FUTURE CITIES AND ENVIRONMENT

Controlling Thermal Bridging as a Value-Added Technique to Enhance Energy Efficient Building Envelopes

TECHNICAL ARTICLE

ALI TAILEB

MOHAMMED FAREED SHERZAD

*Author affiliations can be found in the back matter of this article

ubiquity press

ABSTRACT

Buildings consume 30% to 40% of all primary energy worldwide and are responsible for 50% of total greenhouse gas emissions. Canada has set a target of reducing greenhouse gas emissions by at least 80% by 2050. The aim of this paper is to investigate thermal bridging in four high-efficient buildings, such as those built to LEED standards. Thermal bridging is a major source of heat loss in many buildings, manifesting itself through exterior envelopes, particularly through studs and wall systems. LEED is an evaluation system that rates how sensitive buildings are to the environment, with one of its main objectives being the reduction of greenhouse gases (GHG) emissions through the implementation of highly efficient mechanical systems and the design of durable and efficient exterior wall systems with appropriate insulation. This research investigates and identifies the location of thermal bridging in high-efficiency buildings using non-destructive testing methods such as thermal imaging and THERM simulations.

The study involves using infrared thermography to inspect surface temperature variations and detect irregular thermal patterns that correspond to thermal bridging. By collecting record drawings to identify the construction systems used in the external wall compounds, capturing thermal images with high-resolution infrared cameras, and comparing these images with simulation results, the research provides a comprehensive analysis of thermal performance. The findings from this research are significant, particularly in the context of window curtain walls, steel studs, brick shelf angles, timber frames, and roof hatches—all of which were identified as critical areas of concern due to their propensity to thermal bridges. For instance, window curtain walls, with their metal frames and large glass surfaces, showed temperature drops of up to 8°C. Steel studs, which are highly conductive of heat, resulted in temperature drops of up to 5°C, while brick shelf angles showed a temperature drop of 4°C due to heat conduction through the metal. In timber frame structure the building envelope connector showed temperature drops of up to 7°C. Additionally, roof hatches, necessary for rooftop access, were found to cause the most significant temperature drop of 10°C. The findings highlight the significant impact of thermal bridges on overall energy efficiency, emphasizing the need for careful design and construction practices to minimize heat losses. Addressing these thermal bridging issues is crucial for achieving the ambitious GHG reduction targets and enhancing the sustainability of high-performance buildings.

CORRESPONDING AUTHOR:
Mohammed Fareed Sherzad
Department of Architecture, College of Architecture, Art and Design, Ajman University, Ajman P.O. Box 346, United Arab Emirates
msherzad@ajman.ac.ae

KEYWORDS:
LEED; thermal bridging; energy efficiency

TO CITE THIS ARTICLE:
Taileb, A and Sherzad, MF. 2024. Controlling Thermal Bridging as a Value-Added Technique to Enhance Energy Efficient Building Envelopes. *Future Cities and Environment,* 10(1): 27, 1–15. DOI: https://doi.org/10.5334/fce.294

1. INTRODUCTION

Buildings consume 30% to 40% of all primary energy worldwide and are responsible for 50% of total emissions (Green building, 2010). Canada has set a target of reducing greenhouse gas emissions by at least 80% by 2050. The Canadian federal government has invested in cleaner energy and energy efficiency by making buildings more energy efficient, purchasing sustainable products, and using greener power. GHG emissions from federal operations have been reduced by 28% from 2005 levels, and the government is committed to further reducing them by 40% by 2030 (Secretariat, 2017).

In general, green buildings are becoming increasingly important in the construction industry. As a result of this shift, the industry is seeing a surge in green building programs and initiatives, particularly in developed countries. The growing awareness of the potential of green building to positively impact the environment is pushing for green buildings to be at the forefront. Therefore, building owners and investors are willing to learn more about the advantages and values of green buildings, which have a direct effect on global warming. In addition, construction-related material manufacturers are becoming more aware of the environmental benefits of their products. Builders are adapting to new techniques and technologies that purport to reduce environmental impact. Lenders, insurers, municipalities, code officials, and design professionals are reinterpreting their roles in terms of green design objectives. Green buildings are the forerunner of sustainable development in this era, focusing on the social, economic, and environmental balance of sustainability (Yoon & Lee, 2003; Ando et al., 2005). Green buildings have the potential to create environmentally efficient buildings by incorporating an integrated design approach to reduce the negative impact of buildings on the environment and occupants. Additionally, rating systems such as LEED offer an effective framework for assessing building environmental performance and integrating sustainable development into building and construction processes. They can also be used as a tool for designing sustainable design strategies and decision-making processes (Ando et al.,2005; Cole, 2003). Furthermore, LEED reduces operating and maintenance costs, increases the market value of the building, and improves occupant comfort and productivity (Fowler & Rauch, 2006).

Theodosiou (2019) investigated the magnitude of point thermal bridging and its effect on the overall heat flow estimation on advanced cladding systems and smart facades (Theodosiou et al., 2019). Transmission heat exchange through thermal bridges was about eight times greater than the standard, leading to a higher building energy need of about 21% (Theodosiou et al., 2017). Thermal bridges in metal cladding systems can be a significant weak point in thermal insulation protection if no special care is given during the design and construction process (Smusz & Korzeniowski, 2018). The infrared thermovision technique has been used to assess thermal bridges in situ. The IR thermography technique allowed the determination of the influence of thermal bridges on the additional heat losses. Research shows that thermal bridges may cause up to 30%–60% of the additional heat losses through the building envelope (Smusz & Korzeniowski, 2018). Therefore, one key aspect in assessing the real thermal state of buildings is the identification of heat losses through thermal bridges (Smusz & Korzeniowski, 2018). IR thermography was used to detect missing thermal insulation and thermal bridging in the building envelope (Fokaides & Kalogirou, 2011). Analysed the efficiency of the building envelope by critically analysed the thermal bridges (Asdrubali & Bianchi, 2012). Perez (2024), assessed qualitatively and quantitively the thermal bridges in balconies and their impacts on buildings in dry Mediterranean climates and semi-arid climates (Pérez-Carramiñana et al., 2024). Chandrasiri et al. (2024), investigates numerically the thermal bridges through Light-gauge steel panels by examining various insulation rations (Chandrasiri et al., 2024). M.J. Romero (2021), analysed thermal bridges in residential buildings between the façade junction with the floor slab, the research proposes two construction improvements that will impact in the reduction of the energy demand (Romero & Vicente, 2021). Terentjevas et al. (2021), examines the thermal performance of point thermal bridges, which are noticed in regions where there's increased thermal conductivity at the connections between windows and supporting structures using various fastening methods. The evaluation of heat transfer was carried out through the utilization of two analytical instruments (THERM and HEAT3) (Terentjevas et al., 2021). Theodosioua et al. (2017), analysed thermal bridging in ventilated facades, the findings indicate that without proper attention during design and construction, thermal bridges within metal cladding systems can become a notable vulnerability in thermal insulation (Theodosiou et al., 2017). Taileb and Dekkiche (2015), investigated thermal bridging in a LEED building, the study recommended to integrate infrared imaging into the LEED certification process (Taileb & Dekkiche 2015). The researcher addressed the challenge of identifying thermal bridges on building façades during the conceptual design stage by architects. They proposed an integrated method to calculate dynamic thermal bridges under transient conditions by incorporating field observations and computational simulations. Measurement tools like HOBO data loggers and thermal cameras were used to record indoor and outdoor temperatures and identify the surface temperatures of building junctions. The collected data was integrated with Building Energy Simulation (BES) tools, the outcome of the research would enable architects to identify potential thermal bridges and support material and geometric exploration in the early design phase (Alkadri et al., 2024). The researcher investigated the influence of coupled heat and moisture transfer (HAMT) within thermal bridges on building energy consumption, particularly in humid climates. Field experiments and validated numerical models were conducted to study the wall-to-floor thermal bridge (WFTB) in Hangzhou, China. The study found that heat transfer is underestimated if moisture is not considered, and that moisture significantly affects the thermal performance of the WFTB. Additionally, the research revealed that adding a thermal insulation layer might counterintuitively increase the overall thermal conductivity of the WFTB due to increased moisture content (Yucong et al., 2023). Used infrared thermography as a diagnostic tool to identify and analyze thermal and moisture problems in historical buildings, allowing for the precise detection of temperature variations and moisture intrusions that could lead to structural damage or deterioration over time (Taileb & Sherzad, 2023).

This paper aims to investigate thermal bridging in highly efficient buildings, such as LEED buildings, which are a major source of heat loss through wall systems. LEED is an evaluating system that rates how buildings are sensitive to the environment, and the objectives of these green buildings are to reduce greenhouse gases by installing highly efficient mechanical systems and designing durable and energy-efficient wall systems. Unfortunately, in most cases, these wall systems and their respective insulations are supported by thin-gauge steel studs that are highly conductive of energy. The paper aims to investigate the impact of thermal bridging in highly efficient buildings, particularly LEED-certified structures, and explore solutions for minimizing energy losses through wall systems. Specifically, it seeks to address how thermal bridges contribute to heat loss and what strategies can be implemented to reduce their impact in green buildings. The study contributes to existing knowledge by providing a focused analysis of thermal bridging in LEED Gold-certified buildings in Canada, highlighting gaps in current inspection practices and offering recommendations for improving the thermal performance and sustainability of high-efficiency buildings in cold climates.

2. METHOD OF INVESTIGATION USED

In this research, infrared thermography is utilized as a qualitative test method to inspect surface temperature variations to detect irregular thermal patterns that correspond to thermal bridging. The method of investigation (Figure 1) consists of three steps (amongst the 7 research steps). The first step is collecting record drawings to identify the construction systems used in the external wall compounds of the investigated buildings (Figure 1aa). The second step involves capturing images with a Flir infrared camera b60 series (Figure 1ab). The InfraRed Camera features a high resolution of 180 × 180 IR, producing 32,400 pixels of detailed infrared images. This advanced imaging capability allows for the detection of areas that do not meet insulation requirements. The infrared images were taken during winter when the temperature was below zero, very early in the morning to visually capture heat losses. The camera operates within an optimized temperature range from –4 to 248°F (–20

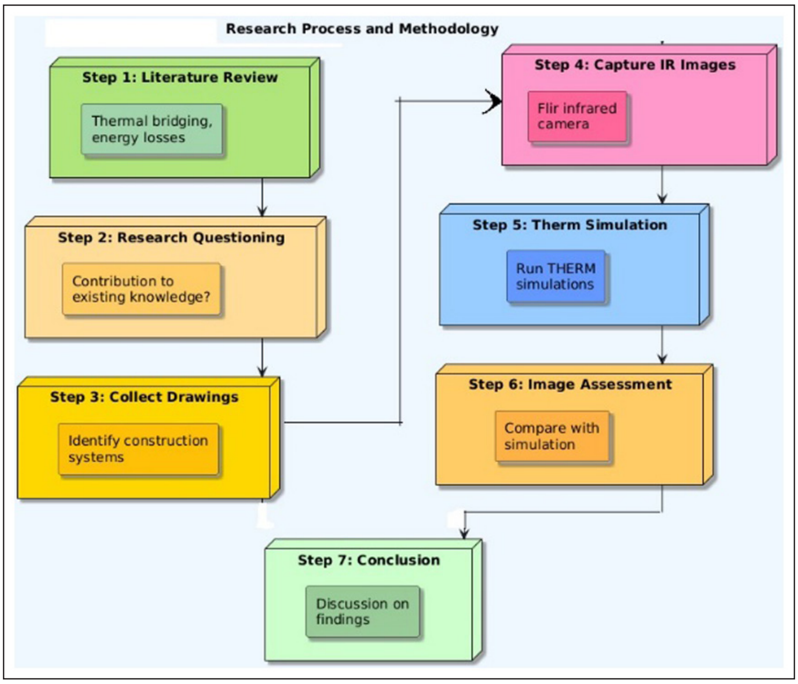
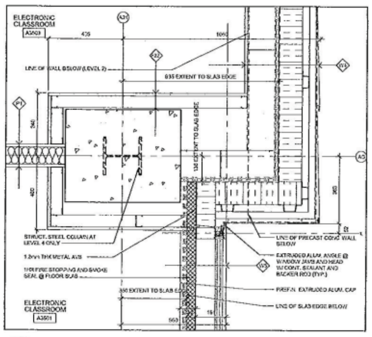
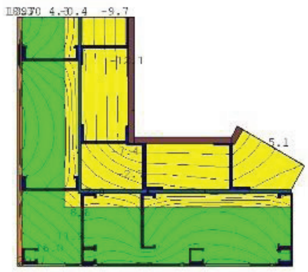


Figure 1 Research method and methods of investigation.



a- Architectural details (step 1 identify construction systems)

b- Flir infrared camera b60 series (capture of detailed)



c- THERM 7.4.4 software thermal bridging simulation

Figure 1a Method of investigation.

to 120°C), making it ideal for insulation targeting. With a reliable ±2% accuracy in temperature measurement, it ensures precise readings. Additionally, the Area (Min/Max) Mode displays the minimum or maximum temperature readings within a selected area, enhancing its functionality for thorough thermal analysis. The third and final step involves assessing the thermal images of the existing external walls and comparing them with the THERM 7.4.4 simulation images based on the construction details of the external envelopes (Figure 1ac).

3. INVESTIGATED BUILDINGS

In this study, the investigated buildings are all LEED-certified and located in Toronto, Canada. The buildings selected for this study were chosen due to their LEED Gold certification, which signifies high standards of energy efficiency and sustainable design. As representative examples of best construction practices, these buildings offer valuable insights into the real-world performance of high-efficiency building envelopes, particularly in the context of thermal bridging. Located in Canada, these structures also provide region-specific data relevant to cold climates, making them ideal for studying the challenges and potential improvements in sustainable building practices. The first building (Building 1) was built in 2011 (Figure 2a). It is a four-story building covering a gross floor area (GFA) of 9400 m^2. It was certified as a LEED Gold building by the Canadian Green Building Council in 2011 under LEED NC 1. The building's main wall systems are cast-in-place concrete with modular bricks used for cladding, along with fiberglass rigid insulation. The second prevalent main wall system is made of copper and comprises a 152 mm steel frame system, an air/vapor barrier, 100 mm rigid insulation, steel sheathing, and is cladded with copper panels. The window frames are made of aluminum. The exterior walls oriented towards the northern side are built with brick and copper cladding (metal studs, rigid insulation, and drywall).

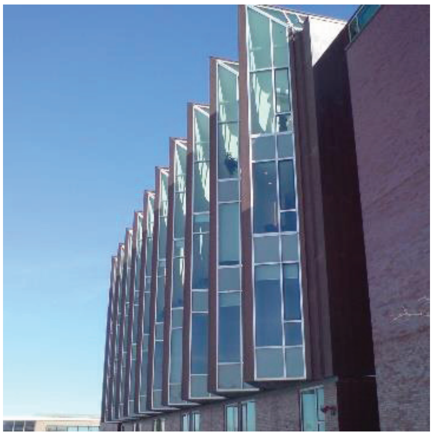
The second building (Building 2) is also a LEED Gold building (Figure 2b). It was awarded Gold in 2012, and later with improvements and retrofits, earned the Platinum upgrade in 2014. The investigated building envelope is composed of the following components: 16 mm gypsum board, 152 mm galvanized steel studs, 16 mm exterior gypsum board, a vapor barrier, 125 mm semi-rigid mineral fiber insulation with an RSI of 3.7, a 125 mm galvanized steel sub-girt, and 0.8 mm zinc cladding. The third investigated building (Building 3) is the Toronto Pan-Am Sport Centre (Figure 2c), a facility covering 312,000 square feet. It has two Olympic-sized 10-lane swimming pools, a 25 m diving tank with both diving platforms and spring diving boards, and four gymnasiums built to international standards. The building consists of glass curtain walls and precast concrete. The fourth building (Building 4) is Canada's first higher-education facility to achieve LEED Gold certification, zero carbon status, and mass timber construction (Figure 2d). This recognition was awarded in 2023. Constructed using black spruce from Chibougamau, Quebec, the structure features cross-laminated and glue-laminated columns, beams, and floor slabs, showcasing extensive wood exposures. The project includes six stories and over 130,000 square feet, along with a 15,000-square-foot renovation. The building's zero-carbon certification is due to its highly efficient building envelope, all-electric domestic hot water heating, and HVAC systems.

4. THERMAL BRIDGING IN BUILDING ENVELOPES

A thermal bridge, also known as a cold bridge or heat bridge, is an area of a building that has significantly higher heat transfer than the surrounding materials, resulting in an overall reduction in the building's thermal insulation. Thermal bridges can occur in three ways: through materials with higher thermal conductivity than the surrounding materials, through penetrations of the thermal envelope, and discontinuities or gaps in the insulation materials.

5. ASSESSING THE THERMAL BRIDGING

Building envelopes are designed to provide comfortable indoor conditions, protect the interior from the outside, and give the building its external appearance. In Figure 3a of Building 1, IR thermography was used to detect any missing thermal insulation and thermal bridging in the building envelope. The IR thermograph in Figure 1ab clearly shows the locations of the thermal bridges. The



a- **Building 1**, Steel frame construction, building envelope systems using steel frame construction and curtain wall systems. LEED Gold building, awarded in 2012. (by the author).

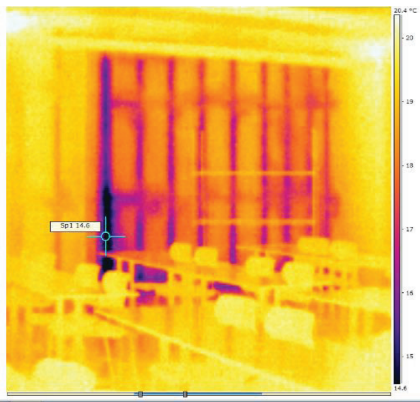
b- **Building 2,** Steel frame construction, building envelope built using concrete precast construction, steel frame and curtain walls. LEED Gold building awarded in 2014. (by the author).

c- **Building 3,** Steel frame construction, building envelope built with concrete precast and curtain wall system. LEED Gold building awarded in 2012.

d- **Building 4,** Timber frame construction, building envelope steel studs and cladding systems, curtain wall. LEED Gold building, zero carbon awarded in 2023. (by the author).

Figure 2 Investigated LEED buildings.

a



b

Figure 3 (a) Façade of the LEED building (Centennial Campus), composed of bricks and copper cladding **(b)** Thermal imaging showing thermal bridging through the steel studs (by the author).

temperature of the steel studs was shown as 14.6°C, while the indoor temperature was around 21°C.

The exterior wall and its components are designed with a higher thermal resistance value to reduce heat gains during the summertime and heat losses during the winter. Thermal bridges occur when a conductive element passes through or bypasses the thermal barrier. Thermal bridges provide a path of lesser resistance through the insulation, allowing more heat to bypass the thermal barrier and raise or lower interior temperatures, in this case through the steel studs. In Figure 4a, b and c of the same building, thermal bridging and heat losses were visible through the brick shelf angles and the glass framing of the curtain wall.

Using architectural details of the building (Figure 5a), it was possible to simulate the heat flux using THERM 7.4.4 (Figures 5b, 6a and b). The exterior cladding of the building envelope is made of copper, while the inner structure consists of steel studs. The heat flux simulations show the paths of heat (Figure 6a), illustrating areas where heat transfer is most significant. This data helps identify potential improvements in

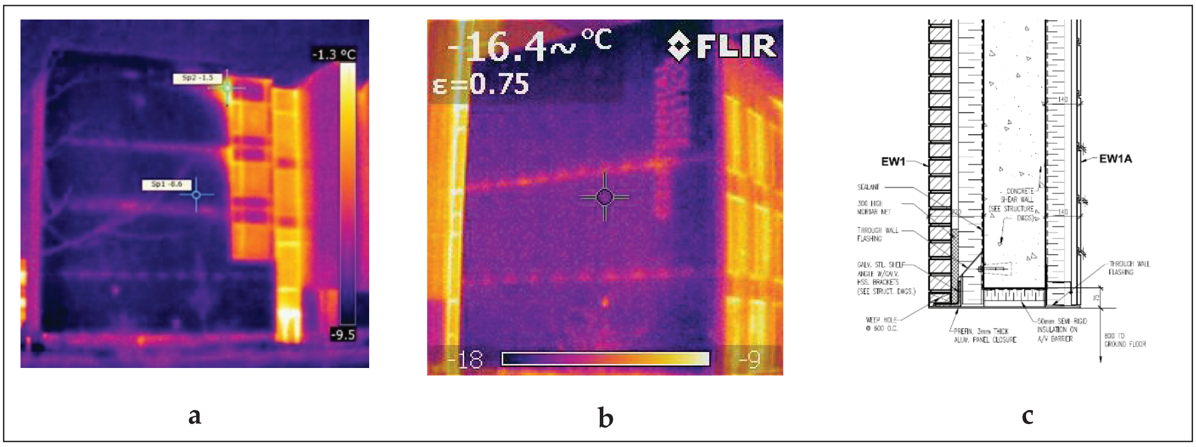


Figure 4 (a, b & c) Infrared camera showing the thermal bridging through shelf angles and curtain wall glazing (by the author).

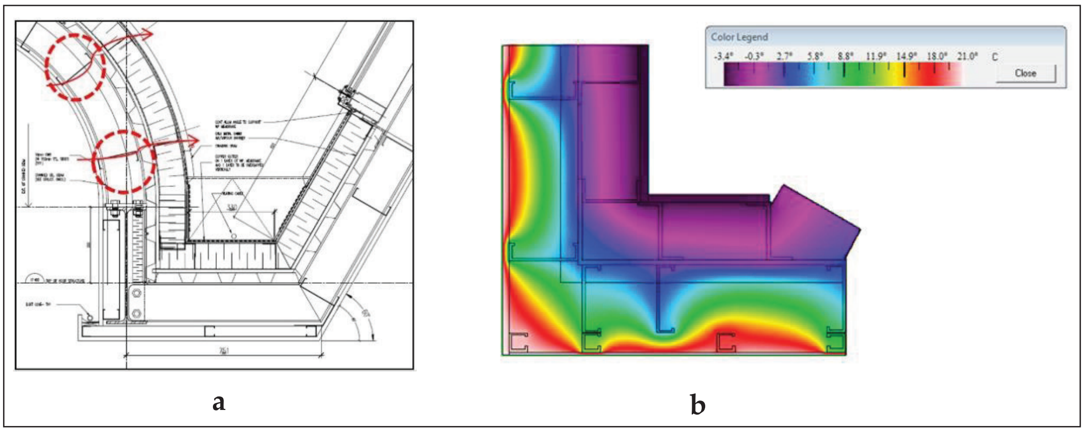


Figure 5 (a) Construction detail shows different layers of the exterior wall: Copper cladding, Z girts, rigid insulation, metal clad, steel studs and drywall. B) Thermal simulation using THERM 7.4.4 showing colder areas within the building wall system **(b** (by the author).

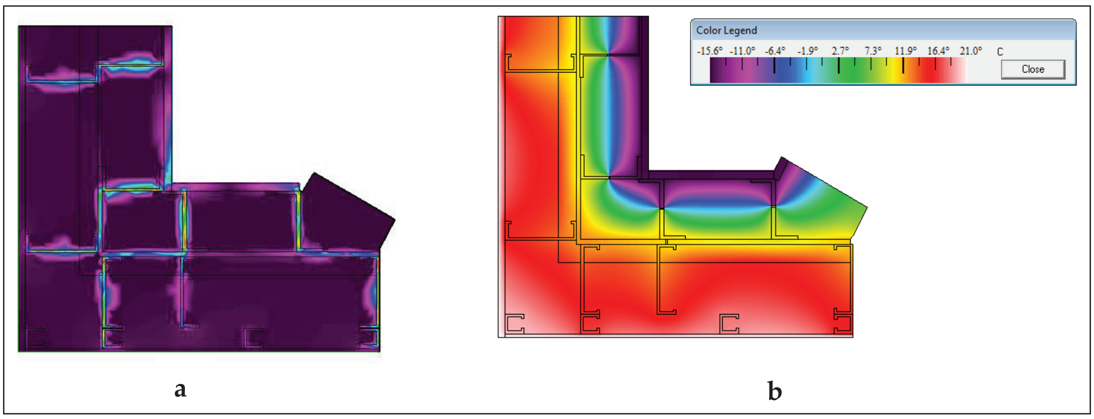


Figure 6 (a) THERM 7.4.4 simulation showing thermal bridging and heat loss path through the cold formed stud and Z girts **(b)** Reduced thermal bridging by the installation of thermal breaks (by the author).

the building envelope design to enhance thermal performance and energy efficiency.

In Building 2 below from Figure 7a–i shows the architectural details and THERM 7.4.4 simulation at the window and zinc-cladding façade on the North and West elevations of Building 2 (Building A) reveal no thermal bridging. The wall cladding is composed of 16 mm gypsum board, 152 mm galvanized steel studs, 16 mm exterior gypsum board, a vapor barrier, 125 mm semi-rigid mineral fiber insulation with RSI 3.7, a 125 mm galvanized steel sub-girt, and 0.8 mm zinc cladding. Additionally, images and details from a classroom and IR pictures of the zinc cladding show no visible thermal bridging.

From (Figure 8) of building 3, thermal bridging and heat losses are visible in the framing of the glass curtain walls and the in the concrete precast, stains

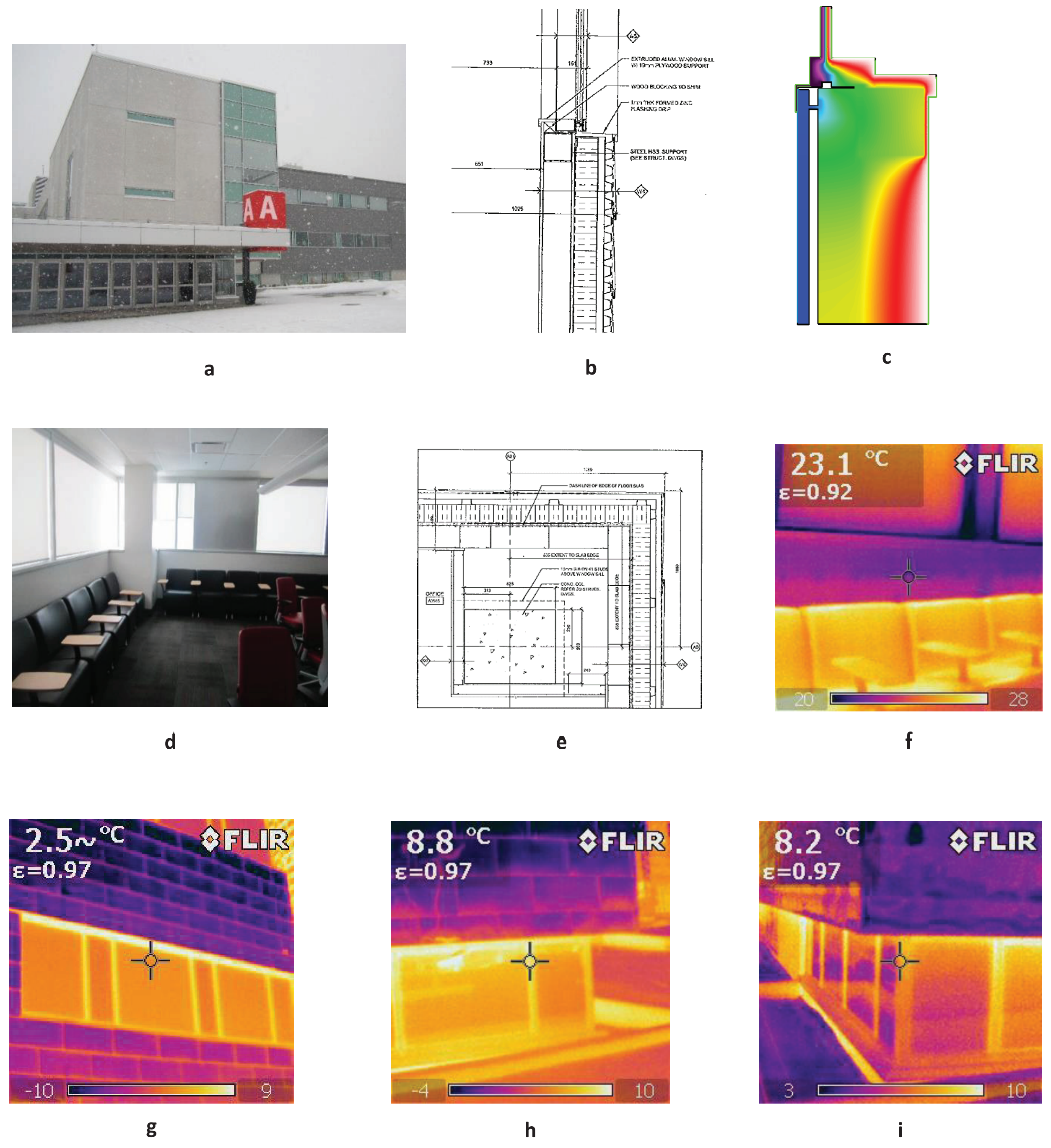


Figure 7 (a) Building 2 (Building A) main entrance **(b)** shows the architectural detail and THERM 7.4.4 simulation at the window and zinc-cladding façade located on North and West elevations, no thermal bridging were observed (wall cladding composed of the following wall components from the interior to the exterior: 16 mm gypsum board, 152 mm galvanized steel studs, 16 mm exterior gypsum board, vapor barrier, 125 mm semi rigid mineral fiber insulation RSI 3.7 a 125 mm galvanized steel sub girt and 0.8 mm zinc cladding. From **(d)** to **(f)** picture and detail taken from a classroom, no thermal bridging was shown. **(g)** to **(h)** shows IR pictures of the zinc cladding with no visible thermal bridging (by the author).

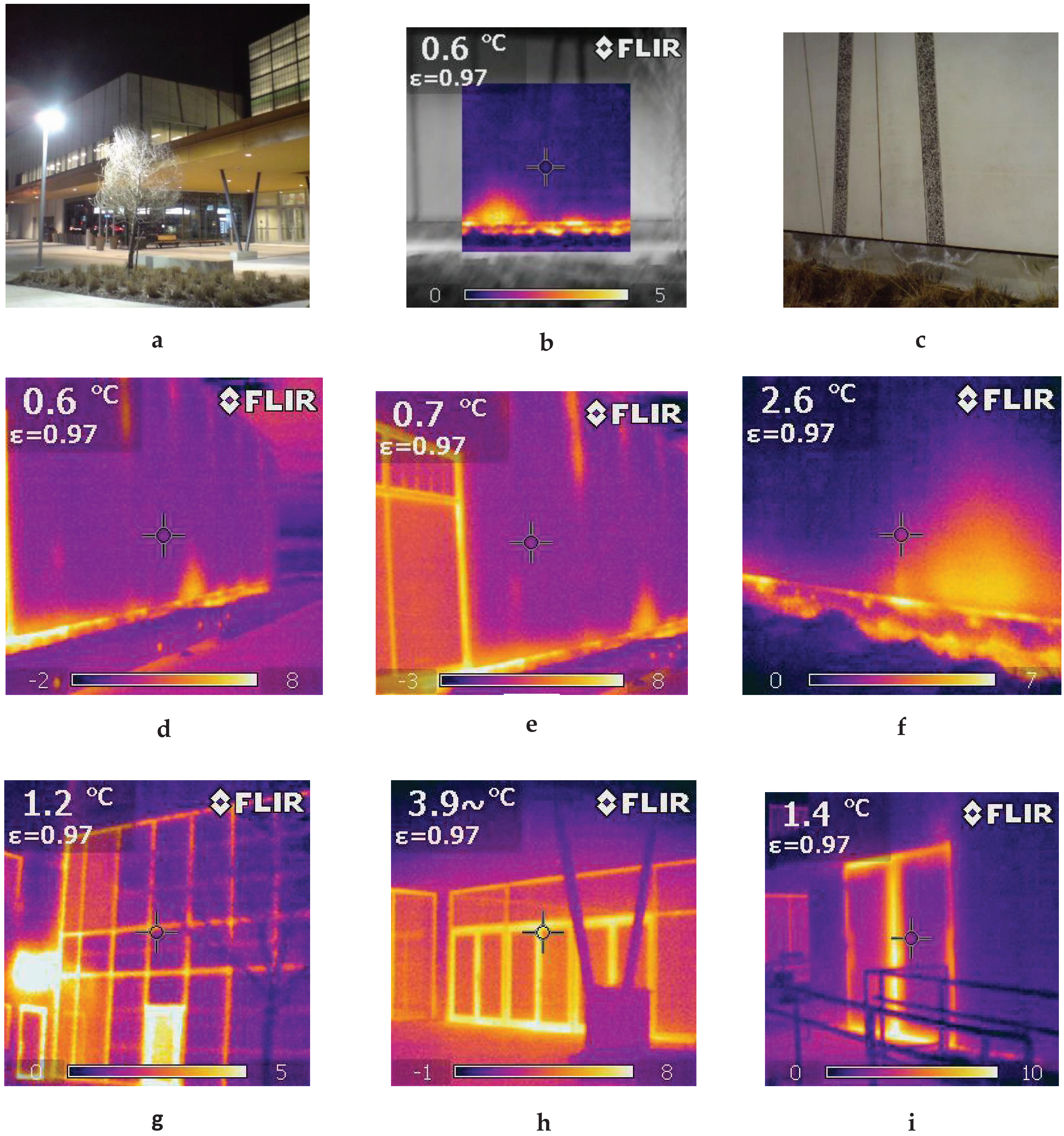


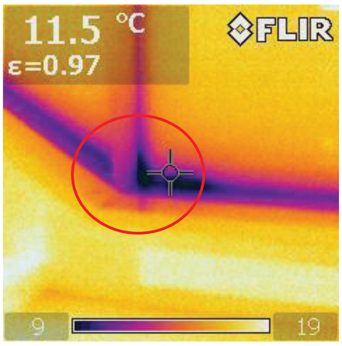
Figure 8 (a) Building 3 – Pan Am center (swimming pool) **(b)** and **(c)** effect of moisture on heat loss and thermal bridging **(d)** IR outside the swimming pool showing thermal losses through the concrete precast curtain wall, from **(g)** to **(i)** thermal bridging through the glass curtain walls (by the author).

due to moisture and condensation was visible through the foundation wall and the precast concrete panels (Figure 8b–f). In glass curtain walls, thermal bridging primarily occurs at the framing components, such as mullions and transoms, which are often made of metal with high thermal conductivity. This can create pathways for heat to transfer between the interior and exterior environments, leading to increased energy consumption for heating or cooling from Figure 8g–i.

The section below refers to building 4, the building is considered as the first LEED cold and NetZero timber framed building. From Figure 9a–h, localised thermal bridging was observed through windows curtain walls, timber frame steel connectors, window frames and steel studs. From Figure 9i–p localised thermal bridging was observed from the roof hatch, door entrance and building envelope steel cladding indicating areas where heat loss or gain is significant.

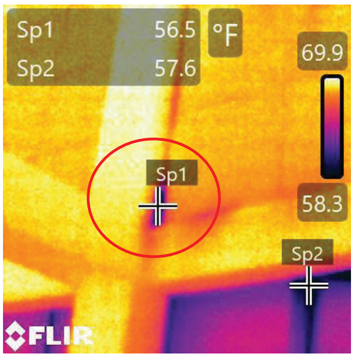
6. DISCUSSION

Recognizing the urgency of addressing climate change, Canada has set ambitious targets to reduce greenhouse



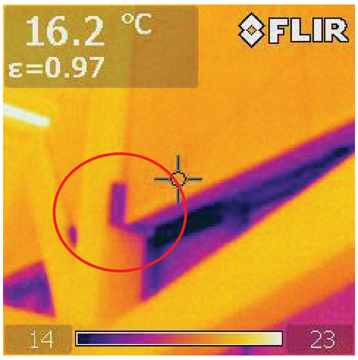
a- Visible thermal bridging through window curtain walls

b- Visible thermal bridging through window curtain walls



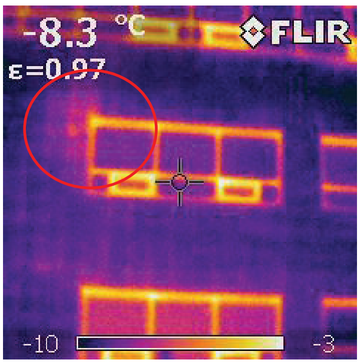
c- Thermal bridging connector of timber frame and building envelope

d- Thermal bridging connector of timber frame and building envelope



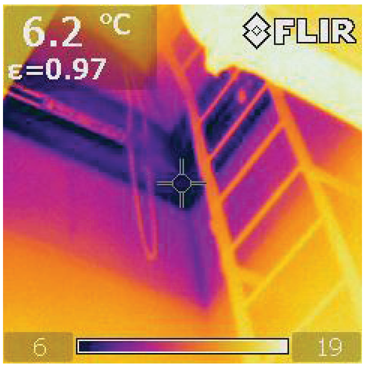
e- Thermal bridging connector of timber frame and building envelope

f- Thermal bridging connector of timber frame and building envelope



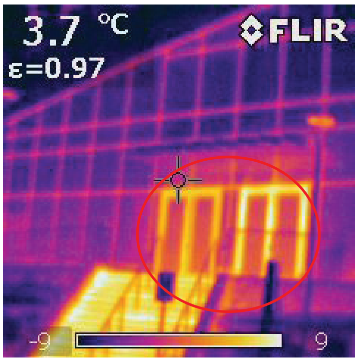
g- Visible thermal bridging through window frames and building envelope studs

h- Visible thermal bridging through window frames and building envelope studs

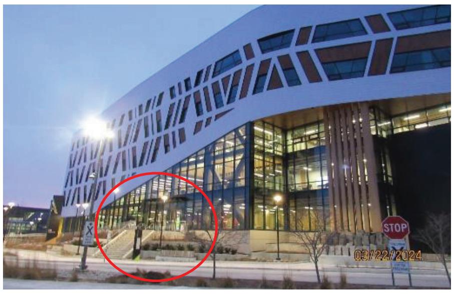


i- Visible thermal bridging through roof hatch

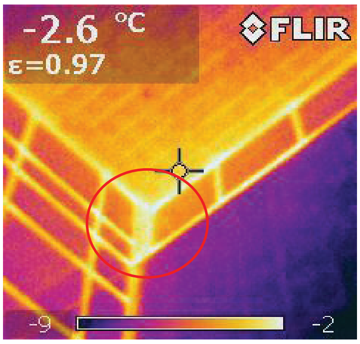
j- Visible thermal bridging through roof hatch



k- Heat loss through the exterior door

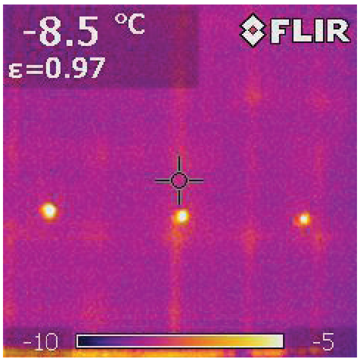


l- Heat loss through the exterior door



m- Thermal loses through the ceiling due to stack effect

n- Thermal loses through the ceiling due to stack effect



o- Thermal bridging through steel cladding and venting pipes

p- Thermal bridging through steel cladding and venting pipes

Figure 9 Areas of major heat losses (timber framed building) identified (by the author).

gas emissions by at least 80% by 2050. There is a growing awareness of the potential of green buildings to have a positive impact on the environment, leading to an increased emphasis on green building programs and initiatives. Code officials, and design professionals, are revaluating their roles to align with green design objectives. Green buildings represent the forefront of sustainable development, focusing on achieving a balance between social, economic, and environmental sustainability.

THERMAL BRIDGING ANALYSIS IN BUILDING CONSTRUCTION

The investigated building employs various wall systems and insulation materials, and the thermal bridging analysis aims to identify areas of heat loss and inefficiency. Thermal bridging occurs when materials that are poor insulators come into contact, allowing heat to flow through the path of least resistance. This can significantly impact the overall energy performance of a building. By identifying and addressing these areas, we can improve the thermal efficiency of the building envelope, reduce energy consumption, and lower greenhouse gas emissions.

Addressing the issue of energy consumption and greenhouse gas emissions in buildings is a critical step in combating climate change. Buildings are responsible for a significant portion of global energy use and carbon emissions. Therefore, enhancing the thermal performance of buildings can lead to substantial environmental benefits. The construction industry is increasingly recognizing the importance of green buildings and implementing measures to enhance energy efficiency and reduce environmental impact. This includes the adoption of advanced materials and construction techniques designed to minimize thermal bridging.

Most of the investigated thermal bridging occurs in the following areas:

Window Curtain Walls: These systems often involve metal frames and large glass surfaces, which can create significant thermal bridges. As shown in Figure 10c, d, f, h, and j, the temperatures across window curtain walls drops by as much as 8°C due to these thermal bridges. This temperature differential indicates substantial heat loss, particularly in colder climates where the indoor environment is warmer than the outside. Such heat loss not only increases energy consumption for heating but also affects the comfort of occupants near the curtain walls, leading to drafts or cold spots. Improving the thermal breaks within these frames and using high-performance glazing can reduce heat loss.

Steel Studs in Building Envelopes: Figure 10a illustrates a temperature drop of up to 5°C in Building 1, showing how the steel framework allows heat to escape through the walls. Solutions include the use of thermal breaks, continuous insulation, and alternative framing materials.

Brick Shelf Angles: These are used to support the weight of brick veneer walls. Figure 10b shows a drop of up to 4°C (Building 1). The metal angles can conduct heat, creating a bridge. Incorporating thermal breaks and using materials with lower thermal conductivity can mitigate this issue.

Timber Frame and Building Envelope Connections: While timber has better thermal performance than metal, connections between timber frames and other building envelope components can still create thermal bridges. Figure 10i shows a temperature drop to up to 7°C. Careful design and insulation at these junctions are essential.

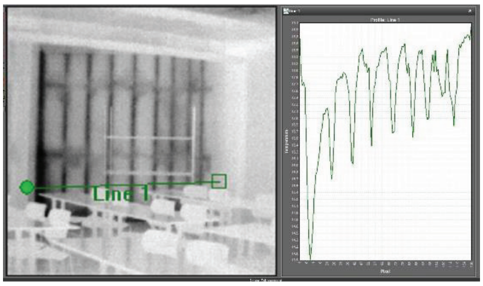
Roof Hatches: These are necessary for access to rooftop equipment but can be a source of thermal bridging. Figure 10g shows a drop to up to 10°C. High-performance, insulated hatches and proper sealing can reduce heat loss.

By focusing on these critical areas, the construction industry can make significant strides in improving building energy efficiency. Implementing these solutions requires a collaborative effort among architects, engineers, and builders to ensure that thermal performance is a priority throughout the design and construction process. As the industry continues to innovate, the goal of constructing buildings with minimal environmental impact becomes increasingly attainable.

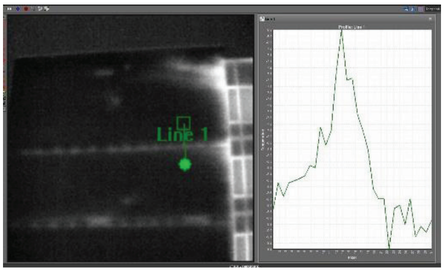
7. CONCLUSION

This paper aims to investigate thermal bridges in a LEED Gold building located in Canada. Infrared thermography is used in this research as a qualitative test method to inspect surface temperature variations in the search for irregular thermal patterns that correspond to thermal bridging. This study also identified a lack of rigorous building inspection and diagnostics within LEED Canada to evaluate the efficiency of the building envelope. The investigation of thermal bridges in LEED Gold buildings in Canada is crucial in ensuring that buildings are operating at maximum efficiency, both in terms of energy conservation and thermal comfort for occupants. In this study, infrared thermography was utilized as a qualitative test method to inspect surface temperature variations in the search for irregular thermal patterns that correspond to thermal bridging. The results of this research highlighted a lack of rigorous building inspection and diagnostics within LEED Canada to evaluate the efficiency of the building envelope.

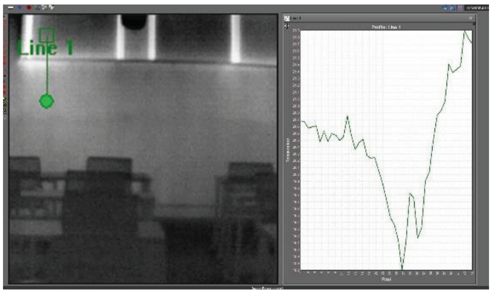
To address this issue, it is recommended that, prior to construction, thorough building envelope simulation and energy modeling should be incorporated into the building envelope study. This would help to identify potential



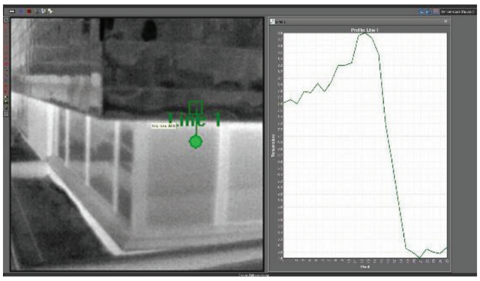
a) The temperature drops by 5°C due to thermal bridging (building 1) through the curtain wall



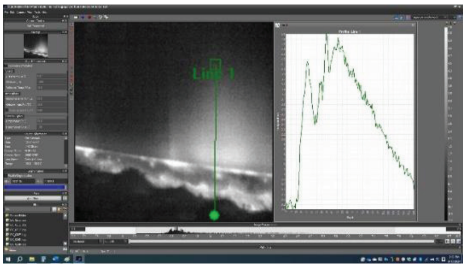
b) The temperature drops by 4°C due to thermal bridging (building 1) through the curtain wall



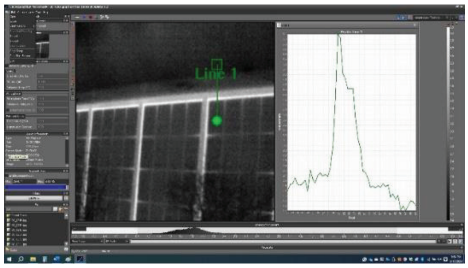
c) The temperature drops by 3.4°C due to thermal bridging (building 2) through the curtain wall



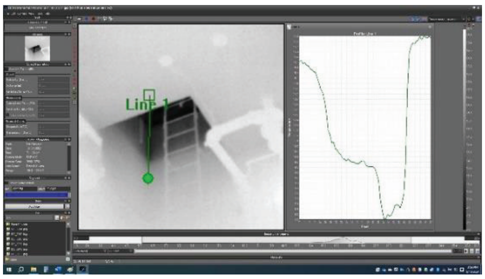
d) The temperature drops by 5°C due to thermal bridging (building 2) through the curtain wall



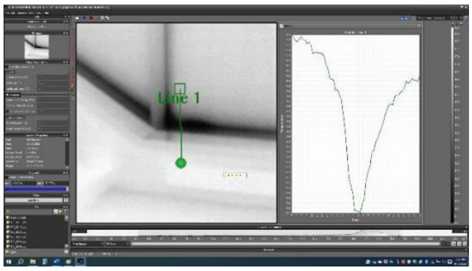
e) The temperature drops by 5ºC due to thermal bridging and humidity deposits (building 3) through the precast concrete wall



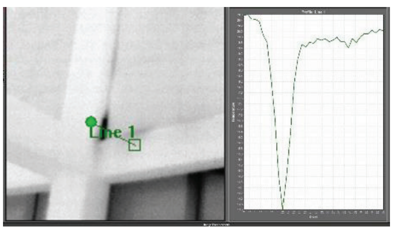
f) The temperature drops by 4.5°C due to thermal bridging (building 3) through the curtain wall



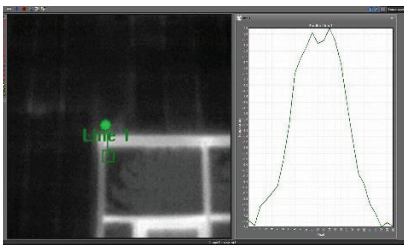
g) The temperature drops by 10ºC due to thermal bridging (building 4) through the roof hatch



h) The temperature drops by 8ºC due to thermal bridging (building 4) through the curtain wall



i) The temperature drops by 7ºC due to thermal bridging (building 4) through the steel and wood timber connection



j) The temperature drops by 4.5ºC due to thermal bridging through the window frame (building 4)

Figure 10 Temperatures drops of areas of major heat losses due to thermal bridging (by the author).

thermal bridging areas and insulation defects before the construction process begins. During construction, rigorous inspections of the building envelope using thermal imaging should be conducted to identify any missed insulation or thermal bridging that may occur.

SIGNIFICANCE OF FINDINGS IN SUSTAINABLE BUILDING PRACTICES

The findings from this research are significant, particularly in the context of **window curtain walls**, **steel studs**, **brick shelf angles**, **timber frames**, and **roof hatches**—all of which were identified as critical areas of concern due to their propensity to create thermal bridges. For instance, window curtain walls, with their metal frames and large glass surfaces, showed temperature drops of up to **8°C**. This substantial heat loss not only increases energy consumption but also affects occupant comfort by creating cold spots and drafts. **Steel studs**, which are highly conductive, resulted in temperature drops of up to **5°C** while **brick shelf angles** showed a temperature drop of **4°C** due to heat conduction through the metal. In **timber frame connections**, despite timber's better thermal performance compared to metal, the connections between timber and other building envelope components still caused temperature drops of up to **7°C**. Additionally, **roof hatches**, necessary for rooftop access, were found to cause the most significant temperature drop of **10°C**, highlighting a major source of heat loss if not properly insulated and sealed.

The findings of this research underscore the importance of thorough inspection and diagnostics in the construction and certification of high-performance buildings. By identifying and mitigating thermal bridges, we can ensure that buildings not only meet but exceed energy efficiency standards. This is vital in the broader context of sustainable building practices, as reducing energy consumption and enhancing thermal comfort contribute significantly to the overall sustainability goals.

Moreover, integrating advanced technologies such as infrared thermography into standard inspection protocols can set a new benchmark for building performance evaluation. This will facilitate the development of more rigorous certification processes within frameworks like LEED Canada, ultimately leading to more reliable and sustainable building practices. By adopting these recommendations, the construction industry can move towards a more sustainable future, where buildings are designed, constructed, and operated with maximum efficiency. This will not only reduce the environmental impact but also promote healthier, more comfortable living and working environments.

POTENTIAL AREAS FOR FUTURE RESEARCH

Interdisciplinary Collaboration

Future research should focus on exploring effective strategies for integrating various professionals in the design and construction process. This includes architects, building envelope consultants, and building scientists. By fostering interdisciplinary collaboration, these professionals can contribute their expertise to improve the design process and enhance construction and site reviews. Investigating the best practices for such collaboration can lead to more cohesive and efficient project outcomes, ensuring that all aspects of building performance are optimized.

Certification

There is a need to develop standardized protocols and guidelines for the implementation of infrared imaging in building inspections. Establishing more rigorous building inspection and diagnostic processes within LEED Canada is essential. These protocols would ensure a consistent approach, enabling professionals to make informed decisions based on recognized standards. Standardized guidelines would also facilitate the integration of advanced technologies into the certification process, improving the overall quality and reliability of building assessments.

Material properties

There is a need for future research to provide comprehensive data on the thermal properties of materials, such as thermal conductivity and R-values, to gain a deeper understanding of thermal bridging. It is also essential to conduct on-site temperature measurements to supplement thermal imaging data. Integrating empirical data—including thermal imaging and temperature measurements—with simulation tools like THERM is crucial for enhancing the accuracy and reliability of the findings.

By addressing these areas, future research can significantly strengthen the knowledge base surrounding the integration of infrared imaging in high-efficiency buildings. This advancement will not only contribute to the academic and professional discourse but also provide practical guidance for industry stakeholders. Enhanced collaboration and standardized certification processes will lead to more effective use of infrared imaging, ultimately advancing the field and promoting the development of more sustainable and energy-efficient buildings.

LIMITATIONS OF THE RESEARCH

This study faced several limitations that affected the comprehensive evaluation of thermal bridging in the investigated buildings:

Lack of Available Data: One of the significant limitations encountered during this research was the lack of access to detailed plans and construction documents for the buildings under investigation. These documents are crucial for several reasons: accurate evaluation of detailed bridging, detailed architectural and construction plans provide critical information about the materials, construction methods, and design features used in the buildings. Without this information, it is challenging to pinpoint the exact locations and causes of thermal bridges. The absence of detailed plans limits the ability to conduct Therm simulation and fully understand the heat flux that contribute to thermal bridging.

Impact on Overall Building Performance: Comprehensive construction data is necessary to assess the broader impact of thermal bridges on building performance. This includes understanding how thermal bridging affects energy consumption, indoor thermal comfort, and overall building efficiency.

In summary, the lack of access to detailed plans and construction documents significantly constrained the ability of this research to thoroughly evaluate thermal bridging in the investigated buildings. Addressing this limitation in future studies would require ensuring that such critical data is available, allowing for more precise and comprehensive analyses.

FUNDING INFORMATION

The authors would like to express their gratitude to Ajman University for APC support.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Ali Taileb orcid.org/0000-0002-6179-4268
Faculty of Science, Engineering & Information Technology, Durham College, Whitby Campus 1610 Champlain Avenue, Whitby, ON L1N 6A, Canada

Mohammed Fareed Sherzad orcid.org/0000-0002-7417-9125
Department of Architecture, College of Architecture, Art and Design, Ajman University, Ajman P.O. Box 346, United Arab Emirates

REFERENCES

Alkadri, MF, Cahyadi Agung, MR and **De Luca, F.** 2024. 'An integrated computational method for calculating dynamic thermal bridges of building facades in tropical countries'. *Frontiers of Architectural Research*, 13(1): 201–218. DOI: https://doi.org/10.1016/j.foar.2023.11.003

Ando, S, Arima, T, Bogaki, K, Hasegawa, H, Hoyano, A and **Ikaga, T.** 2005. *Architecture for a sustainable future*. Tokyo: Architectural Institute of Japan.

Asdrubali, F, Baldinelli, G and **Bianchi, F.** 2012. 'A quantitative methodology to evaluate thermal bridges in buildings'. *Applied Energy*, 97: 365–373. DOI: https://doi.org/10.1016/j.apenergy.2011.12.054

Chandrasiri, D, Gatheeshgar, P, Ahmadi, HM and **Simwanda, L.** 2024. 'Numerical study of thermal efficiency in light-gauge steel panels designed with varying insulation ratios'. *Buildings*, 14(1): 300. DOI: https://doi.org/10.3390/buildings14010300

Cole, R. 2003. 'Building environmental assessment methods: a measure of success'. Special issue article in: *The Future of Sustainable Construction*.

Fokaides, PA and **Kalogirou, SA.** 2011. 'Application of infrared thermography for the determination of the overall heat transfer coefficient (U-Value) in building envelopes'. *Applied Energy*, 88(12): 4358–4365. DOI: https://doi.org/10.1016/j.apenergy.2011.05.014

Fowler, KM and **Rauch, EM.** 2006. Sustainable Building Rating Systems Summary. DOI: https://doi.org/10.2172/926974

Green building: Project Planning and Cost Estimating. 2010. R.S. Means.

Pérez-Carramiñana, C, de la Morena-Marqués, A, González-Avilés, ÁB, Castilla, N and **Galiano-Garrigós, A.** 2024. 'Influence of balcony thermal bridges on energy efficiency of dwellings in a warm semi-arid dry Mediterranean climate'. *Buildings*, 14(3): 703. DOI: https://doi.org/10.3390/buildings14030703

Romero, MJ, Aguilar, F and **Vicente, PG.** 2021. 'Analysis of design improvements for thermal bridges formed by double-brick façades and intermediate slabs for NZEB residential buildings in Spain'. *Journal of Building Engineering*, 44: 103270. DOI: https://doi.org/10.1016/j.jobe.2021.103270

Secretariat, TB of C. 2017. *Government of canada sets ambitious GHG reduction targets for Federal Operations*. Canada.ca. 19 December 2017. Available at: https://www.canada.ca/en/treasury-board-secretariat/news/2017/12/government_of_canadasetsambitiousghgreductiontargetsforfederalop.html.

Smusz, R and **Korzeniowski, M.** 2018. 'Experimental investigation of thermal bridges in building at real conditions'. *E3S Web of Conferences*, 70: 03013. DOI: https://doi.org/10.1051/e3sconf/20187003013 [Accessed on 10 August 2024]

Taileb, A and **Dekkiche, H.** 2015. 'Infrared Imaging as a means of analyzing and improving energy efficiency of building envelopes: The case of a LEED gold building'. *Procedia Engineering*, 118: 639–646. DOI: https://doi.org/10.1016/j.proeng.2015.08.497

Taileb, A, Dekkiche, H and **Sherzad, MF.** 2023. 'HBIM: A tool for enhancing the diagnosis of historical buildings: The case of st. george's memorial anglican church, Oshawa'. *Heritage*, 6(8): 5848–5866. DOI: https://doi.org/10.3390/heritage6080307

Terentjevas, J, Šadauskaitė, M, Šadauskienė, J, Ramanauskas, J, Buska, A and **Fokaides, PA.** 2021. 'Numerical investigation of Buildings Point Thermal Bridges observed on window-thermal insulation interface'. *Case Studies in*

Construction Materials, 15. DOI: https://doi.org/10.1016/j.cscm.2021.e00768

Theodosiou, T, Tsikaloudaki, K and **Bikas, D.** 2017. 'Analysis of the thermal bridging effect on ventilated facades'. *Procedia Environmental Sciences*, 38: 397–404. DOI: https://doi.org/10.1016/j.proenv.2017.03.121

Theodosiou, T, Tsikaloudaki, K, Tsoka, S and **Chastas, P.** 2019. 'Thermal bridging problems on advanced cladding systems and smart building facades'. *Journal of Cleaner Production*, 214: 62–69. DOI: https://doi.org/10.1016/j.jclepro.2018.12.286

Yoon, SW and **Lee, DK.** 2003. 'The development of the evaluation model of climate changes and air pollution for sustainability of cities in Korea'. *Landscape and Urban Planning*, 63(3): 145–160. DOI: https://doi.org/10.1016/s0169-2046(02)00186-x

Yucong, X, Yifan, F, Shuqin, C, Zitao, W, Weijun, G, Zhijian, S and **Ge, J.** 2023. 'Heat and moisture transfer in wall-to-floor thermal bridges and its influence on thermal performance'. *Energy and Buildings*, 279: 112642. DOI: https://doi.org/10.1016/j.enbuild.2022.112642

TO CITE THIS ARTICLE:
Taileb, A and Sherzad, MF. 2024. Controlling Thermal Bridging as a Value-Added Technique to Enhance Energy Efficient Building Envelopes. *Future Cities and Environment,* 10(1): 27, 1–15. DOI: https://doi.org/10.5334/fce.294

Submitted: 12 July 2024 **Accepted:** 30 September 2024 **Published:** 16 October 2024