Wayne P. Ellis[1]

Summary of Symposium Papers

SESSION I—Construction Aspects and Needs

Moisture Transport in Walls: Canadian Experience—Jim H. White

A survey of moisture problems in Canada showed wide variations in the frequency of problems, geographically, as well as a number of different problems with different causes. When the Canada Mortgage and Housing Corporation (CMHC) mandated the use of furring strips under siding for all east-coast provinces, the industry association demanded repeal on the grounds that the need was not yet conclusively proven. A joint task force was set up to investigate the need and to provide solutions to moisture problems in the maritimes. Three test huts were constructed of wet wood and heavily instrumented. The huts were built in three different cities, each having 16 panels of eight different designs, each on the south- and north-facing sides of the huts.

The airtightness of the panels was tested one year into the project, and was found to be widely variable. The calculated moisture diffusion resistance also was found to be quite variable. Some panels were completely dry several weeks into the project, while others are still not dry after 17 months of monitoring. On decommissioning, mold growth was observed on most of the slow-drying panels. Several of the wetter panels are still being monitored unchanged, while a new set has been built to look more extensively into drying of the outer layers.

Several years of analysis of the processes involved has recently been supplemented by months of laboratory investigation into some of the construction detail and material performance characteristics. The study of the flows of energy, air, and moisture in the outer layers of walls has been upgraded to include the whole wall. Drying times of days to years are predicted, as observed in the field, with the latter most likely when liquid-phase water is present, and diffusion is the dominant mechanism for moisture transport. Few material properties were found in the literature, in the form needed for a sufficiently rigorous treatment of the processes, when simultaneous flows of heat, air, and moisture were present.

A wall system model has been developed by which to simulate these processes. The model can make a simulated one-year run in one night on a high-speed personal computer. It can predict both slow and rapid drying. The presence of liquid water slows the process dramatically. The model, WALLDRY, is being updated into a "builder-friendly" version. Seriously needed are moisture transfer properties of materials—from basic material properties right up to occupied house performance.

*Moisture Transport: Buildings in Hot, Humid Climates—Fairey et al. (Florida Solar Energy Center)**

Building materials absorb and desorb moisture. There are large errors of prediction in different models; 30 to 40% difference in predicted cooling loads. A research program was

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* These papers are not included in this publication.

undertaken to look into moisture effects in hot, humid climates. It involved both moisture research and analytical measurements. A data base was assembled on materials properties. A first-year literature search revealed several different theories of moisture transport and a variety of databases. The Solar Cooling Research Project investigated surface effects that were found to be rapid and brief, while interior effects took much longer, looking at whole buildings now, not samples of materials. Next, computer algorithms will be developed to model combined heat and moisture flow (transport). Three simple standard moisture modeling methods have been developed. Using imposed moisture versus building response in dewpoint and moisture absorption/desorption, looking at the building materials effect, not just the interior air response, moisture is forced into materials. The moisture storage capability of the entire building is observed—a "lump" material approach. In attic behavior, removal rates of heat and mass transfer due to the ventilation air stream are almost the same. Total energy transfer at night is negative due to mass transfer from ventilating air to attic surfaces. Behavior of composite walls can be predicted by the model, and vapor density vacillates wildly. A report will be available in about 90 days.

Moisture Transfer Through Materials and Systems in Buildings—Anton TenWolde

The relationship of practices, models, and standard test methods was discussed. Consensus is needed on guidelines within a consistent approach. Vapor retarders are defined in terms of diffusion, but airflow delivers much more moisture than diffusion. Moisture flow control is air flow control, and retarders really function as air barriers. A building wall is very complex. A viable analytical model is essential to meld materials properties and field measurements. Older methods, such as the dewpoint method or the Kieper method are no longer acceptable because moisture movement is much more complex. All models need data such as hygroscopic input, diffusion coefficients, and airflow rates, and test methods must provide such data. Methods such as ASTM Test Methods for Water Vapor Transmission of Materials (E 96-80) report in terms of vapor pressure, but no information is given on the effect of temperature. A new, non-isothermal method is needed. Additional E 96 data should include sorption, wet and dry cup data, and temperature gradients. Air flow modeling is essential. Moisture movement in materials is greatly influenced by moisture content, and moisture movement occurs by several different mechanisms. Mathematical modeling holds the most promise for understanding moisture movement, but much data must first be provided to characterize transport mechanisms other than diffusion.

Water Vapor Transmission and Moisture Accumulation in Polyurethane and Polyisocyanurate Foams—Norman V. Schwartz, Mark Bomberg, and Mavinkal K. Kumaran

At the Institute for Research in Construction, a modified test cell was devised by clamping specimens of rigid polyurethane foam between cold and hot plates, having on one side of the foam a desiccant and on the other side, water. It was thus possible to measure the accumulation of water within the foam specimen. About 40 days were required to reach steady state, while the measurements were usually complete in about 80 days. Observation of moisture distribution within specimens after nine weeks showed the greatest accumulation toward the warm side. Weight gain by desiccant is a straight line. Temperature dependence up to 21°C is a straight line. From 20°C to 50°C, the rate of gain climbs rapidly.

In conclusion, the three methods gave the same coefficients. Temperature dependence is easy to determine with the modified cell. It allows determination of moisture distribution within specimens. Significant moisture accumulates under a temperature gradient. Water vapor travels through the foam specimens at the same rate, whether or not there is accumulation. Contrary to the isothermal process, the moisture transport in the presence of a thermal gradient results in a large quantity of moisture accumulated in these foams. This phenomenon may be partly attributed to the temperature dependence of the water vapor transmission coefficient.

Condensation Problems in a Refrigerated Storage Building—A Case History—Peter E. Nelson

In a building operated as a cooler, having metal-panel walls and a concrete block wall insulated on the interior side with 4 in. of expanded polystyrene board, a survey to locate causes of observed condensation problems disclosed that the underside of the roof deck was exposed to the cold building interior. The interior moisture level was high. The real problem was found to be inward and outward air flow. Condensation occurred on the underside of the steel roof deck. Air could penetrate through the gasketing of roof vents, creating a stack effect, and resulting in severe condensation and dripping throughout the warm months. Examination of the roof level disclosed EPDM single-ply roofing over 4 in. of polyurethane-200 foam boards laid over a ribbed steel deck. Air could flow into the deck channels as well as up wall cavities to the roof deck channels. There was a minor air flow problem at doorways where there was no vapor stop. Remedial action was to install a seal between the steel deck and the perimeter of the building using neoprene flashing and polyurethane foam to fill the voids. It was the absence of foam filling at installation that led to the dripping. Laboratory tests were run by ASTM E 96-80 at 100°F and 90°F relative humidity (RH) in a bell chamber inside an oven. The unweathered EPDM roofing had a permeance of 0.0330 perm; the weathered EPDM, 0.0606 perm. Aluminum foil had been installed over the foam deck insulation just under the EPDM sheet, which was then stabilized with a layer of crushed stone. The foil had failed by corrosion. A calculation of the moisture intake was made, using the laboratory test values. However, there was no evidence of wet insulation.

SESSION II—Problems and Experiences with Test Methods

Results of the 1985 Round-Robin Test Series Using ASTM E 96–80—Murray Toas

In 1985, a Committee C-16 Task Force initiated a test series with two objectives: (1) to prepare a new statement of precision and bias for ASTM E 96, and (2) to evaluate possible new water vapor transmission (WVT) standard reference materials for National Bureau of Standards (NBS) consideration. Plastic films selected for the test series were 1-mil Mylar, 5.5-mil Teflon FEP, and 5.5-mil high-density polyethylene (HDPE). Mylar was formerly the NBS standard reference material, having a nominal permeance of 1-perm. The FEP and HDPE films were considered to be low-permeance materials. Twelve laboratories participated, each tested all three films in triplicate using ASTM E 96-80 Procedure A (desiccant method), and Procedure B (water method), both at 23°C. Only three laboratories were judged to be skilled in the correct technique of sealing the test cups. Of these laboratories, the standard deviation in permeance was found to be:

Mylar	HDPE/FEP	
0.08	0.013	within laboratory
0.16	0.013	between laboratories

However, there was wide variability in test results. Critical factors were cup seal, balance sensitivity, and reliability of atmosphere control. For the next series, the following will be observed: (1) include dummy specimens, (2) carefully inspect cup seals, (3) discard outlier results, (4) combine wax with gasket seals, (5) apply wax under specimen rim, and (6) include extruded polystyrene and polyurethane foam specimens.

Results of a Water Vapor Transmission Round-Robin Test Using Cup Methods—Kurt K. Hansen and Niels H. Bertelsen

The objective was to find the uncertainty of WVT measurements made in the Nordic countries and to make a proposal for reducing this uncertainty in the future. Ten laboratories participated. Materials tested were 12-mm porous board, 40-μm polyethylene film, and 0.8-mm tarred paper. Both wet-cup and dry-cup procedures were used. The test series showed that the uncertainty is considerably larger than the variations of the WVT among the individual test specimens. The test results were greatly influenced by the moisture levels. For the tarred paper, there was a 50-times difference in WVT resistance from a moisture level of 80% RH to 20% RH. The results show about 15% gross errors in the tests; and if one laboratory's results are excluded, still about 8% gross errors remain. The spread found among laboratories for all three materials is surprising. It seems possible to reduce the uncertainty only by better calculation methods taking into account the removal of gross errors, making corrections for different variations, and by calculation of the stochastic and systematic errors in the measurements.

Variability of Water Vapor Transmission Rates of Extruded Polystyrene Using ASTM E 96-80 (Desiccant Method)—Alisa R. Hoffee

The study compared test results on 12.7 mm (½-in.) extruded polystyrene board from outside and in-house laboratories. Two outside laboratories were used; one was certified by NVLAP for ASTM E 96 testing. Tests were run at 24°C (75°F) and 50% RH using test chambers and a conditioned room. Results were plotted as curves of weight gain versus time. Factors of variability were the assembly technique, temperature and humidity control, and interpretation of data. Each laboratory used a different cup design and sealing technique. Results were quite variable. More standardization is needed, and ASTM E 96 must become more specific on cup assembly, instrument calibrations, and data interpretation.

*Effect of Relative Humidity on the Permeance of High-Build Coatings—Batdorf (H. B. Fuller Company)**

The coatings tested in this study were of heterogeneous composition, most of them hydrophilic in nature, and susceptible to swelling and plasticization by water. A humidity effect on permeance was expected. Four different coatings were tested, using the MOCON Permatran W-1 infrared apparatus of ASTM Test Method for Water Vapor Transmission of Flexible Barrier Materials Using an Infrared Detection Technique (F 372-73). Tests were run at 38°C (100°F) with 0% RH on one side of the specimen and varied humidity on the other. Below 70% RH, coatings showed little difference in WVT values, but in the range of 80 to 100% RH, a decided effect was observed. Permeance increased significantly at high relative humidity. Swelling of the films caused by moisture absorption allowed greater diffusion of water vapor. The relationship is not linear, as it is with hydrophobic coatings.

*Early Method for Measuring WVT through Materials—Shuman (Penn State University)**

Early interest in the WVT of building materials is ascribed to Teesdale of the Forest Products Laboratory, Rowley of the University of Minnesota, and Joy of Pennsylvania State University. Isothermal cup methods invariably were used, but the limitations were recognized. Joy and Gavan of Armstrong Cork Company devised a divided test cell in which temperature and relative humidity could be varied on each side of the divided cell, each independent of the other. In this way, both a temperature difference and a vapor pressure differential could be maintained at will. A simpler Version 3, known as the "banjo cell" (from its shape) also was used isothermally. Although funded by Armstrong and Penn State, the method was developed as an ASTM Committee C-16 project. The apparatus could accommodate both thin and thick specimens, and, since only weight changes of specimens were measured, the actual specimen weight was not a part of the measurements. Although useful data were obtained through some years of testing, it was decided not to standardize the method because of the apparatus cost and complexity.

Review of Correlations of Infrared Detection Techniques for Water Vapor Transmission Rates (WVTR) with ASTM E 96-80 and Some Approaches to Gravimetric Calibration—LeRoy Pike

This paper reviewed work completed in 1972 and reported in *ASTM STP 548*.[2] A brief description of the operating principles of the MOCON IRD-2 Water Vapor Diffusometer was given, together with a detailed description of the gravimetric calibration procedure. The round-robin series proved that the calibration procedure was accurate, and that the IRD-2 yielded the same results as ASTM E 96 with improved precision. Test method ASTM F 372 was adopted in 1973. The method is said to be 35 to 50% more reproducible between laboratories than ASTM E 96.

*Effect of Barometric Pressure Variations on Precision of WVT Measurements—Pullan and Wilkens (Fiberglas Canada)**

A study was performed using a kraft paper/scrim specimen by ASTM E 96 dry cup. Sealing methods were evaluated. Change in permeance with change in barometric pressure was plotted against average permeance. Results of this study confirmed that, for materials of very low permeance, all measurements take into account the effect of barometric pressure; confirmation of Note 8 of ASTM E 96–66(1972) that cautioned: "For specimens of very low permeance, buoyancy effects due to changes in barometric pressure may cause a greater change in measured weight between weighings than is due to moisture transfer. Long periods of test are required to obtain significant results in these instances."

*Testing WVT under Thermal Gradients—Strzepek (Dow Chemical USA)**

Most commonly used WVT test procedures are isothermal. It is recognized that thermal gradients can have a significant effect on WVT; but only recently have laboratories in Europe concentrated on measuring this effect. The German heavy insulation test, and Swiss Standard SIA 279 are being investigated by ISO/TC 163 and by ASTM Committee C-16. To simulate end-use conditions in measuring WVT, Dow has constructed a test assembly "sandwich" consisting essentially of a cold plate, the test specimen, a water source, and a hot plate. Specimen size is 508 by 508 by 50.8 mm (20 by 20 by 2 in.). Test duration is 28 days. It is possible to vary the temperature gradient as well as the vapor pressure gradient independently. The aim is to accelerate moisture accumulation in thermal insulation under simulated field conditions. Results will be made available to standards organizations as investigatory work proceeds.

[2] *Technical Advances in Packaging with Flexible Barrier Materials, ASTM STP 548,* American Society for Testing and Materials, Philadelphia, 1973.

SESSION III—Other Technologies

Vapor Transport Characteristics of Mineral Fiber Insulation from Heat Flow Meter Measurements—Mavinkal K. Kumaran

The transport of moisture through several specimens of glass fiber insulation in the presence of a thermal gradient was investigated. Quasi-steady states that characterize the transport of moisture through the specimens were established in a heat flow meter apparatus. For the amount of moisture content and for the experimental conditions chosen, the moisture is transported predominately as vapor through the specimens. A thermodynamic model is suggested to represent the transport process. A model is used to calculate the moisture flux at the quasi-steady state. For each specimen, the moisture flux is calculated for several pairs of hot and cold surface temperatures, ranging between 0 and 50°C. Vapor transport coefficients are calculated using the values derived from the thermodynamic model. The results of these investigations show that a test method can be proposed (at least for fibrous insulations) that leads to two moisture transport coefficients in addition to the conventional apparent thermal conductivity of the dry material. Together, these three coefficients are expected to describe simultaneous heat and water vapor transport through the material.

Electric Field Probes for Quantitative Moisture Measurements in Building Materials—George E. Courville, James O. Hylton, William P. Murray, Allan Blalock, and Carl J. Remenyik

A novel capacitance concept application that potentially provides quantitative moisture distribution and concentration measurements in building materials is under development. It is focused on roofing materials, but is suited for *in situ* measurements with thermal insulation as a localized and dynamic procedure. Multiple sensors provide several independent signals from overlapping depths within a roof. A unique analysis procedure has been developed to identify the effective electrical properties of successively deeper layers of material. A prototype microprocessor-based instrument and the associated probes have been built and are being tested. Porous material moisture measurements using a multi-probe capacitance technique require the development of solutions in three problem areas. First, the instrument must be capable of measuring small electric currents (10 to 100 μA) with very high resolution (nanoamps). Next, the signal analysis is computationally complex and uses tomography concepts to separate electrical property information by layers. Finally, the values and variations of the electrical properties of material mixtures are uncertain, which makes it difficult to calibrate the instrument. The prognosis is good for future simulation modeling.

Measurement of Unsaturated Wood Permeability by Transient Flow Methods—Graig A. Spolek and Farid Piroozmandi

This study employed the transient flow of water through wood to calculate unsaturated permeability. Previous works have used standardized steady-state methods. Those results were inconsistent with other experimental data, probably because of the difficulty in achieving uniform unsaturated conditions within wood samples. In experimental work, pine specimens were initially saturated with water. A low-speed centrifuge was then used to force the water to flow out of the porous wood cell structure while minimizing evaporative drying. Periodically, the moisture distribution within each sample was measured with a scanning gamma-ray densitometer. When water movement ceased, the steady-state moisture distribution was used to define the capillary properties of the wood. The calculated results demonstrate the trend that unsaturated wood permeability is relatively large at much lower saturation levels than previously reported; therefore, capillary transport of liquid through wood can significantly affect industrial processes.

Sorption Isotherms: A Catalog and a Data Base—Kurt K. Hansen

The connection between the equilibrium moisture content in a building material and the relative humidity of ambient air at constant temperature is called a sorption isotherm. It is well known that most hygroscopic materials exhibit hysteresis in the adsorption and desorption isotherms. In this catalog, sorption isotherms for more than 100 materials are plotted. Measured sorption values published in different literature sources are put into a database, and for each set of values, the best curve through desorption and adsorption measuring points, respectively, are fitted. A page of the catalog shows both data values and a figure with data points and approximated curves. An IBM personal computer has been used to build up the database that is stored on a diskette marked SORPTION. The necessary data input and plotting programs for the database, as well as programs for curve fitting of data points, are also stored. The programs have been described in a separate report, and the execution of the programs is included.