THE EFFECT OF FAÇADE PLANT-SHADING ON REDUCING INDOOR AIR TEMPERATURE IN MEDIUM-RISE WORKING AREA (A Case Study Of Architecture Student's Studio In Surabaya, Indonesia)

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Abstract

Indonesia as a hot-humid region has in average high temperature and humidity. The temperature is usually higher than 30°C and the humidity is over 60 % in the afternoon. This condition can reduce the comfort of the indoor occupants. The building designer in this region should produce a good and creative design in accordance with this situation, especially in designing a medium-rise building.

The façade of a medium-rise building, especially when it is exposed to the sun rays, is more influencing than the roof in controlling the solar penetration into the building because the façade area is wider than the roof area. In order to reduce the indoor temperature, some ways to shade the façade should be done.

This research, which has been conducted in two periods of time (in dry and rainy season), attempts to do so by using the façade plant shading. The result is that the façade with plant shading makes the indoor temperature lower than the indoor temperature without façade plant-shading.

1. Overview

The air temperature and humidity in Surabaya, Indonesia, tends to be hot and humid in all season. The rainy season lasts from October to April, and the dry season is from May to September. In the annual report of Meteorological and Geophysics Office in Juanda, Surabaya, the air temperature and humidity in Surabaya were recorded to be 21.77 – 33.15 °C in air temperature and 77.83% humidity in 1999, followed by 22.09 – 33.48 °C in air temperature and 71 % humidity in 2001, and 22 – 33.8 °C in air temperature and 76 % humidity in 2002.

Based on those average annual records, the air temperature in Surabaya tends to be around 21 – 33°C and 71 – 77 % humidity. The hot and humid air in Surabaya has affected the uncomfortable indoor air quality because of the sun radiation. The sun radiation penetrates buildings from the windows, and convection and conduction from the building envelope. The hot air temperature and high percentage of humidity also influence to the human thermal comfort and human effective work.

Based on the research of Canada's National Occupational Health & Safety Resource, the air temperature should be in between 23 – 26 °C, and 50 % humidity for human thermal comfort to reach effective working activity. The indoor thermal comfort could be reached by minimizing the sun radiation which penetrates into the building. Much solution as well as we know to minimize the sun radiation penetrating into the building is by controlling the sun radiation with sun shading or using the air conditioner to get the indoor temperature more comfortable to thermal.

The common sun shadings use several building materials which transfer the heat they absorb from the sun radiation and transfer it to indoor air by convection and conduction. This heat transfer could increase the indoor heat gain and increase the air temperature. On the other hand, using air conditioner to get the indoor thermal comfort means consuming energy. The problem is how to minimize the solar radiation affecting the indoor air quality, decrease the indoor air temperature, and consume efficient energy.

2. Decreasing Indoor Air Temperature In Hot Humid Climate

At this recent time, the world issue is to how to consume energy efficiently, so the priority of cooling the building in hot humid climate is to reduce the indoor climate by focusing on natural or passive way. The first reason to apply natural or passive cooling is to avoid building heat gain from the sun radiation (Cook, 1990). Passive cooling is also a low energy intensive method of keeping a building cool in hot climate. Non-mechanical methods of reducing heat gain in hot climate involved decreasing the amount of solar radiation absorbed by the building to reduce the use of electric energy. Passive cooling depends on the natural heat transfer by convection, radiation and phase change (Moore, 1993). At the very least, natural or passive cooling allows to install smaller or no cooling equipment that will consume energy but to minimize the sun radiation absorption of the building (Dulley, 2003). All the effort of cooling the building in hot humid climate is to turn the uncomforted heat to the thermal comfort condition in the building. The indoors thermal comfort is absolutely needed to the human activity, especially to get the optimum working effectively.

The comfortable indoor air temperature in hot humid climate roughly said is the lower indoor air temperature than the outdoor air temperature, and consumes the lowest energy. According to Szokolay, the indoor air temperature is the most important factor that determines the thermal comfort to human activity but it is not the only one. The various heat exchange processes at the body surface are influenced by an environment factors and the sensation of comfort or discomfort which depend on the joint effect of all of these. The four factors can be distinguished are the air temperature (DBT), humidity (RH), air movement and radiation.

Olgyay (1992) recommended the air temperature between 23 – 26 ° C with 30 – 65 % relative humidity for human thermal comfort in a good activity condition. The research at Canada's National Occupational Health & Safety Resource (CCOHS) has pointed out that the air temperature for the thermal comfort condition in hot humid climate should be between 23 and 26 ° C, 50 % relative humidity and 0,15 m/second wind speed. To reach 100 % working effectively at the working room for medium working category in 8 hours working time for 5 days per week, with conventional break, according to CCOHS, the indoor air temperature must be 25 ° C in wet bulb globe temperature (WBGT).

The strategies to have thermal comfort in hot humid climate in natural or passive cooling are to avoid the sun radiation by shading and reflection, to avoid heat exchange to the building envelope with heat insulation, and to free the heat from the building to the atmosphere by ventilation and evaporation from the building and to the earth by conduction (Moore, 1993).

Moore (2003) suggested some general principles of passive cooling include ventilate cooling, radiate cooling, evaporative cooling, dehumidification and mass effect cooling. Ventilate cooling applicated by exhausting warm building air and replace it with cooler outside air and cross ventilation through the occupants' skin to cool by combination convection and evaporation. Radiate coolingi is the transfer of heat from the building envelope surface to the cooler air surrounding it. Evaporate cooling by evaporation of wetted or humid building element. In de-humidification, by removal of water vapor from the room by dilution with drier air, condensation, or desiccation. The use of thermal storage to absorb heat during the warmest part of a periodic temperature cycle and release it during a cooler part, is the mass effect cooling.

Natural cooling techniques work in one of three ways are (Oikos, 2002) shading blocks the sun before it get into the building, building features prevent heat from reaching the occupied spaces as radiant barriers and insulation, and ventilation moves air through the building to remove excess heat so that the occupants feel more comfortable.

The solution to indoor thermal comfort condition in the building on hot humid climate, and consume the energy efficiently, is in passive or naturally cooling. The better passive cooling are blocking the sun radiation entering the building and to shade all the building opening and the building surface. Cooling the building in ventilating way in hot humid climate is rarely successful because the outdoor air temperature is usually hotter than the indoor air temperature. The ventilating cooling in warm humid climate could cause uncomfortable result for the human working area, because the hot outdoor air is admitted into the building and trapped there.

3. Radiation Control For Shading And Cooling

The primary determent in selecting a shading device is the sun exposure to which you are responding and the requirements of sun radiation. Sun shading outside the window or the building opening is more effective to shade the building opening and to block the sun radiation entering the building. The inside sun shading could only shade the sun light, but not the sun radiation because it already enters the opening and increase the indoor heat gain.

The shading characteristics that are also necessary in cooling the building are *total shading*; block all the sun radiation entering the building in all seasons and *partial shading*, to shade the area but admitted the sunlight.

The main considerations in selecting an option for shading and cooling (Robinette, 1983), are cost versus effectiveness and time versus effectiveness. Besides these, sun shading for the passive control must be economical, ecological and aesthetical (Szokolay, 1987).

In this paper, the passive cooling of the building is by using vegetation to shade the building which admitted the sunlight. Vegetation could be the natural and passive cooling sun shading, because it is:

- Economical in energy
- Ecological, produce no negative impact to the ecosystem and the environment
- Aesthetical, to have more naturally and aesthetical expression of the building
- Effective because vegetation reflects, absorbs the sun radiation and shades the area surrounds it. Vegetation also evapo-transpirated heat it absorbed and it cools the air temperature between the window or building façade and the vegetation. This air becomes a barrier between the hot outdoor air and the window glass.

4. Vegetation As Sunshading Façade In Medium-rise Working Area

In medium-rise building in a tropical country, façade gives an important contribution to the energy consumption for cooling the building. A medium-rise building usually has a façade wider than the roof which can be four times the roof. If the façade is not being designed correctly, the energy consumption for cooling the building will be excessively great.

In order to reduce the energy consumption, we usually use the shading device upon façade to block the penetration of the sunrays into the building. Some shading devices that are usually used are made of metal and other unnatural material. These man-made shading devices give some negative impacts to the environment because these reflect the sunrays to the surrounding area. According to Szokolay (1987), shading devices as a passive control of energy should be economical, ecological and aesthetical.

Another aspect in medium-rise office building, by loosing its connection to the environmental surroundings, people become easier to get depressed, lacking concentration and finally it can reduce the productivity (Kolosova, 1999). Manos and Synodinos (1998) convince that vegetation brings a good impact to the human psychological and physical being to feel convenient and by doing so it reduces stress at work. In medium-rise or high-rise building with working activities, vegetation is recommended as a good shading device. Plants near a building can lower the air temperature next to the building skin as it has been measured by UCLA student Al Hemiddi (1991). Plants can thus reduce the conductive and infiltration heat gains. In addition, during the wet season, plants can reduce the desired solar gain and may increase wall wetness after rains. (Givoni,1994). As a consideration, vegetation can be cultivated in planter boxes around and next to the outdoor side of windows, and can also be cultivated on the overhangs or along balconies.

4.1 Benefits of Using Vegetation As Solar Control

Vegetation controls the solar radiation by *absorption*, by the most part of vegetation and especially by the dark leaves, *reflection*, *a form of long-wavelength radiation* and *radiation transmission.*

The advantages of using vegetation as a façade shading such as it's effectiveness in cooling the surroundings because the most of sunrays are absorbed. Vegetation has a phenomena which it is always face it's leaves to the sunrays. Leaves usually dark and coarse so that they reflect only a little part of the sunrays, 20-30% of the heat gain, while the most heat will be exited from the process of evaporation. (Watson, 19..) Cooling by vegetation called an evapo-transpiration process can add the moisture into the air; and in the following by the convection can lower the air-temperature. As an example, a medium-size tree can absorb 600,000 Btu/h of the solar radiation. Vegetation can obstruct and filter the solar radiation so that it can control the daily and seasonally air temperature; it can also direct and reduce the wind, and control the smog intensity. Besides, vegetation can reduce the sound pollution, glare reducing and lower the feeling of stress.

Benefit of Trees As Shading Device (Coder,1996)

1. 20 ºF lower temperature on a site from trees
2. 35 ºF lower hard surface temperature under tree shade than in full summer sun.
3. 27 % decrease in summer cooling costs with trees.
4. 75 % cooling savings under deciduous trees.
5. 50 % cooling energy savings with trees.

By those advantages, we made a research upon the using of vegetation as a façade shading.

4.2 Application

A kind of vegetation that is recommended as façade shading should have some of these requirements :

1. Growing easily to horizontal direction.
2. Resistence, long life and easy to maintain.
3. Having dense crown and wide leaves, good-shape in order to minimize cutting, beautiful and can block the solar radiation penetrate into the building.
4. Would not fell down its leaves in dry season.
5. Wind resistency.
6. The root is growing regularly and safe for the building element.

7. Reachable placement; easy for watering, replacement and maintaining.
8. Adaptable to the local climate.

4.2.1 Soil Mixes

Mixing of some good quality media is important. The mixture should consist of two parts of sandy loam soil, one part of spaghnum peat moss and one part of builder's sand. This mixed media should be free of disease organism, insects and weeds.

4.2.2 Containers Selection

Container material is also important for vegetation fertility. Some usual materials are plastic, clay and wood. The clay is the best material because it has a porosity to maintain the soil humidity. It is important to have a hole for water run out at the base of the container.

4.2.3 Maintenance

Vegetation needs watering and fertilizing regularly because of its limited cultivation media and easiness of the water and fertilizer to run out from the hole at the container base.

5. Research Methods.

The aim of this research is to know how effective vegetation is as façade plant shading. The research is conducted by experimenting at the location by measuring indoor and outdoor air temperature and relative humidity of the conditioned room. Both conditioned rooms have the same orientation and being measured at the same time and climate condition. One is with vegetation applied while the other is without vegetation applied at the façade.

5.1 Sampling Technique.

5.1.1. Location

The conditioned rooms are the student studios, located on the 7th and 8th floor of Building P, Petra Christian University, Surabaya. The façade orientation is 56 degree north-west. The following plan and section shows the façade detail drawing.

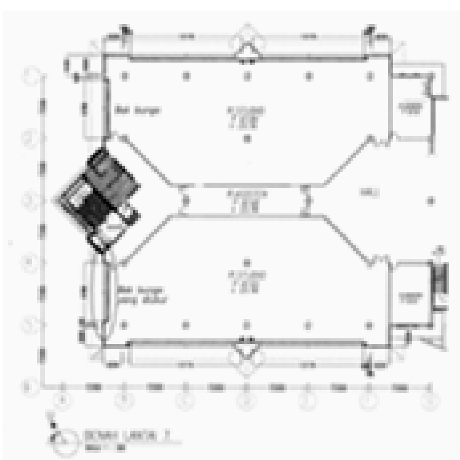


Figure 1. Plan 7th Floor
(Without Vegetation)

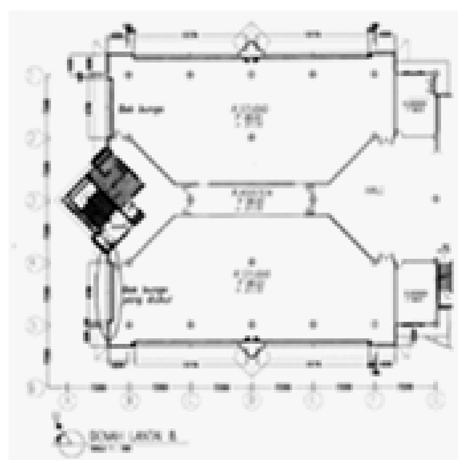


Figure 2. Plan 8th Floor
(Without Vegetation)

North

Figure 3. The studios of
7th and 8th Floor in Building P

Figure 4. Window façade of the
7th and 8th floor studios

The 8th floor studio is exactly above the 7th floor studio, with the orientation, condition and furniture, all are the same. The elevation of the 7th floor is +27.763 m, while the 8th floor elevation is + 27.722 m from ground floor (+0.00m). When the experiment is conducted, both rooms are empty and without activities.

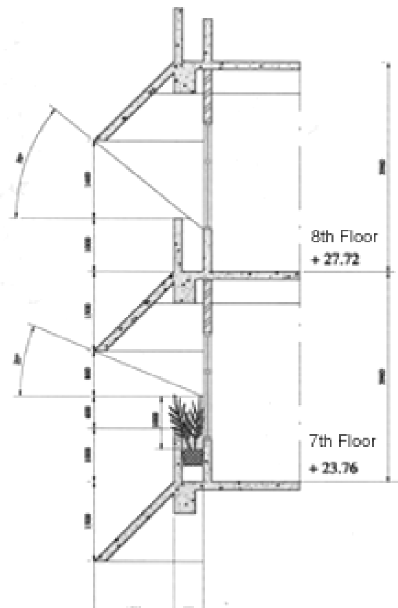


Figure 5. Section of the facade
7th and 8th floor studios

5.1.2 Selecting Time Measurement

In order to prevent the influence of the different activity and condition between both rooms, the measurement was conducted in time without activities and with no occupants (the room is empty). The data survey was carried on in two periods of time to represent the rainy season and dry season, and the data were recorded in a week for every period. The first recoreding was from the 8th to the 15th of August 2003; while the second from the 5th to the 13th of February 2003.

The measurement was conducted for five times a day with an interval of two hours, that is, at 08.00 am, 10.00 am, 12.00 am, 02.00 pm and 04.00 pm everyday. The selected times represent the working hours between 08.00 am and 04.00 pm, while the interval of two hours seved as the significant differences of the local weather.

5.2. Instruments

Measurement was taken by some of these instruments as the main instrument. These include a lightmeter, thermometer indoor and outdoor with probes, and humidity meter. And also the vegetation selected.

5.2.1. Indoor/Outdoor Thermometer and Humidity

To measure temperature and humidity, we use Indoor/Outdoor Thermometer with Humidity dial ex Taylor (The Professional's Choice for Accuracy and Performance since 1851); produced from Mexico. This instrument use fahrenheit as a based, so that a conversion from Fahrenheit to Celsius has to be done; relative humidity is in percentage.

5.3. Scale of Measurement

Measurement applicate International System as followed :

- Temperature be converted from Fahrenheit to Celsius.
- Relative humidity (RH) in percentage (%)

Figure 6. Indor Outdoor Thermometer
and Humidity-meter

5.4. Vegetation Selected

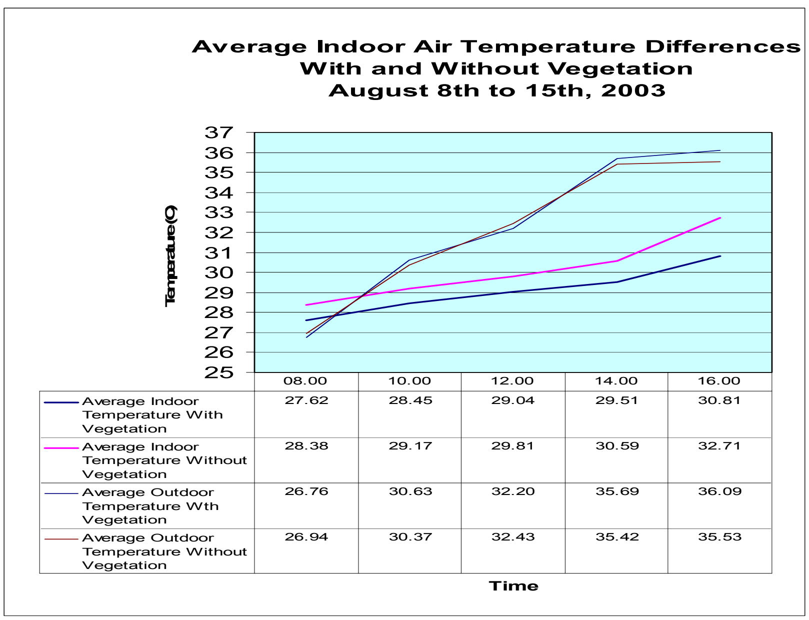
GOLDEN CANE PALM (Chrysalidocarpus Lutescens) is selected as of it's easiness to maintain and very common in our local environment. Besides the size is suitably variative. They would not highly growing if cultivated in potteries, dense enough but would not block our view from inside to outside the window. Need only enough water, in order to keep of damage from root growth. This plant cultivated in 28x28cm pottery, height 40cm. Placed in rows in planter boxes outside the 7th floor studio.

Figure 7. Chrysalidocarpus Lutescens

5.5. Vegetation Placement Consideration

In Indonesia, the most intensive sunrays received on west and north side of the building. That's why this side of façade need sun-shading the most. Placing the vegetation can also influence the wind velocity, those need to be considerated which side would need air flow and which side need not air flow . Vegetation should be prevented from public installation and circulation. The consideration of how long it takes for photosynthesis process for every type of vegetation maintained is very important. Vegetation should be placed aesthetically upon other building elements, and would not close the best view from inside to outside the building.

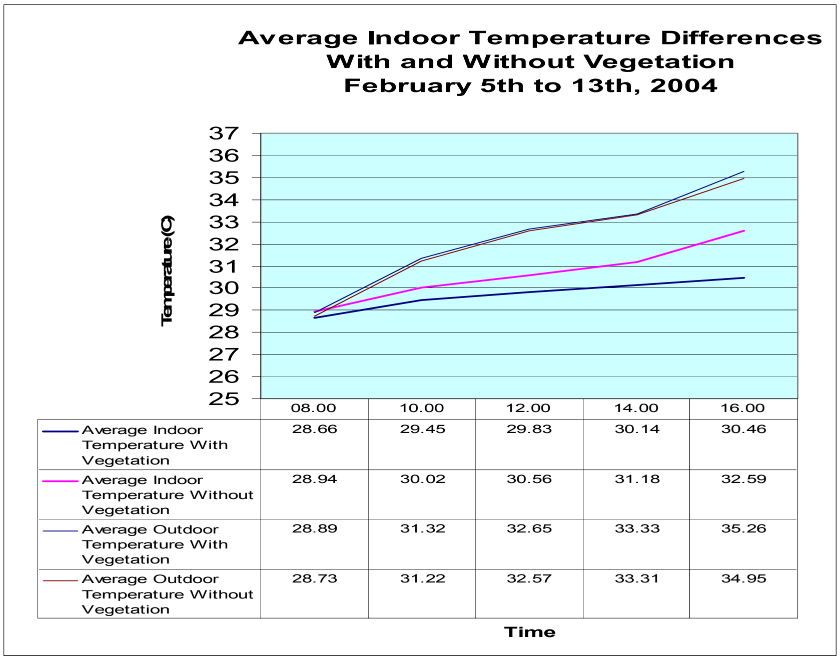
6. Research Result



	08.00	10.00	12.00	14.00	16.00
Average Indoor Temperature With Vegetation	27.62	28.45	29.04	29.51	30.81
Average Indoor Temperature Without Vegetation	28.38	29.17	29.81	30.59	32.71
Average Outdoor Temperature Wth Vegetation	26.76	30.63	32.20	35.69	36.09
Average Outdoor Temperature Without Vegetation	26.94	30.37	32.43	35.42	35.53

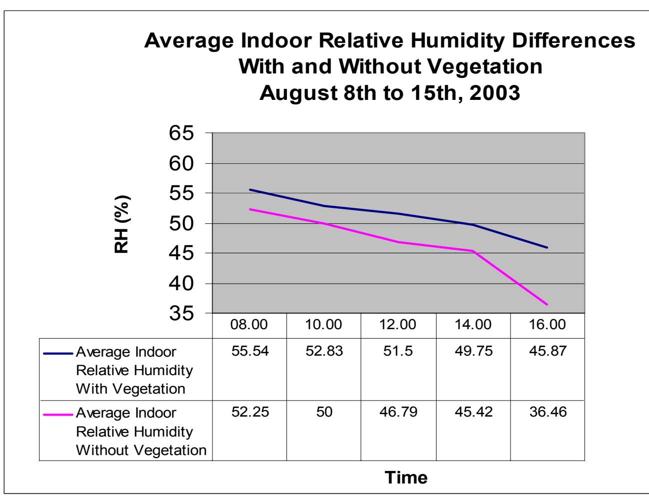
Graphic 1

Based on graphic 1, average outdoor air temperature on façade with and without vegetation pointed 26,8C (at 8 am) and 36 C (at 4 pm).
The average indoor air temperature on façade with vegetation pointed at range 27,6 C (at 8 am) and 30,8 C (at 4 pm) while without vegetation, the average indoor air temperature pointed at range 28,4 C (at 8 am) and 32,7 C (at 4 pm).
So, the average indoor air temperature on façade with vegetation always cooler than without vegetation; with differences minimum 0,72 C (at 10 am) and maximum 1,1 C (at 2 pm). This average indoor air temperature still higher than the recommended air temperature (25 C).

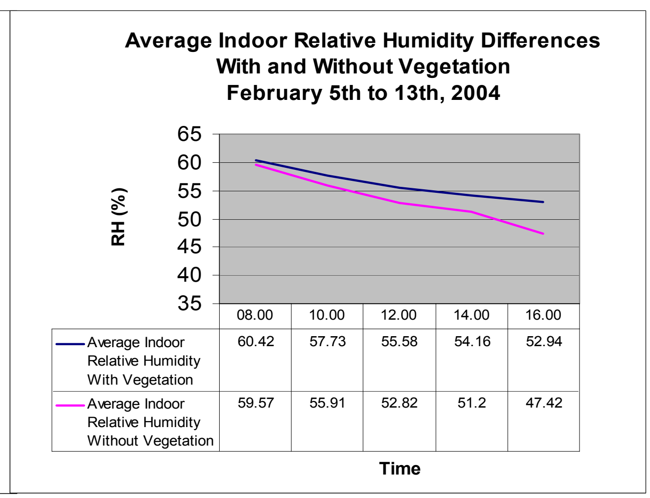


Graphic 2

Based on graphic 2, average outdoor air temperature on façade with and without vegetation pointed 28,8 (at 8 am) and 35,1 C (at 4 pm).
The average indoor air temperature on façade with vegetation pointed at range 28,7C (at 8 am) and 30,5 C (at 4 pm) while without vegetation, the average indoor air temperature pointed at range 28,9 C (at 8 am) and 32,6 C (at 4 pm).
So, the average indoor air temperature on façade with vegetation always cooler than without vegetation; with differences minimum 0,3 C (at 10 am) and maximum 2,1 C (at 4 pm). This average indoor air temperature still higher than the recommended air temperature (25 C).



Graphic 3



Graphic 4

In graphic 3, indoor relative humidity with vegetation always higher than without vegetation; the difference is 2,83 % minimum (at 10 am) to maximum 9,41% (at 4 pm).
The indoor relative humidity with vegetation still higher than the recommendation (50% RH).

In graphic 4, indoor relative humidity with vegetation always higher than without vegetation; the difference is 0,85 % minimum (at 10 am) to maximum 5,52% (at 4 pm).
The indoor relative humidity with vegetation still higher than the recommendation (50% RH).

6. Conclusion.

From this research we found that vegetation as a façade shading can lower until 2°C the indoor air temperature. With vegetation, indoor air temperature can get approximately to the human thermal comfort in working area. This condition minimize the energy consumption for cooling the building. Besides vegetation can block the solar radiation penetration into medium-rise building, these are some more advantages:

- The indoor air temperature at façade or window with vegetation as sun shading is lower than without vegetation.
- In hot air temperature, applying vegetation makes the air more humid, so that the air feels cooler because of vegetation evapotranspiration.
- The average indoor air temperature and humidity with vegetation is still above the thermal comfort air temperature and humidity,. This condition influence the working effectivity could not reach 100 %.
- Blocking the sun light penetration into the building can cause the daylighting decrease. As the effect, it can minimize glare by its surface color and texture.
- Efficient in cost and energy, and easy in maintenance.
- Attractive, more beautiful building appearance.
- To have relation between human and the natural green environment, and it expected to be a positive psychological effect.
- To give a floral fragrance surround it and into the indoor.

6.1. Suggestion

In the future this research can be continued with others vegetation to get the lower in indoor air temperature and humidity. Besides that, it can also be developed to some researches of glare and indoor sky luminance decrease, and to find out how far the psychological effects by using vegetation as façade shading in medium-rise building.

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