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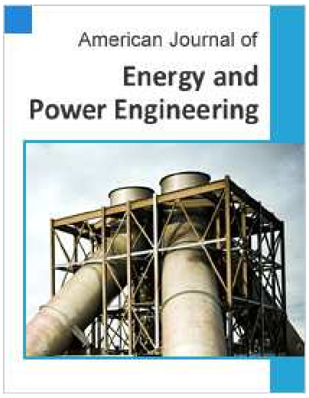

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Combined Ventilation Methods in a Large Scale Warehouse Building to Reduce Indoor Air Temperature

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Abstract
In current warehouse without proper air ventilation is causing the congregation of high humidity and high temperature indoor air which leads to health hazards for occupants in the warehouse building located in Sepang, Malaysia. Proposal offered involves economic and effective solutions targeted to reduce the temperature and humidity of the indoor air. The solutions involved installation of wind driven turbine and increase the openings of warehouse's front and rear walls. The installation of wind driven turbine works based of Bernoulli's principle and stack ventilation, while the increase of opening of warehouse's both directions of walls enable outdoor air enter the building from windward and leeward direction. Overall, the solutions shall improve the human comfort with an expected of at most 4°C temperature drop within the warehouse.

1. Introduction

As the warehouse has minimal air inlets and the roof of the warehouse is heavily insulated, the presence of heat and high humidity is easily sensed in the warehouse compound. The heat gained from Morning to Evening is due to radiation on the roof, human activity and machineries. Such heat gain results in approximately 30-33°C of indoor dry bulb temperature, which is causing the deterioration of human comfort within the warehouse. According to the thermal assessment research by [1, 2], the indicators for thermal comfort are air temperature, air velocity, mean radiant temperature, relative humidity, clothing thermal resistance as well as metabolic rate depending on the settlers as well as the surroundings.

In terms of insulation, the walls of the warehouse consisted partially of grills insulated with nets layer which serves as insulation on the walls, moreover, the roof is insulated with insulation blanket which traps the heat within the building. Next, the mechanical ventilation system within the building is designed in a bizarre manner where the intake air inlet is installed in the rear end of the warehouse within the building. Thus, the amount of fresh air intake from outdoor into the warehouse is very minimal. As the air exchange between the warehouse's indoor air and outdoor air is targeted to be lower dry bulb temperature into the warehouse thus to reduce the indoor temperature. [3] found that the wind driven turbine ventilators work in two modes. [4] crosswind ventilation requires outdoor wind travels into the building. [5] stated that external wind force is not affected by indoor partitions. [6] stated that pressure difference works effectively with buildings that have high area of air inlet, thus, exceeds the resistance of cross ventilation within a building; similarly for the location or placement of the opening inlets and outlets, depending on the designed sizes as stated by [7]. [8] stated that the major factors that improve the wind driven turbine ventilators are the diameter of the turbine and the blade height. The longer taller the blade and larger the diameter of the turbine improves the air flow rate. [9] found that comfort level increased with the presence of rooftop ventilator which is simulated using CFD. [10] found that the size of the wind driven turbine ventilators affects the air flow rate, bigger turbine will draw more air with higher air flow rate. However, the difference between the air flow rates of different sizes is insignificant. According to [11] displacement ventilation increases the ventilation effectiveness when there is drop in difference between indoor and outdoor air temperature which is opposite from mechanical ventilation, which requires high temperature difference between indoor and outdoor air. [12] states that wind driven turbine ventilation is highly dependent on the wind's pattern and stack ventilation depends on the pressure difference in terms of vertical direction. [13] discovers that the rotational speed of the wind driven turbine ventilators is driven by the wind speed. Figures 1, 2 and 3 show the current condition of the warehouse by using different technique of ventilation.

Figure 1. *Insulation on Air Grills.*

Figure 2. *Mechanical Ventilation Return Air intake.*

Figure 3. *Air Vents are too Far from the Floors.*

2. Methodology

2.1. Wind Driven Turbine Ventilators

The first suggested proposal is to install the win driven turbine ventilators on top of the rooftop of the warehouse. The wind driven turbine ventilators are made to work in two modes. The first mode requires wind blows towards the turbine on the rooftop where the spinning of the turbine while create more negative pressure from the warehouse indoor chamber to the outdoor air via Bernoulli's principle. Next, the turbine is able to draw air out from the warehouse without any wind via stack ventilation. As observed in Figures 4 and 5 shows the mechanism of wind driven turbine ventilators via Bernoulli's principle.As according to Bernoulli's principle, the changes in velocity of fluids between two points do affect the pressure difference between two points as well. Such pressure differences allow hot air to escape via the turbine ventilator (red arrow represents the hot air channeled out from the warehouse)

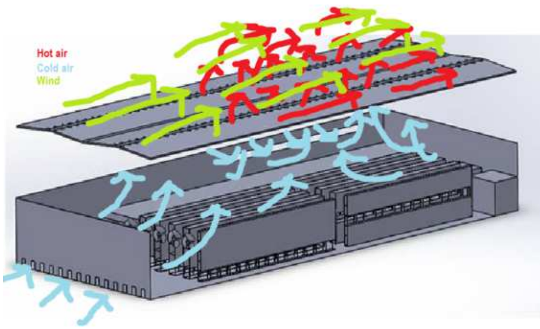

Figure 4. *Mechanism of the Wind Driven.*

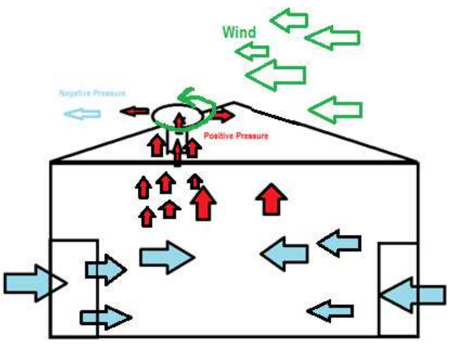

Figure 5. *Air Flow With Wind Turbine Ventilator.*

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} + Z_1 g = \frac{P_2}{\rho} + \frac{V_2^2}{2} + Z_2 g$$

Bernoulli's equation:

P_1 = Pressure at point 1, P_2 = Pressure at point 2, V_1 = Velocity at point 1

V_2 = Velocity at point 2, Z_1= elevation at point 1, Z_2 = elevation at point 2

Next, the turbines will remove the heat from the warehouse via stack ventilation effect as shown in Figures 6 and 7, where hot air inside the warehouse with lower density will rise up to the roof and escape the warehouse via the turbines outlets. As the hot air is removed, outdoor air will be draw into the warehouse via negative pressure generated by the removal of the hot air.

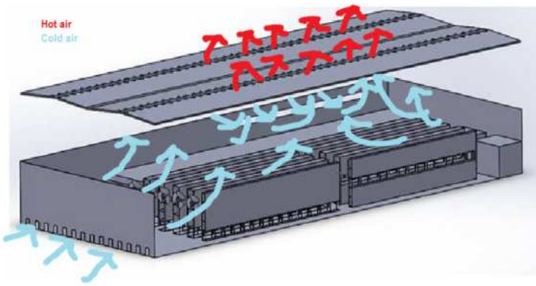

Figure 6. *Mechanism of Wind Driven.*

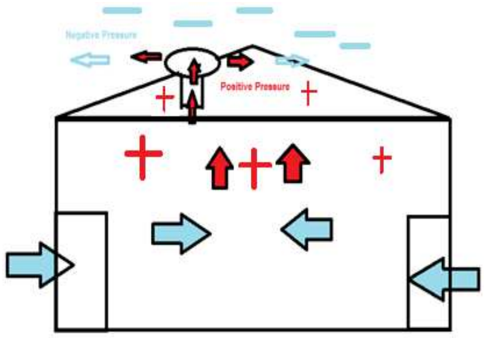

Figure 7. *Air Flow without Wind Turbine Ventilator.*

As the turbine will draw the hot air out from the building using only wind energy, thus no electricity is required to cool down the indoor dry bulb temperature.

2.2. Crosswind Ventilation

The second proposed idea is to create air opening in the front and rear side on the warehouse. This can be accomplished by increasing the inlets' size and quantity (shutter doors and windows) for the air entrance from the windward (front) and leeward (rear) sides of the warehouse allows winds to infiltrate the warehouse from windward and leeward direction of the building. In this solution, where the heat in the warehouse can be removed effective from both sides of the building thus prevent heat builds up at either corner of the building. As crosswind ventilation requires outdoor wind travels into the building and this is a highly economical ventilation solution which does not require any mechanical ventilation equipments. With addition crosswind ventilation shall improve the rate of outdoor air intake, as the area of the inlet from the front and rear side of the building is increased, the ventilation rate can be increased as,

Ventilation rate, $Q = CdA\sqrt{\frac{2\Delta P}{\rho}}$

Where A is the area of the inlet, while ΔP is the pressure difference between outdoor air pressure and indoor air pressure.The pressure difference will cause the indoor air to exit the warehouse via the wind driven turbine ventilators.

The higher the ventilation rate of outdoor air intake, the more hot air can be removed from the building. Thus, with the combination of wind driven turbine ventilators serve as exits for hot air and the wind driven ventilation shall serve as entrance for lower dry bulb temperature of outdoor air, shall result in a drop of indoor temperature depending on outdoor air's dry bulb temperature since the indoor air will be substituted by outdoor air via natural ventilation.

3. Expected Results

3.1. Drop in Indoor Air Dry Bulb Temperature

The result is fully based on assumption and is expected to achieve a maximum dry bulb temperature drop of 4°C, which is considered to be possible under the conditions that if the human occupancy is high, high usage of machineries and artificial lighting and high thermal radiation onto the roof, where these condition will cause extra temperature hike within the warehouse of more than 4°C compared to outdoor air's dry bulb temperature. Due to high area of the warehouse, with an approximate area of 7000m², the high amount of heat absorbed by the roof with large area caused the temperature in the warehouse to increase during noon time. Thus, these heats which trapped in the warehouse are assumed to be possibly removed via the wind driven turbine ventilator. With increased ventilation rate, the trapped hot indoor air will escape from the warehouse and thus reduce the warehouse indoor dry bulb temperature.

3.2. Drop in Indoor Air Relative Humidity

With assumption that due to human occupancy, the indoor relative humidity is higher than outdoor relative humidity as there are minimal air intake from the outdoor. The average relative humidity in Sepang, Selangor is approximately 70%, the minimum relative humidity is 58% and the maximum relative humidity is 82%. As the similar concept in 3.1 mentioned on the ventilation rate Q, will replace the hot indoor air with colder outdoor air, as the warehouse has no consistent air exchange between indoor and outdoor, the humidity builds up in the building due to human occupancy. When the outdoor air enters the building which will displace the indoor air, the relative humidity drops according to the outdoor air relative humidity.

3.3. Increase in Human Comfort

With higher air effectiveness, more heat will removed from the building and more air pollutants will be displaced by fresh air due to pressure difference between the indoor and outdoor temperature. With much temperature drop of 4°C (depending on the outdoor air temperature, lower outdoor temperature implicates lower temperature within the indoor air) and removal of air pollutants caused by machineries and humans, will eventually leads to better human comfort thus create a more human friendly indoor air condition.

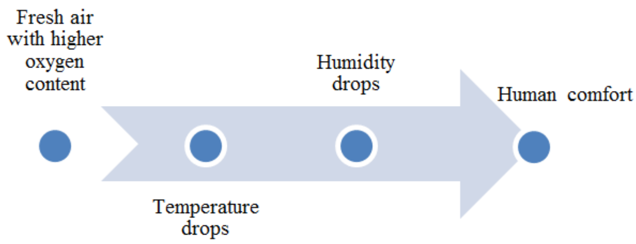

Figure 8. *Flowchart of Achieving Human Comfort in the Warehouse.*

4. Conclusion

As conclusion, the objectives of the research are aimed to improve human comfort in an enclosed warehouse with minimal cost was achieved. The proposed ideas are aimed to enhance human comfort or the workers comfort as the current temperature and humidity that inside the warehouse are way below standard comfort level due to minimal air exits in the warehouse, thus, such condition is physically taxing for the staffs to conduct tasks consistently in the warehouse. By introducing the proposed ideas, the ideal temperature and humidity achieved as shown in expected result are expected to be working effectively in terms of increasing the human comfort via reducing the indoor temperature and relative humidity in the warehouse. Despite, the results are expected to assist the warehouse to increase the human comfort with limited data, the indoor dry bulb temperature is expected to drop with magnitude of 4 °C from the dry bulb temperature during day time and night time. The reduction of indoor dry bulb temperature is effective during day time, as high amount of heats that are trapped in the warehouse can be remove with cooler air from outdoor with lower dry bulb temperature via natural ventilation methods. The proposals suggested are expected to be effective with the two combined natural ventilation methods with minimal installation and maintenance cost as the client prioritizes proposals that possess high effectiveness in improving the human comfort level with minimal cost. Moreover, the two natural ventilation methods do not require electric energy to sustain the heat removal process from the warehouse. Suchideas can be utilized as green technology to remove heat without contributing to the carbon footprint consistently.

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