DESIGNING ROOFS TO AVOID AIR INVASION AND POSITIVE PRESSURE FROM WITHIN

Lyle D. Hogan, P.E.

ABSTRACT

There is a growing consensus that roof assemblies are capable of performing far better than is suggested by wind events of recent years. After all, the often-specified wind rating of 1-90 is equivalent to considerably less than 1 psi (6.89 kPa) of uplift force. It seems reasonable that a roof should withstand such an influence, yet wind events producing seemingly low working pressures have produced catastrophic (sometime wholesale) loss of roof covering. Surely something else must be going on.

Most studies of wind-related loss indicate assistance from air invasion and/or positive operating pressures due to activities within the structure. These maladies in a finished roof assembly may show up as

- *membrane billowing between points or lines of attachment (Figure 1),*
- *unexplained moisture gain below the membrane,*
- *disbonding of adhered flashing sheets, and*
- *loss of roof covering at comparatively low wind speeds.*

These observations can be traced to one or both of the following features:

1. *Positive internal operating pressures particularly common in industrial settings: Air-permeable roof decks (such as plank type) are vulnerable to such pressure, as opposed to monolithic roof decks (poured type). Air movement at roof-to-wall connections may also occur on some decks considered to be otherwise impermeable.*
2. *Invasion of outside air due to architectural features: Wall details and other construction features can vary widely, with little or no consideration given to their effect on the roof construction.*

This paper addresses each of these aspects by examining cause and effect. The role of the air retarder is reviewed as it relates to improving wind uplift resistance. Suggestions are offered to sidestep wind loss from the outset of construction (since retrofit efforts are a far more expensive approach).

POSITIVE INTERNAL OPERATING PRESSURES

Many industrial activities operate in a setting of positive internal pressure. Most building environments operate in a minor positive influence not readily detectable to occupants. Phalen (1992) suggests normal operating pressure on the order of 0.5 to 1.0 in. H_2O (124.5 to 249 Pa). Pressure is brought about by heating, ventilating, and air-conditioning (HVAC) make-up air and has been documented by actual manometer measurements across a roof. Ordinarily the pressure differences created by the air temperature variance (inside to outside) and the negative pressure produced by wind speed are greater in magnitude than those produced by HVAC systems (Griffin 1982). However, the total pressure acting on a surface is the sum of inside and outside influence.

Some portions of a given structure may experience internal pressure well in excess of these values. Difficulty in opening and closing doors is a sure indication that such pressures are at work. Figure 2 depicts the sawtooth monitors of a textile weaving room acting in

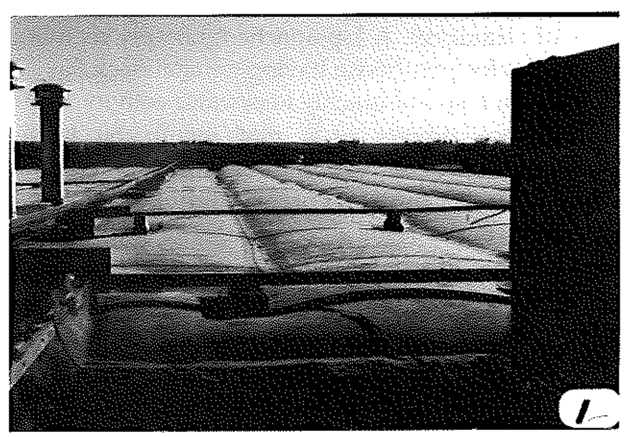

Figure 1

response to positive internal pressure. The billowing condition was remedied by modification to interior ventilation and floor ducts. Figure 3 shows ballooning/inversion of a shallow parapet wall flashing from similar internal pressure.

Lyle D. Hogan, P.E., R.R.C., Principal, Centrum Engineering Consultants, Inc., Winston-Salem, NC.

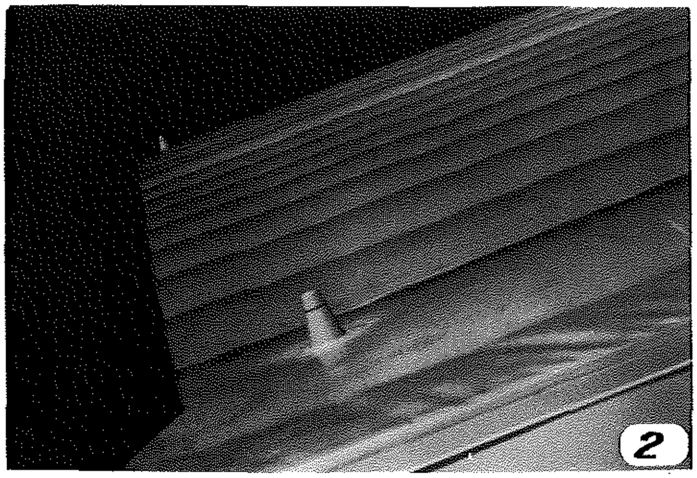

Figure 2

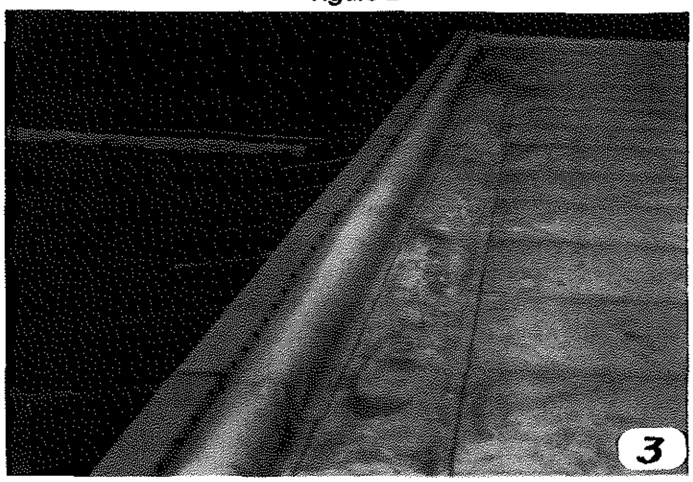

Figure 3

Consider also the influence of a bank of elevators in a high-rise structure. An analogy can be drawn here with a piston/cylinder configuration (although differing by the wall clearance). A lap-attached, one-ply membrane on an elevator penthouse having a metal deck has been observed to respond quickly to elevator activity within.

The susceptibility of a roof membrane to react adversely in these settings is directly related to the type of roof deck. For purposes of this study, decks are either permeable or impermeable. The permeable decks are those that permit pressure equalization across the section. Examples are

- fluted metal decks,
- tongue-and-groove wood,
- precast concrete channel planks,
- plywood (if properly spaced; more on this type elsewhere herein),
- structural cement fiber, and
- structural concrete single tees and double tees.

Impermeable deck systems are those constructed in a monolithic nature, such as

- gypsum concrete on formboards and bulb tee rails;
- lightweight insulating concrete (even when installed over a slotted metal formboard);
- compacted-in-place, thermosetting asphaltic fill carried on some type of subdeck or formboard; and
- cast-in-place structural concrete.

It should be noted that impermeable decks may not be "absolutely" impermeable and do not have to be for satisfactory performance. Claiming such a title, however, mandates an extremely slow *rate* of air diffusion across the section. The better wind performance of roofs on monolithic decks has been recognized (Alumbaugh 1989).

Certain permeable deck types could be made virtually impermeable by treatment at joints or laps of adjacent units. For example, a fluted metal deck could be caulked along side laps and end laps (during original placement). Structural cement fiber could be thoroughly grouted or sealed between joints. While clearly possible, it may be more rational to consider matching permeable decks to roof coverings that are more resistant to air movement influences. For instance, higher-modulus, bituminous membranes do not exhibit the fluttering that an intermittently attached, one-ply membrane may exhibit.

Spray-in-place polyurethane foam (PUF) roofs are capable of enduring the combined effects of high wind speeds and high internal pressures. This has been documented by research in the aftermath of recent natural phenomena. However, when going over an existing roof covering, the ultimate uplift resistance of a spray foam depends on the attachment quality of the substrate to which it is applied. The foam in certain over-roof assemblies under study has been credited with limiting the size of an area peeled by high winds (Smith 1993). Undoubtedly, the monolithic nature of the foam installation plays a role in this performance.

INVASION OF OUTSIDE AIR

Fairly well understood is the partial vacuum created on rooftops under the attack of high winds. This is referred to as "negative pressure," and its influence on a roof is additive with internal positive pressure. Note that the magnitude of this combined uplift is dependent upon the air permeability of the entire system. A steel roof on an oil storage tank (at low slope) may experience considerably more uplift influence than loosely nested clay tiles (McColl 1990).

The focus of this paper is how outside air invades a building envelope and combines with any ambient positive pressure therein. Certain architectural features invite invasion of outside air. Examples are

- recessed masonry surfaces (Figure 4);
- poorly restrained fascia metals;
- void spaces within perimeter carpentry;

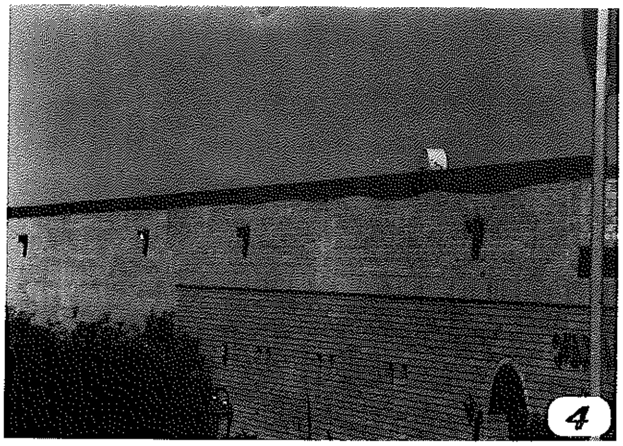

Figure 4

Figure 5

- corrugated claddings joining the roof plane (Figure 5);
- any eave-type overhangs, including entrance awnings and mansards; and
- loosely fitted roll-up doors.

All of these can figure prominently into the loss of roof coverings at comparatively low wind speeds. Alternatively, correction of the condition results in sharply enhanced wind resistance with no modification to the roof. This is the basis for storm shutters, which appreciably reduce pressurization of a building envelope. When attacked on the windward side, the shutters impede the time rate of air diffusion into the structure.

AIR RETARDERS AS A COMPONENT

To avoid confusion (which occasionally surrounds the term *vapor barriers*), the term *air retarders* is used in this paper. Dregger (1991) suggests that any membrane, sheeting, or other material installed onto a roof deck that retards the passage of air meets this definition. Even when flashed and detailed, it is somewhat doubtful that an actual "barrier" has been (or can be) built. As stated earlier, this may not be a necessity since it is the *impedance* of air diffusion upward and through a roof that is sought.

Figure 6

Construction faces enough difficulty with watertightness. To demand airtightness strives for a new plateau. What will be the standard by which air retarder construction is judged? ASTM E-283 is a standard by which building wall panels are evaluated for air infiltration rate. A specification may read "... not more than 0.06 cfm per square foot when tested with a static air pressure differential of 1.57 psf." There is no equivalent for air retarders in roofing.

Meanwhile, many things may serve as air retarders, whether or not by intent. Plywood and OSB decks (properly attached) may behave in the role of air retarders for architectural metal roofs (SMACNA 1993). Some of these installations have withstood hurricane-force winds without loss. The deck units ordinarily have deliberate spacings, and any underlayments present are loosely lapped and nailed; therefore, they are certainly not airtight. Nonetheless, the rate of underside wind attack is less than that of the same metal roof having no subdeck.

An original built-up roof left in place may serve a similar role for a lightweight, one-ply membrane system later placed atop. While this is no substitute for proper edge detailing, staving off positive internal pressure influence throughout the field of the roof is a noble final function for the old bituminous system.

Polyethylene film with taped laps (Figure 6) may be employed as an air retarder. The sheet may rest on a permeable deck and be fastened together with the insulation on top. Such is the recommendation for loosely laid and inverted (one-ply) roof systems in high wind zones. The small percentage of surface area punctured may not violate the intent of the air retarder to *slow* or *impede* air passage.

The topic of unwanted (and possibly unexplained) moisture gain within a compact roof assembly has bearing in the study of air retarders. Note that a psychrometric analysis assumes continuity of insulation and

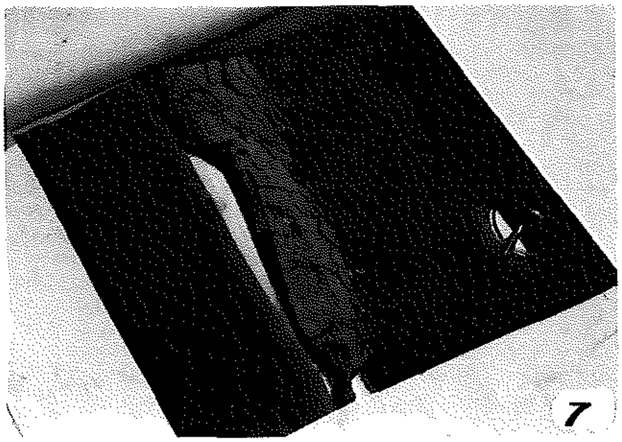

Figure 7

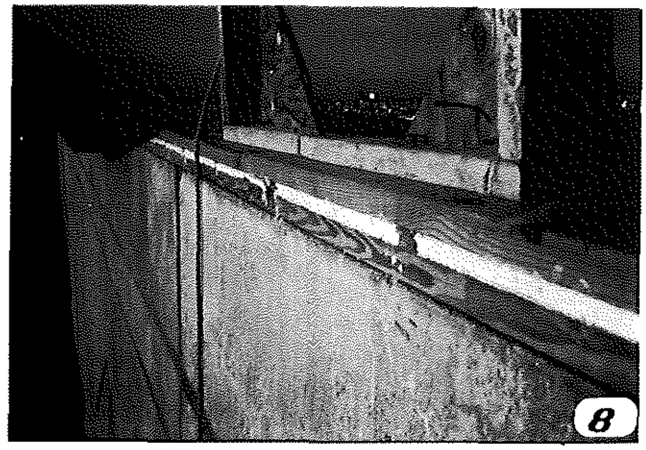

Figure 8

steady-state conditions (no ventilation). Yet, dimensional change (specifically shrinkage) of boards permits thermal short circuiting with possible moisture gain within (Figure 7). Such moisture gain can occur where psychrometric study did not indicate the need for a vapor retarder. An air retarder in the same assembly could serve in a secondary capacity as a vapor retarder. This is especially helpful in loosely laid and lap-attached one-ply roofs subject to wind flutter. These oscillations of the membrane indicate interaction with interior air (Dupuis 1985).

RECOMMENDATIONS

The following suggestions will reduce the rate at which air (from outside or within) infiltrates the envelope. Clearly, for a given project, some of these are more appropriate than others. They should be judged accordingly against the backdrop of rational financial constraints:

- Where practical, close the joints of plank-type roof decks. Gun-grade sealants, specialty tapes, and foam-pack insulation each have appropriate application.
- Avoid recessed masonry or other wall features that invite wind to the underside of a roof deck.
- Consider the use of air retarders for loosely laid, inverted, and lap-attached membranes on permeable decks.
- Include properly fitted sponge tube closures where corrugated claddings join the roof. Proper fit generally requires 15% compression of the molded shape.
- Incorporate two-faced construction tape behind lock strips or fascias of perimeter metals.
- Avoid intermittent perimeter carpentry features that provide an avenue of air entry (Figure 8). This is crucial in freezer construction, where incoming moisture-laden air is more calamitous than a roof leak (Figure 9). Redundancy is appropriate in effectively constructing freezer edges (Figure 10).

Figure 9

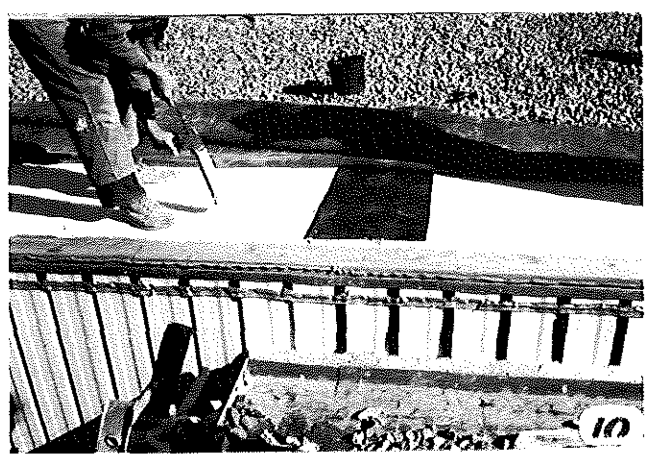

Figure 10

- Consider leaving in place original bituminous roofs when reroofing with one-ply membranes. This decision should still proceed along recognized lines of judgment concerning trapped moisture and deteriorated decks.
- Close the roof-to-wall juncture by appropriate means to prevent pressurization of perimeter flashing.

Figure 11

Foamed-in-place techniques are superior to attempts to custom cut such closures (Figure 11).

- Bolt or otherwise rigidly secure joists and carpentry of overhangs and entrance awnings. Casually nailed connections have not fared well in significant wind events.

CONCLUSIONS

Roof design must take into consideration the inside building pressure (or potential for pressure) in order to meet expected wind resistance. The specific building use is more important than ever as a design parameter. This may lead to the use of air retarders and attention to other factors distinctly apart from the prevention of water entry.

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