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Evaluation of Thermal Environment of Microclimate in Buildings in Hot and Humid Tropical Climate Through Architectural Element Intervention

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KEYWORDS

Thermal environment; microclimate; Hot humid tropics, Intervention, architectural elements

ABSTRACT

The purpose of this study is to evaluate the microclimate thermal environment in buildings to obtain thermal comfort through architectural element interventions. The study covers two objects, namely public and residential buildings in Makassar City, South Sulawesi Province - Indonesia. Data analysis is based on the ASHRAE 55 2022 standard. The data is processed with parametric statistics and then simulated to find a thermal prediction model. The results of the study indicate that the thermal environment with architectural element interventions through increasing water elements, ventilation area, and vegetation can be a microclimate modifier in buildings. The model was created by adding 2.0 m2 of ventilation area, adding 10% vegetation with shade plant characteristics, and moving water features in the form of fountains and adding 15% of the pool area so that the PMV + 0.23, PPD + 8%, TSV-1 - +0, Ta_25.7°C, and relative humidity 63.5 - 66% values were obtained. The evaluation shows that the operating temperature can analyze the comfortable temperature range for visitors by >80% and is in accordance with the ASHRAE 55-2022 standard.

1. INTRODUCTION

Indoor environmental quality refers to the quality of a building's environment in relation to the health and comfort of the people occupying the space within it. The quality of the environment is influenced by many factors, such as thermal comfort and thermal environment.

Thermal comfort has various factors that affect the creation of human satisfaction such as environmental temperature, solar radiation, air humidity, wind speed, clothing and activities [1]. Thermal comfort can be influenced by solar radiation, reflection and absorption, temperature, air humidity and air movement. Thermal comfort factors other than clothing and human activities can be engineered by designing good buildings [2].

The design of comfortable room conditions requires attention to several factors, one of which is microclimate conditions such as humidity, air temperature, air movement, and physiological aspects of humans in the room such as activities and clothing worn. The indoor thermal environment is greatly influenced by the local climate, and the movement of air through a building to reduce indoor discomfort due to overheating conditions in hot and humid tropical climates [3]. The indoor environment is influenced by outdoor conditions, so factors that influence the indoor thermal environment are very important in improving a comfortable and healthy environment in residential buildings [4, 5].

The influence of microclimate is formed from factors such as air temperature, ground surface temperature, wind speed, intensity of sunlight received by the building surface, and air humidity [6].

Microclimate conditions, especially temperature and relative humidity of the air, are not completely at the thermal comfort threshold because they are influenced by several factors of sky and season conditions. In clear sky conditions, the availability of solar radiation is quite large compared to cloudy, overcast or rainy sky conditions. The climate support conditions, especially temperature and relative humidity of the air outside the building, cannot fully support the application of a passive conditioning system to achieve indoor thermal comfort [7]. Air humidity becomes an important factor in thermal comfort when the air temperature approaches or exceeds the comfort threshold and air humidity is more than 70% and less than 40%. To compensate for these high humidity conditions, sufficient wind speed is needed inside the room. Several factors that affect air humidity According to Rahim, R., et al [8], namely: temperature, air pressure, wind movement, quantity and quality of solar radiation, vegetation, altitude, air density, and water availability. Research by Zhang , et al. [9] stated that increasing indoor relative humidity can effectively improve the overall thermal comfort of subjects. Therefore, when setting the initial heating temperature, adequate personnel population density and indoor relative humidity have been identified as key factors to improve the thermal environment of the classroom.

Factors that affect effective temperature are air temperature, air humidity, solar radiation and air movement [10]. Meanwhile, Hamzah et al [11] stated that the influence of wind speed factor on the thermal environment greatly affects the thermal comfort sensation of users in the classroom. Other studies on building design related to thermal environmental comfort [12, 13, 14] emphasize the exploration and ventilation opening model in buildings and conclude that wind speed factor affects building design to achieve thermal comfort.

Design of opening systems in buildings to achieve thermal comfort requires knowledge complete information about the movement of air inside room, simulation modeling techniques can be used to estimate temperature, humidity, and speed indoor air [15, 16, 17, 18]. The presence of water and vegetation elements in the consideration can be a microclimate changer in the room so that the desired comfort conditions are created based on the local climate [19].

Water as an element in architecture can be analyzed in various ways and perspectives in defining a space. The analysis is done on water, because water plays an important role as an element in architectural design and the aspects that are separated as physical effects, dimensions and sensory (auditory, visual, touch and texture). The water element defines space according to its size, placement and proportion [20] .

During the day, radiation from the heat of the sun's rays can be used as energy to change water into water vapor which will change the microclimate in surroundings [21]. Water elements play an important role in controlling the microclimate of a room. The presence of water elements greatly influences the humidity and room temperature conditions. The presence of water increases air humidity, thereby lowering the room temperature. [22, 23].

Vegetation has the ability to lower air temperature depending on the type of vegetation and its application [24]. According to Adityo [25], in his research in Yogyakarta using Envi-Met simulation, he said that tree vegetation is more effective in reducing regional temperatures than groundcover vegetation. Trees have a canopy that is able to cover the area below it and are also effective in reflecting back solar radiation, absorbing solar radiation and helping to break and direct the wind. In addition to architectural elements, landscape elements such as trees and vegetation can also be used as protection against solar radiation. The presence of trees will directly/indirectly lower the temperature of the surrounding air, because solar radiation will be absorbed by the leaves for the photosynthesis and evaporation process. The shadow effect by vegetation will prevent heating of the building surface and the ground below [26]. According to Yulita [27], the arrangement of landscape elements that has the most influence on thermal comfort is the presence of shade vegetation. Meanwhile, Fibrianto and Hilmy [28] said that the shadow formed by vegetation with a small canopy does not have a different effect on reducing air temperature.

The research gap is that previous research that discussed the elements of water and vegetation as microclimate modifiers was more focused on the external environment and the courtyard of the building as well as the architectural composition of the building, especially in hot and humid tropical climates, which differs, especially in terms of air humidity.

The aim of the research is the intervention of water and vegetation elements as microclimate modifiers for comfort and thermal environment. Through this research, the benefits obtained are the development of sustainable solutions that combine environmental aspects, comfort, energy efficiency and environmental friendliness in hot and humid tropical areas. This research is expected to provide an integrative approach that combines air movement, water elements, and vegetation in considering the quality of the thermal environment in buildings. Novel aspects may include a better understanding of occupant preferences regarding air movement, evaporative cooling effects, and the psychological impact of an improved thermal environment.

1. Method

This research is a quantitative research using survey, measurement, and simulation methods with the research subjects being residential buildings (Maxone Hotel) and modern shopping centers (Nipah Mall) located in the Makassar City area, Panakkukang District, Makassar City, South Sulawesi Province .

Objective measurement surveys include measuring environmental parameter data including: air temperature, relative humidity, solar radiation, and air movement.

The research instruments used are digital air flow anemometer to measure wind speed, HOBO UX100-023A External Temp/RH data logger, Hobo MX2302 series data logger, and RC-5 temperature data logger to measure temperature, radiation temperature, and relative humidity (figure 1). Each measuring instrument has specifications, measurement limits, and accuracy as shown in table 1.

Figure 1. Objective measurement instrument

Table 1. Measurement tool specifications

Parameter	Instrument	Make	Range	Basic Occupation
Water temperature Relative humidity	Hobo MX2302	Onset Corporation	-40 to 70˚C 0 to 100% RH	±0.25˚C from -40 to 0˚C ±2.5% from 10% to 90%
Air temperature	RC5 Logger	Elitech	-40 to 70˚C	±0.5% from -20/ +40˚C
Relative humidity	Hobo UX 100	Onset Corporation	1% to 100% RH	± 2,5% from 10% to 90% Resolution 0,05%
Globe temperature	Hobo Ext H21	Onset Corporation	-20C° to 50˚C	0 to 2 seconds for the first data poin
Outoor temperature	Hobo Ext H21	Onset Corporation	-20˚C to 50°C	0 to 2 seconds for the first data point
Air velocity	Digital Anemometer	Mastech instruments	0~30 m/s	±5% ±0.1 Resolution 0.01

Measurements were carried out inside the building and its surroundings with a total of 6 measurement points for each research object, measurements based on distance parameters of 2, 5, 10, 15, 20, 30 meters while air movement measurements were based on the orientation of the building on the North, South, East, West, and top (void) sides. The measuring instrument was placed in a position as shown in Figure 2 and placed at a height of one meter above the floor surface following the Wong and Khoo method [29, 30]. The water and vegetation elements in the study were located on the ground floor.

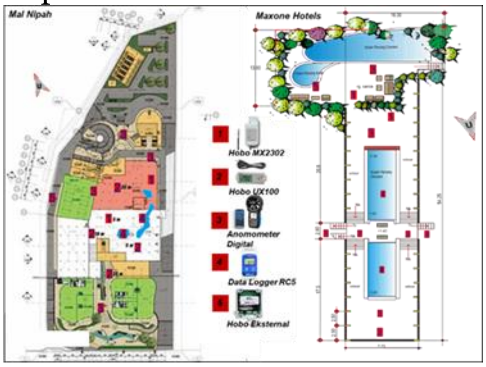
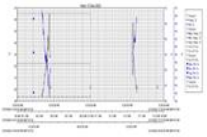
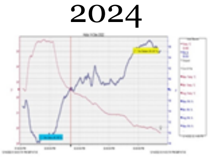


Figure 2. Layout and placement points of research tools

Measurement and questionnaire collection were carried out simultaneously with separate time spans for the effectiveness of the use of measuring instruments. The implementation of measurements and questionnaire collection in June (Nipah Mall) and December (Maxone Hotel) in 2024 as seen in table 1. Thermal environmental measurements and questionnaire collection were carried out for 2 (two) consecutive days with a measurement time span starting in the morning (08.30 - 12.30), afternoon (13.00 - 14.00), and evening (15.00-17.00).

Table 2. Field measurement conditions

Research object	Measurement time	Parameters (variables)		O'clock	
		Distance (m)	Orientation	Measurement	questionnaire
Nipah Mall	26 - 27 June 2024 	2, 5, 10, 15, 20, and 30	North, South, East, West, and up (void)	08:30 – 12:30	08:30 – 12:30 10 samples
				13:00 – 14:00	13:00 – 17:00 15 samples
				15:00-17:00	
Maxone Hotel	28-29 Dec 2024 	2, 5, 10, 15, 20, and 30	North, South, East, West, and up (void)	08:30 – 12:30	08:30 – 12:30 10 samples
				13:00 – 14:00	1:00 PM – 5:00 PM 10 samples
				15:00-17:00	

analysis is taken from the instrument tools used and physical data of the building. Thermal environment analysis in the form of temperature, relative humidity, solar radiation, and air flow velocity observed according to the ASHRAE 55 standard (55 2022) to assess the PMV and PPD scales. Furthermore, thermal sensation is based on the thermal sensation/sensation scale TSV (*thermal sensation vote*), a questionnaire is used to evaluate the thermal environment at the time of measurement, then an examination of the type of clothing used, the activities carried out, and experimental tests on the age category of respondents. The results of the questionnaire distributed as many as n = 32 respondents who have an age range of 18-55 years with the majority of respondents being women. The clothes used are measured in clo units (1 clo = 0.155 m^2.K / W), while the activities carried out are measured in met units (1 met = 58 W / m^2).

PMV, PPD, and TSV are produced and refer to the ASHRAE 55-2022 standard. The ASHRAE 55-2020 standard has 7 criteria, namely, very cold (-3), cool/cold (-2), somewhat cool (-1), neutral (0), somewhat warm/hot (+1), hot (+2), very hot (+3).

The PMV, PPD, and TSV values were processed using the *Thermal Comfort Tool* (CBE) software which produced a Psychometric diagram. Furthermore, regression and correlation tests were used as control tools for the thermal comfort and environmental index. The next stage is based on the research study, namely the thermal environment is simulated using *Computational Fluid Dynamics* (CFD) analysis, then evaluated and compared on the two simulation models. Thermal environment simulation in the form of improved water features, arrangement of vegetation elements, and addition of ventilation area.

2. Results and Discussion

The modern shopping center building Mal Nipah is a modern multi-storey shopping center and office center, the building located east of the administrative area of Makassar City is built on an area of 121,426 m^2 with a land area of 3.5 Ha. There is vegetation on the front and back of the site including vegetation in the building. The lighting and ventilation systems use more natural systems. There is a void corridor without a membrane that makes the air circulation fresher and looks bright and spacious.

In this area there is a pool and an artificial waterfall located in the middle of the building. In this research, the water elements in the building are in the form of artificial waterfalls and ponds. The height of the artificial waterfall consists of a waterfall height of 1 ± 15 m, a waterfall of 2 ± 18 m, and a waterfall of 3 ± 22 m. The volume of the pool when fully filled is ± 31.92 m^3 with a pool water temperature of 27.1˚C. The operation of the artificial waterfall is automatic every day at 15:10 - 17:00.

Maxone Hotel is one of the hotels in Makassar City that carries the concept of a resort hotel, has a fairly large and well-arranged green open space. The hotel stands on 2.4 hectares of land and a building area of around 8,000 m^2, has 155 rooms and is equipped with various supporting facilities.

With a tropical architectural concept, Maxone Hotel makes greater use of natural lighting and ventilation systems. Artificial lighting and ventilation systems in the room also utilize natural ventilation with window openings. The swimming pool area utilizes natural ventilation and lighting through openings on the south, west, east and roof sides. There are green areas and trees surrounding the building.

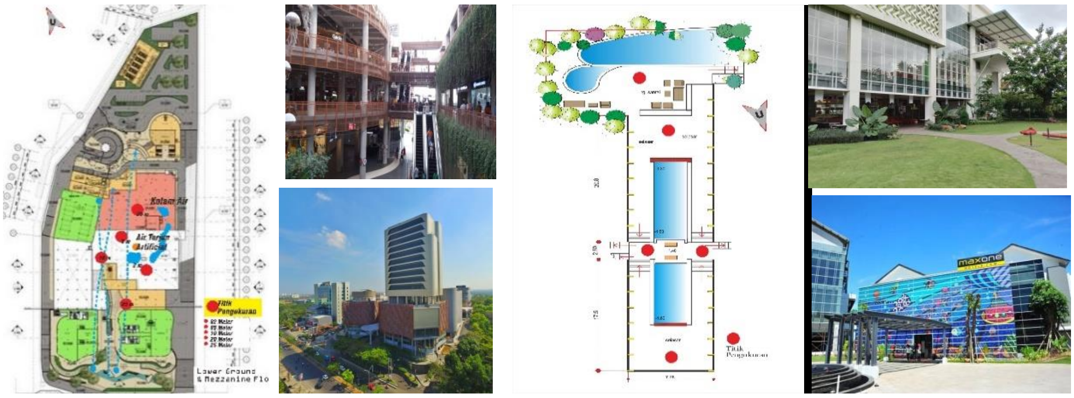


Figure 3. Research location: Nipah Mall and Maxone Hotel

The water element in the building is a swimming pool with an area of 81.92 m^2. The volume of the pool when fully filled is ± 118.78 m^3 with a pool water temperature of 26.6˚C.

Figure 3 shows the research location with the focus of the observed objects in the form of the presence of water and vegetation elements as microclimate modifiers in buildings, thermal environments, and thermal comfort sensations that integrate environmental factors and behavioral adaptations as well as analysis before and after modeling to determine the level of change in the thermal environment. The condition of the research objects is as shown in table 3.

Table 3. Conditions and situations of research objects

Research Subjects	Building Orientation	Form of Space
Nipah Mall 121.46 m^2	North-South	Trapezoid
Maxone hotel 420.44m^2	North-South	Rectangle

Facade	Water element	Characteristics	Vegetation	Openings/ventilation
Passive Window with Double Skin	waterfall, ornamental pond ,	Area = 63.84 m^2 Height = 0.50 m Volume = 31.92 m^3 Waterfall Height 22 m	Green area outside the building, vegetation inside the building such as palm plants (Chamaedore seifrizii), ferns, snake plants, and Chinese evergreen, Spreading pattern. Vegetation proportion	Open rooftop and some semi-transparent membrane roofs Void corridor without membrane

			25% of the floor area	
Passive windows with massive glass material	Swimming pool mature Children	Area = 81.92 m^2 Height = 1.50 m Volume = 118.78 m^3 Area = 96m^2 Height = 0.50 m Volume = 48m^3	Green area outside the building , Vegetation inside the building such as palm plants (Chamaedore seifrizii), ferns, snake plants, and golden pothos (golden photos), Wide canopy, cluster pattern. Vegetation proportion 15% of floor area.	Open rooftop and some semi-transparent membrane roofs

2.1. Air temperature , relative humidity, and radiation temperature data

The process of measuring temperature, humidity, radiation temperature, and air flow from both research objects, data was taken from the instrument and then processed using statistics to obtain the average measurement results.

The Nipah Mall and Maxone Hotel buildings have building orientations that respond to the climate in the area, because in both buildings the longest sides of the building facade face North and South. Measurement of average indoor and outdoor temperature, humidity, and wind speed with measurement points, distances, and measurement times were carried out on the ground floor area where there were water and plant elements.

Measurements at 08.30 – 12.30 Nipah Mall and Maxone Hotel with 6 observation measurement points showed minimum - maximum temperatures ranging between 27.32 – 30.2° C so that the average temperature in the Nipah Mall building ranged from 28.82° C , humidity 62.65%, outdoor temperature ranged from 32.5 ° C and average wind speed 1.78 m / s, while in the Maxone Hotel building the minimum - maximum temperature ranged from 28.5 – 32.6° C so that the average temperature is 30.0° C , humidity is 67%, outdoor temperature ranges between 32.1 - 33.7° C , and average wind speed is 0.66 m/s

Measurements at 13.00 – 15.00 Nipah Mall and Maxone Hotel with 6 observation measurement points showed minimum - maximum temperatures ranging between 29.3 - 29.7° C so that the average temperature in the Nipah Mall building was 29.54° C , humidity 61.34%, outdoor temperature ranging from 31.15° C and average wind speed 1.56 m / s, while at Maxone Hotel the minimum - maximum temperature ranged from 31.2 - 33.4° C so that the average temperature was 31.8° C , humidity 66%, outdoor temperature ranging from 33.6 - 34.9° C , and average wind speed 0.88 m / s.

Measurements at 15.00 – 17.00 Nipah Mall and Maxone Hotel with 6 observation measurement points shows the minimum - maximum temperature ranges between 26.6 - 28.4° C so that the average temperature at Nipah Mall is 27.38° C , humidity 63.74%, outdoor temperature ranges from 31.10° C , and average wind speed 2.56 m / s while at Maxone Hotel the minimum - maximum temperature ranges between 32.5 - 33.5° C so that the average temperature is 32.7° C , humidity 65%, outdoor temperature ranges from 33.0 - 33.8° C , and average wind speed 1.28 m / s.

Measurement conditions based on measurement time for the two research objects are shown in the following image.

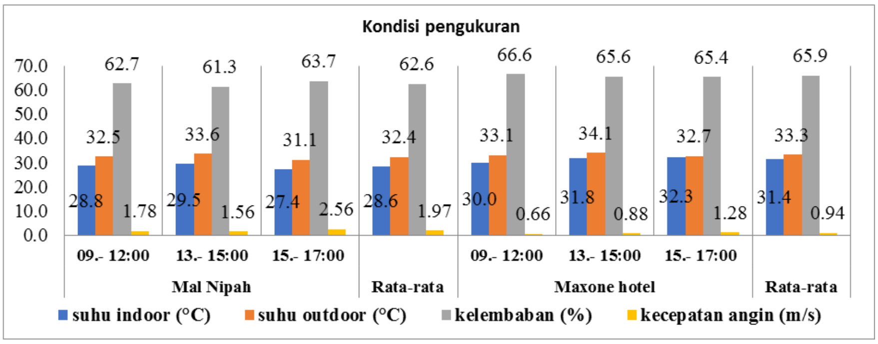


Figure 4. Average measurement conditions of temperature, humidity, and wind speed at two research objects

Figure 4 shows that there are differences in temperature, radiation temperature , humidity and wind speed in the measurements of the Nipah Mall and Maxone Hotel buildings , measurements at 08.30 - 12.00 WITA Nipah Mall and Maxone Hotel temperatures and humidity are low and the average wind speed is 1.22 m / s then measurements at 13.00 - 15.00 the temperature increases between 29.54 - 31.80°C and the average wind speed is up to 1.22 m / s while at the measurement hours of 15.00 - 17.00 the temperature and humidity gradually decrease to an average of 29.08° C with a humidity of 64.57% and wind speeds between 1.28 – 2.56 m/s.

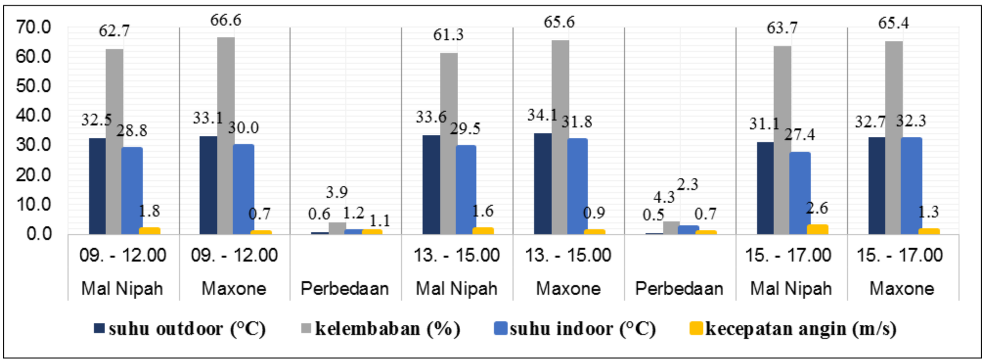


Figure 5. Graph of the relationship between temperature, humidity, outdoor temperature, and
Wind speed of Nipah Mall and Maxone Hotel

The measurement floor at the first point to the fifth measuring point has vegetation but no water, but the temperature and humidity fluctuate due to several factors, namely at the first object point the temperature and humidity are very high due to the lack of vegetation, the absence of a roof, and open spaces that are directly exposed to sunlight, at the second measuring point the temperature and humidity are rather high because there is not too much vegetation and the space is open, at the third measuring point the temperature and humidity are rather low due to the presence of vegetation and the space is slightly closed , at the fourth and fifth measuring points the temperature and humidity are low due to the large amount of vegetation and the space is slightly closed.

The results of the analysis of the average temperature, humidity, and radiation temperature measurement data were then entered and analyzed in a Psychometric graph chart to determine the air characteristics of the two research subjects as shown in the following image.

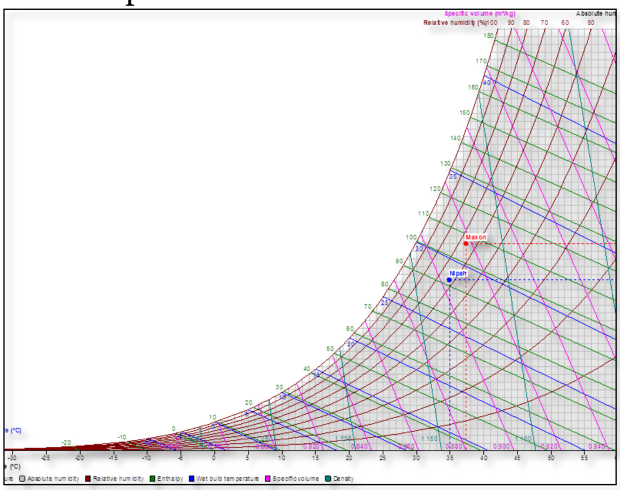


Figure 6. Psychometric graph of air characteristics at Nipah Mall and Maxone Hotel
Source. Psychrometrics Program is property of Daikin Europe NV

Figure 6 shows a Psychometric graph, a graph or chart that contains components to determine the nature/characteristics of air. The psychrometric graph relates to various parameters included in the energy and mass balance of humid air. The psychrometric graph, the vertical axis (on the right) is the specific humidity, while the horizontal axis is the temperature in the building.

2.2. Air speed and flow data

Measuring wind speed inside a building is necessary to determine the effect of wind movement on the thermal environment with architectural elements such as water and plants as microclimate modifiers in the building.

Wind coming from the East or from the West will provide the same portion to enter the room facing North and South. If the position of the research room faces North, the wind speed that enters in the morning until evening is greater than the position of the room in the East or West of the building. While the side facing East and West has small air movement because it is closed by the room wall and the opening is only the entrance door access. Air movement around and inside the building from the results of field measurements can be seen in the following picture:

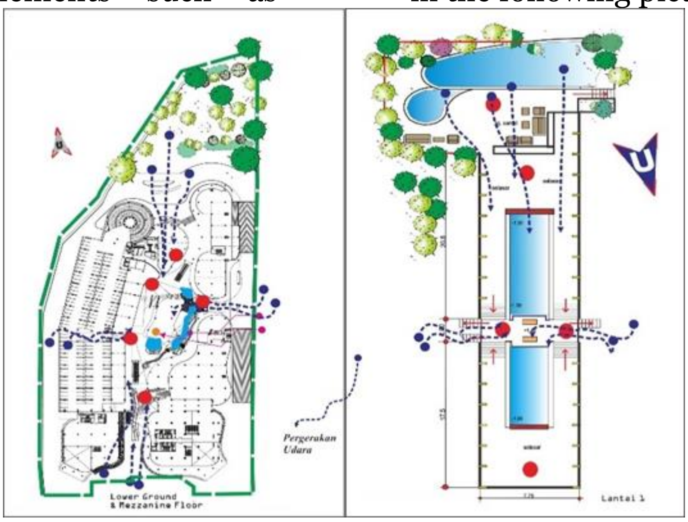


Figure 7. Air movement and wind speed measurement points at At Nipah Mall and Maxone hotel

With the orientation of the building facing North - South, the air movement around the building and inside the building is adjusted to the conditions in the field to provide a comparison of the type of opening, orientation, green open space, and surrounding buildings. By entering measurement data in the field, the results of the speed and air flow in the two building objects are as follows:

2.2.1. Nipah Mall Building

Analysis of air speed and flow around and inside the Nipah Mall building (Figure 8) as follows the average wind speed (V) inside in the morning to evening tends to be high at 1.03 m /s. The upper side (roof) of the building is an area of greater air movement reaching an average of 2.18 m/s and the North side is 1.29 m/s. The large air movement on the North and upper sides is caused by the entrance and exit access and the rather large openings (voids). Furthermore, the air movement in the building during the day

(12.00 - 15.00) is quite high at 1.09 - 1.34 m/s and towards the afternoon the wind speed decreases to 1.00 m/s. This is in accordance with the global wind speed conditions where the wind speed will be felt strong during the day, while in the morning the wind tends to change direction and speed. This is due to the shift in air movement from West to East. Meanwhile, in the afternoon the wind speed decreases where the air movement from the East reverses direction to the West.

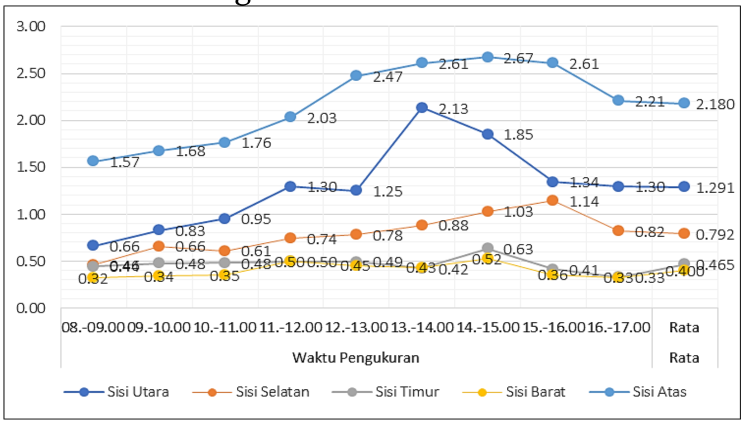


Figure 8. Air movement graph and measurement points speed at Nipah Mall

The graph above shows that the wind speed in the North-South, East-West directions, and in the top floor area of the building increases during the day by 1,010 m/s and decreases when the wind passes through the outer corridor of the building floor (0.544 m/s). Furthermore, the wind speed decreases further when the wind reaches the room (0.044 m/s) . This reduction in wind speed is caused by friction when the wind hits the walls of the building and when the wind passes through the outer corridor of the building and then when the wind passes through the ventilation into the room.

2.2.2. Maxone hotel building

Analysis of air speed and flow around and inside the Maxone hotel building (figure 9) as follows the average wind speed (V) in the morning to evening of 0.86 m/s. The upper side (roof) of the building is an area of greater air movement reaching an average of 1.76 m/s and the North side of 0.65 m/s. The large air movement on both sides is due to the access to the rear area of the building which is a pool area and green open area and the opening (void) at the top which is quite large (±95m²). Furthermore, air movement in the building in the afternoon (13.00 - 17.00) is quite high at 1.02 - 1.09 m/s. The speed and movement of the wind from morning to afternoon tends to change direction and speed. This is due to the shift in air movement from East to West. Meanwhile, in the afternoon the wind speed is high due to the movement of air from the West turning to the East.

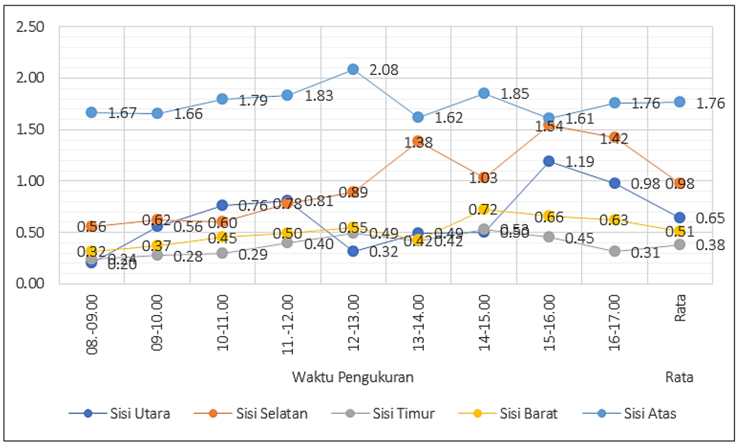


Figure 9. Air movement graph and wind speed measurement points at Maxone hotel

The graph above shows that the average wind speed in the South-North, West-East directions, as well as in the top floor area of the building increases at 11.00-16.00 by 0.92 m/s, then the air movement is relatively stable until the afternoon.

2.3. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) Values

Thermal sensation and comfort predicted using PMV, PPD and TSV Models by including factors that affect thermal comfort, namely: environmental factors (temperature, air humidity, wind speed, radiation temperature) and human factors (type of clothing and activity). PMV is an index that indicates the sensation of cold and warmth felt by humans on a scale of +3 to -3. The PMV scale is determined to find problems from the sensations felt in terms of the building and can provide thermal comfort for space users. Thermal comfort analysis based on PMV, PPD, and SET indices is processed and simulated using *the Center for Built Environment* (CBE) *Thermal Comfort Tools software* . This software feature is able to compare two or three thermal environmental comfort scenarios (*compare tool*) so that it can predict thermal comfort, save a large amount of energy, and assess comfortable designs with low energy consumption. The field data comparison table based on the ASHRAE 55 2020 index shows the results of the PMV thermal comfort evaluation analyzed using the *Center for the Built Environment software* (https://comfort.cbe.berkeley.edu/en-16798) as shown in table 4 below.

Table 4. PMV, PPD, & SET values at each measurement time based on CBE

Data	Nipah Mall			Maxone hotel		
	08.30-12.30	12.-15.00	15.-17.00	08.30-12.30	12.-15.00	15.-17.00
PMV	0.15	0.37	0.10	1.42	1.45	0.23
PPD	5%	8%	7%	47%	48%	6%
SET	25.8	26.6	23.8	30.4	30.5	26.0

Table 3 shows that the PMV, PPD, and SET values on the measurement floor and at each measurement time have significant differences. At Nipah Mall, the highest PMV, PPD, and SET values are at 12.00-15.000. while at Maxone hotel the highest PMV, PPD, and SET values are at 08.30 to 15.00. The PMV, PPD, and SET values in both buildings decrease at 15.00-17.00. Comparison of thermal comfort according to the ASHRAE 55 standard in the two buildings simulated with CBE software (https://comfort.cbe.berkeley.edu/en-16798) can be seen in the following table.

Table 5. PMV, PPD, & SET values at each measurement time based on CBE

	PMV	PPD (%)	SET (° C)	Cooling Effect (° C)	Sensation
Nipah Mall	0.28	7%	26.5	5.7	Neutral
Maxone Hotel	0.76	17%	28.3	5.0	A Little Hot

Table 5 shows that the PMV, PPD, and SET values in the two research objects differ in terms of thermal sensation. In Nipah Mall , the thermal environmental sensation is in a neutral position with a SET value of 26.5˚C, while in the Maxone Hotel the SET value is 28.3˚C or slightly hot. This means that the ASHRAE 55 standard in the Maxone Hotel building is not accepted and visitors feel uncomfortable (+1 - +1.5).

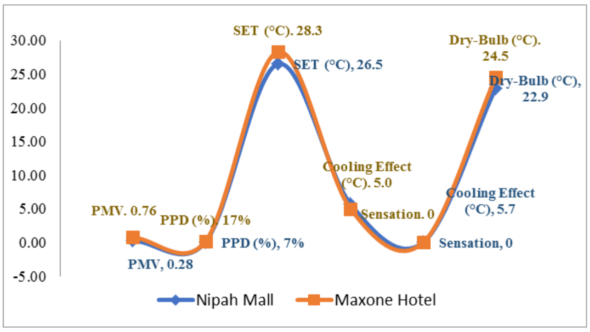


Figure 10. Psychometric PMV graph comparing research objects

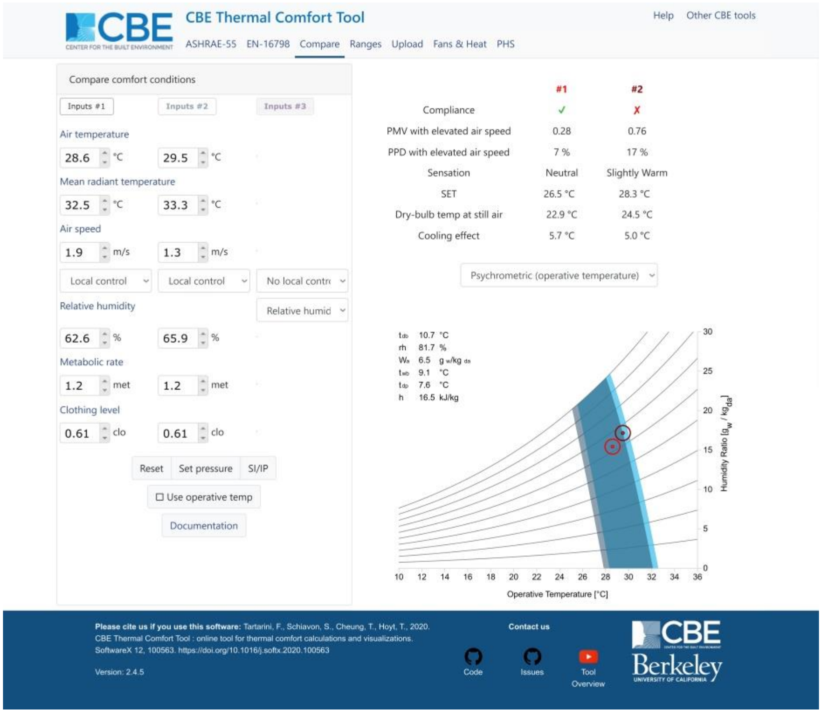


Figure 1 1. Comparison of PMV values from thermal sensation measurements Respondents in research objects
Source: https://comfort.cbe.berkeley.edu/en-16798

Figures 10 and 11 PMV Psychrometric charts show a comparison of PMV , PPD, and SET values at Mal Nipah (input # 1) and Maxone Hotel (input # 2). At input # 1 it tends to be neutral (0). The PMV value is at 0.28 , PPD 7%, SET 26.5˚C, dry-bulb 22.9˚C, and cooling effect 5.7. At input # 2 it is slightly hot (+1). The value PMV 0.76, PPD 17%, SET 28.3˚C, dry-bulb 24.5˚C, and cooling effect 5.0˚C. Air temperature, effective temperature , air humidity , wind speed, humans, and activities have a great influence on the PMV value.

Based on ASHRAE Standard d 55 – 20 20 there are acceptable conditions as comfortable conditions, namely PMV values ranging from -0.5 to +0.5 . The conclusion of the psychometric chart above is that Maxone Hotel based on ASHRAE thermal comfort standards, the red dot is slightly outside the blue line, with a PMV result of 0.76, from the scale included in the warm category. This shows that the presence of water and vegetation in the area has little effect on visitors' thermal sensation.

2.4. Termal sensation vote (TSV)

To calculate the thermal sensation (TSV), a questionnaire was taken from both research objects. The results of the questionnaire distributed n = 30 respondents who were aged 18-45 years with the majority of respondents being women. A total of 20 respondents were housewives, 10 respondents were employees. Activities are done in a relaxed manner, walking, and eating. Generally, respondents wear formal clothes. Respondent characteristics are height with a range of 150-169 cm. In the survey using a questionnaire distributed to visitors with the following provisions, namely respondents were selected randomly, the time span was between 08.30 - 17.00, respondents did not wear thick clothes such as sweaters and the like so that the clothing resistance number was 0.6 clo, and respondents with activities standing, walking, eating, and swimming so that the metabolic rate number was taken as 1.2 met. For the calculation of thermal sensation vote (TSV) based on seven ASHRAE scales with natural ventilation space can be seen in Figure 1 2 .

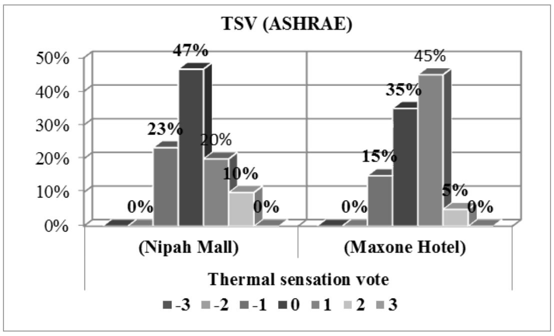
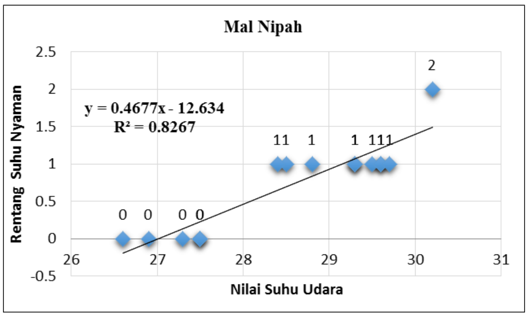


Figure 12. Percentage of thermal sensation (TSV) of respondents on both building objects

Figure 12 shows that the thermal comfort sensation (TSV) at Nipah Mall and Maxone Hotel can be categorized that in the Nipah Mall area, the highest respondent choice is in area 0 (neutral) which is around 46.7% while at Maxone Hotel the highest respondent choice is in area +1 (rather hot) which is 45%. The thermal sensation index in both buildings is in accordance with the results of field measurements that at Nipah Mall the temperature ranges between 27.38 - 29.54 ° C with an average humidity of 61.58%, and at Maxone Hotel the temperature ranges between 28.5 - 33.5° C with a humidity of 64.7%. With these results, the respondent's thermal sensation (TSV) of temperature (air temperature and operating temperature) can be analyzed using a linear regression line as follows.



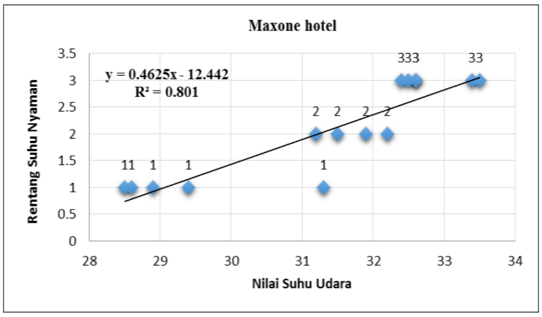


Figure 13 . Linear regression graph of respondents' thermal sensation measurements on the subject of research

resulting data graph shows that the comfortable/neutral temperature = 0, where respondents feel comfortable is achieved at 26.8° C air temperature (Ta) with a range of respondents' comfortable temperatures between -1 and 0, so that the limit at which respondents feel very comfortable (lower limit) is at 26.4°C air temperature and the upper limit is at 27.8°C air temperature.

Table 6. Results of the regression test equation

Regression Statistics	Maxone hotel	Mal Nipah
Multiple R	0.886	0.899
R Square	0.785	0.809
Adjusted R Square	**0.768**	**0.793**
Standard Error	0.417	0.264
Observations	14	14

Table 6 shows the results of the linear regression equation on the two building objects, namely the value of y = 0.4677x-12.634 (Nipah Mall) and y = 0.4625x-12.442 (Maxone Hotel), explaining that the air temperature (X) with a comfortable temperature range (Y) in both subjects is in the range of 0.80 - 1.00 where this figure is included in the category of a very strong correlation relationship, while the coefficient of determination for Nipah Mall is 0.793 or 79.3% while at Maxone Hotel it is 0.768 or 76.8% which means that in both buildings the air temperature value (X) can analyze a person's comfortable temperature range (Y) by >75%.

2.5. Thermal environmental data of research objects

The objective measurement analysis results data are then simulated using CFD to see the simulation depiction before and after modeling of the temperature , relative humidity, and air flow velocity in both research subjects . By entering field measurement data into the CFD simulation as shown in Figure 14 .

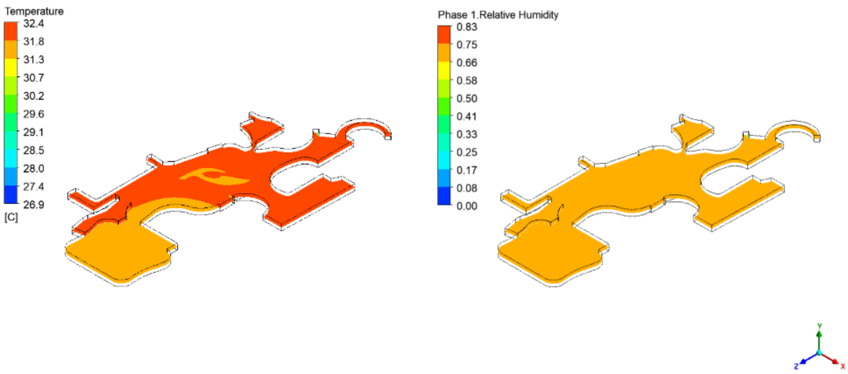


Figure 14. CFD simulation of temperature and humidity at Nipah Mall

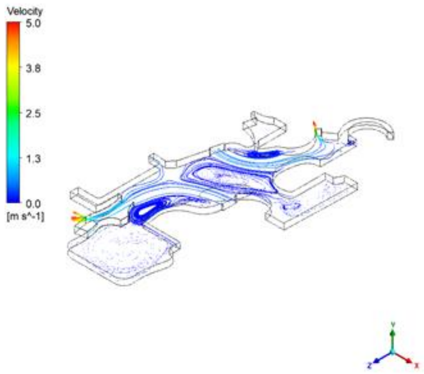
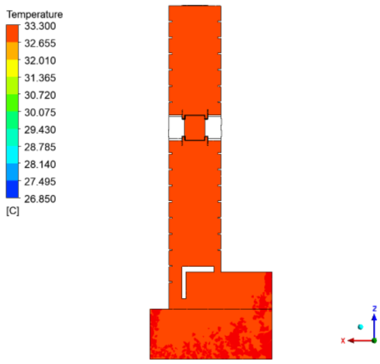


Figure 15. CFD simulation of air velocity and flow at Nipah Mall

Based on the results of the existing simulation of temperature, humidity and air movement (figures 14 and 15) Nipah Mall shows that the average temperature reaching 32.2˚C and humidity of 67% and air movement ranging between 0.5 – 1.0 m/s so it can be said that the influence of the pool and artificial waterfall in the area does not affect the thermal comfort of visitors.

Next, by entering field measurement data into the CFD simulation, the temperature , relative humidity , and air movement of the Maxone Hotel can be seen in Figures 16 and 17.



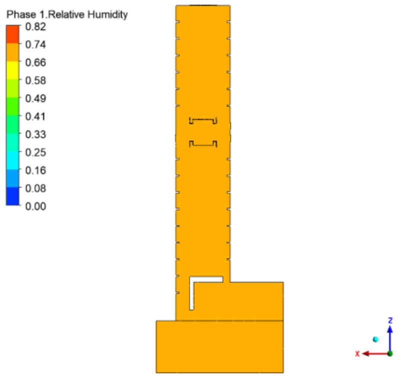


Figure 16. CFD Simulation Results of Maxone Hotel Temperature and Humidity

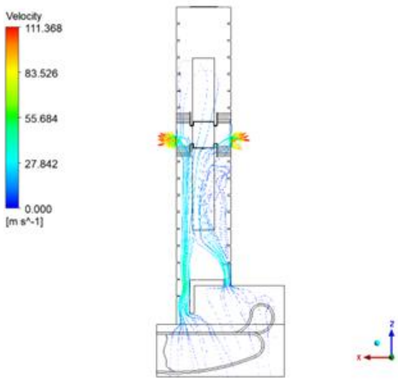


Figure 17. CFD Simulation of Maxone Hotel Air Velocity and Flow

The results of the existing simulation of temperature, humidity, and air movement of Maxone Hotel show that the average temperature reaches

33.3˚C, humidity 72%, and air movement ranges from 0.2 – 0.8 m/s while the area near the swimming pool has a temperature of around 32.1˚C and humidity 69%, so it can be said that the influence of the swimming pool in this area does not affect the thermal comfort of visitors.

Existing simulation data of wind speed and air flow in both buildings where the orientation of the inlet opening not only affects the air speed, but also the air flow pattern in the room, while the location of the outlet only has a small effect on the speed and pattern of air flow. In Mal Nipah, the placement of large air openings on the upper side which is both the inlet and the outlet will create an air flow pattern that moves from the inlet to the outlet. The orientation of the North side inlet is the potential direction of the wind that will affect the air speed to achieve thermal comfort in the building. At Maxone Hotel, the upper side inlet is an opening that provides an air flow pattern that enters the room and is also an air flow outlet, because on the South side there is no opening so that the air flow experiences friction including on the East and West side inlets where the openings are not too large. This is what affects thermal comfort so that the temperature and humidity are rather high.

2.6. Computational Fluid Dynamic (CFD) Modeling Simulation

Integration of thermal environment models with water and vegetation elements to predict and analyze their effects on the microclimate in buildings is evaluated and compared based on existing simulation results and CFD thermal modeling results. This involves assessing and comparing the effects of using these elements on the thermal conditions in the analyzed environment.

The two research objects that were evaluated and compared were the environment and thermal comfort based on the ASHRAE 55 2020 standard. This modeling considers factors such as thermal sensation, air movement (ventilation), and the influence of the thermal environment (arrangement of vegetation and enhancement of water features) in creating comfortable and energy efficient thermal conditions. Based on this, modeling was carried out, namely ventilation variations, vegetation arrangements based on plant types and canopies, increasing moving water features, and water pool dimensions. The CFD simulation modeling indicators of both building objects are shown in the following table.

Table 7. Variations and modeling of research objects

Indicator	**Variations and modeling**	
	Nipah Mall	**Maxone hotel**
Ventilation Inlet and outlet	Increased ventilation size by 2.00 m^2 On the west side	Additional ventilation size of 1.50 m2 on the South, East and West sides

Waterfall	Additional waterfall operating hours twice a day at 12:00-14:00 and 15:30-17:00	Making fountains around swimming pools and moving pool water features.
Water Pool	Increased pool dimensions by 1.00 m	Increase the pool dimensions by ± 30 cm.
Vegetation and landscape	Arrangement of canopy vegetation and canopy density such as palm plants, ferns, snake plants, and aglaonema on the west side.	Addition of vegetation proportion from 15% to 30%. Arrangement of canopy vegetation and canopy density such as palm plants (Arecaceae), ferns (Polypodiophyta), snake plants (Sansevieria), and aglonema on the north side.

Modeling based on ventilation variations, water element and vegetation arrangements in the Nipah Mall building as seen in Figure 18.

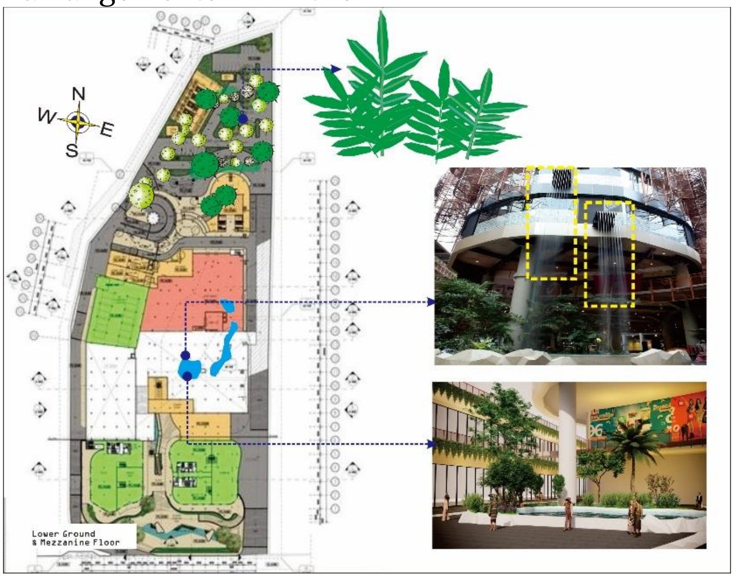


Figure 18. Variations and modeling of Nipah Mall

Figure 18 shows the modeling and variation of the opening on the West side of 2.00m2 then the arrangement and addition of shade vegetation on the North and South sides, as well as the operation of the artificial waterfall twice a day. After modeling and varying the size of the opening, the largest air movement is on the upper side (void) of 2.63 m/s and on the West opening of 0.98 - 1.09 m/s. CFD modeling of the thermal environment as shown in Figure 19 below.

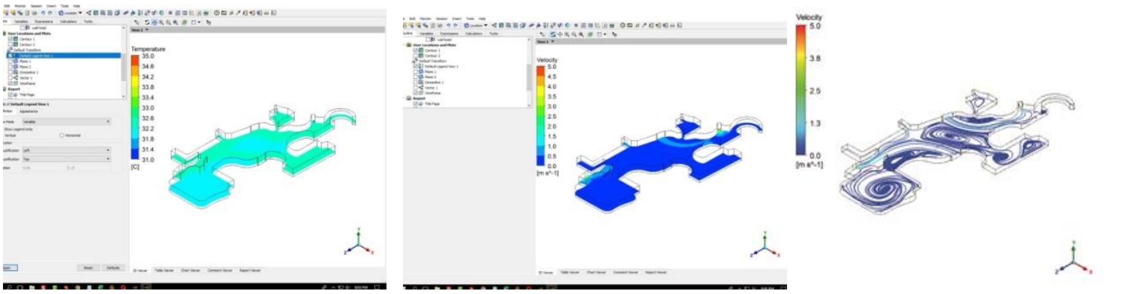


Figure 19. CFD simulation modeling of temperature, humidity, and air movement at Nipah Mall

After modeling was carried out on the Nipah Mall building, the simulation results for temperature, humidity, radiation temperature, and air movement based on Figure 19 showed that the average temperature was around 27˚C, humidity 63%, and air speed ranged between 0.9 – 1.5 m/s.

Modeling variations of architectural elements in the form of water, vegetation, ventilation based on thermal simulation results obtained a thermal decrease in Nipah Mall of 5.2˚C and humidity of 4%, it can be seen that the cooler area is in the middle, the air flow is blue, so the influence of vegetation and the timing of the operation of artificial waterfalls in the area greatly affects the thermal comfort of visitors.

Modeling based on ventilation variations, water element and vegetation arrangements in the Maxone hotel building as seen in Figure 20.

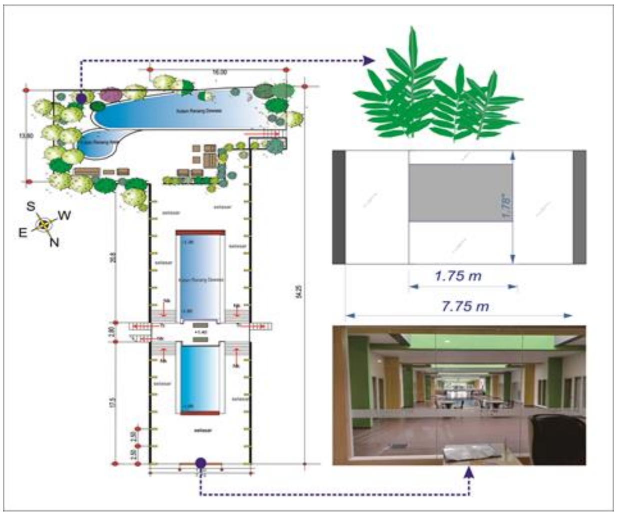


Figure 20. Variations and modeling of Maxone hotel

Figure 20 shows the modeling and variation of openings on the North side of 1.4 m2, on the East side of 4.5m2 , and the West side of 4.52m2 then the arrangement and addition of shade vegetation on the North and South sides, and the improvement of the fountain around the swimming pool. After modeling and variation of the size of the largest air movement openings are on the upper side (void) of 2.63 m/s and on the openings on the North, East, and West sides of 0.98 - 1.09 m/s. CFD modeling of the thermal environment as shown in Figure 21 below.

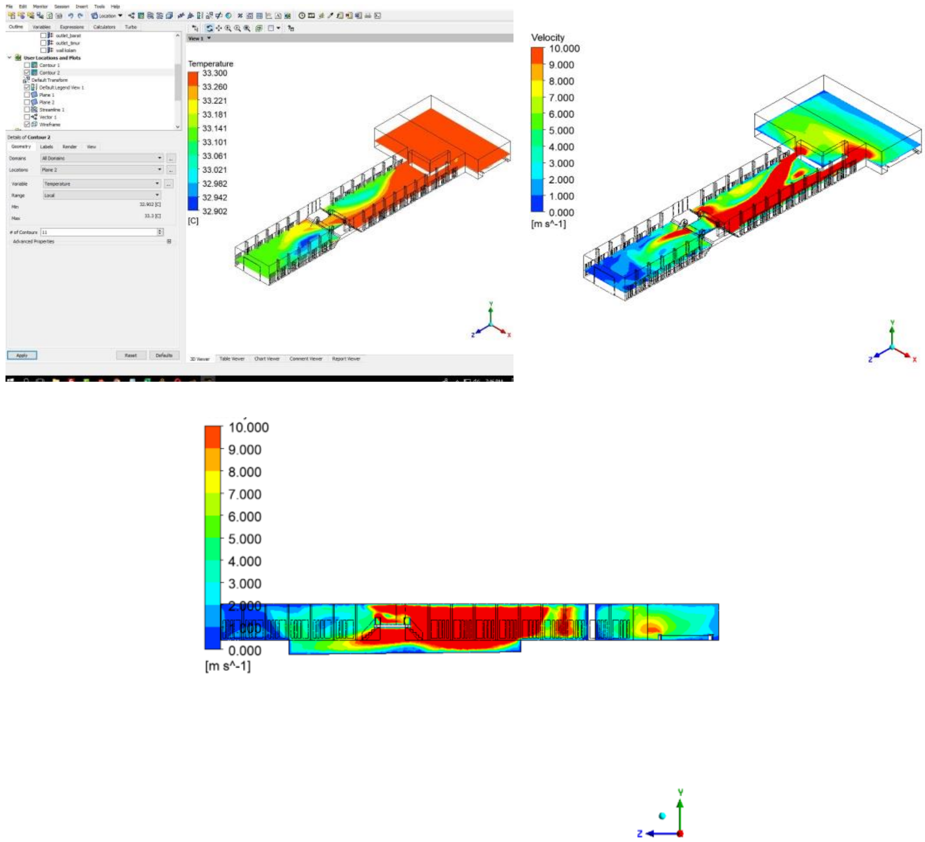


Figure 21. Maxone Hotel Thermal Simulation CFD Model

simulation results show that the outdoor temperature is 34˚C, the average indoor temperature reaches 29.3˚C, the relative humidity is 66%, and the air speed and flow range from 0.98 – 1.09 m/s. Based on the thermal simulation results, a thermal decrease in the Maxone hotel of 2.2˚C and humidity of 4% from the results of field measurements, this shows that the effect of changes in opening variations, vegetation type arrangements, and increasing moving water features is very significant to the environment and thermal comfort of visitors.

Evaluation and comparison of existing simulation data , CFD simulation modeling, and ASHRAE 55 2020 standards can be seen in the following table.

Table 8. Comparison of existing simulation results , CFD model simulations, and ASHRAE standards.
at Nipah Mall and Maxone hotel

Average result	**Nipah Mall**			**Maxon Hotel**		
	Existing CFD	CFD Model	Standard ASHRAE	Existing CFD	CFD Model	Standard ASHRAE
Temperature (temperature)	32.2°C	27.2°C	Acceptance limit 90% = Operating temperat	33.3°C	29.3°C	Acceptance limit 80% = Operating temperature: 25.7 -
Relative humidity	67.1%	63%		72%	66%	

Wind velocity	0.5 – 1.0 m/s	0.9-1.5 m/s	ure: 25.7 - 32.7 °C	0.2-0.8 m/s	0.98-1.09 m/s	32.5 °C

Source: https://comfort.cbe.berkeley.edu/en-16798 and CFD program, 2024

The table above shows that based on the results of thermal environment simulation modeling then compared with the ASHRAE 55 standard to find a thermal prediction model for both research objects, the results obtained were thermal acceptance limits for operating temperatures of 25.7 to 32.7°C so that they were categorized as comfortable conditions.

Comparison of research findings with previous research, namely this research involves a comparison between two different locations, differences in air flow and circulation patterns, the combination of two architectural elements in the form of water and vegetation, and the use of computer simulation models.

This study shows that the use of water and vegetation elements can create micro-cooling zones around buildings by paying attention to air flow patterns, ventilation openings, and the arrangement and placement of water and vegetation elements.

Based on the above, the evaluation carried out is as follows:

1. To what extent the use of water and vegetation can significantly reduce air temperature in a certain area. The difference in temperature with and without these elements.
2. The use of water and vegetation elements can reduce heat leakage from buildings and its impact on temperature reduction and cooling needs.
3. Observation of different evapotranspiration rates from water and vegetation elements can affect air temperature and humidity around the building.
4. The influence of water elements and vegetation on natural ventilation and indoor air quality.
5. Use of water and vegetation elements in architectural design.

3. Conclusion

The results of this research evaluation show that the PMV, PPD, and SET indices on both building objects at each measurement time have significant differences, where the highest PMV, PPD, and SET values in Nipah Mall are at 12.00-15.00 while at Maxone Hotel the highest PMV, PPD, and SET values are at 08.30 to 15.00. The PMV, PPD, and SET values in both buildings decrease at 15.00-17.00. At Nipah Mall the thermal environmental sensation is in a neutral position with a SET value of 26.5˚c while at Maxone Hotel the SET value is 28.3˚C or slightly hot, this means that the ASHRAE 55 standard in the Maxone Hotel building is not accepted and visitors feel uncomfortable. The PMV value of 0.76 on the scale is included in the warm category. This shows that the presence of water and vegetation in the area has little effect on the thermal sensation of visitors.

Based on the results of the thermal environment simulation , the highest temperature at Nipah Mall is 32.2˚C and humidity is 67% while at Maxone Hotel the highest temperature is 33.3˚C and humidity is 72%. The CFD simulation value based on the presence of water and vegetation in the building obtained a thermal decrease at Nipah Mall of 5.2˚C and humidity of 6% while at Maxone Hotel the thermal decrease in temperature is 1.2˚C and humidity of 2%. The CFD simulation results show that the presence of water and landscape elements at Maxone Hotel does not have a significant effect. This is because the air movement in the area is not good because the inlet and outlet positions are not balanced. The results of the wind speed simulation on both buildings with the building orientation facing North South, the East inlet and West inlet sides must pay attention to the width and height of the openings.

Areas with hot and humid tropical climates such as in Indonesia which have high humidity, then the modification of outside air entering the building is done by creating moving water features (fountains) and landscape elements. Water can lower the temperature and vegetation can lower indoor humidity through the evaporation process and the movement of air flow through the inlet and outlet can change the microclimate in the building. Based on this, the thermal environment simulation model in the context of microclimate in buildings, thermal comfort, air movement, and architectural elements are important potentials that can provide positive value, improve the quality of the indoor environment, passive cooling effects, and maintain microclimate stability on a room and building scale.

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