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Optimization Thermal of Public Open Space Based on ENVI-met Simulation with the Application of Water Sensitive Urban Design Principles

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ABSTRACT

Global climate change and the Urban Heat Island (UHI) phenomenon have significantly impacted outdoor thermal comfort in urban environments, particularly in equatorial tropical cities such as Pontianak, Indonesia. This study evaluates the effectiveness of integrating *Water Sensitive Urban Design* (WSUD) principles into the design of public open spaces, using the case of the Pangsuma Sports Complex in Pontianak. The research employs urban microclimate simulation through ENVI-met software to assess key parameters such as air temperature, humidity, and wind speed. The results demonstrate that WSUD-oriented urban design—incorporating water bodies, dense vegetation, and permeable materials—can effectively improve thermal comfort. Simulations indicate a reduction in ambient temperature from 25°C to 24°C, an increase in wind speed from 0.8 m/s to 1.35 m/s, and a decrease in humidity from 72.94% to 68.37%, achieving optimal thermal comfort based on national standards. These findings affirm WSUD as a responsive urban design strategy that addresses microclimatic discomfort while enhancing ecological sustainability, water resilience, and public well-being in water-based cities. This research underscores the critical role of climate-responsive urban design in shaping livable, adaptive, and sustainable public spaces for tropical urban futures.

Keywords: Water-Sensitive Urban Design, Urban Microclimate, ENVI-met; Thermal comfort, Urban Heat Island Mitigation.

ABSTRAK

Perubahan iklim global dan fenomena Urban Heat Island (UHI) *telah mempengaruhi kenyamanan termal di ruang terbuka kota, terutama di wilayah tropis seperti Kota Pontianak. Penelitian ini mengevaluasi efektivitas penerapan desain ruang terbuka publik berbasis prinsip* Water Sensitive Urban Design *(WSUD) dalam meningkatkan kenyamanan termal kawasan Gelanggang Olahraga Pangsuma, Pontianak. Metode yang digunakan meliputi pemodelan dan simulasi menggunakan perangkat lunak ENVI-met untuk menganalisis parameter iklim mikro seperti suhu udara, kelembapan, dan kecepatan angin. Hasil penelitian menunjukkan bahwa penerapan elemen WSUD seperti badan air, vegetasi tinggi, dan material permeabel secara signifikan menurunkan suhu dari 25°C menjadi 24°C, meningkatkan kecepatan angin dari 0,8 m/s menjadi 1,35 m/s, serta menurunkan kelembapan udara dari 72,94% menjadi 68,37%. Kondisi ini menciptakan kenyamanan termal optimal berdasarkan standar nasional. Konsep WSUD terbukti tidak hanya sebagai solusi terhadap ketidaknyamanan termal, tetapi juga sebagai strategi adaptif terhadap perubahan iklim yang mendukung keberlanjutan lingkungan dan meningkatkan kualitas hidup masyarakat kota berbasis perairan. Penelitian ini merekomendasikan integrasi WSUD dalam perancangan ruang publik sebagai bagian dari strategi pembangunan kota berkelanjutan di iklim tropis.*

Kata kunci: Water Sensitive Urban Design*, Iklim Mikro Perkotaan, ENVI-Met, Kenyamanan Termal, Mitigasi Pulau Panas Perkotaan*

1. INTRODUCTION

Climate change is driving increased sea temperatures, storms, sea level rise, and shifting coastal to inland ecosystems. The ocean in Indonesia has experienced an increase in temperature of about 0.18°C over the past 30 years. Warming will continue and sea surface temperatures are expected to increase by 1.39 ± 0.39 °C in the low global emissions scenario (SSP1-2.6), and by 3.68 ± 0.86 °C in the high global emissions scenario (SSP1-8.5) by the end of the century compared to 1850-1900, (WordBank.org Publication November 7, 2023. The Urban Heat Island (UHI) effect is the most frequently discussed microclimate problem in cities. This problem can also be caused by heat escaping from vehicles, air conditioning, and industrial processes. In cities, space cooling through evaporative processes decreases due to lack of green open spaces and high humidity. This problem can be exacerbated by smog, which is a combination of air pollution and water droplets. Haze can form a dome that traps pollutants and heat, blocking cool breezes from entering the city from outside. At night during the dry season, some cities may be 10°C warmer than the surrounding countryside. Open space with plants (green open space) can provide several effects such as reducing noise (van Hove et al., 2015), reducing stress (Peschardt et al., 2012), improving air quality (Akbari et al., 2001) and increasing social interaction in urban environments (Aram et al., 2019). In addition, greening can help reduce the impact of Urban Heat Island (UHI) and improve the thermal comfort of outdoor spaces (Gago et al., 2013; Gherraz et al., 2018; Karimi et al., 2020) in (Rahmadyani et al., 2023).

The existing condition of the design area which is located in the strategic zone of the city and has functions as a center of economic growth, a water transportation node, and a sports and recreation area. the application of a system based on the principles of Water Sensitive Urban Design (WSUD) is carried out with an approach that adjusts building design and land layout to optimize water absorption while minimizing surface runoff. This approach includes the provision of green open spaces that act as rainwater infiltration and treatment areas, the use of permeable materials, and the use of drainage systems that allow water to seep into the ground naturally. WSUD not only contributes to sustainable water management, but also provides important benefits in creating an urban cooling effect. This is realized through the provision of green spaces and water elements in the cityscape that can reduce ambient temperatures, reduce the heat island effect, and generally improve the quality of life of urban communities. Gehl Architects in publish A City For People, 2016 Explains in designing public open spaces there are 12 criteria for the quality of Open Space, some of which must have a positive sensory experience by building design details and using good materials, beautiful scenery with views of trees, plants, and water. The advantage of enjoying the positive aspects of the microclimate also needs to be considered for the impact of sun/shade, heat/coolness, and shelter form wind/breeze. the design area located in the strategic zone of the city functions as a center of economic growth, a water transportation node, as well as a sports and recreation area, and the application of the principles of Water Sensitive Urban Design criteria.

Pontianak as an Urban Based Water city has distinctive characteristics where the embryo of its city development from the establishment of kingdoms and settlements on the banks of the river with the Dutch colonial area is a separate new area (Mentayani et al., 2013) in (Nurhidayati and Arianti, 2021), Recent infrastructure developments related to the problem of loss of green space due to urbanization include the urban heat island (UHI) effect which manifests itself with increasing heat waves both in frequency and intensity (Gunawardena et al. 2017). Providing solutions for cooling outdoor spaces through evapotranspiration, water storage for extreme rainfall, peak discharge attenuation, and groundwater recharge are solutions for urban development with WSUD or Water Sensitive Urban Design. Handling of thermal discomfort is the main focus in this study that is integrated with the principles of Water Sensitive Urban Design as a form of conceptual handling solutions and measure how much impact and benefits of water as a natural element ecologically that can be used to reduce microclimate problems through shelter space in the area of public spaces whose existence can increase the thermal comfort of a space for the surrounding area to be cool. This study aims to examine the effectiveness of the application of the principles of Water Sensitive Urban Design (WSUD) in improving the thermal comfort of public open spaces.

2. METODOLOGI

In this research process, ENVI-met software was used as a tool for modeling the study area and simulating the microclimate. ENVI-met enables quantitative analysis of the influence of urban design and planning on microclimate conditions. The software is a non-hydrostatic three-dimensional microclimate model designed to simulate the surface environment in urban areas. ENVI-met 5.8 is capable of performing microclimate simulations at horizontal resolutions ranging from 0.5 to 10 meters, with simulation durations ranging from 24 to 48 hours. This resolution allows the analysis of small-scale interactions such as between buildings, individual spaces, courtyards, and other landscape elements. As an urban environment modeling tool, ENVI-met supports various types of simulations such as atmospheric, surface, and ground dynamics. It can analyze the heat exchange process between buildings and the ground, as well as the evapotranspiration process of plants. Thermal support variables analyzed include air temperature, wind speed, and humidity, while physical variables include building height, material type, ground cover, and vegetation type.

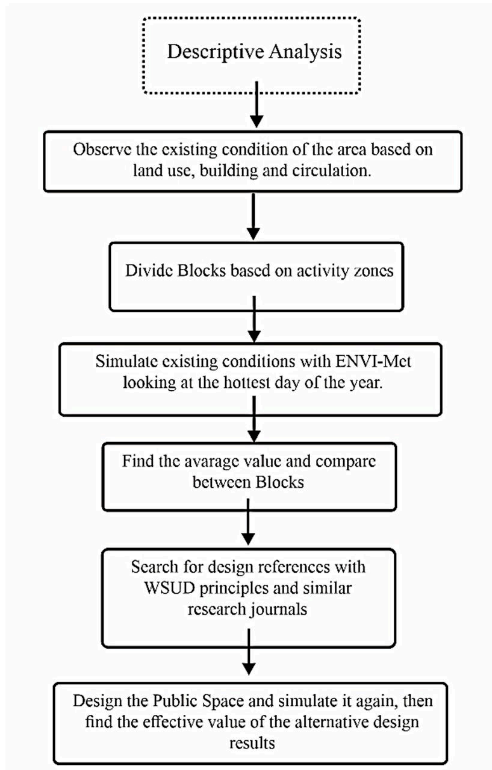


Figure 1 Analysis Method and Steps in Research

2.1 Existing Conditions of the Area

The weekly activity in this area is car free day with a large number of masses and spread along ayani road. Starting from the intersection of ayani road with sultan syarif abdurahman road to the ayani road area at the pointed bamboo monument. Daily activities include jogging and leisurely walking also on pedestrian ways that have been connected in the city center during the morning or afternoon towards the evening. Gathering in public spaces is also done in several places, such as the Kapuas River waterfront area and parks that are open late into the night. This gathering and leisure activity occurs almost every afternoon and evening, along with the activities of street vendors or kiosks with loose tents selling their wares in the area of the crowd with various activities in the public space.

2.2 Simulation Process

Input data used in the analysis process using ENVI-met as a simulation process of the existing conditions of the area. The variables used are measured variables in the form of thermal comfort determinants, such as humidity (%), temperature (℃) and wind speed (m/s). in the ENVI-met application The larger the grid area used during the simulation process, the longer the simulation running process used (Abdollahzadeh & Biloria, 2021) in (Mulya, 2022). To ensure that the ENVI-met simulation runs stable and free from boundary effects that can reduce the accuracy of the results, it is necessary to determine the height of the vertical domain (z-axis) adequately. Based on the formula proposed by (Lai et al. 2021), the minimum height of the vertical domain is set at twice the height of the tallest building minus one, i.e. 2(z) - 1: 2(z) - 1. The physical elements contained in the data input process are as follows:

Tabel 1 Object Input to Envi-Met in the Simulation Process

Object	Description
Building	Building code using a gray grid box with a height adjusted to the scale of existing conditions
Vegetation	The green box code reads "dm", has a height of 20m (maximizing the maximum limit of vegetation height that does not block the appearance of the building facade) and the width of the crown takes a width of 1 grid (meaning that in real conditions, the maximum width of the vegetation crown is about 10 meters), this adjusts the size of the grid map by 10 meters between grids due to the limitations of the simulation workspace on a 250 x 250 grid and a site area that reaches 33Ha.
Material	Material provision focuses on corridor pavement data input, namely Aspalt, material in the area inside the GOR using Pavement, Brick Road (Red Stone), as for building materials, using the most dominant building material in the area, namely brick and the entire green space using grass material.

This study uses temperature data on the hottest day of the year. This is done to obtain an overview of the thermal conditions of the area in extreme situations, which is precisely the most crucial moment in determining the comfort and safety of users of outdoor spaces. Simulation based on the hottest day allows a sharper assessment of the effectiveness of the design in reducing the heat load during the worst weather conditions. This approach is also in line with the principles of mitigation and adaptation to climate change, where the frequency of extreme temperature events is increasing, so the design of the area needs to consider resistance to the hottest conditions, not just average conditions.

Tabel 2 ENVI-Met Settings Configuration Input

ENVI – met Configuration	Hottest Day of the Year		Data Source
Simulation start day		14-07-2024	ENVI – met Configuration
Simulation start hour		13.00	ENVI – met Configuration
Total simulations in one day		24 jam	ENVI – met Configuration
Average wind speed		3,3	BPS Kota Pontianak 2025
Wind direction		160 S	Dataonline.bmkg.go.id
Roughness length		0,1	ENVI – met Configuration
Temperature	Min	25,2℃	Dataonline.bmkg.go.id

ENVI – met Configuration	Hottest Day of the Year		Data Source
	Max	34℃	Dataonline.bmkg.go.id
Relatif Humadity	Min	46%	BPS Kota Pontianak 2025
	Max	100%	BPS Kota Pontianak 2025

Researchers make the division of zones to see which sites can be a priority handling based on the relationship of temperature conditions and humidity thermal comfort level of outdoor space. This site is considered to require handling of space that is more important than the results of the average temperature assessment and the combination of high temperature and high humidity can increase thermal discomfort because the process of evaporation of sweat becomes less effective (Fanger, 1970). The analysis considers the relationship with previous research as a basis for space configuration and looks for the average value of the development graph of air temperature, humidity and wind speed in the design delineation measured for 24 hours in the hottest month with the highest temperature in July at 34 ° C, wind speed of 3.3 m/s and wind direction 160 S with the highest humidity level of 100%.

2.3 Configuration and Space Requirement

The concept of space and activity is used in designing public open spaces by providing a combination of protection, enjoyment, and comfort. Gehl Architects in their publication A City For People, 2016 analyzed successful public spaces around the world have common characteristics. they categorized and summarized these characteristics into 12 quality criteria how Public spaces should be attractive, engaging, and provide spaces for recreation, sports, play, and so on. Public spaces should appeal to a wide range of people, from children, teenagers, adults, the elderly, and people with special needs to feel welcome. Some of the activities that can be conceptualized in public open space specifications such as sports arenas are as shown in Table 3.

Tabel 3. Concept of Design Space Requirement

Time	Activity Type	Microclimate / Supporting Design Needs
Morning (06.00–10.00 AM)	– Jogging/walking – Gymnastics/yoga – Light exercise (athletics, futsal, etc)	– Open space with light sunlight – Comfortable circulation path – Low vegetation/shrubs as visual boundary
afternoon (10.00 AM–14.00 PM)	– Sitting and lounging areas – Reading rooms – Social/community gatherings	– Shaded areas (canopy or shady trees) – Non-absorbent surface materials – Water access (drinking facilities or WSUD such as water features) – Natural ventilation (unobstructed wind flow)
Afternoon (14.00–18.00 PM)	– Community exercise – Social/community gatherings	– Semi-open areas with indirect natural lighting – Seating under trees

Time	Activity Type	Microclimate / Supporting Design Needs
	– Cycling – Jogging/walking – Gymnastics/yoga – Light exercise (athletics, futsal, etc)	– Combination of vegetation & porous paving – Water access (drinking facilities or WSUD such as water features) – Natural ventilation (unobstructed wind flow)
Malam (18.00–24.00 PM)	– Game night – Hanging out / casual gathering	– Directional artificial lighting – Non-dazzling surfaces – Safe and comfortable landscape design (no puddles)

Several studies have shown that the integration of water elements in open landscape design can have a positive impact on thermal comfort. Qiu and He, (2024). At the microscale, the cooling effect is greatly influenced by the shape of the water body, both linear and surface, the size and geometry of the water body, the configuration of the landscape and surrounding buildings, and the synergy between green and blue elements in the landscape that help reduce microclimate temperature and humidity. Syafii *et al.*, (2017). In the design process, aspects such as the orientation, size and position of the pools need to be considered to optimize thermal comfort. The ideal configuration can be one large pool or two parallel pools placed in the direction of the dominant wind direction, so as to support natural air circulation. In addition, factors such as the distance between the water body and the human activity zone, the orientation of the water corridor, and the time of use of the area also affect the microclimate conditions along the road corridor adjacent to the water element. Syafrina and Koerniawan, (2018). These variables, including the shape and size of the water body, dominant wind direction, landscape orientation, vegetation placement, and height and density of surrounding buildings, are key considerations in determining the configuration of climate-responsive and environmentally friendly public open spaces.

The results of thermal simulation of the outdoor space of 3 fairly complex Blocks using thermal averaging data are carried out to identify blocks with temperatures that are considered no better than other blocks based on urban thermal environment assessment standards and human thermal comfort outdoors, so that it can be known which areas require further improvement or control in order to maintain the efficiency and stability of the microclimate.

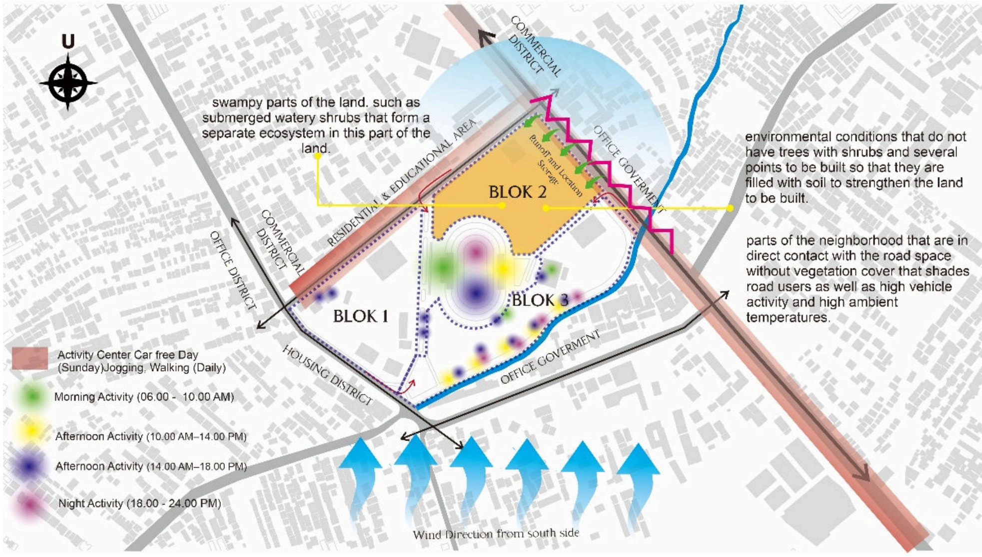


Figure 2. Analysis of Potential Design Blocks

Figure 3. Main Block Handling.

2.4 Alternatif Design Simulation

The area is designed as an area for light and social activities, such as jogging, morning exercises, or relaxing. These activities rely heavily on thermal comfort, so it is important to design shaded areas through the use of canopies and vegetation, ensure good airflow, and choose surface materials that do not absorb excessive heat. In the book A City for People (Gehl Architects, 2016), it is explained that a good public open space should be able to provide a pleasant sensory experience. The experience is formed through the sense of place created in the space. This is achieved through detailed design that pays attention to the use of appropriate materials, as well as creating visual interest through the presence of trees, plants, and water elements. To this end, Block 2 is designed with a large round or oval-shaped pond placed at the center of the urban open space. The pond is surrounded by low vegetation and public benches, creating a comfortable, open atmosphere that supports social interaction amidst a cool and refreshing environment.

3. RESULT

3.1 Reserch Site

The location of planning and design is in South Pontianak District, GOR Sultan Syarif Abdurahman Area with an area of ± 33 Hectares. The condition of this GOR area is located on the city's primary arterial road and is passed by the Pontianak City primary drainage network, housing centers, trade / services and city-scale SPU. Inside the GOR area, it is allocated as an MSME activity on the side of the Tokaya ditch. On weekends this area is crowded with car free days activities and motorcycle racing championships. In addition, this location is strategic to be part of the city's green open space because it is in a linear line with the city forest and Pontianak city green corridor with good pedestrian quality.

Figure 4. Design Location
Source : https://www.google.co.id/intl/id/earth/

The weekly activity in this area is car free day with a large number of people and spread along ayani road. Starting from the intersection of ayani road with sultan syarif abdurahman road to the ayani road area at the pointed bamboo monument. Daily activities include jogging and leisurely walking also on the pedestrian ways that have been connected in the city center during the morning or afternoon towards the evening. Gathering in public spaces is also done in several places, such as the Kapuas River waterfront area and parks that are open late into the night. This gathering and leisure activity occurs almost every afternoon and evening, with street vendors or kiosks with loose tents selling their wares in the public space.

3.2 Simulation Result

Based on the results of the ENVI-met simulation, the graph of air temperature development in the design delineation is measured for 24 hours in the hottest month with the highest average temperature in July, namely 29.79°C. ENVI-met simulation at 14.00 (Temperature 31.36 ° C) increased until 16.00 at a temperature of 32.03 ° C, then decreased when entering the night. The decline occurred up to 1 ° C almost every hour and ended at 05.00 (Temperature 26.32 ° C) as the time with the lowest temperature and increased until 13.00 (Temperature 33.49 ° C), an increase in temperature of up to 7.17 ° C. Humidity measurements were obtained at the highest average design delineation at 04.00 - 05.00 at 77% and the lowest at 47% at 13.00, while wind speed measurements obtained the highest wind rate in the first hour of measurement at 04.00 at 3.83 m / s. and the lowest wind rate at 13.00 the next day at 3.10 m / s.

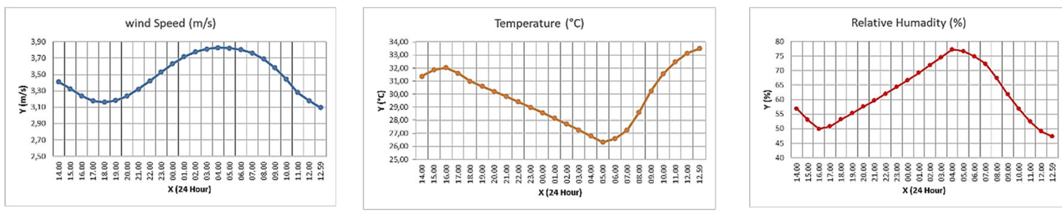


Figure 5. Graph of Thermal Existing Simulation Results of the Area within 24 hours

From the graph, we can infer the climatic parameters for 24 hours obtained from the ENVI-met simulation results. However, this study looks at the time based on the activities that drive this public open space to come alive at representative times that are often used to analyze temperature dynamics, thermal comfort or the effects of vegetation and surfaces. The time chosen to see the delineation analysis of this design area as a step to determine which area is the scope of the design based on the simulation results of the area with high temperatures during activity hours in public open spaces.

Researchers took the results of thermal simulations resulting in temperature levels, wind speed and air humidity delination design. From these results obtained points that have the highest temperature levels, so there are points that will be handled systematically design based on the concepts and principles described in the background of the problems and issues raised as well as the theory of the concept in designing. The ideal relative humidity for human thermal comfort ranges from 40% to 60%. At high temperatures, humidity >70% can cause serious discomfort, especially in tropical open spaces. Some time conditions are taken as representative of the environment at 13.00, This condition is the peak of environmental thermal loads such as air temperature, solar radiation, and the surface is at the maximum value and illustrates the worst limit of thermal comfort in outdoor spaces. At 21:00 is taken to find out whether the space remains comfortable for night activities, such as night markets, sports, recreation and detect the urban heat island effect how quickly the environment releases heat as a residual thermal effect during the day.

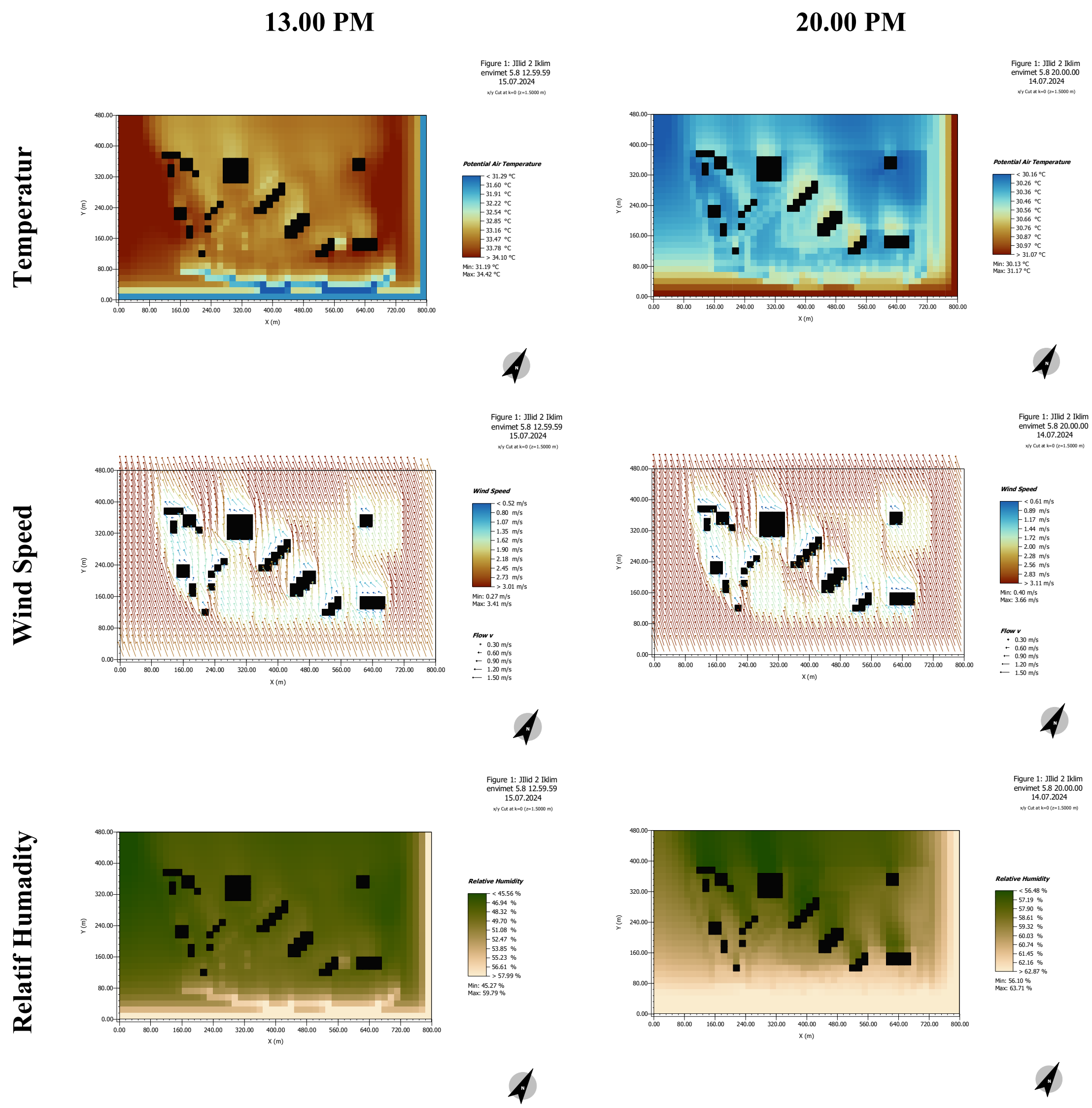


Figure 6 Thermal Simulation Results of Existing Area Based on Temperature, Wind Speed and Humidity

Tabel 4. Design Block Avarage Value

Location	Temperature	Wind Speed	Relatif Humadity
BLOK 1	29,83°C	3,18 m/s	61,92 %
BLOK 2	29,76°C	2,02 m/s	63,55 %
BLOK 3	29,67°C	1,36 m/s	67,58 %
*uncomfortable humidity > 60% *High wind speed > 1.5 m/s *Temperature above >27.2 degrees Celsius = uncomfortable heat			

Tabel 5. Interaction of Three Variables in Microclimate

Temperature Level	Relatif Humadity Level	Wind Speed Level
Hight Temperature	Hight RH	Low Wind → Very hot and uncomfortable (PMV > +2)

Hight Temperature	Hight RH	High Wind → Somewhat more comfortable (PMV close to +1.5)
Hight Temperature	Low RH	High Wind → Can be neutral or comfortable (PMV ~0 to +1)

Researchers made a division of zones to see which sites can be prioritized based on the relationship of temperature and humidity conditions to the thermal comfort level of the outdoor space.

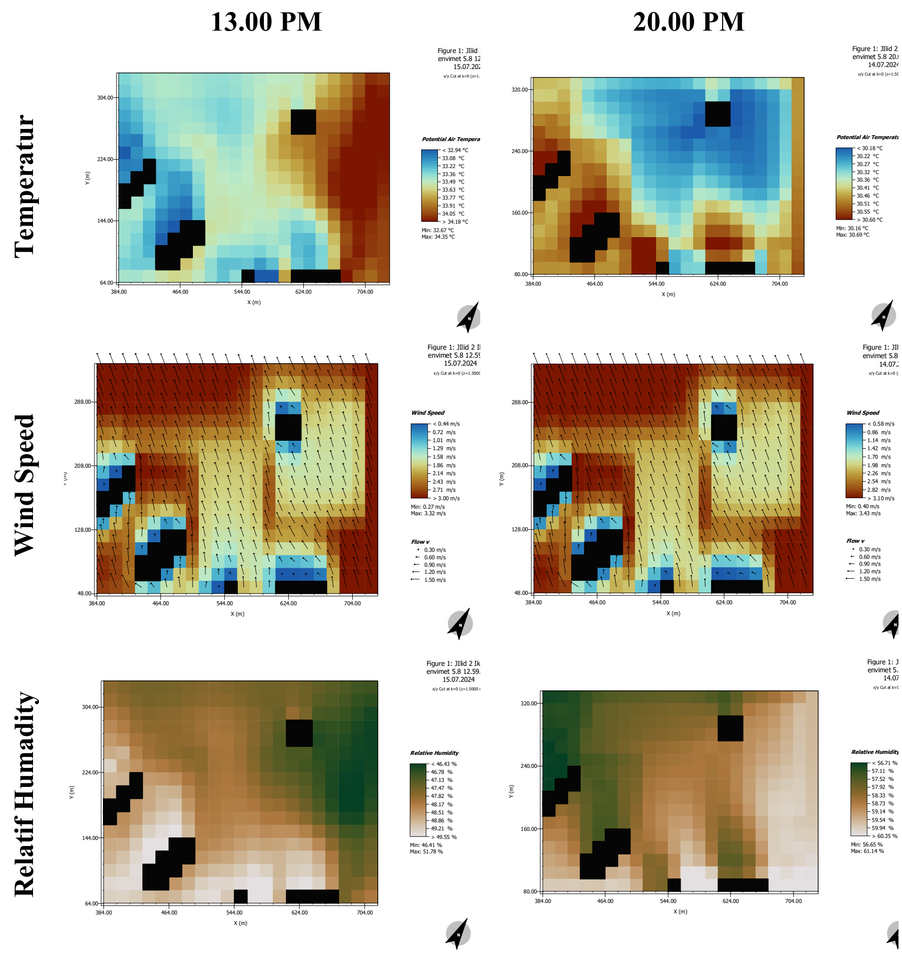


Figure 7. *Heatmap* Blok 2 Design

3.3 Recommendation Design

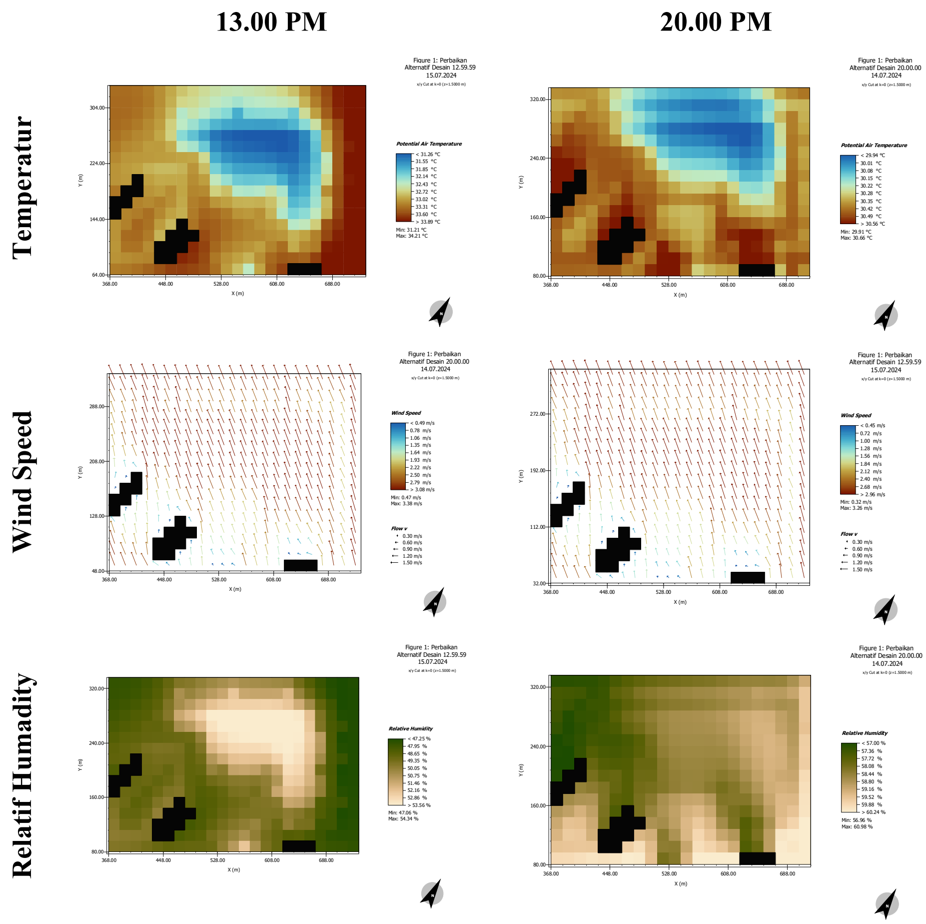
Block 2 is an area with relatively low user activity and less vegetation than Block 1 and Block 3. It is strategically located on the north side of the site directly adjacent to the city's main road, so it has potential as an active public space and ecological function. Existing Block 2 consists of a small amount of marsh and biotic plants that can be developed through Water Sensitive Urban Design (WSUD) principles to improve environmental quality and ecosystem functions. With an average temperature of 29.76°C, humidity of 63.55%, and wind speed of

2.02 m/s, the site experiences thermal discomfort challenges due to the combination of high temperature and humidity, as found by Fanger (1970). Increased vegetation and management of green open space, retention, and infiltration of rainwater in an area of ±7.40 ha can reduce surface runoff, support the natural drainage system connected to the Kapuas river on the south side, and improve microclimate comfort according to WSUD principles.

Figure 8. Masterplan of the Design Area

Block two is designed with round and oval pools with large areas placed in the center of the city's open space. A large oval or circular pond in the center of the urban park and surrounded by low vegetation areas and public benches. The percentage of water area is 50% of the total land area, the next 50% as part of permeable pavement and vegetation. Tall vegetation (trees) is placed on the west and north sides to provide shade and reduce afternoon radiant heat. Walking to Jogging activities surrounding the pond Low plants and hardscape on the south and east sides keep the wind circulation smooth from the dominant direction. Seating spaces are positioned within 5-10 meters from the pool, within the zone of maximum thermal effect.

The site temperature decreased to 1.41°C during the day with wind speed and humidity also increasing, even the humidity also increased from the maximum existing condition of 51.78% to 54.34%. At night the temperature drops by about 0.25°C, the wind speed also decreases and the minimum relative humidity tends to increase. The relationship between air temperature, relative humidity and wind speed forms a thermal system that influences each other in creating a comfortable level of microclimate. An increase in air temperature directly increases the heat load on the body, but the impact can be exacerbated by high relative humidity because it inhibits the process of sweat evaporation. Conversely, sufficient wind speed can accelerate evaporation and reduce body surface temperature, playing an important role in neutralizing the combined effects of temperature and humidity extremes.(Fanger 1970; Oke 1987; (ASHRAE, 2020).



Picture 3.3. 1 Heatmap of Block 2 Design Simulation Results

The designed condition is able to reduce the temperature of the environment during the day so that the space can be used comfortably with a humidity level that is still below the 60% range and a fairly high wind speed with the presence of water material as a landscaping area that can bring faster spread of temperature and humidity to low. But at night, water releases heat into the surrounding environment. The air temperature around the water body also affects the water temperature. If the air at night is very cold, the water will cool faster. However, the environmental conditions around the design area have temperatures that are still quite high until the evening so that water cooling is slower and there is no large temperature drop until 20.00 PM.

The combination of canopied shade trees and water elements such as ponds or canals in one spatial unit can produce a significant synergistic effect in reducing the temperature around water bodies. This combination increases the efficiency of the evaporation process and provides more optimal thermal comfort. The arrangement of vegetation in the area needs to consider the creation of effective shadows and pay attention to the dominant wind direction to support natural air circulation.

4. CONCLUCION

Water-based landscape design is proven effective in improving thermal comfort in public open spaces. Simulations with the Water Sensitive Urban Design (WSUD) approach show significant improvements in microclimate parameters to reach a comfortable category according to national standards. The application of WSUD is becoming increasingly relevant in tropical cities like Pontianak to deal with climate change, as it not only reduces Urban Heat Island (UHI) but also supports sustainable water management. By considering microclimate, public open spaces can function optimally as places for social, educational, and recreational activities in a cooler and healthier atmosphere, while strengthening the resilience of an inclusive and sustainable city.

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