

INDOOR ENVIRONMENT AS AN EFFECT OF HEAT, AIR AND MOISTURE TRANSFER THROUGH BUILDING ENCLOSURES

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

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 interact with others. 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 enclosure perform effectively, we must deal with heat, air and moisture transport collectively. In some ways, this approach represents a return to the thinking of 70 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 enclosure. So, while we preserve the basic approach of the past, it is easier to apply the fundamental concepts first introduced in the 1930s.

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 enclosure. Pioneering work by University of Minnesota on air leakage (1929-32) led to acceptance of the building paper weather barrier. The building paper impeded the movement of air and rain while permitting moisture to breathe 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.

Moisture effects -- material durability

The building enclosure must perform, separating the interior and exterior environments. To do this, the enclosure 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 to 60 to 80 percent of damages in building enclosures.

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 together may result in freeze-thaw damage.

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

Thermal energy -- dynamic performance

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

- quantity of heat transferred through the walls, windows and other elements of the building enclosure -- 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
- thermal bridge lowers winter temperatures on the inner surface of the wall and may cause condensation of water vapor

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

The second level of accuracy considers thermal bridge effect and the RSI 3.5 wall now becomes an RSI 3.1 wall. The next level incorporates transient weather conditions into the calculations of thermal performance. The wall is still dry and no air flows through it but now we need to use a computer model to calculate how much heat storage will contribute to the thermal performance of the wall.

Now, however, the concept of R-value or its inverse U-value does not work. It varies depending on temperature of the wall, if the wall is warming up or cooling down, how much sun radiation fall on it and we would rather talk about the energy loss over the given surface area over one day or one year. And this is what we do in energy models.

The energy models do not deal with real walls; they deal with perfect walls, no penetrations and no air flows, no rain or moisture effects on the walls – just the perfect walls and perfect weather from the typical weather year. European thermal insulation standards attempt to 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 is to describe 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 enclosure. This component is directly proportional to air pressure differences across the enclosure and inversely proportional to the airflow resistance of the building enclosure.

The next component of energy performance evaluation relates to the water vapor condensation on the surface of thermal bridges or inside of the building enclosure. At these locations, lower temperature

causes condensation and liquid water find its way to the construction. So, the general requirement to eliminate the critical thermal bridges links thermal and durability consideration for buildings.

Design for environmental control

Accommodating environmental control in building design requires iterative analysis and a willingness to change not only minor details, but often to alter the basic concepts if information e.g, too high moisture content indicates that a change is desirable. Thus, the design must remain as flexible as possible until all the consequences are fully examined.

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 air flow control 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 buildability 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, a rain leak may develop at the connection of wall and window. 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, mould 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.

Addressing the thinking 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 enclosure 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 enclosure. On the qualitative side is a sense of how a particular building enclosure would function.

For example, a vapor barrier is typically classified with a water vapor permeability value that represents retardation of wood planks used in old housing. Yet calculations made with a complex model of heat, air and moisture transport for Canada, showed that providing that an air barrier system was in place, the vapor barriers ranging from 0.1 to 10 perms were suitable depending on the climate. Furthermore, some materials that qualify as vapor barriers are ineffective when wet. Thus, the selection of the most appropriate barrier involves both conceptual logic and mathematical analysis.

So it is with all aspects of environmental control. Designers must still conduct an overall qualitative assessment to determine whether the materials, chosen for its quantitative properties, would actually function in the specific application.

This is a strategy reminiscent of 70 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 enclosure designed for environmental control -- a building enclosure that works.