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# Measurement of Thermal Comfort in Urban Public Spaces Semarang, Indonesia

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## ABSTRACT

Indonesia reported a maximum annual temperature rise of 0.3°C in urban regions. Semarang, the largest metropolitan city in the province of Central Java, is also experiencing an increase in temperature due to climate change therefore activities in urban public spaces are disrupted due to the absence of a comfortable temperature. Urban design elements, including land cover materials, road geometry, vegetation and traffic frequency expressed significant effects on micro-climate. Measurement of Thermal Comfort in Urban Public Spaces Semarang was carried out s at the micro level as an old historical district The Old Town and Chinatown. This increment indeed influences thermal comfort level in its outdoor environments which are important for comfortability of outdoor activity. This study aims to analyse surface temperature through Thermal Comfort Measurement. Data was obtained by measuring air temperature, wind speed and humidity in the morning, afternoon, and evening. Inverse distance weighted (IDW), thermal comfort calculations and micro-climate model were employed to evaluate existing physical conditions of these settlements. The results showed both Old Town and Chinatown observed thermal comfort value above 27°C and are categorized as uncomfortable for outdoor activities. This research is contributing to the need to further develop public spaces to potentially adapt to environmental changes.

*Keywords:* Public space, thermal comfort, urban design element

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## INTRODUCTION

Climate change is more common on a global scale with significant impact in several local population (Handayani et al., 2017; Donaghy, 2007). This phenomenon is

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characterized by a rise in sea level, increased surface temperature, abrasion in coastal areas, and damage to marine ecosystems (Zikra et al., 2015). Population growth and its impact on land use triggers temperature increase. Most severe conditions occur in certain urban areas dominated by built-up land with high population density. Increasing urban population poses a critical challenges as a result of the impact to rising surface temperature (Mathew et al., 2018). This phenomenon instigates an extremely intensified city temperatures or is often referred to as the surface urban heat island (SUHI) phenomenon (Mirzaei & Haghighat, 2010).

Indonesia, the fourth most populated country in the world, shows a yearly increase in average surface temperature up to 0.3°C due to the effects of climate change (Emmanuel, 2005). Land use change and illegal logging trigger approximately 85% loss of green open spaces assumed to also contribute to the rising temperatures. Major cities, including Semarang continue to expand and in turn consequently convert agricultural land for building purposes (Pamungkas et al., 2019). Over the last decade, land use diversion had significantly expanded by 13%. This condition triggered a warm surface temperature in the entire Semarang area from 22-40°C in 2018, while the average range was estimated at 18-33°C in 2008. However, the need for land, infrastructure, and buildings are very important to support community activities and are known to greatly influence urban life sustainability. In the debate on the importance of a city in creating a comfortable and safe living conditions, surface temperature is a major indicator with an essential role. Therefore, a city design with the potential to adapt to increasing surface temperature is also very crucial (Djukic et al., 2016).

Semarang City is in the North-Coast of Central Java (Figure 1). As the biggest city in Central Java Province, Semarang grows as busies city which has so many important activities such as trade and services, logistic and port activities as well as the central of government in its province. Transport mass, such as airport, harbour, train station and bus station are developed to support these activities as well as people's travel. Besides, Semarang has potential historical tourism attractions. Historical buildings, old settlements and Dutch colonial heritage areas with European-style architecture still exist in Semarang. Two of a big heritage area is The Old Town and Chinatown.

The Old Town and Chinatown has a strategic location which near to centres of transportation mass such as Tawang Station, Bus Station and Tanjung Mas Port. The proximity of public transports can attract and ease travellers to visit these heritage areas. Besides, The Old Town and Chinatown has been recently positioned as the centre of tourist activities and attractions in Semarang. Since 2014, the local government have continued to carefully revitalize the Old Town into a tourist region. In January 2015, the Old Town and China Town were accepted to be a part of a world heritage temporary list by UNESCO. After revitalizing the Old City and Chinatown area tends to experience an increase in

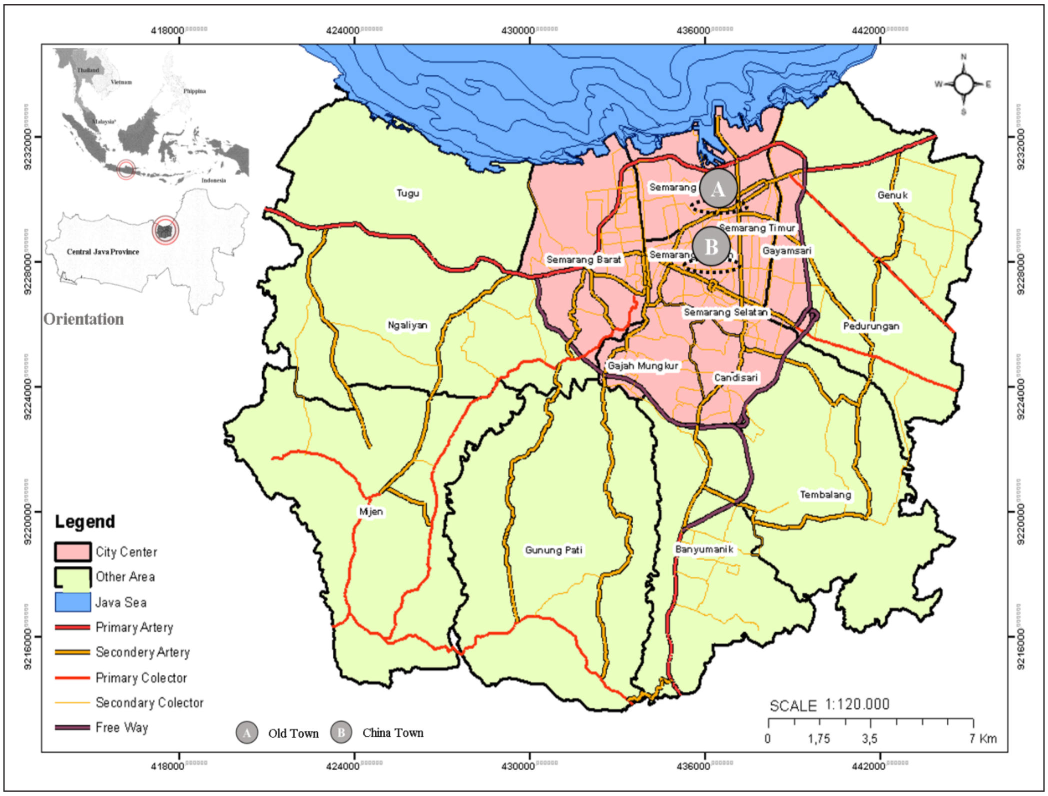


*Figure 1.* Semarang City, Indonesia

tourist visits compared before revitalization. Tourists visiting the area between the ages of 19-28, which is dominated by the age of 22 (Putri, 2020). Apart from being a hub for tourism development, these two locations are also included in the Bagian Wilayah Kota I (City Area Section) believed to be a centre for trade and services. Most of the tourism activities are carried out in an outdoor setting, including history tours, bicycle rides, and photo hunting. The condition of the hotter open-air environment certainly causes discomfort to the tourists. Therefore, a thermal approach was used to structure the environment to adapt to the urban heat island phenomenon is needed to support tourism activities.

This research was carried out in three primary stages to assess urban design elements. First, the Inverse Distance Weighted (IDW) method is employed to determine the value of an unidentified position using a combination of linear weights from a set of sample points. In this paper, surface temperature sample points were used as an assessment indicator. Second, thermal comfort is calculated by comparing the average temperature of the two locations with standard Temperature Humidity Index (THI), while the third process involved conducting microclimate modeling for urban design elements through correlational and simulation methods.

## LITERATURE REVIEW

### Urban Public Space

Urban public space is an open space with infrastructures used to support community activities in obtaining protection, satisfaction, and comfort in social life. According to Huat (1992) (as in Purwanto, 2014), it is divided into outdoor public space including roads, pedestrian ways, parks and indoor public spaces include trade and service centers. Whyte (1980) (as in Purwanto, 2014) stated that it is necessary to pay attention to the factors that influence the activities of urban public space, such as the physical factors that connect it with circulation. Therefore, urban public space is not only a landscape design, rather it is also influenced by human activities and tends to impact on the micro climate to provide better air quality (Meziani, 2016).

### Climate Sensitive Urban Design (CSUD)

Climate sensitive urban design (CSUD) is a concept in planning and design at the regional level, and is responsive to climate elements as a sustainable development approach (Emmanuel, 2005). The criteria applied in CSUD are micro-climate characteristics including solar lighting, wind speed, and temperature on an urban scale (Kaya & Mengi, 2011; Tapias & Schmitt, 2014). This concept is a potential solution to problems in the context of urban design and a basis to achieve a level of thermal comfort for space users. Kusumastuty et al. (2018) stated the assessment of climate sensitivity to urban design involves two main principles, termed urban environment and the available buildings.

### Outdoors Thermal Comfort

Thermal comfort major component in planning and urban designs with a benchmark based on micro-climate element factors influencing regional conditions (Koch-Nielsen, 2002). In addition, the thermal comfort level affecting activities occurs both outside and inside of space. Evaluation of thermal comfort is necessary to become an urban design guide in order to improve the quality of life of urban communities (Koerniawan, 2015), where people get to appreciate on a certain scale. According to Laurie (1990), the condition is comfortable for a standard value of temperature humadity index (THI) estimated between 21-27, and with an ideal temperature acceptable by humans, ranged between 27-28°C with a 40% humidity. However, several factors unarguably influence thermal comfort of outdoor activities, including air temperature, wind speed, humidity, sun exposure (radiation), and other individual active human factors within the environment.

### Urban Design Element and Climate

Urban development, believed to increase every year, is possibly responsible for the decline in green open spaces instigating the urban heat island (UHI) phenomenon. Urban design elements and building functions are among the major factors contributing to thermal comfort in cities (Ragheb et al., 2016). Based on the results of research conducted by Oke (2006), urban design elements, in this case, is categorized as urban landscapes with four basic features assumed to affect open-air temperature (thermal), including urban structure (building dimensions and the spaces formed e.g., road width and distance), land cover (buildings, paving, vegetation, empty land, and water), urban fabric (construction and natural materials), and urban metabolism (heat, water, and pollution due to human activities).

**Vegetation as a Natural Component**

The availability and arrangement of vegetation shows a positive effect on the formation of the micro-climate (Hakim, 2013). Sufficient vegetation layout tends to influence the direction of movement and wind strength, groundwater quality, micro-climate decline, and passive cooling with shadows. However, the temperature during the day above the open ground surface is higher compared to the temperature under the shade as a result of solar radiation (Lakitan, 2004). Furthermore, vegetation centered on a green open space potentially reduces air temperatures by 2-3°C in the city (Yu & Hien, 2009)

**Pavement / Soil Coating**

Pavement or soil coating is a significant factor affecting thermal comfort of surrounding buildings against sun exposure (Nikolopoulou & Lykoudis, 2006). According to Johansson (2006), the thermal properties of land cover components greatly contribute to the climatic conditions. These are also affected by the reflectance and absorption values of various materials and the land cover surface. Based on research conducted by Nichol et al. (2009), close relationship between surface temperature and air temperature on changes and types of land cover was established.

**Shading**

Shading of objects or buildings is among the primary factors to consider in minimizing thermal discomfort due to direct solar radiation in outdoor space. The amount of this energy is influenced by the geometric shape of the surface believed to determine the cover arising from an object or building. In addition, building geometry creates shadow comparable to the sky view factor (SVF). Therefore, there is a large correlation between road geometry, SVF, and surface temperature that is capable of reducing the local air temperature (Shashua-bar & Hoffman, 2003). According to Yeang (2006), in tropical areas, urban heat load from the land cover surface is reduced by optimizing shading. Previous studies have observed a cooling effect caused by the shading element from the geometry and characteristics of trees, e.g., in Tel-Aviv, Israel (Shashua-bar & Hoffman, 2003). Based on the lighting direction, shading is categorized into two types, including vertical shading angel (VSA) and horizontal shading angel (HSA).

### Inverse Distance Weighted (IDW)

Inverse distance weighted (IDW) is a multi-variable interpolation method in processing irregularly spaced data (Gholipour et al., 2013). The interpolation value appears more accurate for close distances between the sample data. However, the weight is not influenced by the location, but linearly changes based on the distance (Pramono, 2008), with evenly or randomly distributed sample data points. The IDW approach is performed using ArcGis10.3 software designed to produce a digital map containing graphic data and attributes.

### Thermal Comfort Calculations

The perception of thermal comfort by individuals is basically different even in areas with similar climatic conditions. This awareness is significantly influenced by the wind reaching the skin and the use of clothes and activities. In addition, the thermal comfort is affected by air temperature and humidity. Therefore, the temperature (T) calculation and humidity at each station is measured using Equation 1 (Handoko, 1995):

$$T = (Tmaximum + Tminimum)/2 \quad [1]$$

Average air temperatures (Tr) based on measurements at 6 stations randomly distributed in Old Town and Chinatown at 09.30, 12.30 and 16.00, are evaluated by Equation 2:

$$Tr = (2T\ 09.30 + T\ 12.30 + T\ 16.00)/4 \quad [2]$$

Average humidity / Relative humidity (RH) based on measurements at 6 stations randomly distributed at 09.30, 12.30 and 16.00, are calculated using Equation 3:

$$RH = (RH\ 09.30 + RH\ 12.30 + RH\ 16.00)/3 \quad [3]$$

Calculation of the temperature humidity index (THI) through the values of air temperature and relative humidity uses the following Equation 4 (McGregor & Nieuwolt, 1998):

$$THI = 0{,}8\ x\ Tr + \left(\frac{RH\ x\ Tr}{500}\right) \quad [4]$$

The results of the THI calculation were compared with the standard THI of a comfortable category ranging between 21-27°C, and 40-70% humidity (Laurie, 1990).

### Micro-Climate Modelling and Perception of Urban Design

Correlational and simulation methods were applied to model the micro-climate conditions of urban design elements. The correlational method detects the interconnection of variables in a factor with other specified variables (Groat & Wang, 2002). In addition, previous researches have already applied this approach, e.g., Oke (1976) studied to determine the leverage of wind speed on temperature differences . Another research conducted by Shashua-bar and Hoffman (2003) used similar method to describe the effects of tree shadows on surrounding air surface temperatures. For both instances, the effects of urban design elements, including material, shadow, orientation, geometry (H/W), traffic frequency, and the presence of vegetation to micro-climate conditions, with multiple linear regression methods were ascertained. Therefore, in this research, correlational methods were applied in multiple linear regression through statistical data processing application (SPSS).

Subsequently, simulation method was employed to model the system characteristics by using another system, e.g., computer programme. These techniques covered thermal comfort simulation and shadow using ArcGIS, Ecotect Analysis and Sketchup. In addition, 2D data was introduced into the Sketch-up to be converted to a 3-D model and then shadow-modeling was achieved with ArcGIS 10.3. Ecotect analysis is used to model the sunlight direction and the percentage of shading in the area.

## METHODS

The research method used is quantitative research methods. Data was collected in a few days by measuring the microclimate, such as solar lighting, wind speed, and air temperature as well as the external thermal comfort, i.e., air temperature, wind speed and humidity in the morning (09.00 am), afternoon (12.30 pm) and evening (04.00 pm). The location points of measurement have been carried out at Old Town which shown in Figure 2 and at Chinatown which shown in Figure 4. This research has been conducted in three stages to evaluate the physical conditions of Old Town and Chinatown. First, inverse distance weighted (IDW) was applied to interpolate the surface by weighting the distance. Second, thermal comfort calculation was employed to identify the level of existing thermal comfort, while the third involved micro-climate modelling to detect the correlation of variables (urban design elements) to air temperatures.

This research was carried out in two major urban public areas used as tourism centers in Semarang, namely Old Town and Chinatown.

### Old Town, Semarang

Old Town is a cultural heritage area with colonial architecture and historical tour covering an area of approximately 33 hectares. This area is known as “The Little Nederland” because historically the area was where the Dutch built with European-style architecture (Pratiwo, 2004).


*Figure 2*. Old Town, Semarang, Indonesia


*Figure 3*. Six Stations in Old Town, Semarang, Indonesia

Old Town also commonly called *De Hollander* or *Little Netherland*, was initially used as special Dutch residence, and currently documented as a building and environmental planning document as stipulated in the Regional Regulation of Semarang (Number 8 /2003) Lembaran Daerah Kota Semarang, 2003). Old Town is currently used as a designated tourist attraction used to describe the historical architectural, aesthetic, scientific and culture growth of Semarang.

Figure 2 uses points to shows the temperature measurement that are randomly distributed in six stations. Figure 3 shows the current situation in those stations at several locations in Old Town, namely (1) Station 1 pedestrian in front of the Marba building, (2) Station 2 pedestrian in front of PT Indonesian Trading Company, (3) Station 3 in Dream Museum Zone (DMZ) parking area, (4) Tawang polder, (5) Spigel Restaurant, (6) Srigunting Park.

### Chinatown, Semarang

Chinatown is a Chinese settlement where trade and service covering an area of approximately 25.25 hectares. The development of this location is inseparable from Semarang's history, which is a city often visited by foreigners, including the Chinese.

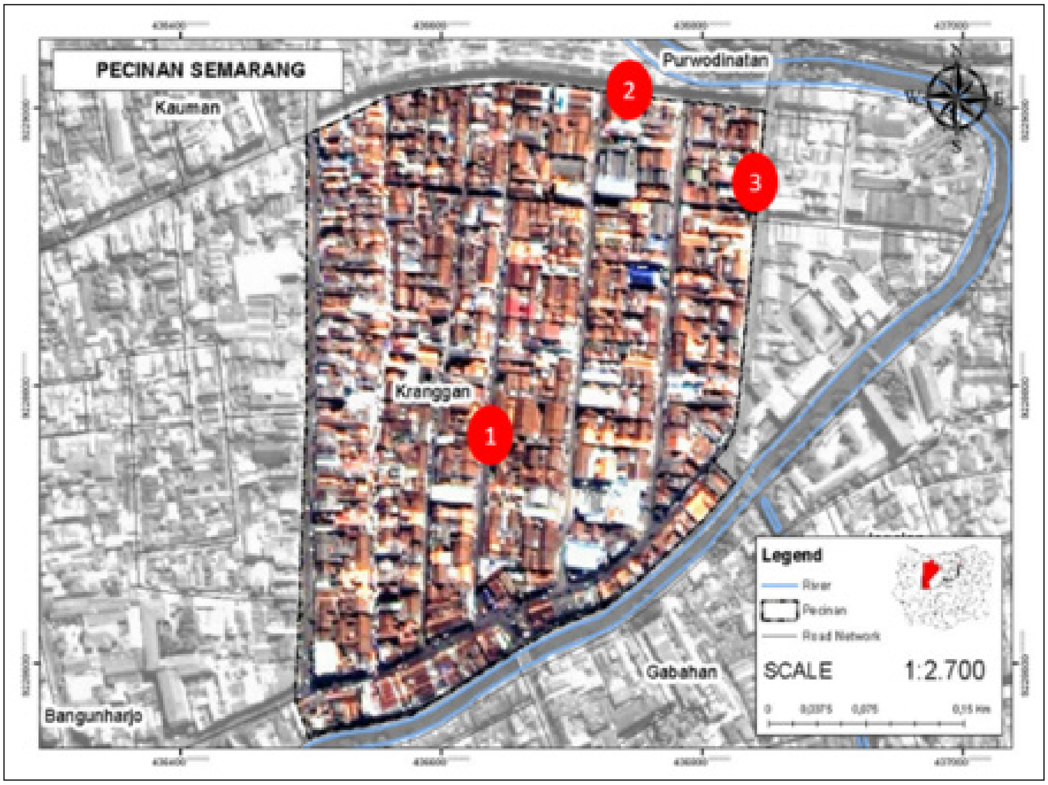


*Figure 4*. Chinatown, Semarang, Indonesia

Figure 5. Three Stations in Chinatown, Semarang, Indonesia

The buildings in this settlement are grouped in based on functions, namely place to live, trade, provide services, and warehouse for storage. Chinatown is dominated by structures with floors of 8-10 meters large, and floor area ratio (FAR) of 1.0. Figure 4 shows the random distribution of 3 stations in several locations, namely (1) Station 1 in Gg Gambiran Street, (2) Station 2 in Gg Warung Street, (3) Station 3 in Gg Pinggir Street. Figure 5 illustrates the situation at the measurement point in the Chinatown area.

## RESULTS

### Microclimate Measurement: Air Temperature in Public Space Old Town Semarang

Figure 6 presented three measurements of air temperature in different times. Based on the IDW interpolation results of six stations, the highest average temperature attained was within a range of 35.5 - 36.9°C, while the lowest was 30.0-31.4°C. The results obtained as at 09:30 a.m. in station 1, 2, 5, and 6 were between 30.0-32.7°C. This was lower in 3 and 4 with an average of 34.1-35.5°C and 35.5-36.9°C respectively. Meanwhile, the region outside the evaluation area had a value of 32.7-34.1°C.

The IDW interpolation results at 12:30 p.m., obtained a temperature between 33.7-34.3°C for station 3 and 4, while the highest was at location 1 with an average of 35.4-35.9°C. Also, 5 and 6 had a value of 34.8-35.4°C, while the lowest was at 2 with about 33.2-33.7°C. The region outside the measurement station had a range of 34.3-34.8°C. Furthermore, the highest value measured at 16.00 p.m. was 32.5-32.8°C for 5, and subsequently 6 with an average of 32.1- 32.5°C. Meanwhile station 1 and 3 had a temperature of 31.7- 32.1°C with the lowest range of 31.0-31.3°C detected at station 2 and 4. The area outside was between 31.3-31.7°C.

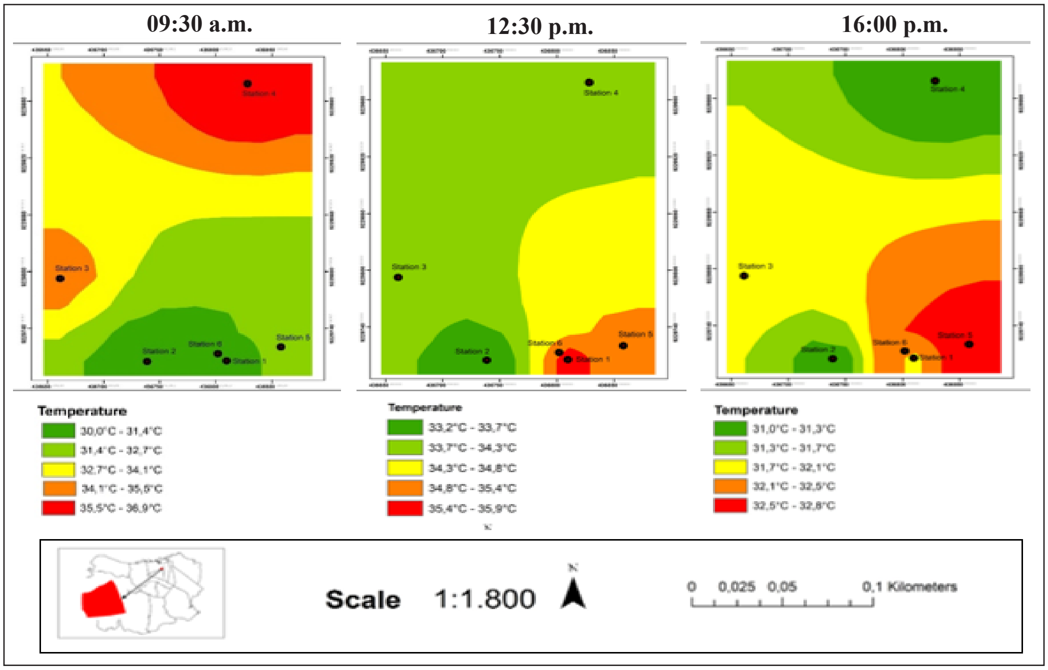


*Figure 6*. Temperature Measurements in Public Space Old Town Semarang, Indonesia

## Microclimate Measurement: Humidity in Public Space Old Town Semarang

The percentage of humidity at station 1 and 2 decreased and attained a value of 62% at 09:30 a.m, while at 12.30 p.m. there was a decline to 52%. This parameter was stable at 09.30 a.m. and 12.30 p.m., then decreased to 52% at 16.00 p.m for 3. Meanwhile there was a regular decline in 4 from 62% to 55% at 12.30 p.m. reaching 52% at 16.00 p.m. while 5 and 6 tend to fluctuate. The result at each station indicates the humidity level was categorized as normal because the percentage was above the standard intervals of 20-90%. Table 1 demonstrated the influence of temperature range at each location in Public Space Old Town Semarang

## Microclimate Measurement: Thermal Comfort in Public Space Old Town Semarang

Table 1 contains the results of the thermal comfort measurement obtained where each station fall into the uncomfortable category. The highest average temperature was at 36.2°C while the lowest at 30.7°C in the Old Town area. Meanwhile, the peak Temperature Humidity Index (THI) was only 31°C while the base was 29°C. According to According to Stathopoulos et al. (2004). the ideal air climate for human comfort as an outdoor user is between 27-28°C, while the comfort value ranges from 21-27°C.

## Effect of Wind, Vegetation and Air on Thermal Comfort in Public Space Old Town Semarang

The wind speed at each station also affects the thermal comfort level of the outdoor activity. Table 1 demonstrated the average values were between 2-4 m/s, which was categorized as high compared to the standard range of 0.15-0.25 m/s. The beufort scale classified the wind speed into categories, including light Airs at 09.30 a.m. and 16.00 p.m. for all locations, gentle for 1, 2, 3, and 4, and light breeze for 5 and 6 at 12.30 p.m. In addition, the parameter has no effect on activities based on the outdoor users' perception, because direction and speed basically assist in temperature reduction.

The lack of vegetation is one of the reasons for discomfort in outdoor activity. This is because the presence of plants assist in temperature reduction to 2-3°C. Furthermore, look at Figure 7 is station 1, 2, 5 and 6 that have a higher comfort value than 3 and 4 because of some shady plants' presence. This is able to provide a cooling effect on air through the absorption of solar radiation. The station 3 does not have any vegetation, therefore the climate is hotter in comparison. Meanwhile at 4, there is a little growth, although considered less optimal for lowering the heat in the Tawang pedestrian.

The presence of water in large amounts basically provide a cooler temperature effect to the surrounding region. Also, solar radiations on the surface of water converts the liquid into vapor, therefore humidity is increased with a cooling effect on the area. The expanse of water present in station 4 of polder Tawang assist in surface heat reduction around the region. Furthermore, at 09.30 a.m the temperature in the riverine area termed polder had a range between 35.5-36.9°C, while at 12.30 p.m the value decreased to 33.7- 34.3°C, and continued declining to 31.0-31.3°C at 16.00 p.m. However, this reduction is considered less than optimal because only places with water bodies are reached with a higher value at a radius of 10 meters away.

*Figure 7*. Existing Vegetation in Public Space Old Town Semarang, Indonesia

Table 1
*Micro Climate and Urban Design Elements in Public Space Old Town Semarang, Indonesia*

| Characteristics | Sun Directions | Shadowing | Temperature | | Wind Velocity (m/s) | Humidity | Air Quality | | THI | Building Orientation | Vegetation | Material | Geometric Path (H/W) | Traffic Frequentation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | IS | BS | | | Aqi | Explanation | | | | | | |
| **Station 1** | | | | | | | | | NOT COMFORTABLE (>27°C) | North-South | Decoration, Linier | Paving and concrete | 3 | High |
| 09.30 a.m. | 50° | 19% | 0 | 30° | 2 | 62% | 21 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 0 | 36,6° | 4 | 59% | 19 | B | | | | | | |
| 16.00 p.m. | 60° | 58% | 0 | 34° | 2 | 52% | 14 | B | | | | | | |
| **Station 2** | | | | | | | | | | North-South | Decoration, Shading, Linier | Paving and ceramics | 2 | High |
| 09.30 a.m. | 50° | 19% | 30° | 32° | 3 | 62% | 18 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 32,9° | 34° | 4 | 59% | 16 | B | | | | | | |
| 16.00 p.m. | 60° | 58% | 31,4° | 34° | 2 | 52% | 13 | B | | | | | | |
| **Station 3** | | | | | | | | | | East-West | Lack of Vegetation | Paving | - | Low |
| 09.30 a.m. | 50° | 19% | 0 | 35° | 3 | 62% | 17 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 0 | 34,2° | 4 | 59% | 16 | B | | | | | | |
| 16.00 p.m. | 60° | 58% | 0 | 31,6° | 2 | 52% | 14 | B | | | | | | |
| **Station 4** | | | | | | | | | | North-South | Shading, Linier | Paving | - | Low |
| 09.30 a.m. | 50° | 19% | 0 | 37,2° | 3 | 62% | 17 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 0 | 33,7° | 5 | 59% | 15 | B | | | | | | |
| 16.00 p.m. | 60° | 58% | 0 | 31° | 2 | 52% | 12 | B | | | | | | |
| **Station 5** | | | | | | | | | | North-South | Decoration, Linier | Paving and concrete | 2 | High |
| 09.30 a.m. | 50° | 19% | 32° | 33° | 2 | 62% | 20 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 0 | 34° | 3 | 59% | 11 | B | | | | | | |
| 16.00 p.m. | 60° | 58% | 30° | 33° | 2 | 52% | 14 | B | | | | | | |
| **Station 6** | | | | | | | | | | North-South | Shading, Grid | Paving dan Grass | - | High |
| 09.30 a.m. | 50° | 19% | 29° | 32° | 3 | 62% | 17 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 33° | 34° | 3 | 59% | 12 | B | | | | | | |
| 16.00 p.m. | 60° | 58% | 32,7° | 33° | 3 | 52% | 13 | B | | | | | | |

IS= In the Shadow, BS = Beyond the Shadow, Highest (37,2°) Lowest (29°)

## Microclimate Measurement: Air Temperature in Public Space Chinatown Semarang

This parameter in public space Chinatown is identified through mapping with IDW interpolation in three stations. Figure 8 displays the result with the highest average temperature between 38-39°C while the lowest had a range of 32-33.4°C. The area outside the measurement station was between 33.4-34.7°C and 36.2-37.6°C.

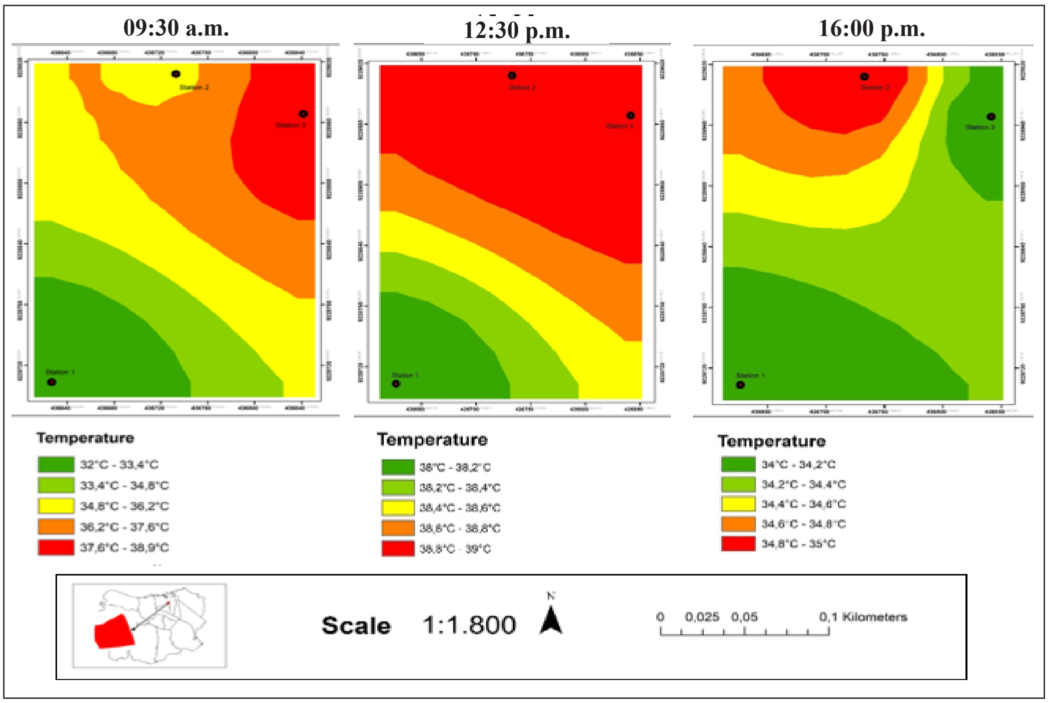


*Figure 8*. Temperature Measurements in Public Space Chinatown Semarang

## Microclimate Measurement: Humidity in Public Space Chinatown Semarang

Table 2 demonstrates the decline in humidity percentage at the three stations. Furthermore, at 09:30 a.m. the level attained a value of 66% and then further decreased to 62% at 12:30 p.m. Meanwhile, at 16.00 p.m., there was a decline to 43% in 1, while at 2 and 3 reached 41%. The humidity per station was categorized as normal because the score between the standard intervals was 20-90%. In addition, this parameter is affected by the change in temperature range.

## Microclimate Measurement: Thermal Comfort in Public Space Chinatown Semarang

The result of thermal comfort at each station indicated an uncomfortable category, where the highest and lowest average temperature was determined as 38.9°C and 32.7°C, respectively.

Table 2
*Micro Climate and Urban Design Elements in Public Space Chinatown Semarang, Indonesia*

| Characteristics | Sun Directions | Shadowing | Temperature | | Wind Velocity (m/s) | Humidity | Air Quality | | THI | Building Orientation | Vegetation | Material | Geometric Path (H/W) | Traffic Frequentation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | IS | BS | | | Aqi | Explanation | | | | | | |
| **Station 1** | | | | | | | | | NOT COMFORTABLE (>27°C) | East-West | Decoration, Shadowing, Linier | Asphalt and Concentrate | 3 | Low |
| 09.30 a.m. | 30° | 18% | 29,2° | 31,7° | 1 | 66% | 4 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 0 | 37,5° | 1 | 62% | 10 | B | | | | | | |
| 16.00 p.m. | 20° | 55% | 34° | 0 | 3 | 43% | 16 | B | | | | | | |
| **Station 2** | | | | | | | | | | North-South | Lack of Vegetation | Paving and Concentrate | 2 | Medium |
| 09.30 a.m. | 30° | 18% | 34,6° | 35,8° | 2 | 66% | 4 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 36,5° | 38,6° | 2 | 62% | 9 | B | | | | | | |
| 16.00 p.m. | 20° | 55% | 30,8° | 35° | 4 | 41% | 21 | B | | | | | | |
| **Station 3** | | | | | | | | | | East-West | Decoration, Shadowing, Linier | Paving and Concentrate | 3 | High |
| 09.30 a.m. | 30° | 18% | 37,3° | 38,9° | 4 | 66% | 5 | B | | | | | | |
| 12.30 p.m. | 80° | 0% | 0 | 39,4° | 2 | 62% | 16 | B | | | | | | |
| 16.00 p.m. | 20° | 55% | 34,1° | 0 | 2 | 41% | 16 | B | | | | | | |

IS= In the Shadow, BS = Beyond the Shadow, Highest (orange) Lowest (blue)

Meanwhile, the peak Temperature Humidity Index (THI) was 34.1 and the base value attained was 33.0. According to Stathopoulos et al. (2004), the ideal air temperature for human comfort as an outdoor user was between 27-28°C, while the comfort value ranges from 21-28°C.

### Effect of Wind, Vegetation and Air on Thermal Comfort in Public Space Chinatown Semarang

The wind speed of each station was between 1-4 m/s. This was categorized to have a higher value than the standard of 0.15 -0.25 m/s. According to the beufort scale classification, the wind speed at 1 and 2 was categorized as Light Airs, while at 3 as Light Breeze. Particularly, based on the outdoor users's perception, this parameter does not disturb the activity, because the direction and velocity of the breeze along with vegetation basically assist in temperature reduction. This creates comfort for the space users.

Figure 9 showed the vegetation map in Chinatown with barely any plant form. However, the location was dominated by built-up areas, characterized by the presence of shops and settlements. This city lacks vegetation assemblage, including park, linier or mini gardens in front of the houses due to limited space. The air temperature tends to be high, therefore facilitating the growth of more plants, especially the hanging and creeping varieties necessary to maintain a cooler microclimate.

Furthermore, station 3 is located near to Semarang River. The water body of the river assist in temperature reduction of the surrounding region due to the evaporation effect.

*Figure 9*. Existing Vegetation in Public Space Chinatown Semarang

The measurement at 09:30 a.m. indicates a range of 37.6-38.8°C. Meanwhile, at 12.30 p.m. there was a rise to 38.8- 39°C with a further decline at 16:00 p.m. to 34 -34.2°C. The waterbody area was lower at 37.4°C at 09.30 a.m., while the value increased to 37.8°C at 12.30 p.m. and 16:00 p.m. respectively.

## Climate Analysis on Urban Design Element in Public Space Old Town Semarang

The results of Multiple Linear Regression between microclimate elements, including temperature, wind speed (m/s), and air quality (Aqi)) with urban design elements involving land cover materials, geometry (H/W), vegetation, structure orientation, and traffic frequency, contribute to the different relationships between these component. These results demonstrate the effect of material constituents and other factors, including vegetation and traffic frequency on the formation of temperature and air quality. The building geometry element towards the road (H/W) affects the wind speed.

The research conducted by Nichol et al. (2009) demonstrated a significant relationship between land surface and air temperature on changes and types of land cover or thermal material. Also, paving materials in the public space Old Town area produced a thermal value of 1000 J/Kg with a heat absorption and reflectance range of 85-95% and 15-5% respectively. According to Shashua-bar and Hoffman (2003), there is a large correlation between road geometry and land surface heat, especially for creating shadows of objects. In addition, the presence of vegetation with higher LAI reduce thermal radiation by almost 92.55% or air temperature by 2-3°C (Yu & Hien, 2009).

Figure 10 shows the overlay between thermal comfort, wind direction, and building distributions. In general, public space Old Town obtained a thermal comfort value above

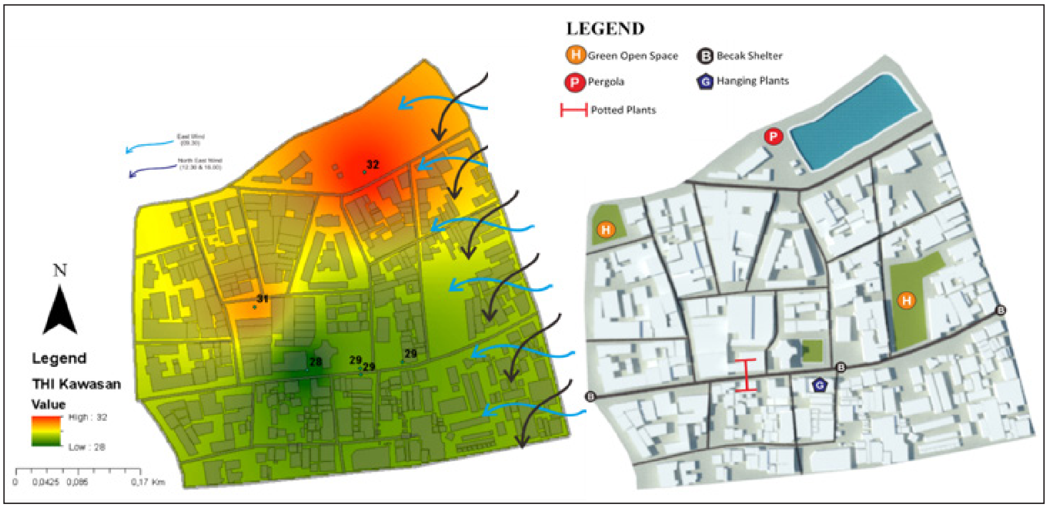


*Figure 10*. Simulation of THI Value and Wind Direction, and Design Recommendation in Public Space Old Town Semarang

27°C, and was then categorized as uncomfortable for outdoor activities. Irregular structure layout in several partitions contributes to wind flow obstruction and further results to rotating air pockets in the lobby. The northern section of Old Town observed high temperatures due to the movement of dry winds towards the sea. Previous research reported a significant variation in temperature extending to 2.1% between areas closer to the sea level and sections with an altitude away (Purwantara, 2015). These locations prior to the sea level attained relatively warmer surface temperatures characterized by high wind speeds.

### Climate Analysis on Urban Design Element in Public Space Chinatown, Semarang

Regression analysis on public space Chinatown showed homogeneous results among the various elements. In general,the micro-climate was influenced by land and building cover materials as well as the traffic rates or environmental activities. Furthermore, public space Chinatown is dominated by two-storey buildings with high density and are mostly built using paving and concrete materials. These materials reflect heat effectively compared to natural products (Nichol et al., 2009). In addition, public space Chinatown is known to perform mixed functions, including historical tourism, residential, and trade area, and therefore activities are always extensive on every occasion.

The simulation results of thermal, wind, and building comfort showed varied wind movement patterns every hour. However, wind movement in this location was more stable compared to public space Old Town due to a more uniform pattern of building layouts with the tendency of a grid shape (Figure 11). The dominance of buildings with square

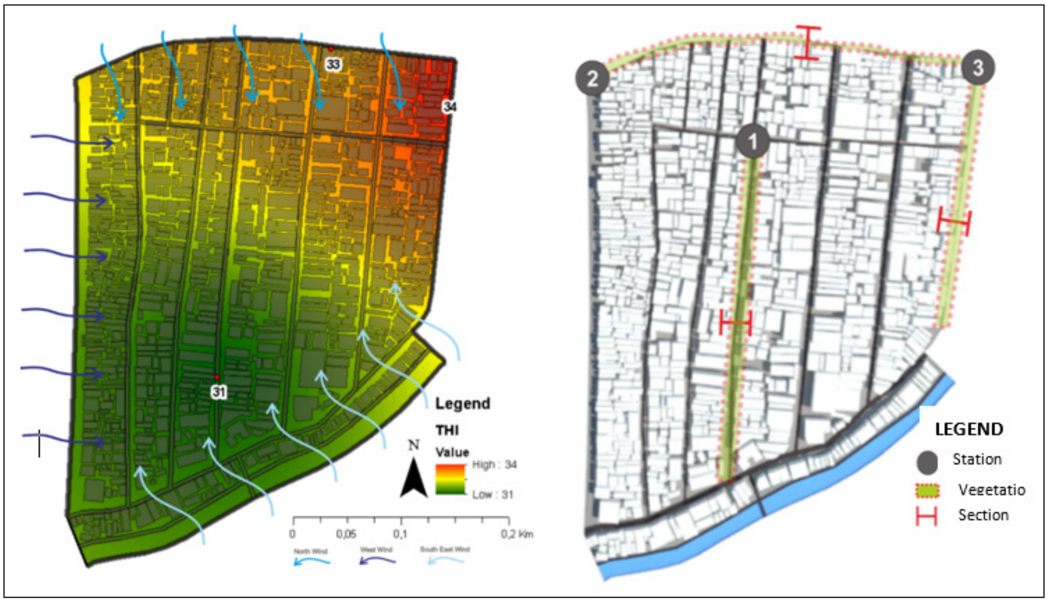


*Figure 11*. Simulation of THI Value and Wind Direction and Design Recommendation in Public Space Chinatown, Semarang

facades on a straight road led to a more stable airflow in and out the area (Shishegar, 2013). Moreover, the average thermal comfort of public space Chinatown indicated uncomfortable conditions with temperatures above 27°C. Meanwhile, the northern part, including Station 2 and Station 3 appeared the warmest with a thermal comfort level extending to 34°C. The road geometry to the building (H/W) also influenced the formation of air temperature and wind flow (Dursun & Yavas, 2015), where both locations demonstrated a large geometry, and the shading of objects occurred less significant to fill the alley.

## DISCUSSION

Table 3 shows the variations in micro-climate characteristics between both locations, where the thermal comfort for public space Old Town was better compared to public space Chinatown. Shading in Old Town is greater than Chinatown, thereby leading to a lower temperature that is far from an ideal condition and nearest 100% in the tropics area. Conversely, lower SVF rate was achieved in the Old Town, which also affected the temperature. Air quality index (Aqi) of Chinatown is better than Old Town, therefore, the score still in the range of ideal condition. Furthermore, the SVF and shading score of Old Town affecting Thermal Comfort in lower than Chinatown. It means the Old Town has a

Table 3
*Simulation Results between Old Town and Chinatown Semarang*

| Categorization | Ideal Condition | Old Town | Chinatown |
|---|---|---|---|
| Configuration | - | Irregular Pattern | Grid |
| Building Height | - | 8-14 m | 8-14 m |
| Vegetation | - | More Vegetation | Lack |
| Wind Direction | - | East and Northeast | North, West, and Southeast |
| Shadowing | The tropics require up to 100% coverage<br>Source: Yeang, 2006 | 58% | 55% |
| Thermal Comfort | 27° - 28 °C<br>Source: Stathopoulos et al. (2004) | 31°C | 34°C |
| SVF | The greater the SVF score, the warmer the temperature<br>Source: Lin (2009) | 16% | 52% |
| Peak Hours Activity | - | In the Afternoon (Tourism) | Every time (Economic and Business) |
| Air Quality (Aqi) | <50<br>Source: U.S. U.S. Embassy and Consulates in Indonesia | 15,5 | 5,6 |
| Factor Affecting | - | Materials, Geometry, Frequency, and Vegetation | Materials and Frequency |

cooler temperature than Chinatown, even though both are far from the ideal condition of 27-28°C.

The formation of micro-climate in Old Town area was more influenced by land cover material, geometry, traffic frequency, and the presence of vegetation. Meanwhile, Chinatown was more affected by land cover materials, land cover, and traffic rates. In general, both towns were affected by the conditions of land cover material and traffic due to tourism, economic and business activities.

In Old Town, land cover materials were produced from paving, while historical buildings generally portrayed brightly coloured concrete material structures. The bright colours further increased the surface temperature due to heat reflection and increase in light effects. In addition, the presence of vegetation also influenced the formation of air temperature with higher values during the day above the open ground surface than under the shade as solar radiation on plants are not returned (Lakitan, 2004). Locations with high intensity vegetation tend to effectively reduce air temperature. Meanwhile, areas with high traffic rates and large geometric values generated warmer climate. The building geometry (the ratio of the building's height to the road and its facing orientation) is an important factor known to serve as an indicator for assessing thermal safety in open space (Dursun & Yavas, 2015). Furthermore, building orientation also affects shadow formation, where the best pattern is assumed to face south.

To create a comfortable micro-climate, the arrangement and placement of vegetation is carefully considered (Boutet, 1987). In Old Town, the vegetation was assigned to areas with low thermal comfort levels and high temperatures. Maximization of hanging, potted, vine, and hydroponic vegetation is highly recommended to prevent damaging the natural structure of the existing cover in the cultural heritage area. Conversely, Old Town contained some availabe land to serve as passive green open space for certain outdoor activities. In addition, the optimization of public transportation, including Bus Trans Semarang and proper parking arrangements is assumed to effectively minimize air pollution and further manage regional traffic activities. Traffic emissions present a significant impact on outdoor thermal comfort as a result of air pollution (Li et al., 2020).

The frequency of traffic directly influences the formation of micro-climate in Chinatown. According to Johansson (2006), materials from land cover components affect the value of reflection and sunlight absorption. The road is made of paving and asphalt materials, while the building is brightly coloured, thereby forming hot climate, where less heat is absorbed. In addition, the land cover generated is very minimal thereby providing limited spaces between buildings. Similarly, as one of the trade and service areas and settlements, traffic in Chinatown is always busy daily. However, this is different from the Old City, where major activities are carried out in the afternoon. Moreover, the position of the sun at certain period, as well as the direction towards the building shows significant effects on lower surface shadows (Bourbia & Awbi, 2004). The shade from the building greatly reduces the high temperatures occurring in the morning and evening, however, the building orientation does not affect structures with high density. Therefore, vegetation is recommended for these areas in an effort to minimize increasing temperatures.

Chinatown is a protected cultural heritage in Semarang, therefore, there is need to minimize the rate of development causing damage to natural structures through the provision of portable vegetation in pots, vines, and hydroponics to create a serene atmosphere. The selection of hydroponic formation in public space Chinatown varies from Old Town due to a relatively narrow landscape, due to the appearance of more streamlined and easily modified hydroponics in areas with greater residential activities during the day. According to Hendrawati (2016), the provision of water pipes tends to create a peaceful climate, therefore, this plant type is suitable for storage of water and green plants. Apart from vegetation, traffic regulation and activities, such as the *Trans Semarang* public transportation, are also recommended to minimize air pollution and improve connections between areas in Old Town.

## CONCLUSION

This study aims to analyse surface temperature in Old Town and Chinatown, Semarang through Thermal Comfort Measurement. Measurement was implemented by collected the microclimate data's such as solar lighting, wind speed, and air temperature as well as the external thermal comfort, i.e., air temperature, wind speed and humidity in the morning, afternoon, and evening. Three stages for evaluate the physical conditions of Old Town and Chinatown are inverse distance weighted (IDW), Thermal Comfort Calculation, and Micro-climate Modelling. The results of thermal comfort measurements in Old Town and Chinatown are categorized as uncomfortable public space for outdoor activities. In general, thermal comfort value is estimated above 27$^{o}$C, with the highest temperatures occurring at station 4 and station 3. The simulation results and correlations in public space Old Town showed land cover material, road geometry to buildings (H/W), presence of vegetation, and traffic frequency are urban design elements with significant effect on micro-climate formation. Meanwhile, land cover material and traffic rate or environmental activities indicated a considerable consequence in public space Chinatown. In addition, the correlation results revealed building orientation close to the sun also influences shadow formation. The results of data analysis affirmed the presence of shadows with a high tendency to reduce air temperature.

Furthermore, the general concept of applying for increase the thermal comfort involves urban design element factors. The application of environmental adaptation, e.g., optimization of abandoned land as green open spaces, improving the provision of potted gardens, creeping vegetation on building walls, enhancing the use of public transportation modes, boosting parking pockets, and procuring tourist rickshaws. Optimizing public transportation, procurement of potted plants, hanging plants on building canopy, and vines on building walls are very effective in maintaining a feasible temperature in public space especially Chinatown.

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