

THERMAL COMFORT STUDY IN CONVERTING PROCESS OF PLASTICS MANUFACTURING INDUSTRY

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ABSTRACT

Thermal comfort is one of environment factors that can have a significant impact on workers performance. For a better thermal comfort, several factors that affect thermal conditions should be considered. Air temperature is a factor that give significant effect on thermal conditions. This paper is study about thermal comfort in a building for converting process at plastics manufacturing industry located in Malang. During the day, temperature on that building can reach as high as 36 °C. CFD (Computational Fluid Dynamics) simulations is use to determine the air properties inside the building. Thermal comfort experienced by workers through this study was based on PMV (Predicted Mean Vote) model and PPD (Predicted Percentage of Dissatisfied) model. The result of this study shows that thermal comfort in building of converting process can be increased by reduced heat sources on that building. Thermal comfort can be said increased when PMV and PPD value are decreased. After improvement recommendations is given, the PMV value for existing conditions in range 1.83 to 2.82 is decreased into range 1.63 to 2.18, while the PPD value for existing conditions in range 68.9% to 98% is decreased into range 58.2% to 84.2%.

Keywords: Thermal Comfort, Plastics Manufacturing, CFD, PMV, PPD

1. INTRODUCTION

Physical environmental conditions is one of some factors that can give a major influence on human performances. Although the human body has adaptive physiological mechanism that allow us to tolerate a range of physical environmental conditions, but it isoften at a cost to the body (Stanton et. al, 2005). When physical environmental conditions give impact to human body, it also can affect human

performance. To avoid that conditions, it is necessary to adjust physical environmental conditions with the type of work performed by human. If physical environmental conditions match with the type of work performed, human performance will be stable or even increase.

As one of physical environmental conditions, thermal can have significant impact to human performance. Thermal comfort can be define as a condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation (Ashrae, 2004). Several factors that affect thermal conditions include humidity, air velocity, and temperature. If environment temperature is too high, heat disorders like heat stroke, heat exhaustion, heat syncope, and heat rash may occur (Osha, 2012).

This study is taking place on one of plastics manufacturing company that mainly produce blown plastic film. There are three main processes in order to produce blown plastic film, namely extrusion, printing, and converting. In the extrusion process, plastic resin is melted and converted into plastic sheet that called blown plastic film. Furthermore, the blown plastic film will be given a pattern image on a printing process. In the final process, blown plastic film rolls will be cut to the desired shape and packaged. This study focused on converting process on a building that called Building G. Although inside Building Ghave 14 air ventilator that arranged lengthwise, but the temperature inside that building is still quite high. Temperature inside the building can reach 36 °C during the day, where it is already exceeding the threshold value determined by the Minister of Manpower and Transmigration Republic of Indonesia that is 32.2 °C (Menteri Tenaga Kerja dan Transmigrasi Republik Indonesia, 2011.) That condition would make the workers feel the impact of converting part due to heat exposure.

Results of preliminary observations indicate that the effects due to heat exposure felt by worker in converting process decrease the performance of workers and increasing the mistakes made by workers. Based on the results of preliminary observations, further research on thermal comfort experienced by workers in the converting process and prevention efforts are needed. There are several methods that can be used to analyze the thermal comfort, some of which are Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). PMV is able to predict the heat sensation perceived by the human metabolic rate, clothing insulation, as well as pay attention to four environmental parameters, namely air temperature, mean radiant temperature, air velocity, and relative humidity. PMV index can be calculated when the metabolic rate and clothing insulation can be estimated, and environmental parameters include air temperature, mean radiant temperature, air velocity relative, and the relative humidity can be calculated (ISO, 1994). While PPD is a derivative of the PMV index is used to determine the percentage of a person's discomfort against the thermal environment. After knowing the value of PMV and PPD workers in the converting, can further efforts to improve the thermal comfort improvements with the help of Computational Fluid Dynamics (CFD) simulation (Chung, 2002)

Efforts that can be done to improve the thermal comfort is to perform the engineering control at the building site of the converting process. CFD simulation can help identify the flow of fluid inside the building to obtain the areas that need improvement. After simulating recommendation conditions, recalculation of thermal comfort felt by workers will be made. Thermal comfort index PMV is said to increase when approaching the number 0 and the value of PPD close to the value of 5%. When the thermal comfort of workers in the converting increase, labor productivity in the converting process will be increase.

2. RESEARCH METHOD

In order to calculate thermal comfort experienced by workers, CFD simulation for existing conditions are made. Before starting

CFD simulation, the entire machinery and equipment located in Building G depicted in the form of 3D CAD models. There are 22 DB machines, 10 tables for plastic sheet recount, 5 punch machines, 5 press machines, 12 tables for packaging process, 5 SHF machines, 4 tables for finished good, 16 COSMO machines, and 14 air ventilator in Building G. Making 3D CAD machinery and equipment in Building G conducted using statistical software SolidWork 2014. After making a 3D CAD model of each machine and equipment in Building G, the next step is to perform the assembly process. Assembly process or the preparation is done to adjust the layout of 3D CAD models according to the original layout of Building G. Results of Building G assembly process can be seen in Figure 1. Building G 3D CAD models that have been made are used for CFD simulations. In general, CFD calculation process consists of three main parts: the preprocessor, processor and post-processor.

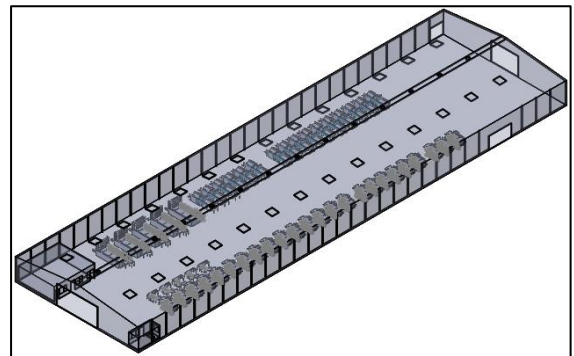


Figure 1. 3D model of Building G

Preprocessor phase starts with the initial setting of the general settings. Analysis used is a type of internal analysis. Consideration of the earth's gravity based on the Y axis from 3D CAD models. Fluids or type of fluid being analyzed is the air with laminar and turbulent flow type. In this study, humidity are also taken into calculation. Wall conditions or the condition of the walls of selected types of adiabatic wall or walls that can not transfer heat and air from both sides. Initial conditions or initial conditions of the simulation environment regulated by the state of thermodynamic parameters at a pressure of 1 atm and a temperature of 30 °C. Humidity is set in the condition of 80%.

The next process is defining boundary conditions of Building G. It will be defined on

the boundary conditions include the air inlet path and the air outlet path in Building G. The boundary conditions at the entrance and exit of air in the building G, as follows:

1. Inlet velocity 0.121 m/s, 28 °C, with 70% relative humidity from front door
2. Inlet velocity 0.007 m/s, 34 °C, with 50% relative humidity from right door
3. Inlet velocity 0.064 m/s, 28 °C, with 70% relative humidity from left door
4. Inlet velocity 0.013 m/s, 33 °C, with 52% relative humidity from rear door
5. Outlet volume flow 680,400 cm³/s from each air ventilator

After defining boundary conditions, the process is done next is to defining a heat source that is in Building G. The rate of heat transfer of each heat source is expressed in watts. There are five heat sources in Building G, including the following:

1. Heat power of 1800 W of each DB machine
2. Heat power of 7000 W of each press machine
3. Heat power of 800 W of each SHF machine
4. Heat power of 5100 W of each COSMO machine
5. Heat power of 491348.7 W of sunlight through each glass on Building G roof

The next stage after the preprocessor is to stage the processor. At this stage it will be running CFD simulations based on models that have been created. Running the model Building G is performed based on the input that has previously been defined at this stage of the preprocessor.

3. RESULT AND DISCUSSION

3.1. Thermal Comfort Calculation of Existing Conditions

Interpretation of CFD simulation in this study is described by a plot or cut pieces of a flat surface. Cut plot that used a cut plot with a height of 1.5 meters from the Y-axis or as high as the human respiratory area. Figure 2, 3, and 4 show the results of the post-stage processor existing condition Building G.

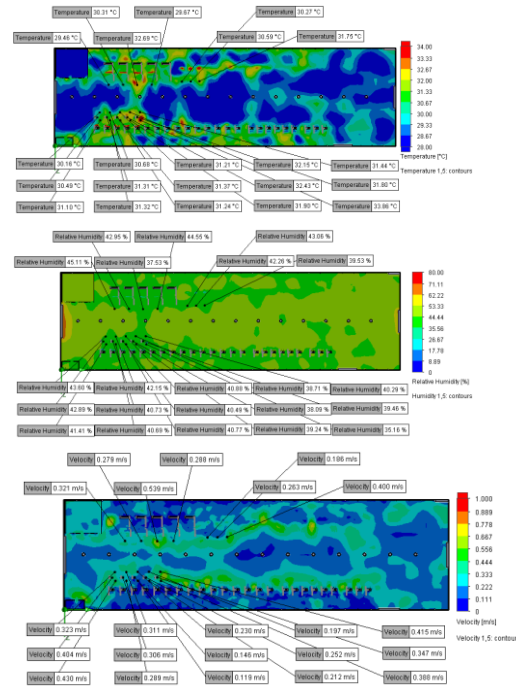


Figure 2. (a) Temperature, (b) relative humidity, and (c) air velocity distribution of existing conditions

Thermal comfort of workers in converting process is assessed using Predicted Mean Vote (PMV) index. First step taken for the assessment of PMV index is to assess the clothing insulation and metabolic rate workers. Clothing insulation of workers is based on any item of clothing used by workers and metabolic rate of workers based on activities performed by workers. Result of observations show that worker's clothing insulation value is 0.42 clo. Workers metabolic rate value are 2.1 met for workers performing packing activities and 2.4 met for workers that operating machine. After assessing the clothing insulation and metabolic rate workers, the next step is to enter the value of clothing insulation, metabolic rate, and environmental data obtained from CFD simulation results into the equation PMV and PPD. temperature at a height of 1.5 meters in Building G. The distribution of temperature shown is in the range of dark blue for temperature 28 °C until the red color to the temperature 34 °C. From Figure 2 the distribution of temperature in the area below the glass ceiling is at Building G has a high enough temperature distribution. The location of workers with the lowest temperature is 16th worker's location with a temperature of 29.46 °C. While the worker's

location with the highest temperature is 13th worker's location with a temperature of 33.86 °C. Figure 2 (b) shows the distribution of relative humidity at a height of 1.5 meters in Building G. The distribution of relative humidity are shown in dark blue color range for relative humidity of 0% to red to 80% relative humidity. From Figure 3 it can be seen that the location of the worker with the lowest relative humidity is 13th worker locations with relative humidity of 35.16%. While the location of the worker with the highest relative humidity is 16th worker locations with relative humidity of 45.11%. Figure 2 (c) shows the distribution of air velocity at a height of 1.5 meters in Building G. The distribution of air velocity is displayed in the range of dark blue air velocity of 0 m/s up to a red color to the air velocity of 1 m/s. From Figure 4 it can be seen that the location of the worker with the lowest air velocity is the location of 8th workers with a air velocity of 0.146 m/s. While the location of the worker with the highest air velocity is the location of 18th workers with air velocity of 0.539 m/s.

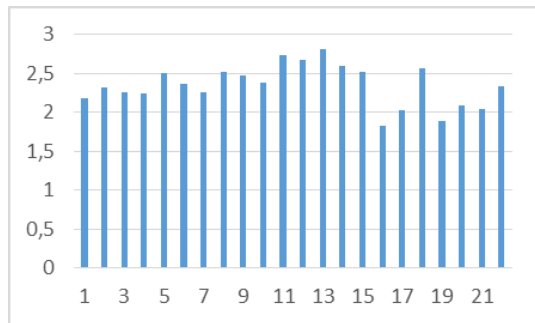


Figure 3. PMV value of existing conditions

Figure 3 shows that the highest PMV value perceived by 13th worker that has value of 2.82. When viewed as a whole, based on Figure 5 the PMV value is range between 1.83 to 2.82. This means that thermal sensations experienced by workers is vary from slightly warm to warm.

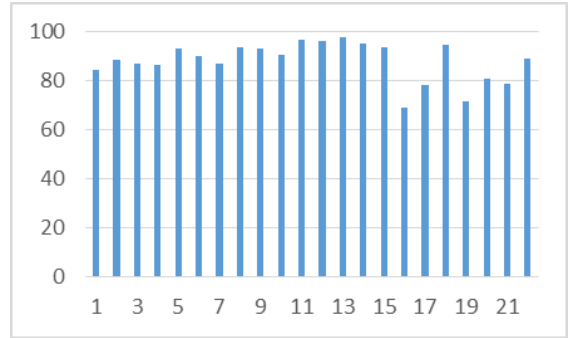
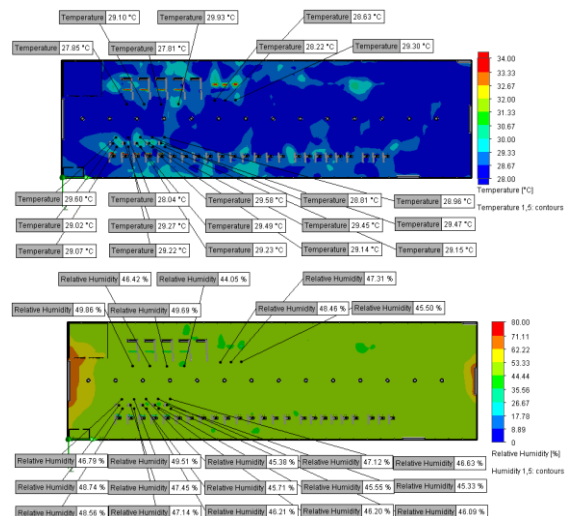


Figure 4. PPD value of existing conditions

Figure 4 shows that PPD value is range between 68.9% to 98%. This means that less than 2% of worker in Building G will be thermally satisfied.

3.2. Thermal Comfort Calculation of Modification Conditions

The main factors that contributing high value of PMV experienced by workers at converting process is the high value of air temperature. High temperature value was in the area below the glass ceiling is in Building G. In the study conducted by Chaiyapinunt et. al. (2004), the heat caused by the intensity of solar radiation entering through the glass can be reduced by changing the type of glass used as a medium of solar radiation into a room. Based on this, the making recommendations for improve-ments in this research is done by changing the type of glass ceiling in Building G.



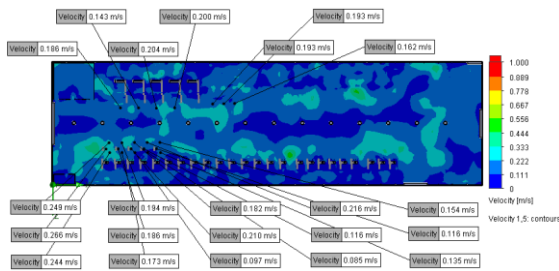


Figure 5. (a) Temperature, (b) relative humidity, and (c) air velocity distribution of recommendation

Figure 5 (a) shows the distribution of temperature at a height of 1.5 meters in Building G after improvement recommendation are given. The location of workers with the lowest temperature is 18th worker's location with a temperature of 27.81 °C. While the worker's location with the highest temperature is 19th worker's location with a temperature of 29.93 °C. The highest temperature values on the simulation results show a decrease of about 4 °C than the highest temperature values in existing models. Figure 5 (b) shows the distribution of relative humidity at a height of 1.5 meters in Building G after improvement recommendation are given. From Figure 8 it can be seen that the location of the worker with the lowest relative humidity is 19th worker locations with relative humidity of 44.05%. While the location of the worker with the highest relative humidity is 16th worker locations with relative humidity of 49.86%. Figure 5 (c) shows the distribution of air velocity at a height of 1.5 meters in Building G after improvement recommendation are given. From Figure 5 (c) it can be seen that the location of the worker with the lowest air velocity is the location of 7th workers with a air velocity of 0.097 m/s. While the location of the worker with the highest air velocity is the location of 2th workers with air velocity of 0.266 m/s.

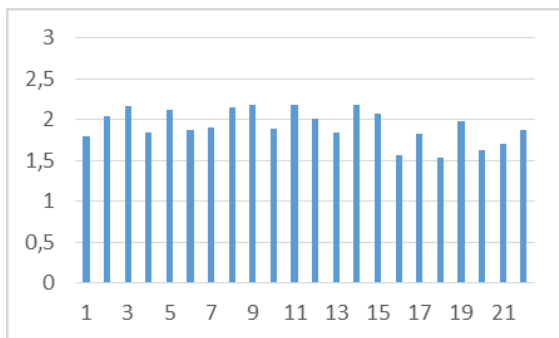


Figure 6. PMV value of existing conditions

Figure 6 shows that the highest PMV value perceived by 9th worker that has value of 2.18. When viewed as a whole, based on Figure 5 the PMV value is range between 1.63 to 2.18. This means that the highest PMV values on the simulation results show a decrease of about 0.64 point than the highest PMV values in existing models.

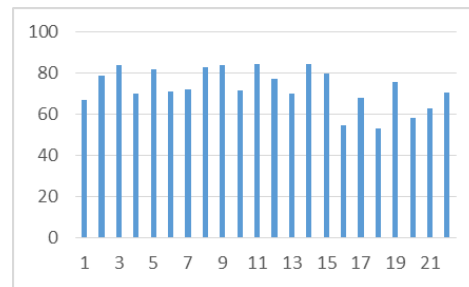


Figure 7. PPD value of existing conditions

Figure 7 shows that PPD value is range between 58.2% to 84.2%. This means that less than 15% of worker in Building G will be thermally satisfied and it shows 13.8% increasement from existing models.

4. CONCLUSION

Thermal comfort of workers in the converting process calculated based on the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). The calculations show that the highest value is perceived by 13th worker who had PMV value of 2.82. These values indicate that the thermal sensation felt by 13th worker is hot. While the lowest value perceived by 16th worker who had PMV value of 1.83. These values indicate that the thermal sensation perceived 16th worker is warm. The PPD calculations show that the level of inconvenience for workers that are in the value range of 68.9% to 98%. The location of worker who feel most comfortable is the 16th worker, while workers who feel most uncomfortable is 13th worker. Thermal comfort of workers in the converting process calculated based on the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). The calculations show that the highest value is perceived by 13th worker who had PMV value of 2.82. These values indicate that the thermal sensation felt by 13th worker is hot. While the

lowest value perceived by 16th worker who had PMV value of 1.83. These values indicate that the thermal sensation perceived 16th worker is warm. The PPD calculations show that the level of inconvenience for workers that are in the value range of 68.9% to 98%. The location of worker who feel most comfortable is the 16th worker, while workers who feel most uncomfortable is 13th worker.

Improvement recommendations are given because air temperature Building G has a high enough value on certain areas within the building. The recommendation is to replace the existing type of glass ceiling in that building which was originally a clear replaced with a reflective clear glass. With the change given, impaired PMV and PPD mostly workers at the converting at 19th worker increased value of PMV and PPD due to the increasing value of relative humidity. But the change is not significant and does not increase the thermal comfort experienced by 19th worker. All the workers PMV value calculated after repair shows the value <2.5, it indicates that all workers feel the sensation of warm.

5. REFERENCES

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