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CONTROLLING COMFORTNESS OF BIG PRODUCTION BUILDINGS IN TROPICAL REGION FACTORIES BY PROPER FAN ARRANGEMENT

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ABSTRACT

A production building is one of important buildings in a factory. A lot of factories in Indonesia are still considered labor intensive factories. People need a convenient place to work to produce quality products. A discomfort workspace condition for workers often causes not only poor productivity but also poor quality of product. Therefore, it is important to create healthy working environment for workers. Air comfort is determined at least by five factors that are temperature, relative humidity, oxygen content, air pressure and air flow. Common working space in a production building is a huge space, so it is almost impossible to apply air conditioner system to such a big space due to too high investment cost and operational cost and economically unfeasible. In tropical region, oxygen content, air pressure and air flow can be controlled by letting the fresh air from outside to enter the building. Air movement will also lower temperature sensation on human skin. Commonly in factories, the managements equip the factories with fans to improve air comfort in the production building. However, this current research found that improper fan system configuration and direction does not help to improve air comfort and even worsens the air condition because the air movement blown from improper fan configuration and direction can cancel each other and trap the heated air recirculated inside the building. This research found that arranging the fans in one direction will poster air movement from one end to the other end of building as well as keep the fresh air entering building from one side and the used air exiting the building through the other side. Because a fan is not a cooling device, the air temperature inside the building similar to that of fresh air, but the air movement pushed by the fans will reduce temperature sensation on human around 2 ^{0}C.

Keywords: building, human comfort, air comfort, fans, air temperature

1. INTRODUCTION

There are usually several buildings in a factory, such as office building, utility building, canteen and production building [1]. In production buildings, materials are usually processed until becoming finished products. Sometimes, packaging is also done in this building. Hence, quality of product is somehow determined by works done in this building. It is not a question that a production building is one of important buildings in a factory. As an important building, it is interesting to find how this building condition can support the vision and mission of the factory. In Indonesia, many factories are still considered as labor intensive factories, such as shoes and garment factories. Therefore, it is important to create healthy working environment for workers [2].

It has been studied that people need a convenient place to work to produce quality products [3]. The workers tend to be tired and loss of concentration more easily when the workspace is unfavorable for them. A discomfort workspace condition for workers often causes not only poor productivity but also poor quality of product both in short and long terms. This condition can lead to loss of potential profit for the company because poor quality products may lead to many product rejection by customers or being downgraded to cheaper price [4][5]. The worst condition is that the factory may loss its business because customers cancel the purchasing contracts or purchasing orders. Hence, it is very important for a factory to keep the production building as a convenient place for the workers to work to produce good quality products.

There are many factors that can lead a production building to be an unfavorable place for workers. The unfavorable conditions can come from noise, limited working space, poor air quality and social tension [6]. The most common unfavorable condition in industrial buildings is due to poor air quality, such as hot temperature, high air humidity, unpleasant odor, lack of oxygen (not fresh air) and too strong or too weak air movement [7][8]. It is commonly thought that air comfort is only determined by temperature. Actually, air comfort is determined at least by five factors, that are temperature, relative humidity, oxygen content, air pressure and air flow [9]. Hence, temperature is only one of criteria in air comfort. In tropical region, oxygen content, unpleasant odor, air pressure and air flow can be controlled by allowing the fresh air from outside entering the building.

Unlike office buildings which are commonly partitioned into small rooms, production buildings are usually not partitioned. It is not uncommon that a production workspace occupies one production building floor. Machineries dan workers are together in a large space room. Machineries emit heat, so they can increase air temperature in the building and make inconvenient working space [10]. Because the size of space is large and a lot of machineries inside the space, it is almost impossible to apply air conditioning to the production room or building. Installing the air conditioning systems for this such kind of room/space is extremely costly and electricity bill will be tremendously high so that it is likely not economically feasible. Lowering air humidity and temperature, as well increase oxygen content in a production building can be achieved partly by increasing air exchange rate and air movement (wind) in the building [11][12]. Therefore, installing fans may be the solution to provide a convenient work space for people to work in production buildings. In this case, it is important to study the arrangement of fans that can effectively improve working environment.

Many production buildings in factories install fans, both fans on the wall and internal fans to achieve comfortable working space. However, many of them find that installing fans does not guarantee to make the buildings convenient for workers. Even, many of them experience that adding the number of fans sometimes do not make improvement. This current research studied if the direction and position arrangement of fans can affect the performance. A case study in this research is the production building in a factory in Banten Province, Indonesia. The type of factory selected for this study is a labor-intensive factory. There were a lot of machineries as well as workers inside the building. Originally, the factory had installed plenty of fans in the production room space. The primary big fans were installed on the walls and inside. There were also plenty of small fans next to individual worker. However, the workers still filled that the air comfort still need to be improved. The objective of this research is to investigate and analyze the wind flow in the building in order to improve the thermal comfort inside the building.

2. LITERATURE STUDY

2.1 FACTORS OF ROOM COMFORTNESS

The main criteria of comfort air are temperature and humidity of air [13][14]. As illustrated in the **Error! Reference source not found.**, the average comfortable criteria for average human being are in between 22-27°C and Relative Humidity (RH) between 40-60% [15][16]. The criteria all depend on the people accustomed to. For example, people from northern hemisphere have different comfortable criteria from people from tropical region, such as Indonesia. People from tropical region tend to have in between 25-26°C and 60% RH, while people from northern hemisphere require less temperature and humidity level for being comfort. Indonesian government suggest that the temperature setting for air conditioner is 25 ^{0}C [17]. The temperature setting recommended by the government actually has at least two reasons. One is the criterion of comfort temperature and the other reason is energy efficiency.

Widely people think that the room comfort is determined solely by the temperature of air in the room. However, it is not correct. The comfort index of room at least is dictated by five factors, that are temperature, oxygen content, relative humidity, air pressure and air flow. Air comfort index (ssd) can be calculated using equation (1)[18].

$$\text{Comfort index} = (1.818T+18.18)(0.88+0.002F) + (T-32)/(45-T) - 3.2V + 18.2 \quad (1)$$

Where T = temperature; F = relative humidity and V = velocity of fresh air flow. For example, an air-conditioned room, T = 25 C, F =50%, V = 0.2 m/sec, has air comfort index 73.26.

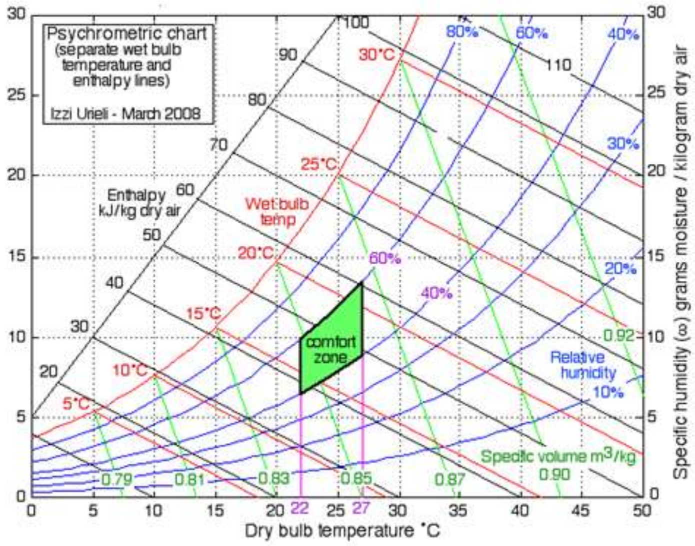

Figure 1. The comfort temperature and humidity

Based on factors that determine air comfort, human comfort index can be divided into nine levels as shown in Table 1 [18]. Air pressure and oxygen content can be inferred from velocity of fresh air flow. Fresh air provides oxygen air pressure to the rooms in the building. The air of rooms continuously supplied with fresh air are healthier as compared the air of closed room. Supplying fresh air into the rooms will push warm and used air inside rooms to outside. This process results in the rooms air to be healthy and fresh and this will avoids building sickness syndrome in which when a person has sickness transmitted through the air, other people inside the building become sick [19][20].

Table 1: Human Comfort Index Level: [18]

Human Comfort Index	Comfort Level	Remark
86 - 88	Level 4	The body feels burning hot, highly uncomfortable, and needs to be cooled to prevent heatstroke.
80 - 85	Level 3	The body feels quite hot, very uncomfortable, and needs to be cooled.
76 - 79	Level 2	The body feels a bit hot, uncomfortable and some proper cooling is needed.
71 - 75	Level 1	The body feels a bit warm, relatively comfortable.
59 - 70	Level 0	The body feels most comfortable.
51 - 58	Level -1	The body feels a bit cool, relatively comfortable.
39 - 50	Level -2	The body feels quite cold (cool), uncomfortable, better to keep warm.
26 - 38	Level -3	The body feels very cold, highly uncomfortable, and needs to keep warm.

It is important to be noted that fans do not bring down the temperature of air. Fan is only an equipment that let the air to flow. Do not expect the fans will bring down the temperature of air like an air conditioner. However, air movement will bring the temperature sensation of human down between 2 to 3 ^{0}C, depending on the speed of air movement (wind) on human skin surface [18]. This effect is partly due to when air moves on the surface of human skin, it will vaporize liquid, such as sweat from skin surface. This vaporizing process will absorb heat from the human body and people feel colder. Table 2 shows the temperature sensation on human due to various speeds of air movement (wind) on the surface of skin. Table 2 explains that when air passes over human skin, it causes a sensation of 2 – 3 ^{0}C lower degree than supply air temperature.

Table 2. Temperature Sensation on Human [18].

Air Velocity m/s	Supply Air Temperature ^{0}C							
	25	26	27	28	29	30	31	32
	Equivalent Temperature Sensation on Human ^{0}C							
8	22.1	23.5	24.7	26.5	27.8	29.2	29.8	32.2
9	22.1	23.5	24.7	26.5	27.8	29.2	29.8	31.2
10	22.0	23.3	24.5	26.2	27.4	29.0	29.6	31.0
11	22.0	23.3	24.5	26.2	27.4	29.0	29.6	31.0
12	21.9	23.1	24.3	26.0	27.2	28.8	29.4	30.6

3. RESEARCH METHODOLOGY

Materials and tools used and how the study conducted are explained here.

3.1 Materials and Tools

The primary materials and tools used are as follow:

1. OpenFOAM CFD software
2. Infrared thermometer gun for measuring temperature of machine bodies
3. Thermometer for measuring room air temperature
4. Anemometer for measuring wind speed (air movement)
5. Humidity meter for measuring humidity of air
6. Laser distance meter for measuring the distance

3.2 Survey

The survey is conducted in one of the production buildings in a labor-intensive factory in Banten Province, Indonesia. This building was chosen because it would give good idea how arrangement of fans could make the comfort feeling to the workers.

Outside air temperature, and humidity as well as general wind direction and speed were measured. The green zone at outside of the building was also noted. The green zone here means the zone which has a lot of trees and other plants. As it is understood that green zone usually affects microclimate around the building.

After observing the building space, it was decided twenty-one location points were measured mainly for temperature and humidity during data collection. The measurement was taken approximately 1-1.5 meters height from the floor. During the measurements, all fans were run. The directions and speed of air movement (wind) at several spots inside the building were measured and observed. The surface temperature of machineries was also measured. The layout of building utilization, such as the positions of machineries and workers was sketched and noted. The positions, directions and number of fans were observed, sketched, and noted. Wall openings and ventilations were measured, observed and sketched.

The data of annual regional weather conditions were taken from the websites of BMKG and NASA.

4. RESULTS AND DISCUSSION

The climate of Banten Province, Indonesia is warm and humid climate. The average air temperature around surveyed building was in the range between 23-37°C and the relative humidity was in between 60-80%. The wind speed measured in 1 meter height was 2.8 m/s in average. The building is located in the industrial estate which may affect the microclimate of the building. There is green zone around the building. The green zone influences the microclimate. It can reduce temperature of air temperature up to 5 ^{0}C [21]. The comfortable wind speed for human is between 2.5 – 3.0 m/s [22]. However, it is difficult to be achieved in the industrial complex, because the green zone available is usually not enough and distances between buildings are very closed each other.

In this research, the surveyed building was surrounded by other buildings except in the western part. It means that the external wind flow from ambient entering the building was very limited. The measurement during survey confirmed that the external wind flow entering the building was very small in all areas except west side. The wall façade of front view of the building used roaster cement-based material which was used together with glass with steel frame in the bottom.

In general, the standard comfort zone for workers in Indonesian in general are shown in Figure 2. Figure 2 also shows the original condition of the surveyed building was far outside the comfortable zone even though a lot of fans both wall fans and internal fans installed and operated. Figure 3 illustrates the layout of building utilization and primary wall fan positions and directions. The height of fans was approximately 3.4 meters above the floor in average. Besides primary fans illustrated in Figure 3, there were also plenty of small fans installed near to each worker working table. The wind flow direction was be analyzed by using OpenFOAM, Computational Fluid Dynamic which is an open-source software. It was tested with various scenarios to find the best fan flow direction.

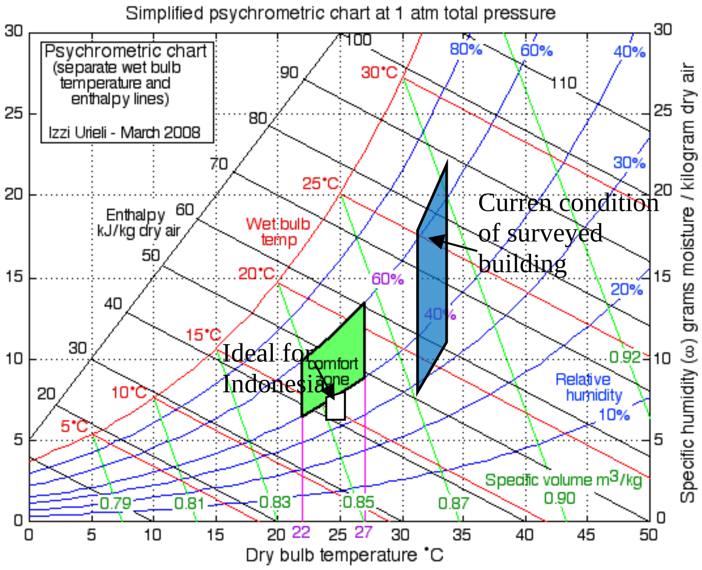

Figure 2. Comparison ideal comfort zone and the condition of the studied building.

The measurement of wind direction and speed shows that fan arrangement at Figure 3 resulted in chaotic wind direction and some places wind directions cancel each other which resulted in no air movement at those places. Outlet flow through ventilations was not well defined and was not strong enough. It tended to keep the warmed air circulating inside the building and rise the temperature inside the building. The speed of wind flow (air movement) 0.33 m/s is far slower than the designated fans, more than 2 m/s. The relative humidity inside the building was higher than that of outside the building. The temperature inside the building was staggered up to 33 ^{0}C. These results strongly indicate that the thermal condition in the building was unfavorable for the workers.

Fluid dynamics models were developed by using CFD software. The model as shown in Figure 4 was developed as close as possible to the actual surveyed building. For the first case, simulation parameters were based on the original fan configuration as seen in Figures 3. Then, the simulation result was compared to air direction and air movement measurements. Other variables such as number of people, machineries and lighting were neglected. Also, the ambient wind was assumed to be less significant compared to the fan blows. Therefore, zero ambient wind was considered in the simulation. This situation is also the worst condition of the air circulation inside the building. Any ambient wind should improve the air circulation from what is simulated here.

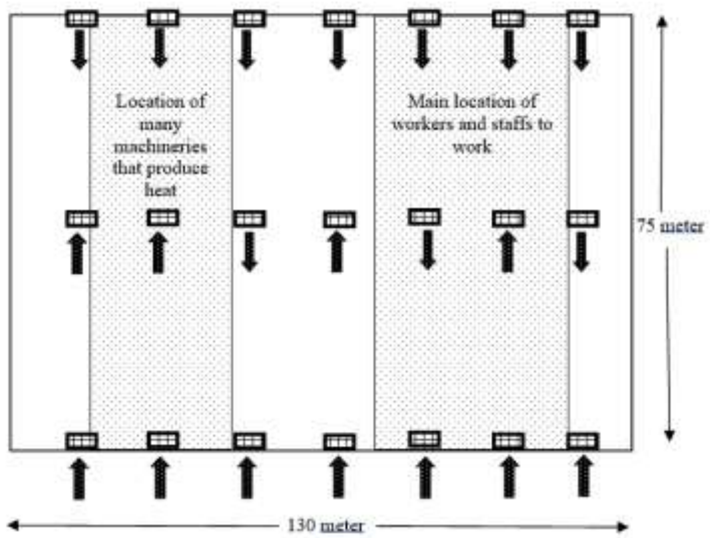

Figure 3. Sketch of space utilization with big primary fans and their directions in the surveyed production room/building.

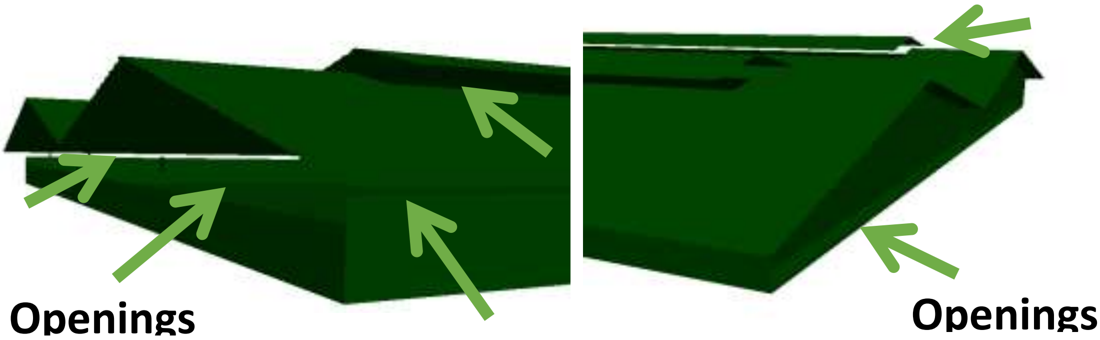

Figure 4. Simulation model.

Figure 4. shows the simulation result of air circulation inside the building with the original fan configurations. Wind directions from the simulation in the Figure 5 at some points were compared to wind measurement results. From the comparisons, it can be concluded:

- Wind directions inside the building were very irregular.
- By comparing the wind direction at some points, it shows that CFD simulation gives reasonable approximation to the measurement results. It proves that the model is reasonable.
- The building did not have a clear flow outlet. It can indicate the air inside the building just circulate inside the building.
- Hot air from the heaters inside the building could be recirculated inside the building.
- Some areas had almost zero wind speed. It may be caused by the wind forces cancel each other at those areas.

In order to solve the chaotic condition of the wind directions shown in the Figure 5, it is proposed to rearrange the existing fan arrangement. There are two simulated scenarios of fan arrangement, called Scenario 1 and Scenario 2, reported here.

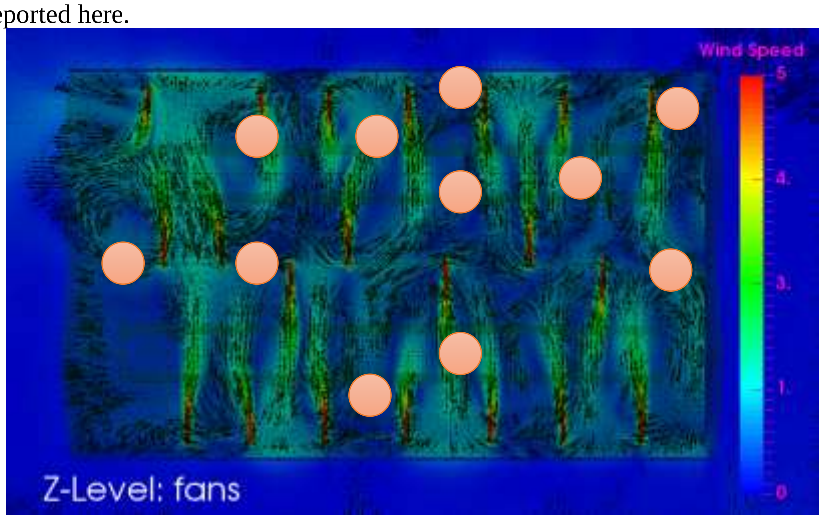

Figure 5. Simulated wind flow with existing fan arrangement compared to wind direction measurements

For scenario 1, the proposed fan arrangement and direction are depicted in Figure 6. It is expected that this arrangement will push air from one end to the other end of the building. It will provide good air exchange and air movement (wind) inside the building. The arrangement in Figure 6 will provide the direction of the flow inside the building to remove the heated air from the heat sources to escape from the building trough outlet as quickly as possible so that the machines, particularly the main heat sources, will not heat up the room. The Scenario 1 requires 21 fans. Since the original arrangement was using also 21 fans, it means that there would be no investment cost to apply Scenario 1. Three fans are placed at the intake side and other 3 fans are also placed at the outflow side. Other 3 columns also use 3 fans each, except the column in the area around heat source machines which are occupied by 6 fans. The fans are not arranged in one line but the direction of all fans is the same which hopefully will cause more efficient wind force.

The simulation result for scenario 1 in the Figure 7 shows that the wind direction becomes clearly one direction. The wind flow is well defined and strong at the intake and outlet. It can be seen that the consecutive fans support one another, so that it will create constructive force. It is expected that the proposed arrangement will result in more comfortable thermal working condition as compared to the existing fan configuration because the wind flow will force out the heat inside building to outside and the workers will feel the wind blow. Because a fan is not a cooling system, the fan itself cannot help to reduce room air temperature below ambient air temperature. However, the wind blow will help to reduce temperature sensation on the human. If a person feels wind blow about 3 – 5 m/s, the temperature sensation on that person will be lower 2 – 3 °C below the real air temperature [18].

For the scenario 2, the fan arrangement and direction are depicted in Figure 8. It is expected that the proposed fan arrangement will push air from one end to the other end of the building, even more effectively than the Scenario 1 due to stronger inlets with 5 fans and stronger outlets with also 5 fans. Like scenario 1, the proposed arrangement in Scenario 2 also places the main heat source machines near to the outlet flow of the wind so that the machines will not heat the building.

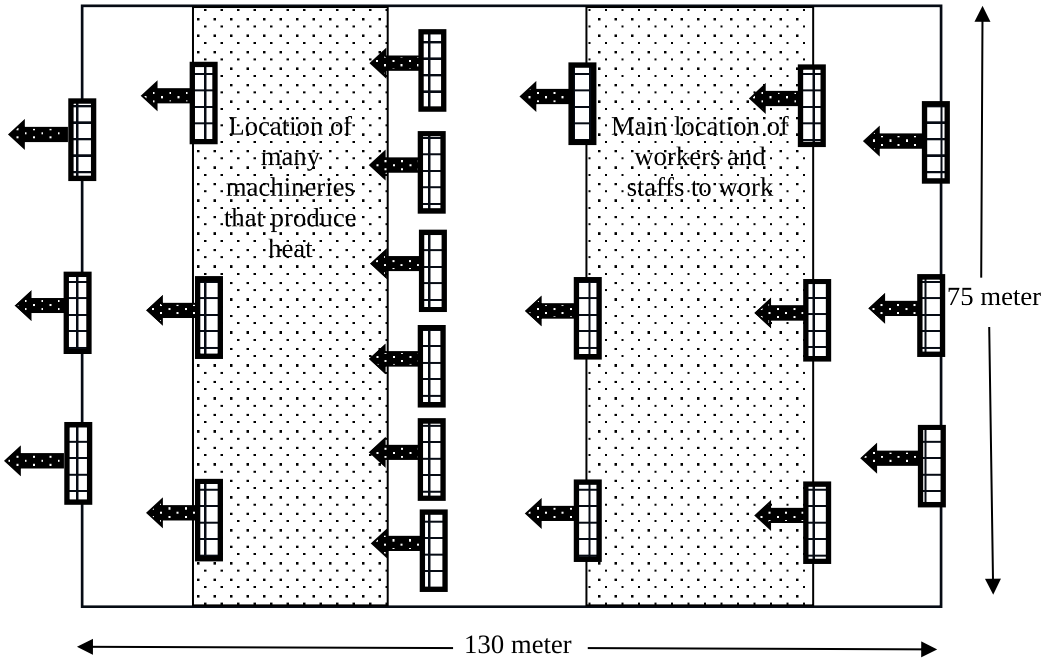

Figure 6. Sketch of space utilization with big primary fans and their directions in the surveyed production room/building based on Scenario 1.

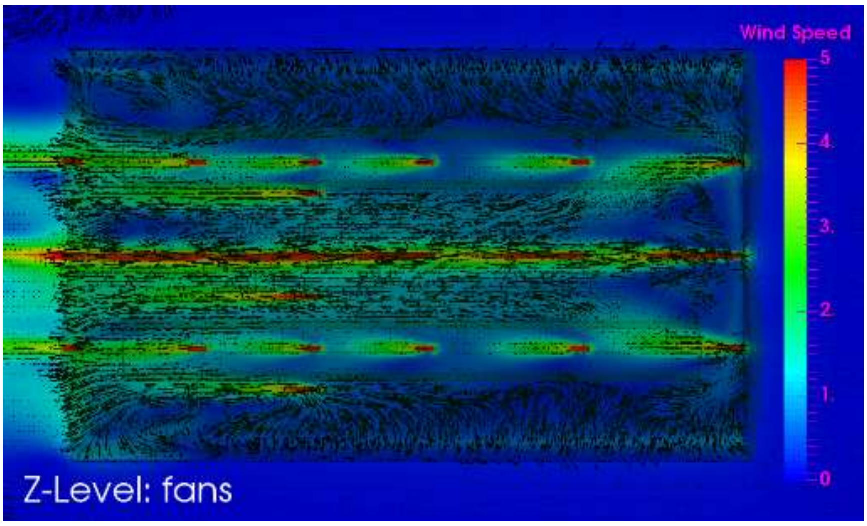

Figure 7. The simulated result of wind direction and speed based on fan arrangement in Figure 6.

Scenario 2 used 22 fans instead, so that Scenario 2 would need one additional fan. Different from Scenario 1, in the Scenario 2, the intake and outflow sides are occupied by 5 fans each, while 4 columns in between are occupied by 3 fans each and they are in-line to each other. It is expected that Scenario 2 with 5 fans each at the intake and outlet will provide more ARH (air exchange rate per hour) compared to Scenario 1. The simulation result for Scenario 2 in Figure 9 shows less air recirculation as compared to Scenario 1. It means that it will result in more comfortable room and better temperature sensation with small investment.

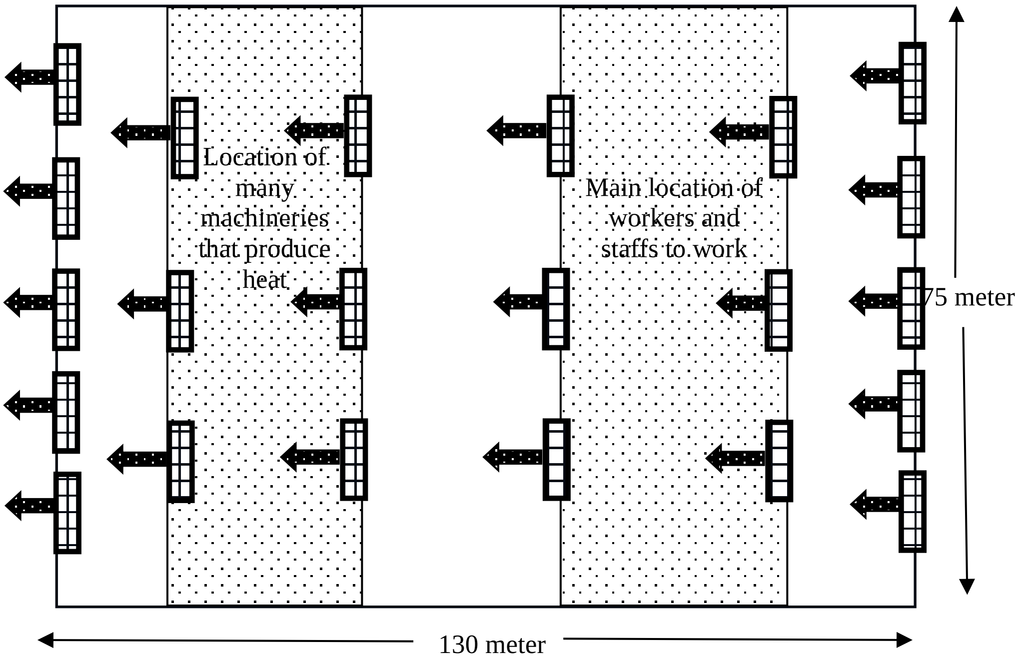

Figure 8. Sketch of space utilization with big primary fans and their directions in the surveyed production room/building based on Scenario 2.

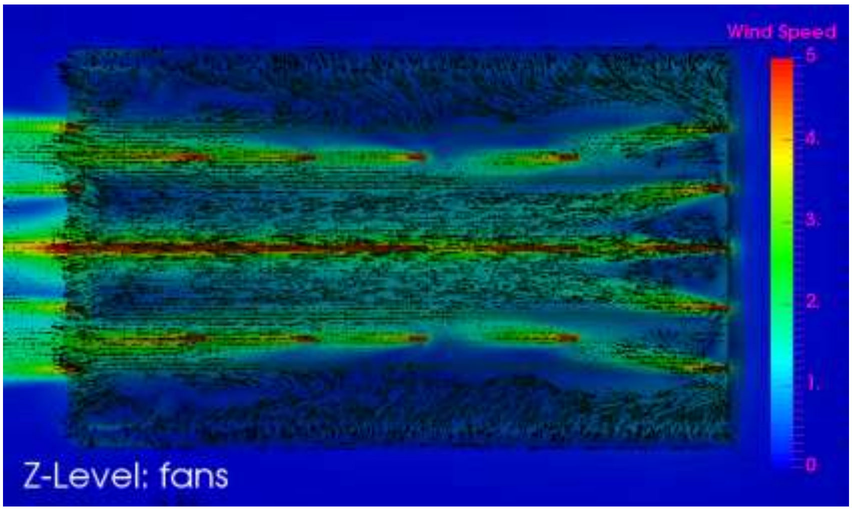

Figure 9. The simulated result of wind direction and speed based on fan arrangement in Figure 8.

The simulation result in the Figure 9 clearly shows that wind direction of Scenario 2 becomes one direction. The wind flow is better defined and stronger at the intake and outlet as compared to Scenario 1. It is clearly shown that the consecutive fans support one another better so that it creates stronger constructive force. Based on simulation, side openings also provide additional inlets. Hence, it is expected that the proposed arrangement in Scenario 2 will result in more comfortable thermal working condition as compared to original condition and Scenario 1 because the wind flow forces out the heat inside building to outside more efficiently and the workers will feel better wind blow creating lower temperature sensation.

Both Scenario 1 and Scenario 2 show that side openings become effective inlets to the building. Simulations for Scenario 1 and Scenario 2 used the worst-case scenario with no ambient wind. If there is ambient wind, the building air circulation will be most likely better. Both Scenario 1 and Scenario 2 will result in the air room temperature inside the building similar to the temperature of microclimate air because these fan configurations avoid heated up air trapped (recirculation) inside the building. At the same time, the temperature sensation felt by workers inside the building is about 1 – 2 ^{0}C lower than the real air temperature because there is air movement (wind) inside the building about 3 – 5 m/s.

5. CONCLUSION

The space in a production building is commonly very big so it is costly to install and to run air conditioners to make air temperature convenient for workers. Hence, many factories applied fans to improve the comfort of space in production buildings. However, the arrangement of fans must be designed carefully. Otherwise, installing fans may not improve the condition or it even can worsen the condition. Wrong fan arrangement may trap the heated air recirculating inside the building, or air movement directions cancel each other. Fans must be arranged to make the fresh air flowing from outside to enter the building through ventilation or inlet fans and then exiting the building through the ventilation or exhaust fans. So, the arrangement of the fans must not make the air being recirculated and heated up.

A Fan is not a cooling system so the fan itself cannot help to reduce room air temperature below ambient air temperature. It only makes the air to move. However, the air movement will make temperature sensation felt by people down 1 – 2 ^{0}C. A fan can only help to reduce sensation temperature by blowing the air on human skin. Therefore, proper fan arrangement will make the temperature of air inside the building not hotter than outside the building and temperature felt by people lower about 2 ^{0}C than the outside air temperature. The direction of air movement due to fans can be simulated using CFD as a pre-assessment tool.

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