# 博士論文

URBAN MICROCLIMATE OF
BUILDING FORM AND MASSING IN BANDUNG, INDONESIA

インドネシア・バンドンにおける建物の形体とﾏｯｼﾝｸﾞによる都市の微気候への影響に関する研究

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# 1. Introduction

## 1.1 Background

As the largest archipelago country in the world, Indonesia has a total land area of 1,904,569 $km^2$ and contains 17,508 islands. With 237,641,326 inhabitants, this makes it the 4th most populous country in the world. Somehow up to now still dealing with uneven population distribution, there are 12 cities with high populations, from a total of 510 cities spread throughout 34 provinces. These cities

have population densities of more than 10,000/$km^2$, and all of them are located on Java island (**Fig. 1.1**). Central Jakarta is the most populated region with 17,591/$km^2$ , meanwhile the most sparsely populated region is Tidore Island, which has only 10/$km^2$. Java is a main island in Indonesia, with only 6.87% (**Fig.1.3)** of the total land area of Indonesia, but 57.25% of the total population are living on this island as seen in **Fig. 1.2**. Java Island itself, which contains six provinces, that are: Banten, DKI Jakarta, West Java, Central Java, D.I Yogyakarta, and East Java, also has a different population spread. From **Fig. 1.4** can be seen that West Java has the biggest population of Java Island. (BPS, 2013)[1]

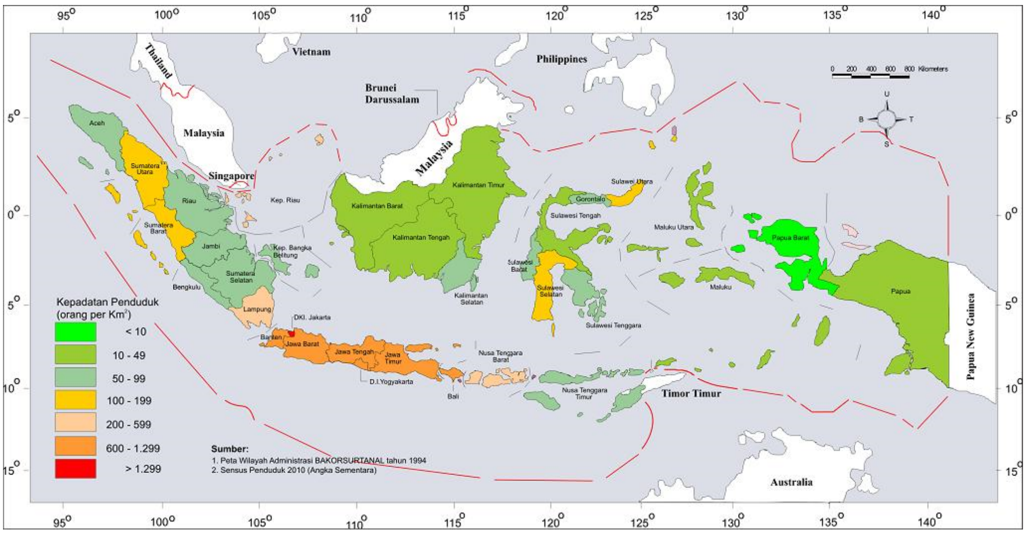



***Fig 1.1.*** *Population Density in Indonesian province*
*Source: BPS, 2013*

[1] BPS also can be accessed at http://www.bps.go.id/hasil_publikasi/SI_2013/index3.php?pub=Statistik%20Indonesia%202013

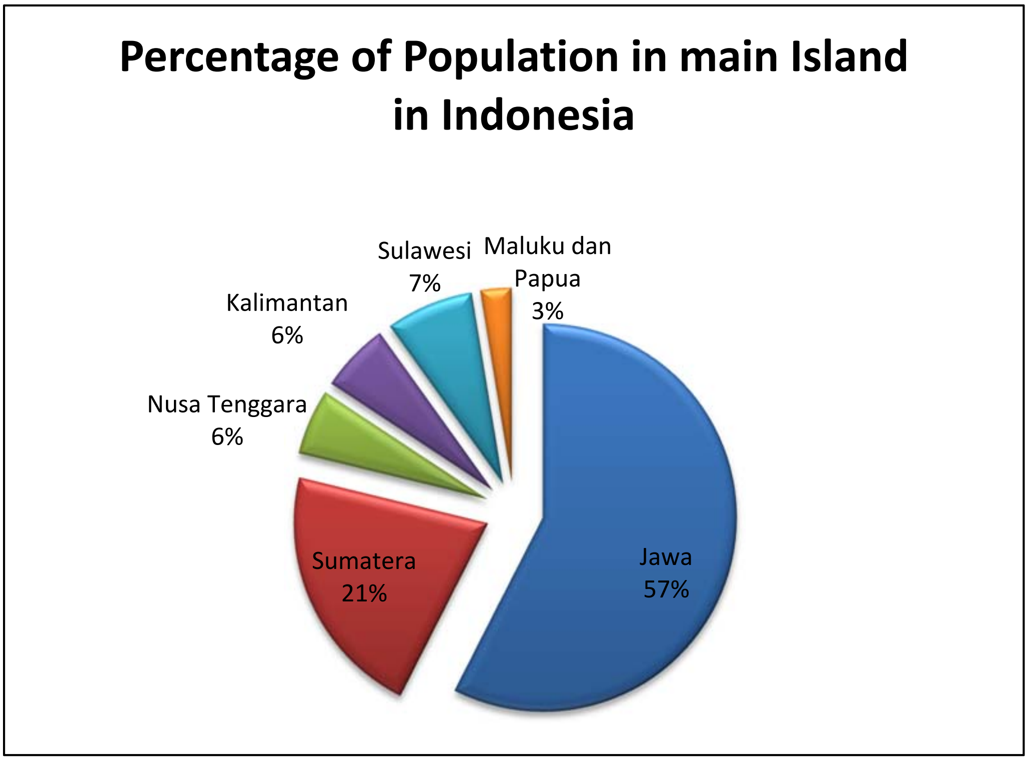



***Fig 1.2.*** *Percentage of Population in main Island in Indonesia*
*Source: processed from BPS, 2013*

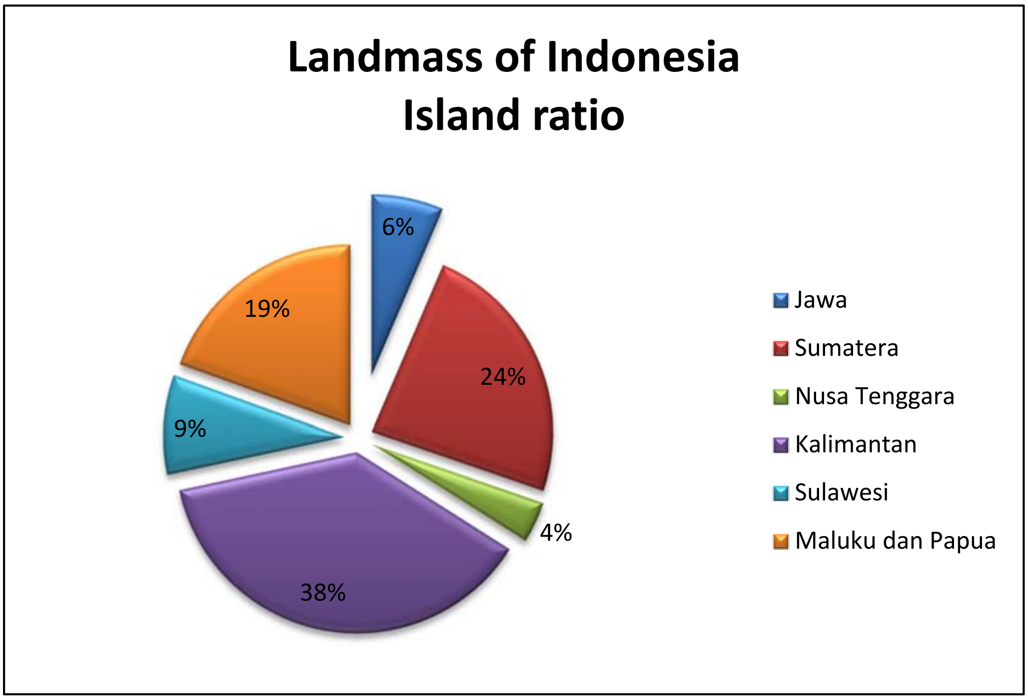



***Fig 1.3.*** *Landmass of Indonesia Island Ratio*
*Source: processed from BPS, 2013*

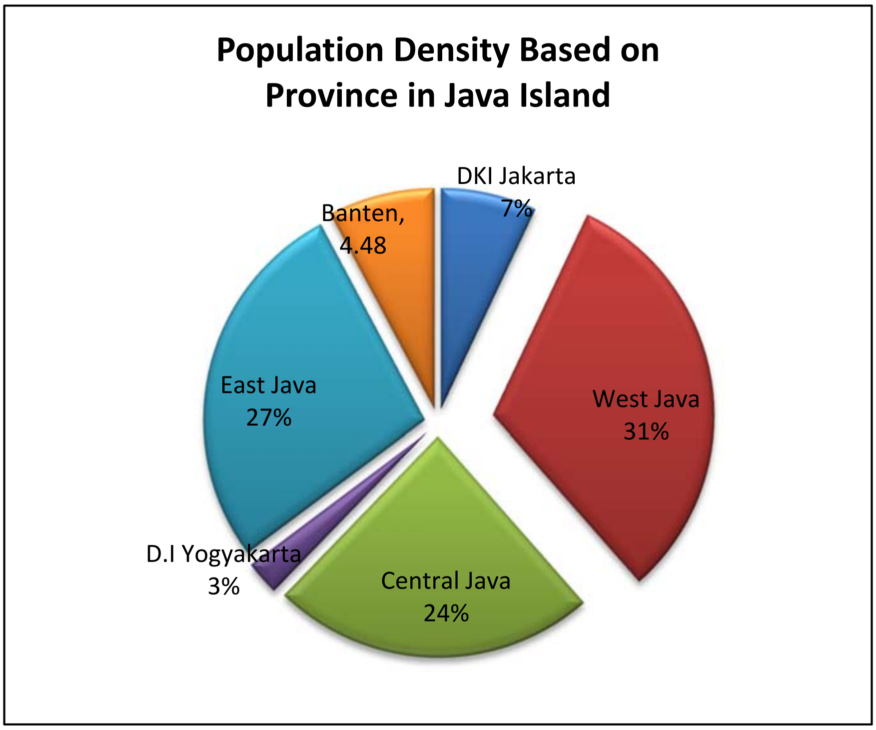



***Fig. 1.4.*** *Population Density Based on Province in Java Island*
*Source: processed from BPS, 2013*

The program of population distribution of the main island to other islands which are more sparsely inhabited appears to be less successful, resulting in the congregating of populations in several big cities, which are becoming more populous year by year. Unequal infrastructure, quality of education, also the lack of job opportunities is a classic and common reason in developing countries for potentially raising urbanization. Demography problems related to urban spaces has risen, such as overcrowded settlements, mostly inhabited by squatters, spread throughout the downtown area. The unpreparedness of spatial planning and law enforcement to keep implementation on track seems to become a big ‘ unresolved headache’ for many urban spatial planners in some cities in Indonesia. Urban environmental problems tend to increaseexponentially.. This study was conducted in the city of Bandung, the capital of West Java Province, which has the biggest population of Java Island.

Several problems regarding demographic matters appear. Bandung has the second highest number of slum areas recorded in Indonesia, after Jakarta, based on ministry of public works records.[2] The other direct effects of excess population density which affect the urban environment are: its building density, changes in land-use, and also the quality of urban living. Previous studies about high population densities that increase exposure to the effects of microclimate, and vulnerability to climate change have been done, such as: localized climatic effects, i.e. increased local temperatures, urban heat-island effects, and high levels of outdoor and indoor air pollution (Coutts, at al.,2007; Cheng. V., 2010). The specific urban microclimate where the urban fabric meets the meteorological environment shows the tendency of the average temperature of the city to rise,and also the microclimate in the dense-area. This study is focused on the building form, massing and layout, which significantly impact microclimate.

***Table 1.1*** Top Ten Highest Population Density, Based on City.

| no | City | Province | Landmass (km2) | Population | Population density/km2 |
|---|---|---|---|---|---|
| 1 | Central Jakarta | DKI Jakarta | 47.9 | 889,448 | 18,569 |
| 2 | West Jakarta | DKI Jakarta | 126.15 | 2,093,013 | 16,591 |
| 3 | South Jakarta | DKI Jakarta | 145.73 | 2,001,353 | 13,733 |
| **4** | **Bandung** | **West Java** | **167.3** | **2,288,570** | **13,679** |
| 5 | Cimahi | West Java | 40.36 | 546,879 | 13,549 |
| 6 | Yogyakarta | DI Yogyakarta | 32.5 | 433,539 | 13,340 |
| 7 | East Jakarta | DKI Jakarta | 187.73 | 2,391,166 | 12,737 |
| | | | | | 11,501 |
| 8 | Surakarta | Central Java | 44.03 | 506,397.00 | |
| 9 | North Jakarta | DKI Jakarta | 142.3 | 1,445,623.00 | 10,159 |
| 10 | Bekasi | West Java | 210.49 | 1,993,478.00 | 9,471 |

Source: *Proceed from BPS, 2013*

[2] http://ciptakarya.pu.go.id/bangkim/kumuh/main.php?module=home

## 1.2 Problem Statement

Based on the geographical location, Bandung is classified as a tropical monsoon ‘Am’ by Köppen-Geige, having a climate with high humidity and precipitation. This region also tends to have less variance in temperature throughout the year. As it lies in tropical regions and near to the equator, it’s significantly influenced to large amounts of insolation, known as incident or incoming solar radiation. This is the total energy received at a certain time over a given surface area. This solar radiation, then, becomes the main factor for urban microclimate in a tropical city, which potentially induces the heat, since this region is facing solar radiation longer than other climate regions.

,. The size, shape, scale, orientation and distribution of green spaces in urban, built up environments, particularly in relation to the form and mass of buildings, is well positioned to gain outdoor thermal comfort; but when their planning and design does not adapt to the local climate, then the opposite will happen naturally. The heat from solar radiation during the daytime is trapped in surface areas, such as walls, rooves and ground areas, which potentially gain the mean radiant temperature (Tmrt). During sunny weather in the hot season, this Tmrt is the most important meteorological input parameter for the human energy balance (Matzarakis, 2011). Therefore, outdoor thermal comfort is significantly influenced by the Tmrt value. Outdoor thermal comfort, then, is not merely a perception, it is correlated with a living environmental condition which affects the quality of urban life.

The idea of designing urban forms is to improve the microclimate and comfort of people who live in those areas. Thus, passive building design and massing in urban areas becomes a necessity, and possible to explore in the tropical region, given the absence of extreme temperature changes throughout the year, especially in outdoor areas. The amelioration of microclimate itself will give a positive impact to urban climate.

## 1.3 Aims of Study

This study presents a thorough discussion within the Bandung city that divided into: (1) The trend of heat intensity in a city which correlated with land use changes and differences; (2) Urban forms that contribute to the alteration of microclimate by description of how its urban physics meets meteorological aspects. In this part, we will present an example of assessment of building form and massing which influences outdoor thermal comfort; (3) Passive design strategy of building form and massing which takes into consideration population density and its microclimatic effects.

## 1.4 Scope of Study

The trends of urbanization in many countries, especially developing countries, cause an increase in problems regarding urban environment. This is analogous with building physics, which previously recognize discussions about heating, cooling and ventilation within the building. (Blocken, 2012) states that '…urban physics is the engineering discipline that covers the transfer of heat, air, moisture, pollutants, light and sound in urban areas.'

The field science of outdoor thermal comfort correlated with urban microclimate becomes the focus for this study. The main parameters of thermal properties, such as wind speed and incoming or outgoing radiation are significantly influenced by urban form, particularly in relation building density, and the size and space between them.

Outdoor thermal comfort is estimated based on a calculation from field measurements and simulation. The compilation of this data describes the comfortability level of the living area which was assessed through the comparison of PET (heat budget), $Y_{JS}$ (thermal sensation) and PMV (PET and ENVI-met).

## 1.5 Structure of the Thesis

This thesis consists of annexed journal papers and peer-review conference proceedings. This thesis is mainly based on the papers, but also includes some urban regulation, building code, guidelines and standards, which consider the climate aspect of planning and design.

**Chapter 1** describes the overall thesis content. C**hapter 2** is a literature review that is used as a theoretical basis, the studies that have been done and the position of this study among other studies in the same field. Included in this discussion are: hot-humid climate characteristics, urban form and configuration which are adaptable to the hot-humid climate, outdoor thermal comfort in the hot-humid climate, and modelling and simulation of microclimate. **Chapter 3** provides the information of Bandung city, the problem caused by rapid urbanization which affected the urban built environment, its building density, the change of land-use, and also the quality of urban living. **Chapter 4** gives the understanding of the methodology of this research. From the field measurement calibration and collection, the description of urban form and massing, it's potential to affect the microclimate, and the use of prognostic models to understand microclimate and urban living comfort. And finally, the correlation of each study to provide the recommendation of building group passive design. **Chapter 5** shows how the urban form significantly influences the microclimate by providing several results of field measurement. Three different land-uses as samples, which are: a high-density settlement; an educational area and an industrial area, will show the correlation between the building coverage ratio (BCR), floor area ratio (FAR) and urban canyon (H/W) with the mean radiant temperature (Tmrt). The Sky view factor (SVF) formed by the urban fabric, also shows correlation with the mean radiant temperature (Tmrt) though not with significant values. This chapter also shows the trend of increasing average temperatures for the past 25 years, and recent diurnal temperatures for four different regions of Bandung. This chapter also assess five public flats (*rusun*) to find the correlation between building block design and urban meteorology. The recommendations of building group planning and design are given based on the meteorological and climatic approaches. **Chapter 6** explains the urban microclimate prognostic model, and the meteorology alteration due to rapid measurement. These are: (1) Envi-met is a tool to diagnose and project urban microclimate change within urban areas, and to know the mean radiant temperature and outdoor thermal comfort; (2) RayMan stands for 'radiation on the human body'. It estimates the radiation fluxes and effects of clouds and solid obstacles on short wave radiation fluxes (Matzarakis, 2011). This chapter also gives the strategy of building group planning and design, with respect to outdoor thermal comfort in hot/humid climate regions. By describing PET (Physiologically Equivalent Temperature), PMV (Predicted Mean Vote) and $Y_{JS}$ (Nyaman Jalan Santai – Indonesia rate) to know the meteorological parameters which are important within the urban form. In **chapter 7** It discuss the legal aspects of flat construction in Indonesia. As the main method of providing affordable housing, it is necessary to examine the technical guideline of *rusun* construction, which is then used as a basic input to do the experiments of building form and massing. Conclusions in **chapter 8** contains the conclusion of urban microclimate in building form and massing in Bandung, Indonesia. The recommendations for urban planning and design, especially for building groups of form and massing. The last part is about future studies that are expected from the result of this research.

The Thesis includes the following papers:

1. Paramita, B., Fukuda, H., 2014 Heat Intensity of Urban Built Environment in Hot Humid Climate Region, American Journal of Environmental Sciences 10 (3) 210-218. DOI : 10.3844/ajessp.2014.210.218

   This paper shows the trend of increasing average temperature for the past 25 years and the recent diurnal temperature for four different regions of Bandung. Specific discussion on three different land-uses namely: UPI, an educational area; Tamansari, a high-density settlement; and Cigondewah, an industrial area, show the correlation between BCR, FAR, H/W and SVF with Tmrt

2. Beta Paramita et al., 2014, Public Housing in Bandung, an Assessment and Approach through Urban Physics. Advanced Materials Research, 935, 273
   DOI : 10.4028/www.scientific.net/AMR.935.273

   A comparison of five public flats in Bandung, reveal the better urban fabrics, including building form and massing, height, width and space between them, also their correlation with Tmrt reduction.

3. Beta Paramita, 2013. Solar Envelope Assessment in Tropical Region Building Case Study: Vertical Settlement in Bandung, Indonesia. Procedia Environmental Sciences, 17, 757 DOI : http://dx.doi.org/10.1016/j.proenv.2013.02.093

   This paper describes a passive design strategy using a solar envelope in a high-density settlement in order to maximize the site assets, determining the building setting and layout to optimize the availability of daylight.

4. Paramita, B., Fukuda H., 2013. Building Groups Design Strategies in Hot-humid Climate: A Dense Residential Planning in Bandung, Indonesia. The 28th PLEA, TU Munich, Germany.

   An experiment of 28models consists of different building length ratio, building height and building coverage to find the better building groups for passive design in a hot humid climate region.

5. Paramita, B., 2013. Bandung Land-use Management Toward a Compact City. The 1st Asian Urban Environment and Compact City. The University of Kitakyushu, Japan.

   This paper gives a description of urban land-use in Bandung and its effect on urban sprawl, especially in the downtown area.

6. Paramita, B., Fukuda, H. 2012 Shaping Urban Spatial Structure. Energy Supply Security of Asia and Energy Saving in the Field of Architecture-Urban Architectural Energy Saving Technology and Policy in East Asia. The 42th SGRA Forum. WASEDA University, Japan.

   This paper shows a description of the districts in Bandung that have low living environmental quality, and the correlation with population density. This data reveals that high population (most of them are squatters) in one area tends to become overcrowded and negatively impact on living quality.

**Bibliography**

Blocken, B., 2012. Urban Physics: Effect of the micro-climate on comfort, health and energy demand. *Frontiers of Architectural Research,* Volume 1(3), p. 31.

Coutts A, B. J., Tapper N (2007). Impact of Increasing Urban Density on Local Climate. Journal of Applied Meteorology and Climatology. (46): p. 477-493

Cheng, V (2010). Understanding Density and High Density Designing High-Density Cities for Social and Environmental Sustainability. Earthscan. London

BPS, 2013. Bandung City in Figure. Bandung: BPS, p. 358.

Matzarakis, M., 2011. Comparison of models calculating the sky view factor used for urban climate investigations. *Theor Appl Climatol.* 105(3-4), p. 6 pages.

Paramita,B., M. Donny K (2013). Solar Envelope Assessment in Tropical Region Building Case Study: Vertical Settlement in Bandung, Indonesia. Procedia Environmental Sciences (17): p. 757-766.

# 2. Literature Review

## 2.1 Urban Density

Density, as employed in land use planning and related applications, appears to be a simple concept. However, amounts of density are often misinterpreted and distorted due to the numerous technical complexities involved in coming up with them. Therefore, it is significant that the scales of geographical references be explicitly limited in density calculations, otherwise the comparison of density measures will be unmanageable. Nevertheless, there is no standard measure of density; there are only measures that are more widely used than others (Edward Ng, 2010).

Density then becomes the idea of a compact city that has been introduced since 1973. This was largely a utopian vision that was driven by a desire to see more efficient use of resources. In the 1980s, the reconfiguration of metropolitan areas physical urban form was increasingly debated among both theorists and practitioners. Recently, the compact city itself is more focused on developed countries where the population tends to be lower. In contrast, in developing countries, there are many dense cities that promote a high population with their inhabitants living in the mixed land uses area. These cities have a population density of more than 10,000/km$^2$. Therefore, the compact city becomes just a term to describe an amount of density, rather than a well-managed city.

As shown in the **Fig. 2.1**, the continent with the largest urban area population in the world is Asia, which has a population of more than 500,000 people.

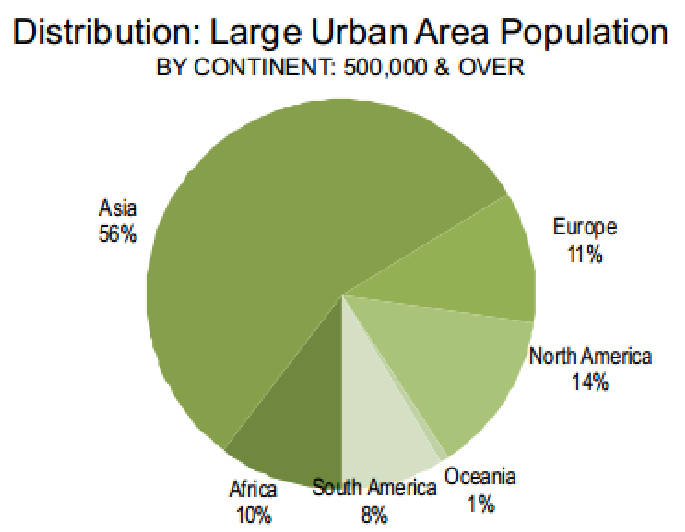



***Fig.2.1*** *Distribution of large urban area population in the world*
***Source***: *Demographia, 2014*

The **table 2.1** describes the top 10 largest urban areas based on population.

***Table 2.1*** *Top 10 largest urban areas based on population*

Urban Areas 500,000 & Over Population

| Rank | Geography | Urban Area | Population Estimate | Year | Base Year Population Estimate | Land Area: Square Miles | Density | Land Area: Km2 | Density | Base Year | Popula-tion Source | Land Area Source | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Japan | Tokyo-Yokohama | 37,555,000 | 2014 | 37,100,000 | 3,300 | 11,400 | 8,547 | 4,400 | 2010 | C | B | |
| 2 | Indonesia | Jakarta (Jabotabek) | 29,959,000 | 2014 | 27,550,000 | 1,200 | 25,000 | 3,108 | 9,600 | 2010 | C | B | |
| 3 | India | Delhi, DL-HR-UP | 24,134,000 | 2014 | 22,250,000 | 800 | 30,200 | 2,072 | 11,600 | 2011 | A | B | |
| 4 | South Korea | Seoul-Incheon | 22,992,000 | 2014 | 22,500,000 | 875 | 26,300 | 2,266 | 10,100 | 2010 | C | B | |
| 5 | Philippines | Manila | 22,710,000 | 2014 | 20,750,000 | 610 | 37,200 | 1,580 | 14,400 | 2010 | C | B | |
| 6 | China | Shanghai, SHG-ZJ-JS | 22,650,000 | 2014 | 21,550,000 | 1,400 | 16,200 | 3,626 | 6,200 | 2012 | C | B | |
| 7 | Pakistan | Karachi | 21,585,000 | 2014 | 19,530,000 | 365 | 59,100 | 945 | 22,800 | 2011 | C | B | |
| 8 | United States | New York, NY-NJ-CT | 20,661,000 | 2014 | 20,366,000 | 4,495 | 4,600 | 11,642 | 1,800 | 2010 | N | N | |
| 9 | Mexico | Mexico City | 20,300,000 | 2014 | 19,250,000 | 800 | 25,400 | 2,072 | 9,800 | 2010 | C | B | |
| 10 | Brazil | Sao Paulo | 20,273,000 | 2014 | 19,400,000 | 1,100 | 18,400 | 2,849 | 7,100 | 2010 | C | B | |

**Source:** *Demographia, 2014*

Nevertheless, the shaping of a city is not merely about population density. Urban fabric – the physical form of towns and cities – plays the most important role in the city's image. Urban fabric has a significant impact on shaping the physical image of city. It is not only the layout of buildings and their dispersion, but also the structure that connects each element within the city. Thus, the density measurement can be described as follow:

### 2.1.1 Density Atlas (MIT)

The Density Atlas (Lee, 2011 ) is a planning, design and development resource for comparing urban densities around the world. It was developed by Massachusetts Institute of Technology, Department Urban Studies and Planning.

The Density Atlas measures projects using dwelling units per acre, population per acre, and floor area ratio (FAR) – the three most common measurements of density.

Projects are grouped into "neighborhood" scales and "block" scales, to allow for proper comparison. Comparing projects within a defined scale is important because the larger the land mass, the more non-residential space will exist in a given area, including retail, parks, services, and more.

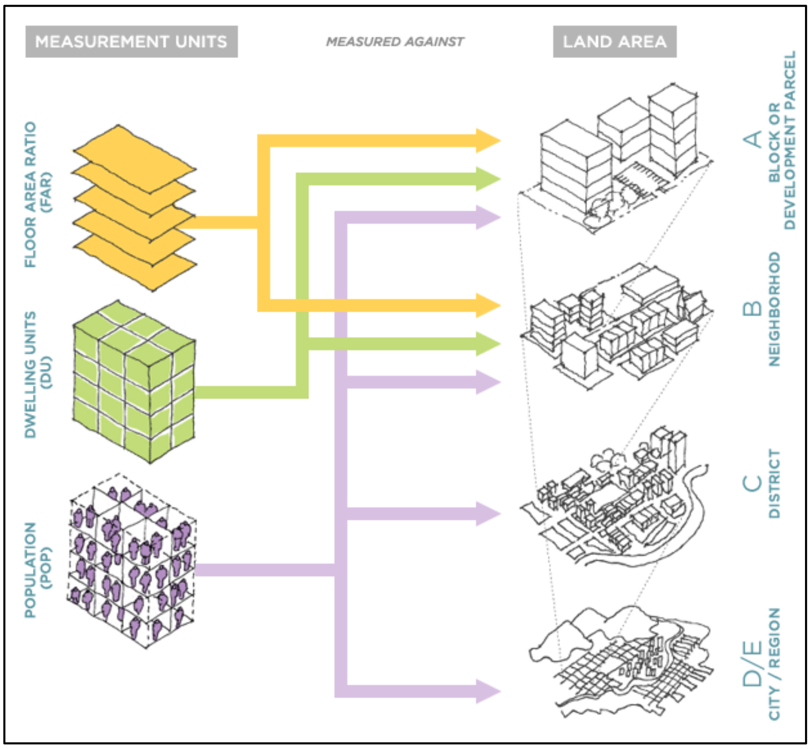



***Fig. 2.2*** *Density Atlas*
***Source*** *: http://densityatlas.org/measuring/*

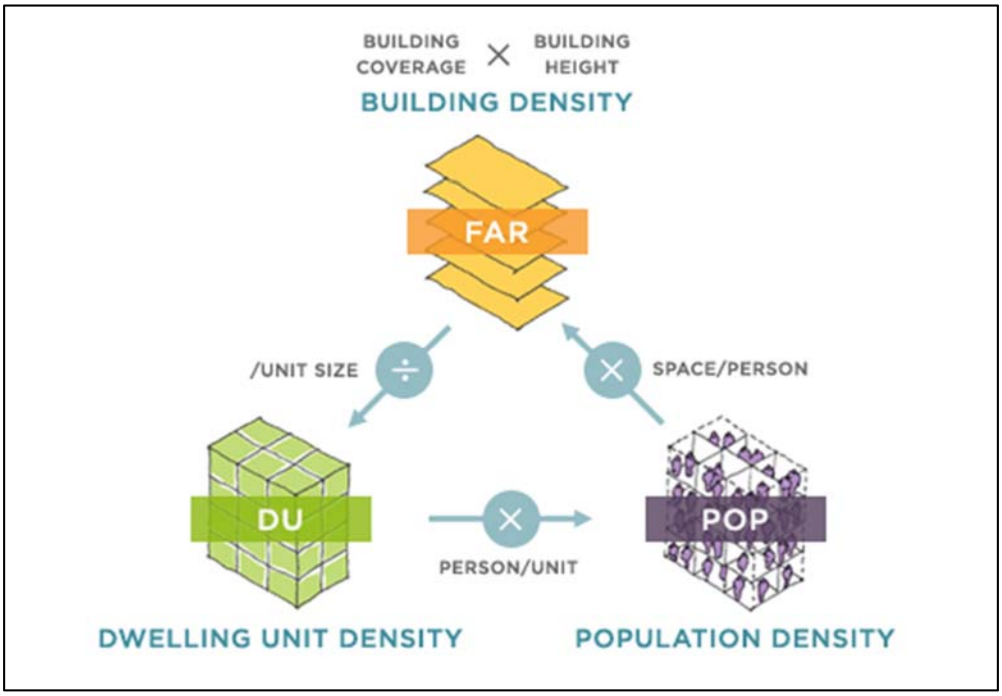



***Fig. 2.3*** *Measurement of Density*
***Source*** *: http://densityatlas.org/measuring*

This automatically lowers the dwelling unit density, population and FAR, thereby lowering total density of an area. Density will almost always be higher at the "block" scale, so it is important to make comparisons within their assigned scales. The diagram below details the three measures:

There are four characters of the Density Atlas, which include:

a. 


High FAR, High DU, High Population: Neighborhoods with high population, dwelling units and FAR can be very livable, comfortable environments, when an efficient development pattern is used. The livability of these neighborhoods is highly dependent on the urban and architectural design of the buildings within this space. This includes ensuring that all units have good access to light and air, and that the streetscape feels pleasant and is not crowded. Examples of cities with this character are as follows in **Table 2.2**:

***Table 2.2*** *Cities with Character of High FAR, High DU and High Population*

| | | |
|---|---|---|
| Ming Court, Tseung Kwan O, HK | The Visionaire, Battery City Park, NY | Man Wai Bldg, Jordan, HK |
| FAR = 12.5 | FAR = 16.4 | FAR = 10.1 |
| DU = 247 / Ha | DU = 755 / Ha | DU = 242 / Ha |
| Pop = 804 / Ha | Pop = 1585 / Ha | Pop = 969 / Ha |

b. Neighborhoods with low population, low dwelling units and low FAR are the least 

dense case studies in this atlas. The following are examples of some of the least dense case studies in the Density Atlas.

***Table 2.3*** *Cities with Character of Low FAR, Low DU and Low Population*

| | |
|---|---|
| City des Fleurs, Paris, France | Ju'er Hutong, Beijing, China |
| FAR = 1.5 | FAR = 1.3 |
| DU = 12 / Ha | DU = 89 / Ha |
| Pop = 62 / Ha | Pop = 264 / Ha |

c. The following examples of neighborhoods with high FAR, low dwelling units and low population illustrate neighborhoods that may appear dense due to the relatively large building size. However, the number of people living in these areas is relatively low, leading to a less crowded environment. Dwelling units are fairly large, which gives each person a sizeable amount of personal living space.

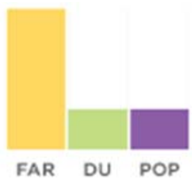



***Table 2.4** Cities with Character of High FAR, Low DU and Low Population*

| | | |
|---|---|---|
| The Esplanade, Cambridge, MA, US | The Plan Voisin, Paris, France | Block 1002 Census Tract 105.01 on 5th Ave |
| FAR = 9.6 | FAR = 7.2 | FAR = 8.0 |
| DU = 59 / Ha | DU = 49 / Ha | DU = 94 / Ha |
| Pop = 97 / Ha | Pop = 196 / Ha | Pop = 186 / Ha |

d. In contrast to the aforementioned examples, the following examples illustrate crowded neighborhoods with relatively low FAR. Most informal developments have a similar density measurement profile.

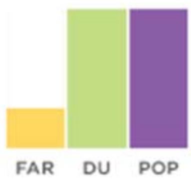



***Table 2.5** Cities with Character of Low FAR, High DU and High Population*

| |
|---|
| Dharavi, Mumbai, India |
| FAR = 2.0 |
| DU = 255 / Ha |
| Pop = 5714 / Ha |

### 2.1.2 Density based on Ciptakarya, Ministry of Public Work of Republic Indonesia [1]

The Ministry of Public Work of Republic Indonesia in 2006 has launched The Guideline of Slum Settlement Identification in Metropolitan area in Indonesia. According to this guideline, the definition of density is as follows:

a. Building density: 80-100 unit / hectare
b. Distance between buildings: 1.5 – 3m
c. Population density: 400 – 500/hectare
d. Building Coverage Ratio (BCR): 50 – 70%
e. Population growth rate: 1.7 – 2.1 % pa.

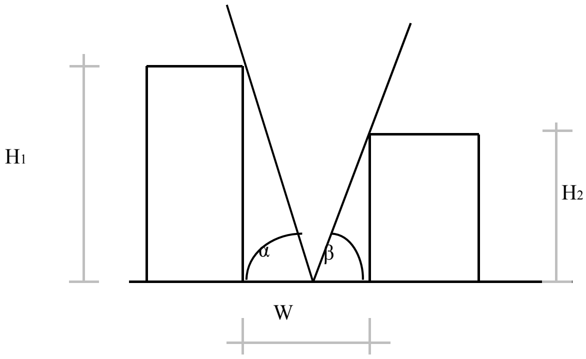
## 2.2 Urban Form

The density of buildings has an intricate relationship with urban morphology. Building density plays an important role in shaping urban forms and also has a significant effect on urban microclimate. For instance, different combinations of plot ratio and site coverage will manifest in a variety of different built forms. In the face of rapid urbanization, the relationship between building density and urban form in land scarce as a consequence of increasing urban population. The following will be discussed the elements of urban form:

### 2.2.1 Urban Canyon

The urban canyon, which is a simplified rectangular vertical profile of infinite length, has been widely adopted in urban climatology as the basic structural unit for describing a typical urban open space, i.e. filtered of irrelevant non-climatic aspects. Urban canyon is calculated as the ratio of building height to street width, as shown in Figure 3.1 below.

[1] http://ciptakarya.pu.go.id/dok/hukum/pedoman/panduan_identifikasi_kawasan_permukiman_kumuh.pdf




$$Tg\ \alpha = H_1 / \tfrac{1}{2} W \quad (1)$$

$$Tg\ \beta = H_2 / \tfrac{1}{2} W \quad (2)$$

***Fig. 2.4*** *Urban canyon as the ratio of H/W*
*Source: modified from Oke, 1981*

### 2.2.2. Plot ratio or Floor Area Ratio (FAR)

Plot ratio is the ratio of total gross floor area of a development to its site area. The gross floor area usually takes into account the entire area within the perimeter of the exterior walls of the building, which includes the thickness of internal and external walls, stairs, service ducts, lift shafts, all circulation spaces, and more (Cheng, 2010).
FAR is calculated as:

$$\frac{\text{Total floor area of the building}}{\text{Total Area of urban block}} \quad (3)$$

### 2.2.3. Site Coverage/Building Coverage Ratio (BCR)

Site coverage represents the ratio of the building footprint area to its site area. Therefore, site coverage is a measure of the proportion of the site area covered by the building [5].
Site coverage is calculated as:

$$\frac{\text{Total base floor area} + \tfrac{1}{2}\text{ pave coverage} \times 100\%}{\text{Total area of urban block}} \quad (4)$$

### 2.2.4. Vegetation cover ratio

The cover is an important vegetation and hydrological characteristic. Cover is generally referred to as the percentage of ground surface covered by vegetation. However, numerous definitions exist. It can be expressed in absolute terms (square meters or hectares), but it is most often expressed as a percentage. In this paper, the definition and type of cover measures are defined as foliar cover, which is the area of ground covered by the vertical projection of the aerial portions of the plants. Foliar cover measures a vertical projection of the exposed leaf area. The cover would equal the shadow cast if the sun is directly overhead. Some remaining conditions about this coverage are:

a. Small openings in the canopy or overlaps within the plant are excluded.
b. Highly susceptible to yearly fluctuations due to climatic or biotic factors.

Plot estimate techniques are used to obtain foliar cover data, and is calculated as:

$$\frac{\text{Total plot estimate foliar or canopy cover}}{\text{Total area of urban block}} \times 100\% \quad (5)$$

### 2.2.5. Building Surface Area ratio

The ratio of surface area to volume (S/V), or the ratio of the three dimensional extrapolation of the perimeter to area, is an important factor to determine heat loss and gain. The greater the surface area the more the heat is gained and lost through it. Therefore, small S/V ratios imply minimum heat gain and minimum heat loss.[2] Building surface area is calculated as:

$$\frac{\text{Total surface area}}{\text{Volume}} \quad (6)$$

## 2.3 Climate and High Density

As previously mentioned in Fig. 3.1, the most populous cities are in Asia. Tokyo and Incheon are the only cities in Asia that have already solved their urban problems. Tokyo, as a leader in governance, public management, urban planning, technology, environment, international outreach, social cohesion, mobility and transportation, human capital, and economy, obtained the first IESE Cities in Motion Index.[3] However, other cities such as those in India, Indonesia and China, still struggling to face the demographic problem which will impact people's living environments. High population may simply imply an increasing need for additional shelter, which can change the land coverage. Nevertheless, developing countries and poor populations everywhere remain the most vulnerable to the impacts of urban environments. The discussion about density above gives wide perceptions of potential attributes of dense neighborhoods, such as they positive qualities including a compact city, cultural richness, increased economic competitiveness, or as negative qualities such as pollution, low quality of living area

[2] http://www.new-learn.info/packages/clear/thermal/buildings/configuration/surcafeareato_vol_ratio.html
[3] http://www.iese.edu/en/about-iese/news-media/news/2014/april/tokyo-london-and-new-york-the-smartest-cities/

and more. Therefore, high density is highlighted in correlation with climate, especially regarding the microclimate that is induced by urban fabric.

### 2.3.1 Urban Microclimate

Chandler dedicated his study of the spatial and temporal character of metropolis' climate to Luke Howard from 1772 to 1864 (Howard, 1833 republished in 2011). Chandler described Howard as the pioneer of urban climatic studies. In 1833, Howard wrote *The Climate of London* and is best known for his work on clouds. Additionally, Howard was the first to recognize the effect that urban areas have on local climate. Furthermore, Chao Ren et.al. (2011) give their reviews on urban climatic map studies over four decades **(Fig. 2.6).**

A microclimate is a local atmospheric zone where the climate differs from the surrounding area. Microclimates can be influenced by urban building configuration and can differ considerably to the local meteorological data that is usually measured for that region. Urban microclimate consists of local variations of wind, humidity, solar radiation and temperature, as a result of many factors. A study demonstrated that the correlation between urban form and microclimate has increased in recent years, along with the increasing trend of average temperature seen in many regions around the world. This data can be found at **Fig. 2.5**.


***Fig. 2.5*** *Urban Climate Map Studies around the world in 2011*
***Source****: City Weather, 2011*

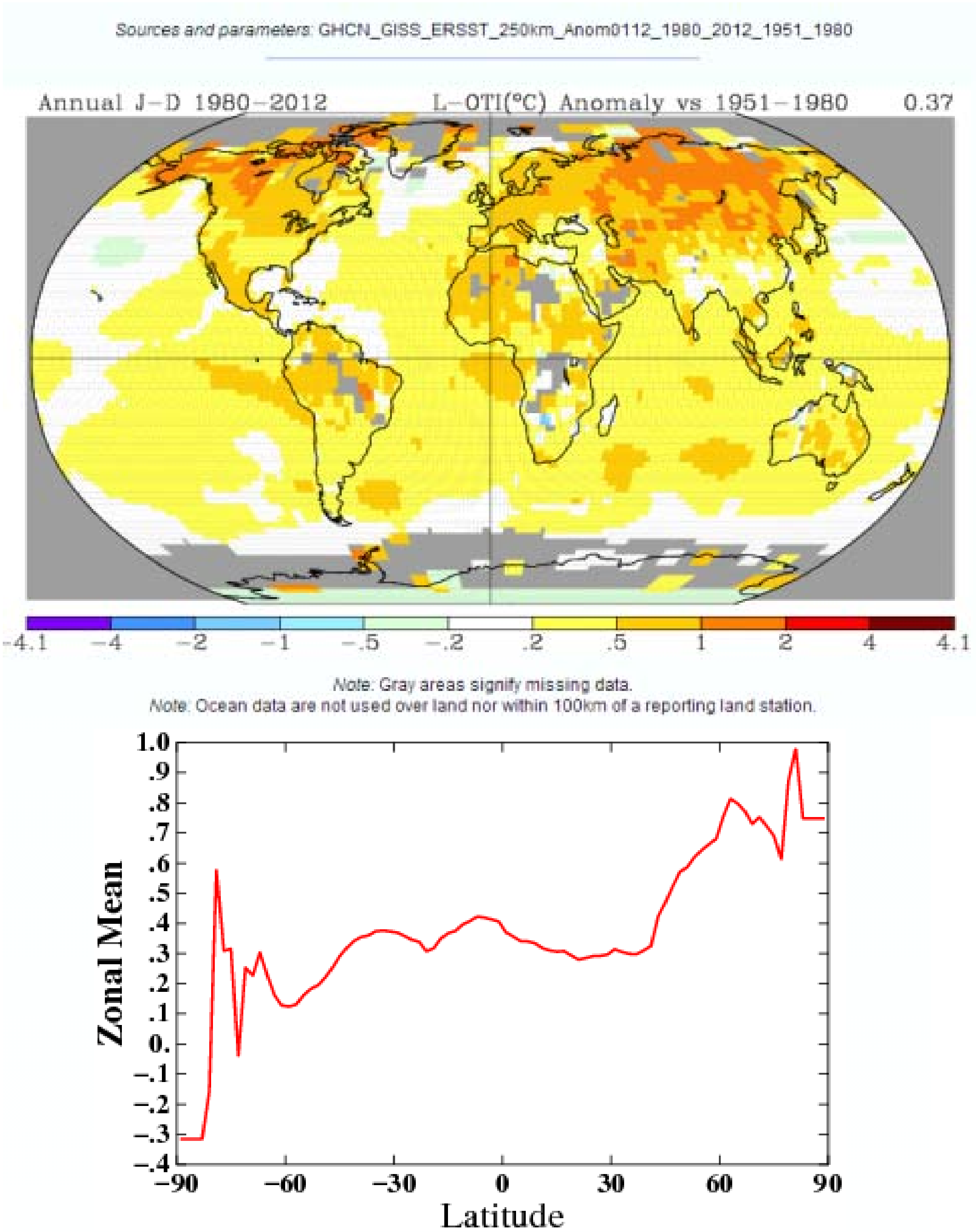



***Fig. 2.6*** *GISS Surface Temperature Analysis*
***Source****: NASA, 2014 generate from http://data.giss.nasa.gov/gistemp/maps/*

Urban built that influences the microclimate, connected with urban heating, is known as an urban heat island (UHI). The U.S. Environmental Protection Agency (EPA) in their book, (Wong, 2008) explains: “As urban areas develop, changes occur in the landscape, buildings, roads and other infrastructure to replace open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry. This development leads to the formation of an urban heat island, which is the phenomenon where urban regions experience warmer temperature than their rural surroundings." Furthermore, urban heat islands are divided into two types: surface and atmospheric urban heat islands. These are detailed in **Table 2.6.**

***Table 2.6*** *Type of UHI*

| Feature | Surface UHI | Atmospheric UHI |
|---|---|---|
| Temporal development | ▪ Present at all times of the day and night<br>▪ Most intense during the day and in the summer (hot season) | ▪ May be small or non-existent during the day<br>▪ Most intense at night or predawn and in the winter (cool season) |
| Peak intensity (most intense UHI conditions) | ▪ More spatial and temporal variation:<br>- Day: 10 to 15 $^{o}$C<br>- Night: 5 to 10 $^{o}$C | ▪ Less variation:<br>- Day: -1 to 3 $^{o}$C<br>- Night: 7 – 12 $^{o}$C |
| Typical identification method | ▪ Indirect measurement: Remote sensing | ▪ Direct measurement:<br>- Fixed weather stations<br>- Mobile traverses |
| Typical depiction | ▪ Thermal image | ▪ Isotherm map<br>▪ Temperature graph |

***Source**: EPA,2008*

Based on the descriptions above, architecture and urban design are correlated with atmospheric UHIs. This is because the urban built environment expresses within a canopy layer of UHI where the layer of air where people live from ground to below the tops of trees and roofs (US-Environmental Protection Agency (EPA), 2008)

As shown at **Fig. 2.7**, surface temperatures have an indirect, but significant, influence on air temperatures. This is true especially in the canopy layer, which is closer to the surface. For example, parks and vegetated areas, which typically have cooler surface temperatures, contribute to cooler air temperatures.

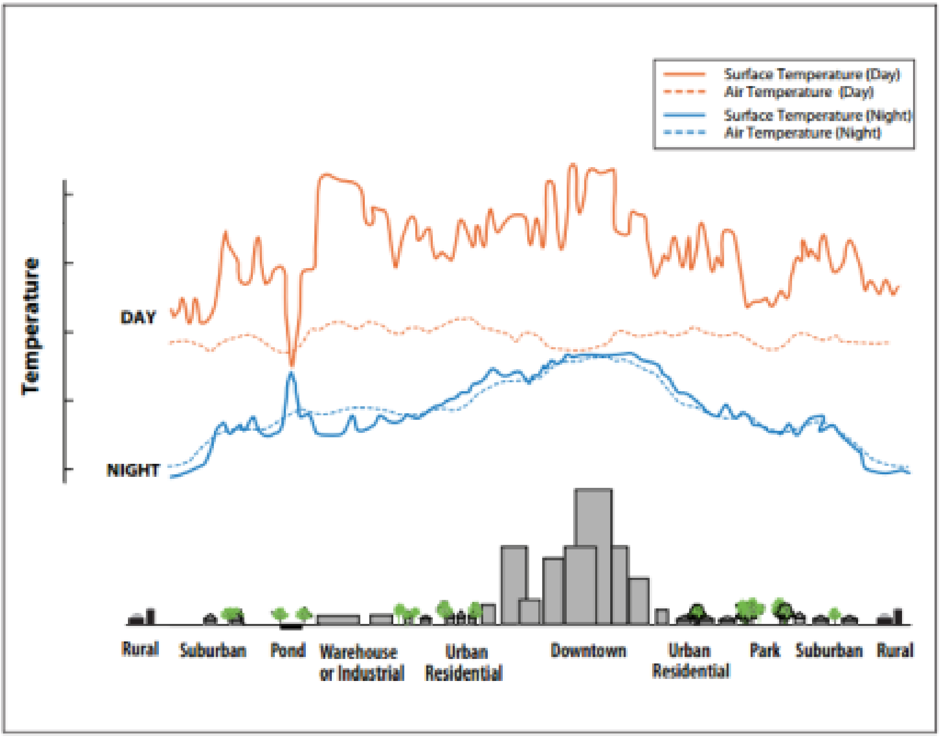



***Fig.2.7*** *Surface temperature and air temperature*
***Source****: US-Environmental Protection Agency (EPA), 2008*

### 2.3.2 Urban Surface Energy Budget

To understand what causes urban heat islands, it is important to understand the energy budget. In 2008, the EPA, in their first chapter "Urban Heat Island Basics" describe an energy budget as an equation that quantifies the balance of incoming and outgoing energy flows. This is shown at **Figure 2.8**. The surface energy budget of urban areas compared to more rural surroundings will differ because of differences in land cover, surface characteristics and level of human activity. Important elements of the budget include shortwave radiation, which is ultraviolet visible light, and near infrared radiation from the sun that reaches the earth. This energy is a key driver in the creation of urban heat islands. Urban surfaces, compared to vegetation and other natural ground cover, reflect less radiation back to the atmosphere. They instead absorb and store more of the radiation, which raises the temperature of an area.

a. Thermal storage increases in cities in part due to the lower solar reflectance of urban surfaces. However, it is also influenced by the thermal properties of construction material and urban geometry. Urban geometry can cause some short wave radiation, particularly within an urban canyon, to be reflected on nearby surfaces, such as building walls, where it is absorbed instead of returning back into the atmosphere.

b. Similarly, urban geometry can impede the release of longwave, or infrared radiation into the atmosphere. When buildings or other objects absorb incoming shortwave radiation, they can re-radiate that energy as longwave energy, or heat. However, at night, due to the dense infrastructure in some developed areas that have low sky view factors, urban areas cannot easily release longwave radiation to the cool and open sky. This trapped heat contributes to the creation of urban heat islands.

c. Evapotranspiration describes the transfer of latent heat, what we feel as humidity, from the Earth's surface to the air via evaporating water. Urban areas tend to have less evapotranspiration compared to natural landscapes, because cities retain little moisture. This reduced moisture in built up area leads to dry and impervious urban infrastructure that can reach very high surface temperatures, thereby contributing to higher air temperatures.

d. Anthropogenic heat refers to the heat generated by cars, air conditioners, industrial facilities and a variety of other man-made sources. This type of heat contributes to the urban energy budget, particularly in the winter.

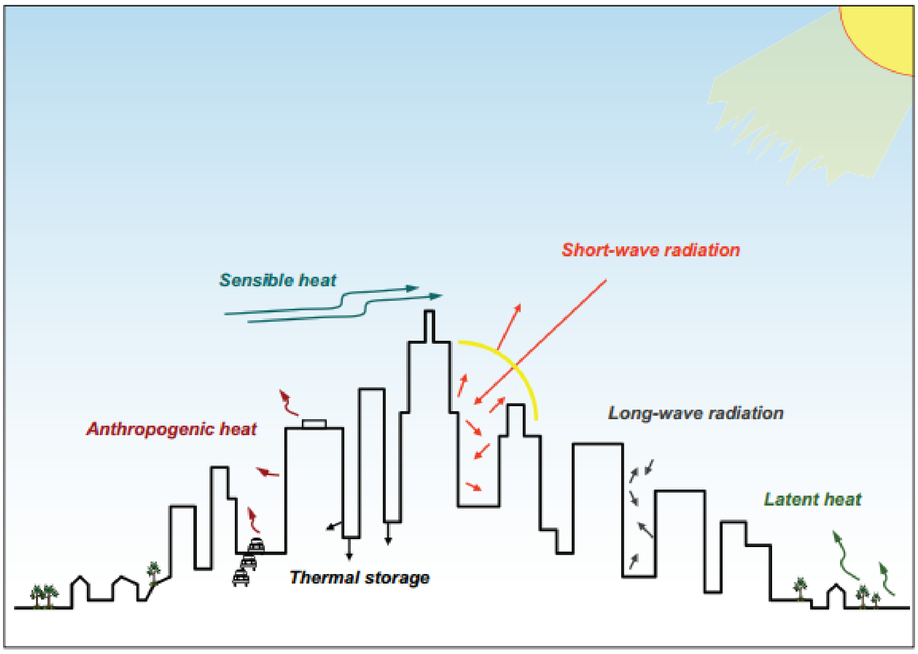



***Fig. 2.8*** *Surface temperature and air temperature*
***Source:*** *US-Environmental Protection Agency (EPA), 2008*

# 2.4 Environmental Aspect of High Density Design

## 2.4.1. Passive Design Strategies in Hot Humid Climate Region

Geographic location determines the urban design of buildings. This research, which takes place in the corridor of the hot humid climate region as shown at **Figure 2.9**, specifically discusses the range of Am, a tropical monsoon. This is based on the Köppen Climate Classification System, which is the most widely used system for classifying world climates. Tropical region categories are based on the annual and monthly averages of temperature and precipitation. Tropical monsoon climates, occasionally known as a tropical wet climate or tropical monsoon and trade-wind littoral climate in climate classification, is a relatively rare type of climate that corresponds to the Köppen climate classification category "Am."

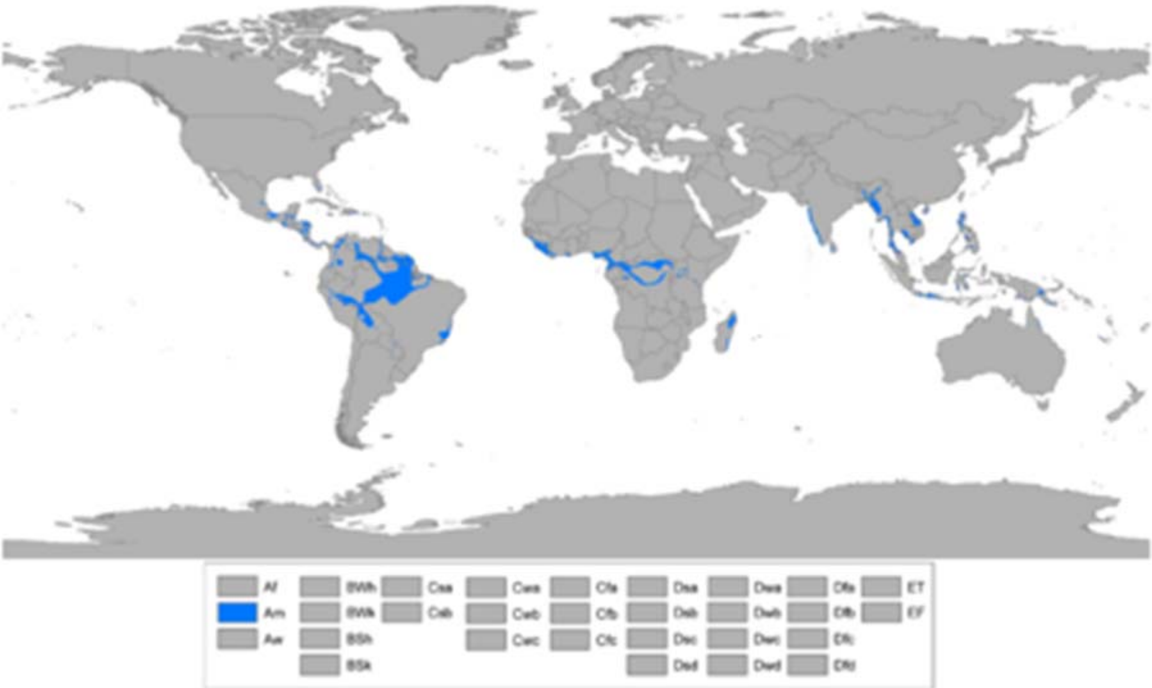



***Fig. 2.9*** *Köppen climate classification category "Am"*
***Source****: M. C. Peel, B.L.F., and T. A. McMahon, 2007*

Researchers (McKnight, 2006) and (M. C. Peel, B.L.F., and T. A. McMahon, 2007) describe the characteristic of tropical monsoons. Tropical monsoon climates have mean monthly temperatures above 18 °C in every month of the year and feature wet and dry seasons, similar to tropical savanna climates. However, unlike tropical savanna climates, a tropical monsoon climate's driest month has less than 60 mm of precipitation, but more than (100 − [total annual precipitation {mm}/25]). Also, tropical monsoon climates tends to see less variation in temperatures during the course of the year than tropical savanna climates. As well, this climate has a month that is the driest, which nearly always occurs at or soon after the winter solstice on that side of the equator.

The tropical climate region lies near the equator, which influences the amount of insolation. This incoming solar radiation potentially effects the heat since this region obtains more solar radiation than other climate regions.

Thus, the passive design strategy is able to be optimized and implemented broadly since there are no extreme temperatures. An urban building configuration which contains building groups, including space between buildings and open space are mostly concerned with having a major impact on reducing heating.

(Dekay,M., Brown, G.Z, second ed. 2001) mentioned for hot-humid and tropical humid climate regions, the first priority response must be wind and the second is shade. Therefore building groups design strategies for this climate response are:

**A. Urban Pattern**

The orientation and layout of streets has a significant effect on the microclimate around buildings and on access to sun and wind in buildings. Thus, hot-humid and tropical-humid climate regions have to respond with street orientations at 20-30° oblique to the predominant winds, responses to secondary wind direction, maximizing street right-of-ways for wind flow, but responses do not include paving.

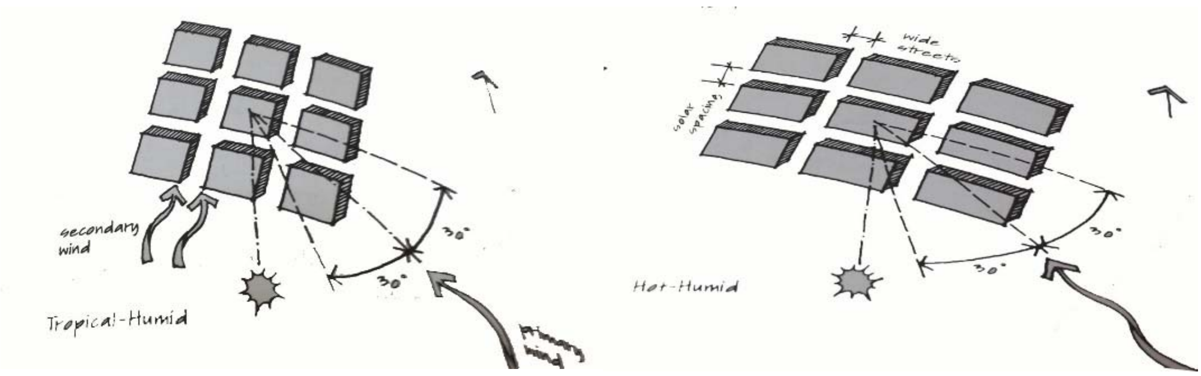



***Fig. 2.10*** *Urban Pattern at hot-humid and tropical-humid climate region*
***Source****: G.Z. Brown and Mark deKay, 2011*

**B. Street and Building**

The relationships between sky condition, latitude, surface reflectivity, building spacing, continuity, building shape and height are complex. Therefore, the spacing distance between buildings may be more restrictive than necessary, as low-latitude climates may be dominated by clear skies. The percentage of annual hours between 9am and 5pm is 95%. The latitude on 0 - 8° N/S required daylight factor 1.0 with H/W range is Tg α = 1.7-2.0. Thus, the minimum spacing angle requires 60° - 70°.

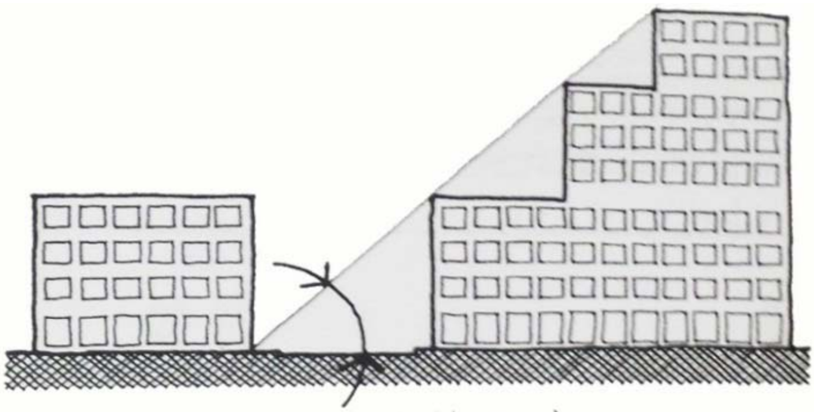


***Fig. 2.11*** *Urban Pattern at hot-humid and tropical-humid climate region*
***Source****: G.Z. Brown and Mark deKay, 2011*

**C. Urban Ventilation and Plot Ratio**

Three distinct flow regimes can be identified between buildings based on their spacing. Skimming flow is caused when buildings are spaced closely together in row and oriented perpendicular to wind. When spacing is larger than that required to create a stable vortex between buildings, but smaller than the sum of the upwind and downwind eddy, a Wake Interference Flow is induced. If spacing between buildings is larger than the sum of the upwind and downwind eddies, wind will drop between the building in a pattern of *Isolated Roughness*, which is good for ventilation (Lee, 2011 ) in (Dekay,M., Brown, G.Z, second ed. 2001) .

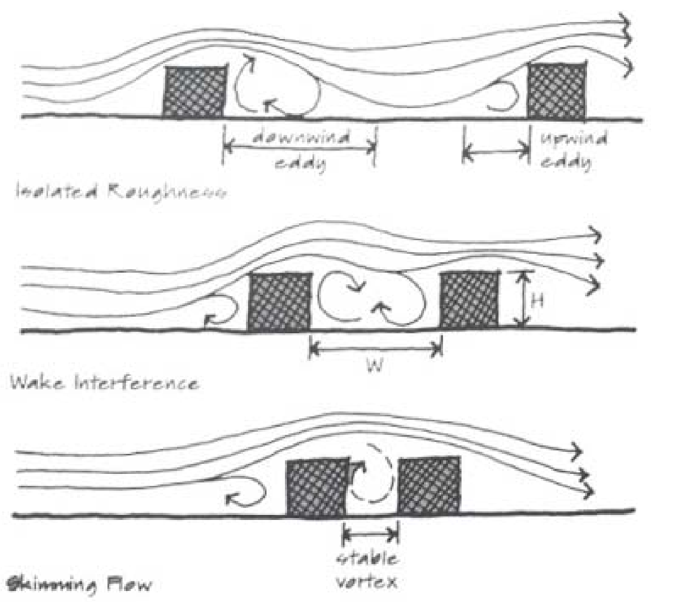



***Fig.2.12*** *Urban Ventilation at hot-humid climate region*

***Source****:G.Z.Brown and Mark deKay,2011*

**2.4.2. Outdoor Human Perception at Hot Humid Climate Region**

The interest of studying outdoor thermal comfort has raised in the recent decade. This is driven by the thermal effects of the environment which impact either heat stress or cold stress. However, the study focuses on outdoor thermal comfort less than indoor thermal comfort, since the HVAC (heating, ventilation, and air condition) is still the main aspect of building design.

(Tahbaz, 2011) groups several thermal stress indices, especially for outdoor conditions. The first group of indices is based on a thermal stress model that accounted for hot condition, such as:

1. Heat Index (HI): by Lans P. Rothfusz,published by US-NOAA can be accessed at http://www.srh.noaa.gov/epz/?n=wxcalc_heatindex
2. Tropical Summer Index (TSI) by M. R. Sharma and Sharafat Ali, 1986
3. Discomfort Index (DI) by Thom, 1959
4. Wet Bulb Globe Temperature (WBGT) based on ISO 7243 (1982 and 2003)

Also, those for cold stress indices include:

1. Wind Chill Index (WCI) developed by Paul Allman Siple and Charles Passel in 1945 is widely used by US-NOAA, and can be accessed at: http://www.crh.noaa.gov/ddc/?n=windchill
2. Wind Chill Equivalent Temperature (WCET) by Osczevski, R. and Bluetein, M., 2005

Another method is based on a heat budget model. This method is able to evaluate both cold and hot conditions such as:

1. Perceived Temperature (PT) by Staiger, 1997; G. Jendritzky, et al., 1999
2. Temperature Humidity Index (THI)
3. Physiological Equivalent Temperature (PET)

The latest index is based on a comprehensive heat budget model of human biometeorology, called the Universal Thermal Climate Index (UTCI). It was created by a group of specialists to cover all of the shortcomings found in the other indices. [4]

Areas near the equator within hot-humid climate region have a special benefit, since there are no extreme temperatures, even though this region is exposed to insolation for longer than any other climate region. The fruitfulness of outdoor thermal comfort can only be achieved when the building group design strategies are well applied. Therefore, the idea of microclimate improvement involves giving better outdoor thermal comfort. Specific studies of outdoor thermal comfort which have been conducted in hot humid climate regions were referred to for this research and are as follows:

***A.*** First, those based on the energy balance of the human body, include the PET (Physiological Equivalent Temperature), which was first developed based on MEMI

[4] The more information about UTCI can be accessed through http://www.utci.org/

(Hoppe, P., Mayer, A.M.F.R.H., 2007) and later acknowledged in VDI-3787 ((VDI), 1998). The PET can make estimates using a free software package called RayMan. In their study, (Lin, 2001) looked at 1644 interviews in Taiwan and developed PET ranges for Taiwan in their hot and humid climate. This is shown in **Table 2.7.**

***Table 2.7.*** *Thermal sensation classification for Taiwan and western/middle Europe*
***Source:*** *Lin T.P., et.al, 2010*

| Thermal sensation | PET range for Taiwan (°C PET) | PET range for western/middle europe (°C PET) |
|---|---|---|
| Very cold | <14 | <4 |
| Cold | 14-18 | 4- 8 |
| Cool | 18-22 | 8-13 |
| Slighty cool | 22-26 | 13-18 |
| Neutral | 26-30 | 18-23 |
| Slighty warm | 30-34 | 23-29 |
| Warm | 34-38 | 29-35 |
| Hot | 38-42 | 35-41 |
| Very hot | <42 | <41 |

B. The other method describes outdoor thermal sensation in terms of several climatic parameters, such as air temperature, humidity, wind speed, global solar radiation, globe temperature and surface temperature using a regression model. However, this model is limited to the specific region where the data are obtained.

YJS describes the comfort level for normal walking and is based on (Sangkertadi, 2012) who conducted an experiment in Manado, Indonesia.

$$Y_{JS} = -3.4 - 0.36v + 0.04Ta + 0.08Tg - 0.01RH + 0.96Adu \quad (R^2=0.7) \qquad (7)$$

Where:

YJS : comfort level (normal walking)

v : wind speed (m/s)

Ta : air temperature ($^oC$)

Tg : globe temperature ($^oC$)

RH : relative humidity (%)

Adu : human surface body ($m^2$)

Average Adu for Indonesian people is $1.7m^2$

***Table 2.8.*** *Comfort Level Perception for Normal Walking*

| Value of YJS | Comfort Level perception |
|---|---|
| -2 | Cold |
| -1 | Cool |
| 0 | Comfort / Neutral |
| 1 | Warm / Slightly Hot |
| 2 | Hot |
| 3 | Very Hot |
| 4 | Start to feel pain |

C. Prognostic model based on fluid and thermo dynamics using ENVI- (Bruse, 2006). The PMV Model used in ENVI-met is a special adaptation to outdoor conditions made by Gerd Jendritzky and Birger Tinz, 2009.

***Table 2.9*** *Adaptation of Perceived Temperature, Predicted Mean Vote based on Fanger (1972)*

| Thermal stress category | Perceived Temperature (PT) in °C | Predicted Mean Vote (PMV) | Thermo-physiological stress |
|---|---|---|---|
| 4 | PT $\geq$ +38 | Very hot | Extreme heat load |
| 3 | +32 $\leq$PT<+38 | Hot | Strong heat load |
| 2 | +26 $\leq$PT<+32 | Warm | Moderate heat load |
| 1 | +20 $\leq$PT<+26 | Slightly warm | Slight heat load |
| 0 | 0 $\leq$PT<+20 | Comfortable | None |
| -1 | -13 <PT$\leq$0 | Slightly cool | Slight cold stress |
| -2 | -26 <PT$\leq$-13 | Cool | Moderate cold stress |
| -3 | -39 <PT$\leq$-26 | Cold | Strong cold stress |
| -4 | PT$\leq$-39 | Very cold | Extreme cold stress |

Jendritzky and Tinz (2009) have stated that the heat exchange between the human body and the thermal environment can be described in the form of the energy balance equation. This is an application of the first theorem of thermodynamics to the body's heat sources, including in terms of metabolism, and the various avenues of heat loss to the environment. This method is as follows:

Heat Exchange:

$$M-W-[Q_H(Ta,v)+Q^*(T_{mrt})]-[Q_L(e,v)+Q_{SW}(e,v)]-Q_{Re}(Ta,e)+S=0 \quad (8)$$

Where:

| | |
|---|---|
| M | metabolic rate (activity) |
| W | mechanical power |
| S | storage (change in heat content of the body) |

Peripheral (skin) heat exchanges

| | |
|---|---|
| $Q_H$ | turbulent flux of sensible heat |
| $Q^*$ | radiation budget |
| $Q_L$ | turbulent flux of latent heat (diffusion of water vapour) |
| $Q_{SW}$ | turbulent flux of latent heat (sweat evaporation) |

Respiratory heat exchanges

| | |
|---|---|
| $Q_{Re}$ | respiratory heat flux (sensible and latent) |

Thermal environmental parameters

| | |
|---|---|
| Ta | air temperature |
| $T_{mrt}$ | mean radiant temperature |
| v | wind velocity relative to the body |
| e | water vapour pressure |

The equation above can be explained by understanding "the meteorological input variables including air temperature *Ta,* water vapour pressure *e*, wind velocity *v* and mean radiant temperature $T_{mrt}$, including short and longwave radiation fluxes, in addition to metabolic rate and clothing insulation."

Furthermore, Jendritzky and Dear (2009) give an overview of the basics in thermo-physiological and the heat exchange modeling. This is done with respect to the adaptation, where the appropriate meteorological variables are attached to the relevant energy fluxes in $W/m^2$. The physiological and internal variables, such as the temperature of the core or of the skin, sweat rate, and skin wetness, all interact with the environmental heat conditions yet are not mentioned here.

### 2.4.3. Microclimate parameters to create outdoor thermal comfort

Llies near the equator, Bandung city is facing a long period of insolation, the improvement of urban microclimates to achieve outdoor thermal comfort simply involves the alteration of surface temperatures of surroundings that cover urban areas. Based on the above description of outdoor thermal perception, it is clear that microclimates play an important role in creating specific atmospheric conditions that impact thermal comfort. According to (PO, Fanger, 1970), there are six factors that significantly determine the human thermal environment and an individual's sensation of thermal comfort. These factors are divided into both environmental factors and human behavioral factors, and are shown in **Table 2.10**.

***Table 2.10**. Six factors of thermal comfort,*
***Source:** (MORAN, 2006)*

| parameter | | symbol | also |
|---|---|---|---|
| Environmental | | | |
| 1. | Dry-bulb temperature | ($T_a$) | $T_o$ |
| | $T_o$=0.5($T_a$+MRT) | | |
| | ($T_o \approx 2/3T_a + 1/3T_g$) | | |
| 2. | Black-globe temperature | (Tg) | MRT |
| | MRT=$(1+0.22V^{0.5})(T_g - T_a)+T_a$ | | |
| 3. | Wind velocity | (V) | |
| 4. | Wet-bulb temperature | ($T_w$) | rh; VP |
| behavioral | | | |
| 5. | Metabolic rate | (M) | met |
| 6. | Clothing | | |
| | Insulation | (clo) | |
| | Moisture permeability | ($i_m$) | |

Therefore, the variables of microclimate are focused on global temperature, air temperature, humidity and wind speed, which also calculate the mean radiant Temperature, or Tmrt. The Tmrt is defined as the "uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure" (ASHRAE, 2001) .

During sunny weather in summer, the Tmrt is the most important meteorological input parameter for human energy balance (Matzarakis, 2011). The value of Tmrt is derived from all relevant radiant fluxes, and can also be calculated in both shortwave and longwave radiation flux. Global temperatures then become an essential part as they represent the weighted average of radiant and ambient temperature. Therefore, based on (ASHRAE, 2001), Tmrt can be calculated by knowing the global temperature, air temperature, and wind speed according to the equation below:

$$\left[(\mathbf{tg}+\mathbf{273.15})^{\mathbf{4}}+\frac{\mathbf{1.1x10^{8}Va^{0.6}}}{\varepsilon \boldsymbol{D}^{\mathbf{0.4}}}\boldsymbol{x}\,(\mathbf{tg}-\mathbf{ta})\right]^{\mathbf{0.25}}-\mathbf{273.15} \quad (9)$$

Where:

Tmrt = Mean radiant temperature (°C)

Tg = Globe temperature (°C)

V = Wind speed (m/s)

Ta = Air temperature (°C)

D = Diameter of globe

E = The emissivity of the human body

According to Krichhoff's laws, ε is equal to the absorption coefficient for longwave radiation (standard value = 0.97).

**Bibliography**

US-Environmental Protection Agency (EPA), 2008. Reducing Urban Heat Islands: Compendium of Strategies. Urban Heat Island Basics. In: a. A. D. ed. J.R. Kathleen Hogan.

(VDI), V. V. 3., 1998. in Part I: environmental meteorology, methods forthe human-biometeorological evaluation of climate and air quality for the urban and regionalplanning at regional level.

ASHRAE, 2001. Fundamentals Handbook 2001 (SI Edition) in American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Bruse, M., 2006. Simulating human thermal comfort and resulting usage patterns of urban open spaces with a Multi Agent System. in PLEA 24. 2007. 21(2006), p. 461-467.

Chao Ren, E.N.a.L.K, 2011. Four Decades Of UrbanClimatic Map Studies: A Review, in City Weathers, meteorology and urban design1950-2010. V. M. Hebbert, ed. Manchester: Manchester Architecture Research Centre, University of Manchester.

Cheng, V., 2010. Understanding Density and High Density, in Designing High-Density Cities, e.a. Edward Ng. In: Editor ed. London: Earthscan, p. 13.

Dekay,M., Brown, G.Z, second ed. 2001. Sun, Wind and Light. Canada: John Wiley and Sons, Inc.

Edward Ng, e., 2010. Designing High-Density Cities for Social and Environmental Sustainability. Sterling: USA: Earthscan.

G. Jendritzky, H.S., K. Bucher , A. Graetz, G. Laschewski, 1999. The Perceived Temperature: The Method of the Deutscher Wetterdienst for the Assessment of Cold Stress and Heat Load for the Human Body.

Hoppe, P., Mayer, A.M.F.R.H., 2007. Modelling radiation fluxes in simple and complex environments—application of the RayMan model. Int. J Biometeorol, Volume 51, p. 12.

Howard, L. 1833 (Republished in 2011). THE CLIMATE OF LONDON Dublin, Ireland, IAUC.

Lee, T., 2011 . The Density Atlas was developed by a team of MIT faculty, students, and affiliated planners, architects and designers. The concept of combining the three commonly used measures of density to better understand and compare city blocks and neighborhoods emer. Atlas Density ed.

Lin, N., 2001. Social capital. A theory of social structure and action. Cambridge: Cambridge University Press.

M. C. Peel, B.L.F., and T. A. McMahon, 2007. Updated world map of the Koppen-Geiger climate classification. Hydrology and Earth System Sciences, 11: p. 11.

Matzarakis, M., 2011. Comparison of models calculating the sky view factor used for urban climate investigations. Theor Appl Climatol, Volume 105(3-4), p. 6 pages.

McKnight, T. D., 2006. Physical Geography: A Landscape Appreciation. Climate Zones and Types: The Köppen System 2000. Prentice Hall: Upper Saddle.

MORAN, Y., 2006. Thermal Comfort and the Heat Stress Indices. Industrial Health, Volume 44, p. 10 .

PO, Fanger, 1970. Thermal comfort. Copenhgen: Danish Technical Press.

Sangkertadi, W., 2012. New Concepts in Districts Planning, Based on Heat Island Investigation. Procedia - Social and Behavioral Sciences, Volume 36, p. 7.

Tahbaz, M., 2011. Psychrometric chart as a basis for outdoor thermal analysis. International Journal of Architectural Engineering & Urban Planning, p. 21(2).

Wong, E., 2008. Reducing Urban Heat islands : Compendium of Strategies.. In: Urban Heat Island Basics. US: Environmental Protection Agency.

# 3. City Studied

## 3.1. Deciding on the City of Study

The decision to select Bandung city as the city studied, was practically motivated by its ease of data access, and the direct involvement of the author (of this research) in various projects in Bandung: notably the mitigation of urban slum areas, planning of the development of priority regions, also the *Rusun* planning and design to revitalise overcrowded areas.

Demographic conditions, and some urban environmental problems, in Bandung was part of the reason for its selection. Bandung has the 2nd highest recorded population of any metropolitan city in Indonesia, after Jakarta. The problems were caused by rapid urbanization, which affected the urban environment, its building density, the change of land-use, and also the quality of urban living.


***Fig. 3.1*** *Bandung city in West Java region*
***Source*** *: https://www.google.co.jp/maps/place/Bandung/@-6.9033101,107.642621,13*

# 3.2. Bandung City

Bandung city, Indonesia, lies on 6.54ºS and 107.36ºE, as shown at **Fig. 3.1,** in the Java Islands, 791 m above sea level. This city is cooler than most other Indonesian cities, having an average temperature of 24.72 ºC (76.5 ºF) throughout the year. The highest point in the north is 1.050m, and the lowland in the south is around 675m above sea level. It is relatively flat in the south part of Bandung, while the north part is mountainous. This topographic character brings Bandung a beautiful scenery filled with the biodiversity of flora, thus making Bandung the 'City of Flowers'. With 2.455.517 inhabitants per 167.31 $km^2$, the population density is 14.676/$km^2$ (Bandung in Figure, 2013).

Bandung City is located in the region of West Java, and constitutes Capital of West Java. The positioning is strategic for communication and economic matters, since it is situated at the highways axes:

a. West – East is connected to the capital city of Indonesia, Jakarta.

b. North – South is the road heading to the plantation area (Subang and Pangalengan).

The geological conditions and soil in Bandung City area have an alluvial soil layer from the Tangkuban Perahu Mount explosion. The kind of materials in the north, generally andosol in the south, and east consist of grey alluvial with clay sediment, while in the central and west is scattered andosol.

Bandung is classified as an 'Am' Tropical Monsoon by Köppen-Geiger. These are very warm climates found in the tropics that experience high quantities of precipitation. The primary distinguishing characteristic of these climates is that all months have average temperatures above 18°C. Based on Bandung's meteorological agency (BMKG Bandung), the highest temperature is 30.9 $^{o}$C in August and the lowest in July 17.4 $^{o}$C, the average annual temperature is 23.4$^{o}$C. The average precipitation is 209.29mm, the lowest in August which is 0mm, and the highest in December which is 637mm. The average annual humidity is 76%, the highest is 83% in December and the lowest 71% in July.

### 3.2.1. Demography

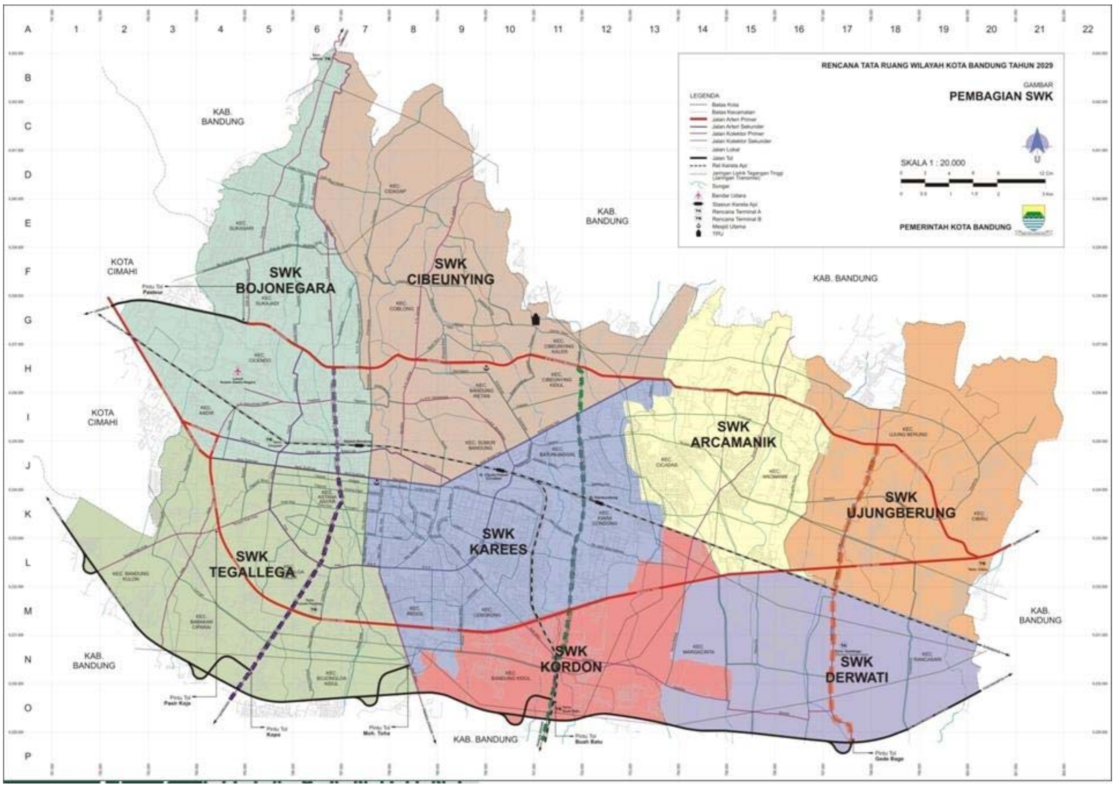



***Fig. 3.2** Bandung city map*
*Source : Bandung Masterplan 2011-2030*

Bandung is divided into eight sub-areas of cities (Indonesia: SWK) as shown at **Fig. 3.2**, that are:

1. Bojonegara
2. Cibeunying,
3. Tegallega,
4. Karees,
5. Kordon,
6. Arcamanik,
7. Ujung Berung and
8. Derwati

The hierarchy of administrative city management is as follows:

1. City / Kota lead by city mayor district/*Kecamatan* lead by *camat*
2. Sub-district / *Kelurahan* lead by *lurah*
3. Community Association / *Rukun Warga (RW)* lead by *Ketua RW* (minimum 10 RT and maximum 50 RT)
4. Neighborhood association / *Rukun Tetangga* (RT) lead by *Ketua RT* (minimum 10 and maximum 50 households)

This city includes 30 districts (*Kecamatan*) and 151 sub-districts (*Kelurahan*). The most densely populated district is Babakan Ciparay with 24.235 / $km^2$, meanwhile Cinambo district has the lowest population density with 6.236/$km^2$. **Table 3.1** shows the details of Bandung population density based on district. The population based on district and its density is shown in **fig. 3.3.**

From the graphic below, Tegal lega SWK has the highest population, followed by Cibeuying, Karees then Bojonegara. The characteristics of densely populated areas are not directly proportional to the population.

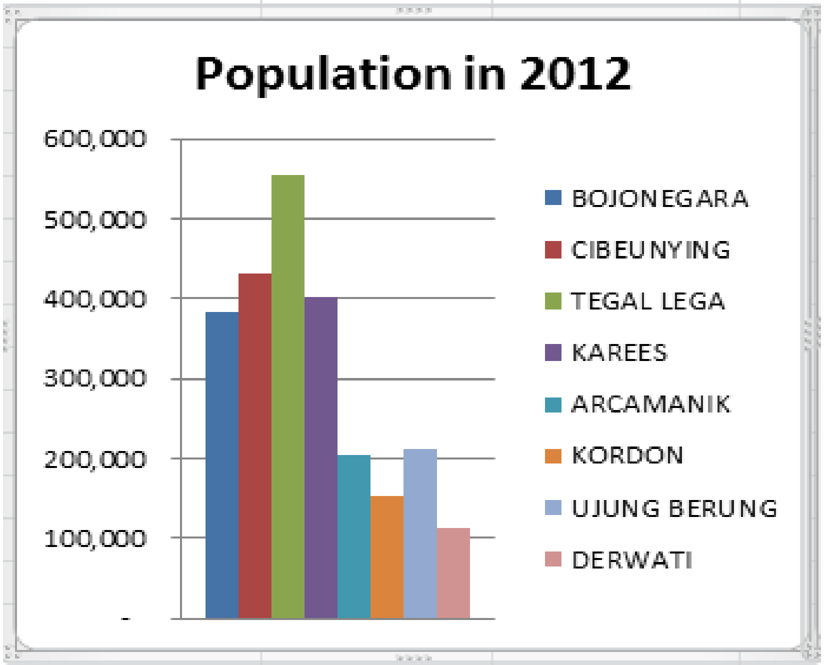



***Fig.** 3.3 Demographic characteristics of Bandung city based on sub-city area (SWK).*
***Source:** processed from Bandung in Figure: (BPS Jawa Barat, 2013)*

***Table 3.1** Population density based on district*

| | District | Population | Area | Population Density | Sub-City Area (SWK) |
|---|---|---|---|---|---|
| 1 | A n d i r | 96,435 | 3.71 | 25,993 | Bojonegara |
| 2 | Cicendo | 98,609 | 6.86 | 14,374 | |
| 3 | Sukajadi | 107,133 | 4.3 | 24,915 | |
| 4 | Sukasari | 80,971 | 6.27 | 12,914 | |
| 5 | Cidadap | 57,999 | 6.11 | 9,492 | Cibeunying |
| 6 | Coblong | 130,023 | 7.35 | 17,690 | |
| 7 | Cibeunying Kidul | 106,571 | 5.25 | 20,299 | |
| 8 | Cibeunying Kaler | 70,111 | 4.5 | 15,580 | |
| 9 | Sumur Bandung | 36,160 | 3.4 | 10,635 | |
| 10 | Bandung Wetan | 30,767 | 3.39 | 9,076 | |
| 11 | Bandung Kulon | 138,644 | 6.46 | 21,462 | Tegal Lega |
| 12 | Astanaanyar | 68,042 | 6.46 | 10,533 | |
| 13 | Bojongloa Kaler | 119,025 | 3.03 | 39,282 | |
| 14 | Babakan Ciparay | 145,411 | 7.45 | 19,518 | |
| 15 | Bojongloa Kidul | 84,686 | 6.26 | 13,528 | |
| 16 | R e g o l | 80,534 | 4.3 | 18,729 | Karees |
| 17 | Lengkong | 70,371 | 5.9 | 11,927 | |
| 18 | Kiaracondong | 130,460 | 6.12 | 21,317 | |
| 19 | Batununggal | 119,541 | 5.03 | 23,766 | |
| 20 | Mandalajati | 62,849 | 6.67 | 9,423 | Arcamanik |
| 21 | Antapani | 73,608 | 3.79 | 19,422 | |
| 22 | Arcamanik | 68,519 | 8.8 | 7,786 | |
| 23 | Bandung Kidul | 58,282 | 6.06 | 9,617 | Kordon |
| 24 | Buah batu | 94,018 | 7.93 | 11,856 | |
| 25 | Cibiru | 71,191 | 13.17 | 5,406 | Ujung Berung |
| 26 | Ujungberung | 76,021 | 10.34 | 7,352 | |
| 27 | Panyileukan | 39,787 | 5.1 | 7,801 | |
| 28 | Cinambo | 24,942 | 3.68 | 6,778 | |
| 29 | Gedebage | 36,657 | 9.58 | 3,826 | Derwati |
| 30 | Rancasari | 76,014 | 13.17 | 5,772 | |

***Source :** Bandung in Figure, 2012*

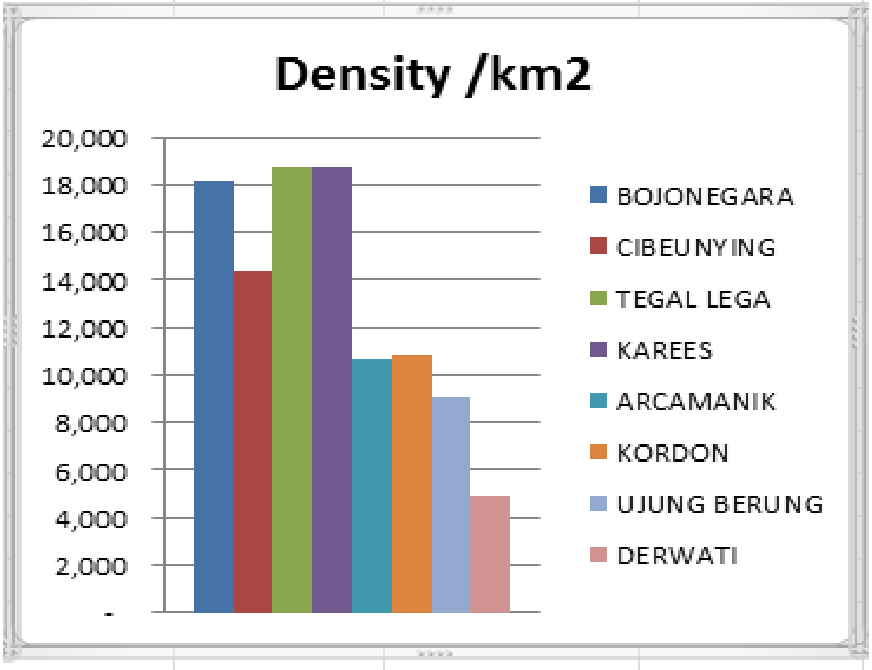



***Fig. 3.4** Population Density of Bandung city based on sub-city area (SWK).*
***Source :** processed from Bandung in Figure, 2012*

The **fig. 3.4** presents the chart of population density based on SWK, Tegal Lega is the most densely populated SWK, followed with Karees then Bojonegara. The characteristics of densely populated areas are not directly proportional to the population.

### 3.2.2. Spatial Planning

Bandung has a total area of 16,310 ha, the land mass is 16,038 ha and 272 ha as irrigation or water functions. The biggest use of land is for settlement which is 56%, industrial 20% and services 10%. The details of land-use of Bandung is shown in **Table 3.2** and **Fig. 3.5**. As seen at **Table 3.1**, Bandung city is divided into eight sub-areas (SWK), this city also having two city service centers, namely Downtown and Gede Bage, which supports and serves two million residents. Meanwhile, this city service center is further divided into eight sub-city service centres that serve 500,000 residents. **Fig. 3.6** shows the spatial planning of Bandung City 2011-2030, meanwhile **Fig. 3.7** shows the spread of land-use in Bandung.

***Table 3.2** Land-use of Bandung*

| Land-use | Area |
|---|---|
| Settlement | 9,290.28 ha |
| Industry | 3,354.49 ha |
| Service | 1,668.28 ha |
| Agriculture, dry land | 647.83 ha |
| Paddy Field | 318.70 ha |
| Passive Land | 545.47 ha |
| Farm plantation | 215.57 ha |
| Pool | 39.90 ha |
| Other Usage | 649.22 ha |

***Source :** Bandung in Figure, 2012*

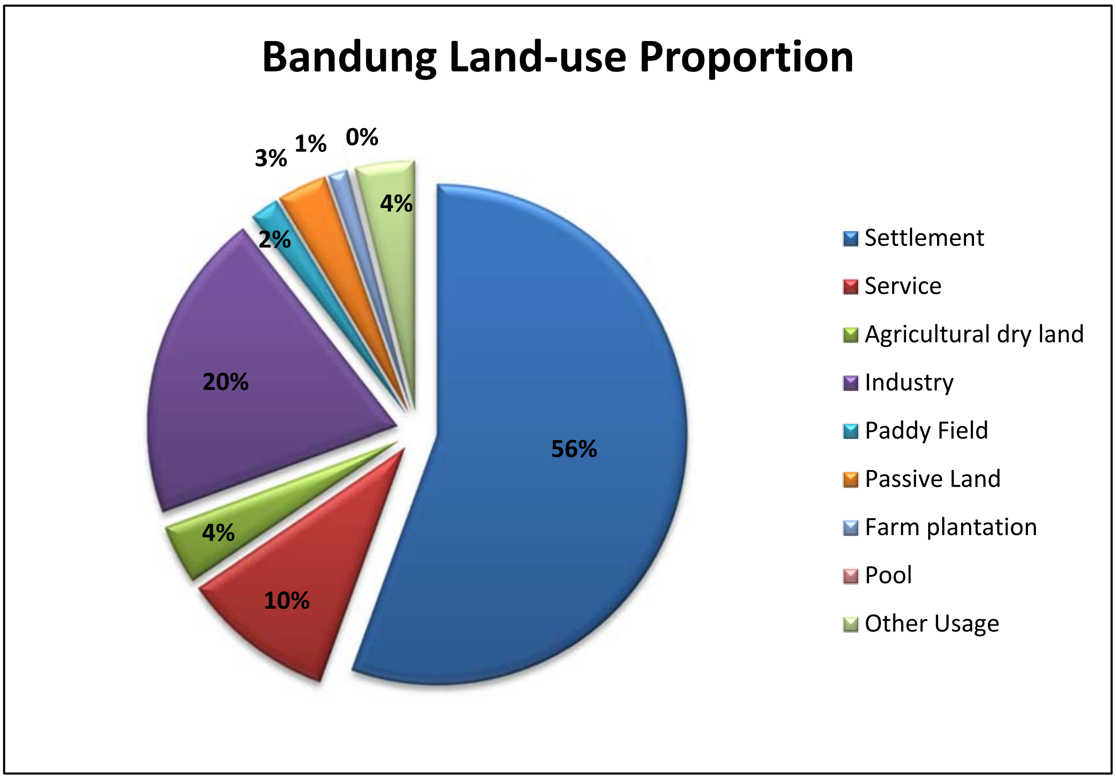



***Fig. 3.5** Bandung Land-Use Proportion*
***Source:** Bandung in Figure, 2012*

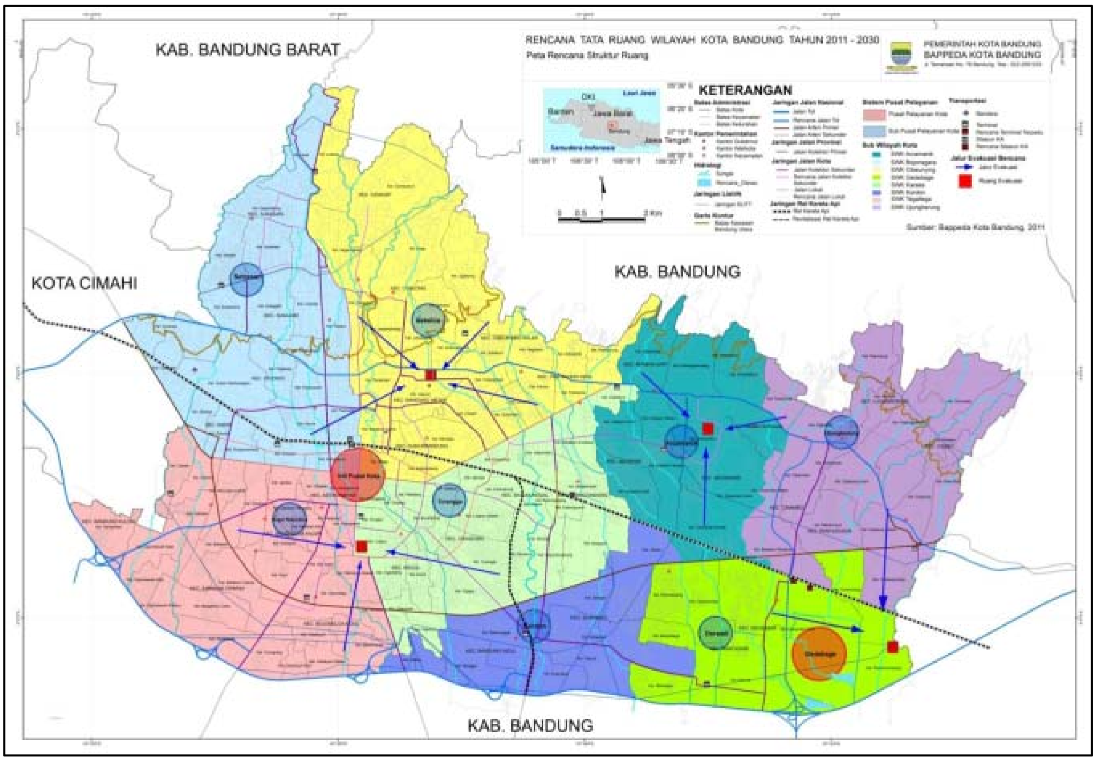



***Fig. 3.6*** *Bandung spatial planning strategy in 2011-2030*
***Source****: RTRW Bandung 2011-2030*

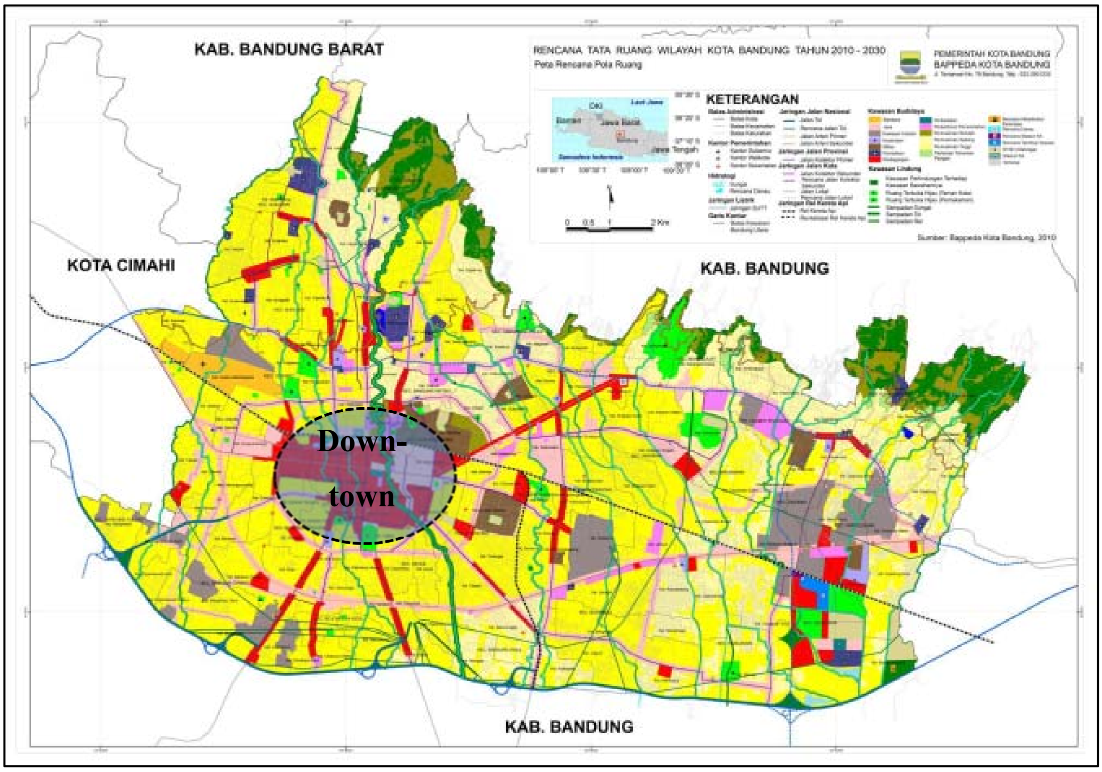



***Fig. 3.7*** *Bandung Land-Use*
***Source****: RTRW Bandung 2011-2030*

## 3.3. Urban Environmental Problems

Density is measurable, somehow high-densely population has both positive and negative impacts on the urban built environment. Tokyo is recorded as the largest metropolis in the world, with 37,329,000 inhabitants, and compared with other cities in China, India or Indonesia, the city government of Tokyo is a leading one, and has been awarded the 1st Cities in Motion Index (ICIM) for its impressive governance, public management, urban planning, technology, environment, international outreach, social cohesion, mobility and transportation, human capital, and economy[1]. Here then, the density is a potential asset for the city. But it also has the opposite impact when the city government is not capable of managing the city. Urban environmental problems arise easily with an increase in the amount of people.

### 3.3.1 Urban Slums

Squatters and slum areas has a complicated position, their presence correlated with unparalleled population growth, and the rush of economically stricken people from rural to urban areas which reputedly offer a better life. Squatter areas do not necessarily become slums, and not all slum areas were a squatters area. Slums are highly congested urban areas, marked by deteriorated, unsanitary buildings, poverty and social disorganization. Meanwhile squatters are settlers on land, especially public or unoccupied land, without right or title. [2]

Here then, the physical aspect of urban built environments which have low living qualities will be referred to as slums. The definition of 'slum area' by UN Habitat: a slum is an area that combines to various extents the following characteristics, such as :

a. Inadequate access to safe water

b. Inadequate access to sanitation and other infrastructure

c. Poor structural quality of housing

d. Overcrowding

e. Insecure residential statutes

[1] (http://www.iese.edu/)

[2] (http://www.gdrc.org/uem/squatters/slumsandsquatters.html)

Meanwhile the ministry of public works of the Republic of Indonesia have launched the Guidelines of Slum Settlement Identification in Metropolitan areas In Indonesia. Slum areas are defined by six criteria, which are:

a. Vitality of non-economic aspect (congruity with urban planning, physical condition of buildings and demographic condition)
b. Vitality of economic aspect (existence to the surrounding, distance to activity, function of surrounding area)
c. Land statue (domination of legal aspect, domination of ownership of land)
d. Infrastructure (street, drainage, water service, sewage, solid waste)
e. Government commitment ( institutional, fund)
f. Priority of problem handling (management plans, physical improvement)

More detail of slum criteria are described in **Table 3.3** .

***Table 3.3*** *Criteria of Slum Settlement*

| No | Typology | Code | Charac |
|---|---|---|---|
| 1 | High slum | HS | Settlement area with water service less than 30%, condition of outer main of sewage and drainage less than 30%, the breakage of neighborhood street and connections more than 70%. Building density more than 100 units/ha, the distance between a building less than 1m, Building Coverage (BC) more than 70% without open space in the neighborhood. The growth of building construction at a high rate. |
| 2 | Medium slum | MS | Settlement area with water service between 30-60%, condition of outer main of sewage and drainage 30-60%, the breakage of neighborhood street and connections is 50-70%. Building density between 80-100 unit/ha, the distance between buildings is 1,5-3 mr, Building Coverage (BC) 50-70%. The growth of building construction at a medium rate. |
| 3 | Low slum | LS | Settlement area with water service more than 60%, condition of outer main of sewage and drainage more than 60%, the breakage of neighborhood street and connections are less than 50%. Building density less than 80 unit/ha, the distance between buildings is more than 3 m, Building Coverage (BC) less than 50%. The growth of building construction in a low rate. |

***Sources :*** *The Guideline of Slum Settlement Identification in Metropolitan area in Indonesia, 2006*

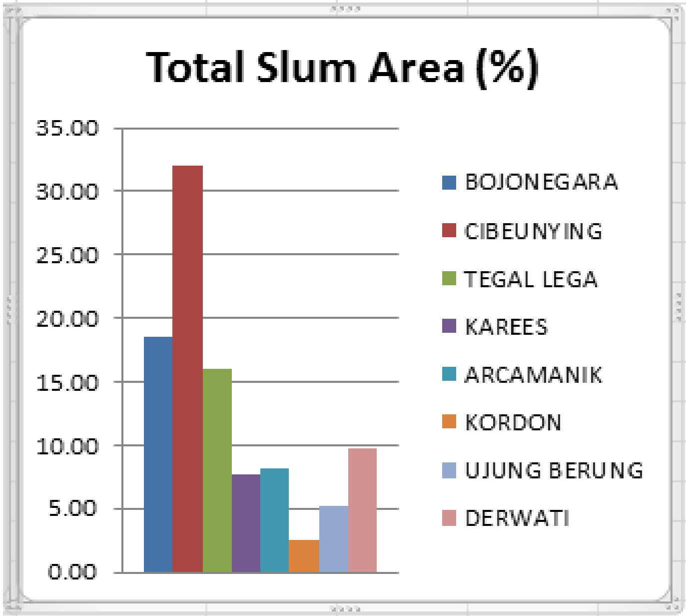



***Fig. 3.8.*** *Total slum area in Bandung*
***Source:*** *Proceed from Bandung Kumuh, 2010*

**Table 3.4** shows the sub-districts including RW/RT which have slum problems. The urban environment quality of sub-districts (*kelurahan*) in Bandung was then assessed based on the slum criteria above. To simplify the presentation of data, the above sub-districts identified as slum areas were grouped by district and presented in **Fig. 3.8.** Based on the graphic of total slum area in Bandung, it is revealed that Cibeunying district is the leading slum area. There are 62 RT/RW in Cibeunying District, from a total of 194 RT/RW, which have slum characteristics. Kordon District has the smallest slum area with 5 RT/RW.

### 3.3.2 The Stacking of Urban Land-use

The urban spatial land-use of Bandung shows that there is uneven spread of land-use, as shown in the **fig. 3.9**, the congestion of urban land-use in the down-town area, which is the intersection of the districts of Cibeunying, Karees, Tegal Lega and Bojanegara. The strategic location becomes the high productivity and economic land which accounted for regional economic growth, but in the same time this has also significantly negatively impacted the urban sprawl.

***Table 3.4*** *Slum Settlement Area in Bandung*

| Typology | Code | Slum Settlement Area | | |
|---|---|---|---|---|
| | | District | Sub District | RT/ RW |
| High Slum | HS | Astana Anyar | Nyengseret | 5 |
| | | Bojongloa Kidul | Situsaeur | 15 |
| | | Bandung wetan | Taman sari | 8 |
| | | Kiaracaondong | Babakan Surabaya | 6 |
| | | Sumur bandung | Braga | 15 |
| Medium Slum | MS | Bojongloa kidul | Cibaduyut kidul | 16 |
| | | Coblong | Dago | 3 |
| | | | Lebak siliwangi | 3 |
| | | | Sekeloa | 6 |
| | | Cinambo | Cisantren wetan | 6 |
| | | Rancasari | Manjahlega | 5 |
| | | Sukasari | Isola | 10 |
| | | Sukajadi | Cipedes | 1 |
| | | | Sukabungah | 8 |
| | | Cicendo | Arjuna | 3 |
| | | | Pajajaran | 5 |
| | | | Husein sastranegara | 2 |
| | | Andir | Ciroyom | 11 |
| | | Buah batu | Cijaura | 2 |
| | | Cibeunying kidul | Cikutra | 6 |
| | | Sumur bandung | Babakan ciamis | 13 |
| | | Antapani | Antapani wetan | 3 |
| | | Mandalajati | Karang pamulang | 8 |
| | | Batununggal | Kebonwaru | 5 |

| Typology | Code | Slum Settlement Area | | |
|---|---|---|---|---|
| | | District | Sub District | RT/ RW |
| Low Slum | LS | Astana anyar | Panjunan | 13 |
| | | Bojongloa kaler | Jamika | 5 |
| | | Cidadap | Ciumbeuluit | 3 |
| | | | Hegarmanah | 7 |
| | | Rancasari | Derwati | 7 |
| | | Lengkong | Paledeng | 2 |
| | | Bandung kidul | Kujangsari | 3 |
| | | Ujung berung | Cigending | 3 |
| | | Panyileukan | Cipadung wetan | 4 |
| | | Gedebage | Rancanumpang | 2 |
| | | | Rancabolang | 4 |
| | | Cibiru | Cipadung | 2 |
| | | Cicendo | Sukaraja | 3 |
| | | Andir | Campaka | 10 |
| | | | Maleber | 5 |
| | | Bandung kulon | Cigondewah kaler | 7 |
| | | | Cigondewah kidul | 6 |
| | | Babakan ciparay | Babakan | 8 |
| | | Cibeunying kidul | Cicadas | 9 |
| | | | Sukapada | 15 |
| | | Cibeunying kaler | Cigadung | 3 |
| | | | Sukaluyu | 1 |
| | | Regol | Ciseureuh | 4 |
| | | Arcamanik | Cisantren kulon | 5 |

***Source:*** *Bandung Kumuh, 2010*

The accumulation of urban land-use in the downtown area consisted of the stacking of public facilities such as a service area, government office, hospital, public school and universities. Commercial areas and the central business district downtown further exacerbated urban land use. The concept of a compact city, then, should besuccessful here, since the amount of density to use the land efficiently and effectively seems achievable. Instead of promoting the 'intensification of the use of space in the city' with higher residential densities and centralization, there is no basic infrastructure such as accommodative public transportation to move the residents from the periphery of city to downtown. The movement from one district to another is caused by inequality of public facilities, especially in education and public health facilities. Thus, the traffic load everyday caused by residents' mobility from their settlement to go to school, office or other facilities not only causes traffic jams, but also has an ongoing impact, such as wasting time, delay, fuel wastage and, the worst of all, air pollution due the carbon dioxide released to the air.

Therefore, to describe the urban land-use problem in Bandung, we need an assessment of level of land-use that generates movement within the city. Based on **fig. 3.5**, there are three major groups of land-users in Bandung, which are: settlement (56%); industry (20%) and service/public facilities (10%). Furthermore, each of them are categorized by their function as followed:

1. Settlement
2. Industry
3. Service / Public facilities :
    a. School (divided from elementary to higher education)
    b. Government
    c. Health Facilities
    d. Commercial

This assessment of land-use based on the accumulation of movement of most of the inhabitants from their living area to their place of activity, such as school or office, which is mostly done in the same range of time everyday. This is conducive to the stability of city activities. Thus, we have chosen three samples for each category based on the interest level of service, such as: quality, favourite, and strategic position.

**Table 3.5** shows the level of land-use in Bandung based on district, to find the nodes of movement.

***Table 3.5** Land-use in Bandung Based on SWK*

| no. | Physical Element | Indicator | Elemen of land-use | Tegal Lega | Cibeu-nying | Karees | Boja-negara |
|---|---|---|---|---|---|---|---|
| 1 | SCHOOL (top 3 from elementary school to University) | Favorite | SDN Sabang | | v | | |
| | | | SDN Merdeka | | v | | |
| | | | SDN Banjarsari | | v | | |
| | | Passing Grade | SMP 2 | | v | | |
| | | | SMP 5 | | v | | |
| | | | SMP7 | | v | | |
| | | | SMAN 3 | | v | | |
| | | | SMAN 5 | | v | | |
| | | | SMAN 8 | | | v | |
| | | | ITB | | v | | |
| | | | UNPAD | | v | | |
| | | | UPI | | | | v |
| 2 | GOVERN MENT | Main office | Cityhall and mayor's office | | v | | |
| | | | governor office | | v | | |
| | | | BAPPEDA | | v | | |
| 3 | HEALTH | Main Hospital | RSHS | | | | v |
| | | | RS. BOROMEUS | | v | | |
| | | | RS. ADVENT | | | | v |
| 4 | COMMER CIAL | Biggest Mall | Cihampelas walk | | v | | |
| | | | BIP | | v | | |
| | | | BSM | | | v | |
| 5 | Industry | trading traffic | Cibaduyut | | | v | |
| | | | Binong Jati | | | v | |
| | | | Cihampelas | | v | | |
| 6 | Settlement | Higest price | Dago | | v | | |
| | | | Setiabudhi | | | | v |
| | | | Batununggal | | | v | |

***Source:** Analysis, Author*

In Bandung, there is no clustering system for education based on living area, especially for elementary school, the choice of school enrolment is based on certain qualities of the school. As seen in **table 3.5** and **fig. 3.9** most of the highest level service for education, government and commercial is in Cibeunying District.

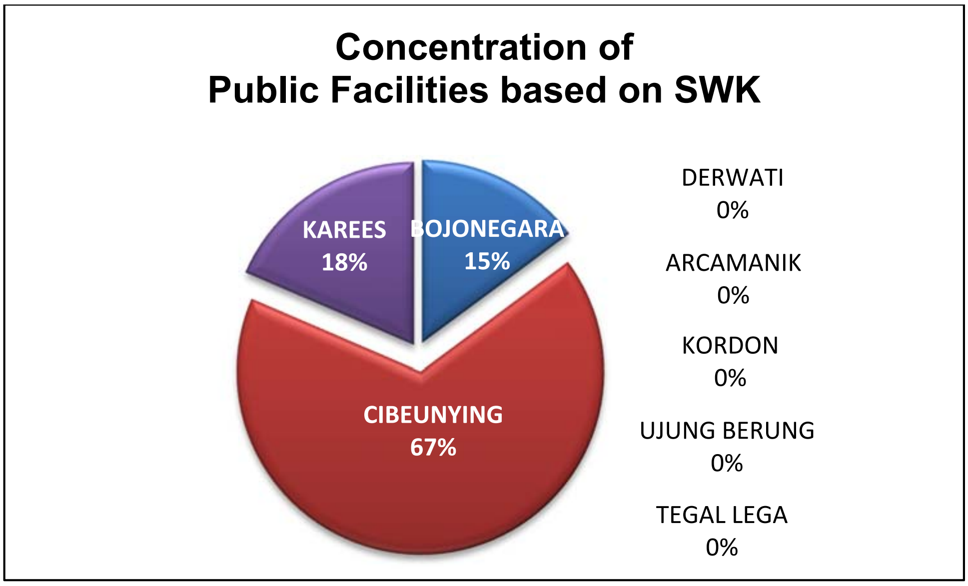



***Fig. 3.9.*** *Concentration of Public Facilities in Bandung.*
***Source:*** *Author*

### 3.3.3 Urban Heating

Large numbers of inhabitants in a dense area require land coverage for sheltering purposes. The anthropogenic heat emission potentially reduces ventilation of urban areas, and brings significant changes in air temperature. Increasing population year by year, and the sprawl of population density gives significant impact to land coverage, like the increase in surface roughness, which in turn reduces ventilation of urban areas and causes significantly higher air temperatures. This part will describe the correlations between urban form and the alteration of urban microclimate for different land-uses.

Finally, the urban slums, and stacking of urban land-use has a significant impact on urban heating, well known as 'urban heat island'. The term urban heat island (UHI) describes the phenomenon in which cities are generally warmer than adjacent rural areas. Tursilowati (2005) has shown that land-use and coverage in Bandung have increased as the result of population growth, and significantly impacted changes of air temperature, humidity index and evapo-transpiration, which thus yield higher surface temperatures.

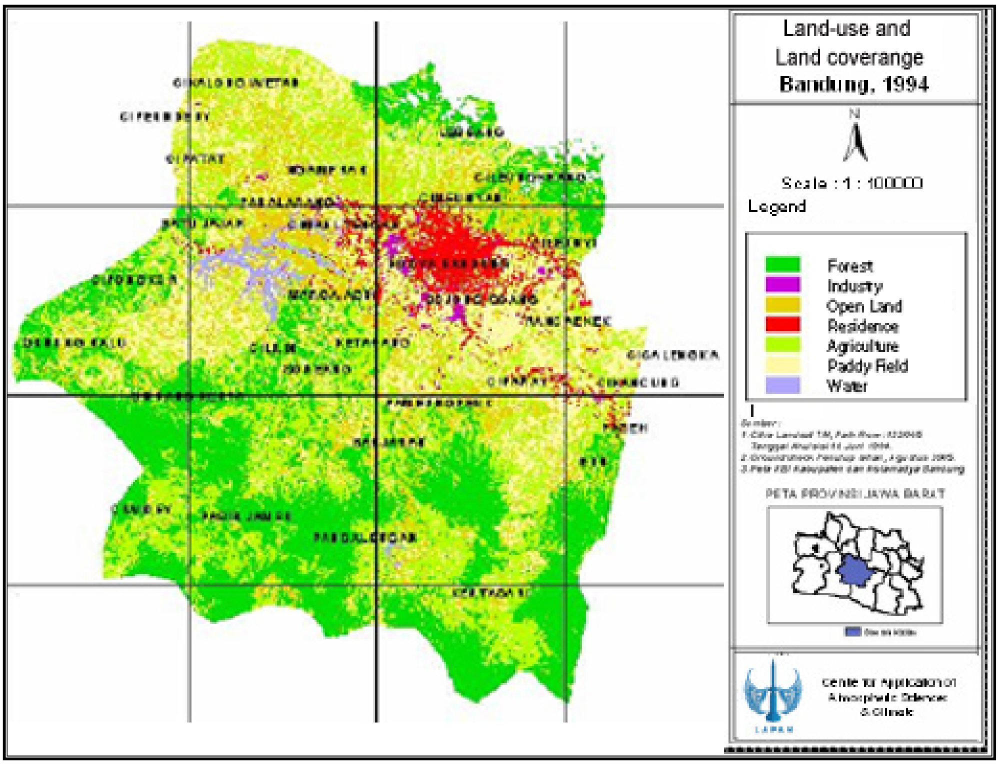



***Fig. 3.10*** *Land-use and coverage in Bandung 1994*
***Source:*** *Tursilowati, 2005*

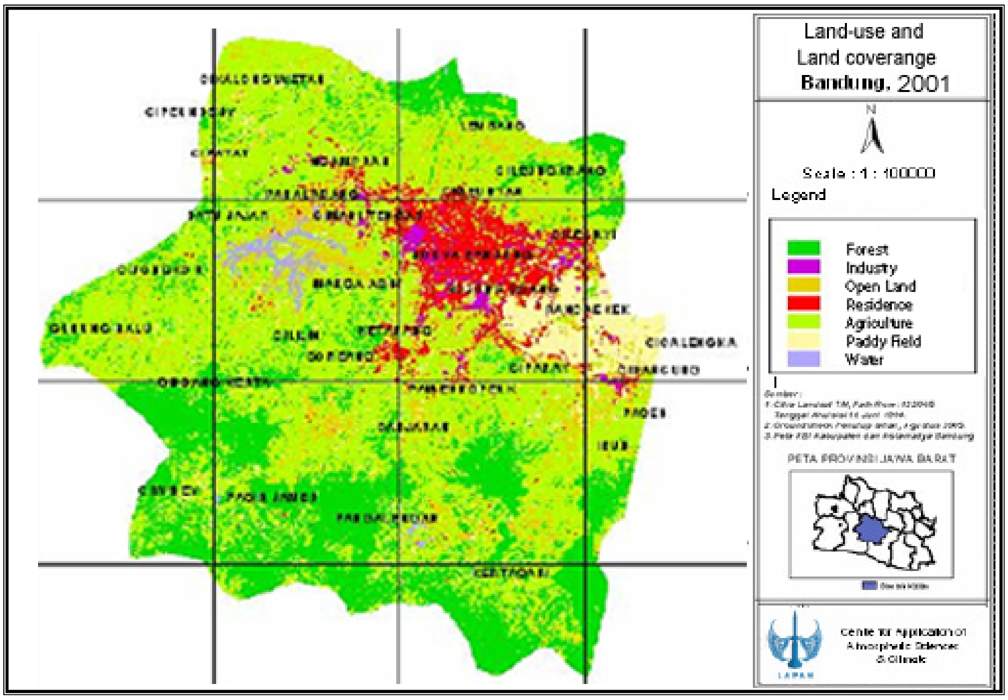



***Fig. 3.11*** *Land-use and coverage in Bandung 2001*
***Source:*** *Tursilowati, 2005*

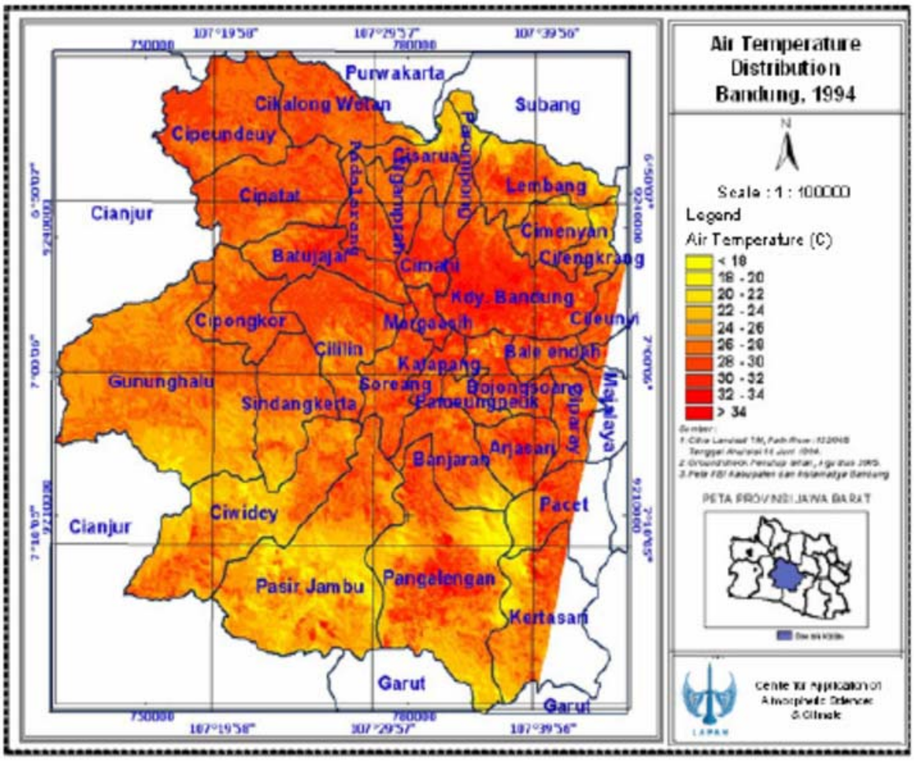



*__Fig. 3.12__ Air Temperature Distribution in Bandung 1994*
***Source:*** *Tursilowati, 2005*

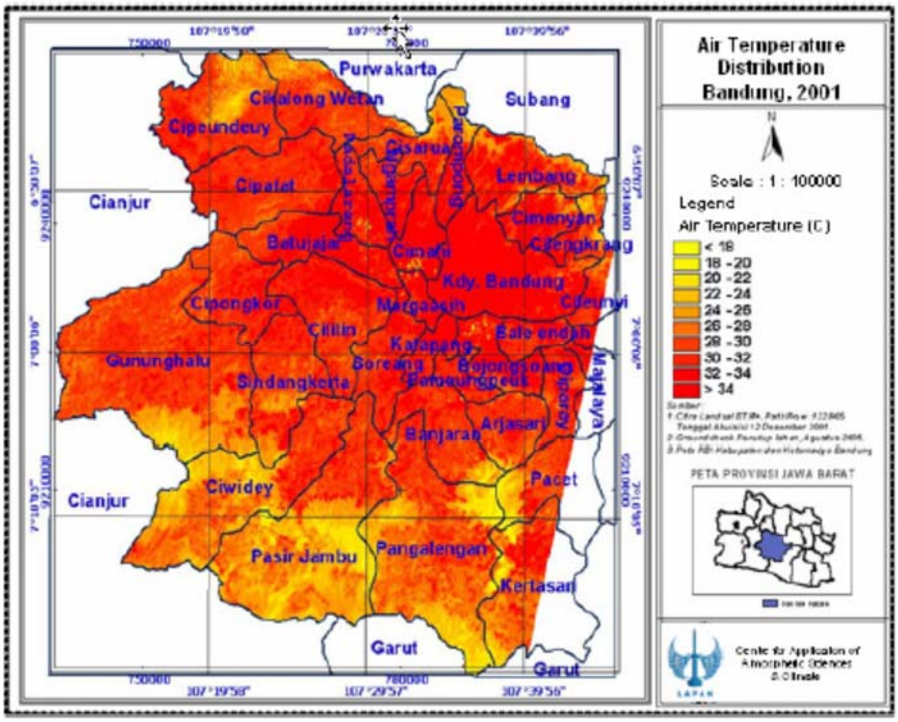



*__Fig. 3.13__ Air Temperature Distribution in Bandung 2001*
***Source:*** *Tursilowati, 2005*

Data set of Bandung's meteorology has shown the trend of increasing average temperature for the past 25 years as shown at **Fig. 3.14**

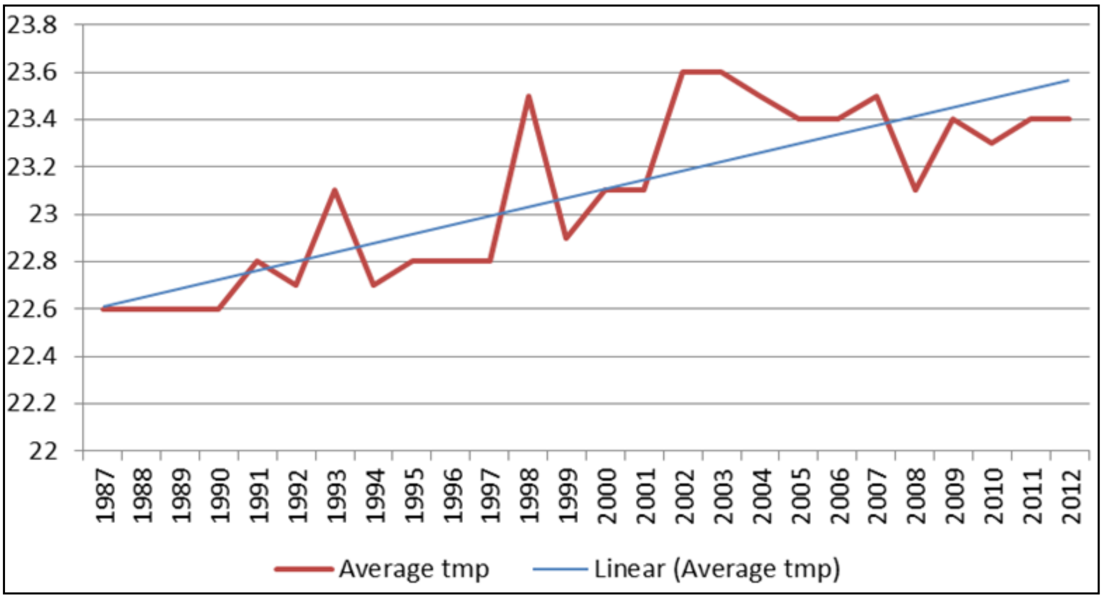



***Fig. 3.14*** *Average temperature in Bandung 1987 – 2012*
***Source***: *BMKG Bandung, BPS Bandung compile from 1987-2012*

Furthermore, a field measurement during the hot season from July 31, 2013 until September 10, 2013 was done in four different locations, i.e., North, East, South and West Bandung. **Fig. 3.15** shows diurnal temperatures on the hottest day.

This field measurement shows that the temperature reached its maximum of 28.7°C at 4 ,and minimum of 18.5°C at 07.00 am at for North Bandung; for East Bandung maximum 28.1°C at 11amand minimum 24.5°C at 04.00 am; for South Bandung maximum 28°C at 11 am and minimum 24.3°C at 6 am,; and for West Bandung maximum 30.7°C at 4 pm and minimum 24.3°C at 6 am. Meanwhile, BMKG Bandung's data shows maximum temperature 27.1°C at 1pm and minimum temperature 15.6°C at 6 am..

BMKG Bandung's weather station has recorded Central Bandung for its longest diurnal temperature range between Tmax and Tmin, i.e., 11.5°C. It is followed by North Bandung with 10.2°C, West Bandung with 6.4°C, South Bandung with 3.7°C and finally East Bandung with 3.6°C. These results are in line with (Pulau Panas Perkotaan Akibat Perubahan Tata Gunadan Penutup Lahan di Bandung dan Bogor, 2005), which has found that the land-use and coverage within Central Bandung and West Bandung are rapidly changing, which in turn significantly raises the diurnal temperature.

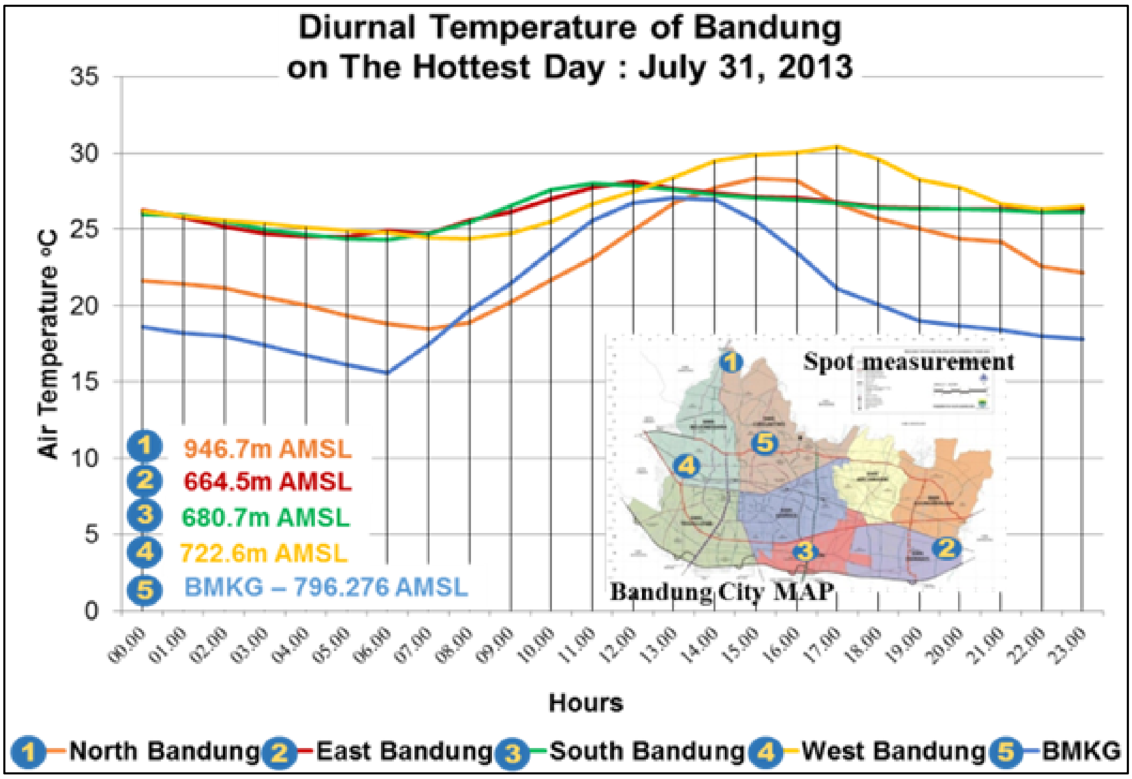



***Fig. 3.15*** *Diurnal Temperature of Bandung on the Hottest Day*
***Source:*** *Field Measurement, Author*

# Closing Remark

The urban environmental problem in Bandung describes the three different aspects

1. Urban slum. There are six *kelurahan* (sub-districts) which are vulnerable facing the overcrowded population, which then increase the high-density settlement by its building density. These six *kelurahan* are: Nyengseret, Situsaeur,Tamansari, Babakan Surabaya and Braga
2. Stacking of urban land-use. The accumulation of urban land-use downtown characterised by the stacking of public facilities as a service area, such as government office, a hospital, a public school and universities. Commercial areas and the central business district downtown further exacerbated the urban land use. Cibeunying, Karees and Bojonegara, which have a land-use load heavier than

other SWK in Bandung, could potentially optimize their land-use so that the compact city concept could be implemented.

**3.** The high-density population in several areas, as well as the building density impacts atmospheric conditions. Urban heating then is inevitable, as there is more surface area in the urban form element which traps long-wave radiation. Direct sunlight is a short wave radiation to the ground and building surfaces; buildings, walls and rooftops of buildings then re-emit the radiation into the surrounding areas, altering the microclimate which tends to increase the air temperature.

## Bibliography

**BMKG. 2012.** Bandung Climate Data B. Badan Meteorologi Klimatologi dan Geofisika Stasiun Geofisika Kelas I. [ed.] Editor. Bandung : Bandung, B., 2012.

**BPS. 2013.** Bandung City in Figure. Bandung : Bandung, B.K., 2013, p. 358.

Dinas Cipta Karya, The Ministry of Public Work, *Bandung Kumuh*, 2010

Dinas Cipta Karya, The Ministry of Public Work *The Guideline of Slum Settlement Identification in Metropolitan area in Indonesia, 2006*

*Pulau Panas Perkotaan Akibat Perubahan Tata Gunadan Penutup Lahan di Bandung dan Bogor.* **Tursilowati. 2005.** 2005, Jurnal Sains Dirgantara, hal. 3 (1).

# 4. Living Comfort of Urban Built Environment Assessment Method

An urban environment is not merely a group of buildings and its physical elements. Both the location of an urban environment and meteorological aspects impact the microclimate. The most important aspect of a habitant is who lives in this environment. An urban environment, simply put, is a place where people both live and work, while a living space is where people live their lives and pursue activities of interest. These three elements of an urban environment impact each other. The details of this method are described in **Fig.4.1**

## 4.1. Procedure of Sequence Studies

### 4.1.1. Urban Form

The physical aspects of an urban environment, such as buildings, open spaces, green spaces or connecting between them dominate the the image of the city. The characteristics of an urban form are then determined by the value of BCR, FAR, GAR, H/ and SA.

In this thesis, the area of study is divided into two, which is an urban area within 37 ha, including the (1) educational area, that is Universitas Pendidikan Indonesia, (2) high-dense settlement, that is *Kelurahan* Tamansari and (3) industrial area, that is Cigondewah. The second study area is public flat complex, which is contain several building blocks. For this study, various types of public flats has been chosen with different building plots and configurations. They are grouped into:

(1) Parallel Plot, which includes: *Rusun* PTDI and *Rusun* UPI

(2) Interspersed Plot includes: *Rusun* Cigugur

(3) Square Plot, which includes: *Rusun* Cingised and *Rusun* Pharmindo

The procedure to get the information of this physical dimension is by field measurements, AutoCAD maps, satellite image studies, and then a 3D model by sketch-up.

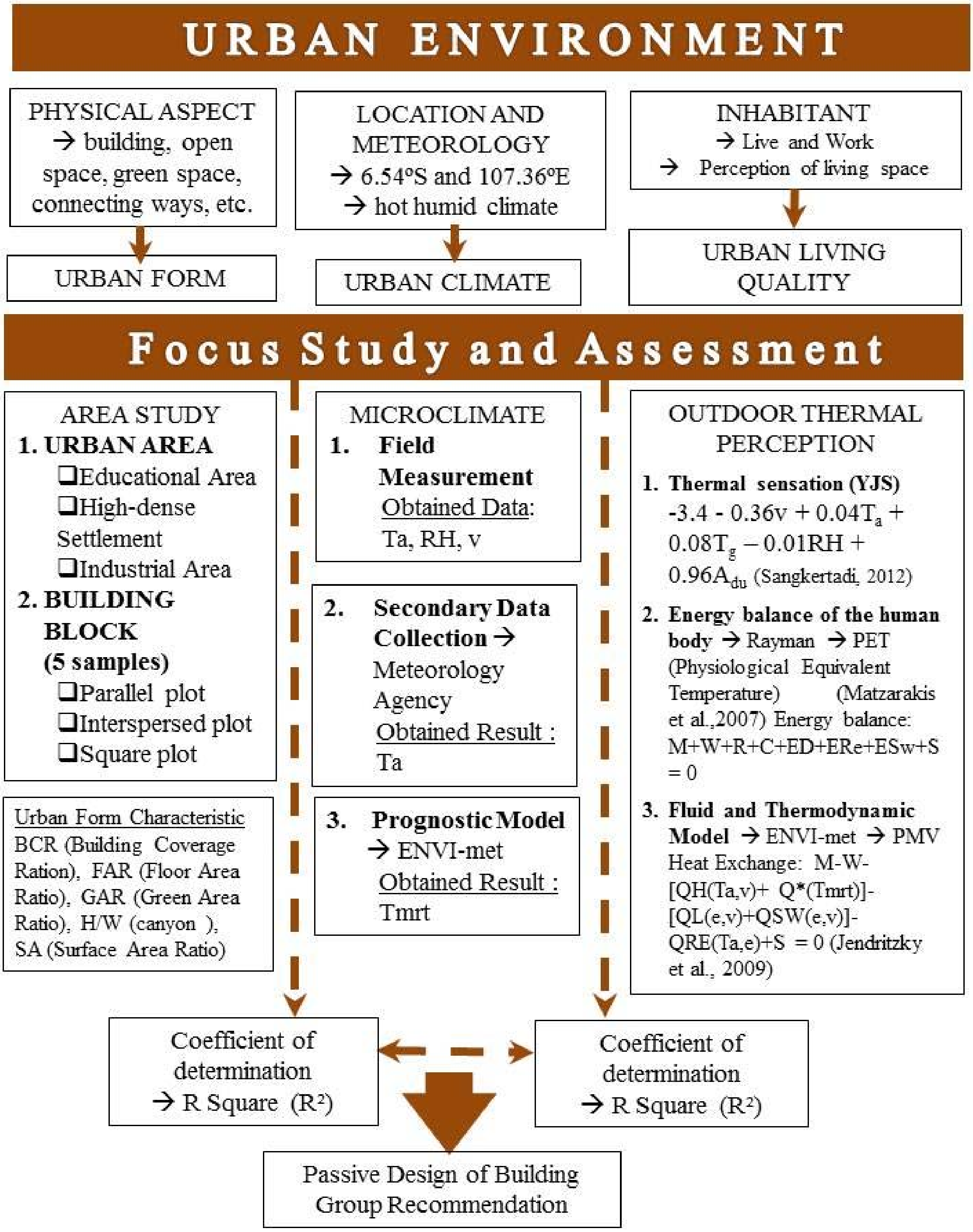



***Fig. 4.1.*** *Living Comfort of Urban Built Environment Assessment Method*
***Source:*** *Author*

A. **Urban Area Study:**

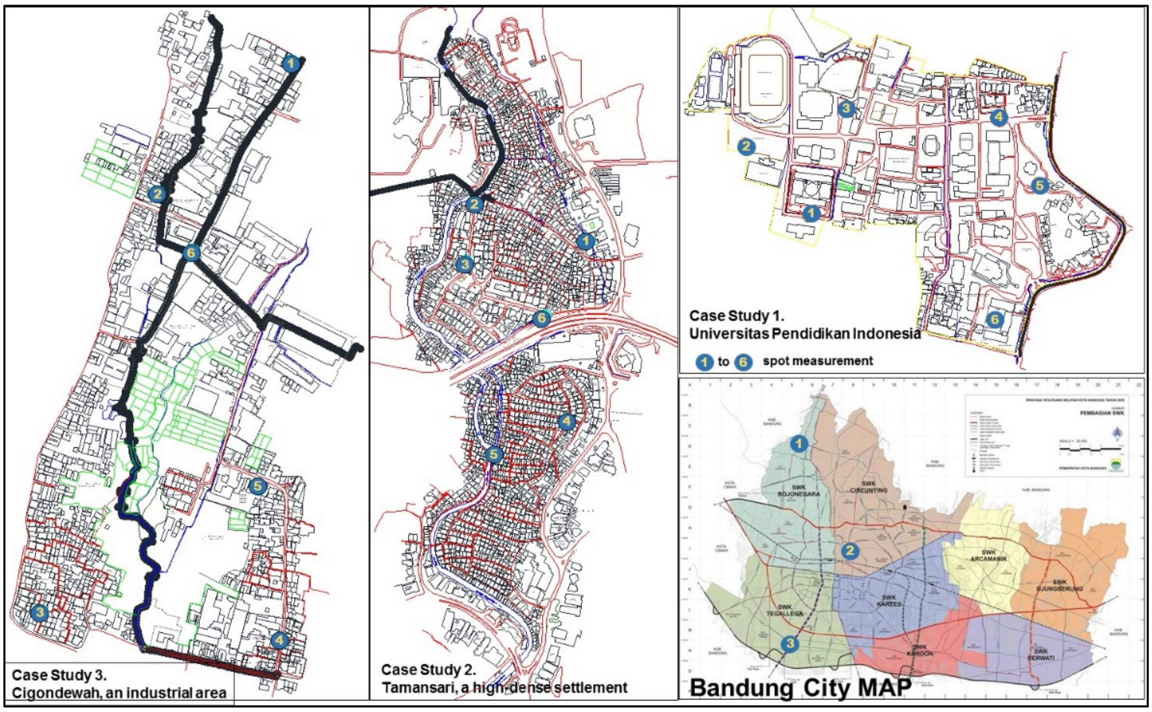



***Fig. 4.2.*** *Urban Area Study, (1) Educational Area →Universitas Pendidikan Indonesia, (2) High-dense Settlement →Tamansari,(3) Industrial Area →Cigondewah*
***Source:*** *Processed from Digital Map of Bandung City, Bappeda Bandung.*

Furthermore, each of the case studies has picked six spot measurements which are assigned with a blue dot no.1 – 6 as seen in **Fig. 4.2** above. The microclimate measurements on the six spots uses handheld weather that is measured based on the mobile method which can move from one spot into another every 10minutes, so that the data on each spot has a time span as long as one hour. The measurement was done within 13 hours from 06.00 – 19.00.

(1) Educational Area →Universitas Pendidikan Indonesia (UPI)

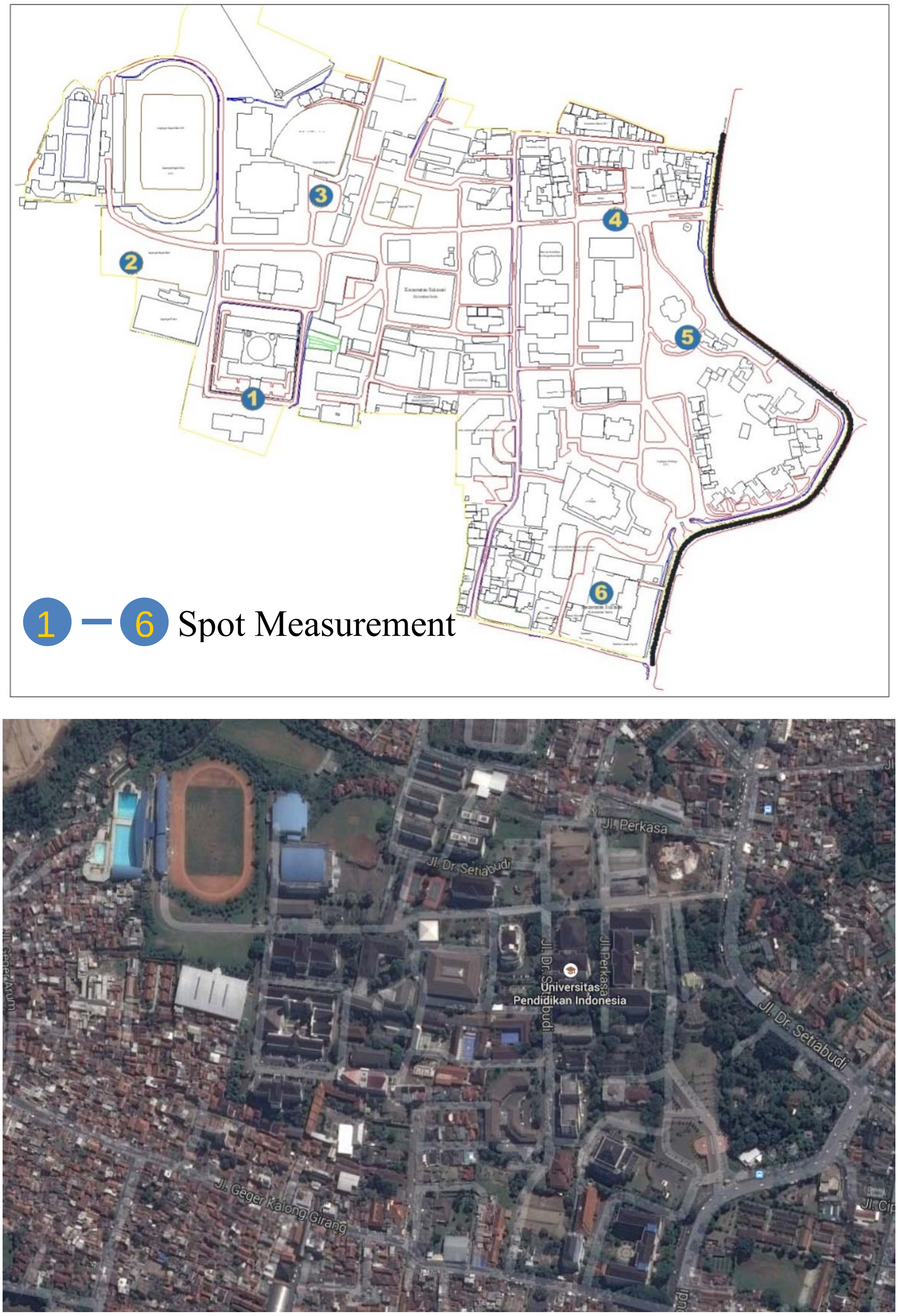



***Fig. 4.3.*** *(a) Map of Universitas Pendidikan Indonesia and six spot of samples* (b) satellite image from https://www.google.com/maps/place/Indonesia+University+of+Education/@-6.860971,107.592921

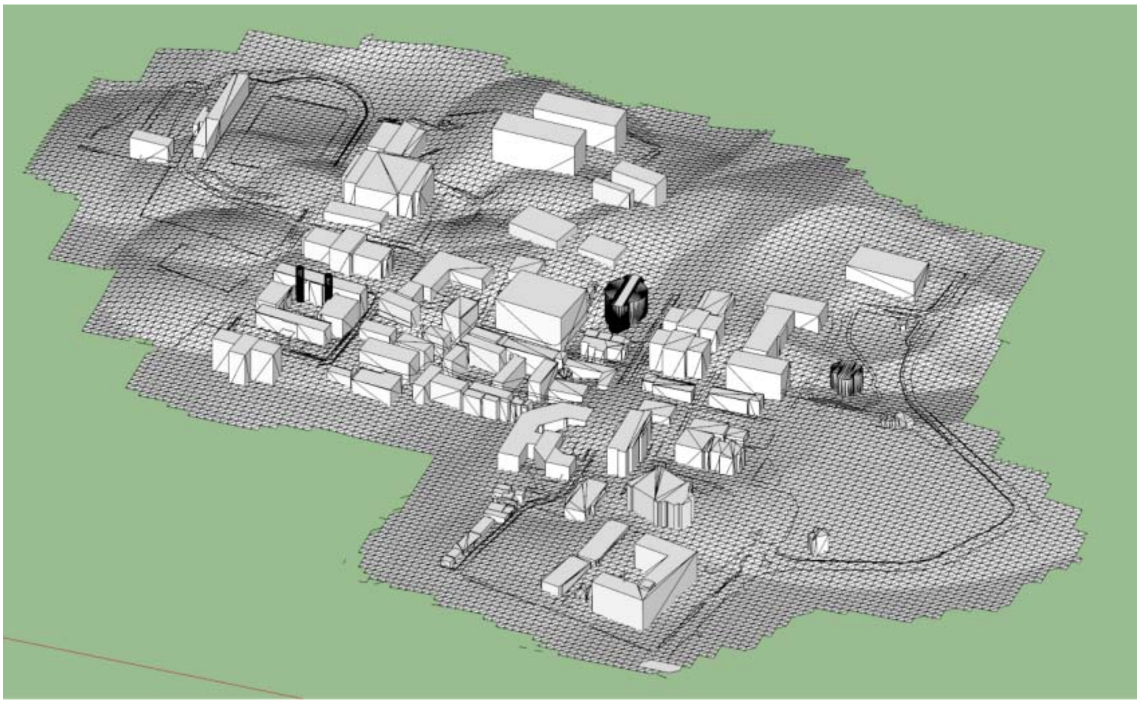


***Fig. 4.4.*** *Urban Form Study of Educational Area*
***Source:*** *3D Sketch-up, author*

**Fig. 4.3** presents (a) a digital map of UPI with six spot measurements, and (b) the satellite image with a geographical location at - 6.860971,107.592921

Meanwhile, **fig. 4.4** shows the three-dimensional urban form characteristic of UPI.

The three-dimensional image somehow gives the understanding of spatial configuration, thus making it easy to understand the physical character of the urban form.

**Fig. 4.5** presents the digital map of Tamansari with six spot measurements and also sattelite image with geographical location at -6.8986298,107.6063948. The three-dimensional image has generated by sketch-up as seen in **Fig. 4.6.**

Industrial area at Cigondewah's map is shown in **Fig. 4.7** with six spot measurement as well as its sattelite image with geographical location at -6.9446115,107.5660263.

This three-dimensional image of study area of Cigondewah as seen in **Fig. 4.8.**

(2) High-dense Settlement Area → Tamansari

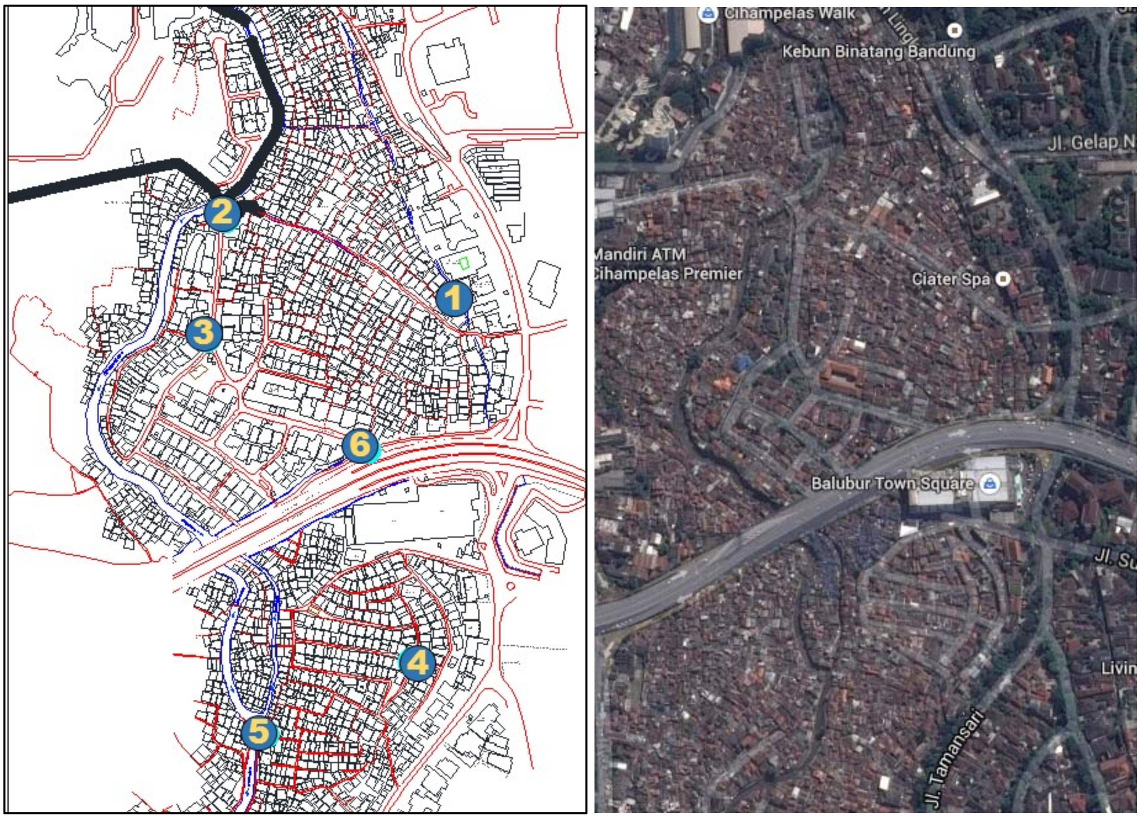



***Fig. 4.5****(a)Tamansari, a high-density settlement with six spot measurements*
*(b)* satellite *image of Tamansari*
***Source:*** *(a)Bandung Digital Map, Bappeda-Bandung*
*(b) https://www.google.co.jp/maps/@-6.8986298,107.6063948*

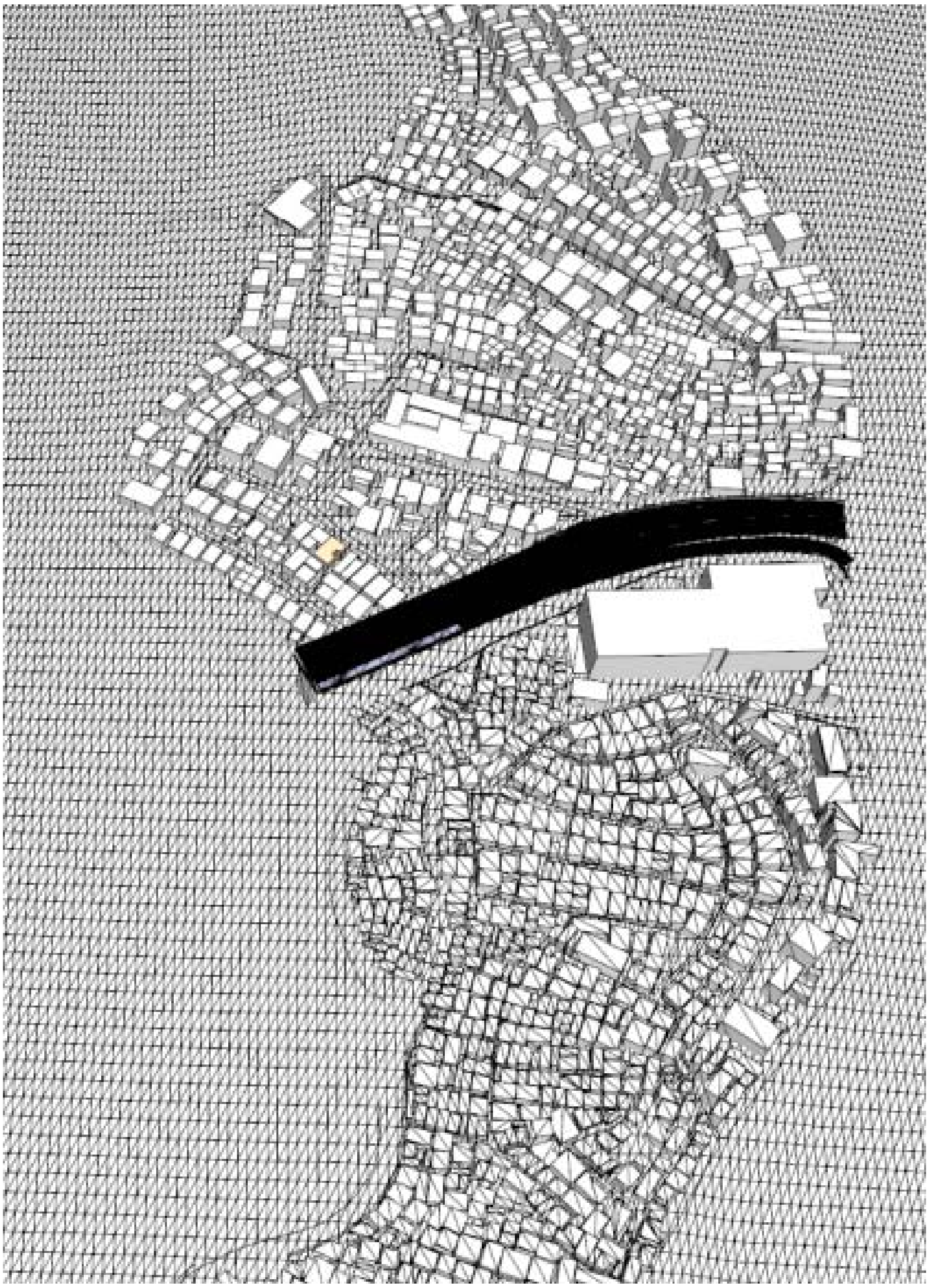


***Fig. 4.6*** *Three Dimensional Model of Tamansari*
***Source:*** *Sketch-up, author*

(3) Industrial Area

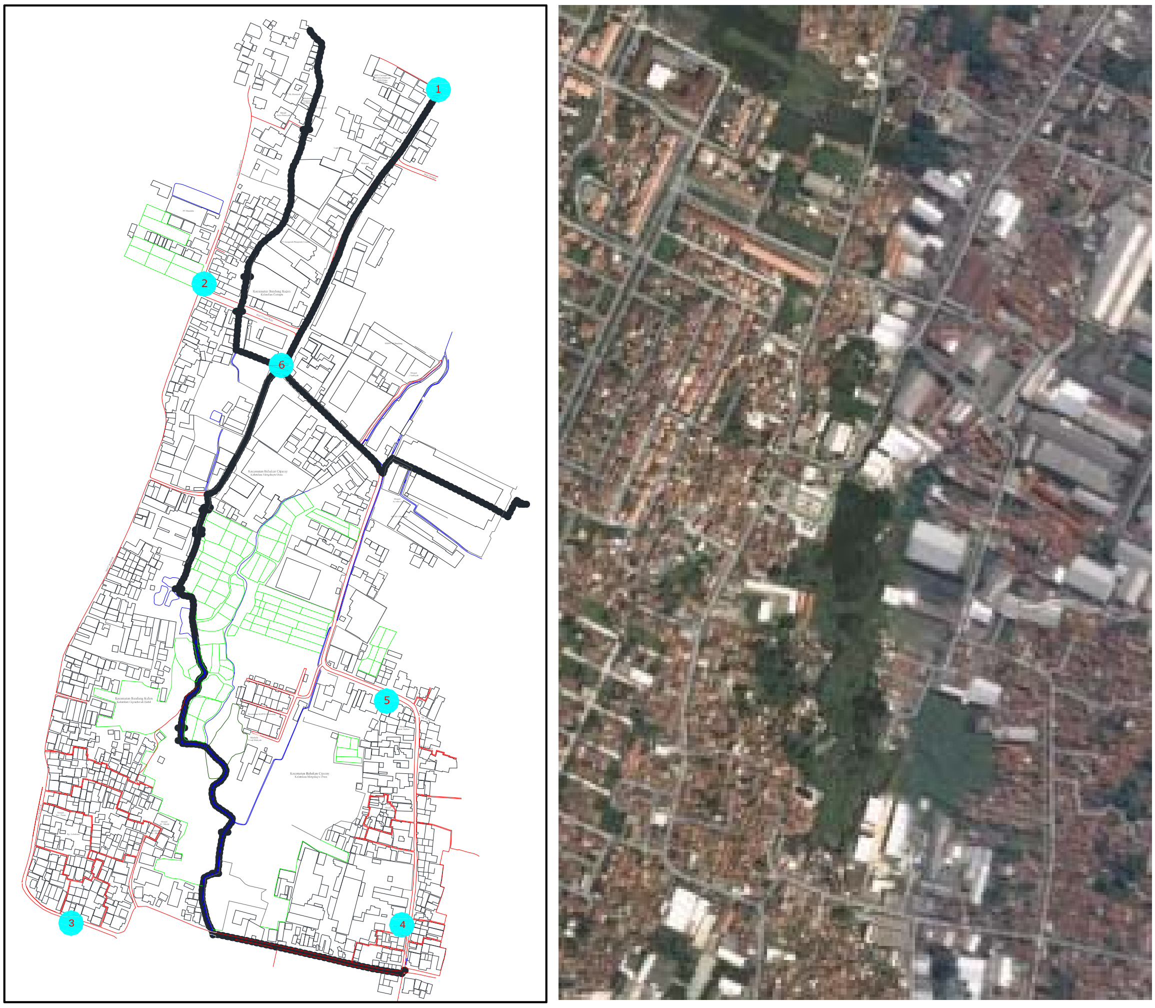


***Fig. 4.7****(a)Cigondewah, an industrial area with six spot measurements*
*(b)* satellite *image of Cigondewah*
***Source:*** *(a)Bandung Digital Map, Bappeda-Bandung*
*(b) https://www.google.com/maps/@-6.9446115,107.5660263*

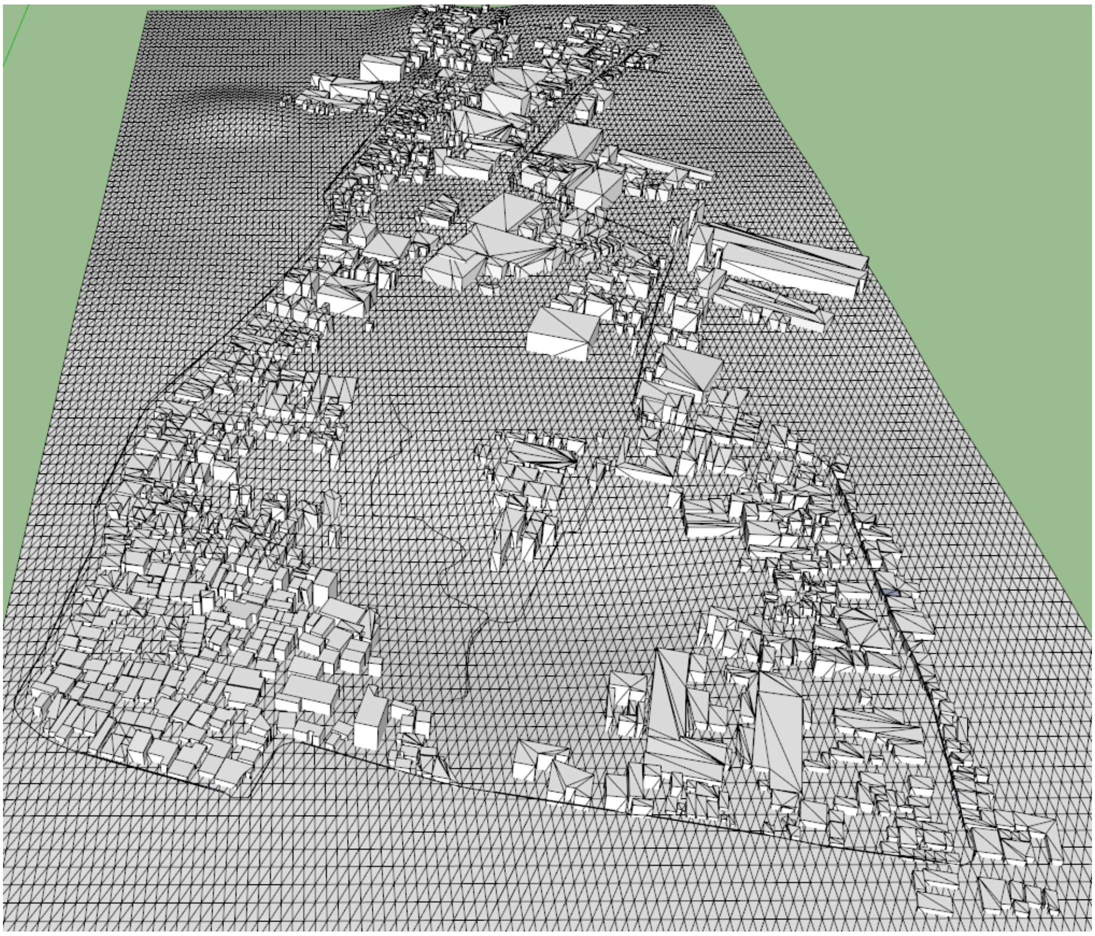


***Fig. 4.8*** *Three Dimensional Model of Cigondewah*
***Source:*** *Sketch-up, author*

**B. Building Group Study Area**

The dimensionality of the building group study area is simple when compared with the urban study area. There are five samples of the building group study area, and it has picked three spot measurements, which is an open area (O), the shading area (S) and terrace (T). The measurement was done from 06.00 – 19.00. The obtained data includes air temperature (Ta), RH (Relative Humidity), and wind seed (v).

A. Parallel Plot

(1) Rusun UPI


***Fig. 4.9*** *Urban Form study of Rusun UPI*
***Source:*** *(a) Site plan, author (b) satellite image*

(2) Rusun PTDI


***Fig. 4.10*** *Urban Form study of Rusun PTDI*
***Source:*** *(a) Site plan, author (b) satellite image*

B. Interspersed Plot

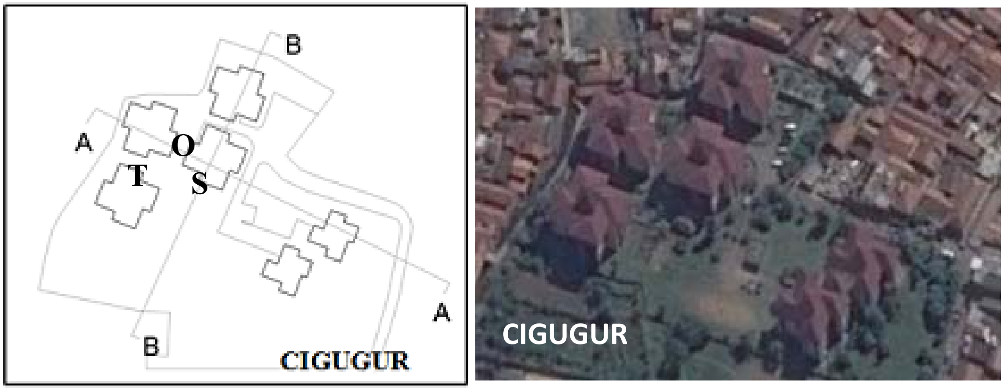



***Fig. 4.11****Urban Form study of Rusun Cigugur*
***Source:*** *(a)Site plan, author (b) satellite image*

C. Square Plot

(1) Rusun Cingised

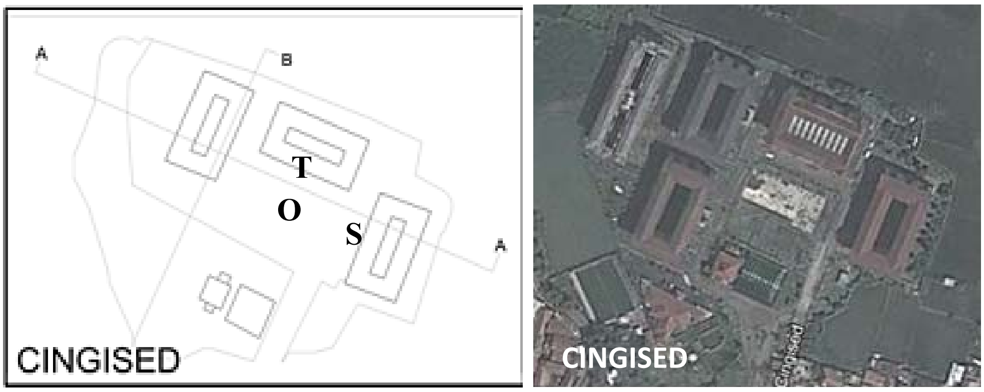



***Fig. 4.12*** *Urban Form study of Rusun Cingised*
***Source:*** *(a)Site plan, author (b) satellite image*

(2) Rusun Pharmindo

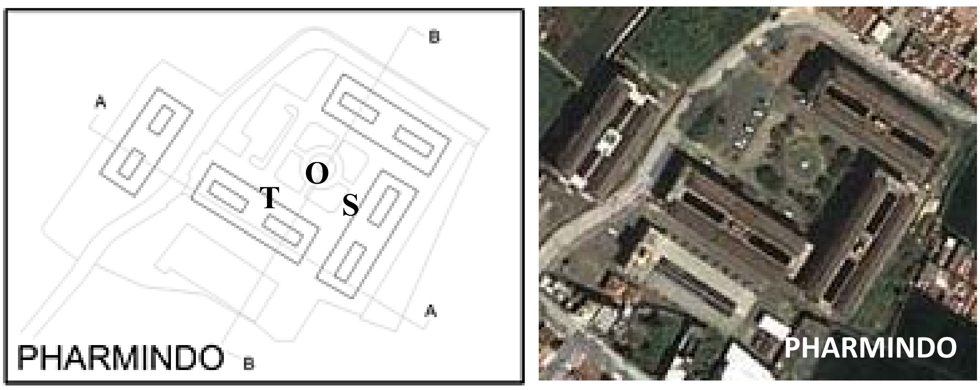



***Fig. 4.13*** *Urban Form study of Rusun Pharmindo*
***Source:*** *(a)Site plan, author (b) satellite image*

# 4.2. Urban Heating

## 4.2.1. Field measurement

The field measurement was done by using two methods on four different spots within the Bandung area, which are: (1) North Bandung at 946.7m , (2) East Bandung at 664.5m, (3) South Bandung at 680.7m, (4) West Bandung at 722.6m, and (5) Bandung Meteorology and Geophysics Agency (BMKG) at 796.28m to identify the diurnal temperature data. This measurement was taken between the hot season; that is July-September. The obtained data includes the highest air temperature value. The aim of this measurement is to know the difference between the air temperatures in each part of Bandung.

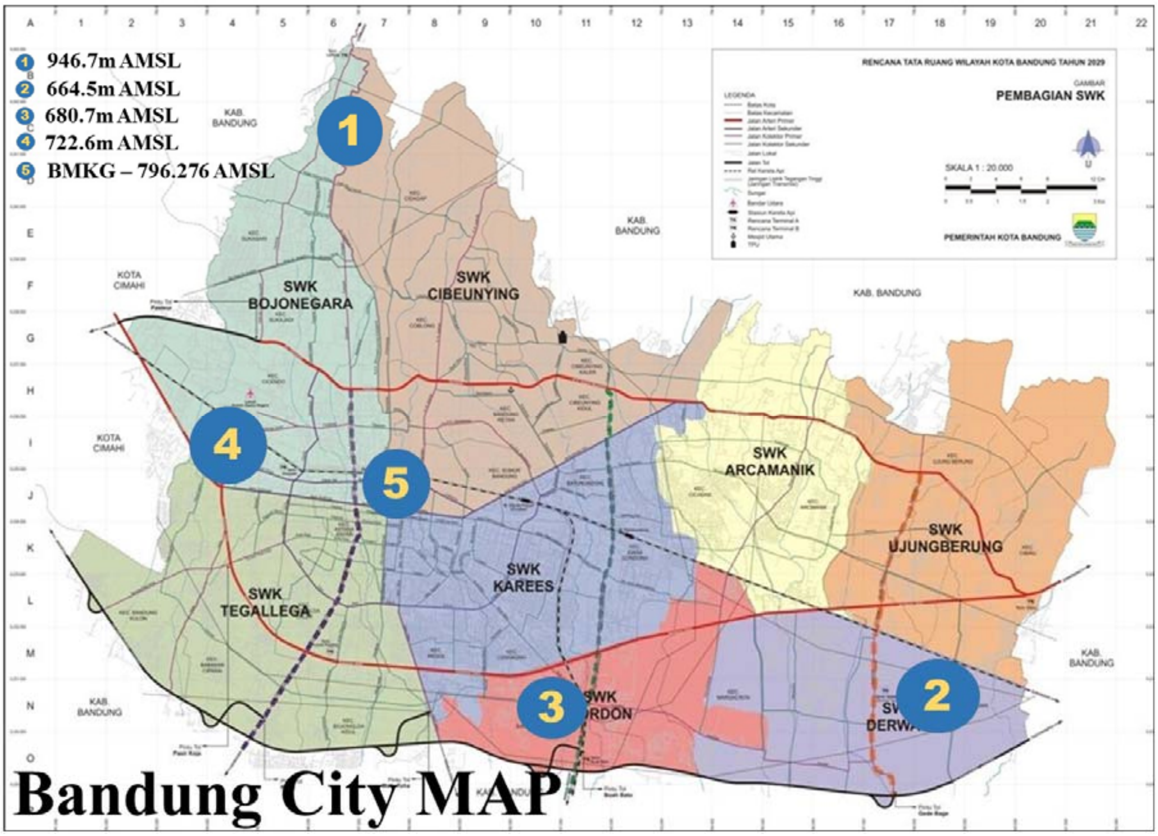



*Fig. 4.14* *Location of Urban Temperature Measurement*
***Source:*** *Processed from Digital Map,*

### A. Recorded Measurement

Recorded measurement was done in four different spots, as shown in **Fig. 4.14.**
The measurement tool is placed in the back yard under the canopy, but in the open wall.


***Fig. 4.15*** *Recorded Measurement*
***Source****: Field Measurement at point 2, author*

**Fig. 4.15** presents the recorded air temperature and globe temperature measurements in the back yard. This method, based on Thorsson S., et al. (2007) and Tan, C.L, et al. (2013), who had conducted the same measurement using a 38 mm ping pong ball. In this measurement, a Thermo Recorder RT-13 (Espec mic Corp) was used with intervals of recording temperatures every 10 minutes. This method has pointed at an easy and reliable method of estimating mean radiant temperature.

Tool calibration

The tools used here include:

1. RT-13 to measure Ta and Tg
2. Luxtron LM-800 to measure Ta, RH and v
3. Extechto measure Ta, Tg, RH and WBGT
4. Davis Pro Vantage Pro2 to calibrate the handheld tools

The use of a handheld measuring instrument is solely for practicality. Before the instrument is used in the field, it was calibrated for measuring instruments such as the weather station Davis Vantage Pro2 for the value of Ta, RH and v , as shown in **Fig. 4.16**. Meanwhile, for the globe temperature, Heat Stress Meter, and Thermo Recorder RT-13, a ping pong ball was calibrated, as shown in **Fig. 4.17** below.

***Fig. 4.16.*** *LM-8000 calibrated with Davis Vantage Pro2*
***Source:*** *author*


***Fig. 4.17.*** *Thermo Recorder RT-13 adjusted with a ping pong ball calibrated with Heat Stress*
***Source****: author*

***Table 4.1** Measurement Variables and Equipment*

| Variable | Equipment | Measurement Range | Accuracy |
|---|---|---|---|
| **Recorded Measurement** | | | |
| Air Temp (Ta) | Thermo Recorder RT-12 | -40 to 110°C | Avg. ± 0.3°C (-20 to 80°C) |
| Globe temp (Tg) | Thermo Recorder RT-12 | -40 to 110°C | Avg. ± 0.3°C (-20 to 80°C) |
| **Mobile Measurement** | | | |
| Air Temp (Ta) | LM-800 | -100 to 1300 ℃ | ± (1% rdg + 1 ) |
| Humidity (RH) | LM-800 | 10 to 95 %RH | ≧70% RH:<br>± ( 4%rdg + 1.2 %RH ) |
| Wind speed (v) | LM-800 | 0.4 to 30.0 m/s | ≦20 m/s : ± 3% F.S. |
| Globe temp (Tg) | Extech HT30 | 0 to 80°C | ±3°C |

### B. Mobile Measurement

Mobile measurement was done to measure the study area, which is the urban and building group area. The area of this mobile measurement is previously mentioned in **Fig.4.2** and period of this measurement is shown in Table **4.2** below:

***Table 4.2** Measurement Period*

| | **Recorded Measurement** | **Mobile Measurement** | |
|---|---|---|---|
| Location | 4 parts of Bandung: | 3 Urban Areas Study | 5 Building Groups Study |
| Measurement Date | 7th Aug –2nd Oct, 2013 | Sunny: 31st August 2013<br>Cloudy: 15th Sept 2013<br>Rainy: 21st Sept 2013 | Sunny: 13,14,24 June 2012<br>Cloudy: 9,11,22 June 2012<br>Rainy: 5,10,21 June 2012 |
| No. of days measured | 33 days (24hours) | 3 days (each 06am-07pm) | 9 days (each 06am-07pm) |
| Data Obtained | Ta of different part of Bandung | Ta, RH, v, Tg | Ta, RH, v |
| Output Data | Diurnal Temperature Range (DTR) → urban heat phenomenon | Tmrt→ heat intensity | Tmrt→ heat intensity |


***Fig. 4.18***. *Mobile Measurement on the study area*
***Source****: author*

### 4.2.2. Data Collection

Besides the field measurement, data collection of the weather condition in Bandung from 1987 – 2012 was conducted. This data had been collected from BMKG and Bandung, as shown in **Fig. 4.19**

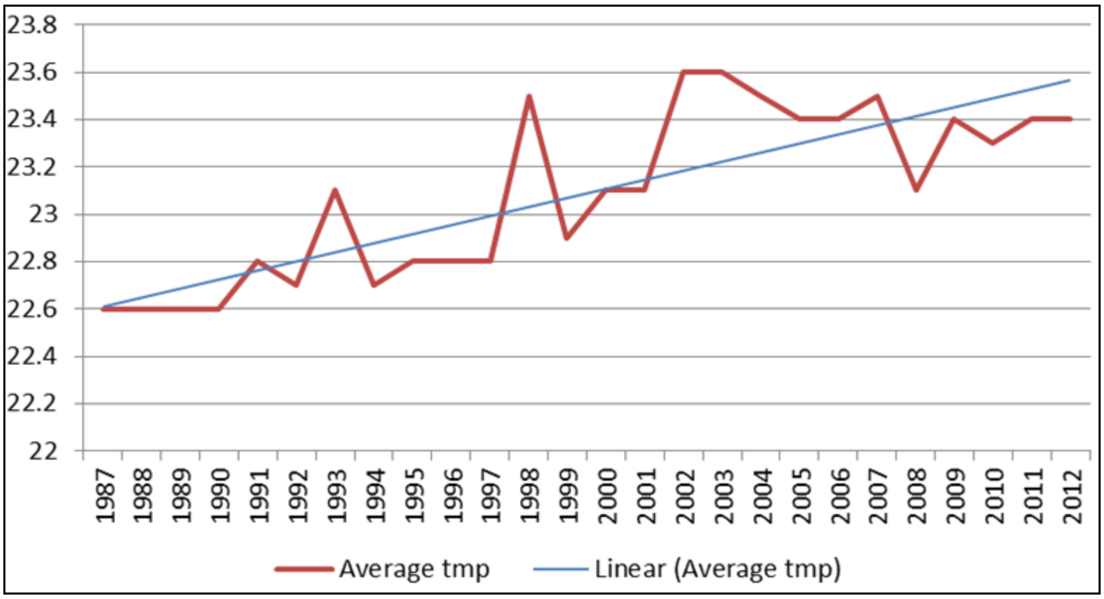



***Fig. 4.19*** *Average temperature in Bandung 1987 – 2012*

***Source****: BMKG Bandung, BPS Bandung compile from 1987-2012*

### 4.2.3. Prognostic Model

By the prognostic model, to get the weather data the model that generated by ENVI-met for two study areas, as mentioned before. ENVI-met is a three-dimensional microclimate model designed to simulate the surface-plant-air interactions in an urban environment with a typical resolution of 0.5 to 10 m in space and 10 sec in time, with a maximum typical time frame of 24 to 48 hours with a time step of 10 sec. This resolution allows the analyze of small-scale interactions between individual buildings, surfaces, and plants.

The model calculation includes:[1]

- Shortwave and longwave radiation fluxes with respect to shading, reflection, and re-radiation from building systems and the vegetation

[1]http://envi-met.com/

- Transpiration, evaporation, and sensible heat flux from the vegetation into the air including full simulation of all plant physical parameters (e.g. photosynthesis rate)
- Surface and wall temperature for each grid point and wall
- Water and heat exchange inside the soil system
- Calculation of bio-meteorological parameters like Mean Radiant Temperature or Fanger's Predicted Mean Vote (PMV) Value
- Dispersion of inert gases and particles, including sedimentation of particles on leafs and surfaces

## 4.3. Outdoor Thermal Perception

The outdoor thermal perception framework is shown below in **Fig. 4.20**

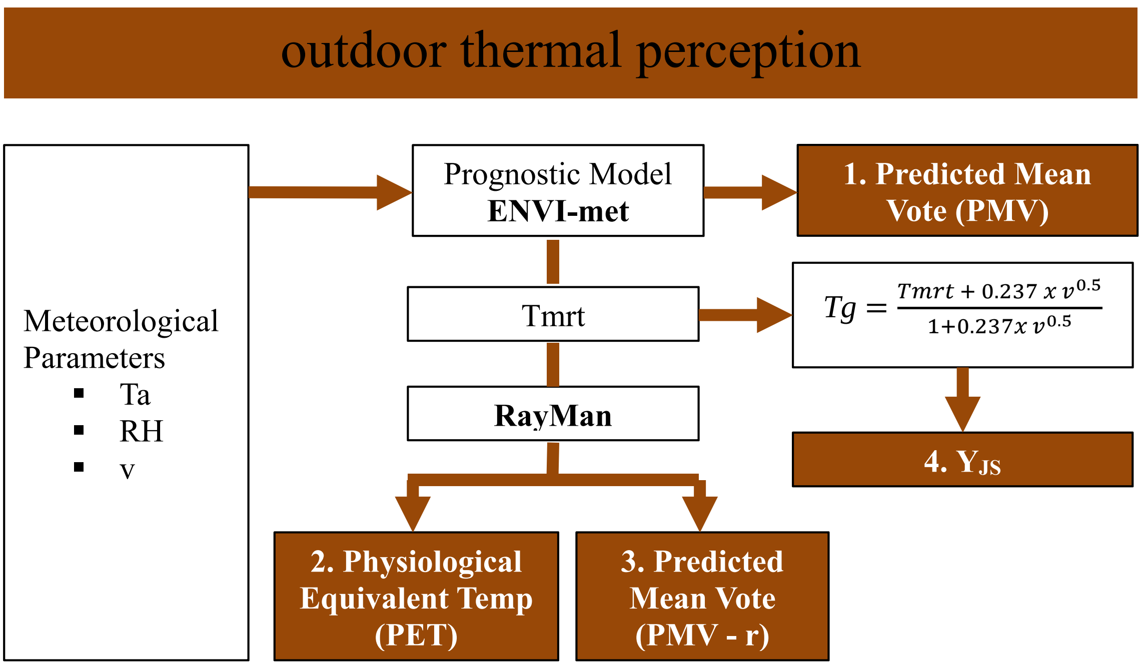



***Fig. 4.20.** Outdoor Thermal Perception Framework*
***Source:** author*

The **Fig. 4.20** presents the framework of outdoor thermal perception, which in this thesis aims to describe the quality of living, in terms of comfort, in the building group study are, which includes: *Rusun* UPI, *Rusun* PTDI, *Rusun* Cigugur, *Rusun* Cingised, and *Rusun* Pharmindo.

From the field measurement of five building group samples, make a prognostic model generated by ENVI-met, which resulting in a Tmrt value as well as a PMV value.
The value of Tmrt, together with Ta, RH and v as an input of RayMan, resulted in a PET and PMV-r value. Meanwhile, a calculation of the globe temperature as an input of the thermal stress sensation equation gives the result of $Y_{JS}$ value.
The final objective of this value is to give feedback to the urban form of its building mass, which includes building height, length, orientation, and the space between buildings. The specific building form and mass is also configured directly to impact the microclimate then finally, result in the living comfort value.

# 5. Heat Intensity of Urban Built Environment in Bandung, Indonesia

## 5.1. Identifying the Heat Intensity in Bandung

Bandung is the third largest metropolitan city in Indonesia. (Paramita, 2011) has shown that as the capital city of the province of West Java, increasing urbanization has caused several problems. These include the demographic and environmental problems such as overly dense settlement in illegal land and inappropriate sanitation and infrastructure. The increasing population density has had a significant impact on land coverage. For example, it causes an increase in surface roughness, which in turn reduces ventilation of urban areas and causes significantly higher air temperatures. Recent studies on the relationship between urban geometry and outdoor thermal in a hot humid region include: Land-use and heat island phenomenon by (Goh, K.C. and C.H. Chang, 1999), [Tursilowati, 2005], (Jusuf, 2007) and air quality studies by (Emmanuel, R. and E. Johansson, 2006). Meanwhile, studies regarding mean radiant thermal that correspond with the perceptions of outdoor thermal comfort have been led by (Emmanuel, R. and E. Johansson, 2006), (Kakon, 2010), and (Tan, 2013). These studies indicate that research in the hot humid climate region regarding urban geometry, outdoor thermal comfort and urban heat islands have not been widely produced, especially compared to studies on these topics done in the other climatic regions.

With a total area of 16,730 $m^2$, Bandung's physical built environment dominates the land use functions, including 55% for settlement, 15% for industry and 5% for public facilities. [Tursilowati, 2005] has shown that land use and coverage in Bandung has increased due to population growth. This has had significant impacts on air temperature, humidity index and evapotranspiration, thus yielding higher surface temperature. An assessment study of five flats in Bandung (Paramita, B., H.F., 2013) also found that the higher the value of the height to width ratio, the more surface area. This has a direct relationship with heat gain and impacts mean radiant temperature.

In contrast, the idea that urban geometry is an important factor in heat island intensity is not new. In his study, (Oke, 1988) mentioned a previous study on heat island intensity; those of (Howard, 1833), (Lauscher, 1934) and (Parry, M.J. and D.G. Walker, 1966). Furthermore, Oke stated that the warm side of buildings can potentially influence air temperature, due to the effect of the increased cold "sky" proportion as well as an increase of the height to width ratio.

Most of the studies on heat intensity take place in mid-latitude cities in Australia, Europe and North America. These include the study by (G. Jendritzky, 1999) who stated that sky view factor, aerodynamics and roughness length, as the result of urban canyon geometry, may exert an influence on the radiation budget, air budget (advection) and the humidity-water budget in heat island development. Therefore, it is necessary to consider urban land use as the main factor in increasing surface roughness, which in turn contributes to the mean radiant temperature, with the sky view factor controlling the heat intensity of urban built environments, especially in hot humid climate regions.

To determine heat intensity in Bandung, this study bases itself on a previous study in 2007 of Bandung Tursilowati, which described the increase of air temperature from 1994 to 2001. This condition in line with BMKG data from the past 25 years that also the recorded measurement from four different part of Bandung. This previous study and data collection examined the specific microclimate in the region on a scale of three different land uses and five building groups. This sequence of urban heating is shown in **Fig. 5.1.**

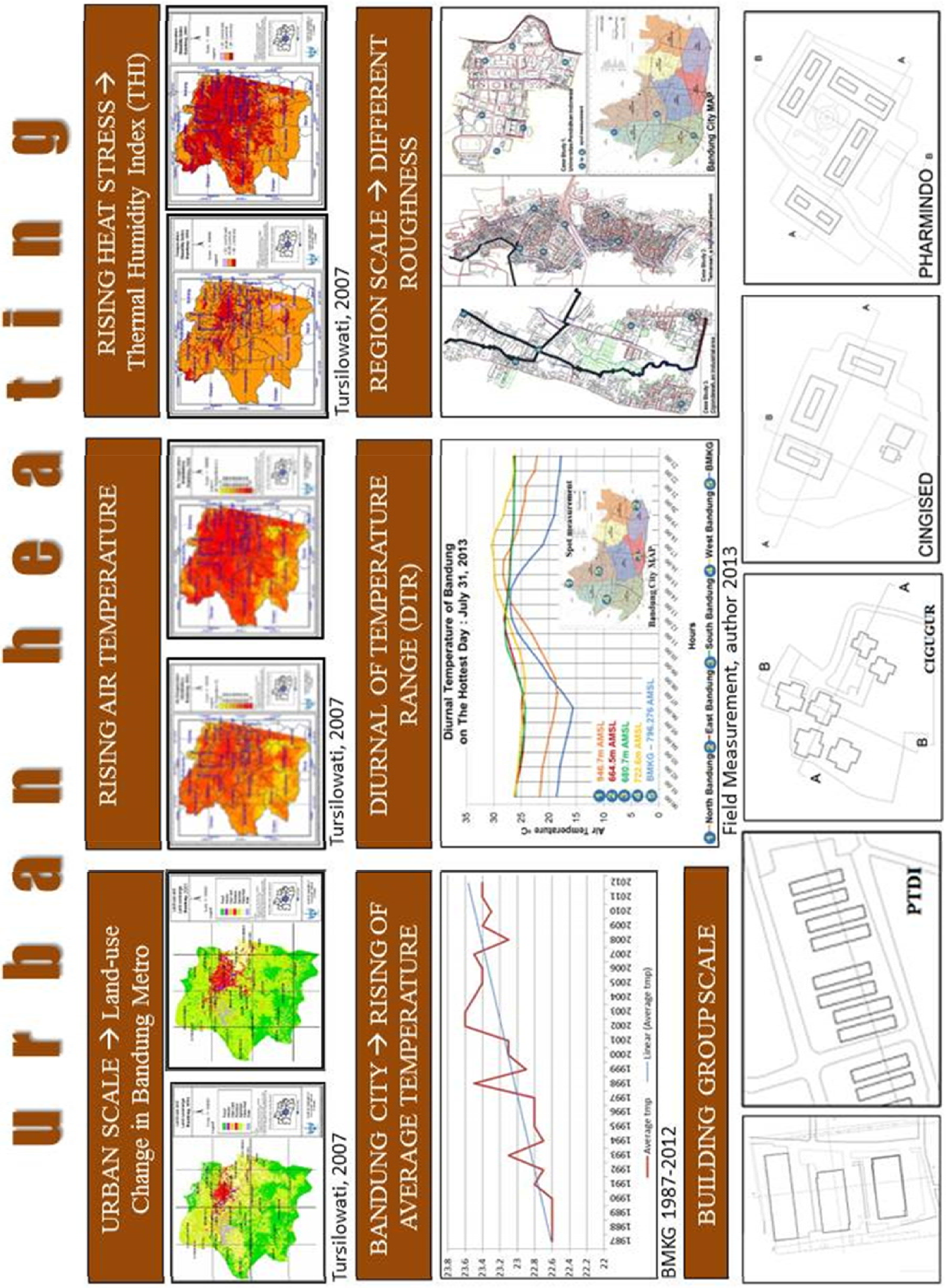



***Fig. 5.1*** *Sequence of Urban Heating Study in Bandung*
***Source**: Author*

## 5.2. Urban Geometry and Urban Heating

The objective of this study is to give statistical correlations between mean radiant temperature (Tmrt) and sky view factor (SVF) from three different land uses in Bandung. These include educational areas, high dense settlements and industrial areas. Microclimate data was obtained, including on air temperature (Ta) and on radiation during the daytime, which is much longer than on the roof and the ground areas (E. L. Krüger, 2013), (Alhaddad, 2013), (Ketterer, C. and A. Matzarakis, 2014). This means building surface area is an important factor to understand heat loss and gain. The larger the surface area, the more the heat is trapped, which significantly rises the mean radiant temperature. Therefore, building density plays an important role by shaping the urban form and its urban geometry due to factors including floor area ratio (FAR), building coverage (BC), height to width ratio (H/W) and the space between them. This has a direct influence on incoming and outgoing radiation as well as wind speeds, which become the main thermal properties of urban surface as mentioned by (Oke, 1988).

## 5.3. Urban Form

Previously, studies have been done to characterize urban canyon geometry through an understanding of its sky view factor (Ψs). (Oke, 1988) has stated that simple canyon as a H/W ratio is directly related to sky view factor. Furthermore, he argues that radiation geometry for the first approximation of a street is infinitely long and is pointed at the center of the floor of the canyon cross section. The view factor of each wall (Ψw) can be described as below in Equation 3:

$$\psi w = (1-\cos\theta)/2 \quad \text{where } \theta = \tan^{-1}(H/0.5W) \qquad (9)$$

Therefore the sky view factor is: $$\psi_S = 1-(\psi_{w1} + \psi_{w2}) \qquad (10)$$

The un-symmetric canyon as mentioned by Oke is seen in **Fig. 5.2**

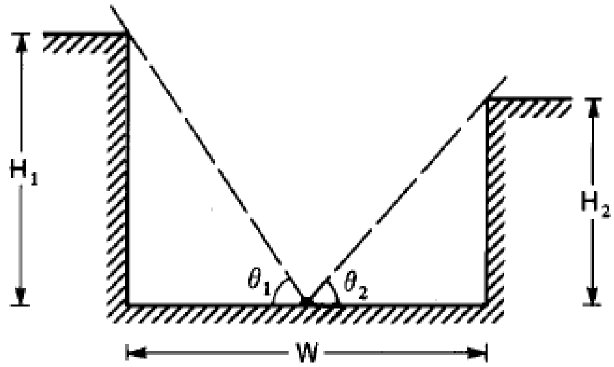



***Fig. 5.2**. Geometry of a un-symmetric canyon flanked by buildings 1 and 2*
***Source:** Oke, 1988*

Similar calculations can be done for any point on the canyon floor or walls, as each surface area has its own radiation geometry. Various methods have been developed to measure sky view factor, especially using softwares to facilitate rapid measurement. (Hämmerle, M., T, 2011) have compared sky view factor models of calculation used for urban climate investigations, which include Sky Helios (Matzarakis, 2011), (Fredrik Lindberg, B.H., Sofia Thorsson, SOLWEIG, 2008) and the ArcView SVF-Extension by (Gál, T, 2009). Recently, modern 3D models provide an opportunity to describe the complexity of urban surfaces and the principle of radiation geometry, which brings the ability to calculate SVF.

This study introduces Chronolux, an extension of Sketch Up, for insolation duration and SVF tests. Using a 3D model of urban form, Chronolux describes sky view factor at specified points by calculating the insolation duration and graphical representation (Bannov, 2013). Developed by Chronolux, the principle of surface radiation performs an approximate calculation of SVF. This is calculated with an approximation of a hemisphere with a center at a test point, then an algorithm is used to calculate the total area of approximated hemisphere by summing up areas of all hemisphere faces. Finally, the sky view factor is estimated by dividing the total area of the visible part with total area of the hemisphere, in a percentage, as shown in **Fig. 5.3.**

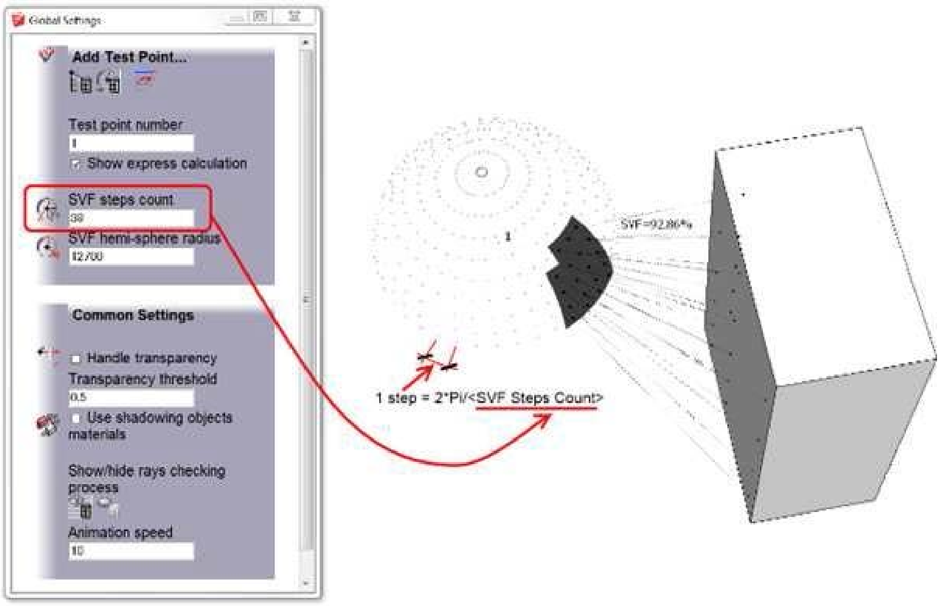



**Fig. 5.3.** Sky View Factor (SVF) by Chronolux
**Source:** Banov, 2013

## 5.4. Region Scale Study Areas

### 5.4.1. Universitas Pendidikan Indonesia (UPI), an Educational Area

Universitas Pendidikan Indonesia (UPI) has been selected since it has the largest area of land compared to other universities in Bandung. UPI occupies around 61 ha, which contrasts the area of other universities that are approximately 25 ha or less (BPSB, 2013). For this research, the land area is bordered in 37 ha. As shown in Fig. 4.2 , the study case map, UPI is located in northern Bandung and has the highest altitude compared to other case studies 920.587 m.

### 5.4.2. Tamansari, a High Dense Settlement

Tamansari is one of subdivisions, or kelurahan, in West Bandung Sub-district/kecamatan. The area of Tamansari is 35.7 ha and it is located at an altitude of 729.153 m. Based on a previous study, this kelurahan is one of the most dense settlements in Bandung. This area is part of the downtown core of Bandung and contains the worst slum neighborhood. Its building density is above 80 units/ha, while the population density is above 500 people/ha and the BC is more than 70% (Paramita, M.D.K.a.B., 2013), (Paramita, B., H.F., 2013) .

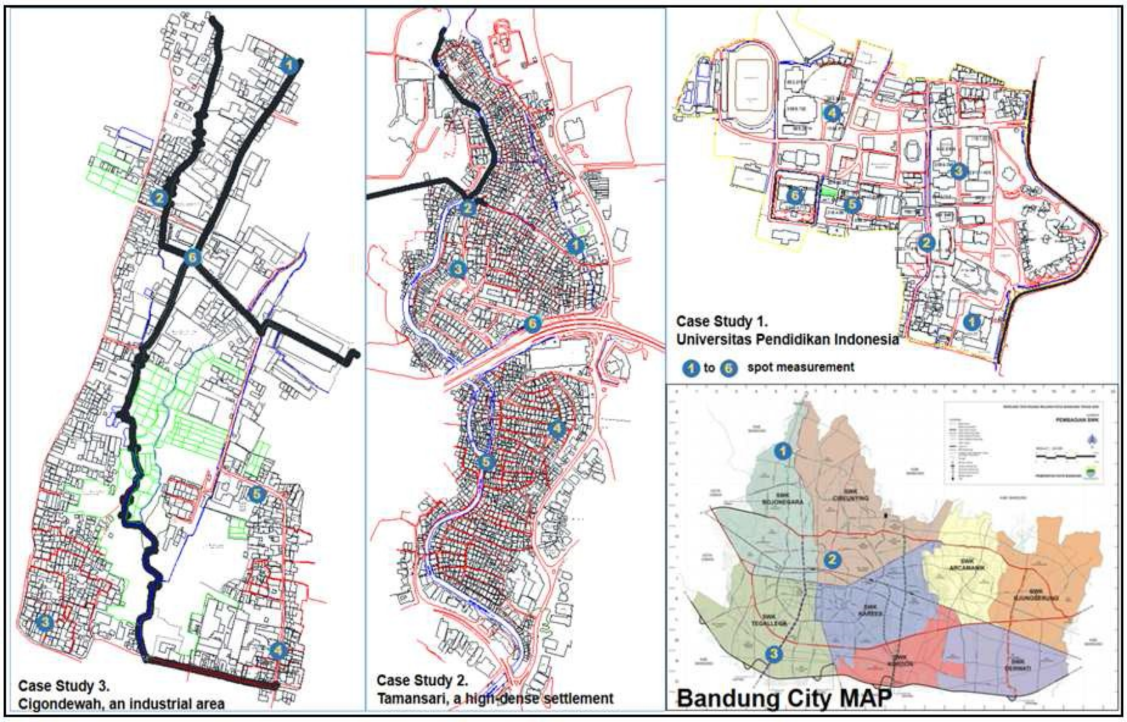



***Fig. 5.4**. Study Area of Heat Intensity in Bandung*
***Source**: Proceed from Bandung Digital Map, 2010*

### 5.4.3. Cigondewah, an Industrial Area

The southern part of Bandung is dominated by industrial areas, with the biggest one located in the Cigondewah Kaler subdistrict. The area of study is 36.7 ha and it is located at an elevation of 684.15 m. Unlike the other study areas, this site is in a suburb of Bandung and part of this area contains paddy fields. The building density is less than 50 units/ha and there is still a high amount of vacant land.

### 5.4.4 Findings

The investigation on urban microclimate was conducted in six areas of study, the results of which are shown in **Fig. 5.4.** The global temperature was measured using a 38 mm table tennis ball which was adjusted into Thermo Recorder RT-13 (Espec mic Corp). This tennis ball method has been tested and shown to be effective in outdoor conditions (Sofia Thorsson, F.L., 2007). Additionally, the LM-8000 Lutron tool was used to measure air temperature, humidity and wind speed.

Measurement results for all of the areas show a positive relationship between air temperature and global temperatures. **Figure 5.5** presents the highest Tmrt for three different land uses. This can be reached on a sunny day in educational areas and high density settlements, and on rainy day in industrial areas. Therefore, radiation caused by direct solar illumination still has a prominent impact on gain heat in outdoor urban built environments. Meanwhile, in industrial areas where much vacant land is still available, the Tmrt is lower than that in other areas.

The highest Tmrt in an educational area that was reached was 62.1°C at 11am on a sunny day, 57.3°C at 12am on a cloudy day and 61.4°C at 12am on a rainy day. Meanwhile, in the case of a high density settlement, the highest Tmrt was 56.47°C at 12pm on a sunny day, 60.3°C at 11am on a cloudy day and 52.2°C at 1pm on a rainy day. Finally, in the industrial area, the highest Tmrt that was reached was 51.18°C at 10am on a sunny day, 51.89°C at 12pm on a cloudy day and 55.77°C at 12pm on a rainy day.

### A. Microclimate at UPI

Based on the field measurement results shown in **Fig. 5.5**, the highest rate of Tmrt was found in the educational area, compared with those of the other two areas. Although located at more than 200 m (AMSL) higher than the other two study areas and with a lower average temperature, the outdoor microclimate is not reduced since it has a higher H/W ratio and also has wide space between buildings as shown at **Fig. 5.6**. The land coverage in this university is mostly asphalt, followed by concrete and also some green open space. This indicates that local radiation is more important than the regional conditions. This heat intensity at UPI is explained by the correlation of urban form and microclimate.

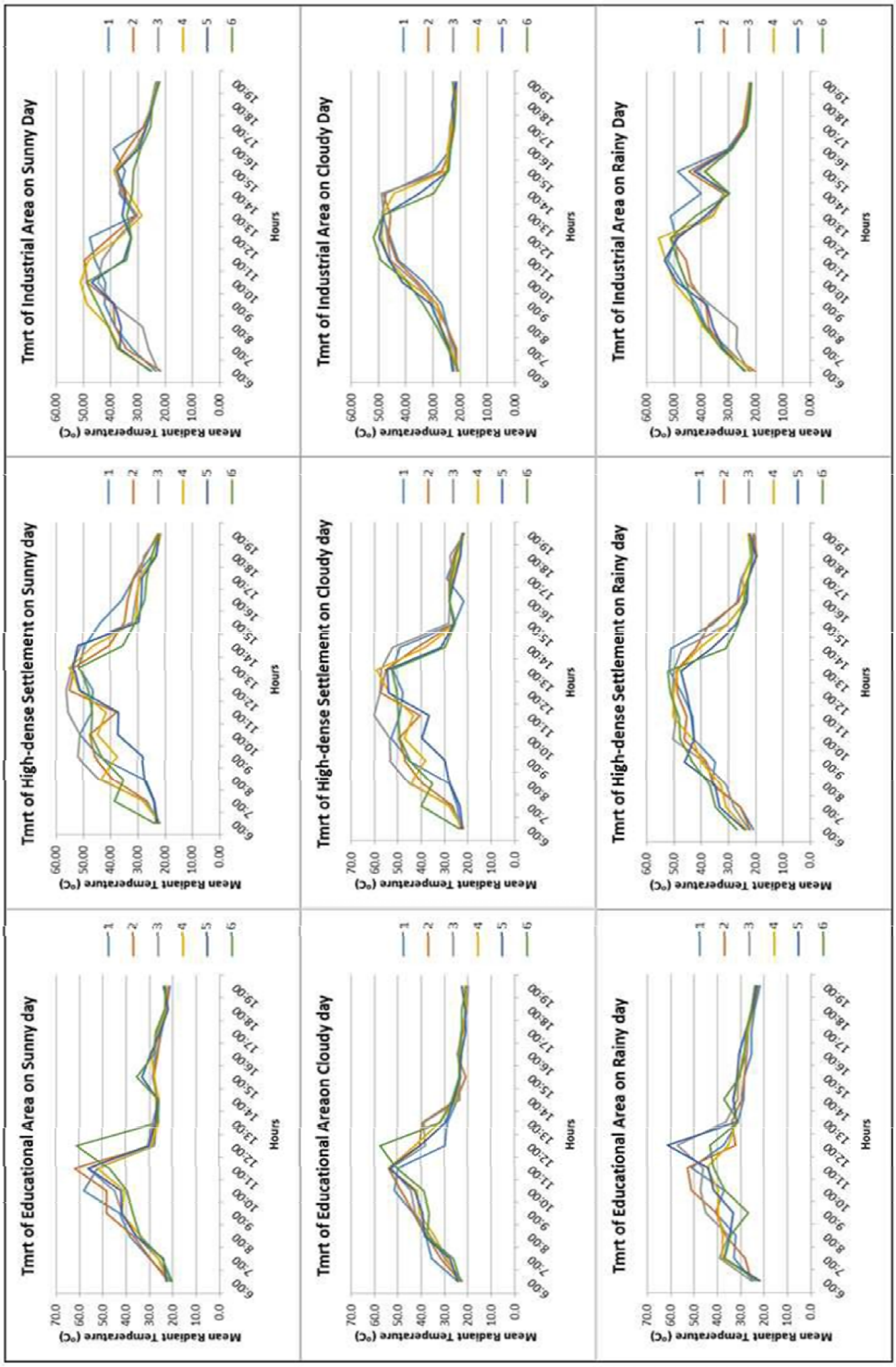



***Fig. 5.5.*** *Mean Radian Temperture of three study areas.*
***Source:*** *Field Measurement, author*


***Fig. 5.6***. *Urban Form and Sky View Factor of UPI-Educational.*
***Source:*** *Modeled by Sketch-up, SVF generated by Chronolux, author*

**Table 5.1** shows the value of Tmrt and urban form parameters at UPI. The regression of the correlation between Tmrt and urban form parameters are shown at **Fig 5.7**. Tmrt shows the coefficient of determination with the H/W in $R^2$=0.52. Other urban form parameters did not provide a significant value to Tmrt.

***Table 5.1.*** *Tmrt and Urban Form Parameters of UPI*

| Point | Tmrt (°C) | SVF (%) | BC (%) | FAR | H/W |
|---|---|---|---|---|---|
| 1 | 60.94 | 0.58 | 0.75 | 1.50 | 1.80 |
| 2 | 56.33 | 0.9 | 0.70 | 1.40 | 0.96 |
| 3 | 52.39 | 0.58 | 0.70 | 1.40 | 1.38 |
| 4 | 56.63 | 0.82 | 0.66 | 0.99 | 1.00 |
| 5 | 62.07 | 0.91 | 0.55 | 0.55 | 2.60 |
| 6 | 58.30 | 0.63 | 0.57 | 1.42 | 1.50 |

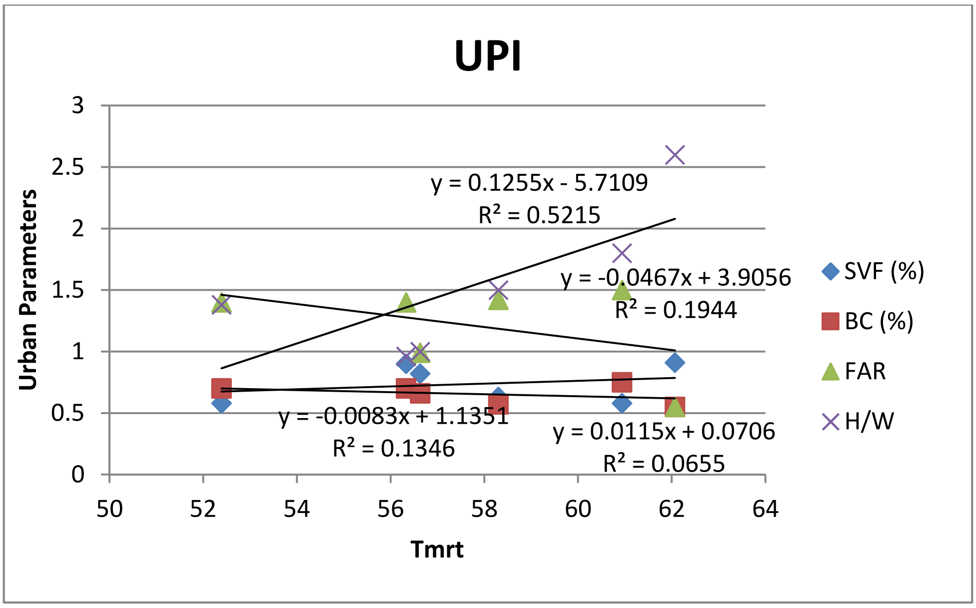



***Fig. 5.7.*** *Regression between Tmrt and Urban Parameters at UPI*
***Source:*** *Author*

**B. Microclimate at Tamansari**

**Table 5.2** presents the value of Tmrt and urban form parameters of Tamansari. The coefficient of determination of Tmrt and urban form parameters is shown at **Fig. 5.9**, where Tmrt and BC have $R^2 = 0.68$. However, the other urban form parameters, such as SVF, FAR and H/W, have an insignificant value on Tmrt. The urban form from 3D modelling and the SVF is generated by the chronolux which is shown at **Fig. 5.8**. The high dense settlement tends to have high temperatures for both air temperature and mean radiant temperature, even though the spot measurement was chosen in an open area, as shown at **Table 5.2** the BC in the range of 0.39-0.71.

***Table 5.2*** *Tmrt and Urban Form Parameters of Tamansari*

| Point | Tmrt (°C) | SVF | BC | FAR | H/W |
|---|---|---|---|---|---|
| 1 | 53.00 | 0.30 | 0.42 | 0.84 | 1.58 |
| 2 | 57.29 | 0.37 | 0.64 | 1.93 | 1.34 |
| 3 | 60.30 | 0.68 | 0.71 | 0.71 | 1.56 |
| 4 | 59.15 | 0.36 | 0.49 | 1.24 | 1.88 |
| 5 | 54.48 | 0.27 | 0.39 | 0.98 | 1.59 |
| 6 | 52.66 | 0.67 | 0.38 | 0.97 | 1.89 |


***Fig. 5.8*** *Urban Form and Sky View Factor of UPI-Educational.*
***Source:*** *Modeled by Sketch-up, SVF generated by Chronolux, author*

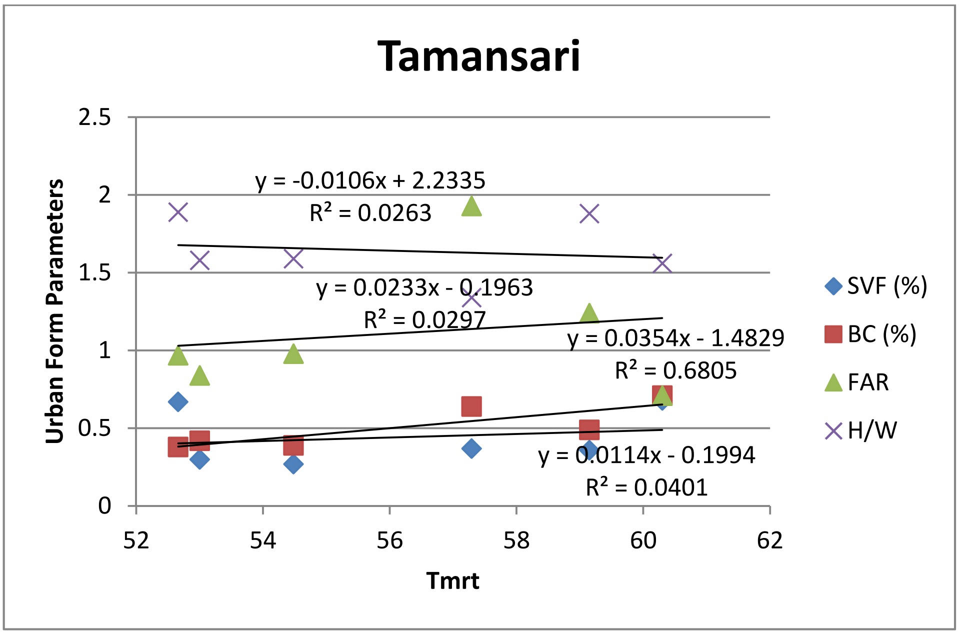



***Fig. 5.9*** *Regression between Tmrt and Urban Parameters at Tamansari*
***Source:*** *Author*

**C. Microclimate at Cigondewah**

The field measurements of air and global temperatures at Cigondewah show that this area has the lowest temperatures compared with that of the other two cases. This impacts the mean radiant temperature, as is seen at **Fig 5.5**. **Table 5.3** presents the Tmrt and urban form parameter of Cigondewah, and its coefficient of determination is shown in **Fig. 5.11.** Tmrt shows its correlation with FAR at $R^2 = 0.53$, meanwhile other urban parameters show an insignificant value to Tmrt. As previously mentioned, this region has the lowest air temperature compared to the areas of the other two cases. This is largely due to the roughness of the land coverage, such as loamy soil and muddy land, which reduces heat intensity.

**Table 5.3** Urban Form Parameter and Microclimate of Cigondewah

| Point | Tmrt (°C) | SVF | BC | FAR | H/W |
|---|---|---|---|---|---|
| 1 | 52.38 | 0.38 | 0.27 | 1.35 | 0.58 |
| 2 | 51.18 | 0.34 | 0.33 | 1.65 | 0.52 |
| 3 | 49.71 | 0.66 | 0.36 | 2.18 | 0.79 |
| 4 | 55.77 | 0.7 | 0.29 | 1.47 | 0.43 |
| 5 | 53.48 | 0.66 | 0.35 | 1.42 | 1.11 |
| 6 | 51.89 | 0.73 | 0.37 | 1.85 | 0.69 |

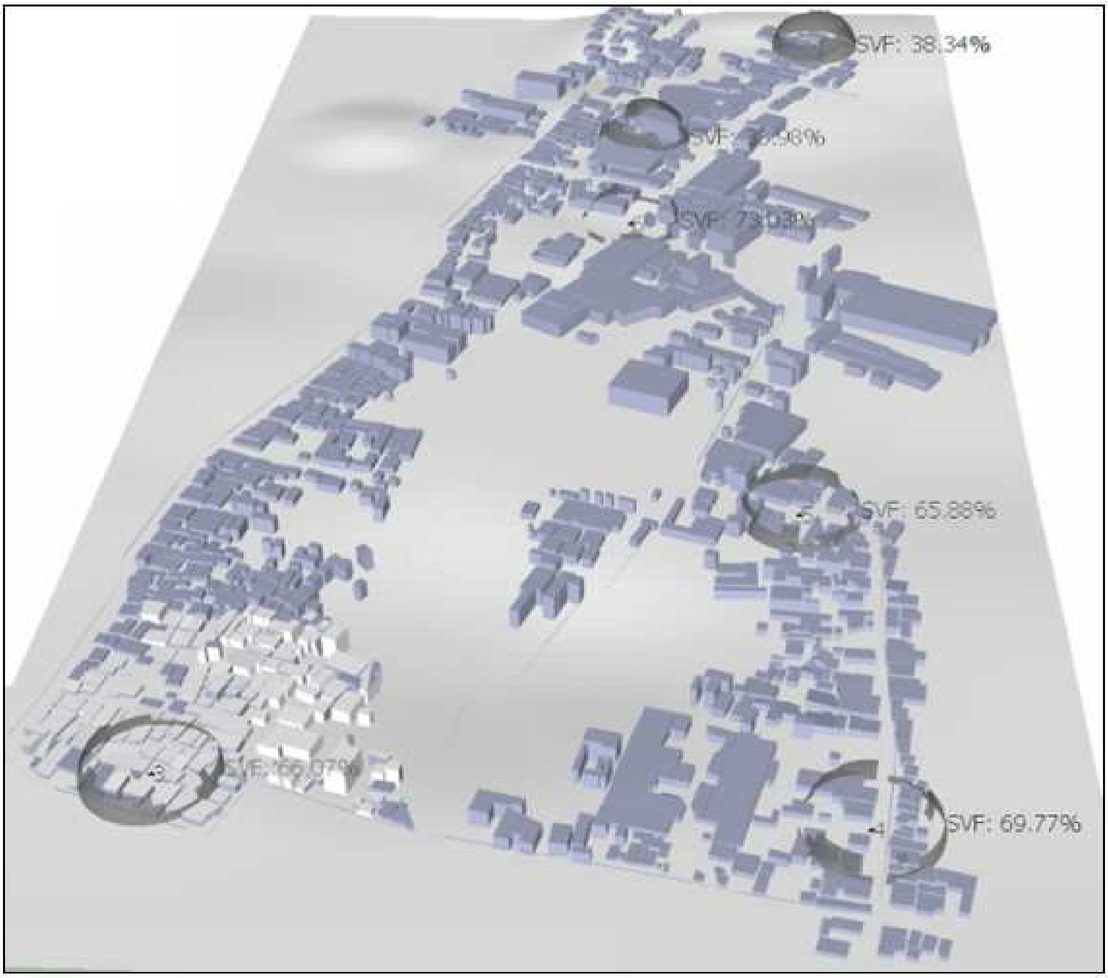



***Fig. 5.10** Urban Form and Sky View Factor of Cigondewah.*
**Source:** Modeled by Sketch-up, SVF generated by Chronolux, author

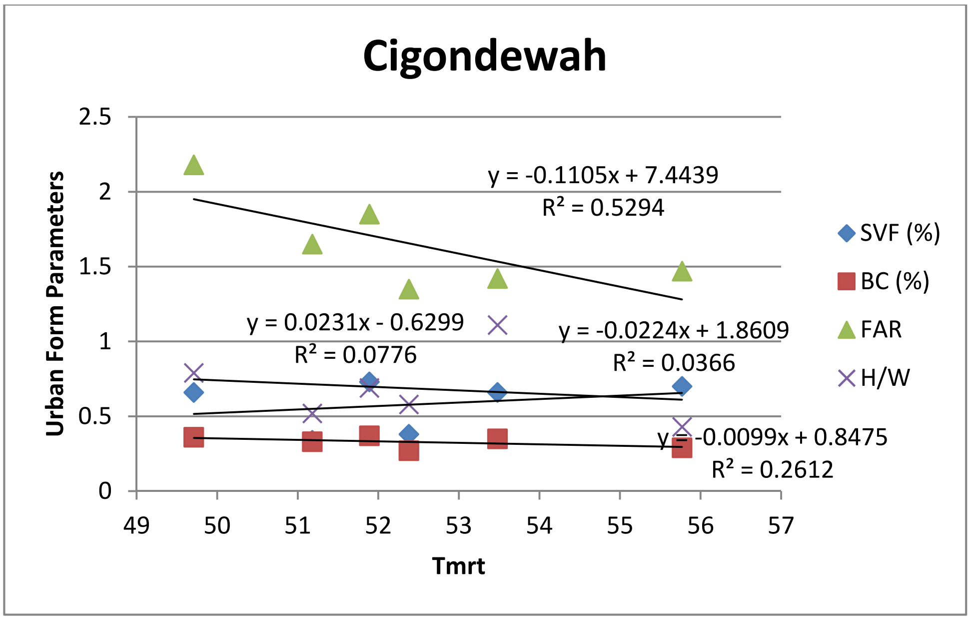



***Fig. 5.11*** *Regression between Tmrt and Urban Parameters at Cigondewah*
***Source:*** *Author*

***Table 5.4*** *Coefficient of Determination between Tmrt and Urban Form Parameters*

| | | $R^2$ | | | |
|---|---|---|---|---|---|
| Region | Range of Tmrt | SVF | BC | FAR | H/W |
| UPI | 56.33 - 62.07 | 0.06 | 0.13 | 0.19 | 0.52 |
| Tamansari | 52.66 - 60.30 | 0.04 | 0.68 | 0.03 | 0.02 |
| Cigondewah | 49.71 - 55.77 | 0.08 | 0.26 | 0.53 | 0.04 |

**Table 5.4** presents the summary of the coefficient of determination between Tmrt and urban form parameters. Results show the highest Tmrt, found at UPI, is determined by the value of H/W. This is due to the appearance of buildings at UPI, which have an average of five to ten floors, which contrasts with the height of buildings in the other two regions which have only one to three floors.

From that table, it can also be seen that the Tmrt at Tamansari is determined by BC, since this region is a high dense settlement with high building density. Finally, the Tmrt of Cigondewah is determined by the value of FAR. The factory building is the industrial area with the highest FAR value, which has a significant impact on the Tmrt on this site. The value of FAR also is higher compared with the two other regions.

This study of three different land uses, each with different characteristics of urban form, shows that heat intensity in each site is controlled by the roughness of the surface area and its insolation. The most important conclusion is that urban form, with qualities such as BC, FAR and H/W, have the potential to manipulate the sun and wind to improve the microclimate surrounding the buildings. Although this research does not discuss advective effects, such as from cars or cooling inside the building, it is still necessary to understand that temperature may change due to the influence of micro-variations of the immediate environments compared to the wider environment.

## 5.5. Building Group Area Study

High population density and vertical buildings appear to be the only aspect that fits the situation of cities in developing countries. Vertical settlements are necessary in the often expensive and limited area of downtown. Surrounded by mixed land use, these settlements can possibly play a primary role in the creation of the compact city by reducing the total length of movement between an individual’s home and work. In a broader sense, sustainable cities are a matter of density. Density and dwelling type effect sustainability because of differences in energy consumption, materials, and land used for housing, transportation, and urban infrastructure. Unlike detached housing, vertical housing, such as flats, apartments or condominiums, appear to be a promising solution to the problem of limited land availability. Also, verticle housing is able to mix well with other functions in a compact city. The utopic idea of the compact city in developing countries requires flats in order to have liveable comfort in a dense area. Therefore, urban physical assessment of flats is important in providing descriptions of building form typology regarding its orientation, building height, width and space between buildings. This chapter addresses the role of urban physics in the study of urban form with regard to wind, temperature and humidity. Therefore, it is evident that flat assessment, as a building group, is important in order to address the role of urban physics and its contribution to microclimates and to heat intensity.

### 5.5.1 Public Flat in Bandung, Indonesia

Rapid population growth is causing problems related to urban spatial use, such as the squatters in the downtown area. Limited access to land, high prices, and high demand for affordable houses in the downtown area created the mass construction of flats which spread throughout large cities in Indonesia. The first flat was built in Bandung, in 1979, to accommodate the housing need of PTDI's employees, giving it the name "PTDI flat."[1] Also, beginning in 2007, the government has announced a national project called "1000 Towers." This project was designed to revitalize the overcrowded area, especially in cities with a population density of more than 10,000 people per km2. Based on the ministry of public housing data (Kemenpera, 2013), from 2005 to 2013 573 twin blocks were completed, meanwhile there is still a backlog of 0.8% demand. The development of *Rusun*, whose construction will be carried out in the following years, is a high dense area which will potentially have a significant impact on the microclimate within the city itself. Thus, the presences of *Rusun* are not only shaping the city's image, but also influence urban living quality. The importance of building form and massing to compose urban microclimates through *Rusun* complexes, especially in Bandung, is seen below in **Fig. 5.12**.

**Fig. 5.12** shows the current *Rusun* mapping in Bandung, Indonesia. There are eight constructed *Rusun,* namely: *R.* PTDI, *R.* SadangSerang I, *R.* Rancacili, *R.* Cingised, *R.* Pharmindo, *R.*Unpas*, R.* Cigugur and *R.* UPI. And there are ten planned *Rusun,* which are: *R.* Sadang Serang II, *R.*Tamansari, *R.* Linggawastu, *R.* Industri Dalam, *R.* Jamika, *R.* Braga, *R.* Lebak, *R.* Gedebage. *R.* Rancacili II, and *R.* Cicadas. *R.* Kebonwaru also a new planned *Rusun* with private-government funding.

Specifically, this discussion involves five *Rusun* samples, which are: *Rusun* UPI, *Rusun* PTDI, *Rusun* Cigugur, *Rusun* Pharmindo and *Rusun* Cingised.

[1] Public flat, in this sense, it is like the Indonesian word *Rusun* and *Rusunawa*, which refer to low cost public housing

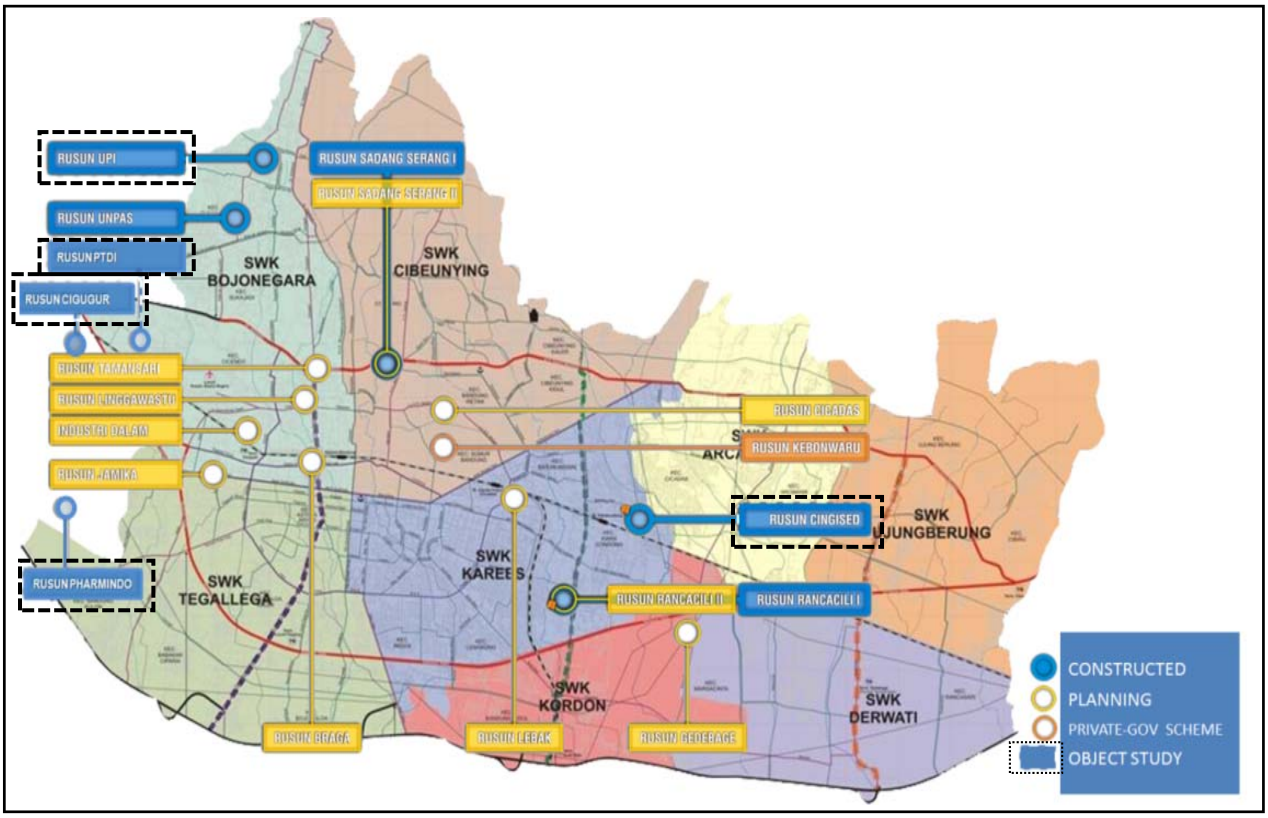



***Fig. 5.12*** *Public Flat Profile in Bandung*
***Source :*** *Profil Rusunawa, Bandung, 2010*

### 5.5.2. Urban Form of Five *Rusun* Samples

Based on the building plot configuration, urban form can be divided into three groups; parallel plot, interspersed plot and square plot.

### A. Parallel Plot

1. *Rusun* PTDI

*Rusun* PTDI is the first *rusun* and was built in Indonesia in 1979. This *rusun* contains eleven twin blocks and each unit has four floors located at 799.74 m above sea level. The main orientation is towards west and east with no proper open space or green coverage. As shown in **Fig 5.13,** the physical condition of this *rusun* PTDI is already in deplorable conditions, since there has been no maintenance during the building's life span. The building is nearly 35 years old.

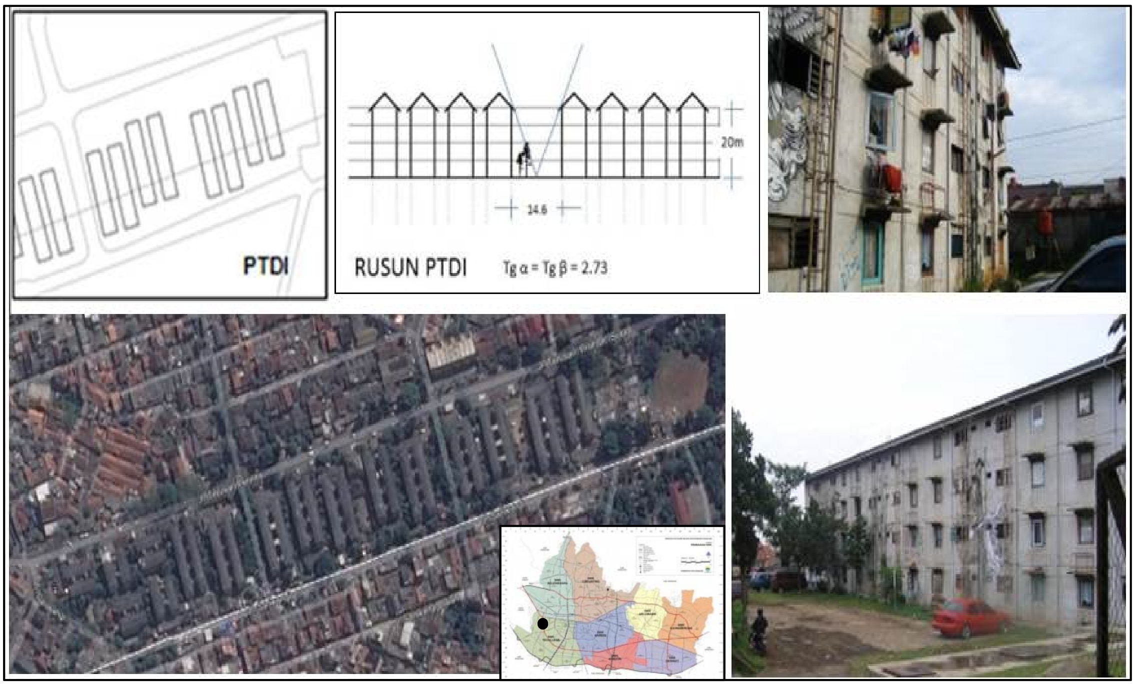



***Fig. 5.13*** *Rusun PTDI*
***Source:*** *Field measurement, Author. Satelit Image Google Maps*

2. Rusun UPI

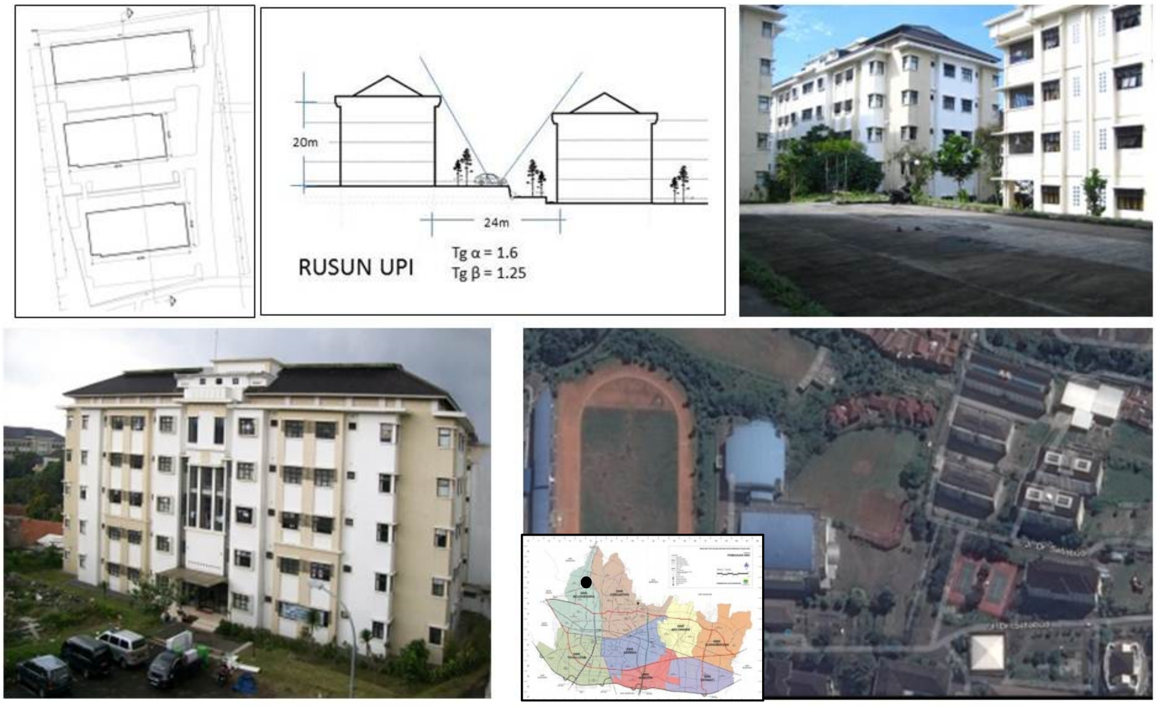



***Fig. 5.14*** *Rusun UPI*
***Source:*** *Field measurement, Satelit Image Google Maps*

*Rusun* UPI was built recently in 2010. This building accommodates the students of Universitas Pendidikan Indonesia (UPI). There are three main buildings with four floors and the main orientation faces north and south. **Fig**. **5.14** presents the situation of *Rusun* UPI in the complex of UPI (Indonesia University of Indonesia). The location of this building is 920.59 m above sea level.

**B. Interspersed Plot**

*Rusun* Cigugur was built in 2004, and it has a different type of building plot and configuration. As seen at **Fig 5.15,** the proportion of the building length is 1:1. This means that the façade equally faces both north/south and west/east. This *rusun* has four building blocks and is located at 689m above sea level.

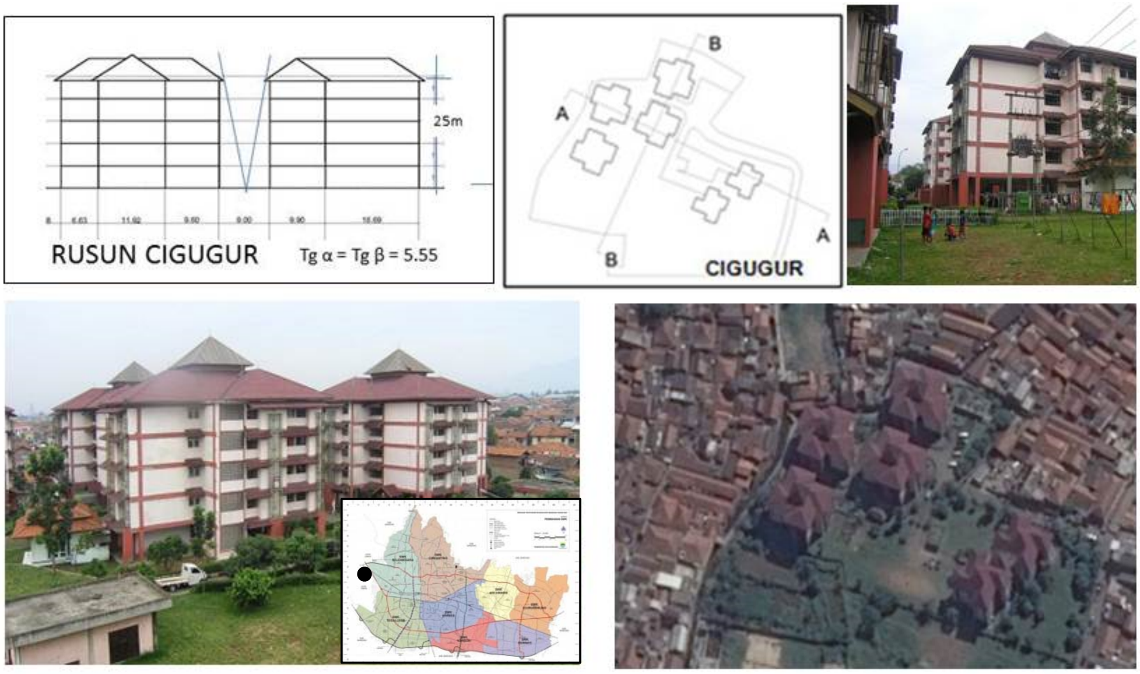



***Fig. 5.15** Rusun Cigugur*
*Source: Field measurement, Satelit Image Google Maps*

**C. Square Plot**

1. *Rusun* Cingised

*Rusun* Cingised was built in 2008. As shown in the **Fig. 5.16**, the first construction only consisted of three blocks, which was later meant to be continued with another two blocks. This *rusun* was not finished until now. This complex has square plot typology and the building contain five floors, with the first floor as a service area. The building type is square with void space. It is located at the elevation 672.85m.

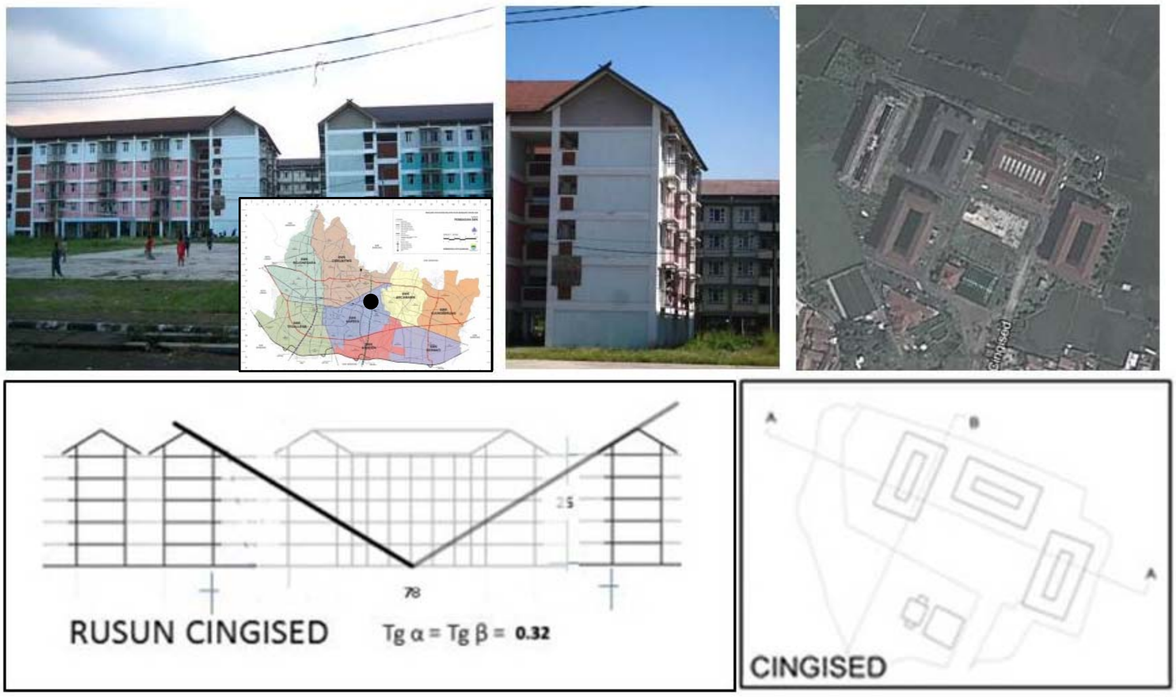



*Fig. 5.16 Rusun Cingised*
*Source: Field measurement, Satelit Image Google Maps*

2. *Rusun* Pharmindo

*Rusun* Pharmindo was built in 2009. It has four building blocks and each has four floors. Since this complex has a square plot, there are two buildings facing north and south, whereas the other two face west and north. From the satellite image in **Fig. 5.17**, it can be seen that this complex has neither proper green coverage nor shadowing area. Thia area is surrounded by a high dense settlement area and is located at 720 m above sea level.

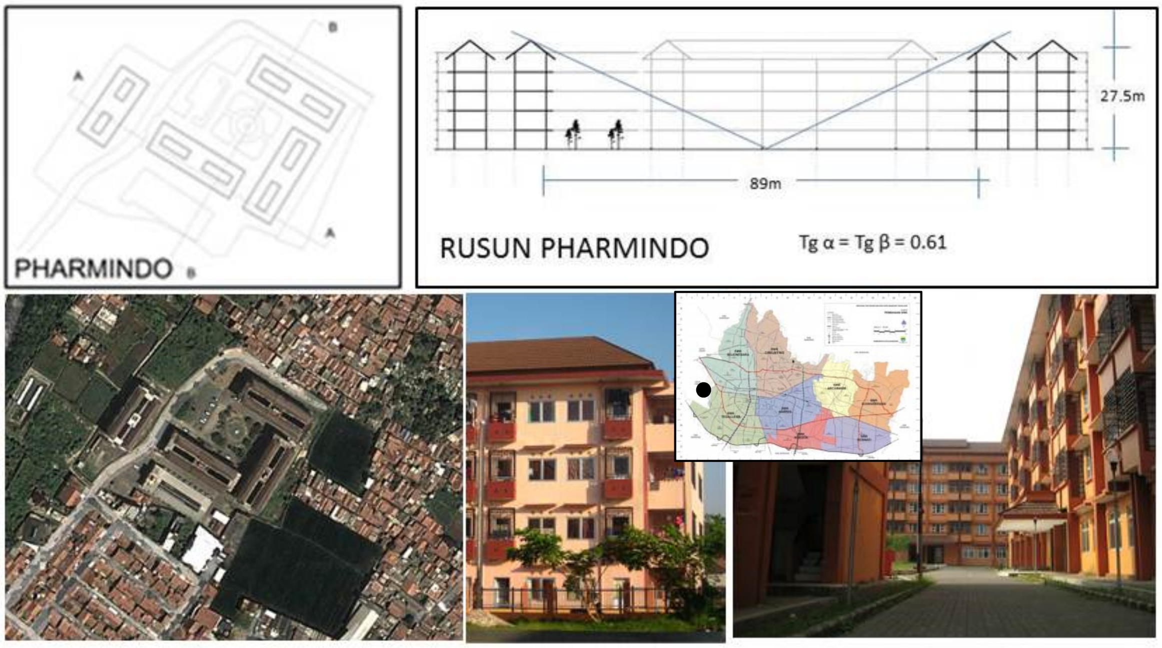



***Fig. 5.17*** *Rusun Pharmindo*
*Source: Field measurement, Satellite Image Google Maps*

**Table 5.5** Urban Form of Five Samples of Building Groups

| Flats | H/W | FAR | BCR | Veg. ratio | Surface area |
|---|---|---|---|---|---|
| *Rusun* UPI | 1.6 | 1.13 | 33% | 17.25% | 0.15 |
| *Rusun* Cigugur | 5.55 | 0.92 | 15.15% | 9.46% | 0.347 |
| *Rusun* Cingised | 0.32 | 0.765 | 17.97% | 1.88% | 0.124 |
| *Rusun* Pharmindo | 0.61 | 1.103 | 22.84% | 0.64% | 0.142 |
| *Rusun* PTDI | 2.73 | 1.08 | 28.99% | 8.93% | 0.347 |

**Table 5.5** presents the urban form of five samples of building groups. It shows that Rusun Cigugur has the highest value of canyon (H/W) at 5.55. This canyon is considered steep, as the suggested maximum canyon in this tropical area is 2. The other canyons in these samples include *Rusun* PTDI with 2.73, *Rusun* UPI with 1.6, *Rusun* Pharmindo with 0.61 and finally *Rusun* Cingised wth 0.32.

The value of FAR in these five samples is seen in the similar values, which are between 0.765 and 1.13. As well, the value of BCR in the five samples has a range between 15.15% and 33%. The suggested BCR for the hot humid climate region is between 20 and 30%.

Vegetation value appears to have a very big gap from one sample to the next. *Rusun* Pharmindo has the lowest value of vegetation coverage at 0.64%, meanwhile *Rusun* UPI has the highest value of vegetation coverage at 17.25%. Surface area, which is correlated with FAR, shows that the more higher the value of FAR, the higher the surface area ratio. In this case, *Rusun* Cigugur and *Rusun* PTDI have the highest value at 0.347. The lowest value is *Rusun* Cingised at 0.124.

### 5.5.3. Microclimate at Street Level

Meteorological data from the five samples of *Rusun* in Bandung is presented in **Fig. 5.18** and was taken from field measurements over nine days in June, 2012. These days include June 9$^{th}$, 11$^{th}$ and 22$^{nd}$, which are cloudy days. June 13$^{th}$, 14$^{th}$ and 24$^{th}$ are sunny days, and June 5$^{th}$, 10$^{th}$ and 21$^{st}$ are rainy days. June is the month with the highest sun position towards the earth and has the shortest daytime, which is 11 hours and 30 minutes. Measurements were performed on three different weather days within cloudy, rainy and sunny conditions in an open space, a shaded area and a transitional area. The obtained data is regarding temperature, humidity, and wind speed.

The character of highest temperature for three *rusun* inlcludes UPI, Pharmindo and Cingised, which was reached on a sunny day. Meanwhile, PTDI and Cigugur show a similar character, which is that the highest temperature is on a cloudy day. The highest temperature in open space indicates insolation through urban form and has significant impact on temperature alteration.

The graphs of humidity from five *rusun* samples show a trend of higher humidity both in the morning and as the afternoon approaches sunset. At *Rusun* PTDI, the humidity value did not change much depending on whether the weather was sunny, cloudy or rainy.

The field measurements also found that building plot has an influence on inducing wind speed. For example, *Rusun* UPI, which is three blocks and whose main orientation faces north and south reached maximum wind speed of 3.4m/s. *Rusun* PTDI with eleven twin blocks and a main orientation facing west and east reached a maximum wind speed at 2.2m/s. As well, *Rusun* Cigugur which has four interspersed blocks reached a maximum wind speed of 2.7m/s. *Rusun* Pharmindo, with four blocks and square plot building configuration, reached a maximum wind speed of 4.3 m/s. Finally, *Rusun* Cingised, with four blocks and a square plot building configuration, reached a maximum wind speed of 3m/s.

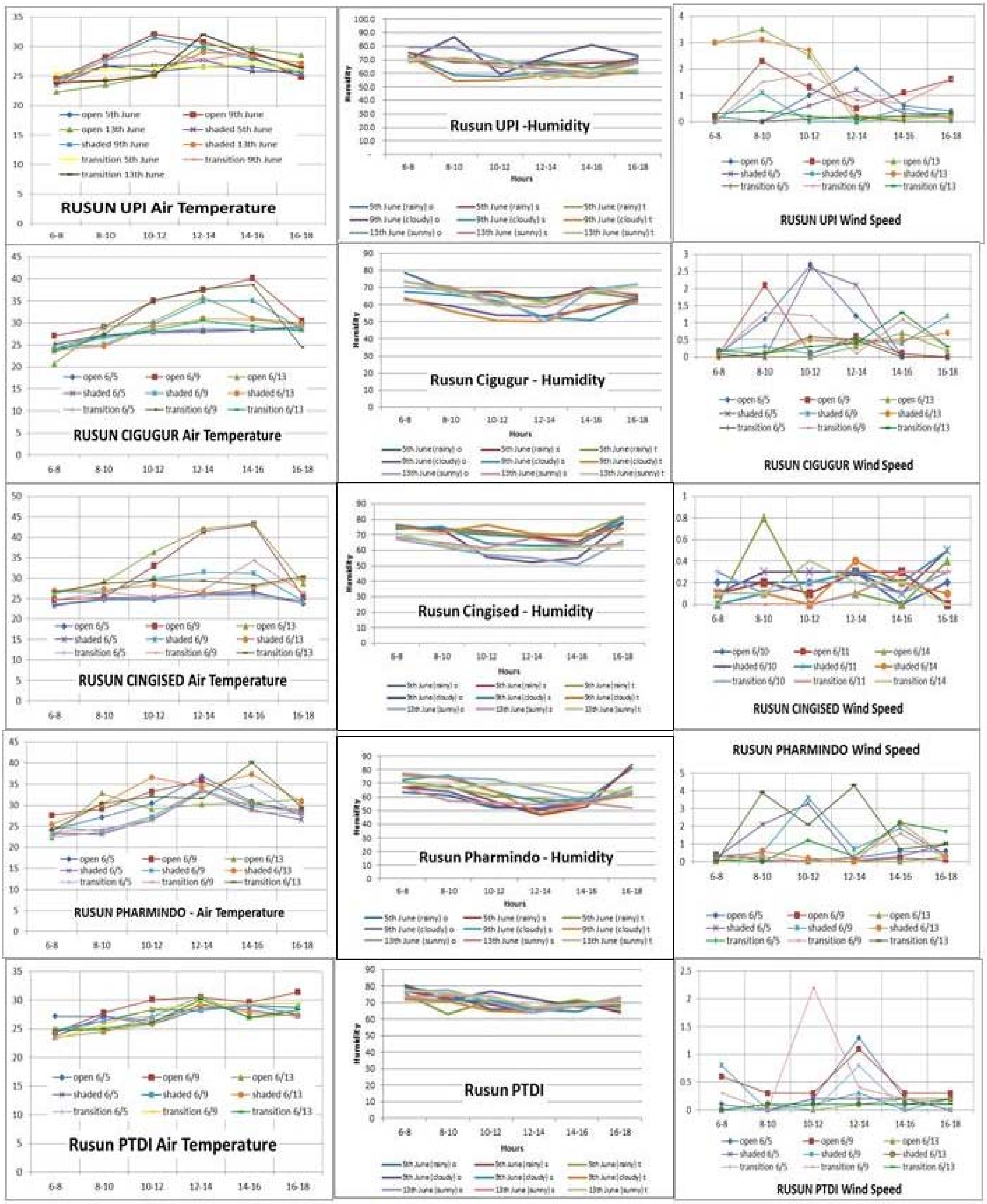



***Fig. 5.18** Microclimate at street level from five rusun samples.*
***Source :** Field measurement, Author, 2012*

### 5.5.4. Correlation of Urban Form and Microclimate at Street Level

Table 5.2 presents the maximum value for air temperature (Ta), humidity and wind speed on a sunny day, on which most the hottest temperature occurred. Based on field measurements, *Rusun* Cingised reached the highest air temperature of 43°C, and *Rusun* PTDI reached the lowest air temperature of 30.6°C. The lowest humidity in *Rusun* Cingised was 70.9%, meanwhile the highest humidity in *Rusun* UPI was 79.2%. The highest wind speed, 4.3m/s, was reached at *Rusun* Pharmindo and the lowest value reached was 1.3 m/s at *Rusun* Cigugur.

***Table 5.6*** *Correlation of Urban Form and Microclimate at rusun in Bandung*

| Flats | H/W | FAR | BCR | Veg. ratio | Surface area | Ta max | Humi-dity | wind speed |
|---|---|---|---|---|---|---|---|---|
| *Rusun* UPI | 1.6 | 1.13 | 0.33 | 0.17 | 0.15 | 32.0 | 79.2 | 3.4 |
| *Rusun* Cigugur | 5.55 | 0.92 | 0.15 | 0.09 | 0.347 | 35.8 | 73.8 | 1.3 |
| *Rusun* Cingised | 0.32 | 0.765 | 0.18 | 0.02 | 0.124 | 43.3 | 70.9 | 3 |
| *Rusun* Pharmindo | 0.61 | 1.103 | 0.23 | 0.01 | 0.142 | 40.1 | 77.7 | 4.3 |
| *Rusun* PTDI | 2.73 | 1.08 | 0.29 | 0.09 | 0.347 | 30.6 | 77.5 | 2.2 |

The correlations between each urban form element within the microclimate are shown from **Fig. 5.19** to **Fig. 5.12**.

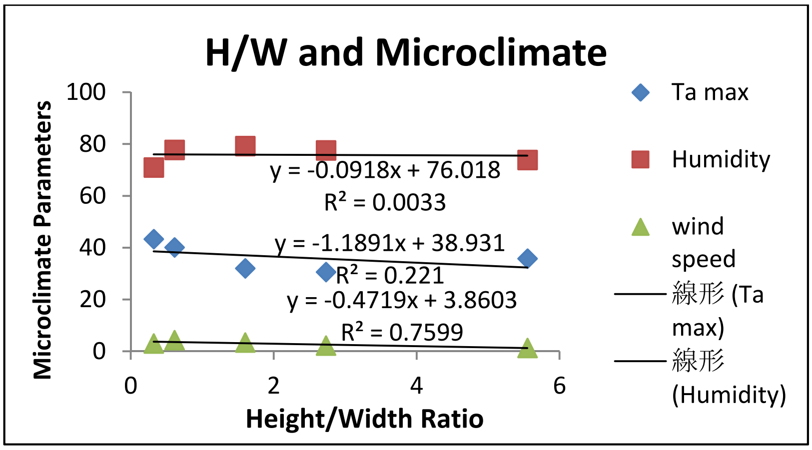



***Fig. 5.19*** *Regression of H/W with Microclimate at street level.*
***Source****: Analysis, 2014*

**Fig. 5.19** shows that H/W is correlated with the wind speed in $R^2$ = 0.76. This shows that H/W significantly impacts wind speed. Air temperature and humidity element show positive value, but it is not significantly impacted by H/W.

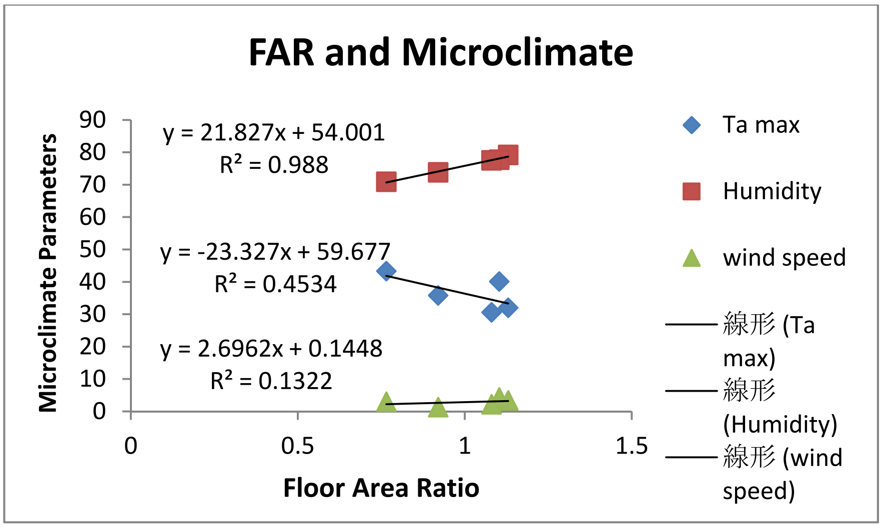



***Fig. 5.20** Regression of FAR with Microclimate at street level.*
***Source**: Analysis, 2014*

According to **Fig. 5.20,** FAR has a significant correlation between humidity and $R^2$ = 0.98. The other microclimate elements, such as air temperature and wind speed, show the positive correlation, but not significantly.

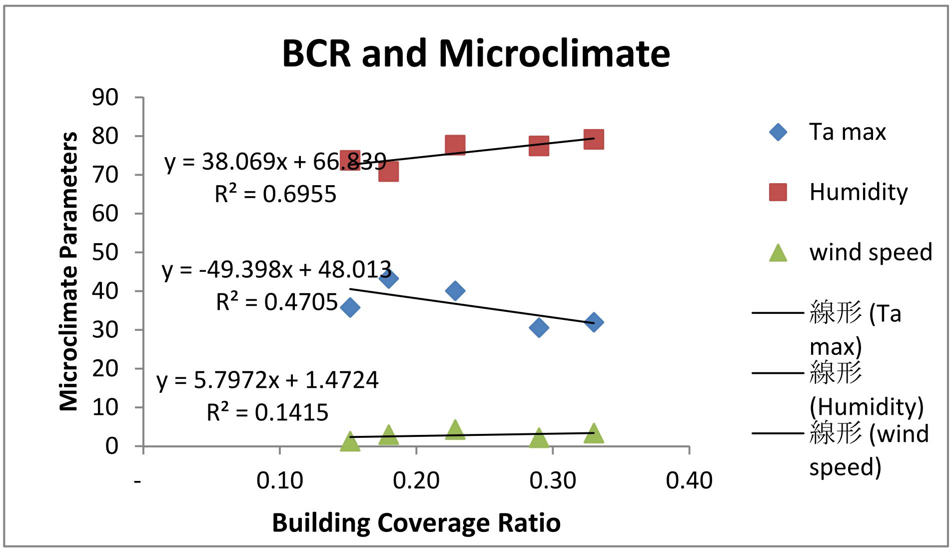



***Fig. 5.21** Regression of BCR with Microclimate at street level.*
***Source:** Analysis, 2014*

**Fig. 5.21** shows that BCR has a significant correlation with humidity and $R^2$=0.7. The other microclimate elements show less correlation between Ta and wind speed.

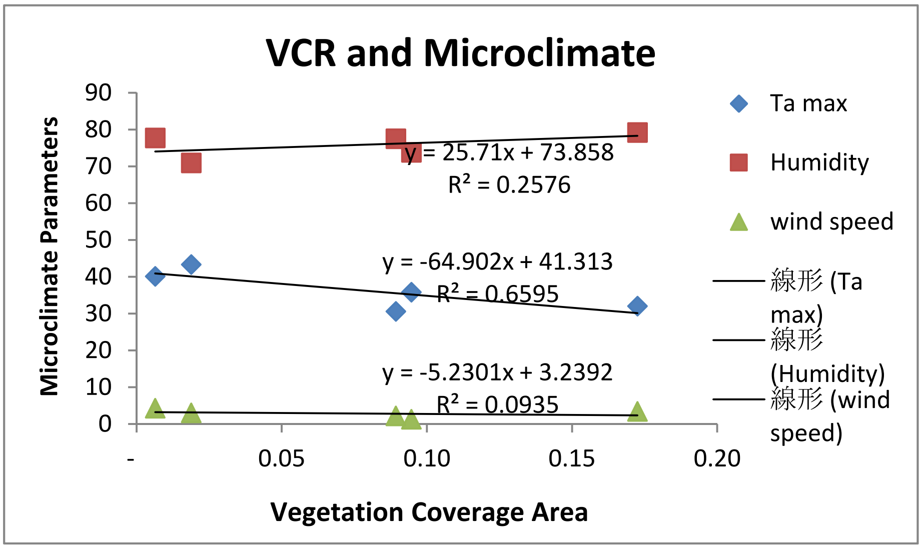



***Fig. 5.22** Regression of VCR with Microclimate at street level.*
***Source**: Analysis, 2014*

VCR has a significant correlation with air temperature and $R^2$= 0.66, as shown at **Fig. 5.22.** Also, it has less of a correlation with humidity and an insignificant value in terms of wind speed.

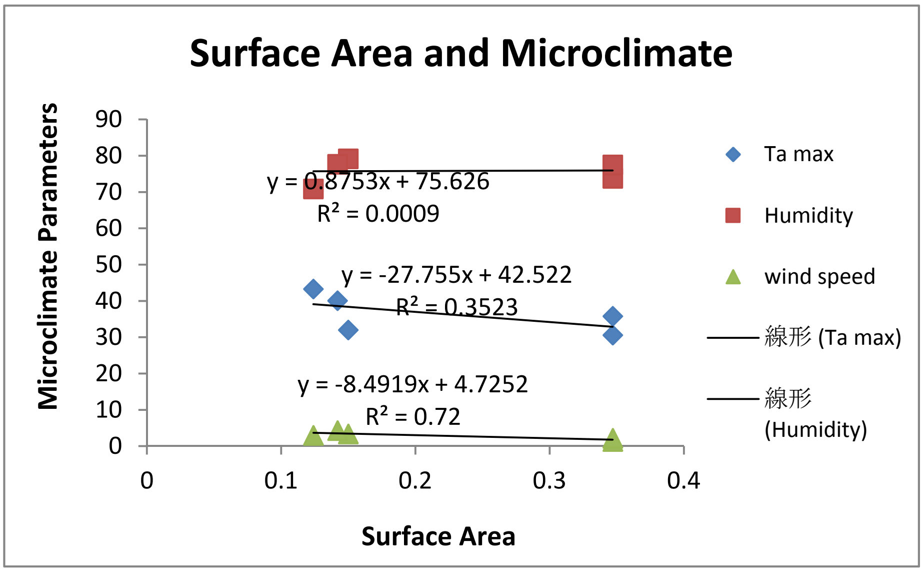



**Fig. 5.23** Regression of Surface Area with Microclimate at street level.
***Source**: Analysis, 2014*

The surface area of the five *rusun* samples show a significant correlation, seen in **Fig. 5.23,** with wind speed. However, the other microclimate elements, including air temperatures, are the less significant, and humidity shows an insignificant value.

### 5.5.5. Correlation Matrix between urban form and microclimate

The correlation between urban form and microclimate is presented as a correlation matrix in **Table 5.7** and the design recommendation is provided at **Table 5.8**. From those tables, the impact of microclimate from the building form and configuration becomes clear. Wind speed is a significant aspect in hot and humid climates to increase comfort levels. This could be induced by considering H/W and SA. The element of high humidity in hot humid climates can be controlled by the consideration of FAR and BCR. Importantly, air temperature can be reduced by the creation of additional vegetation coverage.

***Table 5.7*** *Interrelated Correlation Between Urban Form Parameters and Microclimate*

| | Ta | Humidity | Wind Speed |
|---|---|---|---|
| H/W | 0.221 | 0.003 | 0.76 |
| FAR | 0.45 | 0.98 | 0.13 |
| BCR | 0.47 | 0.7 | 0.14 |
| VCR | 0.66 | 0.26 | 0.09 |
| SA | 0.35 | 0.0009 | 0.72 |

***Table 5.8*** *Passive Design of Building Group in Hot Humid Climate*

| **Microclimate Impact** | **Design Recommendation** |
|---|---|
| Induce the wind speed > 3.4m/s | The space between building (H/W) in the range tangen α = 0.61 – 1.6 |
| The humidity < 79% | Plan the building with the minimum FAR ≥ 1.1 |
| Minimum humidity | BCR ≤ 0.3 |
| Max air temperature in hottest day 30°C | Giving the vegetation coverage area > 17% |
| Rising the wind speed ≥ 3.4m/s | Surface area ratio in the range 0.12-0.15 |

# 5.6. Closing Remarks

**Table 5.8** presents design recommendation for passive design of building groups in Bandung with hot humid climate characteristics. The space between building (H/W) is based on an assessment of building form and microclimate, which has Tg α = 0.61 – 1.6, therefore α = 31.4° - 58°. The H/W also previously mentioned in the region scale study impacts the control of the mean radiant temperature.

Building coverage ratio (BCR) was previously found in the region scale study to be the most significant urban form to reduce mean radiant temperature. In the building groups scale, it was able to control the humidity in the value to a maximum of 0.3. Also, the floor area ratio (FAR) based on this assessment was able to control humidity in the value by as much as 1.1.

This assessment found that the most significant aspect of urban form parameters to control air temperature is the provision an adequate the vegetation/green coverage ratio (GCR). In this building group case study, the maximum air temperature (Ta) reached was 30°C. Therefore, the recommendation can only be to increase the GCR to as much as 17%. However, the more GCR is provided, the more Ta can be reduced.

In the hot and humid climate region where the wind speed is important to increase the comfort level in the outdoor area, the availability of wind speed is this region is still difficult to increase. Yet, the passive design to provide surface area in the range of 0.12 to 0.15 creates the possibility to induce wind speed by as much as 3.4 m/s.

**Bibliography**

Alhaddad, M. a. Z. J., 2013. A comparative study of the thermal comfort of different building materials in sana`a. Am. J. Eng.Applied Sci, 6 (DOI: 10.3844/ajeassp.2013.20.24 ), p. 20- 23.

Bannov, K., 2013. LSS chronolux.Trimble Navigation Limited.

E. L. Krüger, F. A. M., 2013. Comparison of different methods of estimating the mean radiant temperature in outdoor thermal comfort studies. International Journal of Biometeorology.

Emmanuel, R. and E. Johansson, 2006. Influence of urban morphology and sea breeze on hot humid microclimate: : The case of colombo, Sri Lanka.. Climate Res, 30 (DOI: 10.3354/cr030189 ), p. 189-200.

Fredrik Lindberg, B.H., Sofia Thorsson, SOLWEIG, 2008. Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. International Journal of Biometeorology, Volume 52(7).

G. Jendritzky, H. K. B. ,. A. G. G. L., 1999. The Perceived Temperature: The Method of the Deutscher Wetterdienst for the Assessment of Cold Stress and Heat Load for the Human Body.

Gál, T, 2009. Computing continuous sky view factors using 3D urban raster and vector databases: Comparison and application to urban climate. Int. J. Climatol, 95 (DOI: 10.1007/s00704-007-0362-9), p. 111-123.

Goh, K.C. and C.H. Chang, 1999. The relationship between height to width ratios and the heat island intensity at 22:00 h for Singapore. Int. J. Climatol, 19 (DOI: 10.1002/(SICI)1097- 0088(199907)19:9<1011::AID-JOC411>3.0.CO;2-U), p. 1011-1023.

Hämmerle, M., T, 2011. Comparison of models calculating the sky view factor used for urban climate investigations. Theor Applied Climatol, 105 (DOI: 10.1007/s00704-011-0402-3 ), pp. 521-527.

Howard, L., 1833. The Climate of London: Deduced from Meteorological Observations Made in the Metropolis and at Various Places Around it. 1st Edn :Harvey and Darton.

Jusuf, S., 2007. The influence of land use on the urban heat island in singapore. Habitat Int, 31 (DOI: 10.1016/j.habitatint.2007.02.006), p. 232-242.

Kakon, A., 2010. Assessment of thermal comfort in respect to building height in a high-density city in the tropics. Am. J. Eng. Applied Sci., 3 (DOI: 10.3844/ajeassp.2010.545.551), p. 545-551.

Ketterer, C. and A. Matzarakis, 2014. Human-biometeorological assessment of the urban heat island in a city with complex topography-the case of Stuttgart, Germany. Urban Climate, Issue DOI: 10.1016/j.uclim.2014.01.003 .

Lauscher, F., 1934. Warmeausstrahlung und horizonteinengung (zur kenntnis der ausstrahlung von mulden, talern und gassen). Sber. Akad.Wiss. Wein, Volume 143, p. 503-519.

Matzarakis, M., 2011. Comparison of models calculating the sky view factor used for urban climate investigations. Theor Appl Climatol, Volume 105(3-4), p. 6 pages.

Oke, T., 1988. Street Design and Urban Canopy Layer Climate. Volume 11, p. 103-113

Paramita, B., H.F., 2013. Building Groups Design Strategies in Hot-humid Climate: A Dense Residential Planning in Bandung, Indonesia. In: Munich, Germany: PLEA.

Paramita, M.D.K.a.B., 2013. Solar Envelope Assessment in Tropical Region Building Case Study: Vertical Settlement in Bandung, Indonesia. Procedia Environmental Sciences, 2013, Volume 17, p. 757-766.

Paramita, B., 2011. SGRA-Young Researcher, in Sekiguchi Global Research Asosiasion 2011. Sekiguchi Global Researcher Asosiasion Tokyo, p. 11.

Parry, M.J. and D.G. Walker, 1966. Purification and properties of adenosine 5´-triphosphate-D-glucose 6-phosphotransferase from rat liver. Biochem. J, Volume 99, p. 266-274.

Sofia Thorsson, F.L., 2007. Ingegard Eliasson and Bjorn Holmer, Different methods for estimating the mean radiant temperature in an outdoor urban setting. INTERNATIONAL JOURNAL OF CLIMATOLOGY, Volume 27(14).

Tan, C., 2013. Outdoor mean radiant temperature estimation in the tropical urban environment. Build. Environ, 64(DOI: 10.1016/j.buildenv.2013.03.012), p. 118-129..

Tursilowati, 2005. Pulau Panas Perkotaan Akibat Perubahan Tata Guna dan Penutup Lahan di Bandung dan Bogor. Jurnal Sains Dirgantara, p. 3.

Kemenpera. 2013. Program dan Kegiatan Deputi Bidang Perumahan Formal. Jakarta.

Bappeda, 2010. Profil Rusunawa Bandung, Bandung

# 6. Urban Microclimate Prognostic Model

## 6.1. The Urgency of Microclimate Model

The previous chapters have described the microclimate from the level of city, region and building block. The complexity of urban microclimates, their alteration with temperature, wind speed and humidity within urban structures have driven researchers to make various investigations and measurements in the urban environment. However, there are limitations to what an architect and urban planner can understand with respect to urban climate. The fields of meteorology, geography, and mechanics then become important to the area of urban physics. As an analogy of building physics, which has wide applications in urban areas, 'urban physics is a well-established discipline, incorporating relevant branches of physics, environmental chemistry, aerodynamics, meteorology and statistics.' (Peter Moonen, T.D., Viktor Dorer, Bert Blocken, Jan Carmeliet, 2012)
Thus, the knowledge of urban physics is important as a contribution to existing urban problems and challenges.

The rapid development of Geographical Information Systems (GIS) as a basic spatial application, and sophisticated applications like fluid and thermodynamics enables architects and urban planners to make comprehensive plans and designs. The trend of microclimate modelling is also increasing, through the simplification of the mathematics used to calculate the possibility of microclimate alteration. There is software used worldwide for microclimate modelling such as: ENVI-met (Bruse, 2007)[1], Townscope II (Azar, 2001) RayMan (Mayer, et al., 2007)[2], and SOLWEIG (Fredrik Lindberg Sofia Thorsson, 2008) [3]. The most recent software is OTC Model (2013)[4], combining urban microclimate simulation and human perception of their living area, this tool looks promising as it uses urban form input to find the

[1] http://www.envi-met.com/

[2] http://www.mif.uni-freiburg.de/rayman/intro.htm

[3] http://www.gvc.gu.se/english/research/climate/urban-climate/software/solweig/

[4] http://otcmodel.com/

energy consumption, shadow range, sunlight hours, wind comfort and thermal comfort. Even so, this thesis has just used ENVI-met abd RayMan for software validation and comparative measurement in the field. The use of each tool describes two ranges of boundaries, which are regions (area) and building groups (blocks).

## 6.2. ENVI-met as a Microclimate Model

ENVI-met is a three-dimensional microclimate model designed to analyze the small scale interaction between urban design and the microclimate. The model combines the calculation of fluid dynamic parameters such as wind flow or turbulence, with the thermodynamic processes taking place on the ground surface, at walls and rooves or at the plants. With a typical resolution between 0.5m and 10m, the model is able to simulate even complicated geometric forms such as terraces, balconies or complex quarters. The model includes the simulation of:

1. Flow, around and between buildings
2. Exchange processes of heat and vapour at the ground surface, and at walls
3. Turbulence
4. Exchange at vegetation and vegetation parameters
5. Bioclimatology
6. Pollutant dispersion [5]

This simulation will help architects and planners to predict the quality of urban areas with respect to the complexity of urban microclimate, to understand the living area better, or give the optimum decision before construction starts. A meteorological variable such as air temperature (Ta), Humidity (RH), radiant temperature (Tmrt) and wind speed influence the outdoor thermal comfort, beside other human factors such as clothing (clo) and human body surface ($m^2$). Thus, a number of simulations are using ENVI-met BETA4, it's been revealed to be a good tool for the prediction of the urban microclimate changes within urban areas, and also in the assessment of outdoor comfort through a satisfactory estimation of the mean radiant temperature

[5] In this research, pollutan dispersion is not in the topic discussion

(Toudert, 2005).

## 6.3. Solar Insolation Prediction in Specific Area in Bandung

Mean radiant temperature (Tmrt) , influenced by the surface temperature of an open area which directly gets solar insolation, is the most significant aspect of human perception of outdoor thermal comfort. As a tropical city which lies near the equator, it means Bandung is receiving the solar insolation for six months on the north side and six months on the south. Besides the material which determine its albedo to absorb or reflect the solar insolation, the building coverage ratio plays an important role to control availability of open space to provide urban ventilation. Both incoming and reflected solar insolation and wind speed significantly affect the microclimate. Thus, the more buildings the more heat trapped, and less open space will reduce urban ventilation, and raise the mean radiant temperature within the urban space.

The solar insolation prediction is made easier through prognosis modelling, especially due to rapid measurements where the aim of a study is to find the optimum building form and configuration within an urban context. The ENVI-met, then, is a useful tool to ascertain the microclimate through flow around and between buildings, exchange processes of heat and vapor at the ground surface and walls, turbulence, and exchange and vegetation parameters.

### 6.3.1. ENVI-met in a High-dense Settlement Modelling

The total area study is 37 ha, the characteristics of urban form in Tamansari is: low FAR (floor area ratio), high DU (dwelling unit) and high POP (population), which describes a crowded neighborhood. Here, open space consists of only walkways and the river, there is no urban open space let alone a green area. The prognosis model of ENVI-met is taken from google map Fig. 6.1 (a) then, the configuration of an input of the model which is going to determine the output is shown at Fig. 6.1 (b) contain some meteorological data and urban surface conditions. Also, to find the human perception in their area, the human parameter of heat balance is included. The model area, as seen in Fig 6.1 (c), gives the specific physical aspect of urban form. The height, space between buildings, land coverage such as: vegetation, pavement and water are able to be used as a surface input in this model.


***Fig. 6.1*** *(a) Tamansari in satellite image; (b) configuration input; (c) ENVI-met model; (d) Tmrt visualization of ENVI-met at the hottest time*

The given picture of ENVI-met at **Fig 6.1** (d) is at 2pm when the highest insolation occurs and causes the hottest mean radiant temperature. The simulation itself was running from 06.00am to 06.00am the next day (24hours). **Table 6.1** presents the comparison between Tmrt observed and the model, meanwhile **fig. 6.2** shows a graphic chart of **Table 6.1**. The validation value between spot measurement and prognostic model was done from 06:00am – 19:00pm which is shown at **fig. 6.3** and **fig. 6.4**. Among six spot measurements, spots 2 and 6 looked less valid, since the $R^2$ is less than 0.8, meanwhile spots 1, 3, 4 and 5 have significant determination value. The value of coefficient of determination ($R^2$) for both measurement and model are: Spot 1 with $R^2$= 0.88; Spot 2 with $R^2$ = 0.70; Spot 3 with $R^2$ = 0.92; Spot 4 with $R^2$ = 0.82; Spot 5 with $R^2$ = 0.95 and Spot 6 with $R^2$ = 0.62. The highest similarity value of measurement and prognostic model are shown during the raising of insolation within the area, which starts from 7:00 am up to 17:00 pm. The highest difference between measurement and model is 28.5°C, which is at spot 6 , 16.00pm, meanwhile the lowest difference is 0.13°C, spot 5, 12.00pm.

***Table 6.1*** *Presents the comparison of the Tmrt value from measurement and prognostic model.*

| | **Mean Radian temperature (Tmrt) in Sunny day per hour** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **6:00** | **7:00** | **8:00** | **9:00** | **10:00** | **11:00** | **12:00** | **13:00** | **14:00** | **15:00** | **16:00** | **17:00** | **18:00** | **19:00** |
| Observed 1 | 23.41 | 24.14 | 27.71 | 44.05 | 51.23 | 47.06 | 46.46 | 51.55 | 49.23 | 43.75 | 36.02 | 31.37 | 24.89 | 22.39 |
| Model 1 | 15.05 | 20.04 | 22.25 | 43.20 | 51.58 | 46.26 | 51.49 | 55.93 | 53.67 | 26.73 | 26.04 | 20.62 | 16.31 | 15.81 |
| Observed 2 | 22.52 | 26.56 | 39.05 | 45.77 | 47.81 | 37.93 | 55.13 | 53.24 | 40.40 | 35.05 | 33.76 | 31.71 | 27.10 | 22.72 |
| Model 2 | 15.04 | 23.34 | 39.82 | 55.09 | 52.06 | 48.76 | 51.33 | 54.97 | 53.83 | 25.67 | 54.94 | 31.91 | 18.96 | 18.44 |
| Observed 3 | 21.76 | 27.02 | 44.18 | 52.09 | 51.40 | 55.77 | 56.47 | 54.16 | 50.59 | 32.19 | 31.04 | 29.37 | 27.91 | 21.66 |
| Model 3 | 15.04 | 27.21 | 50.70 | 60.34 | 58.26 | 54.78 | 52.48 | 55.8 | 48.82 | 30.24 | 23.78 | 31.30 | 17.28 | 16.43 |
| Observed 4 | 21.94 | 28.02 | 43.15 | 37.72 | 44.78 | 41.63 | 51.61 | 54.83 | 46.09 | 30.82 | 30.22 | 29.80 | 23.81 | 21.55 |
| Model 4 | 15.06 | 35.37 | 50.68 | 53.06 | 58.49 | 54.45 | 52.06 | 55.69 | 59.30 | 25.67 | 23.78 | 34.30 | 17.49 | 16.30 |
| Observed 5 | 22.76 | 23.87 | 27.31 | 28.36 | 37.45 | 37.24 | 51.37 | 53.52 | 51.83 | 29.62 | 28.82 | 28.64 | 23.31 | 22.38 |
| Model 5 | 15.05 | 20.04 | 24.38 | 26.04 | 37.74 | 38.18 | 51.50 | 55.12 | 59.80 | 25.67 | 23.78 | 33.99 | 20.24 | 17.43 |
| Observed 6 | 24.05 | 38.73 | 35.20 | 43.36 | 47.28 | 46.88 | 48.24 | 51.38 | 35.15 | 30.91 | 27.64 | 26.80 | 24.87 | 22.22 |
| Model 6 | 15.04 | 38.20 | 37.05 | 59.62 | 57.75 | 53.39 | 50.86 | 54.51 | 26.61 | 25.67 | 56.23 | 33.61 | 18.82 | 17.60 |

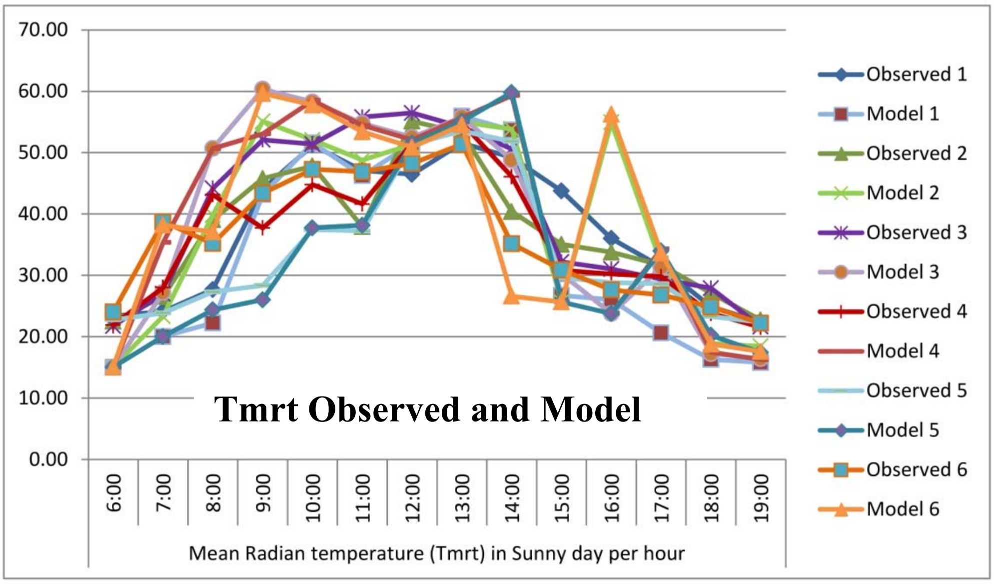



***Fig. 6.2*** *Graphic Chart of Tmrt between Measurement and Model*

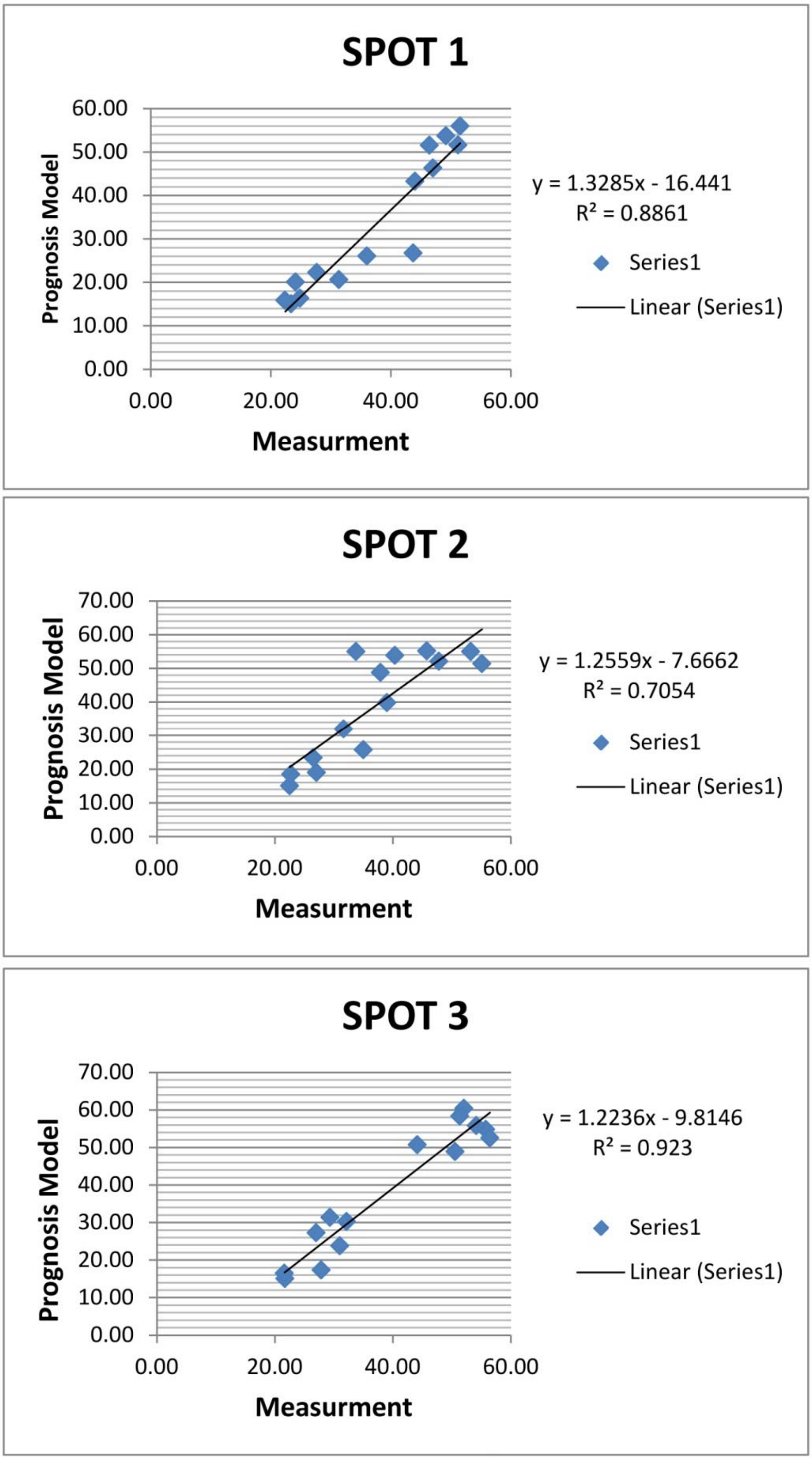



***Fig. 6.3*** *Regression between measurement and prognostic model at Spot 1 -3*

***Source :*** *Author*

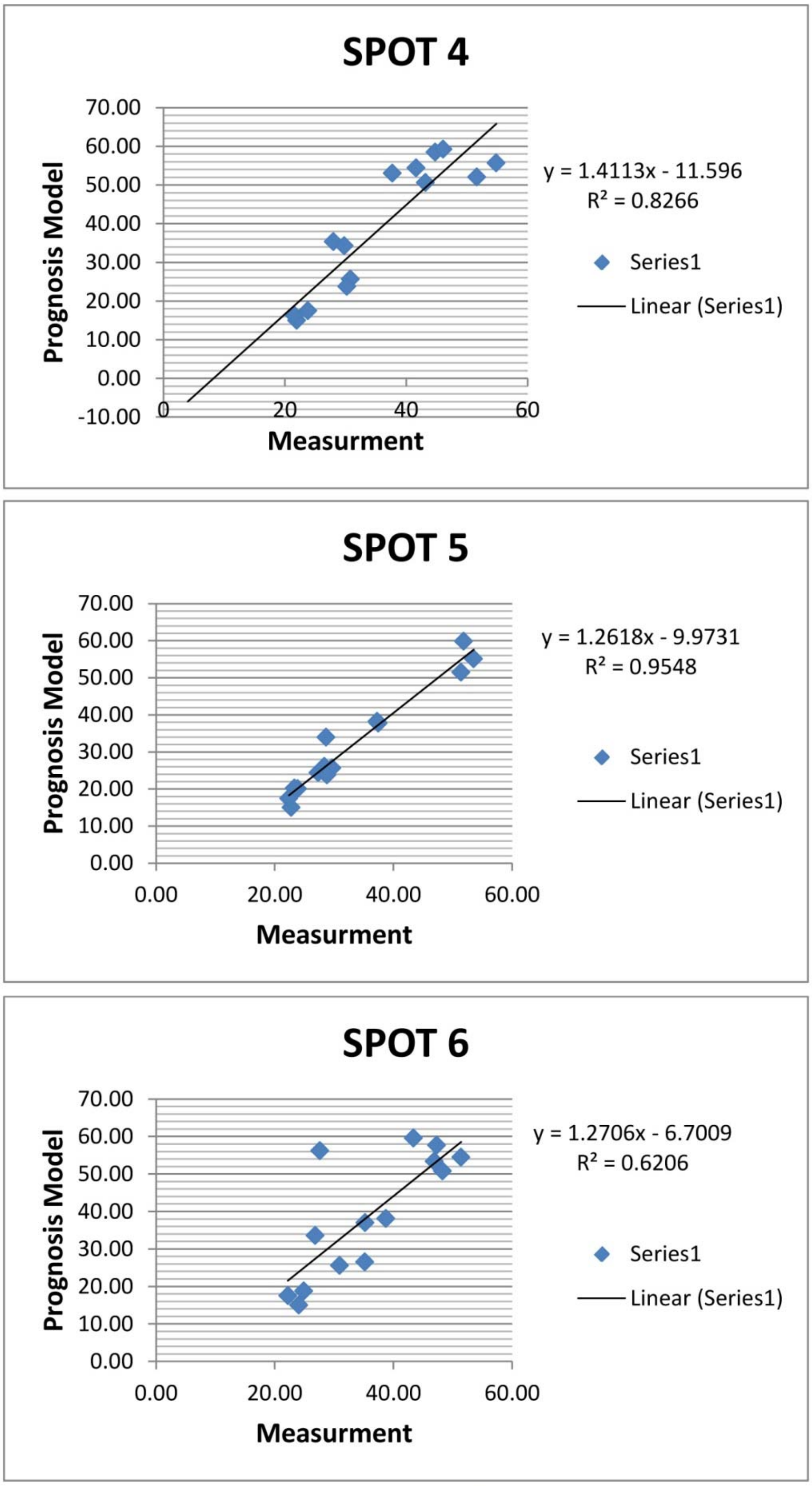



***Fig. 6.4*** *Regression between measurement and prognostic model at Spot 4 -6*
***Source :*** *Author*

### 6.3.2. ENVI-met for building groups

In the previous chapter, it was discussed that building form and configuration are significantly influencing the microclimate, this is especially shown at the five samples of *Rusun* in Bandung, Indonesia. The measurement was done through the climate record and field measurements. In this chapter ENVI-met is used to give a better understanding of building groups, in the term of physical dimensions and microclimate.

A. Rusun UPI

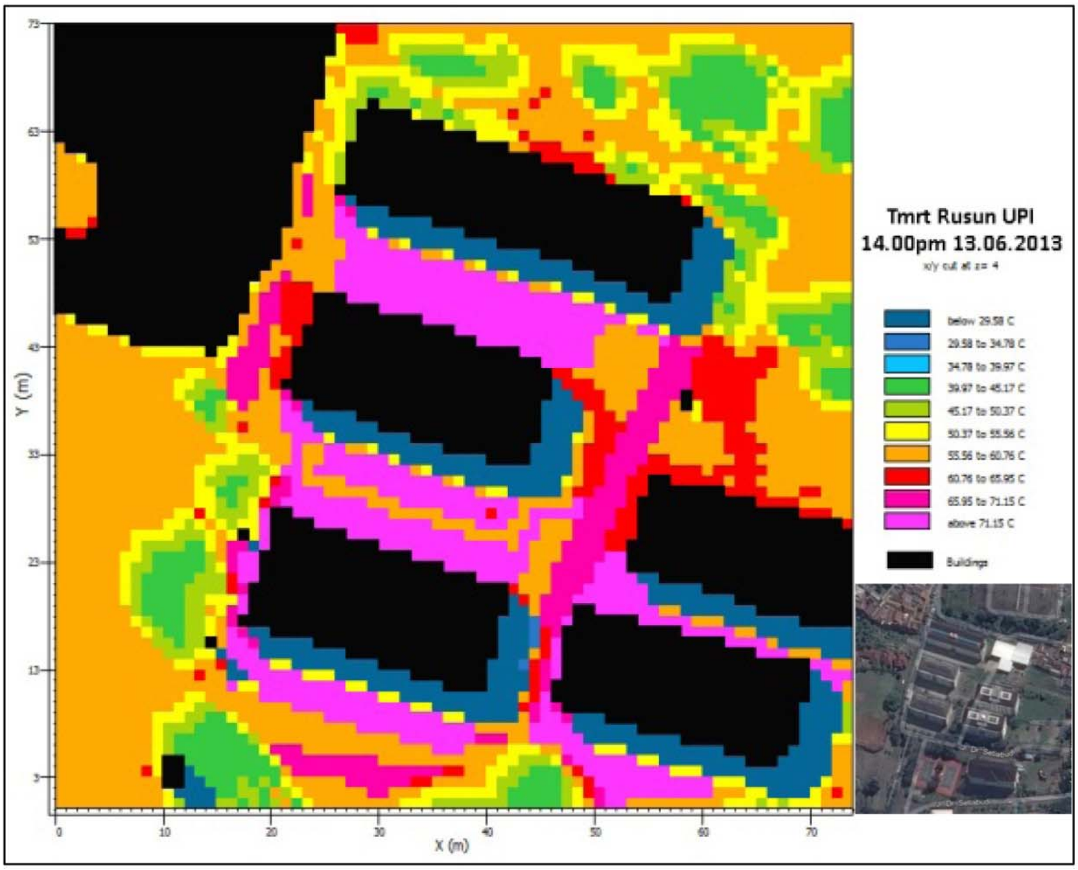



***Fig. 6.5*** *ENVI-met for Rusun UPI*
***Resource****: Author*

B. Rusun PTDI

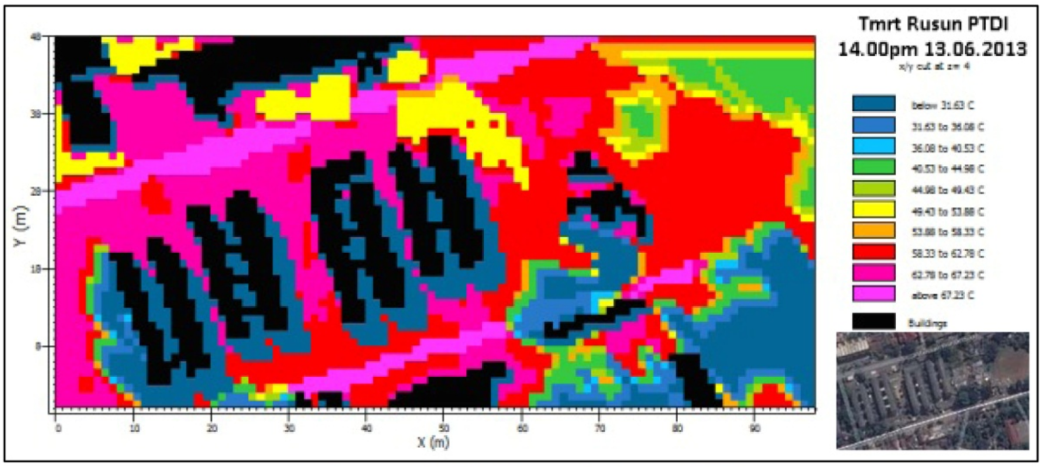



***Fig. 6.6*** *ENVI-met for Rusun PTDI*
***Resource****: Author*

C. Rusun Cigugur

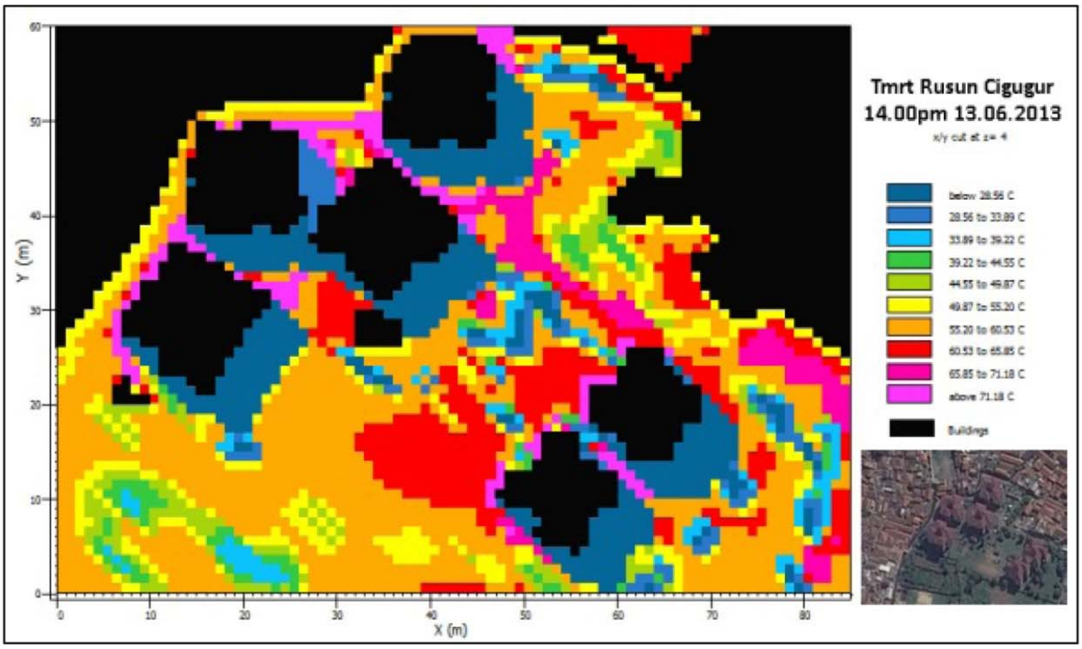



***Fig. 6.7*** *ENVI-met for Rusun Cigugur*
***Resource****: Author*

D. Rusun Cingised

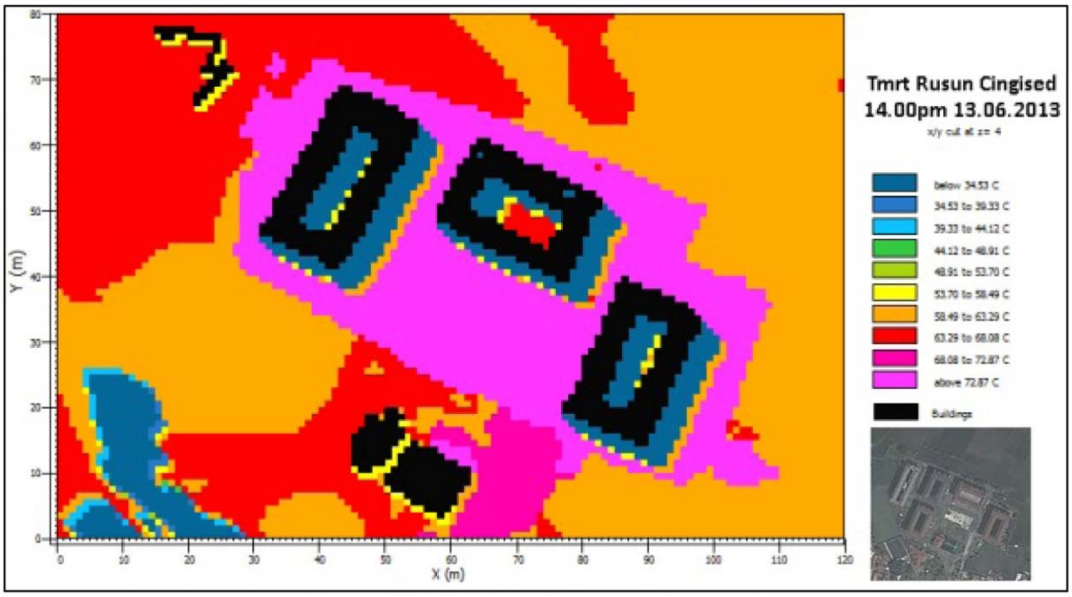



***Figure 6.8*** *ENVI-met for Rusun Cingised*
***Resource**: Author*

E. Rusun Pharmindo

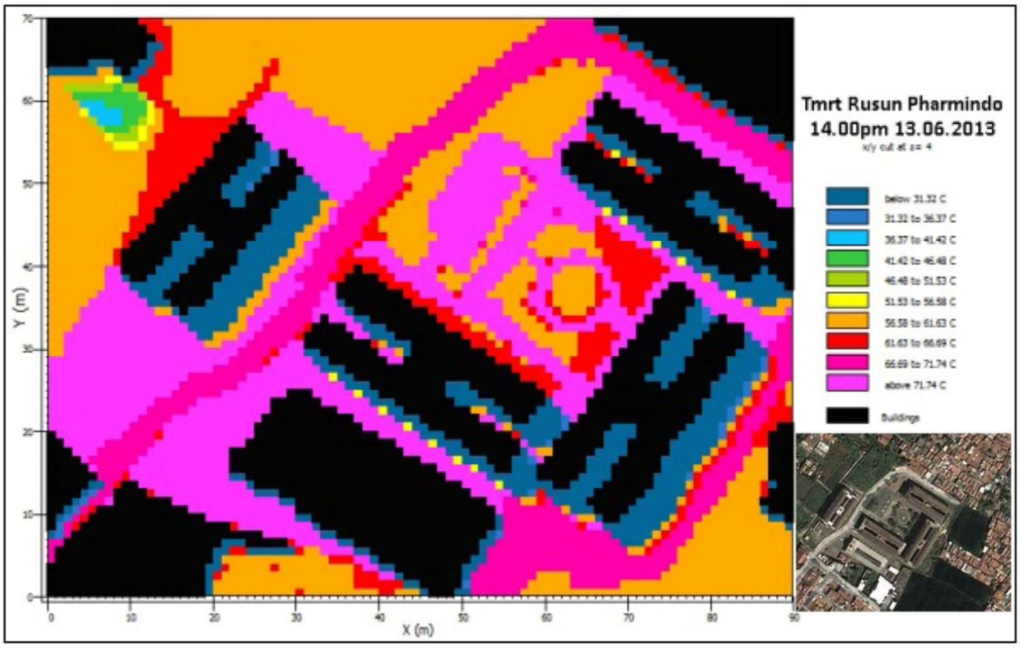



***Fig. 6.9*** *ENVI-met for Rusun Pharmindo*
***Resource**: Author*

**Fig 6.5** until **Fig 6.9** shows that open spaces receive the highest insolation. Without proper absorption of material, this insolation will reflect and release which then becomes the heat intensity within the building groups. As discussed in the previous chapter, the building form and configuration have significant impact on microclimate. These five figures also show the disperse building layout like *Rusun* Cigugur **(fig. 6.6)** gives the possibility of spreading insolation and reaching the lowest Tmrt value, even at the hottest time of 14.00 pm. The parallel building plot like *Rusun* UPI also gives a chance for the spread of insolation, but it has to be remembered that insolation occurs between the buildings' distance, and also along its length. The square plot, like *Rusun* Cingised and Pharmindo, give the possibility of concentration of insolation in the open space, which induces higher heat Compounded by their material, both of these *rusun* present higher Tmrt's.

*Rusun* PTDI, with parallel building plots and the main building facing east-west, shows the spread of insolation evenly in the high Tmrt value, however the highest of Tmrt within the building groups itself is lower, compared with other *rusun*. Because the main orientation is east-west, it provides more shading between the buildings, which keeps the Tmrt lower.

**Table 6.2** shows the Tmrt values from 06.00am until 19.00pm. The following is the Tmrt value of each *rusun*, which are all at 14.00pm, starting from the highest value: (1) *Rusun* Cingised has reached the highest Tmrt value at 53 $^{o}$C; (2) *Rusun* Pharmindo 51.5 $^{o}$C; (3) *Rusun* UPI 50.4 $^{o}$C; (4) *Rusun* Cigugur 49.9 $^{o}$C; (5) and finally *Rusun* PTDI at 49.4 $^{o}$C. From this table it is seen that the initial temperature of each flat will influence the max value, such as in Rusun Cingised, which has the highest initial Tmrt, 19.21$^{o}$C at 0.600 am, as well as the highest Tmrt at 14.00 pm, 53.70$^{o}$C. Rusun Cigugur has the lowest initial Tmrt, but the lowest Tmrt for the hottest hours was reached by Rusun PTDI, 49.45$^{o}$C at 14.00pm.

***Table 6.2*** *Mean Radiant Temperature of five samples Rusun*

| Flat | Diurnal of Tmrt at 13.06.2013 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **06.00** | **07.00** | **08.00** | **09.00** | **10.00** | **11.00** | **12.00** | **13.00** | **14.00** | **15.00** | **16.00** | **17.00** | **18.00** | **19.00** |
| Rusun UPI | 15.48 | 26.81 | 41.92 | 46.77 | 48.48 | 48.88 | 49.21 | 49.97 | 50.37 | 48.74 | 43.55 | 23.96 | 16.76 | 15.99 |
| Rusun PTDI | 15.15 | 24.73 | 40.16 | 45.37 | 47.22 | 47.22 | 48.16 | 48.57 | 49.45 | 48.01 | 42.95 | 25.99 | 19.45 | 18.62 |
| Rusun Cigugur | 13.67 | 26.61 | 41.48 | 46.16 | 48.23 | 48.54 | 48.73 | 49.48 | 49.87 | 48.56 | 43.61 | 27.04 | 15.71 | 15.05 |
| Rusun Cingised | 19.21 | 28.47 | 44.69 | 49.76 | 51.81 | 52.28 | 52.65 | 53.00 | 53.70 | 52.15 | 46.43 | 28.27 | 20.47 | 19.88 |
| Rusun Pharmindo | 14.88 | 26.54 | 42.69 | 47.80 | 49.64 | 50.11 | 50.32 | 51.18 | 51.53 | 50.19 | 44.79 | 26.45 | 18.46 | 17.57 |

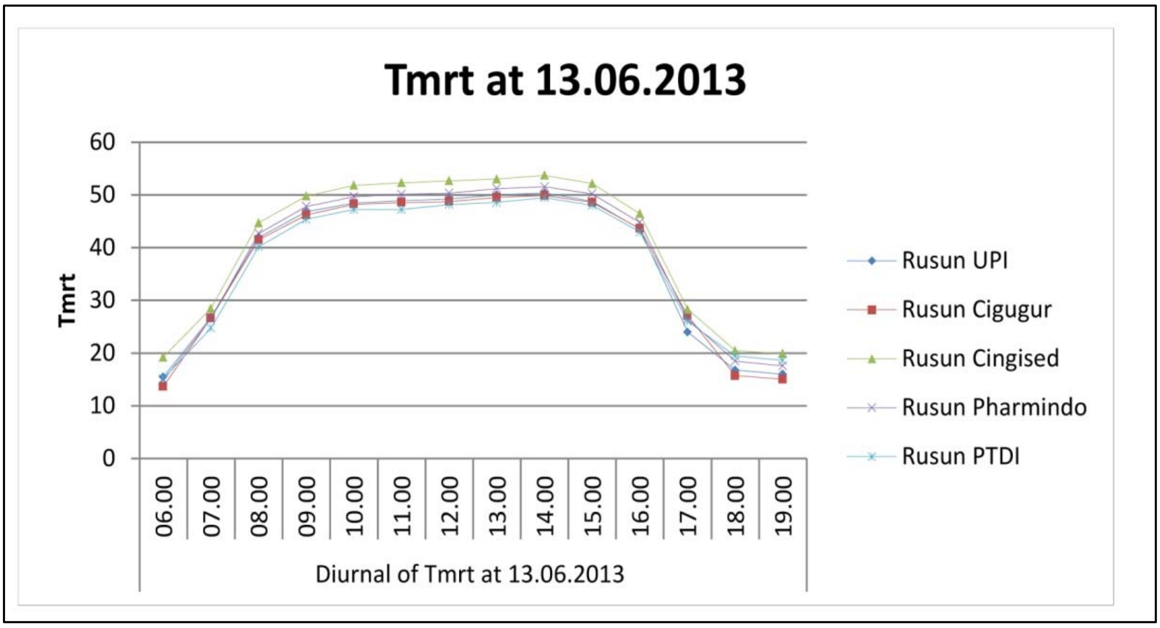



***Fig. 6.10*** *Tmrt Chart for five sample of Rusun in Bandung*
***Source:*** *Author*

# 6.4. Living Quality Assessment

The living quality is determined by many aspects, but it can't be denied that meteorology and atmospheric conditions have significant impact on the quality of urban environments which depend on their physical aspect. Thus it is a logical correlation that air temperature, humidity, wind speed and insolation within the urban space strongly impact on human health. As previously described, with respect tothe idea of microclimate improvement in the frame of building groups, passive design gives better outdoor thermal comfort. In this research, the assessment focuses on the human perception of outdoors, which in this step is merely based on measurement and simulation, not through interview or personal contact. Thus, this discussion on human perception is divided into three parts. These are: (1) prognostic model based on fluid and thermodynamics using ENVI-met, (2) based on the energy balance of the human body and (3) thermal sensation in terms of several climatic parameters. These three indices of thermal perception will put in the same table to make the comparison between them easier to understand.

### 6.4.1. ENVI-met for Human Perception on Outdoor Conditions

The PMV (Predicted Mean Vote) was defined by (PO. Fanger, 1970). It relates the (simple) energy balance of the human body to the thermal comfort of the person. Normally the PMV value used is between -4 (very cold) and +4 (very hot), but as it is related to the energy balance it can also reach higher or lower values. The PMV Model used in ENVI-met is a special adaptation to outdoor conditions made by (Jendritzky, 2009). Jendritzky has explained that the heat exchange between the human body and the thermal environment can be described in the form of the energy balance equation. Among the advanced heat budget models, (PO. Fanger, 1970) PMV- equation can be considered as appropriate if (Gagge AP, F.A., Berglund PE, 1986) improvements in the description of latent heat fluxes by the introduction of PMV* is applied. The meteorological input variables include air temperature (Ta), water vapour pressure (e), wind velocity (v) and mean radiant temperature (Tmrt) including short and long-wave radiation fluxes, in addition to metabolic rate and clothing insulation.

### 6.4.2. PET of Rayman

PET (Physiological Equivalent Temperature) was first developed based on MEMI by Höppe, P, Mayer, H. (1987) which was later acknowledged in VDI-3787 ((VDI), 1998) Here, PET has estimated using free a software package called RayMan. The RayMan model is Windows-based software with code written in Delphi. The model offers several estimation and input possibilities (M. Hämmerle, 2011) The RayMan model, developed for the calculation of the mean radiation temperature and thermal indices in simple and complex environments, is based only on data of air temperature, air humidity and wind speed. The relevant radiation fluxes (short and long wave) are calculated by using existing or non global radiation in different ways, and the modification of them by obstacles (natural or artificial).

### 6.4.3. Thermal sensation of $Y_{JS}$

$Y_{JS}$ is a method describing outdoor thermal sensation in terms of several climatic parameters, such as: air temperature, humidity, wind speed, global solar radiation, globe temperature, and surface temperature, etc. with a regression model. Somehow, this model is limited in the specific region where the data are obtained. YJS (comfort level for normal walking) based on (Sangkertadi, 2012) who conducted an experiment in Manado, Indonesia. With the equation as follows:

$$Y_{JS} = -3.4 - 0.36v + 0.04Ta + 0.08Tg - 0.01RH + 0.96Adu \qquad (R^2=0.7) \qquad (11)$$

Where:

YJS : Comfort Level (normal walking)

v : wind speed (m/s)

Ta : air temperature (°C)

Tg : globe temperature (°C)

RH : Relative Humidity (%)

Adu : Human surface body (m2)

Average Adu for Indonesian people is 1.7m2

### 6.4.4. Indices of Outdoor Thermal Perception

As mentioned above, the four indices of outdoor thermal perception will be placed in the same table, as shown at **Table 6.3**. The first Outdoor thermal index is PMV, which is generated from ENVI-met, second and third are PET and PMV-r which are generated from Rayman, and the last is $Y_{JS}$ which is calculated from meteorological and human aspects.

***Table 6.3*** *Meteorological Parameters and Outdoor Thermal Indices*

| | Meteorological Parameters | | | | | Outdoor Thermal Indices | | | |
|---|---|---|---|---|---|---|---|---|---|
| Flats | max Tmrt | Ta | RH | v | Tg | PMV | PET | PMV-r | YJS |
| Rusun UPI | 50.37 | 25.74 | 87.80 | 1.18 | 45.32 | 2.60 | 34.30 | 2.30 | 2.17 |
| Rusun PTDI | 49.45 | 30.20 | 87.34 | 0.92 | 45.88 | 3.58 | 38.40 | 3.30 | 2.55 |
| Rusun Cigugur | 49.87 | 24.38 | 73.10 | 0.75 | 45.53 | 2.22 | 34.20 | 2.20 | 2.39 |
| Rusun Cingised | 53.70 | 31.81 | 75.75 | 1.30 | 49.05 | 4.20 | 40.70 | 3.70 | 2.64 |
| Rusun Pharmindo | 51.53 | 27.03 | 75.48 | 0.90 | 47.04 | 3.08 | 36.70 | 2.80 | 2.53 |

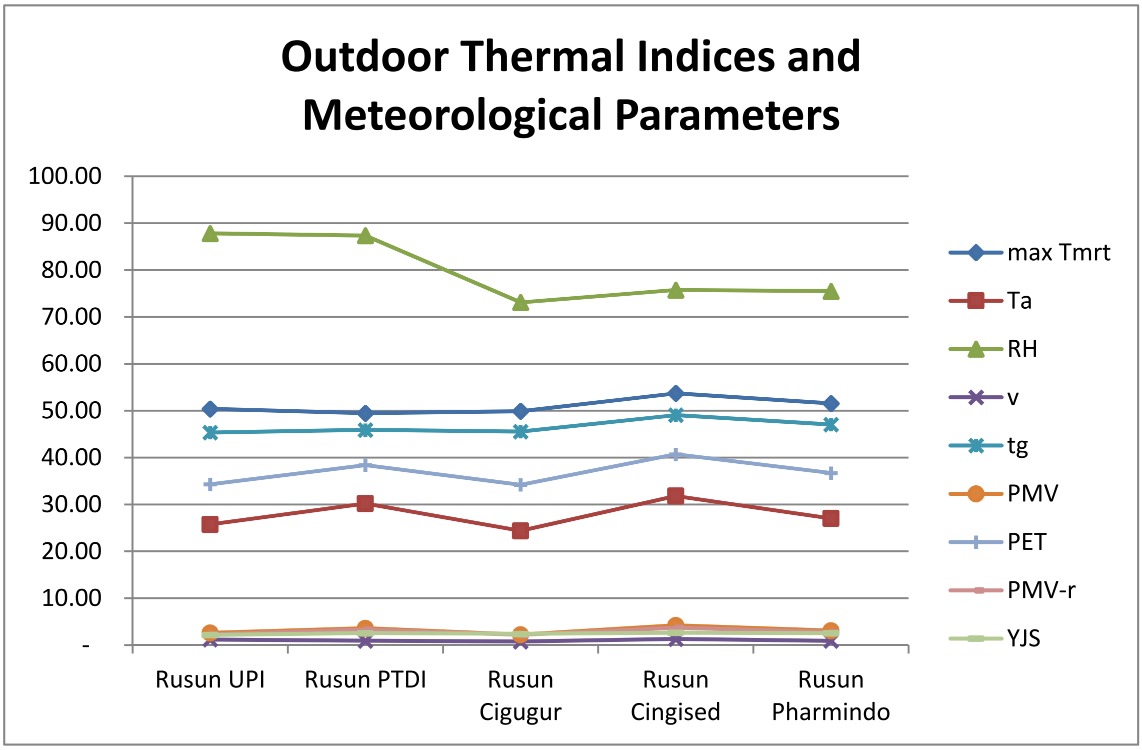



***Fig. 6.11*** *Tmrt Chart for five samples of Rusun in Bandung*
***Source:*** *Author*

**Fig 6.11** shows the condition of four outdoor thermal indices based on the meteorological parameters of five sample building groups. From this figure, it may be seen that parallel plots, which are represented in Rusun UPI and Rusun PTDI, have reached the lowest Tmrt and Tg, which also contributes to the value of outdoor thermal perception. The coefficient of determination of four outdoor thermal indices are shown at **fig. 6.12.** It gives the value of PET and PMV (ENVI-met) with $R^2 = 0.99$, PET and PMV-r (RayMan) with $R^2=0.97$ and PET and $Y_{JS}$ with $R^2 = 0.74$. These values of $R^2$ are such that four of them are interchangeable, since the coefficient of determination between PET (which based on human energy balance) with PMV (based on prognostic model) and also $Y_{JS}$ (based on thermal sensation) have the significant value: $R^2 \geq 0.6$. This statement also means that four of these outdoor thermal indices are valid to use in the hot-humid climate region.

To find the contribution of each meteorological parameter to outdoor thermal perception, a regression of them has been done such as shown at **fig. 6.12** until **fig. 6.14.**

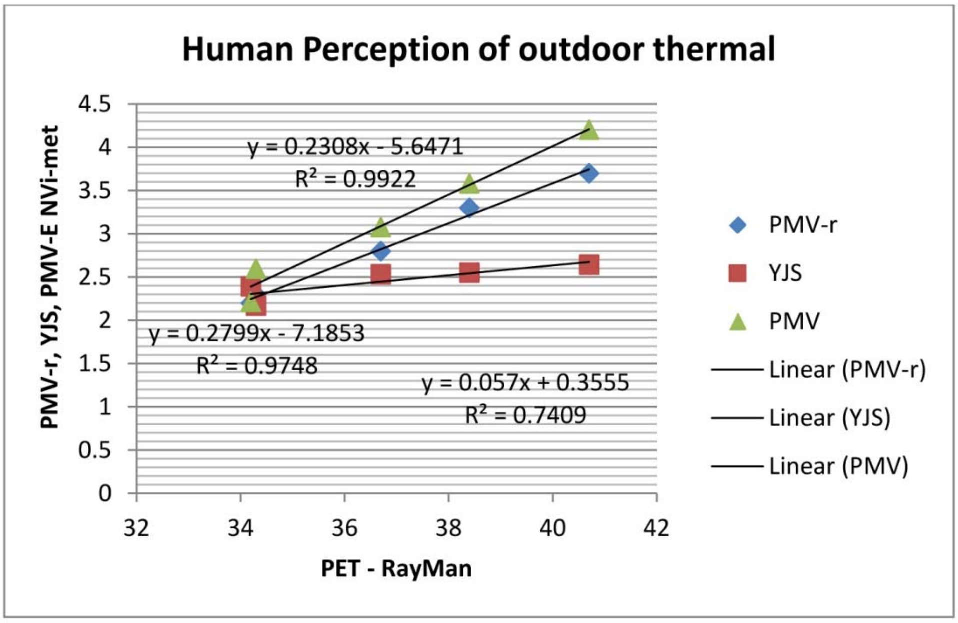



***Fig. 6.12** Human Perception of Outdoor Thermal between PMV, PET, PMV-r and YJS*
***Source:** Author*

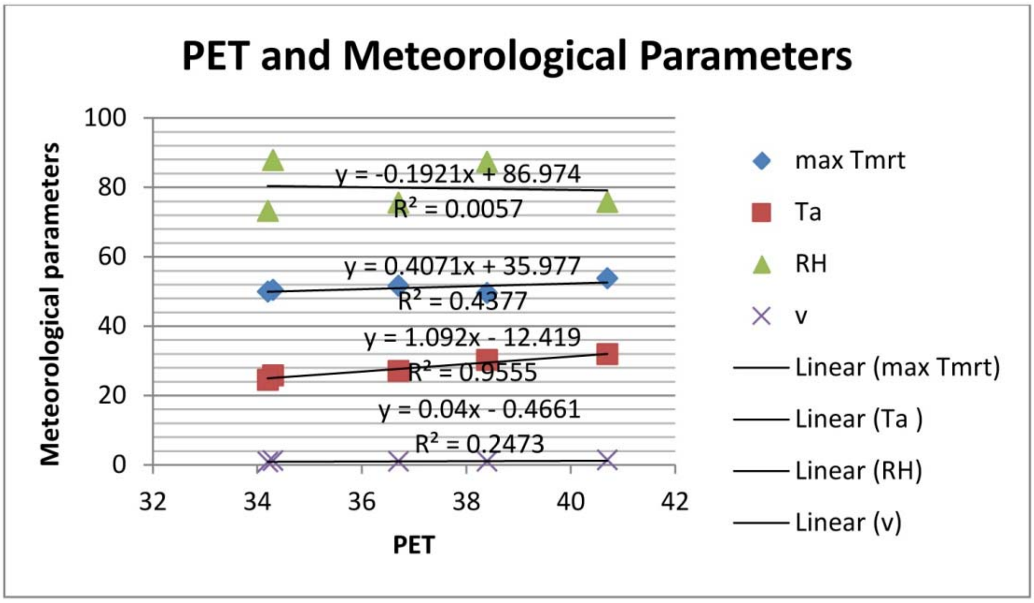



***Fig. 6.13** PET and Meteorological Parameters*
***Source:** Author*

**Figure 6.13** shows that air temperature is the most significant meteorological parameters which influence the value of PET ($R^2$ = 0.95). Tmrt of surround environment, giving the $R^2$ = 0.44, which is not really significant but as an important item to consider.

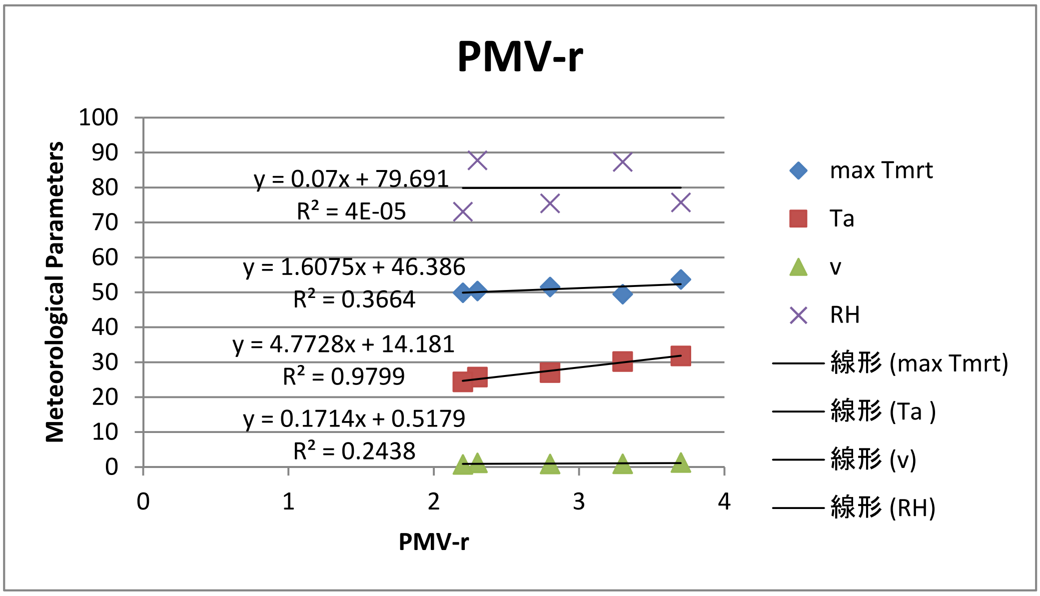



***Fig. 6.14** PMV-r and Meteorological Parameters*
***Source:** Author*

**Fig. 6.14** shows the coefficient determination of PMV-r and meteorological parameters, the most significant being air temperature (Ta) with $R^2$=0.98, other two parameters Tmrt and v show positive values, but insignificant correlation.

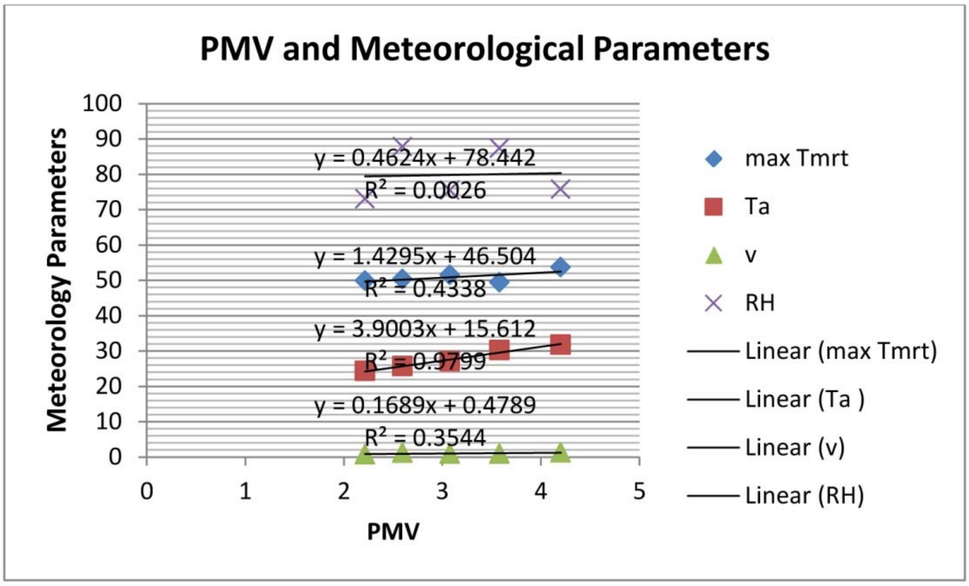



***Fig. 6.15** PMV with Meteorological Parameters*
***Source:** Author*

**Fig. 6.15** presents similar values with figure 6.12 and 6.13, where the air temperature (Ta) is the most significant item compounding the PMV value ($R^2$ = 0.98). Mean radiant temperature (Tmrt) also shows a positive factor, though not in the significant range ($R^2$=0.43)

**Fig. 6.16** presents the coefficient of determination between $Y_{JS}$ and meteorological parameters. Unlike other outdoor thermal indices, thermal sensation based on $Y_{JS}$ is determined by Ta, Tg and v, and from the figure mentioned before, it is seen that both Ta and Tg have equal value up to $R^2$=0.58.

**Table 6.4** Shows the indices of outdoor thermal comfort for Rusun in Bandung, and also that even though Rusun PTDI has reached the lowest mean radiant temperature value the comfort level perception of this living area is hot. An opposite condition exists for Rusun Pharmindo, which has reached a high mean radian temperature value (second highest Tmrt value), however the comfort level perception is warm.

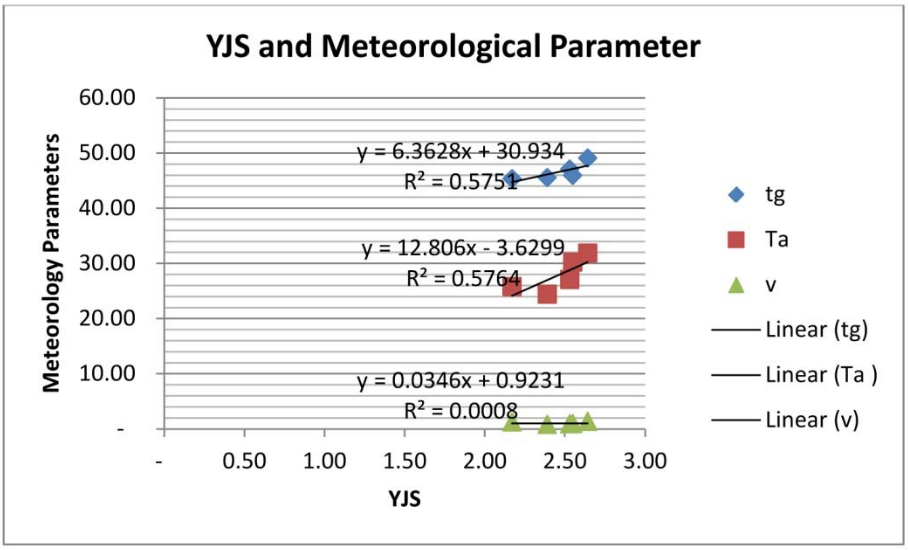



***Figure 6.16*** *$Y_{JS}$ with Meteorological Parameters*
***Source****: Author*

***Table 6.4*** *Indices of Outdoor Thermal Comfort for Rusun in Bandung*

| Flats | PET | PMV-r | PMV | YJS | Comfort Level Perception |
|---|---|---|---|---|---|
| Rusun UPI | 34.3 | 2.3 | 2.595 | 2.17 | Slightly Warm |
| Rusun Cigugur | 34.2 | 2.2 | 2.215 | 2.39 | Slightly Warm |
| Rusun Cingised | 40.7 | 3.7 | 4.2 | 2.64 | Hot |
| Rusun Pharmindo | 36.7 | 2.8 | 3.075 | 2.53 | Warm |
| Rusun PTDI | 38.4 | 3.3 | 3.58 | 2.55 | Hot |

## 6.5. Closing Remarks

From the **figure 6.13,** until **figure 6.16** it may be concluded that air temperature is the meteorological parameter that has the most significant impact on outdoor thermal comfort. It is shown as PET ($R^2$ = 0.95); PMV-r ($R^2$ = 0.98) and PMV ENVI-met ($R^2$ = 0.98), however not at $Y_{JS}$ with $R^2$ = 0.58.

This result, then, connects to the previous chapter which discusses the role of urban forms that potentially generate microclimate, it may refer to table 5.3 where it is stated that vegetation coverage ratio impact on controlling air temperature. This statement implies that in order to gain outdoor thermal comfort, vegetation as the physical aspect of urban form needs to be taken into account as an important part in the passive design strategy in hot-humid climate regions.

## Bibliography

(VDI), V. V. (1998). in Part I: environmental meteorology, methods forthe human-biometeorological evaluation of climate and air quality for the urban and regionalplanning at regional level.

ASHRAE. (2001). Fundamentals Handbook 2001 (SI Edition) in American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

AZAR, J. (2001). Townscope II—A computer system to support solar access decision-making. Solar Energy, 70(3), 14.

Bruse, M. (2007). Simulating human thermal comfort and resulting usage patterns of urban open spaces with a Multi Agent System. in PLEA 24.

Fredrik Lindberg, B.H., Sofia Thorsson, SOLWEIG. (2008). Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. International Journal of Biometeorology, 52, 7.

Gagge AP, F.A., Berglund PE. (1986). A standard predictive index of human response to the thermal environment. ASHRAE Trans, 92, 23.

Höppe, P, Mayer, H. (1987). Thermal comfort of man in different urban environments. Theor. Appl. Clim.

Mayer, Andreas Matzarakis& Frank Rutz & Helmut. 2007. "Modelling Radiation Fluxes in Simple and Complex Environments—application of the RayMan Model." Int. J Biometeorol 51: 12. doi:10.1007/s00484-006-0061-8.

Jendritzky, G. (2009). The Perceived Temperature: The Method of the Deutscher Wetterdienst for the Assessment of Cold Stress and Heat Load for the Human Body.

Peter Moonen, T.D., Viktor Dorer, Bert Blocken, Jan Carmeliet. (2012). Urban Physics: Effect of the micro-climate on comfort, health and energy demand. Frontiers of Architectural Research, 1(3), 31.

PO. Fanger. (1970). Thermal comfort. Copenhgen: Danish Technical Press.

Sangkertadi, W. (2012). New Concepts in Districts Planning, Based on Heat Island Investigation. Procedia - Social and Behavioral Sciences, 36, 7.

Toudert, F. (2005). Dependence of Outdoor Thermal Comfort on Street Design in Hot and Dry Climate. Berichte des Meteorologischen Institutes.

# 7. Strategy of Building Group Passive Design

## 7.1. Public Flats (*Rusun*) and their Role in a High Density City

Previous chapters have discussed how high population densities increase exposure to the effects of microclimates. Also, high population densities are vulnerable to climate change, as they can potentially localize climatic effects, such as increased local temperatures, urban heat island effects and high levels of outdoor temperatures. Therefore, density has become one of a variety of factors that influences the sustainability of urban form. Also, density has an effect of compactness, the need to travel and the feasibility of public transport in reducing emissions. In a broader sense, sustainable cities are a matter of density. Density and dwelling type affect sustainability due to differences in energy consumption, materials, land for housing, transportation, and urban infrastructure. Compared to a detached house, vertical houses, such as flats, apartments and condominiums, provide a promising answer to the limited land availability and also function together as a compact city. Therefore, the utopia of a compact city in developing countries leads *rusun* to be a main actor in contributing to create liveable comfort in dense areas. This is true especially since it has become an important goal of the government to relocate squatters and slum inhabitants to a better living places.

The program of *rusun* is run by the national government. There are two ministries that take responsibility for *rusun* construction; the ministry of public works and the ministry of public housing. In general, the ministry of public housing is has the administrative role of public housing. In contrast, the ministry of public works has a legal role regarding technical requirements and guideline for *rusun* planning and construction. The demand of *rusuns* as affordable housing in Indonesia is rising year by year. Based on the ministry of public housing data (Kemenpera, 2013), from 2005 to 2013, there were 573 completed twin blocks, yet there still remains a 0.8% backlog of demand. Therefore, the development and construction of *rusun*, will be further carried out in the following years to handle the high density in the slum area, is important for city planning and design. The legal aspect is then a basic strategy for *rusun* planning and design. Technical guidelines and building standards play an important role in a building's environmental impact, and they are also related to building performance, a factor correlated with urban built environments. Therefore, the actual and strategic position of legal aspects is the driving force in examining the technical guidelines and building standards of *rusun.*

**Fig. 7.1** shows the hierarchy of legal aspects of *rusun* including technical requirements, guidelines and standards.

Specific discussion of technical guidelines in this paper can be seen in the following:

1. 60/PRT/1992 about Technical Requirement of *rusun* construction
2. 05/PRT/M/2007 about Technical Guidelines of high-rise *rusun*

An explanation of the above legal aspects is as follows:

<u>60/PRT/1992 CHAPTER VII: DENSITY AND LAYOUT OF BUILDING</u> and the detail are as follows:

Article 48

(1),(2) Public flat with five floors and the maximum density of the dwellers is 1,736 persons and the BCR is 25% and FAR is 1.25

(4) The use of land is ratio of total land area for building flats is 50% and for infrastructure is 20%

Article 50

(1) The distance between building require for fire safety, daylighting and air circulation<u>05/PRT/M/2007 CHAPTER III : THE REQUIREMENT OF BUILDING FORM AND CONFIGURATION</u>

III.1. (4) d. The building distances (clearances) are set from the ground floor as far as 4m, with an augmentation of 0.5m for each additional floor or building level until it reaches the furthest distance of 12.5 m.

III.2. (1) b. Building block with T, L or U shape which has building length more than 50m needs to make a dilatation to prevent damage caused by an earthquake or subsidence as seen at **Fig. 7.2.**

c. Building plan with centric shapes such as squares, polygons or circles are better than elongated shapes to prevent earthquake-related damage.

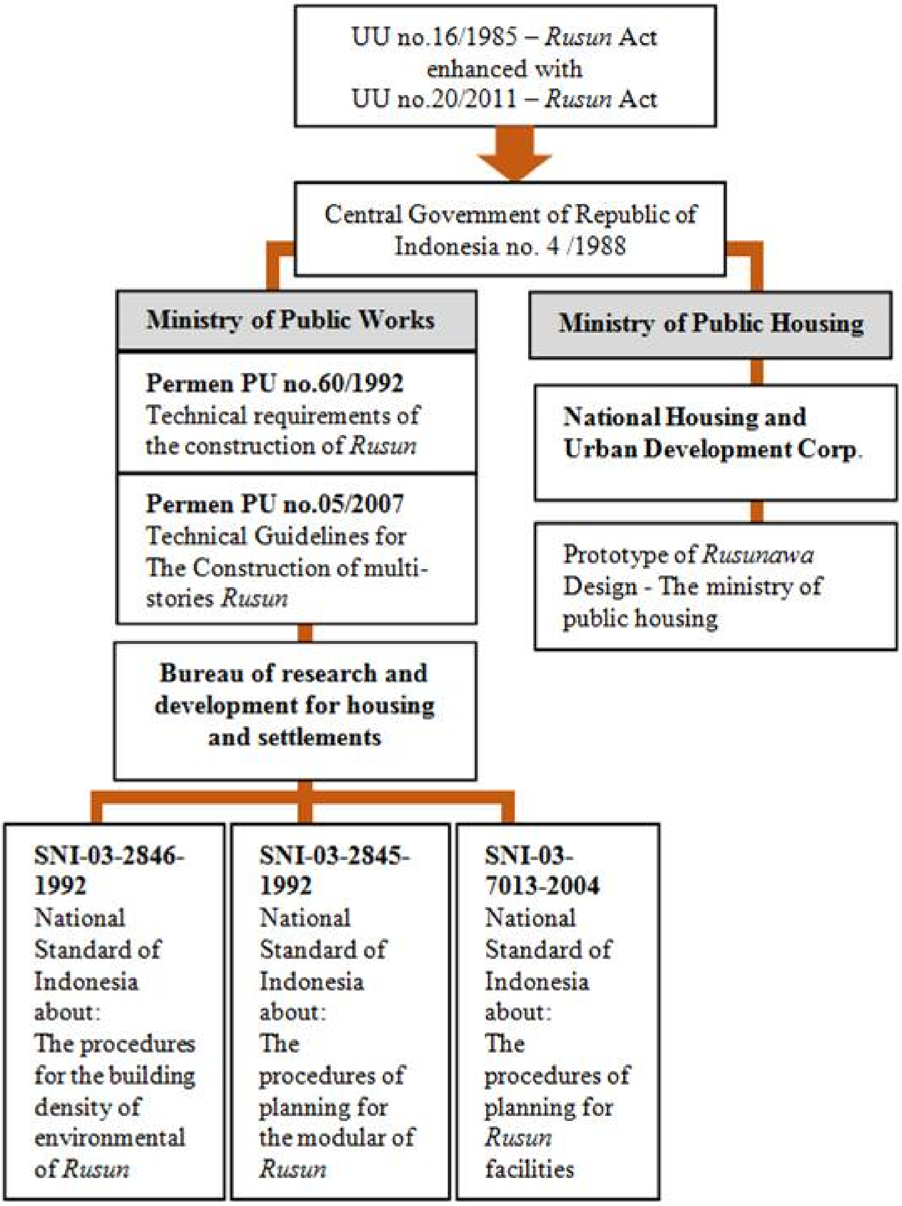



***Fig 7.1*** *Hierarchy of Legal Aspects of Rusun in Indonesia*

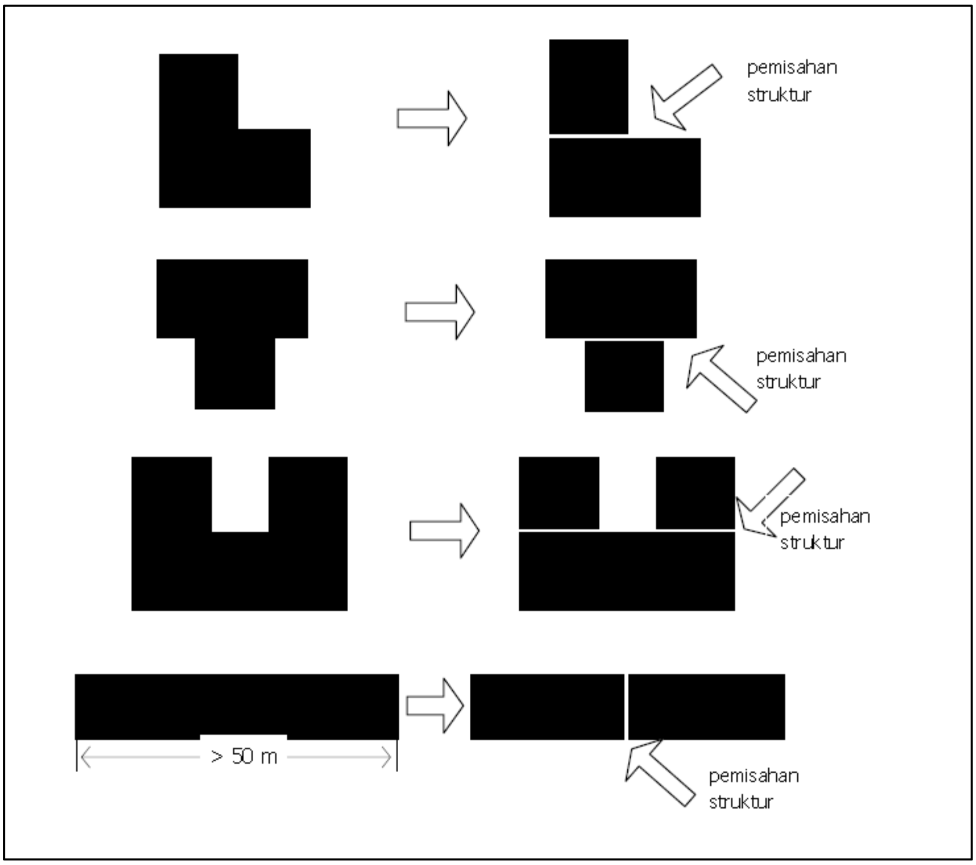



***Fig 7.2*** *Building plan for Rusun*
***Source:*** *Legal Aspect of Rusun 05/PRT/M/2007*

As in the description above, there is an absence of building forms and configurations regarding passive design needed to accommodate the urban microclimate aspect. Furthermore, the low availability of detailed dimensions and the lack of specific explanations make this guideline open to multiple interpretations. Since this guideline is so general, developers will not comply with these rules which in turn puts the law enforcement of building regulations in a difficult position.

Additionally, an important part of this legal aspect is the *rusun* prototype, which has two main building plan type. These include symmetric parallel and symmetric cross, and can be used for eight, fifteen and twenty floors. To accommodate subsequent discussion, the assessment of these flats will then be referred to as the prototype *Rusun*. The objective of this assessment is to provide the specific recommendations for optimum passive building group design, with the goal of creating a better microclimate.

## 7.2. Assessment of *Rusun* Prototype

The assessment of building form and configuration for the two models of this prototype is done using ENVI-met. This assessment will be compared with the five constructed *rusun* in Bandung previously discussed in chapters five and six. Therefore, the meteorological data for the ENVI-met configuration input is adapted with the same weather and climate conditions taken from the data measured on June 13$^{th}$, 2012. Since the prototype only provides a single building for the site, the analysis of this assessment will focus on building orientation, building length, building height, also the microclimate which is impacted by this prototype.

There are two prototypes of *rusun* referenced in 05/PRT/M/2007. The first model is a symmetric parallel model (SP), as shown in **Fig. 7.3** and **Fig. 7.4.** The second model is a symmetric cross model (SC), as shown in **Fig. 7.5** and **Fig. 7.6**. These two models have tilted from the west-east 20 degrees toward north. Accordingly, there is SP_20 for the SP Model titled 20 degrees, and SC_20 for the SC Model titled 20 degrees.

Therefore, the total number of building models in ENVI-met simulation are four models. The model of SP Model is seen in **Fig. 7.7 (a)** and the SP_20 Model is shown in **Fig. 7.7 (b).** Also, the SC Model is seen in **Fig. 7.8 (a)** and the SC_20 Model is shown in **Fig. 7.8 (b).**

In this study, the assessment is limited to prototypes of only eight floors, as fifteen and twenty floor prototypes are not included in the study. The consideration of the impropriety of fifteen and twenty floor prototypes is explained at **Table 7.2**, regarding the implementation of legal aspects toward the practical construction of *rusun*.

### 7.2.1. Symmetric Parallel Model (SP)

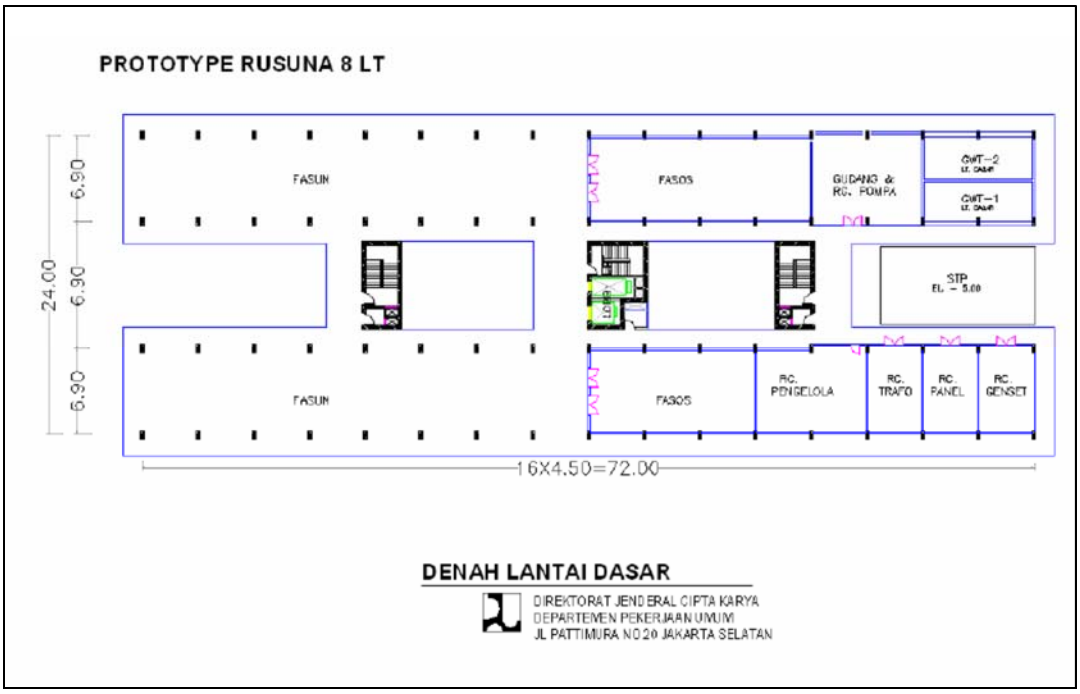



***Fig. 7.3*** *Symmetric Parallel (SP) Model Plan for 8 floors Rusun*
***Source:*** *Legal Aspect of Rusun 05/PRT/M/2007*

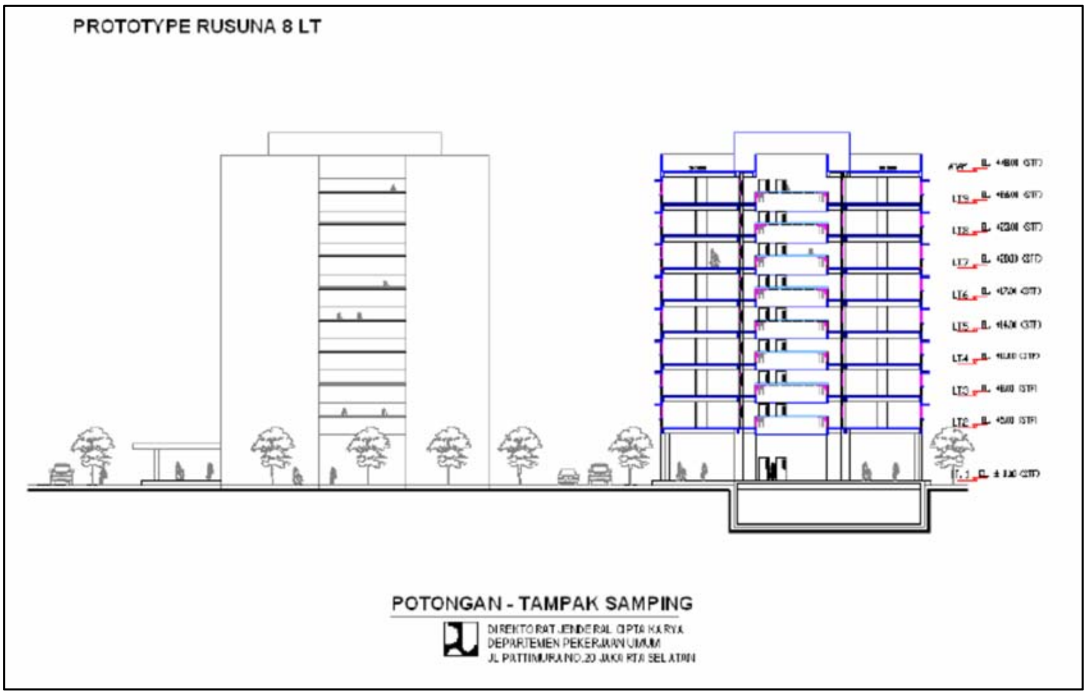



***Fig. 7.4*** *Symmetric Parallel Model Plan Elevation and Side View*
***Source:*** *Legal Aspect of Rusun 05/PRT/M/2007*

### 7.2.2. Symmetric Cross Model (SC)

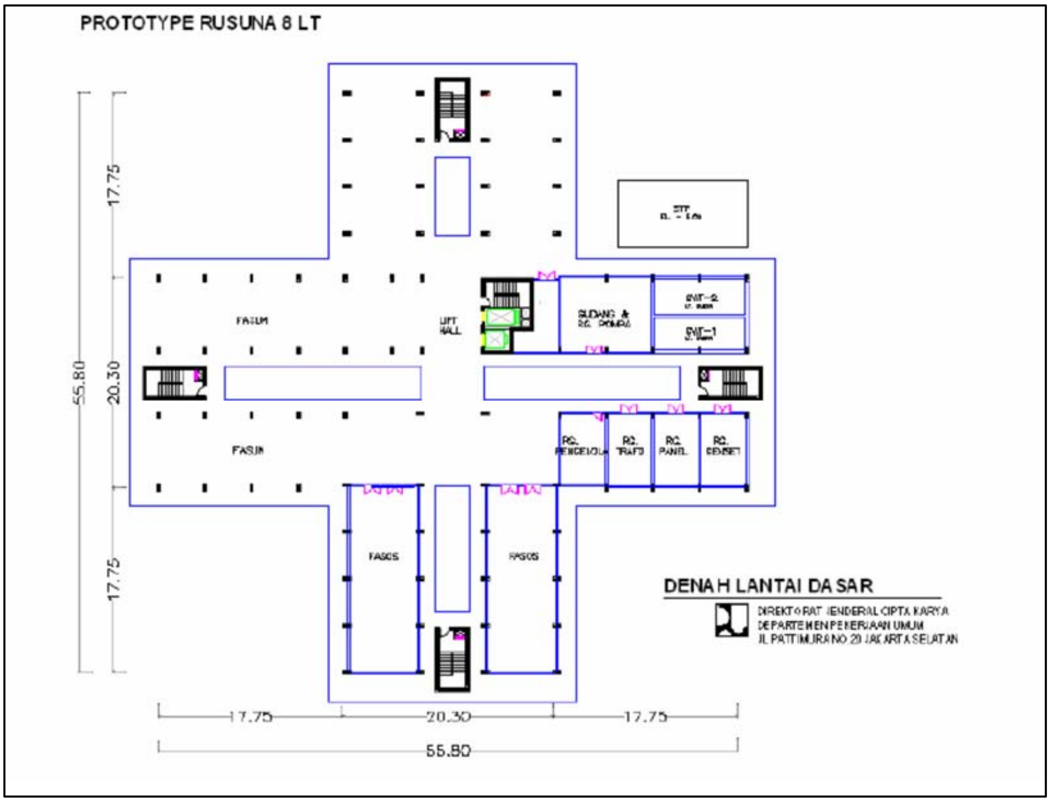



***Fig. 7.5*** *Symmetric Cross (SC) Model Plan for 8 floors Rusun*
***Source:*** *Legal Aspect of Rusun 05/PRT/M/2007*

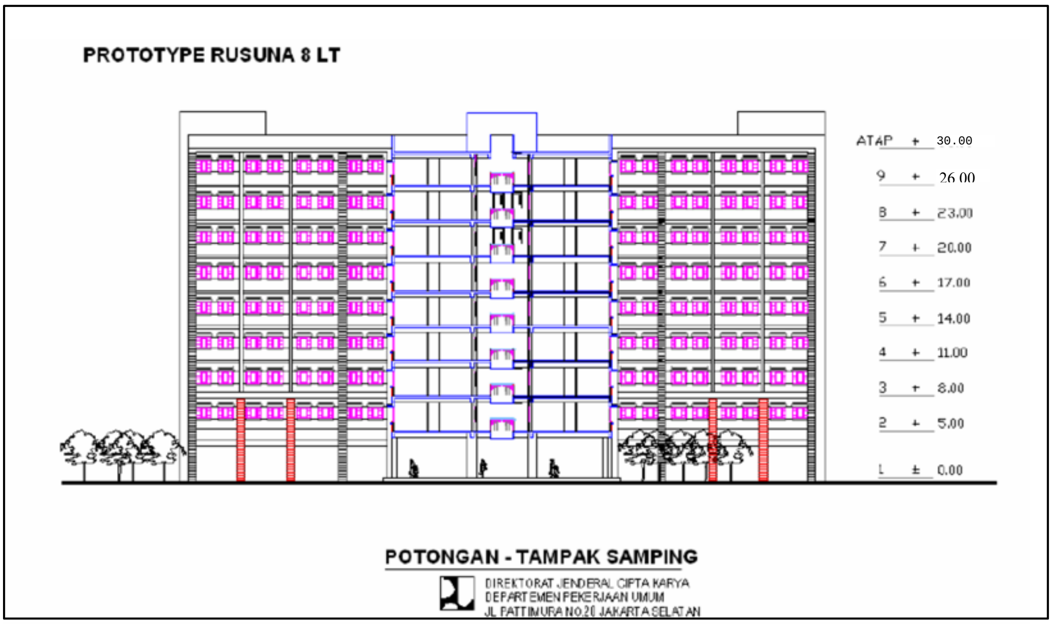



***Fig. 7.6*** *Plan for 8 floors Rusun*
***Source:*** *Legal Aspect of Rusun 05/PRT/M/2007*

### 7.2.3. ENVI-met Simulation

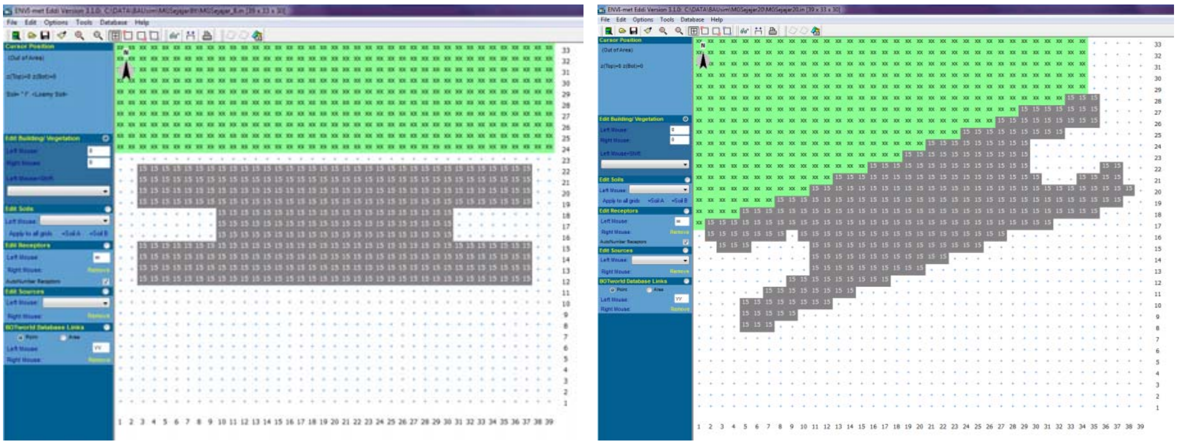


***Fig. 7.7*** *(a) SP Model ; (b) SP_20Model in ENVI-met*
***Source:*** *ENVI-met, Author*

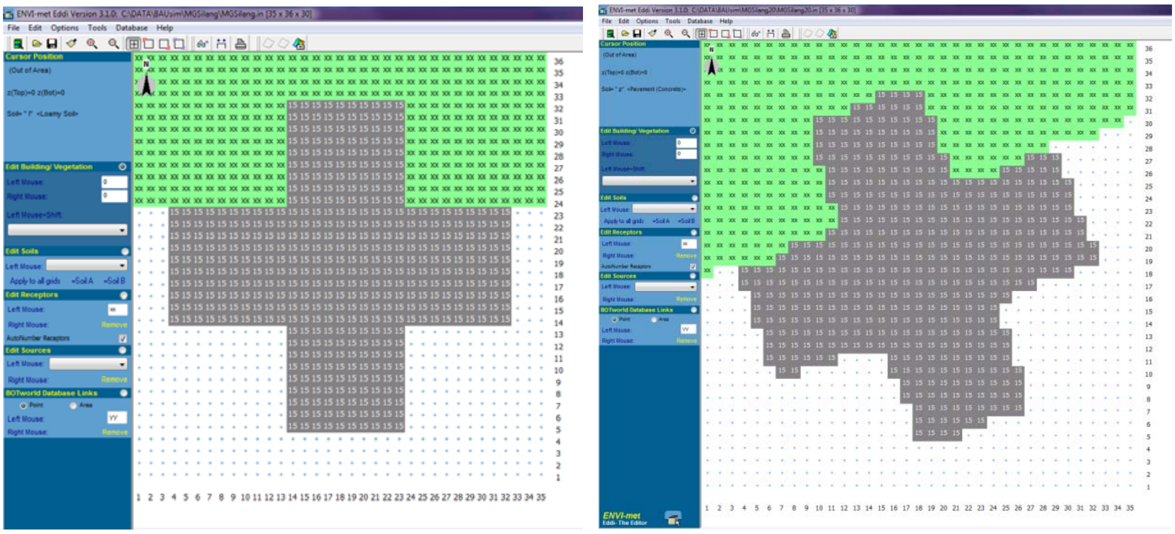


***Fig. 7.8*** *(a) SC (b) SC_20 Model in ENVI-met*
***Source:*** *ENVI-met, Author*

***Table 7.1** General Condition for Simulation*

| | | | |
|---|---|---|---|
| Location | Bandung, Indonesia<br>-6.54S; 107.37E | Building | ▪ Indoor 296.34 K<br>▪ Heat transmission |
| Climate type | Hot humid climate | | Walls: 0.41 W/m$^2$K |
| Simulation day | 13th June, 2013<br>24hours | | Roofs: 0.157 W/m$^2$K<br>▪ Albedo |
| Meteorological Data | ▪ Initial Temperature 298.35 K | | Walls: 0.2<br>Roofs: 0.3 |
| | ▪ Specific Humidity 13 gWater/kg air<br>▪ RH 63%<br>▪ Indoor 296.34 K<br>▪ Wind speed 2.29m/s<br>▪ Direction 321NW | Heat Human Balance | ▪ Walking speed: 1.4 m/s<br>▪ Energy Exchg : 116W/m$^2$<br>▪ Clo : 0.7 |

**7.2.4. Finding**

**A. The Overlapping of Legal Aspect Content**

The legal aspect here refers to 60/PRT/1992 CHAPTER VII, article 48 and 50; 05/PRT/M/2007 CHAPTER III, verses III.1 and III.2; which are included in the Indonesian national standard (SNI) for *rusun* construction. The aforementioned legal aspects overlap each other, and there is also some inconsistency in the statements.

***Table 7.2** Overlapping of Legal Aspects statement*

| Legal Aspect | Realization of Prototype |
|---|---|
| (1) 60/PRT/1992 :<br>▪ Public flat with five floors and a maximum density of dwellers at 1,736 persons and the BCR is 25% and FAR is 1.25<br>▪ Max. uses of land for building is 50%: 20% environmental infrastructure and 30% environmental facilities<br>(2) 05/PRT/2007 :<br>Building distance from the ground floor as far as 4m, and the farthest is 12.5m | (1) 05/PRT/2007<br>Directly provide 8, 15, and 20 floors in the area of 5,000m$^2$<br>▪ 8 floors<br>SPModel:BCR 25%, FAR 2.0, density 1,024persons. SCModel BCR 37%, FAR 2.96, density 1,120persons<br>▪ 15 floors<br>SPModel: BCR 25%, FAR 3.85, density 1,920 persons. SCModel: BCR 37%, FAR 5.55, density 2,040persons<br>▪ 20 floors<br>SPModel: BCR 25%, FAR 6.42, density 2,560 persons. SCModel: BCR 37%, FAR 7.4, density 2,720persons |

| | |
|---|---|
| (3) SNI 03-2846-1992 :<br>8floors → BCR 17.5%, FAR 1.375 and density 1,909 persons<br>The number floors allowed are 11-12 floors | → *Rusun* is not merely a building which accommodates a number of people, but also has to consider the load density regarding the built environment. A density of over 2,000 persons in 5,000m$^2$ will lead to a tremendous burden to the environment. |
| (4) SNI 03-7013-2004<br>Max. uses of land for building 50%: 10% environmental facilities, 20% open space and 20% environmental infrastructure | (2) 05/PRT/2007, the distance between the building is not synchronous with the availability of prototype only for a single building. In case it is applied to the building groups, there will be an impact on the availability of daylighting and possibility of wind turbulence<br>▪ 8 floor tower → the distance between building 12.5m so H/W = 30/12.5 = 2.4<br>▪ 15 floor tower → the distance between building 12.5m so H/W = 51/12.5 = 4.08<br>▪ 20 floor tower → the distance between building 12.5m so H/W = 66/12.5 = 5.28 |

***Source***: *Author*

**B. Prototype (8 floors) and Microclimate at street level (Tmrt value)**

***Table 7.3*** *Diurnal of Tmrt for four models*

| Model | Diurnal Tmrt | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 06.00 | 07.00 | 08.00 | 09.00 | 10.00 | 11.00 | 12.00 | 13.00 | 14.00 | 15.00 | 16.00 | 17.00 | 18.00 | 19.00 |
| SP | 15.73 | 28.30 | 43.20 | 47.76 | 49.54 | 49.89 | 50.29 | 51.08 | 51.50 | 50.30 | 45.20 | 25.47 | 17.67 | 16.97 |
| SC | 15.74 | 28.72 | 43.10 | 48.45 | 50.35 | 51.00 | 51.55 | 52.29 | 52.67 | 50.76 | 45.62 | 27.75 | 18.04 | 17.41 |
| SP_20 | 15.73 | 28.28 | 42.94 | 47.77 | 49.62 | 50.09 | 50.58 | 51.46 | 51.93 | 50.34 | 44.90 | 26.18 | 17.99 | 17.35 |
| SC_20 | 15.74 | 28.22 | 42.85 | 47.81 | 49.72 | 50.12 | 50.31 | 50.88 | 50.97 | 49.40 | 44.34 | 24.66 | 17.15 | 16.61 |

***Source***: *Author*

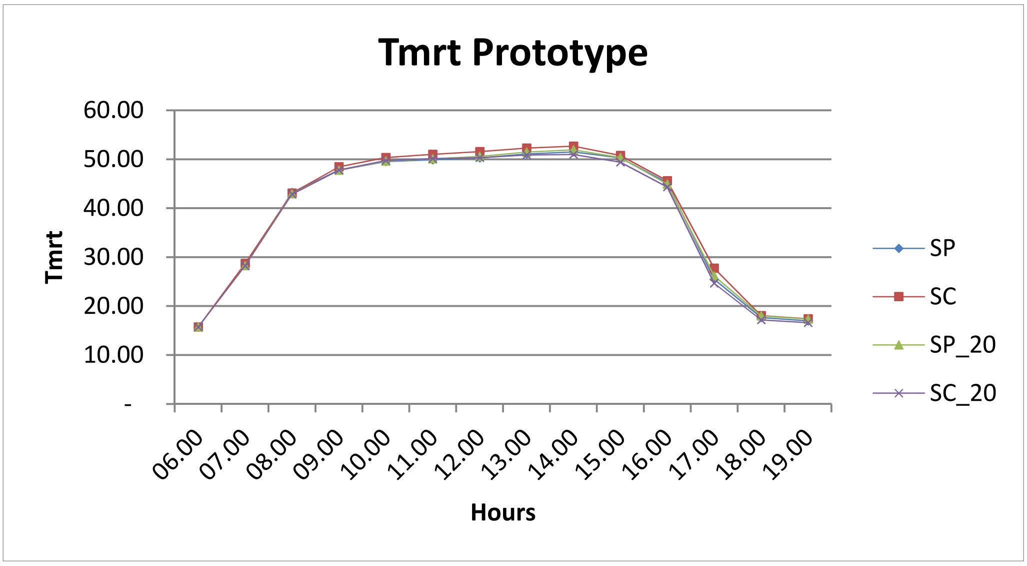



***Fig. 7.9** Simulation result for Diurnal Tmrt value*
***Source:** Author*

The **Fig. 7.9** as a chart from **Table 7.1** presents the Tmrt value for each prototype, in which all of the prototypes reached the highest Tmrt value at 2pm. The SC_20 Model reached the lowest Tmrt value at 50.97 °C, meanwhile the SC Model reached the highest Tmrt value at 52.7 °C.

**C. Outdoor Thermal Comfort Indices**

***Table 7.4** Outdoor Thermal Comfort Indices*

| Model | Tmrt max | Ta | Va | RH | PET | PMV-r | $Y_{JS}$ | PMV |
|---|---|---|---|---|---|---|---|---|
| SP | 51.50 | 27.50 | 1.86 | 83.13 | 34.7 | 2.5 | 1.48 | 3.0 |
| SC | 52.67 | 29.70 | 1.76 | 56.75 | 37.4 | 2.9 | 2.00 | 3.3 |
| SP_20 | 51.93 | 28.28 | 1.80 | 77.18 | 35.8 | 2.7 | 1.64 | 3.2 |
| SC_20 | 50.97 | 27.55 | 1.47 | 84.28 | 35.4 | 2.6 | 1.62 | 3.0 |

***Source**: Author*

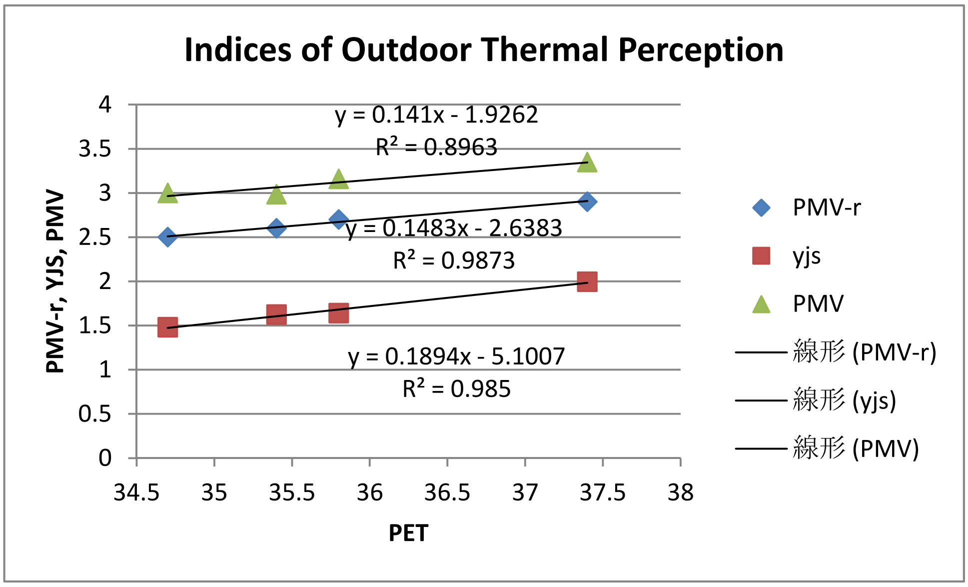



***Fig 7.10** Indices of Outdoor Thermal Perception*
***Source:** Author*

**Table 7.2** compares all four models. All of them show the same tendency of inducing heat, which results in a comfort zone between 40°C < PET > 34 °C. This means that all the models give the outdoor thermal perception as a warm living area.

**Fig. 7.10** provides coefficient of determine between PET and PMV-r (RayMan) → $R^2$=0.99; PET and YJS → $R^2$=0.98; PET and PMV-ENVI-met → $R^2$=0.90.

These results indicate that these four models are valid to be assessed through the outdoor thermal indices parameters.

**D. Symmetric Parallel Model (SP)**

*Table 7.5 Symmetric Parallel Model Simulation Result*

| Orientation | Ta | Tmrt | Tg | RH | v | PMV | PET | Yjs |
|---|---|---|---|---|---|---|---|---|
| N | 30.1 | 76.37 | 65.35 | 53 | 1.74 | 4.78 | 49.5 | 3.51 |
| S | 28.48 | 25.96 | 26.55 | 59 | 1.64 | 1.66 | 25.7 | 0.31 |
| W | 29.31 | 52.91 | 47.89 | 56 | 1.3 | 3.27 | 38.1 | 2.21 |
| E | 28.83 | 29.88 | 29.82 | 57.3 | 0.07 | 1.985 | 29.8 | 1.17 |

***Source**: Author*

**Table 7.5** shows the result of the ENVI-met simulation for the SP Model, that the **south** orientation of this model reached the lowest temperature (Ta) and mean radiant temperature (Tmrt) . This resultantly influenced the value of thermal comfort indices.

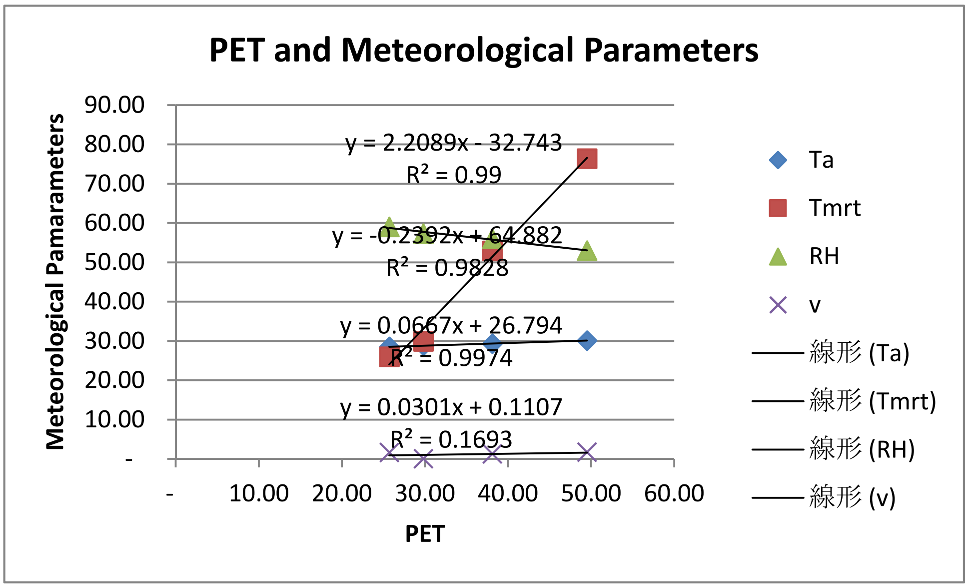



***Fig 7.11** PET for SP Model with Meteorological Parameters*
***Source:** Author*

The **north** orientation shows the highest of both Ta and Tmrt, which also has a direct impact on the value of outdoor thermal comfort indices. **Fig. 7.11** shows the PET and Meteorological Parameters for the SP Model.

From **Fig. 7.11**, it can be concluded that the human perception of thermal comfort in this model will be significantly affected by air temperature ($R^2$=0. 99), mean radiant temperature ($R^2$= 0.98) and relative humidity ($R^2$ = 0.99).

### E. Symmetric Parallel Model titled 20° (SP_20)

***Table 7.6** Symmetric Parallel Model Titled 20° Simulation Result*

| orientation | Ta | Tmrt | Tg | RH | v | PMV | PET | Yjs |
|---|---|---|---|---|---|---|---|---|
| N | 28.31 | 63.13 | 57.37 | 80.2 | 0.7 | 3.9 | 44.9 | 2.90 |
| S | 28.03 | 54.09 | 49.78 | 76.32 | 0.7 | 3.27 | 39.7 | 2.32 |
| W | 27.95 | 50.8 | 46.01 | 80.08 | 1.25 | 3.07 | 36.2 | 1.78 |
| E | 28.27 | 50.78 | 45.85 | 77.66 | 1.4 | 1.92 | 36.2 | 1.75 |

***Source**: Author*

**Table 7.6** shows the result of the ENVI-met simulations for the SP_20 Model. It shows that the **west** orientation of this model reached the lowest temperature (Ta) and the mean radiant temperature (Tmrt), which then influences thermal comfort indices. By tilting the building orientation of west to east leads to N 20°, it reduces the gap of maximum meteorological parameters.

The **north** orientation still shows the highest values for both Ta and Tmrt, but not for the significant different value.

Opposite to the previous model, **Table 7.4** shows that the SP_20 Model had a PET value that only correlated with Tmrt ($R^2 = 0.98$). As seen in **Fig. 7.12**, wind speed also has an influence on outdoor thermal comfort, though not an insignificant value.

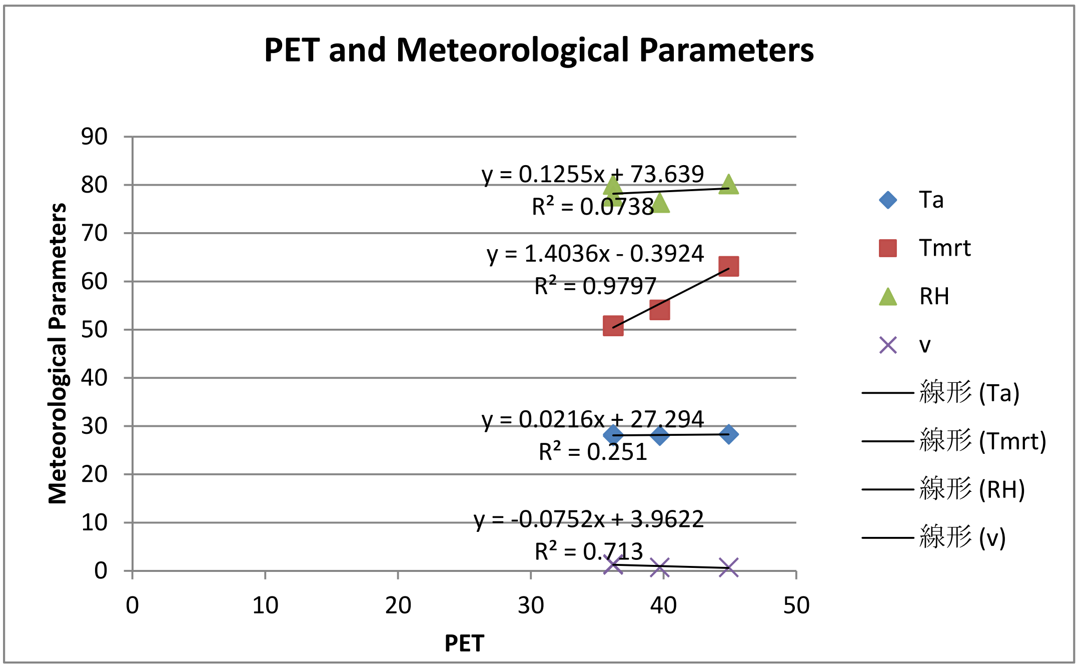



**Fig. 7.12** PET and Meteorological Parameters for SP_20 Model

***Source:*** *Author*

**F. Symmetric Cross Model (SC)**

*Table 7.7 Symmetric Cross Model (SC) Simulation Result*

| orientation | Ta | Tmrt | Tg | RH | v | PMV | PET | Yjs |
|---|---|---|---|---|---|---|---|---|
| NE | 29.50 | 61.77 | 55.05 | 59.50 | 1.23 | 3.81 | 43.0 | 2.78 |
| SW | 29.78 | 75.25 | 65.40 | 55.43 | 1.36 | 4.22 | 49.7 | 3.61 |
| NW | 30.15 | 62.46 | 56.61 | 55.36 | 0.87 | 4.10 | 44.9 | 3.10 |
| SE | 28.99 | 77.05 | 70.72 | 57.41 | 0.41 | 4.21 | 55.6 | 4.33 |

***Source**: Author*

**Table 7.7** shows the result of the ENVI-met simulation for the SC Model, that the **south east** orientation of this model reached the lowest temperature (Ta), but the highest mean radiant temperature (Tmrt), which then implies the PET value.

The **north west** orientation shows the highest Ta, but the lowest RH. However, this is certainly beneficial to increase the value of outdoor thermal comfort indices. Based on the results of this simulation, the SC Model seems to distribute a wider variant of meteorological parameters in the building orientation.

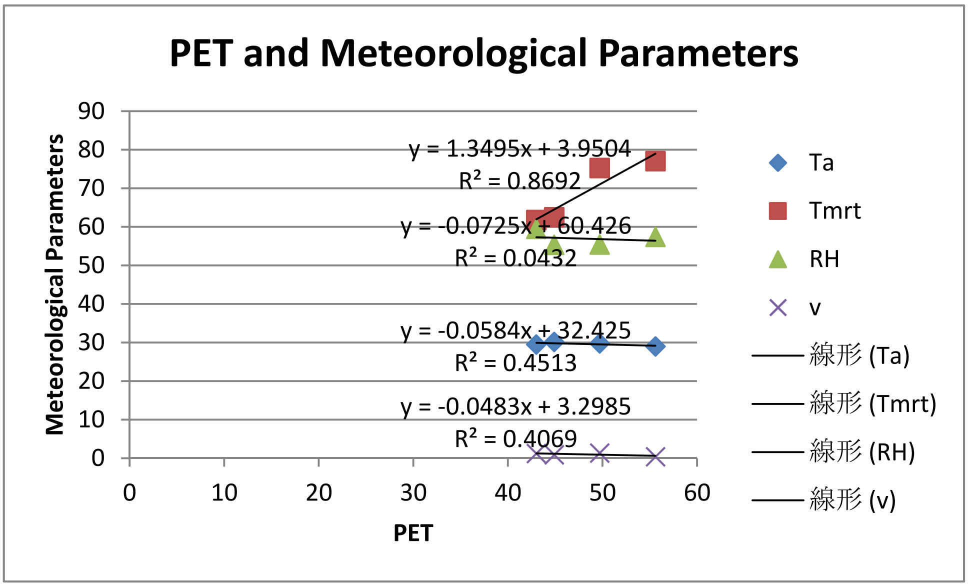



***Fig. 7.13** PET and Meteorological Parameters for SCModel*
***Source:** Author*

**Fig. 7.13** presents the coefficient determiners of PET with Tmrt. It shows a strong correlation (R2 = 0.87), but the other meteorological parameter seem to influence PET in a less significant manner.

**G. Symmetric Cross Model titled 20º (SC_20)**

***Table 7.8*** *Symmetric Cross Model Tiled 20º Simulation Result*

| orientation | Ta | Tmrt | Tg | RH | v | PMV | PET | Yjs |
|---|---|---|---|---|---|---|---|---|
| NE | 27.31 | 65.04 | 57.39 | 87.92 | 1.15 | 3.72 | 43.3 | 2.62 |
| SW | 26.27 | 73.33 | 63.29 | 85.2 | 1.31 | 4.20 | 46.1 | 3.02 |
| NW | 27.42 | 61.50 | 55.48 | 65.72 | 0.82 | 3.64 | 42.7 | 2.81 |
| SE | 27.32 | 75.10 | 68.61 | 81.74 | 0.44 | 4.10 | 53.4 | 3.84 |

***Source***: *Author*

**Table 7.8** shows the result of ENVI-met simulation for the SC_20 Model. These results indicate that the **south west** orientation of this model reached the lowest temperature (Ta) but did not reach low values in other meteorological parameters. The **north west** orientation has the highest Ta, but the other parameters (Tmrt, Tg and RH) show the lowest value. This also significantly reduces the value of PET. By tilting the building orientation of west to east to N 20º, the SC Model does not seem to significantly reduce the gap of maximum meteorological parameters.

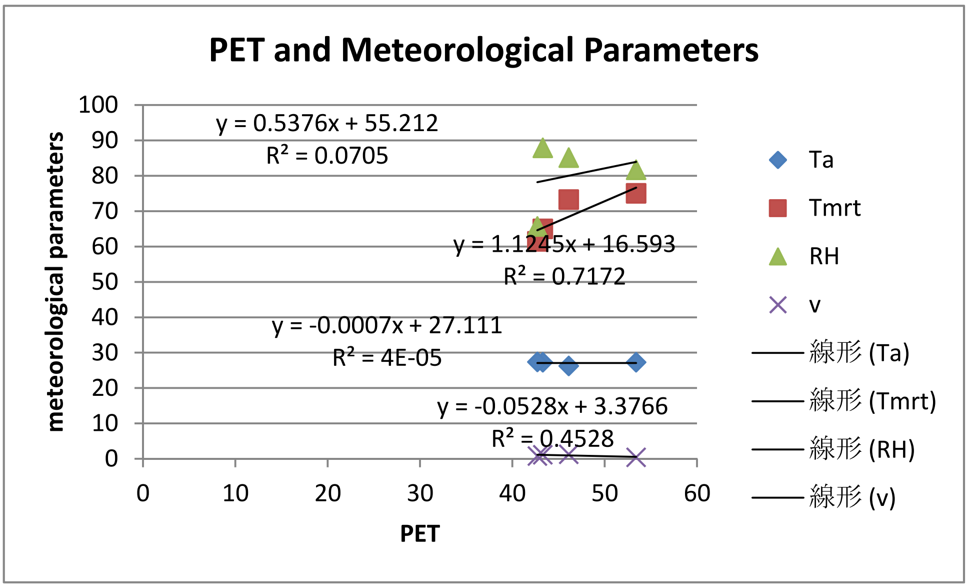



***Fig. 7.14*** *PET and Meteorological Parameters for SC_20 Model*
***Source:*** *Author*

**Fig. 7.14** presents the coefficient determiners of PET to the SC_20 Model. It shows no significant value of meteorological parameters. Tmrt showed a positive correlation, with a significant value ($R^2$ = 0.72). Therefore, this model does not provide a dominant influence factor into meteorological parameters.

## 7.3. Summary of Legal Aspect Assessment

In order to compile comprehensive and complete building regulations, a holistic and complicated approach needs to be utilized. Thus, it must be acknowledged that this research has a huge limitation regarding being implemented in the legal aspects above. Nevertheless, the important finding of this study can be considered as an improvement on current regulatory recommendations. This is true especially regarding the building form and configuration. The most important facets of the study's results are as follows:

1. Based on the four models, it was determined that the northern face receives more insolation compared to other directions such as the west, east or south. Therefore, the layout of outdoor space on the north side should provide as much green coverage as possible, either for shadowing or for the benefit of its albedo.
2. The building ratio of 1:3 produces higher wind speeds, which also control air temperature and humidity. However, this is difficult to apply due to the limited availability of land.
3. The given prototypes of eight, fifteen and twenty floors provide the possibility of opening it up to *rusun* construction unwell planned. Instead of creating bounds with this prototype, it would be better to carefully measure and accommodate the number of people who live in a certain area.
4. The strategy of building group passive design is summarized as follows: the first priority is to accommodate or to determine the population density. It also must consider the environmental load in terms of infrastructure. As discussed in the literature review in Chapter 2, Indonesian cities have similar characteristics with Hong Kong cities due to the high values of FAR, DU, and high population. These can be very livable, comfortable environments, when an efficient development pattern is used.

## 7.4. Experiment Study of Strategy of Building Group Passive Design

Design strategies for building groups in a dense residential areas not only require an accommodation of their density on the plot ratio and site coverage, but also a critical to passive design that controls the access of sun, wind and light. Hot humid climate zones face little seasonal variation throughout the year. Qualities such as air temperature, humidity, and wind speed, have little variation even between day and night. Therefore, passive design in hot humid climates, particularly in relation to the form and mass of buildings, the size, shape, scale and distribution of green spaces is well positioned to promote outdoor thermal comfort, especially for flats. The strategies of building groups deal with the major architectural elements that are being built, street and open space. These strategies are mostly concerned with the relationship between buildings or between building and street/open space (DeKay and Brown, 2001). The following design strategies will be given for hot humid zone. They all have a major impact on reducing heating since they address the sun, wind and light.

### 7.4.1. Climate and High Density

In a dense area, a large number of habitants, anthropogenic heat emission, and the requirement of land coverage to provide shelter for inhabitants increase surface roughness. This accordingly reduces the ventilation of urban areas. This ultimately has the potential to creat an urban heat island (UHI). The change of land use and cover in Bandung, Indonesia significantly creates a change in air temperature, temperature humidity index and evapotranspiration, also creating higher surface temperature (Tursilowati 2007; Ignatius, M. and Eliza, 2011). An ideal level of density, especially in a dense, low-income settlement, has a strong potential contribution to urban sustainability. This is due to the promotion of higher density in buildings and public spaces in urban design, thus making the preservation of green spaces in conjunction with certain kinds of urban development crucial to address. In the previous discussion in Chapter 2, it was found that the Cibeunying district with 1.695 pph (people per ha) have the highest range of slum settlement in Bandung, which is also correlated with inappropriate physical condition . This current density and minimum pph for settlement is based on the SNI 03-7013-2004 (Indonesian National Standard of environmental facilities planning for flats). It then became a reference to determine the density of pph to design flat, which is 1750pph.

### 7.4.2. Urban Form and Microclimate

The legal aspect which have been discussed above indicate there is no specific guideline for public flats in Indonesia i.e. building shape (length/width =L1/L2 ratio), distance between building (H/W ratio). Building form and layout are set depend on site area. The assessment of five public flats in Bandung in chapter 5 and 6 brings the recommendation that interspersed plot with L1/L2 =1 rise wider outdoor comfort zone compare with 2 others plot, which has L1/L2 = 2 and L1/L2 = 3. The deep canyon provides more shadowing to achieve lower mean radiant temperature (Tmrt), but suppose to avoid shadow remain longer, since going to rise more high humidity, therefore require solar access for building spacing that determine H/W = 1.7-2 (De Kay and Brown, 2001; Littlefair,P.J, 2000; Salleh, E.,2006) .

In a hot humid zone, the design strategies are to provide more open space to reduce maximum temperature through the provision of greenery to absorb heat and allow natural ventilation during the day. Measurements in Singapore and Bangkok show that increasing the air speed by 1m/s had a cooling effect equivalent to lowering the temperature by more than 2°C (Givoni, 2010). TR.Oke (1988) mentions that the transitions between these three regimes occur at critical combinations of H/W and L/W (where L is the length of the building normal to the flow) as given in **Fig. 7.15.**

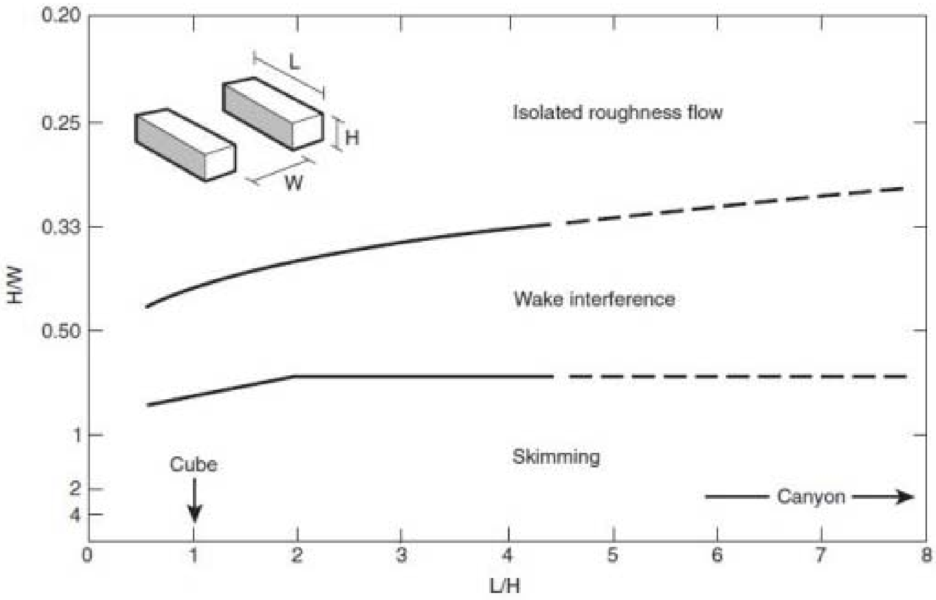



***Fig. 7.15**: Three regimes as function of H/W (canyon) and building geometry (L/H)*
**Source:** *Oke, 1988*

### 7.4.3. Numerical Building Model

The numerical of building model assesses its geometrical layout, including canyon (H/W) and geometrical dimension ($L_1/L_2$), that control sun access to reduce radiation and increase wind flow. Urban parameters directly examine population density regarding how many people can be accommodated, then determine building coverage (BC) which influence plot ratio and building height. This layout all set with canyon (H/D = 1.7) (see **Fig. 7.16**).

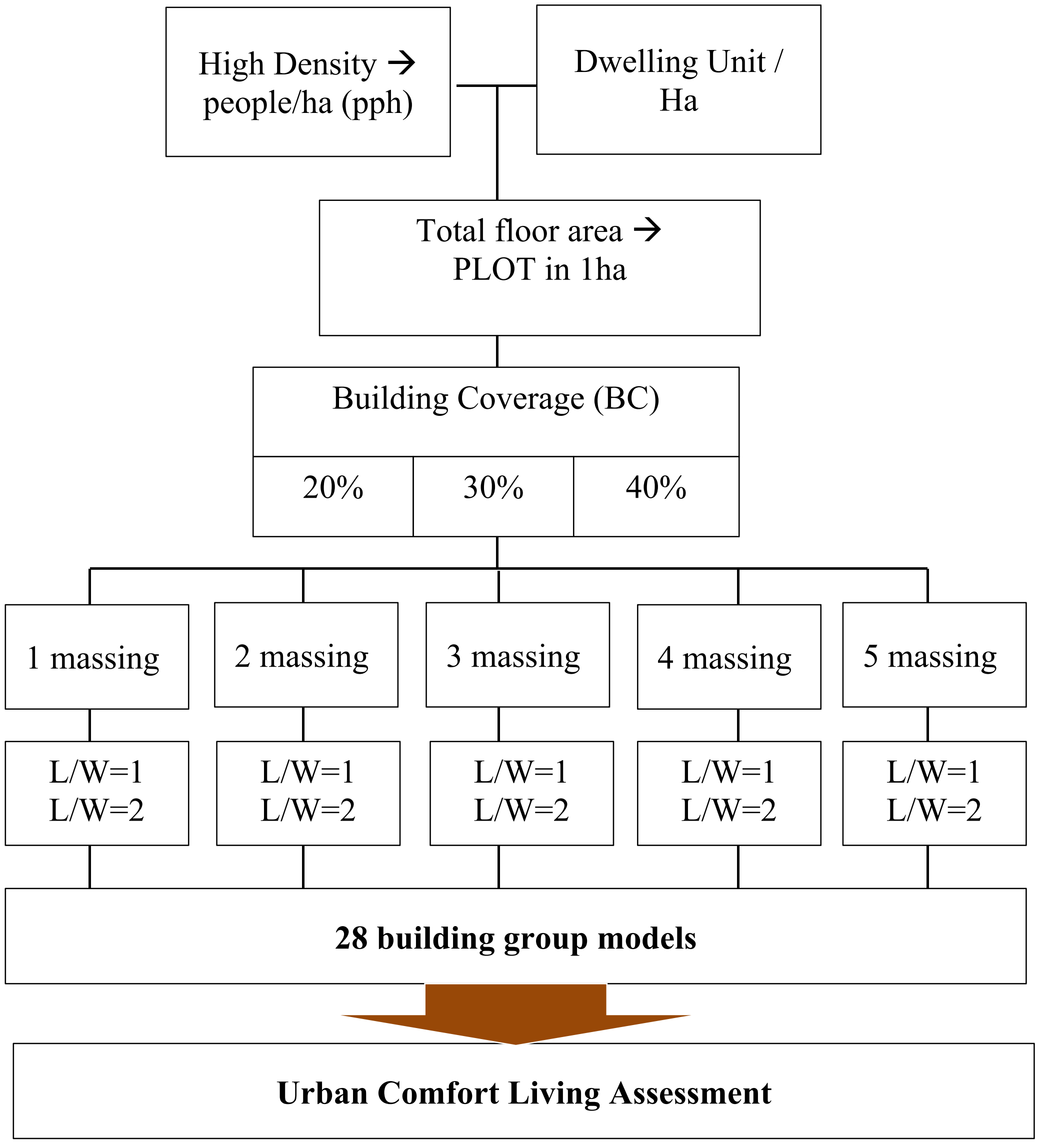



***Fig. 7.16** : Building Form and Massing Numerical Model*
**Source:** Author

This parameter gives the hypothesis that building group models with proper proportion and layout contribute (Tmrt) to levels of urban and outdoor comfort. A comparison of building groups revealed that the time and period of the day when extreme heat stress occurred provide a better building configuration.

**1. Plan**

Urban form typology:

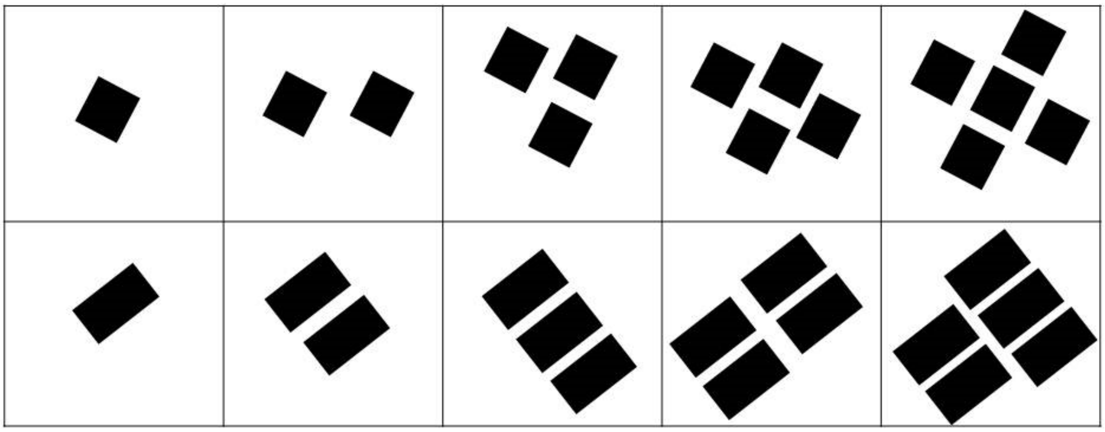


***Fig 7.17*** *Building Plot Plan*

Morphological indicator :

28 of model building groups and each having plot ratio = 1.57, BC = 20%; 30%; 40%, H/W= 1.7

**2. Building Height**

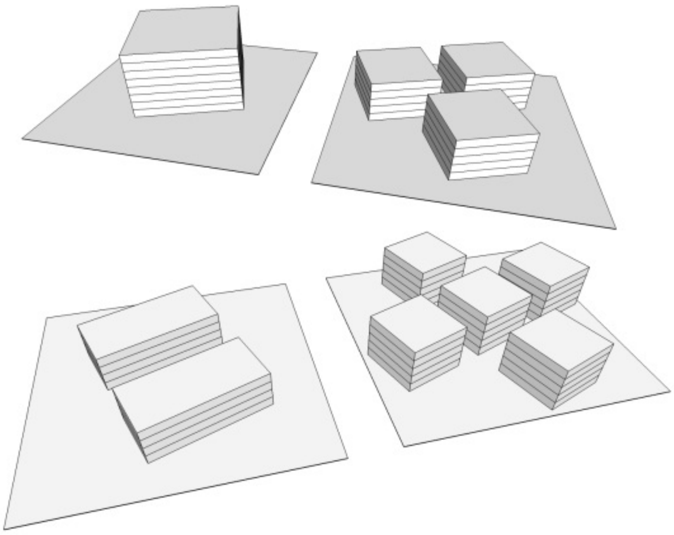


**Fig 7.18** Building Height

Morphological indicator

Plot ratio 1.57 ; BC 20% → H= 28m (8floors)

Plot ratio 1.57 ; BC 30% → H=17.5m (5floors)

Plot ratio 1.57 ; BC 40% → H= 14m (4floors)

## 3. Canyon and Geometry

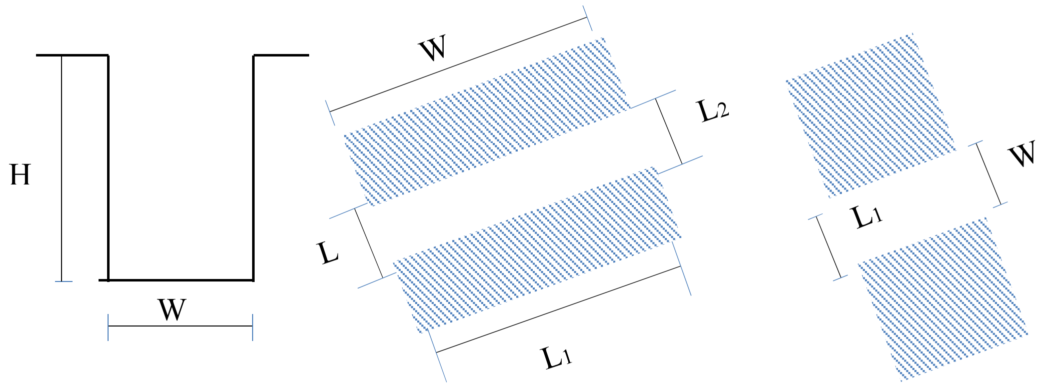



***Fig 7.19*** *(a) urban canyon H/W = 1.7 (b)urban geometry $L_1$:$L_2$ = 1:2 (c)urban geometry $L_1$:$L_2$ = 1:1*

Morphological indicator

Latitude 0-8ºN → building space for solar access : H/W =1.7

Geometry dimension $L_1$:$L_2$ = 1 and $L_1$/$L_2$ = 2

## 4. Orientation

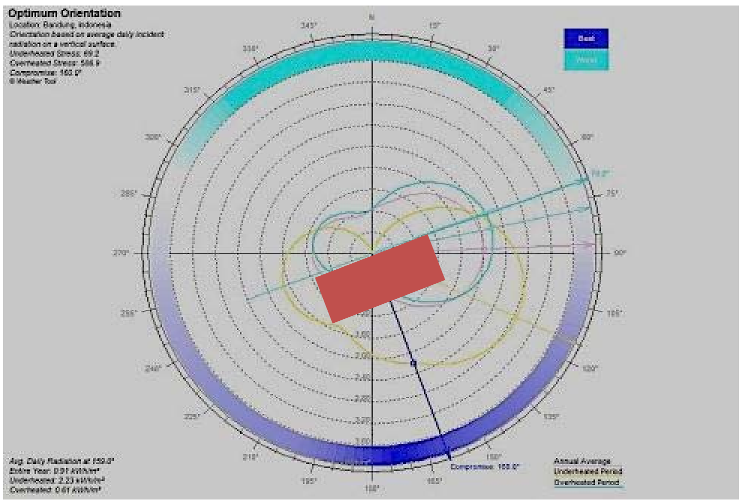



***Fig. 7.20*** *Best orientation for 6.54ºS and 107.36ºE*
Performed by Autodesk® Ecotect®

Morphological indicator

Latitude -6.54N Main building facing SE, rotate from E-W is 20º towards the north

From SW to NE since overheating period and to reduce radiation, used for greenery

**5. Vegetation coverage area**

Though the previous study found that shadowing from vegetation significantly reduced Tmrt, in this study there is no shadowing in this building group design strategies. The goal is to find out the effect of urban physical settings in order to improve the performance of microclimates. Thus, the only vegetation here is ground coverage, such as grass.

Morphological indicator

- BC 20% → green coverage 30%
- BC 30% → green coverage 20%
- BC 40% → green coverage 10%

### 7.4.4 Microclimate Street Level

A microclimate is a local atmospheric zone where the climate differs from the surrounding area. ENVI-met is a three-dimensional microclimate model designed to simulate surface-plant-air interactions in an urban environment with a typical resolution of 0.5 to 10 m in space and 10 seconds in time (Bruse, 2003). This simulation will help architects and planners predict the quality of urban areas amongst the complexity of urban microclimates, before the design of the building will be made. Meteorogical variables such as air temperature ($T_a$), humidity (RH), radiant temperature (Tmrt) and wind speed also influence outdoor thermal comfort, besides other human factors such as clothing (clo) and human body surface (m2). Thus, a number of simulations using ENVI-met BETA5, revealed it to be a good tool for the prognosis of the urban microclimate changes within urban areas. It was also shown effective in the assessment of outdoor comfort through a satisfactory estimation of the mean radiant temperature (Toudert, 2006). The mean radiant temperature (MRT) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure (Hermann and Matzarakis, 2011).

### 7.4.4 Microclimate Street Level

***Table 7.9.*** *Microclimate at street level of 28 models*

| | Tmrt (°C) | | Pot. Temp (°C) | | Wind (m/s) | | Wind Speed Change (%) | |
|---|---|---|---|---|---|---|---|---|
| | min | max | min | max | min | max | min | max |
| 1 | 31.58 | 73.01 | 27.86 | 29.25 | 0.38 | 3.01 | 15.96 | 127.27 |
| 2 | 30.22 | 71.71 | 26.68 | 28.58 | 0.35 | 2.97 | 15.54 | 133.29 |
| 3 | 31.67 | 72.10 | 26.31 | 27.57 | 0.37 | 2.97 | 16.77 | 135.48 |
| 4 | 30.70 | 72.03 | 26.82 | 28.51 | 0.36 | 2.92 | 16.38 | 131.44 |
| 5 | 31.92 | 72.20 | 26.78 | 28.84 | 0.39 | 3.08 | 17.44 | 137.42 |
| 6 | 31.70 | 71.90 | 26.69 | 28.46 | 0.34 | 2.67 | 15.38 | 120.56 |
| 7 | 33.51 | 72.72 | 28.17 | 32.32 | 0.39 | 2.85 | 17.07 | 123.57 |
| 8 | 25.51 | 69.41 | 26.53 | 28.21 | 0.33 | 2.58 | 14.82 | 116.68 |
| 9 | 25.32 | 69.22 | 26.75 | 28.45 | 0.31 | 2.66 | 13.82 | 119.96 |
| 10 | 25.81 | 69.74 | 27.97 | 32.82 | 0.32 | 2.75 | 14.10 | 119.55 |
| 11 | 32.20 | 72.34 | 27.09 | 29.09 | 0.31 | 2.54 | 13.98 | 113.74 |
| 12 | 33.30 | 73.16 | 29.10 | 36.50 | 0.35 | 2.71 | 14.77 | 114.60 |
| 13 | 31.75 | 73.74 | 28.75 | 31.57 | 0.31 | 2.54 | 12.81 | 106.56 |
| 14 | 31.92 | 72.49 | 26.98 | 29.04 | 0.30 | 2.50 | 13.50 | 111.81 |
| 15 | 32.47 | 72.79 | 27.96 | 32.93 | 0.30 | 2.55 | 13.21 | 110.67 |
| 16 | 29.85 | 71.71 | 26.49 | 28.13 | 0.34 | 2.83 | 15.45 | 127.87 |
| 17 | 31.49 | 72.16 | 26.48 | 27.86 | 0.34 | 2.85 | 15.44 | 129.55 |
| 18 | 31.65 | 72.05 | 26.77 | 27.51 | 0.36 | 3.00 | 16.27 | 130.76 |
| 19 | 31.41 | 72.48 | 27.01 | 29.35 | 0.37 | 2.79 | 16.12 | 122.47 |
| 20 | 32.98 | 73.01 | 28.86 | 34.29 | 0.39 | 3.22 | 16.74 | 138.20 |
| 21 | 30.56 | 72.05 | 27.01 | 29.35 | 0.31 | 2.60 | 13.74 | 115.57 |
| 22 | 31.71 | 72.27 | 26.59 | 28.29 | 0.33 | 2.63 | 14.87 | 119.40 |
| 23 | 29.99 | 72.07 | 26.30 | 27.75 | 0.34 | 2.58 | 15.33 | 117.94 |
| 24 | 31.75 | 72.20 | 27.39 | 29.89 | 0.36 | 2.72 | 15.86 | 120.63 |
| 25 | 31.82 | 72.53 | 27.47 | 30.52 | 0.33 | 2.72 | 14.32 | 120.51 |
| 26 | 32.59 | 72.63 | 27.64 | 31.38 | 0.30 | 2.40 | 13.04 | 104.98 |
| 27 | 30.46 | 71.78 | 26.68 | 28.55 | 0.32 | 2.50 | 14.46 | 113.02 |
| 28 | 30.98 | 71.79 | 26.80 | 28.95 | 0.28 | 2.17 | 12.63 | 97.42 |

***Source****: Author*

**Table 7.9** presents the street level microclimate based on the ENVI-met simulation. The detail for each microclimate is described from **Fig. 7.21** to **7.24**

## A. Mean Radiant Temperature

***Table 7.10** Mean Radiant Temperature result of model study*

| | Tmrt | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1massing | | 2massing | | 3massing | | 4massing | | 5massing | |
| | min | max | min | max | min | max | min | max | min | max |
| BC 0.2 L/W = 1 | 31.58 | 73.01 | 30.22 | 71.71 | 31.67 | 72.1 | 30.7 | 72.03 | 31.92 | 72.2 |
| BC 0.3 L/W = 1 | 31.70 | 71.9 | 33.51 | 72.72 | 25.51 | 69.41 | 25.32 | 69.22 | 25.81 | 69.74 |
| BC 0.4 L/W = 1 | 32.20 | 72.34 | 33.3 | 73.16 | 31.75 | 73.74 | 31.92 | 72.49 | 29.85 | 71.71 |
| BC 0.2 L/W = 2 | 29.85 | 71.71 | 31.49 | 72.16 | 31.65 | 72.05 | 31.41 | 72.48 | 32.98 | 73.01 |
| BC 0.3 L/W = 2 | 30.56 | 72.05 | 31.71 | 72.27 | 29.99 | 72.07 | 31.75 | 72.2 | 31.82 | 72.53 |
| BC 0.4 L/W = 2 | 32.59 | 72.63 | 30.46 | 71.78 | 30.98 | 71.79 | - | - | - | - |

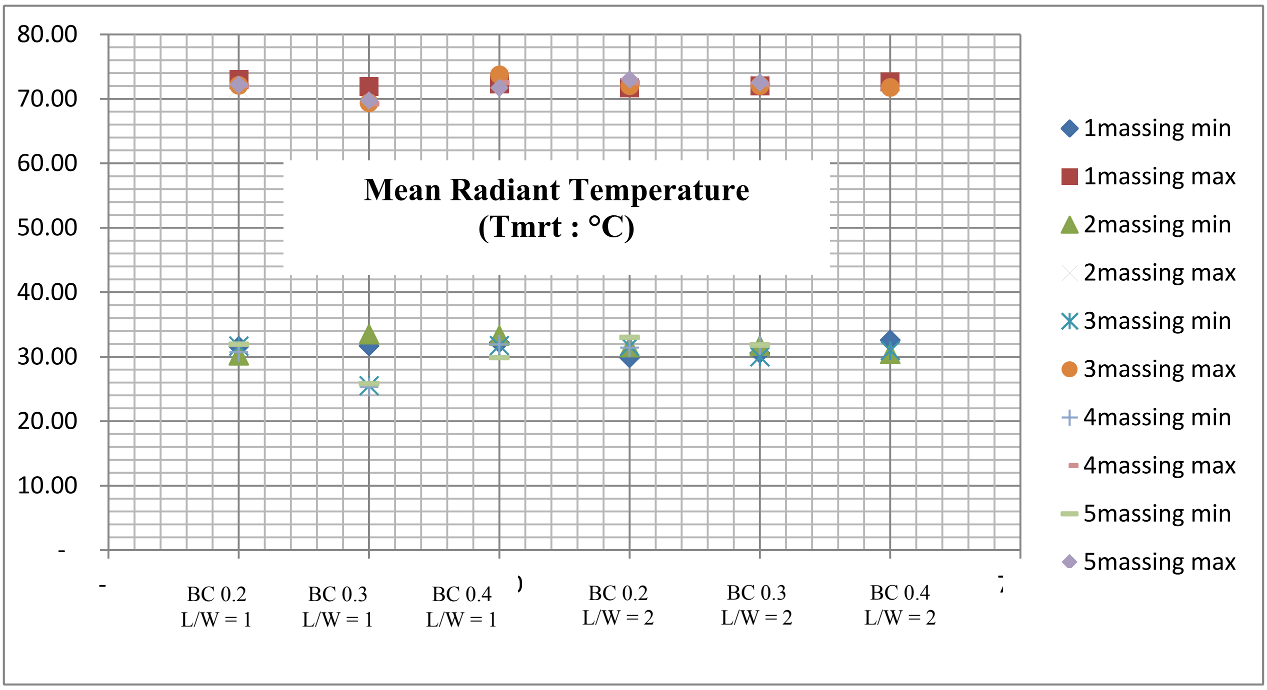



***Fig. 7.21** Tmrt results of the model study*
**Source:** *Author*

**Figure 7.21** presents the result of Tmrt based on the twenty-eight models that show Model 13 with three massing, 0.4 BC and L/W =1 reached the highest Tmrt at 73.74 ºC. Meanwhile, Model 8 reached the lowest Tmrt at 25.51 ºC, which have three massing with 30% BC and $L_1$:$L_2$ = 1. There is no significant difference of Tmrt between low and high BC, and also the amount of massing did not alter the Tmrt.

### B. Wind Speed

***Table 7.11*** *Wind speed result of Model Study*

| | WIND SPEED | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1massing | | 2massing | | 3massing | | 4massing | | 5massing | |
| | min | max | min | max | min | max | min | max | min | max |
| BC 0.2 L/W = 1 | 0.38 | 3.01 | 0.35 | 2.97 | 0.37 | 2.97 | 0.36 | 2.92 | 0.39 | 3.08 |
| BC 0.3 L/W = 1 | 0.34 | 2.67 | 0.39 | 2.85 | 0.33 | 2.58 | 0.31 | 2.66 | 0.32 | 2.75 |
| BC 0.4 L/W = 1 | 0.31 | 2.54 | 0.35 | 2.71 | 0.31 | 2.54 | 0.3 | 2.5 | 0.3 | 2.55 |
| BC 0.2 L/W = 2 | 0.34 | 2.83 | 0.34 | 2.85 | 0.36 | 3 | 0.37 | 2.79 | 0.39 | 3.22 |
| BC 0.3 L/W = 2 | 0.31 | 2.6 | 0.33 | 2.63 | 0.34 | 2.58 | 0.36 | 2.72 | 0.33 | 2.72 |
| BC 0.4 L/W = 2 | 0.30 | 2.4 | 0.32 | 2.5 | 0.28 | 2.17 | - | - | - | - |

The highest wind speed reached was 3.22m/s, found at Model 20 which has five massing with 20% BC and $L_1$:$L_2$ = 2. From the simulation, it was found that the higher BC, the lesser the wind speed. However, it was also found that the amount of building mass does not have a significant impact on wind speed or building geometry. Building geometry with $L_1$:$L_2$ = 2 emerges more wind speed compared to $L_1$:$L_2$ = 1. The result of the ENVI-met simulation is shown at **Figure 7.22** below.

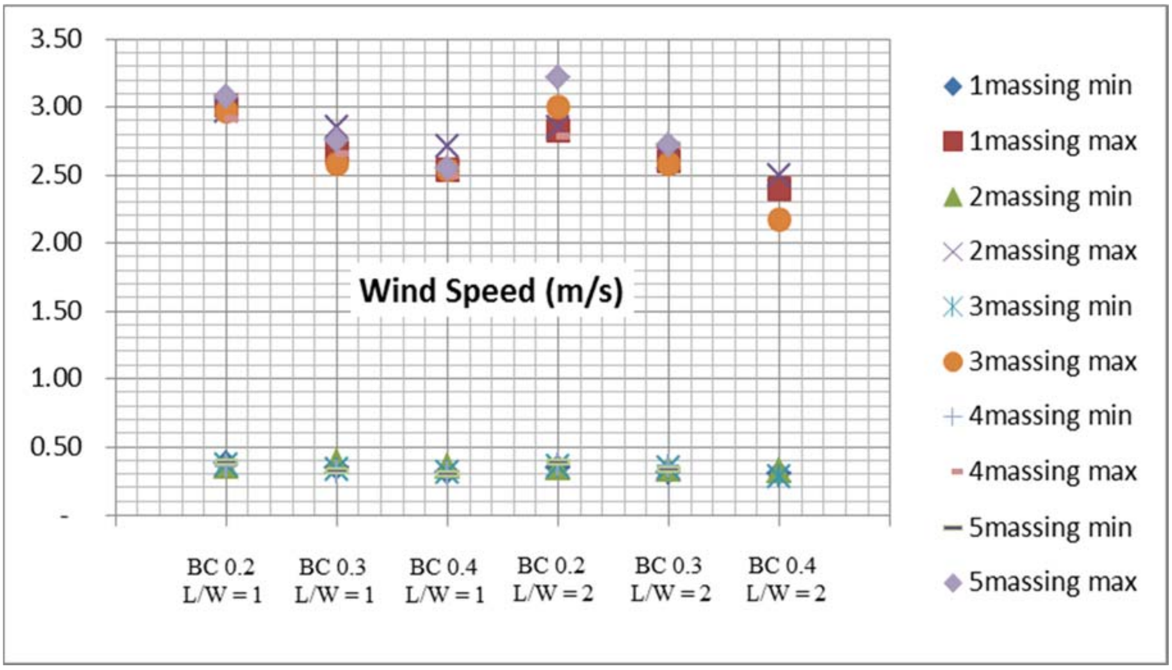



***Fig. 7.22*** *Wind Speed result of the model study*
***Source:*** *Author*

### C. Relative Humidity (RH)

***Table 7.12*** *Relative Humidity Result of Model Study*

| | Relative Humidity (RH) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1massing | | 2massing | | 3massing | | 4massing | | 5massing | |
| | min | max | min | max | min | max | min | max | min | max |
| BC 0.2 L/W = 1 | 52.27 | 60.50 | 69.86 | 82.89 | 68.14 | 80.16 | 71.89 | 113.92 | 71.58 | 85.05 |
| BC 0.3 L/W = 1 | 70.80 | 81.76 | 78.79 | 92.76 | 72.69 | 83.52 | 74.70 | 84.61 | 76.48 | 93.22 |
| BC 0.4 L/W = 1 | 70.80 | 83.22 | 74.30 | 96.12 | 55.48 | 64.56 | 71.14 | 84.50 | 73.89 | 93.48 |
| BC 0.2 L/W = 2 | 69.94 | 80.62 | 70.14 | 80.65 | 69.35 | 80.21 | 77.04 | 89.81 | 78.35 | 95.03 |
| BC 0.3 L/W = 2 | 71.71 | 85.39 | 69.48 | 80.97 | 68.14 | 78.92 | 74.09 | 88.00 | 73.41 | 89.35 |
| BC 0.4 L/W = 2 | 72.38 | 90.80 | 69.66 | 81.54 | 69.91 | 84.50 | - | - | - | - |

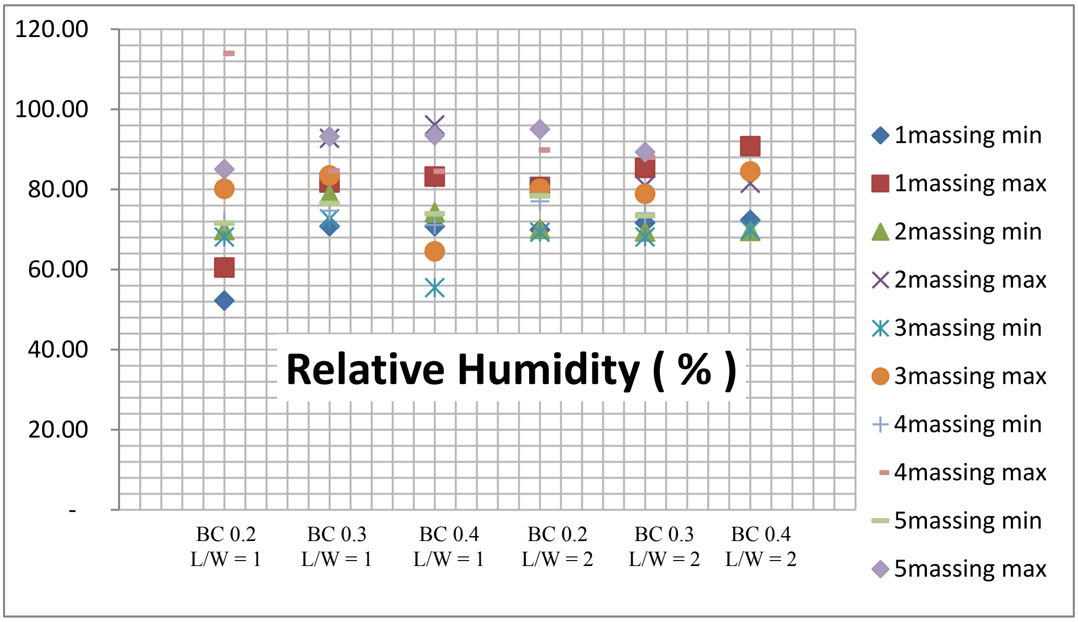



***Fig. 7.23*** *Relative Humidity result of the model study*
***Source:*** *Author*

**Table 7.12** presents the relative humidity results of the model study. From **Fig. 7.23**, it can be seen that Model 14, which has building four massing with BC 0.2 and L/W = 1 has reached the highest value of RH. Meanwhile, Model 1, which has building one massing with BC 0.2 and L/W = 1 reached the lowest value of RH.

### D. Air Temperature (Ta)

***Table 7.13*** *Air Temperature Result of Model Study*

| | Air Temperature | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1massing | | 2massing | | 3massing | | 4massing | | 5massing | |
| | min | max | min | max | min | max | min | max | min | max |
| BC 0.2 L/W = 1 | 27.86 | 29.25 | 26.68 | 28.58 | 26.31 | 27.57 | 26.82 | 28.51 | 26.78 | 28.84 |
| BC 0.3 L/W = 1 | 26.69 | 28.46 | 28.17 | 32.32 | 26.53 | 28.21 | 26.75 | 28.45 | 27.97 | 32.82 |
| BC 0.4 L/W = 1 | 27.09 | 29.09 | 29.10 | 36.50 | 28.75 | 31.57 | 26.98 | 29.04 | 27.96 | 32.93 |
| BC 0.2 L/W = 2 | 26.49 | 28.13 | 26.48 | 27.86 | 26.77 | 27.51 | 27.01 | 29.35 | 28.86 | 34.29 |
| BC 0.3 L/W = 2 | 27.01 | 29.35 | 26.59 | 28.29 | 26.3 | 27.75 | 27.39 | 29.89 | 27.47 | 30.52 |
| BC 0.4 L/W = 2 | 27.64 | 31.38 | 26.68 | 28.55 | 26.8 | 28.95 | - | - | - | - |

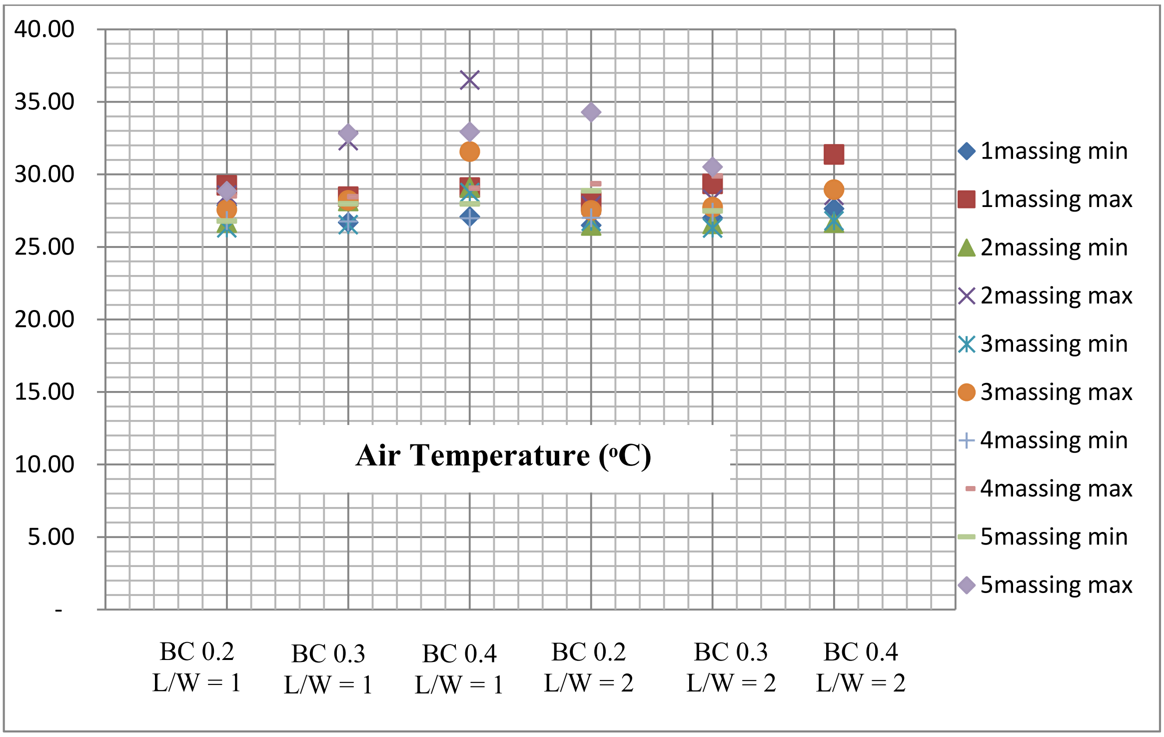



***Fig. 7.24** Air Temperature result of the model study*
***Source:** Author*

**Table 7.13** presents air temperature results from the model study. **Fig 7.24** shows that Model 12 which has building group in two massing with BC 0.4 and L/W = 1 reached the highest air temperature. Meanwhile, Model 17, which has building group in two massing BC 0.2 and L/W = 2, reached the lowest air temperature.

## 7.5. Outdoor Thermal Perception

As mentioned in this early sub-chapter, the final aim of building group passive design is to find the best method to reduce the heat intensity of outdoor thermal. Thus, the perception of humans as users in this built environment becomes the most important point to consider.

The recapitulation of 28 models are shown at **Table 7.14** below. **Fig. 7.25** shows that air temperature is the most significant meteorological parameter which influences outdoor thermal perception.

**Table 7.14** gives an understanding of better urban form and massing for offering better outdoor thermal perception. In this case, Model 8 and 9 are the optimum building groups which offer the "slightly warm" human perception on their urban living area.

Model 8 are the building groups with three massing, BC 0.3 and L/W = 1. Also, Model 9 are the building groups with four massing, BC 0.3 and L/W = 1.

***Table 7.14** Recapitulation of PET and meteorological parameters*

| | PET | TMrt | Ta | V | RH | Human perception |
|---|---|---|---|---|---|---|
| 1 | 36.10 | 52.30 | 28.56 | 1.70 | 56.39 | Warm |
| 2 | 34.80 | 50.97 | 27.63 | 1.66 | 76.38 | Warm |
| 3 | 34.50 | 51.89 | 26.94 | 1.67 | 74.15 | Warm |
| 4 | 35.50 | 51.37 | 27.67 | 1.64 | 92.91 | Warm |
| 5 | 35.50 | 52.06 | 27.81 | 1.74 | 78.32 | Warm |
| 6 | 35.60 | 51.80 | 27.58 | 1.51 | 76.28 | Warm |
| 7 | 38.70 | 53.12 | 30.25 | 1.62 | 85.78 | Hot |
| 8 | 33.50 | 47.46 | 27.37 | 1.46 | 78.11 | Slightly warm |
| 9 | 33.70 | 47.27 | 27.60 | 1.49 | 79.66 | Slightly warm |
| 10 | 36.60 | 47.78 | 30.40 | 1.54 | 84.85 | Warm |
| 11 | 36.60 | 52.27 | 28.09 | 1.43 | 77.06 | Warm |
| 12 | 41.10 | 53.23 | 32.80 | 1.53 | 85.21 | Hot |
| 13 | 38.60 | 52.75 | 30.16 | 1.43 | 60.02 | Hot |
| 14 | 36.50 | 52.21 | 28.01 | 1.40 | 77.82 | Warm |
| 15 | 39.00 | 52.63 | 30.45 | 1.43 | 83.69 | Hot |
| 16 | 34.60 | 50.78 | 27.31 | 1.59 | 75.28 | Warm |
| 17 | 35.00 | 51.83 | 27.17 | 1.60 | 75.40 | Warm |
| 18 | 34.60 | 51.85 | 27.14 | 1.68 | 74.78 | Warm |
| 19 | 36.10 | 51.95 | 28.18 | 1.58 | 83.43 | Warm |
| 20 | 39.10 | 53.00 | 31.58 | 1.81 | 86.69 | Hot |
| 21 | 36.00 | 51.31 | 28.18 | 1.46 | 78.55 | Warm |
| 22 | 35.50 | 51.99 | 27.44 | 1.48 | 75.23 | Warm |
| 23 | 34.60 | 51.03 | 27.03 | 1.46 | 73.53 | Warm |
| 24 | 36.70 | 51.98 | 28.64 | 1.54 | 81.05 | Warm |
| 25 | 37.20 | 52.18 | 29.00 | 1.53 | 81.38 | Warm |
| 26 | 38.10 | 52.61 | 29.51 | 1.35 | 81.59 | Hot |
| 27 | 35.60 | 51.12 | 27.62 | 1.41 | 75.60 | Warm |
| 28 | 36.50 | 51.39 | 27.88 | 1.23 | 77.21 | Warm |

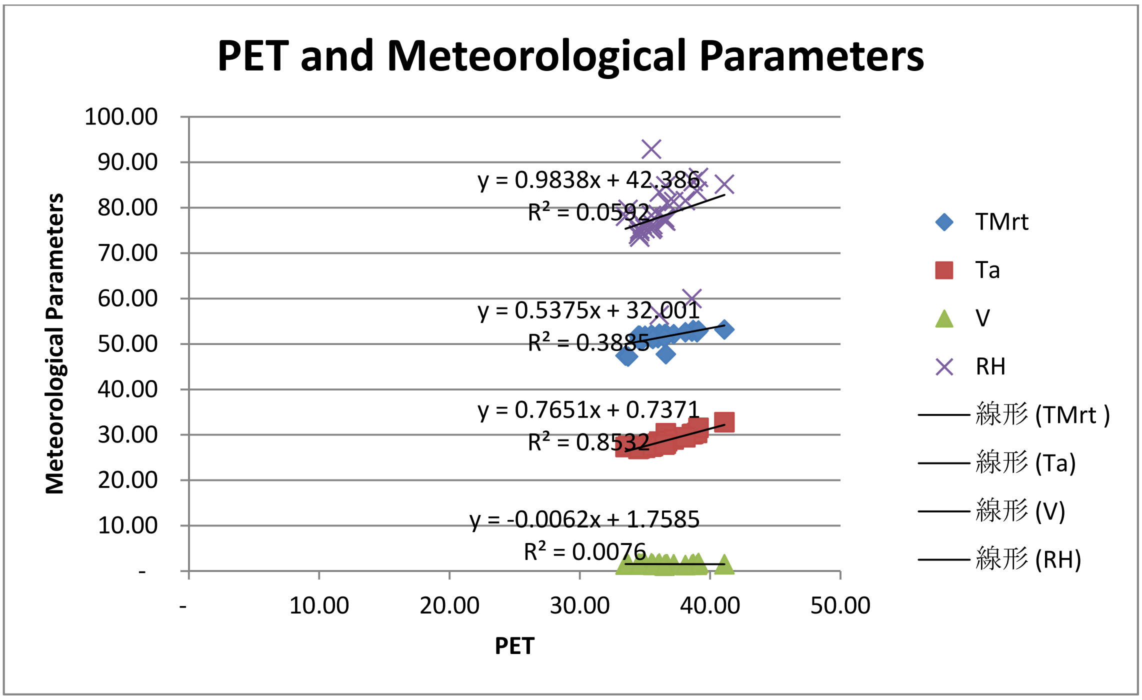



***Fig. 7.25*** *PET and Meteorological Parameters for Model Study*
***Source:*** *Author*

As shown in **Fig. 7.25,** air temperature is the most significant meteorological parameter. Thus, to improve the level of comfort, there is a need to provide more vegetation and green coverage area, as is mentioned in the previous chapter.

## 7.6. Closing Remarks

The conclusions of this study are:

1. This study reinforces the theory of outdoor thermal comfort which states that Ta is a major factor affecting comfort level perception.
2. Fom the total twenty-eight building group models, only two models offer slightly warm outdoor thermal perception. Six models in hot level and the most exist are twenty models which offering the ‘’warm’’ for human perception . Event though maximum wind speed was achieved at 3m/s, it is still difficult to offer neutral or comfort levels. Urban ventilation that encourages wind flow through building masses and forms is not significant enough to reduce air temperature and mean radiant temperature, which also affects comfort level perception.
3. Similar to the data found in the previous studies (R. Immanuel, 2007, E.L. KRÜGER, 2011, Chun Liang, 2013) , this study also emphasizes that vegetation significantly reduces Ta as well as Tmrt. Planned open green spaces at the point of highest radiation are able to reduce the mean radiant temperature (Tmrt).
4. There is no significant different between $L_1$:$L_2$ = 1:1 with $L_1$:$L_2$ = 1:2, both in inducing wind speed or affecting the level comfort perception. However, the greater number of buildings within the site with less BC, the greater the increase in wind speed.

**Bibliography**

Kemenpera. 2013. Program dan Kegiatan Deputi Bidang Perumahan Formal. Jakarta.

Kementerian Pekerjaan Umum, NOMOR : 60/PRT/1992, T*entang Persyaratan Teknis Pembangunan Rumah Susun*, Jakarta

Kementerian Pekerjaan Umum, Nomor : 05/Prt/M/2007, *Tentang Pedoman Teknis Pembangunan Rumah Susun Sederhana Bertingkat Tinggi,* Jakarta

National Standarization Agency of Indonesia (BSN), SNI 03-2846-1992, *Tentang Tata Cara Perencanaan Kepadatan Bangunan Lingkungan Rumah Susun Hunian,* Jakarta.

National Standarization Agency of Indonesia (BSN), SNI 03-2845-1992, *Tentang Tata Cara Perencanaan Rumah Susun Modular,* Jakarta.

National Standarization Agency of Indonesia (BSN), SNI 03-7013-2004, *Tentang Tata Cara Perencanaan Fasilitas Lingkungan Rumah Susun Sederhana*, Jakarta.

Pemerintah Republik Indonesia, UU No.16 Tahun 1985, *Tentang Rumah Susun,* Jakarta

Pemerintah Republik Indonesia, UU No. 4 Tahun 1988, *Tentang Rumah Susun,* Jakarta.

Pemerintah Republik Indonesia, UU No. 20 Tahun 2011, *Tentang Rumah Susun,* Jakarta.

R. Emmanuel, H. R. A. E. J. 2007. *Urban Shading – A Design Option For The Tropics? A Study In Colombo, Sri Lanka.* Int. J Climatol, 27.

E.L. KRÜGER, F. O. M., F. RASIA 2011. *Impact of Urban Geometry on Outdoor Thermal Comfort and Air Quality From Field Measurements in Curitiba, Brazil*. Building and Environment, 46, 621-634.

CHUN LIANG, et.al., 2013. *Outdoor Mean Radiant Temperature Estimation in The Tropical Urban Environment*. Building and Environment, 64, 12.

# 8. Conclusion

## 8.1 Urban Form and High Density

Based on the density observation of Bandung city, which focused on slum areas, it has been found that this city has the characteristics of low floor area ratio (FAR), high dwelling units (DU), and high population. These characteristics, as mentioned by Lee (2011), are mostly found in cities in developing countries with crowded neighbourhoods and informal, unregulated development, such as Mumbai, India.

Table 3.4 shows the slum area within five districts in Bandung. Sumur Bandung with 10,635 person/ha has 15 area with high slum (HS) character, this number also the biggest slum area in Bandung. Somehow, Bojongloa Kaler with 39.282 person/ha has only five RT/RW (neighbourhood cluster) with low slum (LS) character.

This slum's character, then, is explained by the accumulation (stacking) of urban land-use. As shown at Figure 3.8, Cibeunying contains the largest urban slum area in Bandung; this is not because of its dense population, but merely because 32.5% of the public facilities are located in Cibeunying.

The unequal distribution of land use is also seen in Figure 3.5, where the settlement occupies 56% of the total land available; meanwhile, green space, in addition to land for planting (fields, gardens), occupies only 4% of the total Bandung's land. With a population of 2.4 million people and 9,290/ha for the settlement, it means living space for one person equals 38 $m^2$, well above the minimum standard of floor space per person set by the United Nations Centre for Human Settlements (UNCHS), which requires 20m2/person. In fact, there is uneven spreading of settlement locations in Bandung, as well as a wide gap in settlement quality.

## 8.2 Heat Intensity in Bandung

The data collection from Bandung shows that the average temperature from 1987 until 2012 has increased from 22.6°C to 23.4°C (0.8°C). Air temperature measurements were taken within one month at five different spots in Bandung, including North Bandung (+946. m.a.s.l), East Bandung (+664.5 m.a.s.l), South Bandung (+680 m.a.s.l), West Bandung (722.6 m.a.s.l) and BMKG (Bandung Meteorological Agency at +665 m.a.s.l), and these measurements have shown the difference value in diurnal temperature range. The BMKG spot measurement recorded has the biggest gap of diurnal temperature between morning and evening at about 11.5°C. Meanwhile East Bandung has the lowest gap of diurnal temperature at 3.6°C.

The BMKG measurement spot itself is located in Bojonegara, within the center of Bandung, and has the highest amount of activity because services, such as commercial buildings, local government offices, health facilities, and educational facilities, are there. The big gap of diurnal temperature between morning and evening has shown that the downtown area potentially creates the urban heat island. The incoming short-wave radiation which has been absorbed during sunny day, however, at night, due to the dense infrastructure of Downtown area that have low sky view factors cannot easily release long-wave radiation to the cooler, open sky, and this trapped heat contributes to the urban heat island.

The measurement of urban microclimate in the area of each 37ha for three different land uses, such as an educational area at Indonesia University of Education (+920 m.a.s.l), a high-density settlement at Tamansari (+729 m.a.s.l), and an industrial area at Cigondewah (684.15 m.a.s.l), has shown that the highest mean radiant temperature (Tmrt) value is in the educational area, which is located at the highest altitude compared with two other areas, where it is supposed to be the coldest.

In this educational area, the highest value of Tmrt was recorded at 61.39°C, with the peak hours being between 11.00 am – 12.00 pm. Meanwhile, at high-density settlements, the highest value of Tmrt was recorded at 59.2°C; somehow the heat in this area was trapped longer, from 7.00 am until 14.00 pm. The industrial area was recorded with the lowest Tmrt value at 57.2°C, and the peak of the temperature occurred from 10.00 am until 14.00 pm. These show the urban surface coverage that gives different treatment to short wave radiation which hinders the ability to release the long-wave radiation.

The longer heat was trapped during the sunny day at the high-density settlement also showed the absence of urban ventilation, as well as green coverage, hence potentially increasing the heat intensity within the urban area.

Therefore, the slum area would be the most vulnerable area facing urban heat intensity, due to building density and lack of open space and green space. Thus, as mentioned in the table 3.4 in chapter 3, the five sub-districts with high-density settlements, Astanya Anyar, Bojong Loa, Bandung Wetan, Kiara Condong and Sumur Bandung, potentially contribute to urban heat intensity.

Furthermore, based on Figure. 3.8, Cibeunying Area (SWK) has the top priority for urban arrangement and revitalization, based on its condition, because it is the largest slum area and has the highest concentration of public facilities in this area.

## 8.3 Building Form and Massing

Building form and massing include their height, and space between them provide the connection toward urban microclimate. From the three different measurements as shown in Table 5.4, it indicates that specific characteristics of urban morphology result in different urban microclimates. The urban form character of Universitas Pendidikan Indonesia, building canyon (H/W) gives the most significant element which impact to Tmrt value ($R^2$ = 0.52). Meanwhile at the high-dense settlement, building coverage (BC) is the most significant element which influence Tmrt value ($R^2$ = 0.68). Finally at the industrial area which also contain the paddy field brings floor area ratio (FAR) as the most significant element which influence Tmrt value ($R^2$ = 0.53).

Thus, the approach to improve the microclimate also depends on the physical characteristics and the designation of the area. The roughness of the surface area and its insolation play different roles determining the urban microclimate.

On the other hand, the measurement of the five public flats (*rusuns*) in Bandung also give the understanding that building form and massing have the potential to manipulate the sun and the wind to improve the microclimate surrounding the buildings. As shown in Table 5.7, manipulation of H/W gives impact to wind speed ($R^2$ = 0.76), FAR gives impact to humidity ($R^2$ = 0.98), BC gives impact to humidity ($R^2$ = 0.7), VCR gives impact to air temperature ($R^2$ = 0.66), and finally SA gives impact to wind speed ($R^2$ = 0.72).

The strong correlation between building configuration and microclimate provides for the possibility of passive design strategies in hot, humid climates as seen in Table 5.8.

Building a canyon with $\alpha = 31.4^o - 58^o$ and a surface area ratio of 0.12-0.15 has been found to induce wind speeds of $\geq$ 3.4m/s; FAR $\geq$ 1.1, and BCR $\leq$ 0.3 has been found to reduce the high humidity to as low as 79%. In this assessment it has also been found that the most significant aspect of urban form parameters that are able to control air temperature is the providing of vegetation/green coverage ratio (GCR) in more than 17% of the total area.

## 8.4 Urban Microclimate Prognostic Model

The prognostic model for solar insolation being the necessity, due the rapid measurement within the an urban context. The ENVI-met, then is a useful tool to know the microclimate through flow around and between buildings, exchange processes of heat and vapour at the ground surface and at the walls, turbulence also the exchange and vegetation parameters. The validation model as seen in Table 6.1 and Figure. 6.2, have shown for Spot 1 ($R^2$= 0.88); Spot 2 ($R^2$ = 0.70); Spot 3 ($R^2$ = 0.92); Spot 4 ($R^2$ = 0.82); Spot 5 ($R^2$ = 0.95) and Spot 6 ($R^2$ = 0.62). The similarity of the value of measurement and prognostic models are shown by the raising of insolation within the area, which starts from 7:00 am and lasts until 17:00 pm.

This validation means that ENVI-met is usefull and accurate tool to be able to use in hot-humid climate region.

## 8.5 Outdoor Thermal Comfort at Hot Humid Climate Region

Tmrt, as influenced by a surface temperature of open area which directly gets solar insolation, is the most significant aspect regarding human perception of outdoor thermal comfort. This discussion on human perception of outdoor thermal comfort is divided into three types. They are: (1) prognostic models based on fluid and thermodynamics using ENVI-met, (2) based on the energy balance of the human body and (3) thermal sensation in terms of several climatic parameter. The first outdoor thermal indices is PMV, which is generated from ENVI-met. Second and third are PET and PMV-r, which are generated from Rayman. The last one is $Y_{JS,}$ which is calculated from meteorological aspects plus human aspects.

Further more, **Fig. 6.12** gives the value of PET and PMV (ENVI-met) with $R^2$ = 0.99, PET and PMV-r (RayMan) with $R^2$=0.97 and PET and $Y_{JS}$ with $R^2$ = 0.74. These values of $R^2$ are such that four of them are interchangeable, since the coefficient of determination between PET (which based on human energy balance) with PMV (based on prognostic model) and also $Y_{JS}$ (based on thermal sensation) have the significant value: $R^2 \geq 0.6$. This statement also means that four of these outdoor thermal indices are valid to use in the hot-humid climate region.

**Fig**. **6.13**, **6.14** and **6.15** have shown that air temperature is the most significant meteorological parameter which can influence the value all these indices such as: PET ($R^2$ = 0.95), PMV Rayman ($R^2$=0.98) also PMV ENVI-met ($R^2$ = 0.98). Meanwhile, **Fig. 6.16** for $Y_{JS}$, both of Ta and TG have equal value as much as $R^2$=0.58

The importance of air temperature in this outdoor thermal comfort implies that vegetation as the physical aspect of urban form needs to be taken as an important factor in the passive design strategies in the hot, humid climate regions as mentioned in **Table 5.8**.

## 8.6 Legal Aspect of *Rusun*

There are several legal aspects dealing with the development of public flats (*Rusun*) in Indonesia, which are (1) 60/PRT/1992 about Technical Requirement of Rusun Construction, (2) 05/PRT/M/2007 about Technical Guideline of Multiple Stories of Rusun Construction, (3) SNI 03-2845-1992 about Procedures for building density of *Rusun*, and (4) SNI 03-7013-2004 about Procedures of Planning *Rusun's* Facilities.

Based on Table 7.2, these legal aspects have many overlapping statements between regulation and prototype realization. The recommendation regarding this legal aspect of *Rusun*, then can be summarised in the following statements: The first priority is to determine and accommodate for the people density. It also has to consider the environmental load for the infrastructure. *Rusun*, as a public flat complex with high FAR, high DU, and high population, can be very liveable, comfortable environment, by using an efficient development pattern.

## 8.7 Recommendation for Future Research

The investigation into heat intensity can be developed extensively in all districts in Bandung, so that an accurate map of urban climate can be obtained. The creation of an urban climate map of Bandung city is necessary, given the tendency of temperature to increase each year, as well as the urban heat island phenomenon in the northern part of Bandung. This area is supposed to have an average temperature lower than most other Bandung locations, but in fact, it has the highest Diurnal Temperature Range. The increasing of regional expansion (the change of land-use) as well as the increase of the city's roughness level, which the potential to store latent heat, contribute the heat intensity.

This urban climate map will give specific information about heat intensity, which then can provide optimum recommendations regarding land-use strategies, especially for urban environments.

# THESIS RESUME

Tropical cities which lay near the equator line within +23 degrees and -23 degrees latitude are having abundant natural resource of the sun, and it is 6 months facing the North and 6 months facing the South. The temperature remains relatively constant throughout the year, which means solar availability and precipitation become the most influence seasonal variation. Geographical location significantly influences to amount of insolation which known as short for incident or incoming solar radiation, which is the total energy received at a certain time in a given surface area. This solar radiation, then becomes the main factors for urban microclimate in a tropical city, which potentially induce the heat since this region is facing solar radiation longer than other climate region.

The urban microclimate itself has a special local atmospheric condition that its climate differs with the surrounding area. The urban morphology and its configuration which including building form and massing also its density, then becomes the matter of gaining urban thermal by keeping the heat on their surroundings. Specific discussion about urban physics is urban fabrics meet with meteorological aspects then bring into specific urban microclimate. Urban built environment, particularly in relation to the form and mass of buildings. Their size, shape, scale, orientation and distribution of green spaces is well positioned to gain outdoor thermal comfort, but when its planning and design does not adapt the local climate, then the opposite will happen naturally. Its heat from solar radiation during the daytime is trapped on to surface area, such as wall, roof and ground area, which potentially gain the meant radiant temperature (Tmrt). The Tmrt is defined as the ‘’uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure’’ (ASHRAE, 2001). During sunny weather in hot season, this Tmrt is the most important meteorological input parameter for the human energy balance. (Herrmann and Matzarakis, 2011). Therefore, outdoor thermal comfort significantly influenced by the Tmrt value.

Specific study on tropical monsoon, which classified as ‘Am’ by Köppen-Geiger this region also known as tropical wet and relatively rare type of climate. The mean temperature is above 18$^{o}$C every month with wet and dry seasons. This region also tends to have less variance in temperature throughout the year. Monsoon circulation becomes the major controlling factor, which also a seasonal change in wind direction due to the difference in the way water (ocean) and land heat. Thus, building group passive design strategies in urban fabrics becomes a necessity, given the absence of extreme temperature changes especially at the outdoor area. The amelioration of microclimate will give the positive impact to urban climate.

This study presents a thorough discussion that divided into: (1) The trend of heat intensity in a city which correlated with land use changes and differences; (2) Urban form that contribute to the alteration of microclimate by describe its urban physics meet meteorological aspects. In this part will present an example of assessment of building form and massing which influence of outdoor thermal comfort; (3) Passive design strategy of building form and massing take into consideration of population density and its microclimate effects.

Bandung, Indonesia then becomes the object study to observe its potential and urban environment problem, to seek the solving contribution. Located in the low latitude, Bandung city, Indonesia lies in 6.54ºS and 107.36ºE with 706.29 m (2,317.22 ft) above sea level. This city is cooler than most other Indonesian cities since its average temperature of 24.72 ºC (76.5 ºF) throughout the year. With 2,4 million inhabitant, Bandung becomes the 2$^{nd}$ highest population of any metropolitan in Indonesia after Jakarta. The problematic description caused by rapid urbanization, which affected into the urban built environment, its building density, the change of land-use, and also the quality of urban living.

**Chapter 1** describes the overall thesis content. **Chapter 2** is a literature review that is used as a theoretical basis, the studies that have been done and the position of this study among other studies in the same field. Included in this discussion are: hot-humid climate characteristics, urban form and configuration which are adaptable to the hot-humid climate, outdoor thermal comfort in the hot-humid climate, and modelling and simulation of microclimate. **Chapter 3** provides the information of Bandung city, the problem caused by rapid urbanization which affected the urban built environment, its building density, the change of land-use, and also the quality of urban living. **Chapter 4** gives the understanding of the methodology of this research. From the field measurement calibration and collection, the description of urban form and massing, it's potential to affect the microclimate, and the use of prognostic models to understand microclimate and urban living comfort. And finally, the correlation of each study to provide the recommendation of building group passive design. **Chapter 5** shows how the urban form significantly influences the microclimate by providing several results of field measurement. Three different land-uses as samples, which are: a high-density settlement; an educational area and an industrial area, will show the correlation between the building coverage ratio (BCR), floor area ratio (FAR) and urban canyon (H/W) with the mean radiant temperature (Tmrt). The Sky view factor (SVF) formed by the urban fabric, also shows correlation with the mean radiant temperature (Tmrt) though not with significant values. This chapter also shows the trend of increasing average temperatures for the past 25 years, and recent diurnal temperatures for four different regions of Bandung. This chapter also assess five public flats (rusun) to find the correlation between building block design and urban meteorology. The recommendations of building group planning and design are given based on the meteorological and climatic approaches. **Chapter 6** explains the urban microclimate prognostic model, and the meteorology alteration due to rapid measurement. These are: (1) Envi-met is a tool to diagnose and project urban microclimate change within urban areas, and to know the mean radiant temperature and outdoor thermal comfort; (2) RayMan stands for ‘radiation on the human body’. It estimates the radiation fluxes and effects of clouds and solid obstacles on short wave radiation fluxes (Matzarakis, 2011). This chapter also gives the strategy of building group planning and design, with respect to outdoor thermal comfort in hot/humid climate regions. By describing PET (Physiologically Equivalent Temperature), PMV (Predicted Mean Vote) and YJS (Nyaman Jalan Santai – Indonesia rate) to know the meteorological parameters which are important within the urban form. In **chapter 7,** it discusses the legal aspects of flat construction in Indonesia. As the main method of providing affordable housing, it is necessary to examine the technical guideline of rusun construction, which is then used as a basic input to do the experiments of building form and massing. Conclusions in **chapter 8** contains the conclusion of urban microclimate in building form and massing in Bandung, Indonesia. The recommendations for urban planning and design, especially for building groups of form and massing. The last part is about future studies that are expected from the result of this research.

# Abbreviations

| | |
|---|---|
| ASHRAE | American Society of Heating, Refrigerating and Air-conditioning Engineers |
| BCR | Building Coverage Ratio |
| DIKTI/ DGHE | Directorate General of Higher Education of Ministry of Culture and Education of Republic Indonesia |
| FAR | Floor Area Ratio |
| H | Height of building |
| H/W | Height/Width, expression for building canyon |
| PET | Physiologically Equivalent Temperature |
| PMV | Predicted Mean Vote |
| RH | Relative Humidity |
| SA | Surface Area |
| SVF | Sky View Factor |
| Tmrt | Mean Radiant Temperature |
| W | Width : distance between buildings in a street canyon |
| VCR | Vegetation Coverage Ratio |
| $Y_{JS}$ | Human perception of outdoor on walking (Indonesian: *Nyaman Jalan Santai*) |

# Glossary

***Energy balance of the human body*** describes the relationship between the calories (energy) consumed in foods and beverages and the calories (energy) burned by the body.

***Insolation*** is the total amount of solar radiation energy received on a given surface area during a given time. It is also called solar irradiation and expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day.

***Longwave radiation*** is the emittance of heat resulting from the absorption of incoming shortwave radiation.

***Prognostic Model*** is a numerical weather prediction uses mathematical models of the atmosphere and oceans to predict the weather based on current weather conditions.

***Rusun*** is the abbreviation of *rumah susun* (Indonesian) which is in the sense of public flat, a low cost housing, in this research the term of *rusun* refer to public flat which provided by ministry of public housing.

***Shortwave radiation*** is radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra. Solar radiation is to consider as a shortwave radiation.

***Tropical monsoon climate***, occasionally also known as a tropical wet climate, see less than 600mm precipitation but more than 100mm. It tends to see less variation in temperatures during the course of the year

***Thermal sensation*** in terms of several climatic parameters, such as: air temperature, humidity, wind speed, global solar radiation, global temperature, surface temperature, etc. with a regression model

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