofs, and parks (Balany et al., 2020). Vegetation, such as parks, urban forests, green parks, and other open spaces, is an important element in urban green infrastructure. Vegetation is an integral part of green infrastructure which plays a role in providing various ecological, social, and economic benefits for the urban environment. Proper integration of vegetation in the planning and development of urban green infrastructure can help improve the quality of life of city residents, reduce the impact of climate change, and strengthen the resilience of the urban environment (Vargas-Hernández & Zdunek-Wielgołaska, 2021). Research in Cairo by Aboelata & Sodoudi (2020), a hot and arid city, found that the use of tree ratios is an effective strategy that can be applied in various urban areas with different densities to reduce the impact of urban heat islands and can mitigate high temperatures.

Green landscape to provide coolness in urban environments can be done with a nature-based solutions (NBS) strategy using Increased Surface Greenery/Vegetation (ISG). The main mechanisms used by ISG to provide a cooling effect include the shading effect by plant leaves, the evapotranspiration process from plant leaves which helps dissipate heat through evaporation of water from the soil and leaves, and wind barriers. An example of applying Increased Surface Greenery/Vegetation (ISG) is by planting trees, vines, or city parks in urban areas, for example planting trees along sidewalks or in city parks. Apart from that, rooftop gardens are also an example of effective ISG implementation. Rooftop gardens not only provide cooling through shading and evapotranspiration effects, but can also improve air quality, absorb carbon dioxide, and provide habitat for wildlife in urban environments (Hayes et al., 2022).

Water areas and vegetation are assumed to be able to reduce temperatures, so the development of green infrastructure in urban areas is very crucial. The use of Increased Greening/Surface Vegetation (ISG) to provide cooling through shade, evapotranspiration, and wind barriers can help create a cooler environment. Planting trees and increasing vegetation cover are key strategies in urban greening, which include the use of grass and the selection of appropriate vegetation. Additionally, designing roads and sidewalks that integrate vegetation can reduce solar energy absorption and increase water infiltration. The expansion of vegetation with appropriate species and the use of green roofs on buildings are also important. Planting trees on streets and building green walls and roofs will increase vegetation cover. Making recommendations for vegetation scenarios in built-up areas with low urban density with variations in the percentage of vegetation area is one option for determining important steps in reducing environmental temperature. However, from various studies, the implementation of nature-based solutions that increase the percentage of tree cover by a minimum of 16% is highly recommended. Green infrastructure such as trees and grass can be combined with the installation of vegetation modules on concrete surfaces, PVC, or other materials that allow plants to grow. Planting plants, especially those with high evapotranspiration rates, can replace artificial materials that do not provide shade, creating a more comfortable and sustainable urban environment.

3.3 Reducing anthropogenic heat emissions

The increase and expansion of areas experiencing the urban heat island phenomenon is very dependent on natural factors, such as topography, climate, and morphology (Apreda et al., 2019). Meanwhile, there are natural factors that are intervened by humans and cause an increase in the intensity of urban heat islands, such as land use, land cover, and energy use (Mihalakakou et al., 2002). The increase in temperature in urban microclimates affects the energy balance in cities (Santamouris, 2014). This causes the energy demand for electricity supplies for cooling to increase (Asimakopoulos et al., 2012). Areas full of office buildings, maximize buildings with good ventilation to reduce 10% of room cooling (Kolokotroni & Giridharan, 2008). In addition, the increase in supporting facilities in urban areas requires more electricity consumption for lighting and motor drive energy (Rossi et al., 2015). In addition, more energy is needed to reach life-supporting facilities and produce carbon emissions from fuels that are not environmentally friendly.

This falls into the category of heat originating from anthropogenic heat and is one of the results of urban expansion and intensification of human activity (Koralegedara et al., 2016). Anthropogenic heat emissions are one of the main factors causing Urban Heat Island and street air warming (Chow & Roth, 2009). This is because due to limited air volume exchange, anthropogenic heat can accumulate over time (Mei et al., 2016). Anthropogenic heat can directly heat the thermal energy near the surface and affect the microclimate in urban areas, and this influences the emergence of the urban heat island phenomenon in cities (Mei & Yuan, 2021). Increased anthropogenic emissions make a major contribution to the increase in heat island greying effects due to increasing average temperatures and potentially reducing rainfall intensity, thereby exacerbating its impacts (Paulina et al., 2015). Air temperatures in residential areas are likely to increase further in the future due to rapid global warming and urban development (Mei & Yuan, 2021). The role of cities in climate change is mainly caused by greenhouse gas emissions resulting from changes in energy consumption, and this is more influential than changes in land cover in urban areas (Oke, 2017). The increase in air temperature in the daily cycle is predicted using electricity consumption data and urban morphology. Differences in the type of development and how energy is consumed in different regions lead to spatial variations in the anthropogenic heat picture. However, due to differences in population density, functional structure, and heat source emissions within a landscape, variations in anthropogenic heat flow will be more significant, and more pronounced at smaller urban landscape scales (Xu et al., 2021). Analytical modelling results by Chen et al. (2022), show that daily variations in air temperature increases caused by differences in heat emissions are very significant, and these air temperature increases have a significant impact on public health and thermal comfort in densely populated cities.

The use of sustainable transportation, such as public transportation, bicycles, and walking, has a positive impact in reducing greenhouse gas emissions and heat produced by motorized vehicles, thereby helping to reduce the contribution to urban environmental warming. By encouraging the use of sustainable transportation, cities can reduce greenhouse gas emissions produced by motor vehicles. This helps in efforts to mitigate climate change and reduce the impact of warming on the urban environment. By reducing the use of private vehicles that contribute to air pollution, sustainable transportation can help improve air quality in urban environments. Additionally, by encouraging the use of sustainable transportation, cities can also reduce traffic density and road congestion, which can cause an increase in air temperatures around roads and contribute to the Urban Heat Island (Smith et al., 2023). There are still obstacles to implementing urban heat island mitigation strategies widely, including government policy, technological limitations, cost overrun from initial construction and maintenance costs are more expensive, and community unwillingness due to lack of understanding and awareness of the long-term benefits. Several solutions to overcome these obstacles can be done, including by updating experiences and reporting feedback regularly by local governments, continuously developing technology to adapt to various types of buildings, and disseminating information to the community about the environmental, economic, and social benefits of the program. - the program, as well as increasing cooperation between the private sector and government in its development and implementation (Irfeey et al., 2023). Public transportation use must also be increased to reduce heat emissions from private vehicle use (Degirmenci et al., 2021).

Reducing energy use for cooling buildings with lush vegetation is an important step in reducing urban heat impacts. Processing data related to areas that have the potential to experience rising temperatures and be affected by heat is needed to design effective mitigation strategies. Improving energy efficiency in buildings and city infrastructure can reduce heat from cooling and heating systems. Utilizing increased surface reflectivity and reducing greenhouse gas emissions is crucial in this strategy. Developing urban heat island mitigation strategies is important for urban areas with high heat emissions, while encouraging the use of sustainable transport can reduce greenhouse gas emissions and heat from vehicles. Innovative road and sidewalk designs, including the use of reflective materials, can reduce solar energy absorption and heat emissions. The use of grass pavers and new modern cooling materials can reduce energy requirements in cooling systems, as well as water strategies such as irrigation and blue infrastructure to create a more comfortable environment. It is necessary to consider the interaction between surface type, plant planting, and shading in planning sustainable urban heat island mitigation strategies.

4. Conclusions

This paper has highlighted the complexity of the problem of the increasing vulnerability of cities to the negative impacts of urban heat. This is because a review of previous research is considered very important to estimate and analyse the size and intensity of urban heat islands to understand the causes that can increase the severity of this phenomenon. Urban areas have varying levels of severity. This research shows that based on the literature review method, the cause of the increase in the intensity of this phenomenon has very little variability and is based on three main triggers which are considered influential in reducing impacts or problems that can increase the temperature in the urban microclimate, such as increased the surface albedo, the amount of vegetation reduced, and anthropogenic emissions are still produced. The risk of the urban heat island phenomenon can be overcome by implementing mitigation. It felts that mitigation measures need to be taken immediately to increase urban resilience to the urban heat island phenomenon. This research provides mitigation options that can be implemented both in urban planning to reduce the use of reflective construction materials on roads to reduce the increase in surface albedo, increase the amount of vegetation by increasing the area of open space, and reduce anthropogenic activities that can produce more emissions. With this paper, it is hoped that city planners and policymakers will be more aware of the causes and sources of danger that can increase the intensity of the urban heat island phenomenon in urban areas.

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Author Contribution

P.C.A. provided and organize the main ideas, Y.P. developed the research content. P.C.A. and Y.P. conceived, wrote, and approved the final manuscript.

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