RDH BUILDING SCIENCE

November 2026

Thermal Bypass due to Airflow

The effect of airflow-related thermal bypasses on the thermal performance of exterior wall assemblies

AUTHORED BY:

Daniel Haaland | M.A.Sc., P.Eng.
Principal, Specialist
RDH Building Science Inc.
#400-4333 Still Creek Drive
Vancouver, BC V5C 6S6

John Straube | P.Eng.
Principal, Senior Specialist
E: jstraube@rdh.com
T: 548-889-0072
RDH Building Science Inc.

REPORT NO. 27756.001-2026-11

Executive Summary

Exterior wall assemblies are increasingly designed with higher insulation levels to meet energy codes, performance standards, and owner requirements. However, the thermal performance achieved in service depends not only on the nominal R-value of the insulation, but also on whether heat can bypass the insulation layer. This white paper reviews airflow-induced thermal bypass mechanisms in exterior wall assemblies, including natural convection within or around insulation and wind washing caused by airflow through, behind, or around insulation.

The research reviewed shows that these mechanisms can occur even where the primary air barrier is well designed and constructed, particularly where exterior continuous insulation is located outboard of the air barrier and exposed to airflow within the rainscreen cavity or around cladding attachment components. While, well-installed higher-density exterior insulation in substantial contact with the substrate experiences limited impact; gaps between boards, gaps behind boards, and gaps around attachment components can substantially reduce effective thermal performance. The primary recommendation is to treat exterior continuous insulation as an installed system rather than only as a material layer with a nominal R-value. Appropriate design, coordinated cladding attachment detailing, suitable product selection, tight-fitting installation, joint treatment, and construction-stage review can reduce or eliminate the risk of airflow-induced thermal bypass in most practical wall assemblies.

Notice to Reader

This paper was authored by RDH Building Science with financial support from Advanced Architectural Products (A2P). Where specific products or systems are used as examples, their inclusion does not constitute an endorsement or recommendation. Products, standards, codes, and construction practices evolve over time, and readers should consult current technical literature, manufacturer documentation, applicable codes and standards, and appropriately qualified design professionals before applying the information to a specific project. Use of this white paper does not guarantee compliance with applicable regulatory requirements, nor does the omission of a particular product, system, or approach imply that it is unsuitable or non-compliant.

Table of Contents

1. Introduction....1
1.1. Convective Thermal Bypass....1
1.2. Continuous Insulation....4
2. Impacts....5
2.1. Natural Convection within Insulation....5
2.2. Natural and Forced Convection Around Framed Wall Cavity Insulation....5
2.3. Natural Convection Around Continuous (Exterior) Insulation....6
2.4. Forced Convection Through and Around Insulation (“Wind Washing”)....6
3. Practice Recommendations....8
3.1. Uneven/irregular Substrates....8
3.2. Thermal Movement....9
3.3. Cladding/insulation Attachment Approach....9
3.4. Workmanship....11
3.5. Exterior Wind-control Layer....12
4. Conclusions and Recommendations....12
5. References....13
6. Definitions....14
7. Extended Bibliography....15

1. Introduction

The building design and construction industries are continually being challenged to improve the thermal performance of building enclosures. Across both the United States and Canada, not only have prescriptive R-value targets continued to rise, but there has also been a growing understanding of and need to account for thermal bypass mechanisms—such as thermal bridging and air leakage—that can undermine insulation effectiveness. While increasing insulation thickness was a common approach in the past, today's and tomorrow's designs must address the ways in which heat can bypass insulation layers.

The term "thermal bypass" was developed to describe pathways for heat transfer to occur other than directly through insulation layers (Harrje et al. 1979). Thermal bypasses around insulation have been found to lead to significant heat loss or gain and can have major impacts, i.e., they can reduce performance by 50% or more. As a result, professional guidance documents, program standards, and codes include design and construction recommendations targeted at reducing thermal bypasses.

There are two primary physical categories of thermal bypasses, those for which heat flow is by:

1. conductive heat transfer, or
2. convective heat transfer (i.e., heat is transported via air movement)

The former category is today labelled **thermal bridging**, and codes and standards have increasingly added explicit requirements to address this type of thermal bypass (e.g., ASHRAE 90.1-2022 and IECC 2024). Modern trends toward continuous insulation (c.i.), thermally-broken cladding attachments, and thermally improved installation details for windows are all a result of the need to reduce thermal bridging.

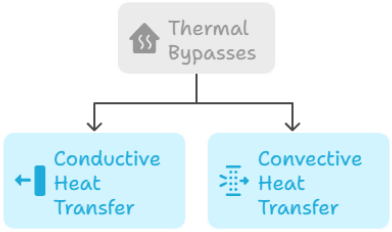


***Figure 1**: Thermal bypass categories based on mechanism (conduction vs. convection)*

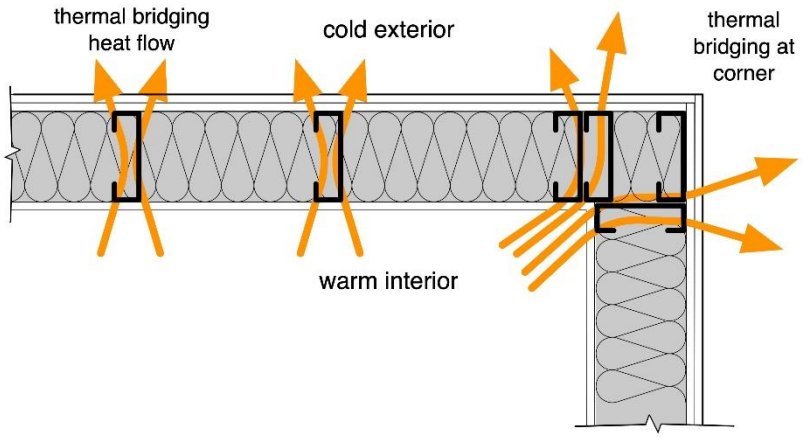


***Figure 2:** Example thermal bridging (i.e., conductive thermal bypass) through steel stud framing*

1.1. Convective Thermal Bypass

The second category of thermal bypass includes mechanisms whereby air flow carries heat through and around insulation. There are numerous complex flow paths possible in a building, but the paths of air moving heat around and through insulation are one of two types:

a. Air leakage through the building enclosure through holes in the air barrier (see Figure 3)
b. Airflow through and around insulation (Figure 4)

The flow of air through the building enclosure (i.e., exfiltration and infiltration or "air leakage") is primarily controlled by providing an effective continuous air barrier. A continuous air barrier is required by most building codes and standards. While this has been true for many years, an important shift in the quality of installed air barrier performance has been the introduction of testing. With the adoption of recent national energy codes (2021 IECC, ASHRAE 90.1-2019) and state-level energy stretch codes (e.g., Massachusetts Stretch Energy Code), whole building airtightness tests are now required in many jurisdictions to measure the effectiveness of the installed air barrier systems prior to completion of new buildings. In jurisdictions such as Washington State, which has required whole building air leakage testing and reporting since 2009, air leakage rates in new buildings have decreased by more than 40% (Ricketts 2017).

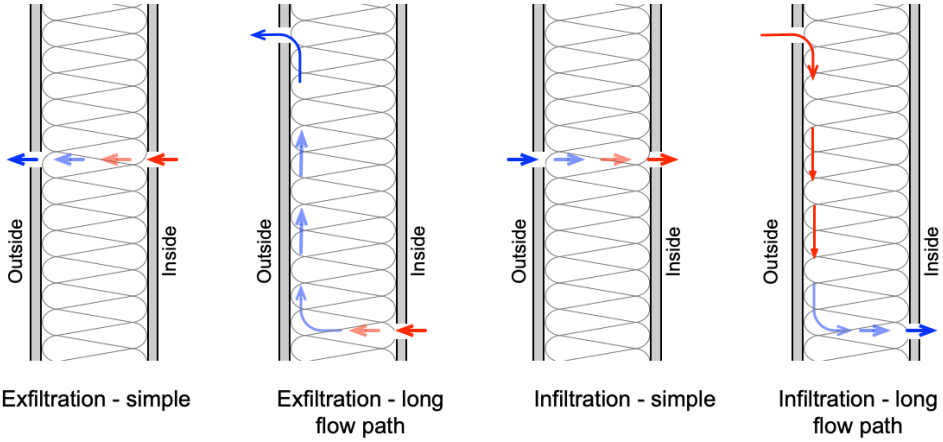


Figure 3: *Airflow leakage through the building enclosure*

Air does not need to flow fully through a building enclosure assembly to result in increased heat flow. Airflow-induced thermal bypass can also be caused by airflow around and within insulation layers (Figure 4). These bypasses can occur even if the air barrier system is perfectly designed and constructed. Common mechanisms of this type include:

a. Convective airflow loops within porous materials,
b. Convective airflow around insulation,
c. Re-entrant convective loops to the inside,
d. Re-entrant convective loops to the outside,
e. Wind-washing (forced convection from the outside).

These thermal bypass mechanisms and their categorization are summarized in Figure 5.

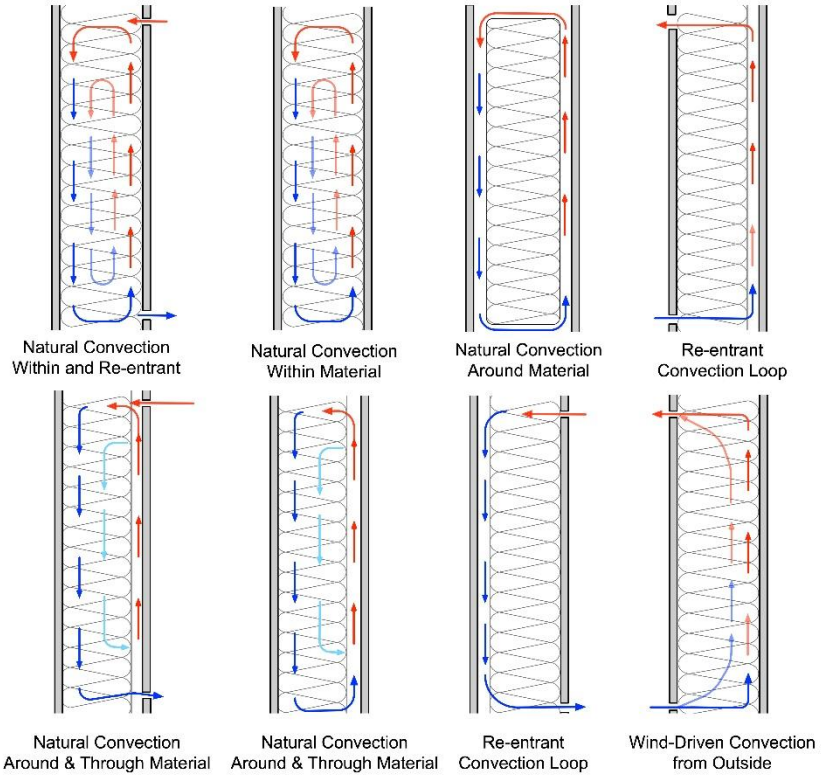


Figure 4: *Airflow paths within and around insulation*

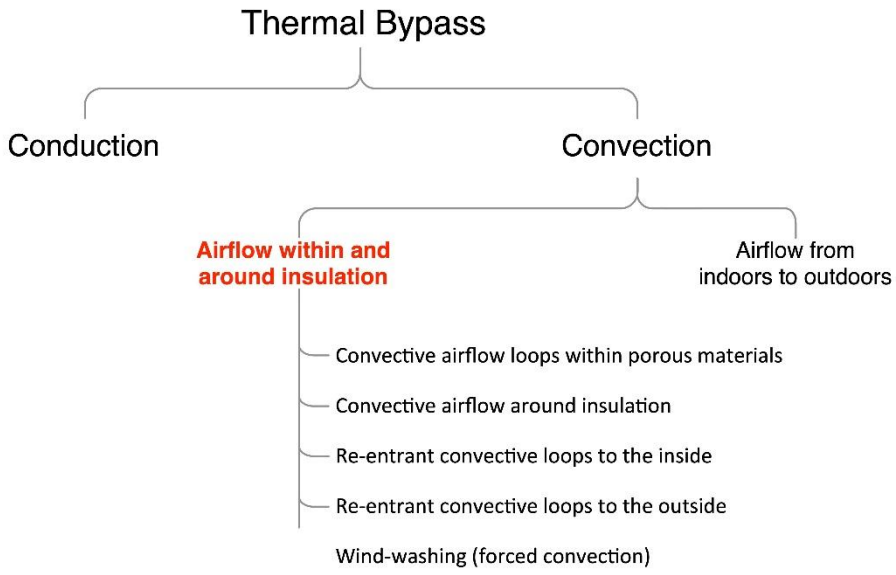


Figure 5: *Categorization of thermal bypasses*

1.2. Continuous Insulation

The thermal bypass mechanisms shown in Figure 4 are within a framing cavity; however, thermal bypass can also occur around exterior insulation leading to poor performance despite often being specified to reduce thermal bridging and improve overall thermal performance.

When continuous insulation is installed on the exterior side of the wall assembly, air movement around or through the insulation can be driven by either temperature differences or wind pressures. Temperature differences across the insulation layer can create buoyancy-driven airflow, or natural convection, where gaps are present between insulation boards or between the insulation and the backup wall. Wind pressures can also drive airflow behind, around, or through the insulation, a mechanism commonly referred to as wind washing. These mechanisms are illustrated conceptually in Figure 6 and Figure 7.

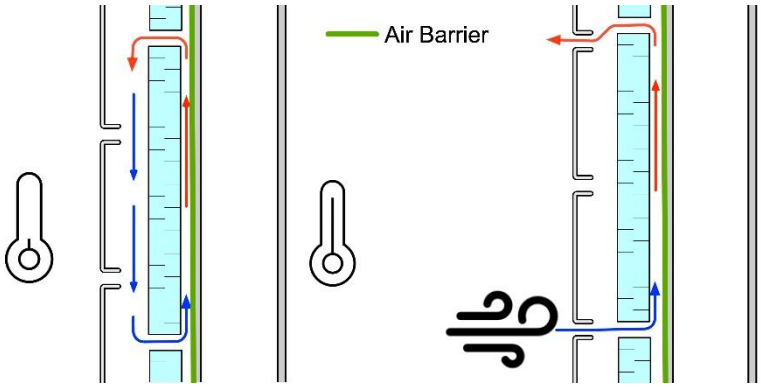


Figure 6: *Convection thermal bypass mechanisms around exterior continuous insulation*

Importantly, airflow-induced thermal bypass at exterior continuous insulation can occur even when the wall assembly has a well-designed and well-constructed air barrier. This is because the continuous insulation layer is typically located outboard of the primary air barrier system. As a result, air movement within the rainscreen cavity, behind insulation boards, or through air-permeable insulation may bypass the thermal resistance of the insulation independent of air leakage through the building.

Airflow-induced thermal bypass requires gaps, air spaces, or air-permeable pathways around or through the insulation. These conditions can occur with low-density fibrous insulation products, but can also occur with nominally air-impermeable materials such as foam plastic insulation or high-density stone wool boards if gaps are present at board joints, behind boards, or around cladding attachment components.

The science behind these thermal bypass mechanisms is well understood; however, some mechanisms are unlikely to occur in real-world applications, while others require substantial design or construction deficiencies. The following section investigates the quantitative impact of airflow-induced thermal bypass in more detail.

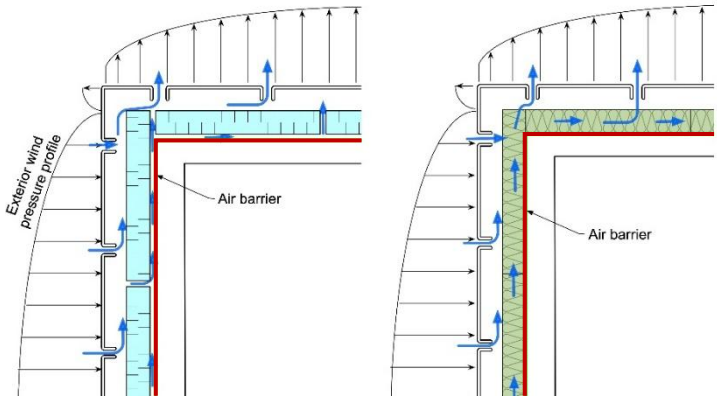
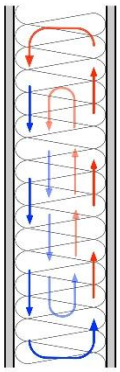


Figure 7: *Wind washing thermal bypasses behind foam insulation and through air permeable insulation*

2. Impacts

The nature of thermal bypasses has been described above. Harrje et al. (1985) clearly identified numerous scenarios that caused convection heat flow thermal bypasses around insulation in then-current residential construction (i.e., interior-insulated wood frame). However, while they described the performance problems observed, they were not able to quantify the impact. This section investigates the quantitative impact of different types of important thermal bypasses.



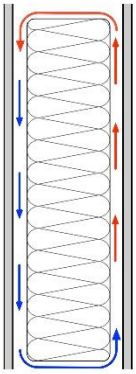
Natural Convection Within Material

2.1. Natural Convection within Insulation

Natural convection within low-density air-permeable insulation installed in framed walls is possible (Bankvall 1972; Huttunen and Vinha 2013). Delmas and Wilkes (1992) studied this concern with sophisticated simulations validated against laboratory tests. They confirmed that for properly installed insulation (i.e., no gaps), the air permeability of the insulation (which tends to drop with density) and the total temperature difference across the insulation were the two factors that predicted when natural convection formed within the insulation and how much impact this would have. They found that for large temperature differences (i.e., between 40 °F and 60 °F) and highly air-permeable insulations (e.g., ½ pcf density glass fiber), heat flow increased by 35%. If one side of the insulation was open to an air cavity, this increase could rise to over 100%, that is, a doubling of heat flow.

As a result, products of higher density (or more precisely, lower air permeability) are now recommended. However, these products must still be installed in tight contact with at least one side of the framing cavity (preferably both sides) and have no gaps between them to achieve their nominal performance.

2.2. Natural and Forced Convection Around Framed Wall Cavity Insulation



Natural Convection Around Material

An extensive study of convective air flow effects on insulation installed within wood-frame cavities was undertaken by Wolf et al. (1966). They showed that insulation that did not fill the cavity was prone to convective loop thermal bypasses that increased the heat flow by as much as 100%. Installing the insulation tight to the sheathing eliminated the convective bypass across the framed cavity.

Brown et al. (1993) conducted an important study that quantified the impact of natural convection loops that can form around insulation in framed walls because of installation defects. They measured heat flow through wood-frame walls with insulation intended to completely fill the framing cavity, as recommended by the manufacturers, but with varying degrees of defects (0%, 3%, and 6%) representative of conditions observed in a survey of seventeen buildings. These defects consisted of localized gaps at the corners of the stud cavities resulting from incomplete batt recovery or from undersizing, oversizing, buckling, or bending of the insulation, as simulated in the experimental setup shown in Figure 8. Their study found that heat flow increased by 10% to 36% for low-density insulation with 3% to 6% defects.

These findings demonstrate that specifying insulation to completely fill a framing cavity is not, by itself, sufficient to achieve the expected thermal performance. Installation quality remains important even in nominally compliant assemblies, as relatively small localized defects can enable convective air flow and materially increase heat transfer.

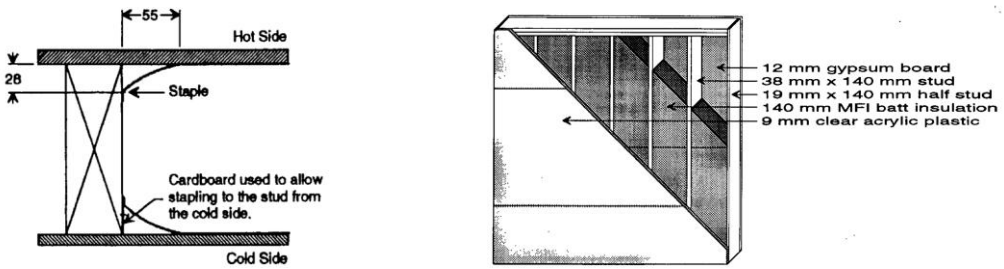


Figure 8: *Simulated installation defect studied by Brown et al. (1993)*

2.3. Natural Convection Around Continuous (Exterior) Insulation

Lecompte (1990) is a valuable reference for understanding the potential impact of thermal bypasses through continuous insulation (c.i.). The authors reported on extensive physical tests of the heat flow through layers of air-impermeable insulation with gaps driven only by natural convection (i.e., temperatures, not wind). Figure 9 plots a summary of the results, with each curve showing the increase in U-value relative to a perfectly installed case as a function of the width of the gap between adjacent insulation boards. The individual curves represent different combinations of the cold-side cavity depth, C, and hot-side cavity depth behind the insulation, H. These cavity depths are separate variables from the board-joint gap shown on the horizontal axis.

As shown in Figure 9, relatively small defects can have a significant effect. For the 40/5 mm C/H configuration - representing a 40 mm (~1 1/2″) rainscreen cavity and 5 mm (~1/4″) cavity behind the insulation - a 6 mm (1/4″) gap between adjacent insulation boards increased heat flow by approximately 30%. If the cavity behind the insulation increased to 10 mm (3/8″), the same 6 mm (1/4″) gap between insulation boards more than doubled the heat flow. This research concluded that gaps between boards should be minimized and that the insulation should be pressed tight (<1/8″) to the backup wall to minimize thermal bypass.

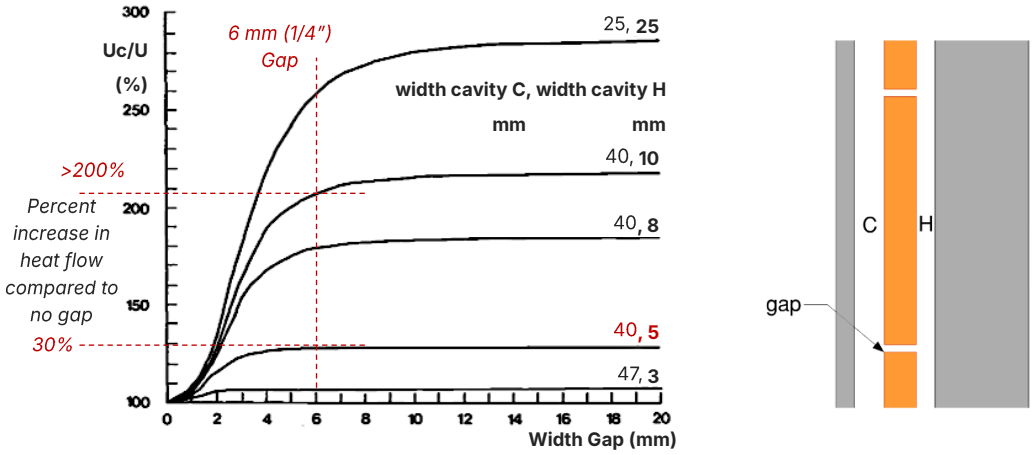


Figure 9: *Summary of Lecompte's (1990) experimental results. Annotations made to increase readability.*

2.4. Forced Convection Through and Around Insulation ("Wind Washing")

Wind pressures can force high-velocity air behind cladding and result in a thermal bypass through insulation. The heat loss due to this thermal bypass can be very significant if airflow is allowed through low-density fibrous insulations, especially low-density batt insulations installed within framing (Bankvall 1978; Silberstein et al. 1991). This phenomenon is often referred to as "wind washing" (Timusk et al. 1991).

For framed walls with a continuous air barrier on the exterior of the framing or with rigid panel sheathing, wind washing is not a practical concern (Straube and Smegal 2018).

However, wind washing can still be a practical concern in the field where low-density insulation is directly exposed to wind-driven air. Cummings and Withers (2012), for instance, provided examples of wind-driven flows through low-density batt insulation used in knee-wall construction when the insulation is not installed in contact with the air barrier. Field and hot-box measurements in Scandinavia (Uvsløkk 1996) examined wood-framed walls with low-density fiberglass and stone wool batt insulation ranging from 21 kg/m³ (1.3 pcf) to 31.9 kg/m³ (2.0 pcf). The tested assemblies had open cladding and an interior air barrier, but no exterior air barrier, allowing wind-driven air to penetrate the exterior layer and bypass through the framed wall insulation, as illustrated in Figure 10. Under high wind-pressure conditions, this configuration was measured to increase heat flow through the insulated wall by more than 50%. The important feature of these assemblies was not simply the use of fibrous insulation, but the combination of significant wind exposure and the absence of an exterior layer providing sufficient resistance to airflow between the ventilated cavity and the batt insulation.

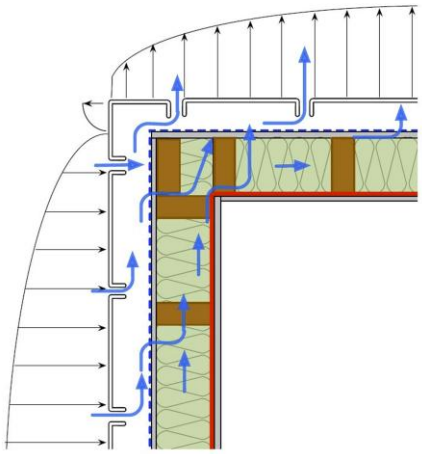


Figure 10: Visualization of the wind washing effect studied by Uvsløkk (1996).

A key finding of the Uvsløkk study was that some resistance to airflow exterior to the stud cavity was required to protect the insulation from these wind-driven flows. This finding was similar to the field and laboratory work by Timusk et al. (1991), which found that deficiencies in exterior sheathing could allow wind cooling at exterior corners, increasing heat loss, and contributing to condensation and mold growth on interior wall surfaces. Their research demonstrated that this effect could effectively be controlled by locating a continuous air barrier exterior to the framing, thereby separating the air-permeable cavity insulation from wind pressures acting on the exterior of the building.

The thermal bypass mechanism investigated by Uvsløkk (1996) and Timusk et al. (1991) should be distinguished from wind exposure of continuous exterior insulation. In the absence of defects, such as those described in Sections 2.1 to 2.3 above, physical testing has generally found the impact on heat loss to be small where the insulation has sufficient resistance to airflow. Tanner and Ghazi Wakili (1996) reported on hot-box testing of multiple exterior insulation types and densities. For mineral fiber insulation, including glass fiber and stone wool with densities between 20 and 62 kg/m³ (1.25 to 4 pcf), tested at cavity air velocities of 0.3 and 1.0 m/s (60 to 200 fpm), there was “practically no influence” on measured thermal performance. Subsequent field measurements by Sedlbauer and Künzel (1999) and laboratory testing by van Straaten et al. (2016) have also concluded that the thermal impact of wind washing is limited to less than a few percent for fibrous insulation with densities above 20 kg/m³ (1.25 pcf) installed in substantial contact with the air barrier and without gaps.

Overall, the available research indicates that wind washing on its own does not materially reduce the thermal performance of the exterior insulation products commonly used in construction when they are well installed. The broader concern is thermal bypass caused by airflow through, around, or behind insulation where gaps, discontinuities, or uncontrolled air leakage paths are present. The practice recommendations in the next section focus on limiting the thermal bypass mechanisms described above through appropriate material selection, detailing, and installation.

3. Practice Recommendations

Good construction practice recommendations have been developed over many decades to reduce the risk of airflow-induced thermal bypass. The most important principle is to prevent unintended airflow paths through, behind, or around insulation. This is achieved through a combination of appropriate material selection, substrate preparation, coordinated attachment detailing, tight-fitting installation, and construction-stage review.

As summarized above, wind washing of low-density batt insulation is generally not a practical concern where framed cavities are protected by a continuous exterior air barrier or rigid panel sheathing. Natural convection within batt insulation is also generally not a concern for modern insulation products where the insulation is installed in good contact with the adjacent sheathing and without significant voids. Similarly, research has shown that exterior rigid or semi-rigid insulation of sufficient density can perform well when installed in substantial contact with the substrate and without gaps that allow air to bypass the insulation.

In practice, the most common risks are associated with gaps between insulation boards, gaps behind insulation boards, and gaps around cladding attachment components or penetrations. These gaps may be caused by:

a. uneven or irregular substrates,
b. thermal movement,
c. cladding/insulation attachment approach + insulation type (e.g., clips), and
d. workmanship

Good practice aims to limit these risks through design, specification, detailing, mock-ups where appropriate, and construction-stage inspection.

In some assemblies, particularly those with open-jointed cladding or relatively air-permeable exterior insulation, additional wind-control measures may also be appropriate to reduce airflow exposure at the insulation layer.

3.1. Uneven/Irregular Substrates

It is not always simple to avoid cavities behind rigid insulation. Substrate irregularities are common in exterior wall construction and may include laps in membranes, cladding attachment flanges, localized fastener heads, transitions between materials, misaligned floor edges, sheathing offsets, or other changes in plane. These irregularities can prevent rigid insulation boards from bearing tightly against the backup wall and can create continuous or localized air spaces behind the insulation (Figure 11).

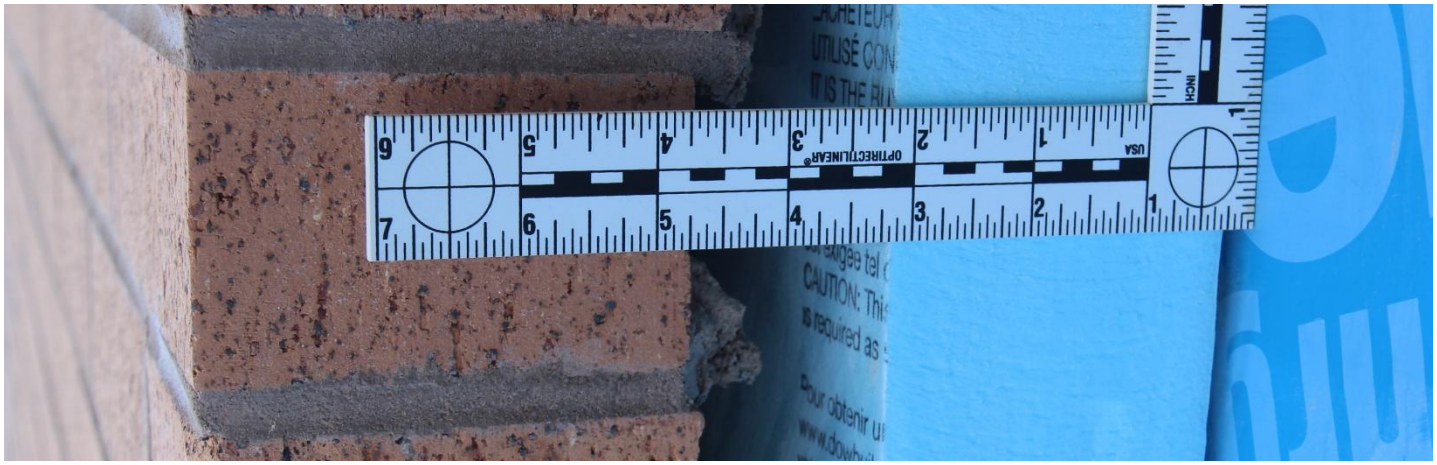


Figure 11: *Gaps of ¼" can easily form behind rigid insulation due to surface irregularities including cladding attachment flanges, localized fastener heads, transitions between materials, misaligned floor edges, sheathing offsets, or other changes in plane*

Where rigid boards are installed over irregular substrates, the risk of airflow behind the insulation should be considered during design and construction. Mitigation measures may include substrate preparation, more frequent insulation fastening, the use of furring or retention components that hold the insulation tight to the backup wall, the use of more conformable insulation materials, or joint treatments that reduce airflow between insulation boards.

The difficulty of correcting substrate irregularities after installation has also led to increased use of improved insulation board joints intended to provide some degree of air control. Common strategies include taped joints, ship-lap joints, tongue-and-groove joints, and offset joints in multi-layer installations. Proprietary profiled joints are also available from some manufacturers (e.g., SMARTci®). Figure 12 illustrates these joint strategies.

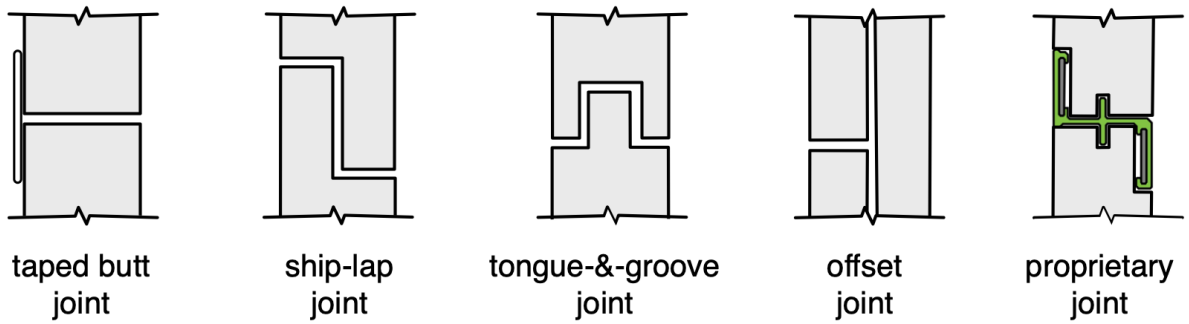


Figure 12: *Five types of insulation board joints*

3.2. Thermal Movement

Joints between insulation boards can open and close as insulation temperatures change. Foam plastic insulation products in particular have relatively high coefficients of thermal expansion compared with many other enclosure materials. Even where boards are installed with tight butt joints, repeated cycles of heating and cooling can cause joints to open over time, particularly where board movement is restrained or where installation occurs at temperatures that differ substantially from service conditions.

The dimensional stability of insulation products varies by material type, density, formulation, and manufacturing process. For example, a nominal 4 ft by 8 ft board of extruded polystyrene may expand or contract by approximately ±0.1% as temperatures fluctuate between 14°F (-10°C) and 104°F (40°C). Relative to a nominal board dimension at 75°F (24°C), this corresponds to potential joint movement on the order of 1/16 in. to 1/8 in.

For exterior insulation thicknesses of 4 in. or greater, installing insulation in multiple layers with offset joints can assist in reducing the risk of continuous airflow paths through the insulation layer. Joint treatments such as ship-lap or tongue-and-groove edges, compatible tapes, sealants, or other durable joint closure methods may also be appropriate, depending on the insulation product, exposure, and wall assembly design.

3.3. Cladding/Insulation Attachment Approach

Cladding attachment solutions, such as girts, clips, brackets, and ties, are used to support exterior cladding outboard of the exterior insulation. The choice of attachment system is influenced by many factors, including structural capacity, adjustability, ease of installation, cost, constructability, corrosion resistance, and effective R-value. Although thermal bridging through these components is commonly considered in effective R-value calculations, gaps in the insulation around or behind cladding attachments are often not explicitly accounted for.

The thermal performance of exterior continuous insulation therefore depends on more than the insulation product alone. The insulation type, installation method, fastening approach, and cladding attachment system must work together as an installed assembly. Checklist recommendations to install insulation in substantial contact with the substrate are useful but may be insufficient where the attachment hardware itself creates discontinuities, stand-offs, localized gaps, or complex geometries that prevent full contact between the insulation and the backup wall. In these cases, maintaining insulation continuity requires coordination between the attachment layout, insulation selection, fastening strategy, and any supplemental infill or pre-cut insulation components.

Gaps around some clip geometries can be of the same scale (1/4") as the board-joint gaps tested by Lecompte (1990). When these gaps are combined with a similarly sized cavity behind the insulation, heat flow can increase by more than 30%. Such cavities are a particular risk where substrates are irregular or insulation is insufficiently supported.

To reduce the risk of gaps behind insulation boards, the insulation should be pressed tightly to the backup wall and held in place durably. Fasteners must be capable of applying sufficient force to maintain contact without damaging the insulation, and adhesives, where used, must be durable and resistant to creep. Furring strips, sub-girts, positive wedges or washers at fastening points, insulation fasteners, and proprietary cladding attachment solutions can all be used to help maintain tight contact between the insulation and the substrate (Figure 13).



Figure 13: *Plywood strapping (left), plastic wedge fasteners used with masonry ties (middle), and insulation stickpins with washers to press insulation tight to wall (right).*

In some cases, more conformable insulation products, such as lower-density fibrous insulation or softer foam insulation, may be used to accommodate substrate irregularities or the geometry of cladding attachment components. When coordinated during the clip layout process, semi-rigid insulation can often be pressure-fitted around thin sheet-metal clips or brackets that might otherwise create gaps. For larger clips, this commonly includes one or more relief cuts at each attachment location. Less conformable insulation boards, more complex clips, or larger penetrations may still require localized patches of insulation to restore continuity (Figure 14).

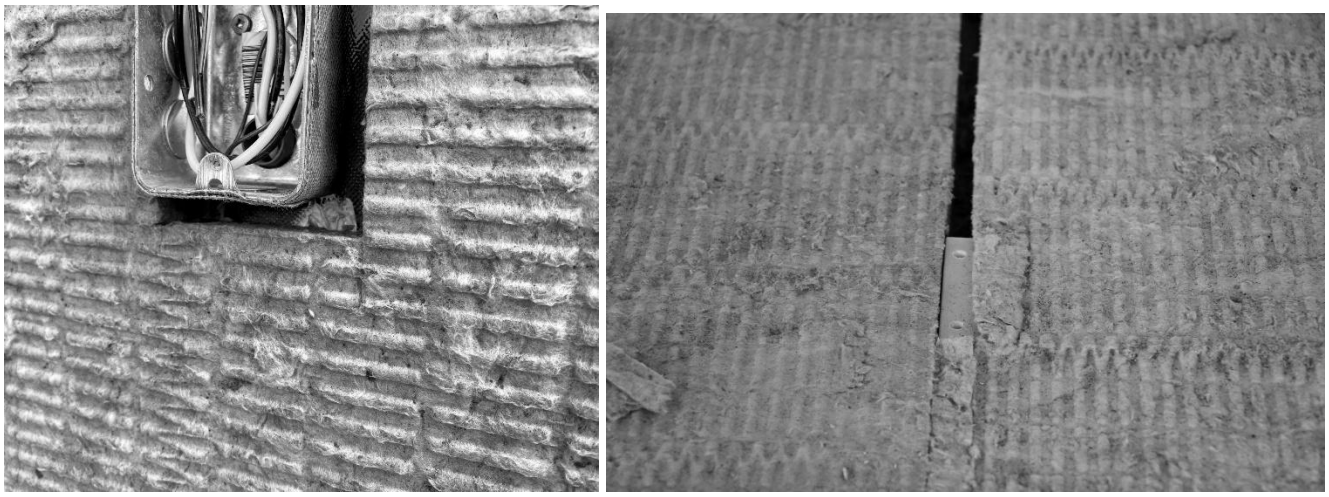


Figure 14: *Gap in insulation around exterior outlet (left) and around a clip (right)*

Proprietary systems, such as Advanced Architectural Products' SMARTci® system, may use specially cut insulation boards or integrated attachment components that fit tightly around the cladding attachment system (Figure 15). This approach can reduce or eliminate gaps around the attachment hardware when coordinated and installed appropriately.



Figure 15: Example of a manufacturer's proprietary solution for fitting insulation tight against the cladding attachment.

3.4. Workmanship

Despite these design strategies, the installation of exterior insulation must always be completed with care. Regular construction-stage inspection is recommended as a means of ensuring this. Understanding the importance of tight-fitting exterior continuous insulation and effective insulation joints is necessary to conduct these inspections. Table 1 presents common defects and recommended practices to mitigate the resultant risk of thermal bypass.

TABLE 1

DEFECT	PRACTICE RECOMMENDATION
Gaps between continuous board insulation	– Seal gaps of over 1/8″ using joint designs, tapes, or sealants – Offset board joints in multi-layer installations – Specify ship-lap or tongue-&-groove board joints – Oversize compressible insulations by ~5% to allow for a tight fit – Precisely cut rigid foam
Gaps at cladding attachment	– Specify a combined clip/insulation system (e.g., clip with matching profiled foam) – Match the insulation to the cladding attachment solution (e.g., compressible insulation for large/complex brackets) – Use an insulative filler (e.g., batts, spray foams, etc.)
Gaps behind continuous board insulation	– Press insulation tight to substrate – Use more conformable insulation
Very low density, high air permeance insulation	– Select insulation products with higher air resistance – Protect relatively air-permeable insulation – Avoid rainscreen air gaps much greater than 1″ (25 mm) – Avoid combining air-permeable insulation with open-jointed cladding, particularly without additional mitigation measures (e.g., exterior wind/water resistive barrier)

The defects listed in Table 1 are not uncommon, and the research summarized above demonstrates that they can reduce the effective thermal performance of insulation. In some cases, the same defects may also increase the risk of condensation, localized wetting, or moisture-related deterioration by allowing cold airflow paths or cold surfaces to develop within the assembly.

3.5. Exterior Wind-control Layer

Where exterior insulation is exposed to significant airflow, an additional vapor-permeable wind-control layer outboard of the insulation may be used to reduce wind-induced thermal bypass. This additional layer is generally unnecessary where the exterior insulation has sufficient air resistance, is installed in substantial contact with the substrate, and is protected from significant airflow through or behind the insulation. However, wind-control layers remain a commonly specified solution for open-jointed cladding systems, particularly where relatively low-density fibrous insulation is used and additional protection from wind washing is desired (Straube and Smegal 2018).

For foam board insulation, it may also be possible to seal board joints with compatible tapes or sealants to create an air-control layer at the exterior face of the insulation. Depending on the climate and wall assembly design, this layer may function as the primary air barrier or as a secondary air barrier. While a detailed discussion of air barrier placement is outside the scope of this white paper, achieving an airtight exterior insulation layer requires careful attention to board joints, penetrations, corners, terminations, and interfaces with adjacent enclosure assemblies.

Some proprietary exterior insulation systems (e.g., SMARTci®, which uses a dual three-point compression seal at board joints) include details tested for air leakage in general accordance with ASTM E283, which can assist with the development of an exterior air-control layer where that approach is used.

4. Conclusions and Recommendations

Modern high-performance buildings need an air barrier, and they need to minimize thermal bridging. The thermal bypasses that remain—primarily those induced by airflow—can be effectively eliminated through appropriate design, construction, and material selection.

Airflow-induced thermal bypasses, whether driven by wind pressure or temperature-driven buoyancy, can reduce the effective thermal performance of enclosure assemblies by anywhere from a few percent to over 100%, depending on the insulation type, detailing, and installation quality. These impacts are well-documented, repeatable, and can negate the intended benefits of increased nominal R-values and exterior insulation.

While gaps between board joints are a well-understood construction defect, gaps behind boards and around cladding attachment systems are additional areas where thermal bypass can occur. Managing these gaps requires coordinating the insulation product with the attachment solution. For this reason, exterior insulation should be designed, specified, and installed as a system. In-service performance depends on proper detailing, coordinated cladding attachment and insulation product selection, tight-fitting installation, and good workmanship.

5. References

Bankvall, C. G. “Forced Convection: Practical Thermal Conductivity in an Insulated Structure under the Influence of Workmanship and Wind.” Thermal Transmission Measurements of Insulation, edited by R. P. Tye, American Society for Testing and Materials, 1978, pp. 409-25. ASTM STP 660.

---. Natural Convective Heat Transfer in Insulated Structures. Report 38, Division of Building Technology, Lund Institute of Technology, 1972.

Brown, W. C., et al. “Measured Thermal Resistance of Frame Walls with Defects in the Installation of Mineral Fibre Insulation.” Journal of Thermal Insulation and Building Envelopes, vol. 16, 1993, pp. 318-39.

Cummings, J., and C. R. Withers, Jr. “Envelope Thermal Failures due to Wind Washing in Two-Story Homes.” Proceedings of the 3rd Building Enclosure Science and Technology Conference, 2012.

Delmas, A. A., and K. E. Wilkes. Numerical Analysis of Heat Transfer by Conduction and Natural Convection in Loose-Fill Fiberglass Insulation: Effects of Convection on Thermal Performance. Oak Ridge National Laboratory, 1992. CON-338.

Harrje, D. T., et al. “Convective Loop Heat Losses in Buildings.” ASHRAE Transactions, vol. 91, no. 2, 1985, pp. 751-60.

Harrje, D. T., et al. “Locating and Eliminating Obscure but Major Energy Losses in Residential Housing.” ASHRAE Transactions, vol. 85, no. 2, 1979, p. 521.

Huttunen, P., and J. Vinha. “Effect of Natural Convection on the Thermal Transmittance of Exterior Walls with Air-Permeable Insulation.” Thermal Performance of Exterior Envelopes of Whole Buildings XII Conference, 1-5 Dec. 2013, Clearwater, FL.

Lecompte, I. G. N. “Influence of Natural Convection in an Insulated Cavity on the Thermal Performance of a Wall.” Insulation Materials, Testing, and Applications, edited by D. L. McElroy and J. F. Kimpflen, American Society for Testing and Materials, 1990, pp. 397-420. ASTM STP 1030.

Ricketts, L. “Impact of Large Building Airtightness Requirements.” Thermal Performance of the Exterior Envelopes of Whole Buildings XIII International Conference, 2017, pp. 206-13.

Sedlbauer, K., and H. H. Künzel. “Luftkonvektionseinflüsse auf den Wärmedurchgang von belüfteten Fassaden mit Mineralwolledämmung” [Effects of Air Convection on Heat Transfer through Ventilated Façades with Mineral Wool Insulation]. wksb, vol. 44, no. 43, 1999, pp. 53-59.

Silberstein, A., et al. “Forced Convection Effects in Fibrous Insulation.” Insulation Materials: Testing and Applications, edited by R. S. Graves and D. C. Wysocki, vol. 2, American Society for Testing and Materials, 1991, pp. 292-309. ASTM STP 1116.

Straube, J., and E. Burnett. Building Science for Building Enclosures. Building Science Press, 2005.

Straube, J., and J. Smegal. Literature Review and Research Summary on Wind Washing of Air-permeable Insulation. RDH Building Science, June 2018. Technical report.

Tanner, C., and K. Ghazi Wakili. Wärmebrücken von hinterlüfteten Fassaden [Thermal Bridges of Rear-Ventilated Façades]. Bericht 158 740, EMPA, Dübendorf, 1996.

United States, Environmental Protection Agency. Thermal Bypass Checklist Guide. Version 2.1, 2008. ENERGY STAR Qualified Homes.

Uvsløkk, S. “The Importance of Wind Barriers for Insulated Timber Frame Constructions.” Journal of Thermal Insulation and Building Envelopes, vol. 20, July 1996, pp. 40-62.

Van Straaten, R., et al. “Wind Washing Effects on Mineral Wool Insulated Sheathings.” Proceedings of Buildings XIII, Dec. 2016, Clearwater Beach, FL.

Wolf, S., et al. “Convective Air Flow Effects with Mineral Wool Insulation in Wood-Frame Walls.” ASHRAE Transactions, vol. 72, pt. 2, 1966.

6. Definitions

Convection (thermal): "… the transfer of heat by the movement or flow of molecules (liquid or gas) with a change in their heat content." Common examples in the built environment include air flow within framed cavities or through exterior wall assemblies.

(Straube and Burnett 2005)

Thermal Bypass: "… the movement of heat around or through insulation, frequently occur[ing] due to missing air barriers or gaps between the air barrier and insulation."

(US EPA 2008)

7. Extended Bibliography

Bankvall, C. G. “Air Movements and the Thermal Performance of the Building Envelope.” Thermal Insulation: Materials and Systems, edited by F. J. Powell and S. L. Matthews, American Society for Testing and Materials, 1987, pp. 124-31. ASTM STP 922.

---. “Thermal Performance of the Building Envelope as Influenced by Workmanship.” Thermal Insulation: Materials and Systems, edited by F. J. Powell and S. L. Matthews, American Society for Testing and Materials, 1987, pp. 679-84. ASTM STP 922.

Bhattacharyya, S., and D. E. Claridge. “The Energy Impact of Air Leakage through Insulated Walls.” Journal of Solar Energy Engineering, vol. 117, no. 3, Aug. 1995, pp. 167-72.

Bomberg, M., and D. Onysko. “Heat, Air and Moisture Control in Walls of Canadian Houses: A Review of the Historic Basis for Current Practices.” Journal of Building Physics, vol. 26, 2002, pp. 3-31.

Brown, W. C., et al. “Developing a Design Protocol for Low Air and Vapour Permeance Insulating Sheathing in Cold Climates.” Buildings X Proceedings, 2007, paper 242.

Cummings, J., and C. R. Withers, Jr. “Envelope Thermal Failures due to Wind Washing in Two-Story Homes.” Proceedings of the 3rd Building Enclosure Science and Technology Conference, 2012.

Derome, D. “Moisture Accumulation in Cellulose Insulation Caused by Air Leakage in Flat Wood Frame Roofs.” Journal of Thermal Envelope and Building Science, vol. 28, no. 3, 2005, pp. 269-87.

Desmarais, G., et al. “Mapping of Air Leakage in Exterior Wall Assemblies.” Journal of Building Physics, vol. 24, no. 2, 2000, pp. 132-54.

Ge, Hua, et al. “Field Study of Hygrothermal Performance of Highly Insulated Wood-Frame Walls under Simulated Air Leakage.” Building and Environment, vol. 160, 2019, article 106202.

Gudum, C. Moisture Transport and Convection in Building Envelopes: Ventilation in Light Weight Outer Walls. 2003. Technical University of Denmark, PhD dissertation.

Hens, H. “Brick Cavity Walls: A Performance Analysis Based on Measurements and Simulations.” Journal of Building Physics, vol. 31, no. 2, Oct. 2007, pp. 95-124.

Janssens, A., and H. Hens. “Interstitial Condensation due to Air Leakage: A Sensitivity Analysis.” Journal of Thermal Envelope and Building Science, vol. 27, no. 1, 2003, pp. 15-29.

Kalamees, T., and J. Kurnitski. “Moisture Convection Performance of External Walls and Roofs.” Journal of Building Physics, vol. 33, 2010, pp. 225-47.

Kronvall, J. Airflows in Building Components. 1980. Lund University, Doctoral dissertation.

Langmans, J., et al. “Hygrothermal Risks of Using Exterior Air Barrier Systems for Highly Insulated Light Weight Walls: A Laboratory Investigation.” Building and Environment, vol. 56, no. 10, 2012, pp. 192-202.

Langmans, J., et al. “Numerical and Experimental Investigation of the Hygrothermal Response of Timber Frame Walls with an Exterior Air Barrier.” Journal of Building Physics, vol. 36, no. 4, 2013.

Ojanen, T., and R. Kohonen. “Hygrothermal Influence of Air Convection in Wall Structures.” Proceedings of Thermal Performance of the Exterior Envelopes of Buildings IV, 4-7 Dec. 1989, Clearwater Beach, FL, pp. 234-42.

Riesner, Katrin, et al. “Condensation Risk within Loose Fill Insulation due to Natural Convection in Vertical Cavities.” Performance of Exterior Envelopes of Whole Buildings IX International Conference, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004.

Saber, Hamed H., and Wahid Maref. “Risk of Condensation and Mould Growth in Wood-Frame Wall Systems with Different Exterior Insulations.” Building Enclosure Science and Technology Conference (BEST4), Apr. 2015.

Siddall, M. Thermal Bypass Risks: A Technical Review. Passivhaus Trust, Sept. 2022.

Silberstein, A., and H. Hens. “Effects of Air and Moisture Flows on the Thermal Performance of Insulations in Ventilated Roofs and Walls.” Journal of Building Physics, vol. 19, 1996, pp. 367-85.

Silberstein, A., et al. “Natural Convection in Light Fibrous Insulating Materials with Permeable Interfaces: Onset Criteria and Its Effect on the Thermal Performances of the Product.” Journal of Thermal Insulation, vol. 14, no. 1, 1990, pp. 22-42.

Timusk, J., et al. “The Control of Wind Cooling of Wood Frame Building Enclosures.” Journal of Thermal Insulation and Building Envelopes, vol. 15, July 1991, pp. 8-19.

Trethowen, Harold Arnold. “Sensitivity of Insulated Wall and Ceiling Cavities to Workmanship.” Journal of Thermal Insulation, vol. 15, no. 2, 1991, pp. 172-79.

Uvsløkk, S. “The Importance of Wind Barriers for Insulated Timber Frame Constructions.” Journal of Thermal Insulation and Building Envelopes, vol. 20, July 1996, pp. 40-62.

Wahlgren, P. “Overview and Literature Survey of Natural and Forced Convection in Attic Insulation.” Journal of Building Physics, vol. 30, 2007, pp. 351-70.

Wilkes, K. E., et al. “Thermal Performance of One Loose-Fill Fiberglass Attic Insulation.” Insulation Materials: Testing and Applications, edited by R. S. Graves and D. C. Wysocki, vol. 2, American Society for Testing and Materials, 1991. ASTM STP 1116.