

The effect of water and vegetation elements as microclimate modifiers in buildings in hot and humid tropical climates

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| ARTICLE INFO | ABSTRACT |
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| <p><i>Article history:</i> Received April 03, 2023 Received in revised form June 22, 2023 Accepted July 21, 2023 Available online August 01, 2023</p> <p><i>Keywords:</i> CFD Microclimate Thermal environment Vegetation Water element Wind speed</p> <p>*Corresponding author: Muhammad Awluddin Hamdy Department of Architecture, Faculty of Engineering, Universitas Hasanuddin, Indonesia Email: awaluddin.hamdy@universitasbosowa.ac.id ORCID: https://orcid.org/0000-0002-8436-9088</p> | <p><i>Thermal comfort in buildings is determined by several aspects of the climate, such as external and internal wind speeds. Therefore, this research aims to analyze the effect of water elements and vegetation as microclimate modifiers in buildings, to obtain thermal comfort through air velocity and flow analysis. In this context, the field analysis emphasized microclimate parameters. Two cases were also encompassed, namely the interior space of a residential building and a shopping center. By using field measurements with quantitative methods, data were obtained through the analysis of the PMV (thermal comfort index Predicted Mean Vote), PPD (Predicted Percentage of Dissatisfied), and TSV (Thermal Sensation Vote). This experiment was conducted to determine the influential levels of the building water and vegetation on comfort and the thermal environment. Data analysis was also processed using a statistical approach, with airflow being simulated through CFD (Computational Fluid Dynamics) method. The results showed that the air movement occurring in the building to the comfort and thermal environment, through architectural elements, reduced the temperature and humidity in the room. This was due to the heat radiation outside the building, leading to an impact on the effective air temperature for the thermal sensation of visitors. In this case, the movement of air in the building with the placement of architectural elements, such as water, vegetation, and good ventilation, was important for various activities. These activities included the following, (1) providing positive value, (2) improving the quality of the indoor environment, (3) maintaining the stability of the thermal environment at the building scale, and (4) achieving a comfortable thermal sensation.</i></p> |

Introduction

The wind is the air moving due to the force caused by pressure and temperature differences (Satwiko 2009), with its speeds being minimal in the humid tropics. This is because wind speeds generally occur during the day or the changing seasons. The

role of moving air is also very helpful in accelerating the release of heat on the surface of the skin. In this case, wind helps to remove the water vapor inhibiting heat release. However, the heat released by the body often becomes excessive when the wind is very strong, leading to cold conditions capable of reducing thermal comfort.



The wind direction is responsible for determining the orientation of a building, with continuous air circulation commonly required in humid tropical areas. For hot-humid areas, the building arrangement pattern is often organized as a grid, with the street design being a perpendicular intersection. In this case, a building will increase an expected smooth breeze capable of being used for ventilation. Meanwhile, the pattern of building arrangement leads to the blockage of air movement due to the presence of an obstacle field. This is less and more suitable for hot and cold humid climates, respectively, because the pattern is considered to inhibit the influence of cool and dusty winds, specifically at night (Golany 1995).

The measurement of thermal conditions is also often conducted using TE (effective temperature), a combination of air heat, humidity, and wind speed. From this context, the factors affecting TE include air temperature, humidity, and movement, as well as solar radiation (Park and Park 2022).

Comfort can only be achieved when a specific wind speed capable of producing a balanced evaporation process is observed in particular atmospheric conditions (Montazeri, Blocken, and Hensen 2015; Pacak et al. 2023). According to Anindita et al. (2022), wind speed was closely related to the density level of existing buildings in the environment, as well as the formation of houses and their constituent elements. Simons et al. (2014); Fanger (1970) also stated that the condition of thermal comfort was influenced by climatic and individual factors. These climatic factors in the room consisted of air temperature and movement, average radiation heat, relative atmospheric humidity, and wind speed. Meanwhile, the individual factors were the type of activity and implemented clothing.

Architectural conditioning of the environment inside the building is commonly carried out by considering the following, (1) the placement of the construction (building orientation to the sun and wind), (2) the use of architectural and landscape elements, and (3) the implementation of the building materials/materials following the characteristics of a hot humid tropical climate. Based on these conditions, the room temperature can be lowered a few degrees without the help of mechanical equipment. Moreover, the modification of the hot external air entering the building is conducted by developing an interior fountain. According to Sastrawan and Darmawan (2018), the distribution of low-temperature levels

around the pond area was observed. This indicated that evaporative cooling by water significantly impacted the air temperature reduction. In this case, the presence of water reduced the temperature of the surrounding air due to heat absorption in moisture evaporation. Besides reducing the air temperature, the evaporation process will also increase humidity. For humid tropical climates, such as in Indonesia, increased humidity needs to be avoided. This shows that the use of the water element should consider the movement of air (wind), to avoid an increase in humidity (Hendrawati 2016).

Based on Latif, Hamzah, and Ihsan (2016) and Latif (2020), the addition of an inlet and outlet area with the appropriate ratio in the lecture classroom of the Faculty of Engineering, Hasanuddin University in Gowa Regency optimized air circulation to develop thermal comfort. Maria Caroine, et al. (2021) also concluded that the passive cooling design of classrooms was influenced by the orientation of openings, local climate, and airflow in surrounding buildings. Furthermore, Rahim (2002) demonstrated that airflow was an important climatic factor in planning. In this case, the comfort temperature in the room directly affected the increase in heat and humidity. This subsequently emphasized the following occurrences without airflow, (1) the room quickly became saturated and unhealthy due to increased CO₂ concentration, (2) oxygen was depleted (humidity close to 100%), and (3) airspeed close to 0 m/s. From this context, thermal comfort was unachievable, with the sweat of the indoor people becoming non-evaporated in saturated air without wind speed. The effect of the ventilation opening width on thermal comfort and natural ventilation was also analyzed. This assessed the effectiveness of the opening area on wind speed inside the building when the windows were both closed and open. Besides this, the tendency of the wind speed to meet building standards was also determined (Toisi and Kussoy 2012).

Based on Rahmawati, Akbar, and Agustin (2016), Ilman Basthian (2015), and A'yun, Wati, and Khafidz (2019), the building design related to thermal comfort was prioritized, namely the wind speed factor. This influenced the design of ventilation and emphasized its exploration and modeling in buildings affecting comfort.

In designing a system of openings in buildings to achieve thermal comfort, a complete knowledge of indoor air circulation is also

required. This emphasizes the implementation of simulation techniques to estimate room temperature and air velocity Tahang (2016); Albatayneh et al. (2020); Rahmat, Cahyanudin, and Ramadhan (2020); Permana and Sawab (2020). Thermal comfort has the most dominant influence on the physical convenience of the interior people, including air temperature, humidity, and airflow velocity. According to Satwiko (2009), thermal comfort in the humid tropics was achieved within limits of $24^{\circ}\text{C} < T < 26^{\circ}\text{C}$, $40\% < \text{RH} < 60\%$, $0.6 < V < 1.5$ m/s, leisure activities, light clothing, and layers. Therefore, this research aims to evaluate the effect of water and vegetation elements in buildings, as microclimate modifiers for comfort and thermal environment. In this analysis, the benefits obtained emphasize the development of sustainable solutions, which combine environmental aspects, comfort, and energy efficiency. These solutions are subsequently environmentally friendly in hot and humid tropical areas. The provision of an integrative approach is also expected, regarding the combination of air velocity, water elements, and vegetation in considering the quality of the thermal environment in buildings. In addition, the novelty aspects should include a better understanding of the occupant preferences related to air velocity, evaporative conditioning effects, and the psychological impact of an enhanced thermal environment.

Method

In this quantitative research, survey, measurement, and simulation methods were implemented, with the experimental objects being a residential building (Maxone Hotel) and a modern shopping center (Nipah Mall) located in Makassar City. Each building had architectural elements in the form of water and vegetation, which had differences and similarities in building orientation, layout, ventilation openings, and facades. The water and vegetation elements were also considered the micro-climate modifiers in buildings, as well as the thermal environment and comfort sensation, prioritizing environmental factors and behavioral adaptation. In this case, the water and vegetation elements located on the ground floor were used.

The experimental instruments included a digital air flow anemometer, to measure wind speed (figure 1). This was accompanied by HOBO UX100-023A External Temp/RH and MX2302 series, as well as RC-5 temperature data loggers, to measure temperature, radiation heat, and relative air humidity, respectively (figure 2).

The measurements were also carried out inside the building and its surroundings, with a total of 6 assessment points for each experimental object. These measurements emphasized the distance parameters of 2, 5, 10, 15, 20, and 30 m, with air movement prioritizing building orientation, namely the North, South, East, West, and top (void) sides. Furthermore, subsequent analysis and questionnaire collection were simultaneously carried out with separate timespans for the effective use of measuring instruments. The implementation of the measurements and questionnaires was also conducted in November (Nipah Mall) and December (Maxone Hotel) 2022, as shown in figure 3. For the thermal environment and questionnaires, appropriate evaluation processes were performed for 2 (two) consecutive days, through specific timeframes in the morning (08.30 - 12.30), afternoon (13.00 - 14.00), and evening (15.00-17.00).



Figure 1. Wind speed measurement tool



Figure 2. Tool for measuring temperature and relative humidity

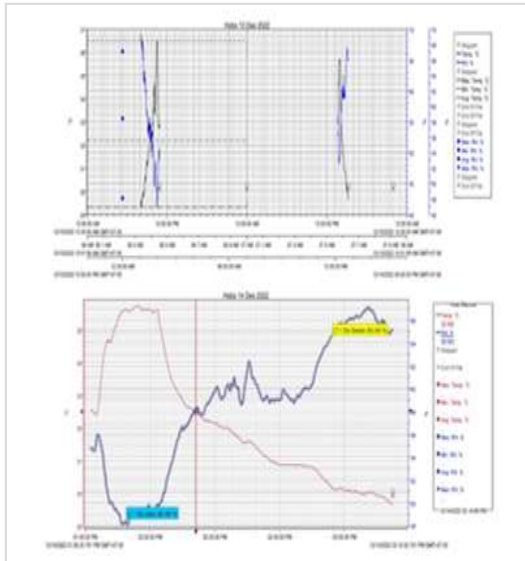


Figure 3. Field measurements (Hobo MX2302 and UX100)

The data analysis process was carried out by using the implemented tools and physical data of the building. From this context, the analysis of the thermal environment, such as temperature, humidity, solar radiation, and wind speed, was observed according to the ASHRAE (2020). This analysis was performed to determine the effective temperature (TE), PMV, and PPD. Furthermore, a questionnaire was used to evaluate the thermal environment regarding the heat sensation. This was conducted through the TSV (thermal sensation vote) impression/sensation scale, based on the standard, the type of clothing used, the activities performed, and the experimental tests on the age category of participants. In this case, the clothing used and the activity performed were measured in clo ($1 \text{ clo} = 0.155 \text{ m}^2\text{K/W}$) and met ($1 \text{ met} = 58 \text{ W/m}^2$), respectively. PMV, PPD, and TSV were also generated and considered the ASHRAE (2020) standard. This standard had 7 criteria, namely, very cold (-3), cool/cold (-2), rather cool (-1), neutral (0), rather warm/hot (+1), hot (+2), and very hot (+3). PMV, PPD, and TSV values were also processed using Thermal Comfort Tool (CBE) software, which produced a Psychrometric diagram. This was accompanied by a validation test as a control tool, using the comfort index and thermal environment. Moreover, the experimental research was encompassed, where air velocity and flow were simulated with WinAir Computational Fluid Dynamic (CFD) analysis, accompanied by

evaluation and comparison in the two simulation models.

Measurement location

The location of the research object was observed in South Sulawesi Province, Makassar City, with the local climate and North-South building orientation. The basic considerations for selecting these objects indicated that both buildings had architectural elements as research topics, namely water and landscape. From this context, the Nipah Mall, one of the largest shopping complexes in Makassar City, was a superblock area of multi-story modern shopping and office centers. This building was located east of the administrative zone and built on an area of $121,426 \text{ m}^2$ with a land surface of 3.5 hectares. The mall and office areas were also $74,352 \text{ m}^2$ and $15,440 \text{ m}^2$, respectively. In addition, the topography of the site was trapezoidal, following the natural shape by using a 1.00 m high contour.



Figure 4. Nipah Mall floor plan and measurement points

Vegetation was observed on the front, back, and interior parts of the site. On the rooftop, an open area serving as normal and roof gardens, as well as a rain collector and harvester, was also observed. Furthermore, the covering of the building rooftop was a semi-transparent membrane capable of withstanding solar radiation and functions as natural lighting. Exposed materials were also primarily used in the building, such as concrete, wood, metal, and terracotta bricks, with lighting and ventilation systems implementing more natural designs.

In this construction site, a void corridor without a membrane was found, enabling fresher air circulation with a bright and spacious exhibition. This system was designed by adjusting the inlet and outlet air, as well as using cross ventilation. Moreover, a pond and an artificial

waterfall were located in the middle of the building, serving as the elements of water. For the artificial waterfall, the heights considered included 1 ± 15 m, 2 ± 18 m, and 3 ± 22 m high. When filled, the volume of the pool was ± 31.92 m³ at 27.1°C. From these descriptions, the artificial waterfall was automatically operational daily at 12.00–14.00 and 15.00–17.00.

Hotel Maxone was one of the hotels exhibiting the concept of a resort in Makassar City, having quite large and well-organized green open spaces. This hotel, standing on 2.4 land hectares and an area of around 8,000 m², had 155 rooms and was equipped with various supporting facilities.



Figure 5. Maxone hotel floor plan and measurement points

By using a tropical architectural concept, the Maxone Hotel highly implemented natural lighting and ventilation systems. In the rooms, artificial lighting and ventilation systems were also used, accompanied by the implementation of natural air with window openings. Furthermore, the swimming pool area capitalized on the air conditioning and natural lighting supplied through openings on the south, west, east, and roof sides. A green area was also found, accompanied by the observation of trees surrounding the building.

In this research, the water element in the building was a swimming pool, which had an area, filled volume, and temperature of 81.92 m², ± 118.78 m³, and 26.6°C, respectively.

Table 1. Conditions and situations of research objects

| Research subjects | Building orientation | Space form |
|-------------------|----------------------|------------|
| Nipah mall | North-South | Trapezoid |
| Maxone hotels | North-South | Rectangle |

| Facade | Architectural elements | Ventilation |
|---------------------------------|-------------------------|--------------------------------------|
| Passive window with double skin | Green area, vegetation, | Open roof with partially transparent |

| Facade | Architectural elements | Ventilation |
|--|--|---|
| | waterfall, pond, exposed bricks | membranes voiding the corridor |
| Passive window with massive glass material | Green area, vegetation, pond, exposed bricks | Open roof with a partially transparent membrane |

Result and discussion

Analysis of temperature, humidity, and radiation heat

When measuring the temperature, humidity, and radiation heat for both research objects, data were obtained from the instrument and processed using statistics, to acquire the outputs of the average measurement. Based on the results, the Nipah Mall and Maxone Hotel buildings should build orientations capable of responding to the climate in the area. This was because the longest sides of the building facades were in the north and south directions. Figure 6 shows the average measurements of indoor and outdoor temperatures, humidity, and wind speed, with measuring points, distance, and time. Measurements were also obtained on the 1st-floor area, where water and vegetation element objects were observed.

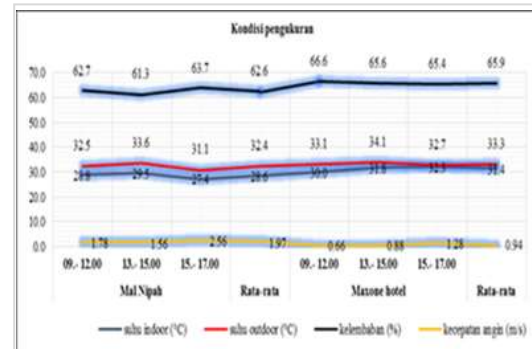


Figure 6. Graph of the relationship between measuring point, space measurement distance, climate, and measurement time

At 08.30 – 12.30 h, Nipah Mall and Maxone Hotel had 5 observation measuring points. This indicated that the minimum-maximum temperature in Nipah Mall ranged from 27.32–30.2°C, with the average internal and external temperatures, humidity, and wind speed being 28.82°C, 32.5°C, 62.65%, and 1.78 m/s, respectively. Meanwhile, the minimum-

maximum temperature in the Maxone Hotel building ranged from 28.5–32.6°C, with the average internal and external temperatures, humidity, and wind speed being 30.0°C, 32.1–33.7°C, 67%, and 0.66 m/s, respectively.

Based on 13.00–15.00 h, Nipah Mall and Maxone Hotel also had 5 observation measuring points. This demonstrated that the minimum-maximum temperature of Nipah Mall ranged from 29.3–29.7°C, with the average internal and external temperatures, humidity, and wind speed being 29.54°C, 31.15°C, 61.34%, and 1.56 m/s, respectively. However, the minimum-maximum temperatures at the Maxone hotel, ranged from 31.2–33.4°C, with the internal and external temperatures, humidity, and wind speed being 31.8°C, 33.6–34.9°C, 66%, and 0.88 m/s, respectively.

At 15.00–17.00 h, Nipah Mall and Maxone Hotel had 5 observation measuring points. This proved that the minimum-maximum temperature at Nipah Mall ranged from 26.6–28.4°C, with the average internal and external temperatures, humidity, and wind speed being 27.38°C, 31.10°C, 63.74%, and 2.56 m/s, respectively. Meanwhile, the minimum-maximum temperature at the Maxone Hotel ranged from 32.5–33.5°C, accompanied by the internal and external temperatures, humidity, and wind speed at 32.7°C, 33.0–33.8°C, 65%, and 1.28 m/s, respectively.

Figure 7 shows the differences in the influence of climate on the two research objects.

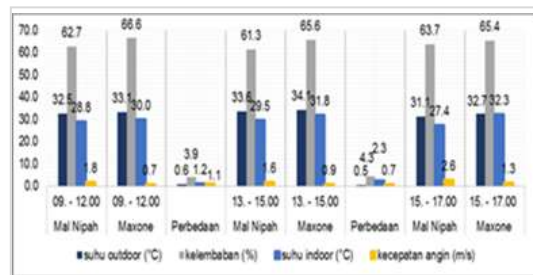


Figure 7. Graph of the relationship between measuring temperature, humidity, outdoor temperature, and wind speed at Mal Nipah and Maxone hotels

Based on figure 7, several differences were observed in the temperature, solar radiation, humidity, and wind speed of the Nipah Mall and Maxone Hotel buildings. This indicated that at 08.30 – 12.00 WITA, the temperature and humidity at both locations were low, with the average wind speed being 1.22 m /s. At 13.00–

15.00 h, the temperature increased between 29.54–31.80°C, with the average wind speed reaching 1.22 m/s. Meanwhile, at 15.00–17.00 h, the average temperature and humidity gradually decreased to 29.08°C and 64.57%, with the wind speed ranging from 1.28–2.56 m/s.

On the measurement floor, from the first to the fifth measuring point, vegetation was observed with no water. However, the temperature and humidity fluctuated due to several factors. Firstly, the temperature and humidity were "Very High" due to the direct exposure of the object to sunlight, little vegetation, no roof, and open space. Secondly, the temperature and humidity were "Rather High" because of little vegetation and open space. Thirdly, the temperature and humidity were "Rather Low" due to the existence of vegetation and slightly closed space. At the fourth and fifth measurement points, the temperature and humidity were then "Low" because of the abundance of vegetation and slightly closed space.

Thermal Sensation Vote

Thermal sensation vote (TSV) was measured based on seven ASHRAE scales. To calculate this parameter, a subjective measurement survey was carried out by distributing questionnaires to the participants, regarding the two research objects. In this context, 30 participants were selected for the experimental process, to achieve the validity of the questionnaire outputs. These samples had an age range of 18-45 years, with the majority of them being women. Many as 20 participants were also housewives, with the remaining 10 being employees. Furthermore, the participants were generally dressed formally, with the analyzed activities including relaxing, walking, and eating. Based on subsequent characteristics, the height of the samples ranged from 150-169 cm. In this survey, questionnaires were distributed to visitors through the following conditions, (1) Participants were randomly selected, (2) At the vulnerable time between 08.30 - 17.00, participants did not wear thick types of clothing, such as sweaters, with the clothing resistance rate (clothing value) being 0.6 clo (ASHRAE 2020), and (3) The samples were subjected to standing, walking, eating, and relaxing activities, for the metabolic rate of the body to reach 1.2 met (ASHRAE 2020). Figure 8 presents the outputs of the questionnaire distribution.

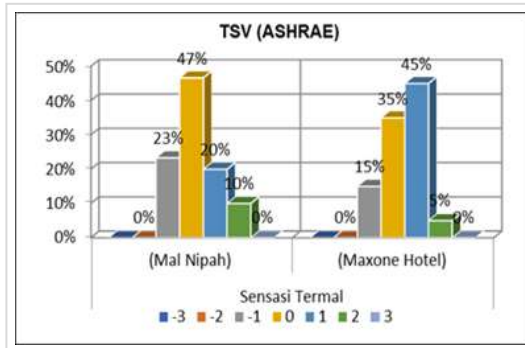


Figure 8. Percentage of results measurement of thermal sensation of respondents on both

This indicated that the highest choices of participants in Nipah Mall and Maxone Hotel were 0 (neutral) and +1 (slightly hot) at 46.7% and 45%, respectively. Based on the field measurements, the indexes of thermal sensation in both buildings were observed. This demonstrated that at Nipah Mall, the temperature ranged from 27.38-29.54°C, with an average humidity of 61.58%. Meanwhile, the temperature ranged from 28.5-33.5°C with a humidity of 64.7% at Maxone Hotel. These results were analyzed by participants thermal sensation of temperature (air and operating temperature) in a linear regression line, as shown in figures 9 and 10.

In figure 8, the sensation of thermal comfort at Nipah Mall and Maxone Hotel was categorized.

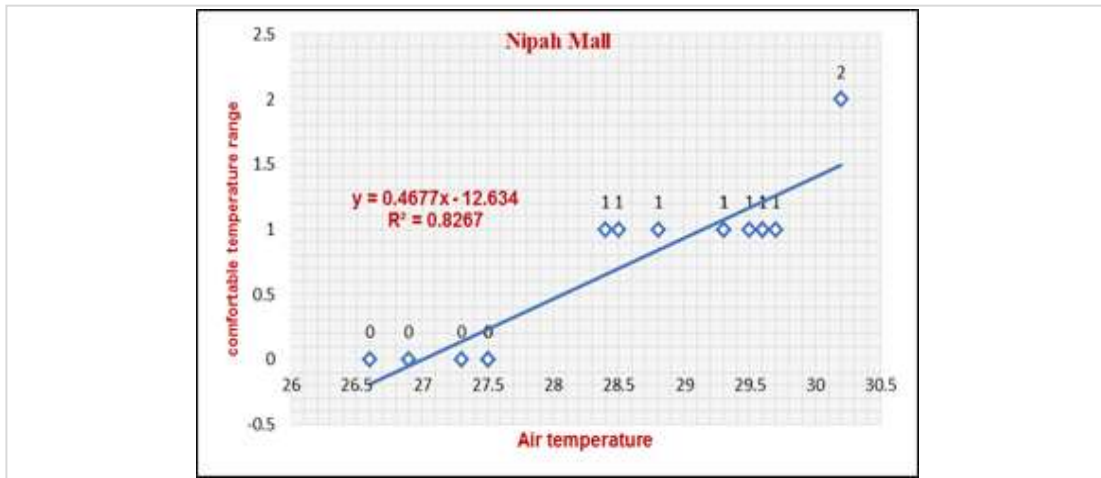


Figure 9. Graph of the percentage of thermal sensation measurement results of respondents in the Nipah Mall area

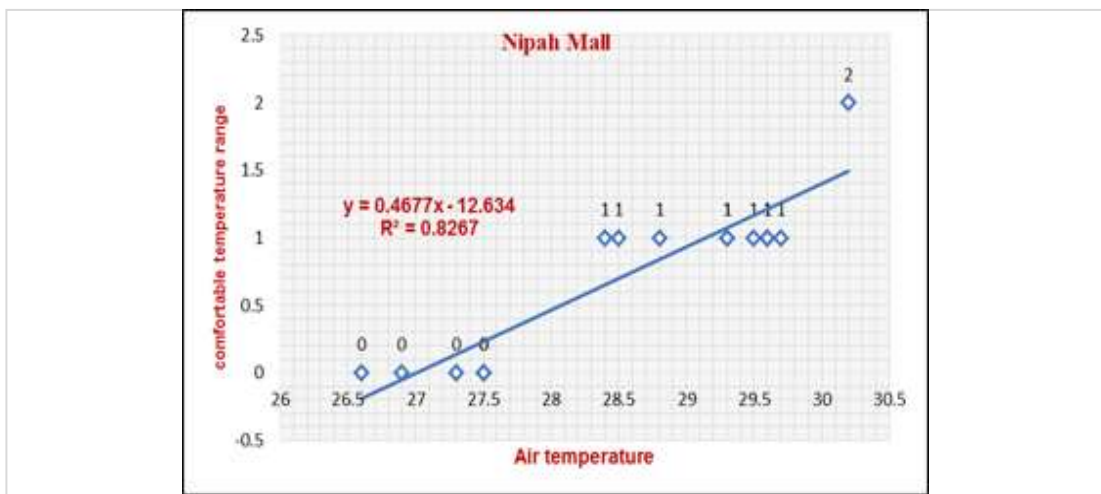


Figure 10. Graph percentage of thermal sensation measurement results of Maxone Hotel respondents

Based on figures 9 and 10, the comfortable/neutral temperature = 0, where the participants felt comfortable at the T_a (air temperature) of 26.8°C air temperature (T_a). This indicated that the comfortable temperatures of the samples were between -1 and 0, with the lower and upper limits of T_a comfortability being 26.4°C and 27.8°C, respectively.

Table 2. Regression equation results

| Regression statistics | Maxone | Nipah |
|-----------------------|-------------|-------------|
| Multiple R | 0.886260452 | 0.899287098 |
| R square | 0.785457589 | 0.808717285 |
| Adjusted R square | 0.767579055 | 0.792777058 |
| Standard error | 0.416745954 | 0.26354097 |
| Observations | 14 | 14 |

The results also showed that the linear regression equations in both buildings were $y=0.4677x-12.634$ (Mal Nipah) and $y=0.4625x-12.442$ (Maxone Hotel). In this case, the air temperature (X) with a comfortable range (Y) on both objects was at a distance of 0.80-1.00, with the value included in the category of a very strong correlation relationship. This proved that the coefficients of determination were 0.793/79.3% and 0.768/76.8% for Nipah Mall and Maxone Hotel, respectively. From this context, the value of air temperature (X) analyzed the comfortable heat range of an individual (Y) by >75% in both buildings.

Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD)

Environmental and thermal comfort were predicted using the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) Models. This was conducted through the inclusion of various influential variables, namely (1) thermal environmental factors (temperature, air humidity, wind speed, radiant heat), and (2) human thermal comfort factors (type of clothing and activity). Furthermore, PMV was an index indicating the sensation of cold and warmth felt by humans on a scale of +3 to -3. Based on PMV, PPD, and SET indices, thermal environment predictions were processed and simulated using the CBE (Centre for Built Environment) Thermal Comfort Tools software. This software feature was capable of comparing two or three thermal environmental comfort scenarios (compare tool), to predict heat convenience, save a large amount of energy, and assess comfortable design with low power consumption. Tables 3 and 4 illustrate the

PMV and PPD evaluation of thermal comfort, by analyzing the ASHRAE 55 scale contained in the CBE.

Table 3. PMV, PPD, & SET values at each measurement time based on CBE Nipah Mall

| Data | Nipah Mall | | |
|------|-------------|-------------|-------------|
| | 08.30-12.30 | 12.30-15.00 | 15.00-17.00 |
| PMV | 0.15 | 0.37 | 0.10 |
| PPD | 5% | 8% | 7% |
| SET | 25.8 | 26.6 | 23.8 |

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

| Data | Maxone Hotel | | |
|------|--------------|-------------|-------------|
| | 08.30-12.30 | 12.00-15.00 | 15.00-17.00 |
| PMV | 1.42 | 1.45 | 0.23 |
| PPD | 47% | 48% | 6% |
| SET | 30.4 | 30.5 | 26.0 |

According to tables 3 and 4, the PMV, PPD, and SET values on the measuring floor were observed, with significant differences found at each evaluation time. This proved that, at Nipah Mall and Maxone Hotel, the highest PMV, PPD, and SET values were at 12.00-15.00 h and 08.30-15.00 h, respectively. Meanwhile, the values in both buildings decreased at 15.00-17.00 h. Regarding the ASHRAE 55 standard, the comparisons of thermal comfort in the two buildings were simulated with CBE software and presented in table 5.

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

| Data | PMV | PPD (%) | SET (°C) |
|---------------------|---------|---------|---------------|
| Nipah Mall | 0.28 | 7% | 26.5 |
| Maxone Hotel | 0.76 | 17% | 28.3 |
| Cooling Effect (°c) | Sensasi | | Dry-Bulb (°c) |
| 5.7 | Neutral | | 22.9 |
| 5.0 | Warm | | 24.5 |

In table 5, significant differences were found in the PMV, PPD, and SET values, regarding thermal sensation observation. This indicated that the thermal environment sensations at Nipah Mall and Maxone Hotel were in neutral and slightly hot positions with SET values of 26.5°C and 28.3°C, respectively. In this case, the ASHRAE 55 standard in the Maxone Hotel building was not accepted and visitors felt uncomfortable (+1 - +1.5).

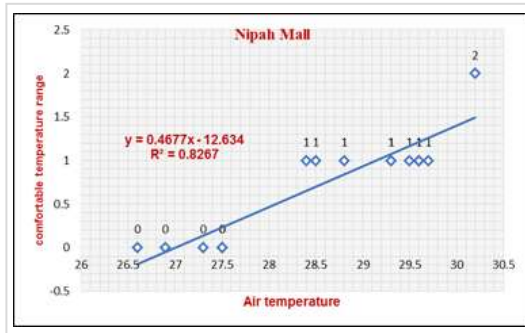


Figure 11. Graph of PMV Psychrometric comparison of research objects

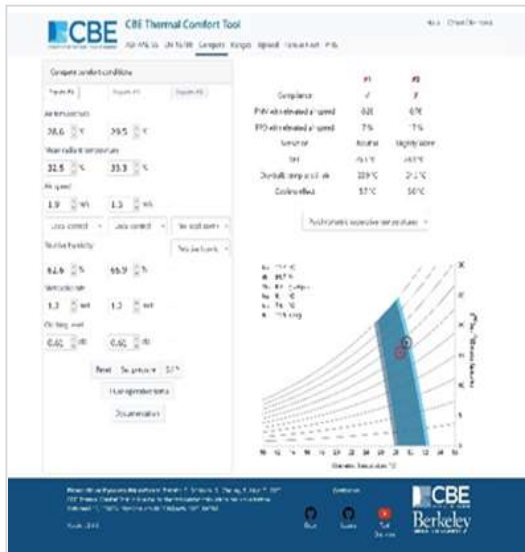


Figure 12. PMV comparison value of the result of measuring the thermal sensation of the respondents on the research object

Based on figures 11 and 12, a comparison of PMV, PPD, and SET values was observed at Nipah Mall (input #1) and Maxone Hotel (input #2). This indicated that a neutral (0) position was observed at input #1, with the PMV, PPD, SET, dry-bulb, and cooling effect values being 0.28, 7%, 26.5°C, 22.9°C, and 5.7, respectively. Meanwhile, a slightly hot (+1) category was found at input #2, with the PMV, PPD, SET, dry-bulb, and cooling effect values being 0.76, 17%, 28.3°C, 24.5°C, and 5.0°C, respectively. From these results, air temperature and humidity, TE, wind speed, people, and various activities greatly affected the PMV value. In the ASHRAE (2020), some conditions were also accepted and considered comfortable, namely the PMV values ranging from -0.5 to +0.5.

In conclusion, Maxone Hotel was emphasized according to the ASHRAE thermal comfort standards. This indicated that the red dot was slightly out of the blue line with a PMV value of 0.76, from the scale included in the warmth category.

Air movement analysis and simulation

The measurement of the wind speed around the Nipah Mall and Maxone Hotel areas was carried out using a digital air flow anemometer. This evaluation was carried out with a total of 5 measuring points, namely the North, South, East, West, and top (void) sides. The measurement of the wind speed inside the buildings was also needed to determine its effect on the thermal environment. This was carried out by using architectural elements, such as water and plants, as microclimate modifiers.

Based on the results, the wind emanating from the east and west provided the same portion, regarding the ability to enter the room facing the north and south directions. When the position of the research room faced the north direction, the incoming wind speed from morning to evening was greater than the room positioned to the east or west part of the building. Meanwhile, the room positioned to the east and west had little air movement due to being closed by a wall, with the entrance observed as the only opening. Figure 13 shows the movement of air around and within buildings, according to field measurements:



Figure 13. Air movement and wind speed measurement points at Nipah mall and Maxone hotels

According to the orientation of the building facing North-South, the air movement around and

within Nipah Mall and Maxone Hotel moved from east to west and south to north of the building in the morning until noon. Meanwhile, the wind moved from West to East and North to South of the building from noon until evening.

To determine wind speed and movement in the area, CFD analysis simulations were used on the ground floor space. These were subsequently adjusted to the field conditions, to provide comparisons of the types of openings, orientation, green open spaces, and surrounding buildings. By inputting the field measurement data, the following air velocity and flow outputs on the two building objects were observed.

A. Nipah Mall Building

Table 7 shows the air movement around and inside the Nipah Mall building.

Table 7. Air movement, time, and measuring point of Mal Nipah

| Mal Nipah | Measuring | 08.-09. | 09.-10. | 10.-11. |
|------------|-----------|---------|---------|---------|
| North Side | 1 | 0.66 | 0.83 | 0.95 |
| South Side | 2 | 0.46 | 0.66 | 0.61 |
| East Side | 3 | 0.44 | 0.48 | 0.48 |
| West Side | 4 | 0.32 | 0.34 | 0.35 |
| Upside | 5 | 1.57 | 1.68 | 1.76 |
| Average | | 0.69 | 0.80 | 0.83 |

| 11.-12.00 | 12.-13.00 | 13.-14.00 |
|-----------|-----------|-----------|
| 1.30 | 1.25 | 2.13 |
| 0.74 | 0.78 | 0.88 |

| 11.-12.00 | 12.-13.00 | 13.-14.00 |
|-----------|-----------|-----------|
| 0.50 | 0.49 | 0.42 |
| 0.50 | 0.45 | 0.43 |
| 2.03 | 2.47 | 2.61 |
| 1.01 | 1.09 | 1.30 |

| 14.-15.00 | 15.-16.00 | 16.-17.00 | Average |
|-----------|-----------|-----------|---------|
| 1.85 | 1.34 | 1.30 | 1.291 |
| 1.03 | 1.14 | 0.82 | 0.792 |
| 0.63 | 0.41 | 0.33 | 0.465 |
| 0.52 | 0.36 | 0.33 | 0.400 |
| 2.67 | 2.61 | 2.21 | 2.180 |
| 1.34 | 1.17 | 1.00 | 1.025 |

Based on table 7, the average internal wind speed (V) was high at 1.03 m/s, from morning to evening. The upper side (roof) of the building was also a larger area for air movement, reaching an average of 2.18 m/s, with the north part being 1.29 m/s. This large amount of air movement was due to the access and exit doors, as well as the huge openings (voids). Furthermore, the movement of air inside the building was quite high during the day (12.00–15.00) at 1.09–1.34 m/s, with the speed decreasing to 1.00 m/s toward the afternoon. This was in line with the state of global wind speed, where the air movement was felt fast during the day, with the direction and velocity changing in the morning. This was due to the transition of airflow from West to East. Meanwhile, the wind speed decreased in the afternoon, where the air movement from the East reversed toward the West.

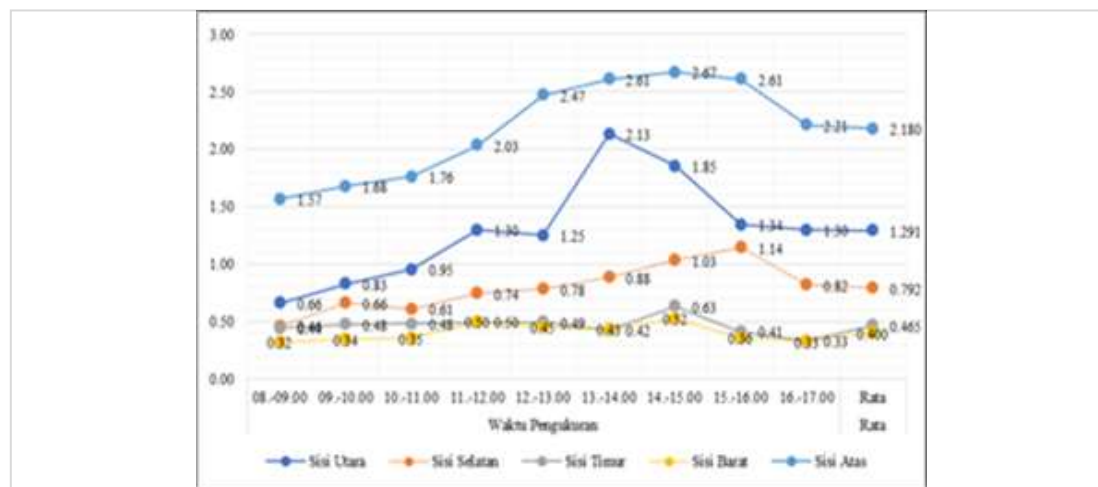


Figure 14. Graph of air movement and wind speed measurement point at Nipah mall

In figure 14, the wind speed in the North-South and East-West directions, as well as the top floor area increased during the day by 1,010 m/s. This speed decreased when the wind passed

through the corridor outside the building floor (0.544 m/s). The velocity also continuously decreased when the wind entered the room (0.044 m/s). This reduction was due to friction when the

wind hit the walls and passed through the outer corridor of the building. The subsequent reduction was also found when the wind passed through the ventilation into the room. By inputting the field measurement data into the WinAir4 CFD simulation, the air movement of Nipah Mall is presented in figures 15 and 16.

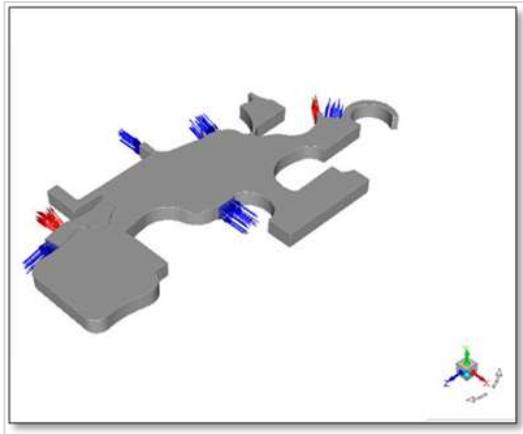


Figure 15. Air movement inlet-outlet position at Nipah mall

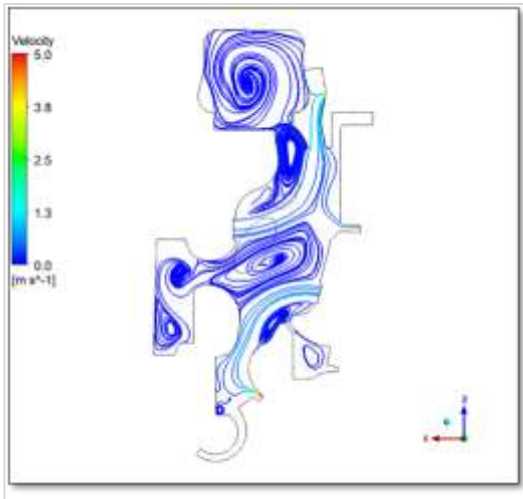


Figure 16. CFD simulation result of air movement at Nipah Mall

In figures 15 and 16, the wind moved from North to South on the ground floor of the Nipah Mall building, where water pool objects, landscapes, and artificial waterfalls were found. The movement of air was also observed from the voids on the top floor, before entering the room and spreading to the central area. This was caused by the location of the inlet at the front of the building and on the rooftop. Based on the

simulation (figure 16), the largest wind movement was in the void and northside openings of 2.98 and 1.14 m/s, respectively. This proved that the cooler area was in the middle, with the airflow being blue. In this case, the artificial ponds and waterfalls greatly influenced the thermal comfort of visitors.

B. Maxone Hotel building

Table 8 presents the air movement around and inside the Maxone hotel building.

Table 8. Air movement and wind speed measurement time in the Maxone hotel building

| Maxone Hotel | Measuring | 08.00-09.00 | 09.00-10.00 |
|--------------|-----------|-------------|-------------|
| North Side | 1 | 0.20 | 0.56 |
| South Side | 2 | 0.21 | 0.21 |
| East Side | 3 | 0.24 | 0.28 |
| West Side | 4 | 0.32 | 0.37 |
| Upside | 5 | 1.67 | 1.66 |
| Average | | 0.53 | 0.62 |
| <hr/> | | | |
| | | 10.00-11.00 | 11.00-12.00 |
| | | 0.76 | 0.81 |
| | | 0.21 | 0.23 |
| | | 0.29 | 0.40 |
| | | 0.45 | 0.50 |
| | | 1.79 | 1.83 |
| | | 0.70 | 0.75 |
| <hr/> | | | |
| | | 13.00-14.00 | 14.00-15.00 |
| | | 0.49 | 0.50 |
| | | 0.18 | 0.13 |
| | | 0.42 | 0.53 |
| | | 0.42 | 0.72 |
| | | 1.62 | 1.85 |
| | | 0.63 | 0.75 |
| <hr/> | | | |
| | | 16.00-17.00 | Average |
| | | 0.98 | 0.645 |
| | | 0.12 | 0.189 |
| | | 0.31 | 0.380 |
| | | 0.63 | 0.513 |
| | | 1.76 | 1.764 |
| | | 0.76 | 0.698 |

According to table 8, the average wind speed (V) from morning to evening was 0.86 m/s. This demonstrated that the upper side (roof) of the building was a larger area for air movement, reaching an average of 1.76 m/s, with the north side being 0.65 m/s. From this context, the amount of air movement on both sides was because of the access to the rear area of the building, consisting of a pool and green open areas, as well as the large void at the top ($\pm 95\text{m}^2$). The wind speed inside the building was also quite high in the afternoon (13.00–17.00 h), at 1.02–

1.09 m/s. In this case, the airflow from morning to noon changed direction and speed, due to the transition of air movement from east to west. Meanwhile, the wind speed was high in the afternoon because of the airflow from the West to the East.

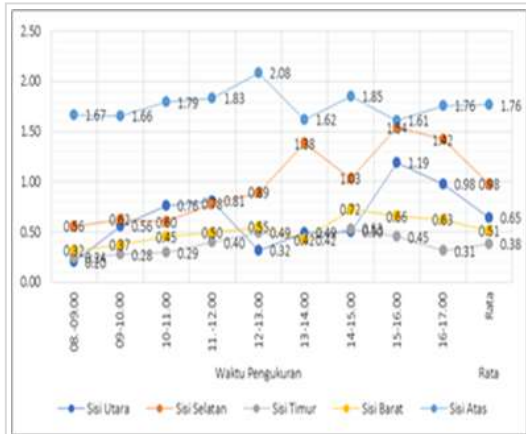


Figure 17. Graph of air movement and wind speed measurement points at the Maxone hotel

In figure 17, the average wind speed in the South–North and West–East directions, as well as on the top floor area of the building increased at 11.00–16.00 by 0.92 m/s. This air movement was relatively stable until noon. By inputting the field measurement data into the WinAir simulation from CFD, figures 18 and 19 show the outputs of the Maxone hotel wind speed.

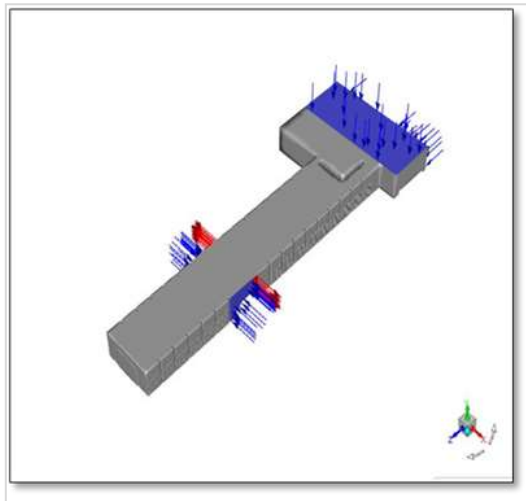


Figure 18. Air movement inlet-outlet position at Maxone Hotel

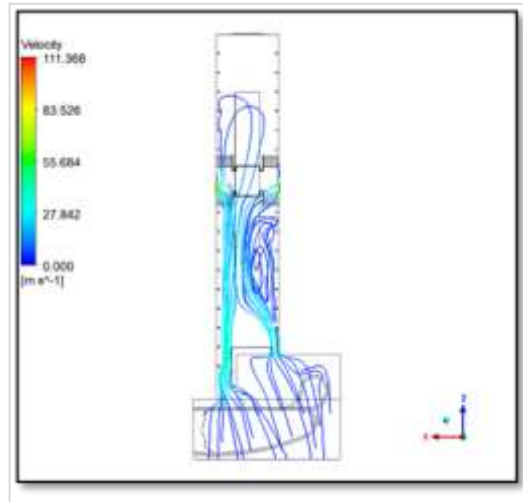


Figure 19. Result of the Maxone Hotel airflow CFD simulation

Based on figures 18 and 19, the airflow moved from the south on the ground floor of the Maxone hotel building, which contained a swimming pool and landscaping object. Besides this, the voids on the top floor then entered the room on the north side, which consisted of no openings. Regarding the simulation (figure 19), the largest air movement was found on the top (void) side and west opening at 2.63 m/s and 0.98 m/s. This indicated that the comparison of the average wind speed in the two buildings was presented in figure 20.

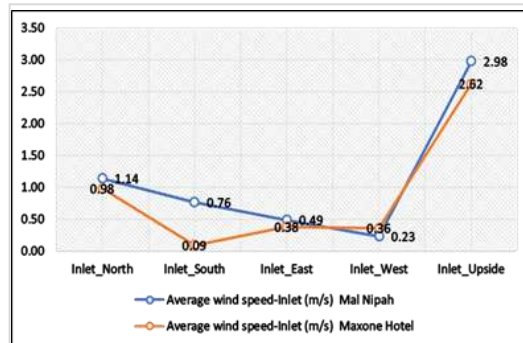


Figure 20. Comparison graph of wind speed at Nipah Mall and Maxone Hotel

Figure 20 showed significant differences in the wind speed of the two buildings, where the orientation of the inlet openings affected the air velocity and the indoor airflow pattern. Meanwhile, the outlet location only had a small effect on the airflow speed and pattern. At Nipah Mall, the placement of large air openings on the

upper side developed a pattern of airflow, which moved from inlet to outlet. In this context, the northside inlet orientation was a potential wind direction affecting air velocity, to achieve thermal comfort inside the building. Regarding the Maxone hotel, the top side inlet was an opening capable of providing a pattern of airflow entering the room. It was also considered an airflow outlet because no openings were found on the South side. This indicated that the airflow experienced friction, specifically on the East and West inlets, where the openings were not very large. Since these conditions affected thermal comfort, the temperature and humidity were slightly high.

Evaluation and comparison of research findings

Based on architectural elements such as water and vegetation, evaluation and comparison involved the assessment and comparison of their effects on thermal conditions in the analyzed environment. In the aspects of both evaluated and compared research objects, environmental and thermal comfort were observed according to ASHRAE 55 standards.

In the Nipah Mall building, [figure 21](#) showed that the average temperature, humidity, and air velocity were 29°C, 63%, and 1.9 - 2.9 m/s, respectively.

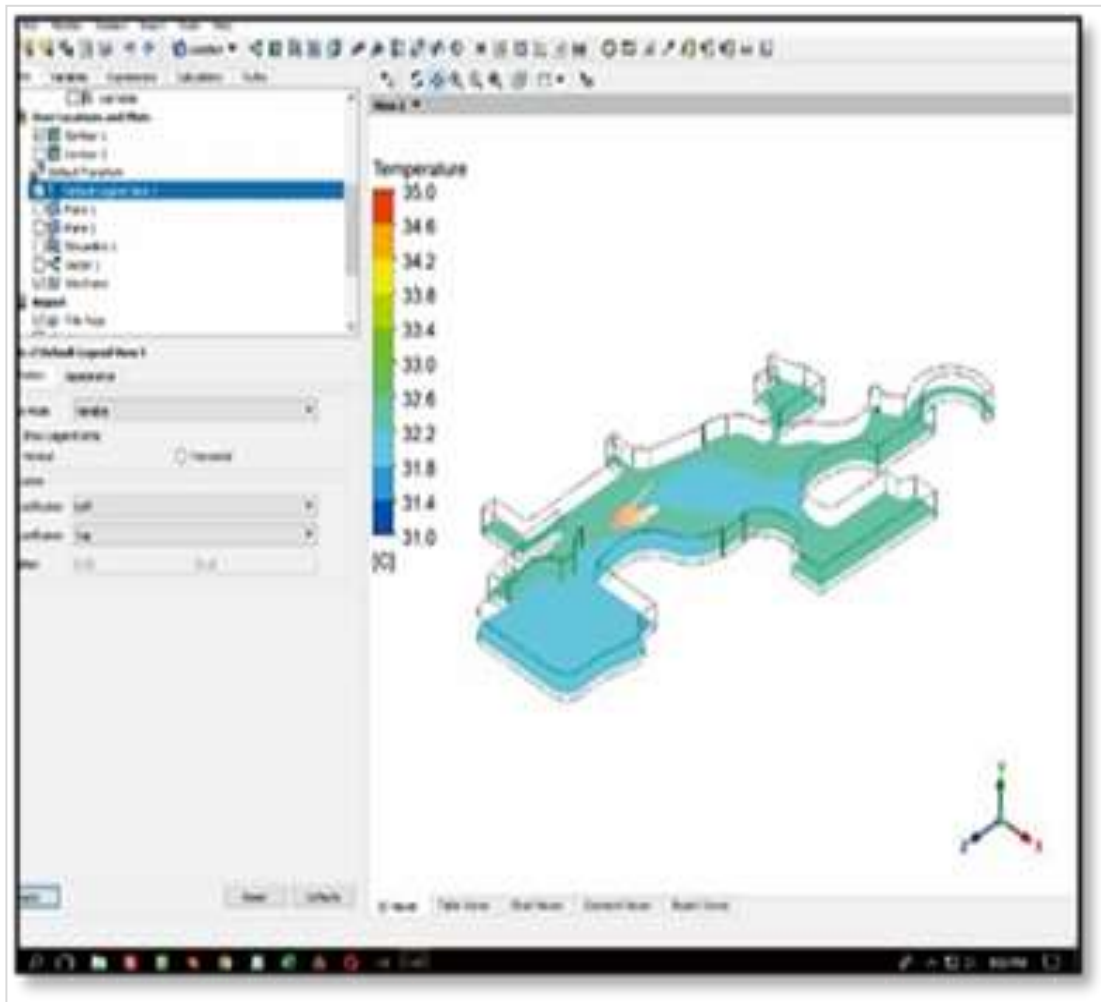


Figure 21. Thermal environment simulation result of Nipah Mall

In the thermal simulations, the existence of architectural elements, such as water and vegetation, obtained heat decline in Nipah Mall at 5.2°C and 6% humidity. This demonstrated that

the influence of artificial ponds and waterfalls in the area was very significant on the thermal comfort of visitors.

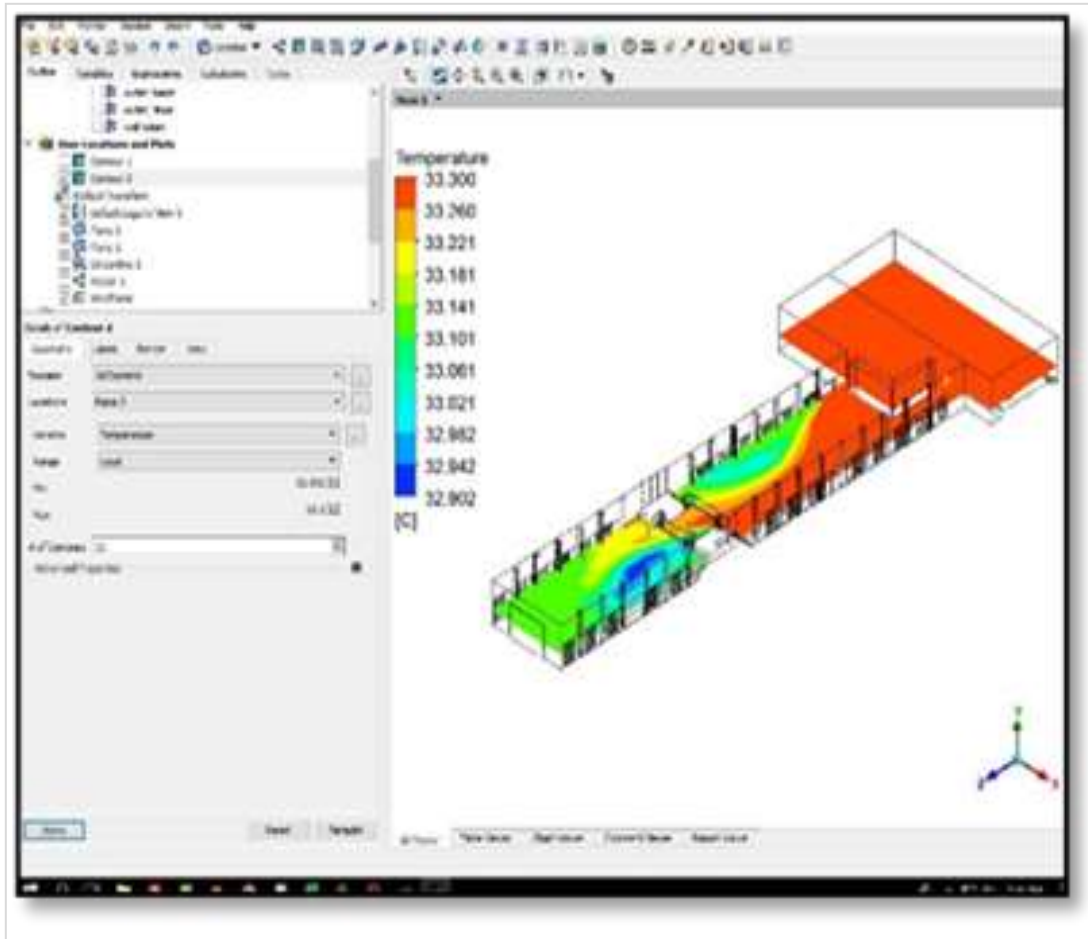


Figure 22. Thermal simulation result of Maxone Hotel

From figure 22, the average heat reached 33.3°C and 72% humidity, with the area near the swimming pool having an ambient temperature of 32.1°C and 69% moisture. The thermal simulations also showed that the existence of architectural elements obtained heat decline in Maxone Hotel by 1.2°C and 2% humidity. In this context, the influence of the swimming pool did not affect the thermal comfort of visitors.

According to the comparative analysis, the comparisons in this research involved two different locations, air movement and circulation pattern differences, the incorporation of 2 architectural elements, and the use of computer simulation models. This showed that the use of ponds or water elements and vegetation was capable of developing micro-cooling zones around buildings. These conditions were performed by considering airflow patterns, ventilation openings, as well as the arrangement and placement of water elements and vegetation.

Based on these comparisons, the following evaluations were observed,

1. The extent to which the use of water and vegetation significantly reduced air temperature in a specific area. This emphasized the difference in temperature with and without architectural elements.
2. The use of water and vegetation decreased heat leakage from buildings, as well as its effect on temperature reduction and cooling requirements.
3. Observation of the different evapotranspiration rates of water and vegetation elements affected the air temperature and humidity around the building.
4. The effect of water elements and vegetation on natural ventilation and indoor air quality.
5. Use of water and vegetation elements in architectural design.

Conclusion

In conclusion, the presence of water and vegetation elements in the thermal environment showed that the PMV, PPD, and SET indices on both building objects had significant differences. From this context, the values of PMV, PPD, and SET in Nipah Mall and Maxone Hotel were neutral and slightly hot, respectively. This indicated that the ASHRAE 55 standard on the Maxone Hotel building was not accepted, due to the PMV of 0.76 considered to be warm. A similar occurrence was observed on the value of thermal sensation (TSV) at Nipah Mall, where 47% of the total participants selected a comfortable temperature (0), with 45% emphasizing the "Rather Hot" category (+1) in Maxone Hotel.

Based on the air movement simulation, the outputs obtained at Nipah Mall were largest at the void opening of 2.98 m/s, accompanied by the Northside ventilation of 1.14 m/s. This proved that the cooler area was in the middle of the pool area and waterfall. Meanwhile, the largest air movement at Maxone Hotel was on the top side (void) and West opening of 2.63 and 0.98 m/s, respectively. This confirmed that the swimming pool did not affect the thermal comfort of visitors.

According to the thermal simulation, the comparative evaluation of the presence of water and vegetation elements obtained heat declines in Nipah Mall at temperature and humidity of 5.2°C and 6%. This decline was subsequently observed in Maxone Hotel at 1.2°C and 2%. From these results, the presence of water and vegetation elements at Maxone Hotel did not significantly affect the ASHRAE 55 standard. This was due to the bad air movement in the area, regarding the imbalanced inlet and outlet positions.

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Author(s) contribution

Muhammad Awaluddin Hamdy contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

Baharuddin Hamzah contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

Ria Wikantari contribute to methodology, supervision, and validation.

Rosady Mulyadi contribute to methodology, supervision, and validation.