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Feasibility of Establishing Criteria for Permeable Envelope and/or Non-Mechanical Ventilation for Detached Single One or Two Family Residential Construction (Final Paper)

Dear Mr. Hernick:

Attached to this letter is Building Science Corporation's Final Paper to the Minnesota Department of Administration of Building Codes and Standards Division, for a proposal to assess the feasibility of establishing criteria for a permeable envelope and/or non-mechanical ventilation for detached single and two family residential construction.

Due to the length of the report, it has been divided up into several documents:

- This cover letter, accompanied by an Executive Summary
- Activity 1: Introduction (16 pages)
- Activity 2: Load Analysis (33 pages)
- Activity 3: Advanced Moisture Engineering/Modeling (12 pages)
- Activity 3 (continued): Advanced Moisture Model Results (20 Pages)
- Activity 3 (Appendices): Appendices A and B (13 pages)

An invoice is attached in the hard copy of this report.

Sincerely,

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Executive Summary

Activity 1: Introduction

Objectives: This report studies whether it is feasible to implement either alone or in combination with a permeable envelope, criteria for non-mechanical ventilation, which will ensure satisfactory air quality, and envelope durability for buildings in the state of Minnesota.

Methodology: The main research task was to select wall systems (permeable & non-permeable envelopes) and indoor and outdoor environmental conditions, and then to run parametric analysis using a holistic hygrothermal model simulator (ORNL MOISTURE EXPERT, Karagiozis, 2001) to determine the feasibility of satisfactory performance. Research was conducted in parallel via a literature search and by applying basic building science principles to available data.

Moisture Control Dynamics: This section functions as a primer on moisture movement through building assemblies. Topics covered include vapor diffusion transport, air-transported moisture, their relative magnitudes, and methods of controlling them.

Envelope Design Strategy: This section covers the design of building assemblies in light of moisture control dynamics. It emphasizes, for this cold climate, vapor and air flow retarders towards the inside surface, relative humidity control through ventilation, and permeable exterior sheathings.

Previous Work on Vapor Control: This section summarizes the findings of Rose (2001) in his research on the history of vapor barriers. It covers the recognition of the need for vapor control in the 1920s and 1930s, as well as the discovery of the relative magnitudes of vapor and convective air transport of moisture.

Moisture Control by Passive Ventilation Systems: This section summarizes Casselman's field work using a passive ventilation stack in Ottawa, Canada. By installing a vertical chimney stack from the conditioned space to the outdoors, he found that natural draft could be used to promote a ventilation flow. It was found that relative humidity could be limited by this natural draft system. However, the research team noted that it did not consider the energy losses: passive ventilation will overventilate during cold weather. Furthermore, it results in underventilation during cooling (air conditioning) seasons, resulting in possible indoor air quality issues.

Air leakage of Minnesota Houses: This section presents collected data on air leakage characteristics for various Minnesota houses. Based on tests on 1994-era Category 2 houses, the value of 4 ACH 50 (air changes per hour at 50 Pascals pressure) was used in the hygrothermal modeling analysis.

Indoor air relative humidity: A basic feasibility study on controlling relative humidity levels with natural ventilation was studied, based on the leakage rates found for Category 2 houses. Two interior moisture generation rates (high, for a family of 4, and low, for a family of 1 or 2) were used; relative humidity was bounded between 15% and 70% (assumed occupant intervention). Weather data for International Falls, and Minneapolis in a 2-year cycle (10% percentile cold year, followed by the 10% hot) were used.

The results show that at the ASHRAE ventilation standard of 0.35 ACH (air changes per hour), a very low moisture generation rate (less than the "low" rate above) would be required. Unless leakage was 0.8 natural ACH or higher, high interior humidities will result, which are likely to cause moisture migration into walls and resultant degradation, as well as surface mold at the interior.

Activity 2: Loads Analysis

Hygrothermal weather data were compiled for the two geographic locations: Minneapolis and International Falls, MN. Thirty years worth of NCDC data were collated to provide Moisture Design Years; the two years selected were the 10^{th} percentile hottest and coldest years. The 10% data was chosen (as opposed to worst-case) because an exceptional event could be assumed to occur extremely rarely, and therefore, the moisture loading could be dissipated through the envelope.

Weather data on vapor pressure (absolute moisture content of the air) showed that on average, drying potentials exist for 6 months out of the year in Minneapolis, and 8 months out of the year in International Falls.

Wind and rainfall data were combined to create wind-driven rain projections, based on ASHRAE SPC 160 P (Driving Rain Load). This information allowed the selection of worst-case faces for rain accumulation and penetration.

Indoor conditions were considered, being a very strong moisture source during the heating season. The interior humidity is governed by the moisture generation rate and the air change rate. A survey of various sources (LBNL, Quirouette) was taken to gauge published moisture source rates. In addition, the ASHRAE bounding values are to maintain relative humidity between 30% and 60%. RH below 30% can cause drying of the mucous membranes and discomfort for many people. RH above 60% for extended time periods promotes indoor microbial growth.

TenWolde and Walker (2001) described a state-of-the-art methodology to obtain the interior environmental conditions in terms of an analysis approach and design values. This methodology, which is intended for inclusion in the ASHRAE SPC 160P standard (Design Criteria for Moisture Control in Buildings) was adopted as the model for determining interior and exterior design moisture loads. This moisture load is computed independent of construction type, but includes the effects of ventilation and air conditioning equipment.

This model was used to approximate the influence of ventilation rates on interior moisture conditions. Minneapolis weather data was used, and winter, spring, and summer conditions were shown (January, April, and July). Three moisture production levels were used (5kg/day, 10kg/day and 20kg/day, or 1.3, 2.6, and 5.3 gal/day), and a house size of 2457 ft^2 was assumed.

The data show that in January, with the exception of a very low moisture production rate of 5 kg/day, the interior relative humidity can be high enough to lead to mold growth on wall surfaces and condensation on windows. At a ventilation rate of 0.25 ACH, center of room relative humidities easily exceed 40%. This will result in condensation on typical glazing, and result in mold growth at exterior walls where the gypsum board surface RH will exceed 80%. However, at a ventilation rate of 0.35 ACH, interior relative humidities will remain in the 20 to 30% range, avoiding window condensation and mold. However, with typical building envelope tightness, average air change rates of 0.35 ACH cannot be achieved. Similar behavior is demonstrated for April where even higher interior relative humidities were found.

From these results, one can observe that under normal building operating conditions with a family of 4, the interior relative humidity becomes prohibitively large without an appropriate mechanical ventilation system that maintains ACH rates at 0.35 for a large part of the year.

Relative humidity values were also plotted out over the course of two years (10% cold and 10% hot), for various air exchange rates and high and low moisture loads (5 and 20 kg/day). These plots show that at the air exchange rates achievable with natural ventilation, interior humidity levels will be unacceptably high.

Activity 3: Advanced Moisture Engineering/Modeling

In this activity, the ORNL MOISTURE-EXPERT hygrothermal model was employed in developing a parametric analysis of the performance of permeable wall systems without mechanical ventilation. The parameters varied included:

- Wall Type (see below)
- Geographic location (Minneapolis or International Falls)
- Indoor moisture production rate (high or low; 6.8 or 16.8 kg/day, or 1.8 or 4.4 gal/day)
- Mechanical pressurization (+3, 0, or –3 Pa)

In summary, the wall types were:

1. "Standard" Wall (polyethylene vapor retarder, OSB Sheathing
2. Permeable Wall A (no polyethylene vapor retarder, OSB Sheathing)
3. Permeable Wall B (no polyethylene vapor retarder, vented rainscreen space on battens, Fiberboard Sheathing)
4. Modified Permeable Wall B (no polyethylene, vented rainscreen battens, EPS interior, Fiberboard Sheathing)

Material Properties: This section functions as a primer on material properties required for advanced hygrothermal models. They are:

- Sorption isotherms (basically absorption of water vs. ambient RH)
- Vapor permeability (allowance of vapor transmission through the material)
- Liquid transport properties

Directional Properties: given the non-isotropic (different in various directions) properties of materials such as wood and OSB, the direction of flow and gradients relative to the material must also be accounted for.

Interpretation and results: Simulation results were shown for a full simulation set of the walls, for both Minneapolis and International Falls. OSB and Fiberboard moisture content was considered the significant value for wall performance: 12% and 10 % (OSB and Fiberboard respectively) were taken as the threshold values for mold growth (relative humidity of 80 %). Based on these criteria, Wall 1 (polyethylene vapor barrier) passed easily. Wall 2 did not pass for both low and high interior moisture production loads. Walls 3 and 4, also had unacceptable performance, but Wall 4 performed better than Wall 3.

Sensitivity study of data: As expected, high and low moisture generation rates had a direct effect on moisture content of the OSB and Fiberboard: low moisture levels reduced the seasonally stored OSB and Fiberboard MC. In terms of weather data, the 10% cold year was shown to result in higher moisture levels in the sheathing, due to increased thermal drive and greater chance of vapor condensation on sheathing. Mechanically induced pressures had their expected effect: positive interior pressures increased moisture loading, and negative interior pressured reduced them. Higher interior moisture loads increased the influence of air-transported moisture.

Conclusions

It is possible to construct wall assemblies and roof assemblies in Minnesota that can dry to the exterior without the need to install interior vapor barriers. The construction of these wall assemblies relies on the use of permeable exterior sheathings and ventilated claddings. The construction of these roof assemblies relies on well-ventilated roof assemblies and low levels of thermal insulation. The effectiveness of attic ventilation at removing attic moisture is dependent on attic temperature – the warmer the attic, the more effective attic ventilation is at removing attic moisture.

However, these permeable walls and permeable roofs cannot be used to diffuse sufficient quantities of interior moisture to keep interior moisture levels low enough to prevent interior surface mold if enclosures are constructed to typical levels of airtightness that result in typical air change.

In other words, it is possible to construct buildings in Minnesota without vapor barriers. However, constructing buildings without vapor barriers is not sufficient to control interior moisture levels. Air change is more significant than diffusion in controlling interior moisture levels. Constructing a leaky house can control interior levels of moisture. However, a leaky house consumes more energy than a tight house with controlled ventilation.

The only currently viable method of controlling interior surface mold without excessive energy consumption is the construction of tight building envelopes with controlled mechanical ventilation.

Although it is possible to construct buildings in Minnesota without controlled mechanical ventilation and avoid indoor environmental problems, it is not possible to do this in an energy efficient manner.