Building Groups Design Strategies in Hot-humid Climate:
A Dense Residential Planning in Bandung, Indonesia

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ABSTRACT: Design strategies for building groups in a dense residential area, not only require to accommodate their density on the plot ratio and site coverage, but also a critical to passive design since it controls the access of sun, wind and light. The form and placement of that building creates a particular set of relationship with the street and with neighbouring buildings, configures open space between buildings, and create distinct microclimates around the building. This paper is continuation of previous papers that a series of studies to examine the available passive cooling technique for flats, particularly in relation to the form and mass of buildings, its size, shape, scale and distribution of green spaces. The numerical 3D models of urban block will generate from urban block flats typology with density approximation method and combine with understanding of urban physical processes leading to the development of new strategies in the design of sustainable cities. ENVI-met then is used to give specific correlation between urban physical aspect connected with meteorology data i.e. temperature, humidity and wind speed which going to simulate the microclimate change within urban environment. This simulation will reveal an alternative of building groups with lower Tmrt and offer outdoor thermal comfort in hot humid climate conditions.

Keywords:Building form and massing, High Density, Hot-Humid

INTRODUCTION

Many studies about high population densities that increase exposure to the effects of microclimate and vulnerability of climate change have been done such as: localized climatic effects such as increased local temperatures, urban heat-island effect, high levels of outdoor and indoor air pollution [1,2,3]. Density then, become one of variety of factors that influences the sustainability of urban form and effect of compactness on need to travel and feasibility of public transport are reducing emissions[4]. Thus, the utopia of compact city in the developing country brings flats as a main actor to contribute its role to create living comfort in a dense area [5]. The first public flat in Indonesia was built in Jakarta in 1981, somehow during 32 years it remains many shortcomings, especially regarding physical problems and comfort for occupants. Construction of flats often targeting unit quantity with limited funds and unscheduled properly, coupled with inadequate of building code, many units even building left empty [6,7]. Previous study found that 4 from 5 flats samples in Bandung recorded with high mean radian temperature (Tmrt). It shows that high of floor area ratio significantly influence the surface area ratio which implies minimum heat gain, vegetation ratio also play important role to reduce Tmrt [5].

Nevertheless, design strategies for building groups in a dense residential area, not only require to accommodate their density on the plot ratio and site coverage, but also a critical to passive design since it controls the access of sun, wind and light. Hot-humid climate zone is facing a little seasonal variation throughout the year, like air temperature, humidity, and wind speed, even between day and night. Therefore, passive design in hot-humid climate particularly in relation to the form and mass of buildings, its size, shape, scale and distribution of green spaces is well positioned to gain outdoor thermal comfort especially for flats.

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LITERATURE REVIEW

The strategies in building group deal with range major architectural elements which are building, street and open space, these strategies are mostly concerned with relationship either between buildings or between building and street/open space [8]. The following design strategies will be given for hot humid zone which have a major impact on reducing heating that address to sun, wind and light.

1. Climate and High-Density

In a dense area, large number of habitants and anthropogenic heat emission, also the requirement of land coverage to provide shelter for inhabitant increase surface roughness, thus reduce the ventilation of urban areas. Its ultimately has the potential to cause urban heat island (UHI). The change of land use and cover in Bandung, Indonesia significantly give the change of air temperature, temperature humidity index and evapotranspiration thus effect into higher surface temperature [9,10]. The definition of an ideal level of density, especially in a dense low-income settlement, and its potential contribution to urban sustainability from promoting a higher density of buildings and public spaces in urban design to make preservation of green spaces in conjunction with certain kinds of urban development then become crucial to addressed. Previous study found that Cibeunying district with 1.695 pph (people per ha) are having the highest range of slum settlement in Bandung which correlated with inappropriate physical condition [2]. This current density and minimum pph for settlement based on SNI 03-7013-2004 (Indonesian National Standard of environmental facilities planning for flats) then become a reference to determine the density of pph to design flat which is 1750pph.

2. Typology of Flats

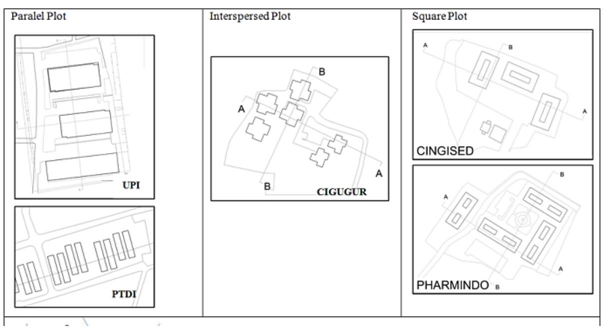


Figure 1: Urban form typology of Flats in Bandung, Indonesia Source: Paramita, 2013 (p.8)

There is no specific guideline about building group for flats in Indonesia i.e. building shape (length/width $=L_1/L_2$ ratio), distance between building (H/W ratio). Building form and layout are set depend on site area. Based on previous study [5], there are 3 types of building group of flats which are parallel plot, interspersed plot and square plot. The resulting study based on assessment of these flats that interspersed plot with $L_1/L_2 = 1$ rise wider outdoor comfort zone compare with 2 others plot, which has $L_1/L_2 = 2$ and $L_1/L_2 = 3$. 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[8,11,12].

3. Urban Ventilation

In hot-humid zone, the design strategies are to provide more open space to reduce max temperature with provision of greenery to absorb the heat and allow natural ventilation during the day. Based on measurement in Singapore and Bangkok, increasing the air speed by 1m/s had a cooling effect equivalent to lowering the temperature by more than 2°C [13]. TR.Oke [14] mention 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. 3.

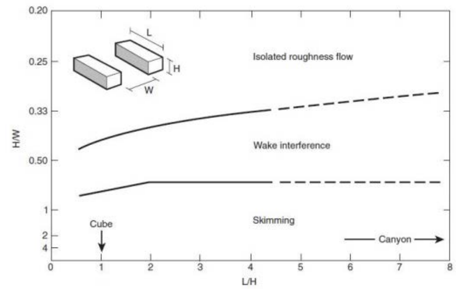


Figure 3: Three regimes as function of H/W (canyon) and building geometry (L/H)

4. Microclimate Assessment

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 the surface-plant-air interactions in urban environment with a typical resolution of 0.5 to 10 m in space and 10 sec in time [15]. This simulation will help architects and planners to predict the quality of urban areas in complexity of urban microclimate, before the design of the building will be constructed. Meteorogical variable such as air temperature (T_a), Humidity (RH), radiant temperature (Tmrt) and wind speed are influencing the outdoor thermal comfort, beside other human factors such as clothing (clo) and human body surface (m2). Thus, a number of simulations are using ENVI-met BETA5, it revealed to be a good tool for the prognosis 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 [16]. 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 [17].

5. Outdoor Thermal Comfort in Hot-Humid Climate

Not so many researches about outdoor thermal comfort, especially in hot-humid tropical zone compared to other climate zone. Some of the researchers who focus on outdoor thermal comfort, have proposed regression equations to predict the scale of outdoor thermal comfort, where the regression is functions of climate variables such are: solar radiation, air temperature, air humidity, wind speed, and radiant temperature, etc. [18-22]. Furthermore, Sangkertadi has managed experiment for predicting outdoor thermal comfort in tropical and humid environments which conducted in Menado, Indonesia. [23]

He successfully formulated three regression equations of thermal comfort in outdoor space for people with activities of normal walking, sitting and brisk walking, limited for conditions where the wind blows with constant speed of about + 1 m/s. The regression equation obtained is as follows:

$$Y_{JS} = -3.4 - 0.36v + 0.04T_a + 0.08T_g - 0.01RH + 0.96A_{du}$$

Where:
Y_{JS} : Comfort Level (normal walking)
v : wind speed (m/s)
T_a : air temperature (°C)
T_g : globe temperature (°C)
RH : Relative Humidity (%)
A_{du} : Human surface body (m2)
Average A_{du} for Indonesian people is 1.7m2

The data obtained from measurement and questionnaires were then compiled and analysed with focusing on the correlation among three groups: the value represent of thermal comfort perception, climate characteristics, and parameters of the human body. Then proceed with regression analysis to obtain the regression equation Y = f (x, y), where Y is a number that indicates a sense of thermal comfort, and x is the climate variables (air temperature, globe temperature, relative humidity, air velocity, and solar radiation), y is the parameters and variable of the body (height, weight, skin temperature and dress). Table 1 shows the definition of the thermal response and value of Y_{JS}.

Tables : Comfort Level Perception for normal walking

Value of Y_{JS}	Comfort Level Perception
-2	Cold
-1	Cool
0	Comfort / Neutral
1	Warm / Slightly Hot
2	Hot
3	Very Hot
4	Start to feel Pain

Significant difference between the results of the regression equation Y_{JS} with other references (Tsp, ASV, Ts_{cheng}, C, and Ts_{givoni}) shows thermal comfort in outdoor space in humid tropics is different from the formula for the situation in other climates. It is also due to differences in human perception and the climate characteristics.
Since this building groups which going to assess are model, and Tmrt is obtained from the simulation of ENVI-met, thus the calculation to find globe temperature (T_g) are using following equation : [24]

$$Tg = \frac{Tmrt + 0.237\ x\ v^{0.5}}{1 + 0.237x\ v^{0.5}}$$

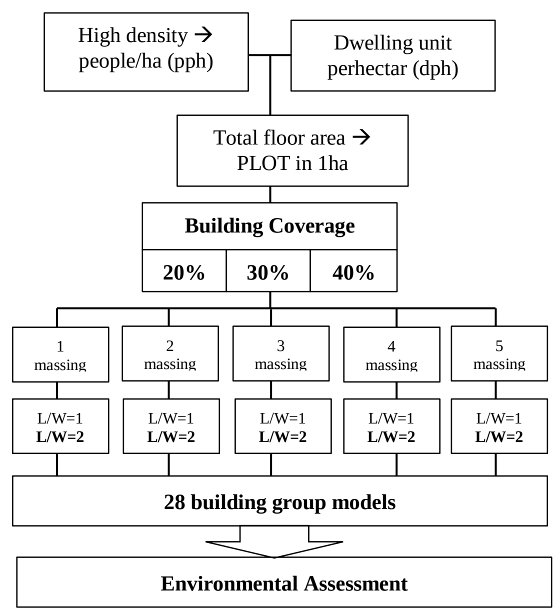
STUDY AREA

Bandung, as the second largest metropolitan area in Indonesia is chosen as a study area, located at 6.54ºS and 107.36ºE, 768 meters (2,520 ft) above sea level, with average temperature 24.72ºC (76.5 ºF) throughout the year made Bandung is cooler than most Indonesian cities. It surrounded by mountain and hill in northern and southern part give an influence for microclimate especially for down-town which located in Bandung Basin. Humidity everyday noted more than 70%, and reach max in 90%, where the wind speed is average on 3m/s. [25] Thus, it is classified as tropical monsoon "am" by Köppen-Geiger [26]

METHODOLOGY

Numerical of building model going to assess its geometrical layout, such as: canyon (H/W), geometrical dimension (L_1/L_2) that control sun access to reduce radiation and propose wind flow. Urban parameter is directly related to population density that how many people going to accommodate, then determine building coverage (BC) which influence plot ratio and building height. This layout all set with canyon (H/D = 1.7) (see Tables 2).

Tables 2: Urban Parameter based on BC and massing



This parameter, given hypothesis that building group models with proper proportion and layout going to contribute (Tmrt) which impact into level of urban outdoor comfort. A comparison of building group revealed that time and period during the day when extreme heat stress occurred provide a better building configuration.

DISCUSSION

The assessment of urban form is using the following two urban form description methods, that mutually and addressed simultaneously in urban forms analysis, which are:

1. Based on urban form typology
2. Based on morphological indicator

A. Plan

Urban form typology:

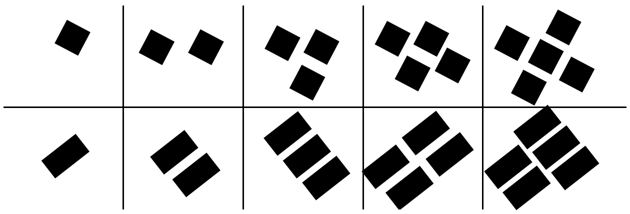


Figure 4: Building group Model Plan

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

B. Building Height

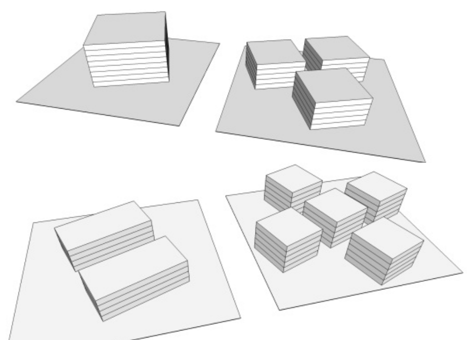


Figure 5: Type of Building Height

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)

C. Canyon and Geometry

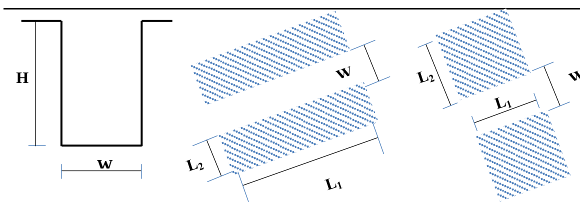


Figure 6: (a) urban canyon H/W = 1.7 (b)urban geometry L_1:L_2 = 1:2 (c)urban geometry L_1:L_2 = 1:1

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

D. Orientation

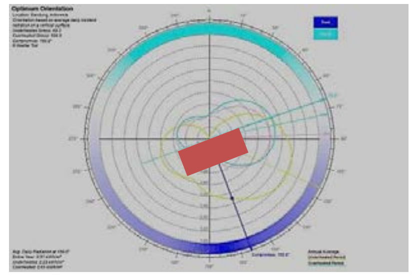


Figure7: Best orientation for 6.54ºS and 107.36ºE Performed by Autodesk® Ecotect®

Morphological indicator
- Latitude -6.54N Main building facing SE, rotate from E-W is 20º toward North
- From SW to NE since overheating period and to reduce radiation, used for greenery

E. Vegetation coverage area

Though the previous study found that shadowing from vegetation significantly reduce Tmrt, but in this study, there are no shadowing put in this building group design strategies. The goal is to find out the effect of urban physical setting to improve the performance of microclimate. Thus, vegetation here only green as a ground coverage, such as grass.

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

RESULTS – Microclimate at Street Level

1. Tmrt (mean radiant temperature)

The highest Tmrt reach at 73.74 ºC in model no.13, which have 3massing with 40%BC and L_1:L_2 = 1. Meanwhile the lowest Tmrt reach at 25.51 ºC in model no.8, which have 3massing 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, didn't give the alterataion of Tmrt.

The result of ENVI-met simulation shown at figure 8 below:

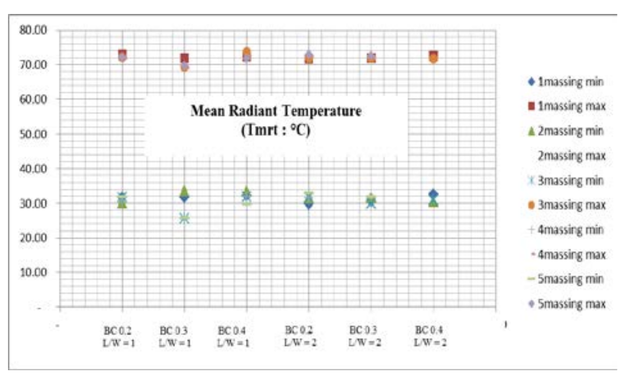


Figure 8: Mean Radian Temperature (Tmrt)

2. Wind Speed

The highest wind speed reach at 3.22m/s, found at model no. 20 which having 5massing with 20% BC and L_1:L_2 = 2. From simulation, it is found that the higher BC, the lesser wind speed, but the amount of building mass doesn't give significant impact for wind speed, nor the building geometry. Building geometry with L_1:L_2 = 2 emerge more wind speed compare to L_1:L_2 = 1. The result of ENVI-met simulation shown at figure 9 below:

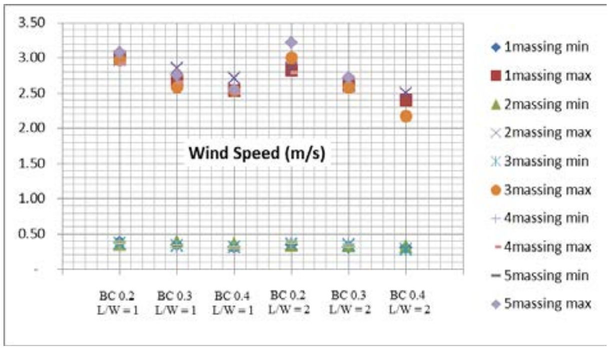


Figure 9. Wind Speed

3. Wind Speed Change

Wind speed change is expressed with (%), it means how many percentages of wind could be raised. Wind speed change spot is depend on wind direction, the more closer to wind direction and parallel flow with air the bigger possibility to increase the wind speed. The highest wind speed change found at model no.20 which having 5massing with 20% BC and L_1:L_2 = 1. The lowest wind speed change found at building group no. 28 which having 3massing with 40% BC and L_1:L_2 = 2.

Positive correlation with amount of massing, the more building massing in one site the more percentage of wind speed change occurred. The opposite with BC, the higher BC for site the lesser percentage of wind speed change. The result of ENVI-met simulation shown at figure 10 below:

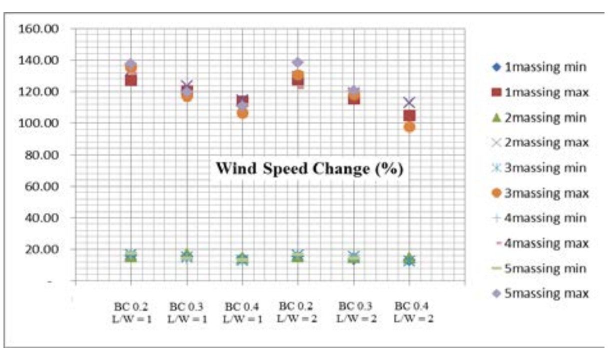


Figure 10. Wind Speed Change

4. Comfort Level Perception

The highest level comfort perception (Y_{JS}) is 2.33 which perceived as hot, found at model no.12, that having 2massing with 40%BC and L_1:L_2 = 1. The lowest Y_{JS} value is 1.03, perceived as warm/slighty hot found at model no. 8 and no.9. Model no.8 having 3massing with 30% BC and L_1:L_2 = 1, meanwhile model no.9 having 4 massing with 40% BC and L_1:L_2 = 1.

Positive correlation between BC and Y_{JS} for building model with L_1:L_2 = 1, the lesser BC the lesser Y_{JS} value (perceive more comfort).

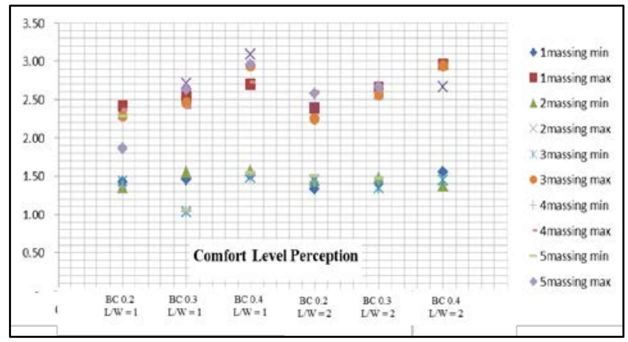


Figure 11. Comfort Level Perception

5. Resume

The result of mean radiant temperature, wind speed, air temperature, globe temperature and comfort level perception are shown at Table 3.

Tables 3: Resume of Simulation and Calculation

	Tmrt (°C)		Wind (m/s)		Ta (°C)		Tg (°C)		Y_{JS}	
	min	max	min	max	min	max	min	max	min	max
1	31.58	73.01	0.38	3.01	24.33	29.25	30.66	60.26	1.42	2.41
2	30.22	71.71	0.35	2.97	24.39	28.58	29.50	59.20	1.35	2.32
3	31.67	72.10	0.37	2.97	24.34	27.67	30.75	59.22	1.44	2.29
4	30.70	72.03	0.36	2.92	24.32	28.51	29.91	59.49	1.37	2.37
5	31.92	72.20	0.39	3.08	24.36	28.84	30.95	59.46	1.44	2.29
6	31.70	71.90	0.34	2.67	24.37	28.46	30.81	59.77	1.46	2.54
7	33.51	72.72	0.39	2.85	24.36	32.51	32.33	61.23	1.55	2.71
8	25.51	69.41	0.33	2.58	24.36	28.21	25.37	58.05	1.03	2.45
9	25.32	69.22	0.31	2.66	24.3	28.45	25.20	57.85	1.03	2.39
10	25.81	69.74	0.32	2.75	24.36	32.82	25.64	59.32	1.06	2.63
11	32.20	72.34	0.31	2.54	24.34	29.09	31.28	60.48	1.51	2.70
12	33.30	73.16	0.35	2.71	24.39	36.5	32.20	62.87	1.57	3.09
13	31.75	73.74	0.31	2.54	24.39	31.57	30.89	62.18	1.48	2.94
14	31.92	72.49	0.3	2.5	24.37	28.89	31.05	60.61	1.50	2.73
15	32.47	72.79	0.3	2.55	24.31	32.93	31.53	61.85	1.54	2.96
16	29.85	71.71	0.34	2.83	24.43	28.13	29.19	59.29	1.33	2.39
17	31.49	72.16	0.34	2.85	24.38	27.86	30.63	59.50	1.45	2.39
18	31.65	72.05	0.36	3	24.39	27.51	30.75	59.09	1.44	2.25
19	31.41	72.48	0.37	2.79	24.34	30.28	30.52	60.51	1.42	2.60
20	32.98	73.01	0.39	3.22	24.36	34.29	31.87	61.46	1.51	2.58
21	30.56	72.05	0.31	2.6	24.35	29.35	29.84	60.24	1.40	2.66
22	31.71	72.27	0.33	2.63	24.38	28.29	30.83	60.06	1.47	2.58
23	29.99	72.07	0.34	2.58	24.4	27.75	29.31	59.85	1.34	2.57
24	31.75	72.20	0.36	2.72	24.39	29.89	30.83	60.31	1.45	2.61
25	31.82	72.53	0.33	2.72	24.32	30.52	30.92	60.72	1.47	2.67
26	32.59	72.63	0.3	2.4	24.32	31.38	31.64	61.55	1.55	2.96
27	30.46	71.78	0.32	2.5	24.31	28.55	29.73	60.00	1.38	2.67
28	30.98	71.79	0.28	2.17	24.27	28.95	30.23	60.70	1.45	2.94

CONCLUSION

As conclusions of this study are:

1. This study reinforces the theory of outdoor thermal comfort that Tmrt is a major factor which affecting comfort level perception
2. All of 28 building group models offer outdoor thermal comfort in warm/slighty hot to hot level. Eventhough max wind speed achieve at 3m/s still difficult to offer neutral/comfort level. Urban ventilation by encouraging of wind flow through building mass and form is not significant enough to reduce mean radiant temperature (Tmrt), which also affects to comfort level perceiption.
3. As the previous study found, this study also give emphasis that vegetation significantly reduce Tmrt, planned open green space at the point of highest radiation is 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 perceiption, but the greater number of buildings with less BC within the site, the greater the change of wind speed will increases.

RECOMMENDATION

The next investigation within change of canyon, also the variety of building height and vary of vegetation and ground coverage will give more deep conclusion of building group design strategies in hot-humid area.

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[i] In this sense, it is like the Indonesian word *rusun*, which refer to low cost public housing