1. Introduction

1.1 Background

Moisture is probably the most important agent leading to deterioration of the building envelope. Understanding and predicting moisture movement into, within and through the vertical enclosure is therefore of fundamental importance to predicting and improving the performance of walls, particularly their durability. Moisture control is especially important for wood-framed, exterior wall systems; not only are many of the materials involved vulnerable to moisture but construction of this type is also the most common form of residential wall.

Various strategies are used to control moisture in exterior wood-framed walls. The current design consensus favors the so-called pressure-equalized, drained rainscreen plus internal weather-barrier approach. The outer, multi-layer sub-system is vented and drained. An idealized wall section is shown in Figure 1.

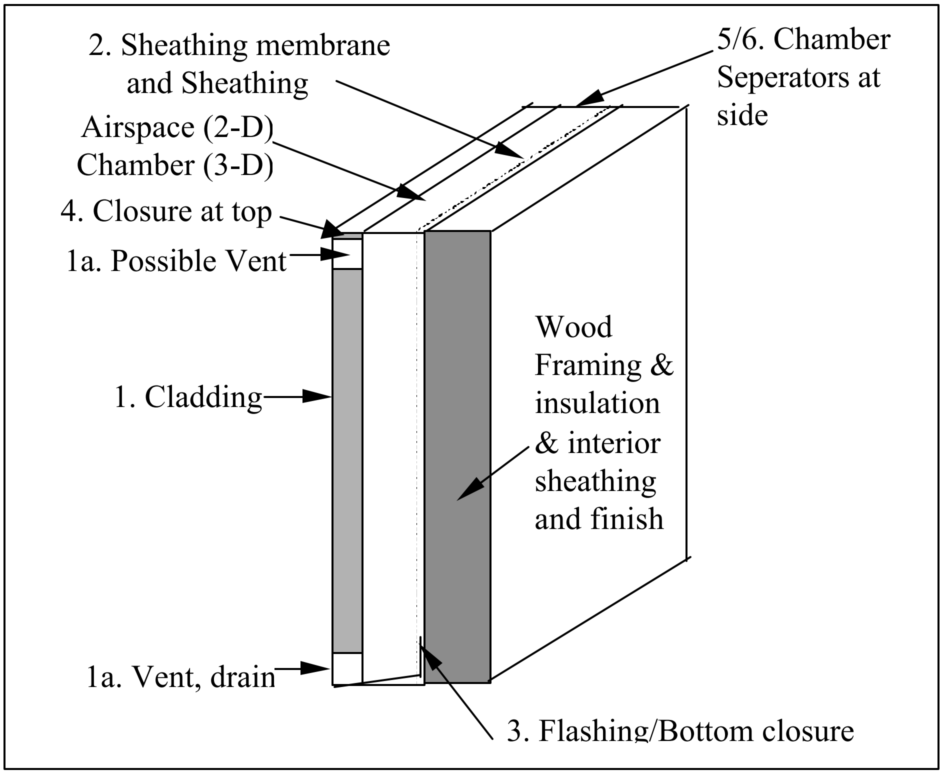

Figure 1: Components of an Idealized Rainscreen Wood-framed Wall System

The outer sub-system typically comprises the following: a cladding which acts as the screen; an air space or cavity which, amongst other things, provides a capillary break; a sheathing membrane which provides a drainage plane as well as a capillary break; and the exterior sheathing to which the membrane is attached. For example, the popular siding-clad wood-framed wall assembly employs the siding to resist most rain penetration, and building paper or a "housewrap" to act as both a capillary break and a drainage plane for water that might accumulate at this location. The use of a sheathing membrane can also reduce convective cooling effects (wind washing) and improve the airtightness of the assembly.

The six sides that enclose the air space actually form a three-dimensional chamber for air. Each of the six sides may have a related moisture control function, as seen in Table 1.

Table 1: Moisture Control Characteristics of the Air Chamber in a "Rainscreen" Wall System (see Figure 1)

Number	Name	Moisture Control Feature
1	Front of Chamber /Screen /Cladding	Provides exterior surface drainage and sheds water and minimizes direct penetration of water from precipitation
2	Rear of Chamber / sheathing membrane	A capillary break to water and a drainage plane, an air barrier, sometimes called a weather plane
3	Bottom of Chamber	Closure, e.g., flashing to accommodate and direct gravity drainage water outward
4	Top of Chamber	Closure, to control airflow (also smoke and fire)
5, 6	Sides (2) of Chamber	Lateral closure to control airflow and water flow
1a	Vent(s)/Drains to and from Chamber	Allow airflow (in & out) and /or water flow (weep hole)

The airspace or, in three dimensions, the air chamber itself could also have several important moisture control functions, including acting as:

- **a Capillary Break** that prevents the inward liquid transport of water from the cladding,
- **a Ventilation Chamber** that facilitates the removal of moist air and thus water vapor, and
- **a Pressure-moderating Chamber** that reduces air pressure differentials and thus, during and after rain, water flow across the claddingor screen, and
- **an Internal Drainage System** that removes any internal water accumulation to the outside.

Despite the theoretical advantages of these so-called rainscreen wall systems, there are numerous difficulties. Most importantly, the expected levels of both in-service performance and long-term durability have not always been realized. Excessive claims for the effectiveness of pressure equalization across the screen have been made. Questions have been raised about the performance, especially in the longer term, of the sheathing membrane. Practitioners do not have authoritative guidance for the choice of sheathing membrane (e.g., building paper or houesewrap). For example, some experts are of the opinion that asphalt-impregnated sheathing paper behind a masonry veneer is to be preferred. Considerable confusion exists. There is no consensus as to the contribution of ventilation drying—some experts maintain, for instance, that furring strips are required to provide an airspace behind wood siding but that vinyl siding does not need such strips. In wet climates, the need for air spaces behind stucco cladding is being hotly debated. The potential benefit of cavity ventilation for North American conditions has yet to be accepted or even quantified.

Building enclosure designers need guidelines for the design as well as the selection of materials for wall systems in the various climatic zones. For instance, criteria to assess whether wall cavity ventilation should be used or not, in different climatic areas, are not available. Research is needed to establish how to design wall systems accounting for all thermal, moisture, structural and other performance considerations. Reliable information on both cavity ventilation and sheathing membranes is needed to design not only for moisture control but also for good performance in general. The hygrothermal performance properties of weather barriers and their effect on wall moisture performance, especially the ability of the wall to dry out irrespective of moisture source (from outside, inside, or built-in), needs further research. At the very least, this information should be incorporated in theASHRAE Handbook of Fundamentals.

1.2 Objectives

The terms of reference for this proposal clearly focus on two of the above concerns: first, the nature and relevance of air cavity ventilation and, second, the performance and contribution of the sheathing membrane. This response to the proposal call outlines a program of laboratory and full-scale field testing and computer modeling to develop an understanding of the contribution of sheathing membranes and cavity ventilation to the overall performance of specific wall systems.

One objective of this project is therefore to generate experimental data on the performance of sheathing membranes and air-cavity ventilation strategies and their effect on the overall performance of wood-framed, screened wall systems.

This information is to be used to modify (if necessary) and to validate computer simulation. A comprehensive program of advanced, state-of-the-art hygrothermal modeling is then envisaged to extend this understanding to other wall systems and at least six representative climatic areas. These data will then provide the basis for developing design guidelines on the combined performance of sheathing membranes and air cavity ventilation strategies as a function of climatic conditions.

All this work will be documented in a report. To transfer this understanding to industry, design guidelines as well as supplementary, builder-friendly documentation will be developed. The information generated from this project will provide the new ASHRAE SPC 160P on "Prevention of Moisture Damage" with valuable data to assess moisture damage. The results from this research project will also provide material to be included in the 2001 ASHRAE Handbook of Fundamentals.

This research and the subsequent deliverables should provide timely and much needed answers to many of the concerns and questions related to screened wall systems. The overall objective is to resolve some very important design and enclosure performance concerns.

1.3 Technical Background

The design of moisture-tolerant enclosures should involve the consideration and balancing of the potentials for wetting, storage, and drying. Unfortunately, many designers tend to focus on the avoidance of wetting rather than on the increase of safe moisture-storage capacity or drying potential. The role of air spaces, cavity ventilation, and sheathing membranes is to reduce wetting and increase drying.

Moisture can be removed from a screened, drained and vented (i.e., the so-called) enclosure wall system in a variety of ways (Figure 1):

1. drainage of free water, driven by gravity
2. capillary transport of bound liquid water to, and evaporation from, the outer surface of the screen
3. diffusion and/or convection of water vapor outward through the screen, and inward into the wall or building interior; and
4. convective flow of exterior air through the air space (i.e., ventilation).

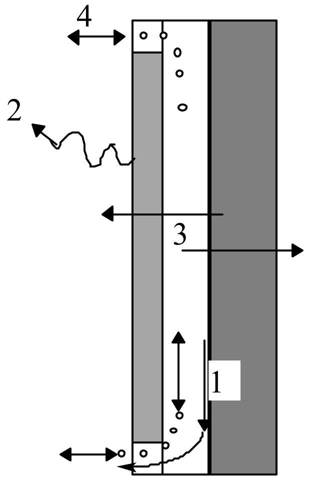

Figure 2: Drying Mechanisms in Rainscreen Walls with Vented Airspaces

Diffusive drying is fairly well understood and appreciated, although the precise calculation of such drying is still not very accurate because of our limited knowledge of moisture transport properties through porous materials. Sheathing membranes may reduce diffusive drying but, preferably, only slightly. Gravity drainage, although well understood, cannot remove moisture that is absorbed and stored in materials such as brick and wood. Convective drying can be a large and important drying mechanism, although uncontrolled air flow could also cause wetting. The flow of air from the exterior, vertically behind the cladding, and back outside, i.e., ventilation, can provide convective drying.

1.3.1 Cavity Ventilation

In theory, ventilating the space behind cladding with outdoor air offers two major benefits:

- relatively dry outside air flow allows convective drying of the inside face of wet cladding and the outside face of the inner wall layers, and
- water vapor diffusing through the inner wall layers can bypass the vapor diffusion resistance of the cladding and be carried directly to the outside.

Thus, ventilation could theoretically increase the drying potential of walls, especially in assemblies that either store significant amounts of water in the cladding or have claddings with high vapor resistance. Our experience in studying ventilation and pressure moderation in both the laboratory and the field has shown that precise monitoring and measurement of the forces driving ventilation flow and ventilation drying or, possibly, wetting are critical to proper understanding and accurate model prediction.

For instance, furring strips are often suggested as a means of improving the performance of vinyl and wood-based sidings. However, there is little physical evidence to support this practice. The CMHC studies referred to in the proposal call [CMHC, 1988], were studies of vented cladding over furring strips, but many of these walls did not allow unimpeded vertical air flow behind the cladding. Ventilation drying can be achieved only with proper detailing (open head joints top and bottom in brick veneers, no blocking at the top of the cavity for sidings) to facilitate vertical air flow over the full height of the wall section. Another issue that also needs to be addressed is nighttime condensation wetting behind light-weight claddings in humid climates.

Probably the most important unknowns are the actual nature and magnitude of the ventilation flows that can occur. Convective drying is necessarily a slow process, largely involving small rates and small amounts of airflow. The forces causing flow are wind and buoyancy. Given the spatial, temporal and stochastic nature of these forcing functions and the flows involved, it is not possible to simulate these conditions accurately in a laboratory. In fact, we have still to quantify these effects. For this reason alone, full-scale field-testing is unavoidable. Once reality has been measured, it is then possible to do laboratory work, using much simpler flow conditions, to conduct parametric testing and to isolate variables.

1.3.2 Sheathing Membranes

Sheathing membranes act as a capillary break to water behind the rainscreen cladding. Although synthetic sheathing membranes have many advantages, their very high vapor permeance means that walls in hot-humid climates [TenWolde and Mei 1985] and walls with rain-saturated absorbent claddings exposed to the sun [Wilson 1966] may be susceptible to inward vapor diffusion wetting.

The fact that synthetic housewraps tend to be much more airtight than building paper will reduce air- leakage-induced condensation, but may also reduce the potential for convective drying (see, for example, Karagiozis and Salonvaara, 1998). Furthermore the vapor permeance of building paper is known to increase significantly with an increase in humidity.

Convective cooling behind air permeable claddings, especially those claddings installed over clear air spaces, could be an issue in cold climates since a moisture problem could occur. Commonly available sheathing membranes are typically sufficiently air tight to control convective cooling [Ojanen, 1993], but this aspect of peformance cannot be ignored.

Work we have done indicates that the manner in which the membrane is attached leaves much to be desired. In addition, little thought has been given to the fact that, if the screen pressure is moderated or even equalized, then the membrane must be subject to suction—in which case ballooning occurs, and the issue of fatigue and wear become fairly important.

There are clearly some fundamental and potentially very important issues to be studied. It is also evident that full-scale testing under real conditions must be conducted if only to avoid the possibility of oversimplification when doing laboratory work.

2. The Project

This project involves a program of laboratory testing and computer modeling, backed by full-scale field verification, that will generate both a new understanding of the role of sheathing membranes and cavity ventilation as well as useful, climate-sensitive design guidelines. The intended project is an ambitious one, and we have deliberately set out to use facilities, people, and tools that are uniquely appropriate to this project.

To meet the implicit objectives of the proposal call, **some well-designed field-testing is essential**. At this time we know that neither the actual wind nor the buoyancy effect, and especially their combination, can be realistically modeled in a laboratory (see Straube 1997). We have to measure the actual conditions before attempting to simplify and model them. In fact we know that overly simplistic lab experiments directed at screen pressure equalization (moderation) have given rise to overly optimistic expectations and claims. A similar situation must be avoided when studying cavity ventilation and sheathing membrane performance.

It is also essential that the appropriate enclosure analysis/simulation software be used. A major drawback with most hygrothermal codes is that they are unable to model lateral airflow, let alone three-dimensional air movement. LATENITE or TRATMO2, simulation software developed by Dr. Karagiozis and Mr. Salonvaara respectively, appear to be suitable programs for this project. As these models were developed as research codes, these models must be adapted and modified for each simulation case. This may only be accomplished by the above-mentioned authors of the codes as the level of sophistication and innovations in both the numerical simulation procedures and transport physics limit the general use of these hygrothermal codes.

Accordingly, we propose that this project is being conducted by three agencies at three locations, namely, the Pennsylvania Housing Research Center, at the Pennsylvania State University (PHRC/PSU); the Building Engineering Group at the University of Waterloo (BEG/UW); and the Oak Ridge National Laboratory in Oak Ridge TN. Some indication of the distrbution of work is given in Table 2.

Table 2 : Distribution of Activities

Activity	Focus	PHRC/PSU	BEG/UW	ORNL
Laboratory Testing	Materials	*	*	*
Laboratory Testing	Sub-assemblies	***	**	
Laboratory Testing	Wall Assemblies	***	*	
Field Testing	Wall Assemblies		***	
Analysis	Wall Assemblies	*	**	***

Legend:		
	***	A primary activity
	**	A supplementary but substantive activity
	*	Some supporting activity

3. The Experimental Program

The experimental program will span the full spectrum from fundamental material properties to full-scale, natural-exposure assembly testing. Each of the components of the experimental work is described below:

3.1 Materials Testing

The hygrothermal material properties of the materials used in the test program have been drawn from existing databases (e.g., IEA Annex 24, BEG, and IRC's extensive database) where possible. However, some information was not available or sufficient or trustworthy. Hence, the properties of the critical materials used in the test program, (e.g., the vapor permeance of the sheathing membranes and the sorption isotherm of the wood-based materials) will be tested to provide confirmation and comparison with the database values. Material property testing will be conducted at both the Oak Ridge National Laboratory and University of Waterloo. The material testing labs at UW will also be employed for vapor permeance and sorption isotherm tests. At Penn State, materials testing will largely be limited to the sheathing membrane. We have already completed studies on housewraps and their attachment, and these data will add value to this ASHRAE project. Material properties that will be defined include the sorption and suction isotherm, liquid moisture diffusivity, vapor diffusivity, thermal conductivity, and density. Based on experience, the framing and the sheathing were chosen to ensure that they were produced from the same lot, are of the same species, etc.

3.2 Sub-Assembly Testing

At Penn State, sheathing membranes will be tested for water permeance and air permeance over a range of conditions as part of a wall sub-system. The influence of strapping, nails, staples, and tape on performance will be evaluated through a series of air permeance and water spray tests, including cyclic wind loading conditions.

The air pressure vs. ventilation flow relationship for claddings such as wood and vinyl siding and brick veneer will be defined through lab experiments. Full-scale samples of the exterior rainscreen sub-assembly will be built and tested for airflow in three directions: perpendicular to the cladding, vertically behind the cladding, and horizontally behind the cladding. The cladding will be installed over a clear backup (representing the sheathing) to allow for flow visualization. Furring strips obviously greatly increase the flow in the direction that it is installed, and this effect will also be studied.

One important consideration is the flow characteristics of the vents, i.e., the openings typically found in screen type cladding. Fortunately, we (Straube and Burnett 1995) recently carried out a major study of venting, primarily directed at masonry veneer systems.

Data from this test program of a range of building vents [Straube and Burnett, 1995] and another study on wood and vinyl siding air permeance [RWDI, 1988] will be incorporated in the results. Use will be made of Penn State's well-equipped BeTL laboratory and UW's Beghut for these experiments.

3.3 Laboratory Wall Assemblies

The ventilation flow vs. drying relationship has been established through experiment for a number of different airflow rates and simplified wall systems.

Experience gained during previous similiar laboratory studies of venting and drying (e.g., Morrison-Hershfield, 1991) and field studies [Straube and Burnett 1995, Straube 1998] show that wind-driven ventilation flow and solar radiation must be correctly simulated if laboratory studies are to properly model drying and wetting processes. Three 2.44 m high wood-framed walls will be built beside one another (but separated hygrothermally) and placed in Penn State's new climate simulator. The walls will be framed with 2x6 studs and plates, insulated with glass fiber batt, and contain saturated wood fiberboard sheathing as a moisture source. One of the walls will use a sheathing membrane of 15-pound building paper, another will use a spun-bonded polyolefin, and a third will use a perforated synthetic housewrap.

The moisture content of the fiberboard and framing will be measured with calibrated electrical resistance pins (at least 8 pairs per wall) and checked gravimetrically. The temperature and relative humidity will be measured in strategic locations. The location of the sensors will be carefully chosen (in conjunction with IRC) so that computer modeling can be accurately compared to the experimental results.

Each series of tests will be conducted for a cold climate and a hot-humid climate. A cold climate will be a simulated average temperature of about -15 ºC at night and with -5ºC days, approximately 80%RH with some diffuse and reflected radiation (equivalent to 8 hours of 40 W/m^2 per day at 45 ºN for a north-facing wall). A hot-humid climate will be defined to have an average daytime high of 30 ºC and a nighttime low of about 24 ºC with a relative humidity of at least 80%. Diffuse radiation will be assumed to be 150 w/m^2 for 12 hours per day (24 ºN). These conditions are not intended to be extreme conditions, but probable month-long conditions representative of well populated areas of the US and Canada. The interior will be maintained at normal room conditions; these will be jointly agreed upon prior to testing to ensure that issues such as internal air pressure and RH are properly considered.

For cold-climate simulations, the interior of the test assemblies will be finished with clear acrylic sheet, so that condensation on this plane can be observed and so that all drying will be to the outside. For hot-climate simulations, painted drywall will be employed, with a special acrylic viewport to visually assess the possibility of condensation on vapor retarders and vinyl wallpaper, but allowing inward vapor flow.

			Hot Climate			Cold Climate		
Cladding	Framing	Sheathing	Sheathing Membrane	Cavity Depth	Venting	Sheathing Membrane	Cavity Depth	Venting
Grey Metal	Polyiso on 2x4 frame	Fiberboard	None	50 mm	Top & Bottom	None	50 mm	Top & Bottom
			Bldg Paper	50 mm	Top & Bottom	Bldg Paper	50 mm	Top & Bottom
Vinyl	2x6	Fiberboard	Tyvek	19 mm	Top & Bottom	Tyvek	19 mm	Top & Bottom
	Polyiso on 2x4 frame		Tyvek	19 mm	Top & Bottom	Tyvek	19 mm	Top & Bottom
Vinyl	Polyiso on 2x4 frame	Fiberboard	Tyvek	19 mm	Top & Bottom	Tyvek	19 mm	Top & Bottom
			Tyvek	19 mm	Bottom only	Tyvek	19 mm	Bottom only
			Tyvek	0 mm	None	Tyvek	0 mm	None
Brick	2x6	Fiberboard	Bldg Paper	50 mm	Top & Bottom	Bldg Paper	50 mm	Top & Bottom
	Polyiso on 2x4 frame		Bldg Paper	50 mm	Top & Bottom	Bldg Paper	50 mm	Top & Bottom
Wax Sealed Brick			Bldg Paper	50 mm	Top & Bottom	Bldg Paper	50 mm	Top & Bottom
Wax Sealed Brick	Polyiso on 2x4 frame	Fiberboard	Bldg Paper	50 mm	Top & Bottom	Bldg Paper	50 mm	Top & Bottom
			Tyvek	50 mm	Top & Bottom	Tyvek	50 mm	Top & Bottom
			Bldg Paper	50 mm	Bottom only	Bldg Paper	50 mm	Bottom only

Walls to be Tested in Climate Chamber

A summary of the drying rates and the moisture transport mechanisms within and through the wall for each test will be presented. The likely role of climate on ventilation flow, sheathing membrane response, and solar radiation will then be described. Finally, some indication of the importance and magnitude of inward vapor drives for wetting and drying will be discussed, with particular reference to hot-humid climates. The data from these controlled experiments will be compared to computer model predictions.

3.4 Natural Exposure Field Testing

At present, the dynamic and spatially varying nature of the forces driving ventilation flow are difficult to model in laboratory studies and on the computer because of a lack of knowledge of the magnitude, duration, and frequency of these forces. The measurement of ventilation driving forces in the field is the only means of providing the necessary information.

The laboratory experiments described earlier are useful since most variables can be isolated and controlled. Although natural-exposure field-testing does not allow exterior environmental variables to be controlled, the performance of real enclosures can be truly assessed only by exposure to real dynamic boundary conditions. Field measurements are also the best and most rigorous means of validating numerical models.

For these reasons part of the proposed experimental work includes full-scale natural-exposure testing. Four test walls, two brick veneer and two vinyl clad, will be installed in UW's unique test facility, the Beghut, and monitored for at least one year—preferably over two heating seasons. The Beghut allows all of the relevant exterior environmental conditions, including driving rain, to be recorded at 15-minute intervals while the interior climate is maintained at, for example, 21 ºC and 50% RH. This test facility, BEGHUT, and available instrumentation are described in more detail in an attachment in the appendix.

All of the test walls will be contructed with 2x6 framing with saturated fiberboard sheathing. The inner finish will be an airtight, vapour tight and non-hygroscopic material. An acrylic "window" allows for observation of summer condensation. In many respects, the walls monitored in the field will be of the same type as those tested in the laboratory. The same materials will be used to minimize variations in material properties.

3.4.1 Brick-veneer clad Wood-framed Walls

Three 1.2 m by 2.4 m high brick veneer clad walls will be monitored, one with an asphalt-impregnated building paper and two other with a spun-bonded polyolefin (SBPO) sheathing membrane. One of the two SBPO walls will have vent openings top and bottom, while the other will be vented at the bottom only. The brick veneers will be installed on special compensated load cells so that their moisture content can be accurately measured gravimetrically. The airspace will initially be 50 mm wide.

The airspace will contain a removable, protected hot-wire thermistors that can measure velocities as small as 2 to 3 mm/s. Each of the vents will be fitted with special integral pressure taps; these have been used successfully in previous studies. A total of 5 taps on the exterior (at the four vents and the center) and 4 on the interior (top, middle, and bottom of the airspace, and middle of the studspace) will be installed. The pressure acting at each vent, across the sheathing membrane, and across the wall be simultaneously measured with low pressure, high-speed manometers.

As will be done in the laboratory studies, relative humidity in the air space and the stud cavity, moisture content in the framing, and the temperature throughout the walls will be measured. Instrumentation type and location to complement computer modeling will be incorporated.

This experimental set-up will allow for the simultaneous and accurate measurement of ventilation driving forces (wind forces, thermal and moisture buoyancy), the quantity and quality of the ventilation air as well as the drying rate and moisture redistribution within a full-scale wall assembly under real environmental conditions. These results will allow for the measurement of the magnitude of ventilation drying and, through validated computer model extrapolation, an assessment of the effect of other climates and assemblies on this drying rate.

The moisture and temperature conditions will be monitored continuously for several wetting events, each at least three months of exposure, to monitor drying in four seasons.. The air space will then be reduced to 19 mm in size by moving the inner wall components outward. Monitoring will be repeated with subsequent wettings.

3.4.2 Vinyl-clad Wood-framed Walls

Two walls with vinyl cladding will also be monitored. Except for the rainscreen cladding, these walls will be of essentially the same construction as the brick clad panels. The difference between the two vinyl wall panels will be the sheathing membrane. The moisture source will be the saturated fiberboard sheathing. Initially, the walls will be clad with vinyl applied directly to the sheathing. The relative humidity within the space formed by the vinyl profile will be measured with special small RH sensors (this has been successfully done in previous Beghut studies). Pressure taps will be installed at five locations on the exterior and three locations on the interior.

After the same initial monitoring period as the brick walls, the vinyl siding will be removed and installed over 19 mm vertical strapping. Provision for measuring the air velocity within the air space in both orthogonal directions with a hot wire anemometer will be provided in the second set of vinyl clad walls.

Data from previous field wall drying studies at the BEGHUT of several OSB and fiberboard sheathed and vinyl and brick veneer-clad 2x4 and 2x6 walls will be re-examined. If relevant, the results will be incorporated in this study.

Results of flow versus pressure will be compared with theory and the ventilation wind pressures measured in this and previous studies [e.g., Straube and Burnett, 1995]. The ventilation flow and drying rate will be compared to theory, the laboratory experiments described above, and computer simulations.

Results will be summarized in graphical form as well as delivered on a CD-ROM in ASCII format.

4. Numerical Modeling

This project relies heavily on the use of hygrothermal modeling to investigate a full range of weather barrier performances, cavity ventilation, and interior vapor control strategies. A full parametric investigation is proposed to provide essential knowledge for the development of design guidelines. Dr. Karagiozis will provide the appropriate simulation model. He will be directly involved in the design of the experimental validation of the model, the model calibration of the system and sub-system wall performances, and the integration of the material properties and weather data. Dr. Karagiozis will be assisted in this task by graduate and/or co-op students from Penn State and the University of Waterloo. Three student assistants will be involved in both the computer simulation and the experimental work.

This complementary program of analysis or numerical modeling is needed for at least two reasons:

1. to interpret and understand the experimental results, and
2. to predict what is likely to occur with different assemblies and different climates (since it is neither feasible nor desirable to fully test every possible scenario).

To analyze wall system response, it is neccesary to be able to mathematically represent:

- the components, elements, and materials involved;
- the physics of energy and mass transfer involved; and
- the appropriate boundary conditions (e.g., the loadings or forcing functions).

The objective of any numerical modeling is obviously to represent reality, but this is difficult because we cannot easily model the physical enclosure (each crack, twist, and imperfection). Our knowledge of needed material properties is incomplete and the properties are variable, and our ability to model the hygrothermal mechanics is somewhat limited. Circumstance, money, and time oblige us to do the following:

- be as complex and comprehensive as possible when accuracy is required
- be as complex and comprehensive as needed when relative accuracy is sufficient.

It follows that an intelligent choice of modeling tools is required. For “absolute” accuracy a hygrothermal model developed Dr. Karagiozis or/and Mr. Salonvaara will be utilized in the numerical analysis. It is proposed that the LATENITE VTT Version (1999) model, or an upgraded and more advanced version or new model, will be employed to characterize the performance of various building envelope designs. This model is currently considered to be the state-of-the-art hygrothermal building enclosure model. Arrangements have been made to secure the use of this model as needed in this project by subcontracting the use of LATENITE VTT

Version or the VTT TRATMO2 model. Mr Salonvaara from VTT will be subcontracted by Dr. Karagiozis to assist in the modeling activity.

This model considers vapor, liquid, and adsorbed phase moisture transport. The moisture transport potentials used in the model are moisture content and vapor pressure. For energy transport, temperature is used as the driving potential. Phase changes due to evaporation/condensation and freezing/thawing are included. Internal moisture sources (e.g., rain leaks), gravity-driven liquid flow, and surface drainage can also be modeled. All material properties can be entered with full moisture content and temperature dependencies. Unlike many less complete models, the flow through cracks, air spaces, and porous materials (such as glass fiber insulation) driven by wind pressures, as well as natural convection within air spaces, and stud spaces can be physically modeled. This feature is critical for the proper modeling of cavity ventilation and wind washing. The model can also include a numerical moisture damage model for mold growth and fungal decay of wood. The model of Viitanen [Viitanen, 1996] is thought to be one of the best for this purpose.

The LATENITE VTT Version has been used for a number of detailed moisture studies and validated against experimental results. Although capable of full three-dimensional modeling, two-dimensional modeling will likely be sufficiently accurate. For complementary parametric assessment, where relative accuracy may be sufficient, we might make use of other analytical tools with which we have some experience, namely, WUFI, WALLDRY, and MOIST. These programs are readily available to ASHRAE members and enclosure designers and building scientists, and permit the impact of some parameters to be easily and quickly investigated. This modeling will also provide some idea of the relative accuracy and usefulness of these currently available models. WUFI, developed and extensively field validated [e.g., Kuenzel and Kiessl, 1997] by the Fraunhofer Institut fur Bauphysik, is a sophisticated 1-D program that models driving rain deposition and absorption — ideal for modeling brick veneers. MOIST, developed by NIST, is used by some practitioners and is readily available. It is appropriate for modeling walls with non-absorbent claddings where air leakage is controlled and hence might be useful for vinyl-clad walls. WALLDRY, developed for CMHC, was developed for the express purpose of predicting the drying of wood-framed walls with and without ventilation. WALLDRY has recently been improved to better model some of the aspects of ventilation and air leakage. For ventilated walls with non-absorbent claddings and some air leakage, WALLDRY may be a useful tool. We are not making any commitment to using these other models but mention them here because it may be necessary to include one or more of them when providing design guidance. They are cheaper and more accessible hygrothermal analysis tools than LATENITE.

It should be noted that the hygrothermal model LATENITE can not effectively model air movement in cavities as it employs Darcy’s equation for porous media. Darcy equations are used for slug flow modeling, that is present in an ideal porous media and not for modeling of air spaces. This simplification of the real physics does not permit the correct representation of the accelaration and decceleration forces of air movement in the cavity. Shear stress of the flow near the wall are NOT correctly accounted for. These differences may predict velocities that may be several times larger or smaller at different places in the flow. As ventilation flow movement is a cornerstone of this research project, correct modeling of the convective movement of air is critical. It is proposed that additional 3-D modeling of the air flow within the ventilation cavities be performed by employing a commercial Computation Fluid Dynamics (CFD) such as TASCflow or CFX. The elaborate modeling of the 2-D and 3-D turbulent flows will done by employing Navier Stokes equation that include all the necessary physics required. Real dynamics wind pressure boundary conditions will be supplied to this part of the modeling activity to determine the effect of shear forces and air velocity distribution. As the convective transport and thus drying capabilities of the air cavity requires an accurate velocity distribution near the wall surface, the engagement in this CFD activity will allow the development of calibration factors for air movement in the cavity for use in the hygrothermal modeling activity. A selected number of simualtions will be performed for vented and ventilated cavities, as the numerical complexities are several times more complex than modeling employing Darcy's equations.

4.1 The Wall Systems

Most of the modeled walls will be 2x6 framed, insulated with glassfiber batt insulation, and sheathed with OSB on the outside and finished with painted gypsum drywall on the inside. Walls for hot-humid climatic conditions may be framed with 2x4 framing. Table 3 outlines the other variables that will be considered. All of these walls will be modeled by the hygrothermal model.

Table 3 : Wall Systems for Computer Simulation

<table>
<tr><td colspan="5">Cold/Mixed Climate Wall: 2x6 wood framed w/batt insulation, OSB
Hot-Humid Climate Wall: 2x4 wood framed w/batt insulation, OSB</td></tr>
<tr><td>Ventilation</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td>Cladding</td><td colspan="2">Brick veneer</td><td colspan="2">Vinyl</td></tr>
<tr><td>Airspace size</td><td colspan="2">19 mm blocked, and
50 mm clear</td><td colspan="2">Flush applied, and
over 19 mm furring</td></tr>
<tr><td>Weather barrier</td><td>Asphalt building paper</td><td colspan="2">spun-bonded polyolefin</td><td>perforated polypropylene</td></tr>
<tr><td>Vapor retarder</td><td colspan="4">Climate dependent - some sensitivity modeling</td></tr>
<tr><td></td><td colspan="2">Total:</td><td colspan="2">Approximately 48 walls</td></tr>
</table>

Two different rainscreen claddings will be the focus of the computer modeling: vinyl and brick veneer. These two claddings command a large fraction of the market, but they also represent the extremes of likely performance. Brick veneer can store a significant amount of heat and moisture and is very capillary active. Vinyl neither stores nor absorbs moisture, and is thermally lightweight. Stucco and wood siding are other common cladding systems that have properties that lie somewhere between these two extremes.

The airspace behind the brick veneer will either be 19 mm, the smallest practical size for masons, or 50 mm, the size recommended by the Brick Institute of America for rainscreen brick veneers.

The air space behind the vinyl siding will be modeled as either applied directly over the sheathing membrane, or on 19 mm vertical furring at 600 mm centers. Three sheathing membranes will be considered: 15 pound building paper, a spun-bonded polyolefin, and one perforated (needle punched) polypropylene housewrap.

In cold climate simulations, a 0.15 mm vapor retarder will be used since it is often required by codes. The impact of removing the poly, and using only paper-faced batts, vapor barrier paints, or normal paint will be considered in some parametric studies. No interior vapor retarder will be provided in walls intended for hot-humid climates, other than normal paint, since they are not used in practice. However, the application of vinyl wallpaper will be considered in a few simulations.

Venting and no-venting situations will be modeled on the basis of the results of the initial lab studies. All vinyl siding is ventilated to some degree, and the difference between the vented and unvented cases needs to be modeled properly. Ventilation driving forces also need to be properly modeled, and these forces will be based on the field studies referenced previously.

4.2 Climatic Conditions

As required in the proposal call, six different climate conditions will be considered. The hot-humid climate zone, as defined the ASHRAE Handbook of Fundamentals, encompasses a geographically small but densely populated and growing area. The cities of Miami and Dallas (slightly less humid, but with a higher design temperature) represent this type of climate.

In the mixed climate zone, the city of Portland, Oregon, reflects a cool wet climate, that might be considered to be in the heating zone, and Charlotte, NC, represents a warm wet climate that requires some heating.

Cold climates will be represented by Halifax, Canada, as a cold and very wet climate and Minneapolis-St. Paul, as a cold and moderately dry climate.

The moisture reference year will be selected by analyzing 30 years of weather data. Then, by employing a procedure developed by the IEA Annex 24 or by Dr. Karagiozis, a representative moisture reference year will be determined.

4.3 Modeling Results

The results of the hygrothermal simulations will be compared to the results from field and laboratory studies. Any necessary and important assumptions required to predict performance will be identified..

A set of CD-ROMs will be created that contain dynamic visualization of the temperature, humidity, and moisture content distribution in the walls. Integral software that allows the viewing of the data will be provided.

5. Deliverables

The following deliverables are to be provided:

a) Progress and Financial Reports shall be made to the Society through its Manager of Research at quarterly intervals.

b) Interim reports with the most recent results will be provided to the Project monitoring chair at least twice a year.

c) The Principal Investigator will personally report on the progress of the project to the TC/TG at least once each year during the period of the contract at the annual or winter meetings.

d) Results will be developed, with prior approval of the Project Monitoring Committee, in a form that results in design guidelines that could be incorporated into the Handbook of Fundamentals. All raw and processed experimental data will be delivered in electronic form with detailed documentation and stored on CD-ROM. Numerical modeling results will also be stored in CD-ROM and will be provided with a custom-made PC Windows-based post-processor to provide easy visualization of the data.

e) A Final Report, that will include guidelines for the type and use of sheathing membranes, climate conditions, and cavity ventilation, shall be prepared and submitted to the Manager of Research, for prior review and approval by the T.C. 4.9 project monitoring committee. This will be conducted at the end of the contract period and will cover complete details of all research carried out during the project.

f) Both Guidelines and results need to reach the wider building enclosure design community. At least one, no more than four-page, builder-friendly document needs to be produced. The PHRC is the logical source for this technology transfer document.

g) At least two Technical Papers will be produced from the research. One of the papers will concentrate on verification of numerical models.

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