

Balancing building science and roof design

by brittney_cutler_2 | April 4, 2022 11:00 am



[1]

Photo courtesy GAF

By James R. Kirby, AIA

The design and construction industries are increasingly using building science concepts to design and construct long-lasting, high-performance buildings. The concepts are not new and have been understood by some in the building and design communities for decades. However, for many designers, it is a shift from traditional practice emphasizing form, esthetics, and programmatic requirements over building science fundamentals.

Understanding the complex nature of building enclosure performance and the science behind it will have a positive impact on how buildings and roofs are designed, constructed, and endure. Building science also assists architects in mitigating the risks of design-related building failures.

Understanding building science

Building science is the study of the effects of heat, air, and moisture (vapour and liquid) on the building enclosure. It involves an understanding of building performance within specific climate and environmental conditions (Figure 1) from a systems perspective rather than as a collection of individual unrelated components.

Building science can be used to mitigate or prevent damage from air and moisture infiltration and high winds, and to improve the energy efficiency, durability, and long-term performance of buildings.

Second law of thermodynamics

The fundamentals of building science are found in the Second Law of Thermodynamics:

- ∞ Heat flow is from warm to cold;
- ∞ Moisture flow is from warm to cold;
- ∞ Moisture flow is from wet to dry;
- ∞ Air flows from higher pressures to lower pressures; and
- ∞ Gravity acts down (think Isaac Newton's apple tree).

In short, energy, air, and moisture are exchanged between two systems until a state of equilibrium or balance is achieved (Figure 2).

The struggle with water



[2]

ASHRAE climate zone maps showing different climate zone conditions in the U.S. and Canada.

Download from source:

www.ecohome.net/guides/3521/climate-zones-map-usa-canada-construction

Of the many challenges a building enclosure faces, water represents the greatest continuous threat. The presence of water in unwanted locations in the building enclosure can contribute to rot, decay, and bio growth, as well as a reduction in thermal efficiency. In other words, while high-wind events, impacts, and fires must be considered in design, ongoing water infiltration should be of primary concern to building designers.

There are four primary moisture transport mechanisms to consider when designing a building's enclosure: bulk water, capillary water, air-transported water, and vapour. The most obvious and impactful is bulk water, such as rain. Buildings must be designed to efficiently shed or manage liquid water, and the design community generally does a good job of properly detailing the building enclosure to achieve this.

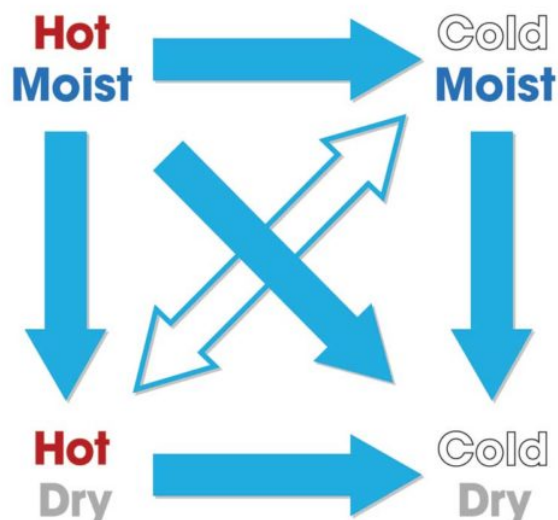
Next is capillary action, which primarily deals with below grade moisture infiltration through pores and small cracks in foundations and the intersections of above- and below-grade systems. The design community does a good job of properly detailing the building enclosure for capillary action, as well.

The last two—air-transported water and vapour diffusion—influence the performance and durability of building enclosures, but the materials and designs used to control air intrusion and reduce vapour diffusion are often less obvious.

Air leakage can carry 10 to nearly 100 times the amount of moisture when compared with vapour diffusion, which is why the *International Energy Conservation Code (IECC)* has required the use of air barriers in building enclosures since 2012. Gaps and discontinuities in air barriers within the building enclosure (including the roof) allow air flow, with its associated moisture. This moisture intrusion can be problematic to say the least.

In contrast, vapour diffusion through building materials is less impactful than air intrusion and its carried moisture. For this reason, codes are nearly silent on the use of vapour retarders in roofs. However, the need for vapour retarders in certain climate zones and high humidity environments has been historically recognized by the design community, yet oftentimes these vapour retarders were beneficial because, unknowingly, they also acted as an air barrier. Due to a lack of building science knowledge, vapour retarders have not always been incorporated into designs correctly, causing building damage.

You May Also Like [Surveying the 2020 design/construction landscape](#)



[3]

Graphical depiction of the Second Law of Thermodynamics as it relates to building science.

Images courtesy GAF

The effects of air movement and pressures within the building enclosure

Controlled and uncontrolled interior air pressures from wind, stack effect, and HVAC systems often combine to create air flow across the building enclosure (Figure 4).

First, wind exerts pressure on the building enclosure. On the windward side there is positive pressure, and on the leeward side there is negative pressure. The stack effect is about warm air rising, increasing pressures higher up in the building. There are also mechanical-related pressures caused by forced air systems.

These pressure differentials create air and moisture movement within a building and through, or across, its enclosure. Proper placement of the thermal layer and air/vapour control layers can help prevent moisture intrusion into the building enclosure. Building science can provide ways of predicting moisture movement within an enclosure and help determine which design configurations minimize or block vapour and moisture intrusion and retention.

The importance of managing uncontrolled air flow, and the moisture it carries, cannot be overstated. The air's ability to hold moisture is dependent on its temperature. Warm air holds more moisture than cold air, and when warm moist air encounters a cold surface, the air will cool (and its ability to hold moisture will decrease). The excess moisture will condense on the cold surface.

Therefore, air barriers are best located on the warm side (in winter) of the dew point; proper placement of air barriers limits the risk of condensation on surfaces within the building enclosure. For roof systems, installing the vapour retarder as an air barrier (*i.e.* sealing all penetrations and transitions) allows one to address vapour diffusion and air transported moisture.



[4]

1) Bulk water, 2) Capillary water, 3) Air-transported water, and 4) Vapour diffusion.

Roof membranes as air barriers

In many respects, air barriers and roof membranes have much in common. Roof membranes require serious attention to terminations, penetrations, and flashings. Air barriers must be approached the same way, the goal being to prevent movement of air up into the roof system.

Air barriers often consist of a roll good, seaming tapes, caulks, and coatings. It is common to see spray-applied foam used to close large holes and gaps, followed by a coating and tapes to transition to the roof membrane.

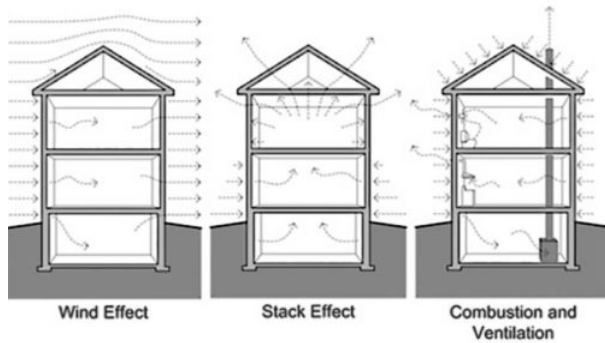
While this is a common practice, questions still arise on how to design and install an effective air barrier system. The general misunderstanding of the concept of an air barrier and its purpose also significantly contributes to confusion on specifying these systems.

Air barrier basics

The primary function of an air barrier is to prevent or restrict air leakage through a building's envelope. Air barriers are intended to control air flow from the exterior to the interior of a building, as well as from the interior to the exterior of a building.

An air barrier needs to be installed continuously on all sides of a building; an air barrier should “wrap” the entire building thermal envelope. For an air barrier to function properly, it should:

- ∞ meet permeability requirements;
- ∞ be continuous when installed;
- ∞ accommodate dimensional changes; and
- ∞ be strong enough to support the stresses applied to it.



[5]

Processes creating air flow across the building envelope. *SOURCE: Building Science Digest, BSD-014: Air Flow Control in Buildings, John Straube, October 15, 2007.*

An air barrier is not a single product or material. Rather, it is a combination of materials assembled and joined together as a system to provide a continuous barrier to air leakage through the building envelope.

You May Also Like [Façades for the future](#)

An air barrier's effectiveness can be greatly reduced by openings and penetrations, even small ones. These openings can be caused by poor design, poor workmanship, damage from non-roofing trades, improper sealing and flashing, mechanical forces, aging, and other forms of degradation.

The National Research Council of Canada (NRC) collected research data illustrating how even small openings can affect overall air leakage performance. For example, only about 0.3 L (0.08 gal) of water will diffuse through a continuous 1.2 x 2.4 m (4 x 8 ft) sheet of gypsum board during a one-month period, even though gypsum board has a high permance.

However, if there is a 25 mm (1 in.) square hole in this same sheet of gypsum board, about 28.4 L (7.5 gal) of water can pass through the opening because of air leakage. This example illustrates how air leakage can cause more moisture-related problems than vapour diffusion.

Air barrier versus vapour retarder

When discussing air barriers, roofing membranes, and the building envelope, another important topic comes to mind: vapour retarders. There is often confusion between air barriers and vapour retarders. The purpose of a vapour retarder is to minimize or reduce water vapour diffusion into a low-slope roof or wall system. In other words, it is used to prevent the formation of condensation in a low-slope roof or wall system.

A vapour retarder is often called a "vapour barrier" and this contributes to getting the terms mixed up. Interestingly, model building codes in the U.S. use the term "vapour retarder," yet confusion still exists. Canadian codes use the term "vapour barrier." A lack of consistency does not reduce confusion.

Generally, a vapour retarder is used where a building's interior humidity conditions are expected to be relatively high, and the building is in a cold climate. A vapour retarder is commonly installed on the warm (interior) side of a roof or wall. In a low-slope roof assembly, the vapour retarder is normally installed under the primary roof insulation.



[6]

Photo of a rooftop after a light snow with snow melt at each fastener. *Image courtesy GAF*

Therefore, one will often see it installed directly on a roof deck (such as a concrete or wood deck) or on a continuous substrate (such as gypsum board or wood panels) installed directly over a metal deck. Conversely, in warm, high-humidity geographic locations, vapour retarders are installed on, or near, the exterior side of roofs and walls of air-conditioned buildings.

Thermal performance

Thermal bridges have an impact on the thermal performance of roofs and buildings. Fasteners can play a significant role in reducing the effective R-value of the building enclosure's thermal layer.

Figure 5 shows roof fasteners acting as thermal bridges, melting the snow on the roof due to conductive heat transfer. Interestingly, the energy codes do not recognize the impact of thermal bridging from fasteners on continuous insulation systems. For this reason, designers should consider adhered roofing systems can be cost competitive once long-term energy efficiency is factored in.

It is also important to be cognizant of the negative effects of moisture-laden air, water vapour, and thermal bridges on long-term building performance, and to incorporate preventative measures into designs to mitigate risk. This requires a strong understanding of the building science principles.

Are minimum codes enough?

Architects can, and often should, design beyond the minimum code requirements within the *National Building Code of Canada (NBC)* and the *National Energy Code of Canada for Buildings (NECB)* to improve the durability and longevity of their buildings. This is especially important with respect to changing climate and increased frequency and magnitude of storms and weather events.

You May Also Like [How AI is revolutionizing construction: New builds embrace emerging technology.](#)

Designing building enclosures from a building science perspective can be an effective way to reduce condensation potential and moisture damage; reduce wind-related roof failures, for example, caused by corroded fasteners; and provide an energy-efficient thermal layer.



[7]

Photo showing material degradation because of moisture intrusion. *Image courtesy Phil Dregger*

Designing with building science in mind

Today, architects are increasingly leveraging new technologies to design buildings of greater complexity. New materials are being incorporated, and traditional materials may be used in new ways. For example, the use of air barriers in roofs and walls is now mandated, so understanding how they can affect condensation potential is critical. The introduction of thermal insulation, tighter building enclosures, and increased mechanization of interior environments means the industry must change the way designs are approached and consider buildings as holistic systems rather than as individual parts.

When building science fundamentals are incorporated into designs, it not only increases the potential of long-term performance, improved durability, and energy efficiency, but also allows design ideas to align with an architect's esthetic vision.

When buildings are not designed or constructed in accordance with sound building science, they are susceptible to:

- ∞ structural failures;
- ∞ building enclosure material degradation (Figure 5);
- ∞ biological growth; and
- ∞ reduced building life expectancy.

Practical ways to incorporate building science into designs

Designing a building in accordance with building science fundamentals is just the first step. Ensuring the as-constructed building aligns with the architect's design intent is also important. The following are some steps the architect can take to meet these goals.

Design phase:

- ∞ Understand the impact of heat and moisture transfer through the building enclosure—hydrothermal analysis may be useful with more complex designs;
- ∞ Calculate temperature gradients across the building enclosure to determine the need and correct location of a vapour retarder/air barrier within the building enclosure; and
- ∞ Account for wind uplift and impact resistance, such as hail or wind-blown debris.

Construction document phase:

- ∞ Include the air barrier and the vapour retarder (when required) in the drawings;
- ∞ Identify specific components of the code-required air barrier system in the drawings;
- ∞ Include specification sections specific to the project, system, and material; and
- ∞ Provide details of the vapour retarder (when required), insulation, air barrier system, and weather-resistive barrier transitions (*e.g.* roof-to-wall) to ensure continuity and avoid the “by others” conundrum.

Bidding phase:

- ∞ Understand the risks of value engineering and life cycle cost implications (initial versus long-term costs); and
- ∞ Clearly communicate why components of the design are critical for long-term building performance and energy efficiency.

Construction administration phase:

- ∞ Review project submittals to ensure the specified products and systems are properly incorporated into the project and alternates are not substituted inappropriately.

Partnering with experts

The most successful buildings will not only meet the architect’s esthetic vision, but they will also be well-functioning for the occupant, as well as long-lasting, durable, and energy efficient. Building enclosure consultants who specialize in building science and energy modelling may be a valuable addition to a project team tasked with navigating the gap that sometimes exists between design and science.

It is also important, during the design and specification process, to work closely with product manufacturers that have experts on staff who understand building and roofing science, to ensure the correct products are used, and systems as designed will provide the expected performance to help lower an architect’s risk.

Author



[8]James R. Kirby, AIA, is a GAF building and roofing science architect. Kirby has a master’s degree in architecture—structures option, and is a licensed architect. He has 30 years of experience in the roofing industry covering low-slope, steep-slope, metal, SPF, vegetative, and rooftop photovoltaics. He understands the effects of heat, air, and moisture on a roof system. Kirby presents building and roofing science information to architects, consultants, and building owners, and he writes articles and blogs for building owners, facility managers, and the roofing industry at large. Kirby is a member of AIA, ASTM, ICC, IIBEC, NRCA, and WSRCA.

Endnotes:

1. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/IMG_9966.jpg
2. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/Fig-1_US-CAN-climate-zones.jpg
3. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/Fig-2_2022-03-07_16-32-22-RECREATED-01.jpg
4. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/Fig-3_Bulk-Capillary-Air-T-Vapor.jpg

5. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/Fig-4_Wind-Stack-Mechanical.jpg
6. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/Balancing-Bldg-Sci_BEAUTY-SHOT.jpg
7. [Image]: https://www.constructioncanada.net/wp-content/uploads/2022/04/Fig-6_Roof-deck-rot_PHOTO-COURTESY-OF-PHIL-DREGGER.jpg
8. [Image]: <https://www.constructioncanada.net/wp-content/uploads/2022/04/Kirby-Head-Shot-2021.jpg>

Source URL: <https://www.constructioncanada.net/balancing-building-science-and-roof-design/>

Copyright ©2023 Construction Canada unless otherwise noted.