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COLUMN

Heat, air and moisture interactions

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1. Introduction

Heat, air and moisture transport across a building envelope are inseparable phenomena. Each influences the others and is influenced by all the materials contained within the building envelope.

Often we simplify the process of architectural design by relating control of each phenomenon to a particular material. The thermal insulation, for example, is perceived to control heat transfer and the air barrier to control air leakage. Likewise, the rain screen and the vapor barrier eliminate ingress of moisture to materials. However, these materials perform many different and interrelated functions, and frequently participate as one of several factors in overall system performance. For instance, while controlling air leakage, the air barrier system may also provide effective moisture control. Similarly, by increasing temperature in the wall cavity, thermal insulating sheathing may also reduce the degree of condensation in the cavity.

Thus the process of environmental control depends on strong interactions between heat, air and moisture transport. And to ensure that all aspects of the building envelope perform effectively, we must deal with heat, air and moisture transport collectively. In some ways, this approach represents a return to the thinking of 60 years ago, long before detailed analyses were routine. The difference today is presence of many standards and requirements related to individual elements that make the building envelope. So, while we preserve the basic approach of the past, it is easier to apply the fundamental concepts first introduced in the 1930s.

Primarily, the building envelope provides shelter from the outdoor environment and encloses a comfortable indoor space. In doing so, the envelope must withstand many mechanical and environmental forces and this durability must extend over its service life. In response to climatic extremes, for instance the Manitoba cold or Arizona heat, the envelope must also be well insulated to provide the required level of thermal comfort at a reasonable cost.

2. A lesson from history

Air transport represents a critical factor in environmental control. It underscores virtually all facets of environmental control as it also moves both heat and moisture through the building envelope. The pioneering work by University of

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Minnesota on air leakage (1929–1932) led to acceptance of the building paper weather barrier. The building paper impeded the movement of air and rain while permitting moisture to breath to the outdoors. In addition, the building paper reduced heat losses by limiting air leakage, improved indoor comfort by reducing drafts, and reduced moisture damage to the walls by preventing the wind washing which decreases the inner surface temperature.

In the quest for indoor thermal comfort, wall cavities were filled with insulation—first wood chips stabilized with lime, then shredded newsprint (1926, Saskatchewan) and eventually mineral fiber batts. Although water vapor passed through the thermal insulation as easy as through the air layer, the presence of thermal insulation introduced durability reduction, it lowered the temperature of the exterior sheathing and condensation appeared.

This situation led to the introduction of vapor barriers to control the flow of vapor from warmer indoor environments. Consequently, the walls of homes built as early as the 1940s already included the outside weather barrier and the inside vapor barrier.

In Canada, vapor barrier has become synonymous with polyethylene sheets, although building codes always permitted many other solutions. One of them is a double-painted drywall in which the paint fulfils the vapor barrier requirement. And the 0.15 mm polyethylene sheathing which controls air leakage in houses functions as a vapor barrier as well.

3. Moisture effects—material durability

The building envelope must perform, separating the interior and exterior environments. To do this, the envelope needs structural integrity and durability, particularly if it is to prevent moisture damage. Of all environmental conditions, moisture poses the biggest threat to integrity and durability, accounting for up 60–80% of damages in building envelopes.

Certainly, many construction materials contain moisture, most notably, masonry or concrete. These materials demonstrate excellent performance characteristics as long as the moisture does not compromise the structural or physical integrity. However, excessive moisture jeopardizes both the material and its functionality.

Consider, for example, the ability of a material to withstand, without deterioration, natural periods of freezing and thawing. This is not a material property but a complex characteristic which depends on both the material and the environment. For instance, in one school building, only the outer surface of the external clay-brick protrusions showed freeze-thaw spalling. These protrusions were more exposed to driving rains and the surface temperature of the bricks was slightly lower, compared to the plain facade where no spalling occurred. Both of these conditions may result in freeze-thaw damage.

Corrosion of metals exposed to air similarly varies with surface temperature and humidity. Likewise, mold growth requires certain temperatures and humidity (temperatures above 5 °C and relative humidity above 80%).

4. Thermal energy—dynamic performance

Assessing the energy performance of the building envelope involves three different considerations:

- quantity of heat transferred through the walls, windows and other elements of the building envelope—the conductive heat transfer,
- quantity of heat needed to bring the temperature of the outdoor air to that of the indoor air—the air leakage characteristics and ventilation rate and
- differences in temperatures on the inner surface of the building envelope—the mold control.

Conductive heat transfer may be represented in four different manners, each with increasing precision. The first approximation considers only the plain, insulated areas of the envelope, ignoring the multidirectional heat flows caused by thermal anomalies. So a frame wall insulated with RSI 3.5 glass fiber batts is called an RSI 3.5 wall.

The second level of accuracy considers how the actual thermal resistance of the wall differs from the one-dimensional flow model. Thus, the RSI 3.5 wall now becomes an RSI 3.1 wall.

The third level of accuracy adds two- or three-dimensional calculations of heat flows, while assuming that the steady-state representation sufficiently describes the thermal performance of the building. The fourth level incorporates transient weather conditions into the calculations of thermal performance.

These last two levels of accuracy underlie the European standards differentiate between the declared and design values when assessing the thermal characteristics of building materials. The declared value represents the expected thermal performance as measured at a reference temperature and thickness and stated with a certain confidence. The design value describes the performance under certain climate and use conditions.

The second component of energy performance—air leakage—relates to the rate of air flowing through the building envelope. This component is directly proportional to air pressure differences across the envelope and inversely proportional to the airflow resistance of the building envelope.

The final component of thermal/energy performance valuation relates to the water vapor condensation on the surface of thermal bridges in the building envelope. At these locations, lower thermal resistance reduces the surface temperature. As a rule, surface condensation does not plague wood frame walls provided the wall cavity is completely insulated and air leakage is not significant.

Conversely, floor junctions in masonry construction and concrete decks connected to balconies do experience problems with condensation because of significant reductions in surface temperature. If a low rate of convective air movement accompanies these surface temperature reductions, then mold and mildew in bathrooms and closets and deterioration of drywall in staircases can be expected.

5. Design for environmental control

Accommodating environmental control in building design requires iterative analysis and a willingness to change not only minor details, but to alter the basic concept itself if information indicates that this is desirable. Thus, the design must remain as flexible as possible until all the consequences are fully examined.

The design of an air barrier system offers an example of how the process of iterative design might work. The information flow may start with a search for suitable materials. Typical questions are asked about possible materials and their air permeability, they ability to be extended, about pliability, adhesion, and means of attachment, connection and support. The review would also address the long-term performance, material aging, stress and deformations during service, as well as projected costs of repairs and maintenance.

After making an initial selection, the designer then specifies the architectural details such as intersections and joints between building elements (for example foundations, walls, floors, windows and doors). Then, to achieve satisfactory performance in these locations, the designer must ask further questions concerning the performance of the whole system, such as rate of air leakage, location of leakage, risk of drafts and impact on condensation. Throughout the design process, the designer consults with structural, electrical and mechanical experts to obtain answers to all these questions and to ensure that the selected materials will perform satisfactorily.

In addition, the designer reviews the build ability aspects such as material installation under different weather conditions, level of labor skill required for installation and construction tolerance. Buildability, as the word suggests, reflects whether the design on paper can be constructed.

Finally, the complexity of heat, air and moisture interactions demands redundancy in the design. For instance, the air barrier plan may be punctured, not connected to some elements of the envelope, or a rain leak may develop. The designer must evaluate how the moisture could be drained, or if not drained, whether it could be dried out. How long would the drying take place and what effect would it have on other materials? Could the prolonged presence of moisture cause corrosion, mold growth or rot?

The entire process of environmental control design must occur off-site, and never at the building site. Addressing only a specific design problem on the job site, without reviewing all the performance effects, courts disaster since integration of other requirements may not be achieved.

6. Addressing the duality

In designing for environmental control, professionals integrate two very different conceptual processes. One involves specific testing and analysis; the other encompasses broad qualitative assessments based on experience, judgment and knowledge of what makes a building envelope function.

On the analytical side is a complex array of tools, models and data which describe the material, structural and environmental factors relating to the building envelope. On the qualitative side is a sense of how a particular building envelope would function.

For example, a vapor barrier is typically classified at one perm, a unit that represents sufficient retardation of water vapor flow for wood frame housing. However, if calculations were made using a complex model of heat, air and moisture transport for various climatic conditions in Canada, barriers ranging from 0.1 to 10 perms would be found suitable for various combinations of materials and climates. Similarly, some materials that qualify as vapor barriers may be ineffective when wet.

So, despite the move to establish a precise measurement to define vapor barriers, the selection of the most appropriate barrier involves both conceptual logic and mathematical analysis. Designers must still conduct an overall qualitative assessment to determine whether the barrier, chosen for its quantitative properties, would actually function in the specific application.

This is a strategy reminiscent of 60 years ago when builders took an holistic approach to performance. But it differs in one important area. In the past, this approach reflected a time of limited knowledge, less demanding performance requirements and few analytical methodologies. Today's achievements, however, derive from designers deliberately consolidating an understanding of complex analysis with the lessons of experience. The net result is a building envelope designed for environmental control—a building envelope that works.

Mark Bomberg is a part time professor at McMaster University, Hamilton, Ontario, Canada and Southeast University in Nanjing, China as well as editor-in-chief of the Journal of Building Physics (Sage Corp. London, UK). His interest on the path from materials to sustainable buildings is possible because of his research background in heat, air and moisture transfer, material science and evaluation methodology with particular interest in durability of construction materials. Currently he is working on integration of HVAC and building enclosures (see Frontiers Architecture Civil Engineering China 2010, 4(4)).

Dr. Bomberg graduated as master of civil engineering at Warsaw Technical University, Poland, but never managed to start work as such. As a graduate student he became a technical assistant to Prof. Bohdan Lewicki, member of Polish Academy of Science, and started research in Building Physics. Later he became one of two people responsible for building the national laboratory and led development of test methods for the Building Physics Section of the Polish Research Institute. He defended thesis in thermodynamics of irreversible processes receiving a title of Doctor of Science (Engineering). Awarded a post doctoral scholarship to Holland and Sweden he became technical assistant to Prof. L.E. Nevander at Lund University, Sweden and for 8 years worked on fundamentals of moisture transport in construction materials. Some findings served for thesis and he received the Swedish title of Doctor of Technology.

He emigrated to Canada, worked for 20 years for National Research Council of Canada, leading the field of thermal insulation. After early retirement from NRCC he taught at

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He published over 200 papers and some books; is one of two people who instituted BEST Conferences in the US and received the highest awards in building physics in both USA and Canada namely Ontario Building Envelope Council (BECKIE, 1999) and Building Enclosure Technology and Environment Committee of the National Institute of Building Science, Washington DC (2012) in addition to awards from ASTM, Society of Plastic Industry (US), CGSB and ULC (Canadian standards), Canadian Plastic industry, NRCC, U. of Baja California, Mexicali, Mexico.