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Outdoor Thermal Comfort and Sustainability of Urban Village Life in The Small Ancient City at Tropic Area Yogyakarta, Indonesia: Approach with ENVI-Met

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Abstract

Several studies examining urban villages, sustainability, and their relation to thermal comfort in Indonesia have stated uncomfortable perceptually. Through this research which was conducted in an urban village in Yogyakarta by using the thermal measurement method, shows that average temperature reaches 30.14°C, humidity 72.90%, wind speed 0.93 m/s, MRT 44.70°C, PMV 0.79 or warm sensation. It shows that thermal comfort in urban villages is still in normal condition. However, several intervention variables which are used in the simulation using ENVI-met to get the better thermal condition do not significantly change the thermal parameters, but only slightly. The sensation remains warm, at certain times it is hot or very hot, the highest PPD level achieved is 59%. Even though the results are less than expected, based on the range of thermal comfort standard the current thermal comfort still supports sustainable urban living.

Keywords: sustainability; simulation; thermal comfort; tropical climate; urban village.

Introduction

Indonesia is a tropical country with high humidity and hot temperatures like most other tropical countries, in almost all regions of Asia, parts of South America and Africa (Ahmed et al., 2016; Das et al., 2020; Efeoma & Uduku, 2014; Karyono, 1996; Nicol, 2004; Shaeri et al., 2018; Sharmina et al., 2019). Outdoor thermal comfort in Indonesia has been extensively researched by Karyono (2015) which results in measurements that the air temperature ranges between 25°C - 34°C, mean radian temperature (MRT) ranges between 32°C - 58°C, humidity ranges between 55% - 80%, wind speed ranges between 0.12 - 2 m/s and predicted mean vote (PMV) ≤ 3,5 means the thermal sensation is very hot or extreme heat stress. Each researcher has their own opinion on the standard of thermal comfort in the tropics. According to Koch-Nielsen (2002) the temperature is 28°C to get optimum thermal comfort. Nicol (2004) stated that outdoor thermal convenience in the tropic regions is represented by temperature < 30°C, MRT about 10°C - 40°C, wind speed about 1.0 m/s, humidity

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about < 80% and PMV between -2 and +2. Sharmina et al. (2019) stated that thermal comfort for tropical humidity range between 29°C - 32°C.

Indonesia has many cities consisting of ancient settlements which in the past were centers of business and trade. Among the popular ones are the ancient cities on the island of Java, one of which is Yogyakarta, which is in the middle of the island of Java. This city has distinctive characteristics because of the large number of urban villages that are currently maintained as cultural heritage due to their role in the history of the formation of cities in the past. Urban villages in Indonesia have a big issues related to sustainability and resilience like most urban villages in other countries such as China (Chen & Zeng, 2020; Jiang et al., 2022; Li et al., 2022; Oostrum, 2021), India (Sarkar & Bhattacharyya, 2015), Bangladesh (Tariq, 2014), Malaysia (Samsurijan et al., 2017; Shaw et al., 2016), also in Vietnam (Thinh & Thinh, 2022). The growth of the city and the rapid development of high-rise buildings have directly destroyed and threatened the sustainability of its inhabitants, whereas the urban village is a residential entity which has certain meaning and philosophy preserved and protected.

Several studies in Indonesia that have been conducted on urban villages and their sustainability, found a number of important issues such as sanitation, communal space, public space, green space, waste, thermal comfort, and disaster mitigation as element affecting sustainability (Sui & Yao, 2018). On the other hand, a number of studies also examine important social, economic, and cultural issues as strong factors influencing sustainability (Marpaung, 2017; Shirleyana et al., 2018). Among the issues in this study outdoor thermal comfort will be discussed and its relation to sustainability of lives of its inhabitants as thermal comfort greatly affects their daily life. Thermal comfort is a serious concern, since a number of previous studies stated that urban villages are very uncomfortable thermally (Amelia, 2021; Amelia & Kusumawanto, 2020; Hartanta & Kusumawanto, 2020; Leny et al., 2015; Nugrahaini, 2016; Sumintarsih & Andrianto, 2014) though the truth is, the citizens still feel comfortable living in it even downward. This is what makes thermal comfort a fundamental issue in urban living research.

Urban villages in Yogyakarta are located in mixed-use areas and some of them are heritage buildings. Currently the urban village area is a conservation area. The density of buildings due to the number of tall buildings such as hotels and malls, as well as the narrowness of land, is a threat to the sustainability of the existence of urban villages and their inhabitants. These conditions affect the increase in temperature in the surrounding area, as well as the situation in urban villages. Nevertheless, it must be acknowledged that the increasing temperature in urban areas is inseparable from the impact of urban development. Several previous studies conducted in Yogyakarta (**Table 1**) mentioned that temperatures were in the range between 23.4°C - 38.2°C, with humidity between 59.9% - 78%, wind speed between 0.23 m/s – 1.36 m/s, MRT in the range between 36°C - 50°C, and PMV on level hot tend to very hot or extreme heat stress. Through this research, the existing thermal conditions of the urban villages will be discussed, then with modeling and simulation approach using the ENVI-met software, it is expected to produce a sustainable urban village arrangement model with more comfortable thermal conditions.

Table 1

Previous Research Related to Thermal Comfort in Urban Villages in Yogyakarta

Previous Researcher	Temperature	Humidity	Wind Speed	MRT	PMV
Dhiningsih (2018)	29,8°C - 33,8°C	78,0%	1.36 m/s	50°C	Not Available
Leny et al. (2015)	23,4°C - 38,2°C	59,9%	1.0 m/s	40.8°C	Not Available
Kartikawati and Kusumawanto (2013)	28°C - 36°C	71,3%.	0.23 m/s	36°C	+2.4 (Hot/Strong Heat Stress)
Octarino (2021)	30°C- 31°C	76,2%	1.0 m/s	40.2°C	+2.6 (Hot/Extreme Heat Stress)

Method and Materials

The research was conducted by direct survey method in the field which was divided into four field zones namely Zone 1 (Sosrokusuman Village), Zone 2 (Suryatmajan Village), Zone 3 (Pajeksan Village), and Zone 4 (Jogonegaran Village) as seen in Fig. 1. The reason why these areas were chosen is because it is the centre of the activity of the area, where the height and function of the buildings have a high variation, between commercial and residential, representing a mixed-use area.

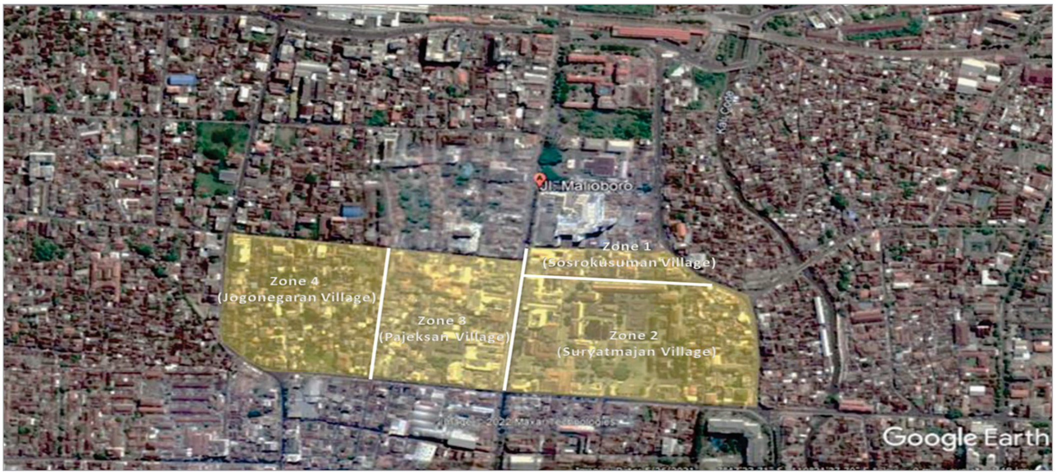


Fig. 1

Intensive Observation Area in The Mid of Ancient City Yogyakarta Indonesia Source:www.google.com (2022)

Table 2

Scale of Thermal Index Predicted Mean Vote (PMV) based on ASHRAE

PMV	Thermal Sensation	Level of Heat Stress
-3.5	Very cold	Extreme cold stress
-2.5	Cold	Strong cold stress
-1.5	Cool	Moderate cold stress
-0.5	Slightly cool	Slightly cold stress
0	Neutral	No thermal stress
+0.5	Slightly warm	Slight heat stress
+1.5	Warm	Moderate heat stress
+2.5	Hot	Strong heat stress
+3.5	Very hot	Extreme heat stress

Source : Modified by Matzarakis and Mayer (1997)

The observed objects are including the psychological factor on the perception of thermal comfort using PMV (see Table 1) (Fanger, 1970; Fanger, 2001; Hoof, 2008), and physical factors carried out on building dimensions, distance between buildings, setback, ratio of road width and building height, distribution and type of vegetation, air temperature, humidity, wind speed, radiation, human activity, and clothing insulation (Fanger, 1970). The PMV will be used as a basic assessment of urban village thermal comfort. In addition to PMV, it is also necessary to calculate the level of dissatisfaction with thermal conditions using the Predicted Percentage of Dissatisfied (PPD) so the level of dissatisfaction with thermal conditions can be measured with certainty. After performing outdoor thermal measurements on both psychological-perception and physical factors, the next stage is simulation with modelling until the most optimal thermal conditions can be achieved.

The equipment that will be used are microclimate measuring instruments, such as thermometers, thermos hygrometer, and anemometer. Another instrument is a questionnaire for a perceptual survey of thermal comfort. Modeling will be carried out using ENVI-Met software. This software is used considering its capabilities in producing the three-dimensional modeling of the urban environment as well as simulating several parameters related to outdoor thermal conditions within the area (Chatzinikolaou et al., 2018; Salata, Golasi, et al., 2016). The software also has capabilities in simulating heat exchange on the surface of land and buildings, transpiration, and plant evaporation (Abdollahzadeh & Biloria, 2021; Manteghi et al., 2016; Nouri et al., 2018; Rosheidat et al., 2008; Salata, Roberto, et al., 2016; Salvati et al., 2022; Tariq, 2014). ENVI-Met refers to the basic laws of fluid dynamics and thermodynamics that have many simulation modules.

To support the analysis of thermal data, daily thermal data in Yogyakarta will be taken for comparation from the actual yield measurements. The average of temperature about 26.6°C, average of humidity about 83.7%, and the annual average wind speed about 1.61 m/s (Yogyakarta, 2022). Analysis of the existing conditions of outdoor thermal comfort will be carried out at an altitude of 1.5 m according to the average height of Indonesian people, in a duration of about 9 hours and starting from 08:00 a.m. -17:00 p.m. local time. This simulation is assumed to apply to all observed zones, as seen in Table 3 for details.

Table 3

Simulation Configuration Data of ENVI-Met

Configuration Data	Zone 1	Zone 2	Zone 3	Zone 4
Dimension of model (x, y, z)	50x40x30	45x40x30	50x40x30	50x50x30
Grid size (dx, dy, dz)	1 x 1 x 1			
Simulation Time	08:00 AM - 17:00 PM			
Total simulation time	9 hours			
Air temperature (°C)	Min. 23; Max. 32			
Relative humidity (%)	Min.70; Max. 90			
Windspeed (m/s)	1			
Wind direction (◦)	230			

Source: Author, 2022

Thermal Comfort Measurements Results

Situation of Urban Villages

Buildings in the urban neighbourhood of the observed village are dominated by one-storey buildings with various functions such as dwelling houses, boarding houses, and lodging. Building density is very high. The road width is about 1 meter, and the average building's height is 4 meters. Circulation path conditions exist between buildings that lead from north to south. The type of pavement is in the form of paving block with a length of 30-38 meters. In short, it can be described that the environment of these urban villages is very crowded and has many difficulties in mobility (see Fig. 2).

Fig. 2

The Situation of Ancient Urban Village in Yogyakarta

Source: Author, 2022

Inhabitants Thermal Sensation

Based on the results of interviews with residents in the village involving 120 respondents who were selected randomly, it was found that temperature conditions in the villages were hot (72,63%) up to very hot (18.95%), with only view respondents who felt neutral (8.42%). The air humidity felt between neutral (12,63%), moderate humidity (50.53%) and high humidity (36.84%). Wind gusts were almost imperceptible between neutral (10.53%), stuffy (71.58%), and very stuffy (17.89%), so that the body sweats easily. Solar radiation (MRT) was felt not sufficient by 6.32% respondents, felt neutral by 10,53% respondents, quite sufficient by 56.84% respondents, and very sufficient by 26.32% respondents. The results of the survey are presented in the Table 4.

Table 4

Residents' Perception on Weather Parameters (From 120 residents who interviewed)

Parameters	Perceptional Answer				
Temperature	Very Cool	Cool	Neutral	Hot	Very Hot
	(0.00%)	(0.00%)	(8.42%)	(72.63%)	(18.95%)
Humidity	Very Dry	Dry	Neutral	Moderate Humidity	High Humidity
	(0.00%)	(0.00%)	12.63%	(50.53%)	(36.84%)
Wind Speed	Very Windy	Quite Windy	Neutral	Stuffy	Very Stuffy
	(0.00%)	(0.00%)	10.53%	(71.58%)	(17.89%)
Radiation	Very Sufficient	Quite Sufficient	Neutral	Not Sufficient	Very Insufficient
	(26.32%)	(56.84%)	10.53%	(6.32%)	(0.00%)

Source: Based on Field Survey by Author, 2022

The measurement of thermal comfort is influenced by the metabolic rate (MET), namely human activity that affects the body's heat output and is related to the metabolic rate during sitting, standing, and walking. Based on the measurement results, most of the respondents felt a hot sensation while standing (32.6%) and walking (42.1%). Thus, in fact, the people of this village are very uncomfortable when engaging in any activity with 77.9% of the respondents feeling hot sensation (Table 5). As urban residents, almost all habitants have high daily activities. The hot temperature is quite enough to make them feel uncomfortable sensation, they feel a hot sensation. However, daily activities as a trader, shop owner, and daily household activities continue as usual. The residents try to overcome hot sensation with air conditioning, fans, or creating small gardens around the house.

Table 5

Perception of Thermal Sensation Based on Activity (From 120 residents who interviewed)

Activities	Resident's Thermal Sensation (%)					
	Very Cool	Cool	Neutral	Warm	Hot	Total
Sitting	0	0	2.1	1	3.2	6.3
Standing	0	0	4.2	5.3	32.6	42.1
Walking	0	0	7.4	2.1	42.1	51.6
Total	0	0	13.7	8.4	77.9	100.0

Temperature

Based on measurements of air temperature, average temperature in all coverage areas was 30.14°C. The lowest temperature occurs at 08:00AM of 25.56°C in Zone 2, in the other zones is higher. The highest temperature occurs at 13:00 PM of 30.58°C in Zone 2, in other zones are lower. The results of temperature measurements are presented in Table 6.

Observed Zone	Minimum	Local Time	Maximum	Local Time	Average
Zone 1	26.14	08:00 AM	32.01	13:00 PM	30.07
Zone 2	25.56	08:00 AM	32.58	13:00 PM	30.23
Zone 3	25.59	08:00 AM	32.38	13:00 PM	30.03
Zone 4	25.89	08:00 AM	32.37	13:00 PM	30.21
Average All Area	25.80		32.34		30.14

Table 6

Result of Temperature Measurement (°C)

Humidity

The highest humidity occurred at 08:00AM reaching 86.67% in Zone 3, in the rest zones are lower and the lowest point, reaching 66.28%, occurred at 16:00PM in Zone 2, with an average humidity reach of 72.90%. The results of humidity measurements are presented in Table 7.

Observed Zone	Humidity (%)				
	Minimum	Local Time	Maximum	Local Time	Average
Zone 1	66.60	16:00 PM	82.89	08:00 AM	71.48
Zone 2	66.28	16:00 PM	86.11	08:00 AM	72.96
Zone 3	66.75	16:00 PM	86.67	08:00 AM	73.19
Zone 4	67.97	16:00 PM	86.25	08:00 AM	73.98
Average All Area	66.90		85.48		72.90

Table 7

Result of Humidity Measurement

Wind Speed

The average wind speed in all of areas reaches 0.93 m/s. The highest wind speed occurred at 13:00PM at 1.21 m/s in Zone 1, and in the other of zones is lower. The lowest wind speed occurs at 09:00AM at 0.68 m/s in Zone 2. The results of wind speed measurements are presented in Table 8.

Observed Zone	Average of Wind Speed (m/s)				
	Minimum	Local Time	Maximum	Local Time	Average
Zone 1	1.15	09:00 AM	1.21	13:00 PM	1.18
Zone 2	0.68	09:00 AM	0.81	13:00 PM	0.76
Zone 3	0.88	09:00 AM	0.92	13:00 PM	0.90
Zone 4	0.83	09:00 AM	0.91	13:00 PM	0.89
Average All Area	0.89		0.96		0.93

Table 8

Result of Wind Speed Measurement

Mean Radian Temperature (MRT)

The average solar radiation temperature (MRT) measurement results reached 57.19°C at 12:00 PM as the maximum temperature and occurred in Zone 1. The lowest point reached 26.03°C at 17:00 PM and occurred in Zone 1. Total average radiation temperatures from all of areas are quite higher and reached 44.70°C, while normal MRT should be less than 40°C (Nicol, 2004). The results of MRT measurements are presented in Table 9.

Table 9

Result of MRT Measurement

Observed Zone	MRT (°C)				
	Minimum	Local Time	Maximum	Local Time	Average
Zone 1	26.03	17:00 AM	57.19	12:00 PM	45.62
Zone 2	25.80	17:00 AM	54.74	12:00 PM	44.49
Zone 3	26.85	17:00 AM	51.85	12:00 PM	43.97
Zone 4	26.92	17:00 AM	55.39	12:00 PM	44.72
Average All Area	26.40		57.79		44.70

Predicted Mean Vote (PMV) and Predicted of Percentage Dissatisfaction (PPD)

PMV is a thermal comfort index that involves climatic data consisting of air temperature, average solar radiation, wind speed, air humidity, and human parameters including clothing, and type of activities (Fanger, 1970). In this study, all thermal variables are taken from the climatic data that have been measured above, and the human parameter using clothing 'a typical summer indoor clothing' and the activity 'standing-relaxed'. The PMV measurements show that the minimum PMV value occurred at 09:00AM of -0.05 in Zone 2 with slightly cool sensation, and the highest value was obtained at 15:00PM of 2.58 in Zone 2 with hot sensation or strong thermal stress. The average PMV in all observed zones is 0.79 or warm sensation with moderate stress level (see **Table 10**). All the measurement results-are still within reasonable limits according to the Fanger's thermal comfort scale (see **Table 2**), and if compared to previous studies in the same area are significantly different (see **Table 1**). Previous studies produced +2.4 and +2.6, which means that the research areas which are observed are cooler than the locations in previous studies.

Table 10

Result of PMV Measurement

Measurement Time	Zone 1	Zone 2	Zone 3	Zone 4	Average PMV	Thermal Sensation
08.00	-0.56	0.48	-0.28	-0.47	-0.21	Slightly Cool
09.00	-0.01	0.05	-0.08	0.10	0.02	Slightly Warm
10.00	0.33	0.17	0.30	0.60	0.35	Slightly Warm
11.00	0.61	0.88	0.72	0.91	0.78	Slightly Warm
12.00	0.92	1.44	1.12	1.33	1.20	Warm
13.00	1.19	2.58	1.42	1.68	1.72	Hot
14.00	1.10	1.46	1.27	1.56	1.35	Warm
15.00	0.94	1.28	1.10	1.33	1.16	Warm
16.00	0.70	0.99	0.86	1.04	0.90	Warm
17.00	0.46	0.70	0.62	0.74	0.63	Warm
Average	0.57	1.00	0.71	0.88	0.79	Warm

To ensure the PMV calculation results, it is also necessary to look at the value of the PPD which will show the percentage of dissatisfaction from residents. **Table 11**. shows the calculation of PPD. Levels of dissatisfaction began to be felt at 11:00 a.m. with PPD average of 18%, it continued to increase successively until 13:00 p.m. then decreased until 17:00 p.m. Thus, the highest dissatisfaction was felt from 11:00 a.m. to about 15:00 p.m. Peak time occurred at 13:00 p.m. with 59% of dissatisfied. **Fig. 3** shows that PPD and PMV do not show thermal neutral.

Table 11

Result of Predicted Percentage of Dissatisfied (PPD)

Measurement Time	Zone 1	Zone 2	Zone 3	Zone 4	Average PPD
08.00	12%	10%	7%	10%	10%
09.00	5%	5%	5%	5%	5%
10.00	7%	6%	7%	12%	8%
11.00	13%	21%	16%	22%	18%
12.00	23%	48%	32%	42%	36%
13.00	35%	94%	47%	61%	59%
14.00	31%	49%	38%	54%	43%
15.00	24%	38%	30%	42%	34%
16.00	15%	26%	21%	28%	23%
17.00	9%	15%	13%	16%	13%
Average	17%	31%	22%	29%	25%

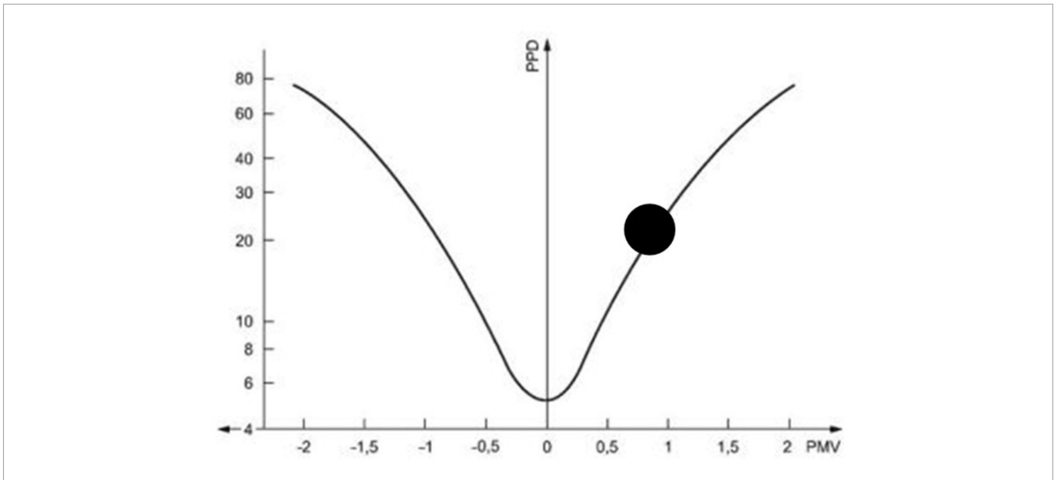


Fig. 3

PPD Measurement

Discussion

Karyono (2015) sets higher standard to max 2 m/s; The radian temperature (MRT) is 44.70°C, this means exceeding the MRT standard limit by 40°C (Nicol, 2004), but still tolerable according to Karyono (2015) who sets the standard MRT 32°C - 58°C; The PMV about 0.79 with warm sensation or moderate thermal stress, it means still within the range of PMV standard values by -2 to +2 (Nicol, 2004) and also according to Karyono (2015) where the PMV should be less or equal to 3.5, , even when compared with two previous studies conducted by Kartikawati and Kusumawanto (2013) with +2.4 and Octarino (2021) with +2.6. The thermal comfort sensation in this research area is much better. There is a possibility of differences due to differences in season and time of measurement, in Indonesia there are 2 seasons, rainy and dry. Measurement time is in hours and duration. Another possibility is due to the accuracy factor in data input. PPD average is 25%, dissatisfaction level of thermal comfort increases at 11:00 a.m. to 15.00 p.m., reaching the peak time at 13:00PM with PPD of 59%, continues to decline until 17.00 p.m.. Therefore, if referring to thermal comfort standards set by Karyono (2015) who has already intensively studied tropical thermal comfort, the urban villages in Yogyakarta are still comfortable and support sustainable living, but if referring to Nicol (2004) the temperature and MRT are still higher than normal standard.

When compared with the average local climate data the results of the calculation show a higher temperature of 30.14°C, whereas the average temperature in Yogyakarta is at 26.6°C, the humidity is 72.90% or lower than the average humidity of about 83.7%, and the wind speed is 0.93m/s, it means lower than the average wind speed of about 1.61 m/s. However, based on the previous research related to urban village (Table 1.) The measurement results show almost the same results. This means that since many years ago the thermal conditions in the urban village area have been quite the same. Although citizens feel warm and uncomfortable as seen from the perception in Table 4. and Table 5, based on the calculation of thermal conditions, it is still tolerable.

Traditional Ways Practicing Greenly Environment

Outdoor thermal comfort will greatly affect the activities of its inhabitants. Differences in location, morphology and typology will affect the results of the formed thermal comfort. In urban areas, someone who is active will experience a large increase in heat if they stand in an open place without shading and are on paved roads (Rosheidat et al., 2008). The morphology of the village will result in differences in outdoor temperature on building facades with higher temperatures, this will, of course, be significantly related to outdoor thermal comfort (Chatzinikolaou et al., 2018).

However, the results of measurements in urban villages in Yogyakarta which were carried out at four observation points produced conditions of thermal comfort that tended to be warm or moderate heat stressed level. This is different from the sensation felt by residents who feel the air temperature is hot or event very hot (see Table 4). This condition will certainly pose a threat to the comfort of residents on an ongoing basis, it needs to be anticipated so the air temperature does not get higher. There are several studies that have tried to reveal the right strategy to overcome these things, Sari et al. (2017) argue that by changing the typology of the road and the presence of edible plants as greenery will greatly affect the temperature conditions in residential spaces. Manteghi et al. (2016) said that vegetation and water bodies would be able to effectively reduce the temperature in cities between 0.5°C to 4.0°C.

Currently, the residents of the urban village have independently created their own green spaces in addition to making environment cooler, making the air fresh, also because of the need for green space due to continuously narrowing space as impact of excessive urban development. The citizens are planting number of trees for both decorative and productive purposes, such as vegetables and pharmacological plants. They utilize empty land around the house or parts of the small fields to plant trees, hydroponic, and vertical gardens. Some of the photos (Fig. 4) below are an overview of society's efforts to reduce heat stress.

Fig. 4
Typical Green Space
Source: Author, 2022

Modelling and Simulation Using ENVI-met

Since the research was conducted by direct survey method which was divided into four field zones namely Zone 1 (Sosrokusuman Village), Zone 2 (Suryatmajan Village), Zone 3 (Pajeksan Village), and Zone 4 (Jogonegaran Village) then the simulation will be done on each zone. By using the ENVI-met software, the simulation will be carried out to obtained urban village with better thermal comfort. The simulation will be done with two scenarios namely Simulation A and Simulation B (see Table 12).

Simulation A is carried out with the following requirements :

1. adding crossroads by improving the network and pattern of internal roads,
2. adding open space and vegetation,
3. the dimensions of the buildings are fixed except for residential houses.

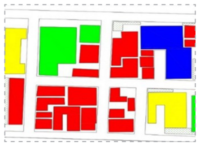
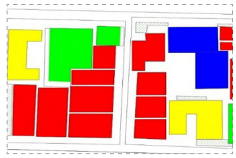
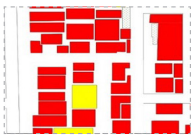
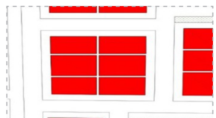
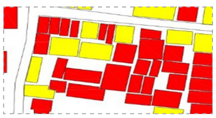
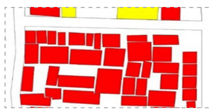
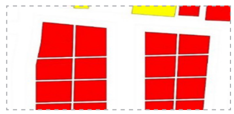
Simulation B is carried out with the following requirements :

1. the dimensions and layout of residential houses were improved,
2. the addition of open space and vegetation,
3. the pattern and network of internal roads were improved by adding intersections and increasing the width of the road.

Based on the simulation, even by adding a number of variables, the result does not significantly change the thermal condition with thermal sensation between slightly warm to warm. However, the average result of simulation A and B (Table 12) is bringing the change a little for each variable, such as the average temperature decreased from 30.14°C to 29.26°C in simulation B by -0.88°C or -2.9% but tended to increase in simulation A to 30.31°C (+0.17°C or +0.6%). The average MRT decreased from +44.70°C to 43.75°C in simulation A (-0.95°C or -2.1%), also decreased in simulation B to 44.49°C (-0.22°C or -0.5%). The average humidity increased from 72.90% to 74.22% in simulation A (-+1.32% or 1.8%) and become 74.80% in simulation B (-0.10% or -0.1%). The average wind speed from 0.93 m/s tended to increase in simulation A to 0.97m/s (+0.04m/s or 4.6%) and decreased in simulation B to 0.83m/s (-0.10m/s or -10.5%). The rate of PMV value decreased in simulation A to 0.75 (-0.05 or -5.7%) but increased in simulation B to 0.85 (+0.06 or 7.0%). The average PMV values show slightly warm to warm sensation from the existing +0.79, show decrease in simulation A to +0.75 (-0.05 or -5.7%) and increase in simulation B to 0.85 (+0.06 or 7.0%). The results of the simulation using ENVI-met at four observation zones are given in Table 12. However, if observed in detail each zone, it is clear that there are differences in the results for each simulated parameter. The differences in the results in each simulation scenario can be influenced by the assumptions included as requirements and also by differences in location conditions. Some intervening variables may have to be added (Chatzinikolaou et al., 2018; Salata, Golasi, et al., 2016).

Each simulation scenario has advantages and disadvantages. There are parameters that decrease but other parameters tend to increase. The only significant change was shown on temperature which turned to 29.26°C or decreased by 2.9% (Simulation B), and PMV decreased significantly in simulation A by +0.75 or -5.7%. There are several possibilities, why there are no significant changes, the area is too narrow while ENVI-met is capable of being used on a city scale. Although the visible changes seem insignificant, this simulation brings good results even though the numbers are small. The results of existing thermal condition measurements, even when compared to other previous research related to thermal comfort in tropical regions (Ahmed et al., 2016; Das et al., 2020; Karyono, 1996; Nicol, 2004; Paramita & Fukuda, 2014; Sharmina et al., 2019) are still acceptable. It means currently thermal comfort still supports sustainable urban living in Yogyakarta.

Table 12. Result of Simulation Using ENVI-met at Four Observation Zones

Location of Measurement	EXISTING CONDITION	**Requirements:** *Addition of crossroads by improving the network and pattern of internal roads, adding open space and vegetation, the dimensions of the buildings are fixed except for residential houses*			**Requirements:** *The dimensions and layout of residential houses were improved, the addition of open space and vegetation, the pattern and network of internal roads were improved by adding intersections and increasing the width of the road*		
		SIMULATION A			SIMULATION B		
Zone 1 (Sosrokusuman City Village)							
	Existing	Result	Change	Percentage	Result	Change	Percentage
Temperature:	30.07°C	30.01°C	-0.06	-0.2%	29.07°C	-1.00	-3.3%
MRT :	45.83 °C	43.90°C	-1.72	-3.8%	44.51°C	-1.11	-2.4%
Humidity :	71.48 %	73.48 %	+0.02	2.8%	70.48 %	+0.01	-1.4%
Wind Speed :	1.19 m/s	1.46 m/s	+0.28	23.7%	0.89 m/s	-0.29	-24.6%
PMV :	+0.57	+0.68	+0.11	19.3%	+0.80	+0.23	40.4%
Thermal Sensation	Slightly Warm	Slightly Warm			Slightly Warm		
Zone 2 (Suryatmajan City Village)							
Temperature:	30.44 °C	30.86°C	+0.63	2.1%	29.21°C	-1.02	-3.4%
MRT :	44.50 °C	44.68°C	+0.19	0.4%	44.62°C	+0.13	0.3%
Humidity :	72.97%	74.21%	+0.01	1.7%	73.87%	-0.01	1.2%
Wind Speed :	0.76 m/s	0.78 m/s	+0.02	2.6%	0.62 m/s	-0.14	-18.4%
PMV :	+1.00	+1.13	+0.13	13.0%	+1.01	-0.16	-16.0%
Thermal Sensation	Slightly Warm	Slightly Warm			Slightly Warm		
Zone 3 (Pejaksan City Village)							
Temperature:	30.07 °C	30.25°C	+0.22	0.7%	29.23°C	-0.80	-2.7%
MRT :	44.85 °C	42.86 °C	-1.11	-2.5%	43.14 °C	-0.83	-1.9%
Humidity :	73.42%	74.62%	+0.01	2.0%	73.84%	+0.01	0.9%
Wind Speed :	0.92 m/s	0.72 m/s	-0.18	-20.0%	0.69 m/s	-0.21	-23.3%
PMV :	+0.71	+1.02	+0.31	43.7%	+0.66	+0.30	42.3%
Thermal Sensation	Slightly Warm	Slightly Warm			Slightly Warm		
Zone 4 (Jogonegaran City Village)							
Temperature:	30.20°C	30.04 °C	-0.17	-0.6%	29.53°C	-1.00	-2.3%
MRT :	44.95 °C	43.57 °C	-0.40	-0.9%	45.67°C	+1.70	3.9%
Humidity :	73.31%	74.55%	+0.01	0.8%	73.02%	-0.01	-1.3%
Wind Speed :	0.88 m/s	0.80m/s	-0.09	-10.1%	0.91 m/s	+0.02	2.2%
PMV :	+0.88	+0.93	+0.05	5.7%	+0.73	-0.15	-17.0%
Thermal Sensation	Slightly Warm	Slightly Warm			Slightly Warm		
Average (4 Zone)							
Temperature:	30.14°C	30.20°C	+0.17	0.6%	29.26°C	-0.88	-2.9%
MRT :	44.70°C	43.75°C	-0.95	-2.1%	44.49°C	-0.22	-0.5%
Humidity :	72.90%	72.22%	+1.32	1.8%	72.80%	-0.10	-0.1%
Wind Speed :	0.93 m/s	0.97m/s	+0.04	4.6%	0.78m/s	-0.10	-10.5%
PMV :	+0.79	+0.75	-0.05	-5.7%	+0.85	+0.06	7.0%
Thermal Sensation	Slightly Warm	Slightly Warm			Slightly Warm		

Source: Author, 2022

Conclusions

Perceptually, the urban village conditions in Yogyakarta are felt uncomfortable and tend to be hot. However, after measurements were made, it turned out that at an average temperature of 30.14°C, humidity of 72.90%, wind speed of 0.93 m/s, MRT of 44.70°C, PMV of 0.79 which shows slightly warm to warm sensation, or moderate heat stress, the results are still within the normal range especially for settlements in humid tropical regions such as Indonesia. This condition needs strategies to create better thermal comfort. By using ENVI-met software separated into two simulations scenario A & B there are changes in each thermal comfort parameter. Even though not significant numerically the simulation still provides sufficient results. By detailed analysis of each scenario, it turns out that the simulation has the effect of changing each parameter. Regarding thermal comfort, even the smallest changes have a big impact on the accumulation of energy use in the area. Several intervention variables in the simulation may not be sufficient to change the overall thermal conditions. Further research should focus on additional intervening variables in order to achieve better results.

Thermal tolerance in tropical climates is quite high, so the measurement results for several thermal comfort parameters, although not precisely meet the thermal comfort standard, are still tolerable. Residents of urban villages can continue their daily lives with various thermal conditioning strategies that have been implemented so far, such as creating small gardens in the house area, using fans, and providing space for wind movement, as well as better mobility. Relevant parties, especially the government, can provide outreach to increase citizens' awareness on how to manage environmental conditions better and more sustainable. Nevertheless, this research still has some limitations, for example on the number of variables used in the simulation. In the future, a number of intervening variables can be added in the simulation in order to obtain more accurate and optimal results.

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