Innovative Wall Selection Approach

Achilles N. Karagiozis, Ph.D. **Tony Stall** **Roland Serino, P.E.**
Member ASHRAE

ABSTRACT

Architects and engineers have recently been introduced for the first time to some very powerful tools that simulate the hygrothermal performance of building envelopes. These tools have been extremely useful in capturing the response of the envelope to interior and exterior hygrothermal environmental loading.

The hygrothermal response of a wall is strongly dependent on the material sequencing of the wall structure, embedded subsystems (wall-window interfaces), and the material thermal and moisture properties of each layer. However, some of these system characteristics, "real performance attributes," can only be captured in the field or in carefully performed laboratory investigations and are needed inputs to advanced models.

To a designer/architect who is required to select and design an envelope for thermal and moisture performance, this task can be overwhelming. Today's engineers and architects have not been trained sufficiently in the area of heat and mass transfer of building envelopes, in particular, building physics; however, they are often tasked with selecting envelopes that perform well. At the same time, certain constraints such as construction costs, projected maintenance costs, heat and cooling annual costs, and service life projection all enter the decision-making process. In this paper, an innovative approach is presented that allows the architect or engineer to select a wall cladding based on moisture engineering principles that have already undergone a series of laboratory-determined hygrothermal material property characterizations, whole wall drainage and drying testing, real environmental analysis, and advanced hygrothermal performance assessment. This new method can be used for any type of envelope system, as the approach is clear and simple and includes the state-of-the-art in current building envelope performance analysis. This paper will provide the foundation and rationale for the development of this next generation of wall design tools for architects and engineers using EIFS wall systems as their application.

INTRODUCTION

The design of buildings is in many ways similar to design in the automotive industry except that advancements in the automotive sector are generally adopted very fast. The typical adoption cycles are within the order of eight months to two years in the automotive sector, whereas those in the construction industry take a minimum of five to twenty years. This rather different rate of adoption of upcoming technologies is largely due to the different available workforce skills and the inertia that exists in the various state and local building code jurisdictions. Another important reason is that the construction industry is made up of various trades and is not represented by one umbrella organization, with many stakeholders, and only a very small fraction, if any, is spent in research and development to advance the collective state-of-the-art understanding of the construction processes.

As energy efficiency is becoming an integral part of today's life-cycle assessment, especially in the commercial building sector, the emphasis is slowly but steadily being redirected at determining ways to increase the energy efficiency of buildings. This emphasis is directed at the many required facets of building design. Some of these are the thermal and

Achilles N. Karagiozis is a senior research engineer and Hygrothermal Program manager at Oak Ridge National Laboratory, Oak Ridge, Tenn. **Tony Stall** is vice president of marketing and **Roland Serino** is system engineering manager at Dryvit Systems, Inc., West Warwick, R.I.

durability performance of the exterior envelope, the selection of the HVAC equipment, the operation strategy of the building, and direct and indirect costs of maintaining the building. All of these factors must be included in the investigative analysis stage of the design of the building.

To date, one of the least understood areas of building performance is durability. As the cost factors in the upkeep and maintenance of buildings are ever increasing, selection features that are attributable to the durability and service of a building are critical during the design period. The presence of moisture in all three states—vapor, liquid, and solid—affects the durability performance of the structure. However, it is our present understanding of the complex moisture transport phenomena that is limiting our technical ability to predict the durability performance of buildings. This includes the complex (heat, air, and moisture flow [hygrothermal]) interaction that is present at both the material level and at the system and subsystem building envelope level.

Currently the ability to analyze this complex mode of heat and mass transport is concentrated in establishments that have all three integrated counterparts in moisture engineering analysis. These are the laboratory, field, and advanced modeling competencies. For example, even the most sophisticated computational analysis toolkit cannot predict the airflow for cavity ventilation unless accompanied by actual flow resistance cavity system measurements. These become inputs to the model to better describe the effect, for example, of mortar droppings, crumbling of weather-resistive sheathing papers, the effects of adhesive channels, and so on. The opposite of this scenario is also true; measurements done to capture the moisture performance of a wall need to be validated against calibrated models because the limit for our measurement capability is very restricted. The air cavity ventilation flows in real dynamic wall air cavity cases, or measured moisture content at high or low moisture contents, have not been measured accurately, and the only approach to understand the transport physics and spatial resolution is by using advanced hygrothermal modeling.

Better understanding can be generated using these moisture engineering competencies, and this is currently being included in new, upcoming, and current state-of-the-art moisture design tools (ASTM 2001). The design tools that exist today demand that the user be competent in the fundamental transport phenomena, and this is not that prevalent. Having a tool available that could perform all of the required analyses and present the data in a generic but useful decision-making tree structure is a much needed tool for engineers and architects alike.

In this paper, an innovative design tool is presented that allows designers to make decisions on the selection of the building envelope system for a particular climate based on a few selected criteria. Although the selected criteria include elaborate building physics fundamentals, the user is not required to provide expert judgement. This thermal, moisture control, cost, and durability design tool allows an architect/engineer to make decisions on the selection of a particular building envelope system that is based on the state-of-the-art in moisture engineering and risk analysis. For the "Wall Wizard" described in this paper, a series of energy efficient EIFS (as well as non-EIFS) walls were analyzed. This tool provides various thermal, moisture, durability, and cost performance criteria outputs for selecting the most appropriate envelope for a specific location.

HYGROTHERMAL DESIGN TOOLS

In a recent ASTM (American Society for Testing and Materials) handbook (ASTM 2001), Manual 40 on moisture analysis and condensation control, a list of the state-of-the-art hygrothermal tools was presented. These advanced tools were classified on multiple criteria, as presented in Figure 1.

Two major classifications were discussed—one category was based on tools used by architects and building envelope designers and the other series of tools has been described as hygrothermal research models. Both of these have many common features, but the level of sophistication employed with these models differs substantially. The simple ones are steady-state, predominantly one-dimensional, and without hygric capacity (moisture storage), similar to the dew-point or Glazer method (see ASHRAE [2001]). The more sophisticated are one-dimensional or multi-dimensional models that are deterministic or stochastic.

For example, currently the most employed hygrothermal design model in North America, with over 2500 users, is the WUFI-ORNL and WUFI-Pro software (Karagiozis et al. 2001; Kunzel 1995). The model was developed to greatly simplify the inputs required and has a very easy to use graphical user interface (Karagiozis et al. 2001) but still resolves the

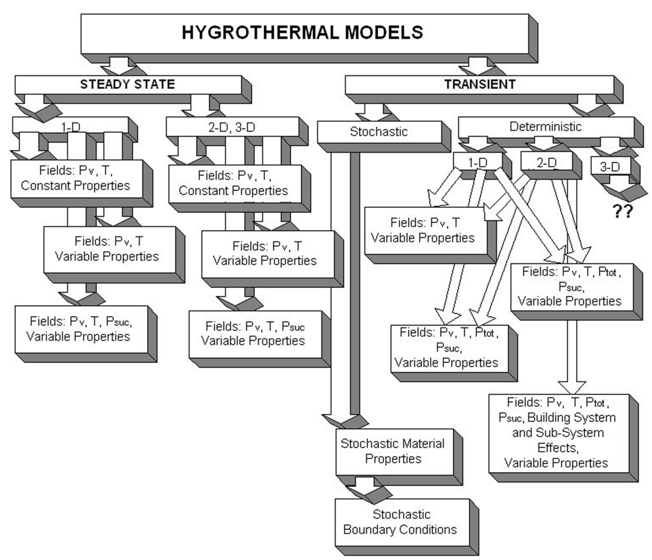

Figure 1 *Classification of hygrothermal models (ASTM 2001).*

sophisticated heat and moisture transport physics. An obvious application of this particular software has been its extensive use to make design decisions regarding the use of vapor retarders for various climatic conditions across North America.

An example of the advanced research model is MOISTURE-EXPERT (Karagiozis 2000c) that has similar transport equations sets as WUFI-ORNL but with the addition of airflow, temperature-dependent sorption isotherms, stochastic and deterministic, water penetration, and inclusion of objects to describe the system and subsystem performance of the envelope (glue line strips, property aging, etc.). A recent application of this model is the ranking of 35 wall systems for the city of Seattle based on the drying performance in the presence of water penetration leaks for climatic conditions in Seattle, Washington (Karagiozis 2002).

In most building applications, the correctness of the application of the model depends on how accurately the user describes the real features of the building envelope system. As such, in most applications, the user of these models must have received appropriate training in the fundamentals that describe the complex heat, air, and moisture transport and must understand the way the particular building envelope system is built. As with the construction of any engineered system, the quality control of the product is workmanship-based. This makes it very difficult to prescribe the performance of envelope systems because of the need for sophisticated tests that quantify the performance of the envelope systems to other critical performance attributes, such as airflow, water penetration, water drainage, and others.

As a result of this type of uncertainty, a moisture engineering approach was developed that used an advanced hygrothermal model as the basis of the simulation, with laboratory input data that were measured to provide the respective performance criteria for the wall envelope systems investigated in this paper. In addition, experts were consulted to provide advice on the construction details of the wall systems. Using the results from this integrated approach, a new class of models was developed at the Oak Ridge National Laboratory (Karagiozis 2004) that essentially provides the architect and building specialist advanced hygrothermal performance data to make engineered decisions for the selection of a specific wall system. All inputs and details of the simulations are stored in a comprehensive database. In many ways this innovative hygrothermal wall wizard is a second generation expert system.

Analysis Inputs

There are four types of inputs required for the analysis of the hygrothermal performance of building envelope systems:

1. Exterior environmental loads (solar radiation, air water content, temperature, sky conditions, wind speed and orientation, and quantity of rain).
2. Interior environmental loads (inhabitant thermal and moisture production behavior).
3. Hygrothermal material properties that describe the transport coefficients of heat and moisture through each of the materials. These are transport coefficients that provide information on the thermal, vapor, and liquid transport and sorption/suction characteristics of construction materials.
4. Construction-specific wall and wall subsystem performances. These inputs provide invaluable data on how the specific wall assembly deals with water ingress, water drainage of the wall system, airflow passage and resistance, vapor and liquid transport reduction due to the presence of adhesive layers, and so on. Comprehensive data on the performance characteristics for any of these systems or subsystems are critical for the hygrothermal tool.

Today, none of the above four types of inputs are standardized in a manner similar to other engineering applications. Currently, ASHRAE's Standard Project Committee 160P is working on developing consensus on design criteria inputs for items 1 to 4 listed above. ASTM has begun reworking and developing standards for the measurement of some of the activities in item 3, while item 4 has only recently been developed in a qualitative manner (SPC 160P and ASTM), and only through the work reported by Karagiozis (2004) was a more quantitative approach for these subsystem characteristics developed.

Wall Wizard

In this section, the Wall Wizard developed at ORNL and adapted for a series of EIFS moisture-engineered wall systems is described. The software is Internet-based, employing Microsoft ASP as its software platform. The intent of the development of this new class of hygrothermal wall decision tools was to provide a new approach to the complex design of wall systems for more than thermal attributes. In this toolbox, multiple assessment criteria are used after the engineering performance assessment is executed. To do this type of performance assessment, additional information is provided to the advanced hygrothermal simulator. In this application, the MOISTURE-EXPERT advanced hygrothermal simulator was chosen. This software has been extensively benchmarked for North American applications on roofs (Karagiozis and Desjarlais 2000), walls (Karagiozis 2004). This research tool provided the moisture engineering engine for the complex analysis of the combined heat, air, and moisture transport for a selected number of wall systems.

The specific Wall Wizard™ has three independent assessment elements:

1. Environmental Load Assessment
    a. Exterior Loads
        i. Specific Location Analysis
        ii. Comparative City Analysis
    b. Interior Loads
3. The Energy Consumption Comparitor
4. The Wall Wizard Selector

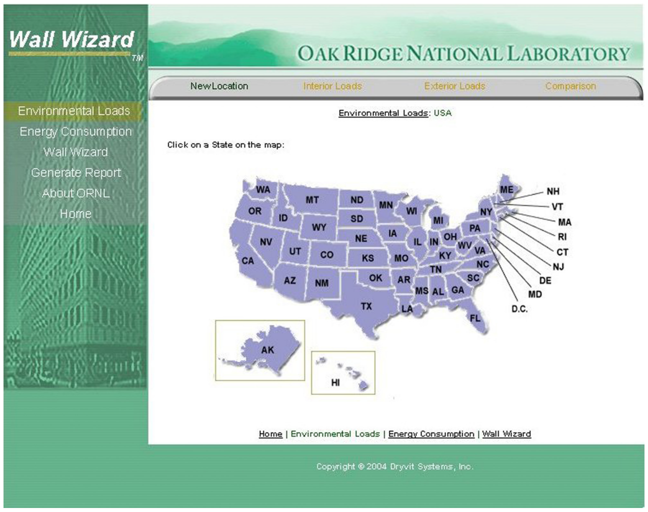

Figure 2 *Functionality of the Wall Wizard software.*

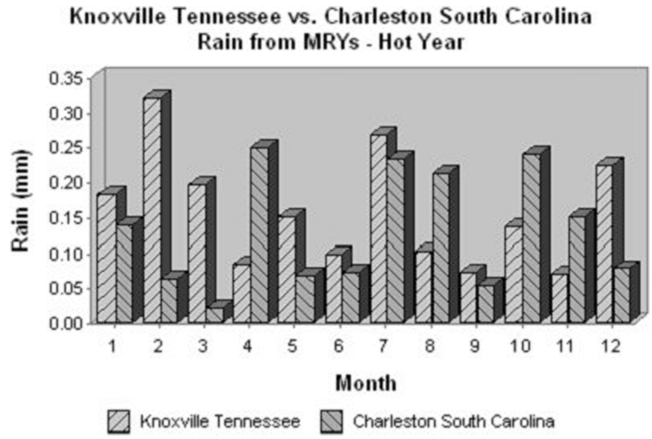

Figure 3 *Comparing the rain loads for two cities (Knoxville, TN, and Charleston, SC).*

In Figure 2, the layout of the Wizard is displayed. All three assessment components are shown.

The first assessment elements were designed to provide a valuable climate-based analysis of the exterior and interior loads. An approach similar to the ORNL WeatherFileAnalyzer (Karagiozis 2002) was included in this assessment tool. In the exterior load assessment, all of the climatic variables employed in the moisture engineering analysis are shown. These are independent of wall systems and can be used by any architect or designer. The user of this software can generate valuable climatic information for either one or two climatic locations. This feature may be of particular importance for investigating the environmental features for selecting one of the two locations for potential building construction. A very important feature of the wizard is the development of wind-driven rain roses that allow the user to investigate the severity of the liquid water and water penetration occurring at any interval and time of the year. This feature is quite unique as it permits the user to investigate the magnitude of the rain load at any chronic interval of time. The two years of climatic data that have been employed in the extensive analysis were selected using 30 years of actual weather data for each specific location. These data were selected based on the tenth percentile cold and hot years. These years were selected for moisture control design purposes as required by the proposed ASHRAE SPC 160P standard. The Wall Wizard™ also includes the effect of inhabitant loads by allowing for the comparison of low, medium, and high interior moisture loads (RH and temperature).

The second assessment element is the energy consumption comparitor that compares the thermal performance of the use of one EIFS exterior insulated wall system with another wall without exterior insulation. This part of the Wall Wizard was designed to provide a comparison of the potential savings

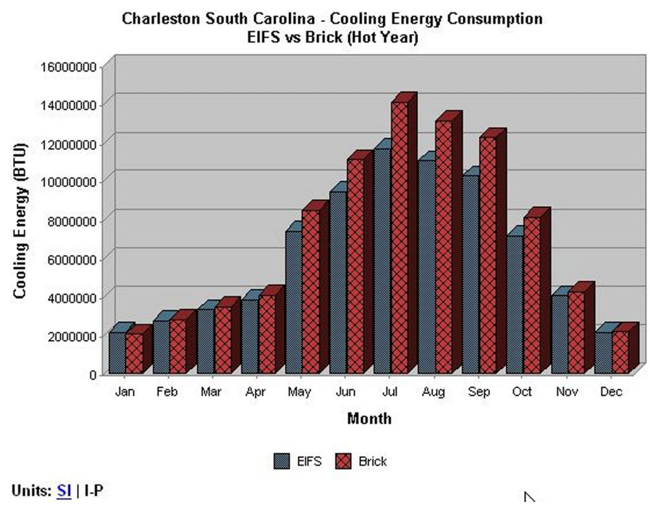

Figure 4 *Comparing the cooling energy of a building using an EIFS versus a brick veneer system.*

of energy employing a wall system that includes exterior insulation features as found in those provided by EIFS systems. An energy balance is performed using setpoint interior conditions as provided by the *ASHRAE Handbook—Fundamentals*. In Figure 4, an example of relatively small savings (15% during August) is shown for Charleston, South Carolina, for an EIFS versus a brick veneer system during the summer cooling months.

The third assessment element, Wall Wizard Selector, is the most extensive element of the Wall Wizard. This component of the software includes the material property data measured and compiled for the simulation, all of the labora-

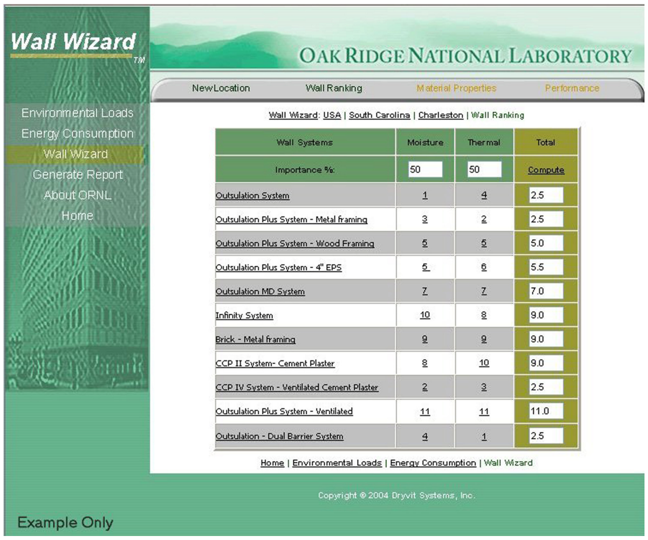

Figure 5 *Example of the relative performance of wall systems (please note artificial numbers were assigned to the table for this example).*

tory system and subsystem assessments performed, and all of the simulation input parameters relating the interior and exterior boundary conditions. The advanced hygrothermal simulator, MOISTURE-EXPERT, integrates the system performance measured data and determines the hygrothermal response of the wall systems to exterior and interior load excitations. The instantaneous results are further processed to determine indexes for moisture load severities, thermal loss, durability indices such as mold growth or corrosion, as well as a total index that the designer can set according to the priorities of the construction. In this element, all of the analyses of the combined heat, air, and moisture transport phenomena are performed. This is the most sophisticated part of the software, as all of the data input and output is managed with the use of a multidimesional database system. In Figure 5, the Wall Wizard is displayed with the ranking of various performance factors (not all factors are shown). In this case, arbitrary values were assigned to this table, as the work is in progress.

The user is not required at this stage to set up complex simulations that could take a professional several days to correctly set up and then, without the appropriate laboratory data, the wall results would still not be representative of the performance of the simulated walls. Both the experimental system and subsystem data are stored in a massive database system that permits comparisons and analysis. One of the unique features of the Wall Wizard is the automatic ranking of a selected number of wall systems. This is conducted for each city the user selects. These rankings can change depending on the climatic location the user selects. At the end of the analysis, a report is generated for the user and can be printed out as needed.

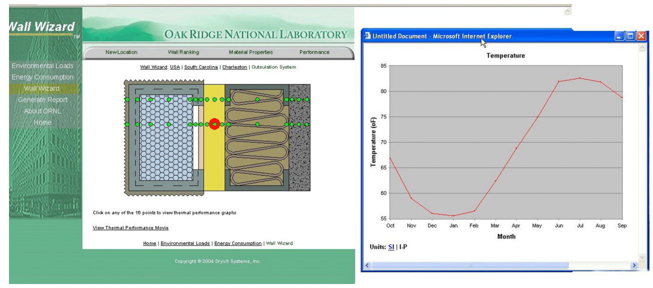

Figure 6 *The performance of the wall at the middle node of the assembly as a function of time.*

COMMON DESIGN ISSUES FACED BY THE BUILDING DESIGNER

Just three years ago, no more than two U.S. engineering firms had in-house expertise that could simulate the hygrothermal performance of wall systems that included the effects of wind-driven rain. Only prescriptive requirements existed, and many times these requirements introduced more moisture-related problems than they solved. An obvious example is the regulation of vapor retarders on the interior side of wall systems in North Carolina. Another such catastrophic prescriptive requirement is the ventilation of crawlspaces in mild-humid climates. Hygrothermal tools were not available three years ago to permit the analysis of these envelope types, and many such failures were blamed on elements that were not at fault.

Recent moisture-related problems of wall systems in various locations in the U.S. have resulted in more awareness of the effects of even small amounts of incidental water penetration. For example, a water leak due to a window-to-wall interface joint with some localized drainage can still cause a considerable amount of damage if it exceeds the threshold for the drying potential of the wall. Current hygrothermal design software do not allow for water penetration, drainage, (see Karagiozis et al. 2004), and cavity ventilation and can only be used to analyze the performance of idealistic envelope systems. Today's envelope designer is interested in "real" performing envelope systems. To respond to this challenge, the state-of-the-art MOISTURE-EXPERT research hygrothermal model was employed to provide performance information on real systems.

In the majority of design applications, cost is a critical factor. It has been difficult, until the development of the Wall Wizard, to justify the additional cost of choosing a higher cost alternative. What has been missing was the needed moisture engineering to quantitatively demonstrate the increase in the moisture threshold of the alternative design. One difficulty in convincing the property owner of the added advantages of an alternative (better) solution has been eliminated with the deployment of the Wall Wizard toolkit. At the same time, the Wall Wizard has given the designer a way to imbed a safety factor in the design, employing the proposed ASHRAE SPC 160P of 1% of water passing the exterior cladding element as water penetration in the wall. Having a toolkit that incorporates the elements of an expert system that is coupled to actual material properties and full wall system measurements with hygrothermal hourly predictions, allows one to evaluate and compare the performances of various walls. In addition, as all the work for the development of this Wall Wizard was conducted by a national laboratory, the work is impartial to any manufacturer's product, making this kind of software an excellent new approach to assist a designer in the selection of a particular cladding system.

SUMMARY AND DISCUSSION

In this paper the concepts of a new class of Wall Wizard selection software was presented for a commercial application case of an EIFS highly insulated wall systems.

This new class of building envelope design tool is very easy to use and includes the state-of-the-art in building physics, integrated with a moisture engineering assessment approach. To create representative replicas of the wall simulated, a series of benchmark data were performed on a number of these walls. Measurements of the hygrothermal material properties were performed and included the simulation analysis. Subsystem testing on the ventilation flow, drainage flow, water storage due to the presence of drainage water, drainage cavity drying, and wall stud cavity drying provided excellent prescription of the wall simulation and benchmarking. The results were then used in the subsequent hygrothermal simulation analysis for 20 locations in the U.S. The results were processed to showcase various performance indexes (to allow the designer to evaluate the most appropriate wall for the location) and constraints of the construction project in a very easy to use application.

ACKNOWLEDGMENTS

The authors wish to acknowledge Dryvit Systems, Inc., for providing materials and funding for this project.

REFERENCES

ASHRAE. 2001. *2001 ASHRAE Handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASTM. 1994. H.R. Trechsel, ed. *Manual on Moisture Control in Buildings*. Manual 18. ISBN: 0-803102051-6, Philadelphia, Pa.: American Society for Testing and Materials.

ASTM. 2001. H.R. Trechsel, ed. *Moisture Analysis and Condensation Control in Building Envelopes*. Manual 40, West Conshohocken, Pa.: American Society for Testing and Materials.

Hukka, A., and H. Viitanen. 1999. A mathematical model of mould growth on wooden material. *Wood Science and Technology* 33(6):475–85.

Karagiozis, A.N. 1997. Moisture engineering. In *Proceedings of the Seventh Conference on Building Science and Technology, Durability of Buildings—Design, Maintenance, Codes and Practices, Toronto, Ontario*, March 20, pp. 93-112.

Karagiozis, A.N. 2001a. Advanced hygrothermal model MOISTURE-EXPERT. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Karagiozis, A.N. 2001b. Advanced hygrothermal models and design models. Presented at ESIM Canadian Conference on Building Energy Simulation, Ottawa, Ontario, Canada, June.

Karagiozis, A.N. 2001c. Advanced hygrothermal modeling of building materials using MOISTURE EXPERT 1.0. 35th International Particleboard Composite Materials Symposium, Pullman, Washington, April.

Karagiozis, A.N. 2002. Building enclosure hygrothermal performance study. Oak Ridge National Laboratory Report, ORNL/TM-2002/89.

Karagiozis, A.N. 2002. Development of the Weather File Analyzer, ORNL Internal Document.

Karagiozis, A.N. 2004. Application of advanced tools to develop energy efficient building envelopes that are durable. *Proceedings of Performance of the Exterior Envelopes of Whole Buildings IX International Conference.*

Karagiozis, A.N., and M.H. Salonvaara. 1999b. Hygrothermal performance of EIFS-clad walls: Effect of vapor diffusion and air leakage on drying of construction moisture. *Water Problems in Building Exterior Walls: Evaluation, Prevention and Repair*, eds. J. Boyd and M.J. Scheffler. ASTM STP 1352.

Karagiozis, A.N., H. Kuenzel, and A. Holm. 2001. WUFI-ORNL/IBP North America Hygrothermal Model Performance of Exterior Envelopes of Whole Buildings VIII, International Conference, December.

Karagiozis, A.N., R. Serino, and M.H. Salonvaara. 2004. Development of wall assembly system properties used to model performance of various wall claddings. *Performance of Exterior Envelopes of Whole Buildings IX*, International Conference, Dec. 2004.

Künzel, H.M., and A. Holm. 2001. Simulation of heat and moisture transfer in construction assemblies. http://docserver.fhg.de/ibp/2001/kuenzel/001.pdf.

Künzel, H.M., A.N. Karagiozis, and A. Holm. 2001. Moisture Analysis for Buildings. ASTM Manual 40, Chapter 9.

Künzel, H.M. 1995. Simultaneous heat and moisture transport in building components—One- and two-dimensional calculation using simple parameters. IRB, Verlag.

Salonvaara, M.H., and A.N. Karagiozis. 1998. Hygrothermal performance due to initial construction moisture as a function of air leakage, interior cavity insulation and climate conditions. *EIFS Thermal Performance of the Exterior Envelopes of Buildings VII, Clearwater, FL*, pp. 179–88.

Straube, J., J. Lstiburek, A.N. Karagiozis, and C. Shumacher. 2001. *Investigation of Water Drainage in Walls Systems.* Building Science Corporation Report.