SUMMER 2026

BUILDING SCIENCE perspective

TOWARDS AIRTIGHT BUILDING ENCLOSURES: LESSONS LEARNED ABOUT MULTI-ZONE AND LARGE BUILDING AIRTIGHTNESS TESTS

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President, ABEC (North)

Message from the ABEC North president

A new term brings a fresh wave of energy to ABECN, and I'm excited to welcome you to this edition of *Building Science Perspective*. As I begin my 2026–2028 term as president, I'm energized by the momentum we've built and the vibrant, ever-growing community that continues to shape our council.

This past year, our third-annual ABECN Appreciation BBQ with our friends from Construction Specifications Canada – Edmonton Chapter proved once again that nothing—not even a steady dose of rain—can slow this group down. Roast pig, burgers, and a sea of smiling faces reminded us just how strong and connected our community truly is. I'm already looking forward to our fourth-annual BBQ in August 2026, and I hope to see you there, hungry, laughing, and ready for another great time.

We kept the pace high with plant tours, industry events, and a refreshed venue for our Casual Night Series. Every gathering sparked new ideas, new conversations, and new connections. These moments of curiosity and camaraderie are the heartbeat of ABECN, and we're thrilled to carry that energy into the new term with even more tours, events, and engagement opportunities ahead.

At our recent AGM, we celebrated the contributions of board members who completed their service. Thank you to Armin Mueller and Lisa Henderson for everything you've brought to ABECN. We also welcomed new directors, Amy Huynh and Maysoun Ismaiel, whose expertise and fresh perspectives will help shape our next chapter. And we're excited to welcome back Jamie Murphy, returning with renewed insight and valuable experience. This dynamic team is ready to elevate ABECN and spark new adventures in building science.

Looking ahead, 2026 is shaping up to be a standout year, with a full lineup of plant tours, workshops, luncheons, and Casual Nights, each designed to expand our knowledge and strengthen the relationships that make our council such a vibrant, inspiring place to belong. Together, we'll keep pushing boundaries and making building science a driving force for progress.

Thank you for your continued support and enthusiasm. Our strength comes from the passion, expertise, and camaraderie of our members, and I'm honoured to serve as your president for the next two years.

Christa van Dyk


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ABEC North Schedule of Events

Monthly Luncheons

May 21, 2026 – Highlands Golf Club

June 18, 2026 – Highlands Golf Club

September 17, 2026 – Highlands Golf Club

- and third Thursdays of every month

Casual Night Series

May 12, 2025
Resistive Barriers and Drainage Planes
- what, where, why?
At ReImagine Architects

June 9, 2026
Where is the Dew Point and why isn't
somebody doing something about it?
At ReImagine Architects

- and second Tuesdays of every month

ABEC BBQ

August 2026 at Victoria Park

ABEC South Schedule of Events

Monthly Luncheons

May 27

September 23 – AGM

October 21– BuildEx

November 25

Social Events

June 17 – Annual Golf Tournament

TOWARDS AIRTIGHT BUILDING ENCLOSURES: LESSONS LEARNED ABOUT MULTI-ZONE AND LARGE BUILDING AIRTIGHTNESS TESTS

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Abstract

This paper presents the data collected for airtightness tests of large and multi-zone buildings. The data was obtained over a span of four years, encompassing more than 500,000 m^3 of volume across 29 buildings in accordance with ASTM E779-19 for both new construction and existing buildings. This study delves into the influence of various factors on airtightness including the following: i) archetype, e.g., office, residential, mixed-use, institutional, hotel, courthouse, and community centre; ii) air barrier strategy, e.g., sealed interior membrane, exterior self-adhered membrane, taped weather-resistive barrier, and window-wall system; iii) number of storeys (ranging from one to 21 levels); and iv) building enclosure area. The Normalized Leakage Rate at 75Pa (NLR_{75Pa}) of pressurization/depressurization is calculated for the tests and compared with the pertinent literature. The level of airtightness for the built environment in British Columbia has evolved considerably since 2017 in order to align with the rigorous BC Energy Step Code requirements. Given the recent nature of the gathered data presented, this study provides the basis to establish a new benchmark that can be used in airtightness standards/regulations/guidelines.

1. Introduction

Air leakage in buildings, often referred to as "air infiltration/exfiltration" or "uncontrolled air flow", is the unintentional movement of air in and out of a building through gaps, cracks, holes, and other openings in the building envelope [1]. It is predominantly driven by pressure via wind, stack effect, and induced pressure by building ventilation systems [2]. Air leakage is a significant concern in the construction industry since it can considerably increase building energy consumption and result in moisture damage in assemblies as a result of interstitial condensation, comfort issues from local drafts, and poor indoor air quality due to introducing pollutants and allergens from the outside [3].

Measuring building air leakage at normal (operating) conditions is extremely difficult and time consuming due to the variability of in-situ conditions [4-6]. As a result, air leakage of the building enclosure is typically tested at an artificially elevated pressure difference between the test space and ambient pressure to negate the 'noise' of the stack effect, wind, and humidity pressures, where the results are extrapolated to determine the air leakage at operating conditions [7]. The initial assessments of building airtightness using pressurization methods involved the use of various prototypes of pressurization equipment, primarily driven by the need to address heat loss issues [8-12]. The practice of employing fan-based pressurization or depressurization techniques for whole-house air leakage testing gained popularity in the 1980s, initially in Sweden as a window-mounted fan [13-15] and the United States [16-18].

Following the oil crisis of 1973, many countries developed policies aimed at reducing energy consumption in their national building stock [19]. The first airtightness testing standards [19, 20] for North America were ASTM E779-81 "Standard practice for measuring air leakage by the fan pressurization method" [21] and the Canadian standard CAN/CGSB-149-GP-10M "Determination of airtightness of buildings by the fan pressurization method [22]. These standards included requirements regarding flow rate, wind speed, pressure measurements, and overall uncertainty of the test.

Airtightness testing for small- and single-zone buildings such as single-family homes is well understood, and many practitioners across the world can perform the test in accordance with the applicable standards. There is a large database of airtightness for houses; a recent review on airtightness testing [20] outlines a few resources such as Walker's residential diagnostics database (ResDB) including 75,000 entries in 2013 [23], the ATTMA database in the UK including 192,731 records in 2017 [24], and national database in France containing measurements of approximately 219,000 tests in 2019 [25]. The test for small single-zone buildings can be conducted by a single fan. For dwelling units that share a wall with another unit (e.g., row houses), the air flow through the partition wall can be cancelled out by simultaneously running the fan for the test space and the fans for adjacent suites (i.e., guarded test) to keep all zones at the same pressure [26]. Nonetheless, the tests for small buildings are straight forward and minimal building preparation is required.

Contrary to single-family homes, there is not a large database available for airtightness of large buildings. Previous research frequently highlights the limited availability of measured data for the leakage rates of large buildings. A review study on airtightness of apartment and commercial buildings states that "the available database is extremely deficient" [27]; in addition, the literature review conducted states that "the literature on air flow and air leakage measurements in high-rise multifamily buildings is quite limited" [28]. Due to the scarcity of available data, a research project (ASHRAE 1478) [29] was performed to measure enclosure airtightness of 16 non-residential mid- and high-rise buildings in the United States. Another study [30] conducted a comprehensive literature review and gathered the large building airtightness data for 566 buildings where only 16 per cent of buildings (approximately 90 buildings) are located in Canada.

The primary reason for the limited data available for large buildings is attributed to the greater complexity of the testing process, the absence of regulations, and the need for large-scale equipment. Typically, taller buildings are exposed to higher wind speeds combined with a much larger stack effect. Such large bias pressures make it difficult to collect reliable data for mid- and high-rise buildings. In addition, there will often be several days of preparatory work to seal intentional openings. Also, the size of some buildings require many fans to be set up with a complex arrangement of data cables and pressure tubes [31].

To address the knowledge gaps in literature, the main objectives of this study are as follows:

- Provide additional data for large buildings airtightness to address scarcity of available measurements;
- Compare the measured values with the existing literature to establish a benchmark for large building airtightness in British Columbia;
- Evaluate the impacts of different air barrier strategies on large buildings airtightness.

In this study, the results of airtightness testing for 29 buildings are presented (20 new construction and nine existing buildings). The data was obtained over a span of four years, encompassing more than 500,000 m^3 of volume and 145,000 m^2 of floor area for buildings ranging from one to 21 storeys. The tests were carried out in accordance with ASTM E779-19, and the impacts of building archetype, air barrier system, height, and enclosure area on the airtightness are investigated.

2. Methodology

The following sections outline the methodology used in this study to obtain the airtightness data.

2.1 Test buildings

The data used for the study are test results from 29 buildings collected over four years, comprising 20 new constructions and nine existing buildings. These buildings can be categorized into the following archetypes:

residential, office, institutional, mixed-use, community centre, courthouse, and hotel. Air barrier strategies used for buildings are window wall (WW), interior sealed membrane (ISM), taped weather resistive barrier (TWRB), and self-adhered membrane (SAM). The building volume ranges from 369 m^3 to 104,570 m^3 with the average volume being 17,795 m^3. Similarly, the enclosure area ranges from 200 m^2 to 17,161 m^2 with an average area of 5,089 m^2. An average of five storeys is seen in the data with a minimum of one storey and a maximum of 21 storeys, and building heights ranging from about five m to 93 m. Table 1 summarizes the test building data and the air leakage parameters.

2.2 Building preparation

The goal of the airtightness tests was to test the air barrier of the buildings. As a result, building preparation was required to be completed before conducting the airtightness test. All interior doors within the pressure boundary were left open to achieve a uniform pressure in every room throughout the building. All exterior doors not being used for the fan set-up were closed and locked if possible. Doors to areas excluded from the pressure boundary were sealed off. All exterior windows were closed and locked. Ventilation openings in the building envelope area were sealed through the use of poly barriers taped to the exterior louvers/openings. Figure 1 shows building preparation for an institutional building, i.e., all intentional openings are sealed.

Figure 1: Examples of sealing louvers and mechanical vents for airtightness testing.

2.3 Test method

To create an induced pressure in the building enclosure, fans were used for the airtightness tests as they can uniformly pressurize/depressurize the space. Retrotec Model 6000 blower door fans were used for testing and the number of fans required for each test was based on a calculation using the height of the building above ground, enclosure volume, building floor area, and enclosure area (floor, ceilings, and walls) of the building's pressure boundary. Those blower door fans were connected to Retrotec Model DM-32 fan control gauges which were used to automatically control the test from a central location. The test calculated data in two conditions: pressurization and depressurization. Figure 2 illustrates the fan setup for a whole building airtightness test for a 15-storey residential building with six fans.

Figure 2: Example of a whole building airtightness test with six fans.

The fans were set up at exteriors doors throughout the building enclosure between ambient conditions (outdoors) and the interior pressure boundary. This setup assists with achieving a uniform induced pressure across the pressure boundary as required by ASTM E779. Before pressurizing or depressurizing the space, pressure sensor tubes measured the baseline bias (zero flow) pressure. Additionally, pressure sensor tubes were placed within the interior pressure boundary and the pressure of the building interior was measured and averaged by the

Table 1: Test building data and air leakage parameters

Building Number	Air Barrier Strategy [1]	New Construction or Existing Building	Archetype	Volume (m^3)	Enclosure Area (m^2)	Number of Storeys	Building Height (m)	Flow (L/s @ 75Pa)	Air leakage coefficient, C ($L/s/Pa^n$) Depressurization	Air leakage coefficient, C ($L/s/Pa^n$) Pressurization	Flow Exponent, n Depressurization	Flow Exponent, n Pressurization
1	SAM	New	Hotel	1,844	980	4	13	1,034	24.2	80.7	0.833	0.622
2	ISM	New	Mixed-Use	13,112	4,931	6	20	10,455	553	642	0.625	0.691
3	TWRB	New	Residential	369	200	5	5.5	260	23.3	-	0.558	-
4	ISM	New	Residential	2,523	1,222	3	10.9	2,531	150	194	0.621	0.628
5	ISM	New	Residential	2,441	1,249	3	10.9	2,030	146	168	0.633	0.607
6	ISM	New	Residential	3,744	1,761	2	7.6	2,737	171	339	0.651	0.526
7	WW	New	Residential	29,919	7,733	13	37.2	9,076	669	1580	0.57	0.534
8	WW	New	Residential	29,920	7,733	14	37	7,772	439	984	0.662	0.532
9	WW	New	Residential	30,070	7,508	15	47.9	10,220	547	1020	0.651	0.556
10	SAM	New	Residential	12,833	4,223	4	12.4	2,327	137	144	0.629	0.667
11	SAM	New	Mixed-Use	17,511	7,433	4	15.8	5,310	353	314	0.632	0.65
12	SAM	New	Residential	13,404	4,585	6	19.5	4,701	613	444	0.518	0.605
13	SAM	New	Institutional	26,149	7,740	4	19	7,983	723	819	0.537	0.545
14	SAM	Existing	Institutional	14,729	5,348	6	24.7	6,231	243	559	0.747	0.562
15	SAM	Existing	Institutional	21,998	7,339	3	16.5	4,321	369	-	0.57	-
16	ISM	Existing	Office	104,570	17,161	21	93	17,160	1070	-	0.642	-
17	ISM	Existing	Community Center	16,476	5,585	2	8.5	10,335	910	1090	0.557	0.526
18	ISM	New	Mixed-Use	24,123	7,887	6	24.3	14,745	1400	1080	0.524	0.624
19	SAM	New	Community Center	8,266	3,653	1	9.6	1,030	40.7	43.1	0.714	0.764
20	ISM	Existing	Office	9,137	2,440	2	6.2	11,070	828	668	0.594	0.656
21	SAM	New	Residential	15,240	5,035	5	20	2,578	156	140	0.634	0.687
22	ISM	Existing	Courthouse	41,244	10,584	5	27.7	19,410	1470	1660	0.581	0.584
23	ISM	Existing	Office	2,191	1,293	2	7	3,550	229	224	0.629	0.629
24	SAM	New	Residential	44,238	11,113	6	21	5,427	566	334	0.568	0.591
25	ISM	Existing	Courthouse	7,700	2,740	3	17	9,086	615	558	0.623	0.647
26	ISM	Existing	Office	5,880	2,670	2	8	11,920	973	827	0.581	0.617
27	TWRB	New	Office	3,607	2,093	1	5.2	940	55.3	38.8	0.609	0.777
28	TWRB	New	Office	7,650	2,940	1	7.6	1,933	77.8713	117.043	0.744	0.649
29	SAM	New	Mixed-Use	5,169	2,328	3	11.5	1,868	115	90.8	0.636	0.709

[1] Air barrier strategy acronyms: window wall (WW), interior sealed membrane (ISM), taped weather resistive barrier (TWRB), and self-adhered membrane (SAM).

Retrotec software (Fantestic Pro). In accordance with ASTM E779-19, the software also calculates the pressure difference between each interior reference location and the average interior pressure, ensuring there is no more than 10 per cent difference to confirm that the interior pressure is uniform throughout the building. The tests were done in conformance with ASTM E779-19 with the following modifications: i) tests were conducted for both pressurization and depressurization, ii) the test pressure range was from 25Pa to 80Pa, and iii) intentional openings in the enclosure were sealed during the test.

2.4 Data analysis

The power law equation in Equation (1), was used to calculate the airflow through the building enclosure where Q is the volumetric airflow rate (m^3/s), ΔP is the pressure difference between the ambient conditions and the interior pressure boundary (Pa), C is the air leakage coefficient ($m^3/s/Pa^n$), and n is the flow exponent (dimensionless) [2].

$$Q=C(\Delta P)^n \qquad \text{Eq. (1)}$$

Equation (1) is used to calculate the airflow rate (Q) between the ambient conditions and the interior pressure boundary. The values for flow exponent (n) range between 0.5 to 1.0 to conform with the power law equation and to reflect if the flow is completely turbulent or laminar, respectively [20]. To get the values of the air leakage coefficient (C) and flow exponent (n), unweighted, log-linearized, linear regression analyses were calculated at various pressure differences. Q was then extrapolated at the reference pressure difference [2, 20].

The metric that is typically used to report the air leakage of large buildings is normalized leakage rate (NLR_{75}). Test results for different projects can be compared with NLR_{75} as it normalizes the air leakage over the envelope area at 75Pa. The equation for NLR_{75} is seen in Equation (2) where Q is the volumetric airflow rate at 75Pa (m^3/s), and A is the area where the pressure difference is observed, e.g., enclosure area (m^2) [32]. The values of NLR are typically reported in [l/s/m2], and the same convention has been used in this study.

$$NLR_{75Pa} = \frac{Q_{75Pa}}{A} \qquad \text{Eq. (2)}$$

Another metric that is typically used to report the air leakage rate is Equivalent Leakage Area at 10 Pa ($EqLA_{10Pa}$), and it can be calculated as follows:

$$EqLA_{10Pa}=\frac{Q_{10Pa}}{0.61}\sqrt{\frac{\rho}{2\Delta P}} \qquad \text{Eq. (3)}$$

Where Q_{10Pa} [m^3/s] is the air flow at 10Pa, ρ [kg/m^3] is air density, and ΔP is 10 [Pa].

3. Results

The results of the conducted airtightness tests are presented in this section. As seen in Figure 3, the tested buildings are primarily located in British Columbia, and two buildings are in Calgary, Alberta. It should be noted that at the time of writing this paper, there is no airtightness requirement in Alberta, however, performing a whole building airtightness test is mandatory in B.C. under the BC Energy Step Code.

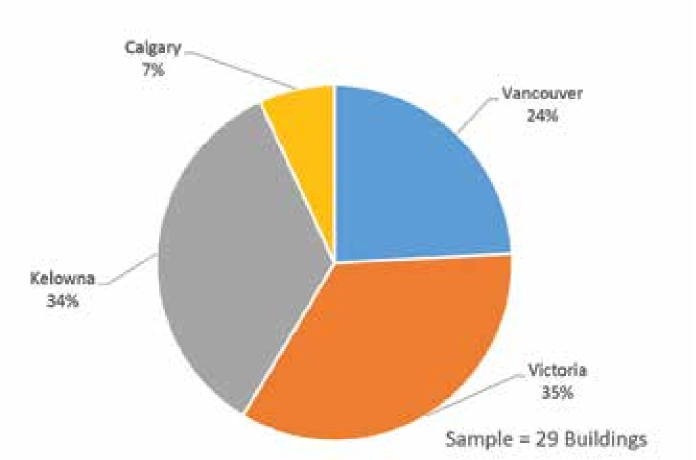

Figure 3: Geographical distribution of tested buildings.

Figure 4 depicts the NLR_{75Pa} for the tested buildings where the average NLR75Pa is 1.09 $l/s/m^2$ for new construction and 2.39 $l/s/m^2$ for existing buildings, respectively. The data for new construction ranges between 0.28 and 2.12 $l/s/m^2$ while it varies from 0.58 to 4.53 $l/s/m^2$ for existing buildings. Given that a majority of the new construction buildings were under the BC Energy Step Code, they had a maximum NLR_{75Pa} requirement of 2 $l/s/m^2$ which was satisfied for most of the tests. As expected, existing buildings are generally less airtight than new construction with the exception of existing buildings that were a full recladding retrofit project resulting in less than 1.2 $l/s/m^2$. The data obtained in this study for "average" normalized leakage rate of existing buildings is fairly close to what is reported in Ref. [30] for post 2000 construction, i.e., 2.39 versus 2.12 $l/s/m^2$. However, the average NLR_{75Pa} for new construction is approximately 50 per cent better, i.e., 1.09 $l/s/m^2$. Considering the data presented in Figure 3, it is evident that the current New Construction Code Requirement of 2 $l/s/m^2$ in the Vancouver Building Bylaw (VBBL) seems fairly achievable, it appears that this target should be reduced to observe a continuous improvement in the airtightness of the built environment. With respect to the data obtained for existing buildings, it can be concluded that the projects with full recladding scope have a potential to significantly improve the airtightness of the buildings, given a new continuous exterior air barrier can be installed for the building.

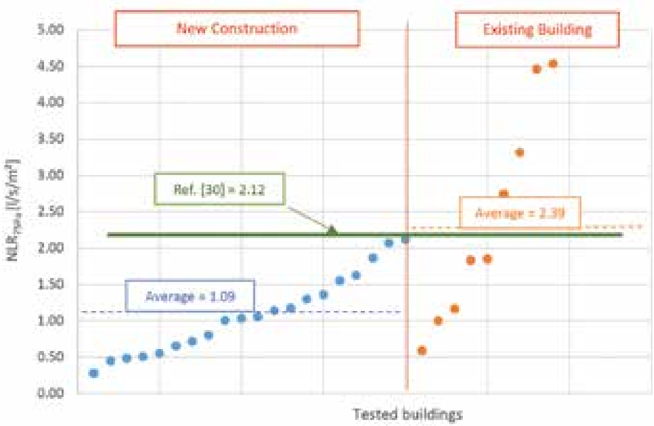

Figure 4: Airtightness data sorted from minimum to maximum (NLR $_{75Pa}$ l/s/m²).

As discussed earlier in this paper, C (air leakage coefficient) and n (flow exponent) are two factors that describes the physics of fluid flow where n=1 represents a fully laminar flow through a porous medium and n=0.5 represents a turbulent flow through a sharp edge orifice [20]. Since flowthrough air leakage paths of the air barrier is a combination of laminar and turbulent flow, the values of n are always between 0.5 and one for the actual airtightness test. In the absence of multi-point testing to precisely determine the flow exponent (n) value for a specific building, the industry has conventionally relied on assuming a value of 0.60 or 0.65. To evaluate the suitability of these assumptions, an analysis of the measured flow exponents for the tested buildings within the database was conducted and is depicted in Figure 5. The calculated average of the flow exponents was determined to be 0.61 to 0.62, aligning closely with the frequently adopted values of 0.6 and 0.65. A value of 0.63 is reported in Ref. [33], and it is pointed out that using a value of 0.6 is gaining wider industry acceptance which aligns well with the findings of this study.

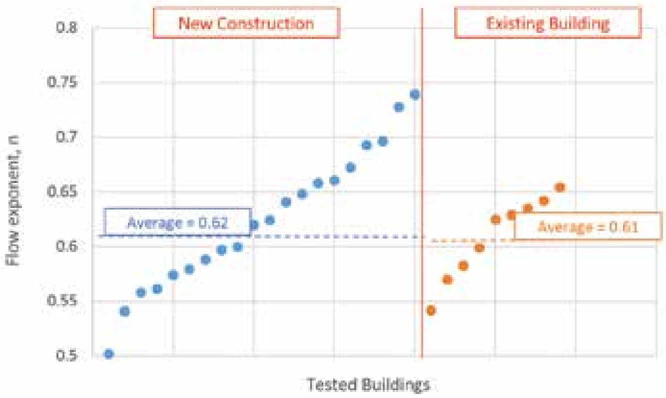

Figure 5: Flow exponents sorted from minimum to maximum.

Figure 6 shows the distribution of airtightness data. As seen in Figure 6, the airtightness of the majority of buildings falls below 1.9 l/s/m² with only six buildings (approximately 20 per cent of the data) having NLR_{75Pa} higher than 2 l/s/m². As mentioned before, most of the existing buildings in the dataset manifested high air leakage except the ones undergone a full envelope retrofit.

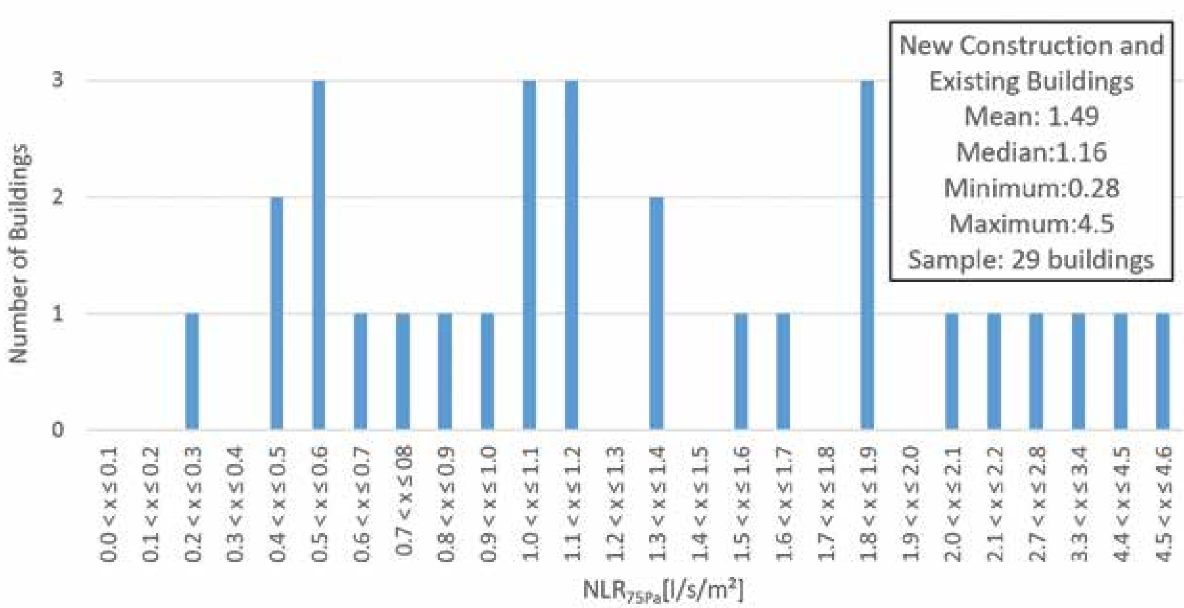

Figure 6: Distribution of airtightness data.

The analysis of the airtightness data was extended to examine its correlation with the building envelope area as illustrated in Figure 7. Based on this analysis, the airtightness of buildings increases with the building envelope area. However, one may argue that because buildings with larger enclosure surface area are generally taller, a more robust air barrier system had to be used to withstand higher wind and stack pressures.

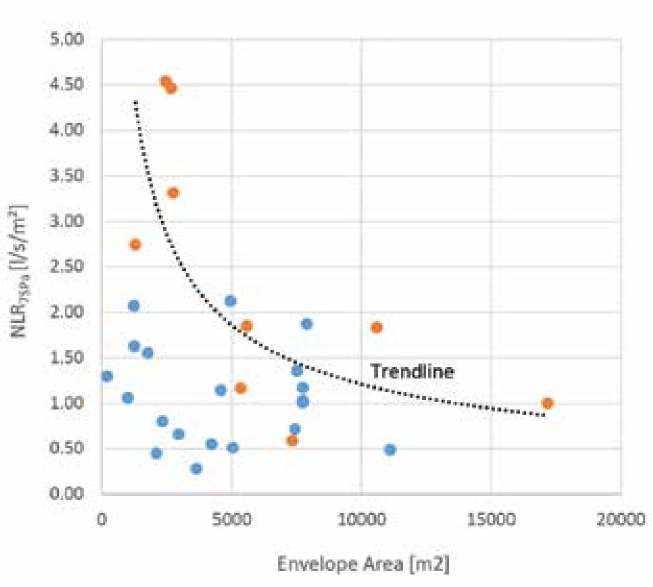

Figure 7: Airtightness versus envelope area for the tested buildings.

Figure 8 further investigates the impacts of the air barrier strategy on the airtightness of the tested buildings. Four main air barrier strategies that had been used in the tested buildings were: i) Interior Sealed Membrane (ISM); ii) Exterior Self-Adhered Membrane (SAM); iii) Taped Weather Resistive Barrier (TWRB); and iv) window wall system (WW). It is evident from Figure 7 that buildings with SAM and TWRB demonstrate better airtightness levels compared to other buildings in the dataset. In addition, the high-performance characteristics of SAM has been confirmed for both new construction and existing buildings in the dataset. A wide range of performance was determined for ISM approach compared to other strategies making the results prone to the quality of installation, detailing, and workmanship. In general, the values obtained for SAM and TWRB were almost order of magnitude lower than other data.

Figure 9 shows the Equivalent Leakage Area (EqLA) @10Pa in m² for the tested new construction projects. EqLA is a metric used to represent the size of a hypothetical sharp-edged orifice that would allow the same amount of air flow at a specific pressure (in this case, 10 Pa) as the cumulative air leakage through all the actual leakage paths in a building enclosure. It helps in comparing the air leakage characteristics of different buildings or assessing the effectiveness of air sealing measures. The 10 Pa reference

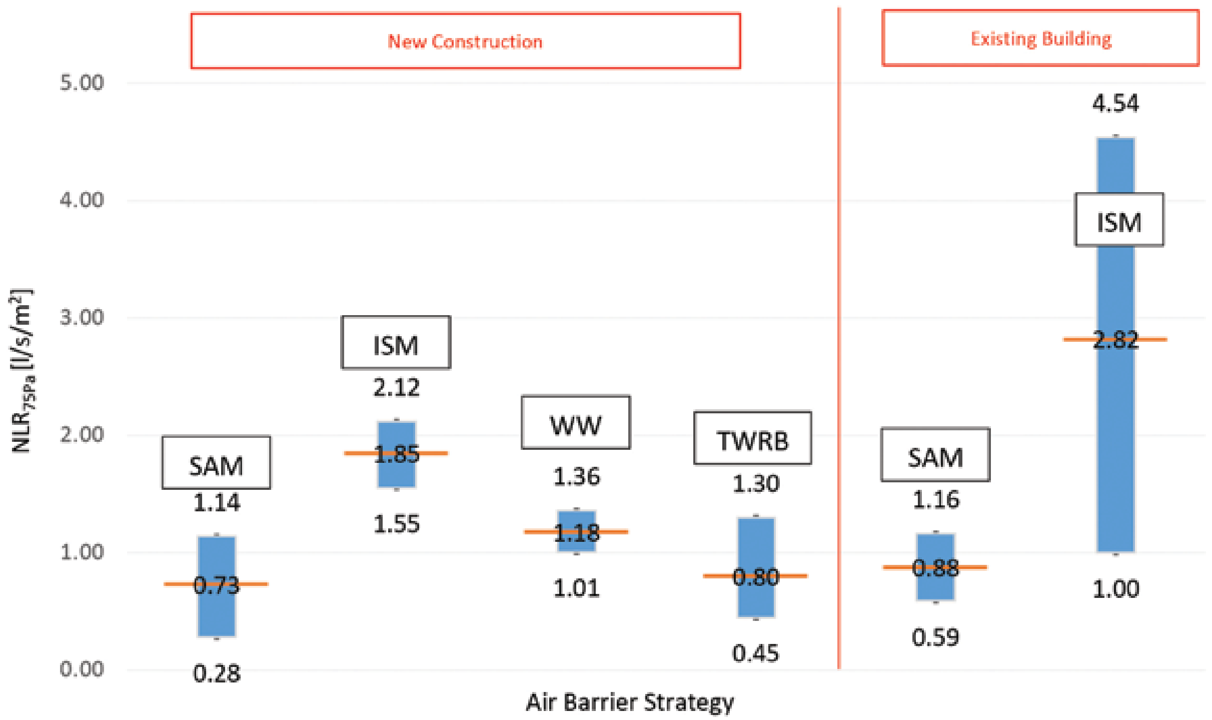

Figure 8: Minimum, maximum, and average leakage results for different air barrier strategy.

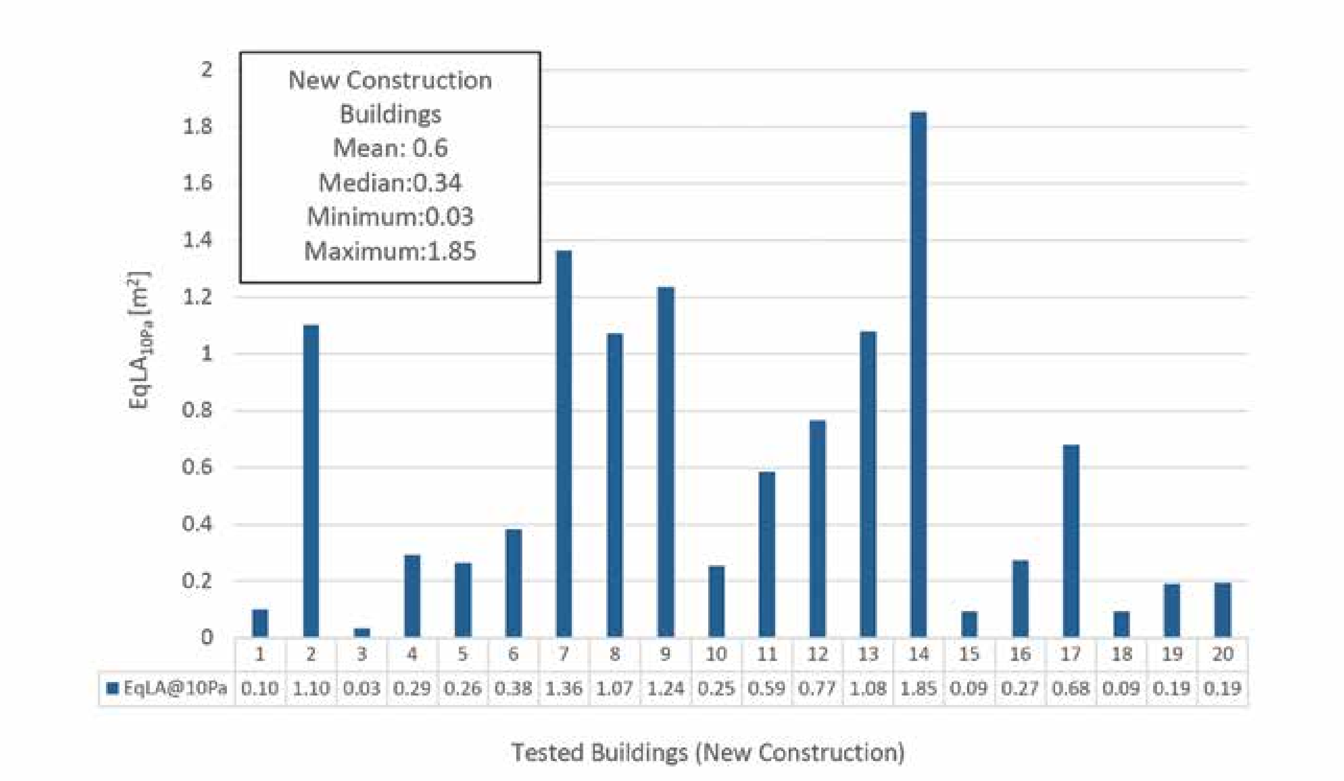

Figure 9: Equivalent Leakage Area (EqLA) at 10Pa for the new construction dataset.

Blower door/air tightness testing.

pressure is commonly used in building performance testing to simulate real-world conditions. As seen in Figure 9, the EqLA for the tested buildings ranges from 0.03 to 1.8 m^2. The average EqLA was determined to be 0.6 m^2 with a median value of 0.34 m^2.

4. Conclusion

This paper represents the data gathered for whole building airtightness testing of 29 large and multi-zone buildings. This study was conducted over a span of four years, and the main goal of the tests was to address the scarcity of the available airtightness data for large buildings. The following conclusions can be drawn from this study:

- Existing buildings which had undergone a major envelope retrofit manifested exceptional airtightness level compared to other existing buildings in the dataset.
- New construction projects generally demonstrate a better airtightness level compared to existing buildings.
- An average of 1.09 $l/s/m^2$ and 2.39 $l/s/m^2$ was calculated for the airtightness levels of the tested new construction and existing buildings, respectively.
- An average value of 0.61 to 0.62 was determined for the flow exponent value of pressure-flow equation which aligns with existing literature.

- The airtightness of the tested buildings increases with building enclosure area; however, this might be related to better air barrier strategies used for larger buildings.
- The air barrier strategy has a significant impact on airtightness. Exterior self-adhered membrane and taped weather-resistive barrier demonstrate order of magnitude improvements over other methods.

This study provides a platform to establish a new benchmark for airtightness targets of new construction buildings. The current airtightness level of 2 l/s/m² @75Pa which is addressed in the Vancouver Building ByLaw (VBBL) and other resources [34] seems fairly achievable, and it should be reduced to observe a continuous improvement in the airtightness of the built environment.

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BEYOND R-VALUE: THE HIDDEN RISK OF MODERN ROOF ASSEMBLIES

By Jon Solland, P.Eng., RRC, RWC, RRO

Solland is a unique consultant in Alberta, professionally designated as both a registered roof consultant (RRC) and a professional engineer. An active leader in the industry, he serves as a region director on the Board of the International Institute of Building Enclosure Consultants (IIBEC).

Abstract

Low-slope roofing practices have advanced significantly over the past half-century, driven largely by the pursuit of improved thermal performance and airtightness. Where mid-20th century assemblies typically contained two to three inches of insulation (around R10) and modest vapour control, modern systems commonly incorporate four to eight inches of insulation (around R20 to R40), tapered packages, and fully adhered air and vapour barriers that are also functionally watertight. These advances reduce air leakage and visible moisture leakage to occupants but introduce a new, emerging challenge: hidden structural overload.

Older assemblies, with thinner insulation and discontinuous vapour barriers, often allowed incidental water to redistribute or escape. By contrast, today's conventional assemblies trap moisture, preventing drying and allowing water to accumulate within commonly used insulation types such as polyisocyanurate (PIR) and expanded polystyrene (EPS) insulation. Insulations such as extruded polystyrene (XPS) installed in protected (aka inverted) membrane assemblies can take on significant water weight over time, even without roof membrane failure. The combined effects of saturated insulation, ponding from blocked drains, freeze/thaw cycling, and coinciding snow loads can impose loads far beyond those anticipated by code-based live load assumptions. Six inches of saturated insulation can contribute loads exceeding 31 psf (1.5 kPa), exceeding the specified roof snow load for many existing Alberta buildings, which is typically in the range of 20 to 31 psf (1.0 to 1.5 kPa) across major urban centres. This potential load increase is not unique to any single insulation type, as most rigid insulation materials can retain substantial water when exposed to prolonged hydrostatic pressure.

The risk of structural overload is compounded by aging building stock, retrofits carried out without structural review, and the growing impact of climate change in the form of extreme precipitation and rain-on-snow events. Structural failures attributed to heavy snow often overlook the fact that hidden water entrapment could play an equally important role.

The good news is that the risks are manageable with appropriate design and maintenance. Mitigation strategies include requiring structural review when roof assemblies are upgraded, factoring potential water saturation into design loads, and designing redundant drainage. Reconsidering vapour control strategies by, for example, using "smart" vapour retarders may provide benefits related to the issues discussed in this article, but won't be explored herein. Regular inspections, non-destructive testing, and leak detection monitoring can further reduce the risk of unnoticed water accumulation. Ultimately, the industry must recognize that more insulation is not a neutral change: it can fundamentally alter roof performance and structural safety. To prevent future failures, roof assemblies must be designed, maintained, and evaluated as both thermal envelopes and structural systems.

Introduction

Over the past 50 years, roofing practices have evolved dramatically. Mid-20th century assemblies typically included about two to three inches of insulation, modest vapour control, and assemblies that were far from airtight by modern standards. While these assemblies were thermally inefficient, they were generally lighter, simpler, and in some ways, more forgiving when moisture inevitably made its way into the system.

Modern roofs, by contrast, are typically engineered to be airtight and watertight. Current practices commonly include four to eight inches (or more) of insulation, tapered packages for drainage, and continuous, fully adhered vapour barriers (some specifically intended to perform temporarily as a roof membrane). The increased insulation thicknesses are largely driven by continuous updates to the National Energy Code for Buildings. These innovations have improved energy performance, air leakage resistance, and occupant comfort. However, they have also created a less visible problem: the risk of hidden structural overload.

Today's roof assemblies, while more efficient, can behave like sealed containers. If moisture enters the system, whether through a leak, condensation, or absorption into insulation materials, it often becomes trapped with no way to escape. Over time, this can result in significant and unanticipated structural loading that may exceed code assumptions and, in the worst cases, contribute to roof failure.

Evolution of Albertan roof assemblies

Older roofs (1950s–1970s)

- Insulation depth: Typically two to three inches (50 to 76 mm).
- Insulation layering: Fewer layers of insulation, less capacity to stagger joints.
- Vapour control: Tar paper or felts with poorly detailed laps, relatively permeable by today's standards.
- Drying pathways: Assemblies were "leakier". Incidental moisture could often redistribute through gaps, evaporate, or present itself quickly as a leak.
- Structural implication: Limited insulation meant limited capacity for hidden water storage. Any problems typically became apparent before significant hidden loads developed.

Modern roofs (2000s–present)

- Insulation depth: four to eight-plus inches (102 to 203-plus mm), plus sloped packages for drainage.
- Insulation layering: Staggered joints primarily to limit thermal bridging, but also air/water migration.
- Vapour control: Fully adhered, continuous vapour barriers, often rated to be watertight.
- Drying pathways: Creates a "sealed box" condition whereby assemblies have little to no drying potential.
- Structural Implication: Added cover boards, ballast, and multiple insulation layers increase dead load even before water intrusion.
- Protected membrane roofs: Extruded polystyrene (XPS) is often installed above the membrane and intentionally exposed to water, relying on its resistance to water absorption relative to other common insulations. Over time, XPS can absorb water and increase in weight substantially, even without membrane leaks. The rate and extent of water uptake depends on several factors, including drainage conditions, the presence of drainage boards, and the assembly's ability to dry.

Overload risks – A gap in current codes and practice?

Increased imposed loads

The additional thickness of insulation translates to higher permanent dead loads. When buildings are retrofitted, it is not uncommon for new insulation layers to be added without a detailed structural review. If moisture finds its way into the insulation, modern vapour barriers tend to trap it in place. Common rigid insulation materials used in roofing assemblies, including EPS, fiberboard, polyisocyanurate, mineral wool, and XPS, can retain water if moisture enters the system. Insulation behaves like a sponge, absorbing water and dramatically increasing in weight. Freeze/thaw cycling can worsen the problem, as moisture expands and contracts, gradually increasing both the volume of water retained and creating other damage such as delaminating insulation facers and fracturing the cell structure of foam insulation.

Combined effects

The most critical conditions occur when snow weighing down from above and/or ponded water pooling on the surface coincides with saturated insulation stealthily loading the structure from within the roof assembly. Blocked drains or neglected maintenance turn roofs into reservoirs, while hidden water trapped in insulation quietly compounds the weight. The combined load can exceed code-based live load assumptions, creating conditions for structural failure. While such scenarios are not inevitable, they highlight the importance of coordinated design, regular maintenance, and consideration of hidden loads when upgrading or replacing roof assemblies.

Over 30mm (1-3/16 inches) of standing water inside an SBS modified bitumen roof assembly. Photo credit: RJC Engineers.

Over 50mm (two inches) of standing water inside a TPO roof assembly. Photo credit: RJC Engineers.

Compounding and overlooked factors

Several broader trends amplify the risks associated with these modern roof assemblies:

- Aging structures: Many older structural systems were never designed for today's heavier assemblies or modern climate loads. Retrofits may introduce a risk of excessive imposed load to a building that is already noncompliant with modern code.
- Retrofits without review: Roof replacements often emphasize meeting energy code requirements (R-value, airtightness) but omit structural analysis of the increased loads.
- Climate change: More frequent extreme rainfall, rain-on-snow events, and freeze-thaw cycles mean more opportunities for water entrapment and added loads.
- Drainage neglect: Roof drains are often obstructed by debris or ice, preventing effective drainage and leading to ponding. Ponding water further stresses membranes, accelerating defects, and increasing the rate of water ingress into the insulation.
- Misaligned priorities: Current building codes heavily emphasize thermal performance but provide little guidance on assessing or designing for hidden load risks associated with water entrapment.

Evidence and case insights

Field investigations and forensic reports provide compelling evidence of this issue:

- Load of saturated insulation: For context, six inches of saturated insulation can add as much as 31 psf (1.5 kPa), which is higher than the design live load for many structures in Alberta. This underscores the need for the industry to acknowledge water entrapment as a potential load source and to clarify how such conditions should be treated in design, maintenance, and insurance disputes.
- Collapse attribution: Roof failures are frequently attributed in the media to "heavy snow", yet post-failure analysis can reveal a more complex interaction: snow loads compounded by ponding and the hidden weight of waterlogged insulation.
- Insurance disputes: When failures occur, insurance coverage can hinge on whether the proximate cause was an acute peril (e.g., heavy snowfall) or a chronic condition (e.g., long-term water entrapment). The latter is frequently excluded from policies as progressive deterioration. Few legal precedents exist specifically for water entrapment, forcing courts and arbitrators to rely on conflicting expert testimony. This uncertainty results in protracted disputes, delayed claims, and costly litigation.

Mitigation strategies

Addressing these risks requires a shift in design, construction, and maintenance practices:

- Structural review: Any major change in insulation depth or roof assembly type should trigger a structural analysis, especially on older buildings.

- Load allowances: Engineers should consider the potential weight of saturated insulation in addition to prescribed snow loads, particularly on inverted membrane roofs with XPS.
- Drainage design: Roofs should include redundant drainage, with secondary or emergency drains as standard practice.
- Vapour control may also be considered at the design stage, similar to rainscreen wall assemblies, but specific methods aren't considered in this article.
- Maintenance protocols:

  - Routine cleaning and inspection of drains.

  - Scheduled roof inspections by building operations teams (weekly to biannually depending on roof complexity).

  - Professional reviews every two to five years, including non-destructive testing (infrared thermography, capacitance testing).

  - Leak detection systems, active or passive, to provide early warning of water entry into insulation.
- Education: Owners, architects, and engineers should understand that modern roofing practices have successfully advanced energy efficiency, but there may be unintended new challenges and risks that must be explored to equip the design team in making a fully-informed decision.

Conclusion

Modern roofing assemblies have achieved impressive gains in thermal efficiency and airtightness, but those benefits can come with unintended consequences. Roofs are now heavier, less tolerant of incidental moisture, and more susceptible to hidden water entrapment. Failures once blamed solely on snow must increasingly be understood as the combined effect of snow, ponding, and saturated insulation.

The industry must evolve to inform owners and address these risks. Energy and enclosure design cannot be separated from structural safety. Codes should be updated to reflect the potential for hidden loads, while practitioners should adopt more conservative design assumptions, robust drainage, and ongoing inspection protocols.

Resilient buildings in the 21st century demand that no element be designed in isolation. Roofs, walls, structure, and mechanical systems are all interdependent, and the performance of one directly influences the others. The structural design of a building relies on critical assumptions for loads from adjacent systems and changing the roof loads invariably affects the structure that supports it. A roof is not only a thermal and moisture barrier, but is tied to drainage, snow management, and long-term durability. True resilience comes from considering these connections holistically and treating every system as part of the larger building ecosystem. Only through this integrated perspective can we deliver buildings that are efficient, durable, and safe within their anticipated conditions and service life.

Years of specialized building envelope project work have provided Jon Solland with a strong understanding of what buildings in Calgary need to withstand local environmental factors. He focuses on supporting large clients with effective envelope designs, asset management tools, and condition reports, as well as skills in project management, contract administration, and construction review that will lead their projects to success. Solland's priority is solving clients' problems through creative solutions that will meet both their needs and constraints. ■

BEYOND BLACK AND WHITE
THE PHYSICS, ECONOMICS, AND LIFECYCLE OF ROOF COLOUR

By Garratt Grenier, RRO, GRP
Registered roof observer and green roof professional

Garratt Grenier is a roofing and building enclosure professional with over 20 years of industry experience spanning Northern Alberta, Northern British Columbia, and Northwest Territories. He is a green roof professional and holds a Registered Roof Observer designation. Edmonton's unique climate has shaped his involvement in product development and testing throughout his career. He is currently on the board of directors of ABEC North and is a proud father, mentor, and has a passion of improving the industry.

Abstract

Roof colour is rarely treated as an engineering variable; yet it governs membrane chemistry, peak electrical demand, occupant productivity, urban thermal dynamics, and condensation risk. This article synthesizes more than three decades of peer-reviewed research, covering the physics of solar reflectance, the lifecycle chemistry of every major membrane type, the real economics of cool roofs (and their hidden costs), the nuanced truth about urban heat islands, and the emerging technologies that may make the black-vs-white debate obsolete. The correct specification is always climate-specific — and for most Canadian building sites, the default assumption of 'white is right' demands careful scrutiny.

1. The physics of cool: Beyond visible light

Two numbers govern every roof's thermal fate: solar reflectance (SR), the fraction of incoming solar energy bounced back into the sky, and thermal emittance (TE), the material's ability to radiate absorbed heat as longwave infrared. Emittance (equivalent to emissivity, the "e" in low e glass coatings) is frequently misunderstood. As an example, bare galvalume or galvanized steel can have a high SR of 0.61, yet a low TE of 0.04, so it is unable to radiate the heat it collects, negating the reflectance benefit. Dark roofs score SR 0.05–0.10; cool white membranes reach SR 0.75 to 0.85. Because 52 per cent of the sun's energy is invisible near-infrared radiation (NIR) that we feel only as heat, and just 43 per cent is visible light, a surface that looks dark is also a powerful heat collector. On a summer day in Calgary or Phoenix, a black membrane can reach 77°C to 88°C. On the same day, a white membrane may peak at 43°C to 52°C.

Colour only matters when the sun is out. During nighttime hours, white and black membranes drop to nearly identical surface temperatures due to the TE values of the materials. Under clear night skies, any membrane can radiate heat into the three degrees Kelvin outer-space heat sink through the 8 to 13 μm atmospheric window, which is the physical foundation for Passive Daytime Radiative Cooling (PDRC) technology discussed in Section 6.

2. Lifecycle chemistry: How colour dictates durability

Colour affects surface temperature and that heat can cause deterioration. The Arrhenius equation describes that chemical degradation doubles in rate for every 10°C rise in temperature. Because of this, a dark membrane at 80°C is not aging twice as fast as a white membrane at 50°C. It is aging approximately eight times faster, because the 30°C gap accounts for three times the rate doubled.

Standard PVC

PVC requires substantial liquid plasticizer content (typically 25 to 40 per cent by weight of phthalate-based compounds) to remain flexible. These plasticizers migrate toward the surface continuously and heat accelerates that migration. A dark PVC roof reaching 77°C on a summer afternoon loses plasticizer at roughly double the rate of a white PVC roof at 43°C. Field studies report white standard PVC reaching 15 to 22 years in moderate climates. As a result, dark PVC in hot climates can fail in 10 to 14 years.

TPO: A promising polymer with a troubled track record

TPO entered the commercial roofing market in the late 1980s and expanded rapidly. Within a decade, the industry was documenting widespread premature failures: seam adhesion loss, surface chalking, cracking, and embrittlement. ASTM D6878 was revised multiple times and ultimately tightened to require heat aging survival at 116°C for 32 weeks.

TPO has no standardized formulation. Independent testing (McGroarty, Taylor, and Pierce, 2015) found that solar reflectance retention after ASTM heat aging varied from 71 per cent to 94 per cent across manufacturers on nominally identical white 60-mil TPO products. The specifier has no reliable way to know which they are purchasing without independent laboratory verification of the specific lot. As a result, it is recommended that specifiers request ASTM D6878 third-party heat aging data, CRRC three-year aged SR values, and warranty terms for the specific colour specified.

KEE: The permanent plasticizer solution

Ketone Ethylene Ester (KEE) as a stand-alone membrane, governed by ASTM D6754, is a distinct product from both standard PVC sheet roofing (ASTM D4434) and the widely marketed PVC-KEE blend membranes, which remain primarily PVC-based. This distinction matters critically when interpreting performance data. In a true KEE membrane, KEE is the base polymer, typically comprising 40 to 60 per cent of the blend, and replaces conventional liquid phthalate plasticizers entirely. KEE molecules are too large to migrate and are not volatile, they cannot leave the membrane under normal field conditions, including sustained surface temperatures exceeding 82°C. The membrane that is flexible on installation day remains measurably flexible decades later. ASTM D6754 reflects this chemistry with more stringent performance thresholds than D4434, particularly for heat aging and low-temperature flexibility.

Autopsy testing of KEE membranes after 20-plus years of service has shown flexibility values still meeting original manufacturing specifications, a result not replicated with standard PVC or any TPO formulation.

European roofing researchers tracking pure KEE installations over 25-year periods have documented consistent service lives of 30 to 35 years in moderate climates, with autopsy samples still meeting or exceeding original manufacturing specifications. These results are specific to pure KEE membranes meeting ASTM D6754. PVC-KEE blend membranes, which retain a PVC-dominant polymer matrix and are susceptible to the same plasticizer migration mechanisms as standard PVC, albeit at a slower rate depending on the KEE content. Specifiers must confirm whether a proposed product is a true KEE membrane under D6754 or a PVC membrane with KEE as one component among several plasticizers. KEE carries a 25 to 40 per cent material cost premium over standard PVC, but on a lifecycle basis a verified 30-year KEE membrane two standard PVC membranes, and perhaps three TPO membranes.

EPDM: The carbon champion

Black EPDM's polymer backbone resists ozone, UV, and heat through carbon black at approximately 47 per cent by weight. It is not merely a pigment; it is the primary UV absorber and a reinforcing filler contributing directly to EPDM's documented 38-year service life. White EPDM replaces carbon black with titanium dioxide and clay fillers to achieve reflectance, but it is worth noting upfront that white EPDM is a niche product with limited market presence, the overwhelming majority of EPDM installed in Canada and North America is black. This is not incidental: the substitution carries a measurable and documented service penalty. Independent testing has confirmed lower tensile and tear strength in white EPDM formulations, and field reports consistently track meaningfully shorter effective service lives than the black EPDM benchmark, with surface chalking, loss of elasticity, and seam-area brittleness appearing earlier. The honest specification position: white EPDM is an environmentally attractive option on paper, and lifecycle assessments confirm it has the lowest global warming potential of any single-ply membrane, but specifiers should treat manufacturer service-life claims for white EPDM with significant skepticism and request independent third-party test data, not assume that black EPDM performance figures apply. Where long-term membrane performance is the priority, black EPDM remains the substantially more dependable choice. The industry's recycling story is a genuine bright spot: cryogenic grinding facilities now convert reclaimed EPDM into durable polyurethane and silicone roof coatings.

Ballasted BUR: The lifecycle champion

Ballasted gravel built-up roofing delivers the best documented long-term lifecycle performance of any low-slope system, and does so through physics rather than chemistry. A minimum 38 mm layer of smooth river stone (49 to 59 kg/m^2) provides: (1) complete UV shielding; (2) thermal mass buffering, reducing peak membrane temperatures by 17 to 28°C; (3) mechanical protection; and (4) self-ballasting wind resistance. ORNL/SPRI research confirmed ballasted roofs deliver peak energy performance equivalent to highly reflective white single-ply systems, through thermal mass rather than reflectance. Building owners with ballasted BUR report functional service lives of 40 to 60 years, a track record no commercially available single-ply membrane has matched.

The primary limitation is structural: the system requires sufficient deck load capacity (typically 122 to 146 kg/m^2), making it unsuitable for lightweight steel deck construction.

BUR, modified bitumen, and reflective coatings

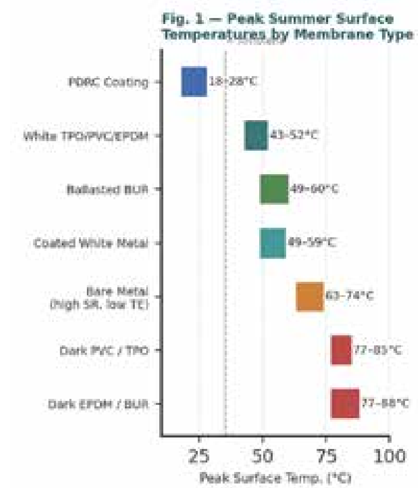
Modern polyurethane-modified SBS creates a resilient molecular bond that retains protective surface minerals far better than standard SBS, significantly slowing photo-oxidation. Applying a white elastomeric coating or white cap sheet drops SBS surface temperatures by up to 33°C, reducing thermal aging by large margins, supported in the reference to the Arrhenius equation above.

Traditional aluminum coatings achieve SR of 0.40–0.50 and remain a cost-effective field option for aging SBS assemblies. When it comes to liquid-applied reflective coatings, product selection matters significantly in the Canadian climate. White acrylic coatings are inexpensive and widely available, but they perform poorly in cold climates due to freeze-thaw cycling. These coatings also degrade rapidly under ponding water conditions common on low-slope roofs. Polyurethane coatings are the better choice for Canadian applications: they maintain adhesion and flexibility through freeze-thaw cycles, resist ponding water, and provide a more durable reflective surface over the long term. Both acrylic and polyurethane coatings require a sound substrate and proper surface preparation to perform as intended.

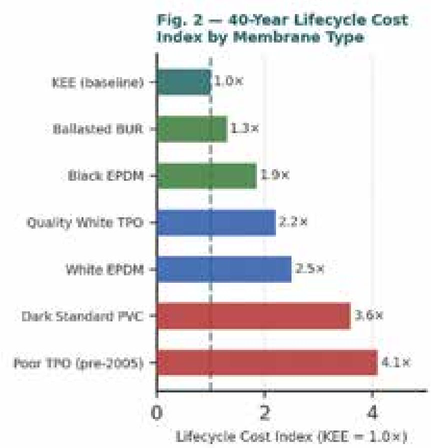
3. Customer economics: Demand, productivity, and a paradox

In cooling-dominated climates, the economic case for white roofing is compelling, but the most important number is often not energy (kWh) but demand charges ($/kW). Peak demand charges can dwarf volumetric usage charges by a factor of 10. A groundbreaking 1985 study ("Building for the Future") demonstrated that white surfaces actively delay peak electrical demand to later in the day, giving power grids critical relief. A foundational 1996 study by Parker established that cooling benefits are highest in older building stock where ceiling insulation is RSI-1.9 (R-11) or below.

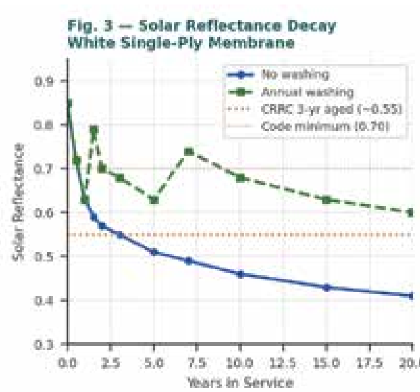
For unconditioned buildings such as warehouses, manufacturing plants, and distribution centres, the most important economic metric is worker productivity. Organizations spend



Estimated peak summer surface temperatures by membrane type. Ballasted BUR reduced by thermal mass buffering.



Relative 40-year lifecycle cost index by membrane type. KEE baseline = 1.0×. Early TPO based on documented 1990s–2000s field data.



Solar reflectance decay for a typical white single-ply membrane. Always specify by CRRC three-year aged SR (~0.55), never initial factory value.

approximately 100 times more per square metre on staff than on energy. Studies have shown that a white roof can drop interior temperatures by up to 11°C. Above 25°C, productivity declines approximately two per cent per degree Celsius. Even a one per cent productivity gain from improved thermal comfort yields a return equivalent to the building's entire annual energy cost in some cases.

One underappreciated factor to be cautious about: if a white roof works too well, the A/C runs less frequently to remove heat and consequently runs less frequently to dehumidify. Interior relative humidity rises and moisture-laden air migrates upward into the roof assembly. The cool roof's energy-saving success can cause interior condensation that never occurred when the old hot dark roof forced the A/C to run constantly.

4. Drawbacks: Condensation, moisture, and hidden costs

The self-drying roof and hygrothermal reality

In heating-dominated climates, dark roofs historically absorbed winter solar heat, creating a thermal drive that pushed interior moisture back down into the building. This is the 'self-drying' roof effect. White roofs reflect that energy away, remaining cold and acting as a condensation plane. Hygrothermal (WUFI) modelling by Ennis and Kehrer (ORNL/SPRI) confirms the gradient: in Phoenix, any colour performs well; in cities such as Toronto or Ottawa (NECB Climate Zone 5–6), white roofs develop more than double the winter moisture content of black roofs (17 to 23 per cent vs. 10 to 15 per cent); in Anchorage or Yellowknife (NECB Climate Zone 8), white roofs may fail to self-dry entirely, which could lead to permanent moisture accumulation and deck rot. Under hygrothermal analysis criteria consistent with NBC 2020 Part 5 requirements, modelling shows white roofs over wood decks exceed the critical Mould Growth Index threshold of 3.0 within approximately one year; black roofs stay well below it.

However, real-world field surveys temper the alarm. A multi-site cold-climate field study evaluated 26 commercial buildings with 10- to 14-year-old white single-ply roofs. Moisture was found in only two of 53 core cuts. A subsequent Zone 5 study by SPRI confirmed that while white roofs experience more winter condensation than black, both roof types return to a completely dry state during summer in most temperate climates.

The difference between the white and dark roof colours in hygrothermal performance is the “straw that breaks the camel's back” theory: a cool roof rarely causes catastrophic condensation entirely on its own. More often, an older assembly already has a latent moisture imbalance, and replacing a dark roof with a white one reduces surface temperatures just enough to tip a marginal assembly into failure. The cool roof is the catalyst, not the root cause.

Air leakage and construction moisture

Building scientists emphasize that air leakage (advection) is the dominant moisture pathway, transporting up to 200 times more water vapour than diffusion alone. Two layers of rigid insulation with staggered (offset) joints are recommended by SPRI and NRCA to break the air movement pathway entirely.

Normal-weight structural concrete releases approximately 10 litres of water per square metre of a 100 mm slab. The 28-day cure time is a myth; that metric indicates compressive strength, not dryness. Each 91 kg propane tank burned during winter construction generates roughly 115 litres of water vapour.

Soiling, the algae window, and potato chipping

White roofs do not stay white. Airborne particulates and biological growth reduce solar reflectance by 20 to 50 per cent within the first one to three years. Pressure washing can restore 80 to 90 per cent of reflectivity, but economic analyses consistently show that washing costs ($0.54 to $1.08/m^2) exceed the cooling energy savings recovered ($0.11 to $0.32/m^2). Always use CRRC three-year aged SR values, not the initial factory value, for energy modelling.

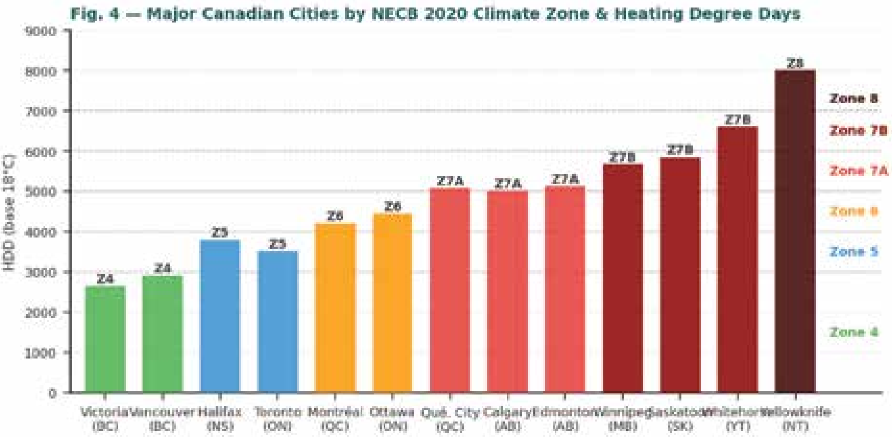
Copper-oxide granules (10 per cent blend) and zinc strips are standard algae remedies; copper ions are 10 times more toxic to algae than zinc.

Collateral damage and the west-wall effect

Reflected solar radiation from a white roof can melt vinyl siding, accelerate masonry parapet deterioration, and create visual hazards. A white membrane installed beneath a highly reflective west-facing glass curtain wall receives a concentrated reflected solar load. While the general roof surface sits at 52°C, the localized zone beneath the wall can spike to 77°C, causing rapid premature heat-aging of the membrane.

5. Urban thermal dynamics: Height, canyons, and the global penalty

The assumption that more white roofs always produce cooler cities is incorrect. A 2024 vertical temperature study in Wuhan found that the surface cooling generated by a white roof is



Major Canadian cities by NECB 2020 Climate Zone and Heating Degree Days (HDD, base 18°C). Zone boundaries: <3,000 HDD = Zone 4; 3,000–4,000 = Zone 5; 4,000–5,000 = Zone 6; 5,000–6,000 = Zone 7A; 6,000–7,000 = Zone 7B; ≥7,000 = Zone 8.

concentrated within approximately 1.5 metres of the surface. By eight metres above the roof, the air temperature difference is statistically negligible.

In a 2014 study, Erell *et al.* demonstrated the urban canyon paradox: in narrow street canyons, high-albedo surfaces lower air temperature slightly but raise mean radiant temperature (MRT), the radiant heat bouncing off white walls and pavements directly onto pedestrians. The net result is a higher physiological equivalent temperature (PET) in a white canyon than a dark one.

The most powerful counterargument to universal cool roof mandates is the 2010 global climate model by Oleson *et al.* (NCAR): universal white roof adoption actually increases total global energy use. In cold climates, white roofs reduce the passive solar heating that partially offsets mechanical heating loads, forcing buildings to burn additional fossil fuel. The space-heating energy penalty exceeds the air-conditioning savings globally.

Because of this, the fuel-cost argument cuts differently than it appears. Natural gas used for heating is approximately 2.5 times cheaper per gigajoule (GJ) than electricity used for cooling. Even in heating-dominated climates, the financial heating penalty is often smaller than the electrical cooling savings, but the carbon penalty may not be, particularly where electricity is grid-decarbonized and heating remains fossil-fuel-dependent.

6. Passive daytime radiative cooling: The next frontier

PDRC materials are engineered to emit longwave radiation specifically at 8 to 13 µm, the atmospheric window where Earth's atmosphere is transparent to outer space. In a 2015 study, researchers demonstrated an outdoor PDRC surface that remained 2°C below ambient under full mid-summer sun, while a standard white cool roof was 13°C above ambient. PDRC removes heat from the urban system entirely rather than redirecting it, delivering two-to-three times the street-level cooling of conventional white roofs. In 2024, Science published a breakthrough extending PDRC coatings to vertical walls, potentially transforming dense urban canyon performance.

7. The Canadian regulatory landscape

Canada does not currently have a national prescriptive mandate for minimum roof solar reflectance. The governing documents are the National Energy Code of Canada for Buildings (NECB 2020) and the National Building Code of Canada (NBC 2020). NECB 2020 sets minimum whole-assembly roof thermal resistance requirements by climate zone, but does not prescribe SR or TE thresholds for roof surfaces. Voluntary programs such as LEED Canada, Green Globes, and the Canada Green Building Council's Zero Carbon Building standard award credits for high-reflectance roof surfaces, providing market incentive without regulatory mandate.

The U.S. experience is instructive. California's Title 24 mandates cool roofs for non-residential buildings (minimum SR 0.70, TE 0.75). Some U.S. municipal codes have moved to eliminate uncoated metal panels and gravel-surfaced BUR. Pushback is growing where building science contradicts blanket policy: in one semi-arid city, a proposed mandate was unanimously rejected after aerial photography of roofs only one to two years old documented rapid reflectance loss from dust and arid conditions. The advocates' modelled savings were based on pristine initial reflectance, a value most roofs in that climate never approach after year one.

The Cool Roof Rating Council (CRRC) remains the primary third-party database for initial and three-year aged SR values across North America. The U.S. ENERGY STAR program for roofing products was retired in June 2022; CRRC is now the standard reference for performance verification.

9. Advanced technologies

NIR "Cool Colours": Military stealth meets building science

Complex inorganic pigments used in NIR 'cool colour' products were derived from U.S. military stealth technology, originally developed as camouflage materials that match the NIR reflectance signature of foliage. Today, that same technology allows a chocolate-brown shingle to shed heat like a white roof, at only two to five per cent additional cost.

Smog-eating TiO_2 tiles

Concrete tiles with photocatalytic TiO_2 coatings use UV radiation to oxidize nitrogen oxide (NO_x) car exhaust into harmless calcium nitrates that wash off in rain. 185 square metres of this tile can oxidize the NO_x produced by a car driven 17,400 kilometres per year. The same TiO_2 chemistry produces hydrophilic self-cleaning action, reducing soiling-related reflectance loss.

The thermeleon: Adaptive phase-change tile

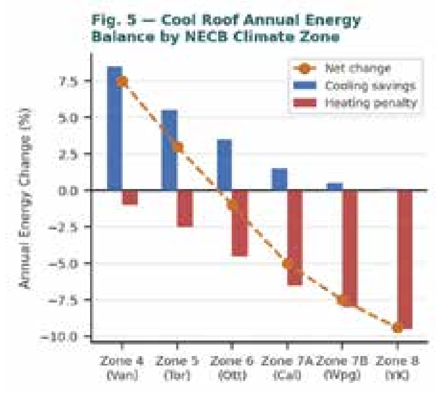
MIT researchers developed a roof tile that solves the cold-climate cool roof dilemma. A polymer dissolved in water and micro-encapsulated against a dark backing transitions based on temperature: cold → stays dissolved, dark backing absorbs heat; hot → condenses into light-scattering droplets, turning the surface white and reflecting 80 per cent of sunlight. A sprayable version is in development.

Green roofs, blue roofs, and vacuum insulation panels

Heavy stone ballast (49–59 kg/m²) over EPDM time-shifts peak heat flux by up to two hours, delivering energy-efficiency benefits virtually identical to highly reflective white single-ply roofs, via an entirely different physics mechanism. Green roofs and smart blue roofs completely shield membranes from UV and sharply cut thermal cycling. Vacuum Insulation Panels (VIPs) achieve RSI-6.3 (R-36) per inch through vacuum-core technology, three-to-four times the performance of standard polyisocyanurate at the same thickness.

10. Specifying with science: A framework for Canadian projects

True sustainability is achieved by treating the roof as a system, not a surface. The following framework synthesizes all the evidence above into actionable specification guidance for Canadian building projects.



Estimated cool roof annual energy balance by NECB Climate Zone. Cooling savings decline sharply as climate severity grows while the heating penalty increases.

Align colour with NECB climate zone. In cooling-dominated climates (NECB Zone 4 and warmer, including coastal B.C.), highly reflective white roofs are the clear specification choice. In heating-dominated climates (NECB Zones 6 to 8, covering the vast majority of Canada), dark roofs promote self-drying and reduce the winter heating penalty. In mixed climates (NECB Zones 5 to 6, applicable to southern Ontario, Québec, and Atlantic Canada), the correct answer depends on building type, insulation level, and vapour control quality.

Prioritize insulation over surface colour. Upgrading insulation to RSI-4.2 (R-24) reduces the cool-roof energy benefit to approximately five per cent. A well-insulated dark roof outperforms a poorly insulated white one. NECB 2020 Climate Zones 7 and 8 require RSI-5.3 to RSI-8.5; at these levels, surface colour has minimal energy impact.

Mandate vapour retarders and offset insulation joints. If white roofing is installed in NECB Climate Zone 5 or colder, which includes virtually all Canadian building sites outside coastal B.C. A continuous Class II vapour retarder on the warm side of the insulation is non-negotiable. Two layers of rigid insulation with staggered joints eliminate the air-leakage pathway.

Specify by aged SR, not initial SR. Use CRRC three-year aged values (typically ~0.55 for white membranes) for all energy modelling. Manufacturer variation can exceed 20 percentage points on the same nominal product.

Use NIR cool colours where dark aesthetics are required. Military-derived inorganic pigments deliver dark visual appearance with white-roof thermal performance at two to five per cent cost premium. Specify copper-oxide granules for algae resistance in humid climates.

Conclusion

The science of roof colour has matured into a sophisticated, multi-variable discipline. White is not always right, and dark is not always wrong. The correct specification is always specific to climate zone, building type, occupancy, insulation level, vapour control detailing, urban geometry, and maintenance economics.

Passive daytime radiative cooling is approaching commercial readiness. Phase-change adaptive tiles are in field trials. Photocatalytic TiO_2 surfaces are deployable today. Specifiers who understand the full evidence base are positioned to deliver assemblies that will outlast, outperform, and out-economize anything a simple colour mandate can produce.

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PRESERVING THE PAST: BUILDING ENVELOPE CHALLENGES IN HISTORIC STRUCTURES

By Gordon Gauvin, Perma Seal Windows & Doors

Gordon Gauvin (B.1956) is the founder and CEO of Perma Seal Windows & Doors Ltd., where he has spent decades advancing evidence-based heritage restoration in Edmonton. Gauvin's heritage approach and commitment to longevity and material integrity is relentless, saving historic wood windows, doors, and architectural elements from the dump using detail-oriented restoration practice rooted in traditional joinery and modern building science. This dedication to heritage began in 1996, when restoration projects solidified a blend of craftsmanship, technical vigour, and respect for architectural history. Today, Gauvin serves heritage through his firm Perma Seal, as a mentor and advocate for owners and stewards of historic structures throughout Edmonton and Alberta.

Introduction

Rehabilitating the building envelope of historic buildings represents a unique intersection of engineering performance requirements and conservation principles. In modern construction, engineers can design assemblies from scratch. In historical projects, though, they have to deal with the limitations of historic materials, building methods, and preservation rules.

The stakes are considerably higher in Alberta's heating-dominated climate, where envelope assemblies are exposed to freeze-thaw cycling, wind-driven moisture, and significant seasonal temperature differentials.

This paper analyzes several of the main technical issues that will be related to heritage building envelope projects using building envelope assemblies with old windows, doors, and wall interfaces, as well as what engineers need to consider in order to achieve a balance between performance and authenticity.

Heritage envelopes were not built to meet today's performance standards

Many of today's heritage building envelopes were built prior to the establishment of many of the current code requirements for thermal and air barrier and moisture control.

Assemblies were typically designed to be vapour permeable (to allow moisture vapour to escape), built using thermal mass rather than insulation, and designed to be ventilated (to allow air infiltration). While these assemblies have shown to be durable over long periods of time, they were not designed to meet the performance goals of the current day, including air leakage and thermal performance. Their performance depended largely on the ability of building materials to absorb and release moisture, allowing assemblies to dry over time rather than completely preventing moisture entry.

A common mistake during retrofits is applying modern envelope strategies, such as highly restrictive vapour barriers or excessive sealing, without considering how historic assemblies manage moisture. When drying potential is reduced, moisture can become trapped within the assembly, increasing the risk of wood rot, corrosion, or masonry deterioration.

For this reason, engineers must evaluate not only energy performance targets but also how retrofit interventions interact with the building's existing hygrothermal behaviour.

Why failures often occur when modern assumptions are applied to heritage buildings

Engineers frequently observe failures in historic building envelopes when modern performance assumptions are applied without considering the behaviour of legacy materials. Many heritage wall assemblies in Western Canada were constructed using masonry constructed with lime mortar and other vapour-open materials, which allow moisture to move and dry through diffusion and capillary action. When modern retrofit strategies introduce low-permeability membranes or rigid insulation systems, the vapour resistance (μ-value) of the assembly can increase significantly. In Alberta's heating-dominated climate, this change can shift condensation planes and reduce drying potential, leading to moisture accumulation within wood interfaces or masonry substrates.

Window systems as important envelope interfaces

From a building envelope perspective, window and door openings represent concentrated zones of thermal discontinuity, structural irregularity, and potential moisture risk, particularly in historic construction.

From an engineering standpoint, the challenge lies in balancing:

- thermal performance
- controlling air leaks
- stability of the structure
- preserving historic profiles

Historic assemblies often relied on the tolerance and flexibility of traditional materials rather than tightly controlled interfaces. Consequently, openings in walls can also experience settlement-related distortion, irregular framing and inconsistent support conditions.

Common issues seen with retrofits include:

- out-of-level openings due to settlement or long-term movement in the structure
- inconsistent flashing/drainage planes
- conflicts between existing framing and new wall membranes on the interface between the two surfaces

Because of these factors, retrofit strategies frequently require project-specific interface detailing rather than standardized assemblies. In many cases, improving interior air sealing while maintaining effective exterior drainage paths provides a more compatible approach than attempting to fully replace historic assemblies.

For engineers, the key consideration is recognizing that overall performance is determined by the interface detailing between components, rather than the individual product elements alone.

Managing moisture risk and vapour behaviour in retrofit conditions

Moisture control in heritage building envelopes is very different from that in new buildings.

Historic masonry structures that are made with lime mortar, and vapour-permeable materials, tend to have a fairly low vapour density (μ-value) in relation to modern membranes, which allows for the ability to allow vapour diffusion and rainfall to evaporate in all directions. The introduction of materials that have considerably higher vapour resistances disrupts this balance and may cause the condensation plane to be located on the more vulnerable portion of the substrate.

The simplified diagram below illustrates how vapour diffusion and drying behaviour change when interior insulation and vapour-resistant layers are introduced into a historic masonry wall assembly.

This change affects vapour diffusion rates and can significantly reduce the drying potential of assemblies that historically relied on multi-directional moisture transport.

Historically, these assemblies relied on multi-directional drying through vapour diffusion and capillary transport. When engineers introduce new impermeable layers, such as foam insulation or synthetic membranes, the drying path may be affected.

Some common reasons for failure are:

- condensation between the new insulation and the wall
- moisture building up at the wood-masonry joints
- moisture that was trapped in old wall cavities

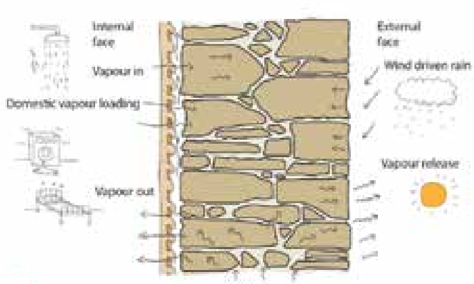
Hygrothermal modelling can be useful, but it needs to be backed up with site investigation. Before concluding retrofit solutions, it is typically required to take samples of the materials, measure the moisture content, and look at the current ventilation channels.

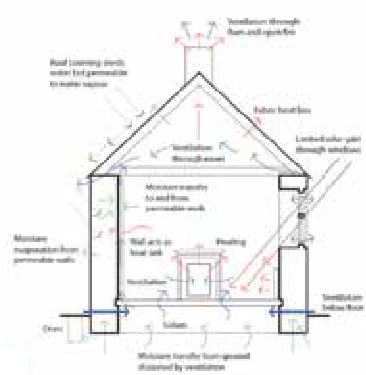
Successful heritage projects often focus on controlled drying potential and durability instead of trying to achieve theoretical airtightness.

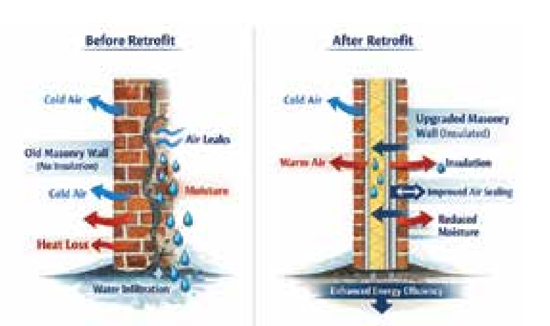
Structural movement and interface tolerances

Heritage structures frequently exhibit conditions such as:

- settlement of the foundation
- seasonal structural movement
- variance in the size of wood parts







As a result, rigid installation methods may introduce stress concentrations, leading to sealant failure, cracking, or loss of air and water continuity over time.

Engineers should consider:

- sealants with appropriate movement capability
- adjustable installation systems for window frames
- tolerance allowances in flashing and interface components

Structural assessment is sometimes needed before envelope work can start when masonry or heavy timber is involved. Installing high-performance assemblies into structurally unstable openings often leads to premature system failure.

Limits on conservation and trade-offs in engineering

Performance goals are not the only thing that controls heritage projects. Conservation rules typically limit:

- replacement of original materials
- change in the way the facade looks
- changing the patterns or profiles of the glass

These constraints introduce unavoidable trade-offs during design and implementation.

For example, achieving full triple-glazed thermal performance may require modifying original sash dimensions. Similarly, adding exterior insulation may not be permitted if it alters façade depth, proportions, or historic detailing.

In heritage contexts, engineering judgment often prioritizes optimized performance within system constraints rather than maximum theoretical performance. Incremental improvements in airtightness, drainage management, and material durability can often deliver greater long-term value than aggressive upgrades that conflict with the behaviour of the existing assembly.

The value of working together across disciplines

Most of the time, successful heritage envelope initiatives don't depend on just one field. Instead, they require coordinated collaboration among:

- experts in restoration
- architects who work on conservation
- experienced tradespeople familiar with historic materials

Engineering analysis must take into account the realities of craftsmanship, and judgments for restoration must take into account the long-term effects on building science.

Working together early usually leads to:

- fewer construction-stage changes
- more durable assemblies
- better congruence between goals for conservation and performance

Conclusion

Heritage building envelope projects require engineers to rethink conventional approaches. Instead of designing for perfect conditions, these projects have to work with the materials that are already there, the old ways of building, and the rules for conservation.

In regions such as Alberta, where the climate imposes heavy thermal and moisture loads on building envelope components, making incorrect decisions can have a significant impact on the overall performance of the building. To be successful at preserving buildings and improving their performance, it is important to understand that these two objectives are not mutually exclusive; rather they are interrelated.

Many heritage buildings can be preserved through the application of engineering principles that consider both the mechanics of how the structure operates, as well as an in-depth knowledge of the historical details of its construction. This will help ensure that these buildings continue to function properly, are structurally sound, and are energy efficient for many years to come.

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TRANSITIONS, NOT WORKERS, DRIVE CONSTRUCTION INJURY CLAIMS

Safety risk on construction sites does not increase evenly over time. It tends to rise during periods of change—when workers move to a new employer, join a different crew, or step onto an unfamiliar worksite. In a sector where projects involve multiple contractors, workers face these transitions frequently.

According to the Workers' Compensation Board (WCB) - Alberta data, more than half of construction injury claims involve workers in their first year with a company. The trend appears across all age groups and experience levels. Even seasoned tradespeople may still be adjusting to a new site's routines, equipment, supervision styles, and expectations.

The most frequently reported injuries during this period involve workers being struck by objects or experiencing back strains. Falls to lower levels remain the costliest incidents, with ladders involved in nearly half of those claims.

Although injuries most often affect workers in their 20s and early 30s, claims data show the pattern extends across all age groups. The common factor is transition — not age or experience.

What crews see and what works

Conversations with new and returning workers point to a clear pattern: time pressures limit pre-job briefings and supervision, and crew cultures can normalize unsafe shortcuts. On worksites with multiple contractors and overlapping responsibilities, those pressures intensify.

The consistent message from crews is that early supervision and clear expectations matter most — and that safety improves when leaders reinforce safe habits from the start.

"What the data shows is that risk is tied to timing rather than the worker," says Mark Hoosein, CEO of the Alberta Construction Safety Association. "When someone is new to a company or job site, the way expectations are communicated and reinforced early on can have a real impact on safety outcomes."

The ACSA's 2026 campaign is built around that principle—starting with the Safety Showdown contest, which invites crews to put their safety knowledge into practice. In 2025, more than 500 workers across 150 crews took part in the contest, with expanded team-based activities planned for 2026.

What reduces first-year injury risk

First-year worker safety improves when leaders and crews treat the early months as a planned risk window, not an informal ramp-up. Small, consistent actions during transition make the biggest difference.

- ***Supervisors and managers:*** Set expectations on day one and correct techniques before unsafe shortcuts develop. Use the ACSA's first-year resources at firstyear.yourACSA.ca, including the New Worker Orientation: Leaders Guide to structure early conversations.
- ***Experienced workers:*** Encourage questions and step in early when something looks off, especially during a new crew member's first week on site.
- ***Trainers:*** Reinforce learning on-site and adjust coaching as conditions change. Ensure new and returning workers have completed the ACSA's Construction Safety Training System (CSTS), available free at yourACSA.ca/courses.
- ***Health and safety representatives:*** Use the ACSA's Activity Tracker to log IPC activities, including Safety Showdown participation and use of first-year resources as part of the company's COR or SECOR maintenance year action plan.
- ***Crews:*** Reinforce expectations daily and speak up about small issues early. Consider entering the Safety Showdown contest to build team engagement around safety habits.

When employers and crews treat the first year as a planned priority, accountability improves and injury risk declines.

Recognizing safety leadership

Companies and crews already embedding these practices into their first-year approach are exactly who the ACSA's Safety Excellence Awards recognize. The awards honour employers, crews, and safety leaders building strong safety foundations across the industry. Apply or submit an entry before the May 29 nomination deadline. Learn more at yourACSA.ca/safety-excellence-awards.

Get involved

During Safety and Health Week (May 4–8, 2026), the ACSA will bring Crew Brew to job sites across Alberta. Learn more at yourACSA.ca/crewbrew. The Safety Showdown online contest returns in 2026. Crews can win daily gift cards, weekly team lunches, and a grand prize luxury suite at a Calgary Flames or Edmonton Oilers regular-season game. Subscribe at firstyear.yourACSA.ca to stay updated. ■

The first year doesn't have to be the riskiest. Start at firstyear.yourACSA.ca.

Alberta Construction Safety Association™

ENERGY, COMFORT, & PERFORMANCE

WHY GLAZING DESIGN MAKES OR BREAKS HIGH-PERFORMANCE BUILDINGS

By Mark Estrada, window expert with Centra Install Pros

From an energy perspective, high-performance glazing improves U-values and can help manage solar gains to meet NECB prescriptive or energy modelling compliance paths.

In cold climates like Alberta's, glazing decisions strongly influence whether high-performance buildings actually deliver on comfort and energy performance. While energy models often use centre-of-glass values and emphasize compliance targets, real-world outcomes are driven by detailing, installation, and how glazing interacts with the rest of the enclosure and the mechanical systems.

I've seen buildings that technically meet aggressive modelled targets under the National Energy Code for Buildings (NECB) and the Alberta Building Code but still struggle with winter discomfort near windows, shoulder-season overheating, and mechanical systems that never seem to operate in their "sweet spot". The common thread is almost always the same: glazing strategy, detailing, and integration with enclosure and mechanical design weren't aligned.

Here's why treating glazing as part of an integrated design strategy rather than a late-stage product specification significantly improves both occupant comfort and building performance.

Energy efficiency vs. comfort: The glazing disconnect

From an energy perspective, high-performance glazing improves U-values and can help manage solar gains to meet NECB prescriptive or energy modelling compliance paths. From a comfort perspective, glazing controls radiant temperature, radiant asymmetry, and downdrafts, factors that show up in occupant complaints long before anyone looks at the energy dashboard.

Common issues we see on Alberta projects include:

- Cold interior glass surface temperatures at large, glazed areas on winter nights, pulling down operative temperature even when air temperature meets design setpoints (ASHRAE 55 / ISO 7730 comfort targets are technically met on paper, but occupants still report "feeling cold")
- Frame and edge-of-glass losses significantly underperform relative to centre-of-glass values used in NECB compliance models
- Radiant temperature asymmetry near curtain wall and spandrel interfaces, especially at slab-edge conditions in mid-rise multi-family and office buildings

Occupants respond in predictable ways: bumping thermostats, adding space heaters, or blocking diffusers. The model says the building is efficient; the people inside make it inefficient just to stay comfortable.

The performance gap: Modelled glazing vs. as-built reality

Energy models typically rely on centre-of-glass U-values and idealized installation assumptions to demonstrate compliance with NECB or the Alberta Building Code. In the field, glazing performance is dominated by details.

Energy models typically rely on centre-of-glass U-values and idealized installation assumptions to demonstrate compliance with NECB or the Alberta Building Code.

On real projects, the biggest gaps usually come from:

- Thermal bridging at slab edges, shelf angles, anchors, and window-to-wall interfaces, especially in concrete buildings
- Air leakage at rough openings and curtain wall transitions that can dominate infiltration, even when the overall enclosure tests well
- Curtain wall performance in the field that doesn't match lab-tested assemblies due to tolerances, sequencing, and trade coordination

Infrared thermography and enclosure commissioning in cold Alberta winters make this painfully visible. Window perimeters and spandrel transitions light up as dominant heat-loss pathways. Without project-specific thermal modelling of façade details and verification through whole-building blower door testing and enclosure commissioning, the "high-performance glazing" narrative stays optimistic on paper and disappointing in practice.

Heat pumps, peak loads, and glazing-driven demand

Glazing strategy drives peak heating and cooling loads, which in turn dictate heat pump sizing, in designs that increasingly are electrified designs to align with net-zero and decarbonization goals.

Large, glazed areas increase winter peak losses in Alberta design conditions and drive summer peak gains during shoulder seasons when solar angles are low and shading is often ineffective.

That creates a few predictable problems:

- Heat pumps sized for glazing-driven peaks spend most of the year cycling at part-load, hurting the seasonal performance

Glazing is not just an architectural feature or compliance checkbox. It is one of the most influential elements in determining real-world building performance.

- Cold surfaces near glazing trigger setpoint overrides that undermine electrification efficiency gains
- Solar gains through east- and west-facing glazing create short-duration cooling peaks that exceed system capacity, particularly in spring and fall

Without coordinated façade and mechanical design, high-efficiency heat pumps end up compensating for façade-driven comfort problems they were never meant to solve.

Solar gains, glazing ratios, and overheating risk

As wall and roof insulation levels improve to meet or exceed NECB and Alberta Building Code requirements, glazing becomes the dominant pathway for heat gain. High window-to-wall ratios, especially on east and west façades, are a consistent source of overheating risk on high-performance projects.

Key factors that matter in practice:

- SHGC selection by orientation (one SHGC value for all façades is almost always a compromise)
- Exterior shading effectiveness versus interior blinds, which do nothing to stop solar heat from entering the space
- The interaction between glazing areas, thermal mass, and ventilation strategies

Triple glazing with low SHGC reduces heat gain but does not magically solve solar-driven overheating. Dynamic energy and comfort modelling that accounts for Alberta solar geometry, shading devices, and internal gains is increasingly necessary if comfort is a real project goal and not just a line in the sustainability brief.

Is "Net Zero Ready" compatible with glazing-dominant design?

"Net Zero Ready" and low-energy targets, increasingly referenced in Canadian policy frameworks and municipal programs, often push designs toward aggressive glazing ratios to capture daylight and modelled passive gains. In Alberta's climate, that strategy carries real performance risk:

- More frequent overheating and higher cooling energy use
- Larger peak loads and oversized mechanical systems
- Greater sensitivity to occupant behaviour and shading use
- Higher façade costs with diminishing real-world performance returns

Dialling back glazing ratios and investing that budget into better thermal detailing, exterior shading, and airtight installation can deliver more reliable performance than maximizing glass area ever can.

Ultimately, glazing is not just an architectural feature or compliance checkbox. It is one of the most influential elements in determining real-world building performance.

When façade design, thermal detailing, solar control, and mechanical system sizing are coordinated early, buildings are far more likely to achieve both the energy targets predicted in models and the comfort occupants expect. In Alberta's climate, high-performance buildings succeed not because they have more glass or better glass, but because glazing strategy is treated as a core part of the building performance conversation from the start. ■

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