QUANTIFYING WINDOW EFFECTIVENESS TO AFFECT WIND VELOCITY BY EXPERIMENTAL STUDY

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QUANTIFYING WINDOW EFFECTIVENESS TO AFFECT WIND VELOCITY BY EXPERIMENTAL STUDY

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Abstract

Particular ventilation design can create effective natural air movement into the indoor environment by flowing the outside wind. The window, as a kind of ventilation, has various designs. It combines three primary constructions: simple opening, vertical-pivot, and horizontal-pivot opening. Each has a particular characteristic to control air velocity and direction which flows through it. However, the wind is not always certain in the mean of its velocity and direction, which heavily relies on the season. This study is written to investigate the single window's performance by measuring its effectiveness to control wind velocity in some directions. The effectiveness is conceived as a percentage rate that a window could maintain the outside wind velocity when it flows through the window. This experimental study employs three factors that are wind direction, window design and opening angle. This study operated 1:1 model of ten window designs, a simulation wall, and an electric fan to generate the Building Physics Laboratory's intended wind in the Department of Architecture, Institut Teknologi Indonesia. The result shows that maximum opening angle with perpendicular wind is the most effective situation to flow wind through all window—except simple casement window—with the rate ranging at 85,16% – 123,76%. The wind could also be more speeded up 109,63% – 193,90% when it aligned to all windows. Simple casement window even reaches 266,22% when the wind perpendicular.

Keywords:
Effectiveness;
Natural ventilation;
Experimental study;
Wind velocity;
Window;

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INTRODUCTION

As a space for human activities taking place, the building must provide thermal comfort for its users [1]. Thermal comfort is human satisfaction to perceive the thermal situation in a space [2]. Thermal comfort is influenced by individual factors, which are activity, clothing, adaptability to the surrounding environment, environmental factors, air temperature, radiation temperature, humidity, and wind velocity [3].

Most buildings now use artificial air conditioning, though, for some building types, such as low-rise buildings, it is an exaggeration, to meet user's thermal comfort in the interior environment. Using this mechanism causes much energy consumption. To power air conditioners, buildings in tropical countries consume even as much as 56% of its total energy consumption [4]. Besides, maintaining air conditioner with less fresh air exchange will increase CO_2 concentration in an indoor environment [5] that is unhealthy. Therefore, the less energy consumption strategy to create a more comfortable and healthier interior environment is necessary, one of them, using natural ventilation through windows [6].

This passive design strategy could be maximally achieved by applying certain window design and placement on certain wall areas of the building façade, such as application of the jalousie windows, both horizontal and vertical, in Khoo Teck Puat Hospital Building to catch and to direct outside wind flowing in [7]. This strategy also needs active action by building occupants, called window opening behavior, to open the window to get comfortable air temperature and velocity inside the interior room [8]. Nevertheless, an automatization of window opening that needs passive occupants' action has been developed by adding a mechanical system to automatically open window at certain angle regulated based on the gas concentration and air temperature situation in the interior environment [9].

This natural air conditioning mechanism with ventilation is to let outside wind flow into the chamber to create air movement with the general comfortable rate ranging from 0.25-1.5 meters/sec [10] or 0.75-1.5 meters/sec for office space [11]. However, the outside wind velocity can be very strong, very slow, even not flowing at all for some time. Wind energy relies heavily on location characteristics and altitude. The high-velocity wind particularly takes place at high altitude. It slows down as it gets closer to the ground because buildings and ground features make the ground's texture prone to rough dissipate wind energy [12]. For example, at an altitude of 30 meters the wind speed varies, where on a large city 13,85 meters/sec, country and outskirt 20.11 meters/sec, and open country 32.18 meters/sec [13]. The outside wind needs to be slowed down as much as 98-99% by the ventilation to create comfortable wind velocity in interior space. The direction is another dynamics of the outside wind, especially in Indonesia, where the wind direction can change by 180^0 along one year because it is heavily influenced by the eastern and western monsoon wind [14] [15].

Previous research on natural ventilation have been conducted mostly through digital simulation by using CFD analysis to determine the effectiveness of cross-ventilation by using at least two ventilation pits as inlet and outlet [16], effective area and placement windows affecting air movement in the interior space [17], examination of ventilation performance of some window types placed on four building's sides [18], and using solar chimney's to generate air movement helped by solar heat [19]. Natural ventilation heavily depends on the window as the single ventilation pit unit flows outside the wind into the interior space. Various windows are actually developed by three main window construction types, namely simple opening, vertical-pivot, and horizontal-pivot opening [20]. However, some research to examine the window's effectiveness as ventilation is still limited. It mostly used a single wind direction variation, limited opening angle, deployed single wind direction, and not resulted in a quantitative rate. Gao and Lee [18] research limited the opening angle of windows sash on 30^0 and 45^0. The results showed that the single-sided window has the best performance to create air movement effectively. Other research by Chang et al. [20] used one type window equipped with a revolving motor that is sensitive to air temperature in the space, middle construction vertical-pivot window, varies the sash opening at the angle of 30^0, 60^0, and 90^0. However, it is necessary to note that windows, contradictive, may also contribute to increasing thermal loads on building as they are exposure pits on the building skin that allows the entry of sunlight radiation [21].

In designing a building façade, certain window types are chosen more because of the consideration of harmony with the façade and suitability with the interior space's activities. Whereas, by these different constructions of a window, the natural air movement inside can be achieved. Each window has a particular optimum opening area and characteristic in controlling wind velocity and direction getting through [20].

Examining the outside wind utilized to generate air movement in interior space related to various types of window construction is essential to meet a comfortable wind velocity for the user effectively. Previous research on the window to examine natural ventilation performance mostly conducted through a simulation study were limited by the factors used—only the window designs, angle of openings or wind direction—and the results were unexpressed in quantitative rate. Therefore, this research is developed in its method and factors. This experimental study looks the window performance of natural ventilation closely by resulting quantitative rate, which is more obvious to distinguish a window design to another on some wind directions situation, through more variations from three factors crossed.

MATERIAL AND METHOD

Material

This research uses ten window designs that have been developed from two basic window construction types in a size of 60 cm x 60 cm and the placement orientations, whether vertically or horizontally, as depicted in Figure 1.

The first one is a simple window construction with one sash. This window has four hinge locations that are on the left, left-middle, middle, and right-middle. Those make adjustable construction in order to obtain four window designs. As the window placed vertically, the designs are annotated as simple casement, vertical-pivot 1, vertical-pivot 2, and vertical-pivot 3. However, the designs totally change when the window is turned 90^0 with the sash positioned horizontally. It becomes top hung, horizontal-pivot window 1 where the hinge located upper, horizontal-pivot window 2 with hinge on the centre, and horizontal-pivot window 3 when the hinge is lower on the frame.

Another window employed is a jalousie window with five slats fixed. Each window design then is to be mounted on a rectangular pit in the simulation wall. An electric fan is positioned in a front simulation wall to generate artificial outside wind.

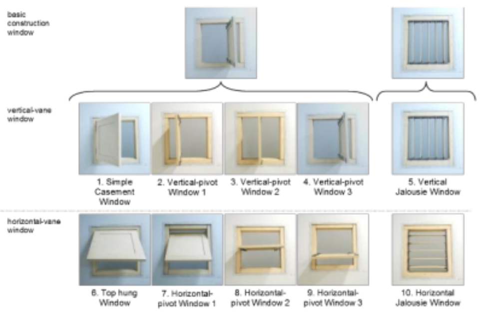

Figure 1. Two basic construction of windows are adjustable to create ten window designs

Method

The experimental study was conducted in the Laboratory of Building Physics, Architecture Department of Institut Teknologi Indonesia. The research design consists of three factors,: the wind direction consists of three variables, the window construction type with ten variables, and the window opening angle with five variables, as shown in Figure 2 and Figure 3.

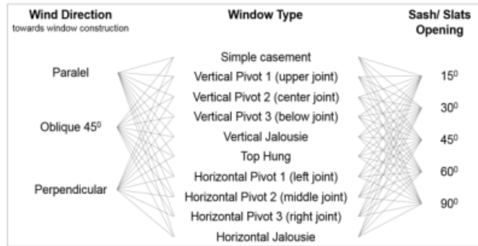

Figure 2. Variations in experiment generated by three factors crossed

Window opening angle highly affects the velocity of the wind flowing through the window by controlling wind direction and volume [22]. All the variables crossed to create 150 variations.

Two anemometers are positioned in front of and behind the window. The front anemometer is located 10 cm from the window to measure exterior wind through the window. This distance is considered where the air movement in this area comes from the windblown and avoids air vortex, which could occur at the edge of the window frame. Simultaneously, the back anemometer sat 50 cm away behind the window to measure air movement generated by the exterior wind. The distance between window and anemometer is considered a space usually for user activity or filled with furniture. Both anemometers are at the same level with the bottom edge of the window at 125 cm height from floor. Placement of anemometer is considered as the height of the working plane of users. Figure 4 shows the Experimental Set Area in Building Physics Laboratory Room

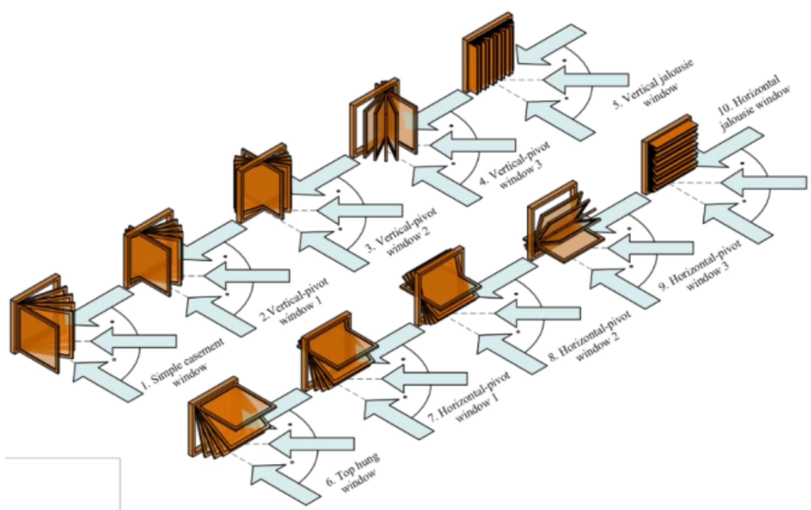

Figure 3. The Windows' Sash Opening Angles and Wind Directions Would be Tested

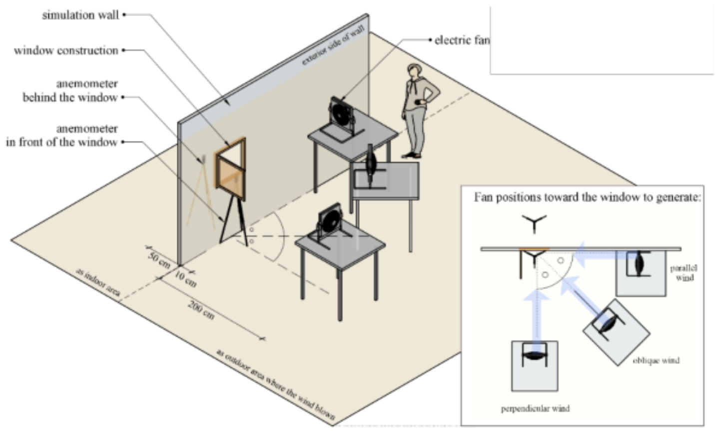

Figure 4. The Experimental Set Area in Building Physics Laboratory Room

After set already prepared, the window sash is opened at a certain angle. Then, the fan is switched on. The air velocity numbers shown in both anemometers are noted. These steps are repeated three times for each research variation.

The air velocity data obtained from the two anemometers measurements then processed to determine the window performance's effective rate. The effectiveness is conceived as the rate that the window could maintain the outside wind's speed flowing through. The effectiveness rate is calculated by using the formula as follows:

$$Effectiveness\ (\%) = 100\% - ((v_o - v_i)/v_o * 100\%) \quad (1)$$

which v_o and v_i are the outside wind velocity and indoor air velocity around the measurement location. Hence the bigger the number, the less the air velocity is reduced by the window, which means the more effective the window to use as ventilation.

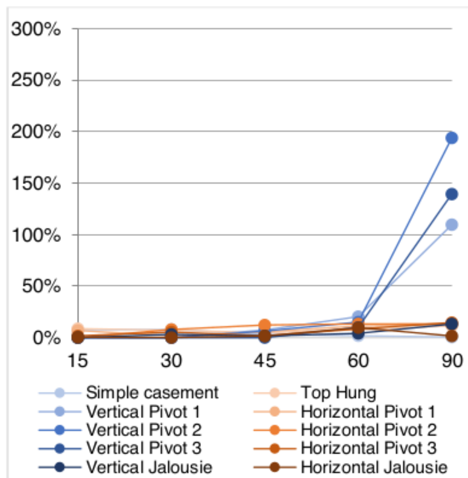

Figure 5. The graph shows the effectiveness of the average window on some opening angles when the wind aligned toward the window

RESULT AND DISCUSSION

Wind Aligned toward Window

The average window effectiveness is low, between 0%-20.40%, when the wind aligned towards all window types opened in 15^0, 30^0, 45^0, and 60^0, and some windows opened at 90^0, as shown in Figure 5. The condition means that the outside wind velocity is experiencing large declines. Meanwhile, the rate accelerates when wind flows through the vertical pivot 1, 3 and 2 windows opened at 90^0. The wind velocity becomes 109.63%-193.90%.

Wind Oblique 45^0 toward Window

The oblique wind creates wider exposure to the window. Figure 6 shows this wind situation generates higher and obvious magnitude of window effectiveness in a particular angle. The range of effectiveness on all windows when opened at 15^0 is 0%–8.7%, at 30^0 1.31%-25.43%, at 45^0 4.59%-58.11%, at 60^0 8.04%-90.83%, and 90^0 16.43%-157.65%.

Flowing through the window, the wind velocity, instead, is speeded up, increasing the effectiveness rate be more than 100%. This occurs at the maximum opening angle of 90^0 on horizontal pivot 1, 2, 3 windows, vertical jalousie window, and vertical pivot 2 and 3 windows with effectiveness ranging between 110.18%-157.65%.

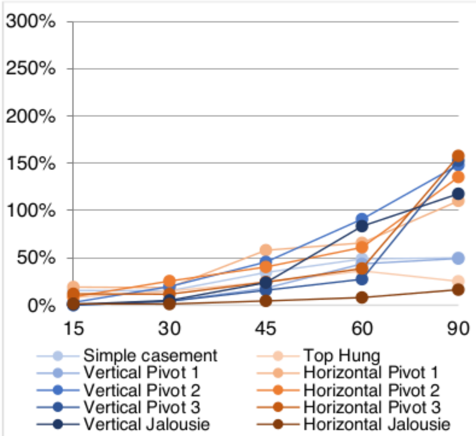

Figure 6. The graph shows the effectiveness of the average window on some opening angles when the wind oblique 45^0 toward the window

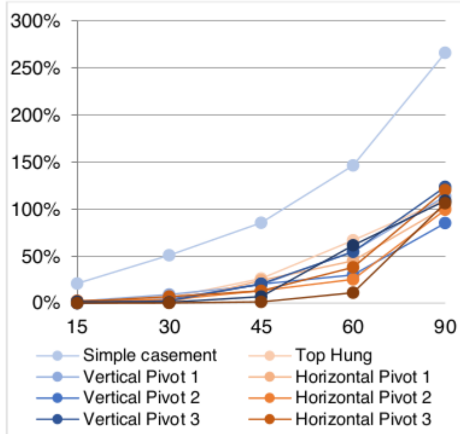

Figure 7. The graph shows the effectiveness of the average window on some opening angles when the wind perpendicular toward the window

Wind Perpendicular toward Window

Generally, most windows' magnitude of effectiveness rate, except the simple casement window, as wind perpendicular to the window is smaller than when the wind is oblique to the window as depicted in Figure 7. The number from each angle shows the disparity is smaller, meaning this perpendicular wind flows more evenly. However, it is noticeable that the effectiveness of a simple casement window is very prominent compared to other windows.

Temporarily ignoring the simple casement window, the effectiveness rates as the wind perpendicular ranges effective rate of 0%-2.51% at an opening angle of 15^0, between 0.28-9% at 30^0, 1.2%-26.14% at 45^0, 11.03-66.96% at 60^0, and 85.16-99.30% at 90^0. Acceleration of wind velocity behind the window higher than in the front occurs at the 90^0 opening angle. This happens on the type of horizontal pivot one window, the horizontal jalousie window, top hung window, the vertical jalousie, the vertical pivot 1, 2, and 3 windows with effectiveness rate ranges between 102.26%-123.76%.

The obvious effectiveness number of simple casement window starts from the narrowest opening angle to the widest. The number increases remarkably from 20.93% to the maximum one 266.22%. Wind velocity accelerated when the window opened at 60^0 and 90^0.

Discussion

The formula of air continuity is as follows:

$$Q = C_v \, A \, v \qquad (2)$$

which, Q, C_v, A, and V respectively are airflow velocity (m^3/hour), aperture effectiveness constants of inlet and outlet, opening area (m^2), and outside air velocity (meter/hour) [20]. In general, the results are aligned according to the airflow continuity formula. The airflow velocity is maintained well when the window opened optimally.

However, the graph of each wind direction indicates different numbers among windows at every opening angle. Ventilation area cannot be solely put with window size. The effective pit must consider the aperture area or free area shaped between wind direction and sash opening angle. Free area is calculated as:

$$A = d * h \qquad (3)$$

which, A, d, and h respectively are a free area of the window opened, distance perpendicular of sash and frame, and height for vertical window or width for horizontal window [23].

The oblique wind generates the largest disparity of effectiveness rate over each opening angle on all window types among three different wind directions. Particular windows are only effective to reduce or to boost indoor airflow as situated in this wind direction. Perpendicular wind generates the effectiveness rate tends to be more stable increasing. Perpendicular wind direction is more flexible to offer choice more diverse.

Any window types are more flexible applied toward the perpendicular wind. The narrow or wide opening angle may be set up either to reduce or to flow outside wind with small air vortex occurred optimally. Meanwhile, parallel wind generates effectiveness rate too low or too great, causing the ten window designs to be ineffective as flowing outside wind parallel to the window.

Boutet [20] explained that the vertical window could only control horizontal airflow, while the horizontal one against the vertical airflow. In this study, the wind which is blown in front of the window is identified as horizontal airflow. Horizontal airflow generates a higher effectiveness rate of vertical pivot windows than horizontal airflow in the three-wind situation.

The effectiveness rate further is worthwhile to examine window flexibility in any wind direction situations. One needs every single window's effectiveness rate from the fifth opening angles in a wind direction to identify the minimum and maximum numbers. These numbers create a difference or disparity of a window. A window is more flexible when the disparity between the minimum and the maximum effectiveness rate is high, calculated as follows:

$$Disparity = effectiveness_{max} - effectiveness_{min} \quad (4)$$

which $effectiveness_{max}$ and $effectiveness_{min}$ respectively are the highest and lowest effectiveness rate of a window opened at any angle in each wind direction situation. Each window has three disparities which are in parallel, oblique, and perpendicular wind situations. These disparities rates were accumulated; it will show a window design's flexibility profile in any wind direction, as shown in Figure 8. It shows that the vertical window types tend to be more flexible than the horizontal ones. High disparity bar on vertical pivot window type 2 and 3 indicates both windows are the most adaptive in three wind directions.

This research also results from another interesting finding that window sash's position upon its frame plays a significant role in controlling air velocity. Further understanding air movement distribution pattern involving window sash is necessary to explain why middle vertical pivot window is, by those numbers, more effective than the simple casement window. Investigation on the mechanism of air movement that flows through the window is still limited [24].

Research by Lee and Chang [25] or Varughese and John [26], for instance, could be taken into consideration to explain air movement pattern around horizontal jalousie. However, it cannot be compared due to limited window types which have been investigated.

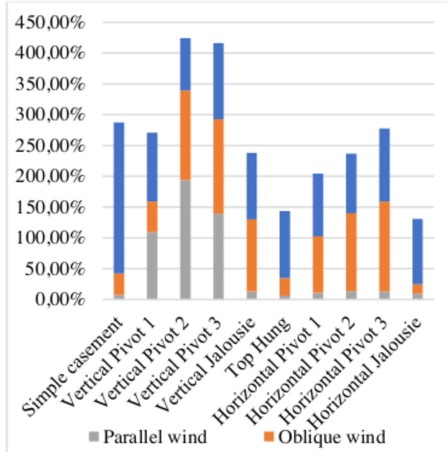

Figure 8. The graph shows accumulated effectiveness rate disparity of each window in three wind situations

CONCLUSION

With this research, utilizing outside window to generate indoor airflow can be optimized using window design's effectiveness rate. Almost all window designs at the maximum opening angle with perpendicular wind are effective and stable to flow outside wind into the interior without causing minimum turbulence from air vortex, with a range of effectiveness rate of 85.16%-100%. The windows can potentially maintain outside wind velocity when flowing it in. However, the rate can be even higher, mostly happening to the vertical pivot window when the wind aligned -with the rate of 109.63%-193.90% -and reaches the maximum number of 266.22% wind direction is perpendicular. This situation accelerates the outside wind velocity when flowing through the window. The vertical window design has better effectiveness rate than horizontal ones in any angle of horizontal wind direction. Finally, among the ten window designs, the vertical pivot two windows are recommended as the most effective to reduce and boost the velocity of exterior wind that flows into an interior environment on any wind velocity direction without causing high turbulence.

However, this research is limited for horizontal wind situation only, though it explores some wind angles. The next inquiry is highly worth examining window effectiveness toward vertical wind and investigating the air distribution that flows through the window assisted with CFD analysis. Examination on window effectiveness rate will help decide window design to create natural interior airflow in a multi-storey building where the wind is vertically blown and high.

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