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Master of Urban Climate and Sustainability (MURCS)

**Developing Protocol
on Jakarta Green Area Target Setting
for Urban Overheating Mitigation**

Hanna Meiria Naomi Stepani

August 2020



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Hanna Meiria Naomi Stepani

Submitted in partial fulfilment for the requirements of
Master of Urban Climate & Sustainability (MUrCS)

Glasgow Caledonian University, UK;
LAB University of Applied Sciences, Finland;
University of Huelva, Spain

Supervisor:
Prof. Rohinton Emmanuel
Dr. Eeva Aarrevaara

August 2020

*To Laura,
for what you've been through because of this.*

DECLARATION

This dissertation is my own original work and has not been submitted elsewhere in fulfilment of the requirements of this or any other award

Hanna Meiria Naomi Stepani
August 2020

ABSTRACT

Climate change contributes to heat stress in cities. Massive transitions from natural habitat to built environment triggers urban heat island effects. In the context of urban climate adaptation, green open spaces have been recognized as a mitigation strategy. To enforce the application of green infrastructure, the Jakarta Government has created a target of 30%, supported by the Green Space Masterplan that indicates the development of Green Space Weighting Factor. This study aims to develop a systematic framework on target setting for the green areas of Jakarta for urban overheating mitigation through microclimate simulation (ENVI-met) on targeted local climate zone areas, with green infrastructure quantified by the newly-developed weighting factor. The results of the study shows that in order to mitigate UHI and address climate change, urban design policy should not rely entirely on green infrastructure, and only a comprehensive, site-specific spatial and functional analyses can bring targeted green infrastructure that really improve thermal conditions.

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1. INTRODUCTION

1.1. Background

Climate change creates heat stress in cities. Elevated temperature and heatwave events in urban areas create a severe public health concern. As the biggest metropolitan areas in South East Asia, Jakarta, with its massive infrastructure developments and urbanization, experiences changes in the environment which threaten its resilience on climate change. The economic growth of 5.06% that is higher than 2.97% national economic growth (Bank Indonesia, 2020) makes Jakarta the highest contributor of the national economy, as well as the most top accelerator in national infrastructure development. The development tendency to fulfil activity functions created a massive transition of the natural habitat to the built environment that triggered Urban Heat Island (UHI) effects.

Green Infrastructure (GI) has been proposed as one possible intervention that may help mitigate the UHI effect that creates an impact on human health and comfort. Trees and other types of vegetation can reduce surface temperatures and also tend to maintain a daytime canopy temperature close to that of the surrounding air temperature via evaporative cooling related to site-specific influences (Adams and Smith, 2014).

To enforce the application of GI, the Jakarta Government created a target of 30% of the total area need to be green, following the national law and central government. Due to the necessary land capacity to accommodate urbanization and economic activity, less than 1/3 of this target has been achieved in 20 years. This shows that a legitimate number of green open space calculation should be considered for Jakarta city, compared to other cities in Indonesia.

To accomplish the implementation of the target set by the national government, Jakarta developed a Green Space Masterplan that indicates the development of a GI quantification factor. This factor serves as a standard to calculate the achievement of the green area target and mainstreams green infrastructure development.

In order to gain hard evidence as a rational basis for the GI target on supporting urban heat island mitigations, a protocol on how to develop a target and to evaluate whether or not the current policy on target set green area of 30% is an effective contribution to the strategy of tackling urban overheating.

1.2. Research objectives

Jakarta city has severe environmental problems that can be reduced by improving the condition of the green infrastructure quality. Urban Heat Islands are major events that trigger other environmental problems in cities like Jakarta. This problem requires a solution through upgrading the green infrastructure. Together with targets set by the national government, Jakarta needs to achieve environmental problem solutions as well as the green open spaces area target. But can 30% of green area of land, regardless of the primary function the green infrastructure serves and the area of implementation, solve the urban overheating problem that continuously occurs in Jakarta?

This study aims to develop a protocol for Jakarta Green area index target setting using the green infrastructure weighing factor as an approach to mitigate urban overheating. With the proposed development of Jakarta green space quantification index, it is needed to further analyse the connection of green infrastructure elements with the attempt on UHI mitigation in the local

climate context of Jakarta. Systematically developed stages on target setting the green area of Jakarta for urban overheating mitigation will assist local and national decision makers to prioritize efficiency on green infrastructure implementation in developing climate-sensitive urban planning and design guidelines. As a precondition to address the objectives of the study, a model of green elements quantification factor and a WUDAPT protocol method for classification of Jakarta Local Climate Zone which will be particularly useful in a modelling context will be developed.

The objectives of this study are:

1. critically evaluate current knowledge of UHI mitigation in tropical cities
2. develop a weighting factor model for urban overheating adaptation to analyse the contribution of green infrastructure
3. demonstrate the limitations of green area target setting by the Jakarta government for cooling purposes
4. evaluate different options on target implementations of green infrastructures through microclimate simulations
5. present an input for planning and land use policy in terms of green area target setting to promote urban cooling

1.3. Methodological framework

Green infrastructure is expected to reduce the exposure to heat in urban areas. While climate change is projected to increase the frequency and intensity of extreme climate conditions, temperature is the most significant atmospheric parameter to explore the impact of urban heat islands. A combination of the new developed green space quantification factor with WUDAPT Local Climate Zone map for Jakarta has been used to simulate the occurrence of temperature reduction by applying a green elements scenario. The simulation is performed for different LCZ which correspondent with the majority of land use in the Jakarta metropolitan area. The impact of Green infrastructure implementations area is examined for two different scenarios, base case and best case. The base scenario describes the actual condition of land, while the best scenario represents a condition where a maximum of green intervention has been implemented.

The overall framework of this thesis, as illustrated in Figure 1.1, consist of three structures: scientific literatures review, methods and analysis procedures, and implication of the thesis.

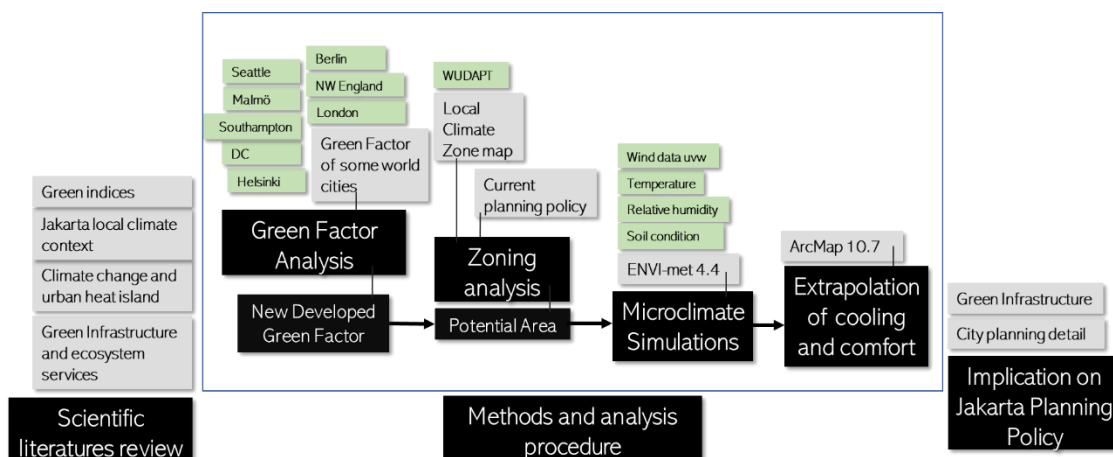


Figure 1.1 Thesis framework

Data processing and analytical procedures are divided into four types of analysis (Fig. 5.1). The analysis procedure will be presented in Chapter 5. Methodology.

1.4. Thesis structure

This master thesis comprises three parts. The first part contains a summary of scientific publications that structure a simulation model. The second part is the build-up of simulation models for green infrastructure implementation in potential areas in Jakarta, extrapolation of the study and discussions of the result. The third part is an extrapolation of the study and its implications on Jakarta's urban planning strategy for thermal comfort enhancement, limitations and direction for further studies, which is presented in Table 1.1.

Table 1.1 Thesis Structure

Part	Sections
summary of scientific publications	<ol style="list-style-type: none"> 1. Climate Change and Urban Green Infrastructure <ol style="list-style-type: none"> 1.1. Climate Change and Urban Heat Island 1.2. Role of Green Infrastructure in Urban Heat Island Mitigation 1.3. Green Infrastructure Quantification Function for Thermal Comfort 2. Previous Approach in Green Infrastructure Quantification <ol style="list-style-type: none"> 2.1. Berlin Biotope Area Factor 2.2. Malmo Green Space Factor 2.3. Southampton Green Space Factor 2.4. London Green Space Factor 2.5. North West England Green Infrastructure Factor 2.6. Helsinki Green Factor 2.7. Seattle Green Factor 2.8. DC Green Area Ratio 3. Local Context - Jakarta and Climate Change <ol style="list-style-type: none"> 3.1. Overview of Land and Environmental Issues 3.2. Jakarta and Warming Temperature 3.3. Green Open Space Regulation And Masterplan
simulation model development, results and discussions	<ol style="list-style-type: none"> 4. Methodology <ol style="list-style-type: none"> 4.1. Study Design <ol style="list-style-type: none"> 4.1.1. Development of a New Green Space Quantification Factor 4.1.2. Zoning analysis 4.1.3. Extrapolation of cooling and thermal comfort in Jakarta Metropolitan Area 4.2. Data and Analysis Procedure 5. Results and Analysis <ol style="list-style-type: none"> 5.1. New Green Spaces Weighting Factor 5.2. Jakarta Local Climate Zone Mapping 5.3. Representative Sampling Selection for Simulation 5.4. Microclimate Simulation result and analysis 5.5. Extrapolation of Cooling and Comfort for Jakarta
Implications and conclusions	<ol style="list-style-type: none"> 6. Implication and Conclusions <ol style="list-style-type: none"> 6.1. Summary of Findings 6.2. Implications for Jakarta Urban Planning and Land Use Policy 6.3. Limitation of Study and direction for Further Research

2. CLIMATE CHANGE AND URBAN GREEN INFRASTRUCTURE

2.1. Climate Change and Urban Heat Island

Before the 2019-2020 coronavirus pandemic declared by the WHO in March 2020, humankind was facing climate change and urbanisation as the most severe challenges in centuries. 55% of the world population resided in urban areas in 2018, with a significant increase of 30% since 1950 and projected to increase by 68% by 2050. All countries in the world are following the increased urbanisation trend that changes the landscape of human settlement with significant implications for living conditions, environment and development (United Nations, 2019). Cities are sensitive to climate variability and change. Together with their inhabitants, cities are critical drivers of global climatic change (Grimmond et al., 2010). Along with the development in the urban sector as a response to urbanization, temperatures in cities are higher than in the peripheral areas; as a result, Urban Heat Island (UHI).

The UHI effect is caused by specific changes in urban environments which gave rise to a separate warming mechanism (Stone et al., 2014., WHO, 2016, US EPA, 2014): the loss of natural vegetation to urban construction, the introduction of non-vegetative surface materials that are more efficient at absorbing and storing thermal energy than natural land covers, high-density urban morphology that traps solar radiation, and emissions of waste heat from buildings and vehicles.

Heat islands' elevated temperature in the urban area have a significant impact on the community environment and the quality of life in multiple ways: 1) Compromised Human Health and Comfort, 2) Elevated Emissions of Air Pollutants and Greenhouse Gases, 3) Increased Energy Consumption, and 4) Impaired Water Quality (US EPA, 2014).

Stewart and Oke (2012) present Local Climate Zones (LCZ) to extract UHI magnitude. The LCZ system consists of units of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in horizontal scale (Stewart and Oke, 2012). UHI magnitude is an LCZ temperature difference (e.g., $\Delta\text{TLCZ } 1 - \text{LCZ D}$), not an "urban-rural" difference ($\Delta\text{Tu-r}$). LCZ differences are more conducive to analysis, and less prone to confusion, because they highlight the common surface and exposure characteristics of the compared field sites, and they invite physically based explanations of UHI magnitude. In global climate change studies weather stations and observatories classify into LCZ classes rather than urban and rural classes, which can lead to more accurate assessments of urban bias in the climate record. (Stewart and Oke, 2012).

The temperature changes, ground-level ozone (O₃), and UV radiation as climate change impact lead to increased greenhouse gas emissions (Adams and Smith, 2014) and cause negative effects on health, affecting the respiratory system and potentially leading to chronic diseases and in some cases, increased mortality. Heat-related morbidity is expected to increase as a result of warming global temperatures and intensification of urban heat island in cities and has become a major public health concern (WHO and WMO, 2015). Excessive Heat Events (EHEs) amplify heat stress imposed on city dwellers, post a threat on outdoor pedestrian comfort, and will even increase health risks. (Lu et al., 2017, Hu et al., 2019). Aiming for a reduction of the Urban Heat Island effect is one of the pathways linking urban green space to improved health and well-being (WHO, 2015).

2.2. Role of Green Infrastructure in Urban Heat Island Mitigation

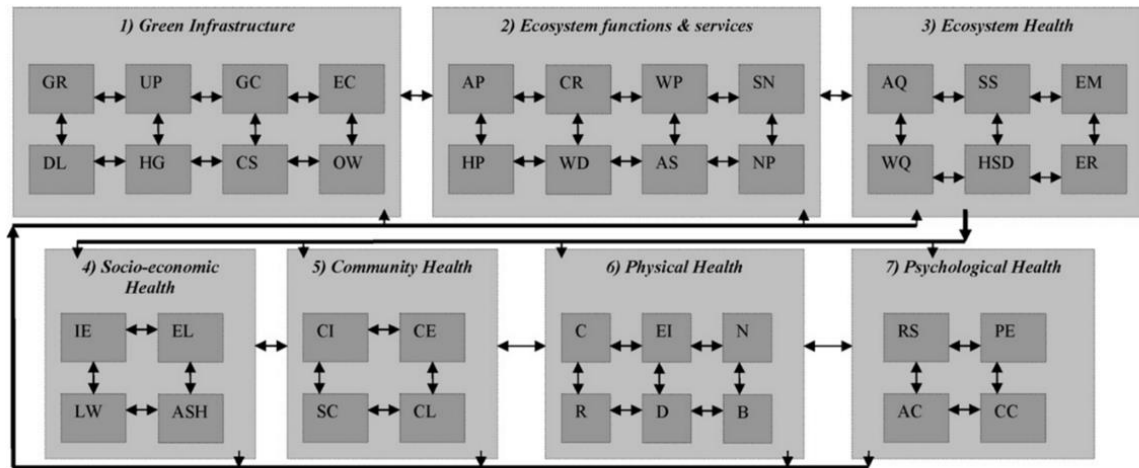
The UHI mitigation strategies can be grouped into three major themes: 1) Increase vegetation cover, 2) Increase thermal reflectivity (albedo) of urban surfaces, particularly roofs, and 3) Manipulate urban geometry (Emmanuel, 2005). Increasing the vegetation cover by urban greening efforts has been proposed as one possible intervention that may mitigate the human health consequences of these changes (Bowler 2010). Green infrastructure can reduce the impact of pollutants from the air, carbon sequestration, contribute to rainwater infiltration and flooding risk control, provide shade, cool the air through tree transpiration, and reduce energy consumption in summer and the urban island heat effect. (Basnou, 2015., Markevych et al., 2017) provides a framework in which the many potential pathways link greenspace to health benefits in three domains that emphasise three general functions of greenspace: reducing harm (air pollution, heat, and noise), restoring capacities and building capacities. Trees and other vegetation can reduce surface temperatures and also tend to maintain a daytime canopy temperature close to that of the surrounding air temperature via evaporative cooling related site-specific influences (Adams and Smith, 2014).

Subsequently, several studies have been conducted on how urban vegetated areas have an impact on cooling the cities in various regions using the three-dimensional microclimate simulation tool. According to Gill (2007), in study conducted in the greater Manchester area, adding 10% green cover to areas with low green coverage, such as city centre and high density residential areas, decrease the maximum surface temperature. Adding green rooftops to all buildings has a significant effect on surface temperature, since roof greening causes the biggest difference in urban morphology types where the building proportion is high and the evaporating fraction is low. Adams and Smith (2014), examining the Sydney region, were able to calculate that an increase of 10% in foliage projective cover leads to a reduction in Land Surface Temperature (LST) of 1.13°C when Photosynthetically active Vegetation (PV) > 0.4, and a 10% increase in PV cover would lead to a reduction in LST of 1.16°C. Emmanuel and Loconsole, (2015) indicate that a green cover increase of approximately 20% over the present level in the Glasgow Clyde Valley Region, UK, could eliminate a third to a half of the expected extra-urban heat island effect in 2050. This level of increase in green cover could also lead to local reductions in surface temperature by up to 2°C. Lu et al. (2017) studied the cooling effect of a 4.5 ha urban forest park located in a dense city centre area in a hot and humid climate with and without the influence of wind. When wind speed is 1.5m/s, park cool island (PCI) intensity is about 2 °C if PCI centre is offset from the park centre if a preponderant prevailing wind direction exists. Without the influence of wind direction and considering equal probability for each wind direction, PCI intensity is about 0.8 °C if PCI centre is near to the centre of the park.

2.3. Green Infrastructure Quantification Function for Thermal Comfort

In high-density urban environments, the role of green infrastructure will help to cool the air and provide shade. It can also lower the buildings' energy consumption with better outdoor boundary conditions. (Tan et al., 2014).

Even though not all studies find evidence of the beneficial relationship between greenspace and health, (Markevych et al., 2017), Tzoulas et al., (2017) conducted a literature review on promoting the ecosystem and human health in urban areas using Green Infrastructure. Fig. 2.1 shows the conceptual framework of the study on linking green infrastructure and human health.



The framework has two main parts separated by two-way arrows. The top half (ecosystem) has three interrelated boxes and the bottom half (human health) four interrelated boxes. Two-way arrows indicate two-way interactions. Key: GR: green roofs; UP: urban parks; GC: green corridors; EC: encapsulated countryside; DL: derelict land; HG: housing green space and domestic gardens; CS: churchyards, cemeteries and school grounds; OW: open standing and running water; AP: air purification; CR: climate and radiation regulation; WP: water purification; SN: soil and nutrient cycling; HP: habitat provision; WD: waste decomposition; AS: aesthetic and spiritual; NP: noise pollution control; AQ: air quality; SS: soil structure; EM: energy and material cycling; WQ: water quality; HSD: habitat and species diversity; ER: ecosystem resilience; IE: income and employment; EL: education and lifestyle; LW: living and working conditions; ASH: access to services and housing; CI: sense of community identity; CE: community empowerment; SC: social capital; CL: culture; C: cardiovascular; EI: endocrine functions and immunity; N: nervous system; R: respiratory; D: digestive; B: bone tissue; RS: relaxation from stress; PE: positive emotions; AC: attention capacity; CC: cognitive capacity.

Figure 2.1. Conceptual framework of the study on linking green infrastructure and human health.

Nazarian et al., (2019) showed that thermal comfort is considered as a top priority with a direct impact on productivity and cognitive performance, well being and health of urban dwellers, and to achieve a climate-responsive urban design, comprehensive, accurate, and easily comprehensible evaluations of outdoor thermal comfort are needed. Nazarian proposed outdoor thermal comfort autonomy, metrics that quantify outdoor space performance with regards to thermal comfort and heat stress. Potchter et al., carried out several investigations of 165 human thermal indices. Based on the study, the most used indices for outdoor thermal perception studies are PET, PMV, UTCI, SET, and WGBT. Table 2.1 shows the comparison of thermal sensation index based on various bioclimatic comfort indicators.

Table 2.1 Thermal sensation based on various bioclimatic comfort/stress index (Source: Nazarian et, al., 2019)

Thermal Sensation	Thermal Comfort Indices					
	PET	UTCI	SET	PMV	WGBT	WCT
Frosty (extreme hazard/Very strong cold stress)		-40 to -27				< -55
Very cold (very cold/Strong cold stress)	4	-27 to -30		-3		-54 to -40
Cold (cold/Moderate cold stress)	4 to 8	-13 to 0		-2		-39 to -28
Cool (moderate hazard/Slight cold stress)	8 to 18	0 to 9	< 17	-1		-27 to -10
Comfortable (no danger/No thermal stress)	18 to 23	9 to 26	17 to 30	0	< 18	> -10
Warm (caution/Moderate heat stress)	23 to 35	26 to 32	30 to 34	1	18 to 24	-
Hot (extreme caution/Strong heat stress)	35 to 41	32 to 38	34 to 37	2	24 to 28	-
Very hot (danger/Very strong heat stress)	> 41	38 to 46	> 37	3	28 to 30	-
Sweltering (extreme danger/Extreme heat stress)		> 46			> 30	-

According to Chaudhuri et al., (2016), the most popular method to study human thermal comfort is the PMV (predicted mean vote). Fanger (1973) developed PMV as an index to determine the predicted percentage of dissatisfied (PPD). PMV expressed comfort conditions in physical parameters which constitute thermal environment: 1) air temperature, 2) mean radiant temperature, 3) relative air velocity, and 4) vapour pressure in ambient air, with additional personal factors: 1) activity level, and 2) thermal resistance. Mean Radian Temperature (MRT) is considered as one of the main factors contributing to both indoor and outdoor thermal comfort (Tan et al., 2014).

The impact of vegetation on the local microclimate can be simulated with ENVI-met. ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. ENVI-met consists of dozens dynamic subsystems ranging from atmospheric dynamics, over soil physics, vegetation response down to building indoor climate (Bruse and Fler, 1998). ENVI-met considers as micro-scale computational fluid dynamic model that is capable of analysing the thermal comfort regime at fine resolutions (Huttner et al., 2008). It is used to assess the effectiveness of urban planning measures to tackle the UHI problem in a variety of climate contexts (Emmanuel and Loconsole (2015).

Looking at the positive impact of green infrastructure, Tan et al, (2014) also identified that many authorities have initiated policies to improve the environmental condition of the cities through green infrastructure quantification, which is categorised in various ways such as Green Plot Ratio (GPR), a combination concepts of Leaf Area Index (LAI) and Building Plot Ratio (BPR).

3. PREVIOUS APPROACH IN GREEN INFRASTRUCTURE QUANTIFICATION

The warming climate increases temperatures in urban areas that already experience the heat island effect. A cooling strategy to reduce the impact of urban overheating will help communities to adapt to climate change impact as well as lower greenhouse gas emissions that cause climate change (US EPA, 2014). Urban morphology plays a substantial role in determining microclimates. According to Wong et al., (2011) besides Green Plot Ratio (GnPR), Sky View Factor (SVF), surrounding building density, the wall surface area, pavement area, and albedo, there are three major urban elements which influence local-scale urban temperature: buildings, greenery and pavement. Wong conducted 32 case studies with different urban morphologies with varying density, height, and greenery density to see the degree of impact on altering microclimates. The highest degree of altering temperature impact (can be up to 0.9-1.2 °C) are shown to be influenced by variables such as GnPR, height and density. GnPR has the highest impact due to the shading effect of trees.

Several cities have green calculation tools as a metric on greenery value on development sites. There are different names for green infrastructure quantification tools. Most cities named it Green Area Factor (GAF) or Green factor. The GAF is a planning instrument developed by cities to achieve an environmental agenda of human and nature reconnection, energy consumption reduction, flood control and the restoration of the full hydrological cycle, preservation and enhancement of wildlife habitats, improvement of urban aesthetics and build a new green identity in a thermally comfortable urban environment (A Vartholomaios et al., 2013). The GAF is composed of three adaptable, interconnected components: a set of ratings, a set of targets, and a final ratio determined for each parcel (Keeley, 2011). This chapter will elaborate on the previously developed green infrastructure quantification factor based on the local context of selected cities around the world.

3.1. Berlin Biotope Area Factor (BAF)

The Biotope area factor is developed to compensate the deficit of green open space in densely populated inner cities. (Landschaft P.& B.+ B.G.M.R., 1990). The high degree of soil sealing, insufficient accumulation of groundwater, caused by the rapid run-off of precipitation into the sewerage system, lack of humidity and overheating, decreasing habitat for plants and animals due to insufficient green spaces make BAF correspond to the weighting factor based on ecological significance. The formula was created to improve microclimates and air hygiene quality, safeguard soil function and water management efficiency and increase habitat for plants and animals. The following criteria derived from an individual type of area evaluation target of BAF:

- high evapotranspiration efficiency
- capacity for binding dust
- infiltration ability and storage of rainwater
- long-term guarantee of the conservation or development of soil functions concerning the filtering, buffering and transformation of hazardous substances
- availability as a habitat for plants and animals

Based on these criteria, the weighting factor of BAF are assessed. Figure. 3.1 illustrates the types of surfaces, descriptions, and weighting factors of BAF.

Types of surfaces and weighting factors:

(Surface types not mentioned can be calculated as long as they have a positive effect on the ecosystem)



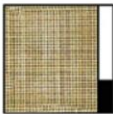

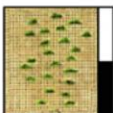

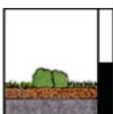
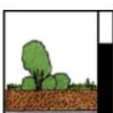
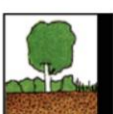
Weighting factor / per m ² of surface type	Description of surface types			
 <p>Sealed surfaces 0.0</p>	<p>Surface is impermeable to air and water and has no plant growth (e.g., concrete, asphalt, slabs with a solid subbase)</p>	 <p>Rainwater infiltration per m² of roof area 0.2</p>	<p>Rainwater infiltration for replenishment of groundwater; infiltration over surfaces with existing vegetation</p>	
 <p>Partially sealed surfaces 0.3</p>	<p>Surface is permeable to water and air; as a rule, no plant growth (e.g., clinker brick, mosaic paving, slabs with a sand or gravel subbase)</p>	 <p>Vertical greenery up to a maximum of 10 m in height 0.5</p>	<p>Greenery covering walls and outer walls with no windows; the actual height, up to 10 m, is taken into account</p>	
 <p>Semi-open surfaces 0.5</p>	<p>Surface is permeable to water and air; infiltration; plant growth (e.g., gravel with grass coverage, wood-block paving, honeycomb brick with grass)</p>	 <p>Greenery on rooftop 0.7</p>	<p>Extensive and intensive coverage of rooftop with greenery</p>	
 <p>Surfaces with vegetation, unconnected to soil below 0.5</p>	<p>Surfaces with vegetation on cellar covers or underground garages with less than 80 cm of soil covering</p>			
 <p>Surfaces with vegetation, unconnected to soil below 0.7</p>	<p>Surfaces with vegetation that have no connection to soil below but with more than 80 cm of soil covering</p>			
 <p>Surfaces with vegetation, connected to soil below 1.0</p>	<p>Vegetation connected to soil below, available for development of flora and fauna</p>			

Figure 3.1 BAF weighting factor illustration (source: www.berlin.de)

The consideration of the sites connection with the underlying general urban development model and landscape-planning development concepts results in the minimum standards of BAF target values for the scope of ecologically effective areas. This target values are applied in several urban forms. Urban forms of use covered by BAF are residential, commercial, and infrastructural. BAF formulates minimum ecological standards for structural changes and new development. Table 3.1 shows the BAF values applied to the various development and use structures.

Biotope area factor has target which is associated with a weighting factor. The BAF then has been adopted by so many cities regarding their location to achieve a more sustainable environment through green open spaces.

Table 3.1 Area application and Target implementation for BAF (source: www.berlin.de)

BAF Targets for		
Alterations / Extensions of construction sites Creation of additional residential space or increase in the degree of coverage (DC)		New structures
DC	BAF	
Residential units (Residential use only and mixed use with no commercial use of open space)		
up to 0.37	0.60	0.60
0.38 to 0.49	0.45	
over 0.50	0.30	
Commercial use (Commercial use only and mixed use with commercial use of open space)		
	0.30	0.30
Typical use in key areas (Commercial enterprises and central business facilities Administrative and general use)		
	0.30	0.30
Public facilities (for cultural or social purposes)		
up to 0.37	0.60	0.60
0.38 to 0.49	0.45	
over 0.50	0.30	
Schools (General-education schools, Vocational centres, Education Complexes, Outdoor Sports facilities)		
	0.30	0.30
Nursery Schools and Day Care Centres		
up to 0.37	0.60	0.60
0.38 to 0.49	0.45	
over 0.50	0.30	
Technical Infrastructure		
	0.30	0.30

3.2. Malmö Green Space Factor

Malmö's green infrastructure planning tool was developed in the new Malmö city district of Västra Hamnen (Western Harbour) in the late 1990s to reach the vision of creating a sustainable district. The aim of using the Green Space Factor was to secure a certain amount of green cover in every building lot, and to minimise the degree of sealed or paved surfaces in the development (Kruuse A., 2011).

The approach of Malmö Green Space Factor (GSF) is to quantify essential factors with different surface types, which must reach a specified target level. The overall target of achievement is 0.5, which was revised to 0.6 after the Flagghusen development was completed, with lower factors of some individual surface elements.

Green Points

- 1 A bird box for every apartment
- 2 A biotope for specified insects in the courtyard (water striders and other aquatic insects in the pond)
- 3 Bat boxes in the courtyard
- 4 No surfaces in the courtyard are sealed, and all surfaces are permeable to water
- 5 All non-paved surfaces within the courtyard have sufficient soil depth and quality for growing vegetables
- 6 The courtyard includes a rustic garden with different sections
- 7 All walls, where possible, are covered with climbing plants
- 8 There is 1 square metre of pond area for every 5 square metres of hard-surface area in the courtyard
- 9 The vegetation in the courtyard is selected to be nectar rich and provide a variety of food for butterflies (a so-called 'butterfly restaurant')
- 10 No more than five trees or shrubs of the same species
- 11 The biotopes within the courtyard are all designed to be moist
- 12 The biotopes within the courtyard are all designed to be dry
- 13 The biotopes within the courtyard are all designed to be semi-natural
- 14 All stormwater flows for at least 10 metres on the surface of the ground before it is diverted into pipes
- 15 The courtyard is green, but there are no mown lawns
- 16 All rainwater from buildings and hard surfaces in the courtyard is collected and used for irrigation
- 17 All plants have some household use
- 18 There are frog habitats within the courtyard as well as space for frogs to hibernate
- 19 In the courtyard, there is at least 5 square metres of conservatory or greenhouse for each apartment
- 20 There is food for birds throughout the year within the courtyard
- 21 There are at least two different old-crop varieties of fruits and berries for every 100 square metres of courtyard
- 22 The facades of the buildings have swallow nesting facilities
- 23 The whole courtyard is used for the cultivation of vegetables, fruit and berries
- 24 The developers liaise with ecological experts
- 25 Greywater is treated in the courtyard and re-used
- 26 All biodegradable household and garden waste is composted
- 27 Only recycled construction materials are used in the courtyard
- 28 Each apartment has at least 2 square metres of built-in growing plots or flower boxes on the balcony
- 29 At least half the courtyard area consists of water
- 30 The courtyard has a certain colour (and texture) as the theme
- 31 All the trees and bushes in the courtyard bear fruit and berries
- 32 The courtyard has trimmed and shaped plants as its theme
- 33 A section of the courtyard is left for natural succession (that is, to naturally grow and regenerate)
- 34 There should be at least 50 flowering Swedish wild herbs within the courtyard
- 35 All the buildings have green roofs

Figure 3.2 Malmö Green Points (Source: Kruuse A., 2011)

Figure 3.2. shows lists of the green points of which should be chosen at least 10 points by the developer. To encompass the quality of green cover, 35 green points were added to the green space factor to achieve certain additional qualities. The points are aiding biodiversity and help to improve architectural quality and stormwater management. Malmö Green Space Factor (GSF) is shown in Figure 3.3.

Green Space Factor	
Surface type	Factor
Vegetation on ground	1
Vegetation on trellis or facade	0.7
Green roofs	0.6
Vegetation on beams, soil depth between 200 millimetres and 800 millimetres	0.7
Vegetation on beams, soil depth more than 800 millimetres	0.9
Water surfaces	1
Collection and retention of stormwater	0.2
Draining of sealed surfaces to surrounding vegetation	0.2
Sealed areas	0
Paved areas with joints	0.2
Areas covered with gravel or sand	0.4
Tree, stem girth 16-20 centimetres (20 square metres for each tree)	20
Tree, stem girth 20-30 centimetres (15 square metres for each tree)	15
Tree, stem girth more than 30 centimetres (10 square metres for each tree)	10
Solitary bush higher than 3 metres (2 square metres for each bush)	2

Figure 3.3 Malmö Green Space Factor (Source: Kruuse A., 2011)

3.3. Helsinki Green Factor

The aim of the Helsinki Green Factor (HGF) is to mitigate the impact of construction by maintaining the existing green infrastructure while improving the quality of the remaining plants. HGF helps the city to adapt climate change by promoting green efficiency of on-site plants and conserving remaining green structures. HGF provides 43 different green elements which are divided into 5 major groups regarding plant and soil preservation, with consideration on four aspects in the weighting; ecology, function, landscape and maintenance. HGF calculates the ratio of the green area score value to the total area. (City of Helsinki, 2017). The elements and weighting factor of HGF can be seen in Table 3.2.

Table 3.2 HGF Elements and Weighting Factor (City of Helsinki, 2017)

Element Group	Elements	Weighted average
Preserved vegetation and soil	Preserved large (fully grown > 10 m) tree in good condition, at least 3 m (25 m ² each)	3.5
	Preserved small (fully grown ≤ 10 m) tree in good condition, at least 3 m (15 m ² each)	3
	Preserved tree in good condition (1.5–3 m) or a large shrub (3 m ² each)	2.4
	Preserved natural meadow or natural ground vegetation	2.2
	Preserved natural bare rock area (at least partially bare rock surface, not many trees)	1.9

Planted/new vegetation	Large tree species, fully grown > 10 m (25 m ² each)	2.8
	Small tree species, fully grown ≤ 10 m (15 m ² each)	2.3
	Large shrubs (3 m ² each)	1.7
	Other shrubs	1.4
	Perennials	1.6
	Meadow or dry meadow	1.8
	Cultivation plots	2
	Lawn	1.1
	Perennial vines (2 m ² each)	1.3
	Green wall, vertical area	0.9
Pavements	Semipermeable pavements (e.g. grass stones)	1
	Permeable pavements (e.g. gravel and sand surfaces, stone ash)	1.4
	Impermeable surface (calculated automatically)	0
Stormwater solutions	Rain garden (biofiltration area, no permanent pool of water) with a broad range of layered vegetation	2.8
	Intensive green roof/roof garden, depth of substrate 20-100cm	2
	Semi intensive green roof, depth substrate 15-30 cm	1.5
	Extensive green roof, dept substrate 6-8 cm	1.4
	Infiltration swale covered with vegetation or aggregates (no permanent pool of water, permeable soil)	2.3
	Infiltration pit (underground)	1.5
	Wetland or water meadow with natural vegetation (permanent water surface at least part of the year; at other times the ground remains moist)	2.8
	Retention swale covered with vegetation or aggregates (no permanent water surface, permeable soil)	2
	Retention pit or tank (underground)	1.4
Biofiltration basin or swale	2.7	
Bonus elements	Capturing stormwater from impermeable surfaces for use in irrigation or directing it in a controlled manner to permeable vegetated areas	0.7
	Directing stormwater from impermeable surfaces to constructed water features, such as ponds and streams, with flowing water	0.8
	Hardwoods and aspen, planted or preserved large tree (25 m ² each)	
	Coniferous trees, planted or preserved large tree (25 m ² each)	
	Coniferous trees, planted or preserved small tree (15 m ² each)	
	Shading large tree (25 m ² each) on the south or southwest side of the building (especially deciduous trees)	0.9
	Shading small tree (15 m ² each) on the south or southwest side of the building (especially deciduous trees)	0.9
	Fruit trees suitable for cultivation (15 m ² each)	1
	Berry bushes suitable for cultivation (3 m ² each)	
	A selection of native species – at least 5 species/100 m ²	0.9
	Tree species native to Helsinki and flowering trees and shrubs – at least 3 species/100 m ²	0.9
	Butterfly meadows	0.8
Plants with pleasant scent or impressive blooming		

Boxes for urban farming/cultivation	0.6
Permeable surface designated for play or sports (e.g. sand- or gravel-covered playgrounds, sports turf)	0.7
Communal rooftop gardens or balconies with at least 10% of the total area covered by vegetation	0.6
Structures supporting natural and/or animal living conditions such as preserved dead wood/stumps or birdboxes (5m ² each)	1.2

In the weighting factor development, each green element quantification is based on the results of surveys and studies of ecological impacts and social impacts of each green element. If the literature review on a relevant topic is not available, the weighting is carried out using a direct evaluation approach where the expert opinion is used as the basic data (expert judgment).

The Helsinki Green Factor uses a land-use specific target and minimum levels. Four land-use classes were included: residential, services, commercial, and industrial/logistics (Table 3.3). Each land-use class has different target level that sets the goal for the green factor score and a minimum level that is required of the land-use. The range between target and minimum levels allows the flexibility of regional and lot-specific factors that may limit the available space for green surfaces or set specific requirements for the quality of the green surface. (City of Helsinki, 2014)

Table 3.3 Target and minimum levels for land-use classes of HGF implementations (City of Helsinki, 2017)

	Land use class	Target level	Minimum level
1	Residential	0,8	0,5
2	Services	0,7	0,4
3	Commercial	0,6	0,3
4	Industrial / logistics	0,5	0,2

3.4. North West England Green Infrastructure Factor

Following Malmö's Green Space Factor and Green Points system, the North West England Green Infrastructure Factor (NWEIGIF) aims to support the green infrastructure objective of the Northwest Regional Development Agency's Sustainability Policy for the Built Environment. NWEIGIF was developed by the North West Development Agency (NWDA) as part of its "Sustainable Buildings Policy". (NWDA, 2010)

Table 3.3 sets out the potential benefits delivered in relation to the seven green infrastructure functions and the connection with the planning policy priorities. It demonstrates how green infrastructure contributes to spatial planning and sustainability objectives and the functions it fulfils with a concise identification of resulting benefits in relation to government policy priorities. The greening Interventions correspond to the eleven economic benefits set out by Natural Economy Northwest, which include climate change adaptation, flood alleviation, biodiversity and place quality.

Table 3.4 NW England Green Infrastructure Policy Priorities (Source : NWDA, 2010)

	Policy priorities							
	Economic	Environmental					Social	
	Economic growth and employment	Protect and enhance cultural heritage	Protect and enhance the landscape, geodiversity and natural environment	Biodiversity conservation and enhancement	Climate change mitigation and adaptation	Promoting sustainable transport and reducing the need to travel by car	Community cohesion and life long learning; volunteering	Healthy communities; health and well being
Access, recreation, movement and leisure								
Habitat provision and access to nature								
Landscape setting and context for development								
Energy production and conservation								
Food production and productive landscapes								
Flood attenuation and water resource management								
Cooling effect								

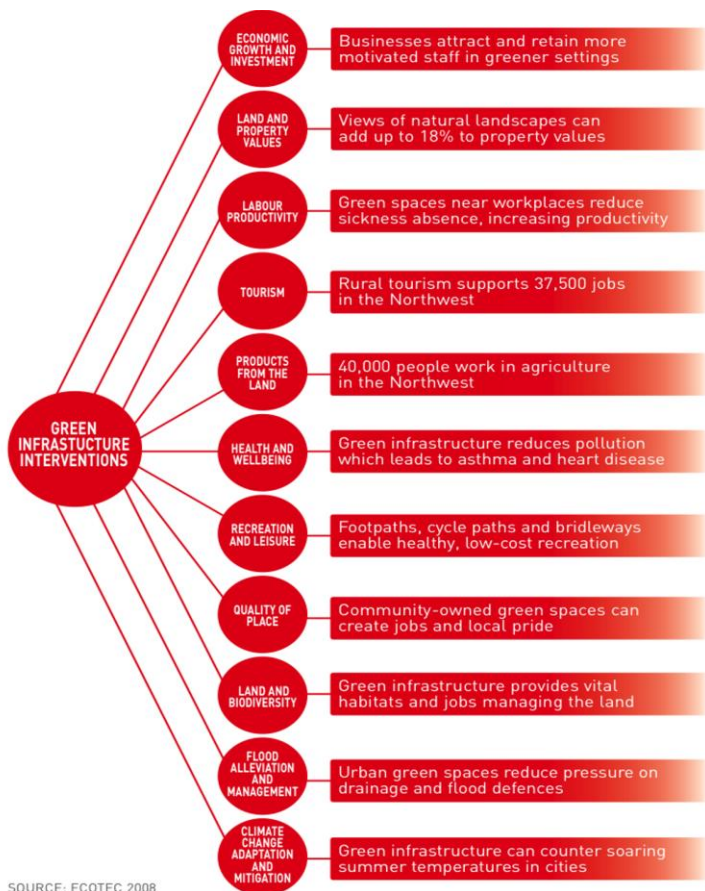


Figure 3.4 Economic benefits set out by Natural Economy Northwest (adopted from NWDA, 2010)

The other concepts that are embedded in the NW England Planning Policy on Green Infrastructure are Place making and Multifunctionality. Green infrastructure plays a key part in place making, from formulation of design principles that respond to landscape character, sense of place and vernacularity, to also identifying opportunities for community involvement.

Multifunctionality refers to the potential of green infrastructure to have a range of functions. It is central to the green infrastructure concept and approach and delivers a broad range of ecosystem services. Figure 3.5 shows some of the ideas which combine the concepts of multifunctionality and place-making. It illustrates the considerable potential of the green infrastructure approach of NW England.

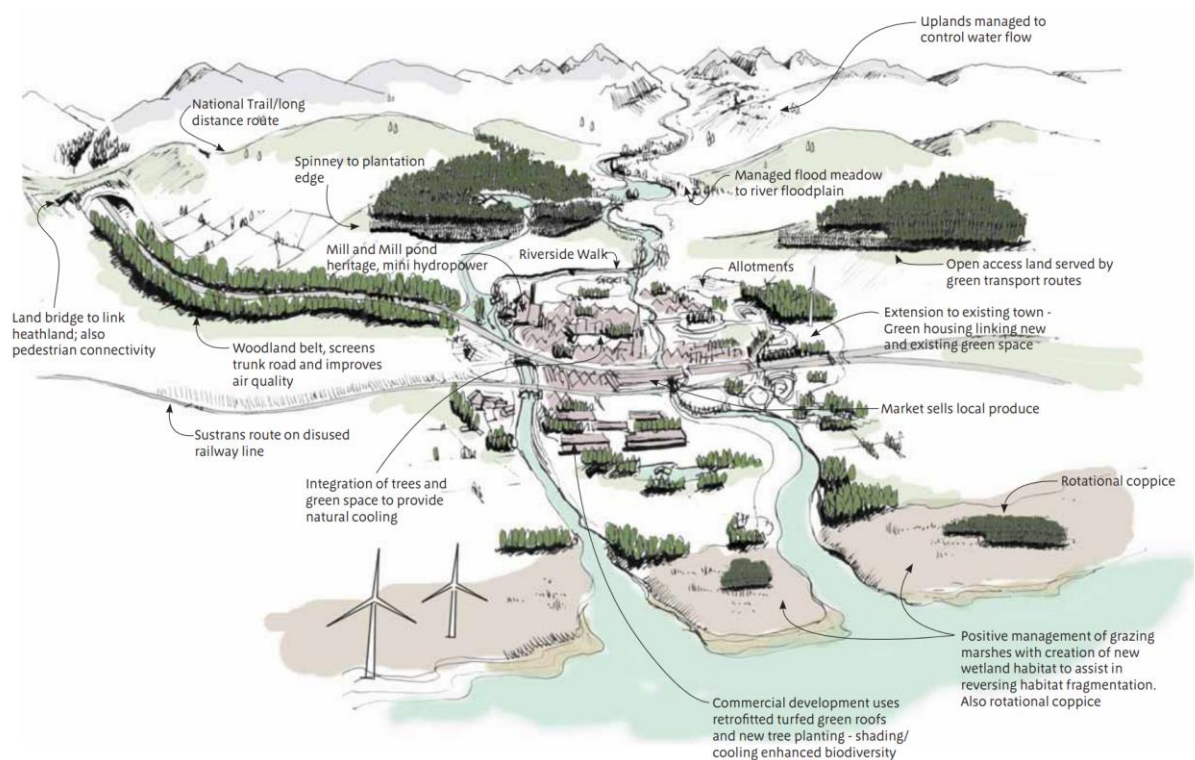


Figure 3.5 Combine concepts of multifunctionality and place-making (Source : NWDA, 2010)

A holistic understanding of the landscape and environmental setting and sensitivities related to green infrastructure is critical to build character and place as a response to landscape and townscape. Table 3.5 shows the factors of considerable landscape elements that support the green infrastructure quantification of NW England.

Table 3.5 North West England Green Infrastructure Factor (NWDA, 2010)

Non-overlapping surface types		GI Factor
A1	Buildings (without green roofs)	0.0
A2	Buildings (with green roofs). N.B. Please only include the area of the roof that is covered by vegetation here, if part of the roof is not vegetated include it in A1).	0.7
B1	Non-permeable road surfaces	0.0
B2	Non-permeable footpath surfaces	0.0
B3	Non-permeable parking / driveway surfaces	0.0
B4	Semi-permeable surfaces such as stone paving with joints (where water can infiltrate)	0.2
B5	Semi-permeable surfaces such as gravel	0.4
C1	Vegetated or open soil surfaces (where plants have direct contact with deeper soil)	1.0
C2	Vegetated or open soil surfaces (where soil depth is more than 60cm but there is no direct contact with deeper soil; e.g. roof of underground parking). N.B. Please do not use this for green roofs on buildings - use A2 instead.	0.6
C3	Vegetated or open soil surfaces (where soil depth is less than 60cm and there is no direct contact with deeper soil; e.g. roof of underground parking). N.B. Please do not use this for green roofs on buildings - use A2 instead.	0.4
D	Open water surfaces (including ponds and swales covered by water for at least 6 months of the year)	1.0
Overlapping surface types		GI Factor
E	Shrubs and hedges. N.B. Should not exceed development site area. Can overlap surfaces A1-D and F.	0.3
F	Trees (canopy cover area). N.B. Should not exceed development site area. Can overlap surfaces A1-D and E.	0.4
G	Green walls (area up to a height limit of 10 m)	0.6

The minimum green infrastructure target of 0.6 is specified for development on vacant areas. However for development on areas with existing structures, the green infrastructure target of the proposed development should be higher than that of the pre-development by 0.2.

3.5. Southampton Green Space Factor

Southampton Green Space Factor (GSF) is a tool which allocates a score to different types of surfaces based on infiltration potential. Like the other cities before, this factor is used as a proxy for ecosystems services provided by the different surfaces, e.g. cooling, air quality, biodiversity. (Southampton City Council, n.d)

The aim of the green space strategic action plan of Southampton is to provide a network of high quality green spaces to contribute a unique sense of place. There are six key objectives in the scope of Southampton strategy of green spaces:

- People are proud of their city and making a positive contribution
- Learning and innovation at its heart
- A dynamic business environment

- An attractive, sustainable and stimulating environment
- Imaginative arts and cultural opportunities
- A unique sense of place

The linkage of Southampton green spaces strategy shown in Figure 3.6

Linked strategies

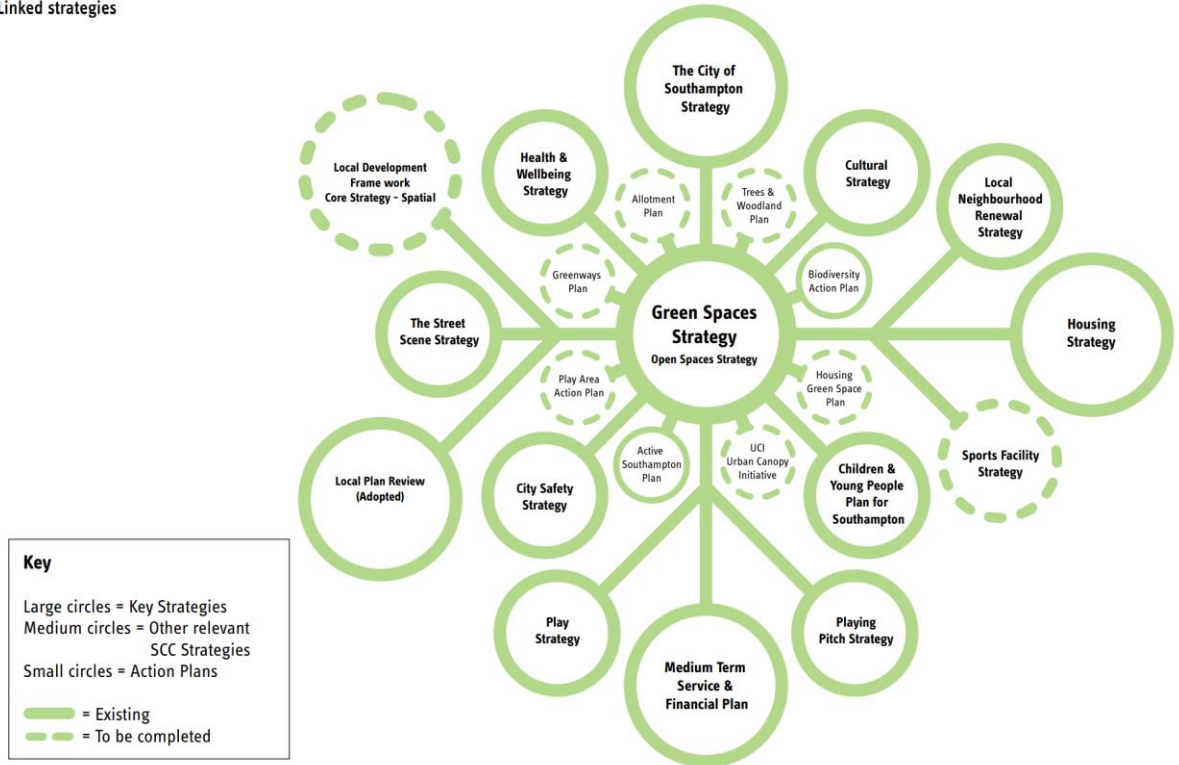


Figure 3.6 Southampton green spaces linked strategy (Source: Southampton City Council)

The GSF tool is now required for the development of one or more dwellings or any development of more than 500 m². The tool is used as part of the sustainability checklist of green infrastructure sufficiency in the proposed development. No minimum GSF target is set. This checklist is used by applicants who wish to obtain planning permission by demonstrating compliance to key principles of sustainable development as set out by the City of Southampton’s Core Strategy Policy. The GSF is scored from 0 to 1, where impermeable surfaces are scored as 0 and surfaces with the highest green space factor are scored 1. Table 3.6. Shows Southampton’s Green Space Factor.

Table 3.6 Southampton Green Space Factor (Source : Southampton City Council)

Surface Type	Factor
Primary (Ground Level) Layers	
Building surface area with no green roof	0.0
Extensive greenroofs	0.6
Intensive greenroofs	0.7
Non-permeable surfaces	0.0
Permeable paving	0.2
Semi-permeable surfaces e.g. sand and gravel	0.4
Grassland (short, amenity)	0.4
Grassland (long, rough)	0.5
Shrubs	0.6
Trees on shallow soil/ tree pits	0.6
Woodland/ Trees on deeper soil	1.0
Open Water	1.0

3.6. London Green Space Factor

The London Green Space Factor (LGSF) aims at emphasizing an initiative on functional green infrastructure at the building plot level provision, rather than new public green space. The recommend use of LGSF are projects in the Central Activity Zone, or projects in locations where large-scale urban renewal is planned. LGSF could also be used in a voluntary way to evaluate any development in any location, particularly where there is a concern that cumulative development will create a potential loss of green cover in the locality (GLA, 2017).

The LGSF score is presented in Table 3.7. It assigns a factor to a range of surface cover types that are likely to be included within development proposals in London. The factors briefly describes the landscape elements type and provides references that give additional technical descriptions of the surface cover type. The table covers most eventualities, however, if a surface cover type is encountered which is not listed, it is suggested that it is assigned the same factor as the category in the table that is most functionally similar. The scale of LGSF is between 0 assigned to sealed, hard surfaces and 1 assigned to the most natural and or permeable features.

Table 3.7. London Green Space Factor (Source: GLA, 2017).

Surface Cover Type	Factor
Semi-natural vegetation (e.g. woodland, flower-rich grassland) created on site.	1
Wetland or open water (semi-natural; not chlorinated) created on site.	1
Intensive green roof or vegetation over structure. Vegetated sections only. Substrate minimum settled depth of 150mm – see livingroofs.org for descriptions ⁶ .	0.8
Standard trees planted in natural soils or with a minimum of 25 cubic metres soil volume per tree (preferably with load-bearing substrates and connected pits) – see Trees in Hard Landscapes for overview ⁷ .	0.8
Extensive green roof with substrate of minimum settled depth of 80mm (or 60mm beneath vegetation blanket) – meets the requirements of GRO Code (2014).	0.7
Flower-rich perennial planting – see Centre for Designed Ecology for case-studies ⁸ .	0.7
Rain gardens and other vegetated sustainable drainage elements – See CIRIA for case-studies ⁹ .	0.7
Hedges (line of mature shrubs one or two shrubs wide) – see RHS for guidance ¹⁰ .	0.6
Standard trees planted in individual pits with less than 25 cubic metres soil volume.-	0.6
Green wall –modular system or climbers rooted in soil – see NBS Guide to Façade Greening for overview ¹¹ .	.0.6
Groundcover planting – see RHS Groundcover Plants for overview ¹² .	0.5
Amenity grassland (species-poor regularly mown lawn).	0.4
Extensive green roof of sedum mat without substrate or other systems that do not meet GRO Code (2014) ¹³ .	0.3
Water features (chlorinated) or unplanted detention basins.	0.2
Permeable paving - see CIRIA for overview ¹⁴ .	0.1
Sealed surfaces (e.g. concrete, asphalt, waterproofing, stone).	0

All developments (in areas targeted in strategic plans) should deliver additional urban greening. However, targets are different depending on the development type and its location. The LGSF is set out in Policy G5 of the Draft New London Plan. There is no specific target, however the project examples in Ecology consultancy report, GLA (2017) indicate an overall minimum target score of 0.3 will be suitable for most proposed developments on previously developed land in London. Developments that are predominantly residential may justify the application of a higher target score of 0.5, particularly if the development results in additional pressure on already limited green space. Adjustments to the 0.3 target should be supported by the testing of design options that are appropriate to the location, its context and the needs assessment supporting the local development plan.

3.7. Seattle Green Factor

The Seattle Green Factor is a landscaping strategy that is required for all new developments in business districts with more than four dwelling units, more than 4,000 square feet of commercial uses, or more than 20 new parking spaces. The aim of the Seattle Green Factor is to increase the

amount and quality of urban landscaping in dense urban areas while allowing increased flexibility for developers and designers to efficiently use their properties. Other Landscape improvements and urban design goals to be achieved by the Seattle Green Factor are: Landscape improvements to accomplish urban design goals: helping to fit new buildings into their surroundings, buffering incompatible uses, providing screening and privacy, reducing headlight glare, and creating a pleasant urban environment. (Seattle Government, Department of Construction & Inspections, 2020)

The City of Seattle Regulation related to land use and zoning requires the equivalent of 30% of a parcel in the commercial zones to be vegetated by using the Seattle Green Factor. The Green Factor encourages to maximize the “vegetation potential” through planting layers of vegetation and larger trees in areas visible to the public. The Seattle green factor includes an additional bonuses segment for rainwater harvesting and low water use plantings. Larger trees, tree preservation, green roofs, green walls and water features are encouraged by this requirement.

Standards for landscaping and green factor in Seattle are classified by general standards, green factor elements standards, and green factor bonuses standards, presented in Table 3.8:

Table 3.8. Seattle Landscaping Standard (source: www.seattle.gov)

General Standards	Green factor element standards	Green factor bonuses standards
Soil quality, depth, and volume Plant selection Preservation of trees and other vegetation, New trees categorization Shrubs and large perennials, Ground covers Mulch Landscape elements in the right-of-way drought tolerance container plantings, driveway and parking areas clearance and access for maintenance	bioretention facilities green roofs, vegetated walls water features, permeable pavements structural soil systems	Drought-tolerant or native plant species irrigation with harvested rainwater landscape features visible to passers-by food cultivation

The application of the Seattle Green Factor is also expected to provide environmental benefits for reducing stormwater runoff, improving air and water quality, decreasing the urban heat island effect, improving energy efficiency, helping new buildings to fit into their surroundings, incompatible uses buffer, providing screening and privacy, reducing headlight glare, creating a pleasant urban environment, and providing wildlife habitat. Table 3.9 shows the target on zoning related minimum score of green factor implementation, and Table 3.10 elaborates on the landscape elements and the multiplier of the Seattle Green Factor.

Table 3.9. Minimum target of green factor implementation (source: www.seattle.gov)

Zoning	Minimum Score
Commercial and Neighborhood Commercial	0.3
Industrial Commercial within urban village or urban center boundaries	0.3
Development in South Downtown (variety of zones within the South Downtown planning area)	0.3 for development with 20,000 gross square feet or more
Midrise and Highrise Multifamily Residential	0.5
Lowrise Multifamily Residential	0.6
Yesler Terrace	0.30 per development, 0.50 per sector
Seattle Mixed	0.3

Table 3.10. Landscape elements and the multiplier of the Seattle Green Factor (source: www.seattle.gov)

Green Factor landscape elements	Multiplier
A. Planted areas (choose one of the following for each planting area)	
1. Planted areas with a soil depth of 24 inches or more:	0.6
2. Bioretention facilities meeting standards of the Stormwater Code, <u>Title 22</u> , Subtitle VIII	1.0
B. Plants	
1. Mulch, ground covers, or other plants normally expected to be less than 2 feet tall at maturity	0.1
2. Medium shrubs or other perennials at least 2 feet tall, but less than 4 feet tall, at maturity	0.3
3. Large shrubs or other perennials at least 4 feet tall at maturity	0.3
4. Small trees	0.3
5. Small/medium trees	0.5
6. Medium/large trees	0.7
7. Large trees	0.9
8. Preservation of existing trees at least 6 inches in diameter at breast height	1.0
C. Green roofs	
1. Planted over at least 2 inches but less than 4 inches of growth medium	0.4
2. Planted over at least 4 inches but less than 8 inches of growth medium	0.6
3. Planted over at least 8 inches of growth medium	0.8
D. Vegetated walls in C and NC zones only	0.4
E. Permeable paving	
1. Installed over at least 6 inches and less than 24 inches of soil and/or gravel	0.2
2. Installed over at least 24 inches of soil and/or gravel	0.5
F. Structural soil	0.5
G. Bonuses applied to Green Factor landscape elements:	
1. Landscaping that consists entirely of drought- tolerant or native plant species	0.1
2. Landscaping that receives at least 50 percent of its irrigation through the use of harvested rainwater	0.2
3. Landscaping visible from adjacent rights-of-way or public open space	0.2
4. Landscaping in food cultivation	0.1

3.8. DC Green Area Ratio

The DC Green Area Ratio (GAR) is a zoning regulation that integrates landscape elements into parcel site design to promote sustainable and aesthetically pleasing developments. The GAR assigns a weighted score to development sites based on the types of landscape and site design features that are implemented and the size of coverage area. The aim of GAR is to promote greater liveability, ecological function, green space accessibility and climate adaptation in the urban environment. (DC DOEE, 2017)

The GAR quantifies environmental performance of each landscape element by assigning a unique multiplier to each feature. This multiplier gives landscape elements with greater environmental value. DC GAR application is intended to benefit climate adaptation, urban heat island mitigation, air quality improvement, and stormwater mitigation.

The minimum required GAR score needed to reach compliance differs by zoning district. This score is based on an assessment of the square footage of landscape elements that can be incorporated with each type of land use, between 0.1-0.4. Sites that require a Certificate of Occupancy must submit a GAR plan as part of the building permit application, with limited exceptions. These sites include new building construction as well as additions and interior renovations where the cost of work exceeds 100% of the assessed building value.

Table 3.11. Landscape elements and the multiplier of DC GAR (Source DC DOEE, 2017)

GAR Landscape Elements	Multiplier
Landscaped areas with a soil depth of less than 24 inches	0.3
Landscaped areas with a soil depth of 24 inches or more	0.6
Bioretention facilities	0.4
Ground covers, or other plants less than 2 feet tall at maturity	0.2
Plants at least 2 feet tall at maturity	0.3
Tree canopy for all trees with mature canopy spread of 40 feet or less calculated at 50 square feet per tree	0.5
Tree canopy for all new trees with mature canopy spread greater than 40 feet calculated at 250 square feet per tree	0.6
Tree canopy for preservation of existing trees 6 inches to 24 inches in diameter	0.7
Tree canopy for preservation of existing trees 24 inches diameter or larger	0.8
Vegetated walls, plantings on a vertical element	0.6
Extensive vegetated roof over at least 2 inches but less than 8 inches of growing media	0.6
Intensive vegetated roof over at least 8 inches of growing media	0.8
Permeable paving over at least 6 inches and less than 2 feet of soil or gravel	0.4
Permeable paving over at least 2 feet of soil or gravel	0.5
Enhanced tree growth systems	0.4
Renewable energy generation (area of)	0.5
Water features (using at least 50% recycled water)	0.2
Bonuses	
Native plant species listed in Subtitle C §603.9	0.1
Landscaping in food cultivation	0.1
Harvested stormwater irrigation	0.1

4. LOCAL CONTEXT - JAKARTA AND CLIMATE CHANGE

4.1. Jakarta and Warming Temperatures

Along with climate change and the global temperature rise due to urban development, Jakarta city dwellers are subject to outdoor heat exposure, especially in the centre area. Jakarta, with its 10,467,630 inhabitants in 2018 (BPS), is the first destination city of Indonesia's urbanization. The city with its 15,804 per km² population density, (having increased from 14,506/km² in 2010 (BPS)) has experienced a massive development in building construction sectors as a response to accommodate urbanization pressure to intensify the use of the urban area by Land Use Land Cover Change (LULLC) created a considerable ecological change within the city.

A study by Tursilowati (2012) investigates the effect on LULCC in UHI phenomenon in Jakarta, using Landsat TM/ETM+ data from 1989 and 2002. This study shows the LULCC in 1989 has transformed the 5,218 ha of vegetation area to residential (3,407 ha), industrial (1,549 ha) and water body (262 ha) in 2002, simultaneously shows the distribution of UHI with high Ts (more than 30 °C) from 8,453 ha in 1989, to 56,834 ha in 2002, in the central area where buildings, roads and non-vegetation surfaces are dominant, and spreading to the southern hills part. In 1989, 41% of Jakarta's land cover was dominated by vegetation (26,488 ha), 37% residential, 15% industry and 5% water body. Within 13 years of development, 43% of Jakarta land cover were dominated by residential and 33% vegetation, 18% industry, and 5% water body. The surface temperature between 19-29° C in 1989 no longer existed in 2002. Spatial temperature distribution in 2002 is nearly 4-8° C higher than it was in 1989.

Ramdhoni et al.(2016) further continued Jakarta land cover change analysis between 2001 and 2014. This study shows that in 2001 Jakarta was dominated by built-up area (68.44%) which increased to 81.41% in 2014, with decreased vegetated land from 26.27% to 13.59%.The area with surface temperatures >30°C significantly increased from 37.03% in 2001 to 79.04% in 2014. In addition to this, air temperature in Jakarta is also increasing from an average between 24-30° C in 2001 to an average between 27-30 °C in 2014. According to Ramdhoni, Jakarta temperature increase is linearly proportional with the increase of construction inland, and the decrease area of green open spaces.

4.2. Overview of Land and Environmental Issues

Geographically, Jakarta has an area of 7,660 KM², with 662 km²of land area including 110 islands in the Thousand Island region, north of Jakarta. Administratively, Jakarta's Government is divided into 5 Administrative Cities, 1 Region, 44 districts and 267 sub-districts. (Jakarta Governor Regulation No. 171/2007 about Planning, Establishment, and Area of Sub-districts in Jakarta Province)

Jakarta is situated in a tropical climate region with an average rainy season from October to March and a dry season from April to September. Jakarta's rainfall is generally of the monsoon type with one peak in November to March, affected by the northwest monsoon, and another one through May to September which is affected by the dry southeast monsoon that distinguishes the dry and rainy season (Jakarta Province Disaster Management Plan 2013-2017).

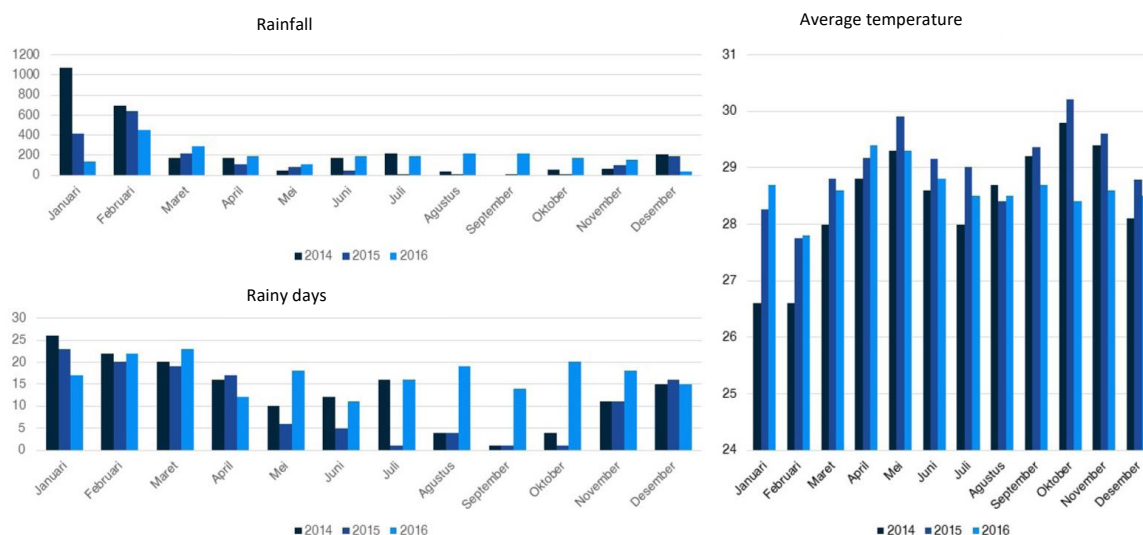


Figure 1. Jakarta Climatic Figure from 2014 – 2016 (Source: Jakarta Green Space Masterplan)

In 25 years (1975-2000), Jakarta temperature increased by an average of 0.17°C . Jakarta temperature tends to be higher than in it's surrounding areas. At present, the temperature tends to be 0.7-0.9°C higher and has an impact on the microclimate and the climate comfort of the region. (Jakarta Green Space Master Plan).

4.3. Jakarta's Environmental Issues

The impact of urbanization in Jakarta and land development induces the changing ecosystem in the environment. According to the Jakarta Disaster Management Department, flooding is one of the significant issues with an increasing intensity. In 2007, flooding was labelled as a national disaster with the total loss of 5 trillion rupiahs. Due to Jakarta topographic position with 40% of the land's elevation under the sea level, Jakarta is also the downstream area of 16 substantial rivers (202km).

The city's high population also increases demand for clean water. According to Health ministry standard No. 493.2010, 80-85% of Jakarta water can not be categorized as clean water, and the PAM Jaya (Jakarta Drinking Water Company), needs to import water from the surrounding area. This problem continues while the community still use the groundwater that causes the land subsidence, that could reach a 5-10cm drop per year due to the groundwater use and accelerated development without profound attention to inland carrying capacity (Jakarta Green Space Master Plan 2018).

One of Jakarta's recent major issues is air pollution that bustled the media during the long dry season at the end of 2019. Landrigan et al., (2018) stated that pollution is the most significant environmental cause of diseases and premature death in the world. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide— three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence. This mortality is caused by exposure to small particulate matter of 2.5 microns or less in diameter (PM2.5), which cause cardiovascular and respiratory disease, and cancers (WHO, 2015). The WHO(2015) specified air quality guidelines (AQGs) with the base target level of PM2.5 for short-term (24-hour-average) of are 25 µg/m³, and long-term (annual average) exposure of 10 µg/m³. Jakarta's annual average exposure of PM2.5 in 2018 is 45 µg/m that puts Jakarta as one of the highest average annual levels of PM2.5 in South East Asia. Pollution threatens health and destroys ecosystems, and it is intimately linked to global climate change. (Landrigan et al., 2018).

Related to a study by Kusuma et al. (2019), PM_{2.5} pollution in DKI Jakarta was strongly influenced by humidity, NDVI, temperature and residential areas, whereas pollution, has a positive correlation with residential areas and temperatures, and adverse relationship with NDVI and humidity.

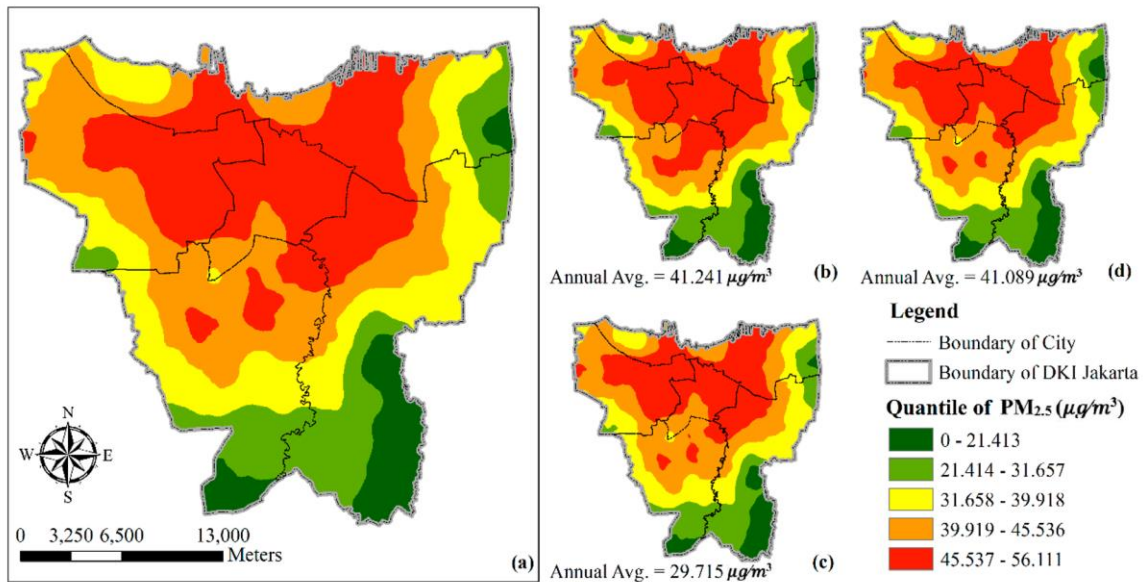


Figure 2. Prediction maps of spatial-temporal variability of PM_{2.5} concentration using the developed LUR model in Jakarta. (a) 2016-2018, (b) 2016, (c) 2017, (d)2018. (Source: Kusuma et al., 2019)

4.4. Green Open Space Regulation and Masterplan

Under Indonesian Law No. 26/2007, the proportion of ideal green area in big cities like Jakarta is 30% of the total city area, with 20% public green areas and 10% for the private sector. Minister of Home Affairs Regulation No. 1/2007 concerning the Arrangement of Green Open Spaces in Urban Areas classified the functions of green area as a buffer for urban conservation areas, pollution control and environmental damage, biodiversity protection, water system control, and as urban aesthetics. The aim of providing green open spaces in Jakarta is to maintain the harmony and balance of urban ecosystems, both natural and human-made environments.

The Jakarta Government, in Provincial Spatial Plan 2030, further arranged the utilization of green open space to consider the distinctive character of Jakarta as delta city, Jakarta carrying capacity of natural resources, and environmental sustainability. The target number remains 30% of total Jakarta area with 20% plotted as public green space and 10% as private. Based on Ministry of Public Works Green City Roadmap 2015, the total area of Jakarta Green space recently was 9.97% out of 20%, and the total Green area that still needs to be met is 6,520 ha. One of the strategies to improve Jakarta's green open space, according to Jakarta Spatial Plan 2030, is to increase the quantity and quality of green open space distribution throughout the city's districts and to maintain the availability of green open space, one of which is the implementation of the Green Area Factor particularly for Government buildings and vertical greenery.

Table 4. Shows the type of green spaces and the public/private ownership (Adapted from Ministry of Public Work Regulation No. 5/2008)

Type of Green Space		Public	Private
Yard	Residential garden		√
	Office, shops, and commercial yard		√
	Roof Garden		√
City Park/Urban Forest	Green belt	√	
	Urban Forest	√	
	City Park	√	
	District Park	√	√
	Sub-district park	√	√
	Community park	√	√
	Neighbourhood park	√	√
Street Green Corridor	Street patch and median	√	√
	Pedestrian	√	√
	Space under fly over	√	
Green space with special function	Railway setback	√	
	Green corridor under high voltage electricity network	√	
	River setback	√	
	Shore/coast setback	√	
	Springs buffer	√	
	Cemetery	√	

The Green spaces in private areas target is regulated by city planning detail regulation according to land use, function, and location. There is no explanation on where this target came from, since it followed the previous planning pattern and has no update in the City Planning Detail Regulation in 2014. The concept of Jakarta Greenspace is to redefine the definition of Green Open Space (GOS) by the Indonesian Law No. 26/2007 as “*elongated area/path or group, the use of which is more open, a place to grow plants, which grows naturally or intentionally planted*”. However, in Jakarta, where the built form is already established, vast new green spaces are not feasible any longer which leads to difficulties in the implementation and likelihood to be able to reach the 30% target.

Two major aspects of GOS implementation are public accessibility and spaces with growing plants. Somehow, with the improvement of environmentally friendly technology, the current use of the term green space provides enough limits with the development effort both in quantity and quality. Calculation of the area of GOS that is limited to flat surfaces minimizes the possibility of utilizing other potential spaces such as walls and roofs as GOS. Green spaces can be either open or closed green spaces by a canopy tree; it can be owned by the public or privately, or in the elements forming the space, it can be hardscape or softscape or a combination of both. GOS is carrying three concepts, GOS for healthy Jakarta, resilient Jakarta, and making Jakarta as a city in the forest by 2038.

The definition of Green Open Space by the Indonesian Law No. 26/2007 and the city planning detail requirement of green area ratio (GAR) in every development site is inflexible and questionable. There is no justification of the target set of each area of the site, and the calculation of the GAR is quantified only to the total area of the gross area ratio.

In December 2019, Jakarta launched Building Layout Guidelines to provide technical provisions for buildings that have not been regulated in city planning detail and to create a uniform perception

about building layout in the context of compiling physical details in city plans. This guideline elaborates the specific requirement on calculating GAR in a development site by engaging ecological and microclimatic function as a consideration in determining the calculation on GAR. However, like some other cities that put the green area factor into account for calculating the impact of the environment, these guidelines do not provide enough evidence on their factor scale concerning the ecological adaptation that they will achieve and local climate context on the implementation. No specifications are given regarding the quality and suitability of vegetation, and no distinction is made for larger diameter/mature trees, which should be preserved as much as possible. Mature trees are significant for the roles they play in providing shade and intercepting rainfall. Also, in times of drought, they may provide a cooling function much longer than grass, which will dry out faster (Gill, 2007, A Vartholomaios et al., 2013). Moreover, there is still a question on how target setting on green area could quantify the value on mitigating urban heat islands while providing the thermal comfort for the community in Jakarta as city in the tropics.

4.5. Knowledge Gap

Previous studies have explored the role of green infrastructure for climate change mitigation specifically in the tropics. Many studies on Jakarta demonstrate that changing land cover will increase surface temperatures (Tursilowati et al., 2012, Ramdhoni et al., 2016). However, there is no evidence that additional green infrastructure in Jakarta, in certain areas, a certain amount will reduce the temperature and contribute to the thermal comfort of the community, and there has been no study that shows Jakarta predicted mean vote and predicted percentage of dissatisfied Jakarta citizen regarding climate condition in specific zones. The study on the green area factor was not done in Jakarta. In Jakarta's Green Space Masterplan, there is an indication that this will come forward with the adaptation on Berlin Biotope area factor. However, there is no explanation on the construction of the target and weighting factor decision. Based on this reality, it is necessary to explore the quantification of green infrastructure implementation as the strategy on urban overheating mitigation. Specifically the implementation on local context, in order to set the rational amount of green area target for the whole city.

This thesis will present the role of green cover in specific urban patterns, using the Local Climate Zone classification system (Stewart & Oke, 2012) to identify a majority of areas that are most vulnerable to facing heat problems. Computational fluid dynamics (CFD) simulations will be performed to check how the green infrastructure application has an impact on temperature reduction in the Jakarta area, and input for further climate sensitive urban planning policy are presented.

5. METHODOLOGY

5.1. Study design

To develop a protocol for the Jakarta Green area index, a target setting using the green infrastructure weighting factor serves as an approach to mitigate urban overheating. A systematic method will be presented in this study.

The objectives of this study are to critically evaluate the current knowledge of UHI mitigation in tropical cities, to develop a weighting factor model for urban overheating adaptation, to analyse the contribution of green infrastructure, to demonstrate the limitations of green area target-setting by the Jakarta government for cooling purposes, to evaluate different options on target implementations of green infrastructures through microclimate simulations, and to present input for planning and land use policy in terms of green area target-setting for urban cooling.

In the previous chapter, the first target of this thesis on the evaluation of the current scientific literature on UHI mitigation in tropical cities has been described. This chapter will present the study design to address the balance objectives, data sources of the methods, analysis procedure, and the limitations of this study.

5.1.1. Development of a New Green Infrastructure Quantification Factor

Following the review on green calculation tools in eight cities in chapter 3, a developed model to calculate a green area index in simulations is needed. This model is constructed by codifying landscape elements and green infrastructure in the general classification in each city that have been reviewed in the previous chapter.

The process will start by breaking down all the landscape elements in precedent cities and classifying them in general categories. Further analysis on factor interval rating also will be conducted to have a proportional scale. The end value of the factors will be obtained by the average of each category score to accommodate an appropriate range of factor scale.

5.1.2. Zoning Analysis

5.1.2.1. Identification of Jakarta Local Climate Zone Mapping

This process is taken to characterise the land use/land cover patterns in Jakarta. Developed by Stewart and Oke (2012), The Local Climate Zone (LCZ) system categorizes regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in horizontal scale (Stewart and Oke, 2012). Each LCZ has a characteristic screen height temperature regime that persist year-round and are associated with homogenous environments or ecosystems of cities, nature biomes, and agricultural lands. It is most apparent over dry surfaces, on calm, clear nights, and in areas of simple relief.

The model of Jakarta LCZ map was developed by following the World Urban Database and Access Portal Tools (WUDAPT) protocols (wudapt.org).

The use of the Local Climate Zone (LCZ) classification framework is the starting point for characterising cities consistently. In this stage, Jakarta is mapped using Local Climate Zone (LCZ), which categorises landscapes into ten urban and seven natural surface cover types. Each LCZ type is described in terms of the typical appearance of each in ground-based and aerial photographs and is linked to some urban parameter values.

This data of Jakarta will describe neighbourhood scale urban landscape (> 1KM²) spatial unit using the LCZ scheme. The classification of Jakarta urban area into LCZ types is based on a semi-automated process (Bechtel and Daneke, 2012, Bechtel et al. 2015) using available multi-spectral satellite imagery (Landsat8), Google Earth software and free SAGA (Conrad et al., 2015). Samples of training areas that identify LCZ types across a selected city are needed in order to enable the process. These training areas will identify the statistical characteristics of LCZ pixel values within the available multi-spectral images to develop a model that categorises the entire images into LCZ types.

The pathway of WUDAPT classification is divided into five steps:

1. LCZ Data collection hierarchy understanding
2. Input Jakarta as selected city
3. Jakarta data downloads. The data consist of Landsat image for Jakarta, Region of Interest (ROI), and Landsat data preparation with SAGA GIS.
4. Open data file in Google Earth, and
5. Training areas digitation.

Training area digitation follows some key points

1. The LCZ neighbourhoods scheme corresponds to an area greater than one km² of large 'homogenous' areas where the optimal size and shape of training areas is more than 1 km² and more than 200 m wide at the narrowest point. (because pixel size of LCZ classification Landsat image is 100-120 m on one side).
2. Preferably local scale digitation instead of small side areas.
3. The classification of Landsat images is based on a relatively coarse grid which made the training area geometry not critical. Hence, it is needed to leave a buffer of about 100 m between LCZs if there is a clear boundary.
4. Several examples will be needed (5-15) to process the automatic classification.
5. Natural surface cover (e.g. dense trees) receives as much attention as the urban types to delineate the urban footprint.
6. Suitable features to digitise which area is relatively persistent over time, and features like construction sites and harvested fields.
7. Street view and geo-referenced images were available to confirm categorisation of the neighbourhood can be used.

After conducting the WUDAPT protocol, the calculation on LCZ area will be processed in ArcGIS to conclude the majority of land use/land cover pattern of Jakarta. From this calculation, the representative area will be chosen as the simulation base model.

A LCZ verification check is performed with visual mapping, using area imagery from Google maps, street view, LIDAR, drone video capture from Jakarta City Planning and data comparison with city planning reports.

5.1.2.2. Representative Sample Selection

A representative model for Jakarta LCZ is defined by choosing the zoning that covers the majority of the area and compares it to the Jakarta City Planning Detail Regulation. Some guidelines are created to make the limitation:

1. Define specific size dimension for optimising ENVI-met simulation with high possibility same class of LCZ

2. Consider the development plan, urban design guidelines, conservation area, and some conflicts that occur in the area due to the land use and land cover planning. Other considerations to select the area are ownership, demography context and other supporting regulations.
3. The location of the possible Green infrastructure application.

5.1.3. ENVI-met Simulation

ENVI-met is a three-dimensional non-hydrostatic microclimate model for the simulation. It includes a simple one-dimensional soil model, a radiative transfer model and a vegetation model, especially within the urban canopy layer (Bruse and Fleer, 1998). ENVI-met is considered a micro-scale computational fluid dynamic model that is capable of analysing the thermal comfort regime at high resolution (Huttner et al., 2008). It is used to assess the effectiveness of urban planning measures to tackle the UHI problem in a variety of climate contexts. (Emmanuel and Loconsole (2015).

At this stage, the microclimate simulation will be run in two scenarios for each LCZ model area. The first scenario will be the base case, representing the existing conditions of the site and the second scenario will be the absolute maximum green intervention, with no consideration regarding practicality or activity in the area. Both scenarios of green infrastructure quantification will be calculated using the newly developed green infrastructure quantification factors.

The base case will be compared with the best greening scenario to determine the effect on green infrastructure implementation. The result of ENVI-met simulation's atmosphere file will be generated in BIO-met, to assess the implication of thermal comfort using the BIO-met standard personal human parameters that include body parameters, clothing parameters and human metabolism. BIO-met will generate the Predicted Mean Vote and Predicted Discomfort percentage to identify the distribution of thermal comfort in the model area for analysis purposes.

5.1.4. Simulation Result Extrapolation for Jakarta Metropolitan Area

This steps will be performed using ArcGIS to extrapolate the distribution of simulation result in the entire Jakarta area representatives, to see the impact of green infrastructure for overheating mitigation represent by each LCZ in Jakarta.

5.1.5. Implications for Jakarta Urban Planning and Land Use Policy

Based on the simulations results from analysis, the conclusion will be drawn to propose a protocol on the target set green area of Jakarta, as an input for future urban planning of a climate-responsive guidelines development.

5.2. Sources of Data

1. The data used in the study are secondary-gathered from the literature of Green index portfolio of Berlin, Helsinki, Malmo, North West England, Southampton, London, DC, and Seattle.
2. LCZ mapping data and verification are downloaded through WUDAPT protocol, area imagery from Google maps, street view, LIDAR, drone video capture from Jakarta City Planning and data comparison with city planning report.

The Local Climate Zone mapping will follow the WUDAPT objective on level 0 data collection hierarchy for Jakarta to develop a local character classification suitable to urban climate studies, following a consistent manner on the urban form (surface cover, material, and building geometry) and function (human activities which drive the use of water and energy) (Table 5.1).

Table 5.1 WUDAPT objective on level 0 data collection hierarchy

Characteristic	Parameters
Cover	Vegetation, buildings, impervious surface cover
Material	Wall type, roof type, window type, road materials, window fraction on the wall, colour/albedo
Geometry	Building height, width of streets, contiguous or isolated buildings, roof geometry
Function	Building use, irrigation, road type, temperature setting, occupancy, air conditioning, shutters or shading, window opening, building age, building renovation post 1990.

- The input climatic data for ENVI-met simulation are gathered from Met Office, the UK's national meteorological service (<https://www.metoffice.gov.uk/>) with the coordinate of the location is -6.117, 106.65 and altitude 8 m above sea level.

5.3. Analysis Procedure

Data processing and analytical procedures are divided into four types of analysis (Fig. 5.1).

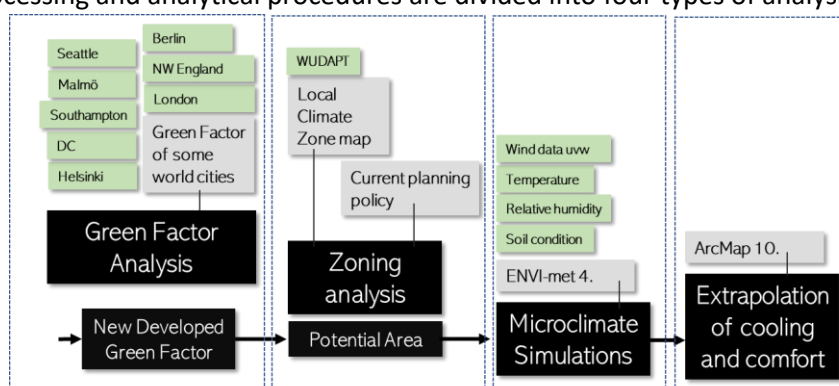


Figure 5.1. Methodological framework for analysis procedure

- Green factor analysis**
This analysis will break down landscape elements from green factors of some cities of the world and develop a new appropriate green factor to be used in the simulation
- Zoning analysis**
This step will determine the potential area selection to implement the microclimate simulation with Green area quantification based on the newly developed green factor
- Microclimate modelling**
The outputs of ENVI-met simulation will show the PMV/PPD, MRT, and potential air temperature from the existing condition and best greening scenario.
- Extrapolation of Cooling and Comfort**
In this stage, the result of simulation in representative areas will be extrapolated in the whole city to determine the general impact on temperature by green infrastructure application

5.4. Limitations

This study aims to develop a protocol for Jakarta Green area target setting using the green infrastructure quantification factor as an approach to mitigate urban overheating with

microclimate simulations. The limitation of the methodology relates to the method stages explained below:

The stages developed in this study are a concept to build a way of green infrastructure target calculation in a simplified model, not by the real existing urban and architectural condition.

1. Limitation on the newly developed green factor
The green factor is developed for the purpose of simulation model quantification. The details of green infrastructure are limited to general landscape element classification, and will not cover further details on materials or species.
2. Limitation on Local climate zone mapping
The WUDAPT protocol relies on satellite images ---Some areas with pixel unclarity of satellite image will cause inaccuracy of LCZ classification. A comprehensive accuracy check, visual and ground truth verification is needed in order to have an accurate Jakarta LCZ classification map.
3. Limitation on the ENVI-met simulations
The climatic data input for the simulation is obtained from a weather station and not primary data collected on site. The simplification of the model due to the limitation on time and on-field data also can determine the simulation result, but still accommodates the aim of this study, and still appropriate in terms of the result based on the use of existing base case model data and on the best scenario model.

Other limitations of the study are related to accuracy of existing conditions of model areas, limitation of time and limitation on access during the pandemic COVID-19. But overall methodology and analysis procedure will be done with appropriate procedure based on the aim of the study and general parameters.

6. RESULTS AND ANALYSIS

This chapter will present the results and discussion of the study. Following the constructed methodological framework, this chapter will be divided into four parts which cover elaboration on and discussion of the results: development of a new green factor, zoning analysis, microclimate simulation results, and extrapolation of cooling and climate comfort in Jakarta.

6.1. Development of a New Green Space Weighting Factor

The Weighting factor of this study is developed based on the portfolio of existing condition applied by eight cities in the world that have been discussed earlier in chapter 3. The green infrastructure quantification model was developed by codifying landscape elements in the general classification. Almost all cities consider the urban heat island mitigation as an aim of their index development, however it is not clear which aspect brings value with which landscape elements. Hence, an average number of all factor combined will be the proposed multiplier in this study.

Fifteen general categories were selected to structure the unify value of each landscape element with the consideration of equivalent elements calculation applied in every city. To reach an equal interval of indices, the apportion scale was set to 0 - 1, this applied to Helsinki's indices that originally accounted for 0-3.5 and the consideration on Malmö's original indices, that is rated from 0-20.

In Malmö's factor, higher values are assigned for trees which gives a higher score in comparison to the ratio of other cities' majority scales (between 0 to 1). It is widely recognized that trees as part of urban green infrastructure have a significant cooling effect on UHI (Lindén et al., 2015, Zhou et al., 2017, Wang et al., 2020, Richards et al., 2020), which is reflected in Malmö's green space factor. Therefore, apart from the proportion value of 0-1, a specific number of 10-20 is applied for trees in Malmö's factor. However, Malmö doesn't have multiplier for large preserved tree. For this purpose, the same value as for large trees will be assigned.

The 15 elements with the average measurement of the equal elements factor were categorized and apportioned to accommodate as many possibilities as possible for further modelling of green infrastructure development, looking into the difficulties of possibly applying green infrastructure in the Jakarta Metropolitan area.

Based on the consideration of value, Table 6.1 shows the new developed green infrastructure quantification factors.

Table 6.1. Developed Value for New Green Space Weighting Factor

	Landscape Elements	Berlin	Helsinki	NW England	Malmö	Southampton	London	Seattle	DC	Developed Value for New Green Space Weighting Factor
1	Sealed areas, (non-permeable surfacings without plant growth, including buildings without greenroof)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Partially sealed areas (semi permeable surfacing)	0.30	0.29	0.30	0.30	0.40		0.20	0.40	0.31
3	Semi-enclosed areas (permeable surfacing)	0.50	0.40	-	-	0.20	-	0.50	0.50	0.42
4	Vegetation surface not connected to surrounding soil with depth <70 cm	0.50	-	0.40	0.70	0.60	0.60	-	0.30	0.52
5	Vegetation surface not connected to surrounding soil with depth >70 cm	0.70	-	0.60	0.90	1.00	0.80	0.60	0.60	0.74
6	Vegetation surfaces connected to surrounding soil	1.00	-	1.00	1.00	-	1.00	-	-	1.00
7	Lawn, grass, other groundcover (plants less than 2 feet tall)	-	0.31			0.45	0.45	0.10	0.25	0.31
8	Shrubs	-	0.49			0.60	0.65	0.30	0.30	0.47
9	Tree - small	-	0.66		10.00			0.30	0.50	2.86
10	Tree - medium	-	0.00		15.00			0.60	0.60	4.05
11	Tree - large	-	0.80		20.00			0.90	0.70	5.60
12	Large tree - preserved	-	0.85		20.00			1.00	0.70	5.64
13	Façade vegetation (Green vertical areas on windowless external walls and walls)	0.50	0.26		0.70		0.60	0.40	0.80	0.54
14	Roof greening	0.70	0.47		0.60	0.65	0.60	0.60	0.70	0.62
15	Rainwater infiltration and stormwater features	0.20	0.47		0.20		0.20	0.20	0.20	0.25
16	Bonuses Elements	No	Yes	No	No	No	No	Yes	Yes	No

Table 6.1 describes that the main weighting factors are mostly defined by cities’ preferences. The highlight shows average of the elements. Some cities have several classes for particular landscape elements that are considered as one value for this development purpose. No bonus elements are considered based on major cities’ preferences on bonuses application.

There are two major factors that differentiate the calculation:

1. connection to surrounding soil as the highest value without counting in the factor of vegetation, and the depth of soil structure rather than the vegetation factor
2. Inclusive calculation of tree existence and other vegetation covers on top of the soil structure

Berlin and NW England are within the first category, followed by Southampton and London with the inclusion of ground cover vegetation such as grass and shrubs in their calculation. Helsinki, Seattle, DC and Malmö add the value of ground cover, shrubs, and trees in the calculation.

Considering the objectives of each city and the similarity of values, the average number of 8 cities' green factors are taken as a model base weighting factor for this study that will be applied in the representative sampling area for further microclimate simulation.

6.2. Zoning Analysis

6.2.1. Identification of Jakarta Local Climate Zone Mapping

The Jakarta Local Climate Zone map was developed following the World Urban Database and Access Portal Tools (WUDAPT) protocols on 17 LCZ class using 145 samplings of training areas distributed in the whole Jakarta metropolitan area. The result of Jakarta Metropolitan area are generated through LCZ semi-automated classification process with SAGA. With GIS tools, each LCZ area was calculated to define the majority climate zone classification in Jakarta. The mapping result and area calculation of all Jakarta's WUDAPT LCZ analysis were extrapolated with ArcGIS as shown in Figure 6.1 and Table 6.4Table 6.2.

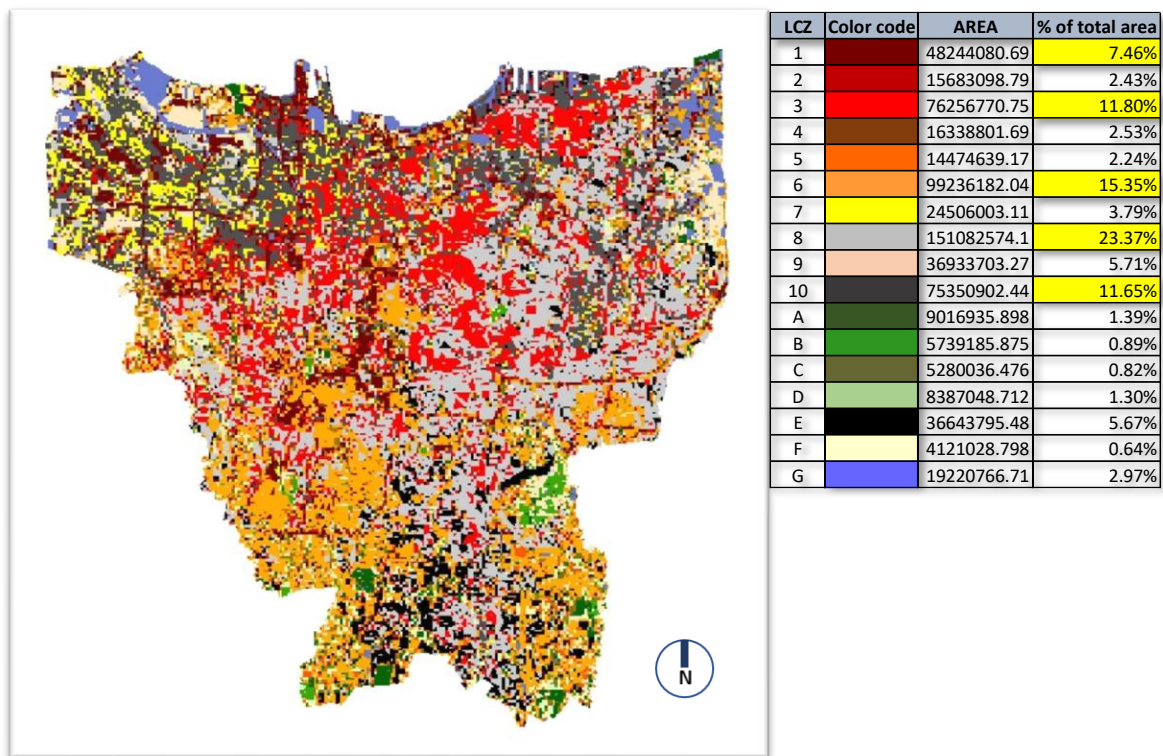


Figure 6.1. Local Climate Zone Map of Jakarta Metropolitan Area and Table 6.2. Total LCZ Area Distribution

Based on the LCZ mapping, the majority of climate zones in the Jakarta area are dominated by LCZ 8 (23.37%), LCZ 6 (15.35%), LCZ 3 (11.80%), LCZ 10 (11.65%), and LCZ 1 (7.46%), which accounted for 69.63% of the total area of Jakarta.

LCZ verification checks are performed with two assessments; 1) visual mapping using Google satellite imagery 2018, street view, LIDAR, and drone video capture from Jakarta City Planning Department. The accuracy verification was done as replacement for ground-truth verification

which can not be done at the time of the study, to have an appropriate stage on map development. 2) data comparison with city planning report.

LCZ verification data were used for accuracy analysis in ArcMap 10.7.1, by categorizing the five largest areas in a five-grid-code that represents the chosen LCZ. Based on visual mapping verification, the accuracy of sampling results for the developed LCZ map is 36%, with 25 points check out of 14,189 total sampling. Taking into account that the purpose of this step is to select a representative sample, the accuracy check of LCZ class will not be the main purpose of this study. According to data of existing land use compatibility between planning and existing condition from Jakarta City Planning Department, the majority of Jakarta’s area is dominated by residential, commercial and industrial area, which refer to LCZ 1, LCZ 2, LCZ 3, LCZ 6, LCZ 8, LCZ 9, and LCZ 10. To further analyze the role of green infrastructure in the whole majority area, within each major LCZ, a representative sample will be taken as a model for the simulation.

6.2.2. Representative Sample Selection

Following the result map and area calculation of WUDAPT LCZ analysis of Jakarta, five LCZ classes representing the majority area of Jakarta that cover almost 70% of the majority climatic area of Jakarta were selected.

There are four basic approaches currently being adopted in selecting the representative sample of model areas based on their LCZ classification:

1. An area of 400 meters X 400 meters, for ENVI-met simulation optimization
2. The sampling located in the same class of LCZ
3. Considering development plan, urban design guidelines, conservation area, and some conflict occurs in the area due to the land use and land cover planning. Another consideration to select the areas are ownership, demography context and other supporting regulations
4. The possibility of green infrastructure application

Following these stages, five locations are chosen to be representative of LCZ sampling to perform microclimate simulations.

6.2.2.1. LCZ 8, Prepedan Industrial Area

LCZ 8 represents 23.37% of the total area of Jakarta metropolitan area. Table 6.3 describes the area representatives of LCZ 8. Figure 6.2 shows the district location and the selection area for model simulation by 400 m x 400 m.

Table 6.3. LCZ 8 Area description

Location	Tegal Alur sub district, Kalideres, West of Jakarta
Sub district Area	4.97 km ² (16.44% of total district area) based on Governor Decree of DKI Jakarta Number 171 in 2007.
Population	101.137; Population density: 20.36 people/km ² (BPS, 2019)
Area highlight	taken as an example of the expansion of industrial zone to tenement housing to support industry workers. The growth of residential areas then also followed by the newly grow home-industry, which made this area considered unorganized and some zoning problem according to Jakarta Territorial Regulation on City Planning Detail

General Form	Build	The build form of this area consist of 1-2 stories tall industrial building which extend outward and not upward, variant construction materials, few trees, mostly paved or hard-packed. Moderate cooling demand and moderate traffic flow.
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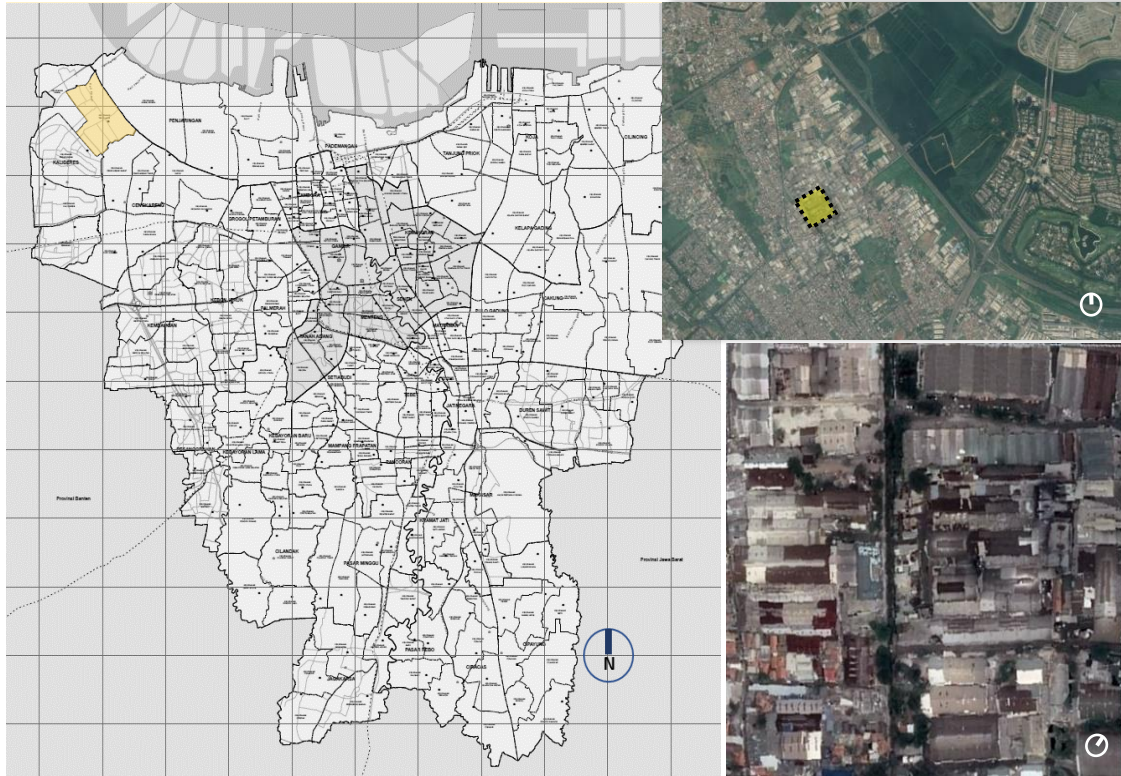


Figure 6.2. LCZ 8, Prepedan Industrial Area

6.2.2.2. LCZ 6, Menteng Residential Area

LCZ 6 represents 15.35% of the Jakarta metropolitan area. Table 6.4 describes the area representatives of LCZ 6. Figure 6.3 shows the district location and the selection area for model simulation.

Table 6.4. LCZ 6 Area description

Location	Menteng District, Centre of Jakarta
Sub district Area	2.44 km ² (37.37% of total district area) based on Governor Decree of DKI Jakarta Number 171 in 2007.
Population	29,347; Population density: 12.03 people/km ² (BPS, 2019)
Area highlight	Based on Jakarta Territorial Regulation No. 9 of 1999 about Restoration of the environment and cultural heritage buildings in Jakarta Province, this area is considered as one out of three Conservation Areas in Jakarta (Governor Decree of DKI Jakarta Number D.IV6098/d/33/1975).
General Form	Build Residential area. Constructed of 1-2 stories tall detached residential building, variant construction materials, dense trees and abundant plant cover, low space cooling demand, low traffic flow.



Figure 6.3. LCZ 6, Menteng Residential Area

6.2.2.3. LCZ 3, Kalityar Residential Area

LCZ 3 represents 11.80% of the total Jakarta metropolitan area. Table 6.5 describes the area representatives of LCZ 3. Figure 6.4 shows the district location and the selection area for model simulation.

Table 6.5. LCZ 3 Area description

Location	Tambora District, West of Jakarta
Sub district Area	0.32 km ² (5.9% of total district area)
Population	29.728 people/km ² ; Population density 92.9 people/km ² (BPS, 2019)
Area highlight	Its densely populated area makes this subdistrict one of the most populated subdistricts in South East Asia.
General Build Form	Residential area. Attached or closely spaced 2-3 storey tall residential buildings, narrow streets, heavy construction material, mostly paved or hard-packed which occupy more than 70% building surface factor and less than 30% pervious surface fraction, few trees, moderate cooling demand, and moderate traffic flow



Figure 6.4. LCZ 3, Kalianyar Residential Area

6.2.2.4. LCZ 10, Pertamina Depot Plumpang

LCZ 10 represents 11.65% of the total of Jakarta's metropolitan area. Table 6.6 describes the area representatives of LCZ 10. Figure 6.5 shows the district location and the selected area for model simulation.

Table 6.6. LCZ 10 Area description

Location	Rawabadak Selatan Sub District, Koja District, North of Jakarta
Sub district Area	1.0162 km ² (7.70% of total district area)
Population	49.817; population density of 49.022 people/km ² (BPS, 2019).
Area highlight	part of state-owned oil and natural gas mining company based in Jakarta
General Build Form	construct of mid-rise industrial structure, openly spaced on hard-packed surface, with construction material dominated by steel, concrete and metal, few trees and low traffic flow

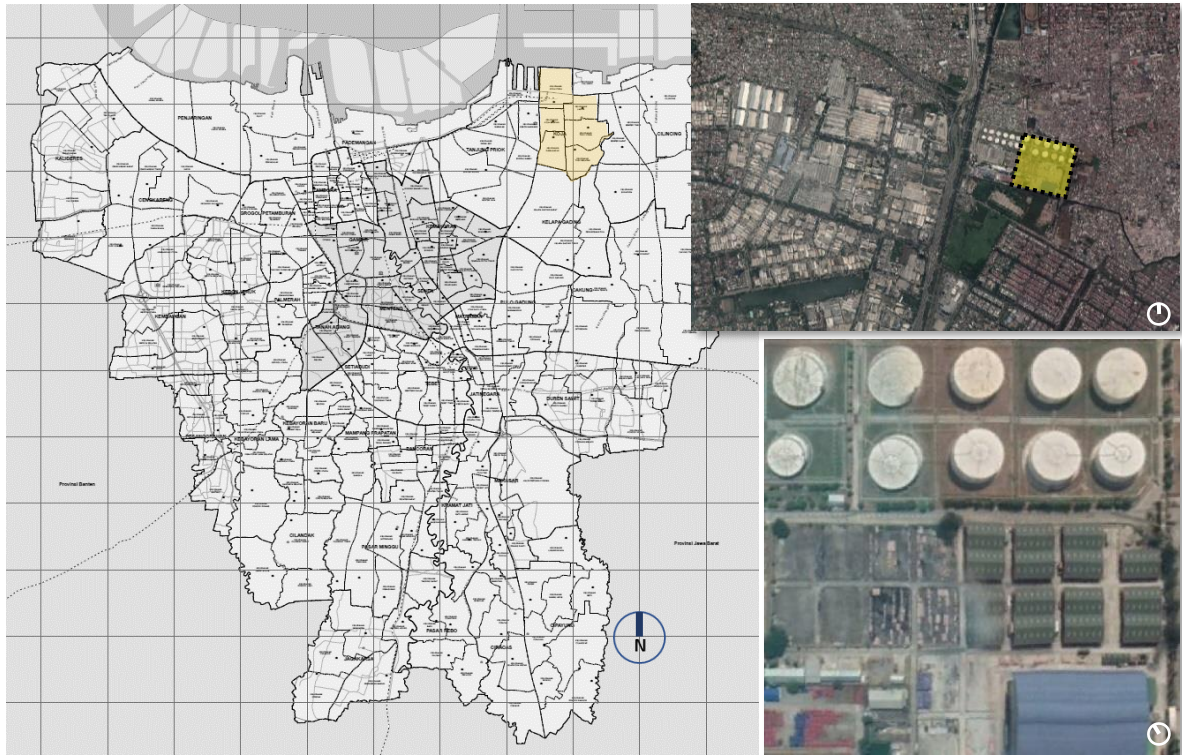


Figure 6.5. LCZ 10, Pertamina Depot Plumpang

6.2.2.5. LCZ 1, Sudirman Central Business District

LCZ 1 represents 7.46 % of the total area of Jakarta’s metropolitan area. Table 6.7 describes the area representatives of LCZ 1. Figure 6.6 shows the district location and the selection area for model simulation by 400 m x 400 m.

Table 6.7.. LCZ 1 Area description

Location	Senayan Sub District, Kebayoran Baru District, South of Jakarta
Sub district Area	1.53 km ² (11.84% of total district area)
Population	5969; population density: 12.03 people/km ² (BPS, 2019).
Area highlight	One of the major Central Business Districts in Jakarta
General Build Form	Dense mix of tall buildings with more than ten storeys. Building free-standing, closely spaced. Significantly reduced sky view from street level. Material of the building is dominated by steel, concrete and glass surface construction. Mostly paved, few trees, high cooling demand and heavy traffic flow.

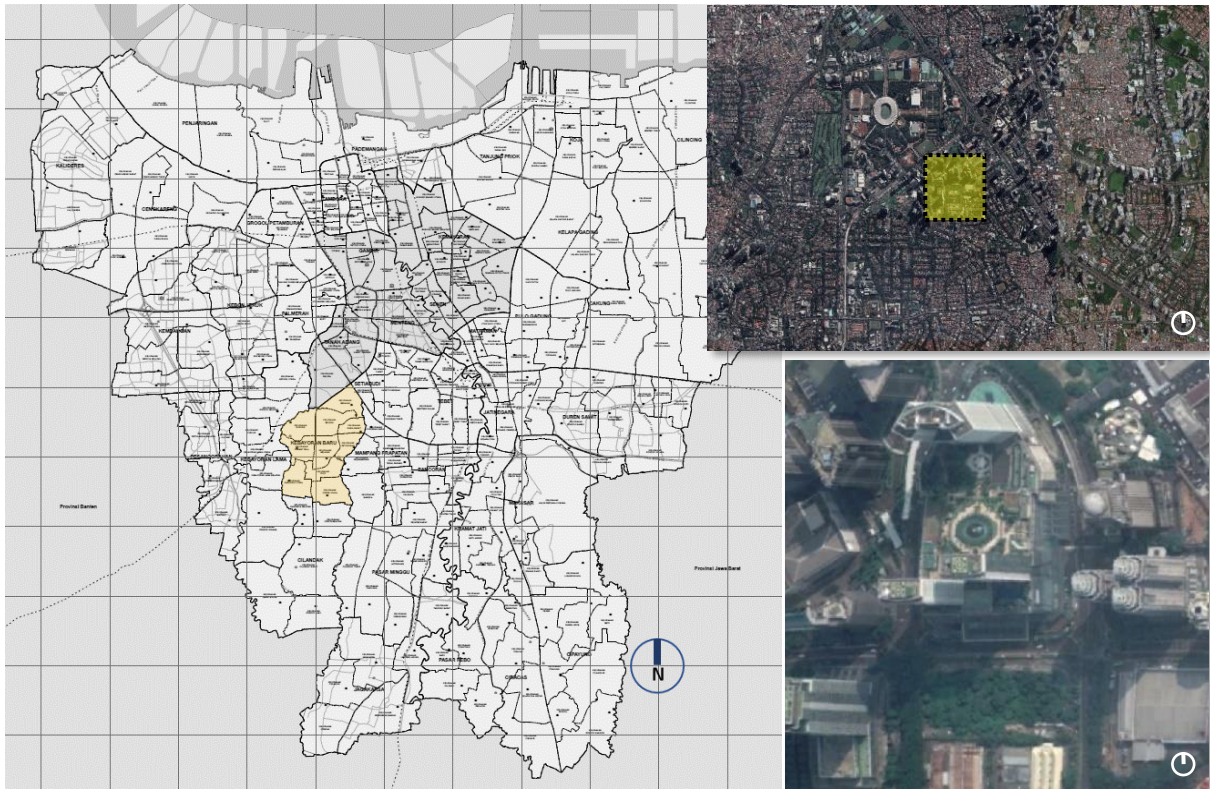


Figure 6.6. LCZ 1, Sudirman Central Business District

6.3. ENVI-met simulation for Green Infrastructure effect in Jakarta Metropolitan Area

The ENVI-met simulation will be performed in five representative area by comparing two scenarios, the base case scenario and the best greening scenario. The base scenario simulation will be performed in the existing condition of the site, while the best scenario intends to put a maximum greenery on top of the base case scenario, without paying attention on practicality of the landscape elements' implementations. Table 6.8 indicates the ENVI-met simulation parameter input for all models in both scenarios. Both scenarios will be quantified using the new developed green space weighting factor (see Table 6.1). Table 6.9 shows the comparison of green infrastructure score of both scenarios, with the base case as the existing condition of green space, and the best case as the additional green that was added to the base case layer. The models are developed using ENVI-met 'Space' using the default material and modified in AutoCAD for graphic enhancement and area calculation. The result of the simulation will be classified in MRT and PMV/PPD to see the variable distribution of cooling and comfort in the model area.

Table 6.8. ENVI-met simulation input parameters

Main parameter	Domain size	400m x 400m
	Grid size	dx = 5; dy= 5; dz=3; (for LCZ 1, dx=5; dy=5; dz=15)
	Start date	15/06/2020
	Start time	18:00
	Total simulation time	30 hours
	simple/full forcing	simple forcing
	Nesting grid	no nesting grid for LCZ 8, LCZ 6 and LCZ 3; (8 for LCZ 10 and 1)
Wind uvw	Wind speed measured in 10 m height (m/s)	6
	Wind direction (degree)	230
	Roughness length at measurement site	0.01
Temperature T (°C) and humidity q (%)	T min	26
	T max	32
	q min	71
	q max	93
Soil data	Initial Temperature upper layer (0-20 cm) (°C)	29
	Initial Temperature middle layer (20-50 cm) (°C)	28
	Initial Temperature deep layer (50-200 cm) (°C)	27
	Initial Temperature bedrock layer (below 200 cm) (°C)	26
	Soil humidity upper layer (0-20 cm) (%)	86
	Soil humidity middle layer (20-50 cm) (%)	78
	Soil humidity deep layer (50-200 cm) (%)	70
Soil humidity bedrock layer (below 200 cm) (%)	65	

Table 6.9. comparison of green infrastructure score of base and additional green for best case scenario

Landscape Elements	Factor	LCZ 8				LCZ 6				LCZ 3				LCZ 10				LCZ 1			
		Base case		Best Scenario		Base Case		Best Scenario		Base Case		Best Scenario		Base Case		Best Scenario		Base Case		Best Scenario	
Sealed areas, (non-permeable surfacings without plant growth, including buildings without greenroof)	0.00		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Road	0.00	7362.30	0.00	7362.30	0.00	22367.83	0.00	22367.83	0.00	8348.10	0.00	8348.10	0.00	55458.08	0.00	55458.08	0.00	68693.72	0.00	68693.72	0.00
Buildings	0.00	105876.57	0.00	105876.57	0.00	103146.16	0.00	103146.16	0.00	145852.07	0.00	145852.07	0.00	44077.61	0.00	44077.61	0.00	52175.02	0.00	52175.02	0.00
Partially sealed areas (semi permeable surfacing)	0.31	23380.56	7300.46	23380.56	7300.46		0.00		0.00		0.00	8348.10	2606.65	60464.31	18879.67	60464.31	18879.67		0.00		0.00
Semi-enclosed areas (permeable surfacing)	0.42	23380.56	9819.84	23380.56	9819.84		0.00		0.00		0.00		0.00		0.00	29356.60	12329.77		0.00		0.00
Vegetation surface not connected to surrounding soil with depth <70 cm	0.52		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Vegetation surface not connected to surrounding soil with depth >70 cm	0.74		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Vegetation surfaces connected to surrounding soil	1.00		0.00			34486.01	34486.01	34486.01	34486.01	5799.83	5799.83	5799.83	5799.83		0.00		0.00	39131.26	39131.26	39131.26	39131.26
Lawn, grass, other groundcover (plants less than 2 feet tall)	0.31		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Shrubs	0.47		0.00				0.00	4757.61	2222.48	740.00	345.69	740.00	345.69	984.70	459.99	984.70	459.99		0.00		0.00
Tree - small	2.86	16.00	45.83	116.00	332.26	123.00	352.31	123.00	352.31	31.00	88.79	31.00	88.79	18.00	51.56	81.00	232.01	34.00	97.39	77.00	220.55
Tree - medium	4.05	9.00	36.45	29.00	117.45	92.00	372.60	107.00	433.35		0.00	83.00	336.15	4.00	16.20	58.00	234.90	13.00	52.65	62.00	251.10
Tree - large	5.60		0.00	3.00	16.80		0.00		0.00		0.00	13.00	72.80		0.00	23.00	128.80		0.00	24.00	134.40
Large tree - preserved	5.64		0.00			10.00	56.37	10.00	56.37		0.00		0.00		0.00		0.00				0.00
Facade vegetation (Green vertical areas on windowless external walls and walls)	0.54		0.00			0.00	0.00	8276.45	4492.93		0.00		0.00		0.00		0.00			280227.49	152123.49
Roof greening	0.62		0.00	105876.57	65276.15	0.00	0.00	9678.73	5967.23		0.00	116681.65	71937.81		0.00	25388.28	15652.65			56366.00	34751.36
Rainwater infiltration and stormwater features	0.25		0.00				0.00		0.00		0.00		0.00		0.00		0.00				0.00
TOTAL AREA 160000		17202.58		82862.95		35267.29		48010.69		6234.31		81187.72		19407.42		47917.80		39281.30		226612.17	
		10.75%		51.79%		22.04%		30.01%		3.90%		50.74%		12.13%		29.95%		24.55%		141.63%	

6.3.1. Scenarios comparison on LCZ 8

Figure 6.7 shows a comparison based on LCZ 8 for base scenario and best scenario. The total time needed for this base case simulation is 64h 29min 42s and the total time needed for the best scenario is 63h 59min 51s.

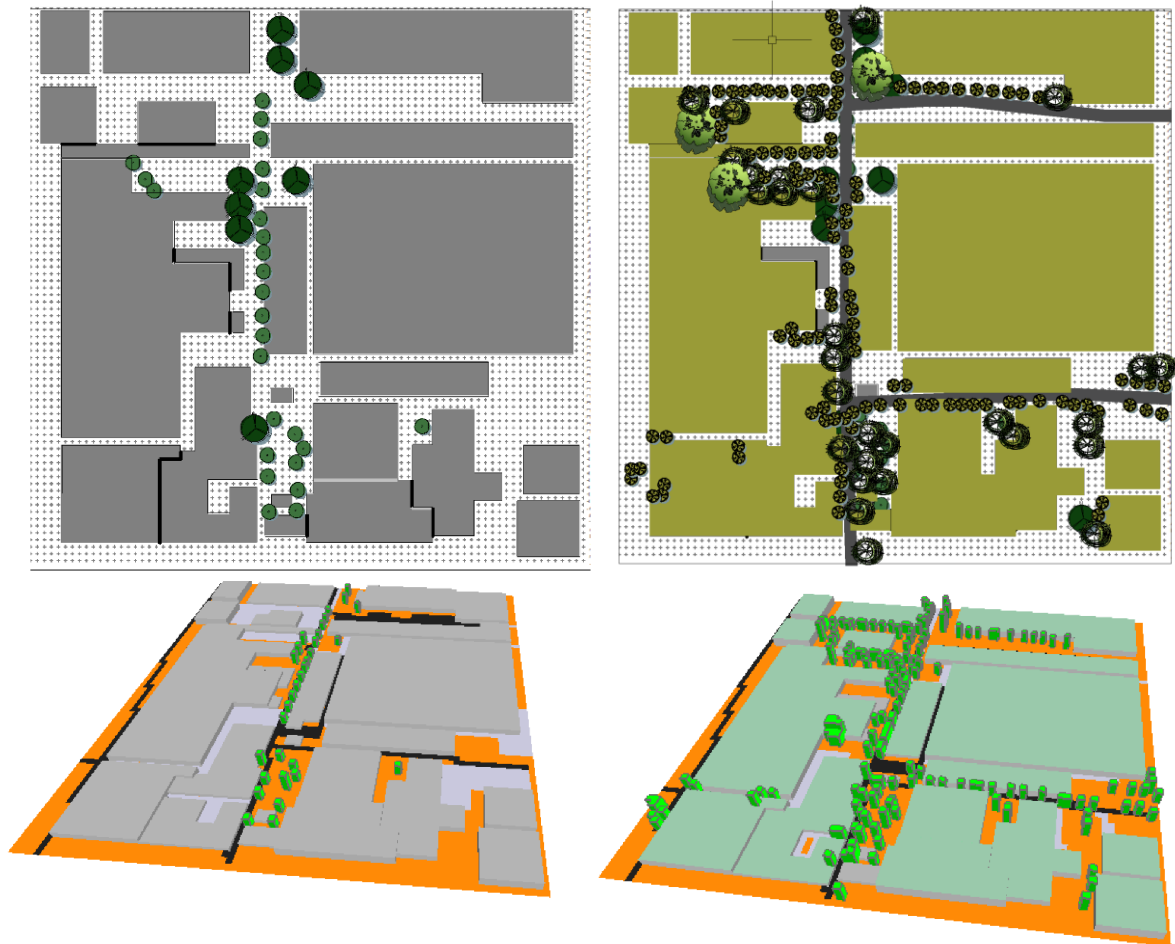


Figure 6.7. Base case (left) and best scenario (right) model

The best greening scenario in this model consists of tree planted in various sizes in the open spaces between trees along the transport corridor and on available open private areas, Another attempt is made by green roof application on top of all the buildings in the model area. The receptor coordinate located in grid $i=32, j=35$.

The PMV map Figure 6.8 shows the distribution of expected thermal comfort vote of occupants with the body parameter default by ENVI-met (Age 35, male, weight 75 kg and height 175cm). Normally, the PMV scale is defined between -4 (very cold) to +4 (very hot). However, the condition of the base case shows that the majority area in model simulation are within the range over 4.07 and up, with the maximum of 4.92. There are areas where slight differences have been found around the implementation on green infrastructure. The best scenarios show the majority area occupied by the distribution of PMV over 4.05 and up with a maximum of 4.72 scattered in the entire area, although there is no significant decrease on PMV value, some parts with PMV between 2.70 to 3.03 increased where the green infrastructure is allocated. The PMV and PPD value have

a linear relationship, this PMV value associated PPD value (Predicted Percentage of Dissatisfied) which shows in Figure 6.9.

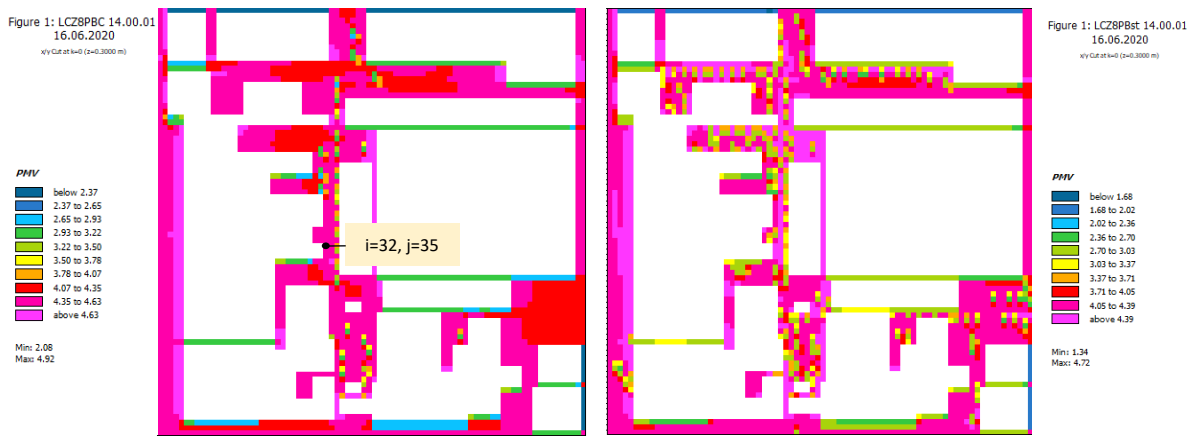


Figure 6.8. PMV comparison base case and best case

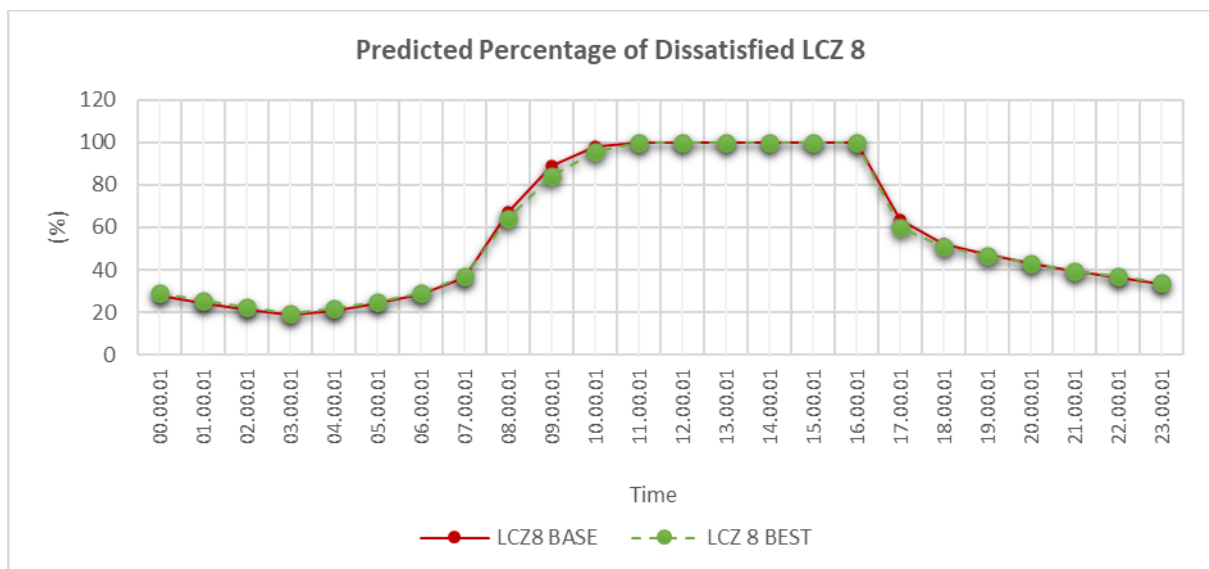


Figure 6.9. LCZ8 PPD base case vs. best case comparison

The simulation results show that between 11:00 and 16:00 PPD score, both base case and best scenario are reaching 99%, which describes almost everybody is dissatisfied with the climate conditions in the area within this selected time range.

Figure 6.10 shows the impact of the best scenario application of greening on MRT. The best case got a maximum reduction of temperature that occurred at 16:00. Overall, MRT shows the estimation of increase during midday starting at 08:00 and drops in 17:00. Figure 6.11 shows the range of MRT distribution from both scenarios.

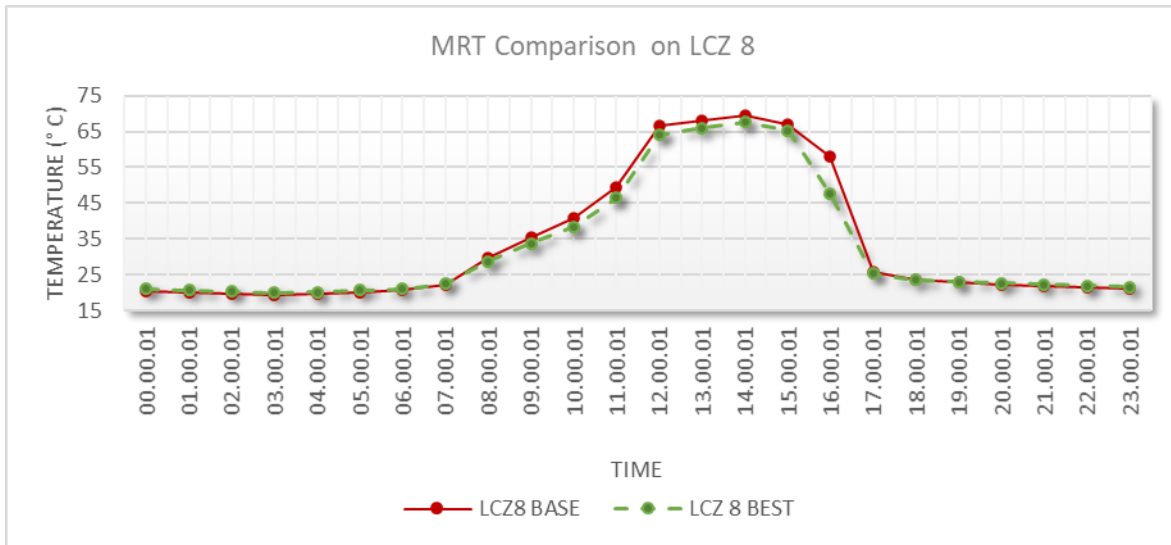


Figure 6.10. Base case and best scenario MRT comparison

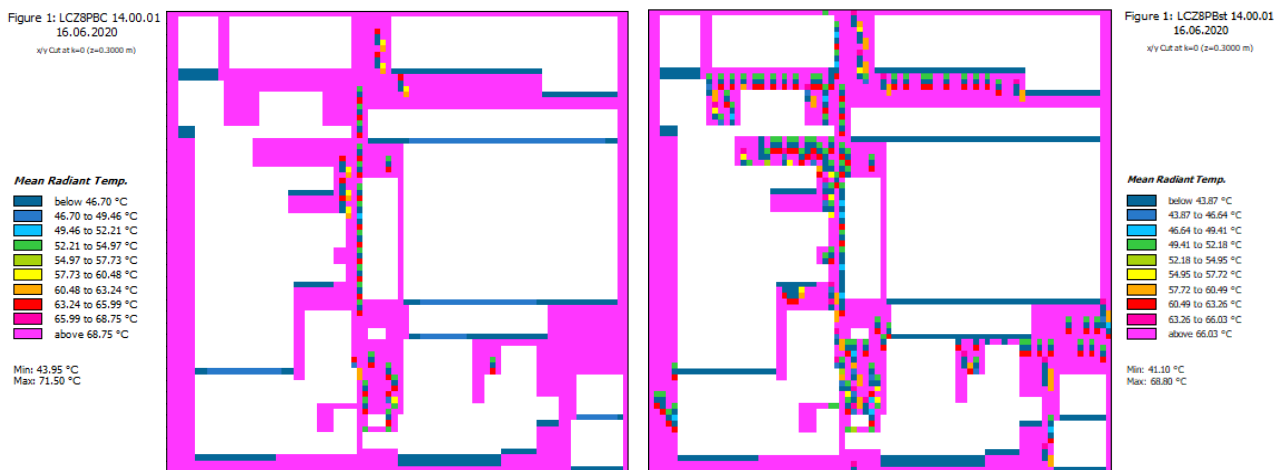


Figure 6.11. Base case and best scenario MRT comparison

The simulation reveals that the peak MRT in the receptor happens at 14:00, and there are some general pattern points of declining temperature in the area with the additional tree plantings. With the additional green area up to 41.09%, the MRT of majority area of the simulation decrease from max. 71.50°C to 68.80°C. The minimum MRT also decrease from 43.95°C to 41.10°C. The results shows that application of green infrastructure causes a significant impact on the area. However, the greening approach reached 40% which is higher than initial target set.

6.3.2. Scenarios comparison on LCZ 6

Figure 6.12 shows a comparison of build up model on LCZ6 for the base and the best scenarios. The total time needed for the base case simulation was over 35 hours and for the best scenario was over 25 hours. LCZ6 base case has a high percentage of green area consisting of some small to medium-sized trees, and the vegetation connected to the surrounding soil from every house, which brought the green area calculation to 22.04%. There, the greening approach was

accomplished by adding shrubs along the road, adding 15 medium-sized trees and adding wall and roof greening for the public buildings.

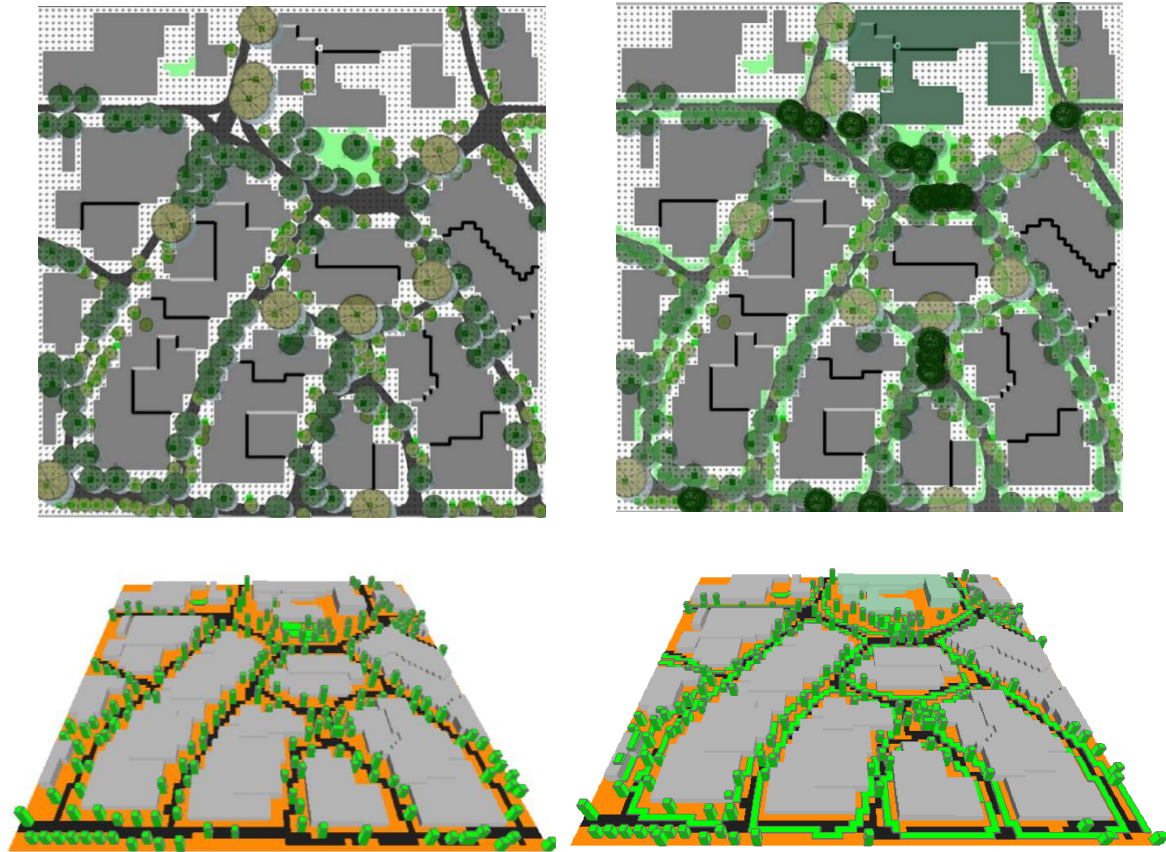


Figure 6.12. LCZ 6 Base case (left) and best scenario (right) model

The coordinate point of this simulation is located in grid $i=51, j=48$. The 24-hour plot on the base case scenario indicates that the highest temperature in the simulation area appeared at 14.00 WIB. Below are explained the variable thermal comfort output of the simulation.

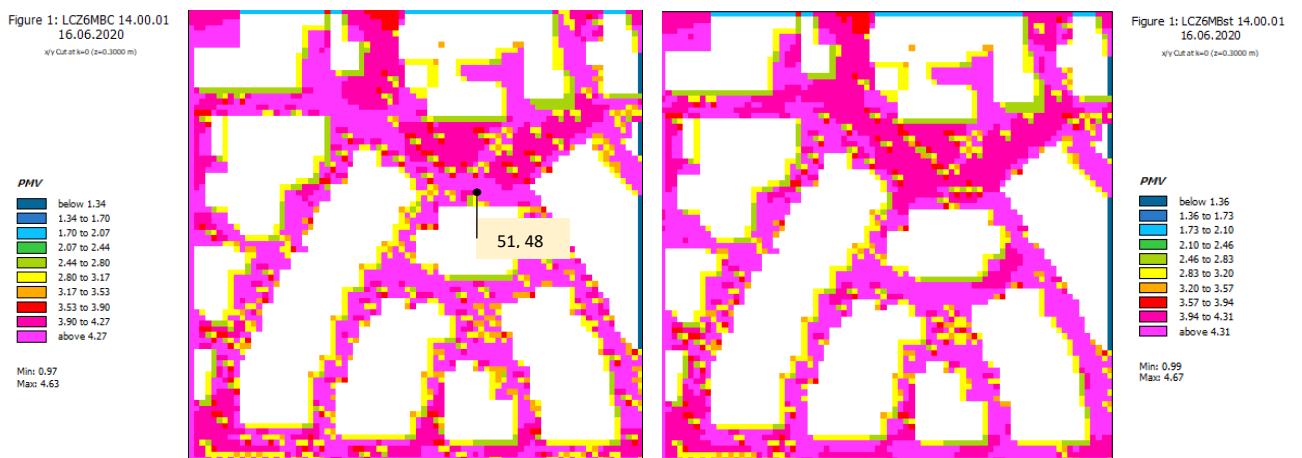


Figure 6.13. LCZ 6 PMV comparison Base case and best scenario

The application of green infrastructure shows a distributed range of PMV, with a slight increase (minimum 0.97 for the base case to a minimum 0.99 for the best case scenarios, and a maximum of 4.63 for the base case to a maximum of 4.67 for the best case scenario). The PPD graph indicates a long period of discomfort time range (from 09.00 to 16.00 hrs) in the base case scenario. However, the best scenario indicates that there is an increase of comfort at 09:00, which leads to shorter period of 100% PPD compared to the base case.

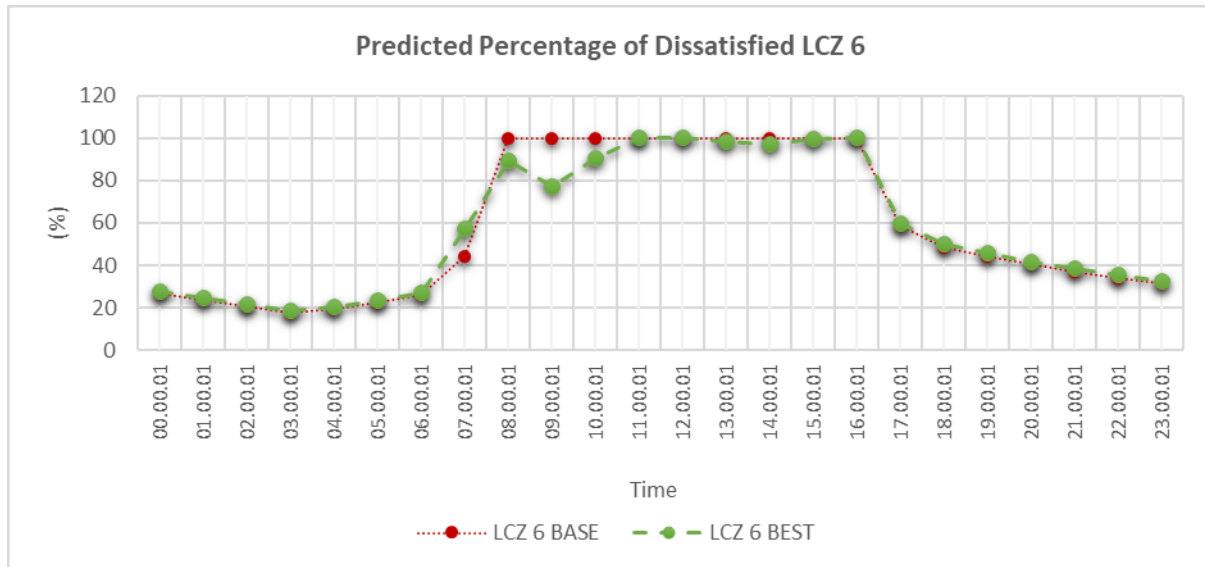


Figure 6.14. LCZ 6 PPD base case vs. best case comparison

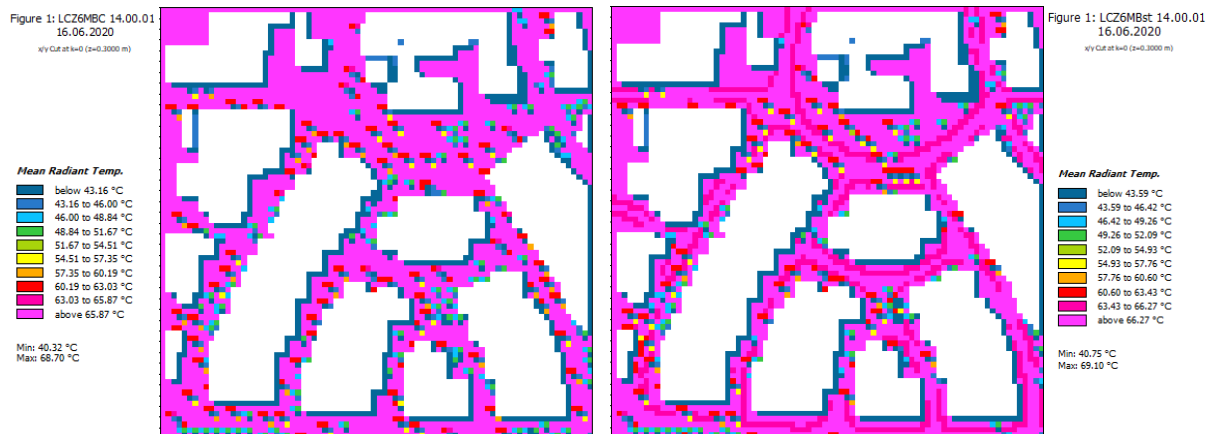


Figure 6.15. Base case and best scenario MRT comparison

The result obtained from Figure 6.15 shows how the small percentage of additional greenery didn't contribute a significant impact to the MRT reduction, instead this figure shows the opposite. With the additional 7.96% of green area, the MRT in the majority area of the simulation increases from max. 68.70°C to 69.10°C and the minimum MRT also increase from 40.32°C to 40.75°C. The receptor was located in an area where medium-sized trees were added in the middle of the road. Figure 6.14 shows the impact of trees on MRT in this coordinate, where MRT has dropped twice within 24 hours and made the cooling time longer (Figure 6.15).

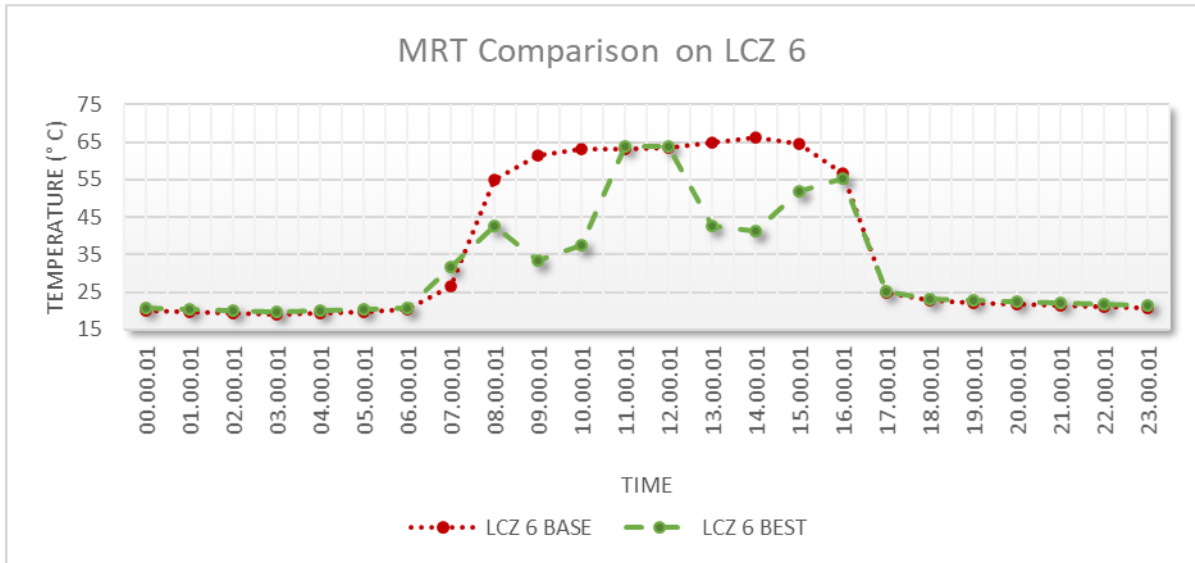


Figure 6.16. Base case and best scenario MRT comparison

6.3.3. Scenarios comparison on LCZ 3

This model area has a green area ratio of 3.9% due to the occupancy of land for housing, with almost no possibility of additional greening on land. The best scenario approach is to add green roofs to every building, and add medium-sized trees along the main roads with no consideration of transport lines for cars. Big trees were put on every junction and as many as possible in the field in the middle of the site. The other experiment on this scenario was to change the asphalt roads to loamy soil. The best scenario added 45.22% of greening on the base case to reach 49.12%. The total time needed for the base case simulation was more than 63 hours, and over 29 hours for the best scenario simulation.

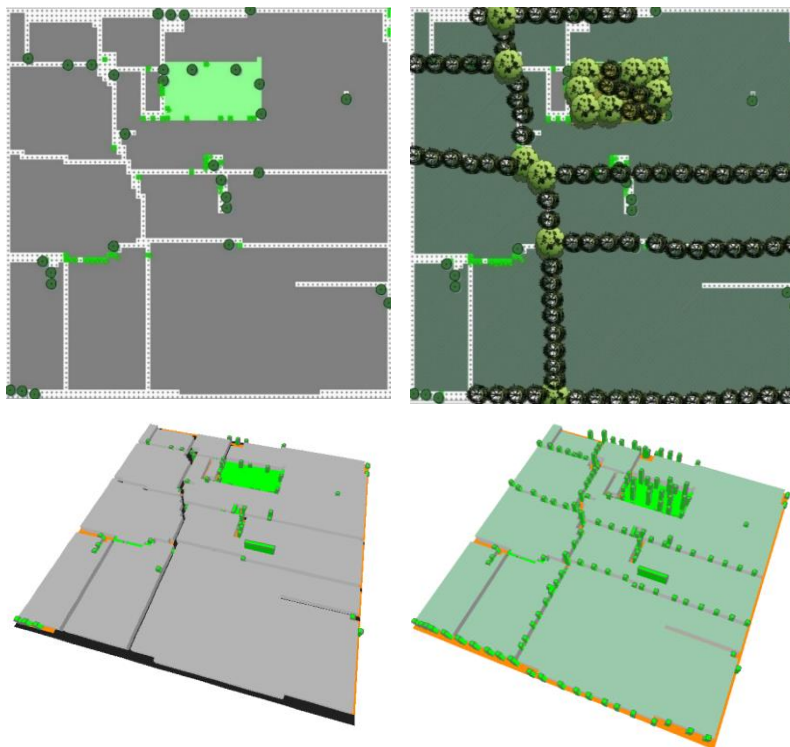


Figure 6.17. Base case (left) and best scenario (right) model

The receptor is located in grid i=44, j=46. The highest temperature in the simulation area appeared at 14:00. Below is explained the variable thermal comfort output of the simulation.

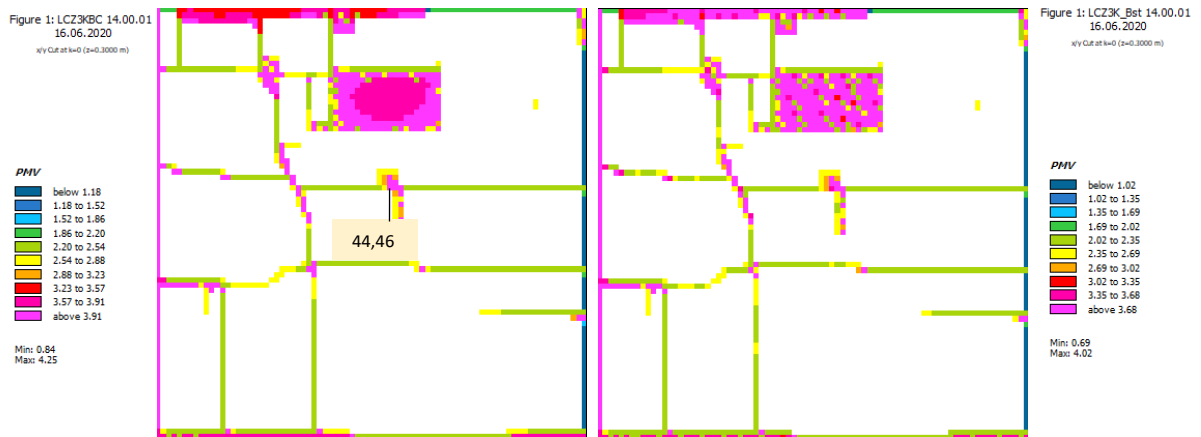


Figure 6.18. LCZ 3 PMV comparison Base case and best scenario

The condition of the base case shows that there is a not so wide outdoor area, and the area between buildings has a PMV level of 2.2 to 2.54, compared to the field and other narrow open spaces with the range around 3.91. The PPD value is shown in Figure 6.19.

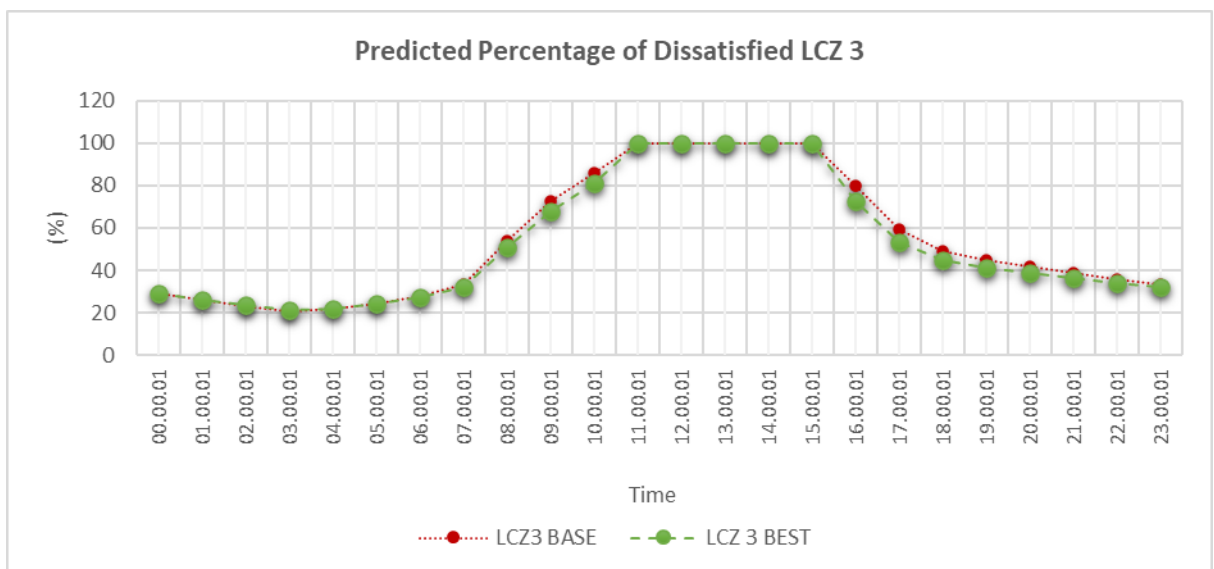


Figure 6.19. LCZ3 PPD comparison base case vs. best scenario

The graph shows an overall slight reduction of PPD percentage during the transition time to the highest temperature time range (11:00-15:00). However, during 11:00-15:00, the PPD percentage still reached >99% which indicates a discomfort of the whole area climate conditions.



Figure 6.20. LCZ3 Base case and best scenario MRT comparison

Figure 6.20 shows the MRT data from both scenarios, with the additional green area up to 45.22%, the MRT of the majority area of the simulation decreases from max. 64.19°C to 61.86°C. The minimum MRT also decrease from 35.71°C to 32.86°C. The reduction of MRT can be seen in the whole area. However, the base case MRT indicates that the road area between the buildings has a contrast cool temperature compared to the open area, due to the impact of shades from the building geometry, even with no adequate greening scale.

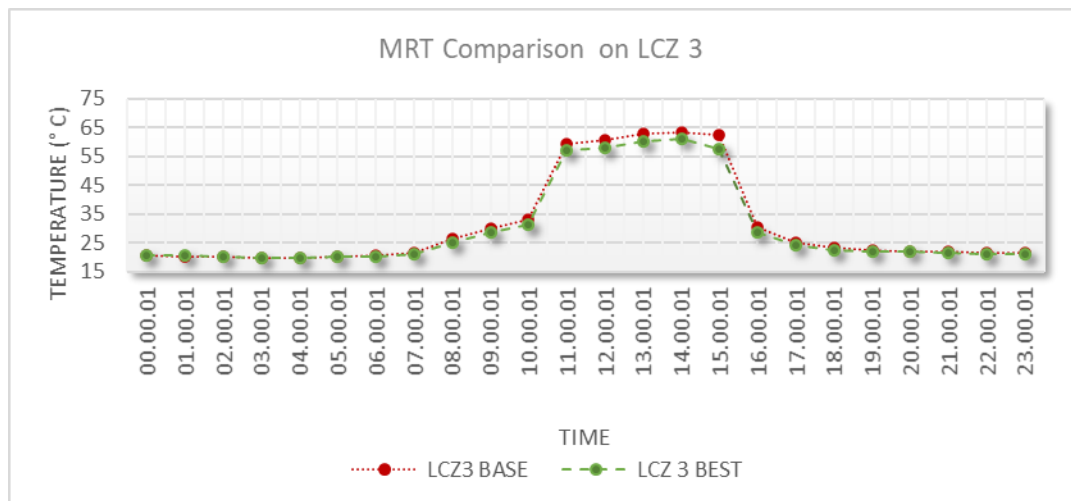


Figure 6.21. Base case and best scenario MRT comparison

The LCZ 3 simulation shows that greening contributes an impact on MRT reduction, however, findings on the base case thermal comfort condition show that there is already a lower discomfort level compared to the two simulations before. This could be a result from the impact of shading provided by the building geometry in the area. Cooling from shading of the buildings potentially seems to be effective in high density areas especially during the daytime.

6.3.4. Scenarios comparison on LCZ 10

This model has around 27% of built area and it is dominated by open areas for storage/parking space for tank trucks. The greening approach was taken by converting rooftops to green rooftops in office buildings and truck ports, planting trees and grass in the open areas and around the office building, and changing some parts of the semi permeable surfaces to permeable areas (parking area to park conversion). The best scenario experiment brings the green area calculation up to

31.12% from 12.13%. The total simulation time for base case was 44 hours and more than 48 hours for the best scenario.

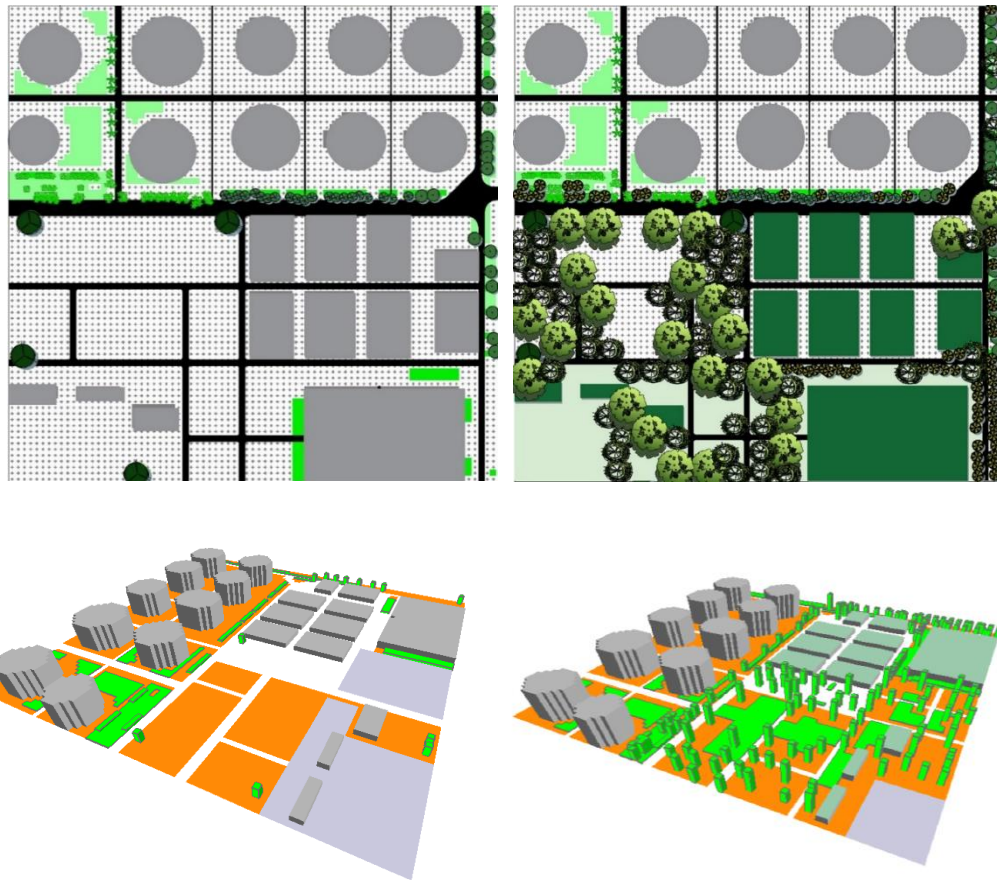


Figure 6.22. LCZ 10 base case (left) and best scenario (right) model

The application of greenery shows a distributed range of PMV, with a slight reduction (minimum 2.9 for the base case to minimum 2.79 for the best case, and a maximum of 4.9 for the base case to maximum of 4.87 for the best case (Figure 6.23). The PPD comparison value is shown in figure 6.24.

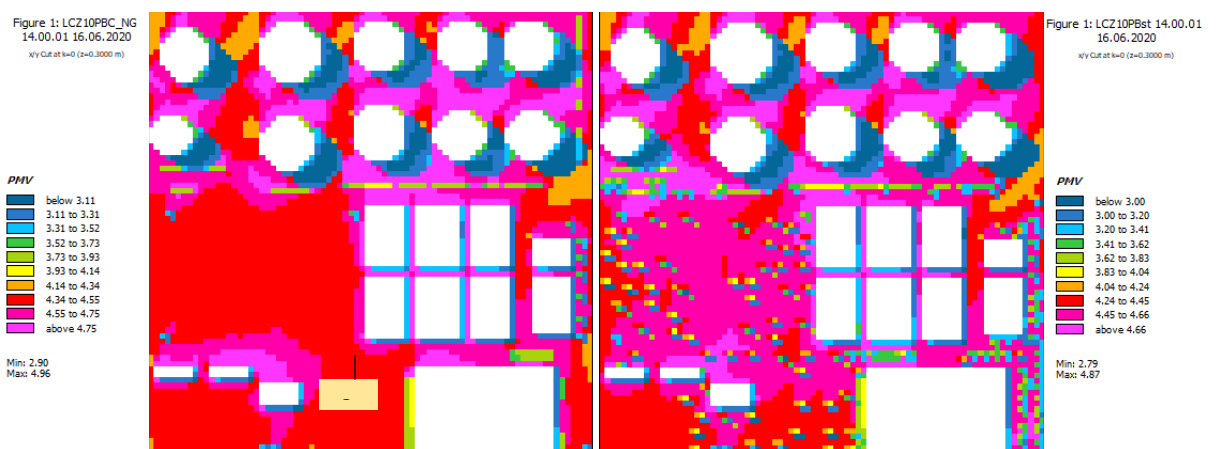


Figure 6.23. LCZ 10 PMV comparison Base case and best scenario

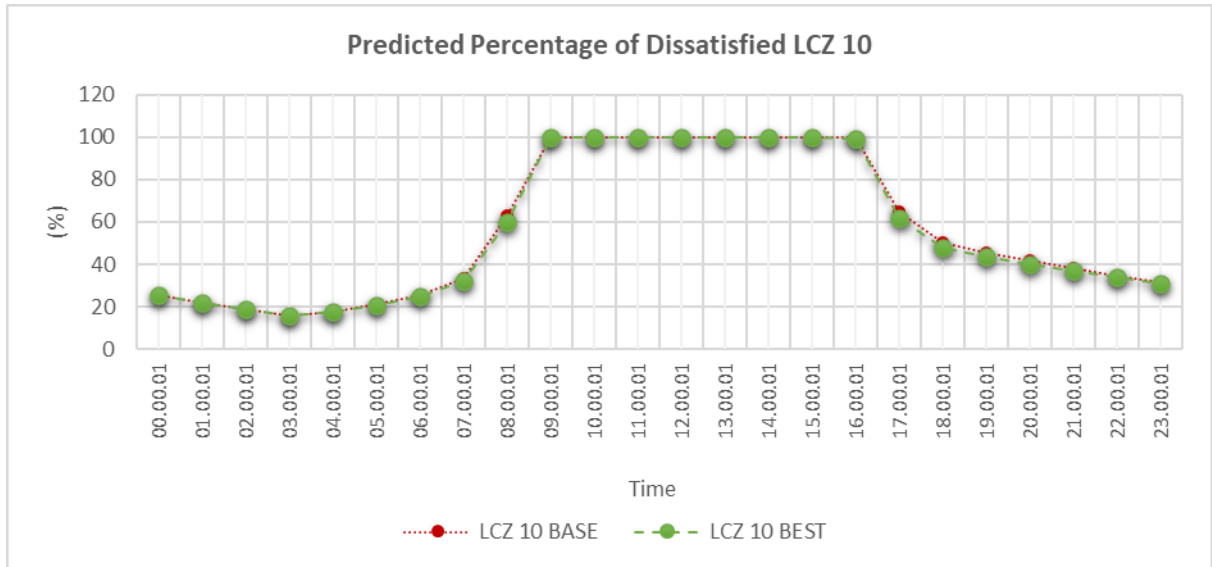


Figure 6.24. LCZ10 PPD comparison base case vs. best scenario

Figure 6.25 shows the MRT data from both scenarios. The reduction of MRT can be seen in the whole area. The area where there are no greening interventions still became the area with the highest MRT. The placing of trees in the field area contributed patches of lower MRT surrounded by high MRT. Overall, with the additional 18.99% of green area, the MRT of the majority area of the simulation decreased from max. 75.16°C to 73.86°C. The minimum MRT also decreased from 46.87°C to 45.18°C.

Figure 6.26 shows a comparison of MRT between base case and best scenario. It indicates a longer exposure to high temperature, supporting the finding on PPD. By this finding, there is an indication that everybody feels discomfort for long periods during the day time, and appearance of greening does not necessarily contributes to comfort improvement. Tree plantings don't show a significant impact on the whole area. However it creates comfortable cooling patches around the existing trees. Overall MRT reduction can be seen slightly in accordance to the adding of greenery.

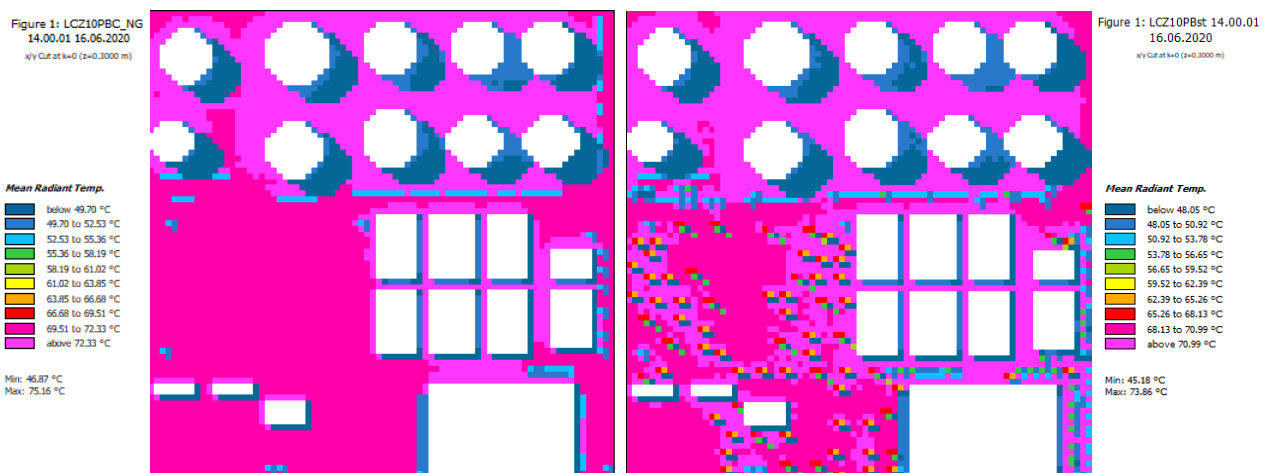


Figure 6.25. LCZ10 Base case and best scenario MRT comparison

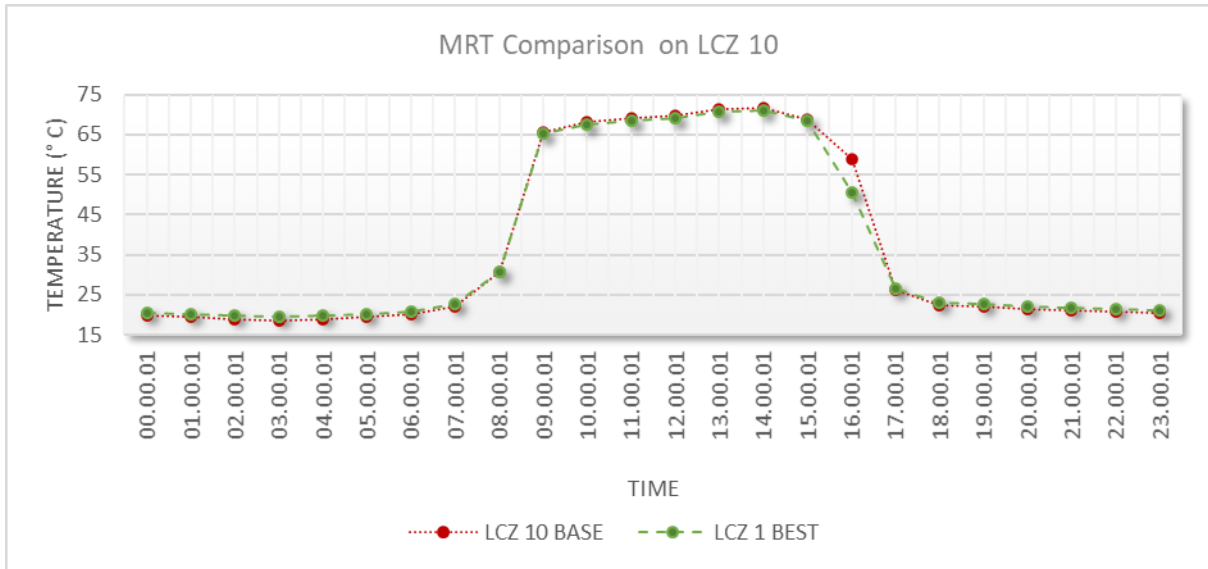


Figure 6.26. Base case and best scenario MRT comparison

6.3.5. Scenarios comparison on LCZ 1

The approach on increasing an absolute maximum target of green area ratio in LCZ1 was done by constructing green walls and green rooftops on all the buildings in the whole area of the simulation. Additionally, varying number of trees were added. Due to the moderate factor of green walls and green rooftops and the height of the buildings, the greening intervention created an increase of 117.08% additional green area which made the total green area calculation rise to 141.63%. The total time needed for the base case simulation was 37 hours, and more than 78 hours for best scenario simulation. Simulation model of base case and best scenario can be seen in Figure 6.27.

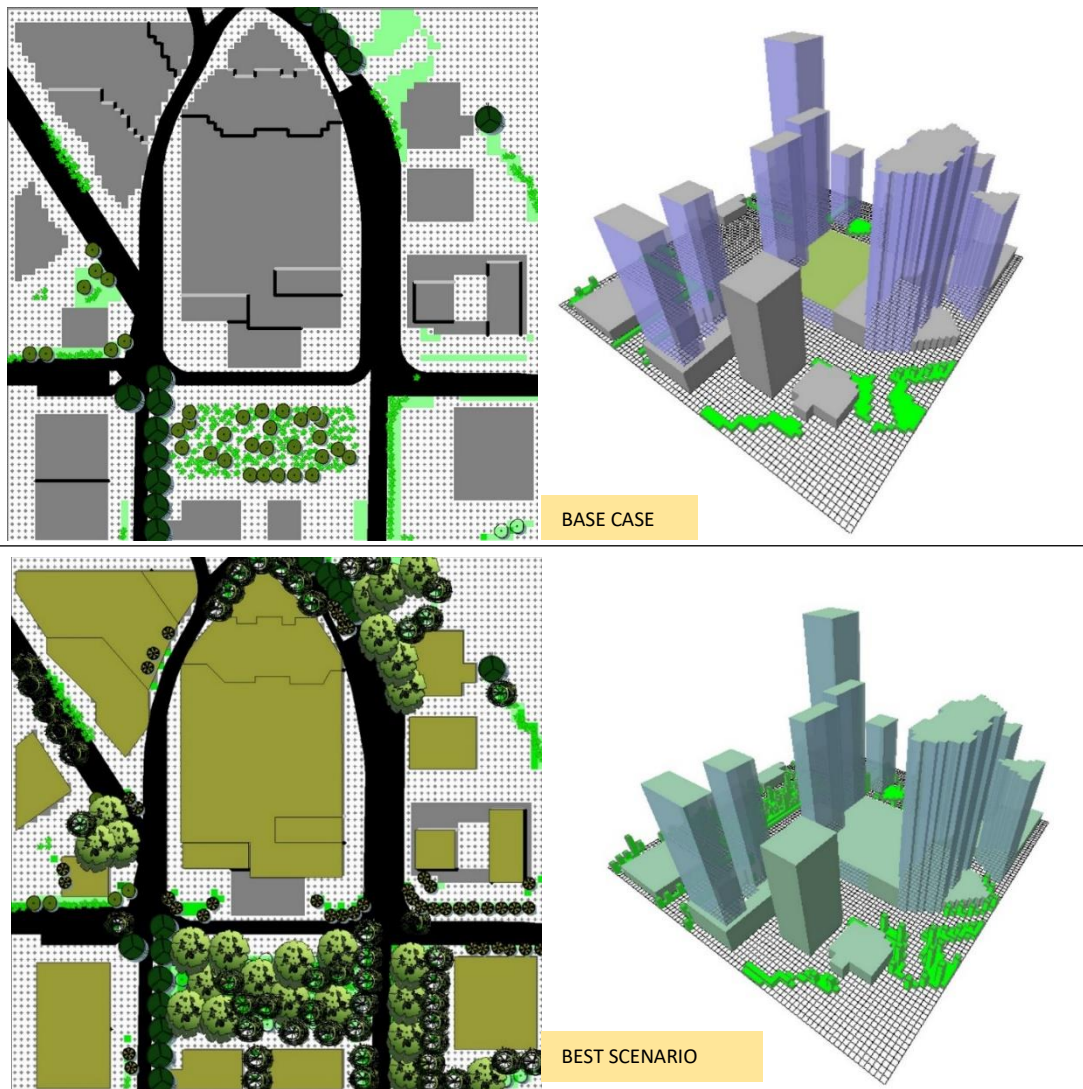


Figure 6.27. LCZ 1 Base case and best scenario model

The area where the trees are located shows a significant change in the PMV rate. The receptor coordinate was located in grid coordinates $i=21$, $j=33$. Within the whole model area, the distribution of PMV increased slightly by an average of 0.03. The PMV and PPD value are shown in Figure 6.28 and Figure 6.29.



Figure 6.28. LCZ 10 PMV comparison Base case and best scenario

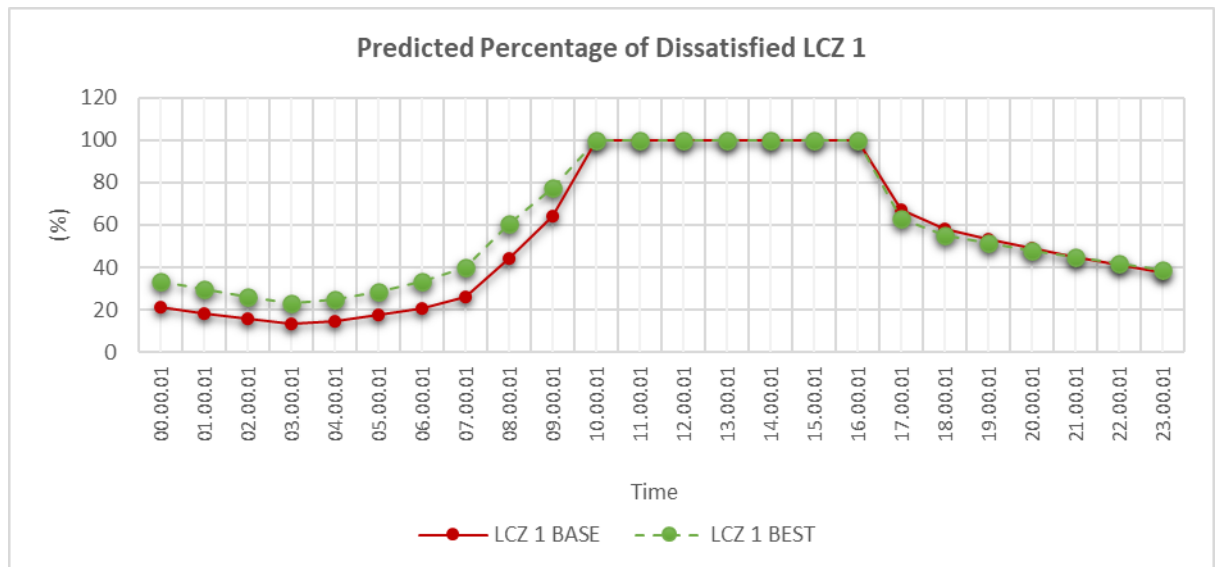


Figure 6.29. LCZ1 PPD comparison base case vs. Best case

The graph shows an overall increase of PPD percentage during the highest temperature range (10.00-16.00) reaches >99% which indicates a discomfort of the whole area's climate conditions. Intense additional greening also doesn't show a significant relief, instead it contributes to the increase in temperature and to the level of discomfort.

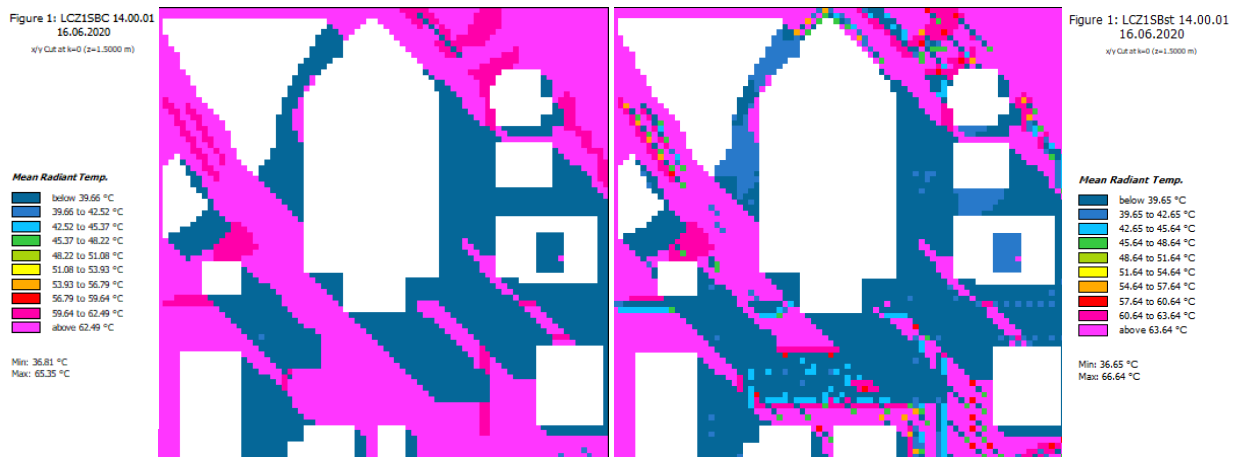


Figure 6.30. LCZ1 Base case and best scenario MRT comparison

Figure 6.28 shows the MRT data from both scenarios, despite the additional green area up to 117.08%, the MRT of the majority area of the simulation increases from max. 65.35 °C to 66.64 °C. The minimum MRT also increases from 36.81 °C to 36.65 °C.

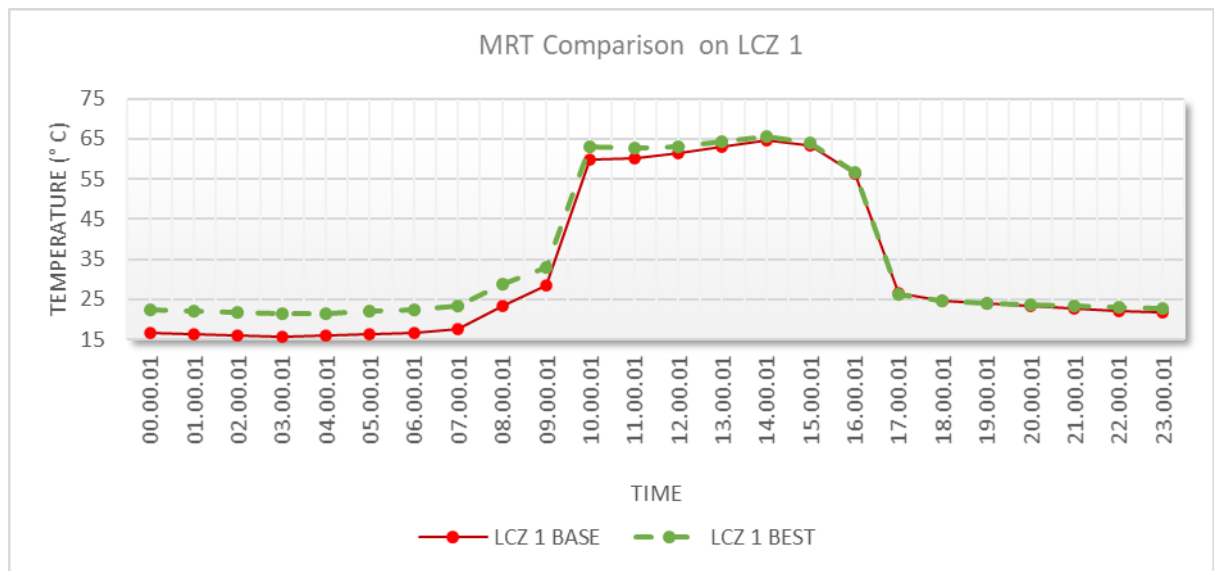


Figure 6.31. LCZ1 Base case and best scenario MRT comparison

Compare to other LCZ, the area of LCZ 1 is consider heavily built up area , both plan base and height. Implementation of high level of green infrastructure that is already impractical, also give no contribution on reducing temperature and increase thermal comfort. On average the greening target is not improving the condition and even increase the MRT. However, there are pockets of cool areas which improve the comfort, but this couldn't be uniformly distributed in the whole LCZ 1 representative area.

6.4. Extrapolation of Cooling and Thermal Comfort in Jakarta

Based one information extracted from the simulation, a mean radian temperature reduction can be obtained from scenarios represent by LCZ 8, LCZ 3, and LCZ 10. Figure 6.31 shows the extrapolation of cooling and comfort in the whole area of Jakarta by the three LCZ representations. The application of an additional of 41.09% green area of land, or by setting the target by 51.84% area of LCZ 8 (23% of total Jakarta area) will reduce the MRT by 2.78°C. This can be done

simultaneously with LCZ 3 and LCZ 10. Figure 6.31 shows the extrapolation on cooling and comfort in Jakarta.

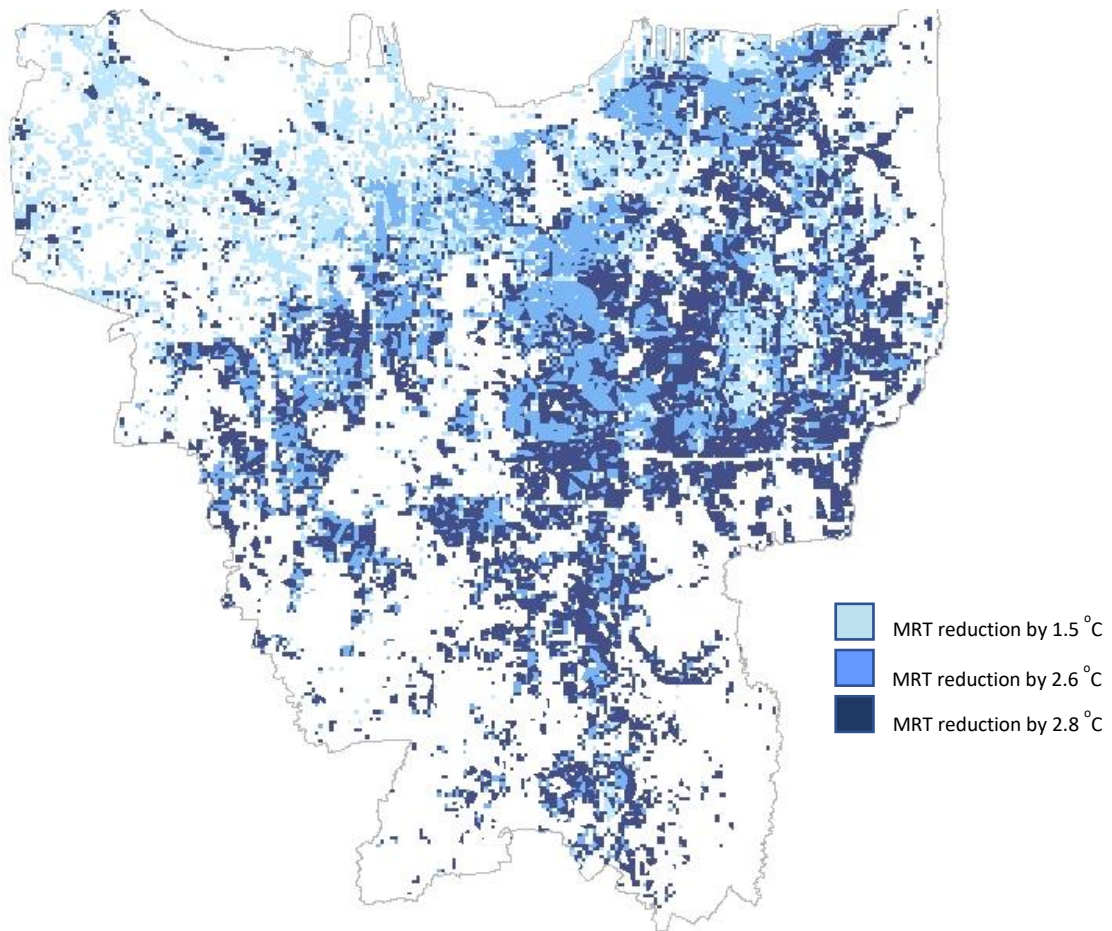


Figure 6.32. Extrapolation of Cooling and Comfort in Jakarta Metropolitan Area

Table 6.10 shows the correlation of target setting green area on tackling urban overheating. In this case, green infrastructure plays a role in mitigation urban overheating. However, it shows a slight decrease of temperature with impractical application of green infrastructure. The next chapter will discuss the implications of this study for Jakarta’s Planning Policy.

	Green Target	Area	MRT reduction	% of total land area of Jakarta
LCZ 8	52.00%		2.8	23.37%
LCZ 3	49.00%		2.6	11.80%
LCZ 10	31%		1.5	11.65%

Table 6.10. Green area target and temperature reduction

7. IMPLICATIONS AND CONCLUSIONS

7.1. Summary of findings and discussions

This study aims to develop a protocol for the Jakarta Green area calculation basis, using a Green infrastructure quantification factor as an approach to mitigate urban overheating. From the simulations performed by this study, which was conducted in 5 local climate zone areas in Jakarta as a representation of 69% of the whole metropolitan area, it is informed that the application of additional green infrastructure generally has impact on the climatic condition certain areas that will then affect the thermal comfort. However, the attempt of adding green infrastructure in the whole model area didn't show uniform results. The summary of the simulation result is shown in Table 7.1

This chapter will present the summary of the simulation result of how the impact on adding proportion of green areas on the temperature that will be represent by MRT and PMV index. Table 7.1 show sthe summary of best scenario application. And Figure 7.1 shows the 24-hour plot of MRT difference in every LCZ. The values are obtained by calculating the MRT on best scenario minus MRT of the base case. Negative means decreased value on MRT/PMV, and positive value means the increase MRT.

Table 7.1. Summary of best greening scenario impact on MRT and PMV

LCZ8					
Parameter		Base case	Best scenario	Change	Average
Green Space Ratio		10.75%	51.84%	41.09%	
MRT	min	43.95	41.1	-2.85	-2.775
	max	71.5	68.8	-2.7	
PMV	min	2.08	1.34	-0.74	-0.47
	max	4.92	4.72	-0.2	
LCZ 6					
Parameter		Base case	Best scenario	Change	Average
Green Space Ratio		22.04%	30.00%	7.96%	
MRT	min	40.32	40.75	0.43	0.415
	max	68.7	69.1	0.4	
PMV	min	0.97	0.99	0.02	0.03
	max	4.63	4.67	0.04	
LCZ 3					
Parameter		Base case	Best scenario	Change	Average
Green Space Ratio		3.90%	49.12%	45.22%	
MRT	min	35.72	32.86	-2.86	-2.595
	max	64.19	61.86	-2.33	
PMV	min	0.84	1.34	0.5	0.485
	max	4.25	4.72	0.47	
LCZ 10					

Parameter		Base case	Best scenario	Change	Average
Green Space Ratio		12.13%	31.12%	18.99%	
MRT	min	46.87	45.18	-1.69	-1.495
	max	75.16	73.86	-1.3	
PMV	min	2.9	2.79	-0.11	-0.1
	max	4.96	4.87	-0.09	

LCZ 1

Parameter		Base case	Best scenario	Change	Average
Green Space Ratio		24.55%	141.63%	117.08%	
MRT	min	36.81	36.65	-0.16	0.565
	max	65.35	66.64	1.29	
PMV	min	2.25	2.29	0.04	0.03
	max	4.28	4.3	0.02	

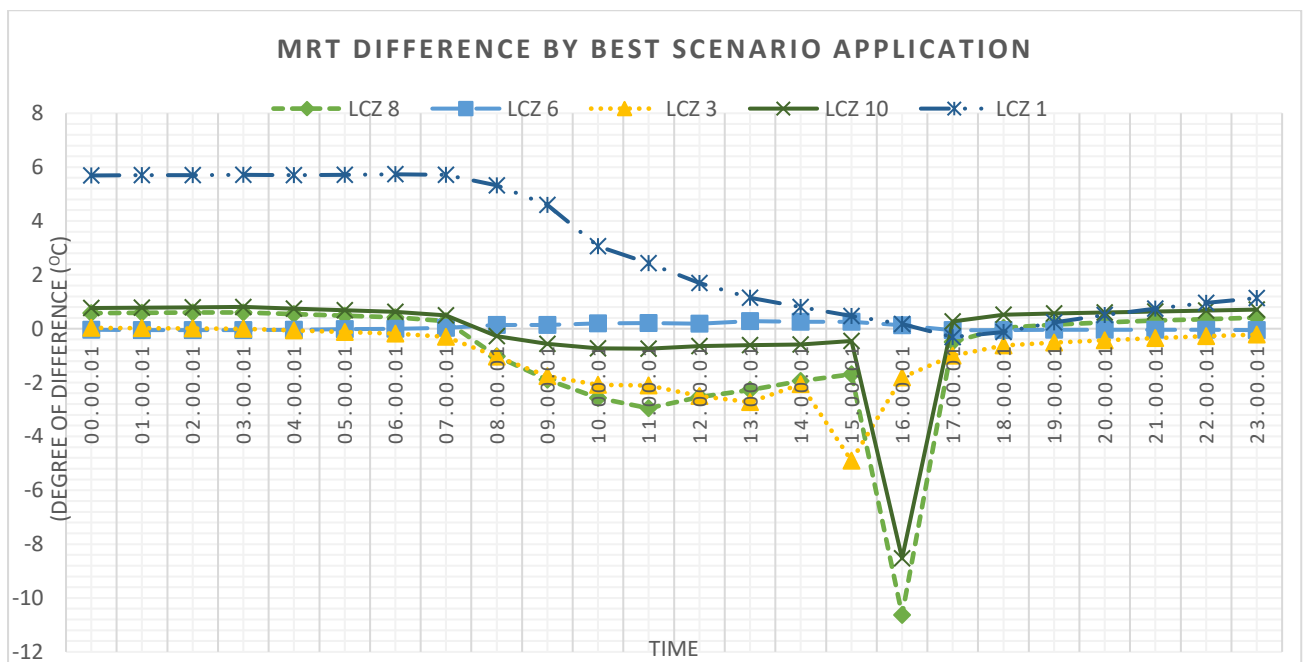


Figure 7.1. 24 hours plot of MRT difference by best scenario application

Figure 7.1 also indicates the correlation of the greening impact in every LCZ. It shows that the highest decrease of MRT in most LCZ happened at 16:00, with LCZ 8 have the highest value (over 10°C).

The ENVI-met simulations shows the uneven distribution of minimum and interval MRT in different local climate zone area. The percentage of additional greenery also depends on the availability of the area. The absolute maximum green scenario effect at 2.00 PM in each location is shown in table 7.2.

Table 7.2. MRT range on simulation models base and best case

GAP	LCZ 8		LCZ 6		LCZ 3		LCZ 10		LCZ 1	
	BASE	BEST	BASE	BEST	BASE	BEST	BASE	BEST	BASE	BEST
MRT min	43.95	41.1	40.32	40.75	35.72	32.86	46.87	45.18	36.81	36.65
MRT max	71.5	68.8	68.7	69.1	64.19	61.86	75.16	73.86	65.35	66.64

Based on the simulation of thermal comfort level, it is shown that in diurnal time everybody is uncomfortable with the climatic condition of all the model areas, with the PPD index reaching 100%. Figure 7.2 illustrates the predicted percentage of discomfort of all LCZ area and comparison between base case and best greening scenario. It can be conclude that between 11:00 and 15:00, everyone feel the thermal discomfort. However, slight visible reduction of discomfort only appear on LCZ 6 best greening scenario.

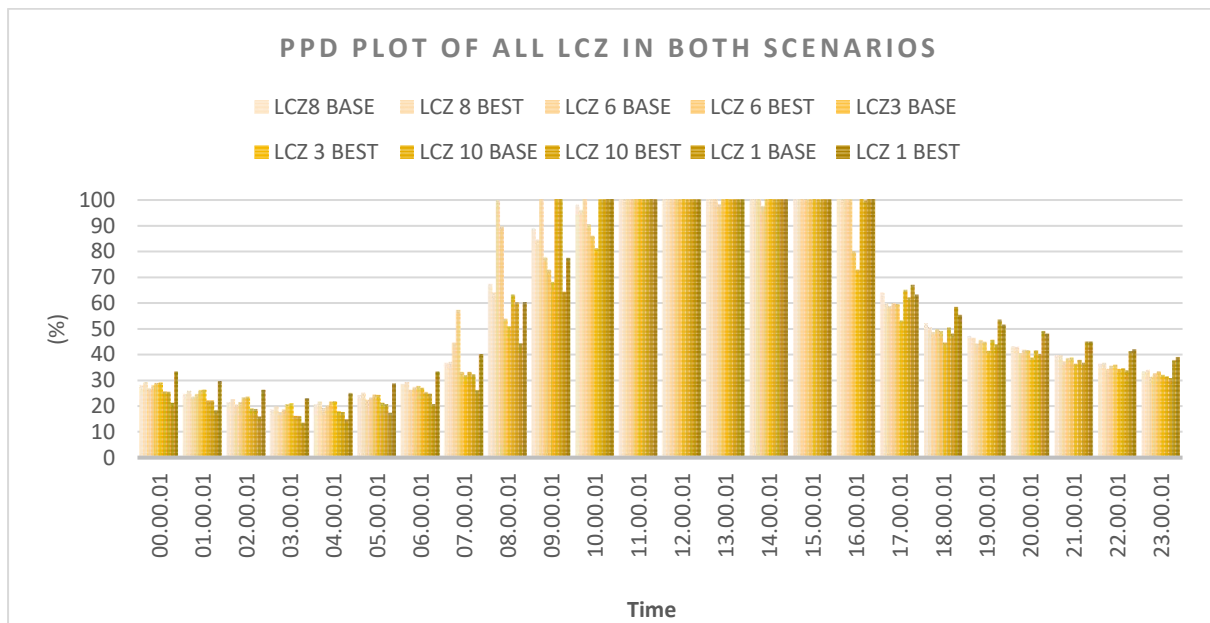


Figure 7.2 PPD plot of all LCZ base case and best greening scenario

Table 7.1 shows overall data that in LCZ 8 and LCZ 3, the additional >40% green cause a reduction of >2.5 °C MRT. In LCZ 10, the additional 19.99% green lowers MRT up to 1.5 °C. However in LCZ 6, which only has less than 8% of green, MRT level is increased, also for LCZ 1 by an additional a very high greenery factor by (117%) MRT is increased. The PMV level shows the reduction or increase on PMV in conjunction with MRT level in all models.

The results show positive effects on green infrastructure in LCZ 8, LCZ 3, and LCZ 10. Based on these three models, the higher index of green infrastructure shows a higher reduction of MRT. This finding supports the previous study on reducing temperature by an increase of green percentage that has been discussed in chapter 2. On contrary, LCZ 1, the heavily built up area, shows an increase of temperature even with extreme greening percentage. Shadows from high rise building also create wide cooling pockets, however the impact of heavily built area in outdoor thermal comfort can be seen in the simulation result. The contrast also shown In LCZ 6, that the low implementation of greenery index also shows increased on MRT.

To further analyse the different impacts of green in LCZ 6, another simulation was conducted by increasing the value of greenery index by 33.12%, greening the roof of all buildings in the entire

area simulation to 55.16%. Table 7.3 and Figure 7.3 show the effects of additional greening by 8% in comparison with additional 33% greening in LCZ 6.

Table 7.3. Additional greening in LCZ 6

LCZ 6							
Green Infrastructure Quantification	Factor	Base case		8% increase (without green roof)		Additional greening for Best Scenario	
Sealed areas, non-permeable surfacings without plant growth, including buildings without greenroof	0.00		0.00		0		0.00
Road	0.00	22367.83	0.00		0		0.00
Buildings	0.00	103146.16	0.00		0		0.00
Partially sealed areas (semi permeable surfacing)	0.31		0.00		0		0.00
Semi-enclosed areas (permeable surfacing)	0.42	0.00	0.00		0		0.00
Vegetation surface not connected to surrounding soil with depth <70 cm	0.52		0.00		0		0.00
Vegetation surface not connected to surrounding soil with depth >70 cm	0.74		0.00		0		0.00
Vegetation surfaces connected to surrounding soil	1.00	34486.01	34486.01		0		0.00
Lawn, grass, groundcover plants less than 2 feet tall	0.31		0.00		0		0.00
Shrubs	0.47		0.00	4757.61	2222.484	4757.61	2222.48
Tree - small	2.86	123.00	352.31		0		0.00
Tree - medium	4.05	92.00	372.60	15	60.75	15.00	60.75
Tree - large	5.60		0.00		0		0.00
Large tree - preserved	5.64	10.00	56.37		0		0.00
Green vertical areas on windowless external walls and walls, façade vegetation	0.54	0.00	0.00	8276.452	4492.931	8276.45	4492.93
Roof greening	0.62	0.00	0.00	9678.729	5967.233	74965.048	46218.25
Rainwater infiltration, stormwater features	0.25		0.00				0.00
TOTAL AREA			35267.29		12743.40		52994.41
160000			22.04%		7.96%		33.12%

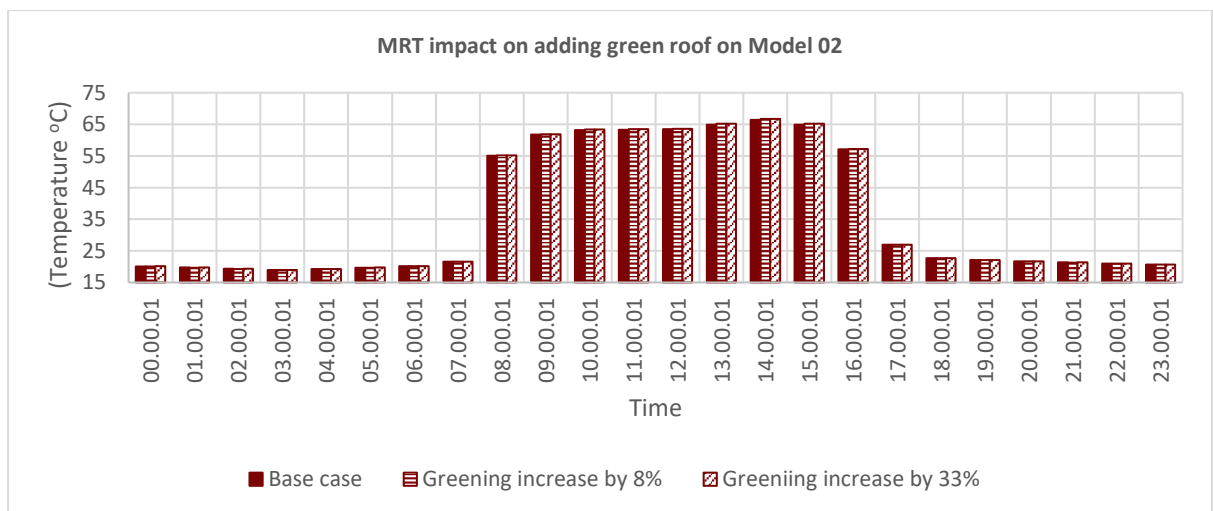


Figure 7.3. Effect of additional greening in LCZ 6

The result shows the maximum additional 33% green through green roof doesn't create an impact on MRT reduction.

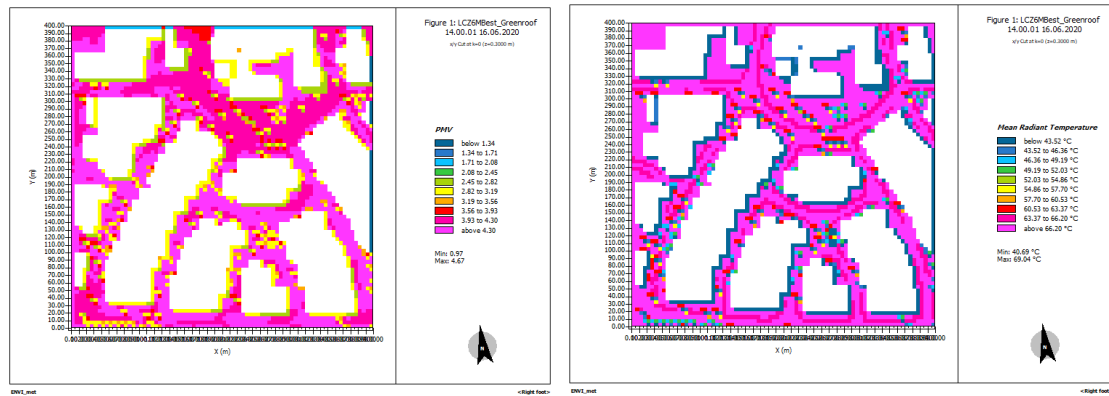


Figure 7.4. MRT and PMV distribution on 33% additional greening for LCZ 6

Table 7.4. MRT and PMV distribution on 33% additional greening for LCZ 6

		Base Case	8%	change	Ave- average	33%	change	Ave- average
Additional greening		22.04%	30.00%	7.96%		55.16 %	33.12 %	
MRT	min	40.32	40.75	0.43	0.415	40.69	0.37	0.355
	ma			0.4		69.04	0.34	
	x	68.7	69.1					
PMV	min	0.97	0.99	0.02	0.03	0.97	0	0.02
	ma					4.67	0.04	
	x	4.63	4.67	0.04				

In contrast to studies on the significant impact of green roof to all buildings on surface temperature (Gill, 2007, USEPA, 2014), this study finds that instead of causing a reduction, the MRT level actually increases, regardless whether 8%, or 33% of greenery were added. Some studies show green wall impact has a reduction impact on MRT. A study by Ariaudo et al., (2015) shows the effect of vegetation layers on walls in terms of solar load reduction. The research indicates that bare wall surfaces always has a significantly higher temperature than the green covered wall surfaces. As a consequence, the heat flux transmitted by the walls will reduce when the green layer is adopted. In contrast to the simulation of LCZ 1, there is no significant impact in PMV level up to 4.5 meters height in the receptor area for maximum green wall implementation in the model area. Other factors will need to be considered in the application of green walls in Jakarta to maximize the impact on outdoor thermal comfort.

One of the more significant findings to emerge from this study is that in order to reach the green area target with optimum MRT reduction, a maximum green intervention approach should be conducted. However, this approach might not be practical in certain areas. And by reaching the maximum target, the maximum MRT reduction that can be obtained is below 3 degrees.

The following conclusions can be drawn from the present study:

1. Only comprehensive, site-specific spatial and functional analyses can bring targeted green infrastructure index solutions with optimal shape, structure, and distribution that improve thermal conditions. This effect could contribute to other urban green infrastructure benefits, such as urban aesthetics, flooding and pollution control or air purification, enhancing biodiversity, etc. in urban areas.

2. Although there is just slight difference in temperature reduction, there are some areas that is comfortable due to the adding of trees. For a climate sensitive planning, there is a need to consider a landscape design that is located where people are doing the activities. This effort is to enhance quality of pocket area that contributes to cooling and benefits for the people.
3. Jakarta is located in a tropical climate where diurnal cooling is necessary to reduce the level of discomfort in the outdoor environment. The study shows that in terms of PPD, even maximum greening does not support an increase of the thermal comfort level.
4. Other cooling options should be taken into account to reduce temperature and improve thermal comfort. In order to mitigate UHI and address climate change, we can not rely entirely on greenery. Green infrastructure has many values that support the environment, biodiversity, aesthetic, psychology, health and many other aspects, but for climate control, the role of urban planning in a climate-sensitive design should be considered.

7.2. Implications for Jakarta Urban Planning and Land Use Policy

Jakarta has reached a certain point of land cover change and development triggered by increased population that need an immediate mitigation strategy of UHI. The green area target set is one of the methods. This study found that for the development of the Jakarta metropolitan area, three points should be considered regarding target setting of Green Area in the whole region of Jakarta:

1. Targets should be relevant to the local and existing conditions of the city. The implementation of the general target set will not bring the same climatic value in different zoning. There is no such a uniform way on target set that will increase the comfort. Green infrastructure makes difference in different areas. In some areas, greening for cooling doesn't work, or even could worsen the thermal sensation. However, even in the area where greenery increase the MRT, there are pocket areas that could benefit people by cooling. Some other areas shows that building alone can create the decrease the temperature.
2. The whole area of Jakarta needs diverse cooling strategies to reach a lower percentage of discomfort during the day that can not entirely be created by green infrastructure alone. In order to achieve a substantial cooling effect by green infrastructure, a different development model should be considered. The greening approach should focus on areas with high impact in UHI mitigation function, and area that still have a significant greening potential In the areas with less significant effects of greenery, a different mitigation approach can be considered.
3. Current urban development will need urgent climate-sensitive urban planning to mitigate overheating that is already happening in the entire area of Jakarta. Related to green area target, the urban planning consideration can set target in the area with high possibility of temperature and comfort improvement by green infrastructure. Another way of planning consideration is the changing of land use, to have a better chance in green infrastructure improvement.

7.3. Limitations

The purpose of this study is to demonstrate on how to build the protocol on green infrastructure target setting and how it works. There are some limitations on the process. The stages developed in this study are a concept to build a way of greening target calculation in a simplified model, not by the real existing urban and architectural condition. To overcome these limitations, some stages have been done. The limitation on the process and following steps needs to be done before this study could be used as a new index and quantification of the effects on greenery in Jakarta

1. The new green space weighting factor developed in this study is based on secondary data gathered from cities in countries distributed across several climatic zones that don't cover the Jakarta climate zone. Even though the cities included are some representatives from the UK, EU, and the USA, other cities could be included. But with a quite different rating and green infrastructure objectives and also the limitation of time, the model only built upon the included cities. Calculation of green elements average, index prorating, and averaging the final classification of green infrastructure elements is not the ideal way of establishing a suitable local index. The index model in this study is a built-up concept. The ideal calculation of Jakarta green infrastructure should be done with primary data and analysis according to the local context of the city.
2. Local climate zone mapping with WUDAPT protocol relies on a satellite image with pixel unclarity which created inaccuracy of classification. The accuracy sampling result is 36%, with 25 points check on 14189 total samplings, that was conducted by satellite imagery and street view, which has a particular area with no access on the online virtual check. The study methods didn't go through ground-truth verification of the actual data on site due to the lack of time and the pandemic restrictions at the time of this study. Notwithstanding the relatively limited sample, this work offers valuable insights into zoning analysis. A comprehensive accuracy check, visual and ground truth verification is needed in order to have an accurate Jakarta LCZ classification map.
3. The ENVI-met simulations are applied in a simplified model that might eliminate certain building features and complex landscape elements to make sure all the models can be simulated within the same framework. The tree input used in this study is the simple tree from ENVI-met, the specific parameters on tress and other landscape parameters are needed The used parameters on BIO-met features are default options, with no deliberation based on demographic context. To have a more accurate value on thermal comfort of the community in the area, the parameters input needs to be assign according to the majority residence as the personal human parameters in the BIO-met.
4. Other limitations of the study are related to the accuracy of existing conditions of model area, limitation of time and limitation on access during the pandemic COVID-19. This created implication on the result related land use/land cover, vegetation species, buildings geometry and total area. The aim of this study is to develop a protocol on target setting of green area in Jakarta for overheating mitigation with the same base model on best greening scenario. The aim is not a study on developing real local context indices or Local Climate Zone maps, or species accuracy on microclimate. To have real practical value, further studies on Jakarta or other cities' local context will be needed.

7.4. Direction for further research

This study tries to develop a protocol for the Jakarta Green area target setting based on the green infrastructure quantification factor as an approach to mitigate urban overheating. The strategy of the study is putting more emphasis on Green Infrastructure on urban overheating mitigation, and does not to consider changing the architectural/urban planning parameter elements.

Jakarta doesn't have a green infrastructure quantification factor by the time this study is performed. Further study of Jakarta's green infrastructure quantification factor with primary data in the local context of Jakarta is needed to further analyse the implications of green infrastructure services in the mitigation of urban overheating.

A Local Climate Zone-based approach can be a useful tool in building the guidelines for an innovative climate-responsive urban design. Further studies need to be carried out in order to validate Jakarta Local Climate Zone development, to encourage more planning priority on balancing functional demands and boost Jakarta's resilience dealing with the challenges of climate change.

There is a need to develop a further study of Climate-sensitive urban design with climatic simulation in Jakarta, especially the major land use such as low residential and industrial areas, where urban elements and buildings geometry play an important role along with green infrastructure. This study shows some areas where building and tree interaction contributes benefit in reducing temperature. A further study on this will develop the design possibility on enhancing thermal comfort in built up urban area.

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