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SINGLE-SIDED NATURAL VENTILATION THROUGH A CENTRE-PIVOT ROOF WINDOW

Ahsan IQBAL[1*], Peter V NIELSEN[2], Amalie GUNNER[1]and Alireza AFSHARI[1]

[1]Danish Building Research Institute, Aalborg University, Copenhagen Denmark
[2]Department of Civil Engineering, Aalborg University, Aalborg, Denmark.

[*]Corresponding email: ala@sbi.aau.dk

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SUMMARY

Only one window is often used for local airing and ventilation of enclosed spaces. The ventilation due to opening of a single window is called single sided ventilation. The ventilation rate depends upon external wind, wind direction, turbulence in the wind, and fluctuation in external pressure over the window opening, and inside and outside temperatures. Usually, these factors are unsteady. However, if a quasi-steady situation is considered then the flow characteristics of windows can be obtained. These characteristics can be used in estimation of airflow rate at design stages. In this study numerical methods were used to characterise a centre-pivot roof window for wind driven single sided ventilation. The effect of temperature is not included in this study. A 1:20 scaled model house of Energy Flex House (Denmark) was used in this study. Roof slope was 36^{o}. It was found that the single sided airflow through the centre-pivot roof window can be characterises by a factor called flow factor. It was found that the flow factor is a function of sash opening angle and wind direction.

INTRODUCTION

Controlled replacement of room air with fresh air for the purpose of acquiring comfort in an inhabited space is called ventilation. In spite the fact that the definition of comfort is varies among people, ventilation has been used for achieving comfort in occupied spaces (Shaw 1907). Ventilation can be done through fan (force movement of air) or by utilizing natural forces i.e. natural ventilation. The time has long passed when it was necessary to demonstrate and justify the benefits of natural ventilation (Baturin 1972). However, Heiselberg (2006a & 2006b) has enlisted all major advantages and disadvantages of natural ventilation, interested people can refer these small booklets for detailed knowledge of fundamentals and advantages of natural ventilation. Three main scenarios of natural ventilation are cross ventilation, stack ventilation and single sided ventilation. Ideally airflow through openings in cross and stack ventilation are unidirectional. Air inflows from one (or a set of) opening(s) and flow out from another. The dominant driving force for cross and stack ventilation is the difference in mean static pressures between indoor and outdoor environments. This pressure difference is caused by the natural wind and/or differences in buoyancy due to temperature difference.

SINGLE SIDED VENTILATION

Third scenario is single sided ventilation. Bidirectional airflow through an opening occurs in single sided ventilation. The dominant cause of single sided ventilation is the different in thermal buoyancy and the wind effect. Net airflow rate across an opening in ideal single sided ventilation is zero. Single sided ventilation caused by the temperature difference is usually defined as:

$$q = \frac{1}{3} C_d A_o \sqrt{\frac{g \Delta \theta h}{\theta}} \qquad \text{Eq.(1)}$$

Where C_d is the coefficient of discharge of the opening and its value is same as the value for cross ventilation, g is acceleration due to gravity, θ is temperature and h is the height of the opening. If opening is a window with sash then a sash opening factor – $J(\alpha)$, must be multiplied with the other factors in Eq.(1) (Warren 1978). Hence often the value of C_d* $J(\alpha)$ is used to characterise bouncy driven single sided ventilation. In wind driven single sided ventilation, mean outside and inside pressures are same. The flow through an opening is mainly due to wind speed, turbulence in wind and fluctuation in pressure over the opening. Eddies that are less than or equal to the side of an opening can only contribute to in single sided ventilation (Warren 1978; Cockroft & Robertson 1976). There are different approaches that scientist has been following to estimate the single sided airflow rate through openings due to wind. Warren derived an equation for wind driven single sided ventilation. The airflow rate can be characterized by F_L.

$$\mathrm{q} = \mathrm{F_L A_o U_{ref}} \qquad \text{Eq.(2)}$$

OBJECTIVE

Windows are elements of buildings that are often used for (or for enhancing) natural ventilation. For practical purposes airflows through different types of windows has characterise separately. *CPRW* are the often used to naturally ventilate occupied spaces in northern Europe. The characteristics of this kind of windows have not been discussed in literature. The authors of this paper have already published the characteristics of this type of window for unidirectional flow (i.e wind driven cross ventilation (Iqbal et al. 2013, Iqbal et al. 2012)). The objective of this paper is to characterise *CPRW*s for single sided ventilation due to wind. Single sided ventilation is an efficient method for local airing and to acquire quick comfort. Moreover, single sided ventilation can be used to cool down individual rooms of residential buildings during night hours.

METHOD

Single sided ventilation through the *CPRW* was analysed in a commercial CFD package. A simplified 1:20 scale model of energy flex house (EFH)[1] was used in this study (Figure 1 to Figure 3). CFD domain was selected according to the dimensions of a wind tunnel located in Gavle. Some of the findings from CFD simulations are verified from the wind tunnel test of the exactly same model. The CFD domain was 4*m* upstream and 4*m* downstream from the centre of the model house. The domain was 3*m* wide and 1.5*m* high. The CFD simulations were performed using unstructured hybrid meshes. Prism layer meshes were used to simulate the flow in the vicinity of the walls (for boundary layer i.e. viscosity dominated region). Polyhydral meshes were used in the region away from the boundaries - where the fluid behaves like the inviscid flow.

The inlet boundary conditions and outlet boundary conditions in the CFD domain was the velocity inlet (4*m* upstream) and the pressure outlet (4*m* downstream). The boundary conditions used in the CFD simulations were experimentally measured in the wind tunnel.

[1] Energy flex house is an experimental house located in the outskirt of Copenhagen

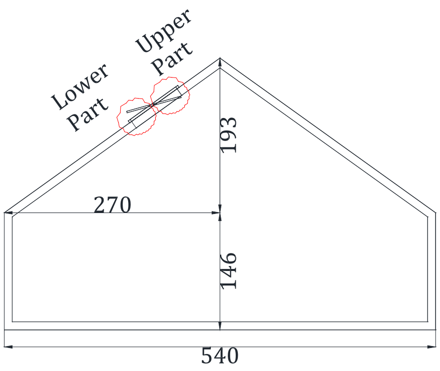

Figure 1 Side view of the model house

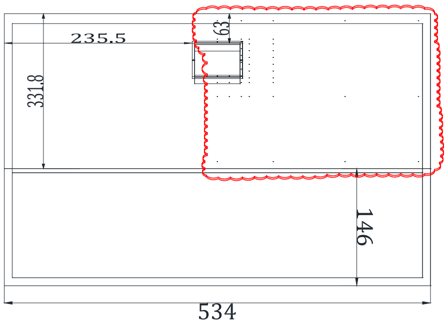

Figure 2 Front view of the Model house - Clouded area is the location of pressure taps. Figure 3 shows the enlarged view of the clouded area

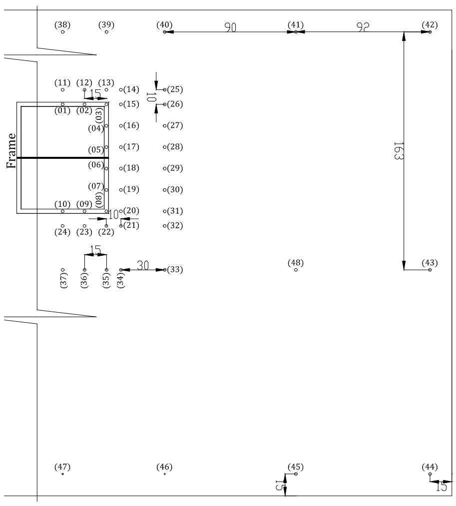

Figure 3 Enlarged view of the pressure taps and their numbers – clouded area of Figure 2

The realizable *k-ε* turbulent model was used for the CFD simulations. To ensure that the solution was grid independent, drag coefficient of the model house was evaluated for several mesh sizes. The mesh size was chosen when the drag coefficient did not change by further decreasing in the mesh size.

MODEL HOUSE

The dimensions and side view of model house (in *mm*) are shown in Figure 1. Wall thickness of the model house was 10*mm*. The front view of the model house is shown in Figure 2. The roof pitched angle is 36°. On the roof of the model house 48 pressure points were design. These points and distances between them are shown in Figure 3. Surface pressures coefficients $\{C_p=(P-P_{ref})/(0.5\varrho U_{ref}^2)\}$ at these points were compared with the C_p values exactly at the same points with exactly same physical model by using wind tunnel tests.

THE CENTRE-PIVOT ROOF WINDOW (*CPRW*)

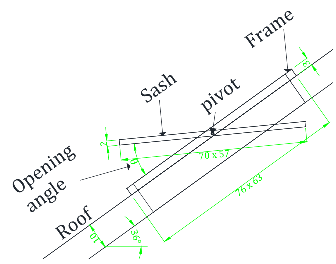

Figure 4 The centre-pivot roof window

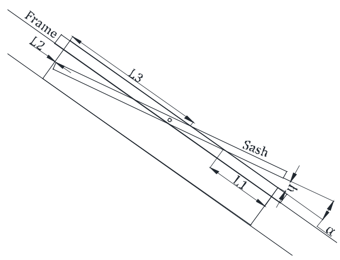

Figure 5 the centre-pivot roof window

The *CPRW* in EFH is VELUX [2] roof window. Therefore, in CFD simulations a simplified and scaled model of the VELUX *CPRW* was used. The detailed dimensions of the *CPRW* are shown in Figure 4. For understanding purpose the *CPRW* is divided into two parts i.e. the Lower part and the Upper part – as shown in Figure 1. The geometrical opening areas can be defined in several ways. The possible opening areas can be calculated from Figure 5. The possible opening areas on the lower part of *CPRW* are {(2 x 0.5 x L1 x h)+(h x w)} and (L1 x w) i.e. w is the width of *CPRW*. The selected opening area is the geometrical opening which has the minimum magnitude in the mentioned two areas. In the similar manner opening area of the upper part is calculated. The overall opening area (A_o) is the sum of minimum opening areas of upper and lower parts

FINDINGS AND DISCUSSION

[2] VELUX is a Danish window manufacturer

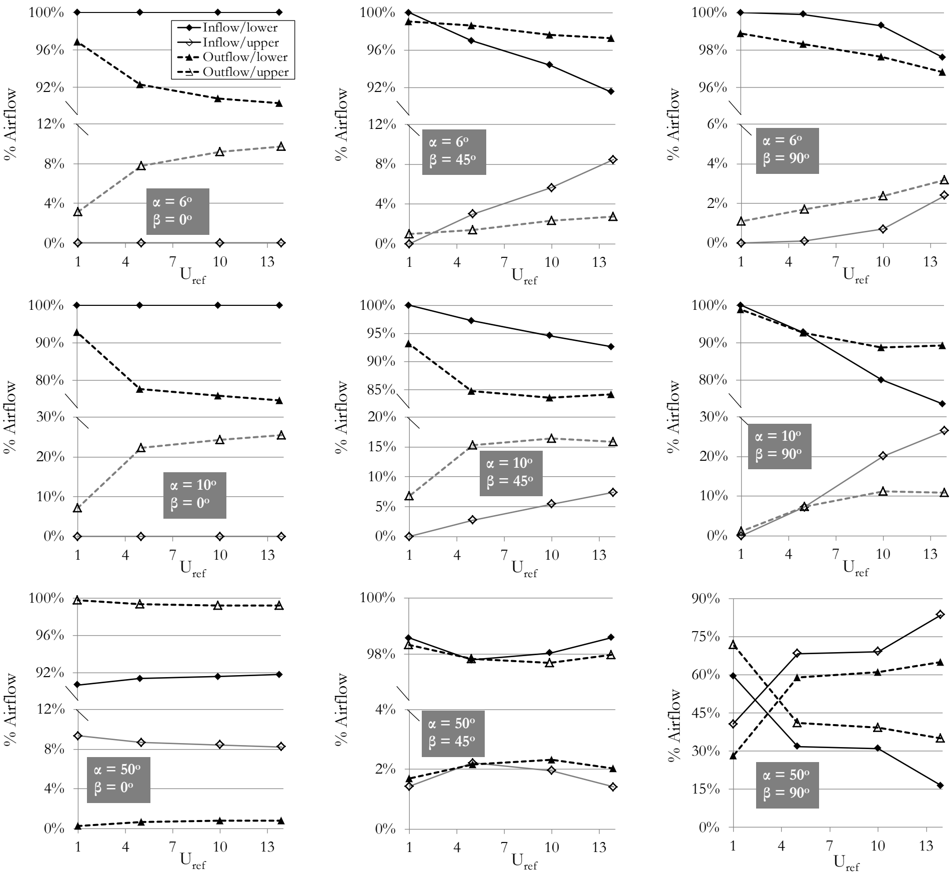

Figure 6 Behaviour of airflow through the CPRW

The C_p values (for 48 points shown in Figure 3) extracted from CFD simulations were in close relation with wind tunnel measurements – see Appendix I. These findings are bench mark for the authenticity of the other findings from CFD simulations. The q through the *CPRW* was analysed in both lower and upper part of the *CPRW*. The inflow and outflow from lower and upper are described as percentage of total inflow and outflow. These percentage inflows and outflows are shown in Figure 6. In Figure 6 vertical axes are the percentage of inflow and outflow. Horizontal axes are the U_{ref}. Inflow/lower means inflow from the lower part of the *CPRW*. Other legends are also clear from their names. α is the opening angle of the sash of *CPRW*, β is the wind direction. $\beta = 0^o$ means exactly windward direction, and β increases counter-clockwise. For $\alpha = 6^o$ & 10^o;$\beta = 0^o$, the total inflow is from the lower part of the *CPRW* whereas, outflow is from both lower and upper part of the window. However, dominant percentage of outflow is from the lower part. For $\alpha = 50^o$;$\beta = 0^o$, around 92% of the inflow is from lower part and around 8% is from upper part. The 99% of the outflow is from upper part of the *CPRW*. The exact percentage varies with U_{ref}.

For other values of α and β inflows and outflows are shared by both upper and lower parts. Therefore for simplifying the phenomena, *CPRW* was considered as a single opening instead of considering two separate openings i.e. lower and upper part. Hence the inflow (q) means the sum inflow from lower and upper part. Magnitude of inflow and outflow are the same. Inflow through the *CPRW* was analysed and it was found that the q and A_oU_{ref} are almost in linear relation – see Figure 7. Where A_o is the total opening area and U_{ref} is the wind velocity at the height of the model house measured in the undisturbed wind in front of the model house. The slope of the curves in Figure 7 are so called flow factor – F_L. Hence the F_L can be used to characterise the single sided ventilation through *CPRW*s. In Figure 7 it is clear that the F_L

decreases with increase in β. Moreover, F_L also varies with α.

For α = 6^o (Figure 7) the F_L for β = 45^o is higher than the F_L for β = 0^o. This is in contrary to other two cases. One reason could be the numerical error – because of very narrow opening area it was not possible to reduce the size of mesh below certain magnitude. Therefore, the results are obtained for minimum possible mesh size at the opening. Another possible reason could be the fact that at α = 6^o opening is very narrow so it may behaves like a crack. However, for other values of α (i.e. 10^o and 50^o) the q was analysed with several mesh sizes and the presented results are grid independent results.

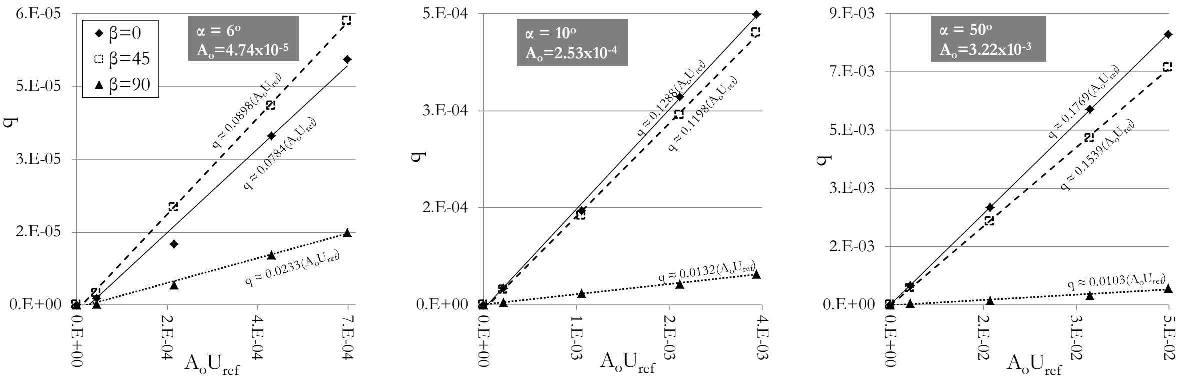

Figure 7 Total inflow through the *CPRW*

Figure 8 shows the effect of α and β on F_L. The F_L decreases with β and increase with α. These results depict the variation in F_L due to wind direction and sash opening. There is a need to evaluate the variation F_L with roof slope and aspect ratio for more concrete results.

CONCLUSION

In this study CFD simulations were used to analyse single-sided ventilation due to wind through a *CPRW*. The CFD findings were verified with wind tunnel experiments. F_L can be used to characterise the *CPRW* for wind driven single-sided ventilation. F_L increases with increase in α and decreases with increase in β. The effect of aspect ratio and roof slope was not analysed in this study. However, for more concrete results, the effect of these two parameters is also needed.

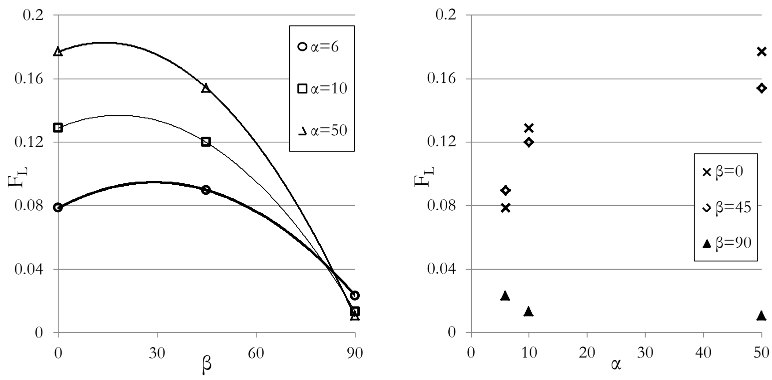

Figure 8 Flow factor of the *CPRW*

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SYMBOLS

CPRW = Centre-pivot roof window
α = window sash opening angle
A_o = Total geometrical opening area
q = Total air inflow rate
U_{ref} = Wind speed at the height of the model house
β = Wind direction
F_L = (q/A_oU_{ref}) = Flow factor

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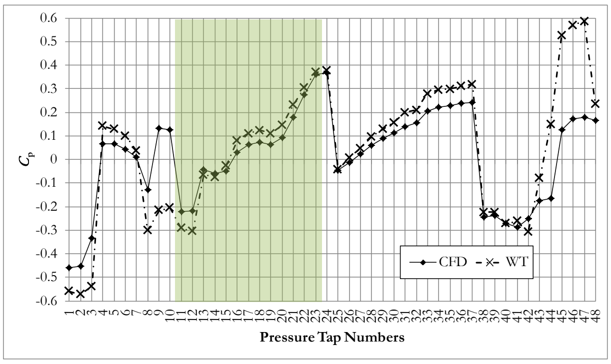
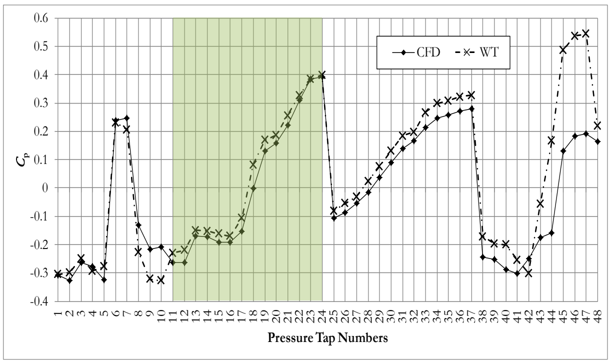
Appendix – I

This Appendix shows the comparison of C_p values that were obtained through wind tunnel measurements (WT) with values that were predicted through CFD simulations. These results are for β = 0. The vertical axes in all figures are the C_p values. The horizontal axes are the same pressure taps as shown in Figure 3. The CFD predicted outside pressures in close agreement with the wind tunnel tests except for the values over the frame of the CPRW and for values near the edge of the roof i.e. taps 1 to 10 & 42 to 47. The values nearby the opening are in very close agreement with the wind tunnel. These values are highlighted with light green colour.



α = 6°

α = 10°



α = 50°