Wind Pressures on a Permeable Tile Roof

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1. Introduction

Research on the effects of wind flow over air permeable tile roofs is not new. For instance, it is widely accepted (1,2,3) that the net negative pressures (uplift) on a permeable tile roof is smaller than the negative external pressure on a similar impermeable cladding. This is because in a permeable roof assembly the combined effect of negative external pressures and negative batten space pressures results in a negative net pressure smaller than the roof's negative external pressure. Moody (4) stated that the negative net pressure on a permeable roof may be up to 30% smaller than the negative external pressure. Following Cheung et al(3), the negative net pressure may be even smaller (40%).

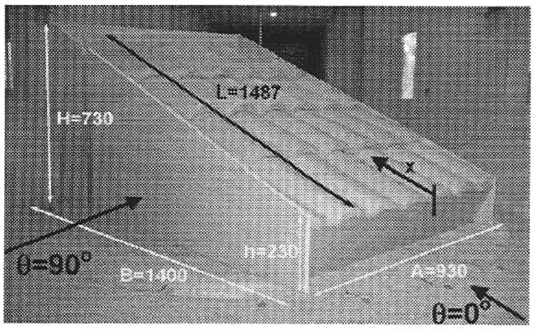
A net negative pressure on permeable surfaces is acknowledged in a number of standards worldwide such as the BS5534 (6) and the ASCE 7-05 (7). Australian standard AS/NZ1170.2:2002 (5) recommends a permeable cladding reduction factor (K_p) for permeable roofs and side walls which varies along the horizontal distance from the windward edge. This factor varies between $0.7 \leq K_p \leq 0.9$ and applies only to external surfaces subjected to negative pressures having a solidity ratio, δ, between $0.99 < \delta < 0.999$. This recommendation is based on findings from Cheung et al(3).

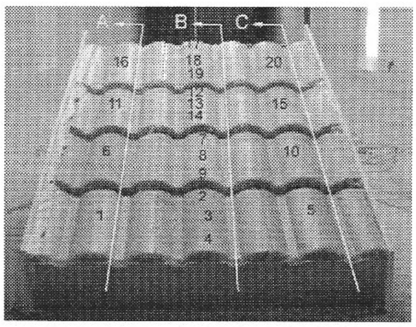
This paper examines the effect of the wind direction on net pressures (external - batten space pressures) of a permeable tile roof and quantifies the likely increase or reduction in pressures with respect to a similar but impermeable roof.

The research work undertaken was limited to a monopitch tile roof. For simplicity of testing, the flexible sarking, widely used in Australia, was replaced with a rigid sarking. In addition, only one batten size and tile type, associated with a specific batten space volume, was used.

2. Experimental Arrangement

The roof specimen consisted of a 20° degree monopitch tile roof with plan dimensions of A=930, B=1400, and H= 730 mm, as shown in Figure 1a. The roof comprised of timber pieces modelling the rafter/trusses on which a 5 mm rigid MDF board sarking was fixed. Timber battens, 35mm high, were subsequently fixed on the sarking and a popular type of concrete tile was attached to the battens using recommended fixing clips. The roof structure envelope was completely sealed with the exception of the tile surface. The height of tile heads at overlaps was 30 mm.





(a) Dimensions and Wind Direction **(b) Roof sections and location of pressure taps**

Figure 1. Monopitch tile roof specimen

The test specimen was tested in the 2.5m wide and 2.0 m high working section of the Boundary Layer Wind tunnel at James Cook University. The test specimen was placed on the 1.7 mm diameter turntable. Pressure measurements were taken as the model was rotated anticlockwise at 15° intervals from θ=0° (wind direction perpendicular to the ridge) to θ=90° plus an additional reading taken at 180°. The blockage ratio of the test roof is 14% which is slightly higher than the maximum recommended of 10%(8).

External pressure measurement taps (1 to 20) were installed along the roof surface as shown in Figure 1b. Four taps were placed in the middle of all tiles along Sections A, B and C. Two additional pressure taps per tile were placed along Section B just beside tile heads at overlaps to examine generated local effects. Four pressure measurement taps (21 to 24) were also placed within the batten space. Atmospheric and wind flow pressures within the tunnel were measured with a pitot tube placed 480mm above floor level.

Pressure measurements were conducted using a dynamic pressure measurement system providing both time-averaged and time-varying pressure measurement in real time for every wind flow direction.

Conclusions were derived from mean pressure readings. The measured pressures were transformed to non-dimensional pressure coefficients as per the following expression:

$$C_{pe} = \frac{P_t - P_o}{\frac{1}{2}\rho \bar{u}_h^2} \qquad C_{pb} = \frac{P_b - P_o}{\frac{1}{2}\rho \bar{u}_h^2}$$

where C_{pe} = Mean external pressure coefficient, C_{pb}= Mean batten space pressure coefficient, P_t= Mean external pressure, P_b= Mean batten space pressure, P_o= Mean atmospheric pressure, ρ =Air density and $\bar{u}_h$ =Mean wind speed at height h=480mm.

3. Experimental results

Wind tunnel testing confirmed that external wind pressures over two identical tile roofs, one permeable and the other impermeable, were essentially the same and not affected by the wind direction. This conclusion was reached after comparing external pressure measurements taken from the permeable roof specimen with those taken from the same roof after sealing all tile heads and side gaps. Hence the fact that wind flow can leak in or out the batten space through uniformly distributed gaps does not have a noticeable effect on wind-induced external pressures.

The angle of wind incidence had a significant effect on external pressures. Figure 2(a), 2(b) and 2(c) shows that for a wind direction of θ=0°, external pressure coefficients measured on the roof from 0 to 0.5L were positive but soon after turned negative as the wind flowed toward the top. As expected, positive external pressure coefficients turned into increasing negative external pressure coefficients as the roof was gradually rotated from θ=0° to θ=90°. Negative external pressure coefficients were larger along leading edge Section A, in comparison to those along Sections B and C, respectively.

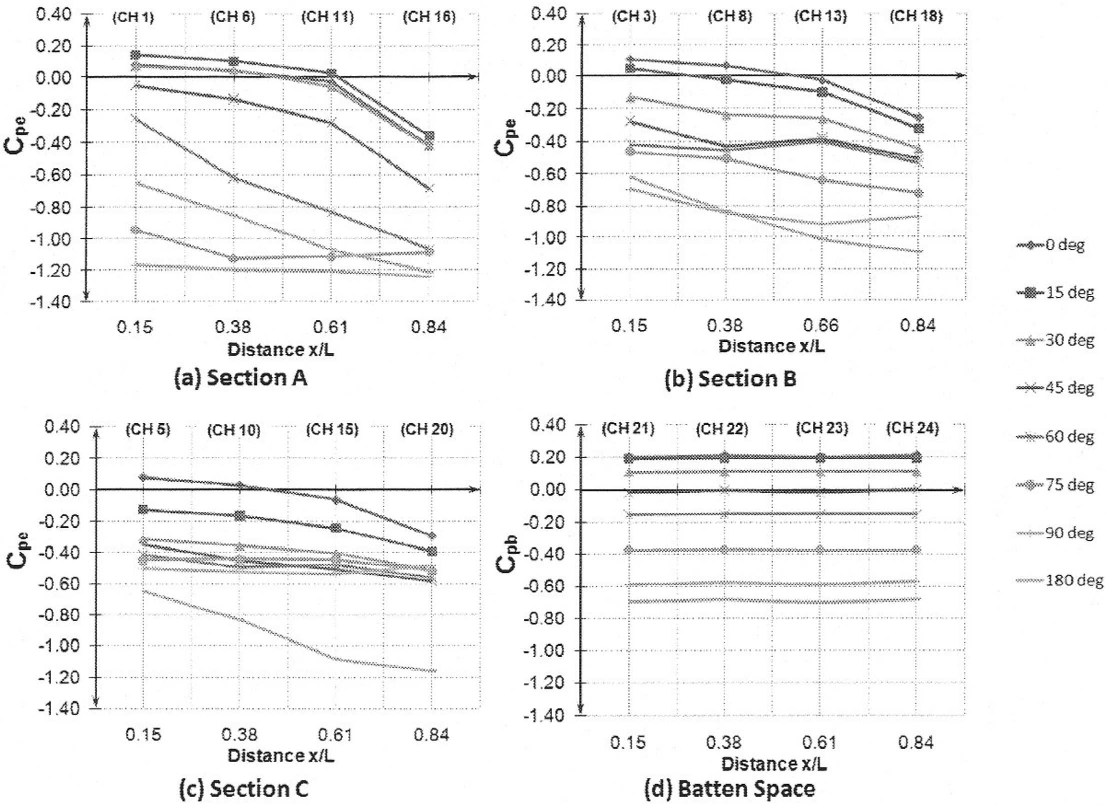


Figure 2. Mean external pressure coefficients at Sections A, B and C and mean batten space pressure under tiles

Batten space pressure coefficients were also influenced by the wind direction as shown in Figure 2(d). A pressure coefficient of +0.20 was measured on all pressure taps located within the batten space when the test specimen was placed at $\theta=0^{\circ}$. Pressure coefficients reduced to zero as the model was rotated 45° and increasing negative pressures developed as the test roof was subsequently rotated to $\theta=90^{\circ}$. The largest mean negative pressure coefficient of -0.70 was measured when the test specimen was rotated 180°.

Tile heads at overlaps generated flow stagnation along the roof surface just beside tile heads. This stagnation generated a local increase in positive external pressure coefficients for $0^{\circ}\leq\theta\leq30^{\circ}$ or a reduction in negative external pressure coefficients for $30^{\circ}<\theta\leq 90^{\circ}$ and $\theta=180^{\circ}$ relative to those pressure coefficients measured away from tile heads, as shown in Figure 3. Comparison of results in Figures 2(d) and 3 confirmed that pressure coefficients measured in the batten space were similar to the external pressure coefficients measured locally just beside tile heads at overlaps.

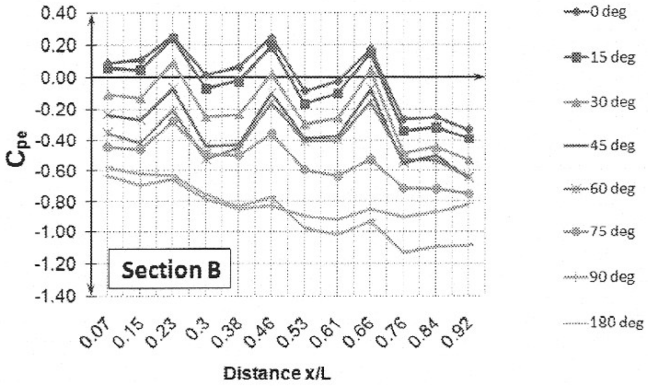
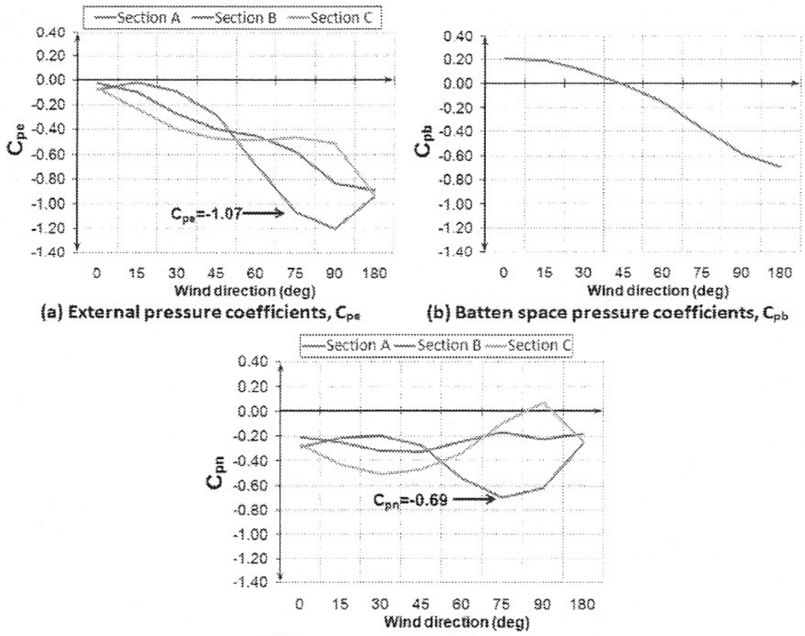


Figure 3. Mean external pressure coefficients measured along Section B at the middle of tiles and beside the tile head

To better understand the effect that wind direction has on external, batten space and net pressure coefficients, Figure 4 plots the relationship between pressure coefficients and the wind direction for Sections A, B and C. Pressure coefficients displayed are simply the average of all mean pressure coefficients measured per section for each wind direction.

Figure 4(a) shows that the largest negative external pressure coefficient of -1.20 was measured along leading Section A at θ=90°. Interestingly, between 0°<θ< 45°, downwind Section C exhibited pressure coefficients larger than those measured for leading Section A. Nevertheless, this behaviour was inverted between 45°<θ<90° where, as expected, leading Section A exhibited larger negative pressure coefficients.



(a) External pressure coefficients, C_{pe}
(b) Batten space pressure coefficients, C_{pb}
(c) Net pressure coefficients, C_{pn}

Figure 4. Average of external, batten space and net mean pressures to wind direction relationships

Batten space pressure was also affected by the wind direction. Figure 4(b) shows a maximum positive external pressure coefficient of +0.20 for θ=0° which reduced to 0 for θ=45°. Increasing negative pressure coefficients developed between 45°<θ<90° and reached a maximum of -0.70 for θ=180°. It is recognised that batten space pressure coefficients also depends on the level of permeability of the tile roof (i.e., size of gaps between tiles) and will also be affected by the roof surface shape, the pitch angle and if the roof is single or double pitched (3).

Net pressure coefficients (i.e., $C_{pn}=C_{pe}-C_{pi}$) were affected by the wind direction as shown in Figure 4(c). Negative net pressure coefficients between $0^{o}< \theta<45^{o}$ were larger than the measured negative external pressure coefficients. This happened either because a positive batten space pressure happened together with a smaller positive external pressure or because a positive batten space pressure happened in conjunction with a negative external pressure. On the other hand, the opposite occurred, as expected, when the roof was subjected to a wind direction between $45^{o}<\theta<90^{o}$. Here all net pressure coefficients reduced along Sections A, B, C; being Section A the critical. The largest negative net pressure coefficient was -0.69 (see Figure 4c) for a wind direction of $\theta=75^{o}$ along leading Section A while its associated negative external pressure coefficient was -1.07 (see Figure 4a). The negative net pressure coefficient resulted to be 35% $(1-(C_{pn}/C_{pe})*100)$ less than the negative external pressure.

These results demonstrate that, although not a critical scenario, not all negative net pressures on permeable tile roofs were smaller than the negative external pressure. Only the minimum (critical) negative external pressure predicted on a roof (wind direction parallel to the roof ridge ($\theta=90^{o}$)) may be reduced to account for air permeability.

4. Conclusions and recommendations

The experimental results demonstrated that:

- Wind-induced external pressures over two similar tile roofs, one permeable and another impermeable, were essentially the same and independent of the wind direction.
- The batten space pressure was affected by the wind direction and the shape of the roof surface.
- Although not a critical scenario, not all negative net pressures over a permeable monopitch tile roof were smaller in magnitude than the associated negative external pressure. Only the critical negative external pressure generated when the wind flowed along $\theta=90^{o}$ (i.e., parallel to the ridge) may be reduced by 35% to predict the negative net pressure on the tile roof.
- The K_p factor recommended in AS/NZS 1170:2002 will be a useful factor for design if there is data available to practising engineers on solidity ratios (porosity) for permeable roofs built with tiles manufactured in Australia.

Further research is needed to examine the effect on roof net pressures of batten space volume, use of flexible sarking, different shapes of roof surfaces and hence porosities, double pitch roofs and pitch angles.

5. Acknowledgements

The assistance of undergraduate student Wong Wai Hoe in the wind tunnel testing of the roof specimen is gratefully acknowledged.

6. References

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