

DESIGN AND WIND TUNNEL PERFORMANCE TESTING OF A NEW OMNI-DIRECTIONAL ROOF VENT

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Abstract: Low-slope roofs are subjected to potentially high levels of suction pressure. Traditional methods of attaching roof membranes to substrates are prone to failure when the low pressure on the roof surface instigates a transfer of forces to the roof membrane. Existing pressure-equalized roof systems use the power of the wind to transmit low pressure to the space immediately beneath the roof membrane, pulling the membrane down to the roof surface. The object of this study is the design of a wind vent which, when coupled with a single-ply roof membrane in a complete roof assembly, will successfully equalize low pressure throughout the entire field of the roof. The proposed wind vent differs from existing equalizer valves in its use of the Bernoulli effect to create low pressure. Optimized for ease of manufacturing and installation, the vent is omni-directional and contains no moving parts. After the wind vent prototype is developed, future study will be required to determine the tributary area of each vent and other roof system parameters.

Introduction

The following describes the design and wind tunnel performance testing of a new omni-directional roof vent for membrane roof systems. The new vent is designed to take advantage of fluid mechanics and aerodynamics principles to eliminate the uplifting pressures that develop on membrane roofs during high wind conditions. The new vent design is based on two elements, one mounted above the other. The convex curvature of the upper and lower elements are designed to induce a Venturi effect which, by smoothly constricting the airflow as it passes between the base and upper element, creates a low pressure zone inside the vent base relative to the ambient free-stream pressure. This low pressure zone draws the membrane down onto the roof deck, thus preventing uplift and possible detachment of the membrane layer. The vent is designed to be omni-directional, functioning efficiently with any wind direction. The vent is unique and differs from other commercially available roof vents in that: 1) It takes advantage of airflow principles such

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as the Bernoulli and Venturi effects, differently. 2) It functions for winds from any orientation (360 degrees). 3) It has no moving parts. 4) It is an active vent utilizing airflow through the vent to create negative pressure as opposed to a passive vent utilizing the negative pressure zone to transfer the vacuum. The design and preliminary performance test results are described.

Background

Membrane roof systems often have lower first cost when compared to other roofing approaches due to the relative ease and speed of installation. Membrane systems can be applied to both new and existing roofs making them widely applicable. Many new roof membranes are highly reflective to solar radiation thus reducing cooling loads and energy costs. One of the challenges for the installation of a membrane roof system is the use of an attachment method sufficient to prevent uplift during high wind conditions.

Traditional methods of attachment for single-ply membranes in common use today fall into one of three categories: mechanically attached, fully adhered, or ballasted. Each system has a feature that increases heat transmission to the inside and/or adds pollutants to the atmosphere during the installation process. An alternative to fasteners or ballast is a pressure-equalized roof vent system. Two currently used vent devices include a turbine vent manufactured by Burke Industries, Inc. and a passive vent used by the 2001 Company to achieve negative pressure under the membrane roof system. Both require air-tight deck assemblies for efficient operation and have a higher manufacturing cost than that expected for the newly developed vent. The new omni-directional vent employs an engineering principal that uses the dynamic flow of air across the roof surface to create negative pressure in a different way from existing devices and with greater efficiency. The new vent design uses energy from the wind, taking advantage of fluid mechanics and aerodynamic principles to eliminate the uplifting pressures that develop on the membrane during high wind conditions.

Description

The new low-pressure vent is designed with two primary elements, a hollow hemispherical dome base and an inverted, hemispherical dome upper element, or cap. The configuration is shown in Figure 1. When placed in an air stream the vent induces low pressure in the vent base. The 5 inch radius base has a 1 inch

circumferential flange and an open bottom, while the cap is sealed all around. The base has a 1 inch diameter opening at the apex of the dome. The base and the cap are vertically separated by a small gap that was experimentally determined to be 40.6 mm (1.6 inches), or .32 times the diameter of the hemispheres, based on results shown in Figure 2. The cap is held in place above the base by vertical supports as shown in Figure 1.

Operating Principles

The new roof vent is designed to take advantage of fluid mechanics and aerodynamic principles to induce a low-pressure region inside the base of the vent. The primary fluid mechanics principle involved in the new vent design is the Venturi effect. Bernoulli's law is a statement of conservation of energy, essentially indicating that the sum of the kinetic energy per unit volume and pressure are conserved:

$$\frac{1}{2} \rho u^2 + p = \text{constant} \quad \text{Eq. 1}$$

where p is pressure, rho (ρ) is the density of the fluid and u is its velocity.

A consequence of this law is that if the velocity increases then the pressure falls. This is exploited by the wing of an aeroplane, which is designed to create an area of fast flowing air above its surface. The pressure on this area is lower than the ambient pressure and so the wing is drawn upwards. The Venturi effect is a special case whereby if an air stream is smoothly constricted between converging solid surfaces, then low pressure is established along the throat between the two elements. For the new low-pressure roof vent the hemispherical base and cap form the flow convergence that induces higher speeds and therefore low pressure. By introducing an opening at the apex of the dome-shaped base, a low-pressure region is established inside the base relative to the pressure in the free-flow region. The hemispherical shape allows the low pressure to develop for any wind orientation.

Construction and Manufacturing Issues

The vent can be constructed of a variety of materials such as polycarbonate, metal or fiberglass; however a rigid plastic material is most compatible with PVC roof membranes. The plastic is strong enough to resist wind speeds in excess of 150 mph, yet lightweight enough to be easily handled and installed, and to

minimize the amount of material used in its production. The hemispherical dome-shaped geometry of the vent permits cost effective mass production using a plastic forming process. Because the system includes two domes rigidly held in position by the vertical supports that maintain the desired air gap distance, the new low-pressure vent has no moving parts.

Proof of Concept

A prototype for the new vent was constructed and tested. Tests were first performed in the low-speed wind tunnel in Norris Hall on the Campus of Virginia Tech, see Figure 3. These tests were performed to determine the pressure that developed in the vent base as a result of changing wind velocity for five alternative vent designs: two alternative geometries (hemispherical and ellipsoid), with and without a center structural post to support the upper element (for the ellipsoid model only), and with or without an upper dome. Figure 4 shows the results of the pressure measurements taken for the new vent design (double hemisphere) as compared to the other alternative designs tested at four levels of wind speed. As can be seen, the pressure conditions inside the vent base are lowest for the double hemispherical design shown in Figure 1. This supports the assumption that, due to the hemispherical design, the pressure will be lower inside the vent base relative to the ambient pressure field. A second series of tests were performed to determine the optimum separation between the upper and lower elements, which is indicated by the location of minimum of each graph curve shown in Figure 2. As shown, the pressure coefficient C_p^2 was lowest with a separation distance of 50.8 mm (2 inches) for a study model using hemispheres with a diameter of 158.8 mm (6.25 inches).

Final Design

Once the form and separation distance of the low pressure vent was determined, the design was modified to include provisions for rain penetration. Two design features were added to address this issue. First a small circumferential groove was added to the cap. This groove acts as a drip-edge to prevent water from running down the side of the cap to the lowest point directly above the opening at the top of the base. Secondly,

² The pressure coefficient C_p is equal to the gauge pressure divided by the dynamic pressure. The gauge pressure is the difference between the static pressure in the vent base and the static pressure in the wind tunnel.

inside the base a drip pan was added to collect any moisture that might enter the base through the apex opening.

Results and Conclusions

Finally a full-scale model of the roof vent was constructed and studied in the high speed wind tunnel on the campus of Virginia Tech. The full-scale vent model was mounted on the floor of the wind tunnel and the wind speed was increased to near 150 mph, the design wind speed for coastal regions of the United States. The experimental setup is shown in Figure 5. The results of the high wind tests indicated that the pressures inside the vent base were significantly lower than the ambient pressure and capable of drawing the roof membrane down onto the roof substrate. Pressures inside the vent base were 2447 Pa (9.8 inches of H₂O) below the ambient pressure in the free air stream at a maximum wind speed of 145 mph. This low pressure condition can be transferred beneath the membrane thus drawing the membrane down onto the roof substrate. Testing of the prototype indicates that the vent is structurally stable in high wind conditions, and further testing is planned to confirm this.

The new vent has the potential to substantially increase the application of membrane roof systems in locations susceptible to high wind. While the preliminary results suggest the potential benefits of the new vent, other questions remain. For example,

- 1) What is the most desirable porous material to use beneath the membrane to insure maximum propagation of the low-pressure zone?
- 2) What are the most appropriate installation details for the system?
- 3) What is the desired vent spacing distance?

These and other questions will be answered in follow-up studies.

Appendix. References

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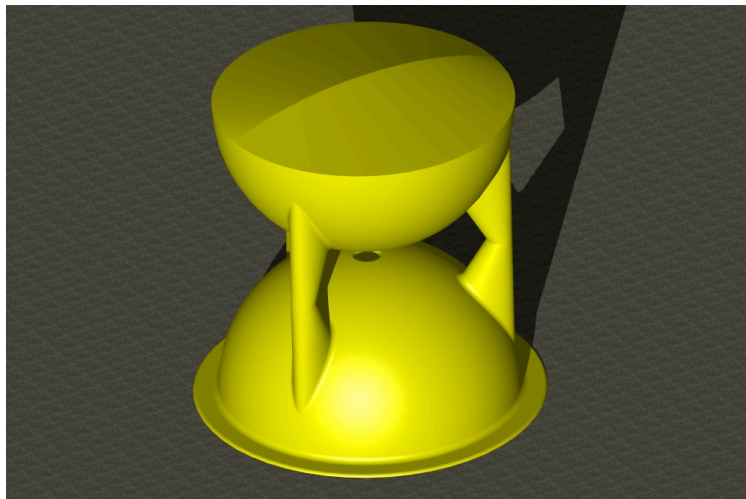


Figure 1. Three-D Model of the New Roof Vent

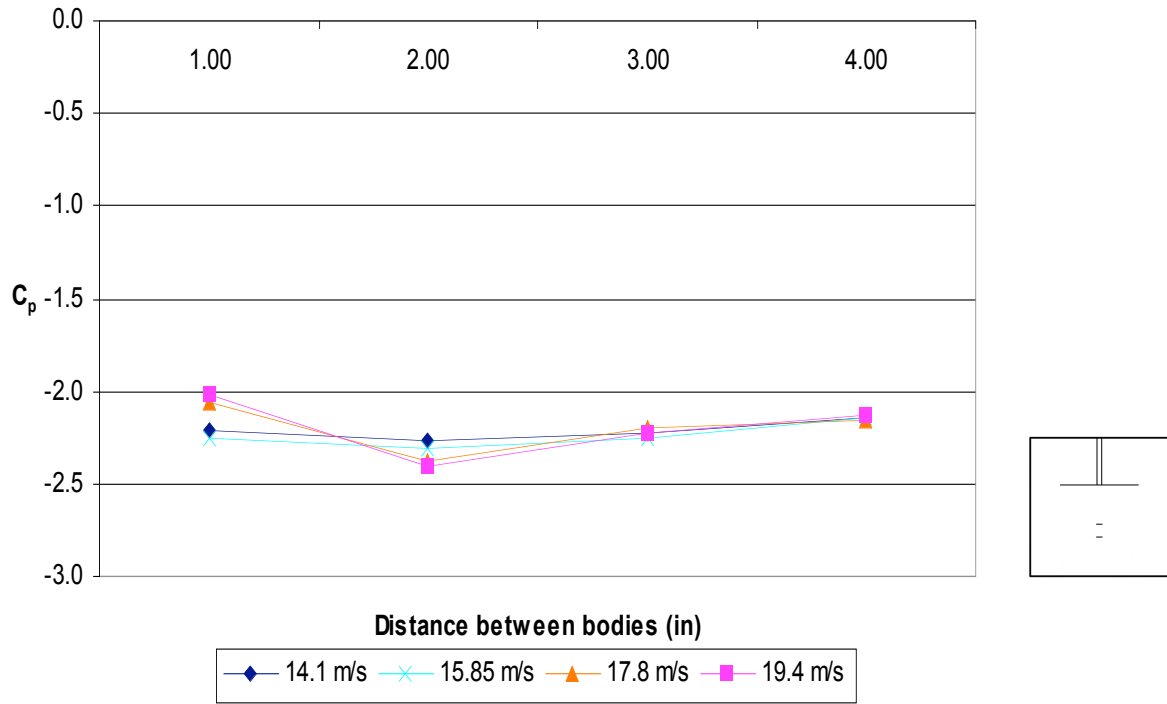


Figure 2. C_p vs. Distance Between Bodies (inches) for Double Hemisphere Study Model



Figure 3. Experimental Setup for Pressure Measurements in the Low Speed Wind Tunnel.

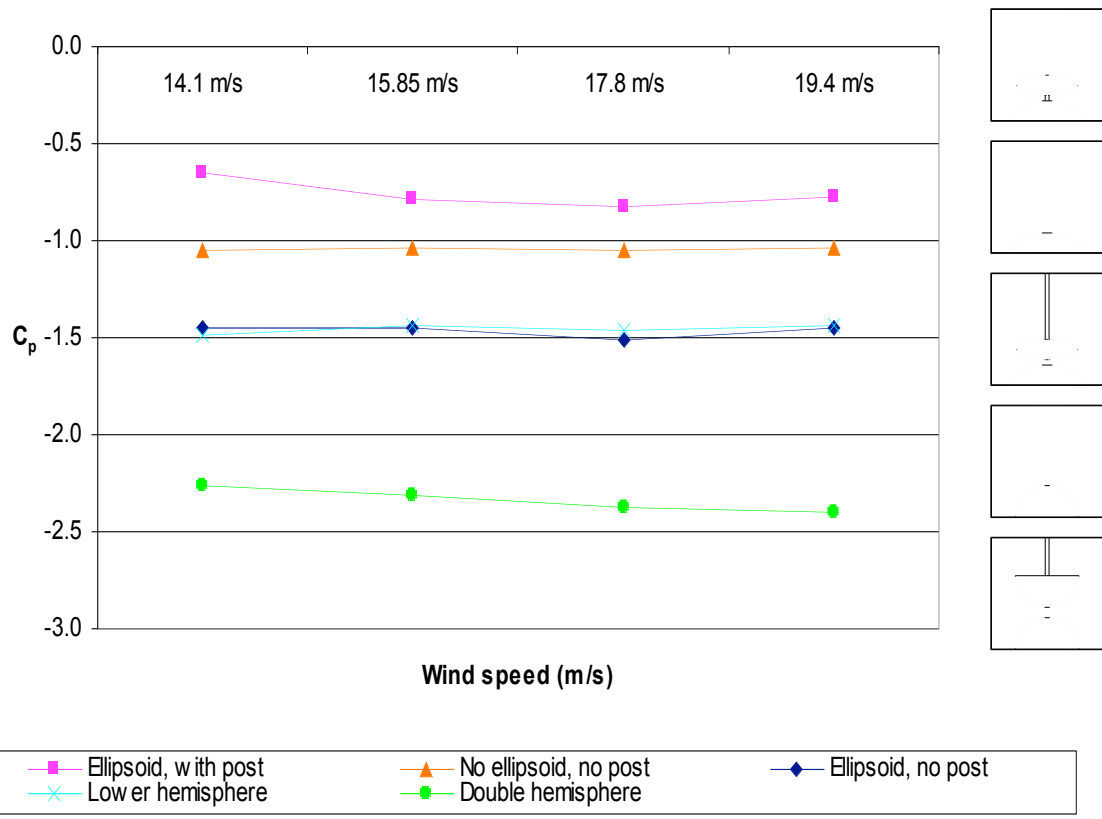


Figure 4. Experimental Results Showing Pressure Drop Inside the Roof Vent Base.



Figure 5. Experimental Setup in High Speed Wind Tunnel.