Ice Damming: Case Studies in Diagnosis and Remediation

Mark Lucuik, P.Eng.

William C. Brown, P.Eng.
Member ASHRAE

ABSTRACT

Ice damming is a problem that annually affects a large number of buildings in Canada. It is generally associated with interior leakage and with accompanying mold and rot and can also present a danger of falling ice. However, it can also affect the service life of roofing materials and components, even if leakage to the interior doesn't occur.

Ice damming is a building science issue that arises from differential melting and freezing of snow on a roof. The root causes of the melting are frequently far from the roof deck. As a consequence, methods to alleviate ice damming often treat the leakage without addressing the fundamental cause. Such methods can reduce or eliminate the leakage in the short term but, because they do not address the cause of the melting and freezing, they often do not provide a long-term solution. In addition, they frequently do not address the durability issues caused by ice buildup on the roofs. The best solution is to determine the causal factors and undertake appropriate remediation in order to solve the problem on a longer-term basis.

This paper will discuss the factors that contribute to ice damming through detailed case studies on three low-rise condominium complexes in Ottawa, Ontario, Canada. Each complex has suffered severe ice damming since its construction. To develop a remediation strategy, we performed a systematic diagnosis of the cause of the ice damming and the implementation of trial repairs at each site. These trial repairs were monitored (temperature and visual indicators), and it was found that the suggested repairs had some benefit on two sites and little benefit on the third.

The aim of this paper is to present a methodology to provide long-term solutions to the problems associated with ice damming, with emphasis on utilizing sound building science knowledge and principles.

INTRODUCTION

The mechanisms associated with the formation of ice dams are poorly understood by most contractors and many consultants. It is for this reason that many inappropriate and nonworking remedial strategies are implemented in attempts to alleviate ice damming problems.

The purpose of this study is to investigate the potential to reduce or eliminate ice damming by focusing on air leakage between the interior and attic space in low-rise row housing.

Scope of Work

The scope of work for this project involved the following tasks:

1. **Identify Problem Buildings**: A mixture of multi-unit low-rise residential complexes were selected for inclusion in this project. Each project site was selected due to past ice damming that we believed may be associated with attic heat gain. Each building site is described in more detail later in this paper.
2. **Investigation**: We performed detailed visual reviews of all accessible areas of the problem buildings. The purpose of this investigation was to determine contributory factors associated with the ice damming at each site.
3. **Brainstorming Session**: A brainstorming session was performed that consisted of a meeting with established building science specialists to review the outcome of our

Mark Lucuik, LEED AP, is a principal and **William C. Brown** is director of building science at Morrison Hershfield Limited, Ottawa, Ontario.

investigations of the problem buildings and to develop remedial strategies for each complex or building.

4. **Develop Remedial Solutions**: Remedial solutions were developed for each of the buildings to a level that allowed the work to proceed. These solutions were discussed with the building owners in hopes they would undertake the suggested repairs. In each of the cases presented within the project, the owners proceeded with the recommended strategy to reduce ice damming.
5. **Monitoring**: Repairs were monitored for effectiveness on similar adjacent units through periodic visual reviews and monitoring of attic temperatures.

Report Format

The following general section includes a brief discussion of ice damming, as well as information that would apply to all of the project sites (such as general weather information and monitoring details), and also includes a brief discussion of other pertinent studies on ice damming. The next section describes the project sites, including the history of ice damming at each site, the results of our investigation at each site, and the trial repairs implemented at each site. Observations and analysis are presented, as well as a discussion of the findings in both general and site specific terms. Conclusions are reported on a non-site-specific basis.

GENERAL INFORMATION

Factors Affecting Ice Damming Potential

When reduced to its simplest form, the formation of rooftop ice dams requires three elements:

1. Roof top snow
2. Upper areas of roof at or above the temperature at which snow or ice melts
3. Lower areas of roof that are below the temperature at which water freezes

If any of the above elements is not present, ice dams will not form. It is not uncommon for building owners to attempt to resolve ice damming problems through the elimination of items 1 or 3 of the above list (e.g., snow rake use or electric cables). However, it is our opinion that the preferable method to eliminate ice damming problems is to resolve item 2 above (reduce the temperature differential across the roof).

Both internal and external sources of heat could potentially result in problematic roof temperature differentials from an ice dam perspective. Internal heat sources, including conductive heat flow from the interior, air leakage from the interior, or conductive or radiative heat flow from elements within the attic (such as chimneys, plumbing stacks, or skylight walls) are often major factors affecting problematic ice dams. Other factors affecting ice dam formation include the potential for solar gain (roofing color and material), roof shape and complexity (dormers, slopes), complicated building designs (e.g., cathedral ceilings over conventional attics), lack of attic ventilation, and heat-emitting rooftop elements, such as skylights or mechanical ventilation outlets.

This study will focus on the potential to reduce or eliminate ice damming by resolving problematic air leakage into attic spaces. Air leakage is believed to be a major contributor to problematic ice damming in many cases. When air leakage is a major contributor, the solution often utilized in the construction industry is to increase attic ventilation. This increased ventilation could be counterproductive if the most airtight element in the roofing assembly is the sheathing. It is our opinion that the best solution to problematic air leakage into an attic is to reduce or eliminate the number and size of air leakage paths.

Monitoring Procedures

Monitoring at the sites to determine ice damming potential included repeated exterior visual roof reviews (during the winter) and temperature readings in and around the unit attics.

With respect to temperature, measurements were taken using thermocouples attached to self-contained data loggers (Smart Reader Plus 6, by ACR Systems Inc., seven-channel thermocouple data logger). Specific areas for measurement included several attic locations, a unit interior location, and an exterior air location.

The location at which exterior air temperatures were taken (for all sites) was at the back of the Morrison Hershfield Ottawa office. The specific location was on the north side of the building, approximately 1 m (3 ft) from the face of the building and 5 m (16 ft) above grade. This location did not allow direct sunlight on the thermocouple, and it was far from any lights, mechanical ventilation units, or other heat-emitting devices.

To resolve the effects of interior temperature, temperature indices were calculated using the following equation:

$$TI = \frac{T_{attic} - T_{exterior}}{T_{interior} - T_{exterior}}$$

The temperature index is a unitless ratio ranging from 0 to 1 in cold weather (winter). A temperature index near zero represents an attic temperature near the exterior temperature. A temperature index near 1 represents a cold weather attic temperature near the interior air temperature. Attics with temperature indices closer to zero are less likely to exhibit ice damming.

Solar effects were minimized by reviewing temperature data from nighttime only and after a minimum period of two hours after sunset.

When selecting comparable data from two different time periods, consideration was given to the length of continuous data as well as exterior air temperatures. The primary focus was to select data from periods with similar exterior temperatures that could be conducive to ice dam formation (exterior air temperatures colder than –5°C [23°F]). We also attempted to provide data sets for approximately seven continuous days. Due to the variable nature of exterior air temperatures, it was not always possible to obtain comparable data with similar exterior temperatures or for seven-day periods. On these occasions, some comparable sets of data had different exterior temperatures and/or shorter periods of measurement.

The temperature analysis assumes a steady-state condition and generally ignores the effects of thermal mass. We recognize that this is not a valid assumption, but we are of the opinion that the effects of thermal mass are minimal with respect to attic temperatures.

Weather Conditions in the Winter of 2004

From our visual reviews of other sites within this project and across the city, the winter of 2004 was not a particularly problematic year for ice damming. This winter included relatively long durations in which temperatures were very cold, followed by short periods in which temperatures rose above the freezing mark. Further, snow accumulation was relatively low.

Other Ice Damming Studies

There have been many studies of ice dams by Canadians, Americans, and Europeans. Here we have commented on two important studies that we believe include information valuable to this report.

CMHC Research Report: Ice Dam Research Data Analysis (CHMC 1996). A research report was prepared for Canada Mortgage and Housing Corporation in 1996. The authors of this study monitored attic temperatures in 33 houses of which 16 reported problematic ice damming and 17 did not. The goal was to determine common elements of the houses exhibiting ice damming that could provide an explanation for the warm attics.

Notable findings from this study were:

- Ice dam house attics were about 4°C (7°F) warmer than those without ice dams during a period with an average exterior temperature of –6°C (21°F).
- Insulation amounts did not appear to be a major contributor.
- All ice dam houses had chimneys that passed through the attic, while most non-ice-dam houses had exterior chimneys.
- Complexities of house and roof design can create problematic details that might contribute to high wintertime attic temperatures.

Study by Tobiasson, Buska, and Greatorex (1998). A study by Tobiasson et al. (1998) in particular offers valuable information directly pertaining to this project. That study investigated problematic ice damming in upstate New York. They monitored attic temperatures in several buildings that experienced no, some, or severe icing problems. These results were used to provide equations to indicate when ice damming might occur. Specifically, three equations were provided:

$t_a = 0.844t_o + 10.206$: No icing problems

Figure 1 *Site 1, ice formation on non-repaired unit.*

$t_a = 0.784t_o + 14.44$: “Some” icing problems

$t_a = 0.472t_o + 38.461$: Severe icing problems

where t_a is attic temperature in degrees Fahrenheit, and t_o is exterior air temperature in degrees Fahrenheit.

Assuming an interior temperature of 21°C (70°F) and an exterior temperature of –10°C (14°F), these specific equations can be used to produce a temperature index of 0.15 at which no icing problems will occur, 0.2 above which ice problems might occur, and 0.55 at which severe ice problems might occur. Similar temperature indices are apparent at exterior temperatures of –5°C (23°F) and –15°C (5°F).

We recognize that the equations provided within the Tobiasson et al. study were based on measurements taken from three different building attics. This is a small sample size, so the equations should not be relied upon as definitive proof of the degree of ice damming. However, we believe they provide an indication of ice damming potential related to high attic temperatures.

PROJECT SITE DESCRIPTIONS

Three sites were selected for inclusion in this paper. Each site consists of row housing units with a history of ice damming problems. All sites are located in Ottawa, Ontario, Canada. A more detailed description of each site is provided in the following subsections.

Site 1

Site 1 is a wood-framed townhouse complex constructed in 1984 (Figure 1). The buildings have been experiencing severe ice damming problems since occupancy. The problems have been well documented with reports and photographs. Approximately 85% of the units have experienced ice dam-related roof leaks within the last nine years. Seven consultants

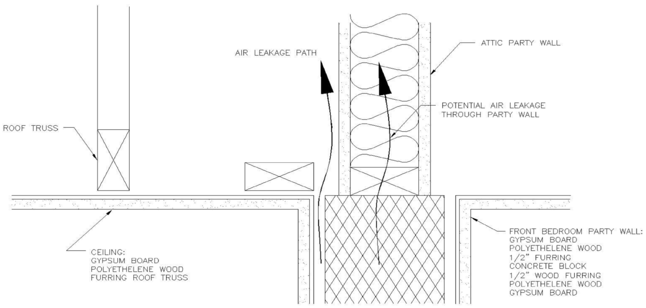

Figure 2 *Air leakage path at party wall.*

had provided opinions and implemented various repairs prior to our involvement in 2001.

Investigation. Our investigation at this site consisted of visual reviews of roof and attic spaces in three dwelling units. We also reviewed the general interior conditions in two units. Included within this review were several test openings through the exterior roof covering at cathedral ceiling locations.

We noted that the units have unconventional floor plans and framing designs. The units had several half-floors with short series of stairs connecting them. The roofs had a 4/12 pitch and were protected with asphalt shingles on plywood sheathing. The attic utilized sloped wood trusses within the main attic areas and parallel chord trusses at cathedral ceiling areas. The roofs utilized a modified bitumen ice and water shield underlayment extensively (at roof eaves and other potentially problematic locations) at the time of roof shingle replacement in 1995. Concrete block party walls were present between the living spaces of adjacent units, while wood stud and drywall party walls were used to separate attics between units. These wood stud walls were installed directly above the concrete block walls.

Eight units were selected for review and trial repairs, and one additional unit was selected as a baseline. The basis for unit selection was to provide typical units with similar roof constructions and with the same orientation and general construction, all of which had exhibited previous leakage related to ice damming. At the time of the attic reviews, we utilized a blower door that pressurized the interior of the unit relative to its attic to help identify potential air leakage paths between the unit's conditioned space (interior) and the attic.

Within the attic spaces, we observed several large areas of potential air leakage, as described below:

- We observed a 12 to 16 mm (1/2 to 5/8 in.) gap between the concrete block party wall and the gypsum wallboard below the attic. This gap was created by the furring between the concrete block wall and the gypsum wallboard, as shown in Figure 2.
- We noted that the floor framing that was extended past the line of the uppermost interior room wall into the attic spaces was not sealed to prevent air leakage. A similar condition also existed at the rear middle roof. Effectively, this created a 200 mm deep hole that ran the entire length of the wall through which air could freely enter the attic space.
- Many of the penetrations from the conditioned space below into the attic utilized square holes for round elements, such as plumbing vents. These penetrations were not sealed, resulting in several potential air leakage paths into the attic.
- The fireplace chimney chase was not sealed as the chimney passed into the attic. A sheet metal baffle was present, but it fit loosely in the chase.
- The furnace chimney (B vent) was not sealed as it passed through the cathedral ceiling (Figure 3).
- The attic hatch was found to be poorly sealed.
- The tops of concrete block party walls in cathedral ceiling areas were not grouted, resulting in the potential for free flow of warm air into the attic spaces.
- Near the peak of the cathedral ceiling areas, interior wall framing followed the slope of the roof, while the ceiling below was horizontal (the cathedral ceiling did not extend all the way to the peak). This created a potential air leakage path through the wall framing studs into the attic.

Figure 3 *Site 1, air leakage path at furnace flue in cathedral ceiling.*

Site 2

Site 2 is a 62-unit townhouse complex located in Ottawa that the owners reported has been exhibiting moderate to severe ice damming in past years. The complex was constructed in the 1980s and includes units with mansard and conventionally styled roofs with a 4/12 slope. The roofs do not have dormers but do have two chimneys and smaller (vent) penetrations.

Investigation. Our investigation at this site consisted of visual reviews of the interior of two dwelling units including their attics. The units selected had conventional roofs (as opposed to mansard style roofs). The basis for unit selection was to provide typical units with similar roof constructions and with the same orientation and general construction. At the time of the attic reviews, we utilized a blower door that pressurized the entire unit relative to the attic to help identify potential air leakage paths between the unit's conditioned space (interior) and the attic.

We noted that all units have relatively conventional floor plans and framing designs, although some units had mansard style roofs and others had conventional roofs. The conventional building roof had a 4/12 pitch and was protected with asphalt shingles on plywood sheathing. The attic utilized engineered wood trusses, and the ceiling below consisted of gypsum board, 6 mil polyethylene, and approximately 125 mm of loose fill fiberglass insulation over 100 mm of fiberglass batt insulation. Attic ventilation was provided with continuous soffit vents at the front and back of each unit, as well as four mushroom type vents near the peak of each unit roof. According to the owners, no material had been utilized for ice and water protection at the roof eaves below the shingles. Concrete block party walls were present between the attics of adjacent units.

Within the attic, we observed several large areas of potential air leakage, as described below:

- We observed a 16 mm gap between the concrete block party wall and the gypsum wallboard below the attic, as shown in Figure 2. This gap was created by the furring between the concrete block wall and the gypsum wallboard. This gap could be a potential air leakage path between the interior conditioned space and the attic.
- We noted that the wall framing below the attic did not follow the concrete block at a jog in the concrete block wall. This jog was created by the fireplace chimney that was integrally connected to the concrete block wall. This created a relatively large gap (approximately 300 mm × 600 mm [12 to 24 in.]) that could represent a large air leakage path between the interior conditioned space and the attic.
- Many of the penetrations from the conditioned space below into the attic utilized square holes for round elements, such as plumbing vents. These penetrations were not sealed, resulting in several potential air leakage paths into the attic.
- The attic hatch was found to be poorly sealed.
- Several electrical junction boxes in the ceiling were not well sealed, resulting in potential air leakage paths into the attic.

Site 3

Site 3 is an 11-unit townhouse complex located in Ottawa that has been exhibiting moderate to severe ice damming in past years. From our conversations with unit owners and involved contractors, we understand that the condominium has been looking for methods to reduce ice damming for several years. In the summer of 2002, some new attic vents were installed in the roofs in an attempt to alleviate ice damming, but this had limited success.

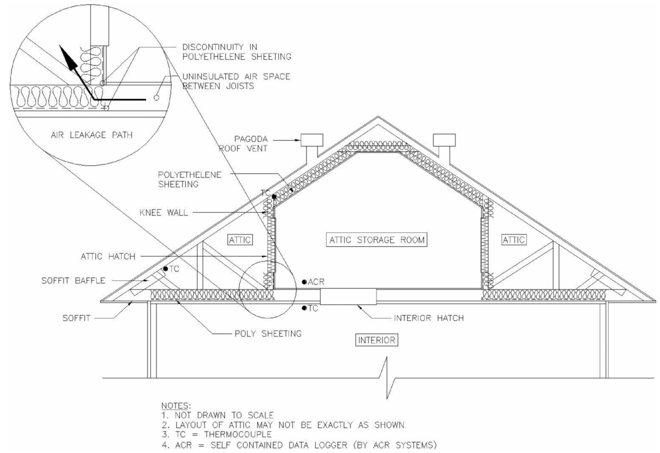

Figure 4 *Site 3, building cross section displaying major air leakage path.*

The complex was constructed circa 1994 and includes units with conventional roofs with an 8/12 slope. The buildings have dormers and tend to be stepped in plan.

Investigation. Our investigation at this site consisted of visual reviews of the interior of two units including attic areas. The basis for unit selection was to provide typical units with similar roof and attic construction and with the same orientation and general construction. At the time of the attic reviews, we utilized a blower door that pressurized the entire unit relative to the attic to help identify potential air leakage paths between the unit's conditioned space (interior) and the attic.

We noted that the units have unconventional floor plans and framing designs (see Figure 4). The units had several half-floors with short series of stairs connecting them. The roofs had an 8/12 pitch and were protected with asphalt shingles on oriented strand board (OSB) sheathing. The attics utilized unconventional engineered wood trusses creating a storage room at the center of the attic. Roof access was not available, and we are not certain what material, if any, had been utilized for ice and water protection at the roof eaves below the shingles. Concrete block party walls were present between the attics of adjacent units.

The attic storage rooms had unpainted plywood floors and gypsum board clad walls and ceilings. This storage area was accessed through an attic hatch incorporating an integral ladder. The attic storage room was not heated, but the walls and ceiling of the storage room were insulated, and its floor was not. Figure 4 displays a cross section of the attic including the attic storage room.

Three distinct attic types were noted, as described below:

1. Near both roof eaves were knee wall type attics that ran the entire width of the units. These attics were accessed through hatches in the walls of the storage area. These hatches did not have any hardware but were fastened to the walls using eight wood screws. The ceiling below these attics consisted of gypsum board, 6 mil polyethylene, and approximately 250 mm of loose fill cellulose insulation. The knee wall construction consisted of gypsum board, 6 mil polyethylene, and approximately 150 mm (6 in.) of glass fiber batt insulation.

2. Near the peak of the roof was a shallow conventional style attic as shown in Figure 4. There was no hatch for this attic space, and it was not accessed as part of this project. The construction of this attic space is not known.

3. Between the knee wall and upper attics was a cathedral ceiling (above the attic storage room). The ceiling construction of this attic consisted of gypsum board, 6 mil polyethylene, approximately 250 mm (10 in.) of fiberglass batt insulation, and an approximate 100 mm (4 in.) air space between the insulation and the underside of the sheathing.

Attic ventilation was provided with continuous soffit vents along both eaves, two pagoda style vents (one per elevation) in the cathedral ceiling areas near the roof peak, and two mushroom type vents (one per elevation) in the cathedral ceiling areas near the roof peak. The air space within the cathedral ceiling area allowed passage of air between the knee wall and upper attic areas.

Within the attic, we observed several large potential air leakage paths, as described below:

- We noted that the floor framing that extended past the line of the attic storage room knee wall into the attic spaces was not sealed to prevent air leakage. Effectively, this created a 200 mm (8 in.) deep hole that ran the entire length of the each knee wall through which air could freely enter the attic space (as shown in Figure 4).
- We noted that a 12 to 16 mm (1/2 to 5/8 in.) gap existed between the concrete block party wall and the gypsum board wall below the attic, similar to that shown in Figure 2. This gap was created by the furring utilized behind the gypsum board, resulting in an air leakage path that vented directly into the attic.
- Many of the penetrations from the conditioned space below utilized square holes for round elements, such as plumbing vents. These penetrations were not sealed, resulting in several potential air leakage paths into the attic.
- The knee wall attic hatch weatherstripping was in poor condition with gaps at its corners.
- A 6 to 12 mm (¼ to ½ in.) gap was present along the base of the walls separating the attic storage room from the knee wall attics.

Figure 5 *Site 1, ice formation on repaired units.*

Remedial Solutions

The remedial solutions developed for each site included air sealing of all of the potential air leakage paths noted above and installing new weatherstripping on attic hatch doors. All repairs were performed under our direction by a contractor familiar with air sealing repairs.

Air sealing was performed using one-component polyurethane foam for smaller gaps and extruded polystyrene (cut to fit) and one-component polyurethane foam for large penetrations. The attic hatch was weather-stripped using a closed cell foam strip with a self-adhesive backing.

A second round of pressure testing (using a door fan) was undertaken during and after the repairs. The purpose of this door fan testing was to determine if the repairs sealed each potential air leakage path. No measurements of whole house air leakage were undertaken.

The repairs for site 1 were performed in the fall of 2001, while the repairs for sites 2 and 3 were performed in the fall of 2003.

The repairs for site 1 were monitored in the winter of 2002/03, and it was found that attic temperatures were reduced but that problematic ice formation still occurred. During the summer of 2003, a second round of attic reviews revealed that several key locations of potential air leakage had not been sealed by the contractor. A second round of repairs was undertaken in 2003, after which the 2004 monitoring was undertaken.

OBSERVATIONS AND ANALYSIS

Visual Reviews

Visual reviews were taken from grade throughout the winter months. Visual monitoring was undertaken on both repaired and comparable unrepaired units. Unrepaired units selected for comparison appeared to be of similar construction and were of the same general orientation as the repaired units. Figures 5 and 6 display ice formation on repaired and unrepaired roofs at various times in the winter for site 1.

Visual reviews at site 1 noted a significant reduction in ice formation during the winter of 2003/04 as shown in Figures 5 and 6. Visual reviews at sites 2 and 3 generally revealed little ice formation and no appreciable difference in the amount of snow or ice buildup between the repaired and unrepaired units.

Figure 6 *Site 1, ice formation on unrepaired units.*

It is important to note that the winter of 2004 was not a particularly problematic year for ice damming, so even small amounts of roof ice could be an indication of a problematic roof from an ice damming perspective.

Temperature Readings

Temperature monitoring was undertaken on one repaired unit and one similar unit without repairs. For the purpose of this report, the unrepaired unit was labeled “Unit A” while the repaired unit was labeled “Unit B” for each site. Both units at each site had the same orientation and the same general attic and roof constructions and similar potential air leakage paths.

Temperature readings were taken using thermocouples attached to self-contained data acquisition systems. Temperatures were taken at several locations within each attic, at one interior location in each unit, and at one exterior location.

Figures 7 through 12 and Tables 1 through 3 display the temperature monitoring results within the repaired and unrepaired attics for the various sites. The periods of time provided in these graphs and tables represent approximately one-week periods before and after the repair took place. The specific periods were selected to include similar ranges of exterior air temperatures and also exterior air temperatures that could be conducive to ice dam formation.

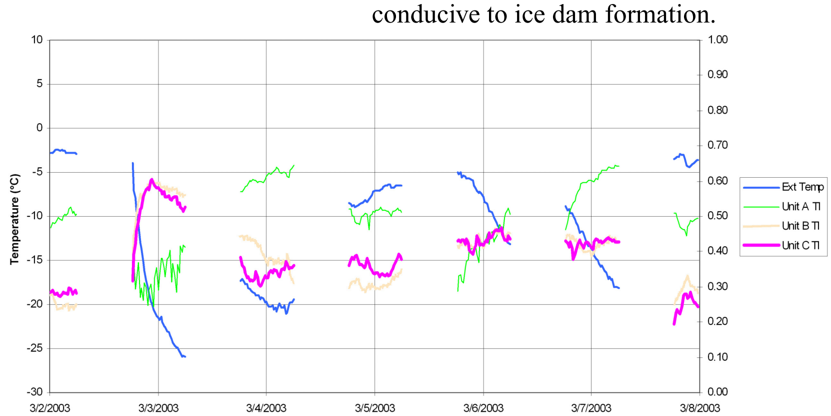

Figure 7 *Site 1, pre-repair, temperature index comparison —night data only.*

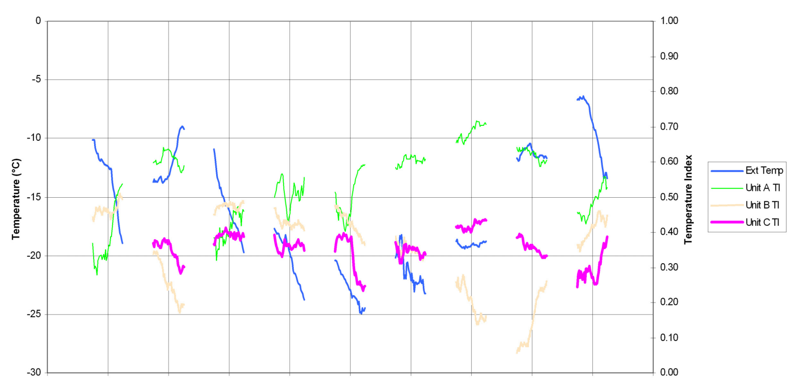

Figure 8 *Site 1, post-repair, temperature index comparison —night data only.*

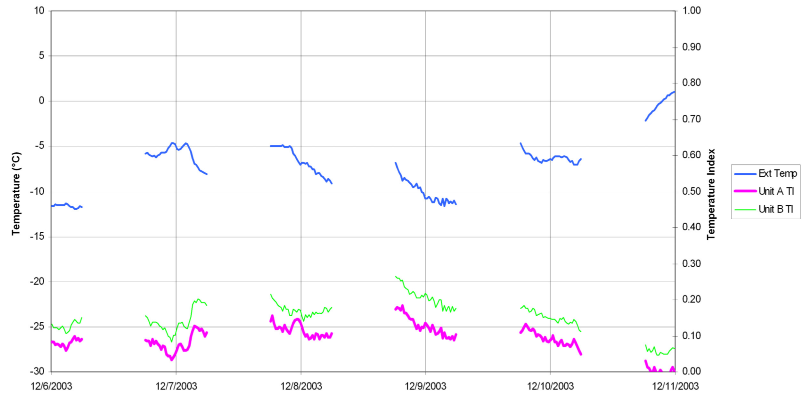

__Figure 9__ Site 2, pre-repair, temperature index comparison—night data only.

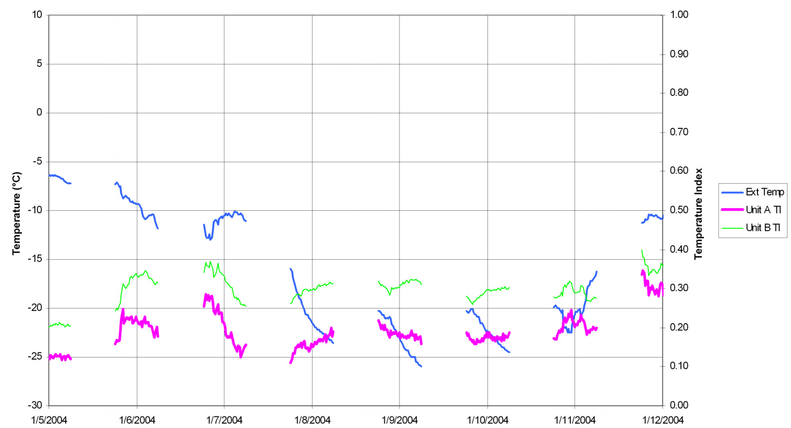

__Figure 10__ Site 2, post-repair, temperature index comparison—night data only.

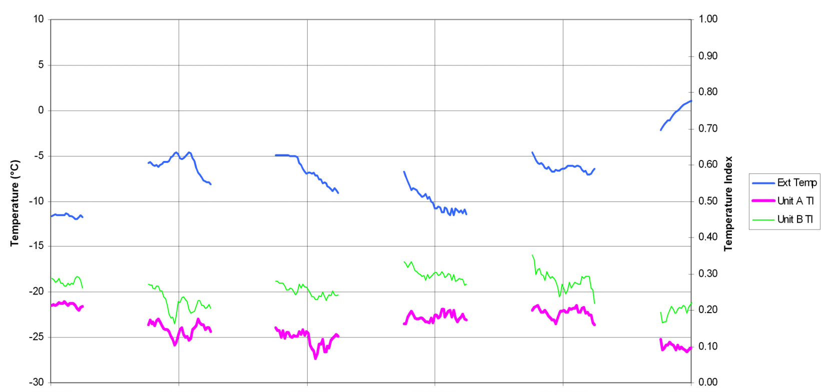

__Figure 11__ Site 3, pre-repair, temperature index comparison—night data only.

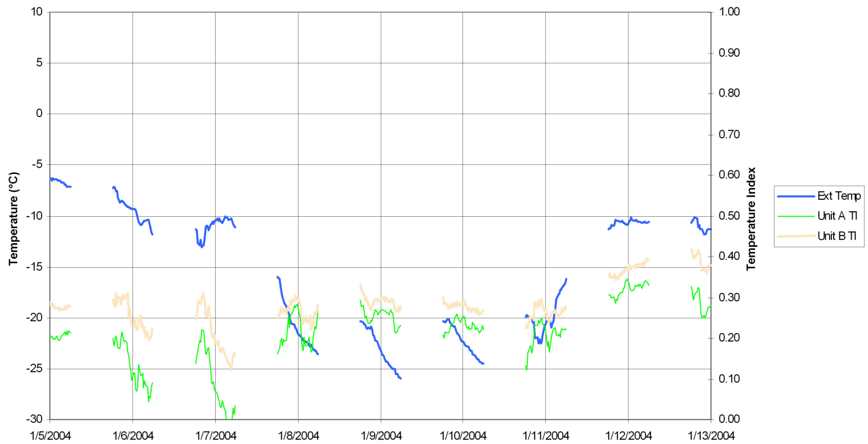

Figure 12 *Site 3, post-repair, temperature index comparison—night data only.*

Table 1. Summary of Monitored Temperatures at Site 1

	Average Condition*	Unit A (unrepaired)	Unit B (full repair)
Before Repair	Attic Temp.	5.6°C (42.1°F)	1.1°C (34.0°F)
	Exterior Temp.	–11.9°C (10.6°F)	
	Interior Temp.	23.6°C (74.5°F)	20.4°C (68.7°F)
	Attic Temp. Index	0.49	0.39
After Repair	Attic Temp.	5.6°C (42.1°F)	–2.8°C (27.0°F)
	Exterior Temp.	–16.2°C (2.8°F)	
	Interior Temp.	24.4°C (75.9°F)	21.8°C (71.2°F)
	Attic Temp. Index	0.54	0.36

* Average conditions are for approximately one-week periods, nighttime data only

Table 2. Summary of Monitored Temperatures at Site 2

	Average Condition*	Unit A (unrepaired)	Unit B (repaired)
Before Repair	Attic Temp.	–2.3°C (27.9°F)	–0.7°C (30.7°F)
	Exterior Temp.	–4.8°C (23.4°F)	
	Interior Temp.	20.3°C (68.5°F)	19.7°C (67.5°F)
	Attic Temp. Index	0.10	0.16
After Repair	Attic Temp.	–9.4°C (15.1°F)	–5.8°C (21.6°F)
	Exterior Temp.	–16.5°C (2.3°F)	
	Interior Temp.	20.2°C (68.4°F)	19.0°C (66.2°F)
	Attic Temp. Index	0.19	0.30

* Average conditions are for approximately one-week periods, nighttime data only

Table 3. Summary of Monitored Temperatures at Site 3

	Average Condition*	Unit A (unrepaired)	Unit B (repaired)
Before Repair	Attic Temp.	–1.9°C (28.6°F)	1.5°C (34.7°F)
	Attic Storage Room Temp.	16.9°C (62.4°F)	17.3°C (63.1°F)
	Exterior Temp.	–5.5°C (22.1°F)	
	Interior Temp.	19.6°C (67.3°F)	22.4°C (72.3°F)
	Attic Temp. Index	0.14	0.25
After Repair	Attic Temp.	–8.2°C (17.2°F)	–5.7°C (21.7°F)
	Attic Storage Room Temp.	16.6°C (61.9°F)	12.9°C (55.2°F)
	Exterior Temp.	–15.8°C (3.6°F)	
	Interior Temp.	19.6°C (67.3°F)	20.0°C (68.0°F)
	Attic Temp. Index	0.21	0.28

* Average conditions are for approximately one-week periods, nighttime data only

DISCUSSION

Temperature Readings

Temperature readings provided results comparable by reviewing temperatures on unit B before and after repairs, and by comparing temperatures from unit A to unit B after the repairs were undertaken to unit B.

In comparing the before and after temperature indices in unit B, we noted that the temperature indices changed in the following ways:

- **Site 1**: A drop from an average of 0.39 to 0.36 (8%) over the period. For comparison purposes, the temperature index in unit A increased from 0.49 to 0.54 (10%) over the same period.
- **Site 2**: A rise from an average of 0.16 to 0.30 (90%) over the period. For comparison purposes, the temperature index in unit A changed from 0.11 to 0.19, a rise of 73%.
- **Site 3**: A rise from an average of 0.25 to 0.28 (12%) over the period. For comparison purposes, the temperature index in unit A changed 0.14 to 0.21, a rise of 50%.

Our second avenue of analysis involved comparing the temperature indices of unit A to those in unit B. After the repair, the average temperature indices (over a one-week period) for units A and B for the different sites were as follows:

- **Site 1**: After the repair, the temperature indices of unit B were an average of 0.18 lower (35%) than those of unit A. Prior to the repair, the temperature indices of unit B were 0.10 lower (20%) than those for unit A.
- **Site 2**: After the repair, the temperature indices of unit B were an average of 0.11 higher (37%) than those from unit A. Prior to the repair, the temperature indices of unit B were 0.06 higher (38%) than those for unit A.
- **Site 3**: After the repair, the temperature indices of unit B were an average of 0.07 higher (25%) than those from unit A. Prior to the repair, the temperature indices of unit B were 0.11 higher (44%) than those for unit A.

At first glance, the post-repair temperature index difference at site 1 appears to indicate that the air sealing may have resulted in a small benefit with respect to the propensity for ice dam formation. However, the temperature index for unit A increased over the period, while the temperature index for unit B decreased. Accordingly, the apparent temperature index decrease for units B and C may be a conservative representation of the benefit of the repairs. This indicates the repairs had some effect on the attic temperatures and propensity for ice damming formation at site 1.

For sites 2 and 3, the temperature index differences between the repaired and unrepaired units appear to indicate that the air sealing was counterproductive with respect to propensity for ice dam formation. This is counterintuitive and unlikely to be true—air sealing repairs within an attic cannot possibly be the reason for a rise in temperature index. Air sealing repairs only serve to block paths of potential air leakage, so at worst they would have no effect on attic temperatures related to ice dam formation. Accordingly, some other factors must be present that result in this apparent effect. Other factors potentially affecting ice dam formation are discussed later in this paper.

In our analysis, we also noted that the difference in temperature indices at site 2 before and after the repair is similar for both Units A and B. This method of analysis indicates that the repairs had little effect on the attic temperatures and propensity for ice dam formation at this site.

We also observed that the pre- and post-repair temperature index difference for unit A is larger than for unit B at site 3. This indicates that the repairs may have had some effect on reducing the propensity for ice dam formation at this site but that their effect was overshadowed by the other factors that increased the temperature indices.

We also compared our results to published temperature results from other ice dam studies. The Tobiasson et al. (1998) study defines a temperature index of 0.2 above which ice problems "might occur" or a temperature index of 0.55 at which "severe ice problems" might occur. At sites 1, 2, and 3 we calculated post-repair temperature indices in the range of 0.4, 0.3, and 0.3, respectively, for the repaired units. Accordingly, the results indicate propensity for moderate ice damming due to interior attic temperatures in all repaired units.

Environmental Conditions During Test Period

The units and period selected for monitoring were chosen to reduce the potential for differences. The units were of the same construction, with similar attic constructions and deficiencies. The periods for comparisons were chosen so that they had similar exterior air temperatures and included only nighttime data (to minimize solar effects on the data). Other environmental effects beyond our control could have affected attic temperatures, as discussed below:

Rooftop Snow Cover. Ottawa ground snow cover measurements for the winter of 2003/04 were obtained from Environment Canada. In reviewing this information, we noted that the ground snow load was 0 to 6 cm (0 to 2.4 in.) in the pre-repair monitoring period, while the ground snow load was 0 to 20 cm (0 to 8 in.) in the post-repair monitoring period. On the assumption that ground snow load is an indication of roof snow cover, the increased roof snow will act as an insulating layer. This insulating layer will reduce the conductive flow of heat through the roof covering (sheathing and shingles), which, in winter, would increase the temperature in the attic. Accordingly, the pre-repair temperatures and temperature indices may be lower than if the amount of snow on the roof at that time were the same as in post repair period.

Wind. Higher winds result in increased differential pressures across the exterior of an attic, resulting in increased attic ventilation (with exterior air). This increased ventilation should reduce attic temperatures in cold weather. Average speed of maximum wind gusts for Ottawa during the winter of 2003/04 were obtained from Environment Canada. From this information, we noted that wind gusts for the pre and post-repair periods were at similar levels, so this does not appear to be a factor.

Monitoring Approach

The original scope for this research included monitoring attic and roof conditions before and after air sealing repairs were undertaken. We found that variable weather conditions made the comparison of data obtained before and after repairs difficult. Most notably, the insulating effects of snow cover appear to significantly influence attic temperatures. Snow cover on roofs is rarely consistent in depth and is very difficult to accurately model from a heat transfer perspective. Factors affecting snow depth include how much snow falls, solar gains, temperature, shading, wind, drifting potential (nearby trees, rooftop elements, adjacent buildings), temperature, and roof slope. Accordingly, we do not believe that monitoring conditions before and after repairs provides an accurate representation of repair effectiveness.

Prior to undertaking this project, we understood the limitations of pre- and post-repair monitoring. Accordingly, our original intent for this project was to monitor similar adjacent units of row houses, one with repairs undertaken and one without. The determination of similarity was made based on visual reviews only. We found that this type of monitoring had its own shortcomings. Namely, we believe that factors outside our control significantly affected attic temperatures. While the apparent air leakage paths were similar in units we deemed to be comparable, our results indicate that other sources of heat gain were present that significantly affected the results. Once again, we found that monitoring conditions on units believed to be similar in nature (based on visual reviews only) does not provide an accurate representation of repair effectiveness.

For the sites within this project, we monitored conditions on comparable units both before and after repairs were undertaken on one unit. This combined monitoring method allows a more detailed analysis that takes into account unknown differences between the buildings, variable weather conditions, and real changes as a result of the repair. Analysis of this more detailed information results in a more accurate determination of the success of a repair strategy.

Temperature Indices and Data Variability

At the onset of this project, it was acknowledged that variability of indoor air temperatures would likely play a role in attic temperatures. This factor was eliminated through the comparison of temperature indices, which normalized attic temperatures with respect to indoor temperature.

In reviewing the graphical results, we found that attic temperatures generally tracked exterior temperatures. We would expect that attic temperatures would track exterior temperatures, as a large part of attic air typically comes from the exterior.

We also found that attic temperature indices generally tracked exterior temperatures when reviewing full-day data. The temperature index is a unitless ratio representation of the attic temperature in relation to the interior (conditioned) and exterior temperatures. If conductive heat flow is considered alone, the temperature index should remain constant regardless of exterior temperatures. However, both air leakage and solar effects also affect attic temperature indices. In reviewing night data only, there is not a readily apparent correlation between temperature indices and exterior temperature. Accordingly, it appears that solar effects tend to increase both exterior air temperature and attic temperature indices.

We also noted at each of the sites monitored that temperatures indices had high variability. Standard deviations of temperature indices ranged from 0.05 to 0.12 for ranges of temperature indices between 0.4 to 0.6. Accordingly, standard deviations of temperature indices at all sites were around 12% of their total range. This factor must be considered in the analysis of the results—emphasis should be placed on trends rather than specific particular values.

Attic temperatures are affected by many factors. This project attempts to resolve variability due to solar impacts, equipment error, and major exterior temperature variability. Other factors, such as thermal storage, local air leakage locations, and wind gusts, were not taken into account in our analysis and are likely contributors to data variably.

Ice Dam Contributing Factors

Throughout this report, several conditions were noted that resulted in heat gain into the attics. Common sources of heat gain from the interior of a unit are discussed below.

- Concrete block party walls may play a large role in wintertime attic heat gain. The typical method of furring out gypsum board walls below the attic creates one common potential air leakage path.
- Concrete block party walls can also contribute to attic heat gain by acting as air leakage paths. Party walls containing unfilled concrete block cores that extend from the attic to conditioned space below could result in convective forces within the cores and resulting warm concrete blocks in the attic (in winter). Further, Lux and Brown (1986) quote that concrete blocks have an air permeance that is approximately 100 times larger than the Canadian National Building Code's maximum permeance for an air barrier material. Accordingly, pressure differentials due to buoyancy forces from stack effect (or other forces) might also result in the passage of conditioned air into the attic through the concrete block walls, on the assumption that the concrete block cores are open (allow the free flow of air).
- Most of the units observed exhibited poor air seals at attic penetrations.
- Chimneys deserve special attention. Chimneys should be acknowledged as both potential sources for air leakage (through chases) and as heat generators within the attics.
- From our reviews, it seems that most conventional detailing (such as the tops of party walls) were sealed and insulated reasonably well. Unconventional detailing, however, often resulted in poor detailing from an air barrier perspective. We would suggest that greater consideration must be given to detailing the air barrier, particularly in buildings with complicated or unconventional designs. This concept is also discussed in the CMHC (1996) report.
- We also noted that several of the problematic buildings had large areas of insulated walls or ceilings bordering the attics. All insulated wall or ceiling areas potentially produce some heat transfer into the attic from the building interior (insulation reduces, but does not eliminate, heat transfer). Further, when there is a wall and ceiling both bordering the same attic, inevitably there is a connection between that wall and ceiling that could be prone to air leakage or thermal bridging.
- Chimneys passing through attic spaces may play a significant role in attic heat gain. With the exception of the single-family home, all of the sites had at least one chimney passing through the attics. This concurs with the finding of the CMHC (1996) report.
- Snow cover can indirectly result in increased attic temperatures by providing an insulating cover over the sheathing. These insulating effects will reduce the heat transfer across the sheathing and can exacerbate the effects of attic heat gain from other sources.

In addition to the above, we noted that two of the buildings within this study incorporated both cathedral and conventional attics below a continuous roof surface. This type of detail can be problematic with respect to ice dam potential due to differential heat transfer through the different roof constructions. This type of detail would be very difficult to correct and should be avoided in climates conducive to ice damming.

Many of the above factors result in air leakage into the attic, which is a contributory factor to problematic ice damming. Our analysis reveals that solving air leakage problems may reduce ice dam potential in some buildings but that it cannot be relied upon as the solution for all buildings with ice dam problems. Ice damming is a complicated building science issue with many causal factors. Determination of these causal factors and the degree to which they impact on ice dam potential is very difficult. Accordingly, solving ice damming problems should begin with retaining the advice of a qualified building science specialist. Further, where possible, most ice dam repairs should be undertaken in a phased approach or on a trial basis prior to undertaking full-scale repairs.

Air Sealing

Another important finding from this project was the difficulty in having proper air sealing work performed. We understood and acknowledged the fastidious nature of air remedial sealing work and undertook precautions to help ensure that effective work was performed. Specifically, these precautions included carefully selecting a contracting firm and undertaking field review of the repairs. However, despite these precautions, several major air leakage paths remained unrepaired at one of the sites after air sealing repairs were undertaken. After determination of these deficiencies, discussions were held with the contracting firm and it was determined that the problems resulted from a misunderstanding of one person from the contracting firm (who undertook most of the work). The misunderstanding was based on a lack of knowledge of proper air barrier repairs.

It would be beneficial to perform a quantitative analysis of the success of air sealing for projects of this type. Methods such as comparison of whole house air leakage rates or measuring attic pressurization (and comparing it to indoor air pressures) might be utilized for this purpose. Although this would be beneficial, it is also acknowledged that this type of testing is typically time consuming and relatively expensive and in some cases may result in incorrect results. Further studies specific to defining quantitative methods to confirm the suitability of attic air sealing repairs may be beneficial in this regard.

CONCLUSIONS

The following general, non-site-specific conclusions were reached:

1. Reducing air leakage into an attic will reduce the propensity for problematic ice damming on some buildings.

2. Reducing air leakage into an attic will not solve ice damming problems on all buildings.

3. Evaluating the effectiveness of repairs (to solve ice damming problems) using row housing units of similar construction may not provide comparable results. Similarly, evaluating the effectiveness of repairs through comparison of the same building before and after a repair may not provide acceptable results. In order to evaluate the effectiveness of these repairs, it is important for monitoring to include pre-repair and post-repair information for both repaired and baseline units.

4. In general, row housing tends to be particularly problematic with respect to ice dam formation. Many ice damming contributory factors are common or unique to row housing construction.

5. Ice damming is a building science problem with many causal factors. No single repair method can be relied upon to solve ice damming at all sites. The preferred method to resolve ice damming problems is to gain a thorough understanding of the causal factors at each specific site and to resolve these causal factors.

6. Due to the number of potential causal factors and the potential for failure of a repair to resolve problematic ice dams, repairs should be implemented with an understanding of their potential for failure. Phased or trial repairs should be undertaken when possible.

7. Air sealing repairs should be undertaken by individuals with a good understanding of air barriers from both a theoretical and functional perspective.

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