

## SPATIAL CONTROL TO REDUCE URBAN HEAT ISLAND EFFECT IN URBAN HOUSING

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### ABSTRACT

*As the world's issue of global warming, built environment has to be designed to reduce global warming effects such as urban heat island. A large building coverage with small amount of vegetation tends to have urban heat island effect. Some urban housing have typical spatial character that trigger urban heat island effect. Some physical aspects give wide contribution to urban heat island effects, such as space configuration, vegetation and land coverage. The influences of these aspects can be observed by simulating the aspects. As the heritage preservation region, some urban housing such as Kauman Jogjakarta can't be redesigned by changing its main buildings. Therefore, space configuration changing in a simulation can help to know the influence of space configuration type to thermal comfort of the region. Choosing the right material type to cover the soil will give a good contribution to reduce temperature. The presence of vegetation with various types can reduce heat expose to the areas. Some types of vegetation give a big contribution to reduce temperature. As the material study, choosing the right type of vegetation can reduce temperature and increase microclimate comfort. Areas with high density leafs plants give better contribution to microclimate comfort. High dense leaf plants in existing area were planted with certain pattern. The existing space configuration as perpendicular circulation pattern gives better microclimate condition than random pattern. There are some aspects to reduce the urban heat island effect in urban housing by controlling urban housing space on three main aspect: land coverage, vegetation and space configuration.*

**Keywords:** *urban housing, spatial control, urban heat island*

### ABSTRAK

*Sebagai isu dunia pemanasan global, lingkungan terbangun harus dirancang untuk mengurangi efek pemanasan global seperti urban heat island. Bangunan besar yang tertutup dengan sejumlah kecil vegetasi cenderung memiliki efek urban heat island. Beberapa perumahan perkotaan memiliki karakter spasial tipikal yang memicu efek*

urban heat island. *Beberapa aspek fisik memberikan kontribusi yang luas bagi efek urban heat island, seperti konfigurasi ruang, vegetasi dan tutupan lahan. Pengaruh dari aspek-aspek ini dapat diamati dengan mensimulasikan aspek . Sebagai kawasan pelestarian heritage, beberapa perumahan perkotaan seperti Kauman Yogyakarta tidak dapat dirancang ulang dengan mengubah bangunan utamanya. Oleh karena itu, perubahan konfigurasi ruang dalam simulasi dapat membantu untuk mengetahui pengaruh jenis konfigurasi ruang terhadap kenyamanan termal kawasan. Memilih jenis material yang tepat untuk menutupi tanah akan memberikan kontribusi yang baik untuk mengurangi temperatur. Kehadiran vegetasi dengan berbagai jenis dapat mengurangi paparan panas ke daerah sekitarnya. Beberapa jenis vegetasi memberikan kontribusi besar untuk mengurangi suhu. Sebagaimana studi material, memilih jenis vegetasi yang tepat dapat mengurangi suhu dan meningkatkan kenyamanan iklim mikro. Area dengan tanaman berdaun lebat memberikan kontribusi yang lebih baik untuk kenyamanan iklim mikro. Tanaman berdaun lebat pada daerah eksisting ditanam dengan pola tertentu. Konfigurasi ruang yang ada seperti pola sirkulasi tegak lurus memberikan kondisi iklim mikro yang lebih baik daripada pola acak. Ada beberapa aspek untuk mengurangi efek urban heat island di perumahan perkotaan dengan mengontrol ruang perumahan perkotaan pada tiga aspek utama: tutupan lahan, vegetasi dan konfigurasi ruang*

**Kata kunci:** perumahan perkotaan, control ruang, urban heat island

## INTRODUCTION

Nowadays, world's global issue of environment is global warming effects which have wide effects to the human life and environment, caused by high pollution in the atmosphere from fossil fuels energy consumption of various fields. As the world's need to fossil energy, the buildings take a lot of part of fossil energy consumption to gain comfortable condition inside and around the buildings.

As the nature of solar radiation absorbed and reflected back by land coverage, effects on the temperature around the land coverage. The region with land coverage that easily absorbs the heat tends to increase the temperature and form the phenomenon known as the 'urban heat island'. As a result, the energy requirements for air conditioning in buildings in the area increased. (Tursilowati, 2008).

Since the rapid development of built environment around the world, planning and designing of built environments need to be synchronised to environmental preservation to avoid or at least reduce urban heat island effects. Urban housing is a built environment in urban region which tends to have urban heat island effects. By controlling some urban housing spatial aspects, the increasing temperature as urban heat island effect can be reduced.

The problems to be learned in this theme are:

1. Physical factors influence on microclimate condition in urban housing
2. Guideline step to reduce urban heat island effect in urban housing area

## **THEORY / RESEARCH METHODS**

### **Thermal Comfort Standard**

According to ISO 7730:1994, thermal comfort standard refers to Fanger, influenced by:

1. Air temperature
2. Mean Radiant Temperature
3. Relative Humidity
4. Air velocity

Other factors are metabolism and clothing type. (Karyono, 2001 and Sugini, 2004).

According to SNI T14-1993-03, in Kusumawanto, 2005, thermal comfort standard in Indonesia can be classified in effective temperature as:

1. Cool mild comfort (20,5-22,8 °C ET)
2. Comfortably optimum (22,8-25,8 °C ET)
3. Comfort warm (25,8-27,1 °C ET)

### **Urban Heat Island**

Urban heat island is certain urban area which has higher surface temperature than other surrounding areas. Releasing of air conditioner energy system, energy emission of industrial activities, transportation machine, difference amount of land coverage and difference amount of heat capacity of building material with natural material. Urban heat island implies to air pollutant movement, influence bioclimatic condition, heating and cooling. (Tursilowati, 2008).

### **Microclimate of Urban Housing**

According to Golany, 1996, there are some aspects to be concerned on designing urban housing, such as :

1. Street orientation  
Perpendicular street orientation will enhance air circulation into region.
2. Street width  
In tropical humid climate, a wide street enhances urban ventilation but needs a lot of shading because of big absorbance of sunlight. Sunlight radiation increases on the asphalt surface and decreases when stone or cement is used.
3. Vegetation  
Trees absorb dust and pollutant, decrease noise, sunlight radiation effect, albedo, and build shading area. Vegetation type and its density influence urban thermal comfort, wind velocity and relative humidity.
4. Evapotranspiration  
Evapotranspiration increase relative humidity and decrease air temperature while the environment become warmer and its relative humidity is low. Vegetation absorbs radiation and functioned as wind breaker.

According to Wonorahardjo, 2007, the main physical factors of built environment are:

1. The changing of natural land coverage by artificial land coverage, buildings and other infrastructures.
2. The decreasing plants can cause the decreasing of natural cooling effect from shading and transpiration of soil water and leafs (evapotranspiration)
3. Increasing of buildings causing narrow roads which trap the heat and air velocity (geometry effect)
4. Increasing of heat waste from machines of vehicles, factory and air conditioner also other human activities causing increasing of environment heat and make worse anthropogenic effect.
5. Increasing of air pollution causing the green house gas in the atmosphere.

Jusuf and Hien, 2009, physical factors of built environment influence microclimatic condition such as wall surface, land coverage area, ratio of building height average and building areas, vegetation, sky view factor and albedo of built environment surface areas.

## **Vegetation**

Shading is an important aspect influencing microclimatic comfort. Ideally, each building is designed by adopting shading as an architectural aspect. Plant as a shading in outdoor area can reduce sun radiation almost all the year. Plants have a big influence in microclimatic condition. Loures et al, 2007, in Panagopoulos (2008), plants have some benefits such as oxygen sources, reducing noise, refresh the air, controlling microclimatic condition, preserving soil and water, preserving bio diversity, increasing humidity, decreasing thermal stress, increasing local air velocity, recreation, cultural, social and increasing living quality.

Plants reducing surrounding temperatures by shading the soil, therefore the sun radiation is less on the soil surface and less heat adsorbed, the rest radiation is reflected back to the atmosphere (Panagopoulos, 2008).

The temperature difference between shaded soil surface and without shading, showed significant level. In summer, the soil surface beneath olive trees had 11<sup>0</sup>C lower than plain soil surfaces. In winter, the soil surface beneath olive trees is warmer 4<sup>0</sup>C than the plain soil surfaces. The trees can decrease microclimatic temperature and also control surrounding temperature. (Panagopoulos 2007, in Panagopoulos, 2008). The light coloured roof and land coverage and also trees shade influence energy saving directly or indirectly (Rosenfeld, 2001, in Panagopoulos, 2008).

Green roof with vegetation planted surface increase ecosystem performance in urban areas include increasing of water storm management, better building temperature regulation, decreasing of urban heat effect and increasing of biological habitat in urban areas. In cold climate areas, green roof is filter and save water storm on site. (Panagopoulos, 2008)

## **Spatial Configuration**

According to Toudert and Mayer, 2007, outdoor thermal comfort is influenced by ratio of circulation width and building height and circulation orientation. Other aspects are arrangement of supporting elements, such as vegetation arrangement, additional shading, etc.

Urban ventilation in tropical humid climate needs air velocity and urban ventilation to reduce urban temperature (Golany, 1996). So it is important for urban areas to receive a lot of air or wind into site. Street grid system supports air penetration deep into the region. In the other side, blocked streets slow air penetration into the region.

## **Land Coverage**

Cool Pavement Report, 2005, material for land coverage characters consist of:

1. Albedo  
Albedo is averaged solar reflectance on material surface to reflect the sun radiation to the atmosphere. The dark coloured surface has lower albedo that adsorbs the sun radiation more than the light coloured surface.
2. Permeability  
Permeability is material ability to be water passed as well as its porosity condition. The material with high permeability and porosity is well water passed and less to transfer the heat inside and around the material.
3. Conductivity  
Conductivity is material ability to conduct or adsorb heat from the surface into the material. Material with high conductivity tends to increase the surface temperature faster. Otherwise, material with low conductivity increasing the surface temperature slower.
4. Emissivity  
Emissivity is material ability to radiate the heat inside the material out to the surrounding. Material with high emissivity tends to increase the surrounding temperature faster.
5. Thickness  
The material has its effective thickness which can be cooler faster. Too thin material can be warm faster or too thick material can absorb the heat
6. Convective airflow  
The material porosity condition influences the convective airflow inside and around the material. The more porosity of material means the more permeable material, the convective airflow inside and around the material is better.

## **Research Methods**

Research method approach is experimental method by simulation to know optimization of thermal comfort in Kauman. By changing variable in controlled setting, an interaction of a variable to another variable can be observed. Experimental research tends to be supported by numerical data than narrative one. This research is done by

three steps of experimental plan, refers to Ghozali, 2008, about experimental research design (Table 1):

**Table 1.** Experimental Plan

	<b>I</b>	<b>II</b>	<b>III</b>
Vegetation (V)	V	VC	VM
Space configuration (C)	C	CV	CM
Material (M)	M	MV	MC

Vegetation is modified by adding trees T1 (shady crown, 10 m) and T2 (shady crown, 15 m) types. Existing's space configuration is modified by grid system circulation pattern and material is modified by replacing existing land coverage with light-coloured brick stone (yellow, in Envimet simulation).

1. Collecting Data Method

Collecting data method by interviewing structurally (purposive sampling), spatial data and thermal measurement in typical spaces.

2. Data Analysing

Method Measurable data is analysed by PMV calculator and spatial data is analysed by Envimet 3.1.

3. Research Variable

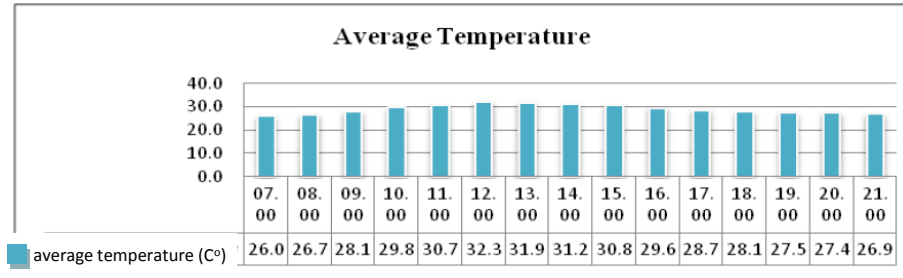
Research variables are measurable variable, subjective variable and spatial variable. Measurable variables are temperature (°C), relative humidity (%), Mean Radiant Temperature (°C) and wind velocity (m/s). Subjective variable is thermal perception of users, spatial variables are land coverage, vegetation presence and spatial configuration.

4. Research Border

This research is limited to Kauman Jogjakarta area with the main focus in urban housing. Result and discussion focuses are interview result, thermal measuring result, physical aspect and modification result in optimalization of thermal comfort.

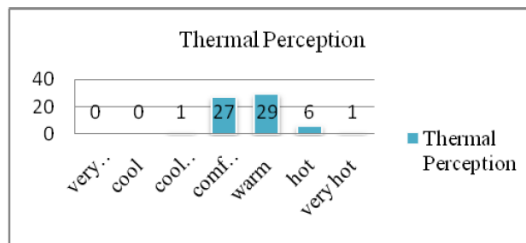
5. Research Locus Kampung Kauman Jogjakarta lies in Kelurahan Ngupasan, Kecamatan Gondomanan, Jogjakarta City. Its building coverage is approximately 80%. Kauman had average temperature 28°C in 2009 and its area is about 192.000 meters square (Maslucha, 2009).

Existing thermal condition can be seen at the Figure 1.



**Figure 1.** Average Temperature  
Source: field survey

The existing condition results average temperature as figure above. Mostly, the average temperatures are not in comfortable range or out of maximum temperature 27,1°C, according to SNI T14-1993-03 or ISO 7730:1994. The average temperature showed the microclimate condition in the area. The microclimate condition is uncomfortable and tends to be warm and hot. Interview result shows the same condition thermal comfort which is uncomfortable, tends to be warm and hot (see Figure 2).



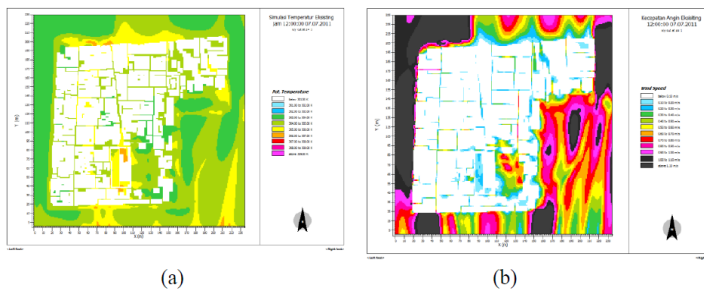
**Figure 2.** Thermal Perception  
Source: survey

As the typical condition of urban housing area, Kauman existing condition can be seen on the Figure 3. The dark green colour showed the presence of shady crown trees T1 (15 m) and the light green colour showed the T2 shady crown trees (10m). The brightest green colour showed grass (gg).

Mostly, existing condition is covered by artificial land coverage which can absorb heat easily. The vegetations are on the east side and some of open space among the buildings. The solid area is covering most of existing. Circulation lines are shown as light grey space among the buildings with various patterns. The existing temperature and wind speed at 12.00 are showed in Figure 4.



**Figure 3.** Existing's Condition in Envimet v 3.1  
Source: Envimet v 3.1 simulation



**Figure 4.** Existing Simulation Result:  
(a) Simulation Result of Existing Temperature at 12.00  
(b) Simulation Result of Existing Wind Speed at 12.00

## RESULTS AND DISCUSSION

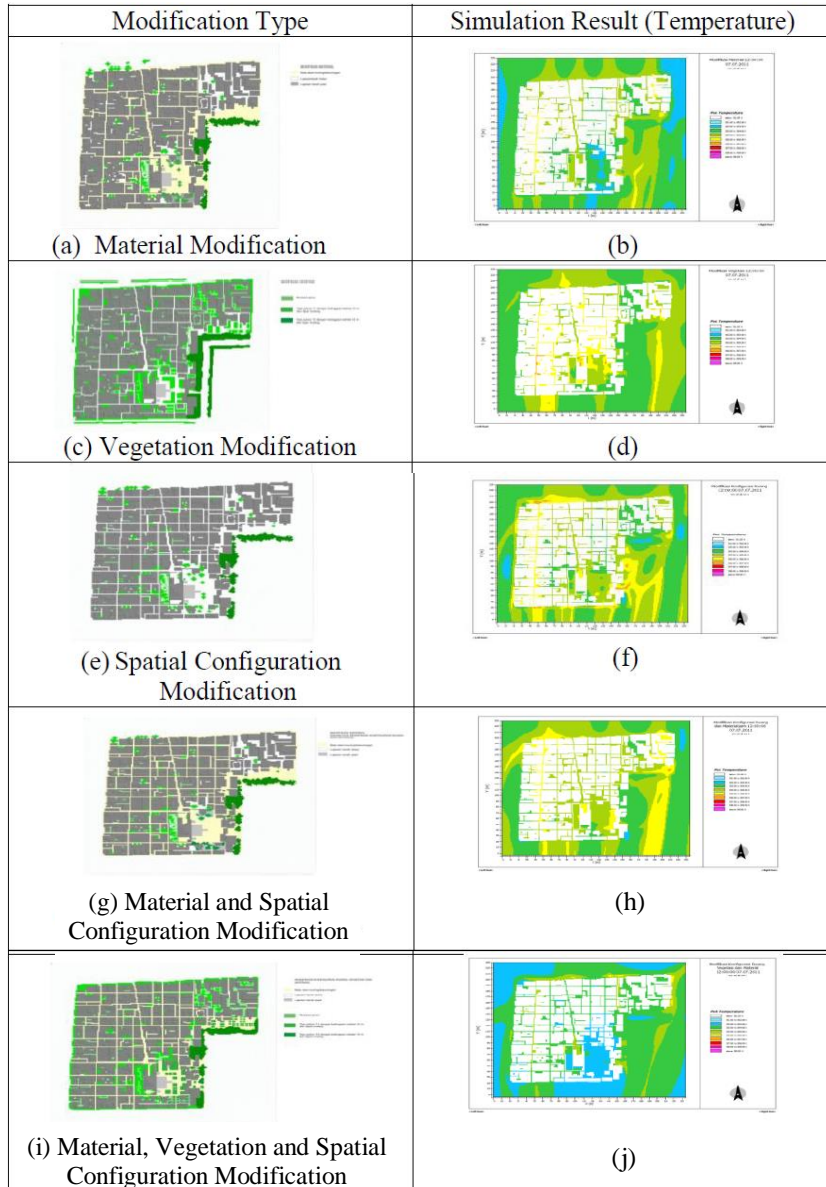
### The Experimental Modification and Simulation Result

The best result of all modification is combination modification of vegetation, material and spatial configuration (Figure 5). The decreasing temperature level can be seen on Table 2 below:

**Table 2.** Decreasing Temperature

No.	Modification	Decreasing Temperature (C)
1.	Vegetation	2-4° C
2.	Material	3-5° C
3.	Vegetation and material	2-4° C
4.	Spatial Configuration	2-4° C
5.	Spatial Configuration and Material	3-5° C (small part)
6.	Spatial Configuration and Vegetation	3-5° C
7.	Spatial Configuration, Vegetation, and Material	3-5° C

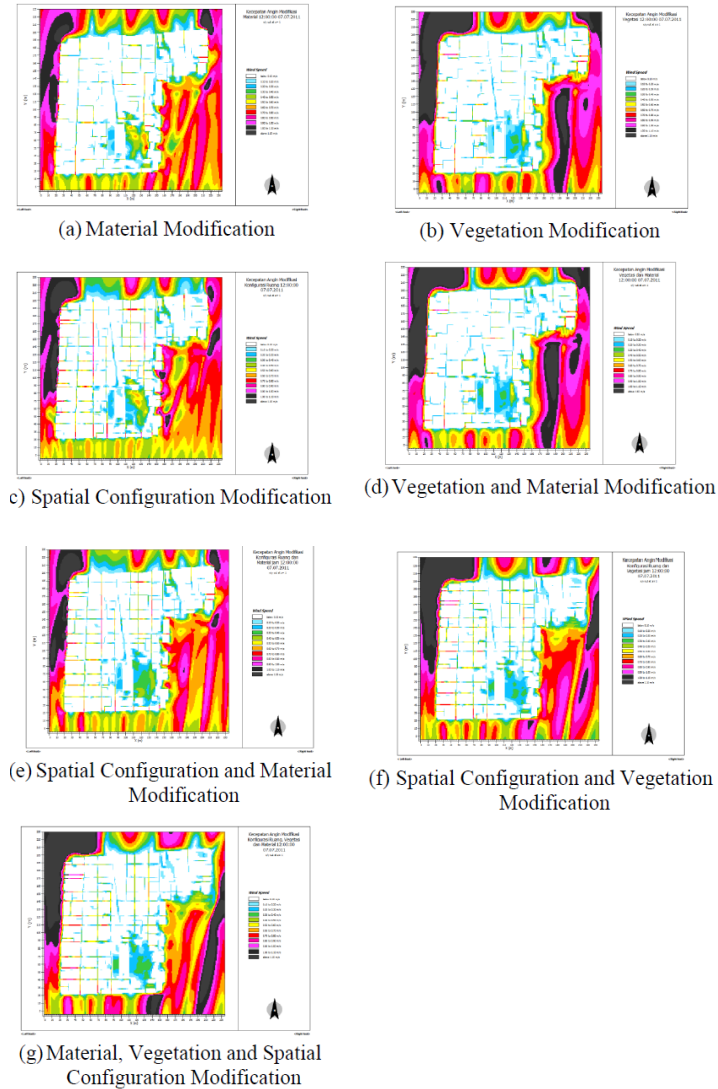




**Figure 5.** The Experimental Modification and Simulation Result

### Simulation Result of Wind Speed

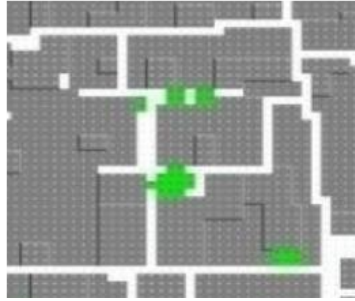
The simulation result of wind speed showed the new spatial configuration with grid system circulation pattern, gave better air velocity into the region (Figure 6). The plant pattern influenced the wind speed, the grid pattern gave better air velocity into the region.



**Figure 6.** Simulation Result of Wind Speed

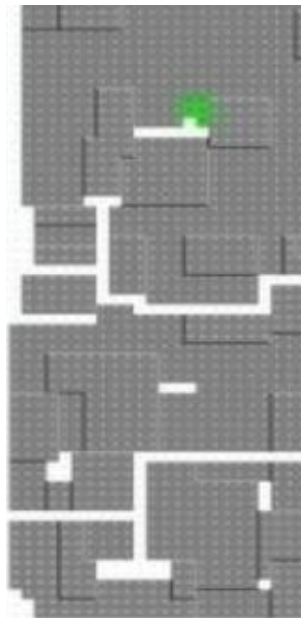
### Spatial Pattern

The existing space configuration is random circulation pattern. This type of circulation pattern tends to block air velocity through the area. According to Golany, 1996, the grid system pattern smoothen air velocity through the area. Grid system circulation pattern in urban housing area should give better air velocity.



**Figure 7.** An Open Space with Indirect Circulation Pattern  
Source: envimet 3.1 simulation

A closed small open space among the buildings tends to have higher temperature. The air velocity is small in the other side the relative humidity and radiation are high. A small open space with indirect circulation pattern also tends to have smaller air velocity and higher temperature (Figure 7).



**Figure 8.** An Indirect Circulation Pattern  
Source: envimet 3.1 simulation

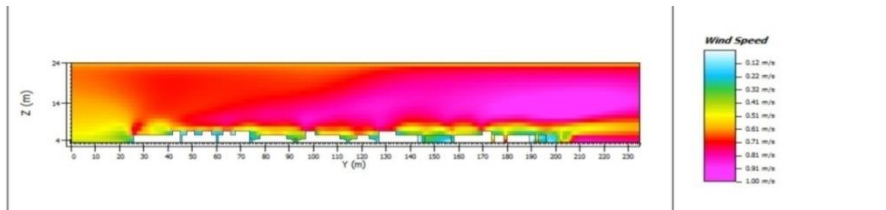
The indirect circulation pattern decreases the air velocity causing the temperature higher (Figure 8). In the other side, grid system circulation pattern tends to smoothen air velocity and reduce temperature.

Some small open spaces are closed by wall on its sides. This type of configuration blocks the wind with high relative humidity and radiation. The result, temper-

ature of this area tends to be higher. Open space should be linked by direct circulation to other open space to get better air velocity.

The circulation pattern with cul-de-sac pattern can block the wind speed, therefore, grid system direct circulation pattern will smoothen air velocity. Grid system orientation is better to be suitable with main wind direction.

Alley type should be better with ratio of circulation width and wall height is 1:1 or higher. This type of alley gives better airflow through the urban housing area (See Figure 9).



**Figure 9.** Alley type section with wind speed  
Source: envimet 3.1 simulation (Kartikawati, 2013)

Considering the main wind direction from south, the new space configuration had south-north and west-east grid system pattern. The new space configuration pattern smoothened wind velocity inside area.

A small open space in the side of direct circulation area results a good air velocity also. The principle thing for the better air velocity is continuous pattern of circulation area inside urban housing area. A cul-de-sac circulation pattern can reduce wind speed; it means that the relative humidity cannot be distributed well. The high sun radiation and relative humidity results to the worse microclimate comfort and the tendency of increasing temperature.

### Land Coverage Type

The wide part of the area is covered by concrete. This type of material absorbs heat easily due to its low permeability and its high capacity of heat. Area in the Masjid yard is covered by dark stone which absorb heat easily. The dark colour tend to absorb the heat better than the light colour.

Land coverage should be chosen by looking for the higher albedo and higher permeability. According to Pavement Report, 2005, material type with lower albedo tends to adsorb radiation better than higher albedo material type. The smaller permeability tends to conduct heat better than the higher permeability material type.

Dark stone has lower albedo than light coloured stone. Concrete has smaller permeability than natural stone. Then, light coloured natural stone can be chosen to replace the existing land coverage because of its high albedo and high permeability. Artificial permeable stone with lighter colour also can be chosen for better microclimate as its small conduction of heat (see Figure 10).



**Figure 10.** Permeable Artificial Paver

Source: <http://www.perviouspavement.org/>, 2013

In this case, the dark stone coverage absorbs the radiation more than light coloured stone. The concrete has lighter colour but it has smaller permeability than natural stone. Some kinds of light coloured natural stone, according to EnviMet 3.1 simulation can reduce urban housing temperature.

### **Vegetation Type and Pattern**

The vegetations on the existing are mostly in the east side of area, lining along the pavement. Some of them are in the open space and Masjid yard. Vegetation has shading effect and reduce temperature around it. Beside the cooling effect, vegetation also reduces wind speed. Thus, the pattern plant should not block the wind. Vegetation with wide crown and grid system single pattern, according to EnviMet 3.1 simulation gave better effect to microclimate comfort. Some pattern type of vegetation:

#### **1. Single Pattern**

Single pattern is using a wide crown tree type, which result shading space below its crown. The large crown such as trembesi tree can be planted in wide open space. The medium crown such as Kiara Payung can be planted in urban housing area which has medium open space.

#### **2. Group Pattern**

The group type pattern is usually like a small forest which the trees are planted in large or small grouping. The tree type for this pattern usually is a medium width crown tree, for example Kiara payung or *Fillicium decipiens*.

#### **3. Line Pattern**

The line pattern can be found along the roads or boulevards. The tree type of this pattern has vertical crown or medium width crown. The type of tree such as pine for vertical crown. Palm also gives vertical effect but small shading space.

#### 4. Vertical pattern

Vertical pattern is used as green wall in urban area with limited space. This type consists of small plants which set on the panel. The green panel can be set on indoor or outdoor wall

#### 5. Roof Garden

Roof garden type usually uses small plants with certain structure follow the roof shape. This structure type can be seen on Figure 18 which has some layers. A roof garden can cover the roof with plants which its effect is similar with common garden.

Single pattern can use a large crown tree such as Trembesi tree for large open space. Trembesi tree or *Samanea saman* has large crown so that a large space can be found below this tree (Figure 11). Trembesi tree is suitable to give shading in public open space such as city park or urban housing park. Trembesi tree can be 25 heights with 30 m diameter of the crown. According to Dahlan, 2008, trembesi 15 m height can absorb CO<sub>2</sub> 28,5 ton every year. That is much better than average trees which can absorb 1 ton CO<sub>2</sub> or less every year. In the other side, the strong water absorbance of trembesi is worried reducing soil water and the wide shade of this tree disturbing other smaller plants.



**Figure 11.** Trembesi Tree with Large Crown

Source: <http://probosetiyawan.blogspot.com/2012/12/macam-pohon.html>, 2013



**Figure 12.** *Filicium decipiens* or Kiara Payung

Source: <http://nurerinyaeka.blogspot.com/2010/08/kiara-payung-normal-0-false-false-false.html>, 2013

Kiara payung tree is about 10 m height and it has medium width crown. The medium width of its crown is suitable for shading urban housing area with single pattern, line or group pattern (see Figure 12). Pine trees can be planted in side of road or pavement (Figure 13). This vertical shape is suitable to be planted in a line pattern.

Vertical pattern can be applied in limited urban housing space. This pattern is flexible to set indoor or outdoor (see Figure 14 and Figure 15).





**Figure 13.** A Type of Pine Tree

Source: <http://deslihutan.blogspot.com/2009/05/cemara-norfolk-araucaria-heteropylla.html>, 2013



**Figure 14.** An Indoor Vertical Garden

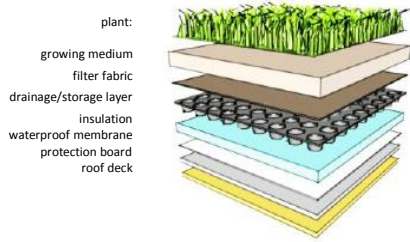
Source: <http://www.contemporist.com/2008/11/29/vertical-gardens-by-michael-hellgren/>, 2013



**Figure 15.** Green Wall along The Pedestrian as A Vertical Plant Pattern

Source: <http://www.vesproine.com/images/success-stories/Greenwall-2>, 2013

Roof garden can be applied in limited urban space on the roof top. The roof garden structure can be seen in Figure 16 and Figure 17 below.



**Figure 16. Roof Garden Structure**

Source:

<http://greengarage.ca/greenroofs/features.php>, 2013



**Figure 17. Roof Garden**

Source: <http://homedesignlover.com/landscape-designs/roof-garden-landscape-designs/>, 2013

The various pattern and plant type can be chosen match to the urban housing area. In this case, vertical pattern and roof garden can be applied in suitable areas such as wall along the circulation areas for vertical pattern and on the top of the roof of some houses. Single pattern can be applied in some wide open space. A large open space can use group pattern. Line pattern can be set along side of the pavement. The vegetation can absorb the dust, reduce noise, reduce temperature and absorb CO<sub>2</sub>.

As the important role of vegetation, some pattern type can be applied. Urban housing with limited open space can use vertical garden pattern and roof garden. In this case, vertical garden can be applied along the circulation wall and also grid system single pattern plant in the wide open space.

## CONCLUSIONS

Land coverage type, space configuration and vegetation type and pattern influence the microclimate comfort. Land coverage type with high permeability and higher albedo will give better contribution to microclimate comfort. Natural stone and artificial permeable paver have higher permeability than concrete. Dark stone has low albedo which means has bigger ability to absorb heat. In the other side, light coloured stone has higher albedo which means less heat can be absorbed. Light coloured natural stone and light coloured permeable material gave better result than dark stone and concrete.

Certain type of vegetation and planting pattern also influence the microclimate comfort. Vegetation with high dense leaves gives good influence on decreasing temperature. With the right pattern, this type of plant can contribute well to decrease microclimate temperature. As the important role of vegetation presence, type of plant pattern can be chosen suitable with the areas. Vertical plant pattern and roof garden type are suitable for urban housing with small open space. For urban housing with large open space can use single, group or line pattern plant of wide crown tree to get better microclimate condition.

The air velocity gives important role to the better microclimate condition. Grid system circulation pattern smoothen the air velocity, this kind of circulation pattern is recommended to be the main urban housing circulation pattern. Urban



housing area must have open space to get better air ventilation and vegetation. An urban housing area with limited open space can use grid system circulation type with some small open spaces with direct circulation interrelated with some small open spaces.

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Figure Download:

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