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Window Installation Quality as a Key Factor in Durability and Operational Efficiency: A Feasibility Study

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ABSTRACT

The performance of window systems in contemporary buildings is influenced not just by their material attributes but also primarily by the quality of their installation. This work examines window installation as a critical element that affects system thermal performance, airtightness, acoustic insulation, moisture resistance, and long-term economic performance. By using recent empirical, experimental, and numerical research, this paper examines how the installed defects at the window - wall interface contribute to thermal bridging, air leakage, and moisture ingress, resulting in decreased system durability and performance. The study introduces a model called the Integrated Window Installation Performance Model (IWIPM). It defines installation quality as the multidimensional variable that connects execution exactness with performance outcomes and interface fidelity and environmental interaction. After an orderly literature review, the research shows that improper installation not only reduces energy efficiency but also increases long-term consequences like structural deterioration and inflated maintenance costs. The findings show how installation quality serves as a performance booster: both near-term technical results and efficiency of cost-effectiveness over the course of a life cycle are influenced in turn by its impact. The paper argues that installation is something that should be seen as a critical engineering process rather than a procedural step, integrating it clearly within design, construction, and quality control.

KEYWORDS

window installation quality, building envelope performance, thermal bridges, airtightness, acoustic insulation, moisture ingress, lifecycle cost, energy efficiency, construction defects, Integrated Window Installation Performance Model (IWIPM).

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Якість встановлення вікон як ключовий фактор довговічності та експлуатаційної ефективності: техніко-економічний аналіз

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СТАТТЯ

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АНОТАЦІЯ

На продуктивність віконних систем у сучасних будівлях впливають не лише їхні матеріальні характеристики, а й, перш за все, якість їх встановлення. У цій роботі розглядається встановлення вікон як критичний елемент, що впливає на теплові характеристики системи, герметичність, звукоізоляцію, вологостійкість та довгострокові економічні показники. Використовуючи останні емпіричні, експериментальні та числові дослідження, у цій статті розглядається, як встановлені дефекти на межі вікна та стіни сприяють утворенню теплових містків, витоку повітря та потраплянню вологи, що призводить до зниження довговічності та продуктивності системи. У дослідженні представлено модель під назвою «Інтегрована модель продуктивності встановлення вікон» (IWIPM). Вона визначає якість встановлення як багатовимірну змінну, яка пов'язує точність виконання з результатами продуктивності, точністю взаємодії та взаємодією з навколишнім середовищем. Після впорядкованого огляду літератури дослідження показує, що неправильне встановлення не тільки знижує енергоефективність, але й збільшує довгострокові наслідки, такі як структурне погіршення та завищені витрати на обслуговування. Результати показують, як якість встановлення служить підсилювачем продуктивності: як короткострокові технічні результати, так і економічна ефективність протягом життєвого циклу, у свою чергу, залежать від її впливу. У статті стверджується, що встановлення слід розглядати як критичний інженерний процес, а не як процедурний крок, чітко інтегруючи його в проєктування, будівництво та контроль якості.

КЛЮЧОВІ СЛОВА

якість встановлення вікон, характеристики огороджувальних конструкцій будівлі, теплові містки, герметичність, звукоізоляція, проникнення вологи, вартість життєвого циклу, енергоефективність, будівельні дефекти, інтегрована модель продуктивності встановлення вікон (IWIPM).

1. Introduction

Performance of building envelopes is a central concern for construction that has increased due to a high demand for energy efficiency, indoor comfort, and long-term durability. Windows, a major part of the envelope, serve two purposes: daylighting and ventilation and could serve as potential weak points in thermal, acoustic, and moisture protection systems. Although major improvements have been achieved in glazing, frame materials, and insulation systems, the result of window installation in real-world conditions may not meet expectations in practice. An increasing number of studies suggest that differences are not primarily about materials but installation quality.

The window–wall interface is an intricate junction for different physical processes of heat transfer, air movement, sound transmission, and moisture migration, as they occur concurrently. According to studies, improper installation at this interface exhibits thermal bridging, air leakage, and moisture ingress that affect the construction [1; 8], which have significant implications for the building performance.

From a thermal aspect, the installation technique contributes to the continuity of the insulation layer, as installation quality is essential for heat transfer and relates to good thermal behavior. Even high-performance window systems may have substantial energy losses if not properly positioned or sealed [5; 11]. Airtightness, another critical aspect for energy saving, is also very sensitive to proper placement and joint precision, particularly when environmental conditions can be inconsistent [7; 18].

The performance of the acoustic component additionally highlights the necessity of the integrity of all the installations. Studies have shown that sound insulation relies not only on glazing systems but is also a function of joint quality: small gaps may be conducive to providing effective transmission paths for noise [2; 12]. At the same time, moisture management is another significant concern due to possible water ingress, condensation, and material degradation due to inadequate sealing and incorrect interface design (Fig. 1) [4; 9].

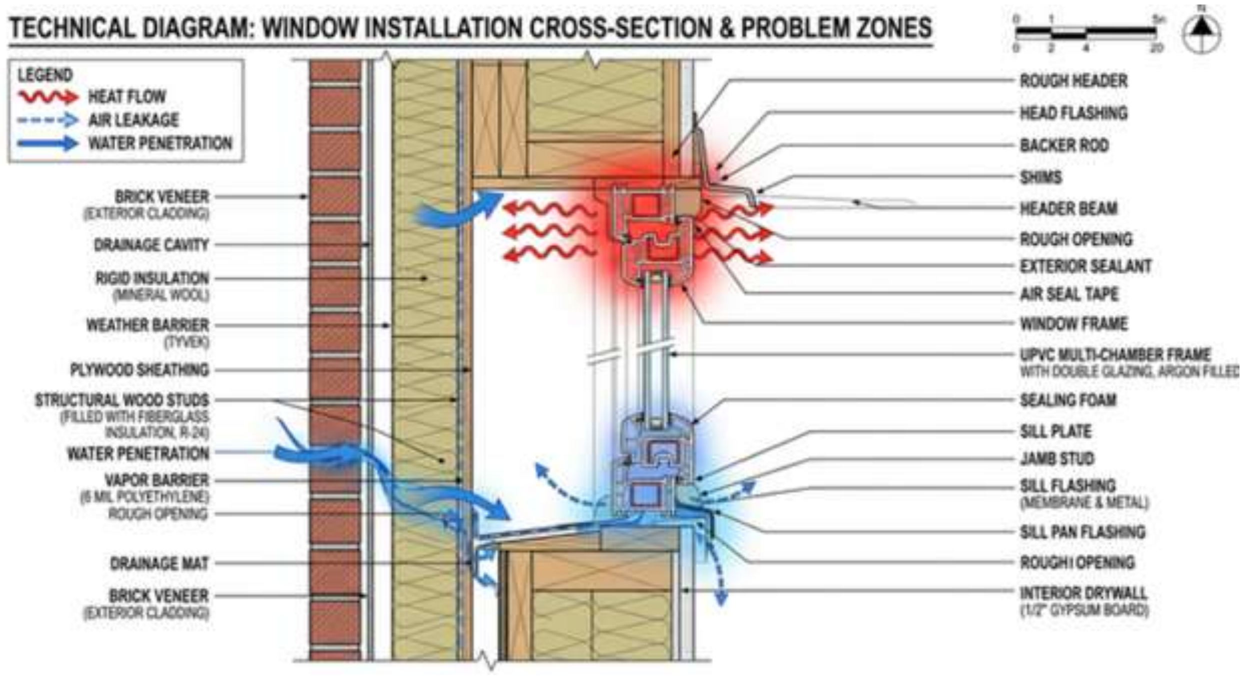

Figure 1. Window–Wall Interface & Defect Zones

Source: Built by the author.

In addition to technical effectiveness, the economic effects of quality installation can also be significant. Poor installation reduces the effectiveness of energy-efficient solutions, increases operational costs, and leads to expensive repairs over the building lifecycle [6; 19]. These consequences undermine the usual industry tendency to relegate installation as a secondary phase of construction, often subjected to cost minimization rather than quality optimization.

The present research attempts to fill this gap by examining window installation quality as a fundamental parameter for the building's performance. It introduces the Integrated Window Installation

Performance Model (IWIPM) – a conceptual framework that links installation precision, interface integrity, and environmental interaction to both technical and economic outcomes. Through an integrated examination, drawing on current literature, and author-driven approach, this paper seeks to re-situate installation within the construction process as an issue of critical engineering concern for sustainable building production.

2. Literature Review

2.1. Thermal Performance and the Role of Installation Geometry

The thermal performance of window systems is strongly dependent on the quality of installation, particularly at the window–wall interface. This junction has been consistently identified as one of the most critical zones for heat loss due to the formation of thermal bridges. Using a model-based thermography method, Choi et al. demonstrated that dynamic thermal bridges at window-wall joints significantly increase localized heat transfer, even when high-performance materials are used [1]. These findings are supported by experimental investigations from Moumtzakis et al., who showed that heat transfer through window frame elements and installation gaps can exceed expected design values due to imperfect installation conditions (Fig. 2) [11].

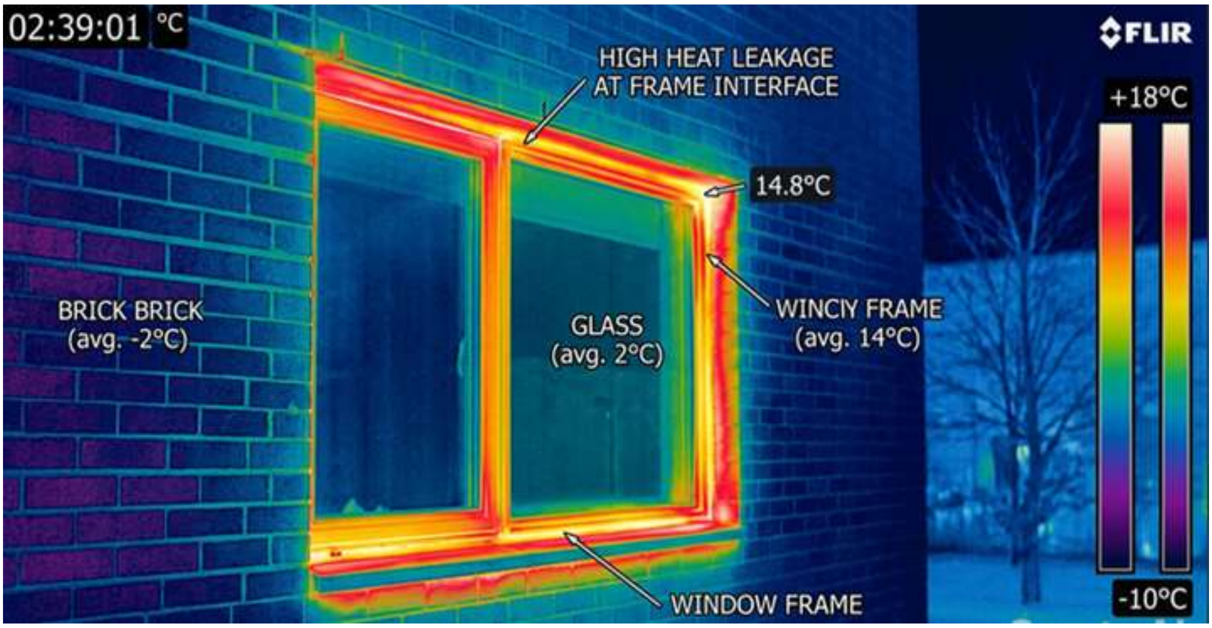

Figure 2. Heat Loss Distribution around Installation Joint
Source: Built by the author.

To further validate this, Qin et al. (2024) investigated the thermal characteristics of window-wall interfaces in renovation projects and concluded that inadequate integration generates substantial deviations from expected energy performance [15]. In a similar vein, Petresevics and Nagy indicated from an FEM-based analysis that the fastening systems and connection points of the façade structures have implications for point thermal transmittance, an effect that is aggravated when the accuracy of the installation is low [14].

Recent advances in optimization modeling allow you to have greater insights into how installation decisions affect thermal performance. Gendelis et al. indicated that the location of windows in the insulation layer greatly influences thermal bridging, finding installation location to be an important optimization variable [5]. Shah et al. also highlighted that for buildings with continuous external insulation, improper window installation prevents the continuity of the thermal envelope, thereby reducing the overall energy efficiency behavior [16].

From a retrofit point of view, Evola et al. and Oh et al. both demonstrated that energy-efficient window solutions can only perform as intended if installation is performed correctly [3; 13]. Moghaddam et al. likewise found that retrofit technologies, including low-emissivity films, offer less benefit if heat losses related to the installation are not controlled [10]. On an economic scale, Hou et al.

have also observed that the influence of thermal parameters, including those that are related to how well an insulation is installed, greatly impacts the economics of insulation investments [6]. Taken together, these works illustrate that the installation is not only an implementation stage, but also an indicator of the thermal performance of the system.

2.2. Airtightness and Energy Efficiency Stability

Airtightness is also an important parameter related to installing quality, determining energy consumption and the comfort of the interior. Kysela et al. investigated the airtightness of critical joints of a timber-based construction and reported that installation precision is a key determinant of air barrier cohesion [7]. Their results also suggest that seasonal conditions could amplify the effects of installation errors but gradually compromise airtightness as time goes on.

Tombarević et al. used a residential case study to present empirical evidence that window replacement increased airtightness and decreased energy consumption only when the installation was done properly [18]. By way of contrast, when installation was poor, performance was not much improved, or worse. Shah et al. further emphasize installation quality as a determinant of energy efficiency who found installation errors to be one of the leading factors restricting the performance of continuous insulation systems [16].

Similarly, Oh et al. stated that retrofit technologies for reducing heating needs are highly sensitive to installation, since air leakage may cancel out potential energy savings [13]. These results are consistent with widespread findings by Yoon et al., who highlighted that construction defects, much of which arise from installation processes, should be systematically controlled to achieve performance consistency [19].

Collectively, these evidences suggest that airtightness is not only a design factor, but rather a function of the installation implementation and long-term interaction with the environment.

2.3. Acoustic Performance and Installation Integrity

The acoustic characteristics of window systems are typically compared using material properties, but studies demonstrate that installation quality is equally relevant. Caniato et al., according to the numerical evaluation of façade systems, found that sound insulation performance is very sensitive to joint conditions [2]. Even slight differences in installation can dramatically reduce acoustic attenuation. Nurzyński extended the analysis to wood-frame façades and showed that poorly sealed window joints serve as acoustic leakage paths, limiting the total acoustic insulation of the building envelope [12].

In urban settings, these results become particularly important. In building performance, noise control is also vital to the system. Furthermore, it is worth mentioning that acoustic and thermal behavior interact. This is why, as pointed out by Tabet Aoul et al., have shown that defects detected by infrared thermography commonly have their origins in thermal inefficiency and acoustic leakage, illustrating that installation quality influences multiple aspects of performance at the same time [17].

This literature indicates that acoustic shortcomings often arise as a consequence of insufficient installation procedures rather than through a limitation of materials. Thus, a full assessment of window performance needs to include installation integrity as an essential variable.

2.4. Moisture Behavior and Hygrothermal Risks

Moisture ingress is one of the most severe consequences of poor window installation, with long-term implications for structural durability and indoor environmental quality. Lopez-Carreon et al. identified the building envelope as the most important conduit of the penetration, with installation faults greatly driving moisture penetration risk [8]. Sealing inadequacies and ineffective drainage systems makes water build up inside, eventually causing deterioration of materials.

Friis et al. studied hygrothermal conditions and reported moisture challenges in residential façades and concluded that moisture-related problems are substantially influenced by joint design and installation quality [4]. Their findings emphasize the fact that even well-preserved façade systems may not work in actual environmental scenarios if installation is not performed properly.

Mattsson et al. explored water damage in the context of building systems in more comprehensive dimensions and observed that a large percentage of such damage is caused by construction and installation defects [9]. This is especially important in window installations, because the interface between materials with different properties makes this a high-risk zone.

Other information is given by Tabet Aoul et al., who used thermographic diagnostics to detect envelope defects, demonstrating that moisture storage frequently occurs at the same time as thermal anomalies [17]. This again affirms the joint relationship of installation-related failures due to moisture, thermal, and airtightness failures at the same time.

These insights highlight the need for a structured approach to moisture conservation in the installation process, as excessive moisture levels in one part of the installation can cause long-term damage at a high cost to the owner.

2.5. Synthesis and Research Gap

From all studies reviewed, one consistent trend appears: window installation quality as a key driver in determining thermal efficiency, airtightness, acoustic performance, moisture resistance, and economic performance. However, the literature is still fragmented, and most of the studies analyze the performance of single items instead of taking an integrated perspective (Table 1).

Table 1. Summary of Literature and Key Findings

Author(s)	Focus Area	Key Variable	Main Finding	Relevance to Installation
Choi et al. (2022)	Thermal bridges	Interface geometry	Significant heat loss at joints	Installation defines thermal behavior
Caniato et al. (2020)	Acoustics	Joint conditions	Sound insulation reduced by gaps	Installation integrity critical
Evola et al. (2022)	Energy retrofit	Envelope integration	Performance depends on execution	Installation affects retrofit success
Friis et al. (2023)	Hygrothermal	Moisture conditions	Joint quality affects moisture risk	Installation impacts durability
Gendelis et al. (2026)	Thermal optimization	Window position	Placement reduces heat loss	Installation is a design variable
Hou et al. (2023)	Economic analysis	Thermal variation	Impacts cost efficiency	Installation affects ROI
Kysela et al. (2023)	Airtightness	Joint sealing	Seasonal degradation observed	Installation affects stability
Lopez-Carreon et al. (2025)	Moisture ingress	Envelope defects	Water penetration at joints	Installation drives risk
Mattsson et al. (2024)	Water damage	Construction defects	High repair costs	Installation errors are critical
Moghaddam et al. (2021)	Retrofit energy	Window performance	Reduced benefit with poor install	Installation affects outcomes
Moumtzakis et al. (2022)	Heat transfer	Frame elements	Increased heat flow at gaps	Installation precision needed
Nurzyński (2023)	Acoustic leakage	Joint sealing	Sound transmission increases	Installation quality essential
Oh et al. (2025)	Energy retrofit	Implementation quality	Dependent on installation	Installation impacts efficiency
Petresevics & Nagy (2022)	Thermal transmittance	Fastening systems	Point losses increase	Installation detail critical
Qin et al. (2024)	Interface analysis	Window-wall junction	High heat transfer risk	Installation integration key
Shah et al. (2024)	Insulation systems	Envelope continuity	Disruption reduces efficiency	Installation breaks continuity
Tabet Aoul et al. (2021)	Thermal defects	Envelope diagnostics	Defects at joints identified	Installation is main cause
Tombarević et al. (2023)	Airtightness	Window replacement	Improved only with good install	Installation determines results
Yoon et al. (2021)	Defect management	Construction errors	Early correction reduces costs	Installation control essential

Source: Formed by the author.

Thermal bridging, air leakage, and moisture ingress have been empirically investigated, but no structural framework connects these elements by installation quality as a system-level variable. This gap emphasizes the significance of an integrated analytical method, which this study seeks to address using the Integrated Window Installation Performance Model (IWIPM).

2.4. Economic Implications of Installation Quality

The economic consequences of window installation quality extend throughout the building lifecycle, influencing both operational costs and maintenance requirements. Hou et al. demonstrated that thermal inefficiencies caused by installation defects significantly reduce the economic benefits of insulation investments, increasing energy consumption and prolonging payback periods [6].

Moghaddam et al. similarly found that energy retrofit measures yield optimal results only when installation quality is ensured [10]. Without proper installation, the expected energy savings from advanced technologies are substantially reduced.

From a construction management perspective, Yoon et al. emphasized the importance of integrated defect management systems, noting that early detection and correction of installation errors can significantly reduce overall project costs [19]. This aligns with the findings of Mattsson et al., who highlighted the high costs associated with water damage repairs, often resulting from installation-related failures [9].

Evola et al. and Oh et al. further demonstrated that the success of energy-efficient retrofit strategies depends not only on material selection but also on the quality of installation [3; 13]. Poor execution can undermine the entire economic rationale of such interventions.

Overall, the literature indicates that installation quality has a direct and measurable impact on economic performance. Initial cost savings achieved through reduced installation quality are often offset by increased operational expenses, maintenance costs, and reduced system lifespan.

3. Problem Statement

This work examines window installation as a critical element that affects system thermal performance, airtightness, acoustic insulation, moisture resistance, and long-term economic performance.

4. Methods and Materials

A qualitative-analytical research design was taken in this study based on a systematic overview of the previous empirical, experimental, and numerical literature pertaining to window installation results. Instead of adhering to pure descriptive reviews, this study focuses on the design of an author-driven analytical framework explaining the logic behind the effect of installation quality on building envelope efficiency at the system level. The proposed research relies solely on the selected literature, characterized by thermographic analytics, FEM, hygrothermal simulations, acoustic studies, and case-based evaluations. These sources were methodically and systematically analyzed using comparative methodology to identify recurring causal relationships between installation parameters and performance results in thermal, acoustic, and moisture domains.

Central to the method of this research is the development of the Integrated Window Installation Performance Model (IWIPM). This model, developed through a methodical literature review and iterative cross-analysis, aims to conceptualize installation not as a mechanical process but as a multidimensional engineering parameter.

The IWIPM comprises three interrelated analytical layers.

- Installation Precision Layer – geometric placement in the insulation zone, its geometrical alignment, and sealing precision. This stratification details how variations in design lead to major issues like thermal bridges and routes of air leakage.

- Interface Integrity Layer – focuses upon the continuity of thermal insulation, airtightness barriers and moisture protection systems. This is the layer under which the impact of installation quality is realized - the functional connection between window and enveloping wall components of the building.

- Environmental Interaction Layer – adjusts for external influence factors, including temperature effects, humidity, wind pressure, and acoustic load. This layer adds a dynamic aspect to the view, highlighting that the installation performance changes over time in operation under the field. With this element, in-situ performance of the solution is enhanced and considered.

A methodological analysis map of the literature of these three levels was performed in order to establish cause-and-effect relations. A possible example is improper positioning (Layer 1) that creates barriers to insulation continuity (Layer 2) and, on the basis of climatic variables change (Layer 3) leads to thermal degradation, condensation and long-term deterioration.

The work also offers an analytical link from technical performance and economic consequences, considering energy lost, the interval of maintenance, and lifetime costs in the framework. As a result, the IWIPM can serve as a tool not only to describe technical aspects of installation, but can also support decision-making on how to determine the quality of installations in economic terms. On a macro level, this approach allows an approach to moving on from performance piecemeal analysis to system-oriented interpretation, where installation quality emerges as a primary variable tying engineering realization together with longevity of the building and the ability to save costs (Fig. 3).

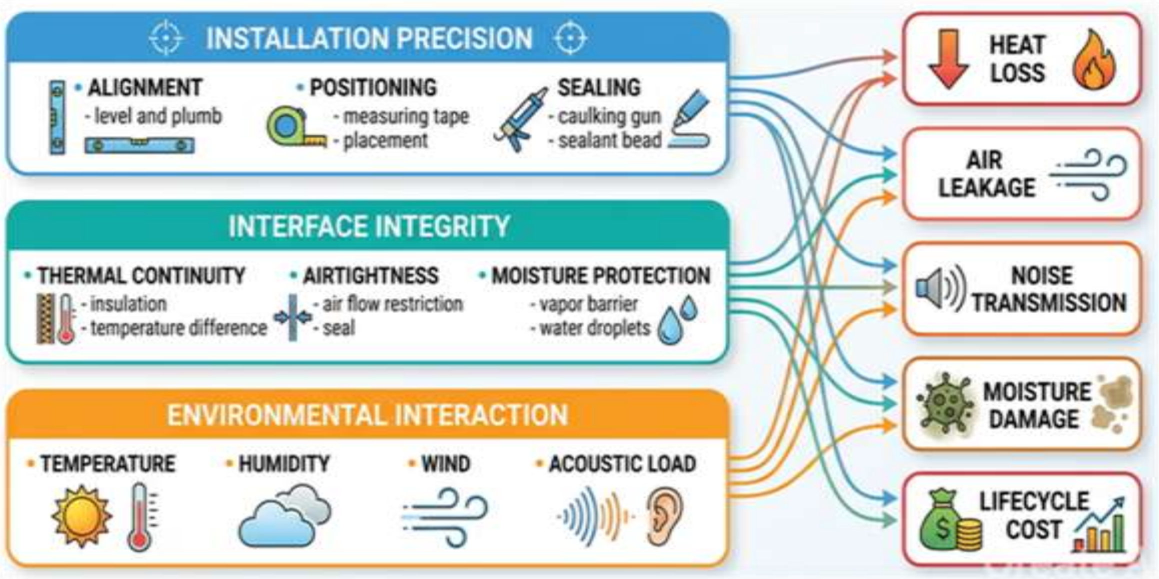

Figure 3. Integrated Window Installation Performance Model (IWIPM)
Source: Built by the author.

5. Results and Discussion

The results further validate that window installation quality performs as the essential control variable in the performance of the building envelope in all thermal, acoustic and hygrothermal terms. The results showed that by viewing them through the Integrated Window Installation Performance Model (IWIPM), the deviations produced during installation are systematic and propagate through the layers of performance rather than producing isolated defects.

From a thermal perspective, the results show that the accuracy of installation will be critical in shaping and distributing the magnitude and distribution of thermal bridges. Improper placement of the window unit in relation to the insulation layer consistently contributes to the increased heat transfer in the interface zone, confirming that installation geometry also has as much influence on heat transfer as material properties do [1; 5]. Even for high-performance systems, certain installation discontinuities negate anticipated increases in energy efficiency, notably for retrofit applications (see Table 2).

This pattern is further reinforced by airtightness outcomes. These findings indicate that small sealing differences at the installation joint contribute to wide air leakage paths particularly in variable weather conditions. This results in higher heating demand and lower comfort in the indoor environment. The work presented by Kysela et al. and Tombarević et al. shows that airtightness degradation is not static, instead progressive, since environmental exposure magnifies the initial installation imperfection [7; 18].

The results indicate that defects during installation act as acoustic weak points, enabling sound propagation through gaps that otherwise bypass good glazing systems. This establishes that acoustic inefficiencies are often not material failures but installers-caused discontinuities [2; 12].

Table 2. Installation Defects vs Performance Impact

Installation Defect	Thermal Impact	Airtightness Impact	Acoustic Impact	Moisture Impact
Incorrect positioning	Thermal bridges	Air leakage paths	Minor effect	Condensation risk
Poor sealing	Heat loss	Significant leakage	Noise penetration	Water ingress
Gaps in joint	Increased heat transfer	Reduced airtightness	Acoustic leakage	Moisture accumulation
Misaligned frame	Uneven insulation	Air infiltration	Sound transmission	Structural stress
Lack of vapor barrier	Thermal inefficiency	Air movement	Minimal	High moisture risk

Source: Formed by the author.

The most important results apply to moisture behavior. It is demonstrated that improper sealing and interface discontinuities provide pathways for moisture ingress through which condensation, degradation, and long-lasting structural damage occur. The effects increase over time and often go unaddressed long before much damage has occurred [4; 8; 9].

From the perspective of economic policy, the results suggest that installation quality can be estimated as highly impactful on lifecycle costs. Energy waste, the cost of maintenance, and the rate of system failure are all combined to prevent any reductions in the short-term costs as a consequence of lowered installation quality [6; 19].

Conclusively, the results confirm the IWIPM by showing that installation quality is a multiplying factor between performance efficiency and risk, and that it impacts not only the short run but long run operational and economic sustainability.

This study's results fundamentally disturb the traditional understanding of window installation as a secondary, execution-level task. Instead, viewed through the prism of the Integrated Window Installation Performance Model (IWIPM), installation functions as a system-level variable that determines the interaction between materials, environmental context, and long-term performance. This article thus proceeds beyond isolated faults by recasting installation quality as its pivotal engineering variable—one which connects design intention and reality in the real world.

5.1. Installation as a Determinant of Thermal System Integrity

The thermal factor of studies in which the findings revealed an important observation, that directly influences whether the quality of the installation affects the practice of engineering is the primary factor that can be realized in terms of practice because as with installation, the quality of the material used is critical for theoretical energy performance. Thermal bridges are not merely design bugs and are commonly introduced during installation [1; 11] and literature review indicates that it has been well established. It highlights the importance of this in light of experiments in optimization, showing that modest variations in window position with respect to the insulation layer can produce measurable reductions in heat loss [5].

The IWIPM takes this a step further by framing the accuracy of the installation itself as a controllable parameter in construction quality. This transition results in material selection being less significant than the integration process itself. In essence, high-performance glazing or sophisticated insulation systems do not compensate for an inefficient installation. This is also supported in retrofit studies, which indicated installation-related inefficiencies did not realize predicted energy savings [3; 13]. Accordingly, the installation becomes the important linkage of design potential and operational performance.

5.2. RisksAirtightness as a Dynamic Performance Variable

The airtightness discussion brings a time dimension to installation quality. The results show that installation defects are dynamic and change due to environmental challenges. In addition to this, the presence of seasonal fluctuations further increases air leakage at installation joints resulting in gradual degradation in performance [7]. This mirrors case-based evidence of poorly installed windows not converting into improved energy efficiency with new materials [18].

This phenomenon is illustrated in the Environmental Interaction Layer of the IWIPM framework, which identifies the fact that installation quality has to be assessed not only upon completion but throughout a building's life cycle. This has real consequences for quality control practices. Traditional methods of inspection emphasize compliance in the moment, while the findings suggest validation on performance, ranging from airtightness testing to long-term monitoring.

5.3. Acoustic Performance as an Indicator of Installation Integrity

The acoustic performance is another way to view installation quality that also supports the idea of the installation joint as an important performance interface. It has previously been reported that sound insulation can be particularly susceptible to discontinuities, with a small gap causing a very large decrease in the acoustic resistance [2; 12]. Unlike thermal losses that may be somewhat mitigated by insulation material, acoustic leakages generally are more closely associated with defects of the installation.

Accordingly, acoustic performance should be considered as a diagnostic criterion for the installation quality. The concordance between thermal and acoustic aberrations, which thermographic studies reveal [17], also suggests that defects in installations occur in multiple domains at once. The IWIPM encapsulates this approach by considering acoustic performance as an integrated system, rather than a specific output.

5.4. Moisture Risks and Long-Term Structural Implications

The most important aspect of the discussion is the moisture behavior dimension of the problem, as moisture behavior is the most pivotal because it directly impacts the durability of the building. The results confirm that installation defects have been indicated as the main conduit of moisture ingress, resulting in condensation, deterioration of material and possible structural damage [4; 8]. These are particularly serious issues because they are usually hidden and never caught until the damage is done.

In the IWIPM, the control of moisture is identified as the most essential part of preserving the interface integrity and proper sealing, drainage design, and continuity of vapor barrier are also seen as important aspects of installation quality. However, literature on water damage in buildings generally supports that conclusion, as construction and installation defects are key contributing factors [9].

From a systems point of view, moisture failures demonstrate how these installation defects compound each other. An error in sealing can cause thermal loss and failure, leading to condensation and the deterioration of the framework. This cascade of effects provides reason for viewing installation as a high-risk phase with strict controls in place.

5.5. Economic Reframing of Installation Quality

One major contribution of this work is providing a direct association between the installation quality and economic outcomes when it comes to technical and economic performances. The results show that poor installation results in high energy consumption, high maintenance costs and lower life of the system. Such results are congruent with economic studies that demonstrate that differences in thermal performance are a key determinant of the ROI of insulation systems [6].

Furthermore, research on construction management shows that early defect prevention is significantly cheaper than repairs after the finished product is constructed [19]. Specifically, these findings are useful for damage due to moisture, which can require a significant amount of remediation [9].

The IWIPM has incorporated these insights by linking installation quality to lifecycle cost implications as this impact how installation is done from the first cost point of view to the second value-generating activity. That reframing has real-world consequences for industry practice. Such investments in skilled labor, quality control systems, and standardized installation procedures must be seen not as additional costs but strategic measures of long-term economic efficiency (Table 3).

5.6. Toward a System-Level Approach

The general theme of this discussion is: The need to move away from fragmented evaluation methods to a system-level approach to installation quality is evident here. The IWIPM serves as a conceptual framework to frame this pivot by unifying installation precision, interface integrity, and environmental interaction into one cohesive model.

Table 3. Lifecycle Cost Implications of Installation Quality

Parameter	Proper Installation	Poor Installation
Energy consumption	Low	High
Heating/cooling costs	Reduced	Increased
Maintenance frequency	Minimal	Frequent
Moisture-related repairs	Rare	High probability
System lifespan	Extended	Reduced
Return on investment (ROI)	Optimized	Delayed
Total lifecycle cost	Lower	Significantly higher

Source: Formed by the author.

This is in line with one of the major shortcomings in the literature, wherein the majority of existing studies consider separate aspects of performance without regard to the interdependence of phenomena. The IWIPM allows a holistic perspective on the effects of installation quality on building performance over time by synthesizing these attributes.

6. Conclusions

This study shows that window installation quality affects the technical performance and economic efficiency of building envelopes. It indicates that installation defects drastically impact thermal behavior, airtightness, acoustic insulation, and moisture resistance, which diminish durability and increase lifecycle costs.

In this respect, the proposed Integrated Window Installation Performance Model (IWIPM) offers a comprehensive framework for understanding these effects through the direct linkages between installation precision, interface integrity, and environmental interaction to performance outcomes. The model presented here is a fundamental contribution of the study and offers a system-oriented view of the design-performance relationship, bridging this gap.

The results suggest repositioning installation as something that needs to be shifted out of procedural tasks and placed within the midst of the construction phase, engineering as an important process in its own right. There is a big part of high installation quality that involves more than complying with not only meeting technical standards, but also considering installation within the design phase and ensuring performance-based quality control systems are in place.

Improving installation quality can be considered a cost-effective strategy to enhance building performance, reduce operational expenses, and extend system lifespan. More extensive research is needed to establish standardized evaluation methods, as well as digital monitoring tools and other techniques for better and consistent installation outcomes.

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