DRYING OF ROOF INSULATION: THE USE OF WICKS TO ENHANCE VENT PERFORMANCE

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There is a need for a positive means to dry wet insulation on horizontal roofs. The effectiveness of vents is questionable unless forced ventilation is included.

The present paper reports results on a different technique for roof drying: capillary action. Vertical wicks are used to draw water out of the insulation and bring it in contact with air above the roof membrane. A horizontal wicking mat also is added under closed cell insulation.

Wet samples of roof insulation were tested under laboratory and field conditions. These were compared to vented samples under identical conditions. In most cases the drying rate of the wick system was an order of magnitude greater than the vent system.

Moisture in insulated built-up roofing systems causes many premature roof failures and unwanted energy losses. When the insulation becomes wet, the air or gas spaces become filled with water. Heat transmission through the water-filled spaces then causes the overall conductance of the insulation to increase substantially.[1] Moisture can enter the roofing system through splits, tears, punctures, and small cracks which may develop at the seams or from weathering. Poorly designed roofs develop ponding which increases the possibility of water intrusion, particularly if a split or puncture occurs.

Breather vents have been suggested as a means to dry out wet insulation. Hollow vent are inserted from above, through the membrane into an insulation to provide a path for external air to contact the wet insulation. Tests carried out by Tobiasson et al[2] indicate that venting methods are very inefficient. Based on their tests, they project drying times for wet insulation which range from one to several decades. This is due to the high air-flow resistance within the insulation. Drying times can be substantially reduced by using mechanical blowers to force the air through the insulation, unless the insulation is closed cell. The cost and complexity of such a system will be a strong bar to its widespread use. In addition, it is not a continuous, permanent solution.

Given the current state of the art, the accepted solution for a roof with wet insulation is to replace all of the affected insulation. The present paper presents preliminary test results of a new passive technique for drying wet insulation. This technique uses a wick to draw water out of the insulation and bring it into contact with ambient air above the membrane.

WICK DRYING SYSTEM

The new drying technique is illustrated, along with the conventional vent, in Figure 1. In the new system, a vent tube, shielded from the rain, penetrates the membrane. A continuous, thick wick is inside the vent. (*Figure 1b*). The wick is forced down into the wet insulation when the vent is installed. An additional horizontal wick also is shown. Water is drawn up the wick by capillary action. The upper end of the vent tube is open so ambient air can circulate directly over the wet surface of the wick. The conventional vent tube, Figure 1a, has a nearly stagnant column of air within it. The evaporation rate from the insulation is limited to the rate at which water vapor can diffuse through the stagnant air. Wind over the roof surface does not substantially diminish this resistance if the insulation is impenetrable to air.

ANALYSIS

In order to compare the order of magnitude of drying rates between the conventional vent tube and the new wick technique, a simplified analysis of the drying rate for each case is presented.

For the open vent tube with impermeable insulation the rate of evaporation is determined by the steady state diffusion of water vapor up the tube. This is estimated by Rohsenow and Choi[3] as:

$$w = \frac{A_0 D}{L}(C_{SAT} - C_{AMB}) \tag{1}$$

where w is the rate of water evaporation; A_0 is the cross-sectional area of the tube; D is the diffusion coefficient of water vapor through air; L is the tube length; and C_{SAT} and C_{AMB} are the saturated water vapor concentration in air at ambient temperature and the water vapor concentration in the ambient air, respectively.

For a wick system the controlling resistance to evaporation is given by the mass transfer from the wet wick to air flowing over it. This can be given in terms of the mass transfer coefficient, h_D:

$$w = A_{WICK} h_D (C_{SAT} - C_{AMB}) \tag{2}$$

where A_{WICK} is the area of the wet wick in contact with the ambient air. The mass transfer coefficient can be related to the velocity of the air flowing over the wick, and the wick diameter d_w:

$$\frac{h_D d_w}{D} \quad 0.26\left(\frac{d_w V_{AMB}}{\nu_{AMB}}\right)^{0.6}\left(\frac{\nu_{AMB}}{D}\right)^{0.3} \tag{3}$$

For V_{AMB} of 5 ft/sec, d_w of 1 inch, h_d becomes approximately 24 D/d_w. Combining this with equation 2:

$$w \approx 24 \frac{D A_{WICK}}{d_w} C_{SAT} - (C_{AMB}) \tag{4}$$

Comparing this with equation 1 for the vent tube, where A_{WICK} and A_0 are the same order of magnitude, it can be seen that in the wick system the evaporation rate is more than one order of magnitude greater than the vent tube.

Experimental Procedure

In order to determine the performance of the wick system, preliminary experiments were carried out both in the laboratory and in outdoor tests. The wick materials initially were tested for vertical capillary action in small closed containers filled with water. The wicks were pushed through tubes placed in a hole through the lid of the container with one end in the water and another exposed to the air. For comparison, a test was carried out using the open tube as a vent.

In a second series of tests the wick material was attached to wet insulation. (*Figure 2*). Wick material in some instances also covered the bottom side of the 2-foot by 6-inch piece of insulation. The wet insulation samples were tightly wrapped in a plastic bag to prevent water loss or air flow over the insulation. At one end a hole was cut, through which the verticle wick could be inserted and brought up through a hard plastic tube. A check test was set up with open vent tubes without wicks at both ends of the insulation. Holes were drilled through the insulation to hold the tubes. However, this exposed the water collected at the bottom of the bag directly to the air and caused abnormally high evaporation rates for the first half of the test. The holes were filled in for the second half of the testing so that the tube extended to the top of the insulation board. This lowered the rate significantly.

Samples were injected with about 200 grams of water and the wicks were suspended vertically above the insulation. Tests for moisture loss were made in the lab, within a tent with high humidity air with low velocity air flow, and outdoors on a roof. The samples were weighed once a day, if possible, and the atmospheric conditions for the period were recorded. As the water level became low, more water was injected through the side of the bag onto the insulation. The tests made in the lab were subject to a constant airflow from a large fan. The plastic tent covered the samples and several pans of water to increase the humidity. A box fan was inserted in the tent to create a consistent flow of air although the air velocity was not measured. The humidity in the tent was tested with a hygrometer, and the air in the lab with a sling psychrometer. The tests conducted on the roof involved covering the wicks to prevent exposure to sunlight and to prevent dew from collecting in the tubes. The wicks and tubes were enclosed in a perforated steel pipe which was covered with a cap of insulation material (*Figure 3*). Some wicks were modified during testing. These changes will be explained in the discussion section.

Various wicking materials and roof insulations were tested. Wicking materials included tight weave felt, cotton terrycloth and fiber glass textile fabric. The first two are less practical than the fiber glass since they tend to deteriorate after remaining wet for extended periods. They were included to determine if wick characteristics were important to results.

Three different commercially available roof insulations were used: urethane foam combined with perlite board with a layer of felt on the foam for a total board thickness 1.9 inches and R = 10; 1-inch thick urethane foam covered on both sides with organic felt R = 6.7; and 2-inch thick fiber glass covered on one side with a layer of felt R = 8. During the tests a layer of wicking material was placed directly under the urethane insulation to facilitate horizontal movement of water.

RESULTS

The tests of the closed water container, with no insulation, in contact with ambient air either by an open vent tube or a vent tube containing a wick indicate the relative performance of the two techniques. The results of laboratory tests and outdoor tests are summarized in Table 1.1 and 1.2. The data in the table are average water evaporation rate per day. It can be seen that the evaporation rates with the wick are more than an order of magnitude higher than those without the wick. As expected, evaporation rates increased as the absolute humidity of the laboratory air decreased. It was found that if wicks were made from a single flat layer of material, wick performance deteriorated as solids deposited in the wick during water evaporation. Cambridge, Mass. city water, which is hard, was used for these tests. This problem was later alleviated by using wicks made of multiple layers of material.

The fabrics giving the best results in the wick tests, terrycloth and doubled fiber glass, were used in the insulation and wick tests. The conditions and results for these tests are listed in Tables 2 and 3. The results were similar for the urethane and urethane-perlite insulation boards because of their water resistance. The average test results indicate that the wick dries the insulation much more effectively than the vents. The humidity outdoors was twice that in the lab, causing the evaporation rate outdoors to decrease more than 50 percent. Likewise, the moisture loss decreased due to the higher humidity when the samples were placed in the tent. Throughout the higher humidity tests the evaporation rate from the wicks was still 4 to 10 times greater than through the vents. The rate doubled when new fiber glass wicks were installed in the samples. The fiber glass was folded over several times to increase the flow area and attached to the base of the original wick. This new wick increased the moisture evaporation by increasing the cross sectional area and by eliminating clogging by deposits left by the evaporating water. These deposits tended to build up and stop capillary flow below the top of the tube, slowly reducing moisture loss. The evaporation rate with the folded wick was at least six to 20 times greater than the corresponding tests with the vent.

The predicted values of the evaporation rate for wicks and vents also are shown in Table 3. The predicted rates are based on equations 1 and 3, and correlate with the relative magnitudes of the actual evaporation rates. Exact agreement with measured values was not expected since the active area of the wet wick is difficult to assess and air speed is only an estimated value. The measured evaporation rates of the vents in Table 2 is somewhat higher than that predicted by equation 1. This suggests that there was a modest bulk air circulation through the insulation.

Using conditions similar to the laboratory or outdoor conditions of this test, a wick with a 6-square-inch wet surface area exposed to air will evaporate 0.13 cubic feet of water per month. This is equivalent to drying a water layer ½-inch thick covering 9-square feet in three months.

CONCLUSIONS

Initial tests indicate that sections of wet roof insulation can be dried by wick systems approximately an order of magnitude faster than by conventional vents. The wick system holds promise as a viable passive system for drying wet roof insulation.

Fine mesh, inorganic fabric such as fiber glass cloth is the preferred material for wicks since it provides good capillary action and won't rot. The wicks should be multilayer to prevent fouling after excessive evaporation of mineral-laden water. The preliminary data with wicks agrees with a simplified analytical model for the drying rate. Extrapolating this model to longer times suggest that to dry a wet roof section initially containing one half inch of water in three months, requires one wick having an exposed area of 6 square inches for every 9 square feet of roof area.

REFERENCES

[1] Hedlin, C.P., "Effect of Moisture on Thermal Resistance of Some Insulations in a Flat Roof under Field-Type Conditions," *Thermal Insulation, Materials, and Systems for Energy Conservation in the '80s, ASTM STP 789,* F.A. Govan, D. M. Greason, and J. D. McAllister, Eds., American Society for Testing and Materials, 1983, pp. 602-625.

[2] Tobaisson, Wayne, Korhonen, Charles, Contermarsh, Barry, and Greatorex, Alan, "CAN WET INSULATION BE DRIED OUT?" *Thermal Insulation, Materials, and Systems for Energy Conservation in the '80s ASTM STP 789,* F. A. Govan, D. M. Greason, and J. D. McAllister, Eds., American Society for Testing and Materials, 1983, pp. 626-639.

[3] Rohsenow and Choi, *Heat Mass and Momentum Transfer,* Prentice-Hall, Engelwood Cliffs, NJ, 1961.

NOMENCLATURE

A_O	Cross sectional area of vent tube
A_{WICK}	Area of wet wick in contact with air
C_{AMB}	Water vapor concentration, ambient
C_{SAT}	Water vapor concentration, saturated at ambient temp.
D	Diffusion coefficient of water vapor through air
d_W	Wick diameter
V_{AMB}	Velocity of air over wick
W	Rate of evaporation
v_{AMB}	Kinematic viscosity of air

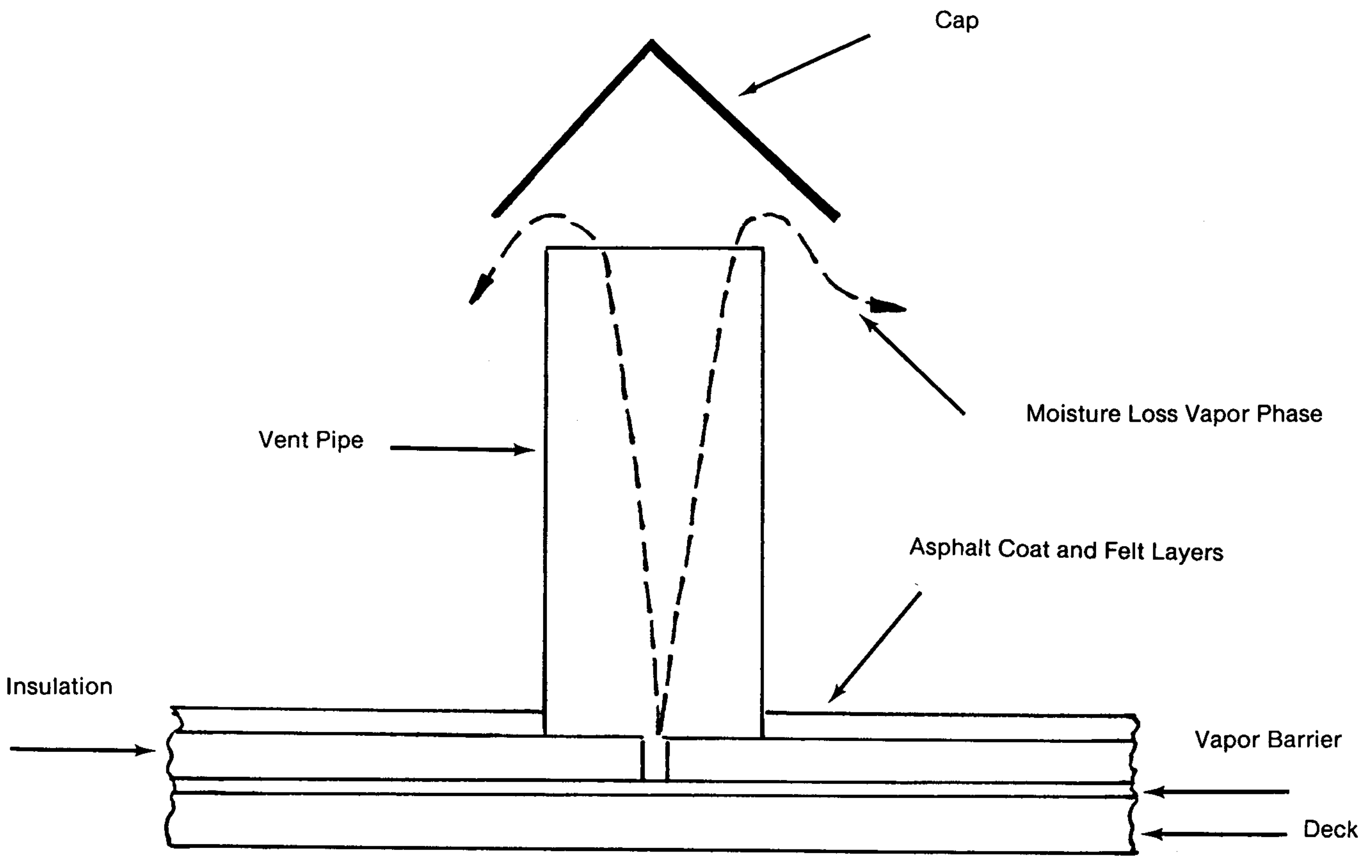

Figure 1-A Moisture loss through top relief vent

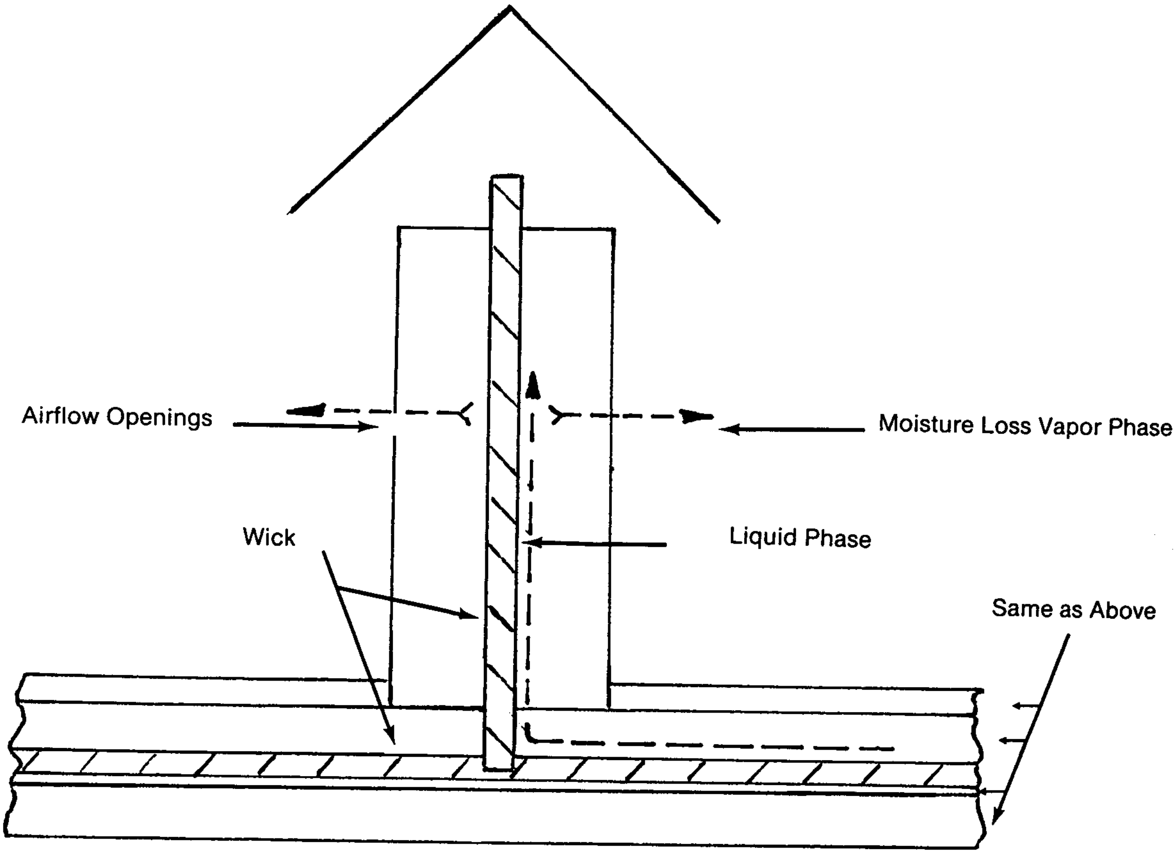

Figure 1-B *Moisture loss through wick*

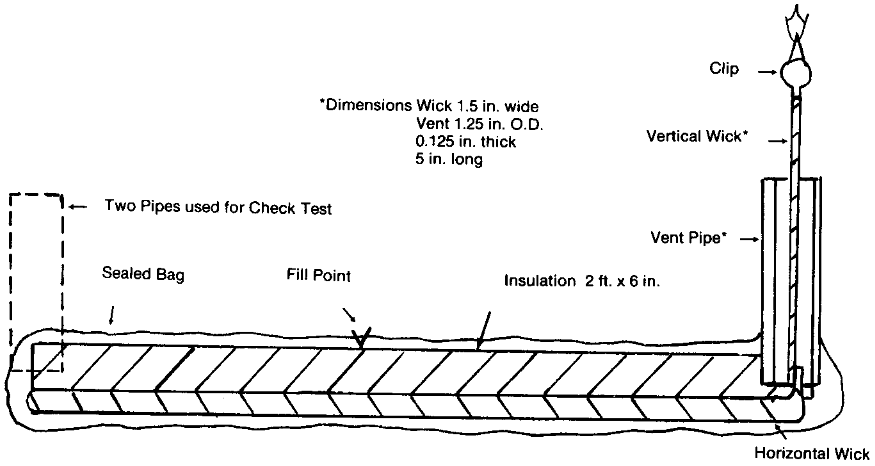

Figure 2 *Insulation and wick test apparatus cutaway side view NOTE: Bag is tightly wrapped around insulation. Metal clip supports vertical wick.*

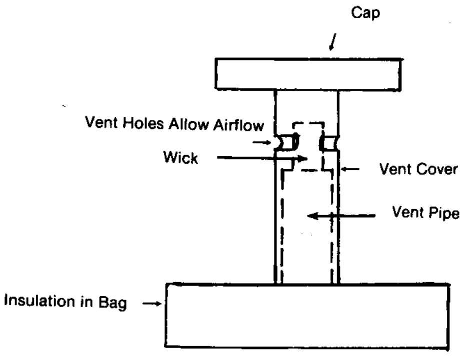

Figure 3 *Roof test apparatus front view*

NO.	Test Description HUMIDITY	TEMP. (°F)	Wick: 1 Terrycloth	2 Fiber glass double layer	3 Vent (No wick)	4 Fiber glass single layer	5 Felt
1	20%	71	44	41	3.5	31	25
2	24%	74	38	32	1.5	25	24
3	25%	74	41	50	3	33	25
4	45%	77	33	29	2	22	21
5	35%	77	7*	25	1	2*	19

*Replaced with old wick

Table 1.1 *Water loss (g/day)*
Wick tests with closed water container (no insulation present)
Indoors, constant air flow

wick No.	I Cloth double	II Glass	III Vent (No Wick)	IV Glass single	V Felt %	Hum °F	Temp mph	Average Conditions Wind % of Total	Sunshine
1	33	31	21	24	23	38	50°	12	100
2	19	22	1	16	18	55	48°	12	100
3	26	22	1	18	20	50	58°	18	83
4	18	23	2	20	15	52	54°	15	80
5	41	38	4	28	32	41	58°	15	98
6	3*	30	4	3*	15	40	48°	11	98

*Replaced original wick with used wick

Table 1.2 *Water loss (g/day)*
Wick tests with closed water container (no insulation present) outdoors

Wick Material	Fiberglass (Plus Hortz. Cloth)	Cloth	Fiberglass	Vent (Mult. Folds)	Humidity (No Wick)	Temp %	Wind Speed (°F)	(Mph)
Laboratory	8	1 3	14	17	3	25	77	5
Test Enclosure	2.5	9.9	6.0		0.7	61	78	
Outside		5	4	19	1	46	52	14*

*Weather Bureau Data - Actual wind speed over sample was lower.

Table 2 *Moisture loss from polyurethane foam insulation with wicks versus vents*

Wick Material	Fiberglass	Predicted* (Mult. Folds)	Predicted Wick, Eqn. 3	Humidity Vent, Eqn. 3	Temp %	Wind Speed (°F)	(Mph)
Laboratory	6	18	30	0.5	25	77	5
Test Enclosure	5		17	0.3	61	78	
Outside	10	19	18	0.2	46	52	14

*Assuming area of wet wick exposed to air is 1 in².

Table 3 *Moisture loss from figer glass insulation with wicks versus vents*