

## COMPARING THE THERMAL PERFORMANCE BETWEEN PASAR PRAWIROTAMAN AND PASAR LEGI IN YOGYAKARTA USING CFD TOOLS

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**ABSTRACT:** Pasar Prawirotaman and Pasar Legi are compared in terms of the natural ventilation system such as the size of the opening, position of the opening, and existing fence in the opening. The building shape and orientation of the building are also considered in the simulation. Therefore, this paper aims to compare the difference in thermal performance between the traditional market and the modern market in terms of layout and ventilation. The method that is used in this paper is quantitative methods for analyzing and collecting the data with variables such as air temperature, wind velocity, and humidity inside and outside the markets measured using CFD tools and simulation. The study demonstrates that variables such as opening size, position, existing fence, building shape, and orientation impact thermal comfort in both traditional and modern markets. Prawirotaman Market's larger, fence-free openings enhance wind access, yielding speeds of 1-7 m/s. In contrast, Legi Market, with smaller fenced openings, experiences wind speeds of 0-4 m/s. Wind direction, predominantly north in Yogyakarta, influences comfort, and Prawirotaman's west-facing orientation creates uneven wind distribution (3.5-7 m/s). Legi Market's direct north-facing structure maintains wind speeds of 2.5-5 m/s.

**Keywords:** CFD tools, modern market, thermal performance, traditional market

### INTRODUCTION

#### Background

According to Koenigsberger (1978) in Roid & Hidayati (2022), the psychological and psychological processes of thermal ventilation and comfort are involved by training one's mind to express self-satisfaction with the thermal environment. While designing a building, it is crucial to consider its geographic surroundings to provide its occupants with high-quality lighting, ventilation, thermal comfort, and physiological comfort. Since buildings are expected to be utilized over an extended period, taking these factors into account before construction can be considered essential because buildings serve as containers that protect and shelter all human activities inside. Ventilation and thermal comfort factors have an impact on how users behave inside a building. Internal and external elements have an impact on both thermal comfort and thermal health. Air temperature, airspeed, average radiation temperature, and humidity are examples of external elements. Levels of metabolic activity and clothing's thermal insulation are examples of internal factors (Ratnasari & Asharhani, 2021). Building design, location and orientation, occupant density, building structure design, and ventilation style are some of the variables that affect indoor temperature conditions. All buildings need to consider ventilation and thermal comfort because these two aspects will affect the physiological and psychological conditions of its users, especially in buildings that are aimed at the public which conduct many activities with various ranges of users at once in one place.

A market is one of the public buildings whose existence is close to human daily activities. The market is a building that is the center of trading activity and generally consists of stalls selling various kinds of goods or food. In the market itself, it can be seen that there are various activities carried out such as buying and selling activities, bargaining, arranging goods, choosing merchandise, and many other activities. Considering the large circulation

of activities and users, both sellers and buyers, a market must be a comfortable place for everyone.

According to the reality that is frequently met and from several earlier research conducted by Ratnasari & Asharhani (2021) and Roid & Hidayati (2022), many visitors to traditional markets still experience discomfort due to the temperature when engaging in certain activities there. According to the research done by Ratnasari & Asharhani (2021) in an analysis of the Kartasura Traditional Market, approximately 65% of users, ranging in age from teenagers to the elderly, have an unsatisfactory assessment of the state of ventilation and thermal comfort, with the duration of the activity being a result of the discomfort. With the nature of visits being infrequent for users, they happen very quickly at the Kartasura Traditional Market, taking only 30 to 60 minutes. In this research, the variables taken were the users' activity and the user's experience. However, in this paper, the variables that will be researched are the performances of the building.

Thermal comfort and air quality in a traditional market and public space have been extensively studied in existing and published research such as in Ratnasari & Asharhani (2021), Roid & Hidayati (2022), Kurniati et al., (2021), and Zang et al. (2023) but have not conducted the research using CFD as tools for the simulation. Therefore, the primary goal of this study is to compare the thermal comfort and air quality of traditional market structures with those of contemporary marketplaces with various building types and openings. Furthermore, this study will analyze air quality in each type of building and compare the difference using CFD (Computational Fluid Dynamics) software.

### **Research Objectives**

This paper aims to examine the thermal performance both in Pasar Prawirotaman and Pasar Legi with natural ventilation based on the existing **size of the opening, position of the opening, shape of the building, and orientation of the building** while considering the average temperature of the site, wind velocity, and humidity. With those aspects being examined, it is expected to compare what factor affects thermal comfort in a public market.

### **Research Questions**

The research questions in this study are as follows to address these concerns for the evaluation and improvement of the building performance:

1. Is there any difference in building performances in terms of the ventilation system (size of the opening, position of the opening, and the existing fence in the opening) between Pasar Prawirotaman and Pasar Legi in Yogyakarta?
2. How will the building shape and the orientation of the building affect the thermal performance between Pasar Prawirotaman and Pasar Legi in Yogyakarta?

## **LITERATURE REVIEW**

### **CFD towards thermal performance**

Many studies are focusing on the development of alternative tools for thermal comfort prediction; one intriguing way might be simulation performed with CFD codes, which allow for the simulation of thermal and velocity profiles within settings. Temperature, air velocity, and relative humidity readings were found to be within thermal comfort norms. In Buratti et al., (2017), experimental data and CFD code were used to assess the thermal comfort impression. The heat and velocity patterns inside the environment were simulated using a 3D simulation model. Because of their ability to evaluate local thermal comfort, the results underscored the usefulness of CFD models in supporting experimental campaigns. CFD code could be a very useful tool to support the experimental campaign and to evaluate the thermal local sensation.

According to Raczkowski et al. (2019), the CFD model was validated using experimental data and was used to forecast local thermal comfort within the room. The CFD simulation

model was utilized to evaluate local thermal comfort, and the PMV and PPD were displayed. The following conclusions can be drawn from the temperature performance calculations of natural ventilation:

1. CFD simulations can predict the thermal performance of naturally ventilated rooms, which can be used to improve the design of the inlet size and location of fresh air valves to set the best results to assess thermal comfort.
2. CFD temperature simulations give overestimated values when compared to in-situ measurements.

#### **Variables of thermal comfort**

According to studies done by Raczkowski et al. (2019) and Pathirana et al. (2019), it can be concluded that the CFD model was validated using experimental data and was used to forecast local thermal comfort within the room. The study was conducted by analyzing 300 different models with four WWR ratios and 24 building orientations. According to Pathirana et al., (2019), the results indicate that a rectangular form with a staircase in the middle will provide greater thermal comfort for WWRs of 20 and that L-shaped models with a staircase in the short corner and middle will provide greater thermal comfort for other WWRs. Square-shaped houses with a central staircase have the most lighting electricity, whereas L-shaped houses have the least. The thermal comfort and lighting electricity are affected by the building shape, zone sizes, and zone locations. Furthermore, WWR alters thermal comfort by 20-55%, and lower WWR delivers both higher thermal comfort and higher lighting electricity. Furthermore, in this case study, the building orientation has no discernible impact on thermal comfort or lighting electricity, owing to the occupancy schedules and even the distribution of windows.

#### **Natural ventilation in the market**

According to Shafira & Setiawan, (2021), current traditional market circumstances remain deplorable. Traditional markets become dirty, muddy, stinky, and stuffy in people's minds, making visitors uncomfortable. This is owing to insufficient natural fatigue elements, which make the market seem hot and stuffy and fail to meet the requirements of air circulation planning. Passive design is a method of exploiting the potential of the micro-climate in buildings, such as natural air conditioning, to preserve the thermal comfort of the area. These fundamental concepts can be implemented through air ventilation. Meanwhile, paying attention to natural ventilation in a building can improve comfort, facilitating daily human activities. As a result, a new market design must be created that adheres to specified market requirements while employing natural ventilation design theory to improve the convenience of conventional market customers. To change the form of the site, mass structures with elongated shapes will be constructed. The inlet will then be located on the north and east sides of the building, while the outflow will be located on the south and west sides.

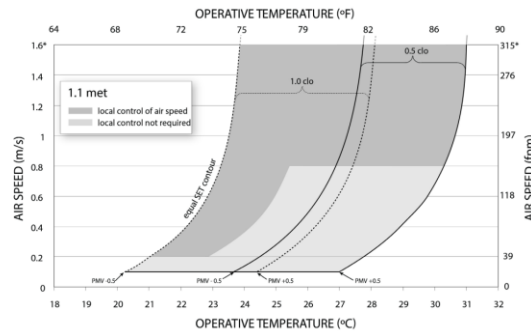
#### **Thermal comfort in urban design**

According to Kurniati et al., (2021), climate change is causing an increase in average surface temperature of up to 0.3°C in Indonesia, the world's fourth most populous country (Emmanuel, 2005). Furthermore, thermal comfort affects activities both within and outside the space. Thermal comfort assessment is required to become an urban design guide to improve the quality of life in urban communities (Koerniawan, 2015), which people may appreciate on a scale. The simulation results and correlations in public space in Kota Tua revealed that land cover material, road geometry to buildings (H/W), presence of vegetation, and traffic frequency are urban design components that substantially affect microclimate creation. Meanwhile, land cover material, traffic rate, and environmental activities had a significant impact on public space in Chinatown. The correlation data demonstrated that building orientation close to the sun increases shadow generation. The data analysis results

confirmed the presence of shadows with a high tendency to lower air temperature. Furthermore, the overall concept of applying for increased thermal comfort includes urban design aspect considerations.

**STANDARD**

The average air speed in nearby areas of a representative occupant which the average is based on place and time. In Yogyakarta itself, the average wind velocity is 6 m/s. According to ASHRAE Guidelines 55, the air speed comfort zone range is greater than 0.2 m/s.



**Figure 1** ASHRAE Standard

WIND SPEED		KIND OF WINDS	INDICATORS
m/s	km/h		
0.0-0.5	0-1	SUBSIDED	UPRIGHT AIR
0.6-1.7	2-6	BREEZE	ANGLED SMOKESTACK
1.8-3.3	7-12	WEAK	LEAVES MOVING
3.4-5.3	13-18	AVERAGE	TREE CHAIN MOVING
5.3-7.4	19-26	KIND OF HARD	BRANCHES MOVING
7.5-9.8	27-35	HARD	TREE TRUNK MOVING
9.9-12.4	36-44	VERY HARD	BIG TREE TRUNK MOVING
12.5-15.2	45-54	NOISY	BRANCH BROKEN
15.3-18.2	55-65	GREAT NOISE	SMALL TREE BROKEN
18.3-21.5	66-77	STORM	BIG TREE FALLING
21.6-25.1	78-90	GREAT STORM	HOUSE COLLAPSING
25.2-29.0	91-104	TYPHOON	HEAVY OBJECTS FLYING
>29.0	>105	GREAT TYPHOON	OBJECTS FLYING FOR KILOMETERS

**Figure 2** Classification of Wind Speed based on the Beaufort Scale

**METHOD**

The research method will be carried out in two stages, the first one collecting primary data and secondary data. Primary data will be gathered by measuring the size of the opening, locating the position of the opening, and assuring the existing fence in the opening on the site of both markets. The data regarding the building will be assessed by using CFD as the main tool will be used to compare the thermal performance of the Prawirotaman Market and Legi Market with 3 different wind velocities which are the speed of 6 m/s, 5 m/s, and 4 m/s. The secondary data will be collected through existing data and journal research that have been published before regarding the buildings for additional sources that can help to enhance the paper's result.

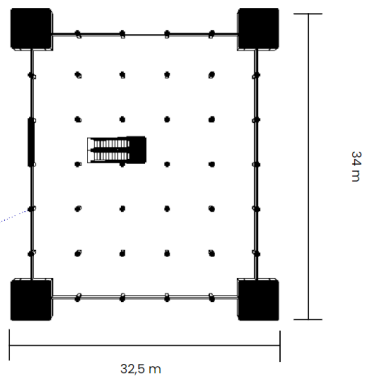


**Figure 3** Pasar Prawirotaman  
(Source: Author, 2023)

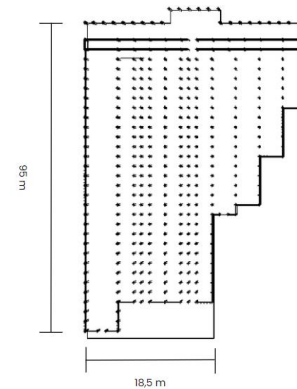


**Figure 4** Pasar Legi  
(Source: Author, 2023)

**FINDINGS**





**Figure 5** Prawirotaman Market







**Figure 6** Legi Market

To conduct the CFD Simulation, various apertures are listed and distinguished by their type. There are 3 types of openings in each market, which for the Prawirotaman Market has a type A with 5.3 x 1.5 m, type B with 2 x 1 m, and type C with 1 x 1.5 m. The Legi market has openings of type A which surround 4 sides of the market with 1.5m high, type B with 2.5m x 2m, and type C is the openings that are created by the gap of each roof inside the market.

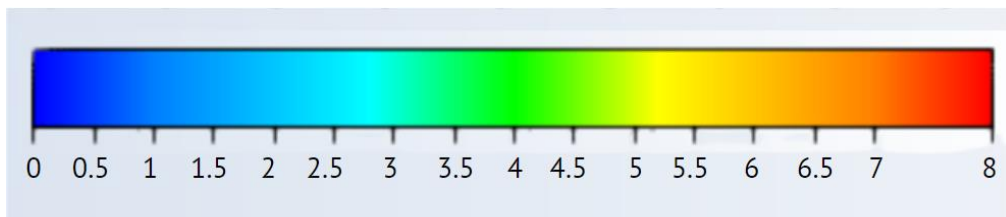
**Table 1** Types of Opening

PRAWIROTAMAN MARKET		LEGI MARKET	
 <p><b>Type A</b></p>	<p>The first existing opening in Pasar Prawirotaman is located surrounding the building on the north, west, south, and east sides. This opening allows natural ventilation as well as natural lighting to enter the market. The size of the opening is 5.3m x 1.5 m. The window-to-wall ratio is 2.75m: 1.5m.</p>	 <p><b>Type A</b></p>	<p>The opening in this market is in the form of a half wall and half opening with a steel fence. It surrounds the north, west, south, and east sides of the market. The height of the wall itself is 1.5m and the half opening with the fence has a height of 1.5m.</p>

PRAWIROTAMAN MARKET		LEGI MARKET	
 <p><b>Type B</b></p>	<p>The second existing opening is located only between the stairs of the stories. This opening cannot be opened but still allows natural lighting to illuminate the room. The position of this opening is facing the south side with a size of 2m x 1m.</p>	 <p><b>Type B</b></p>	<p>Air circulation in this market can also cross through the doors that are located on the north, south, east, and west sides of the market. This opening is also only a steel fence. The size of this door is 2.5m x 2m.</p>
 <p><b>Type C</b></p>	<p>The third type of opening is located facing the south side as well and this opening can be opened. This opening allows natural ventilation and natural daylighting as well but is rarely used because it is located on the side that is not too crowded. The size of this opening is 1m x 1.5m.</p>	 <p><b>Type C</b></p>	<p>There is no other opening inside the market so the circulation inside feels cramped. But there is a hollow between the stack of steel roofs that protect the market inside. The wind breeze and the heat that goes through the hollows can affect the thermal conditions inside the market.</p>

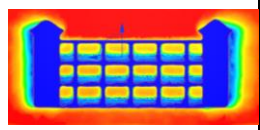
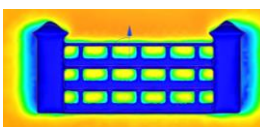
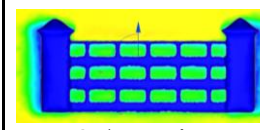
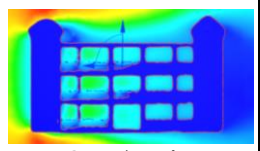
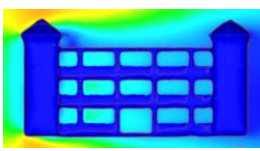
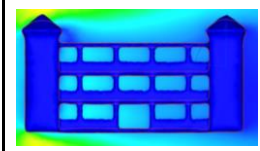
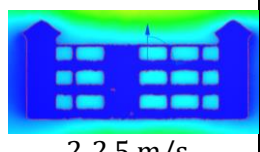
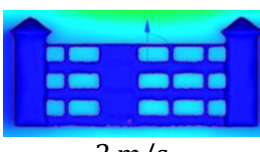
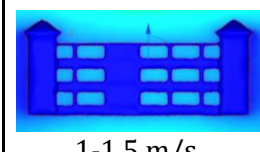
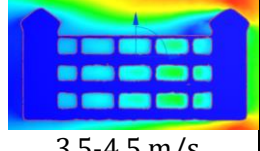
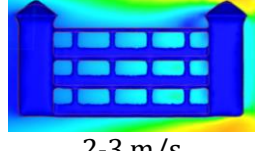
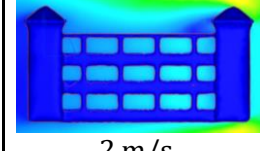
**RESULT**

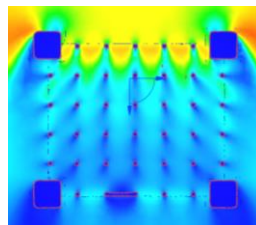
Based on CFD measurement, there are the results inside the Prawirotaman Market and Legi Market airflow when the wind velocity is set to be 6 m/s, 5 m/s, and 4 m/s. According to the windrose in Yogyakarta City (Meteoblue, 2023), the direction of the wind mostly comes from the north. Therefore, the result below explains the airflow inside the market based on the difference in wind velocity and the direction of wind. According to ASHRAE, the wind speed inside the market based on the CFD is not considered as comfortable due to the low intensity of the wind which should be around 0.2-0.8 m/s to be called thermally comfortable. This result happens due to the simulation using CFD not taking furniture layout and the density of people inside. As a result, thermal comfort felt in real conditions could be different from the result using CFD below.



**Figure 7** The parameter of velocity magnitude used in CFD

**Table 2** Result of CFD on Prawirotaman Market

Orientation	6 m/s	5 m/s	4 m/s	Average
North	 5.5-7 m/s	 4.5-5.5 m/s	 3.5-4 m/s	3.5-7 m/s
West	 3-4.5 m/s	 2-3 m/s	 1.5-2.5 m/s	1.5-4.5 m/s
South	 2-2.5 m/s	 2 m/s	 1-1.5 m/s	1-2.5 m/s
East	 3.5-4.5 m/s	 2-3 m/s	 2 m/s	2-4.5 m/s


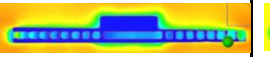
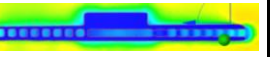
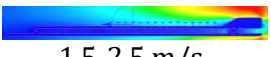
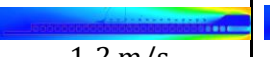
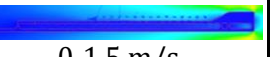
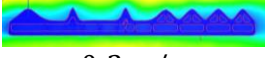
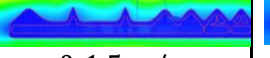

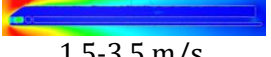
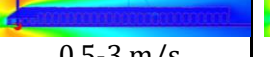
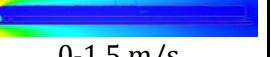


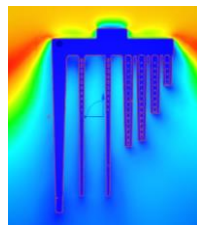
**Figure 8** Plan of CFD Result in Prawirotaman Market

Type A opening with a size of 5.3m x 1.5m is the main access of air to enter the market because it surrounds the facade of the building. It also allows cross ventilation inside the market so that it is not suffocating. Type B is a 2m x 1m glass window which is located on the south side and does not allow the air to enter since it is a 'dead' window. The last type of opening is type C, a glass window located facing the south side of the building and it also allows exchange of air ventilation inside the market with the size of 1m x 1.5m.

The intensity of the wind that enters through the north side is much more than the other sides. It can be seen from the CFD result that on the north side, the average wind velocity ranges from 3.5-7 m/s, 1.5-4.5 m/s on the west side, 1.5-2.5 m/s on the south side, and 2-4.5 on the east side. Prawirotaman Market has a rectangular shape that causes the wind distribution to be not that different inside the market, the average is ranging from 1-5 m/s. This market is built facing the west side where the intensity of the wind varies on each side. From the CFD result, the north side has the highest intensity of wind and the south side has the lowest one which can be seen on the color marks on the simulation.

**Table 3.** Result of CFD on Legi Market

Orientati on	6 m/s	5 m/s	4 m/s	Average
North	 4-5.5 m/s	 2.5-5 m/s	 2-3.5 m/s	2-5.5 m/s
West	 1.5-2.5 m/s	 1-2 m/s	 0-1.5 m/s	0-2.5 m/s
South	 0-2 m/s	 0-1.5 m/s	 0-1 m/s	0-2 m/s
East	 1.5-3.5 m/s	 0.5-3 m/s	 0-1.5 m/s	0-4 m/s



**Figure 9** Plan of CFD Result in Legi Market

Type A openings surround each side of Legi Market which allow the wind to enter from everywhere, it has a height of 1.5m. Type B is a 2.5m x 2m fence door which is opened when the market is open and allows the air to exchange through this door since it is located on the north and south sides. Type C opening is created by the gap of the roofs inside the market. The gap is assumed to be around 5-20 cm which also affects the thermal condition inside the market.

The wind directly enters the market from the access of the opening located on the north side with the wind speed ranging from 2.5-5 m/s. In the other direction, the intensity of wind ranges from 0-2.5 m/s on the west side, 0-2 m/s on the south side, and 0-4 m/s on the east side. In Legi Market, there is the existence of a fence that affects the thermal condition where the airflow does not go as swiftly as it through the inside. From the result, it can be seen also that the average wind speed ranges from 1-2.5 m/s due to its shape which is quite irregular. The south part gets the lowest wind intensity due to the size of Legi Market is also big and elongated.

### DISCUSSION

The result shows that the variables in this paper such as the size of the opening, position of the opening, the existing fence, building shape, and also building orientation have an impact on thermal comfort inside the market, both traditional and modern. Prawirotaman Market has bigger openings with a size of 5.3m x 1.5m and is located on each floor of the market. Those openings are also located on each side of the building facade which provides access for the wind to enter the building from each direction. Additional dimensions of window openings and ventilation can improve the speed and distribution of wind in residential spaces, causing the pattern of wind movement to expand horizontally rather than only flow toward the ceiling of the room (Arifah et al., 2017).



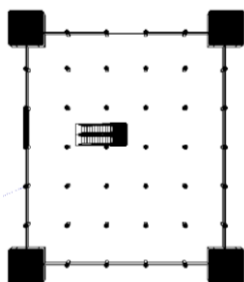
**Figure 10** Main opening in Prawirotaman Market



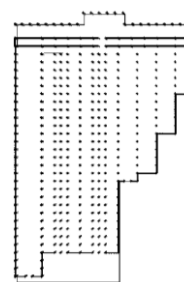
**Figure 11** Main opening in Legi Market

While in Legi Market, even though the openings also surround the facade of the building, the height of the opening is 1.5m with a fence also installed. This factor affects the intensity of the wind that enters the building not as much which only reaches the range of 0-4 m/s compared to Prawirotaman Market which ranges from 1-7 m/s that does not have a fence on the opening.

According to Meteoblue, the wind in Yogyakarta City mostly comes from the north area with the speed average. Orientation to wind direction can also have an impact on thermal comfort because it affects the wind speed that enters the building (Roid & Hidayati, 2022). Therefore, the positioning of the apertures facing the north side allows the wind to come and makes the airflow inside the building not too suffocated. In Prawirotaman Market, the wind speed on the north side reaches in the range of 3.5-7 m/s because the direction of the wind comes mostly according to the location of the building. Since the Prawirotaman Market does not directly face the north but west, the wind intensity inside the market is not distributed evenly. According to the wind speed by Beaufort Scale, the range of the highest wind in Prawirotaman Market could move the tree chain. Compared to Legi Market, the building is directly facing the direction of the wind so that the wind can directly come from the main access of the market itself. Based on CFD results, the wind intensity that comes on the north side of Legi Market ranges from 2.5-5 m/s. In terms of building shape, Prawirotaman Market has a rectangular shape which allows the wind to be distributed evenly inside the building moreover when there are openings located on every side of the building. On the contrary, Legi Market has a more irregular form and it is elongated. It affects the distribution of the wind which mostly comes from the north side and does not reach as much as to the south side. Even though there is also an opening on each side of the market, it needs to perform properly since the experience felt inside the building is stifling.



**Figure 12** Building shape of Prawirotaman Market



**Figure 13** Building shape of Legi Market

This research aims to seek the difference between traditional and modern markets in terms of ventilation systems. From the result above, the size of the opening, the position of the opening, and also existence of the fence installed on the opening affect the thermal performance inside the building. Prawirotaman Market is a modernized market and has

proven to have better thermal performance due to its size the opening being relatively bigger compared to Legi Market which also has a fence installed on the opening. Both of the markets locate their openings in the whole facade of the building so that wind enters the building from all directions even though the intensity of the wind can differ depending on other factors written previously which are the size of the opening and existing of the fence. Building shape and building orientation also have an impact on providing thermal comfort inside the market. In rectangular buildings such as Prawirotaman Market, the wind distribution can be evenly spread because there is no other edge inside the plan of the building. Compared to the Legi Market which has an irregular and elongated shape, the wind is not evenly distributed once it enters the market. In terms of building orientation, Prawirotaman Market is built facing the west side which is not the direction where the wind mostly enters the building so the north side of Prawirotaman Market has high intensity of wind but not as much as the main access of the market which is located in the west side. Legi Market faces the north side so the wind can enter the building directly and distribute it throughout the building.

### **CONCLUSION**

Modern markets such as Prawirotaman Market have better thermal conditions inside due to its opening which is bigger than Legi Market. Moreover, in Prawirotaman Market there is no fence installed on the opening to allow wind to come as much as it can. While for traditional markets, in this case, Legi Market, the thermal performance is uncomfortable because the wind does not distribute well due to its long building and irregular shape even though the building is directly oriented to where the wind is most likely to enter the market.

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