Title: **Increasing Problems of Falling Ice and Snow on Modern Tall Buildings**

Authors: Michael Carter, Director/Consultant, Northern Microclimate Inc. (NMI)
Roman Stangl, Director/Project Manager, Northern Microclimate Inc. (NMI)

Subjects: Façade Design
Fire & Safety

Keywords: Climate
Façade
Life Safety

Publication Date: 2012

Original Publication: CTBUH Journal, 2012 Issue IV

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Increasing Problems of Falling Ice and Snow on Modern Tall Buildings

Michael Carter

Roman Stangl

Reported incidents of hazardous ice and snow falling from buildings are on the rise, specifically for recently completed tall buildings. High performance façades have improved internal thermal performance, but increased the conditions for forming ice on metal and glass skins. This paper sheds light on the issues, describing the factors that contribute to icing and hazardous ice and snow formation, and provides methods to address these issues within the design process.

Authors

Michael Carter, Director/Consultant
Roman Stangl, Director/Project Manager

Northern Microclimate Inc. (NMI)
33 Water Street N.
P.O. Box 277
Cambridge
Ontario N1R 5T8
Canada

t: +1 226 444 0188
f: +1 226 444 0183
e: roman.stangl@northernmicroclimate.com; mike.carter@northernmicroclimate.com
www.northernmicroclimate.com

Michael Carter
Michael is a director and the lead technical consultant of Northern Microclimate Inc., an architectural consulting firm that focuses on the prediction, evaluation and mitigation of falling ice and snow. He has contributed to publications with the National Institute of Building Sciences, Construction Specifications Canada and the International Conference on Snow Engineering. Recognized as an expert in his field, Michael works with architectural and engineering firms, focusing on his ability to visualize and interpret the characteristics of a building design within its local micro-climate.

Roman Stangl
Roman is a director and the lead project manager of Northern Microclimate Inc. A CTBUH member with international experience, he has been actively managing and consulting within the design and construction field since 2005. Roman has contributed to publications with the National Institute of Building Sciences, Construction Specifications Canada and the International Conference on Snow Engineering.

Background

Troublesome ice and snow formations on buildings are in no way a new phenomenon. Building designers and owners have long struggled with the various aspects of winter precipitation. This has led to the development of standards and codes to address such topics as wind loads and snow loads during building design. However, the aspect of falling, sliding or windblown ice and snow from a building is a topic that has not been widely acknowledged, and consequently has generated little in the way of standards, guidelines or prescriptive building code requirements to assist designers. In addressing concerns, designers have largely relied on past experience or trial and error methods for reducing potential risks. The learning process industry-wide has been slow or non-existent due to the reluctant nature of various parties to discuss errors or incidents, for fear of litigation. Open discussion of the issues will accelerate the learning process around the emerging problems created by advancing façade performance and tall building design.

Modern Towers, New Issues

The façades of some recently completed high performance buildings are actively promoting hazardous ice and snow formations under typical winter conditions, rather than unusual, severe or infrequent weather conditions. This realization is unnerving, as modern high performance buildings often show only modest or questionable reductions in energy usage, at times falling short of their prediction models. Furthermore, building codes and standards have shown a trend towards increasing the performance of roof, wall and glass assemblies, as evidenced by comparing ASHRAE Standard 90.1 between the 2004 and 2010 versions (see Table 1). Further exacerbating the issue of ice and snow formations on façades is the addition of various exterior elements intended to control solar gain, which ultimately serve as cold collection surfaces. As a result, reports of falling ice and snow incidents from high performance buildings over the last ten years have shown an increase in the frequency and severity of hazardous ice and snow formation. Although formal records of falling ice and snow incident reports do not yet exist, this trend has been identified through a record of media accounts and project experience. New reports in the last two years have detailed dozens of falling, sliding or windblown ice and snow incidents in North America alone, including such buildings as the Duke Energy Building in Charlotte and the New York Times Building in New York.

Many of the events investigated by the authors have not been found to be caused by a single influencing factor, but rather by a list of factors that tend to have a cumulative effect. True, there are situations where a single design feature, such as a window sill/mullion configuration or a solar shade device, has had a significant impact on the formation of hazardous ice and snow. However, over the course of numerous building investigations, which includes multiple cold room laboratory tests conducted in collaboration with the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), this is found to be the exception rather than the rule when it comes

	2004	2010	% Change
Opaque Elements	**Insulation Min. R-Value**	**Insulation Min. R-Value**	
Roof (Insulation entirely above deck)	R-15	R-20	33%
Wall above grade (mass)	R-5.7	R-9.5	67%
Steel-framed walls	R-13	R-13 +R-7.5 Cont.	58%
Fenestration	**Assembly Max. U**	**Assembly Max. U**	
Vertical glazing 0–40% of wall	U-0.57	U-0.50	14%

Table 1. Building Envelope Requirements – ASHRAE Standard 90.1 2004 – 2010 Comparison (Table 5.5-4, Building Envelope Requirements for Climate Zone 4 - Non-Residential) © ASHRAE

to newly completed high performance buildings.

In the simplest of explanations, the currently achieved reductions in heat loss from many buildings' interiors are promoting an increase in potentially dangerous ice and snow formations. As insulation values, glass technology, and building systems progress in the future to conserve energy, the corresponding further reductions in heat loss through the façade will only increase the probability of hazardous ice and snow formation and release, creating significant challenges for building designers, owners and operators, with further impacts to public safety. Consequently, investigation and research into the causes of these issues is needed and is ongoing. However, at this time empirical data and/or detailed case studies have not been developed due to the reluctance of building owners and designers to discuss their challenges openly.

The following case examples are based on interviews with building owners and operators of recently completed buildings, combined with reviews of incident and cold room test reports. The cases reveal interesting data that initially seemed counter intuitive, but can be explained when the individual design details are investigated.

Figure 1. Example of snow and ice freezing on vision glass panel. © NMI

Case Example 1

Building Type: Tall, High Performance
Location: Northeastern United States

In this example (see Figure 1), observations of ice sheets were reported to form in the center of vertical vision glass of a recently completed building, and would subsequently release and fall to the busy street below. This report was taken with some skepticism as heat loss characteristics of a traditional window and frame relationship call for the exterior skin temperature of the center of the window to be the warmest location, since it is the furthest from the influence of the frame that would typically have the advantage of insulation or a thermally broken profile. However, in this particular case the large insulated glass panels offered an improved thermal performance over traditional glass and there was no spandrel panel, only a minimalistic metal frame. Thus, the glass panels were the main resistive component of the assembly, promoting ice to form directly in the center (the coldest location) of vertical vision glass panels. The key point to this example is the fact that the profile of the assembly is producing skin temperatures that align with exterior temperatures during more typical winter precipitation events, thereby promoting an increase in frequency and severity of icing over more traditional wall assemblies. To be clear, the relationship between glass and frame is not the sole cause, but likely a tipping point for this particular example. Other influencing factors could include: the move to more efficient with under floor displacement ventilation systems, the heat loss characteristics of the whole façade as a system, and external factors such as elevation, building geometry and orientation to prevailing weather. Overall, this example reveals that as improvements in building performance are made, and exterior skin temperatures are reduced or at a minimum modified, there is opportunity for hazardous ice and snow formations to occur in different manners and amounts.

Case Example 2

Building Type: Tall, High Performance
Location: Midwest United States

The second example (see Figure 2) also deals with the relationship between glass and frame. However in this case the focus is on ice and snow formations that accumulate on window sills or mullion caps at the base of vision panels. In this example, significant ice formations were consistently forming at the edge of mullion caps and falling. Historically, sills or mullion caps of a relatively small dimension were not prone to hazardous ice formations, as heat loss through the curtain wall system would create sufficient melting to avoid significant ice formations. However,

> “High performance façades have improved internal thermal performance, but increased the conditions for forming ice on metal and glass skins…”

again we note that as building performance improves, the exterior temperature of the building skin becomes colder, resulting in a change in the typical melting process of accumulated snow on the mullion cap. In this particular example, melting of windblown snow would occur on segments of the vision glass draining to the frame and sill below, as well as in the area of the frame and sill closest to the glazing panel, where heat loss could raise the skin temperature above freezing. The melted or slushy snow formations in these areas would then work their way to the outer edge of the sill and subsequently refreeze and eventually fall or be windblown. This condition is common on larger low-slope ledges. However as the thermal performance of the building façade improves the size of surfaces at the base of a glass panel that can create hazardous ice is getting smaller. Regarding this particular case, the façade has been tuned to generate ice during more common winter precipitation events.

Case Example 3

Building Type: Tall Building Renovation
Location: Western Canada

In this example (see Figure 3), a 20-year old tall building was reported to have experienced a severe falling ice event from approximately 137 meters above street level. The ice sheets were observed to form and then fall from a ledge situated near the top of the building. As this was the first reported incident of this magnitude, it was thought that an unusual meteorological event or changes in the local micro climate due to the addition of other nearby tall buildings had caused the incident. However, the investigation could not directly link the incident to these variables. Upon further questioning of the building operations personnel, it was learned that the interior of the upper floors had recently been renovated to improve occupant comfort. The renovation included repairs to reduce air leakage and the addition of insulation to reduce heat loss. It was evident that the performance of the exterior façade at the top of the building had changed, causing ice buildup in areas that previously drained away as water. This meant that falling ice was likely to occur in most every winter storm, creating the need for an extensive and permanent falling ice and snow solution.

Figure 2. Example of hazardous ice formation on window sill. © NMI

A Complex Issue

These case studies are only three of many. However, they highlight the core issues of changes to skin temperatures that are common to all or most high performance buildings, which are leading to an increase in icing and falling ice and snow incidents. Below is a more general list of other factors that have been known to influence or contribute to potentially hazardous ice and snow formations:

1. The advancement of material properties, often intended to conserve energy or reduce the carbon footprint, which in turn increase the potential for ice and snow formation. The advances include glazing technologies and cladding systems, or the use of non-traditional materials, coatings, surface textures and colors.
2. The addition of exterior architectural features, such as solar shades, fins, turbines, double façades, trombe walls, solar panels and supporting structures intended to conserve or generate energy, results in increased exterior cold surface areas.
3. The advancement of internal and external building systems, which are largely influenced by energy conservation, have modified the heat loss profile of the overall building envelope (e.g., more efficient HVAC strategies or assumptions, displacement ventilation, increased insulation in spandrel panels and more efficient cladding systems).
4. Taller buildings and/or the addition of structures, spires or communication equipment atop buildings, interacting with the surrounding colder climate at elevation.
5. The advancements in design technologies that allow more complex building or façade shapes, angles and geometries.
6. Influences of a building's orientation, massing or geometry relative to wind and solar effects or the influence of the surrounding buildings (e.g., urban buildings can experience wind shelter or strong wind gusts based on their exposure and/or relationship to their surroundings).
7. Any of the above factors can affect the winter performance based on the type of weather the building experiences. This leads to the need for awareness of the various geographic influences and the problematic weather scenarios that arise. For example, the prominence of freezing rain in warmer climates versus multiple freeze and melt conditions in cool climates, or extended cold periods in colder climates.
8. Climate change is increasing the variability and severity of winter weather, thereby creating new challenges not predicted by past assumptions, illustrated by the increase in roof collapses in the northeastern United States in recent years.

Figure 3. Example of hazardous ice formation on a ledge. © NMI

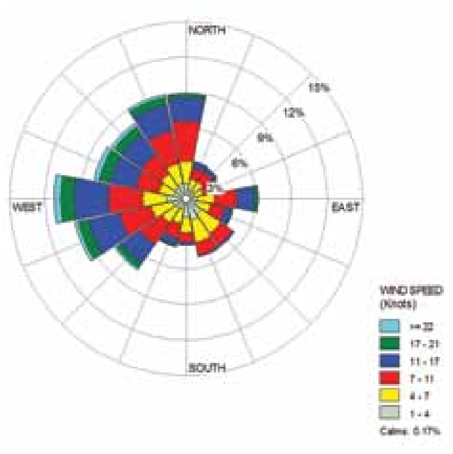

Figure 4. Example of a wind analysis demonstrating wind direction, speed and frequency for winter winds. © NMI

Figure 5. In-cloud/rime ice formations at the Mt. Washington Observatory. © Mt. Washington Observatory

When Ice and Snow Turn Dangerous

Points 7 and 8 above address the topic of winter weather and its variability, leading to the question, "What makes hazardous ice and snow?" The occurrence of winter weather does not guarantee a hazardous ice or snow formation. That said, the occurrence of winter precipitation, whether from snow, sleet, mist or freezing rain, can be thought of as the catalyst for the development of potential hazards.

People who grew up in a northern climate where ice and snow are part of a winter experience will likely have memories of wonder as a child when they awoke in the morning and looked out the bedroom window to find a winter wonderland. They likely observed deep soft snow, wet heavy snow, large drifts of snow or even the hard aged snow of the snowman built the day before. Maybe they have memories of large dripping icicles from the ice-laden gutters of the roof edge outside their window. These are all examples of the various types of snow conditions that can impact a building façade. The tricky part is to understand variables and conditions that transform a winter wonderland into hazardous projectiles of falling ice and snow from a tall building.

To assess a proposed building, it is therefore important to first develop a thorough understanding of the most common meteorological events through a review of historical meteorological data. This analysis will reveal the frequency, directionality and severity of various types of winter storm events, such as freezing rain, wind drifted snow, heavy snowfall, in-cloud icing or freezing mist (see an example in Figure 4).

This analysis is then combined with a review of local micro-climate influences, including geographical influences and neighboring buildings, and a further interpretation of the interdependency between the proposed building's geometry and its micro-climate, such as the interplay between wind and building geometries, surface color or texture-curved versus flat versus sloped geometries and snow or ice accumulation. These variables must then be interpreted in their various states of formation and transition over time on a particular building façade or component. This determines if an accumulation of ice or snow is likely to naturally melt away, slide or be windblown from the façade. Once all these aspects are combined and assessed, a final prediction of performance can be made.

For example, an often misunderstood event that impacts tall buildings in particular is the formation of high elevation in-cloud ice. This type of icing is also known as rime ice and is most often associated with aircraft wing icing. Similar icing formations are also associated with freezing mist and freezing fog formations when they occur with wind at lower elevations. Regular occurrences of this type of icing event has been reported on buildings and structures in major North American cities such as Boston, Chicago, New York and Toronto; as well as other cities around the world. Tokyo Sky Tree recently received icing mitigation to address fears of snow and ice falling from the upper portion of the structure during the winter weather, according to the Tokyo Times. The characteristics of the actual ice formation that ultimately releases can range from thin dense sheets of hard ice that flutter to the ground to bowling ball-sized chunks of white rigid ice that are less dense but make significantly larger projectiles. These ice formations are largely a result of wind-driven super cooled water droplets from visible cloud formations, fog or mist coming in contact with cold building materials (see Figure 5).

Thus, parameters of building shape, orientation and particularly façade heat loss characteristics all play a role in the frequency, massing, density and overall severity of an ice release from tall buildings. Another determining factor is elevation at lower elevations freezing mist and freezing fog are more likely to occur, while higher elevations tend to promote in-cloud and rime ice formations. The latter can be a cause for great concern as weather conditions can be deceivingly pleasant at ground level, while high level clouds on a spring or fall day can be generating hazardous ice formations on vertical surfaces at higher elevations on buildings or structures. These formations build up until their mass can no longer be supported by the connection to the façade and then released.

Paths to Prevention

When confronted with challenging whole façade issues as shown in the first two case examples, building owners and operators often reluctantly decide to manage the revealed difficulties with their building, after a falling ice or snow incident has occurred, instead of implementing mitigation strategies. Typically the available mitigation options such as the addition of retention barriers, coatings or heat products are identified as either extremely costly, difficult to implement, unproven and/or a contradiction of the original design objective. This is obviously not the case for every ice and snow issue that can occur on a building. However when the issue is related directly to the overall high performance aspects of the building and its façade, it is all too often true.

> “The review of winter performance process can further identify unforeseen impacts of winter precipitation on other design aspects, such as structural loading, infiltration or blockage of building ventilation, obstructed views from skylights and clearstories, potential for damage or leakage.”

So what can be done differently within the design process to identify potential risks early and create strategies to reduce future ice and snow challenges? First and foremost, it is recommended that winter weather performance be made a part of the overall design focus. To accomplish this, project specific criteria or a design directive can be developed outlining the expected performance of a building's exterior, given different winter weather scenarios. This raises the question – how often is it acceptable for building operations to be impacted or the need for restricted access required? This question should be addressed within a directive along with the question, what will drive the decision-making process? Is the design vision paramount or will budget play the key role? Since winter performance issues are often brought to light later in design, either by the owner/operator of the proposed building or by the design directive, their mitigation becomes an unexpected expense burden that quickly boils down to cost versus the design vision. However, if a review of winter performance is initiated early, impact can be minimized or avoided completely. Specifically regarding high performance design, an early focus on winter performance can bring forth a holistic view of the true impacts of potential energy reduction strategies and façade design.

Mitigation most often takes the form of design modifications or integrated design solutions; however add-on retention devices, active snow removal systems, or manual removal methods can be used when the less obtrusive mitigation forms are not applicable.

The review of winter performance process can further identify unforeseen impacts of winter precipitation on other design aspects, such as structural loading, infiltration or blockage of building ventilation, obstructed views from skylights and clerestories, potential for damage or leakage.

Tools and studies that can be used to investigate, refine and subsequently validate the winter performance of high performance building design include:

1. A high altitude site specific Historical Meteorological Analysis designed to reveal high elevation climate parameters, including wind direction, frequency and severity of potential icing events.
2. Historical Meteorological Analysis of winter storm events such as snowfall, wind influences, freezing rain, air temperature and solar exposure characteristics during and after storm events.
3. 3D Computer Analysis structured to model interior and exterior wall microclimates for various aspects of the design (e.g., thermal properties of a wall that include the influences of interior near wall climates during specified exterior winter storm conditions).
4. Façade mock-up testing in a climate controlled test laboratory that can be used to validate, refine or compare mitigation strategies.
5. High elevation in-cloud icing testing of a mock-up.
6. Winter operational protocol and maintenance procedure development and implementation.

Conclusion

The investigation of falling ice and snow reports from tall buildings has led to the understanding that multiple factors unique to tall high performance building practices have contributed to an increase in the frequency and severity of falling ice and snow incidents. As thermal profiles of façades are changing, it is evident that a tipping point is being reached as some façades literally promote hazardous ice formation. Subsequently, it is apparent that there is a need for a focus on winter façade performance within the high performance building design process, with increased importance applied to tall buildings. ■