

# Commissioning of Exterior Building Envelopes of Large Buildings for Air Leakage and Resultant Moisture Accumulation using Infrared Thermography and Other Diagnostic Tools

Mario D. Gonçalves, Patenaude-Trempe<sup>1</sup>

## Abstract

Infrared thermography is used extensively in the building construction industry as a quality control and forensic tool to assess air leakage performance and the presence of moisture in exterior wall assemblies. Infrared thermography applied to large buildings however requires a good building science background and understanding of the dynamic forces which act on the building envelope. This paper focuses on diagnosing building envelope anomalies in large buildings using infrared thermography and other diagnostic tools.

The application of infrared thermography to assess building envelope anomalies in large buildings is presented in this paper through several practical case study examples. All the case study examples are from buildings located in the north-eastern Canada region. Given the harsh winter conditions and significant temperature variations throughout the year, air leakage and moisture ingress within exterior wall assemblies is a common source of building envelope failures in large buildings. Canadian building codes and construction methods have consequently evolved considerably over the past several years in order to address these issues.

Building science principles are discussed in this paper in order to highlight the basic fundamental principals pertinent to using infrared thermography as a diagnostic tool to assess building envelope anomalies in large buildings. The use of other diagnostic tools, in conjunction with infrared thermography, such as high power blower doors specifically designed for large buildings and portable high output smoke generators, are also discussed.

The primary objective of this paper is to provide an increased level of knowledge to the building community for an improved awareness of the benefits and limitations of using infrared thermography and other diagnostic tools applied to large buildings.

**Keywords:** building envelope, infrared thermography, air leakage, large buildings.

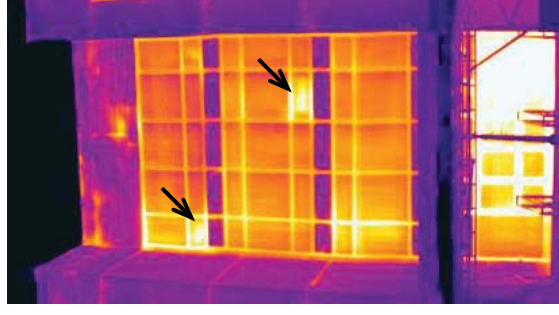
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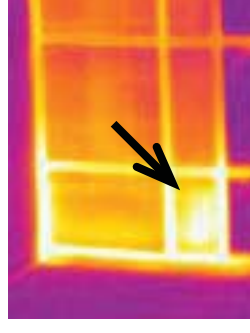
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## Introduction

Infrared thermography applied to large buildings is an excellent tool to help identify and locate air leakage and the presence of moisture in exterior wall assemblies. Infrared thermography alone however will **not identify the cause or source** of any given anomaly. In fact, what appears to be an anomaly based on thermographic imaging alone may not necessarily be a problem at all (as illustrated in Figures 1, 2 and 3 – anomaly noted on exterior is actually an interior heat source). Proper interpretation based on a thorough assessment of the building being evaluated as well as a solid understanding of building science principles and the dynamic forces which act on the building envelope are of utmost importance.



**Figure 1:** What may appear to be a thermal anomaly in the curtain wall assembly is visible in this exterior thermogram (building under positive pressure).



**Figure 2:** Close-up view of figure 1.

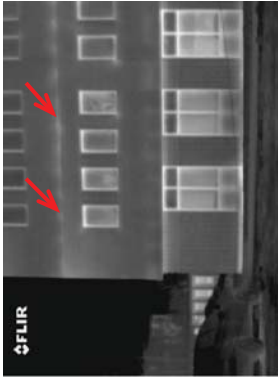


**Figure 3:** An interior heat source located directly against the interior side of the CW assembly yields misleading results.

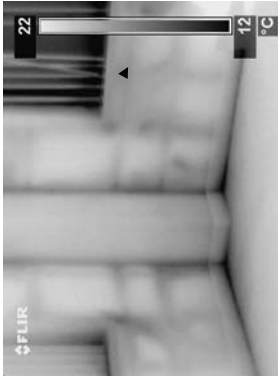
The primary objective of this paper is to provide an increased level of knowledge (and not a detailed guide) to the building community for an improved awareness of the benefits and limitations of using infrared thermography and other diagnostic tools applied to large buildings.

## Principals

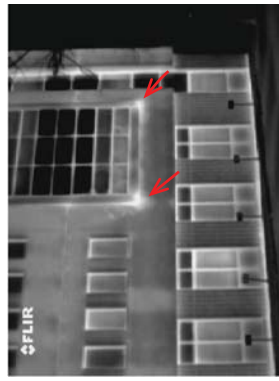
Infrared thermography is a technology that allows infrared or heat radiation to be transformed into a visible image. Combined with other diagnostic tools, infrared thermography can be used to assess the overall air leakage and thermal performance of a building envelope. Heat loss by conduction (Figure 4), convection (Figure 5) and air leakage (Figure 6) as well as the presence of moisture in an exterior wall assembly (Figure 7) can be detected by use of infrared thermography. Each of these different heat and moisture transfers produces different thermal expressions and need to be interpreted accordingly. Strict adherence to the necessary environmental conditions for each type of building inspection is required to ensure suitable results from the thermographic inspection. An inspection carried out under unsuitable environmental conditions will provide no results at best and erroneous results at worst.



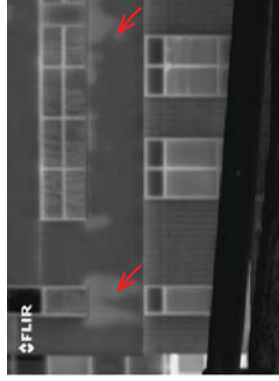
**Figure 4:** Conductive heat loss at masonry structural shelf angle support (building under positive pressure).



**Figure 5:** Convective heat loss pattern noted below windows (building under negative pressure).



**Figure 6:** Air leakage noted at the bottom corners of the curtain wall assembly (building under positive pressure).



**Figure 7:** Moisture noted below the windows in the exterior masonry wall assembly (building under positive pressure).

Infrared cameras for building applications are available in a wide variety of models and price ranges. Apart from using the proper camera and lens for a given application, the qualifications of the person operating the camera and performing the inspection is the most determining factor in obtaining an accurate assessment of the performance of the building envelope. An excellent camera used with the wrong settings and under inappropriate environmental conditions will ultimately yield misleading and inaccurate results. Reporting results based on an inaccurate assessment will have an important impact on the subsequent decision making process. In certain instances, what appears to be an anomaly may in fact not be a problem at all and an inaccurate assessment may result in needlessly recommending extensive remedial measures. In other instances, an inaccurate assessment may result in important anomalies being overlooked. When dealing with large buildings, the inaccurate assessment of a given deficiency can be repeated several times throughout the building and may as a result imply serious implications.

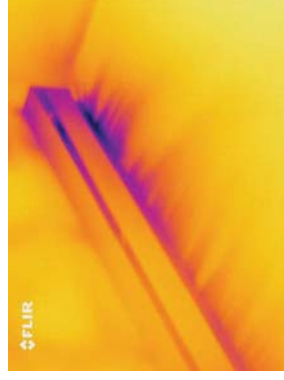
A prerequisite for any thermographer dealing with buildings, particularly large buildings, is a thorough understanding of building science and construction. A thermographer's level of expertise will vary considerably depending on his field of application. An experienced roofing thermographer, for example, does not necessarily have the necessary experience to undertake a building envelope thermographic assessment, just like a building thermographer is not necessary qualified to undertake electrical inspections. Another distinction is the difference between home inspections and large building assessments which require different qualifications and often different equipment and diagnostic tools.

The following consists of a non-exhaustive list of some primary basics which apply to the assessment of the building envelope of large buildings:

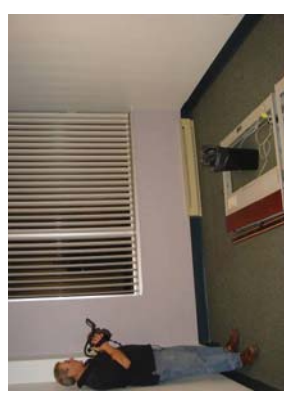
### 1. Camera and settings

The infrared camera shall have the appropriate wave length, thermal and spatial resolution, level of temperature accuracy and temperature operation range. The camera shall also be mounted with the appropriate lens depending on the viewing distance (typically, a minimum of two lenses are required, a telephoto lens for exterior applications and a wide angle lens for interior and exterior applications). The ability to view images in either color or monochrome is an added feature which may facilitate interpretation in certain conditions.

The thermographer must have an in-depth knowledge of the use, operation and limitations of the specific camera he is using. The camera's emissivity, viewing distance, temperature and range as well as relative humidity settings must be calibrated and set accordingly before each inspection. The thermographer must also ensure that he is positioned at a proper viewing angle (often access to neighboring roofs or motorized lift equipment is required when looking at the exterior of tall buildings). Given the complexity and scale of assessing large buildings, in addition to recording infrared still images, the entire infrared inspection should be videotaped and reviewed in detail after the inspection as part of the reporting process. Actual photographs of the areas inspected should also be recorded and referenced to the corresponding thermograms (Figures 8 and 9).



**Figure 8:** Air leakage noted below electric base board (building under negative pressure).



**Figure 9:** Actual photograph of corresponding area.

### 2. Exterior environmental conditions

The exterior environmental conditions play an important role on the quality and accuracy of the infrared inspection assessment. Precipitation in the form of rain or snow will create an obstacle between the infrared camera and the exterior surfaces being inspected (exterior thermographic inspections shall not be undertaken under these conditions). Depending on the type of building envelope enclosure (masonry cladding, solid masonry or curtain wall for example), the exterior ambient temperature and temperature differential across the wall assembly, time lag after sunset, time lag after last rainfall as well as wind intensity and direction will all have an important impact on the infrared results. In the case of a solid masonry wall for example, when assessing air leakage, the temperature differential between the interior and exterior of the building must be much greater than in the case of a metal and glass curtain wall. However, wind conditions are much more critical when assessing air leakage of a metal and glass curtain wall (due to its limited capacity for heat retention) compared to a solid masonry wall assembly.

### 3. Interior environmental conditions

Much like the exterior environmental conditions, the interior environmental conditions also play an important role on the quality and accuracy of the infrared inspection assessment. In occupied buildings, the interior environmental conditions such as temperature and relative humidity are typically maintained at the building's normal operating conditions. Building pressurization is however by far the most important and critical factor which must be monitored and controlled when undertaking a building envelope thermographic assessment. Depending on the type of inspection (exterior or interior), the type of assessment (air leakage assessment, moisture detection or thermal evaluation) as well as the wall composition, different building pressurization conditions will be required (positive or negative pressure at different intensities and duration).

Ideally, building pressurization is controlled by the building mechanical systems. This is accomplished by controlling the supply air intake and exhaust (supply open and exhaust closed for positive interior pressure, supply closed and exhaust open for negative interior pressure). This is however not always possible depending on the building's mechanical system and their limitations. With the exception of the common corridors, residential condominium buildings for example are typically not equipped with a centralized mechanical system. In other instances, buildings with older mechanical systems are often limited in terms of control as well as operating temperatures (fully opening the supply air intake is often not possible during extreme cold conditions). Under these circumstances, the use of portable high-power pressurization equipment is required to create the necessary pressure conditions (Figures 10 and 11).



**Figure 10:** High power three-fan portable building pressurization system installation.



**Figure 11:** Monitoring panel equipped with remote weather station receiver and digital micro manometers.

Depending on the size and level of air-tightness of the building, it is typically possible to pressurize either the entire building, several floors at a time or individual units using a portable three to six high-power fan system. The resulting pressure differential is measured and controlled by using calibrated digital micro manometers. It is also important to monitor the exterior and interior temperature as well as the wind intensity and direction (this can be done by using a calibrated portable remote weather station).

### 4. Inspection process

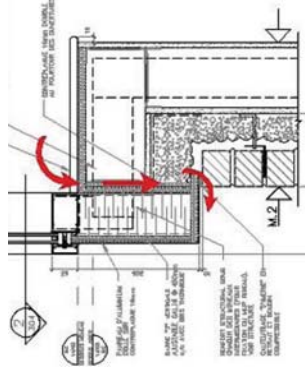
A thorough inspection process must be well established and rigorously followed to ensure consistent and reliable results. The inspection process should proceed in accordance with industry recognized standards. The principal references are listed below:

- CAN/CGSB 149-GP-2MP: Manual for Thermographic Analysis of Building Enclosures;
- ASTM C1060: Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings;
- ANSI-A-SHRAE 101: Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics;
- ASTM E1186: Standard Practice for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems;
- ASTM E779: Standard Test Method for Determining Air Leakage Rate by Fan Pressurization.

In addition to the references listed above, a generic specifications format developed in Canada by the National Master Specification (NMS) will be introducing four new sections relating to specifying inspection services for building envelopes, roof assemblies, electrical and mechanical systems. These generic specifications are intended to be used for bid projects for large buildings in both the private and public sector. The NMS sections will define thermographic and other equipment requirements, thermographic equipment operators and report authors qualifications, general and specific inspection procedures as well as specific submittal and report requirements for the different type of assessments and inspection. Specifiers will be able to use the generic format as a template to add or delete items required for their specific project.

### 5. Validation

An important and often neglected step in the assessment process consists in identifying and validating the causes of the observations noted with the infrared camera. The cause of certain anomalies may be obvious to an experienced thermographer and should be backed at the very least by referencing detail drawings (Figure 12). When further investigation is required, exterior or interior dismantling (Figure 13) and/or smoke testing should be undertaken (Figures 14 and 15). In order to adequately assess the performance of the building envelope of large buildings and provide conclusions and recommendations forming part of the thermographic analysis process, technical or professional training in building envelope design and hygrothermal performance coupled with pertinent field experience dealing with large buildings is essential.



**Figure 12:** Detail drawing illustrating air leakage path.



**Figure 13:** Dismantlement of interior finishes at window head reveals direct air leakage path.



**Figure 14:** Excessive smoke exfiltration below wall assembly.



**Figure 15:** Excessive smoke exfiltration at curtain wall weep hole locations.

## Summary and Conclusion

Infrared thermography is a technology that allows infrared or heat radiation to be transformed into a visible image. Combined with other diagnostic tools and when undertaken in strict adherence to the necessary environmental conditions, infrared thermography applied to large buildings is an excellent tool to help identify and locate air leakage and the presence of moisture in exterior wall assemblies. Given the complexity and scale of assessing large buildings, in addition to recording infrared still images, the entire infrared inspection should be videotaped and reviewed in detail after the inspection as part of the reporting process. Infrared thermography alone will **not identify the cause or source** of any given anomaly. Proper interpretation based on a thorough assessment of the building being evaluated as well as a solid understanding of building science principles and the dynamic forces which act on the building envelope are of utmost importance.

The thermographer must have an in-depth knowledge of the use, operation and limitations of the specific camera he is using. Apart from using the proper infrared camera and lens for a given application, the qualifications of the person operating the camera and performing the inspection is the most determining factor in obtaining an accurate assessment of the performance of the building envelope. A thorough inspection process in accordance with industry recognized standards must be well established and rigorously followed to ensure consistent and reliable results. Identifying and validating the causes of the observations noted with the infrared camera is an important and often neglected step in the assessment process. Observations and recommendations should be backed by referencing detail drawings and conducting further investigations consisting of exterior or interior dismantling combined with smoke testing on an as required basis. In order to adequately assess the performance of the building envelope of large buildings and provide conclusions and recommendations forming part of the thermographic analysis process, technical or professional training in building envelope design and hygrothermal performance coupled with pertinent field experience dealing with large buildings is essential.

## References and Additional Reading

1. National Research Council Canada, "CBD-229, Thermographic Identification of Building Enclosure Effects and Deficiencies", December 1983.
2. Colantoni, T. and McIntosh G.B., "Pressurization Effects on Thermal Images of Building Envelopes", Thermalsense XI 1989.
3. Colantoni, T., "Infrared Thermographic Investigation Procedures for Four Different Types of Generic Exterior Wall Assemblies", Thermalsense XXI 1999.
4. Snell J. and Spring R., "Nondestructive Testing of Building Envelope Systems using Infrared Thermography", InfraMatation 2002.

## Case Study Examples

Three case study examples are presented below in order to illustrate the type of anomalies commonly encountered during a thermographic assessment of the building envelope of large buildings.

### Case study example no. 1

In this example, complaints of flies entering the building at the beginning of the first year heating season were reported by the building owner. A thermographic analysis of the building envelope was undertaken during the heating season. The building was pressurized by means of the building's mechanical systems and excessive air-leakage was noted at the top of several of the curtain wall assemblies (Figures 16 to 20).



Figure 16: Actual photograph of one of the curtain wall sections inspected for air leakage.

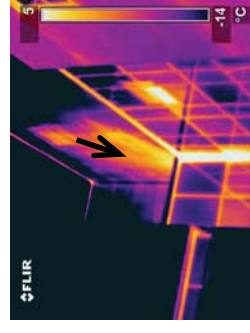


Figure 17: Thermogram of the top portion of the CW assembly in figure 16.



Figure 18: Subsequent smoke testing undertaken to determine and validate air leakage sources.



Figure 19: Excessive smoke exfiltration was clearly visible at the top portion of the CW assembly.



Figure 20: Dismantlement of the top portion of the CW assembly was undertaken to establish appropriate corrective measures.

### Case study example no. 2

In this example, a thermographic analysis of the vertical building envelope was undertaken as part of the commissioning process of this new building construction. Several anomalies were identified, including excessive air leakage via the metal paneling below one of the curtain wall assemblies (Figures 21 to 24) and excessive moisture accumulation in the exterior masonry of part of the building (Figures 25 and 26).



Figure 21: Actual photograph of one of the curtain wall sections inspected.

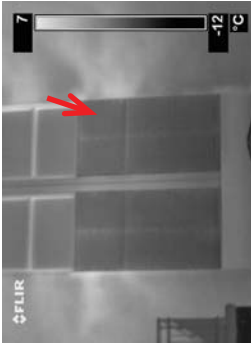


Figure 23: Thermogram of bottom CW section with building under negative pressure.



Figure 22: Thermogram of the overall CW assembly in figure 21.

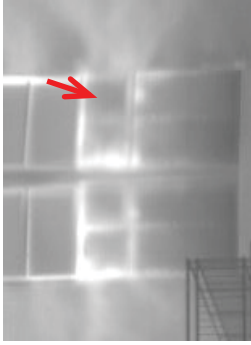


Figure 24: Thermogram of bottom CW section with building under positive pressure.



Figure 25: Actual photograph of one of the masonry wall sections inspected.

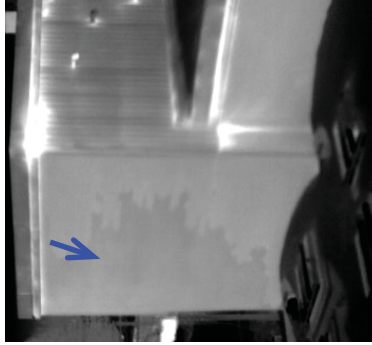


Figure 26: A large portion of the masonry wall assembly in figure 25 noted to contain moisture.

### Case study example no. 3

The interface detail between two different wall assemblies is a common source of air leakage and water infiltration problems. In these two examples, a thermographic analysis revealed excessive air leakage at the curtain wall interface with the adjacent masonry, requiring extensive remedial measures to correct.

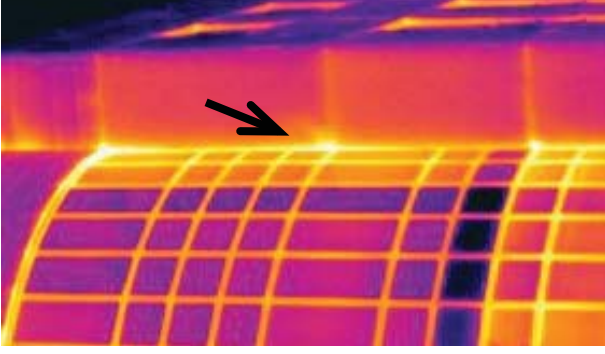


Figure 27: First example thermogram of interface of curtain wall and masonry wall assembly.



Figure 28: Overall view of the interface detail in figure 27 after removing the adjacent masonry.



Figure 29: Close-up view of figure 28 - no air seal at the interface detail (the polyethylene sheet was installed as a temporary measure after removing the masonry).



Figure 30: Second example actual photograph of inspected curtain wall and masonry assembly.

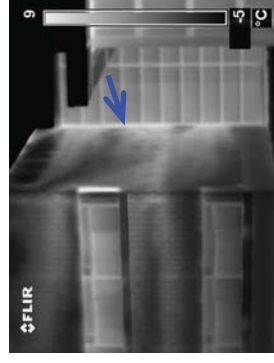


Figure 31: Thermogram reveals excessive air leakage at interface of curtain wall and masonry assembly shown in figure 30. Further investigation confirmed no air seal at the interface detail.