CONDENSATION MODELING OF EPDM SINGLE-MEMBRANE ROOF SYSTEMS

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A computer program has been developed that simulates water vapor diffusion through, and condensation in, a roof system. This program utilizes Typical Meteorlogical Year data for a given locale, a building's interior temperature and humidity, and the diffusion and heat transfer characteristics of all the components of the roof system to determine the amount and location of water vapor condensation in the roof system over time.

The computer program predicts that water vapor diffusion and condensation will occur in cold weather in single-ply EPDM (ethylene, propylene, diene terpolymer) roof systems installed over warm, humid buildings. Additionally, the program predicts that during hot, humid summer weather small amounts of moisture vapor will diffuse through the roof membrane and condense in the roof system of cool, air conditioned buildings. Partial correlation of these predictions to field experience has been achieved. More extensive studies are being carried out to complete the correlation.

MOISTURE CONDENSATION IN SINGLE-PLY ROOFS

The use of single-ply membranes in commercial roofing has increased greatly in recent years. These systems have captured approximately 30 percent of the commercial roofing market[1]. The single-ply membranes consist of EPDM, PVC, PIB, neoprene, Hypalon, chlorinated polyethylene, modified bitumen, and other polymeric-based compositions fabricated into sheets of varying dimensions. The thickness of the sheets has ranged from 20 to 120 mils, although industry trends indicate the minimum thickness of any product is approaching 40 mils. The membranes are utilized with a variety of roof insulation materials including wood fiber, perlite, urethane, isocyanurate, polystyrene, fiber glass, and others. These roofing systems are being used over all of the common deck materials. The system are secured by ballasting, mechanical attachment, or fully adhering to a secured insulation substrate.

As one can see from the above description of single-ply roof systems, the membrane is the only material that is new to the industry. The insulation and deck materials have long been used with conventional BUR construction.

The diffusion of moisture vapor into BUR roof systems has been studied and is well understood. For many years, vapor-retardant membranes have been specified in roof systems for buildings with relative humidity over 45 percent located in cold climates where the mean January temperature is less than 40F. The inclusion of a single-ply membrane as the covering material has not eliminated moisture diffusion and condensation as a potential problem in the roof system. The diffusion and condensation of moisture vapor in a roof system is independent of the type of roof membrane.

Fick's Law (1), the mathematical basis for moisture diffusion, states that the rate of diffusion is dependent on the permeability, thickness, and vapor pressure difference on either side of the material. Water vapor always diffuses from a region of high vapor pressure or humidity to one of low vapor pressure or humidity. Significant water vapor diffusion occurs through the deck, the insulation, and the EPDM membrane. If the concentration of water vapor exceeds the material's saturation limit as determined by its temperature, then condensation occurs.

$$W = U \cdot dP/L \qquad (1)$$

W = the rate of diffusion in pounds per square foot per hour
U = the permeability in pounds per square foot per hour
dP = the difference in vapor pressure in inches of mercury
L = the distance in inches through which the diffusion occurs

Asphaltic roof membranes have essentially zero permeability (U) due to the mass of asphalt in the membrane. EPDM membranes have permeability values that are much higher than asphaltic membranes. Also, the permeability of the EPDM membrane increases greatly with increased temperature.[2] Thus on air conditioned buildings located in warm, humid climates, EPDM membranes can pass moisture through to the roof system.

The harmful effects of moisture in single-ply roof systems are every bit as bad as with conventional BUR. Loss of insulation thermal value, metal deck and fastener corrosion, wood deck rot, and lap adhesive deterioration are just a few of the problems caused by moisture trapped under the membrane. Computer analysis of potential condensation prior to construction should help to avoid design mistakes that would lead to these problems.

THE COMPUTER PROGRAM

Since water vapor diffusion and condensation are dependent on temperature, one needs to consider heat transfer phenomena and diffusion theory when performing a condensation analysis on a roof system. A proprietary computer program entitled COND, short for CONDENSATION, was developed by Manville with this purpose in mind. This program is unique in that it combines finite element transient heat transfer analysis with fundamental diffusion theory to allow for the characterization of time-dependent moisture accumulation in roofing systems.

Components of a roof system are represented in the Finite Element Model shown in Figure 1. Typically the membrane comprises sectors one and two, the insulation three through 10, and the deck 11 through 18. Alternatively, sectors three through 18 can be broken down further to include a vapor retarder or a reroof situation. In each sector an array of "nodal points" exist where heat transfer, vapor pressure, dew point temperatures, and moisture accumulation calculations are made.

Descriptions of inputs, operations, and outputs are given below.

INPUTS

1. A Typical Meteorlogical Year data tape is the weather input. This tape provides fifty-year averaged temperature, humidity, and solar radiation data on an hourly basis for many cities in the United States.
2. Building humidity and temperature.
3. Membrane thickness and permeability, as a function of temperature
4. Insulation and deck material properties
   a. Thermal Conductivity, k-value
   b. Density
   c. Heat Capacity
   d. Permeability
   e. Saturation Point

OPERATIONS

1. A heat transfer analysis is performed, calculating temperatures at each nodal point.
2. External and internal vapor pressures are calculated.
3. The permeability of the membrane is determined, according to its temperature.
4. Vapor pressures are determined for all nodal points.
5. Nodal point dew points are calculated.
6. A temperature check is made to determine if temperatures determined in Step 1) above are below the dew points calculated in Step 5). If this is true, then condensation occurs.
7. Knowing the diffusion rate, the dimensions of the system, and the elements in which condensation occurs, moisture accumulation for a given time increment is calculated.
8. Steps 1) through 7) are repeated for the desired period of analysis, with the moisture accumulations being summed along the way.

OUTPUT

1. An incremental listing of Typical Meterological Year data: radiation, outdoor dry and wet bulb temperatures
2. An incremental listing of the percent moisture content by volume for the total system
3. An incremental listing of the system's thermal conductivity
4. A listing of the distribution of condensed moisture in terms of pounds of water per square foot and percent volume of water per square foot in each level of insulation
5. The density, heat capacity, and thermal conductivity (k) in the various levels of insulation

The program is normally run for a year. The results from this year can then be used as input when computing figures for the following year, to show a continued buildup of moisture in the system.

ROOF SYSTEM MODELING

A number of roof models have been analyzed for moisture condensation. A summary of the findings is located in Table 1 and 2.

ANALYSIS OF OUTWARD MOISTURE VAPOR FLOW

Table 1 describes the results of the analysis of buildings with a high (70 percent) interior relative humidity, with and without a vapor retarder. This is the classical high interior humidity condensation problem. Although these models are tested with New Orleans weather tapes, the examples show that there are sufficient cool periods during the year to condense considerable amounts of moisture with this high internal humidity condition.

More water condenses in the steel deck assembly than in either of the concrete or wood deck assemblies. This is due to the fact that the permeability of the steel deck is considered infinite due to the leakage along the panel's end and side laps, in no way impeding the flow of moisture vapor into the roof system. The concrete and wood decks slow the diffusion of moisture vapor into the roof system, thus acting as "pseudo" vapor retarders themselves.

The inclusion of an asphaltic-type vapor retarder (Permeability Value = 0.001) has a significant and desirable effect on moisture diffusion and condensation in the model roof systems. The asphaltic vapor retarder virtually eliminates moisture vapor diffusion into the roof system.

This model shows that moisture will condense under a single-ply membrane, given the right conditions of high internal humidity and low external temperatures and humidity. The permeability of single-ply membranes has been found to be quite low in cold weather. This is the period of the year when outward moisture diffusion processes will occur in high humidity buildings. The membrane, which now has a very low perm value, will act as a very efficient vapor retarder under those conditions, trapping water vapor underneath it. The trapped moisture vapor will, of course, condense at the dew point.

ANALYSIS OF INWARD MOISTURE VAPOR FLOW

Moisture vapor diffuses from hot, humid environments to cool, dry ones. Thus, on an air conditioned building in New Orleans the moisture vapor would be going into that building in the summertime since the cool, dry interior environment would act as a sink for the outside hot, moist air. The computer model has been used to evaluate moisture diffusion in the roofs of air conditioned buildings. The results of these analyses are summarized in Table 2.

The permeability of EPDM single-ply membranes increases greatly with increased membrane temperature. It has been shown that at 158F the permeability of the membrane is in the range of one to three grains per hour per square foot per inch of mercury vapor pressure differential. These perm values are somewhat higher than the generally accepted standard of ©0.5 perms for good vapor retarders. Thus, at high temperatures the membrane has the capability of passing moisture vapor into the roof system.

Steel deck examples could not be included in this analysis since the permeability of that material is considered infinite due to moisture vapor leakage through the end and side seams.The computer model does not record any moisture accumulation in the insulation although moisture is passing through the roof system. Moisture vapor that does enter the roof system is in concentrations too low to exceed dew point limitations in the insulation and is immediately drawn through the roof system into the building.

The concrete and wood deck examples show that some moisture is condensing in the roof system. The moisture accumulation is in the lower levels of the insulation, condensing in the cooler strata. The amount of water collected in these cases is one-fourth to one-tenth of that collected in the outward moisture diffusion and condensation process for similar constructions.

According to the date pertaining to roof construction with vapor retarders, the inclusion of a vapor retarder in the roof system limits the inward diffusion of moisture vapor. This is expected since the vapor retarder membrane will block the roof assembly above it from the low vapor pressure in the building and also cause a build-up of vapor pressure against the EPDM membrane, decreasing the vapor pressure differential, and slowing the inward diffusion.

For example, if the outdoor condition is 90F and 90 percent relative humidity, the vapor pressure is 1.29 inches of mercury. If the inside condition is 70F and 30 percent relative humidity, the inside vapor pressure is 0.22 inches of mercury. The vapor pressure differential is 1.07 inches of mercury, a rather large driving force to draw moisture vapor through the roof system. If a vapor retarder membrane is included in a roof system consisting of 2 inches of perlite on a 4-inch concrete deck roof system, the membrane will be at approximately 75F and 100 percent relative humidity and the vapor pressure will be 0.88 inches of mercury, for a new vapor pressure differential of 0.41. In addition, with the vapor retarder membrane now blocking the inward flow of moisture the roof system can reach a moisture vapor equilibrium with the atmosphere, stopping the diffusion process.

Thus, inward moisture diffusion and resultant condensation can take place. However, the magnitude of moisture accumulation does not appear to be great enough to cause an immediate problem. The computer model has the capability of doing a year-by-year analysis by inputting new moisture accumulation and insulation parameters into the start of the succeeding analysis. Figure 2 represents one such repetitive analysis for an air-conditioned building at 70F and 30 percent relative humidity, located in New Orleans and covered with a 4-inch concrete deck and 3.5 inches of urethane. With the analysis carried out for 25 years, it is seen that the total moisture accumulation is predicted to be 0.0428 pounds of water per square foot of insulation. This cannot be considered a significant amount of moisture.

CORRELATION OF MODEL TO DATE

A small number of unballasted EPDM single-ply roofs were investigated during the summer of 1984 in an attempt to establish a correlation between the computer model and field experience.[2] The majority of these roofs are located on air-conditioned structures and show a directional correlation for inward moisture diffusion and condensation. That is, on three roofs where either two layers of similar insulation exist or the single thickness material is sliced in half, moisture was found to have accumulated more in the lower section than the top.

Correlation of the absolute amount of condensation was not possible since moisture gains could not be determined based on a one-time moisture analysis. The original moisture content of the insulation was not known. Repetitive analyses of these and other roofs are planned to determine moisture gain for correlation purposes.

CONCLUSIONS AND RECOMMENDATIONS

A computer program has been developed and used to predict moisture diffusion in EPDM single-ply roof construction. The program predicts that outward moisture diffusion and condensation occurs in these roof systems in a manner similar to conventional BUR roof system. Therefore, design considerations for single-ply roofs over buildings that have high internal water vapor pressures should include a vapor retarder membrane.

The program also predicts that inward diffusion and condensation can occur in roof systems on air-conditioned buildings. The program predicts that the quantity of moisture vapor that diffuses into the roof system in this manner is small. This is being confirmed, and the effect of small amounts of condensed moisture is also being investigated at this time.

REFERENCES

[1] Thomas, R., "Built Up Roofing: A Decade of Improvements," *Building Design & Construction,* February 1985, p. 90.

[2] Dupuis, R.M., "Field Survey of Moisture Gain Behavior Under Mechanically Fastened Single-Ply Roofs," *Proceedings-Second International Symposium on Roofing Technology,* September 1985.

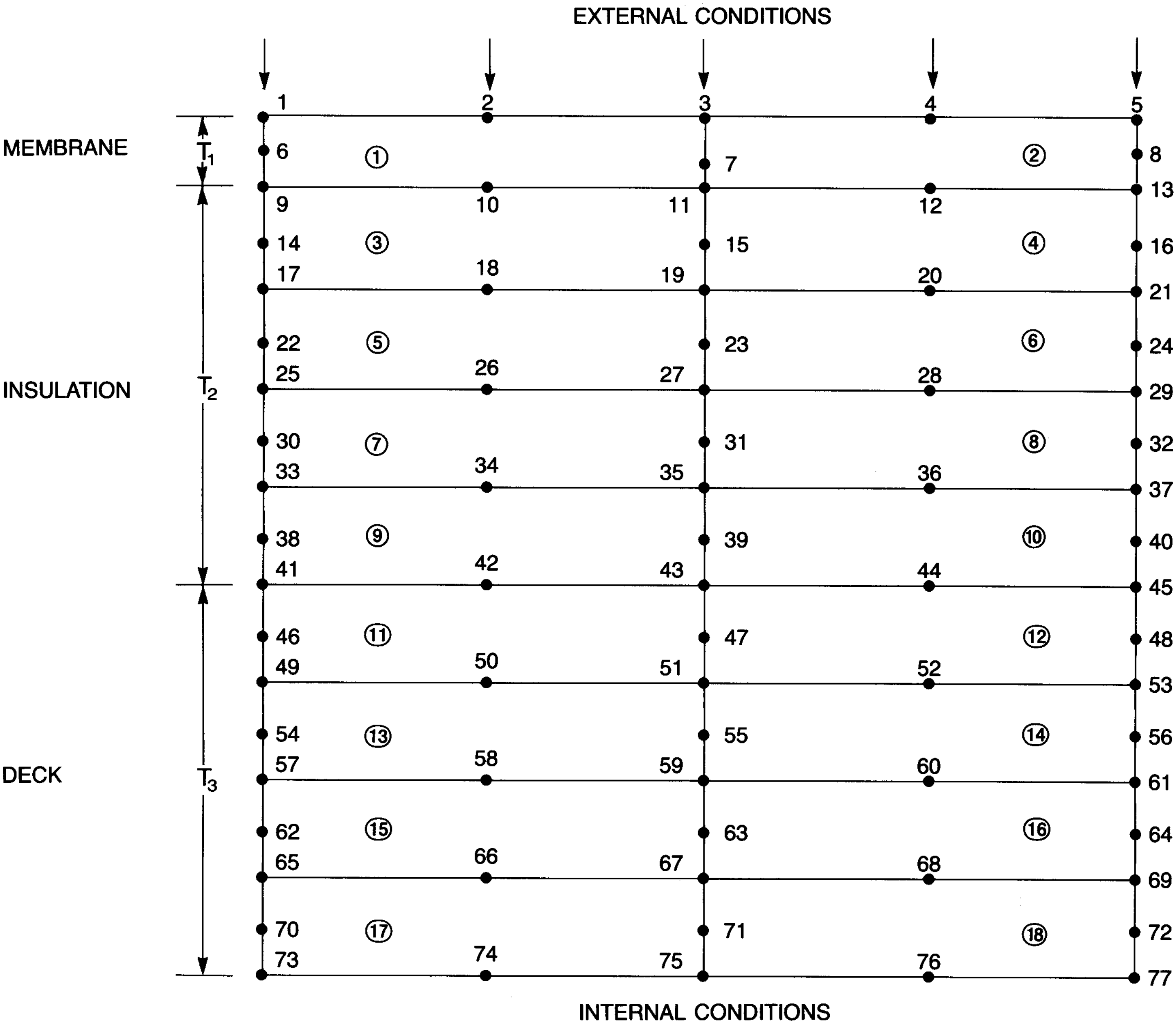

Figure 1 Finite element model of a typical single-ply roof system

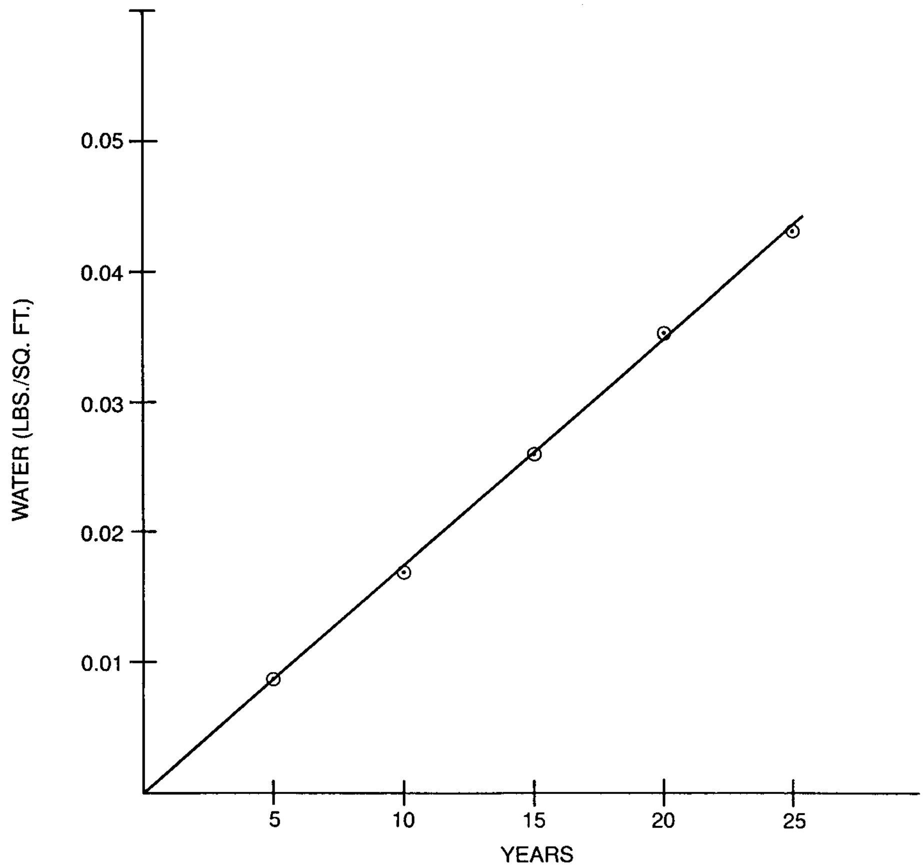

Figure 2 *25-year condensation analysis (New Orleans TMY, 70F-30% RH inside, 45 mil EPDM, 3.5" urethane, 4" concrete deck)*

INSULATION	DECK	WITHOUT VAPOR RETARDER		WITH VAPOR RETARDER	
		Lbs. Water Collected per SQ. FT. YEAR	% Volume of Water per SQ. FT. YEAR	Lbs. Water Collected per SQ. FT. YEAR	% Volume of Water per SQ. FT. YEAR
2 in. Perlite	Steel	0.459	17.65	0.000015	0.00004
	4 in. Concrete	0.0133	0.512	0.00034	0.00976
	3/4 in. Wood	0.0463	1.782	0.000344	0.00964
3.5 in. Urethane	Steel	0.0766	1.683	0.000011	0.00013
	4 in. Concrete	0.00593	0.1303	0.000364	0.00599
	3/4 in. Wood	0.0137	0.3004	0.000369	0.00608

Program Conditions: New Orleans TMY; 70°F-70% RH Inside; 45 Mil Black EPDM.

Table 1 *Roof condensation in humid building*

INSULATION	DECK	WITHOUT VAPOR RETARDER		WITH VAPOR RETARDER	
		Lbs. Water Collected per SQ. FT. YEAR	% Volume of Water per SQ. FT. YEAR	Lbs. Water Collected per SQ. FT. YEAR	% Volume of Water per SQ. FT. YEAR
2 in. Perlite	4 in. Concrete	0.0131	0.5027	0.00054	0.0156
	3/4 in. Wood	0.005	0.193	0.00053	0.0152
3.5 in. Urethane	4 in. Concrete	0.00166	0.0366	0.0006	0.0099
	3/4 in. Wood	0.00127	0.0279	0.00061	0.0101

Program Conditions: New Orleans TMY; 70°F-30% RH Inside; 45 Mil Black EPDM.

Table 2 *Roof condensation in dry building*