ZERO WASTE AIR CONDITIONING FROM TRANSFORMATION OF WASTE MATERIAL

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Abstract

Reuse has become a popular approach in sustainable design as many reuse programs have evolved from solid waste reduction goals. Reuse requires fewer resources, less energy and less labor compared to recycling, disposal, or manufacture of new products from raw materials.

An experimental design method was used in this study to explore possibilities of waste material transformation into zero waste air conditioning to reduce carbon emission and house cooling cost. This was done by analyzing the principles of Venturi effect on different-sized used plastic bottles through manual effectiveness measurement.

The system works on the principle of passive cooling by induced ventilation caused by air velocity difference. The result shows that smallest inlet-outlet ratio of the used plastic bottles gave higher air velocity multiplication, which when utilized in house façade design, could provide natural ventilation through zero waste principles.

Keywords: plastic bottle, waste material, zero waste

1. Introduction

1.1 Plastic Waste

Indonesia is second only to China as the world's largest contributor of plastic pollution. 1.15 to 2.41 million tons of plastic waste contaminate the oceans each year, with Indonesia contributing roughly 200,000 tons from its rivers and streams (Borgen, 2018).

Plastic pollution is also a huge national nuisance. By 2019, the number of plastic pollution in Indonesia is expected to grow up to 9.52 million tons, which is about 14 percent of the country's total waste.

Plastic is easy to get, inexpensive, and can be used for almost everything. Therefore, people who like things easier tend to choose plastic for everyday use. However, we forget the harm plastic brings to the environment and health. Plastic contains an addictive substance called Bisphenol A (BPA) which causes cancer if it enters human body.

For centuries, plastic was considered as an unavoidable consequence of materialism which ended up being disposed. There is a need to close the material cycle loop by transforming plastic waste into material resource. (Fisher-Kowalski, 1998).

Architects and designers can take part to help reduce the amount of plastic waste, one of them by transforming and optimizing it in building designs.

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1.2 Physical Feature

From an architectural perspective, used plastic bottle could be seen as a potential matter to be explored into building designs. Due to its form, assessment of its passive cooling capability for natural ventilation could be done by the basis of Venturi effect principle.

1.3 Zero waste air conditioning

Humans need comfortable temperature to perform activities, which means a balanced heat transfer in the air. In our contemporary mechanized world, most heat in the air is removed using forced air cooled by refrigeration technology, which relies on compression refrigeration machinery and consumes a large amount of electrical energy. In fact, delivering plentiful fresh air into space with as little energy as possible is a complex and tricky endeavor. Therefore, control strategies are becoming more promising as an economical and efficient alternative method.

2. Methods

2.1. Experimental Methods

Experimental method was applied in this case throughout the usage of Venturi effect principle as assessment tool and repeated measurement testing. Venturi effect is an understanding on the physics of air flow which provided an equation between velocity and pressure. Hot wire anemometers were also utilized in this study for its ability to measure flow velocity of gases and inert liquids. Hot wire anemometers offer excellent spatial resolution with minimal flow disturbance, as well as excellent dynamic response to rapid changes in flow velocity.

Plastic bottle was used as the studied object for its compliance to Venturi effect principle. The main parameters for air flow measurement were air velocity and pressure, which relationship was explained in Bernoulli's equation is given by:

$$(P_1\text{-}P_2 = 1/2\rho(V_2^2\text{-}V_1^2)$$

$$\textit{and}\ \ A_1V_1 = A_2V_2$$

Therefore

$$A_2<A_1,\ V_2>V_1$$

$$V_2>V_1,\ P_2<P_1$$

Or

Decrease in area = increase in velocity

Increase in velocity = decrease in pressure

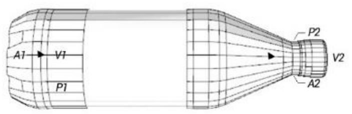

Fig.1 bottle description in formula

Where ρ is the density of the fluid, V_1 is the slower fluid velocity where the tube is wider, V_2 is the faster fluid velocity where the tube is narrower.

Differences in pressure occurs as fluid flows through the bottle, due to the fluid's expansion and compression. This principle can be used in metrology for gauges calibrated for differential in pressure's measurement.

2.2 Feasibility Study

In this paper, experimental wind tunnel study was carried out to measure the difference of air velocity in models with different inlet-outlet ratio. The Venturi effect principle stated that inside a specific flow region, a decrease in static pressure appeared when there was an increase in fluid velocity. In the region with smaller section area, airflow velocity would be higher along with lower static pressure, while in the region with greater section area, airflow velocity would be lower alongside higher static pressure.

2.3 Prototyping

Small-scale experiment were used in this study to model full-scale buildings; as these were more economical and required less space. The size of models in a small-scale experiment could range from 1/10 to 1/100 of the actual building or smaller. In general, the data collected was limited to a small number of measurements and was susceptible to errors. A particular source of error was the use of probes or other intrusive devices which could disrupt the flow patterns. The result also highly depended on the equipment's accuracy levels and measurements' repeatability.

Wind tunnel experiments were used to mimic air flow within a naturally ventilated building, with used plastic bottles acting as wind tunnels and were utilized in a building as secondary skin. The experiment would measure air flow and pressure distribution throughout the building, and whether the usage of plastic bottles were helpful in increasing airflow into the building. Such tests could be performed on a multitude of wind speeds, however the dynamics of an actual air flow were harder to assess than constant airflow employed in this paper.

In this prototype, 3 electric fans were used to pump pressured air for each model, with power draw performance of 12Voltage/14Ampere.

The wind tunnel setup was made from MDF fiber boards and acrylic, with 280mm length and 110mm height.

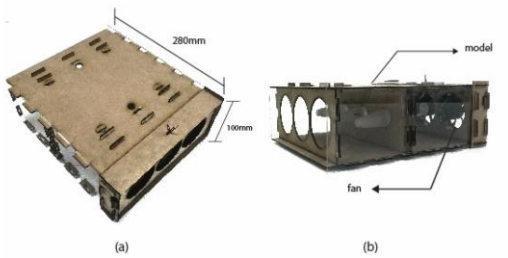

Fig.2 (a) wind tunnel dimension, (b) detail of wind tunnel

Several models with different inlet and outlet types were used in this study and would be assessed through its behavior as Venturi tubes. Type 1 was a glue bottle with 30mm inlet and 10mm outlet (Figure 3), Type 2 had 55mm inlet and outlet sizes (Figure 4), Type 3 was a water bottle with 55mm inlet and 25 mm outlet (Figure 5), and Type 4 was also a water bottle with 80mm inlet and 25mm outlet (Figure 6).

Fig.3. Type 1 (a) section (b) top view

Fig.4. Type 2 (a) section (b) top view

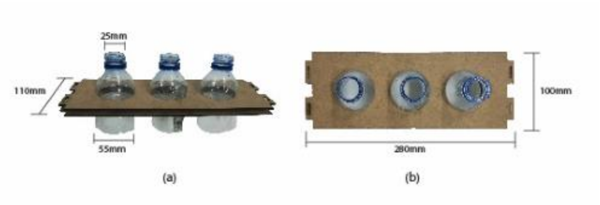

Fig.5. Type 3 (a) section (b) top view

Fig.6. Type 4 (a) section (b) top view

2.4 Measurement

Hot wire anemometer was utilized as the airflow speed measurement device in wind tunnels, as anemometer could detect physical property changes in the fluid or the fluid's impact on the mechanical device inserted in the flow.

A difficulty of wind tunnel testing was encountered during wind profile creation process, in which ambient air flow along the terrain which captured the boundary layer should be represented in the test environment.

There was also an issue during replication of turbulence scales in the wind tunnel. However, the use of a mechanism to trip the air flow helped facilitate the creation of appropriate turbulence structures which were normally present in atmospheric flows. Pressure probes were affixed to a building to provide measurements related to upstream air flow pressure in order to determine pressure coefficients for a set of conditions (building geometry, wind speed, and wind orientation).

The flow uniformity was usually characterized as either as min-max or a deviation from the mean velocity in the viscid core flow of the test section. A single hot wire could be traversed through the core of the test section, and the bridge signal measured and analyzed each spatial locations. In this study, 3 hot wire anemometer locations were placed for each inlets and outlets of the bottle models.

When doing computational analysis, it is common to high-pass filter the data at some cut-on frequency related to the mean flow speed and test section size to separate it from large scale unsteadiness and provide better accuracy. Therefore, the computation of time-averaged statistic testing was decided, with 3 measurements done on each models with an estimation of 100 seconds exposure per area.

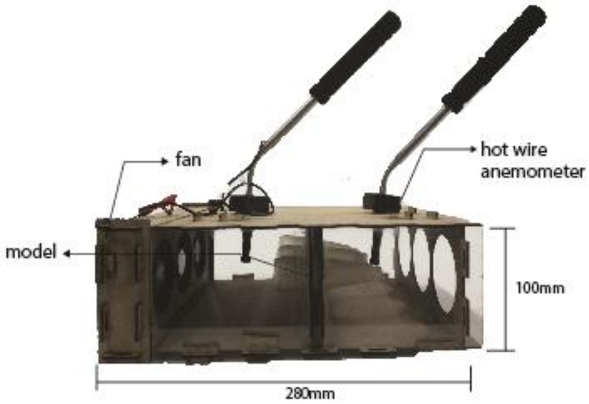

Fig.7. Wind tunnel tools

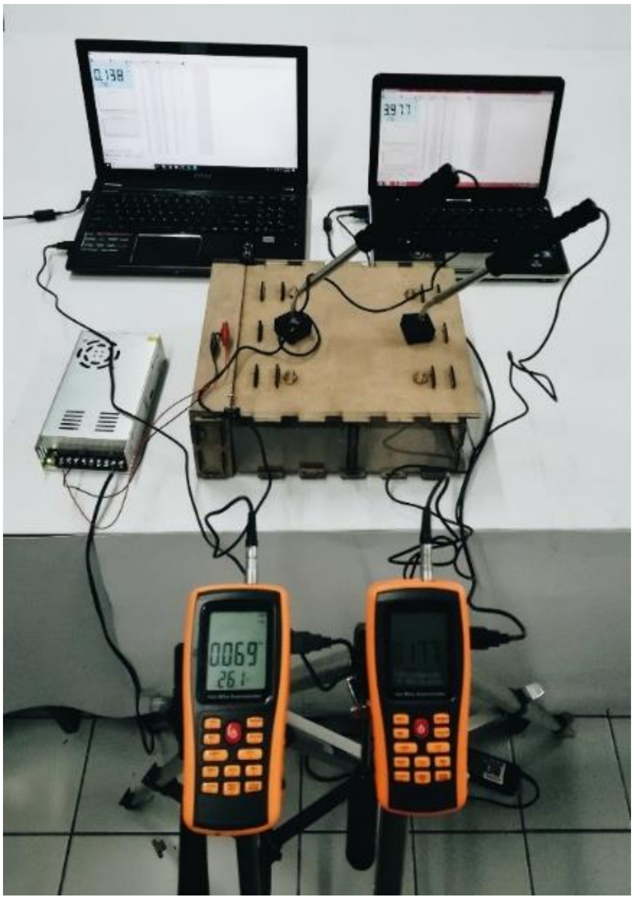

Fig.8. Measurement process

2.5 Test Result

Hot wire anemometers were placed in the center of each section for a measured time or until the instruments were stabilized. This was done to ensure an effective and reliable data for when improvements or changes may be required.

The most important properties were air velocity and pressure on each models. The accuracy of the air quantity measurement depends on many factors, as it is determined by both cross-sectional area in which the air is passing through and the air velocity. In order to estimate a result, a number of measurements must be made on each models with variations between values obtained by successive measurements and some experimental deviations were to be expected.

Finally, different inlet-outlet size ratios of the models would also influence the measurement result, as presented in Table 1. Bernoulli's principle states that as the speed of a moving fluid (liquid or gas) increases, the pressure within the fluid decreases. The Venturi effect is the fluid pressure results when an incompressible fluid flows through a constricted section of a tube.

In this table, ratio value was obtained from the division of outlet value by inlet value. Then, multiplication value was obtained from the subtraction of the air velocity value on the outlet by the air velocity value on the inlet as an average value of three measurements conducted for each tube in the wind tunnel. Finally, it is clear that a smaller ratio led to a better multiplication value.

Table 1. Measurement Result

Details	**Inlet (a)**	**Outlet (b)**	**Ratio (a/b)**	**Multiple of velocity**
Unit	**cm**	**cm**		
Type 1	3.00	1.00	0.33	24.98
Type 2	5.50	5.50	1.00	2.78
Type 3	5.50	2.50	0.45	23.73
Type 4	8.00	2.50	0.31	25.04

2.6 Analysis

The result shown in figure 9 is a calculation of 97 times using hot wire anemometers.

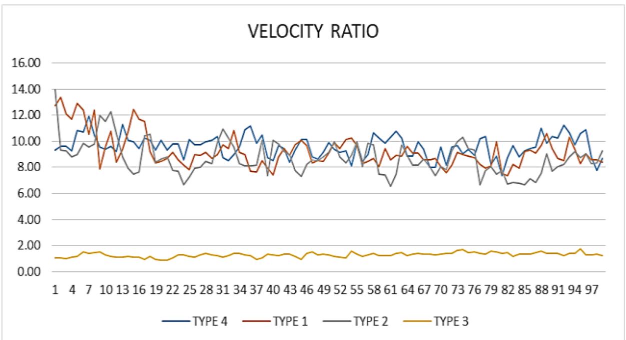

Fig.9. Air Velocity Graph

Based on air velocity measurement using hot wire anemometer, velocity increase from bottle inlet to outlet could be analyzed. The multiplication of the velocity depends on inlet-outlet ratio of different-sized bottles, according to Venturi effect principles. From the result, Type 4 showed higher increase in air velocity, followed by Type 3, Type 1, and Type 2. It could also be concluded that smallest inlet-outlet ratio (Type 4) gave the highest air velocity multiplication.

2.5 Future development

Sustainable design requires a long-term durable approach which passive environmental control offers. Zero waste air conditioning in kinetic façade, suggests potentials for other studies such as further exploration of zero waste air conditioning mechanism based on Venturi effect principle and development of plastic waste material as part of the kinetic façade.

3. Conclusions

The aforementioned studies were proposed in order to facilitate a thorough and complete consideration of zero waste air conditioning during the feasibility study stage, an early to beginning design phase where a quick method of performance prediction is necessary yet specific analysis is also needed to provide design feedback.

The goal of the study was to reach the most optimum air velocity rate. The result of the study, after being processed and multiplied in relation to the materials' inlet-outlet ratio, could be used as a foundation for future design projects.

4. References

1) American Society of Civil Engineers. *Wind Tunnel Testing for Buildings and Other Structures* (Reston, VA: American Society of Civil Engineers, 2012).

2) ASHRAE (2009) Handbook – *Fundamentals, chapter 9 Thermal comfort. American Society Heating,* Refrigerating and Air Conditioning Engineers (ASHRAE), Atlanta

3) Daugherty, R. L., Franzini, J. B., and Finnemore, E. J. (1985). *Fluid mechanics with engineering applications*, McGraw-Hill, Inc., New York.

4) Emiroglu, M. E. and Baylar, A. (2003). *"Study of the influence of air holes along length of convergent-divergent passage of a venture device on aeration."* Journal of Hydraulic Research, Vol. 41, No. 5, pp. 513-520.

6) F. Ozkan, M. Ozturk and A. Baylar, *Experimental investigations of air and liquid injection by venturi tubes, Water and Environment Journal*, 20 (3), 114-122, 2006.

7) G.B. Venturi, *Experimental Enquiries Concerning the Principle of the Lateral Communication of Motion in Fluids*: Applied to the Explanation of Various Hydraulic Phenomena, Translated from the French by W. Nicholson, 1st English Ed., J. Taylor, Architectural Library, High-Holborn, London, 1799.

8) How can Indonesia win against plastic pollution? (Accessed on 12 December 2018). Retrieved from https://theconversation.com/how-can-indonesia-win-against-plastic-pollution-80966

9) Keffer J F.Budny R S and Kawall J G 1978 Digital technique for the simultaneous measurement of velocity and temperature Rex.Sci.Insirum. 49 1343-6

10) Kwok, Alison G., and Walter Grondzik. *"The Logan House: Measuring Air Movement,"* in: Proceedings of 24th National Passive Solar Conference (Portland, ME, 1999).

11) Larsen, T., and P. Heiselberg. *"Single-Sided Natural Ventilation Driven by Wind Pressure and Temperature Difference."* Energy and Buildings, 40, 2008

12) "The Venturi effect". *Wolfram Demonstrations Project.* Retrieved 2009-11-03.