Water Vapor Transmission Through Building Materials and Systems

Mechanisms and Measurement

Trechsel/Bomberg, *editors*

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Water Vapor Transmission Through Building Materials and Systems: Mechanisms and Measurement

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Introduction

The need for water vapor control in building walls has long been recognized in addition to the need for vapor retarders to prevent moisture movement by diffusion through building materials. During the 1948 Conference on Condensation Control in Dwelling Construction, held by the Housing and Finance Agency (a predecessor of the current U.S. Department of Housing and Urban Development), discussions were not primarily about the need for vapor barriers (as water vapor retarders were called at that time), but whether a "barrier" was necessary in all climates or only in some. The level of permeance that will constitute a vapor barrier and how to measure that permeance was also discussed.[1]

Much more recently, it became generally accepted that the movement of moist air is a major mechanism of moisture transport into wall cavities and attic spaces. Moreover, moisture movement due to diffusion becomes more significant when building envelopes are tighter against air leakages.

A consensus seems to have been reached, in general, that in cavity walls and cavity ceilings under roofs, vapor retarders are needed at the indoor side of cavities in moderate and cold climates; that vapor retarders are needed at the outdoor side of cavities in warm climates that do not have a significant heating season, especially in warm humid climates; and that vapor retarders with relatively high permeances are needed on both the indoor and outdoor sides of cavities in some warm climates, even though significant heating seasons occur at times. However, there has been little or no consensus on the definitions of types of climates, nor on the geographical borders of climate zones, because elevations and valleys in rugged terrain affect the thermal/moisture/wind exposures of a particular building.

The level of permeance required to reduce water vapor flow to acceptable levels also has undergone some change. In 1947, Rowley et al. suggested "representative vapor permeability rates" for materials used in frame construction, and classified them as low, below 0.5 perm; medium-low, 1.0 to 1.25 perms (grains per square foot per hour per inch of mercury) (72 ng/Pa · s · m^2); medium, 3.0 to 5.0; and high, above 30 perm.[2] The text makes it quite clear that the lower two classes meet the definition of a vapor retarder. Currently, the more restrictive definition of a vapor retarder is 1 perm (75.5 ng/Pa · s · m^2). That is the definition used in ASTM Recommended Practice for Selection of Vapor Barriers for Thermal Insulations (C 755-85) and is the definition used by most in the building industry as of this date. However, there is a movement under way to substantially lower the allowable permeance of vapor retarders. For example, the Minnesota Energy Code Rules[3] require vapor retarders with a permeance of no more than 0.1 perm (5.75 ng/(Pa · s · m^2) and the same rating is

[1] *Proceedings,* Conference on Condensation Control in Dwelling Construction, Housing and Home Finance Agency, Washington, DC, 17 May 1948.

[2] Rowley, F. B., LaJoy, M. H., and Erickson, E. T., "Moisture and Temperature Control in Buildings Utilizing Structural Insulating Board," Bulletin No. 26, University of Minnesota, Institute of Technology, Engineering Experiment Station, 1947.

[3] *Model Energy Code Amendments,* Minnesota Department of Energy and Economic Development, Amendments to Section 201: Vapor Barrier, Chapter 4215, Paragraph 4215.1400.

currently being considered by the task group in ASTM Committee C-16 converting Federal Standard TT-B-100 B to an ASTM standard.

Finally, during that meeting in 1948, Professor Rowley cited the need for a test procedure. We indeed do have currently an ASTM standard covering this subject. It is ASTM Test Methods for Water Vapor Transmission of Materials (E 96-80), originally published as a Tentative standard in 1952, and last updated in 1980. As the title indicates, there are more than one method in this standard, actually two, the wet-cup and the dry-cup procedures.

There are several problems with these methods. It is not always clear which of the two methods should be used, and the difference in results can be significant. For example, the *ASHRAE Handbook of Fundamentals* lists asphalt-saturated but not coated sheathing paper as 3.3 perm (1190 ng/Pa · s · m^2) dry-cup and 20.2 perm (1162 ng/Pa · s · m^2) wet-cup, and duplex sheet, asphalt laminated, aluminum foil one side as 0.002 perm (00.115 ng/Pa · s · m^2) dry-cup and 0.176 perm (10.12 ng/Pa · s · m^2) wet-cup. In these two examples, the wet-cup method yields values greater than the dry-cup method by factors of 6.12 and 88.0, respectively!

Another problem exists with errors resulting from various tolerances. Although ASTM E 96-80 lists a total possible error of 30% for the dry-cup method and 26% for the wet-cup method, substantially greater discrepancies, by factors up to 80 (8000%), were found, as indicated in the papers by Hoffee and by Toas.

Since vapor retarders with permeances of 0.1 to 1.0 are required both by good practice and by mandatory code provisions, the uncertainties and errors in a range up to several hundred percent potentially associated with measurements of water vapor permeance of materials by ASTM E 96-80 render that method, and the results obtained, of questionable utility at best. Since Committee C-16 is supposed to revise ASTM methods E 96-80 and C 755-85 within the next few years, and since Committee C-16 also is in the process of converting Federal Standard TT-B-100 B, it was determined that a major effort should go toward developing not only an improved procedure, but also a whole new concept of characterizing the water vapor permeance of materials. As a first step in such an assessment, a symposium was held in Bal Harbour on 10 December 1987, to give guidance to Committee C-16 on Thermal Insulation, and to the co-sponsoring Committees D-1 on Paint and Related Coatings and Materials; D-8 on Roofing, Waterproofing, and Bituminous Materials; D-10 on Plastics; E-6 on Performance of Building Constructions; and F-2 on Flexible Barrier Materials.

To make these proceedings most useful in providing assistance to a broad public, we are including a paper by Dr. Hutcheon that discusses the rationale for vapor retarders in building envelopes in greater detail than can be included in this short introduction. We further include a technical summary by Dr. Bomberg that integrates the various presentations and draws some tentative conclusions regarding potential future developments.

The editors hope that this publication will prove useful to those who are engaged in research on moisture movement and to those concerned with material properties relating to water vapor transmission. The final beneficiaries should be the building community, in general, in its effort to develop high-energy efficiency without undesirable side effects from moisture.

A symposium, such as the one on Mechanisms and Measurement of Water Vapor Movement Through Materials, and the preparation of the proceedings as a permanent record, requires the efforts of many. Foremost, of course, are the authors. Their contributions are obvious. Although not recognized by name, the reviewers' contributions are essential for producing a technically first-class publication. Just as important are the contributions of the ASTM Staff: Theresa Smoot who handled the myriads of advance details, Wendy Dyer who assisted during the symposium, Rita Harhut and Kathleen Greene who interfaced so ably with the authors and reviewers, and Helen Hoersch, who was responsible for editing the

entire publication. To all of these people, our most sincere thanks, and a very special acknowledgment of our appreciation to Wayne Ellis for chairing the panel discussion. Without their untiring cooperation this symposium would never have taken place and these proceedings would never have been published.

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Forty Years of Vapor Barriers*

REFERENCE: Hutcheon, N. B., **"Forty Years of Vapor Barriers,"** *Water Vapor Transmission Through Building Materials and Systems: Mechanisms and Measurement, ASTM STP 1039,* H. R. Trechsel and M. Bomberg, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 5–7.

ABSTRACT: This paper covers the history and use of vapor barriers in insulated buildings from the work of F. B. Rowley to the present state of the art. Heat, air, and water movement through buildings and condensation problems are also discussed.

KEY WORDS: water vapor transmission, testing, vapor barriers

Forty-one years ago, Professor F. B. Rowley at the University of Minnesota published his notable paper on the use of vapor barriers to prevent condensation in insulated building constructions. The paper was a disappointment to the insulation industry which had hoped that his research would show that the growing number of cases of wetting in insulated residential constructions was not the fault of the insulation. Insulation was, in fact, shown to be a factor since it changes the temperature gradients under heat flow conditions, making the material on the warm side warmer and that on the cold side colder. Under certain conditions, these colder surfaces experience wetting by condensation of water vapor which has moved through the construction from the warm side.

Professor Rowley demonstrated in laboratory experiments that water vapor could diffuse through many common building materials other than metals when a vapor pressure difference was maintained across them. He then showed that incorporation of a vapor barrier on the warm side of the insulation to provide high resistance to the migration of water vapor by diffusion to the cold surfaces could reduce or eliminate condensation. Rowley's work was quickly taken up by a number of people who were concerned about the problem of condensation. His findings were confirmed, and vapor barriers in the form of paint films, foils, and special papers began to be recommended for insulated construction.

By 1950, insulation and vapor barriers were being used extensively on residential construction in Canada. They were also being applied to other types of construction. Vapor barriers were being used increasingly in conjunction with insulation in flat roof construction which was experiencing many problems. Ten years later, insulation and vapor barriers were being widely used in all types of heated buildings. Commercial and institutional buildings which had traditionally been operated at low indoor humidities in winter were being humidified and were experiencing moisture problems.

There were many apparent successes but also many failures in controlling the condensation problem by means of vapor barriers. Improved understanding of moisture migration and

* This paper originally appeared in the 1978 supplement to *Canadian Consulting Engineer on Moisture Control* and is reprinted with permission of the author and the publisher.

[1] Professor Neil B. Hutcheon is a former Director of the Division of Building Research (now Institute for Research in Construction) of the National Research Council of Canada.

relative humidity in buildings made it possible to identify and to eliminate some poor practices and to achieve an improvement in insulation practices, generally. Condensation problems were not common in wood frame residential construction in Canada after 1960. There were however individual houses and sometimes whole projects in which serious cases of wetting, presumably by condensation, occurred. In many cases, obvious causes such as the venting of kitchens and bathrooms into cold attics could be found but there were also cases in which there were no obvious departures from recommended practices. Progress in identifying and eliminating the causes of condensation in other types of buildings was even less satisfactory.

It was 30 years from the time of Rowley's paper before it was clearly established and widely accepted that the leakage of air from inside a building through constructions and not vapor diffusion alone was often the principal means by which water vapor moved to cold surfaces. The concept of vapor diffusion was not wrong, but it was not the only way. It is incredible, in retrospect, that it should have taken so long to reach this conclusion, but there were many reasons for this.

Heat, air, and water, though familiar in many ways, present many complicated situations in practice. In particular, the ways in which they interact to produce combined heat and mass transfer in building constructions are only partly understood even now. Added to this, buildings are unwieldy, costly, and difficult subjects for study. They vary widely in many pertinent aspects of construction and operation which are not always readily identified or controlled. They can seldom be constructed and taken apart from inspection to suit the convenience of those conducting studies, but must usually be employed under conditions of occupancy and natural exposure which create difficulties in instrumentation and measurement. Finally, they may have to be observed over long periods in order to obtain meaningful results.

Contributions to the studies of condensation, vapor barriers, and the control of air leakage were made over many years by many people working in the field as well as in the laboratory. Many different agencies and a number of countries were involved. Results were shared at conferences and through the publication of papers. In Canada, the Division of Building Research of the National Research Council was in a unique position to maintain a broad and sustained interest and to provide resources for the research which was needed. Central Mortgage and Housing Corporation was an active partner and also a client when technical assistance was required. The story of these activities is set out in the special report, *The First 25 Years,* published by the Division of Building Research in 1973.

The study of air leakage involved many difficulties. It was not too difficult to demonstrate on paper or in the laboratory that air leakage might be an important contributing factor in condensation. It was quite a different matter to establish that it was probably involved in a particular field situation when there were other plausible explanations. It was only after much study and experience in a number of related areas that competence in evaluating and assessing field cases was developed. After this, more rapid progress was possible, aided greatly by later opportunities to study tall buildings.

When attention was directed to the problems of tall buildings, it was possible to bring together and apply much that had been learned from other studies. In particular, it became possible to recognize the dominant role of stack effect in producing a strong outward flow of air through cracks and other openings in the upper portions of tall buildings. It was then possible to relate many known cases of corrosion, water damage, freeze-thaw breakdown of masonry, and icicle formation at the tops of tall buildings to condensation resulting from moisture carried by outward air leakage which was brought into contact with the cold outer parts of the building enclosure under winter conditions. Once this mechanism was established beyond all reasonable doubt, it became possible to recognize it more clearly in many other situations and to develop a greatly enhanced ability to analyze a wide range of condensation problems.

The fact that the reasons for many problems can now be identified does not mean that the problems will go away by themselves. It is necessary on a continuing basis to identify and to eliminate as far as possible the many undesirable paths for air leakage which can occur in buildings of all types. Buildings as commonly constructed are seriously lacking in air-tightness and special efforts are required by designers and builders to effect much improvement. Air-tightness is essential. Not only is it required to reduce the risk of serious difficulties from condensation, but air leakage now accounts for as much as 40% of the energy required for heating in some cases. Other changes such as increased insulation thicknesses which are now being made in the interests of energy conservation will also have to be taken into account.

The vapor barrier is not obsolete. Resistance to vapor diffusion must be added when other materials in the wall are lacking in this respect. Vapor barriers have been effective in many cases because they provided desirable air-tightness although they have not always been installed in the most suitable way for this purpose. The separate wide sheet polyethylene vapor barrier has been of great benefit and may well continue to be the best way to provide resistance to the flow of air and vapor in wood frame construction. It must however be suitably installed and, in addition, it is necessary to eliminate holes around elastic wiring and outlets, plumbing, ducts, stacks, and windows by which undesirable air leakage takes place.

Vapor barriers can now be seen to be a part solution, suitable for certain cases, and not a fundamental requirement. What is required is the proper control of the movement of heat, water vapor, air, and water through building enclosures. Much has been learned in the 40 years since Professor Rowley first proposed vapor barriers. Designers and builders must now take advantage of this knowledge in developing preferred solutions and improved practices to meet the changing situations which must now be faced.

Mechanisms

Anton TenWolde[1]

Moisture Transfer Through Materials and Systems in Buildings

REFERENCE: TenWolde, A., "**Moisture Transfer Through Materials and Systems in Buildings,**" *Water Vapor Transmission Through Building Materials and Systems: Mechanisms and Measurement, ASTM STP 1039,* H. R. Trechsel and M. Bomberg, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 11–18.

ABSTRACT: When many of the current moisture control design guidelines for buildings were developed 50 years ago, they were consistent with analytical approaches and test methods. This consistency deteriorated when the importance of air convection was recognized. Although considerable research on moisture problems in buildings is available, there is no general consensus aimed at prevention. Sophisticated analytical moisture models have been developed, but they are not easily available or are too complex to use as analytical or design tools. Current water vapor transfer test methods do not provide material property data for these models or for design practice.

To restore consistency and make this information more useful to building practitioners, a coordinated approach to mathematical modeling is needed. Practical analytical tools need to be developed and test methods need to be expanded or developed to yield data appropriate for these models. Finally, more detailed information about airflow patterns in building components needs to be obtained.

KEY WORDS: moisture, materials, buildings, water vapor, test methods, modeling, condensation, ventilation, water vapor transmission, testing

Throughout the United States and Canada, moisture problems in buildings are a source of numerous complaints and owner dissatisfaction. Excess moisture occasionally leads to serious structural damage. Despite the importance and pervasiveness of moisture problems, our current understanding of the principles of moisture transfer in buildings and building components is incomplete. Reliable and practical methods to predict condensation and moisture damage in buildings are not available. Although a considerable amount of research has been done on moisture problems in buildings, relatively few firm, practical guidelines aimed at prevention have been developed. Existing guidelines are considered outdated and based on incomplete information, but there is no consensus among the experts to serve as a basis for new guidelines.

No lack of consensus existed in the 1930s and 1940s, when most of our current guidelines for moisture control were conceived and developed. The interpretation of condensation problems in existing buildings was consistent with the dewpoint design and analysis method, which is still widely in use. The test methods for permeability of materials, in turn, were compatible with the data requirements for the dewpoint analysis method and with the definition of vapor retarders, or vapor barriers as they were called then. This consistency among building practice, mathematical analysis, and standard test methods has deteriorated.

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This paper represents my interpretation of the current discrepancies and my views on the need for improved standard test methods and analytical tools.

Moisture Problems and Building Practice

Serious moisture damage in buildings is usually the result of a combination of unfortunate circumstances and design flaws. It often is a failure of the building as a system, not of any individual building material. Although many cases of moisture damage can be attributed to water leaking into the building envelope, other cases of moisture damage to walls, roofs, or foundations are complex and difficult to determine. In one such case, I took part in several site visits and in the formulation of recommendations for repair and preventive measures. Although this was an unusually serious case of moisture damage, it illustrates the premise that moisture damage is often the result of compounding factors. A large number of manufactured homes in Wisconsin and other midwestern states exemplified severe decay in the exterior walls [*1*]. The decay in the walls resulted from winter condensation, which in turn was caused by the unfortunate combination of design details and high indoor humidity. The poorly installed interior vapor retarder with numerous penetrations did nothing to prevent the problem, and a heavy asphalt-coated building paper between the sheathing and the siding may have further exacerbated the problem by retarding the drying of the sheathing in the spring. However, high humidity was the main cause and we therefore recommended increased ventilation of the living space combined with repair of structural damage.

This recommendation contrasted sharply with traditional recommendations for moisture control. Many early design solutions and remedial measures to control moisture in buildings focused on control of vapor diffusion through the installation of vapor barriers (later called vapor retarders) [*2–5*]. A vapor retarder was defined as a material with a permeance of 1 perm[2] or less. This approach seemed effective and generally accepted for many years and is still widely reflected in building codes and building practice. Until quite recently, recommendations for remedial moisture control in older homes without continuous vapor retarders focused on diffusion control by applying vapor retarder paints [*6*].

In the 1960s, the importance of air leakage began to emerge [*7,8*]. Observations and calculations made it clear that the amount of water vapor carried by air currents could be much larger than the amount delivered by diffusion. Little doubt remained that many of the condensation problems in buildings are associated with air leaks. This concept lead to design recommendations that focused primarily on airflow control, such as the Airtight Drywall Approach (ADA) [*9*]. The new Standard Practice for Selection of Air Flow Retarder (AFR) for Insulated Frame Building Walls, under development in ASTM Subcommittee E6.41, is an attempt to reconcile the current practice of controlling vapor diffusion (that is, with vapor retarders) with recommendations for airtightness. This new standard practice will provide useful and needed interim guidelines, but not enough is known at this time about the behavior of the system to make a conclusive recommendation about proper design. Mathematical models are needed to explore the behavior of different building designs under a variety of indoor and outdoor conditions. Such models would also allow us to evaluate the influence of new building materials and minimize the number of needed field tests.

Field studies of moisture in walls show that occasional condensation does not necessarily damage the structure or the materials [*10–12*]. It is possible and even likely that many buildings that seem to perform quite satisfactorily do experience limited condensation at one time or another. To formulate realistic performance criteria, we need to determine to

[2] A perm is a unit of water vapor permeance and is defined as $5.7 \cdot 10^{-11}$ kg/Pa · s · m^2 (1 grain/h · ft^2 · in. Hg).