Optimization of Thermal Comfort in Rifain Digital Printing: Vertical Garden with Water Wall System Concept

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Abstract. Thermal comfort is a major factor for a building’s design, and is associated to room temperature conditions. Thermal comfort depends on climatic variables and several individual / subjective factors such as clothing, acclimatization, age, gender, level of health, and others. Measurements of thermal comfort made via Meteoblue and SunHour software at the Rifain Digital Printing location provide data including temperature, humidity, sun exposure and wind speed. The data is then synthesized using CBE Thermal Comfort, a software that detects conformity to thermal comfort standards in a room. The results of measurement and data synthesis indicated that the building requires a cooling temperature of 5.2 °C. From these results, it can be said that the thermal comfort of Rifain Digital Printing is not optimal. Improvements are needed to the existing thermal conditions. One of the efforts to optimize thermal comfort is the use of vegetation and water (Talarosha, 2005). Based on synthesis result obtained through research and data processing through literature studies, we came up with a solution, namely a vertical garden with a water wall system design as an effort to overcome the problem of thermal comfort in the Rifain Digital Printing building.

Keywords: thermal comfort, vertical garden, water wall system

1. Introduction

1.1. Research Background
Architecture is an artificial habitat that is not merely a link between humans and the environment, but is also a container of expression that can regulate physical life and psychology (Robert Gautman). Therefore, indirectly architecture will shape human behavior in accordance with the design. To design a building that is comfortable to use, an architect must pay attention to several factors, one of which is thermal comfort.

According to American Standard ASHRAE 55 [2], thermal comfort is a condition where there is satisfaction with the surrounding thermal conditions. Factors that influence thermal comfort in humans are divided into three [3], including environmental, individual, and external factors. The role of the environment in thermal comfort can be measured by humidity, temperature and wind speed. Furthermore, individuals play a role in the quality of the thermal comfort of a place. Since the human body's metabolic system emits heat that adapts to the influence of the activities carried out and the use of clothing that is used.
The choice of the place for the thermal comfort analysis is the Rifain Digital Printing Building. Measurements made here then provide several data which are temperature, humidity, and wind speed. The results of the data obtained can be a determinant of the thermal comfort of the building. The data obtained can be analyzed using ASHRAE and CBE Thermal Comfort standards, the results of which can be in the form of a solution of incompatible thermal comfort.

1.2. Aim
The purpose of this research is to find out the thermal comfort in the Rifain Digital Printing building, and to provide solution and improvement to the existing thermal condition of the building.

1.3. Benefit of Research
Since one of the purposes of the research is to find out the thermal comfort that conforms to Standard Ashrae on Rifain Digital Printing, A significant solution to improve the existing thermal condition can be obtained, namely by creating a Vertical Garden with a Waterwall system.

1.4. Suggested Output / Solution
Output of this research is a design of the second façade, which includes a vertical garden with a water wall system that is installed on the south facade of the building.

2. Literature Review
According to the American Standard ASHRAE 55 [2], thermal comfort is a condition where there is satisfaction with the surrounding thermal conditions. The factors that affect thermal comfort in humans are divided into three [3], namely:

2.1. Environment
The humid tropical environment in Bandung City has the following characteristics;

2.1.1. Air humidity. Air humidity is the liquid that is in the air divided by the total air volume of the mixture or it can be interpreted as the concentration of water in the air. The humidity of a place depends on several factors which are: temperature, air pressure, wind movement, quantity and quality of irradiation, vegetation, availability of water in a place (water, soil, waters) [14]. Air humidity can be measured with an anemometer.

    Based on Meteoblue, the city of Bandung has a level of humidity that varies each season and each year. 2019 has a muggier period (humid and hot) that lasts for 10 months, from 25 September to 24 July, during which time the comfort level is muggy, oppressive, or miserable for at least 67% of the time. The muggiest and hottest day of the year is April 23rd, with the least humid and hot conditions, early 99% of the time. In addition, the most humid (but not too hot) day is August 23, with humid conditions occurring 57% of the time.[1][7]

2.1.2. Temperature. Temperature is a measure of how cold or hot a situation or an object is. The unit of measurement for temperature that is widely used in Indonesia is °C (degrees Celsius). Meanwhile, the unit of measure widely used abroad is °F (degrees Fahrenheit).[9]

    The average temperature in Bandung is 23.46 °C, with the maximum average temperature of 30.5°C in September and 28.2°C as the minimum average temperature.

2.1.3. Wind speed. Wind speed can be influenced by several factors, namely location or place, differences in air pressure, altitude and time. Wind speed can be measured with an anemometer or through software such as flow design.[4]

    Based on Meteoblue, the average wind speed per hour in Bandung varies throughout the year. In the transition from 2018 to 2019, from 16 December to 6 March, it had an average wind speed of more than 2.23 m/s with January 31 as the peak, with an average of 2.72 m/s.
2.1.4. Mean Radiant Temperature (MRT). MRT is defined as the uniform temperature of an imaginary environment where the radiant heat transfer from the human body equals the radiant heat transfer within the actual non-uniform environment.[5]

2.2. Individual

The human body gives off heat. The heat released is influenced by the body's metabolic rate and the type and use of clothing. The body's metabolic rate is influenced by the type of activity. The higher the intensity of the activity, more heat is released. Therefore, the metabolic rate needs to be lowered in order to avoid overheating. The following is the metabolic rate of several activities with constants.[2]

![Figure 2.1. Metabolic Rate in Type of Activity][2]

Based on the data above, the user's metabolic rate at the Rifain Digital Printing building can be categorized as Light Machine Work, which has a value of 2.2.

Clothing is one of the dominant factors affecting heat dissipation. The unit of clothing insulation that is in thermal comfort is the clothing level. The following is the level of clothing insulation according to the type of clothing and its constants.[2]

![Figure 2.2. Clothing Insulation Value][2]

Based on the data above, user’s clothing level at the Rifain Digital Printing building can be categorized as Trousers, short-sleeve shirts, socks, shoes, and underwear, which has a value of 0.57 clo.

2.3. Other Contributing Factors

Other factors that contribute to the increase in metabolic value are types of food and drink consumed, the body's adaptation to the environment (acclimation), body shape, obesity levels, and overall body health conditions.

One of the efforts to maintain thermal comfort to suit human needs can be done by using the Vertical Garden and Water Wall System to increase humidity, reduce temperature, and take advantage of wind speed to increase air humidity.[10]
2.3.1. **Vertical Garden.** Vertical garden is a method or system of growing plants vertically.\[12\] The use of vertical gardens can provide benefits, one of which is to increase the coolness of a building by adjusting temperature and humidity. Several roles of the vertical garden and green roof in the environment are \[11\];

- Improving air quality.
- Filtering dust and dirty particles from entering into buildings.
- Absorbing pollution. This is beneficial for humans who have asthma, since vertical gardens absorb dirty particles and filter out dust.
- Cooling the room by lowering the temperature.

2.3.2. **Water Wall System.** Water wall System is a wall of water or a wall that incorporates flowing water. The water wall system can provide a cooling sensation and natural feel to a building. Water in the Water Wall System gives an evaporation rate of 8kg / hour (according to measurements from the journal). Evaporation rate can affect the concentration of water vapor in the air, therefore, increasing the air humidity.\[17\]

### 3. Methods

![Figure 3.1. Method Concept](image)

The method used is the synthesis of the situation in the Rifain Digital Printing building with a thermal measuring device, namely an anemometer. Anemometer is used to get field data that includes temperature, wind speed, and humidity. In addition, synthesis measurements are also done, using software consists of *Sunhour SketchUp* Plugin to see how much direct sunlight is exposed to the building facade, *AutoDesk Flowdesign* software to simulate pressure from wind speed to the building facade, and CBE Thermal Comfort as a comparison of the suitability of the measurements obtained from Anemometer with the American Standard ASHRAE 55 in 2009 \[2\].

### 4. Findings and Discussion

#### 4.1. Results of Field Measurements Using an Anemometer on The Southern Facade

![Figure 4.1. Windspeed, Temperature, and Relative Humidity on The Southern Façade (Exterior)](image)
Table 4.1. Average Windspeed, Temperature, and Relative Humidity on The Southern Façade (Exterior)

|                | 9      | 10     | 11     | 12     | 13     |
|----------------|--------|--------|--------|--------|--------|
| Relative Humidity | 0.673464 | 0.611291 | 0.579342 | 0.515952 | 0.747601 |
| Wind Speed (m/s)  | 0.6    | 0.25   | 0.6    | 0.6    | 0.13   |
| Temperature (°C)  | 27.3866 | 28.57647 | 28.61026 | 28.14715 | 26.26723 |

Figure 4.2. Windspeed, Temperature, and Relative Humidity on The Southern Façade (Interior)

Table 4.2. Average Windspeed, Temperature, and Relative Humidity on The Southern Façade (Interior)

|                | 9        | 10        | 11        | 12        | 13        |
|----------------|----------|-----------|-----------|-----------|-----------|
| Relative Humidity | 0.679877 | 0.663813  | 0.666142  | 0.706312  | 0.721692  |
| Wind Speed (m/s)  | 1.04     | 0         | 0         | 0         | 0         |
| Temperature (°C)  | 27.1     | 27.29475  | 27.11963  | 27.05432  | 26.25821  |

4.2. Measurements Using Meteoblue

Figure 4.3. Meteoblue Measurements of Average Temperature, Precipitation, and Wind Speed at The Rifain Digital Printing Building
Measurements made using one of the global weather forecasts, Meteoblue, at the Rifain Digital Printing location, provide data including temperature, humidity, and wind speed. Obtained data then show that the Rifain Digital Printing building has a room temperature of 32 °C - 34 °C, which causes low humidity. The humidity of the air is equal to 40% - 50%. This condition can be said to be dry and in warm condition.

4.3. Measurements of Thermal Comfort using CBE Thermal Comfort Software
According to the CBE Thermal Comfort measurement above, it shows that the blue area on the chart is the standard area for thermal comfort and the red dot is the position of the thermal state that is on the south facade of the Rifain Digital Printing building. This indicates that the thermal comfort on the south facade is far from ASHRAE standards.

CBE Thermal Comfort is a software system that has the right compatibility with the thermal comfort standards in a room. The standard used in this system is ASHRAE 55 - 2017. The synthesis results obtained from Meteoblue and ASHRAE standards which include temperature, humidity, wind speed, metabolic rate, and fabric level, indicate that at certain building coordinates, a cooling temperature of 5.2° C is required.[8]
4.4. Solution to The Problem: Vertical Garden with Water Wall System

The measurements above show that the thermal comfort in the Rifain Digital Printing Building, especially in the production room and the cutting room, is not in accordance with ASHRAE standards. If this happens continuously, it could impact the performance and health of the workers, who work regularly in the building. Therefore, it can be concluded that significant remedies are needed to the existing thermal conditions. One of the efforts to optimize thermal comfort is by using landscape elements in the form of vegetation and air [16].

Landscape elements such as trees and vegetation can also be used as protection against solar radiation. The presence of trees will directly/indirectly reduce the surrounding air temperature, because solar radiation will be absorbed by the leaves for photosynthesis and evaporation. In addition, the presence of water will reduce the temperature of the surrounding air due to heat absorption in the water evaporation process. In addition to lowering the air temperature, the evaporation process will increase humidity. [6]

Therefore, the use of a vertical garden with a water wall system is intended as a solution to overcome the thermal comfort problems in the Rifain Digital Printing building. This strategy is reinforced by the research on eight variations of the vertical greenery system, the results of which show that the vertical garden is able to reduce the temperature (potential thermal) of the building wall surface by 11.58 °C [18]. In addition, other studies have concluded that a vertical garden configuration can provide a decrease in house temperature by 2-3 °C and increase air humidity by 10% to 20%. [13] The research on the use of water as a medium for optimizing thermal comfort shows that the temperature can be lowered by 30 °C to 26-27 °C if the water temperature is 17-15 °C [15].

Figure 4.6. Measurements of Thermal Comfort on CBE Thermal Comfort Software

Figure 4.7. (a) Location of The Building and Direction of the wind; (b) Southern Facade
This vertical garden with a water wall system will be installed in the south area of the building. This is based on the fact that this part of the building has the most wind exposure, and that the area has the widest opening among the other facades of the building. The following is the location of the vertical garden with a water wall system in the Rifain Digital Printing building area.

![Figure 4.8. Location of the Vertical Garden with Water Wall System](image)

This vertical garden is installed using a construction method as if it was a second facade, starting from the foundation to the installation of plants on each rooster, with dimensions; (see Figure 4.9. Front Elevation and Dimensions of the Vertical Garden) length: 3.6 m, width: 0.5 m, height: 2.8 m. In each vertical garden, the rooster is a medium where the plants are placed with a distance of each vertical rooster as far as 50 cm. The soil is placed in the rooster hole so that the plants can bond and hang. Then, water will flow from the reservoir above, where a hole with a diameter of 2 cm has been made with a distance of 7 cm between the holes, this is one of the implementations of the water wall system that is applied to this vertical garden.

![Figure 4.9. Front Elevation and Dimensions of the Vertical Garden](image)

There are 2 water reservoirs located below and above, the water that has gone down to the lower reservoir will flow back up with the help of a water pump. This will happen repeatedly and the water is changed at least every 3 days. Draining is done by removing the drain cover at the bottom right and left of the vertical garden.
The Water Wall System is also useful as an automatic plant watering agent and also as a major contributor in increasing the quality of air humidity and temperature in the Rifain Digital Printing production room. It can be seen in Figure 4.10 (Details of vertical garden perspective cut with water wall system), that there are several elements in its arrangement, including masonry as the main frame with the help of concrete structures to support the load. Then, there are pipes and pumps that drain water from the bottom to the top, and the rooster that has been filled with soil as a binding medium for vertical garden plants. In the water reservoir located above, it can be covered with zinc or polycarbonate material.

![Figure 4.10. Cross Section Perspective of the Vertical Garden](image)

This Vertical Garden will support the success in showing the natural aesthetics arising from plants and water, and can improve air quality by generating O2 through the photosynthesis process done by the plants in the system. As seen in Figure 4.9., the height of the vertical garden is 2.8 meter, it is designed that way because, with this particular height, the vertical garden can act as a shading factor so that the southern facade will feel cooler than before.

![Figure 4.11. Roster with Plant Detail](image)

It can be seen in Figure 4.11. that the rooster used is 20x20x10 centimeters in size with a custom hole type. In its application, other types of rooster can also be used, but there must be soil support on the other side. The soil is placed densely where the plants are also placed. The adhesive system used between one rooster and another is cement plaster.
The choice of roster as a planting medium is because it will allow light and air to be exposed effectively. Roster is also more durable than other materials. For example, it won't be the best choice if hollow iron is used, since if exposed to water, it often will rust. Another example is if wood is used, it will also won't be the best choice since wood’s resistant qualities will be much reduced because this vertical garden is installed in the exterior area. Another consideration in choosing roster as the main planting medium is that rooster is a material that is easily available and affordable.

4.5. Measurement of The Intensity of Sun Exposure using SketchUp Software with Sunhour Plugin

Figure 4.12. Front View Perspective of Building (South Elevation) Before Vertical Garden Installation

Figure 4.13. Front View Perspective of Building (South Elevation) After Vertical Garden Installation

Figure 4.14. Sunhour Legend

4.6. Measurement of Wind Pressure Intensity Using AutoDesk: Flowdesign Software
5. Conclusion

Previously, the results of the synthesis of the conditions in the Rifain Digital Printing building with a thermal measuring device, namely an anemometer, showed that the thermal comfort, especially in the production room, did not comply with ASHRAE standards. The exterior has the highest wind speed of 0.6 m / s, the highest temperature of 28.6 °C, and the lowest humidity of 0.51. Whereas in the interior, it has the highest wind speed at 1.04 m / s, the highest temperature is 27.2 °C, and the lowest humidity is 0.66. After the measurement, the data is supported by being simulated in the SketchUp Software with Sunhour Plugin to measure sunlight intensity and AutoDesk: Flowdesign Software to measure velocity. The simulation results from Sunhour are based on the indicators in Figure 4.14. It appears that there is a change from Figure 4.12. and Figure 4.13. that is, this concept is quite effective. In the first part, it shows that the sunlight intensity is as much as 40%, down to 20%. The same thing happened to the simulation results from Flowdesign, the velocity decreased from 1.054 m / s to 0.608 m / s. So we can conclude that the use of a vertical garden and water wall system can optimize thermal comfort, especially in Rifain Digital Printing.

References

[1] A. Matzarakis and F. Rutz, “Rayman: A tool for tourism and applied climatology,” 3rd Int. Work. Clim. Tour. Recreat, no. January 2007, pp. 129–138, 2007.
ASHRAE, “American society of heating, refrigerating and air-conditioning engineers, inc, handbook, Atlanta,” 2009.

Auliciems, A. S. & Szokolay, S.V, “Passive and Low Energy Architecture International Design Tools and Techniques, 2nd revised edition. Hongkong: PLEA,” Therm. Comf., 2007.

B. Akay, D. Ragni, C. S. Ferreira, and G. J. W. Van Bussel, “Investigation of the root flow in a Horizontal Axis,” Wind Energy, no. February 2016, pp. 1–20, 2013, doi: 10.1002/we.

D. Manatsa, W. Chingombe, and C. H. Matarira, “The impact of the positive Indian Ocean dipole on Zimbabwe droughts Tropical climate is understood to be dominated by,” Int. J. Climatol., vol. 2029, no. March 2008, pp. 2011–2029, 2008, doi: 10.1002/joc.

Egan, M., 1975. Concept In Thermal Comfort. London: Prentice-Hall International.

E. L. H. and S. W. C. Pack, “Weather Forecasting,” Geogr. J., vol. 113, no. February 2016, p. 120, 1949, doi: 10.2307/1788936.

F. Tartarini, S. Schiavon, T. Cheung, and T. Hoyt, “CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations,” SoftwareX, vol. 12, p. 100563, 2020, doi: 10.1016/j.softx.2020.100563.

M. A. Kedzierski, “Principles and methods of temperature measurement,” Exp. Therm. Fluid Sci., vol. 6, no. 1, p. 106, 1993, doi: 10.1016/0894-1777(93)90045-k.

M. Ilardo and R. Nielsen, “Human adaptation to extreme environmental conditions,” Curr. Opin. Genet. Dev., vol. 53, no. August 2018, pp. 77–82, 2018, doi: 10.1016/j.gde.2018.07.003.

M. Rakhshandehroo, M. J. Mohd Yusof, and M. Deghati Najd, “Green Façade (Vertical Greening): Benefits and Threats,” Appl. Mech. Mater., vol. 747, no. March, pp. 12–15, 2015, doi: 10.4028/www.scientific.net/amm.747.12.

Peck, S., 1999. Greenbacks From Green Roofs.

Rawuli, A., 2013. Taman Vertikal Sebagai Sistem Pendingin Udara Alami Pada Pemukiman Perkotaan Malang. Malang: Universitas Brawijaya.

Santoso. “Kelembaban Udara”. Jakarta: Erlangga. 2007

Seputra, J, “Thermal Effectiveness of wall indor fountain in. Warm Humid Climate.,” 2018.

Talarosha, B, “Menciptakan kenyamanan termal,” J. Sist. Tek. Ind., vol. Vol. 6, No, pp. 148–158, 2005.

Washington State department of Health, “Water System Design Manual,” vol. 123, no. December, p. 325, 2009, [Online]. Available: http://www.sswm.info/sites/default/files/reference_attachments/DOH 2009 Water System Design Manual.pdf.

Wong.N.H., T. A, “Thermal evaluation of vertical greenery systems for building walls.,” J. Build. Environ., pp. 663–672, 2010.