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Climate-sensitive urban design through Envi-Met simulation: case study in Kemayoran, Jakarta

K D Kusumastuty[1,3], H W Poerbo[2] and M D Koerniawan [2]

[1] Magister Student of Urban Design, Department of Architecture, School of Architecture, Planning and Policy Development, Institute of Technology Bandung, Jl. Ganesha No.10 Bandung 40132, West Java, Indonesia
[2] Lecturer, Department of Architecture, School of Architecture, Planning and Policy Development, Institute of Technology Bandung, Jl. Ganesha No.10 Bandung 40132, West Java, Indonesia
[3] Corresponding author: karinadwik@gmail.com

Abstract. Indonesia as a tropical country which the character of its climate are hot and humid, the outdoor activity applications are often disrupted due to discomfort in thermal conditions. Massive construction of skyscrapers in urban areas are caused by the increase of human population leads to reduced green and infiltration areas that impact to environmental imbalances and triggering microclimate changes with rising air temperatures on the surface. The area that significantly experiences the rise of temperature in the Central Business District (CBD), which has need an analysis to create thermal comfort conditions to improve the ease of outdoor activities by an approach. This study aims to design the Kemayoran CBD through Climate Sensitive Urban Design especially in hot and humid tropical climate area and analyze thermal comfort level and optimal air conditioning in the outdoor area. This research used a quantitative method by generating the design using Climate Sensitive Urban Design principle through Envi-met 4.1 simulation program to find out the value of PMV, air temperature, wind speed and relative humidity conditions. The design area considers the configuration of buildings such as the distance between buildings, the average height, the orientation of the building, and the width of the road.

1. Introduction

Indonesia, a tropical country with hot-humid climate, the outdoor space utilization is often disrupted by inadequate thermal conditions. Rapid urban growth and less attention to providing public spaces have impacted on urban microclimate [1]. The escalating of the human population in urban areas motivates a skyscraper massive construction which leads to cut down green areas and recharge that provoking environmental imbalance and triggering microclimate changes by the advancement of surface air temperature. Its existence can affect the thermal comfort, that initiate inconvenience thermal conditions in the surrounding circumstances and stabilizes it through the day [2,3].

Nevertheless, the Climate Sensitive Urban Design concept implementation in Indonesia is still not optimally developed, yet some other tropical cities in Asia have issued design, planning, and management to improve thermal comfort. This research was conducted by designing a Central Business District area through Climate Sensitive Urban Design approach in tropical climate consideration of physical and non-physical parameters and analyzing the outdoor thermal condition by simulation.

2. Outdoor Thermal Comfort in Tropics

Based on ASHRAE Standard 55, thermal comfort is a condition of satisfaction with the surrounding thermal conditions and is assessed by subjective evaluation. It is also affected by the climate zone which is different in any region. People who lived in hot climates are more resistant to high temperatures but sensitive to low or cold temperatures, and vice versa [4]

Outdoor thermal comfort is an essential factor to measure the perception level of urban microclimate quality and take into design consideration which could improve understanding of sustainable development [5]. The main problem related to thermal comfort in the tropics is the cold and hot air movement [6]. He explains that thermo-physiological differences between indoor and outdoor spaces which differ by clothing type, activity level, and solar radiation.

Table 1. Classification of thermal comfort sensation [7]

PMV	PET	Thermal Sensation	Level of Heat Stress
- 3.5	14	Very cold	Extreme cold stress
- 2.5	18	Cold	Strong cold stress
- 1.5	22	Cool	Moderate cold stress
- 0.5	26	Slightly cool	Slight cold stress
0		Neutral	No thermal stress
+ 0.5	30	Slightly warm	Slight heat stress
+ 1.5	34	Warm	Moderate heat stress
+ 2.5	38	Hot	Strong heat stress
+ 3.5	42	Very hot	Extreme heat stress

3. Climate-Sensitive Urban Design

Climate-Sensitive Urban Design is defined as a process that takes into the basic elements of the microclimate (sun, wind, and temperature) for designing purposes [8]. Its application is not only beneficial to a specific site but also it's surrounding through appropriate planning and design. As a concept in a tropical climate, the availability of access to public spaces and pedestrian pathways improved quality become an aspect of tropical climatic conditions approach [9]. In other words, inter-building spaces must be designed sensitive to climate and utilized good accessibility persons.

A design strategy to improve the physical environment quality is a specific step to embody a thermally comfortable development area. There are two parameters that considered in designing responsive areas for micro-climate change, physical and non-physical parameters [9]. Urban geometry such as building average height, a gap within, building H/W ratio, and buildings configuration can affect climate conditions in the area [10]. The effect of buildings on wind conditions and on roads, as well as wind and solar conditions on pedestrian comfort, were examined to find out the strong relationship between urban form and climate, where the road position and the building dimensions affect the city climatic conditions [11]. There are the most frequently used factors in various studies for non-physical parameters, such as air temperature (° C-Celsius, ° F-Fahrenheit, ° K-Kelvin), relative humidity (%), wind speed (m/s, km/h, knots, and mph), and solar radiation (MJ/m^2)

The designs that respond to microclimate conditions have been formulated by urban designer experts with specific principles for each climate area worldwide to enhance the passive energy utilization. This principle can be applied on an urban scale especially in the tropics and can be divided into urban and building environment.

Table 2. Design principle of climate sensitive urban design in tropical climate

Urban Environment	Building Environment
The widening of streets along the prevailing wind direction is considered of high effectiveness, especially for large sites facing narrow urban canyon with building setback on each side of the street [12]	Compactly integrated developments and podium structures with full of large ground coverage on extensive sites which impeding air movement should provide setback parallel to the prevailing wind and reduce site coverage of podium to allow more open space at grade [12]
Buildings should be parallel or up to 30 degrees to the prevailing wind direction to maximize the penetration of prevailing wind through the district [12,13]	Permeability and shading are the main requirements of the building. All vertical surfaces and openings should be protected but not blocking the movement of the wind. Arrangement of landscape and architectural elements should be combined to create a comfortable indoor and outdoor environment [12]
The position of the road on the slope 30° and 60° from the wind direction can enlarge the movement of the wind [13]	Creating free space between buildings to maximize indoor and outdoor ventilation [12,14]
Outdoor space should be shaded from buildings and the availability of vegetation must not block free passage of air [14]	A varying height profile with strategic disposition of low-rise and tall buildings in the dense urban context can help instigate wind flowing throughout the area [12,15]
Cultivate vertical landscaping with vines on the wall or pergola [16]	Using ground cover materials with light and reflective colors can help reduce the urban heat island effect [12]
Waterfront area should be given to appropriate scale, height and disposition of building blocks along the waterfront to avoid blockage of sea/land breezes and prevailing winds [12]	The most suitable orientation for Indonesian territory especially Jakarta which located at 6° south latitude is 10-30 ° from the southern direction which can be applied to areas with latitude 5°-9° [9]
	To circulate the wind flow at the pedestrian level, sufficiently dimensioned corridors between podium should be assured. [15]
	The ratio of the width and length of the building to the optimum humid tropics is 1: 3. [17]

4. Methodology

The quantitative method was exploited in this research, which emphasized the data collection and analysis of information in numbers, collected both individual and group measuring instruments values, and stressed in comparing between groups or linking the individual or group factors within experiments, correlation studies, and surveys [18]. This method was taken by analyzing a simulation result using Envi-Met program to find out the amount of air temperature, wind speed, relative humidity, and PMV in the particular area.

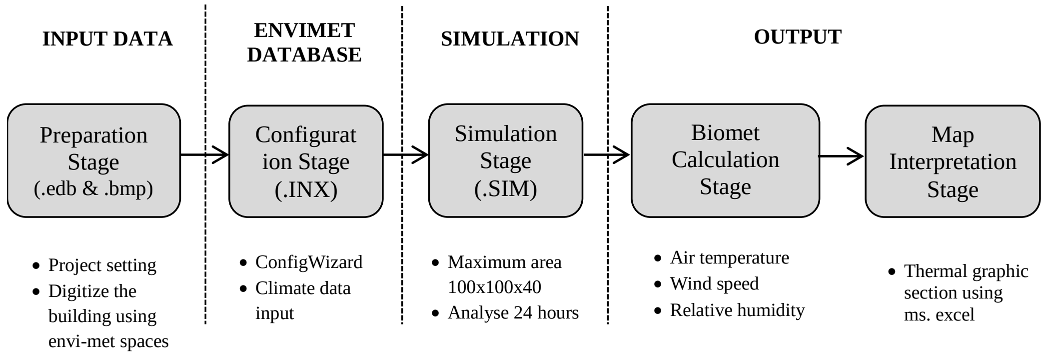


Figure 1. Envi-Met Simulation Stages

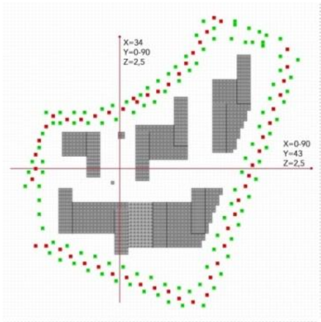
5. Study Area

The site was located in Gunung Sahari Utara, Sawah Besar District, Central Jakarta, in Pekan Raya Jakarta (PRJ) southern area 7.18 hectares of designed area and functioned as trading and services office zone with low Building Coverage Ratio (BCR). According to Panduan Rancang Kota Bandar Kemayoran 2014, the building intensity provisions has 71.892 m^2 of total area, 40% of BCR with a maximum FAR was 7, a maximum 48 floors of building height, and green plot ratio was 30%.

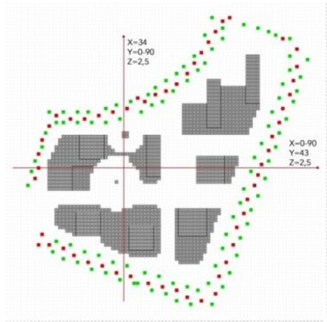
Table 3. Data Configuration of Envi-Met Simulation

Configuration Data	February 15th	October 17th
Boundary model	450m x 450m	450m x 450m
Grids	90x90	90x90
Start Simulation at Time (HH:MM:SS)	06:00:00	06:00:00
Total Simulation Time in Hours	24	24
Save Model State each? Min	30	30
Wind Speed in 10 m ab. Ground (m/s)	1,6	1,9
Wind Direction	315° (+30°)	270° (+30°)
(0: N..90: E..180: S..270: W)		
Roughness Length z0 at Reference Point	0,01	0,01
Initial Temperature Atmosphere (C)	24	29
Specific Humidity in 2500 m (g/kg)	7,0	7,0
Relative Humidity in 2 m	88	72
[BUILDING] Building Properties		
Inside Temperature [K]	293	293
Heat Transmission Walls [W/m^2K]	1,94	1,94
Heat Transmission Roofs [W/m^2K]	6	6
Albedo Walls	0,65	0,65
Albedo Roofs	0,75	0,75
[SOILDATA] Settings for Soil		
Initial Temperature Upper Layer (0-20cm) [K]	301	301
Initial Temperature Middle Layer (20-50cm) [K]	301	301
Initial Temperature Deep Layer (below 50cm) [K]	301	301
Relative Humidity Upper Layer (0-20cm)	60	60
Relative Humidity Middle Layer (20-50cm)	70	70
Relative Humidity Deep Layer (below 50cm)	70	70

The thermal comfort comparison was employed in outdoor space, the examination was done by developing two alternative designs using climate-sensitive design principle. The first alternative was a building configuration which was according to the building ideal shape in a tropical area with length and width ratios was 3: 1 [17] and the second one was a building arrangement which was based to the building typology, whether a residential, hotel, office or commercial building type.



a. Design alternative 1



b. Design alternative 2

Figure 2. Site digitized through Envi-Met spaces features

6. Results and Discussion

6.1. Air Temperature

The air temperature at 5 pm in the afternoon was higher than 7 am in the morning and afternoon at 12 pm. The area of the plaza and public open space which were located at the border area at 2.5 meters of altitude to represent the pedestrian level that has shown the air temperature was quite similar as shown in the graph below which the line tends to be stable.

The air temperature result of both design alternatives at 07 am, on February 15th, 2016 as much as 34% of the area is mostly in 24.40°C - 24.45°C of air temperature, while the most area of 2nd alternative design was in 24.35°C - 24.40°C of the air temperature about 27%. On October 17th, 2016, as many as 41.17% of air temperature in 1st alternative design was in the range of 27.40 ° C - 27.60 ° C, while the 2nd design alternative the most air temperatures were in the same range as the 1st but as much as 43%. Based on the comparison, it can be seen that the alternative air temperature of the 1st alternative design was slightly lower than the 2nd.

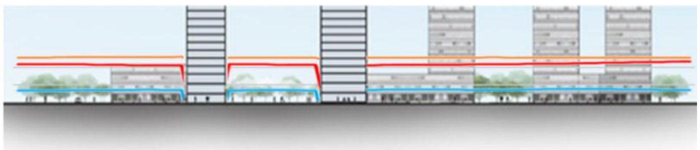
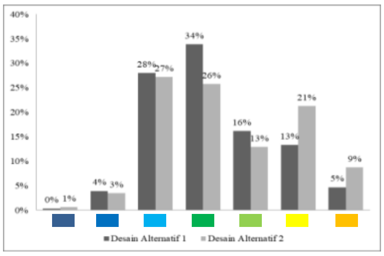


Figure 3. Graphic of air temperature design alternative 1



a. February 15th, 2016

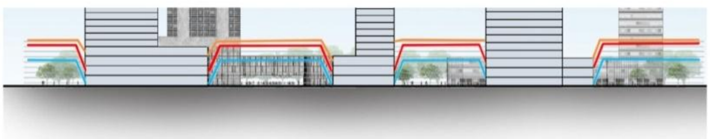
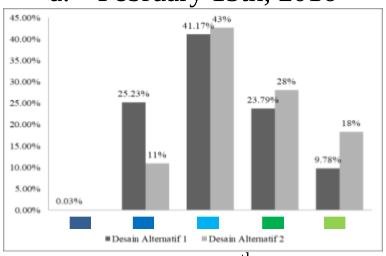


Figure 4. Graphic of air temperature design alternative 2



b. October 17th, 2016

Figure 5. Simulation result of air temperature at 7 am

6.2. Wind Speed

Wind speed in the plaza area located was the middle of the area in the 1st alternative design that looks higher in the graph than other alternatives, can be observed in Figure 5 and 6 which shows the cut graph at all simulation times. Visible graphs increase in the plaza area which indicating 1 m/s of wind movement. On February 15th, the wind speed between 07 am, 12 pm and 5 pm was 0 - 2 m/s. And on October 17th, the wind speed in the central area of a wind condition design in the green space area was almost the same, with the wind power perceived by Beaufort scale largely quiet to a slight wind (0.28 – 3,32 m/s). Overall wind speed at 07 am in the morning also tends to be higher than the other two simulation time which was at 12 pm and 5 pm.

On October 17th, 2016, 18% of the wind speed in 1st alternative design was 1.25 m/s - 1.50 m/s, while in 2nd alternative design as much as 23% by the same wind speed range of 1.25 m/s - 1.50 m/s. Based on these comparisons, it appears that the wind speed on February 15th, design alternative 1 tends to be higher than the design alternative 2. While on October 17th, the 2nd has higher wind speed than design alternative 1.

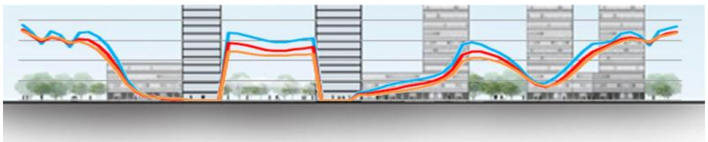
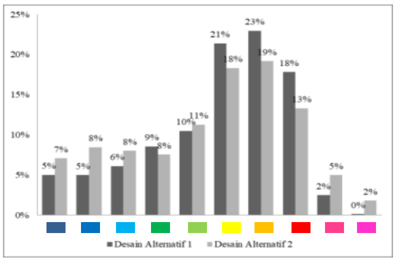


Figure 6. Wind speed graphic of design alternative 1



a. Design alternative 1

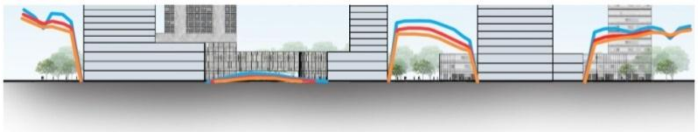
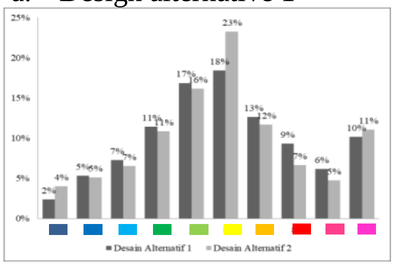


Figure 7. Wind speed graphic of design alternative 2



b. Design alternative 2

Figure 8. Simulation result of wind speed at 7 am

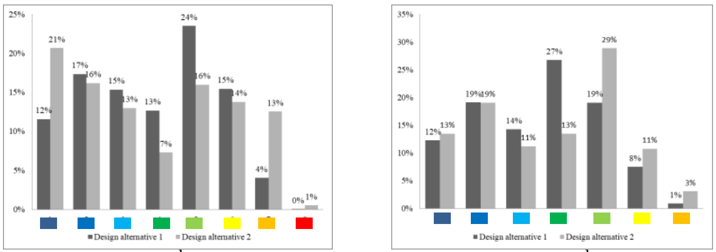
6.3. Relative Humidity

Relative humidity of the area at three specified times has a range of values between 50% - 80% of the highest relative humidity being at 07 am with 70% - 80% of humidity. The humidity were decreased by about 65% - 73% at 12 pm and at 5 pm the relative humidity became 54% - 63%.

The relative humidity comparison from both alternatives design can be seen that relative humidity at 07 am was higher than at 12 pm and 5 pm. The relative humidity value was lower in the afternoon and evening, just as wind speeds were getting lower at 12 pm and 5 pm. The relative humidity in 1st and 2nd alternative designs were measured at three times and it has a humidity between 54% - 77%.

Figure 9. Relative humidity graphic of design alternative 1

Figure 10. Relative humidity graphic of design alternative 2



a. February 15th 2016 b. October 17th 2016

Figure 11. Simulation result of relative humidity at 7 am

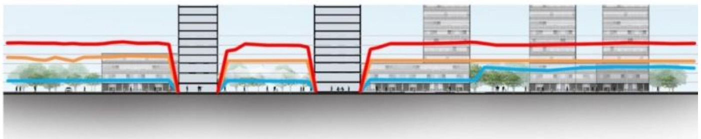
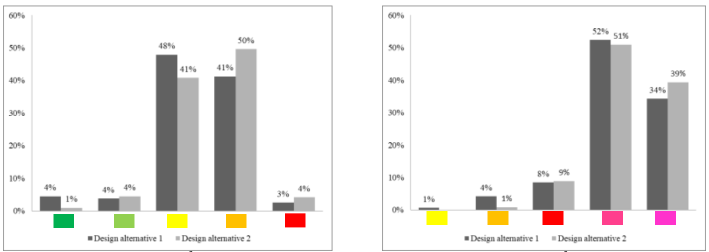


Figure 12. PMV graphic of design alternative 1

Figure 13. PMV graphic of design alternative 2



a. February 15th, 2016 b. October, 17th 2016

Figure 14. Simulation result of PMV at 12 pm

6.4. PMV

Based on the simulation results, the PMV condition at 07 am were in the range of +0,5 to + 2,5 by the thermal conditions from slightly warm to hot. While at 12 pm, the PMV rises to +3.5 were very hot conditions, and at 5 pm the condition is slightly more comfortable than at 12 pm specifically from +2.5 to +3.5.

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The PMV comparison values at both alternatives design were analyzed by looking at the PMV value at 12 pm due to the value was highest compared to other times at 7 am and 5 pm, therefore, it can be used to see the thermal comfort level which felt by some people in hottest thermal condition.

Figure 13 shows that the PMV value at 1st alternative design tends to be lower than the 2nd. The values were indicated by the minimum and maximum value either on February 15th or October 17th.

6.5. Surface Area to Volume Ratio

Surface area to volume (S/V) ratio was one of the important factors that determined the heat transfer. The greater surface area affected the heat to received and released faster in the building, so the minimum value of S/V ratio imposes the minimum heat transfer [19].

After calculating the S/V value of each building block and the total areas, the value of 1st alternative design has a value of 0.123, higher than the 2nd design which has a value of 0,015. It means that buildings at 2nd alternative design received less heat from outside, therefore the thermal conditions in the building will be lower than the 1st design.

6.6. Solar Radiation Analysis

To find out the level of solar radiation in the area through 1 year, Sun Hours program was used to calculate the solar exposure which was indicated by a color grid that represents the intensity level. The darker the color of the area, the more exposed to solar radiation in 1 year.

The comparison results in Figure 15 show about 60% - 80% both of the area was exposed to solar radiation or more than 2373 hours per year, while the 2nd alternative design has a higher solar radiation intensity than the 1st, therefore it was cooler than the 2nd alternative.

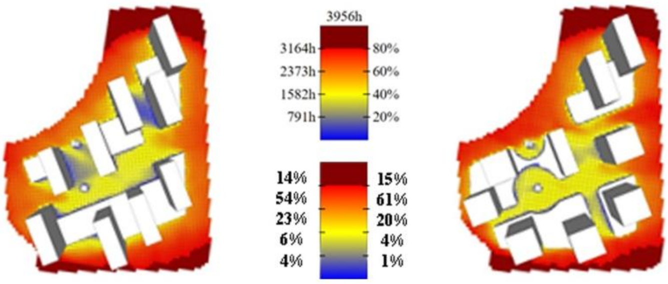

Figure 15. Solar radiation analysis

7. Conclusion

Based on the analysis, thermal conditions in Jakarta in the afternoon on 5 pm were the highest air temperature rather than 7 am and 12 pm. It was caused by the buildings material that stores heat from noon to evening and just released at night. Wind speed has an important role for improving thermal comfort in outdoor space in Jakarta compared to building shading based on solar radiation analysis as the solar radiation level result in outdoor were quite high about 60-80% for 1 year, through the site.

A building configuration with a shape ratio of 1: 3 according to the tropics was more optimally thermal outdoor space than the building configuration with typology which based on shading and air movement analysis.

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