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RESEARCH ARTICLE

SENSATION ON FEET COOLING WITH THERMAL COMFORT IN A PORUS WALLED ROOM

A. A. Ayu Oka Saraswati[a], Cornelia Hildegardis[b], Ida Bagus Gde Primayatna[c]

[a]Udayana University, Indonesia
[b]Nusa Nipa University, Indonesia
[c]Udayana University, Indonesia
*Corresponding Author Email: saraswati@unud.ac.id

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ABSTRACT

Comfort for users is the goal of a arsitectural design. This study aims to propose a new innovations in the meeting room consept design with cases in the Faculty of Engineering meeting room, Udayana University in Jimbaran – Bali. Innovation which provides a sensation of thermal comfort, through the position of the wind speed/air movement. This meeting room is made porous on the underside of the wall. The study was conducted using the Ecotect-Winair(cfd) software to evaluate wind speed/air movement in the meeting room. Then use the CBE Thermal Comfort Tool to reveal the sensation that occurs. The direction of the wind that changes periodically and the sensation of thermal comfort based on different regions/tribes or individuals provide the limitations of this research. Thermal comfort as a bioclimatic approach in the context of green buildings. Green building design is a popular design today as a form of responsibility to the world. A novelty was found in the form of a cooling bioclimatic sensation by the wind speed on the feet which is felt on the skin around the footbridge with a new design concept in the meeting room.

KEYWORDS

green building, wind speed through the porus wall, feet cooling, sensation

1. Introduction

The comfort demanded in a design includes not only visual and audial comfort, but also thermal comfort. In a humid tropical climate like in Indonesia, problems are often faced with hot air conditions and relatively high humidity. Based on these conditions, humans create a comfortable environment, especially comfortable thermic by using several strategies that are applied to buildings and to the surrounding environment. However, this can be used as an advantage by utilizing air/wind flow or with other passive cooling strategies such as applying strategies to openings or by utilizing materials on roofs (Kindangen, 2017). According to a study, air temperature, radiation temperature, air humidity, and wind speed are environmental factors that affect thermal comfort in an environment (Koenigsberger 1975). Sugini added, that there are other personal factors, which can have an influence on thermal comfort such as activity, clothing, age, gender, body posture, and other physical factors (Sugini, 2014).

Until now, many studies have been carried out by engineering the design to obtain thermal comfort. Research conducted in Mojokerto found that using wood as a wall material can lower temperatures compared to using brick wall construction (Purnama et al., 2016). In addition to the building envelope, other studies were carried out on openings. Research conducted in Minahasa found that the area of the opening directly facing the outdoor space has a greater influence on thermal comfort (Toisi and Kussoy, 2012). According to the shape and placement of the right opening leaves can make the room inside more comfortable (Rahmat et al., 2020). There are several forms of openings that can provide thermal comfort in the building. In general, research related to openings in buildings has an influence on the wind speed that enters the building.

Thermal comfort research related to wind speed/air movement has also been widely carried out. Previously it was known that there had been many studies on thermal comfort that combined technology and nature. one of them in a room like a meeting room. As is well known, thermal comfort is affected by the location of openings and the thermal sensations felt on parts of the human body (Sekatia et al., 2018; Arens et al., 2006). Based on these findings, an evaluation was carried out in the meeting room of the Faculty of Engineering, Udayana University, Jimbaran Bali, so that it could be used as a new design innovation in providing a sensation of thermal comfort.

2. Literature Review

In Indonesia there have been several studies conducted on meeting rooms to see the thermal comfort felt by the occupants. One of them is research conducted in Bandung (Latifah et al., 2013). The research conducted at the Itenas Student Center building found that the design of the building and the design of the air openings affect airflow which can support thermal comfort. This is in line with research conducted by who found that inlet and outlet openings are able to influence the flow of air entering the building (Ming et al., 2023). The airflow affects the decrease in temperature so it can have an effect on thermal comfort and health. In addition, it can also affect the reduction in energy consumption.

Based on the previous discussion, it is known that openings have a lot of influence on thermal comfort in buildings. Several studies conducted on churches in Indonesia found that openings are one of the factors that influence the thermal comfort that occurs in churches. one of them with the location of the opening which is 70 cm from the floor surface. Based on research conducted by at the Semarang and Bogor cathedral churches, it was found that the lower the position or location of the opening, the higher the velocity of the air flowing into the building (Sekatia et al., 2015). The existence of openings plays a role in creating thermal conditions in the

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church but this role is not significant because it is related to external conditions, especially wind direction and also the orientation of the opening to the wind direction which can cause wind from outside to not enter optimally (Dewandaru et al., 2019).

This is in line with research conducted in classrooms in which suggests that there is an effect of the shape and orientation of openings on air movement in buildings, especially in high-rise buildings (Machdijar, 2012; Tangerang and Vanessa, 2021). This can have a big impact on air movement and varying wind speeds as well as having an impact on natural ventilation and comfort in the interior. In addition to openings, external environmental factors are one of the factors that affect the flow of air entering the building. In a study, the road is one of the factors around the building, which has an influence on the thermal comfort of a building, both directly and reflected, as well as wind movement (Nikolopoulou and Lykoudis, 2006). It was also explained that reflections originating from road materials were able to influence not only the building but the external environment around it. Another external factor that has an influence is the distance between buildings. Based on research conducted by Swasti in Kampung Naga and on "U"-shaped houses in Yogyakarta, they found that the distance between buildings did not affect thermal comfort inside the building, but did affect the air flow that would flow into the building (Swasti, 2016; Hildegardis, 2022a).

3. Research Method

The study was conducted using Ecotect-Winair(CFD) software to evaluate wind speed/air movement in the meeting room. Ecotect is an analysis tool that enables designers to simulate building performance from the initial stages of conceptual design. It combines detailed analysis functionality with a highly visual and interactive modeling environment that presents analysis results directly in the context of building models. WinAir is a plugin for performing CFD (wind flow) analysis on the mesh using Ecotect. In using Ecotect-WinAir, some data is needed, including research location, room size, and surrounding buildings from the meeting room (Figure 1).

Figure 1: The meeting room at Building No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

Data regarding the local climate were obtained from www.climate.onebuilding.org, namely the climate on the island of Bali. The data obtained is to determine the overall temperature, humidity, and wind speed in the Bali region.

The simulation using Ecotect-Win Air has carried out in 2 (two) stages, namely:

- The outside of the building

On the outside of the building, a simulation is carried out to determine the effect of the presence of surrounding buildings on the airflow entering the building. In this simulation, the presence of vegetation and contour height is ignored.

- The interior of the room

On the inside of the building, a simulation is carried out to determine the effect of openings on airflow entering the building. In this simulation, a simulation comparison is given when the opening is in its original position and when the opening is 70 cm from the floor surface. This comparison is based on several previous findings concerning the effect of the location of openings on the sensation of thermal comfort in occupants inside buildings.

By this simulation there are several steps that must be passed, namely:

- Making 3-dimensional models using SketchUp. The model that has been made is imported into 3ds form so that it can be read by the Ecotect program. The scale in the depiction does not change, where the scale is adjusted to the actual situation.
- Apart from modeling, the next step is to retrieve climate data in accordance with the existence of the object. files in EPW format are taken so they can be read by Ecotect.
- Apart from using SketchUp, this research also uses Climate Consultant, as software that will help determine the temperature, humidity, and wind speed that occur throughout the year in Bali. The EPW files that have been obtained are directly used as a benchmark for wind direction and building orientation which will be used in the simulation later.
- After determining the wind direction using a climate consultant, it is necessary to validate the Ecotect win-air software that will be used. Where the results are declared valid by looking at the input information and control data written OK

After the simulation is done, the next step is to calculate the PMV. This model was developed by Fanger in 1970 known as Fanger's Predicted Mean Vote (PMV) which was later expanded with a convenience equation known as the PMV index. This index also relates thermal conditions to the ASHRAE thermal sensation scale. The PMV equation for thermal comfort is a steady-state model. The PMV model considers six variables of thermal comfort, namely air temperature, average radiation temperature, relative humidity, air movement, type of clothing, and activities performed. In this study, the activity of sitting and the type of clothing used are formal work clothes which are divided into long sleeves and short sleeves.

In measuring thermal comfort, there are several standards used as benchmarks, namely ASHRAE 55–2017, ISO 7730: 2005, and EN 16798–1. CBE's thermal comfort tools incorporate thermal comfort models such as Predicted Mean Vote (PMV), Standard Effective Temperature (SET), adaptive models, local discomfort models, SolarCal, and dynamic predictive clothing insulation. This PMV calculation uses CBE Thermal Comfort. CBE Thermal Comfort Tool for ASHRAE-55 is software that can be accessed where there are PMV methods and adaptive methods for processing. In addition, it can display the desired results based on psychrometric (air temperature) and psychrometric (operative temperature) along with their graphs.

4. Findings and Discussion

4.1 Point 1: Experiment using Ecotect-WinAir (CFD)

Based on the site plan (figure 1) it is known that the location of the meeting room is in building number 9. The location of the building which is between other buildings is an important concern regarding thermal comfort. where one of the comfort factors can be achieved by paying attention to the layout of the mass and density of buildings (distance between buildings) and the influence of barriers, both on vegetation and buildings which result in a decrease in the quality of ventilation in buildings due to the influence of pressure in an area. High building density will increase the level of resistance to the use of wind energy, as one of the natural energy to achieve comfort. Where the density of the building in question is the distance between buildings, building height, and building dimensions (Hang et al. 2010). In this study, the height and dimensions of the building were not taken into account.

Figure 2: The influence of the location of buildings and vegetation at the meeting room - building No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

It is known that based on climate data taken from www.climate.onebuilding.org, Bali has temperatures ranging from 27^{o}C to 30^{o}C with an average wind speed for one year of 2.67m/s. The location of meeting room is on the 1st floor of building 9 (figure 2). The meeting room is the focus of this study because it is a closed space that utilizes natural ventilation. The openings in this space are located 45 cm from the ceiling and there are 8 of them. The opening in question is a window with a size of 76.25 x 50 cm. When seen from the picture (figure 3), the position of the opening is located above the occupant's head in the meeting room.

The meeting room is one of the rooms in building 9 which functions as a place to discuss and solve problems. The room measures 7 x 9 M. In the room, there is a combined pattern of tables and chairs forming the letter U and is equipped with chairs on the outside. The orientation of the building is towards the south with a higher elevation than building no. 13. Around the building there is vegetation with varying heights and are ± 3 meters from the meeting room.

4.1.1 Airflow outside buildings based on the distance between buildings

Based on the simulations carried out on the outer space of the building, it is known that the airflow flowing towards building 9, decreases progressively. The speed value around building 9 is 0,3 – 0,8 m/s. Based on the picture, it can be seen that the airflow spreads irregularly in areas that are empty or have no buildings. whereas in areas that have buildings 2, 13, 9,10,7,6 and 8 (on the site plan image), there is a decrease in the speed value. In the figure, it can also be seen that the airflow coming from the north has a higher velocity when compared to the other side. According to the distance between buildings in an area will affect the airflow around and within the building (Hildegardis, 2022). The closer the building is, the lower the airflow into the building.

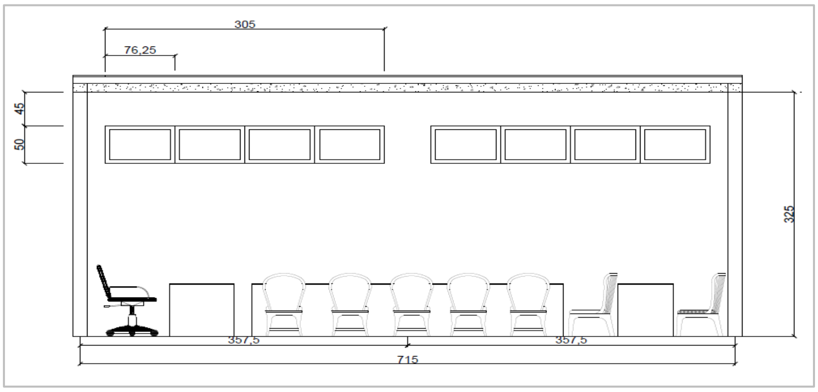

Figure 3: Opening position in the meeting room - building No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

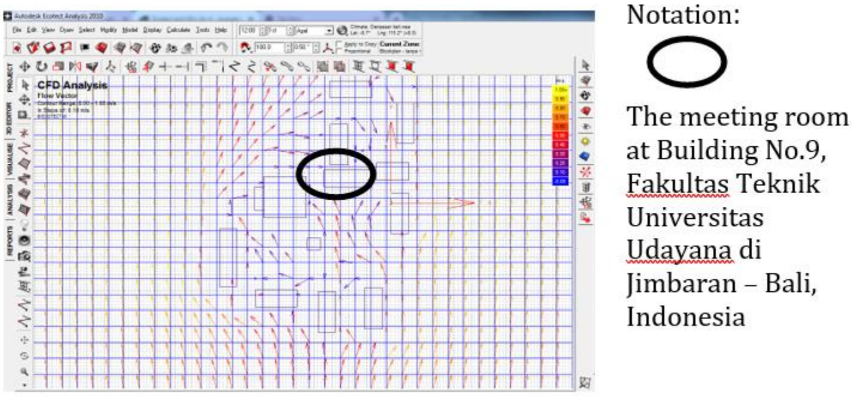

Figure 4: Depiction of wind movement at building: No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

4.1.2 Analysis of Airflow Inside The Building (Location of Openings 45 Cm From The Ceiling)

In the simulation performed, the condition of the openings is in open condition. This analysis is carried out to determine the airflow that occurs inside the building without using artificial ventilation systems such as fans or air conditioners. The results obtained from the simulation carried out are:

The airflow pattern that is formed is a pattern of spreading and rotating in the middle area of the meeting room, where the highest airspeed is the airspeed coming from the entrance. The highest air speed is at a value of 1.12 m/s. while the lowest airspeed is in the area adjacent to the window with an airspeed value of 0.14 m/s.

Height level measurement is done with a height of 1.2 M. This height is adjusted to the height to feel a comfortable thermal sensation on the limbs in a sitting position. In addition, also with the consideration that the room is in Building 9, 1st floor.

1 meter from the north, east and west, no visible wind movement.
Analysis of airflow inside the building (70 cm from the floor surface)

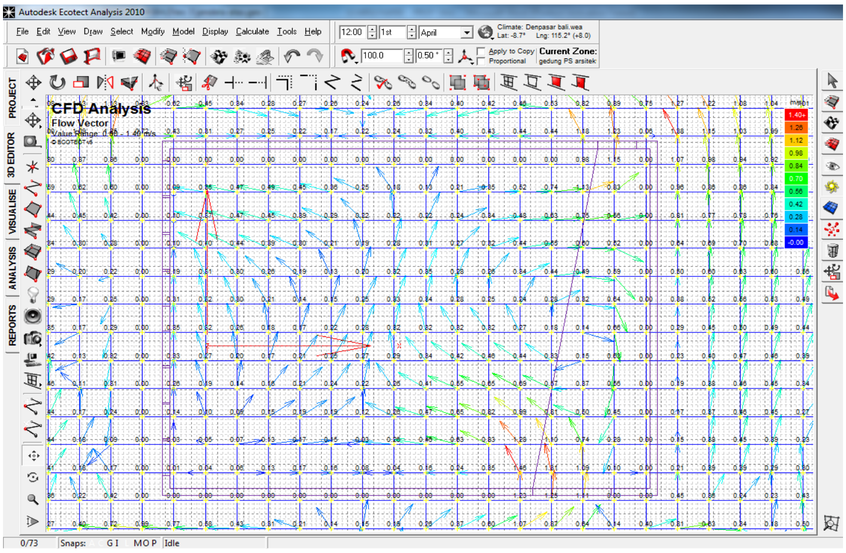

Figure 5: Analysis of airflow inside the meeting room - building No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

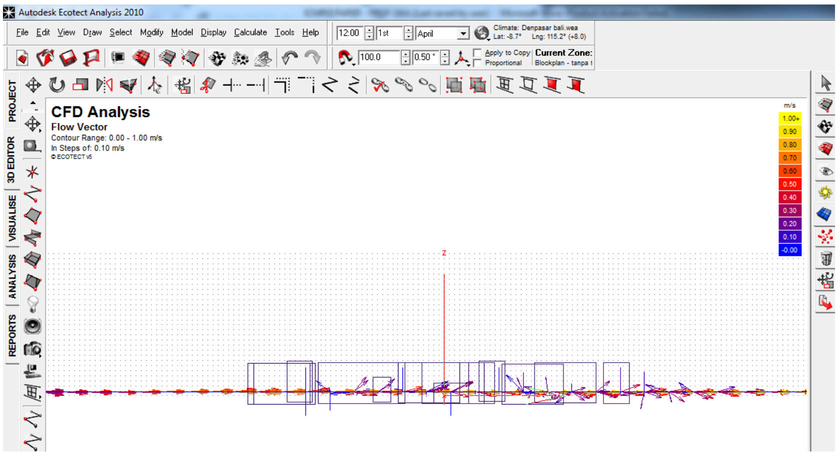

Figure 6: Side view of a wind crash on several buildings in the vicinity at Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

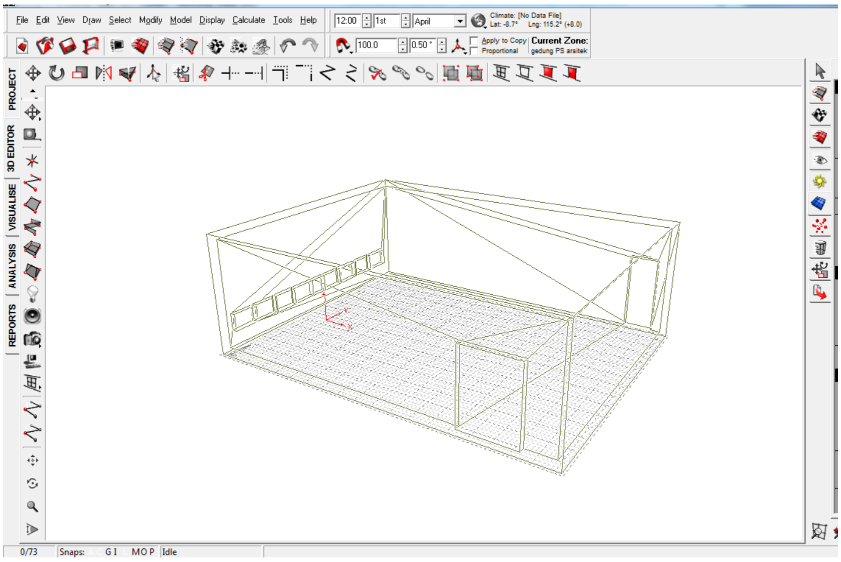

Figure 7: Modeling on ecotect at the meeting room - building No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

In the simulation performed, the condition of the openings is in open condition. The same is the case with the analysis carried out on the location of the opening which is 45 cm from the ceiling. The difference is made, more emphasis is placed on the location of the openings which are 70 cm from the floor surface where the size and number of openings do not change. The results obtained from the simulation carried out are:

The pattern of airflow that is spread throughout the room forms a circular pattern from the entrance to the opening on the south side of the room (door), and out towards the opening on the north side of the room, the window which is 70 cm from the floor surface). In the middle of the room, you can still feel the wind flow with a speed of 0.25 - 0.44 m/s.

The height level measurement is carried out with a height of 1.2 m and 70 cm because it is adjusted to the thermal sensation that will be felt by the occupants in the room. Where there is no difference in the pattern that occurs because changes occur in the speed of airflow occurs in the room. The higher the level of measurement is made, the lower the value of the wind speed. This is inversely proportional to the analysis of the location of the opening 45 cm from the ceiling At a position of 1 meter from the east and west, no visible wind movement.

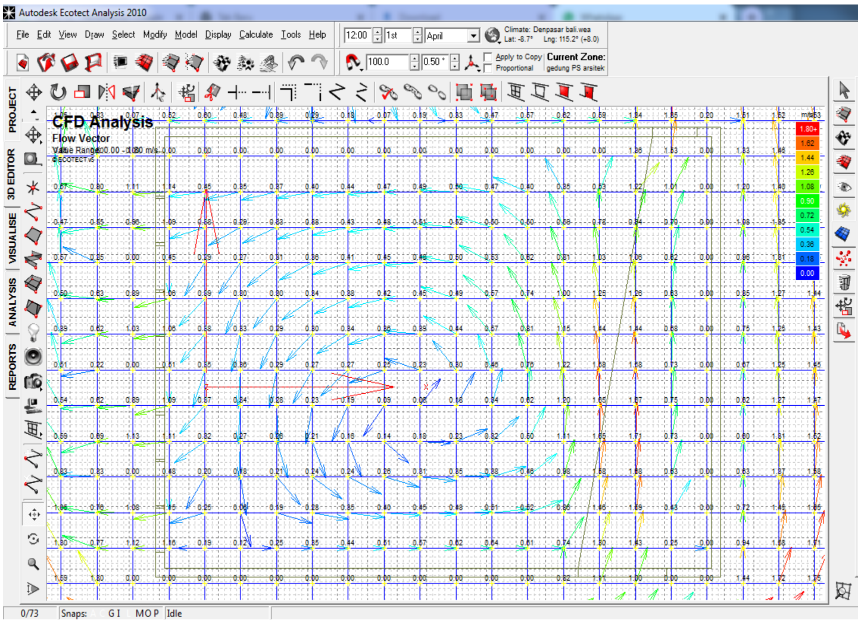

Figure 8: The airflow pattern formed by the location of the window is 70 cm from the floor surface at the meeting room - building No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

The height level measurement is carried out with a height of 1.2 m and 70 cm because it is adjusted to the thermal sensation that will be felt by the occupants in the room. Where there is no difference in the pattern that occurs because changes occur in the speed of airflow occurs in the room. The higher the level of measurement is made, the lower the value of the wind speed. This is inversely proportional to the analysis of the location of the opening 45 cm from the ceiling At a position of 1 meter from the east and west, no visible wind movement.

4.2 Point 2: Predicted Mean Vote (PMV)

Some of the data entered in the CBE Thermal comfort tool are:

- Air temperature, humidity, and wind speed data. In this data division, the data is divided based on several measuring points in the plan.
- The activity (meeting) entered is a sitting activity.
- Type of clothing to wear/clothing insulation in the meeting room: work clothes

NO	CLOTHING TYPE	CLO
1	Long pants, short sleeve shirts, shoes	0,59
2	Trousers, long-sleeved shirt, shoes	0,63

To analyze PMV, the room is divided into several points. These points are determined by the average value of speed and temperature based on the previous simulation using Ecotect. The room was divided into 9 points (point A to point I).

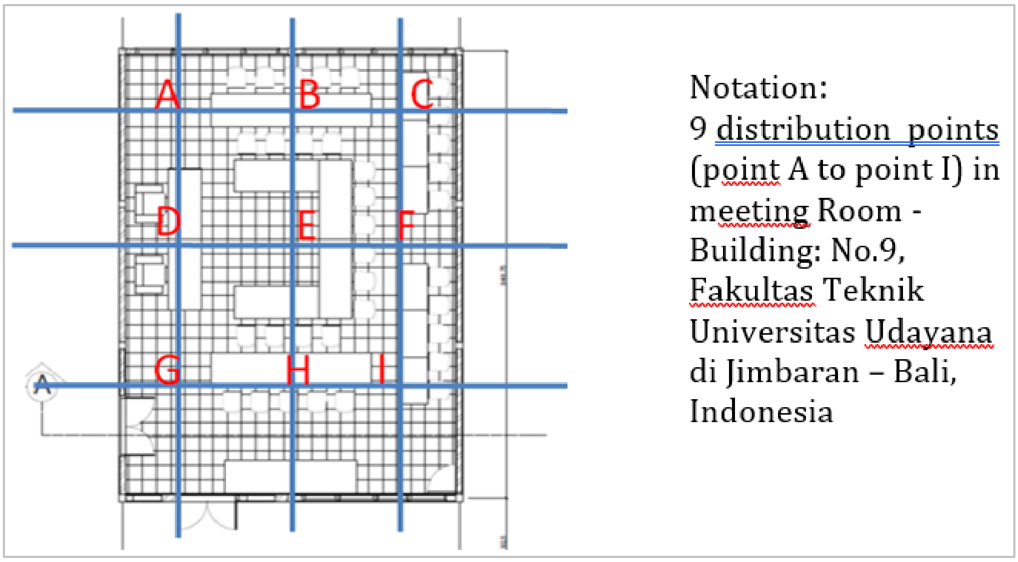

Figure 9: Distribution of PMV measurement points at the meeting room - building: No.9, Fakultas Teknik Universitas Udayana di Jimbaran – Bali, Indonesia

4.2.1 Predicted Mean Vote (location of openings 45 cm from the ceiling)

Zone	Temp (°C)	Humidity (%)	Airspeed (m/s)	Met	Clo	PMV	PPD	SET	Sensation
A	28.15	72	0.08	1	0,59	1,16	33%	29.4	Slightly Warm
	28.15	72	0.08	1	0,63	1.21	36%	29.6	Slightly Warm
B	28.15	72	0.14	1	0,59	1.09	30	29.2	Slightly Warm
	28.15	72	0.14	1	0,63	1.14	33%	29.5	Slightly Warm
C	28.15	72	0,17	1	0,59	0.96	24	28.7	Slightly Warm
	28.15	72	0,17	1	0,63	1.02	27	29	Slightly Warm
D	28.15	72	0.21	1	0,59	0.82	19	28.2	Slightly Warm
	28.15	72	0.21	1	0,63	0.88	21	28.5	Slightly Warm
E	28.15	72	0.28	1	0,59	0.64	14	26.9	Slightly Warm
	28.15	72	0.28	1	0,63	0.71	16	27.9	Slightly Warm
F	28.15	72	0.24	1	0,59	0.74	16	27.9	Slightly Warm
	28.15	72	0.24	1	0,63	0.80	19	28.2	Slightly Warm
G	28.15	72	0.5	1	0,59	0.32	7	26,4	Neutral
	28.15	72	0.5	1	0,63	0,40	8	26.7	Neutral
H	28.15	72	0.49	1	0,59	0.33	7	26.4	Neutral
	28.15	72	0.49	1	0,63	0.41	9	26.8	Neutral
I	28.15	72	1.15	1	0,59	-0.06	5	25	Neutral, the air speed value selected is outside the range defined by the ASHRAE 55 standard for occupants with no local air speed control
	28.15	72	1.15	1	0,63	0.03	5	25.3	Neutral, the air speed value selected is outside the range defined by the ASHRAE 55 standard for occupants with no local air speed control

Based on the measurement results it is known that:

- There are 6 (six) points out of the 9 points that show a slightly warm value. So that it can be represented by 66.67% of the meeting room is in an uncomfortable condition, because the occupants generally feel a bit warm.
- At the point I, the value shows a neutral value, but because the wind speed value is above the value that should be based on the standard from ASHRAE 55
- There is no difference in the sensation felt, for those who wear long sleeves or short sleeves. The difference in PMW values ranges from 0.2 to 0.4.

4.2.2 Predicted Mean Vote (70 Cm from The Floor Surface)

Zone	Temp (°C)	Humidity (%)	Airspeed (m/s)	Met	Clo	PMV	PPD	SET	sensation
A	28.15	72	0.12	1	0,59	1.10	31	29.3	Slightly Warm
	28.15	72	0.12	1	0,63	1.16	33	29.6	Slightly Warm
B	28.15	72	0.81	1	0,59	0.09	5	25.5	Neutral
	28.15	72	0.81	1	0,63	0.18	6	25.9	Neutral
C	28.15	72	0.29	1	0,59	0.62	13	27.5	Slightly Warm
	28.15	72	0.29	1	0,63	0.69	15	27.8	Slightly Warm
D	28.15	72	0.26	1	0,59	0.69	15	27.7	Slightly Warm
	28.15	72	0.26	1	0,63	0.75	17	28	Slightly Warm
E	28.15	72	0.80	1	0,59	0.10	5	25.5	Neutral
	28.15	72	0.80	1	0,63	0.18	6	25.9	Neutral
F	28.15	72	0.48	1	0,59	0,34	7	26.5	Neutral
	28.15	72	0.48	1	0,63	0.42	9	26.8	Neutral
G	28.15	72	0.52	1	0,59	0.30	7	26.3	Neutral
	28.15	72	0.52	1	0,63	0.38	8	26.6	Neutral
H	28.15	72	0.76	1	0,59	0.12	5	25.6	Neutral
	28.15	72	0.76	1	0,63	0.21	6	26	Neutral
I	28.15	72	0.50	1	0,59	0.32	7	26.4	Neutral
	28.15	72	0.50	1	0,63	0.4	8	26.7	Neutral

Based on the measurement results, it is known that:

- There are 3 (three) points out of the 9 points which indicate a slightly warm value. So that it can be represented by 33.33% of the meeting room is in an uncomfortable condition, because the occupants generally feel a bit warm.
- There is a speed ratio that looks evenly distributed at every point in the middle of the room, namely points B, E, and H
- There is no difference in the sensation felt, for those who wear long sleeves or short sleeves. The difference in PMW values ranges from 0.3 to 0.4.

In comparison of the Ecotect-WinAir simulation on the location of openings and PMV, the following results are obtained:

- open windows and closed windows

The different treatment of openings (open or closed openings) has an effect on the airflow that enters the building. This can be seen from the results of the simulations carried out, where the side that has no closed windows/openings does not affect the airflow in the room. This is not much different from the results of research conducted by in Kulon Progo, Yogyakarta, which suggests that an open or closed window will give different results in the temperature, air humidity, and wind speed values in the room (Adilline, 2021). He also added that rooms with open windows have temperatures, humidity, and wind speeds that are close to SNI standards when compared to closed ones.

- Wind dispersal patterns

Based on the simulation that also occurs, it is able to provide different results on the pattern of air distribution that occurs in the meeting room. The difference in this pattern is caused by the difference in the location of the openings that lead directly to the coming of the wind. The size and number of openings are ignored because they have the same size and number. These results are consistent with research conducted which explain that building design and the design of air openings affect airflow which can support thermal comfort (Latifah et al., 2013; Tandafatu and Hildegardis, 2022).

- Distance of occupants to openings

The effect of the occupant's distance to the opening has more influence on the sensation felt by the occupants. Based on the results of the Predicted Mean Vote calculation, it was found that the closer the measuring point is to the opening area, the better the thermal sensation given (neutral). This is in line with research from which explains that the closer the distance between the occupants of the room and the opening (40 cm from the surface of the ceiling or 70 cm from the floor surface) the more it will affect the thermal sensation that is felt (the more comfortable/uncomfortable) (Hildegardis, 2022b).

- The influence of the external environment

One of the variables that influence the air entering the meeting room is the external environment. In this research conducted at Udayana, the position of the building in the middle has an influence on the incoming airflow. The lower the airflow outside, the lower the airflow into the room. So that the orientation of buildings and openings is important in design, especially if the design emphasis is on natural ventilation.

- The type of clothing worn

In calculating the Predicted Mean Vote in the meeting room, it is known that there is no significant difference between clothes with long sleeves and short sleeves. Changes in the thermal sensation that occur are more dominated by the wind speed factor.

5. Conclusion

Based on the analysis and discussion that has been done, it is known that there are several factors influencing the air flow that occurs in the meeting room. These factors are the density of buildings and the location of openings. The location of the openings has more influence on the Predicted Mean Vote value, where the location of the openings which is 70 cm from the floor surface is considered to have more influence on thermal comfort (in neutral conditions) in the meeting room by 66.67%. With an opening at the bottom which is felt as a tightening of the legs, it is hoped that this can help in making further design innovations.

Limitation and Further Research

There are several factors that are not included as variables in this study, including:

- Vegetation is one of the factors that affect airflow outside the building (as a barrier or as a support for thermal comfort outside the building)
- The influence of materials inside or outside the building
- The influence of existing furniture in the building.

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