AUIQ Technical Engineering Science

Volume 1 | Issue 1 Article 7

2024

Urban Heat Island Effects and Sustainable Mitigation Strategies in Urban Areas: Case Study Jakarta City

Hayder Riyadh Mohammed AL-agele
Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, 43400, Seri Kembangan, Malaysia, upmhayder@gmail.com

Mohamad Fakri Zaky Jaafar
Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, 43400, Seri Kembangan, Malaysia, zakyjaafar@upm.edu.my

Mohd Fairuz Shahidan
Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, 43400, Seri Kembangan, Malaysia, mohdfairuz@putra.upm.edu.my

Recommended Citation

AL-agele, Hayder Riyadh Mohammed; Jaafar, Mohamad Fakri Zaky; and Shahidan, Mohd Fairuz (2024) "Urban Heat Island Effects and Sustainable Mitigation Strategies in Urban Areas: Case Study Jakarta City," *AUIQ Technical Engineering Science*: Vol. 1: Iss. 1, Article 7.
DOI: https://doi.org/10.70645/3078-3437.1006

AUIQ TECHNICAL ENGINEERING SCIENCE 2024;1:64–84

REVIEW

Urban Heat Island Effects and Sustainable Mitigation Strategies in Urban Areas: Case Study Jakarta City

Hayder Riyadh Mohammed AL-agele *, Mohamad Fakri Zaky Jaafar, Mohd Fairuz Shahidan

Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, 43400, Seri Kembangan, Malaysia

ABSTRACT

The overabundance of suburbs planned and built on greenfield grounds formerly classified as green-belt property is the consequence of ineffective urban development limits. It would be unnecessary to further intrude onto precious greenfield property, which is vital for future recreational, biodiversity, forestry, agricultural, and food supply needs. Controlling the growth of developed land, prohibiting the construction of tall buildings close to the shore, and establishing green open spaces with an emphasis on areas with elevated surface temperatures are the adaptation strategies for reducing Jakarta's urban heat island phenomenon. Urban population growth contributes to increased carbon dioxide emissions, which exacerbates climate change. Cities are growing as a result of this expansion and require more facilities and infrastructure. Due to heat trapped by urban buildings, part of the energy and CO_2 emissions from this growth are lost. Because of their impermeable surfaces and increased solar radiation, urban heat islands (UHI) impair thermal comfort and have a significant impact on climate-related disasters in modern cities. Threats to infrastructure, human health, and urban ecosystems arise from rising outside temperatures, particularly in lower-altitude cities. These initiatives concentrate mostly on Jakarta, Indonesia, and address UHI mitigation and sustainable building practices. Architecture must fundamentally alter the underlying principles of cities and structures to be considered truly sustainable.

Keywords: Urban heat island, Jakarta city, Urban climate, Urban planning, Review analysis

1. Introduction

In the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (AR5), it is stated that the average air temperature on the Earth's surface will increase by about 3–5°C compared to the pre-industrial level by the end of this century, global sea level surface rose about 0.19 meter from 1901–2010, and the sea surface temperature has increased due to the increased carbon dioxide concentration in the atmosphere [1]. The global mean temperature could increase more than 4°C compared to the preindustrial era, and the intensity and frequency of rainfall could increase if no actions are taken to reduce greenhouse gas emissions by 2100 also stated in the report [2]. The report predicts a higher Earth's surface temperature in the 20th century, potentially worsening global climate conditions like longer waves, extreme rainfall, warmer seawater, and higher sea level. Studies show a 1°C increase in global air temperature since 1900 [3]. Population growth in urban centres increases carbon dioxide emissions, exacerbating climate change. This growth drives city development, requiring more facilities and infrastructure. This expansion results in increased energy and CO_2 emissions, with some lost due to heat

Received 6 July 2024; accepted 25 July 2024.
Available online 23 August 2024

* Corresponding author.
E-mail addresses: upmhayder@gmail.com (H. Riyadh Mohammed AL-agele), zakyjaafar@upm.edu.my (M. Fakri Zaky Jaafar), mohdfairuz@putra.upm.edu.my (M. Fairuz Shahidan).

https://doi.org/10.70645/3078-3437.1006

trapped by urban structures. The urban greenhouse effect is impacted by the size of cities, the kind of buildings used, and their height. It increases heat stress-related diseases and ozone levels. The intensity of urban warming depends on wind speed, direction, and solar flux. Warmer urban materials include high-rise buildings, asphalt, concrete, dark roofs, and impermeable materials. This is called the Urban Heat Island, the air temperature of urban areas is higher than the surrounding air temperature [4, 5].

The UHI significantly impacts climate-related disasters in modern cities due to increased impervious surfaces and solar irradiation, affecting thermal comfort [6]. The elevation of outdoor temperature generates threats to human beings, urban ecosystems, and infrastructures, especially cities in lower altitude areas [7]. Nearly every major city in the globe experiences the UHI phenomenon. The UHI phenomenon also occurs in Jakarta, the capital city of Indonesia [8]. Jakarta faces UHI due to massive urbanization, causing the degradation of Open Green Space (OGS). Mitigation efforts should focus on densely populated areas to prevent climate change impacts. These areas have a relatively higher temperature among others, due to miss-arrangement of spatial layout and poor selection of building materials [9]. Jakarta faces a multifaceted challenge in mitigating the urban heat island effect, including rapid urbanization, land use changes, infrastructure development, flooding, air pollution, and limited green spaces. To overcome these challenges, Jakarta requires sustainable urban planning, policy reforms, green infrastructure investments, and community involvement, requiring collaboration among government bodies, planners, environmental organizations, and local communities. This study proposes some solutions based on the steps and actions taken by Singapore and China to address the problem of UHI in Jakarta.

2. Article selection method

In this review investigation, peer-reviewed English-language articles from Jakarta and Singapore were used, along with some Chinese research that used Google Scholar and the Web of Science database for various dual aspects like road and LULC-related information, urban green space analysis, and UHI in those areas. To search the relevant literature from those two databases, several keywords are used, such as “urban heat island,” “LULC change,” “LULC prediction,” “satellite datasets,” “urban green space,” “blue space,” and “infrastructural development”. All publications are scanned, and information regarding the case studies conducted in Jakarta is included (Fig. 1).

3. Literature review

3.1. The UHI formation

The UHI effect, caused by built infrastructure trapping and retaining heat, leads to higher temperatures in urban areas. As urbanization increases, UHI intensifies due to increased scale and population. The intensity of the UHI is affected by variables such as geography, climate, and human activity [10]. Building energy systems like HVAC generates waste heat, escalating UHI. Rising temperatures increase cooling demand, causing higher energy consumption and greenhouse gas emissions. Urban heat islands are localized warming phenomena caused by the absorption and radiating of heat by surrounding surfaces like roads and pavements [11].

3.2. The UHI effects

The UHI effect is a global issue causing higher temperatures in cities compared to the surrounding countryside, threatening urban life and environmental problems. It impacts health, well-being, human comfort, and the local atmosphere, leading to heat stress (Fig. 2). Elevated temperatures negatively impact urban infrastructure, human health, and comfort, motivating UHI mitigation measures due to health issues, fatalities, and increased electricity and water usage [12]. The UHI effect, exacerbated by urban infrastructure, reduced green spaces, and human activities, increases health risks like heat stroke, dehydration, and respiratory problems, particularly affecting vulnerable populations like the elderly, children, and those with pre-existing health conditions [13, 14].

3.3. Increased Land Surface Temperature (LST)

Urban heat islands arise from impervious surfaces, less vegetation, and increased sources of heat, such as vehicles and buildings, absorbing and retaining heat. Urban heat waves intensify the urban heat island effect, causing increased temperatures in buildings due to heat absorption and energy use [16]. Urban areas experience local warming due to elevated surface temperatures, influenced by land use, vegetation cover, and urban morphology. High impervious surfaces, like roads and buildings, absorb and retain more heat, exacerbating extreme heat events [13].

3.4. Heat absorption by building materials

Climate directly impacts city development, influencing building types, energy consumption, and

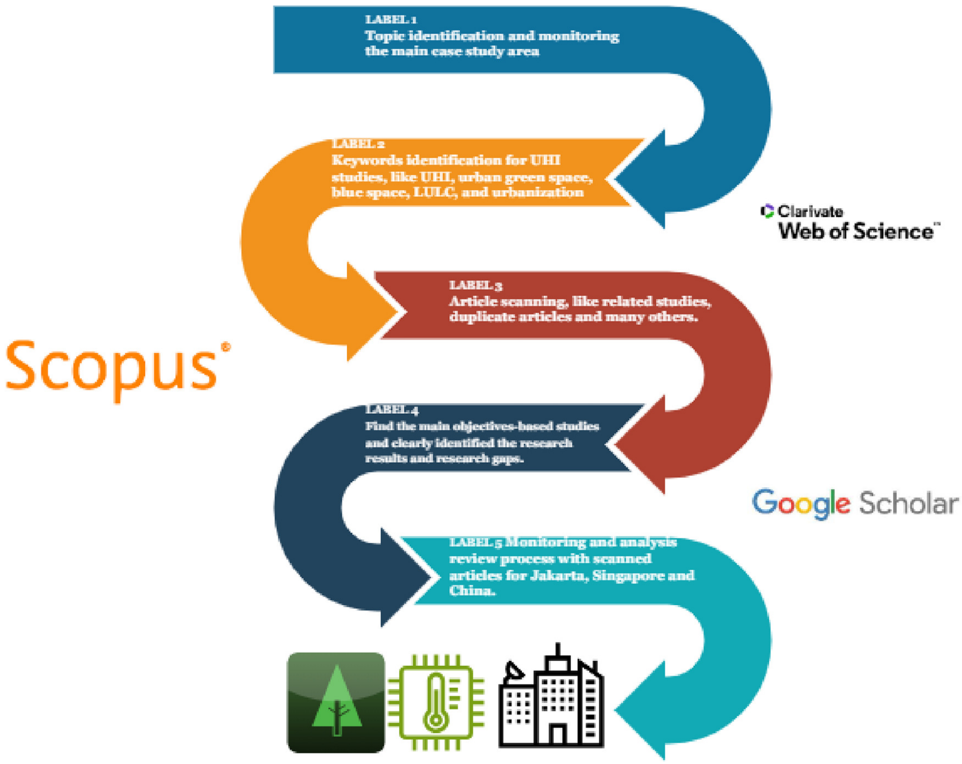

Fig. 1. Details about the review process.

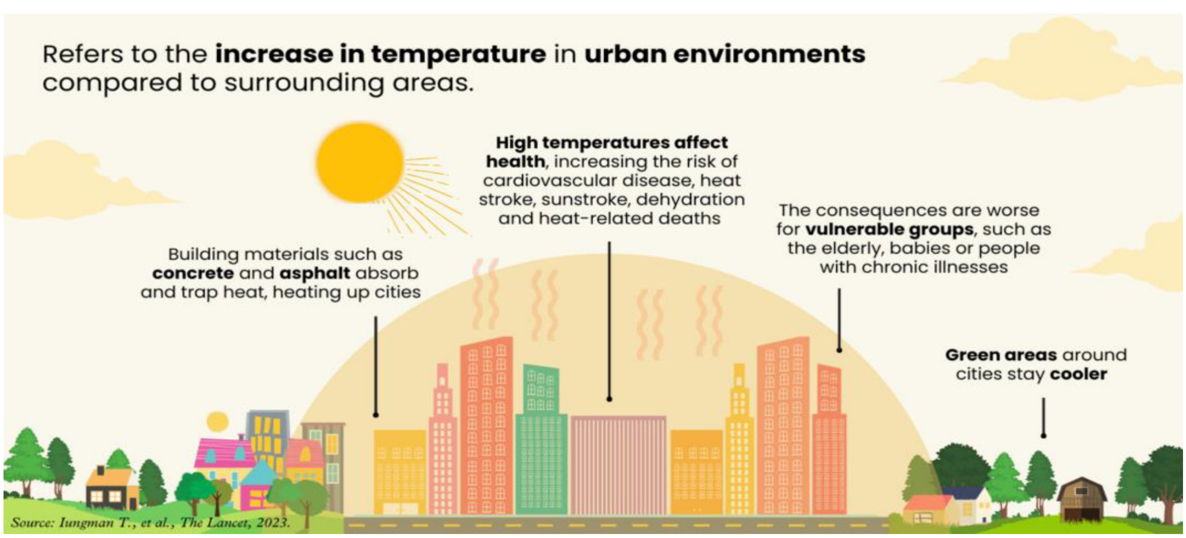

Fig. 2. The UHI phenomena [15].

materials used. Urbanization, density, and non-natural materials like asphalt and curb stone create the UHI effect, resulting in higher temperatures in city centres compared to rural areas. The UHI is primarily caused by increased urbanization and human-made materials, leading to increased energy needs and heating of urban landscapes. On the other hand, pavements and roofs dominate, while high thermal mass building materials absorb and retain heat, causing environmental and public health consequences [12]. Urban greenhouse effect intensity depends on tall buildings, building materials, and city size. Thermodynamic properties of surface materials can accelerate local temperature profiles, with warmer effects observed in high-rise buildings, asphalt, concrete, dark roofs, and impermeable

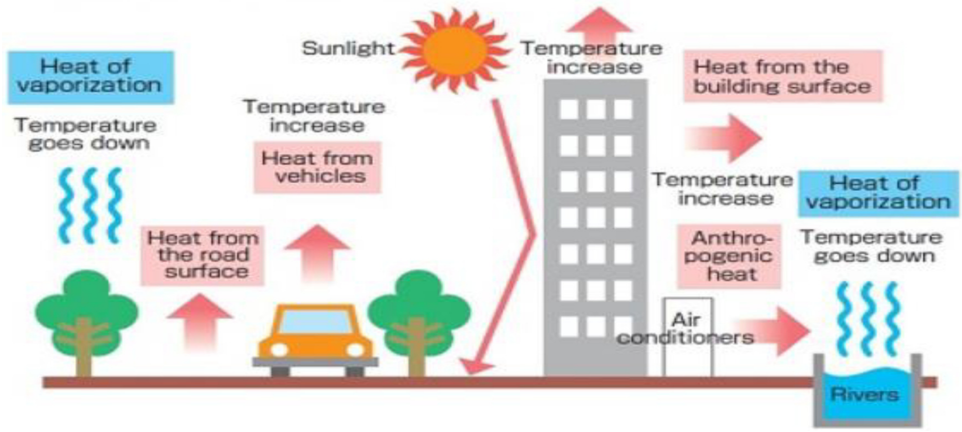

Fig. 3. Variation between surfaces in their ability to absorb heat.

materials [4]. Rapid urbanization has led to pavements covering over 30% of urban areas, causing the UHI effect. This is due to the pavement's higher thermal inertia and lower evaporation rate, leading to higher air temperatures in urban areas. Hot pavements significantly contribute to this effect, particularly in near-surface heat islands. Heat waves cause the sun's energy to absorb and reflect on surfaces, increasing their temperatures (Fig. 3). Permeable surfaces absorb less heat, while construction materials absorb up to 95% of the sun's energy, radiating it back into the atmosphere [17]. Structure material's higher thermal inertia and lower evaporation rate contribute to higher air temperatures in urban areas, forming heat islands due to higher temperatures in rural areas.

3.5. Sky view factor and internal reflection

Urban planning and building geometry influence the formation of Urban Heat Islands. High-rises in urban canyons provide shade but do not cool down at night. The sky view factor, which indicates visibility, influences short-wave sunlight reflection and long-wave radiation emission in urban canyons [12].

3.6. Climate change and urban heat island

Climate change is primarily caused by human activities like burning fossil fuels, deforestation, and burning agricultural crop residue, which releases greenhouse gases into the atmosphere, trapping solar heat and warming the Earth's surface. This increase, which has already increased by 1°C since pre-industrial times, could potentially exceed 2°C by the end of the century if proper strategies are not designed [13]. The effects of climate change are becoming more and more obvious, having an influence on buildings' indoor environment quality and thermal performance. Research focuses on energy consumption, carbon emissions, and system efficiency, but less on thermal comfort and health [18]. Rising temperatures increase the risk of building overheating, posing health risks and potentially causing fatalities for vulnerable individuals exposed to heat and humidity [19]. Urban populations are increasingly exposed to climate-related disasters, including heatwaves, due to rapid urbanization and ecological changes [20]. The UHI intensifies heatwaves and exacerbates urban environmental risks, such as air pollution, in Asian cities, where urban heatwaves are more frequent [21].

A climate change projection suggests that global temperatures could rise by 1.5°C by 2040, primarily due to human activities and the UHI effect. The rising urban population, which is expected to reach over 60% by 2030, is causing the UHI effect, which may increase city temperatures by several degrees, potentially threatening human health [22]. The UHI and climate change significantly impact building energy demand. Climate change affects urban microclimate through factors like canopy layer characteristics, land use patterns, and local climate [23]. Climate change reduces wind speed and cloud cover, increasing UHI intensity and thermal stress. Rapid urbanization increases land use changes, further influencing UHI [11]. Indonesia's tropical climate is impacted by climate change, leading to sea-level rise, extreme weather, and threats to ecosystems [24]. The UHI affects buildings, increasing resource consumption, environmental footprint, health effects, and occupant comfort. Strategic adaptation and mitigation measures are needed to reduce risks associated with UHI in urban planners, designers, and decision-makers [25].

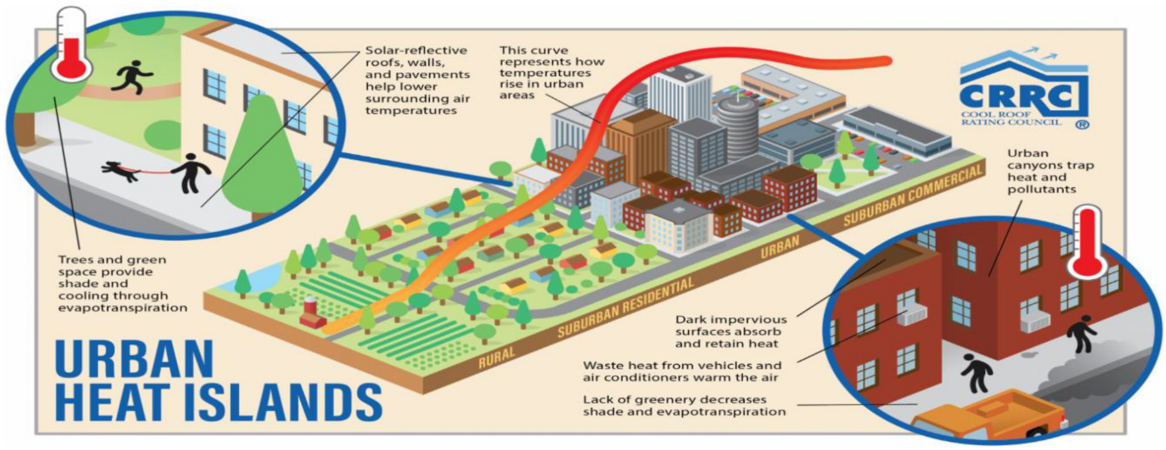

Fig. 4. External units of cooling systems.

3.7. Population density and its impact on UHI

Urban populations now constitute 55% of the world's population, with growth expected to reach 68% by 2050. Cities account for two-thirds of global energy consumption and 70% of annual carbon dioxide emissions [19]. Rapid urbanization is predicted to reach 5 billion by 2030, affecting city development due to increased demand for facilities and infrastructure. This migration of population from rural to urban areas is causing isolated population centres to transform into metropolitan cities, affecting land cover and causing further growth (Fig. 4). As people migrate to metropolitan areas, land surface modifications, such as waterproof material storage, urban microclimate, and outdoor activities, are influenced by factors such as urban configuration, solar radiation trapping, vertical obstruction, and natural vegetation [26].

3.8. Energy consumption and heat generation

UHI significantly increases energy consumption in cities, with indoor cooling energy consumption increasing by up to 4%. In dense cities, monthly cooling energy consumption is 120% higher than in rural areas. UHI effects are more significant in far-east countries like Bangkok and Jakarta [27]. Cities, occupying only 3% of the planet's surface, account for 60-80% of energy consumption and 75% of carbon emissions. Buildings consume 35% of energy and emit 38% of greenhouse gases. Cities are crucial for reducing global warming and sustainable development [28]. Energy consumption in buildings, particularly from cooling systems, can release heat into the surrounding environment. The energy consumption of external cooling systems in urban areas can increase the UHI effects due to theoverall heat load.

3.9. The impact of UHI on building energy consumption

The International Energy Agency reports a rise in cooling energy use in buildings from 2.5% in 1990 to 6% in 2016, with tropical countries consuming 11% of electricity for space cooling due to outdoor weather conditions [29]. The building sector is a significant energy consumer and emitter, necessitating energy audits to identify efficient usage and energy savings. As temperatures rise, buildings require more cooling and less heating, necessitating priority efforts to reduce urban heat island effects [19]. The consumption of UHI, which accounts for 31% of global energy consumption, has a significant impact on building energy consumption, which has increased from 1.4 billion tonnes of oil equivalent (TOE) in 1970 to 5.5 billion TOE in 2040. The high energy consumption in buildings poses significant challenges for sustainable development, including disrupting reliable energy supply, increasing greenhouse gas emissions, and exacerbating air pollution. Factors like ambient temperature, building characteristics, and appliances' performance are crucial in reducing UHI [30].

3.10. The impact of high ambient temperatures on electricity demand

Global warming and urban heat islands increase ambient temperature, intensifying energy consumption for cooling buildings, particularly in tropical regions. This leads to peak electricity demand, increased power plant construction, and increased electricity supply costs, stressing consumers and networks [31]. Thus, global warming and the UHI effect significantly increase energy consumption in buildings, particularly in temperate and mid-latitude

Fig. 5. Map of Jakarta city.

climates. The UHI intensity is crucial for estimating building energy performance due to cooling demands [32].

3.11. The lack of vegetation

Inadequate vegetation leads to the development of urban heat islands, which are areas with surfaces that retain more heat than the natural ground cover. Green spaces and vegetation help lower surface temperatures by evapotranspiration, while the structure of urban environments retains heat overnight. Even smaller green areas can help alleviate elevated temperatures. Natural surroundings, characterized by vegetation and trees, provide shade, reducing surface and air temperatures by 10–15°C, while buildings and impervious surfaces diminish evaporation processes. In general, increasing the green percentage by 10% points leads to a decrease in air temperature by roughly 0.5°C [33]. Urban areas' green percentage is essential for lowering heat buildup, boosting air quality, and increasing microclimate—all of which improve the city's overall liveability.

4. Jakarta city

Jakarta, Indonesia's capital, is a rapidly urbanized megacity with a population of 11 million, predicted to reach 15 million in the next decade. The rapid urban expansion has impacted the local climate [9]. Population activities, such as industrial activities and large-scale migration, significantly impact climate change. Urban regions are more susceptible to the effects of climate change because of their greater demand for natural resources and better living standards and incomes (Fig. 5). The UHI is a climate change risk where cities experience rapid urbanization, leading to higher temperatures in surrounding areas, measured using Land Surface Temperature and atmospheric UHI [34]. Jakarta, the economic hub of Indonesia, has seen a significant increase in population, necessitating increased built-up areas for infrastructure development. This has led to a rise in greenhouse gas emissions and surface temperature, creating a heat island effect and causing long-term inconvenience [26].

The urban heat island effect occurs when inner cities experience warmer temperatures than rural areas. By 2045, 220 million Indonesians will live in urban areas, making up 69% of the total population. Rapid urbanization is changing the climate of the nation, especially in big cities like Jakarta, Bandung, Surabaya, and Medan. Urbanization varies regionally, with megacities expanding in developing countries like Jakarta, potentially worsening climate change impacts due to unplanned urbanization [35]. The UHI is caused by various factors such as increased anthropogenic heat, reduced evaporation, heat storage, radiation, and convection, and population and urban

Fig. 6. Urban planning and residential crowding.

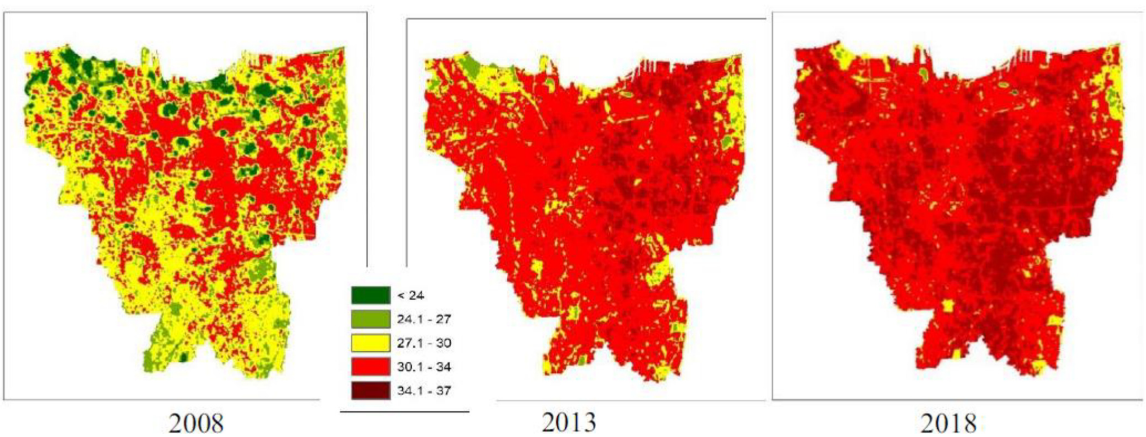

Fig. 7. LST distribution of Jakarta in 2008, 2013, and 2018 [8].

density in Asian cities, such as Jakarta, affecting social and environmental changes (Fig. 6). Jakarta's dense development, involving horizontal and vertical growth, has led to UHI issues, worsening climate change, and challenging sustainable city agendas due to the rapid increase in UHI intensity [26].

4.1. Increased surface temperature in Jakarta

Jakarta's surface temperature reached its highest level in 2019, reaching 34°C, a significant issue due to the UHI vulnerability (Fig. 7). This is a major challenge in achieving climate change mitigation and could lead to an increase in global temperatures [26]. Over the past 12 years, 49.7% of green open space has been converted into other land uses, leading to increased outdoor temperatures, with 1-3°C differences between urban and rural areas [36].

4.2. UHI in Jakarta

The UHI is a phenomenon in major cities like Jakarta, originating from the city's central area and spreading to any direction. Between 2008 and 2013, there was a more marked southerly dispersion of UHI, with temperatures above 340 rising in eastern Jakarta.

The expansion of UHIs in Jakarta is linked to intensified land development, with higher levels of developed land causing higher air temperatures. Land use affects temperature because of the quicker tendency of more developed areas and UHI. The UHI intensity increases with urban area, economic activity, geographical and seasonal characteristics, and population level, indicating a significant influence on UHI formation. Jakarta's high population density and economic activities, supported by commuters, impact land use intensity. The SUHI formation is influenced by various land use types, including building development, commercial and service areas, and transportation facilities. The impact of population on UHI formation is stronger in early urbanization stages, indicating that land use intensity increases with population and activity intensity [8].

4.3. LST

Saputra et al. conducted a Correlation Analysis to generate UHI derivatives from LST values in Jakarta, using data from May, July, September, and December 2020, using Landsat 8 thermal infrared sensors and USGS website data. The LST in Jakarta varies monthly due to cloud cover, causing issues with LST calculation. The maximum LST value is 34.36°C in December, while minimum values range from 13–14°C. Dry season temperatures are hotter than wet season temperatures. The great temperature of LST in July in Jakarta was yellow to red, indicating a high symbol of LST. However, September was the hottest month, reaching 35.73°C. May was the coldest, with 30.65°C. The temperature pattern varies depending on the month, with northeast Jakarta showing the lowest temperature in May, September, and December [34]. The UHI in DKI Jakarta is determined by land surface temperature values. They are highest in May, July, and September, with a high peak in December. The spatial distribution of UHI is influenced by people's activities, with more outdoor activity increasing its value [35]. Based on analysing 300 points in 60 municipalities, finding that built-up land surface temperature is higher than green open space, with differences reaching 2.8°C. Green spaces, particularly in Jakarta West, North Jakarta, East Jakarta, South Jakarta, and Central Jakarta, contribute to decreasing surface temperature [37]. A study reveals a 25% increase in settlement areas in suburban areas due to land use changes, while barren land expansion increased by 25% [35]. Vegetation decreased by 20% and water bodies decreased by 2%, indicating a worsening UHI due to global warming and environmental changes, including increased build-up area and barren land. LST in 2020 decreased due to La Niña's climatic variability, bringing lower global temperatures, unlike El Niño, which increases global temperatures. The study reveals that the Greater Jakarta UHI exhibits higher land surface (LST) and air temperature (SAT) than its surroundings, with differences of approximately 3°C–6°C for LST and 1°C–2.5°C for SAT, indicating a noticeable UHI signal [35].

4.4. Factors contributing to the formation of a UHI in Jakarta

4.4.1. Urbanization without control

The need for developed areas for infrastructure development in Jakarta has surged due to the city's expanding population, resulting in a reported rise from 45,830 hectares (1997) to 55,408 ha (2009). This has also increased greenhouse gas emissions and surface temperature [37]. Jakarta's rapid urbanization since 1991 has led to increased heat retention and reduced radiative heat emission, resulting in a sheltering effect and an increase in the UHI phenomenon due to the increased land development area [36].

4.4.2. The lack of green zones

Jakarta faces heat issues due to overcrowding and inadequate cooling infrastructure, causing UHI harm in informal settlements worldwide. Jakarta is grappling with the challenges of expanding land cover and uneven surface temperature distribution (Fig. 8). The proliferation of built areas is exacerbating rising temperatures, while the reduction of green open spaces is compounding the issue. Between 2000 and 2012, surface temperatures above 30°C in all regions, highlighting the need for improved urban development planning that effectively addresses economic, social, and ecological considerations [37].

Jakarta has experienced a 2.5°C temperature increase in the last 100 years due to the rapid growth of business areas and settlements. Less than 10% of green and open spaces remain, despite the potential to reduce temperatures. Poor planning and spatial control have resulted in only 5.18% of green spaces in 2022 [38].

4.4.3. 3 population density

Jakarta, with a population exceeding 10 million, is a densely populated city with a population density of 16,125 individuals/km^2. This has led to a significant presence of informal settlements, disproportionately affected by the urban heat island effect [38]. The city's development has been influenced by the rise in population, leading to an increase in anthropogenic activities, building numbers, and road length [36].

4.4.4. Transportation

Jakarta and its metro area are a bustling hub of people and traffic, with over 20 million vehicles daily and 11% more annually (Fig. 9). With a population density of 13,000 people per km^2, motorists spend over half their daylight hours stuck in traffic [39].

Fig. 8. The lack of green zones in Jakarta.

Fig. 9. Vehicle density in Jakarta.

Jakarta's urban areas are facing challenges in managing human activities, as reported [40], highlighting the increasing use of cars and the urban heat island effect.

4.5. Mitigation strategies in Jakarta city

Heat is released into the urban environment by automobiles, air conditioners, buildings, and industrial

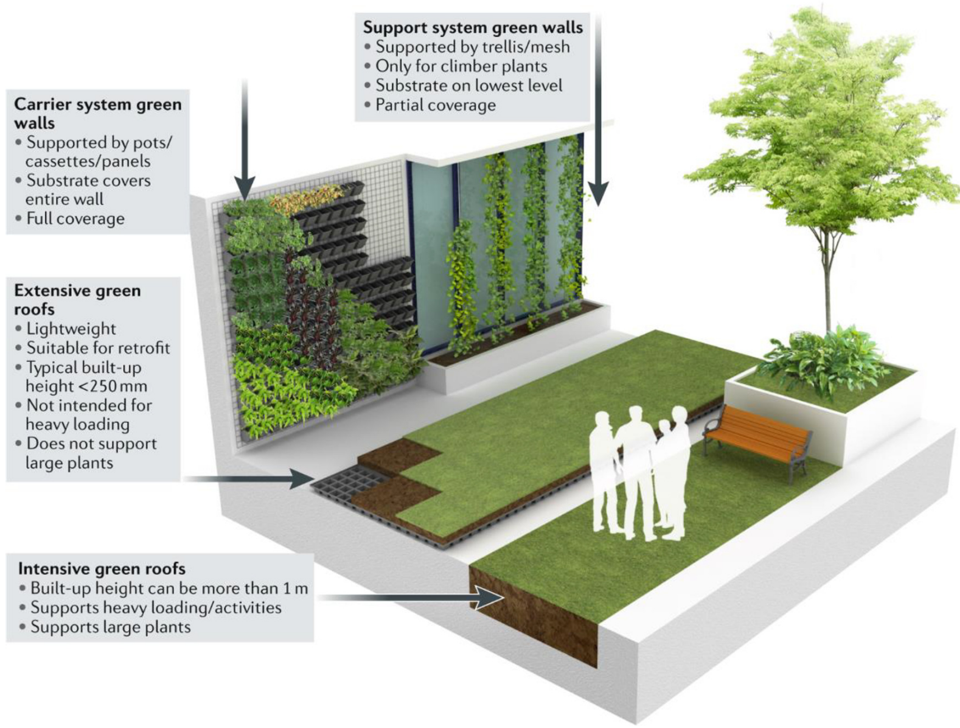

Fig. 10. UHI reduction strategies [41].

operations. Heat island effects may be exacerbated by these sources of waste heat produced by humans or anthropogenic waste heat. One way to lessen the effects of Urban Heat Island in Jakarta is to adopt mitigation methods including garden cities, green roof alternatives, shade and ventilation combined, air quality maintenance, and anthropogenic heat. A city experiences the urban heat island (UHI) effect when its interior encounters much higher temperatures than nearby rural regions. The land and surface air temperatures in the inner cities of the Jakarta region are often greater throughout the day than they are outside. The urban heat island effect is a significant environmental issue that affects all major cities. The economic and environmental effects of increasing cooling are well-documented, as are local increases in the mean annual temperature.

It is warmer because the heat is trapped at lower elevations. Compared to their rural neighbours, urban heat islands may have lower-quality air and water. Because more pollutants—waste products from humans, industry, and vehicles—are released into the atmosphere, UHIs frequently have poorer air quality. Installing reflecting pavement and roof coatings, which absorb less heat than conventional building materials, is an additional choice. To improve ventilation, cities can also enact zoning laws that vary the height of new construction. Similar to green areas, blue infrastructure—which includes water features like rivers, ponds, and dams—can be an effective means of lowering temperatures. Reducing the warmth of the surrounding region may also be achieved by including water features with green spaces. UHI is not a recent problem in Indonesia, especially in Jakarta (Fig. 10). It is commonly recognized that urban heat islands exist and have an impact. But when it comes to the local level, many people are unaware of it (the studied example in this research is Surabaya). Although UHI has a distinct and more complicated meaning than high rising temperatures, sadly, the municipality interprets it as a high temperature in the city (Fig. 11). Furthermore, Surabaya has not yet had a direct UHI measurement performed. Furthermore, this study measures UHI conditions using CDD and maximum-minimum temperature. Furthermore, this state has an impact on how urban planning is established and carried out. People will choose to reside in urban areas due to the municipality's constant expansion in these areas, which is concentrated in the CBD, and the absence of green space.

5. Mitigation strategies (Reference study)

The UHI effect, a result of rising surface temperatures and expanding built environments, threatens a

Fig. 11. Benefit of green space in urban heat island affected areas (https://bjspark.com/green-space-benefit/).

secure and sustainable future. Addressing this issue requires scientific research and policy development, focusing on sustainable solutions for urban planners [42].

5.1. Singapore

Singapore is famous for its high standards in green building, its use of green roofs, and the abundant greenery incorporated into its urban planning, all striving to build a "City in a Garden" (Fig. 12).

The worldwide effect of UHI is causing an increase in temperatures, impacting cities like Singapore. This effect leads to decreased productivity, higher cooling costs, and increased carbon emissions. Singapore's built-up areas are experiencing a 0–2°C hotter day and night temperature. The Centre for Climate Research Singapore (CCRS) predicts Singapore's maximum daily temperature could reach 35-37 degrees Celsius by 2100 due to rising carbon emissions and Urban Heat Island effect. Singapore's Ministry of Sustainability and the Environment and Urban Redevelopment Authority are working together to mitigate urban heat island impacts, focusing on technology and innovation in policy and planning to create a liveable, heat-resilient city. Facing this head-on, Singapore's response zeroes in on three fronts:

I. Crafting wind corridors and optimizing shade.
II. Reducing heat absorption.
III. Curtailing heat emissions.

Notable among Singapore's strategy against urban heat are:

5.1.1. Urban greenery

Singapore's Green Plan 2030 and the City in Nature vision ensure an additional 1000ha of green space will be set aside within 10 to 15 years, with every residence within a 10-minute walk to a park by 2030.

5.1.2. Green building initiatives

The Building and Construction Authority (BCA) in Singapore is promoting the use of green roofs in its construction projects to reduce environmental impacts (Fig. 13).

5.1.3. Skyrise greening

Since its launch in 2009, the Urban Spaces and High-Rises LUSH initiative has encouraged vertical greenery in urban areas, cutting energy cooling demands by 10–31%, improving pedestrian comfort, and lowering cooling expenses (Fig. 14).

5.1.4. Innovative materials

The UHI phenomenon, where city surfaces like pavements and buildings absorb and hold heat, is

Fig. 12. Singapore Marina Barrage as an open green space.

Fig. 13. (a) Urban greenery in Singapore, (b) Park royal Singapore architect as a green building.

Fig. 14. (a) Green walls, (b) Vertical green building tree haus green skyscraper in Singapore.

Fig. 15. (a) Parks and gardens as public spaces, (b) Cooling parks and spaces.

exacerbated by the tropical climate and the warmth produced by air conditioner compressors. These elements have led to a rise in Singapore's average surface air temperature. Consequently, using coatings that maintain surface coolness is crucial. Fig. 15 illustrates a novel solar-reflective coating technology. Eighty percent of the population lives in public housing residential estates where pilot projects employ cool paints to lower the overall temperature. Specific paint system parameters are needed for various surface types, such as highways, buildings, and roofs.

5.1.5. Cooling strategies

The creation of parks and gardens, as well as the extensive planting of trees, are two of the city-state's many cooling initiatives. Singapore's dedication to becoming a "City in a Garden" underscores the significance of green infrastructure in mitigating heat and boosting urban biodiversity (Fig. 15). Singapore has established cooling parks and spaces, like Jurong Lake Gardens, to offer residents pleasant outdoor areas, helping to lower temperatures and alleviate the UHI effect.

5.1.6. Urban planning and design

The Housing and Development Board is implementing sustainable urban planning strategies to mitigate UHI in urban areas, focusing on wind flow optimization, green spaces, and reflective materials.

5.1.7. Cool roofs and green roof installations

Singapore promotes the adoption of cool roofs that reflect more sunlight and retain less heat to decrease building temperatures. In addition, adding flora to a roof may provide insulation, improve biodiversity, and help with cooling.

5.1.8. Public awareness and education

Public involvement and education are crucial components of Singapore's strategy to mitigate the UHI effect. Campaigns, workshops, and educational initiatives inform residents about the effects of UHI and promote sustainable actions like energy conservation and valuing green spaces (Fig. 16).

5.2. UHI mitigation strategies in China

China is actively addressing urban heat island effects by adopting green building practices, increasing green spaces, and utilizing cool pavement technologies in its urban cities to combat the rapid growth of these areas. Here are some strategies along with examples

5.2.1. Green spaces and urban parks

Urban green spaces, such as urban parks, roads, and green spaces around residences and workplaces, are seen as effective in lowering the surrounding air temperature, reducing air pollution, enhancing the well-being of nearby individuals, and decreasing the amount of energy used for cooling during the summer. Effective landscape planning can help alleviate the Urban Heat Island effect by creating Urban Green Spaces, which contribute to the formation of the Urban Cool Island effect. Creating parks with abundant tree planting and green space can effectively lower air temperature and establish a refreshing urban cool island within the park boundaries. The cooling impact of parks extends beyond their physical limits and is impacted by the surrounding environment [43]. Cities like Beijing have been investing in creating more green spaces, such as the Beijing Olympic Forest Park. These areas help absorb heat, provide shade, and improve air quality.

5.2.2. Cool roof and cool coatings on building surfaces

Cool roofs, with high thermal emissivity, can significantly reduce surface temperatures in hot summer cities, saving energy costs by dropping surface temperatures by approximately 20°C and 17°C, respectively. Cool roofs, combined with phase change materials and cool materials, can achieve indoor temperature differences of over 4.5°C (Fig. 17). These innovative roofs effectively reduce temperature peaks

Fig. 16. (a) Cool and green roofs, (b) Beijing Olympic Forest Park.

Fig. 17. (a) Cool roof and cool coatings on building surfaces, (b) Tianjin city and sustainable urban planning, (c) Guangzhou city and green roofs technology, (d) Vertical forest towers of Stefano Boeri in China.

and are recommended in China's green building evaluation standards to alleviate the UHI effect [44].

5.2.3. Urban planning and design

It is essential to properly assess the efficacy of UHI mitigation techniques while thinking about ways to optimize the beneficial influence on urban settings. The UHI effect should be considered and implemented on a large scale during urban planning project design. Buildings in Tianjin are purposely placed to maximize shade, and ventilation, and reduce the urban heat island effect.

5.2.4. Vertical greenery and tree planting program

Recently, Vertical Greening (VG), better known as a vertical greening system, vertical garden, green wall, or bio wall, has become increasingly popular in urban greening because of its compact form,

Fig. 18. Trees-planting programs.

aesthetic appeal, and capacity to reduce the urban heat island effect. These impacts can additionally lead to improved psychological well-being and acoustic insulation, safeguarding the building's structure, and promoting biodiversity [44]. Chengdu and other cities have launched extensive programs to increase tree planting and improve urban tree cover, helping to provide shade and cool the environment (Fig. 18).

5.2.5. Cooling centres and urban water features

Wuhan has created cooling centres and included water features such as fountains and ponds to lower temperatures in public areas, offering relief during warm weather.

5.2.6. Promotion of energy-efficient buildings

Shenzhen has led the way in advocating for energy-efficient building designs, utilizing materials that retain less heat and incorporating innovative insulation methods. Cities like Hangzhou have incorporated smart city technologies to oversee and regulate energy consumption, enhancing cooling system efficiency and minimizing overall heat emissions.

5.2.7. Public awareness and education

Beijing has run public awareness campaigns to inform residents about the effects of Urban Heat Islands and promote habits like conserving energy and reducing heat emissions. China's strategy employs a mix of technological, infrastructural, and policy-based measures to tackle UHI effects, aiming to foster more sustainable and resilient cities.

6. Mitigation strategies of UHI effects

The world is at a climate crossroads where unified efforts and localized measures are crucial. To curb temperature increases resulting from climate change, sustained reductions in carbon emissions and global collaboration are essential. Nonetheless, the UHI effects caused by heat absorption from urban infrastructure and heat generated by vehicles and appliances can be reduced through local interventions. There is a pressing need in cities to devise sustainable strategies for mitigating and adapting to UHI effects. The urban heat island effect has drawn the attention of local and central governments in Jakarta (Fig. 19). Despite numerous measures being implemented, the issue persists. Local and central governments in Jakarta, along with construction organizations, can implement some of the strategies that other countries have used to mitigate UHI, such as:

6.1. Sustainable mitigation strategies of UHI effects

Implementing effective mitigation strategies to reduce UHI effects requires adopting approaches that address heat-related issues while too promoting long-term environmental sustainability.

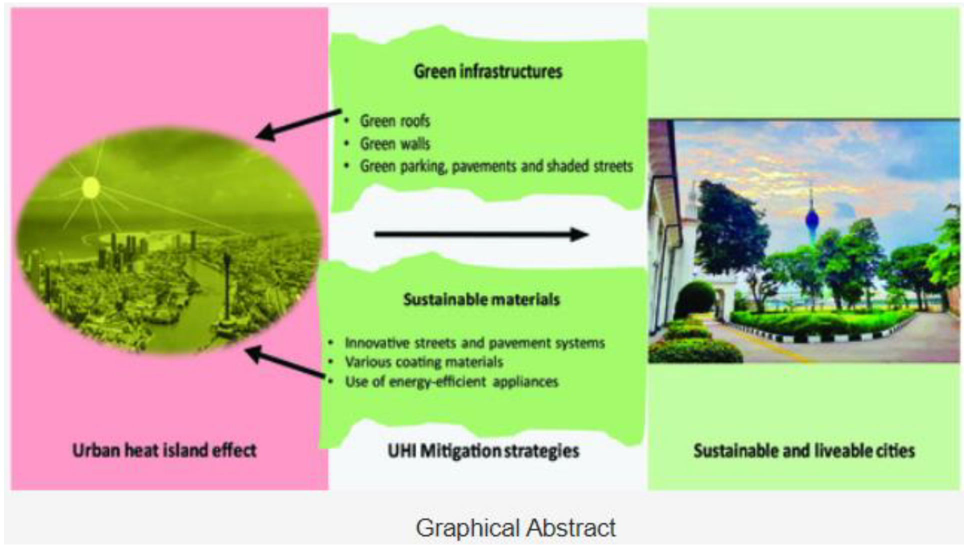

Fig. 19. The environmental balance.

6.1.1. Urban planning and design

Sustainable urban development is closely linked to spatial planning. Approaching it at the administrative level, which involves spatial structure, is highly effective in mitigating and adapting to climate change and rising temperatures. Spatial development planning, which manages the expansion of built environments and adds green open spaces, will foster a pleasant and welcoming urban atmosphere. To address urban environmental challenges, it's essential to preserve urban forests to cool buildings and pavement [37].

6.1.2. Cool impervious materials

Concrete and other construction materials typically retain twice as much heat as natural materials like dry soil and sand. As a result, concrete emits significantly more heat at night than natural materials or surfaces covered in vegetation. Research on heat stress and strategies for mitigating it has been underway for years. For instance, innovations like "cool paving materials" and "cool roofs" have been created. Several cities, such as Chicago, New York, and Houston, are dedicating significant efforts to maintaining and expanding green spaces. In recent years, studies have explored the thermal properties of paving materials, leading to the development of new and improved materials like permeable concrete and asphalt, along with specialized additives and finishing layers to boost albedo and emissivity [45]. Several cities have established policies and programs to implement cool paving materials. Consequently, Jakarta can adopt similar measures to utilize heat-reducing materials in the future.

6.1.3. Sustainable materials for UHI effect mitigation

The preconstruction, construction, and finishing materials of the building significantly contribute to heat absorption. Streets and pavements made from impermeable, highly heat-absorbent materials, accompanied by paints with high thermal effects and energy-efficient appliances that emit substantial heat, contribute significantly to the Urban Heat Island effects. As a result, incorporating sustainable building materials into urban infrastructure is another significant factor influencing the UHI effect. Sustainable construction materials are together economically viable and help reduce harmful emissions and Urban Heat Island effects, thereby lessening their overall environmental impact. Buildings should incorporate sustainable building materials and technology in an appropriate manner and in line with the surrounding environment [42]. Modifying material properties can also reduce UHI. For this situation, "cool materials" are appropriate. Reflectivity, permeability, and light grass cover are desired qualities of these materials [27].

6.1.4. The role of vegetation

Vegetation cover significantly influences the intensity of the urban heat island effect during heat waves. Regions with more vegetation, like parks and green spaces, tend to remain cooler compared to areas with less greenery. Recognizing the difficulties and intricacies linked to urbanization is crucial. Heat waves may initially be somewhat mitigated by urbanization, but with time, the issue gets worse. To address these difficulties effectively, it is necessary to implement sustainable urban planning, promote the development of green infrastructure, and adopt energy-efficient building designs [13]. Limiting the amount of direct sunlight that reaches the ground and absorbing surplus moisture from the air as it evaporates from their leaves, vegetation, and trees serve to regulate urban temperatures. Planting trees in public spaces, in parking lots, alongside roadways, and in private yards helps shade impermeable surfaces, which in turn lowers both actual and perceived city temperatures.

6.1.5. Creating shadow and sun shades

Shading is the most efficient method to reduce local windchill as it prevents the body from experiencing heat from the sun. There are numerous methods to accomplish this. Trees are quite effective because they provide shade and, through evaporation, aid in cooling. One benefit of certain shade structures is their ability to be taken down during the night, which facilitates the release of stored heat in the soil and buildings, resulting in a faster cooling of the city. External sun shading is the most efficient method for maintaining cool temperatures inside buildings [42]. A key strategy for reducing Urban Heat Islands is to increase tree cover and create shade. The density of leaves, leaf area, and evapotranspiration of trees, along with their geometric properties, all contribute to cooling. Thoughtful planning and design of urban landscaping and green spaces can help stabilize urban temperatures and land surface levels to some extent [46]. Urban trees and plants serve multiple purposes: they reduce heat islands, filter out harmful particles, soak up excess precipitation, and enhance residents' quality of life. The value of the living environment is enhanced, which is a consequence that is not to be overlooked.

6.1.6. Green roofing techniques

Green roofing is one of the effective means of mitigating the UHI effect through the process of ambient air conditioning. Altering the attributes of rooftops may serve to mitigate a portion of these concerns. The incorporation of vegetation and soil onto vacant rooftop areas is generally regarded as an effective strategy for enhancing the environmental sustainability of structures. Green roofs are therefore simply rooftops onto which vegetation has been transplanted onto a growing medium. Encouraging the growth of green roofs can benefit the economy, the environment, and the beauty of the structures. A green roof is made up of vegetation, substrate, filter cloth, drainage material, a root barrier, and insulation [42].

6.1.7. Green walls techniques

Another option for mitigating the UHI effect is the use of green walls, which are adorned with lush vegetation. High-rises offer a larger wall surface area compared to low-rise buildings, allowing for more opportunities to incorporate greenery and enhance the effectiveness of these practices. The design includes vertical walls adorned with lush vegetation, creating a visually stunning and vibrant atmosphere. Although it focuses on UHI mitigation techniques, it offers a positive outlook and contributes to a more vibrant environment. Green walls can enhance both air quality and aesthetics by effectively eliminating CO_2 [47].

6.1.8. Use of energy-efficient appliances

Energy consumption in buildings is responsible for a significant portion of emissions, making it a major contributor to the effects of urban heat islands. Efficiently managing energy usage and costs while minimizing environmental impact throughout the entire lifespan of buildings necessitates careful planning and construction, strategic energy sourcing, and the exploration of new materials and promotion of renewable energy [48]. All these elements should be considered in order to optimise energy consumption and consequently mitigate the heat island effect.

6.2. Developing Jakarta city resilience strategies to confront the effects of UHI

Reducing the effects of UHI in Jakarta calls for a comprehensive strategy that combines several tactics catered to the particular difficulties and features of the metropolis. By applying a synergistic blend of these methods and promoting cooperation among stakeholders, Jakarta can successfully mitigate UHI effects and establish a more habitable and environmentally friendly urban setting.

6.2.1. Suggestions strategies to reduce urban heat island effects in Jakarta

Considering the conditions and issues in Jakarta, along with research conducted in various cities worldwide, the following strategy can be implemented to tackle the heat build-up on the city's surface, leading to the urban heat island phenomenon:

- Increase the green area developed evenly throughout areas of Jakarta
- Prioritized the development of green open spaces in areas with high surface temperatures.
- Form of green open spaces, especially urban forest, adapted to the conditions and the availability of existing land.

Table 1. The possibility of applying the experience of Singapore and China in Jakarta to reduce the effects of UHI.

	Suggestions to reduce UHI	SINGAPORE	CHINA	JAKARTA
1	Climate-Responsive Urban Planning	Singapore integrates climate-responsive urban planning principles, such as designing for natural ventilation and optimizing building orientation, to mitigate UHI effects.	Chinese cities incorporate climate considerations into urban planning processes, including land use zoning, green space preservation, and compact development.	Jakarta can adopt similar climate-responsive urban planning approaches by prioritizing green spaces, promoting compact and mixed-use development, and implementing building design guidelines that optimize natural ventilation and reduce heat absorption.
2	Heat-Resilient Infrastructure Design	Singapore invests in infrastructure designs that are resilient to heat stress, such as green roofs, shading structures, and cool pavements, to mitigate heat absorption and reduce UHI effects.	Chinese cities prioritize the development of heat-resilient infrastructure features, such as permeable pavements and rain gardens, to manage stormwater runoff and reduce heat buildup in urban areas.	Jakarta can integrate heat-resilient infrastructure designs into new development projects and retrofitting efforts, incorporating features such as green roofs, shading structures, and permeable pavements to mitigate UHI effects and enhance urban resilience.
3	Increasing Green Spaces	Singapore has prioritized increasing green spaces through initiatives like the "Garden City" campaign. It involves creating parks, preserving natural habitats, and incorporating greenery into urban developments.	Chinese cities have implemented large-scale afforestation projects and green belt development to combat UHI effects.	Jakarta can follow by expanding green spaces within the city, such as parks, gardens, and tree-lined streets. It can also promote rooftop gardens and vertical greenery to maximize green coverage in urban areas.
4	Water Management	Singapore integrates blue-green infrastructure, such as rain gardens and retention ponds, to manage stormwater and reduce heat buildup.	Chinese cities implement similar strategies to enhance water management and reduce UHI effects.	Jakarta can adopt blue-green infrastructure approaches to manage stormwater runoff, reduce flooding risks, and provide cooling through evaporative processes.
5	Promotion of Green Building Standards	Singapore incentivizes green building practices through the Green Mark certification system, which rewards buildings that meet sustainability criteria such as energy efficiency, water conservation, and indoor environmental quality.	China has introduced green building standards and certification systems, such as the Leadership in Energy and Environmental Design (LEED) and China Green Building Label, to promote sustainable building practices and reduce environmental impacts.	Jakarta can introduce similar incentives and regulations to encourage developers to adopt green building standards, such as offering expedited permitting or density bonuses for projects that meet sustainability criteria.
6	Cool Roof and Cool Pavement Technologies	Singapore promotes the use of cool roof and cool pavement technologies to reduce surface temperatures in urban areas.	Some Chinese cities have adopted similar technologies to mitigate heat absorption from buildings and roads.	Jakarta can consider incentivizing the use of cool roof and cool pavement technologies in new construction and retrofitting projects to reduce UHI effects.
7	Adaptive Urban Planning and Design	Singapore incorporates adaptive urban planning and design principles, such as climate-responsive design and green infrastructure integration, to mitigate UHI effects and enhance urban resilience.	Chinese cities prioritize adaptive urban planning and design measures, such as land use zoning and green space preservation, to address UHI challenges and promote sustainable urban development.	Jakarta can adopt adaptive urban planning and design approaches by integrating UHI mitigation considerations into land use planning, zoning regulations, and development guidelines, ensuring that future developments are resilient to heat-related challenges and climate impacts.
8	Cross-Sector Collaboration	Singapore promotes collaboration among government agencies, industry partners, academia, and civil society organizations to address UHI challenges comprehensively, fostering knowledge exchange, resource mobilization, and coordinated action.	Chinese cities engage in cross-sector collaboration and partnerships to develop and implement UHI mitigation policies, programs, and initiatives, leveraging collective expertise and resources.	Jakarta can foster similar collaboration and partnerships among stakeholders from various sectors, including government, academia, businesses, and community groups, to develop integrated UHI mitigation strategies and initiatives that address the city's specific challenges and needs effectively.

- Green open space in Central Jakarta with very limited land, its shape can be a city park, urban forest-shaped paths town, and roof garden
- Control the increase in built-up land area. Settlement and business area (business) focused on vertical development.
- Controlling the construction of tall buildings along the coast, since can lead to stagnation of the flow of air masses.
- Design infrastructure projects with heat-resilient materials and techniques to reduce heat absorption and withstand high temperatures.

- Create water bodies such as ponds, lakes, and fountains to provide evaporative cooling and create cool zones within the city.
- Sustainable urban planning, Jakarta needs to reduce slums and focus on sustainable environment creation.

6.2.2. The possibility of Jakarta benefiting from the experience of Singapore and China for reducing UHI effects.

The potential for Jakarta to gain from the expertise of China and Singapore in mitigating the impacts of UHIs is substantial. China and Singapore have together developed diverse tactics and activities to alleviate the effects of the UHI (Table 1). Jakarta could gain information from these efforts and potentially modify them to suit its circumstances. Several of these tactics encompass:

By researching and incorporating the practices of China and Singapore in mitigating the UHI phenomenon, Jakarta can formulate customized approaches to tackle its specific obstacles and circumstances. Collaboration and knowledge sharing between cities can also have a vital role in promoting new solutions to reduce the effects of urbanization on local climates.

7. Conclusion

In Jakarta, policymakers, developers, and the government continue to fail to give insufficient weight to the redevelopment of derelict land and infill densification over greenfield development. The absence of efficient urban development boundaries has resulted in the planning and construction of an excessive number of suburbs on greenfield sites that were previously designated as green-belt land. Further encroachment upon valuable greenfield land, which is essential for future recreational, biodiversity, forestry, agricultural, and food supply purposes, is unnecessary. The adaptation measures for mitigating the urban heat island phenomenon in Jakarta involve managing the expansion of built-up land, regulating the construction of tall structures near the coast, and creating green open spaces, with a particular emphasis on places with high surface temperatures. Areas that do not allow for the growth of urban forests in a spread-out and concentrated manner can be transformed into urban forests by completing the implementation of pathways, gardens, or rooftop gardens. Aside from spatial planning and infrastructure, public utilities encompass transportation, housing, and education. Notable eco-projects are popping up all over the world, including ones in China and Singapore. These projects focus on sustainable construction and mitigating the impact of urban heat islands. For architecture to truly be sustainable, it needs to deeply influence the foundations of buildings and cities, bringing about fundamental change.

Conflict of interest

The authors declare no conflict of interest to any party.

References

1. B. M. Hashim, A. Al Maliki, E. A. Alraheem, A. M. S. Al-Janabi, B. Halder, and Z. M. Yaseen, “Temperature and precipitation trend analysis of the Iraq Region under SRES scenarios during the twenty-first century,” *Theor. Appl. Climatol.*, vol. 148, no. 3, pp. 881–898, 2022, doi: 10.1007/s00704-022-03976-y.
2. R. K. Pachauri and A. Reisinger, “IPCC fourth assessment report (2007),” *IPCC Geneva*, https://archive.ipcc.ch/pdf/presentations/valencia-2007-11/pachauri-17-november-2007.pdf, Accessed 25th Sep 2019.
3. Y. Malhi et al., “Climate change and ecosystems: threats, opportunities and solutions,” *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, vol. 375, no. 1794, p. 20190104, Mar. 2020, doi: 10.1098/rstb.2019.0104.
4. W. Prayudha, D. A. Pradnyapasa, and R. Nurhasana, “Urban configuration of Thamrin City buildings in Jakarta,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1108, no. 1, p. 12062, 2022, doi: 10.1088/1755-1315/1108/1/012062.
5. B. Halder, J. Bandyopadhyay, and P. Banik, “Monitoring the effect of urban development on urban heat island based on remote sensing and geo-spatial approach in Kolkata and adjacent areas, India,” *Sustain. Cities Soc.*, vol. 74, p. 103186, Nov. 2021, doi: 10.1016/j.scs.2021.103186.
6. B. Halder, A. Karimi, P. Mohammad, J. Bandyopadhyay, R. D. Brown, and Z. M. Yaseen, “Investigating the relationship between land alteration and the urban heat island of Seville city using multi-temporal Landsat data,” *Theor. Appl. Climatol.*, vol. 150, no. 1, pp. 613–635, 2022.
7. S. Zhuo et al., “Cost-effective pearlescent pigments with high near-infrared reflectance and outstanding energy-saving ability for mitigating urban heat island effect,” *Appl. Energy*, vol. 353, p. 122051, 2024, doi: 10.1016/j.apenergy.2023.122051.
8. C. D. Putra, A. Ramadhani, and E. Fatimah, “Increasing Urban Heat Island area in Jakarta and it’s relation to land use changes,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 737, no. 1, p. 12002, 2021, doi: 10.1088/1755-1315/737/1/012002.
9. R. Yunita, A. Wibowo, Supriatna, and A. F. Rais, “Urban Heat Island Mitigation Strategy based on Local Climate Zone Classification using Landsat 8 satellite imagery,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1039, no. 1, p. 12013, 2022, doi: 10.1088/1755-1315/1039/1/012013.
10. B. Halder, J. Bandyopadhyay, K. M. Khedher, C. M. Fai, F. Tangang, and Z. M. Yaseen, “Delineation of urban expansion influences urban heat islands and natural environment using remote sensing and GIS-based in industrial area,” *Environ. Sci. Pollut. Res.*, vol. 29, no. 48, pp. 73147–73170, 2022.
11. A. Kamal, A. Mahfouz, N. Sezer, I. G. Hassan, L. L. Wang, and M. A. Rahman, “Investigation of urban heat island and climate change and their combined impact on building cooling demand in the hot and humid climate of Qatar,” *Urban Clim.*, vol. 52, p. 101704, 2023, doi: 10.1016/j.uclim.2023.101704.

12. A. Mohajerani, J. Bakaric, and T. Jeffrey-Bailey, "The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete," *J. Environ. Manage.*, vol. 197, pp. 522–538, 2017, doi: 10.1016/j.jenvman.2017.03.095.
13. N. Yadav, K. Rajendra, A. Awasthi, C. Singh, and B. Bhushan, "Systematic exploration of heat wave impact on mortality and urban heat island: A review from 2000 to 2022," *Urban Clim.*, vol. 51, p. 101622, 2023, doi: 10.1016/j.uclim.2023.101622.
14. H. Tao *et al.*, "Megacities' environmental assessment for Iraq region using satellite image and geo-spatial tools," *Environ. Sci. Pollut. Res.*, pp. 1–51, 2022.
15. T. Iungman *et al.*, "Cooling cities through urban green infrastructure: a health impact assessment of European cities," *Lancet*, vol. 401, no. 10376, pp. 577–589, 2023, doi: 10.1016/s0140-6736(22)02585-5.
16. B. Rana, J. Bandyopadhyay, and B. Halder, "Investigating the relationship between urban sprawl and urban heat island using remote sensing and machine learning approaches," *Theor. Appl. Climatol.*, pp. 1–28, 2024.
17. J. Naughton and W. McDonald, "Evaluating the Variability of Urban Land Surface Temperatures Using Drone Observations," *Remote Sens.*, vol. 11, no. 14, p. 1722, 2019, doi: 10.3390/rs11141722.
18. S. A. Abed, B. Halder, and Z. M. Yaseen, "Investigation of the decadal unplanned urban expansion influenced surface urban heat island study in the Mosul metropolis," *Urban Clim.*, vol. 54, p. 101845, 2024.
19. Y. Ma, D. Lauwaet, A. Kouti, and S. Verbeke, "A toolchain to evaluate the impact of urban heat island and climate change on summer overheating at district level," *Urban Clim.*, vol. 51, p. 101602, 2023, doi: 10.1016/j.uclim.2023.101602.
20. H. Tao *et al.*, "High-resolution remote sensing data-based urban heat island study in Chongqing and Changde City, China," *Theor. Appl. Climatol.*, pp. 1–28, 2024.
21. D. Marks and J. Connell, "Unequal and unjust: The political ecology of Bangkok's increasing urban heat island," *Urban Stud.*, p. 004209802211409, 2023, doi: 10.1177/00420980221140999.
22. T. S. Elhabodi, S. Yang, J. Parker, S. Khattak, B.-J. He, and S. Attia, "A review on BIPV-induced temperature effects on urban heat islands," *Urban Clim.*, vol. 50, p. 101592, 2023, doi: 10.1016/j.uclim.2023.101592.
23. B. Halder, J. Bandyopadhyay, and N. Ghosh, "Remote sensing-based seasonal surface urban heat island analysis in the mining and industrial environment," *Environ. Sci. Pollut. Res.*, pp. 1–34, 2024.
24. N. Gorai, J. Bandyopadhyay, B. Halder, M. F. Ahmed, A. H. Molla, and T. M. T. Lei, "Spatio-Temporal Variation in Landforms and Surface Urban Heat Island in Riverine Megacity," *Sustainability*, vol. 16, no. 8, p. 3383, 2024.
25. D. P. Sari, "A Review of How Building Mitigates the Urban Heat Island in Indonesia and Tropical Cities," *Earth*, vol. 2, no. 3, pp. 653–666, 2021, doi: 10.3390/earth2030038.
26. S. Ulfiasari and L. Yola, "How Does Urban Development Contributes to Urban Heat Island: A Decade Increase of Urban Heat Intensity in Jakarta Metropolitan Area," *Lecture Notes in Civil Engineering*. Springer Singapore, pp. 67–77, 2021. doi: 10.1007/978-981-16-2329-59.
27. G. Calis, S. A. Yildizel, and U. S. Keskin, "Investigation of color pigment incorporated roller compacted high performance concrete as a mitigation tool against urban heat island," *Case Stud. Constr. Mater.*, vol. 17, p. e01479, 2022, doi: 10.1016/j.cscm.2022.e01479.
28. R. E. López-Guerrero, K. Verichev, G. A. Moncada-Morales, and M. Carpio, "How do urban heat islands affect the thermo-energy performance of buildings?," *J. Clean. Prod.*, vol. 373, p. 133713, 2022, doi: 10.1016/j.jclepro.2022.133713.
29. N. W. Tuck, S. A. Zaki, A. Hagishima, H. B. Rijal, and F. Yakub, "Affordable retrofitting methods to achieve thermal comfort for a terrace house in Malaysia with a hot–humid climate," *Energy Build.*, vol. 223, p. 110072, 2020, doi: 10.1016/j.enbuild.2020.110072.
30. L.-L. Ren *et al.*, "Identification of a novel coronavirus causing severe pneumonia in human: a descriptive study," *Chin. Med. J. (Engl).*, vol. 133, no. 9, pp. 1015–1024, 2020, doi: 10.1097/CM9.0000000000000722.
31. M. Santamouris, C. Cartalis, A. Synnefa, and D. Kolokotsa, "On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review," *Energy Build.*, vol. 98, pp. 119–124, 2015, doi: 10.1016/j.enbuild.2014.09.052.
32. A. Salvati, H. Coch Roura, and C. Cecere, "Assessing the urban heat island and its energy impact on residential buildings in Mediterranean climate: Barcelona case study," *Energy Build.*, vol. 146, pp. 38–54, 2017, doi: 10.1016/j.enbuild.2017.04.025.
33. J. Kluck and F. Boogaard, "Climate resilient urban retrofit at street level," *Palgrave Studies in Climate Resilient Societies*. Springer International Publishing, pp. 45–66, 2020. doi: 10.1007/978-3-030-57537-3_3.
34. A. Saputra, M. H. Ibrahim, S. Shofirun, A. Saifuddin, and K. Furoida, "Assessing urban heat island in Jakarta, Indonesia during the pandemic of Covid-19," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 986, no. 1, p. 12069, 2022, doi: 10.1088/1755-1315/986/1/012069.
35. S. Siswanto et al., "Spatio-temporal characteristics of urban heat Island of Jakarta metropolitan," *Remote Sens. Appl. Soc. Environ.*, vol. 32, p. 101062, 2023, doi: 10.1016/j.rsase.2023.101062.
36. R. Maru and S. Ahmad, "The relationship between land use changes and the urban heat island phenomenon in Jakarta, Indonesia," *Adv. Sci. Lett.*, vol. 21, no. 2, pp. 150–152, 2015, doi: 10.1166/asl.2015.5842.
37. S. B. Rushayati, L. B. Prasetyo, N. Puspaningsih, and E. Rachmawati, "Adaptation strategy toward urban heat island at tropical urban area," *Procedia Environ. Sci.*, vol. 33, pp. 221–229, 2016, doi: 10.1016/j.proenv.2016.03.073.
38. S. Salsabila, S. Amir, and A. Nastiti, "Cooling as social practice: heat mitigation and the making of communal space in Jakarta's informal settlements," *Habitat Int.*, vol. 140, p. 102924, 2023, doi: 10.1016/j.habitatint.2023.102924.
39. R. Martinez and I. N. Masron, "Jakarta: A city of cities," *Cities*, vol. 106, p. 102868, Nov. 2020, doi: 10.1016/j.cities.2020.102868.
40. Badan Pusat Statistik Provinsi DKI Jakarta, "Jumlah kendaraan bermotor menurut jenis kendaraan (unit) di Provinsi DKI Jakarta 2020-2022," 2022. [Online]. Available: https://jakarta.bps.go.id/indicator/17/786/1/jumlah-kendaraan-bermotor-menurut-jenis-kendaraan-unit-di-provinsi-dki-jakarta.html
41. N. H. Wong, C. L. Tan, D. D. Kolokotsa, and H. Takebayashi, "Greenery as a mitigation and adaptation strategy to urban heat," *Nat. Rev. Earth Environ.*, vol. 2, no. 3, pp. 166–181, 2021.
42. A. M. M. Irfeey, H.-W. Chau, M. M. F. Sumaiya, C. Y. Wai, N. Muttil, and E. Jamei, "Sustainable mitigation strategies for urban heat island effects in urban areas," *Sustainability*, vol. 15, no. 14, p. 10767, 2023, doi: 10.3390/su151410767.

43. H. Yan, F. Wu, and L. Dong, "Influence of a large urban park on the local urban thermal environment," *Sci. Total Environ.*, vol. 622–623, pp. 882–891, 2018, doi: 10.1016/j.scitotenv.2017.11.327.
44. L. Tian, Y. Li, J. Lu, and J. Wang, "Review on urban heat island in China: Methods, its impact on buildings energy demand and mitigation strategies," *Sustainability*, vol. 13, no. 2, p. 762, 2021.
45. T. Manteghi, and G. Mostofa, "Evaporative pavements as an urban heat island (UHI) mitigation strategy: a review," *Int. Trans. J. Eng.*, vol. 11, no. 1, pp. 11–12, 2020, [Online]. Available: https://doi.org/10.14456/ITJEMAST.2020.17.
46. Y. Liu, J. Peng, and Y. Wang, "Diversification of land surface temperature change under urban landscape renewal: a case study in the main city of Shenzhen, China," *Remote Sens.*, vol. 9, no. 9, p. 919, 2017, doi: 10.3390/rs9090919.
47. S. Lehmann, "Growing biodiverse urban futures: renaturalization and rewilding as strategies to strengthen urban resilience," *Sustainability*, vol. 13, no. 5, p. 2932, 2021, doi: 10.3390/su13052932.
48. G. Akkose, C. Meral Akgul, and I. G. Dino, "Educational building retrofit under climate change and urban heat island effect," *J. Build. Eng.*, vol. 40, p. 102294, 2021, doi: 10.1016/j.jobe.2021.102294.