RESEARCH REPORT

ICE DAMMING FIELD RESEARCH: ICE DAMMING SOLUTIONS

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REPORT

Ice Damming Field Research
Ice Damming Solutions

Ottawa, ON

Presented to:

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This study was conducted for Canada Mortgage and Housing Corporation (CMHC) under Part IX of the National Housing Act. The analysis, interpretations and recommendations are those of the consultant and do not necessarily reflect the views of CMHC.

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1. ABSTRACT

Ice damming is often resolved by treating the water leakage or ice build-up without addressing the fundamental cause: heat gain into an attic. This research investigated the potential of house-to-attic air sealing to resolve ice damming problems through five detailed case studies in the Ottawa area.

2. EXECUTIVE SUMMARY

Ice damming is a problem that annually affects a large number of houses in Canada. It can cause water leakage inside the house and can present a danger of falling ice. It may also affect the service life of roofing materials and components.

Ice damming arises from differential melting and freezing of snow on a roof. The root causes of the melting, such as air leakage from the interior into the attic, are frequently far from the roof deck. As a consequence, methods to alleviate ice damming (e.g. electric cables, membranes) 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 build-up on the roofs. The best solution is to change attic conditions to prevent ice damming from occurring.

This report describes the factors that contributed to ice damming in detailed case studies of four low rise condominium complexes and one single family house in Ottawa, Ontario. Each site has suffered severe ice damming in the past. The repair strategy at each site primarily focused on reducing air leakage into the attic from the house. The success of these trial repairs were monitored by attic temperatures and visual indicators. The suggested repairs had benefits on some sites and little benefit on others.

RÉSUMÉ

La formation de barrières de glace touche, chaque année, un grande nombre de maisons au Canada. En effet, elle risque de se traduire par des infiltrations d'eau à l'intérieur et par la chute de glace, en plus de compromettre la durée utile de la couverture.

Les barrières de glace s'expliquent par la fonte de neige et le gel sur le toit. Les causes, comme les fuites d'air de l'intérieur jusque sous les combles, se trouvent bien souvent loin du platelage du toit. En conséquence, les méthodes visant à atténuer la formation de barrières de glace (câbles électriques, membranes) viennent bien souvent à bout des infiltrations d'eau sans s'attaquer à la cause première. Ces méthodes peuvent réduire, voire éliminer les infiltrations d'eau à court terme, mais, puisqu'elles ne s'attaquent pas à la cause de la fonte et du gel, elles n'offrent hélas pas de solution à longue échéance. De plus, elles ne tiennent pas compte des enjeux de la durabilité suscités par l'accumulation de glace sur le toit. La meilleure solution consiste à modifier la situation sous les combles pour prévenir la formation de barrières de glace.

Le rapport fait état des facteurs qui ont donné lieu à la formation de barrières de glace lors d'études de cas approfondies consacrées à quatre ensembles de logements en copropriété de faible hauteur et à une maison individuelle situés à Ottawa, en Ontario. Il s'était formé, dans le passé, d'importantes barrières de glace sur le toit des bâtiments. Les réparations visaient principalement à réduire les fuites d'air de la maison jusque sous les combles. La réussite de ces réparations tentées a été contrôlée par la température du vide sous toit et des indicateurs visuels. Les réparations proposées procuraient des avantages dans certains cas et peu dans d'autres.

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3. 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 non-working 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 housing. Air leakage is believed to be a major contributor to problematic ice damming in many cases, as discussed in section 4.1.

3.1 Terms of Reference

3.2 Scope of Work

The scope of work for this project is described in the Morrison Hershfield proposal to CMHC dated October 14, 2003. It involved the following tasks:

3.2.1 Identify Problem Buildings

A mixture of multi-unit low-rise residential complexes and residential homes were selected for inclusion in this project. Each of the project sites were selected due to problematic past ice damming which we believed may be associated with attic heat gain. Each of the building sites are described in more detail in section 5.

3.2.2 Investigation

Where necessary, 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.

3.2.3 Brainstorming Session

A brainstorming session was performed which consisted of a meeting between Morrison Hershfield and CMHC to review the outcome of our investigations of the problem buildings and to develop remedial strategies for each complex or building.

3.2.4 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.

3.3 Report Format

This report is structured with the following main sections:

- Introduction: The introduction includes information about this project and this report.

- General: The general section includes a brief discussion on ice damming as well as information that would apply to all of the project sites (such as general weather information and monitoring details). It also includes a brief discussion on another pertinent study on ice damming.

- Project Sites: The project sites section is broken into five subsections. Each of these subsections discusses one of the specific sites. Each subsection includes a description of the site, information on the investigation, repairs, and monitoring for the site, and an analysis and discussion of the results for the site.

- Discussion: This section provides a discussion of the findings on a non-site-specific basis.

- Conclusions: This section provides report conclusions on a non-site-specific basis.

4. GENERAL

4.1 Factors Affecting Ice Damming Potential

When reduced to its simplest form, the formation of roof top 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 one or three of the above list (ex. snow rake use or electric cables). However, it is our opinion that the preferable method to eliminate ice damming problems is the to resolve item two (reduce the temperature differential across the roof).

Both internal and external sources of heat could potentially result in a problematic roof temperature differentials from an ice damming 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 potential for solar gain (roofing colour and material), roof shape and complexity(dormers, slopes), complicated building designs (ex. cathedral ceilings over conventional attics), a lack of attic ventilation, and heat emitting roof top 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 counter-productive if the most air tight 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.

4.2 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. At three of the multi-unit complexes, temperature readings were taken concurrently on similar repaired and non-repaired units, as well as before and after the repair (on the same unit). At the other multi-unit complex, readings were taken only concurrently on a repaired and similar non-repaired unit (no pre-repair readings were taken). At the single family home, readings were taken before and after the repairs. The specific monitoring strategy for each complex or building is described in more detail in section 5.

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, located at 2440 Don Reid Drive. This specific location was located on the north side of the building, approximately 1 m from the face of the building and 5 m 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 night time 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 which could be conducive to ice dam formation (exterior air temperatures colder than –5ºC). 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.

4.3 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.

Figure 1 displays temperature, ground snow cover, and maximum wind gusts for the winter of 2004. Note that the data presented for maximum wind gusts

4.4 Other Ice Damming Studies

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

4.4.1 CMHC Research Report: Ice Dam Research Data Analysis

A research report[1] was prepared by Scanada Consultants Ltd. for CMHC 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 4ºC warmer than those without ice dams during a period with an average exterior temperature of –6ºC.
- Insulation amounts and levels 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 winter time attic temperatures.

[1] Ice Dam Research Data Analysis, Prepared by Scanada Consultants Limited for CMHC, September 1996

4.4.2 Study by Tobiasson, Buska and Greatorex

One study[2] by Tobiasson, Buska and Greatorex 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 building which experience 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, as shown below:

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

$t_a=0.784t_o+14.44$: "Some" icing problems

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

where: t_a= attic temperature in degrees Fahrenheit, and
t_o= exterior air temperature in degrees Fahrenheit

On the assumption of an interior temperature of 70 ºF, and at an exterior temperature of –10 ºC, 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 –5ºC and –15ºC.

We recognize that the equations provided within the Tobiasson, Buska and Greatorex 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.

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[2] Attic Ventilation Guidelines to Minimize Icings at Eaves, by Wayne Tobiasson, James Buska and Alan Greatorex, January 1998, Interface Magazine

5. PROJECT SITES

5.1 Site 1: Low Rise Condominium Complex

Site 1 is a wood framed townhouse complex constructed in 1984 (Photo 1). The buildings have been experiencing severe ice damming problems since occupancy (Photos 2 and 3). The problems have been well documented with reports and Photographs. Approximately 85% of the units have experience ice dam related roof leaks within the last nine years. Seven consultants had provided opinions and implemented various repairs prior to our involvement in 2001.

Morrison Hershfield performed a detailed investigation into the ice damming in 2001 prior to our involvement in this CMHC project. Our past work at the site included a review of past consultant reports and Photographs, a thorough visual review, overseeing roof top test openings and the implementation of three types of trial repairs on three different units: These trial repairs consisted of two levels of air sealing and the addition of ventilation. We monitored these repairs and compared them to a baseline building on the complex through temperature monitoring devices as well as an analysis of snow melt patterns through the winters of 2001/02 and 2002/03. The initial indications were that the strategy had been somewhat effective although significant icicle formations continued to be observed.

In the fall of 2003, a door fan was used to create a pressure in individual units and smoke was used to identify leakage paths from the home into the attic. This procedure identified deficiencies in the initial air sealing program. Further repairs were undertaken, and the monitoring program was repeated for the winter of 2003/04.

The sections provided below will not differentiate between our past and recent work at the building.

5.1.1 Investigation

Our investigation at this site consisted of visual reviews of roof and attic spaces of 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, as shown in Figure 2. 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 unit 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 which pressurized the interior of the unit relative to its attic to help identify potential air leakage paths between the unit conditioned space (interior) and the attic.

Within the attic spaces, we observed several large areas of potential air leakage, as shown in Figures 3 through 5 and described below:

- We observed a 12 to 16 mm gap between the concrete block party wall and the gypsum wall board below the attic. This gap was created by the furring between the concrete block wall and the gypsum wall board.

- We noted that the floor framing extending 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 an 200 mm deep hole that ran the entire length of the wall through which air could freely enter the attic space (as shown in Photo 5 and Figure 5).

- 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 (Photo 4).

- The furnace chimney (B vent) was not sealed as it passed through the cathedral ceiling (Photo 6)

- 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 (Photo 7).

- 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.

5.1.2 Remedial Solution

Due to the cost implications of the repairs, two remedial solutions were developed for this site. The first solution included air sealing of all of the potential air leakage paths noted above, and installing new weatherstripping on the attic hatch door. The second solution included sealing only the potential air leakage paths accessible from the main attic. The costs associated with accessing the areas to be sealed within the cathedral ceiling roof were prohibitive, so it was hoped that the air sealing able to be performed within the main attic area would reduce air leakage sufficiently to resolve the ice damming problems. Both types of repair were performed on the site. The full repair was implemented at five units, and the half repair was installed on three units. All repairs were performed under our direction by a contractor (Can-Am) familiar with air sealing repairs. Repairs were reviewed by Morrison Hershfield.

Air sealing was performed using two component polyurethane foam for smaller gaps (Photos 9 and 10), and extruded polystyrene (cut to fit) and two component polyurethane foam for large penetrations (Photo 8). The attic hatch was weather-stripped using a closed cell foam strip with a self adhesive backing. This weatherstripping was 9.5 mm wide by 4.5 mm deep. These repairs were performed in the fall of 2001.

The repairs 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 after which the 2004 monitoring was undertaken, as discussed in section 5.1.3.

5.1.3 Monitoring

Visual reviews were taken from grade throughout the winter months. Visual monitoring was undertaken on a bank of eight units, five with the “full repair” and three with the “half repair”. In addition, we performed visual reviews on banks of units with similar construction and orientation. The comparable units were of similar constructions and orientations of the repaired units. Photographs 11 through 16 display repaired and non-repaired roofs at various times in the winter.

Temperature monitoring was undertaken on one unit with the full repair (unit 25), one unit with the half repair (unit 15) and one base line unit (unit 38). For the purpose of this report, the non-repaired unit was labeled “Unit A”, while the half and full repaired units were labeled “B” and “C” respectively.

All units had the same general attic and roof constructions and similar potential air leakage paths. However, Unit A faced north, while units B and C faced south.

Temperature readings were taken using thermocouples attached to self contained data acquisition systems, as noted is section 4.1. Temperatures were taken at four locations within each attic, at one interior location in each unit, and at one exterior location. The system recorded temperatures over various periods during the winters of 2001, 2002, and 2003. The winter of 2001 was very mild with little snow, so analysis of this data was not included within this report. Figures 6 through 15 display the temperature monitoring results within the repaired and non-repaired attics.

5.1.4 Analysis and Discussion

Air Leakage Path Repairs

The visual review of the attic spaces at site 1 revealed several prominent locations where problematic air leakage might occur between the interior space and the attic. The potential for these locations to be problematic with respect to air leakage was confirmed by the observation of air leakage from the building interior while a door fan was pressurizing the interior of the units. Similarly, the success of limiting air passage through these locations was confirmed with a door fan.

Visual Reviews

Our visual reviews noted a significant reduction in ice formation during the winter of 2003/04. Photographs 11 through 13 display icicles on typical non-repaired units while Photos 14 through 16 convey similar information on repaired units. These Photos were taken on February 19, 2004, although similar visual results were noted at other times during the winter. It is important to note that the winter of 2004 was not a particularly problematic year for ice damming, as noted in section 4.3, so even small amounts of roof ice could be an indication of a problematic roof from an ice damming perspective.

Temperature Readings

The temperature readings and related data are presented in Figures 6 through 15, and summarized in table 1, below. These Figures include raw temperature data and / or temperature indices over different periods of time, as discussed in section 4.1. The periods of time provided in these graphs represent approximately one week periods before and after the final (2003) repair took place. Note that the “pre-repair” data was taken on units that had undergone some air sealing repairs, but these repairs were subsequently found to be incomplete (this is discussed in section 4.1). The specific periods were selected to include similar ranges of exterior air temperatures, and exterior air temperatures that could be conducive to ice dam formation.

Table 1: Summary of Monitored Conditions at Site 1

	Average Condition*	Unit	Unit A (non-repaired)	Unit B (½ repair)	Unit B (full repair)
Before Repair**	Attic Temp.	ºC	5.6	1.3	1.1
	Exterior Temp.	ºC	-11.9		
	Interior Temp.	ºC	23.6	20.0	20.4
	Attic Temp. Index		0.49	0.40	0.39
After Repair	Attic Temp.	ºC	5.6	-2.6	-2.8
	Exterior Temp.	ºC	-16.2		
	Interior Temp.	ºC	24.4	22.2	21.8
	Attic Temp. Index		0.54	0.35	0.36

* Average conditions are for approximately one week periods, night time data only

** "Before repair conditions were taken in 2002/03, after incomplete air sealing repairs were undertaken: See section 5.1

Our temperature readings provided results comparable in two ways:

1. comparison of temperatures on units B and C before and after repairs.

2. comparison of unit A to unit B and C temperatures after the repairs were undertaken to units B and C.

In comparing the before and after temperature indices in unit B, we noted that the temperature indices (calculated using average attic temperatures) fell from 0.40 to 0.35, a drop of 12%. For unit C, the temperature index dropped from 0.39 to 0.36 (8%). For comparison purposes, the temperature index in unit A increased from 0.49 to 0.54 (10%) over the same period.

Our second avenue of analysis involved comparing the temperature indices of unit A to those in units B and C. We noted that after the repair, the temperature indices of units B and C were 0.35 and 0.36 respectively, while the temperature index in unit A was 0.54. The difference represent an approximate 35% reduction in temperature index. For comparative purposes, prior to the repair, the temperature indices of units B and C were approximately 20% lower than that for unit A.

Discussion

On first glance, the rise in temperature index 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 indices for units B and C decreased. Accordingly, the apparent temperature index decrease for units B and C may be a conservative representation of the benefit of the repairs. Accordingly, this indicates the repairs had some effect on the attic temperatures and propensity for ice damming formation.

We also compared our results to published temperature results from other ice damming studies (see section 4.4). One of these studies defines 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 site 1, we calculated post repair temperature indices in the range of 0.4 for units B and C, and above 0.5 for the un-repaired unit. Accordingly, the results indicate propensity for moderate ice damming due to interior attic temperatures in the repaired unit, and severe ice damming in the un-repaired unit. Based on past visual reviews of the site, we can confirm that unit A does experience severe ice damming problems.

The general building construction at site 1 is complicated, with many atypical construction details (as discussed in section 5.1.1). Further, the inherent building design included three distinct attic constructions beneath a single roof surface. This type of roof construction could be problematic with respect to ice damming formation if upper levels of roof areas are warmer than lower levels. Further, the attic construction could be problematic with respect to ice damming because the surface area through which heat transfer from the interior might occur is large: The surface area includes flat ceilings, cathedral ceilings, skylight walls, and conventional walls.

We also noted that the roof included two skylights, which could exacerbate ice dam formation due to increased melting on these systems.

Other potential heat sources could include poorly located or designed (bathroom) ventilation fans, chimneys, plumbing stacks, or non-repaired air leakage paths. In particular, no attempts were made to resolve air leakage paths in the cathedral ceiling areas of unit B. Determination of the potential for contribution of these or other sources was not within the scope of this project.

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 night time data (to minimize solar effects on the data). Other environmental effects beyond our control could have affected attic temperatures, as discussed below:

- Roof top snow cover: A graph of the ground snow cover for the winter of 2003/04 is presented in Figure 1. From this graph, it can be seen that the ground snow load was around 12 cm in the post repair monitoring period. During the reporting period prior to the repair, the ground snow load was 44 to 60 cm. 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 slightly higher than if the amount of snow on the roof at that time were the same as in 2004.

- 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. Figure 1 presents the average speed of maximum wind gusts for the winter of 2003/04. From this graph, it can be seen that wind gusts ranged between 30 and 60 kph. Wind speeds for the pre-repair period were at similar levels.

In summary, it is our opinion that the air sealing repairs at the condominium appeared to have a significant effect on the potential for ice damming. However, the post repair attic temperatures are still at levels that could be moderately problematic, and some ice damming should be expected on these units. We believe there are other sources of heat gain within the attic that are resulting in attic temperatures conducive to ice dam formation.

5.2 Site 2: Low Rise Condominium Complex

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 1980's and includes units with mansard and conventional style roofs with a 4/12 slope, as shown in Photos 17 and 18. The roofs do not have dormers, but have two chimneys and smaller (vent) penetrations.

5.2.1 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 style 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 which pressurized the entire unit relative to the attic to help identify potential air leakage paths between the unit 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 wall board below the attic, as shown in Photo 20 (similar to Figure 3). This gap was created by the furring between the concrete block wall and the gypsum wall board. 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 (as shown in Photo 19). This jog was created by the fireplace chimney which was integrally connected to the concrete block wall. This created a relatively large gap (approximately 300 mm x 600 mm) which 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.

5.2.2 Remedial Solution

The remedial solution developed included air sealing of all of the potential air leakage paths noted above, and installing new weatherstripping on the attic hatch door. All repairs were performed under our direction by a contractor (Can-Am) familiar with air sealing repairs. Repairs were reviewed by Morrison Hershfield.

Air sealing was performed using one component polyurethane foam for smaller gaps (Photo 22), and extruded polystyrene (cut to fit) and one component polyurethane foam for large penetrations (Photo 21).

The attic hatch was weather-stripped using a closed cell foam strip with a self adhesive backing. This weatherstripping was 9.5 mm wide by 4.5 mm deep.

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.

5.2.3 Monitoring

Monitoring was undertaken on a repaired unit (#50) and a similar unit (#48) without repairs. For the purpose of this report, the non-repaired unit was labeled "Unit A" while the repaired unit was labeled "Unit B". Both units had the same orientation and the same general attic and roof constructions and similar potential air leakage paths. Monitoring consisted of recurring exterior visual reviews and attic temperature readings for both the repaired and non-repaired units.

Visual reviews were taken from grade throughout the winter months. In general, there was no appreciable difference in the amount of snow or ice build-up between the repaired and non-repaired units. Photographs 23 through 26 display repaired and non-repaired roofs at various times in the winter.

Temperature readings were taken using thermocouples attached to self contained data acquisition systems, as noted is section 4.1. Temperatures were taken at two locations within each attic (near the peak and near the soffit), at one interior location per unit, and at one exterior location. The system recorded temperatures every twenty minutes from November 10, 2003 through to January 16, 2004. Figures 16 through 23 display the temperature monitoring results within the repaired and non-repaired attics.

5.2.4 Analysis and Discussion

Air Leakage Path Repairs

The visual review of the attic at site 2 revealed several prominent locations where problematic air leakage might occur between the interior conditioned space and the attic. These potential air leakage paths were confirmed by the observation of air passage through these paths from the building interior while a door fan was pressurizing the interior of the units.

The air sealing of these locations appeared to be successful based on our visual observations and retesting with the door fan.

Visual Reviews

The visual evidence of ice formation was inconclusive. No significant ice build-up was present on either the repaired or un-repaired unit. 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, as noted in section 4.3.

Due to the lack of relevant information, we do not believe an accurate determination of success of the repairs to mitigate ice dam formation can be presented based on the visual reviews from 2004.

Temperature Readings

The temperature readings and related data are presented in Figures 16 through 23, and summarized in Table 2, below. These Figures include raw temperature data and / or temperature indices over different periods of time, as discussed in section 4.1. The periods of time provided in these graphs represent approximately one week periods before and after the repair took place.

Table 2: Summary of Monitored Conditions at site 2

	Average Condition*	Unit	Unit A (non-repaired)	Unit B (repaired)
Before Repair	Attic Temp.	ºC	-2.3	-0.7
	Exterior Temp.	ºC	-4.8	
	Interior Temp.	ºC	20.3	19.7
	Attic Temp. Index		0.10	0.16
After Repair	Attic Temp.	ºC	-9.4	-5.8
	Exterior Temp.	ºC	-16.5	
	Interior Temp.	ºC	20.2	19.0
	Attic Temp. Index		0.19	0.30

*Average conditions are for approximately one week periods, night time data only

Our temperature readings provided results comparable in two ways:

1. comparison of temperatures on unit B before and after repairs.

2. comparison of unit A and B temperatures after the repair was undertaken to unit B.

In comparing the before and after temperature indices in unit B, we noted that the temperature indices (calculated using average attic temperatures) rose from an average of 0.16 to 0.30, a rise of 90% over the period.

We also compared the before and after temperature indices in unit A. In this unit, the attic construction remained the same before and after the repair was undertaken to unit B. We noted that the average temperature index in this unit changed from 0.11 to 0.19, a rise of 73%.

Our second avenue of analysis involved comparing the temperature indices of units A and B. We noted that after the repair, the temperature indices of unit B were an average of 0.11 higher (37%) than that from unit A. Prior to the repair, the temperature indices of unit B was 0.06 higher (38%) than that for unit A.

Discussion

On first glance, the rise in temperature index between the non-repaired and repaired state of unit B appears to indicate that the air sealing was counter productive with respect to the propensity for ice dam formation. This is counter-intuitive and very unlikely to be true: air sealing repairs within an attic cannot possibly be the reason for the 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.

In our analysis, we noted that the difference in temperature indices before and after the repair are 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 damming formation.

We also compared our results to published temperature results from other ice damming studies (see section 4.4). One of these studies 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 the site 2 site, we calculated post repair temperature indices in the range of 0.3 for the repaired unit, and 0.2 for the non-repaired unit. Accordingly, the results indicate propensity for mild to moderate ice damming due to interior attic temperatures.

The attics at site 2 are relatively simple in design, and we believe that most readily apparent air leakage paths were sealed through the repair. We do not believe that other factors commonly associated with ice damming, such as solar effects, poor insulation, and poor ventilation, were major contributing factors to ice damming at the site. Accordingly, it is our opinion that a different source of attic heat gain must be contributing to the relatively high attic temperatures.

One potential source of heat gain is the concrete block party wall separating the adjacent units. If this party wall contains unfilled concrete block cores (open cores) that extend from the attic to conditioned space below, then convective forces could result in warm concrete blocks in the attic (in winter). Further, Lux and Brown[3] quote that concrete blocks have an air permeance of 2.1 $L/s/m^2$ at 75 Pa, which is approximately 100 times larger than the National Building Code 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).

Other potential heat sources could include poorly located or designed (bathroom) ventilation fans, chimneys, or plumbing stacks. Determination of the potential for contribution of these or other sources was not within the scope of this project.

[3] Air Leakage Control, Building Science Insight (1986), M.E. Lux and W.C. Brown, Institute for Research in Construction, National Research Council of Canada

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. They were oriented in the same direction. The periods for comparisons were chosen so that they had exterior air temperatures potentially conducive to ice dam formation, and included only night time data (to eliminate solar effects on the data). Other environmental effects beyond our control could have affected attic temperatures, as discussed below:

- Roof top snow cover: A graph of the ground snow cover is presented in Figure 1. From this graph, it can be seen that the ground snow load was 0 to 6 cm in the pre-repair monitoring period, while the ground snow load was 0 to 20 cm 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.

- 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. Figure 1 presents the average speed of maximum wind gusts for the periods analyzed. From this graph, it can be seen that wind gusts were similar between the two periods, so we do not believe wind speed has significantly affected the comparative results.

In summary, it is our opinion that the air sealing repairs at the condominium did not have a significant effect on the potential for ice damming. We believe there are other sources of heat gain within the attic that are resulting in attic temperatures conducive to ice dam formation.

5.3 Site 3: Low Rise Condominium Complex

Site 3 is an 11 unit townhouse complex located in Ottawa that has been exhibiting moderate to severe ice damming in past years (Photo 29). From our conversations with unit owners and involved contractors, we understand that the condominium has been looking for methods to reduce ice damming over that past 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.

The complex was constructed circa 1994 and includes units with conventional style roofs with an 8/12 slope. The buildings have dormers and tend to be stepped in plan, as shown in Photos 27 and 28.

5.3.1 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 constructions, and with the same orientation and general construction. At the time of the attic reviews, we utilized a blower door which pressurized the entire unit relative to the attic to help identify potential air leakage paths between the unit conditioned space (interior) and the attic.

We noted that the units have unconventional floor plans and framing designs (see Figure 24). 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 24 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 which 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 of glass fiber batt insulation.

2. Near the peak of the roof was a shallow conventional style attic as shown in Figure 24. 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 of fiberglass batt insulation, and an approximate 100 mm 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 extending past the line of the attic storage room knee wall into the attic spaces was not sealed to prevent air leakage. Effectively, this created an 200 mm deep hole that ran the entire length of the each knee wall through which air could freely enter the attic space (as shown in Photo 31 and Figure 24).

- We noted that a 12 to 16 mm gap existed between the concrete block party wall and the gypsum board wall below the attic, similar to that shown in Figure 3. 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 gap was present along the base of the walls separating the attic storage room from the knee wall attics, as shown in Photo 32.

5.3.2 Remedial Solution

The remedial solution developed included air sealing of all of the potential air leakage paths noted above, and installing new weatherstripping on the knee wall attic hatches. All repairs were performed under our direction by a contractor (Can-Am) familiar with air sealing repairs. Repairs were reviewed by Morrison Hershfield.

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 (Photos 34 and 35).

The attic hatch was weather-stripped using a closed cell foam strip with a self adhesive backing. This weatherstripping was 9.5 mm wide by 4.5 mm deep.

A second round of pressure testing (using a door fan as shown in Photo 33) 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.

5.3.3 Monitoring

Monitoring was undertaken on a repaired unit (#10) and a similar unit (#12) without repairs. For the purpose of this report, the non-repaired unit was labeled “Unit A” while the repaired unit was labeled “Unit B”. Both units had the same orientation and the same general attic and roof constructions and similar potential air leakage paths. Monitoring consisted of recurring exterior visual reviews and attic temperature readings for both the repaired and non-repaired units.

Visual reviews were taken from grade throughout the winter months. In general, there was no appreciable difference in the amount of snow or ice build-up between the repaired and non-repaired units. Photographs 36 through 38 display repaired and non-repaired roofs at various times in the winter.

Temperature readings were taken using thermocouples attached to self contained data acquisition systems, as noted is section 4.1. Temperatures were taken at one interior location per unit, one exterior location, and two attic locations: one within the knee wall attic and the second in the air space near the base of the cathedral ceiling (see Figure 24). The system recorded temperatures every twenty minutes from November 14, 2003 through to January 28, 2004. Figures 25 through 33 display the temperature monitoring results within the repaired and non-repaired attics.

5.3.4 Analysis and Discussion

Air Leakage Path Repairs

The visual review of the attic at site 2 revealed several prominent locations where problematic air leakage might occur between the interior conditioned space and the knee wall attic. In particular, the gaps created by the floor framing extending past the line of the attic storage room wall into the attic spaces were believed to be a large potential contributor to problematic air leakage. This potential was confirmed by the observation of air leakage from the building interior while a door fan was pressurizing the interior of the units.

We did not have access to perform visual review of the upper attic or cathedral ceiling attic spaces. However, the attic room extends the full width of each condominium unit, and the ceiling areas of this room are relatively free of penetrations (only one ceiling fan / light unit was present within the room). Accordingly, we believe that the gypsum board will likely function reasonably well as an air barrier in these areas. However, we expect that the potential air leakage path created by the furring space adjacent to the concrete block party wall (see section 5.3.1) also exists adjacent to the cathedral and upper attics, and likely remains as an air leakage path in the repaired unit.

The air sealing of potential paths for air leakage appeared to be successful based on our visual observations and retesting with the door fan.

Visual Reviews

The visual evidence of ice formation was inconclusive. No significant ice build-up was present on either the repaired or un-repaired unit. 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, as noted in section 4.3.

Due to the lack of relevant information, we do not believe an accurate determination of success of the repairs to mitigate ice dam formation can be presented based on the visual reviews from 2004.

Temperature Readings

The temperature readings and related data are presented in Figures 25 through 32, and summarized in table 3, below. These Figures include raw temperature data and / or temperature indices over different periods of time, as discussed in section 4.1.

Table 3: Summary of Monitored Conditions at Site 3

	Average Condition*	Unit	Unit A (non-repaired)	Unit B (repaired)
Before Repair	Attic Temp.	ºC	-1.9	1.5
	Attic Storage Room Temp.	ºC	16.9	17.3
	Exterior Temp.	ºC	-5.5	
	Interior Temp.	ºC	19.6	22.4
	Attic Temp. Index		0.14	0.25
After Repair	Attic Temp.	ºC	-8.2	-5.7
	Attic Storage Room Temp.	ºC	16.6	12.9
	Exterior Temp.	ºC	-15.8	
	Interior Temp.	ºC	19.6	20.0
	Attic Temp. Index		0.21	0.28

*Average conditions are for approximately one week periods, night time data only

Our temperature readings provided results comparable in two ways:

1. comparison of temperatures on unit B before and after repairs.

2. comparison of unit A and B temperatures after the repair was undertaken to unit B.

In comparing the pre and post repair information from unit B, we noted that the temperature indices (calculated using average temperatures) rose from an average of 0.25 to 0.28, a rise of 12% over the period.

We also compared pre and post repair information from unit A. In this unit, the attic construction remained the same before and after the repair was undertaken to unit B. We noted that the average temperature index in this unit changed from 0.14 to 0.21, a rise of 50%.

Our second avenue of analysis involved comparing the temperature indices of units A and B. We noted that after the repair, the temperature indices of the unit B were an average of 0.07 higher (25%) than that from unit A. Prior to the repair, the temperature indices of unit B were 0.11 higher (44%) than that for unit A.

Discussion

On first glance, the rise in temperature index between the pre and post repair information on Unit B appears to indicate that the air sealing was counter productive with respect to the propensity for ice dam formation. This is counter-intuitive and very unlikely to be true: air sealing repairs within an attic cannot possibly be the reason for the 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.

We also noted that the temperature index increases for the non-repaired unit between the pre-repair and post-repair time periods. This indicates that other factors are present which have resulted in a sweeping increase in temperature indices in all attics.

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

We also compared our results to published temperature results from other ice damming studies (see section 4.4). One of these studies 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 the site 3, we calculated post repair temperature indices in the range of 0.3 for the repaired unit, and 0.2 for the non-repaired unit. Accordingly, the results indicate propensity for mild to moderate ice damming due to interior attic temperatures.

The general building construction at site 3 is complicated, with many atypical construction details, such as the attic storage area. The attic construction could be particularly problematic with respect to ice damming, because the surface area through which heat transfer from the interior might occur is large: The surface area includes cathedral ceilings and walls.

We also noted that the roof shape included dormers and valleys. These elements could exacerbate ice dam formation due to differential solar gains on these roof surfaces.

Although we could not review several attic areas, we believe that most air leakage paths were sealed through the repair (as noted at the beginning of this section). Accordingly, it is our opinion that a different source of attic heat gain must be contributing to the relatively high attic temperatures.

One potential source of heat gain is the concrete block party wall separating the adjacent units. If this party wall contains unfilled concrete block cores that extend from the attic to conditioned space below, then convective forces could result in warm concrete blocks in the attic (in winter). Further, Lux and

Brown[4] quote that concrete blocks have an air permeance of 2.1 $L/s/m^2$ at 75 Pa, which is approximately 100 times larger than the National Building Code 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).

Other potential heat sources could include poorly located or designed (bathroom) ventilation fans, chimneys, or plumbing stacks. Determination of the potential for contribution of these or other sources was not within the scope of this project.

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 and were oriented in the same direction. The periods for comparison were chosen so that they had exterior air temperatures potentially conducive to ice dam formation, and included only night time data (to eliminate solar effects on the data). Other environmental effects beyond our control could have affected attic temperatures, as discussed below:

- Roof top snow cover: A graph of the ground snow cover is presented in Figure 1. From this graph, it can be seen that the ground snow load was 0 to 6 cm in the pre-repair monitoring period, while the ground snow load was 0 to 20 cm 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.

- 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 winter. Figure 1 presents the average speed of maximum wind gusts for the periods analyzed. From this graph, it can be seen that wind gusts were similar between the two periods, so we do not believe wind speed has significantly affected the comparative results.

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[4] Air Leakage Control, Building Science Insight (1986), M.E. Lux and W.C. Brown, Institute for Research in Construction, National Research Council of Canada

In summary, it is our opinion that the air sealing repairs at the condominium appear to have reduced, but not eliminated the potential for ice damming. We also believe there are other factors affecting ice dam formation at the site.

5.4 Site 4: Low Rise Condominium Complex

Site 4 is a three story townhouse complex located in Ottawa that has been exhibiting moderate to severe ice damming in past years. The complex was constructed in the mid 1990's and it has a fairly complex roof system including various roof levels and dormers (Photos 39 and 40, and Figure 33).

5.4.1 Investigation

Morrison Hershfield was retained by Site 4 to investigate their ice damming problems in 1998/9.

Our 1998 investigation at this site consisted of visual reviews of the interior of several units including their attics. We noted that the units have relatively conventional floor plans and framing designs, although some units had dormers and lower roof areas, as shown in Photo 40 and Figure 33. The main roofs had an 4/12 pitch with asphalt shingles on OSB sheathing. The attic utilized engineered wood trusses and the ceiling below consisted of gypsum board, 6 mil polyethylene, and an average of approximately 275 mm of loose fill fiberglass insulation. The insulation depth varied considerably, with some areas having less than 100 mm insulation. Two layers of building paper served as eave protection beneath the shingles. We found a number of contributory factors to their ice damming problems, as described below:

- Many penetrations through the attics were not sealed, resulting in several air leakage paths into the attic (Photos 42 to 44).
- The attic hatch weatherstripping did not provide a good and continuous seal at all locations.
- The loose fill insulation obstructed the soffit vents, reducing attic ventilation effectiveness (Photo 41). Also, the soffit spaces between several of the trusses were not utilized for ventilation.
- The attic hatches were not insulated.
- Some clothes dryers vented directly into the attic (This condition did not exist in either of the units involved in this project).
- The roof trusses were relatively shallow near the eaves, limiting the eave ventilation capability.
- The roofs were fairly complicated, with many dormers and lower roof areas.

5.4.2 Remedial Solution

As part of our original report, we suggested a seven step plan of action, as follows:

1. seal attic penetrations and re-route dryer vents to the exterior.
2. redistribute insulation within the attic to make it a more even depth (Photo 45).
3. add rigid insulation to attic hatches and replace hatch weatherstripping
4. clear out soffit vents, add baffles where necessary (Photo 45)
5. increase soffit ventilation by utilizing soffit spaces between each truss
6. install ridge vents
7. replace eave protection where necessary

The condominium has been phasing in these repairs on a block by block basis. By the summer of 2003, the condominium had completed repairs on all but one block of units. All repairs were performed by a contractor prior to our involvement in this project. Morrison Hershfield staff performed visual reviews of the units included within this study to determine if the repairs were undertaken. During these reviews, we also tested the repairs using a blower door to confirm the repairs were functioning acceptably.

5.4.3 Monitoring

Monitoring was undertaken on a non-repaired unit (#280) and a similar repaired unit (#55). For the purpose of this report, the non-repaired unit was labeled “Unit A” while the repaired unit was labeled “Unit B”. Both units had the same orientation and the same general ceiling constructions and similar potential air leakage paths. However, Unit A was an end unit with three exterior walls while unit B was an interior unit with two exterior walls. Monitoring consisted of recurring exterior visual reviews and attic temperature readings for both the repaired and non-repaired units.

Visual reviews were taken from grade throughout the winter months. In general, there was no appreciable difference in the amount of snow or ice build-up between the repaired and non-repaired units. Photographs 46 through 49 display repaired and non-repaired roofs at various times in the winter.

Temperature readings were taken using thermocouples attached to self contained data acquisition systems, as noted is section 4.1. Temperatures were taken at one interior location per unit, one exterior location, and two attic locations per unit. The system recorded temperatures every twenty minutes from February 5, 2004 through to March 5, 2004. Figures 34 through 37 display the temperature monitoring results within the repaired and non-repaired attics.

5.4.4 Analysis and Discussion

Unit Repairs

The visual review of the attics at Site 4 revealed several contributory factors potentially related to ice damming. The repair methodology included treating most of the contributory factors that could be relatively easily repaired. Factors such as roof complexity and the shallow depth at the truss edge would be very difficult to resolve, and remained un-repaired.

Our visual reviews indicated that, at Unit B, the soffit ventilation had been cleared, the attic insulation was at a reasonably consistent depth, a new ridge vent had been added, new weatherstripping had been added to the hatch, and so excessive air leakage paths (between the conditioned space and the attic) were found. We believe the repairs undertaken met the general intent of those recommended in our original report.

Visual Reviews

The visual evidence of ice formation was inconclusive. No significant ice build-up was present on either the repaired or un-repaired units. 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, as noted in section 4.3.

However, the property manager for the site sated that the repaired units are generally not producing problematic ice dams since the repair program was started in 1999.

The visual reviews from 2004 cannot present an accurate determination of success of the repairs. However, the information provided by the property manager on past years may be an indication of success, based on the relatively long time span since the repairs and the apparent lack of problematic leakage.

Temperature Readings

The temperature readings and related data are presented in Figures 34 through 37, and summarized in table 5, below. These Figures include raw temperature data and / or temperature indices over different periods of time, as discussed in section 4.1. The data provided in these graphs includes two distinct periods of time adding to a total of six days (approximately) during which exterior air temperatures were at levels that could be conducive to ice dam formation.

The days between these periods included exterior temperatures above 0ºC. These relatively warm temperatures would not be conducive to ice dam formation, so the temperature readings were excluded from our analysis.

Table 4: Summary of Monitored Conditions at Site 4

	Average Condition*	Unit	Unit A (non-repaired)	Unit B (repaired)
Post-Repair	Attic Temp.	ºC	-2.7ºC	-6.4ºC
	Exterior Temp.	ºC	-11.7ºC	
	Interior Temp.	ºC	24.2ºC	24.1ºC
	Attic Temp. Index		0.25	0.15

*Average conditions are for approximately one week periods, night time data only

In comparing the temperature indices of units A and B, we noted that the repaired unit had an average temperature index 40% lower than unit A. This trend was also apparent in Figures 34 through 37.

Discussion

The analysis of temperature readings appears to reveal that attic temperatures were significantly reduced through the repair. From this perspective, the repair procedure appears to have functioned well.

We also compared the temperature results to published results from other ice damming studies (see section 4.4). One of these studies 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 site 4, we calculated average temperature indices in of 0.15 for the repaired unit (unit B), and 0.25 for the non-repaired unit (unit A). Accordingly, these results indicate propensity for mild to moderate ice damming due to interior attic temperatures.

However, two factors lead us to question the validity of the above results, as discussed below:

1. In reviewing the results from other sites within this report, it appears that the comparison of similar units may not be valid. Notably, both the site 2 (section 5.2) and site 3 (section 5.3) sites would have resulted in false conclusions if relying on only post repair data on comparable buildings.

2. The non-repaired unit was an end unit. End units differ in construction from interior units in that they exclude one party wall, include (in this case) additional soffit ventilation and roof sheathing area, and often do not accumulate high amounts of roof top snow. We would expect that each of these factors will result in the non-repaired unit performing

better than a typical interior unit with respect to ice dam formation. We recognize that the results appear to be successful regardless of this potential betterment, but we believe the comparison of more similar units would have resulted in more reliable comparisons.

Taking into account the temperature readings, the comparison with published results, the concerns noted above, and the property managers claims that problematic ice damming was not occurring on repaired units, we believe that there are strong indications that the repair procedure succeeded in significantly reducing the propensity for ice damming.

The primary repairable factors associated with ice dam formation at site 4 included air leakage and a lack of ventilation. The solutions implemented resolved these factors, and appeared to produce positive results. Taking into account all of the information presented within this section, it is our opinion that the repairs undertaken have significantly reduced, but may not have eliminated the potential for problematic ice dams.

Additional more extensive monitoring would be required to more definitively prove the success of the repairs in reducing ice damming potential.

5.5 Site 5: Manotick, One and a Half Storey House

This single family house is located in Manotick Ontario and has exhibited many years of ice damming. This house is a balloon framed 1 ½ storey building constructed circa 1938 (Photo 50). The house faces east. The roof incorporates both a cathedral ceiling area, dormers, and a conventional vented attic. This house is owned by the author of this report.

5.5.1 Investigation

Our investigation at this site consisted of visual reviews of the interior of the house including the attic. At the time of the attic reviews, we utilized a blower door which pressurized the entire house to help identify air leakage paths.

We noted that the house utilizes balloon framing. The roof incorporates two large dormers and all roof areas have a 12/12 pitch and were protected with asphalt shingles over one layer of building paper. Self adhesive modified bitumen membrane eave protection was present at the eaves and along the various roof valleys. The house had sections of roof above a conventional attic, and other sections above cathedral ceilings. Figure 38 displays a cross section of the building including the attic.

On the morning of December 2, 2003, we observed that a heavy layer of frost was present on the roof surfaces. This frost had melted at locations of excessive heat loss through the roof, revealing potential melting locations. Photographs of these melting patterns are presented in Photos 51 through 55. These observations revealed that locations susceptible to melting were as follows:

- At the top of the cathedral ceiling areas (where the cathedral ceiling and knee wall intersect)
- Above the exterior wall at the east side of the front dormer.
- Above the exterior walls on the north and south sides of the building.
- Around plumbing stacks, the roof top bathroom vent exhaust, and mushroom vents.
- Near the chimney

The main attic was accessed through a hatch within the bathroom ceiling. The hatch was reasonably well sealed with closed cell foam weatherstripping and had 100 mm of extruded polystyrene bonded to its top. The attic utilized solid wood rafters and solid wood (37 mm) ship-lapped sheathing. The ceiling below consisted of plaster, 25 mm fiberboard, 16 mm wood strapping, 50 mm of rock wool batt insulation, and 75 mm of fiberglass batt insulation.

The cathedral ceiling spaces were reviewed from within the main attics. The construction of the cathedral ceiling roof areas consisted of asphalt shingles above building paper or adhered modified bitumen membrane, 37 mm ship-lapped sheathing, 100 mm loose fill vermiculite insulation, an inner layer of 37 mm ship-lapped wood sheathing, an inner layer of building paper, 16 mm wood strapping, 25 mm fiberboard, and plaster bonded directly to the fiberboard. No air space was present between the insulation and the underside of the sheathing.

The exterior wall construction below the attic spaces was identical to the cathedral ceiling construction, except that brick was present in lieu of asphalt shingles.

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

- Several cavities within the balloon framed walls were not sealed or insulated and vented directly into the attic space (Photo 57).

- We noted that a 12 mm gap existed at several attic locations between the interior wall sheathing and the wall fiberboard. Air could be felt moving into the attic through these gaps.

- At the top of the cathedral ceiling, air could be felt to be moving into the main attic. Upon closer investigation and smoke testing, it was noted that this air leakage appeared to originate at the base of the knee wall in the conditioned space below.

- The main attic had 125 mm of insulation, while the cathedral ceiling areas generally had about 100 mm of insulation. These levels of insulation are lower than current building code requirements.

- There was a 12 mm gap between the fiberboard/plaster wall and the brick chimney (The chimney was on an exterior wall).

- There was no insulation in one of the cathedral ceiling stud spaces.

We also noted that the large dormers on the house had roof areas that faced south which drained directly onto east and west facing roof areas.

We also noted that frost was present on the underside of the rafters and sheathing (Photo 56) at the start of the attic visit in which air sealing repairs were undertaken.

5.5.2 Remedial Solution

The remedial solution developed included air sealing of all of the penetrations noted above, and installation of additional insulation within the attic.

All sealing repairs were performed by the house owner. Repairs were reviewed by Morrison Hershfield.

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 (Photo 58).

In addition, approximately 250 mm of loose fill cellulose insulation was installed over the existing insulation. Also, the empty stud space in the cathedral ceiling (see section 5.5.1) was filled with cellulose insulation. A mechanical insulation blower was used for this purpose.

The repairs were phased so that air sealing was performed several weeks prior to the addition of insulation. This allowed an analysis of the success of the air sealing alone, as well as the air sealing and additional insulation.

5.5.3 Monitoring

Monitoring was undertaken on the unit before and after the repairs were implemented. Monitoring consisted of repeated visual reviews and attic temperature readings before and after the non-repaired unit. Visual reviews have also been taken in past years.

Visual reviews were taken from grade throughout the winter months. Photographs 59 through 62 display the roof top snow cover before and after the repairs.

In reviewing roof snow melting patterns through the winter, we observed that the snow on the south facing dormer roof tended to melt more quickly than on the east and west facing roofs (Photo 61). Snow melt from these dormers fell onto the east and west facing roofs. We also noted that the roof areas above the cathedral ceilings tended to melt more quickly than other areas (Photo 62).

Temperature readings were taken using thermocouples attached to a stand-alone data acquisition systems. Two thermocouples were located in the main attic (one in the east dormer and one in the main attic approximately 3 m from the south wall), and one thermocouple was located in the interior of the house (second floor).

The system took temperature readings every twenty minutes from January 1, 2004 to February 15, 2004. Figures 39 through 43 display the temperature monitoring results before and after the repairs.

5.5.4 Analysis and Discussion

Repairs

The visual review of the attic at the Manotick house revealed several prominent locations where problematic air leakage might occur between the interior space and the knee wall attic. This information was also supported by the analysis of frost melting patterns in December of 2003. The air sealing of potential paths for air leakage appeared to be successful based on our visual observations.

The addition of insulation brought the insulation levels in the main attic well above current requirements (R60), although the cathedral ceiling insulation values remained unchanged (except for the previously empty cavity).

Visual Reviews

The visual evidence of ice formation was inconclusive. A small amount of ice build-up was observed near the end of winter, but the degree of ice build-up was not problematic. 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, as noted in section 4.3.

In reviewing roof snow melting patterns through the winter, we observed that the snow on the south facing dormer roof tended to melt more quickly than on the east and west facing roofs. The snow melt from these dormers fell onto the east and west facing roofs. The east and west facing roofs would receive less solar gain than the south facing roofs, so we believe there is potential for ice formation on these roofs through this mechanism.

We also noted the relatively high amount of snow melt through the cathedral ceiling portions of the roof. Little work was performed in these roof and attic areas due to a lack of access. Snow melt on these roof areas could result in ice dams at eaves.

Due to the lack of relevant information, we do not believe an accurate determination of success of the repairs to mitigate ice dam formation can be presented based on the visual reviews from 2004.

Temperature Readings

The temperature readings and related data are presented in Figures 39 through 43, and summarized in table 5, below. These Figures include raw temperature data and / or temperature indices over different periods of time, as discussed in section 4.1. The periods of time provided in these graphs represent approximately five days prior to the repair, ten days after the repair, and five days after the addition of insulation.

Table 3: Summary of Monitored Conditions at Manotick House

Average Condition*	Unit	Pre-Repair	Post- Air Sealing	Post - Added Insulation
Attic Temp.	ºC	-9.4	-5.2	-3.7
Exterior Temp.	ºC	-15.6	-15.7	-7.8
Interior Temp.	ºC	17.5	18.2	18.5
Attic Temp. Index		0.18	0.31	0.14

*Average conditions are for approximately the periods, night time data only

In comparing the before and after temperature results, we noted that the temperature indices (calculated using average attic temperatures) rose from an average of 0.18 to 0.31, a rise of 72% over the period.

In reviewing the results of the added insulation, we noted that the temperature indices (calculated using average attic temperatures) fell from an average of 0.18 to 0.14, a drop of 20% over the period.

Discussion

On first glance, the rise in temperature index appears to indicate that the air sealing was counter productive with respect to the propensity for ice dam formation. However, in comparing the information on ground snow cover, we found that the ground snow cover in the pre air sealing data period was between 3 to 5 cm, while the snow cover in the post air sealing period was between 10 and 20 cm. The snow cover in the post added insulation period was between 10 and 30 cm. We believe that the insulating effects of the snow resulted in increased attic temperatures, so that the temperatures represented are conservative with respect to benefits achieved.

We also compared our results to published temperature results from other ice damming studies (see section 4.4). One of these studies defines 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 the Manotick house, we calculated post air sealing repair temperature indices in the range of 0.25 to 0.5 and post added insulation (and air sealing) temperature indices near 0.14. Accordingly, the results indicate propensity for moderate to severe ice damming due to interior attic temperatures after the air sealing repair was undertaken, but low likelihood of ice damming after both air sealing and added insulation were performed. It is important to note that these temperature indices were based on main attic temperatures only. Accordingly, problematic conditions might still be present at cathedral ceiling locations.

The general building construction at the Manotick house is relatively complicated and many of the construction details believed to be problematic with respect to ice damming are difficult to resolve. The attic construction does not include soffit vents, and the balloon framing at inaccessible areas could represent relatively large unresolved air leakage paths. Further, the dormers appear to result in solar induced melting and consequential ice build-up on lower roofs. Lastly, the general construction of cathedral ceiling above the eaves may result in excessive snow melt immediately above the eaves, and the cause of this snow melt is very difficult to resolve.

In summary, it is our opinion that the air sealing repairs at the Manotick house did not significantly reduce the propensity for ice damming, but that the air sealing and added insulation may have significantly reduced ice damming potential associated with the main attic. However, we believe other factors, such as unresolved air leakage paths, solar induced melting, and poor ventilation may result in conditions conducive to ice dam formation.

6. DISCUSSION

As discussed in section 4.1, there are many factors that affect a building's propensity towards problematic ice damming. The purpose of this study was to determine the effectiveness of focusing on one of these causal factors, air leakage, at resolving problematic ice damming. Throughout this study, a number of interesting findings were achieved.

Monitoring Approach

The original scope for this research included monitoring attic and roof conditions before and after air sealing repairs were undertaken. This approach was taken on several of the sites included within this study. 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, roof top 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. This strategy was utilized at four of the five sites within this project. The determination of similarity was made, in these cases, 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, which 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 several of 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 (reference section 4.2) which normalized attic temperatures with respect to indoor temperatures.

In reviewing the graphical results, we found that attic temperatures generally tracked exterior temperatures (ex. Figure 17). 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 (ex. Figure 18). 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 in 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 of 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 on trends should be relied upon 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 winter time attic heat gain. The typical method of furring out gypsum board walls below the attic creates one common potential air leakage path. Also, air leakage and / or convective heat flow may result in heat gain through the interior of a concrete block wall.

- 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 Scanada report (see section 4.4.1).

- 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 Scanada report (see section 4.4.1).

Beyond 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 and would be very difficult to correct. This type of detail should be avoided in climates conducive to ice damming.

Lastly, we found that solar effects, particularly as they relate to dormers, can play a role in many cases. Complicated roofs with many dormers are more common today, and we expect these roofs may be more susceptible 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 damming potential in some buildings, but that it cannot be relied upon as the solution for all buildings with ice damming 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 damming 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 damming 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 acknowledges 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.

7. 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 the 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 base-line 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.

Morrison Hershfield Limited

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Mark Lucuik, P.Eng
Principal

APPENDIX A: PHOTOGRAPHS

Photo 03: Site 1, Typical ice formation

Photo 04: Site 1, Air Leakage Path at Chimney

Photo 05: Site 1, Air Leakage Path at Joist Penetration

Photo 06: Site 1, Air Leakage Path at B-Vent (Furnace) Chimney

Photo 07: Site 1, Air Leakage Path at Party Wall

Photo 08: Site 1, Air Sealing Repairs, Joists

Photo 09: Site 1, Air Sealing Repairs, Party Wall in Cathedral Ceiling

Photo 10: Site 1, Air Sealing Repairs, Party Wall in Main Attic

Photo 11: Site 1, Unrepaired Unit, February 19, 2004

Photo 12: Site 1, Unrepaired Unit, February 19, 2004

Photo 13: Site 1, Unrepaired Unit, February 19, 2004

Photo 14: Site 1, Unrepaired Unit, February 19, 2004

Photo 15: Site 1, Repaired Units, February 19, 2004

Photo 16: Site 1, Repaired Units, February 19, 2004

Photo 17: Site 2, Condominium Complex

Photo 18: Site 2, Ice Formation on Mansard Style Roofs

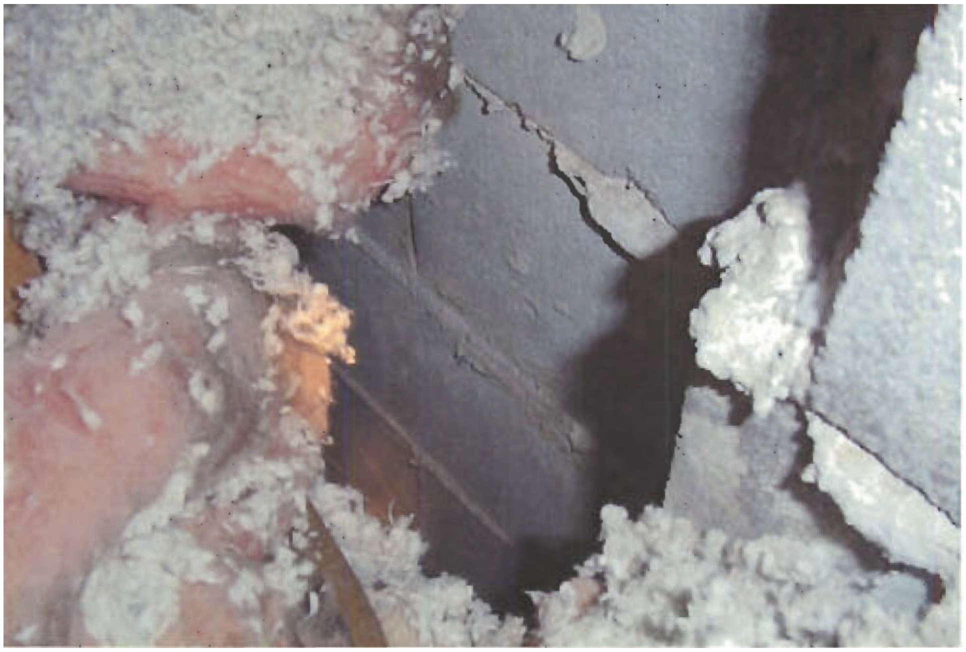


Photo 19: Site 2, Large Air Leakage Path at Party Wall

Photo 20: Site 2, Air Leakage Path at Party Wall

Photo 21: Site 2, Air Sealing Repairs at Large Air Leakage Path at Party Wall

Photo 22: Site 2, Air Sealing Repairs at Party Mall

Photo 23: Site 2, Unrepaired Units, January 20, 2004

Photo 24: Site 2, Unrepaired Units, January 20, 2004

Photo 25: Site 2, Repaired Units, January 20, 2004

Photo 26: Site 2, Repaired Units, January 20, 2004

Photo 27: Site 3, Condominium Complex, Front Courtyard

Photo 28: Site 3, Condominium Complex

Photo 29: Site 3, Condominium Complex, Rear of Units

Photo 30: Site 3, Typical (past years) Ice Build-up

Photo 31: Site 3, Air Leakage Path at Base of Wall

Photo 32: Site 3, Gap at Base of Knee Wall

Photo 33: Site 3, Blower Door Installation

Photo 34: Site 3, Air Sealing

Photo 35: Site 3, Air Sealing

Photo 36: Site 3, Repaired Unit (front) January 20, 2004

Photo 37: Site 3, Unrepaired Unit (front), January 20, 2004

Photo 38: Site 3, Unrepaired Unit (front), January 20, 2004

Photo 39: Site 4, Condominium Complex

Photo 40: Site 4, Snow and Ice Build-up (past)

Photo 41: Site 4, Blocked Soffit Ventilation

Photo 42: Site 4, Air Leakage Path at Plumbing Vent

Photo 43: Site 4, Party Wall

Photo 44: Site 4, Electrical Box in Ceiling

Photo 45: Site 4, New Baffles at Soffit

Photo 46: Site 4, Repaired Unit (front), January 20, 2004

Photo 47: Site 4, Repaired Unit (back) January 20, 2004

Photo 48: Site 4, Unrepaired Unit (front), January 20, 2004

Photo 49: Site 4, Unrepaired Unit Wall (back), January 20, 2004

Photo 50: Manotick Single Family House

Photo 51: Manotick, Snow Melt Patterns (front of house)

Photo 52: Manotick, Snow Melt Patterns (front of house)

Photo 53: Manotick, Snow Melt Pattern (front of house)

Photo 54: Manotick, Snow Melt Pattern (back of house)

Photo 55: Manotick, Snow Melt Patterns (back of house)

Photo 56: Manotick, Front on Underside of Sheating

Photo 57: Manotick, Balloon Framing Stud Space

Photo 58: Manotick, Air Sealing of Balloon Framing Stud Space

Photo 61: Manotick, Post Repair Snow Cover - Back

Photo 62: Manotick, Post Repair Snow Cover - Dormer

APPENDIX B:
FIGURES

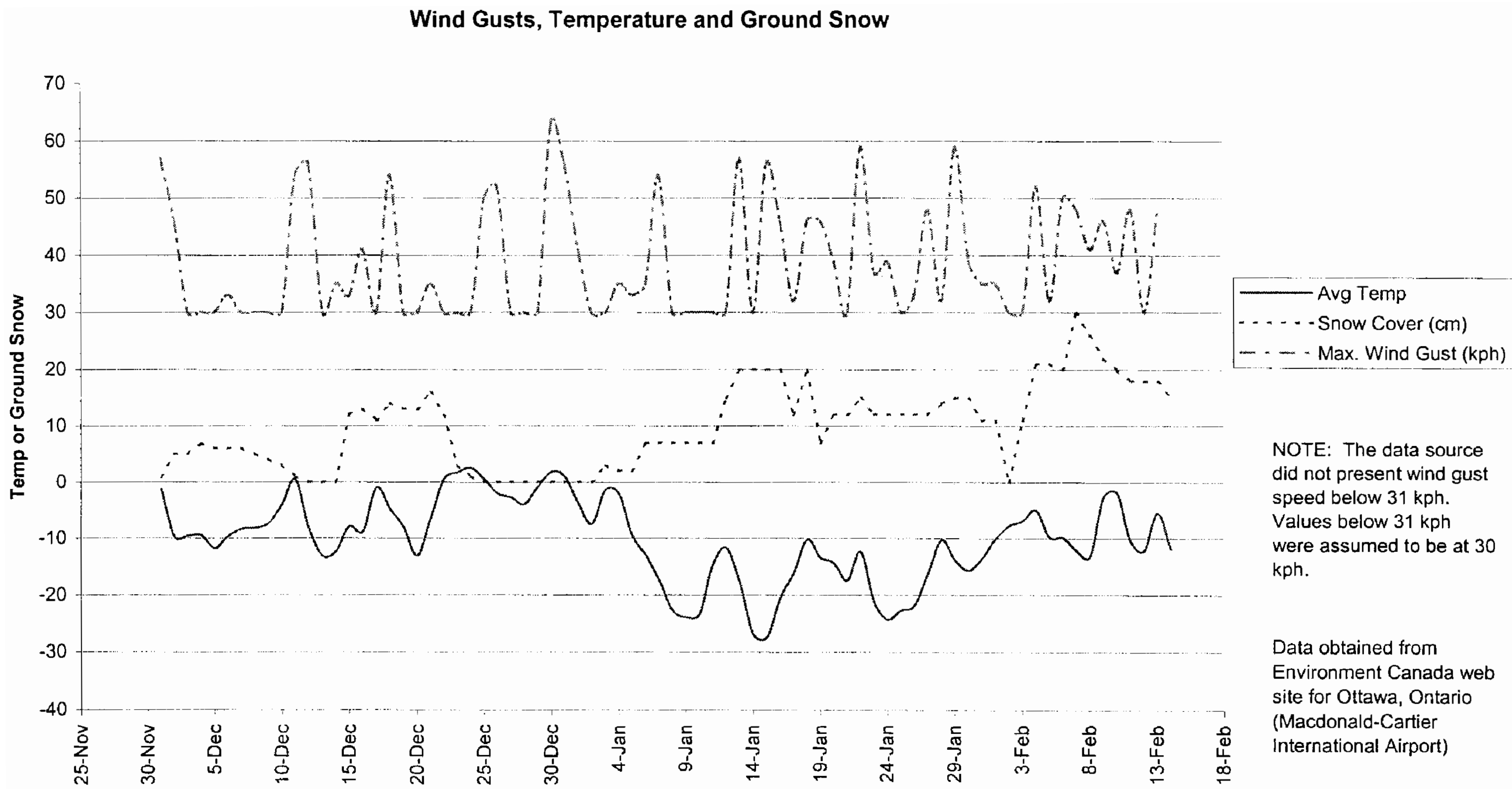


Figure 1: Temperature, Snow Cover, and Wind, Winter 2004

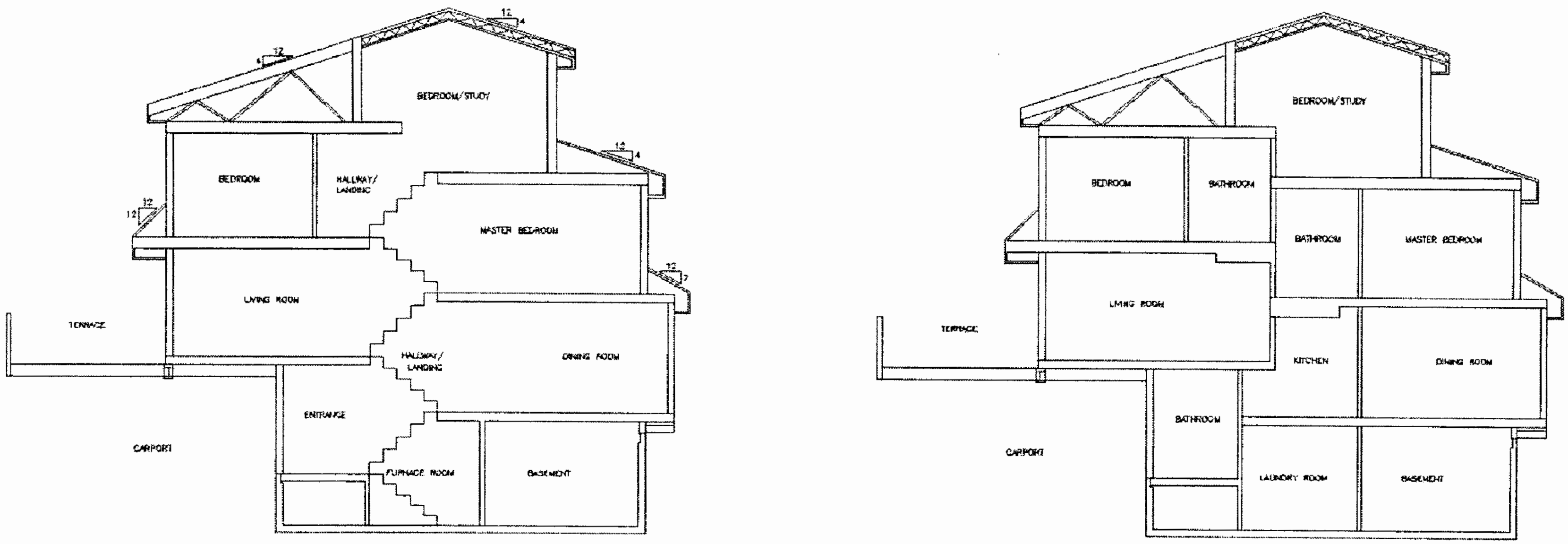


Figure 2: Site 1, Typical Building Sections

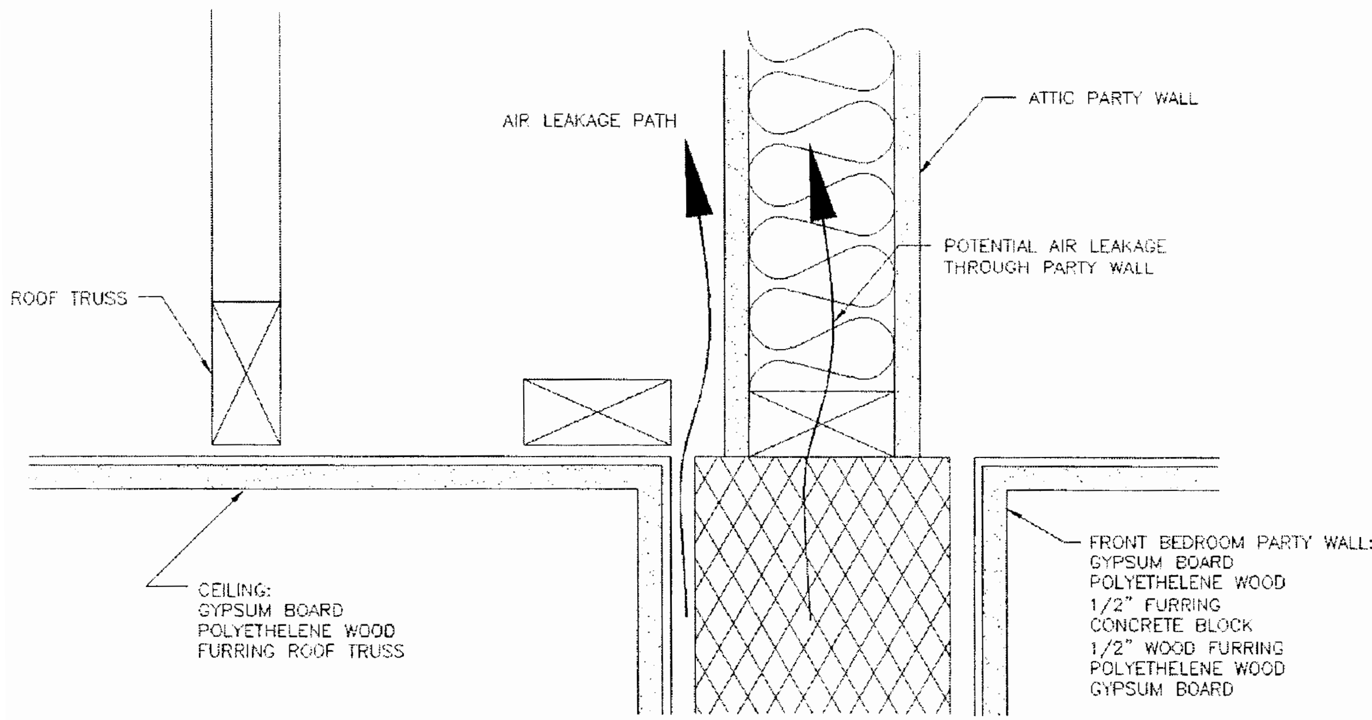


Figure 3: Site 1, Air Leakage Path at Party Wall

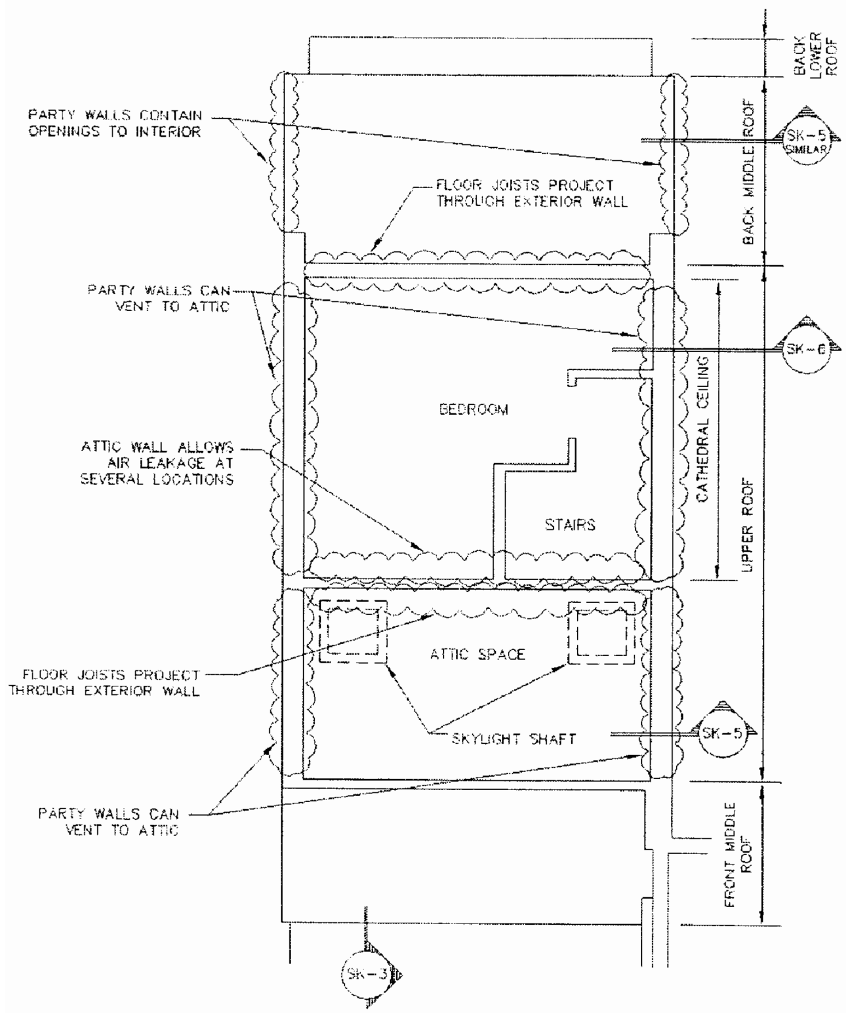


Figure 4: Site 1, Problem Locations

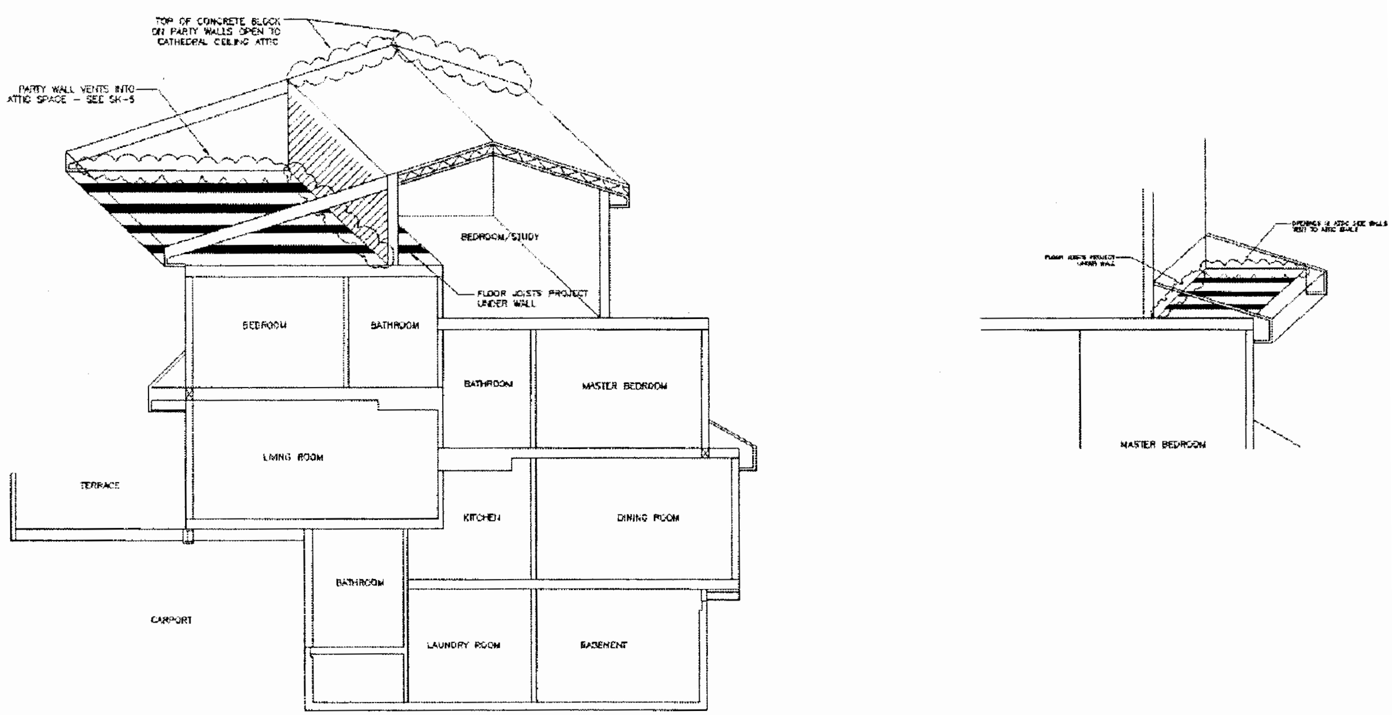


Figure 5: Site 1, Problem Locations (Isometric)

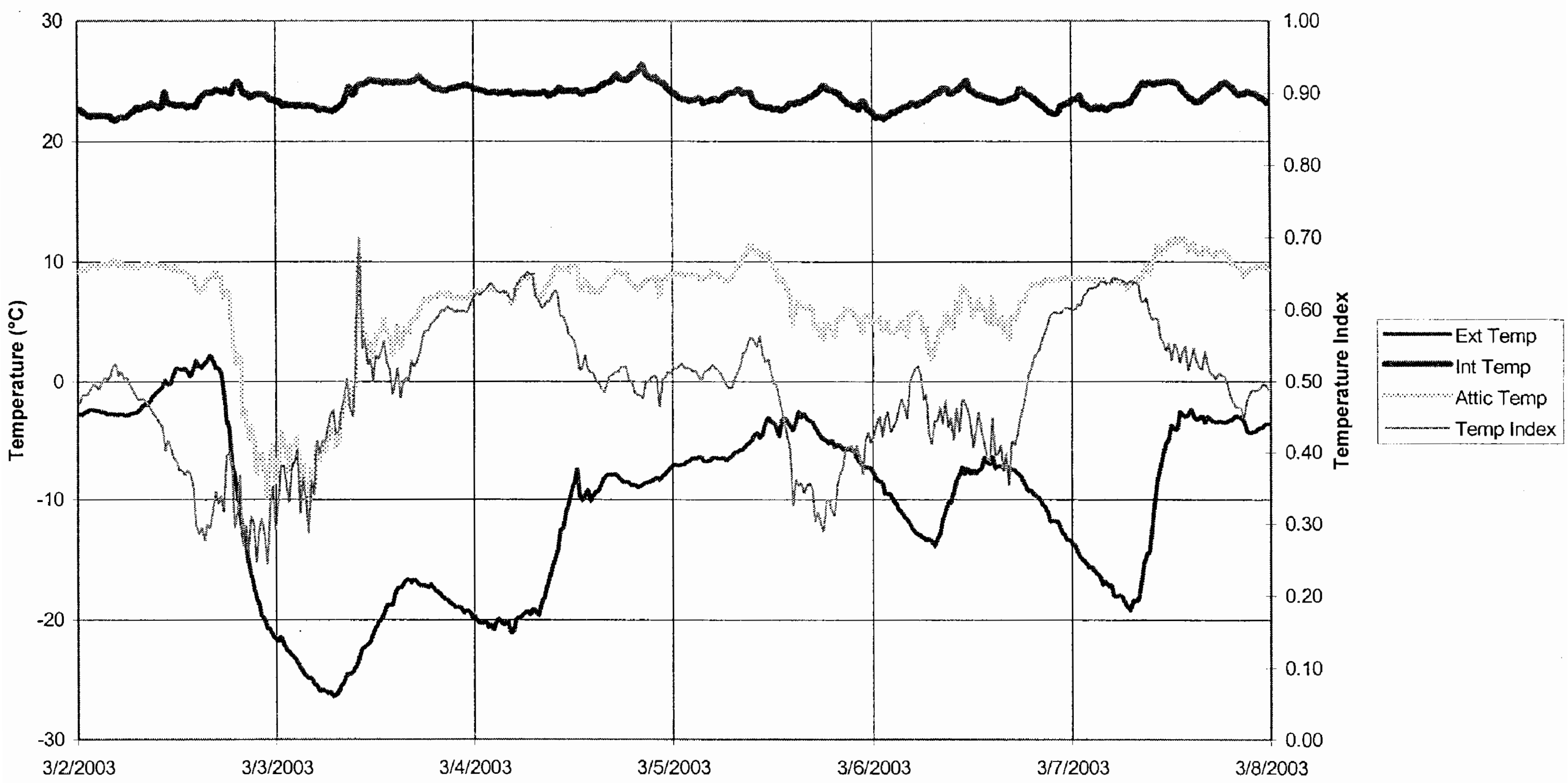


Figure 6: Site 1, Pre-Repair, Unit A Temperature Readings

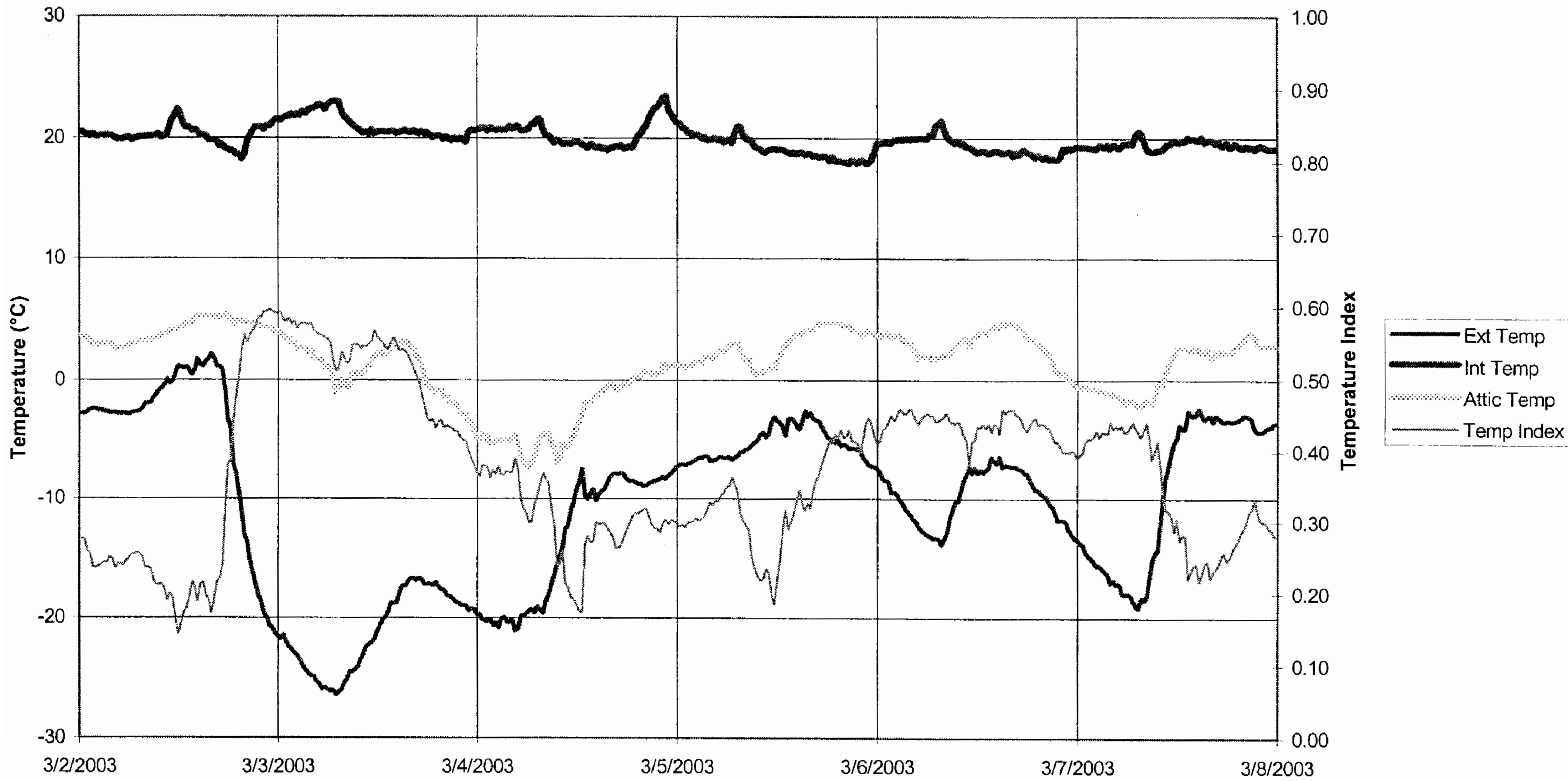


Figure 7: Site 1, Pre-Repair, Unit B Temperature Readings

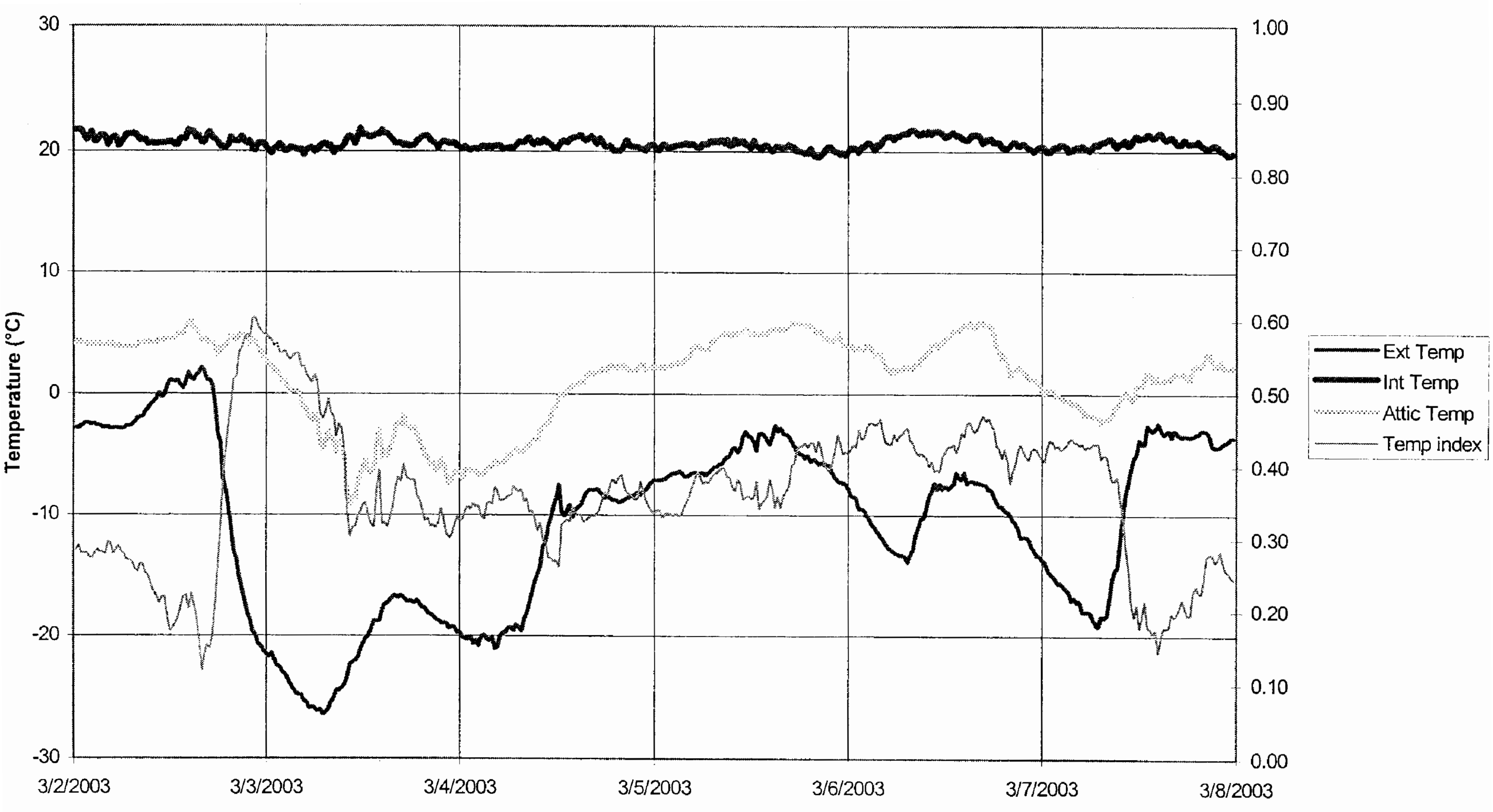


Figure 8: Site 1, Pre-Repair, Unit C Temperature Readings

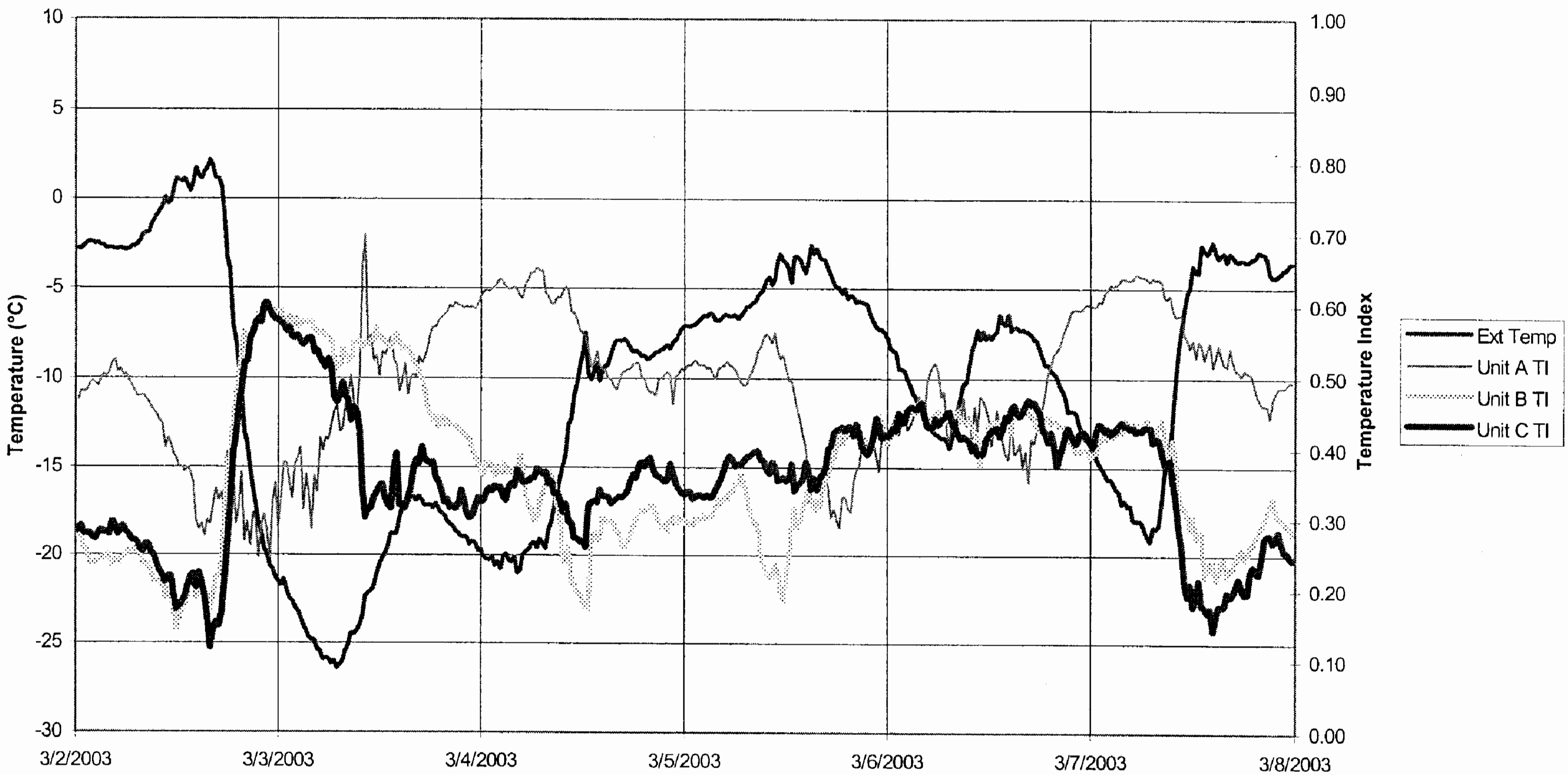


Figure 9: Site 1, Pre-Repair, Temperature Index Comparison

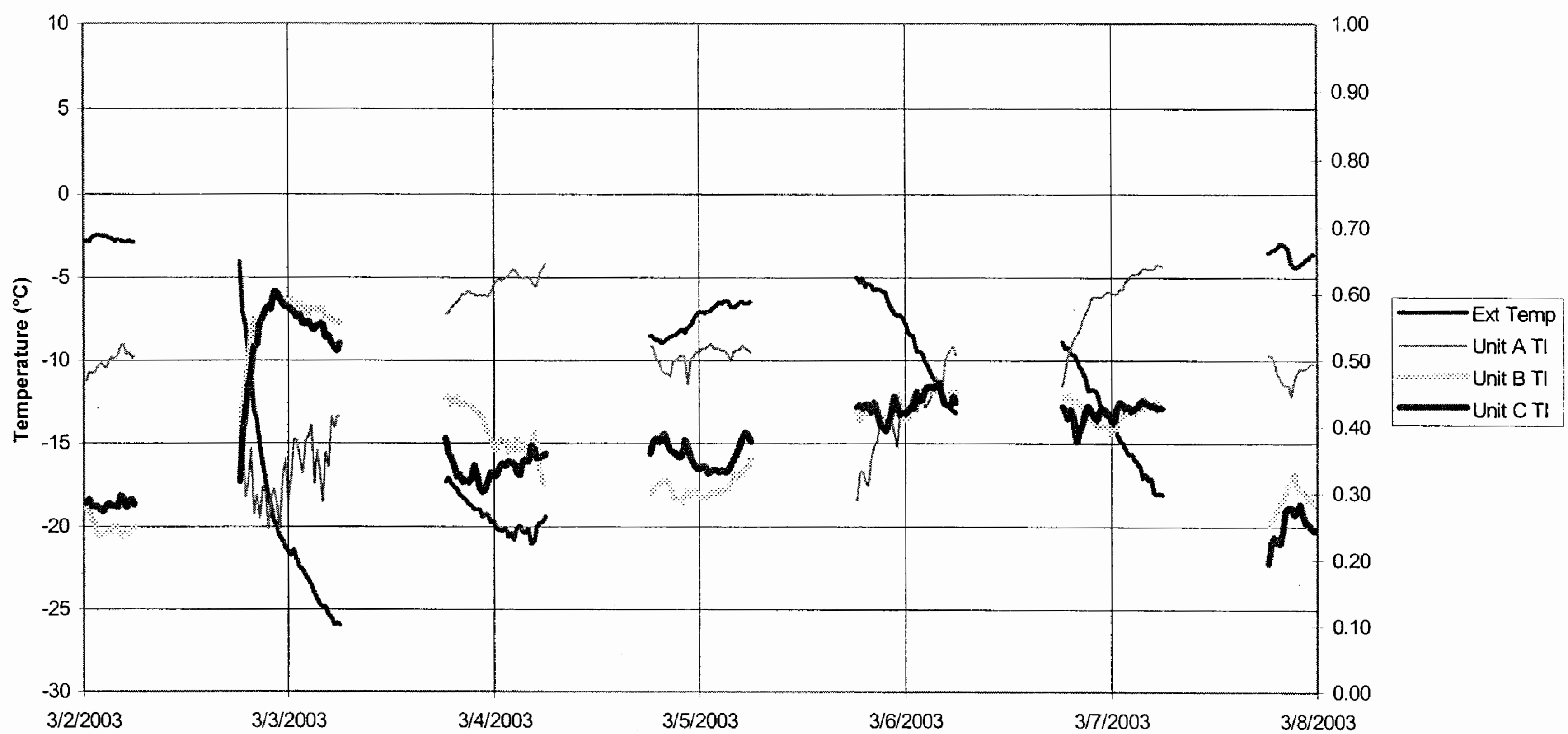


Figure 10: Site 1, Pre-Repair, Temperature Index Comparison – Night Data Only

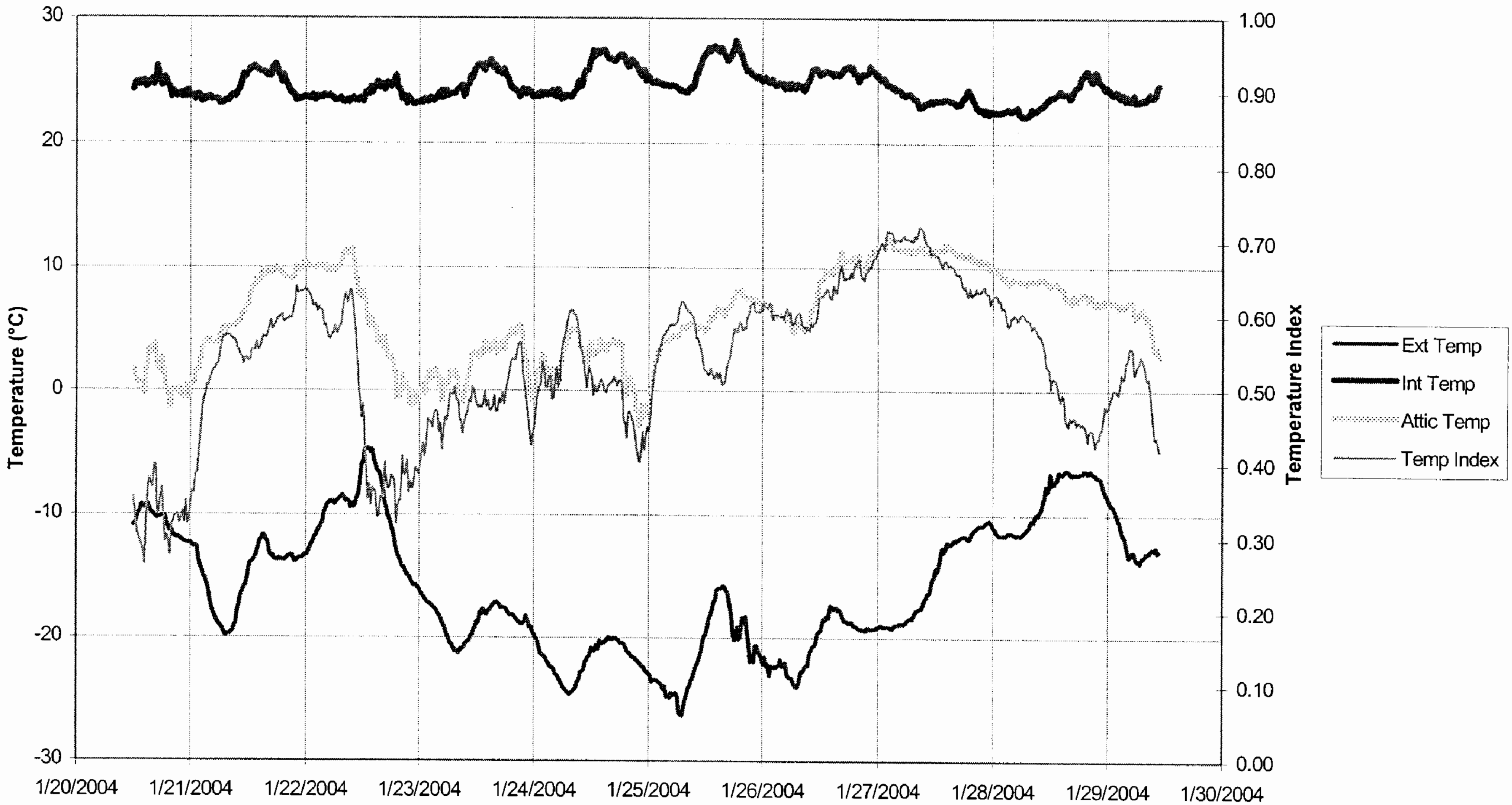


Figure 11: Site 1, Post-Repair, Unit A Temperature Readings

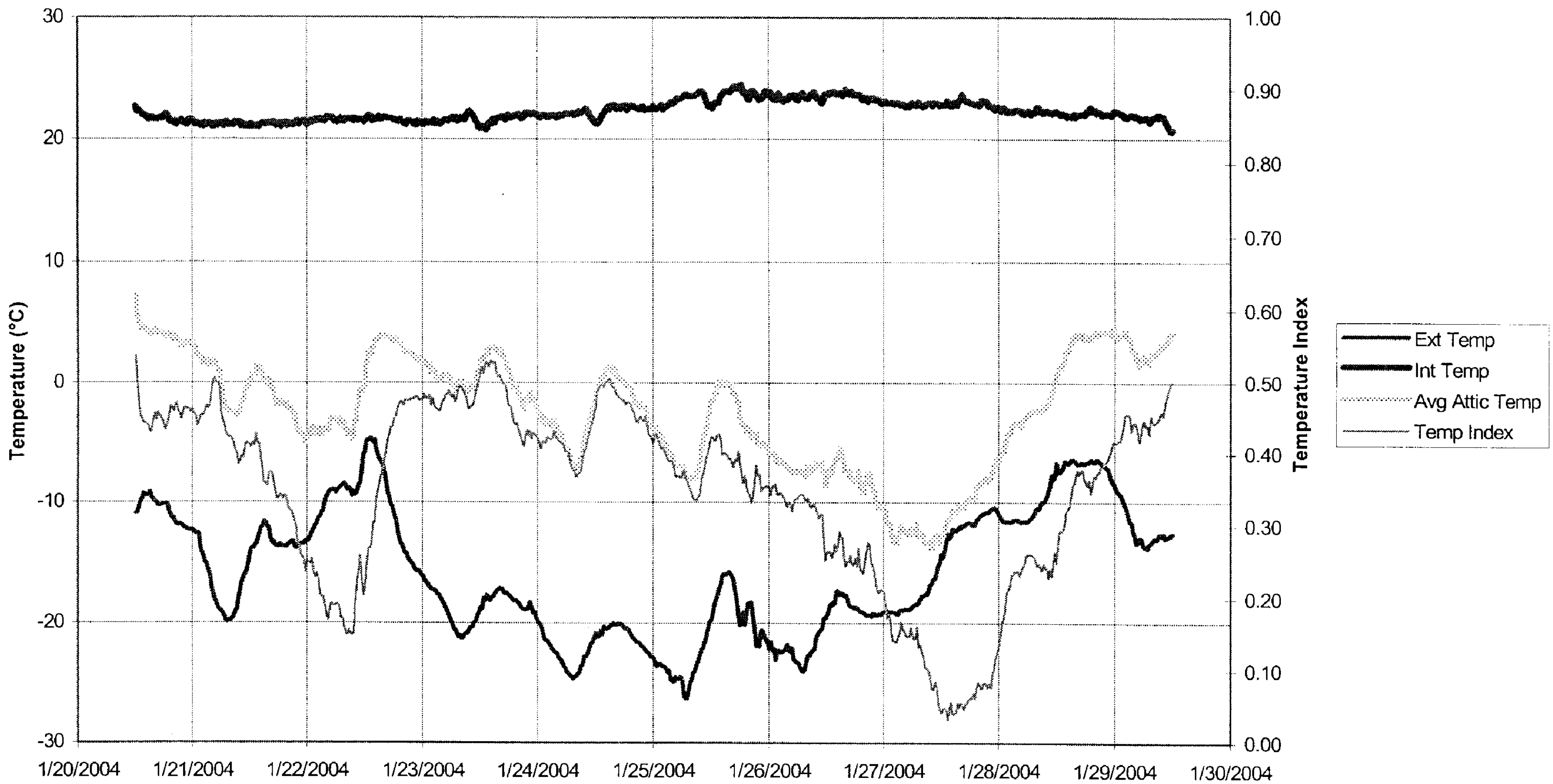


Figure 12: Site 1, Post-Repair, Unit B Temperature Readings

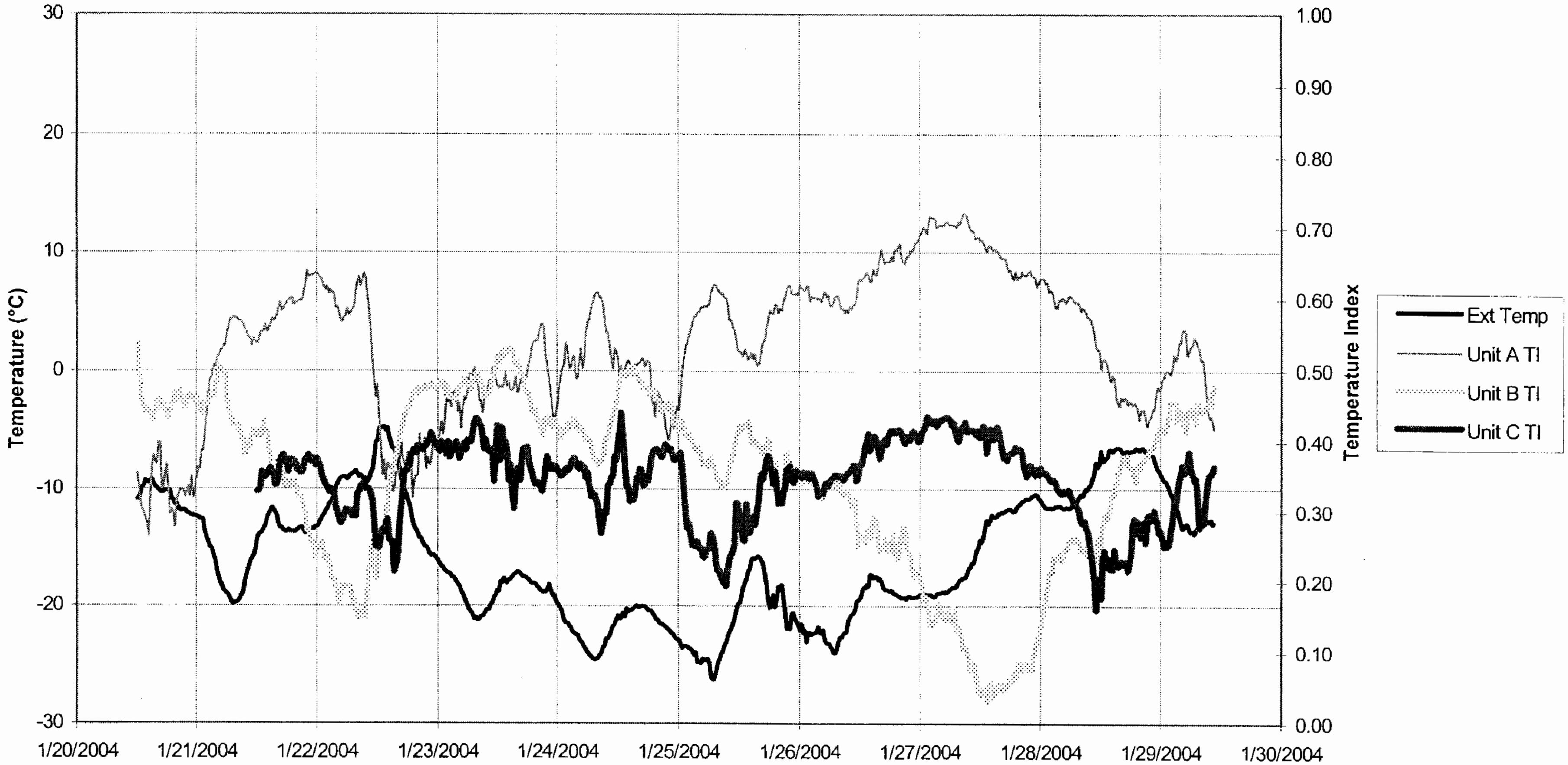


Figure 14: Site 1, Post-Repair, Temperature Index Comparison

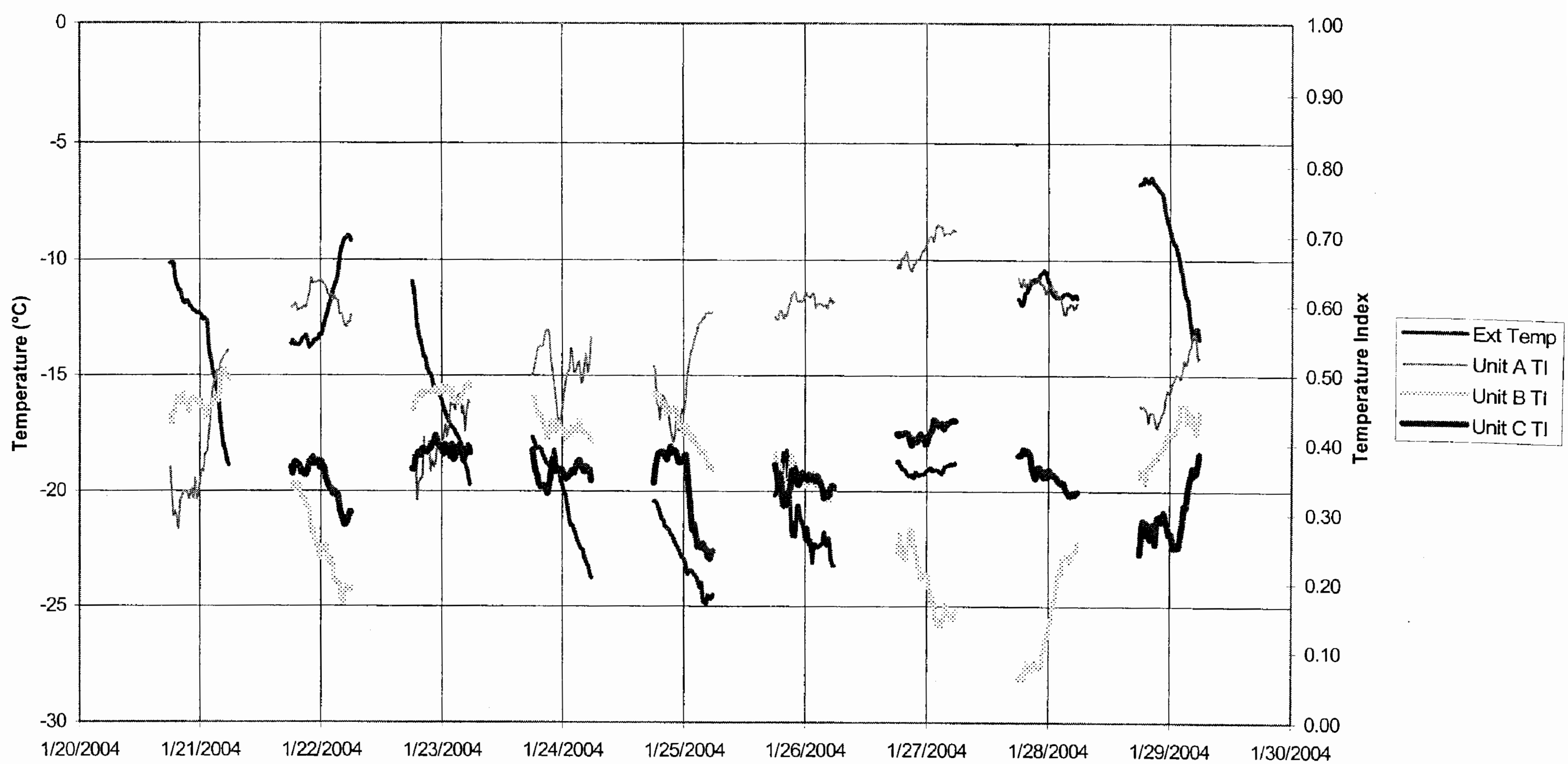


Figure 15: Site 1, Post-Repair, Temperature Index Comparison – Night Data Only

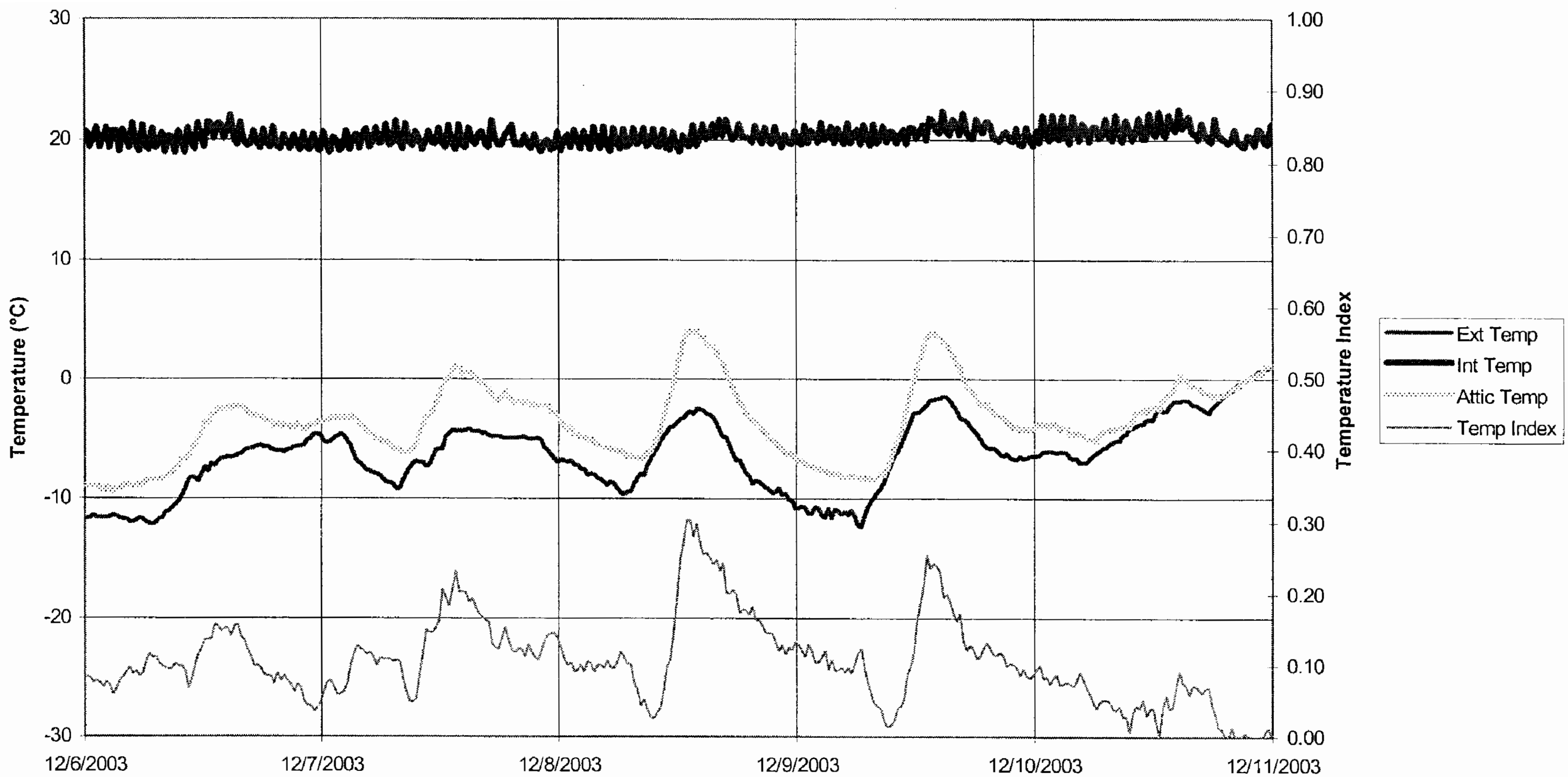


Figure 16: Site 2, Unit A – Pre-repair Data

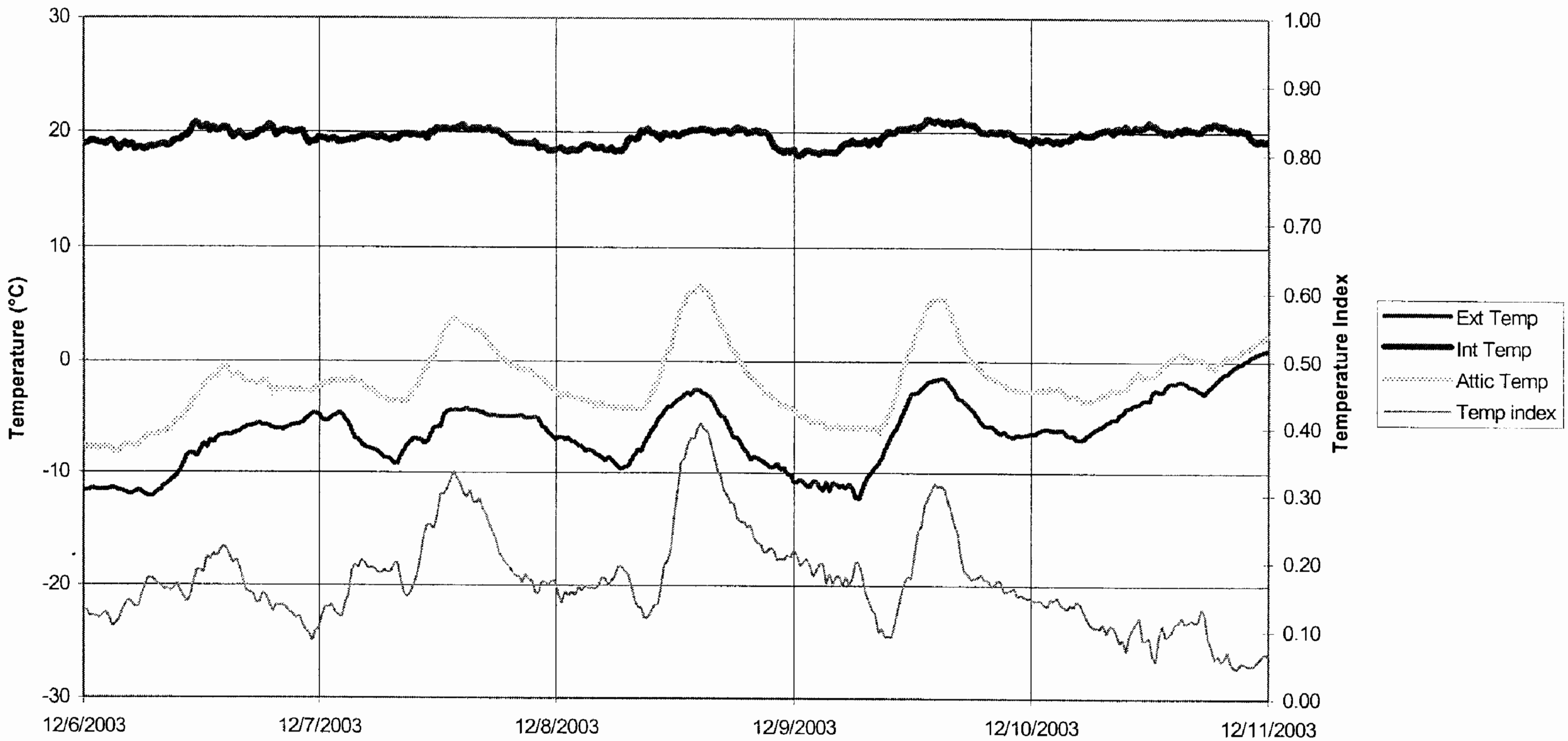


Figure 17: Site 2, Unit B – Pre-repair Data

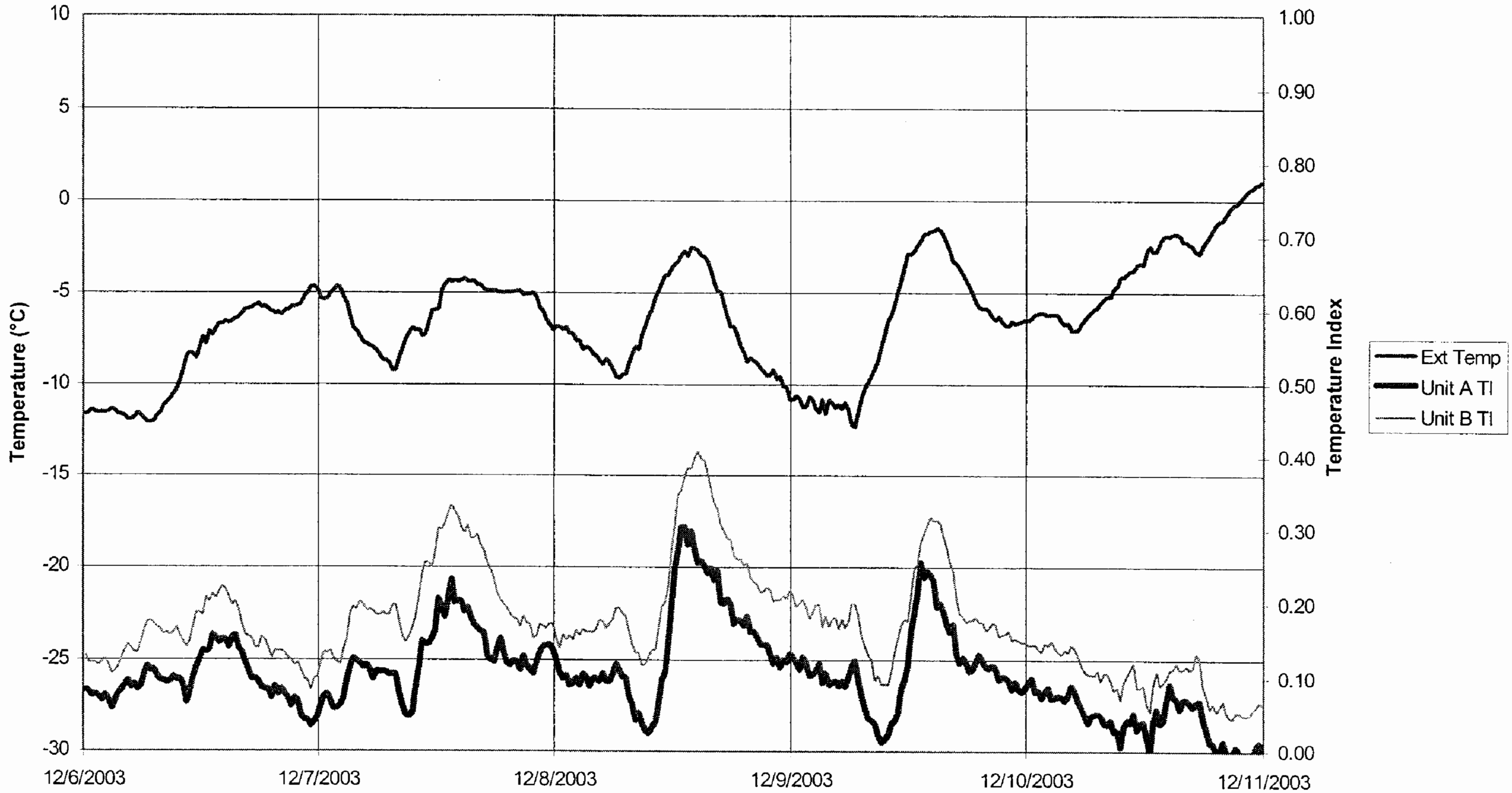


Figure 18: Site 2, Pre-repair Temperature Index Comparison

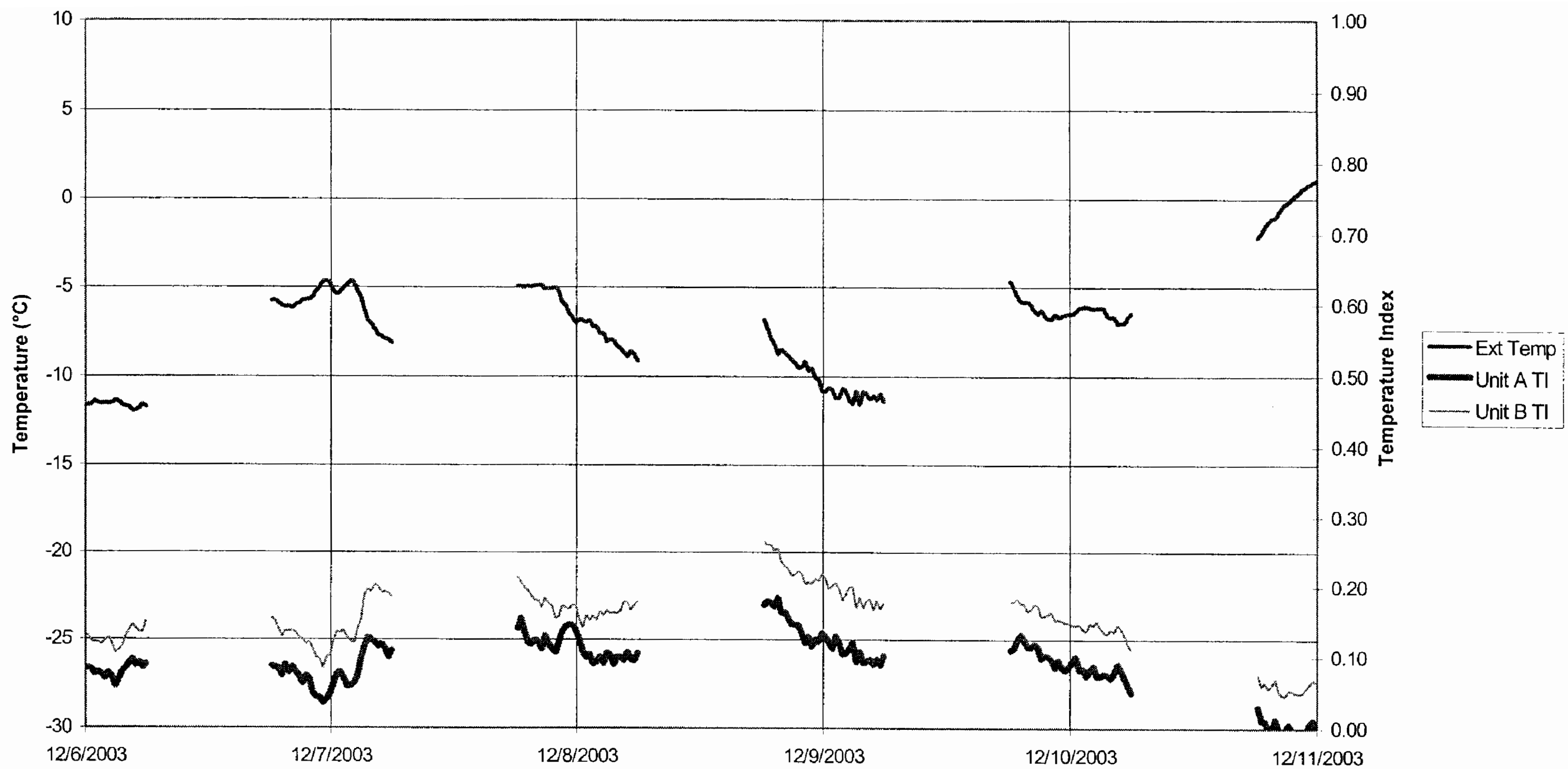


Figure 19: Site 2, Pre-repair Temperature Index Comparison – Night Data Only

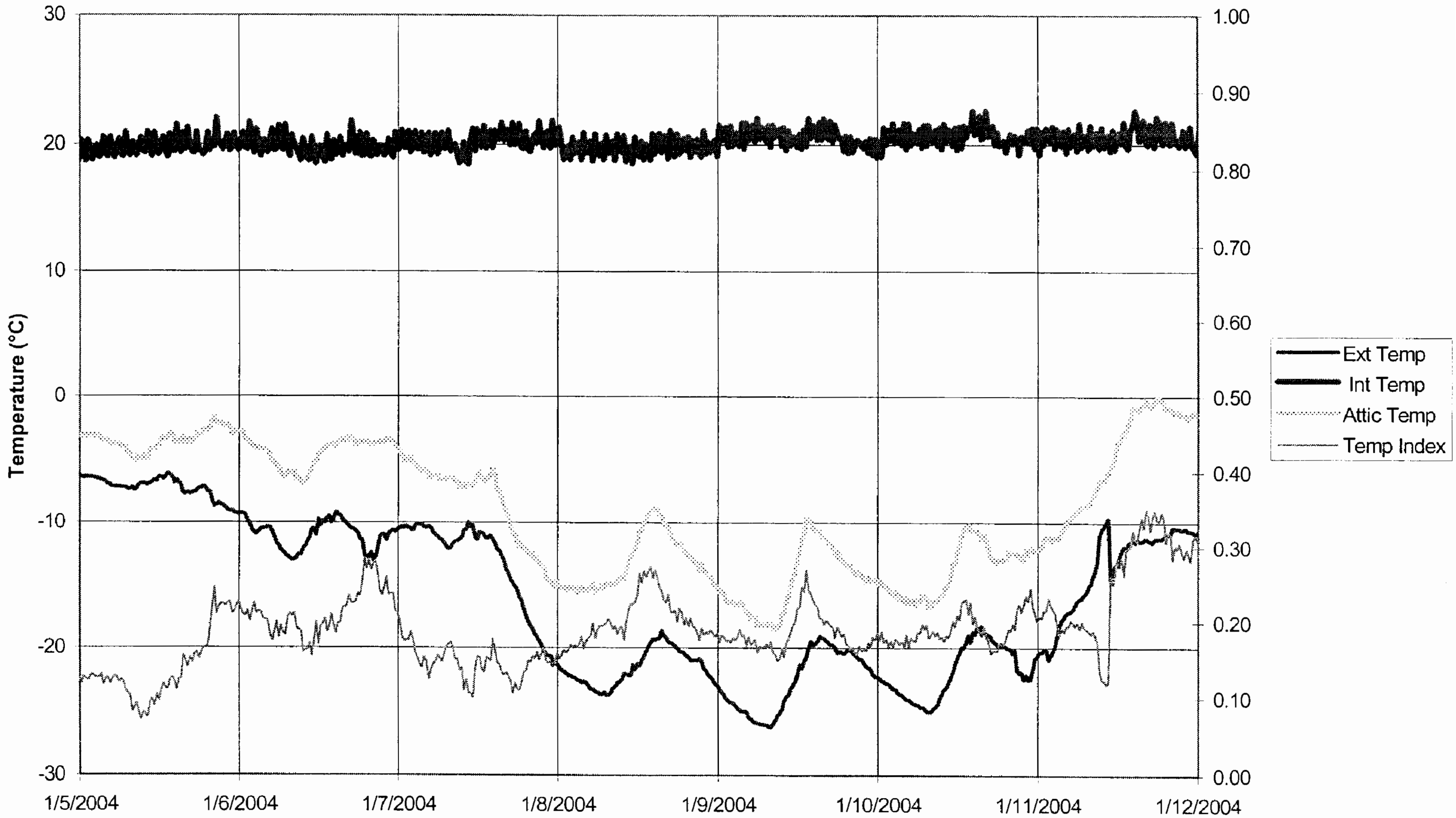


Figure 20: Site 2, Unit A – Post-repair Data

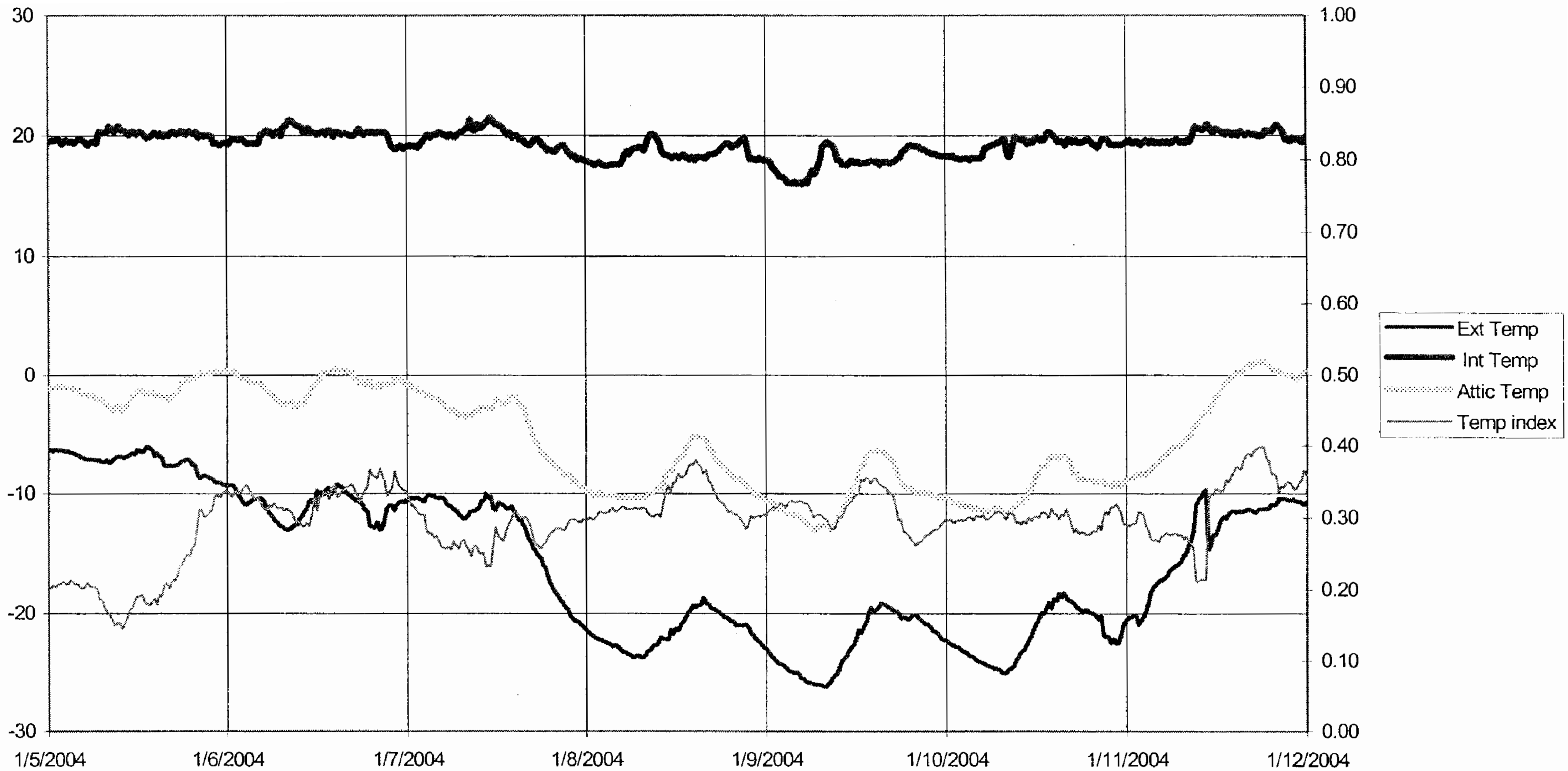


Figure 21: Site 2, Unit B – Post -repair Data

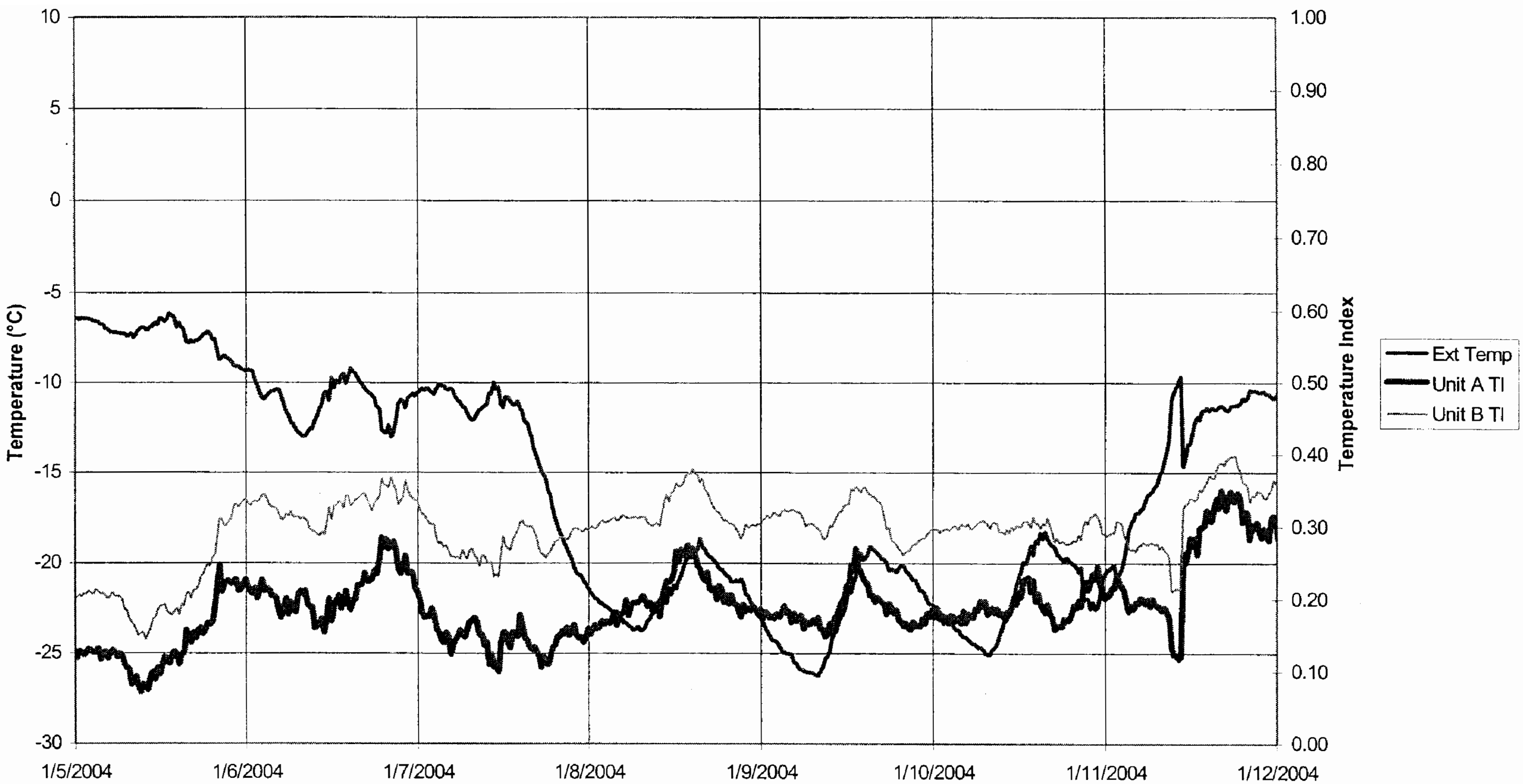


Figure 22: Site 2, Post -repair Temperature Index Comparison

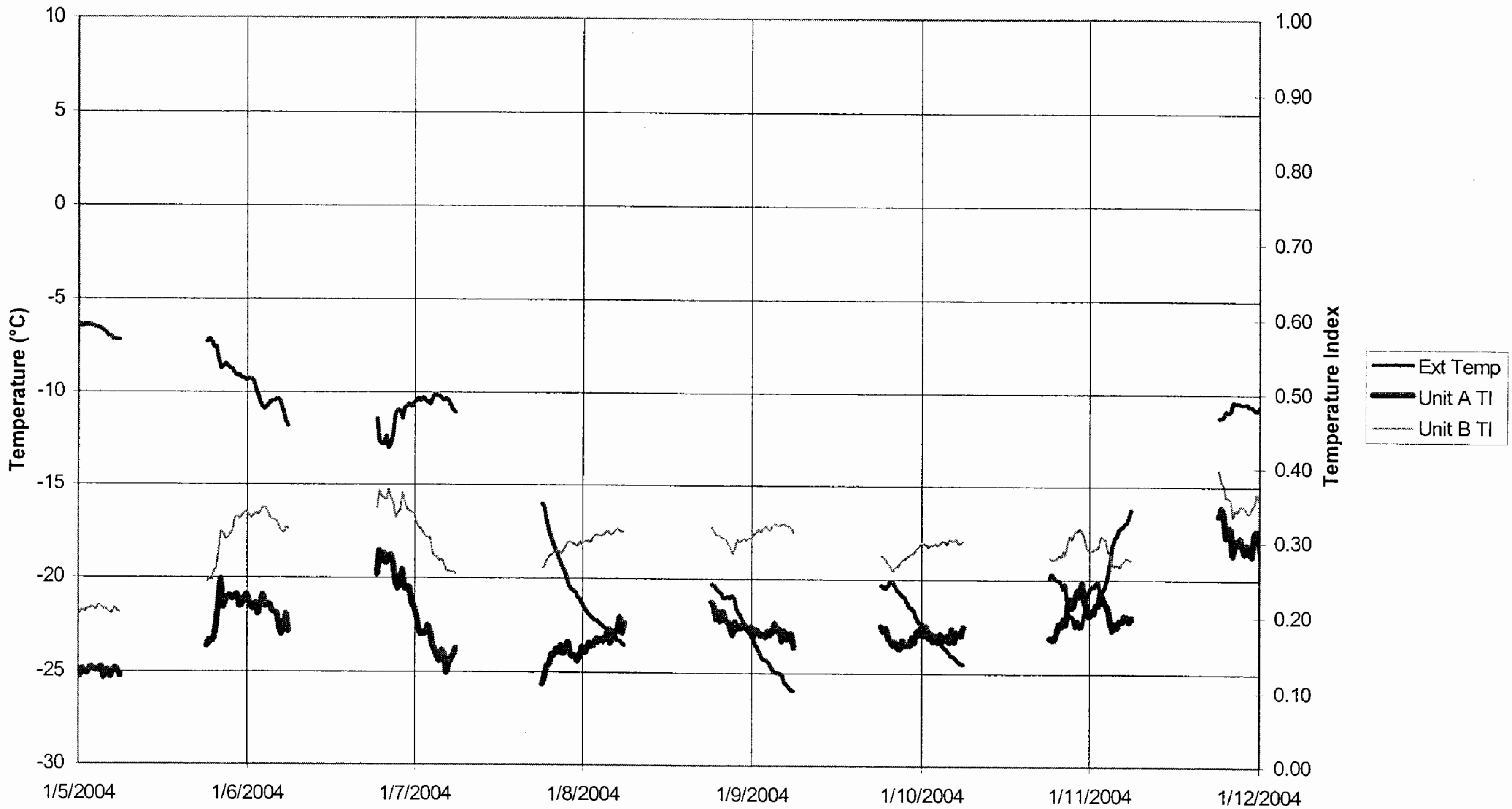
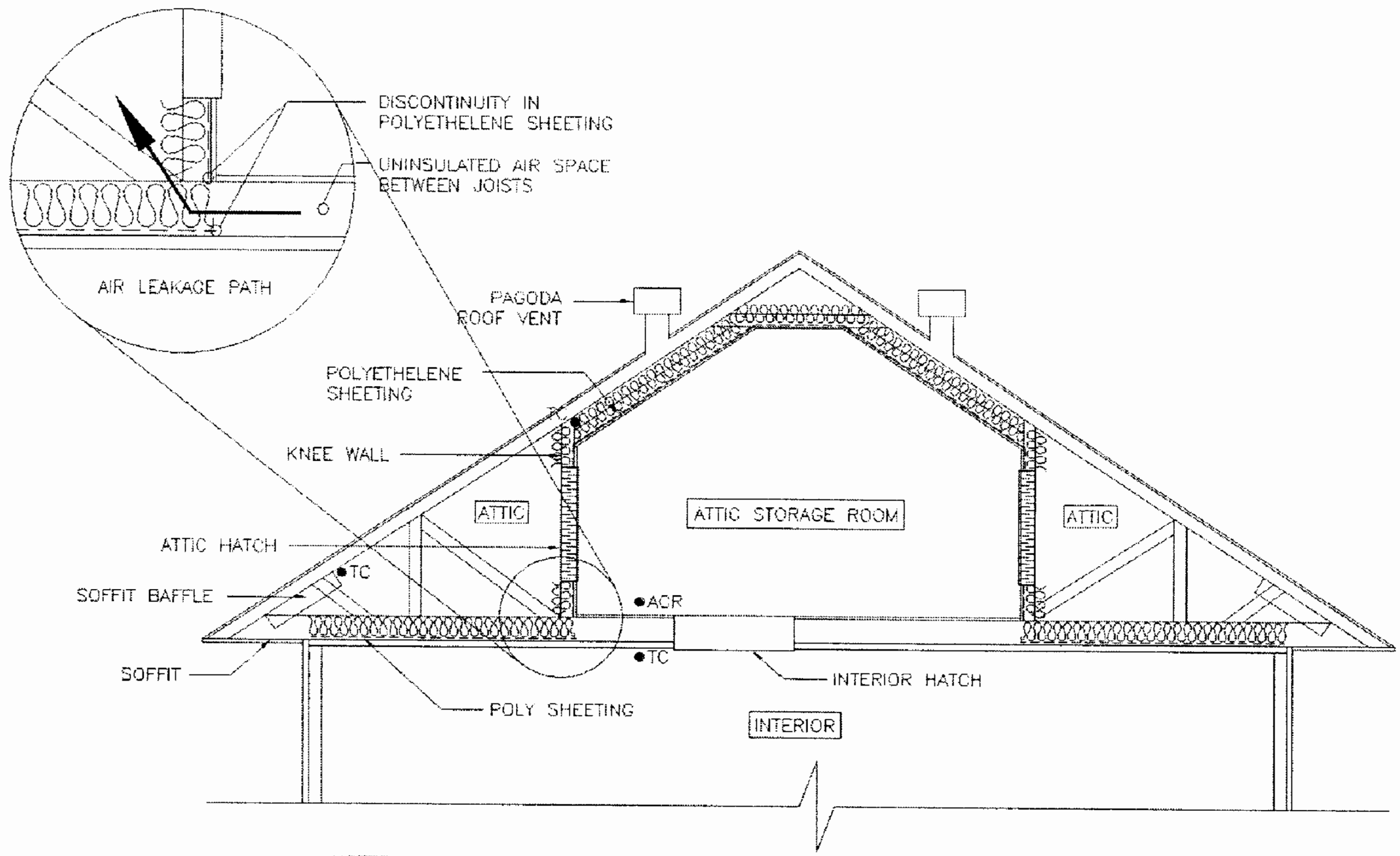


Figure 23: Site 2, Pre-repair Temperature Index Comparison – Night Data Only



NOTES:
1. NOT DRAWN TO SCALE
2. LAYOUT OF ATTIC MAY NOT BE EXACTLY AS SHOWN
3. TC = THERMOCOUPLE
4. ACR = SELF CONTAINED DATA LOGGER (BY ACR SYSTEMS)

Figure 24: Site 3, Attic Cross Section (Schematic)

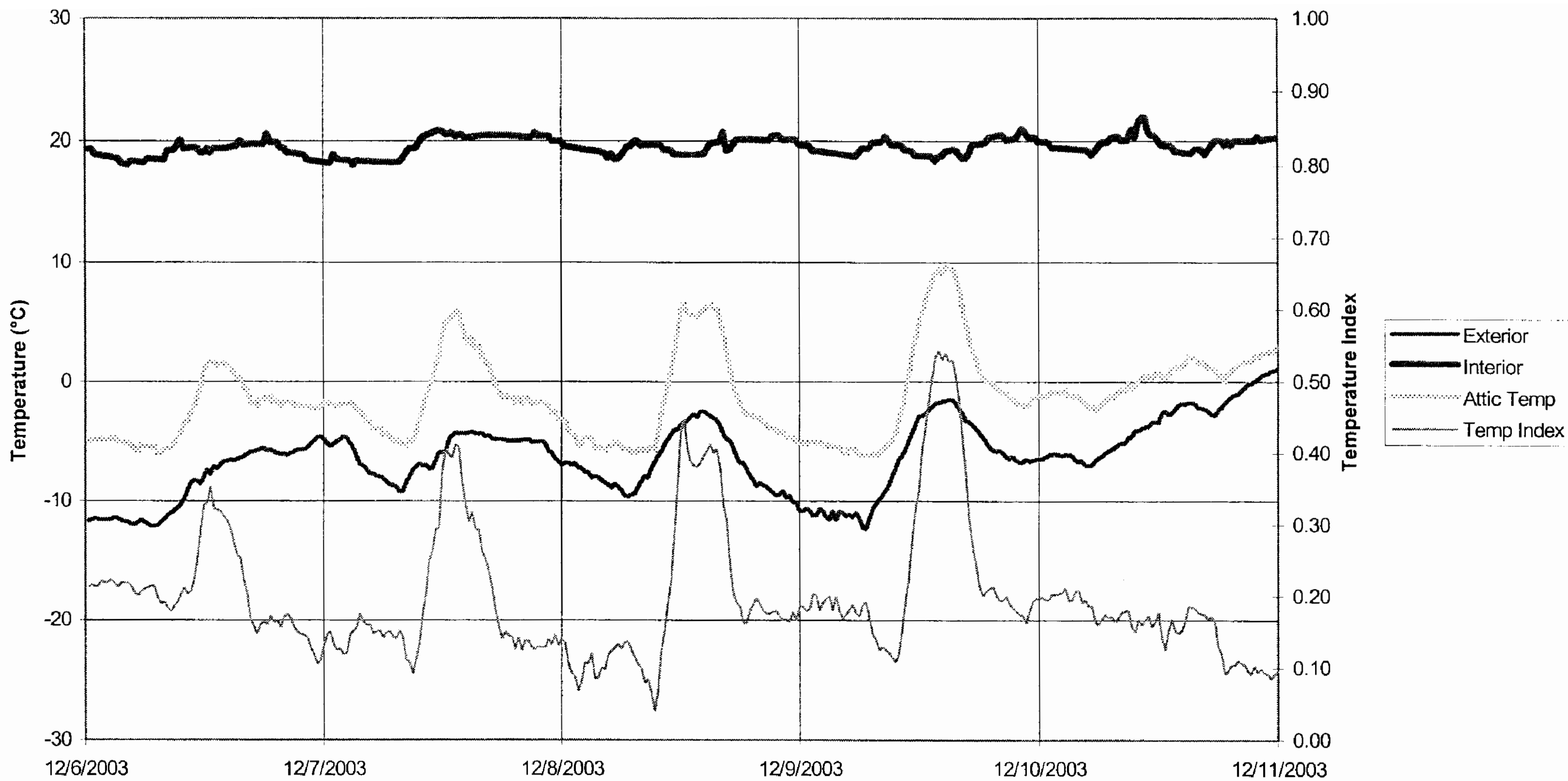


Figure 25: Site 3, Unit A – Pre-repair Data

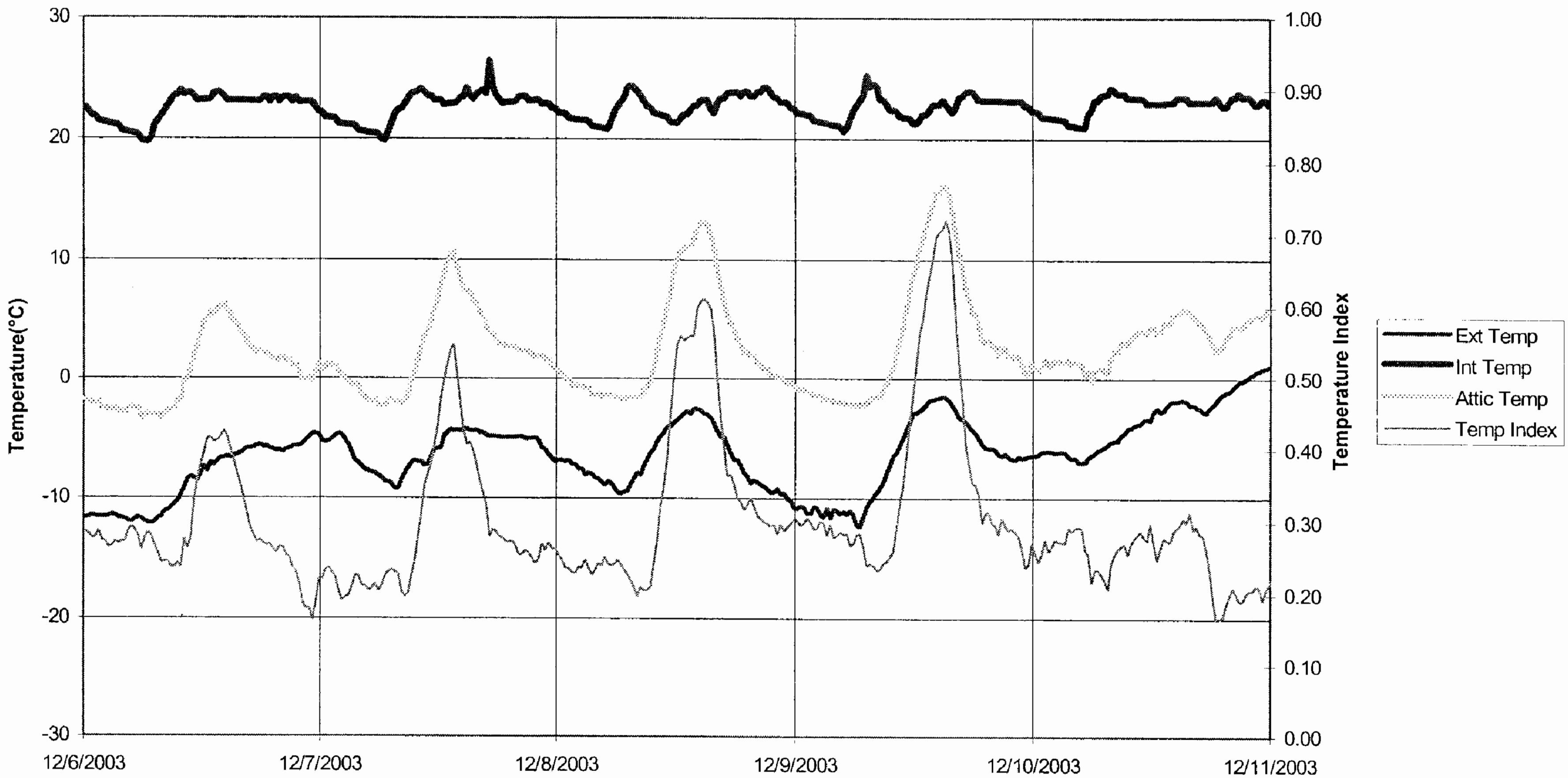


Figure 26: Site 3, Unit B – Pre-repair Data

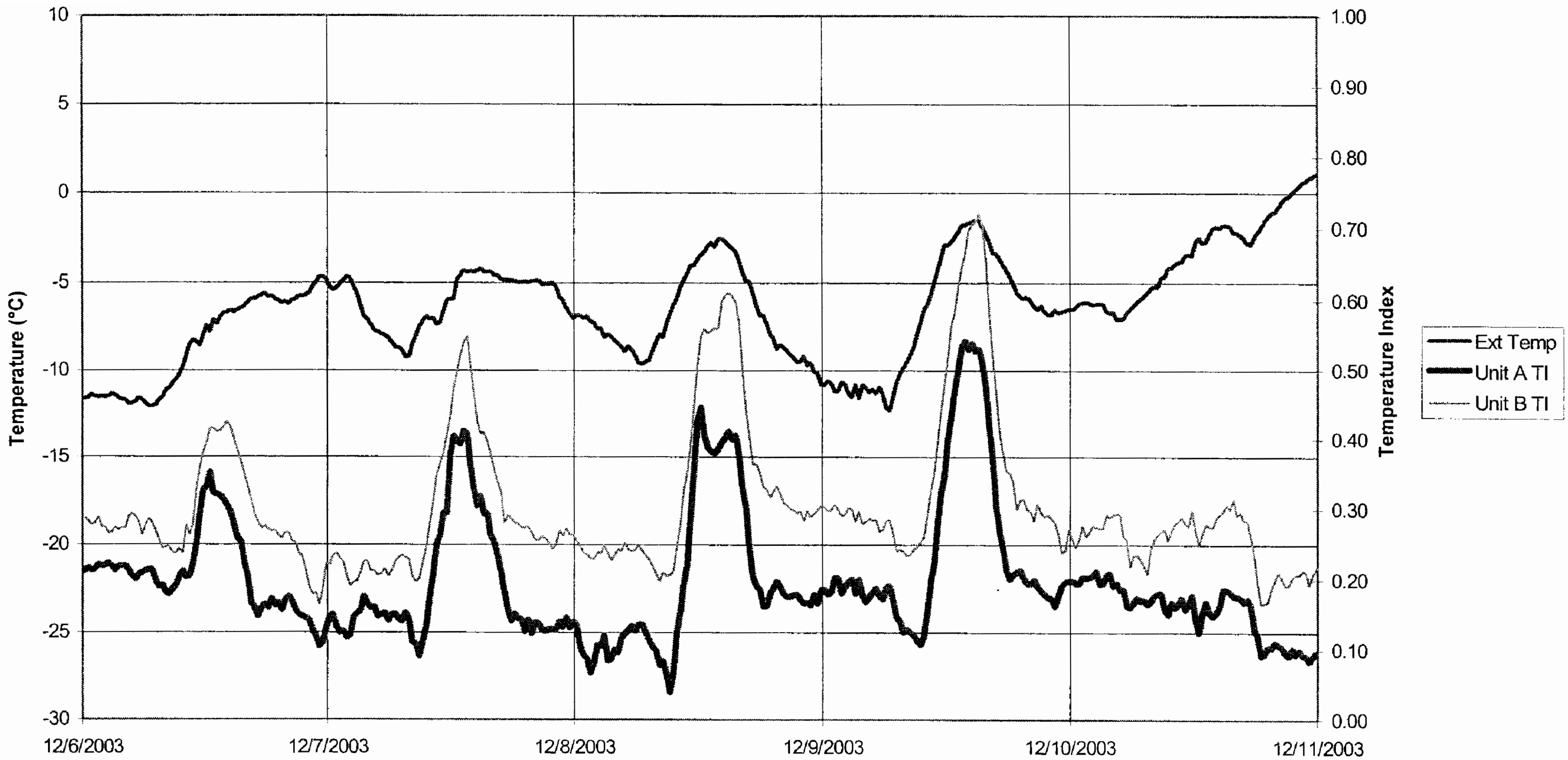


Figure 27: Site 3, Pre-repair Temperature Index Comparison

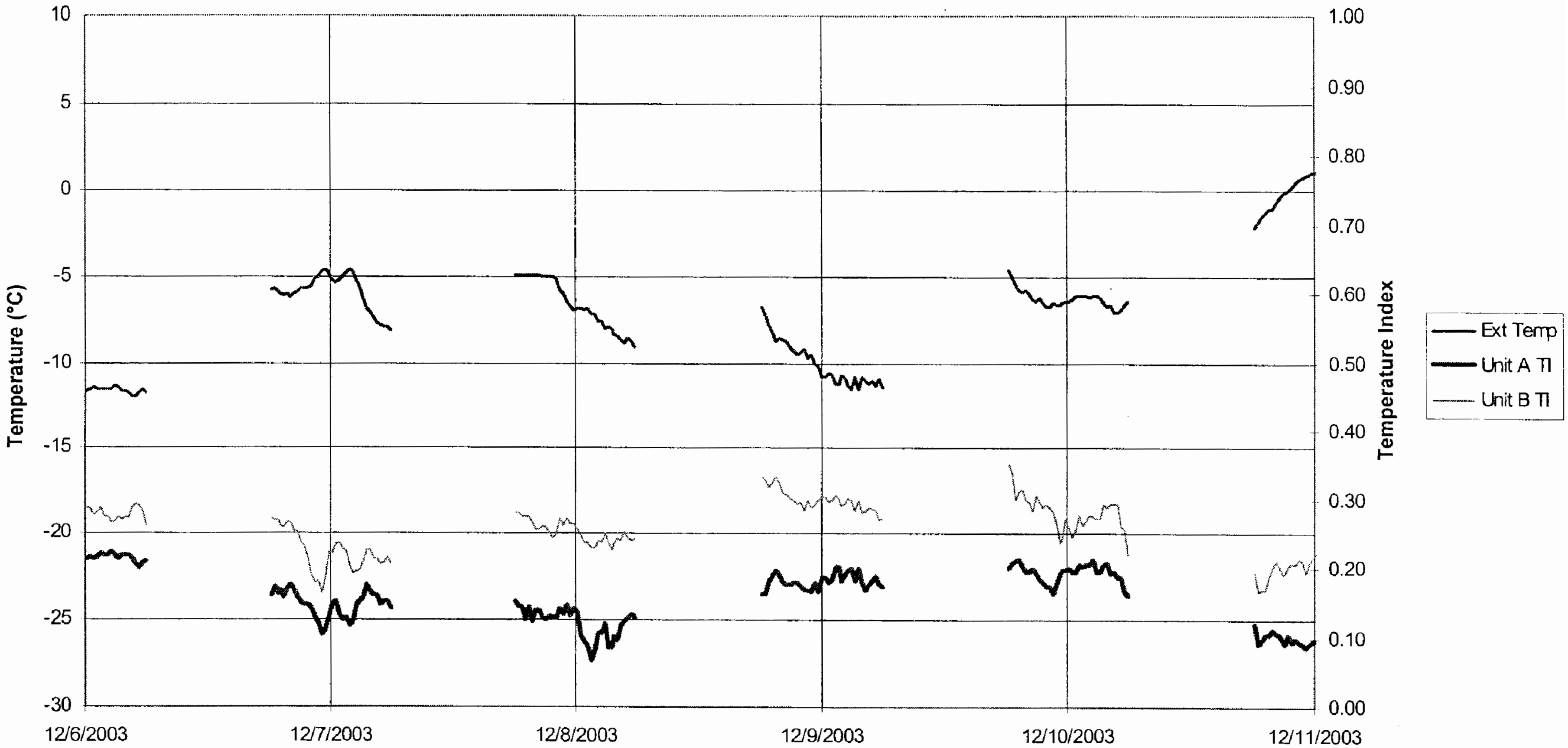


Figure 28: Site 3, Pre-repair Temperature Index Comparison – Night Data Only

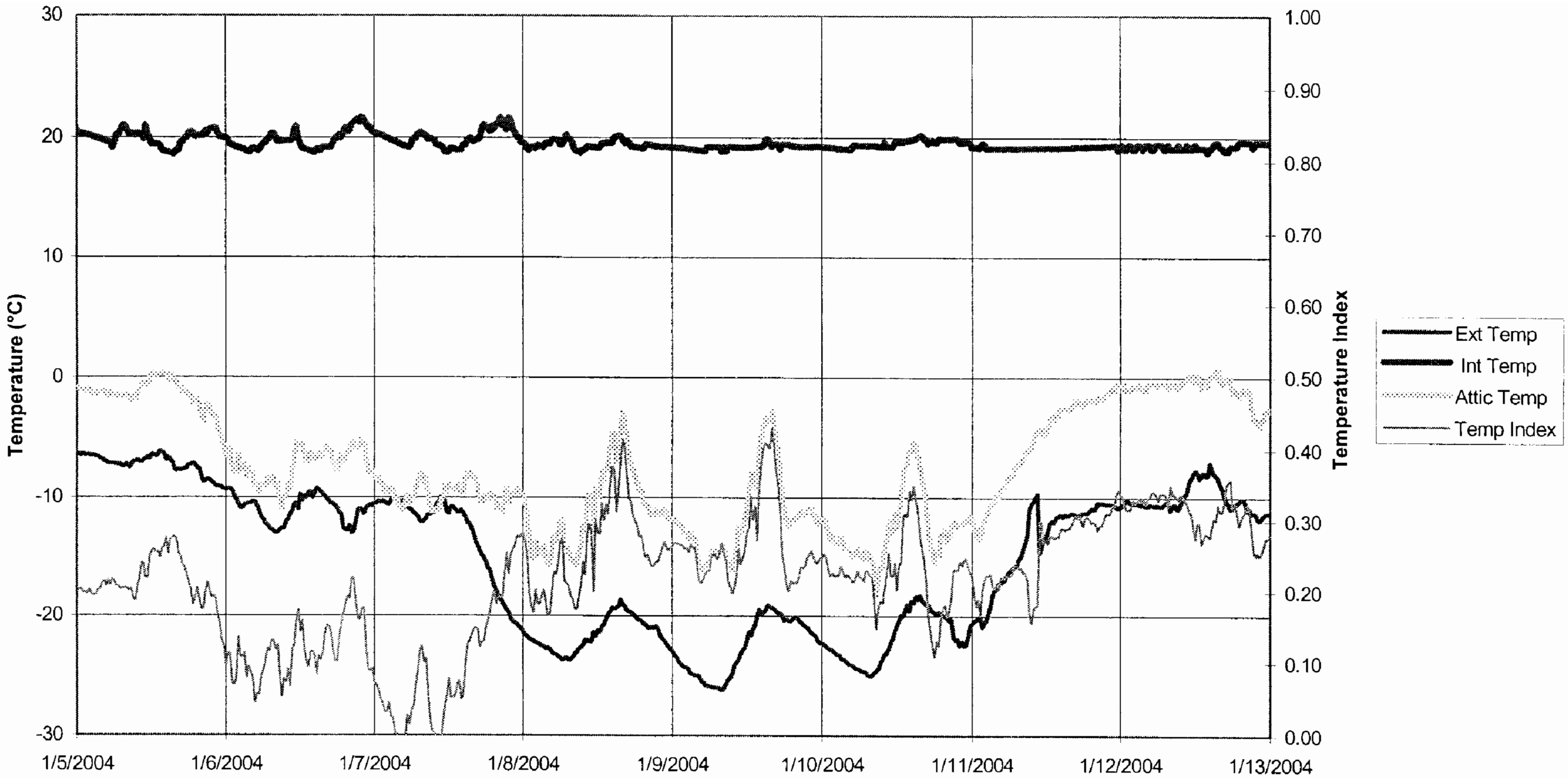


Figure 29: Site 3, Unit A – Post-repair Data

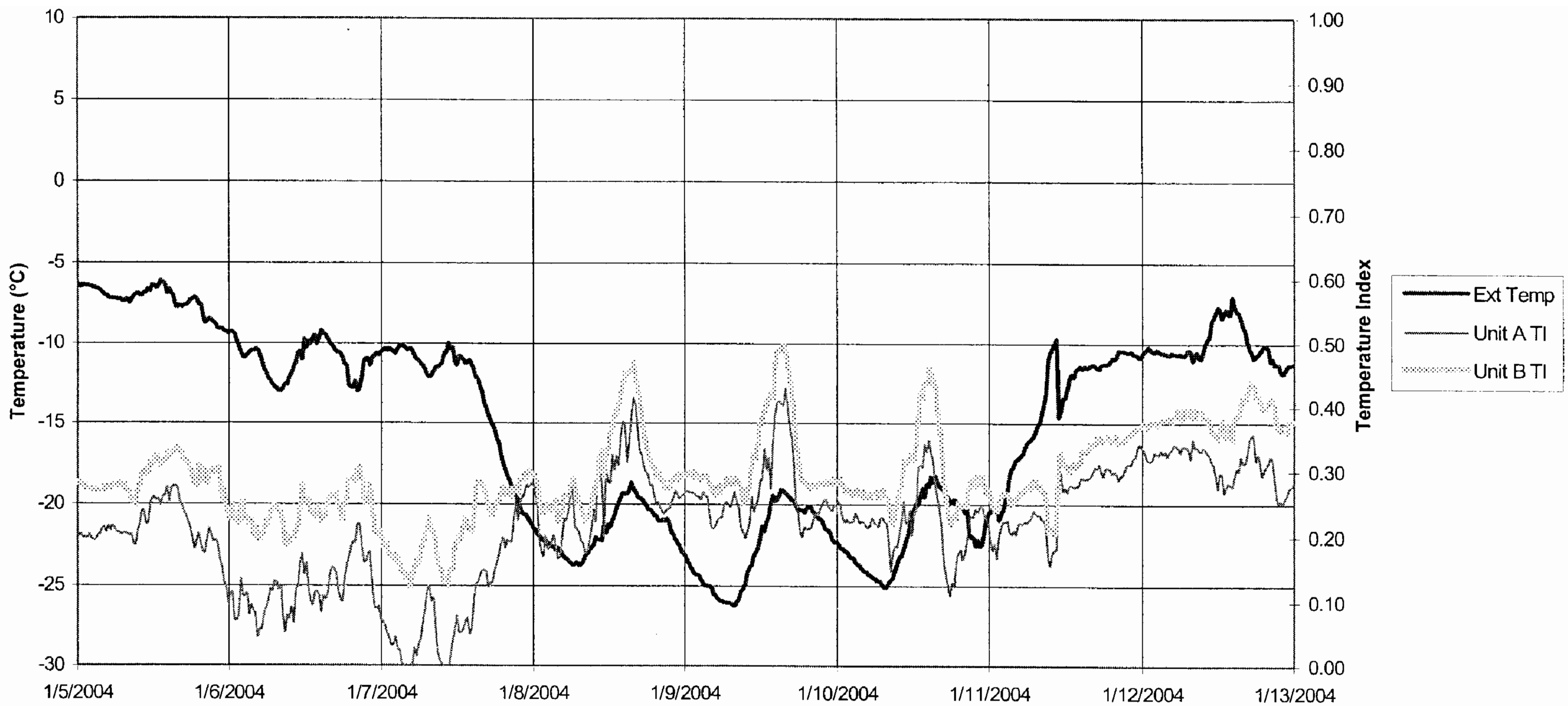


Figure 31: Site 3, Post -repair Temperature Index Comparison

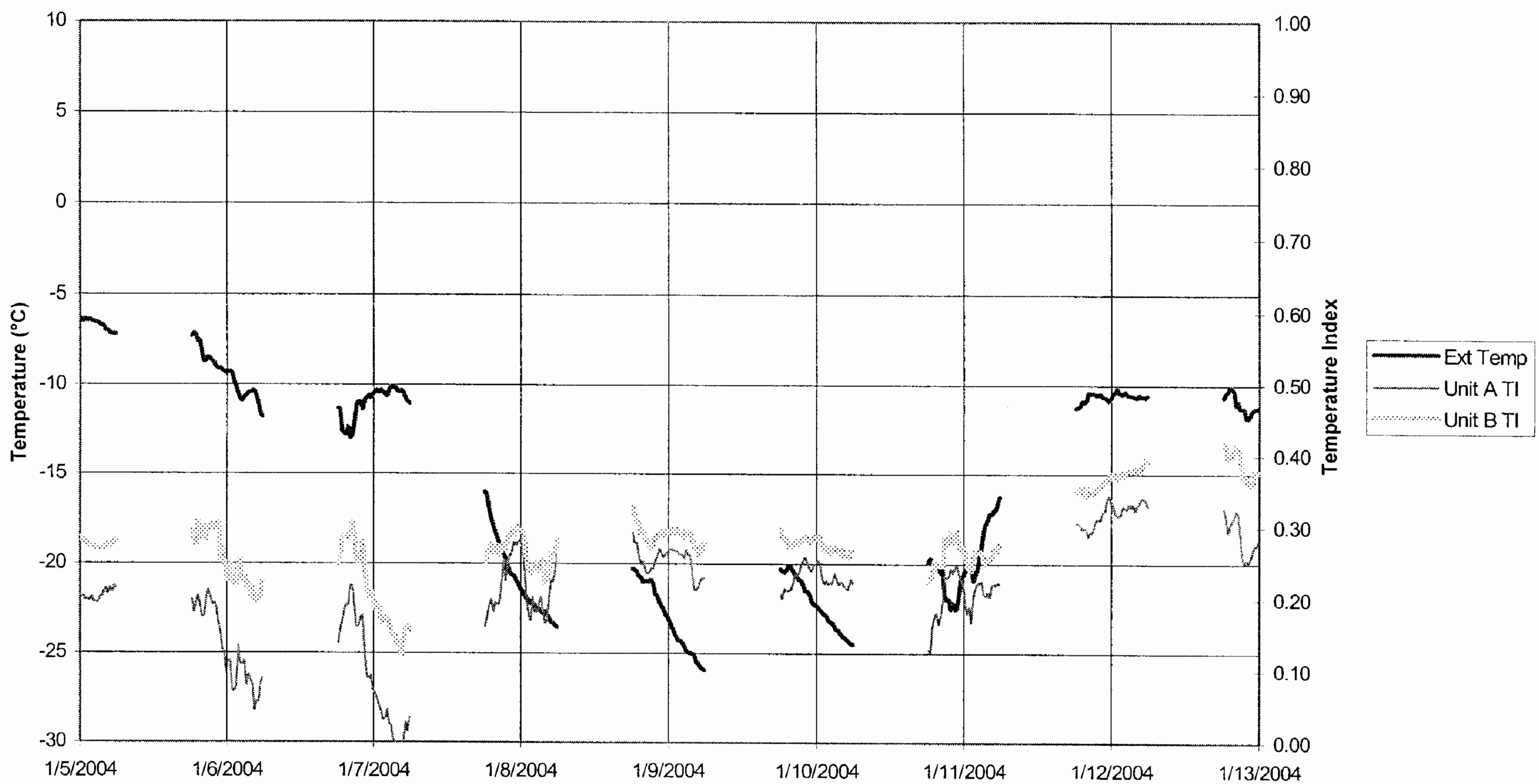


Figure 32: Site 3, Post Temperature Index Comparison – Night Data Only

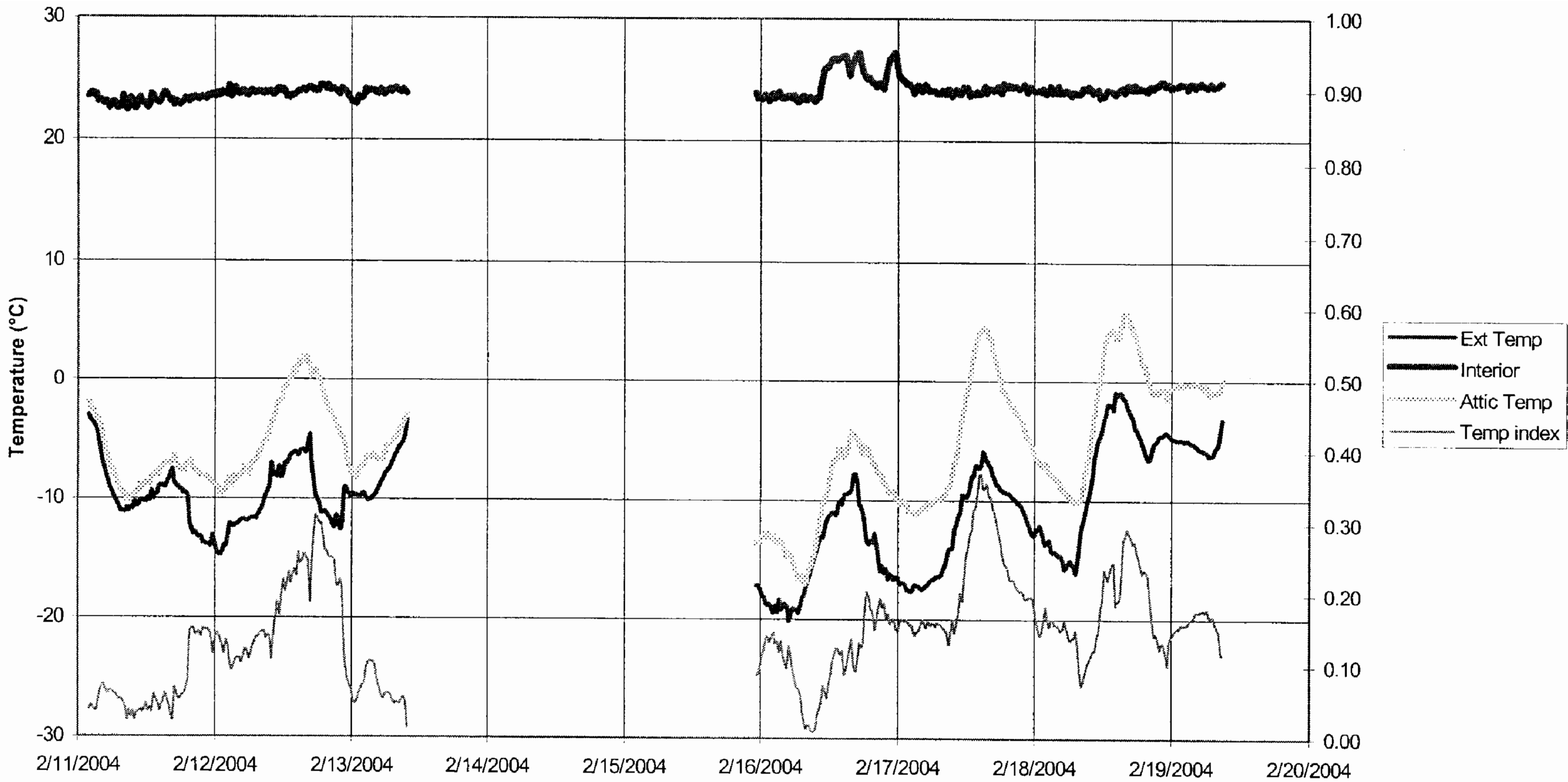


Figure 35: Site 4, Unit B -- Post -repair Data

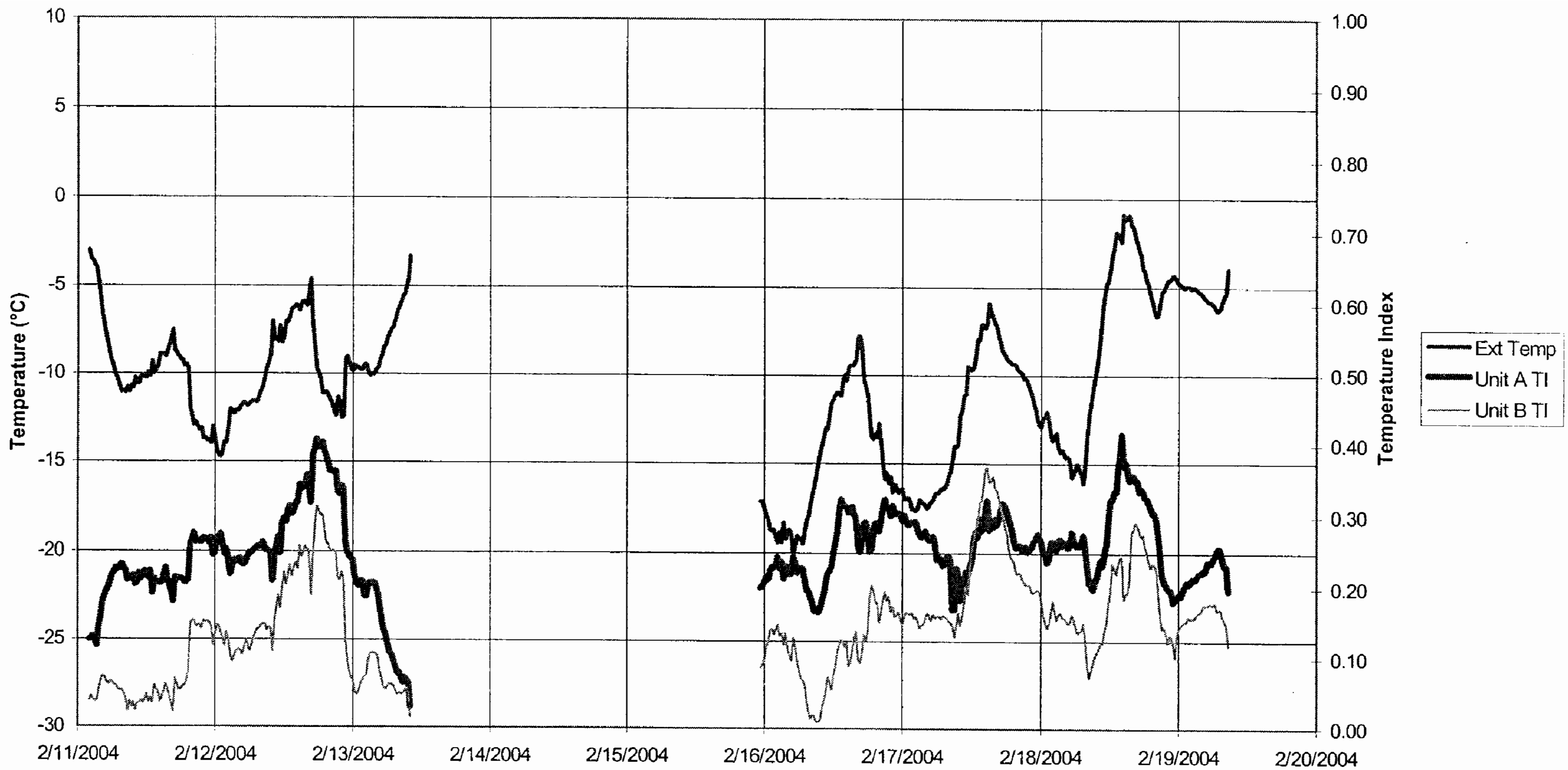
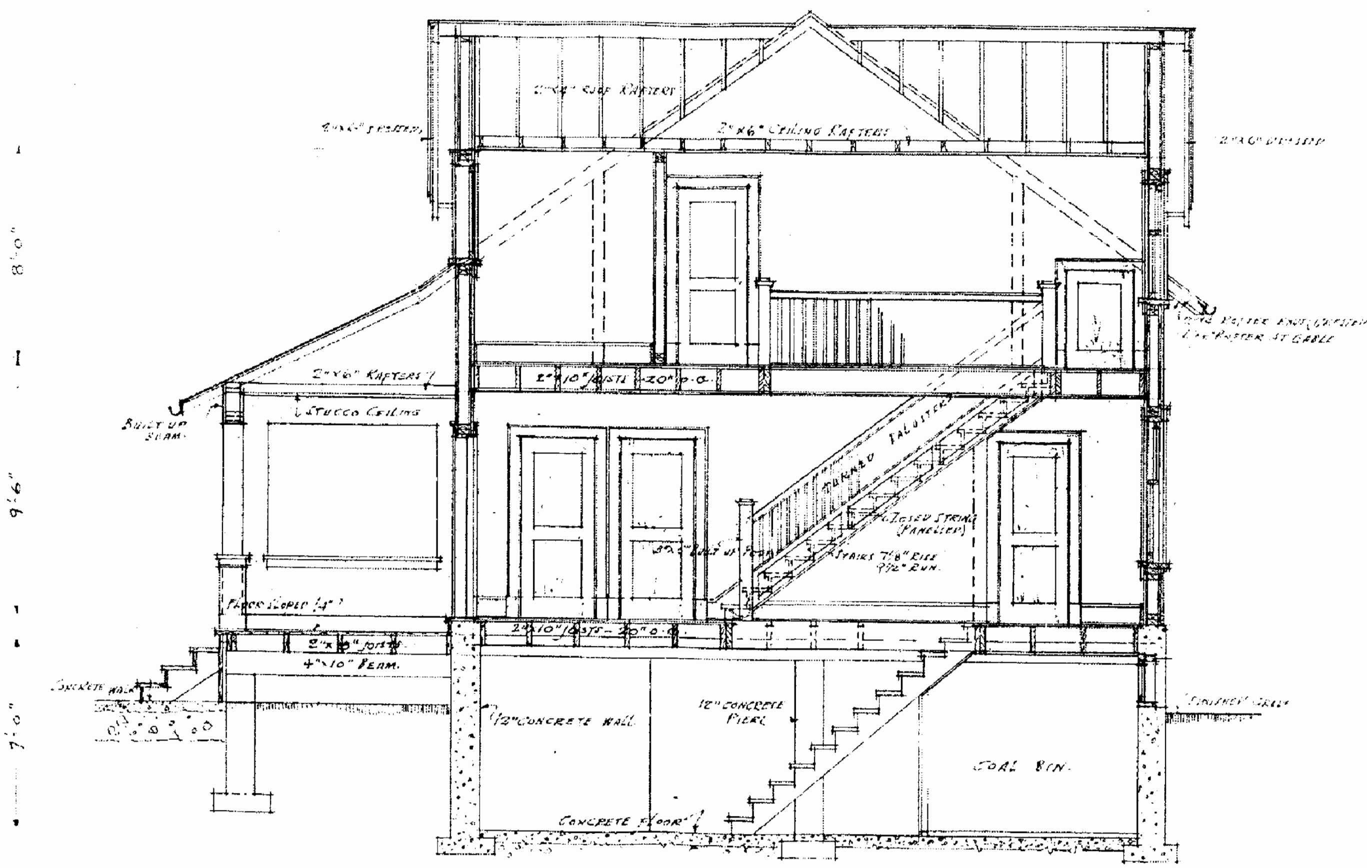


Figure 36: Site 4, Post -repair Temperature Index Comparison



CROSS SECTION THROUGH HALL.

Figure 38: Manotick House Cross Section

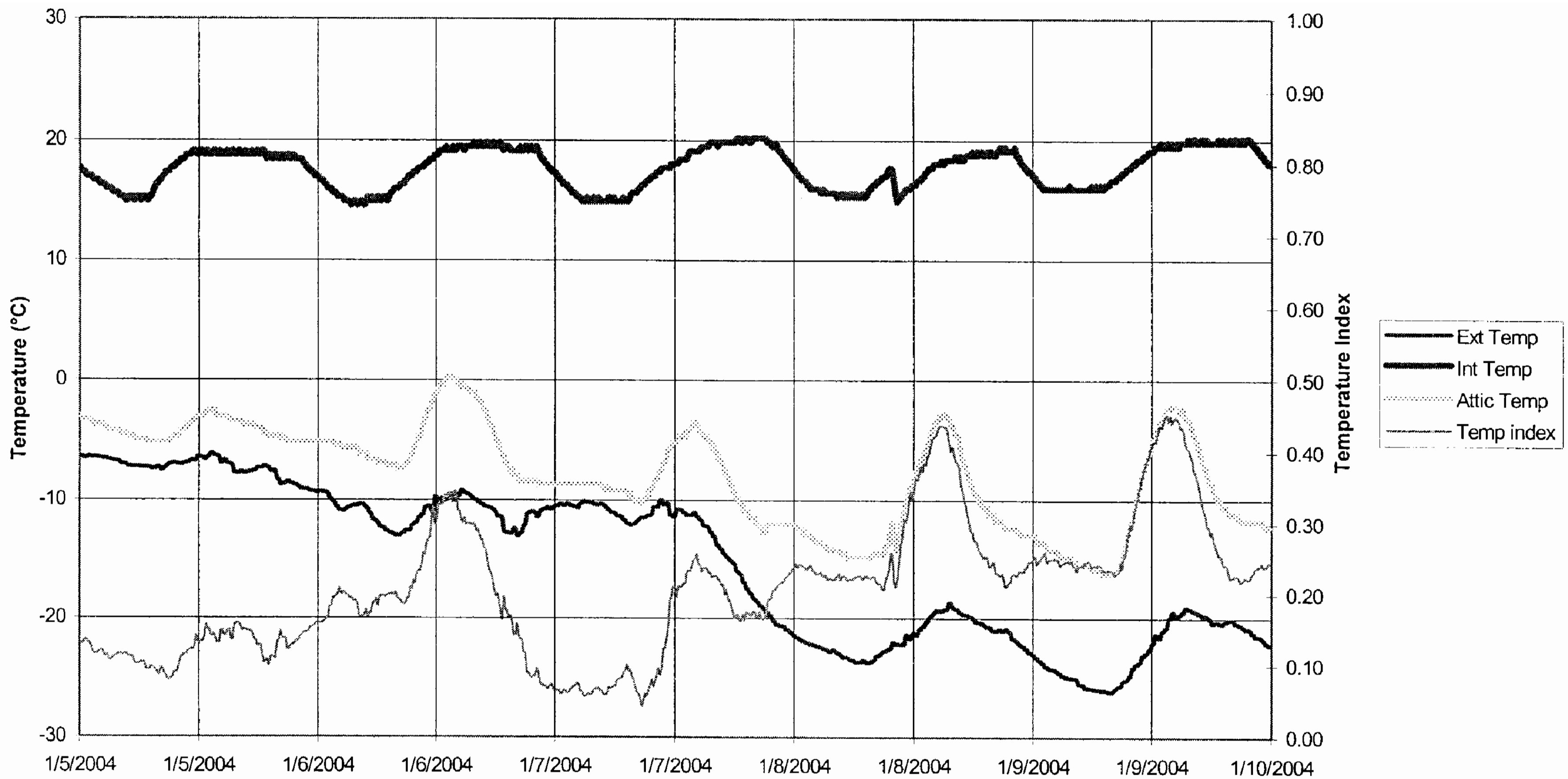


Figure 39: Manotick House, Pre-repair Temperature/Temperature index Data

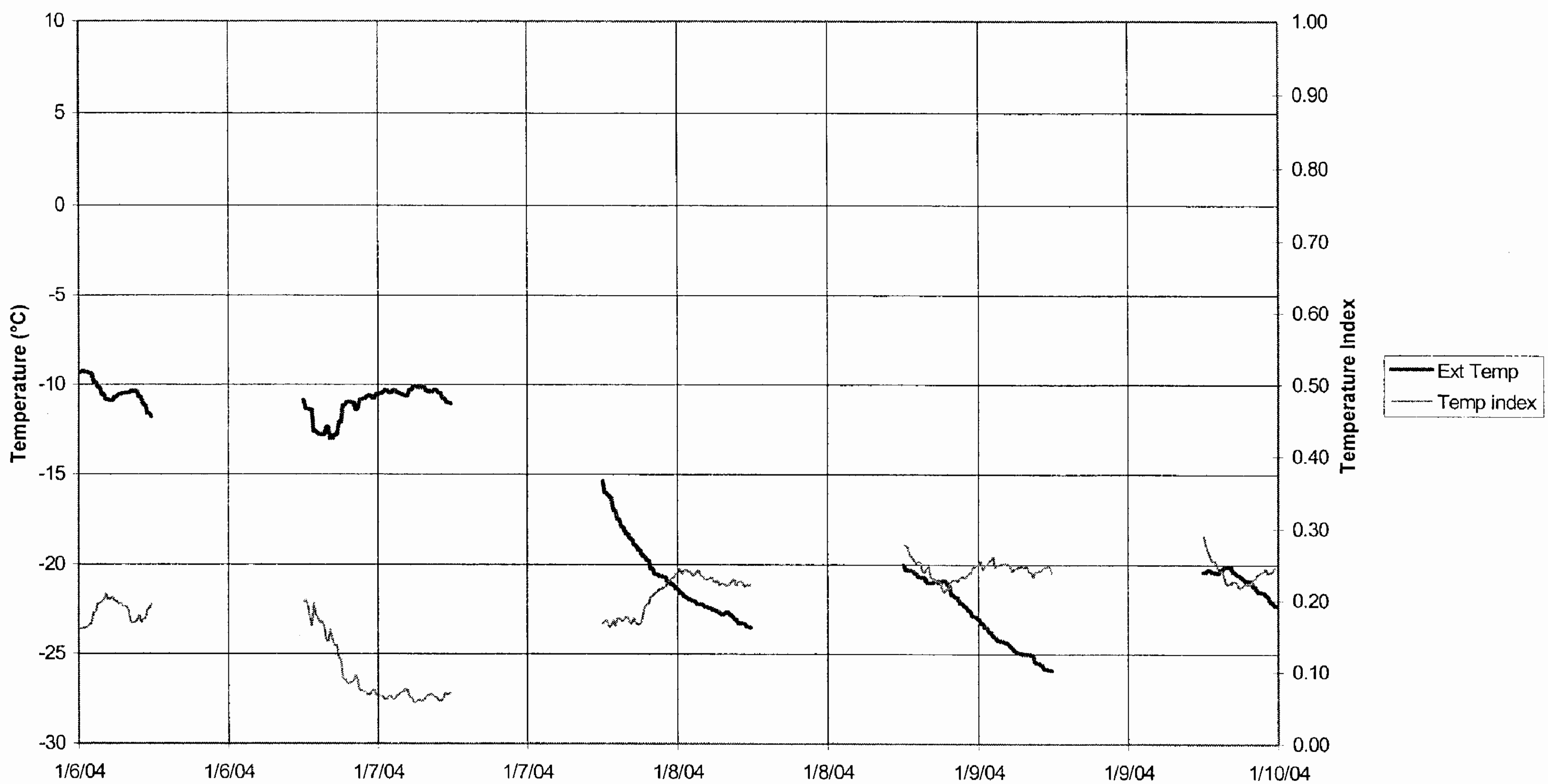


Figure 40: Manotick House, Pre-repair Temperature Indices - Night Data Only

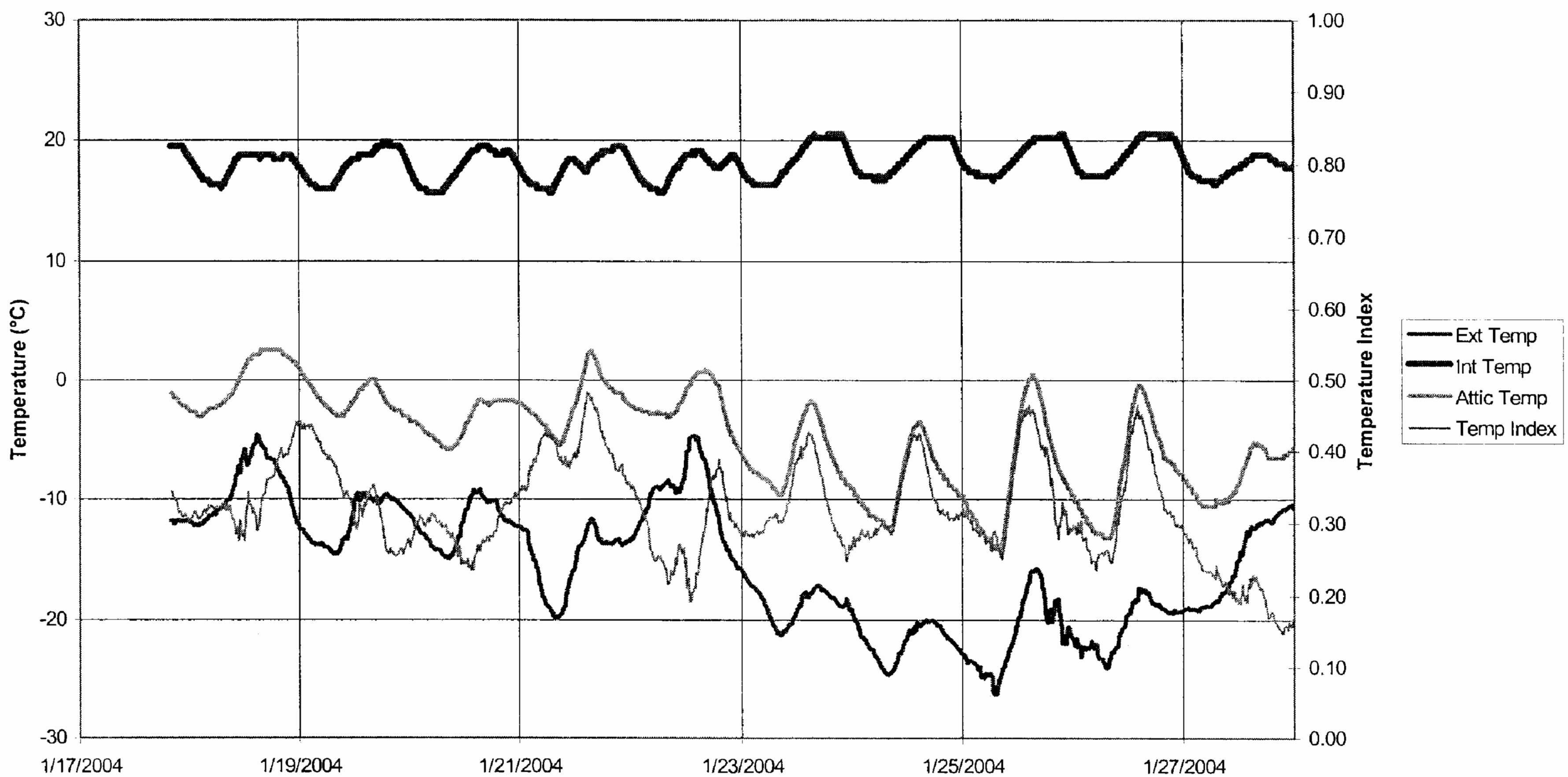


Figure 41: Manotick House, Post Repair Temperature/Temperature Index Data

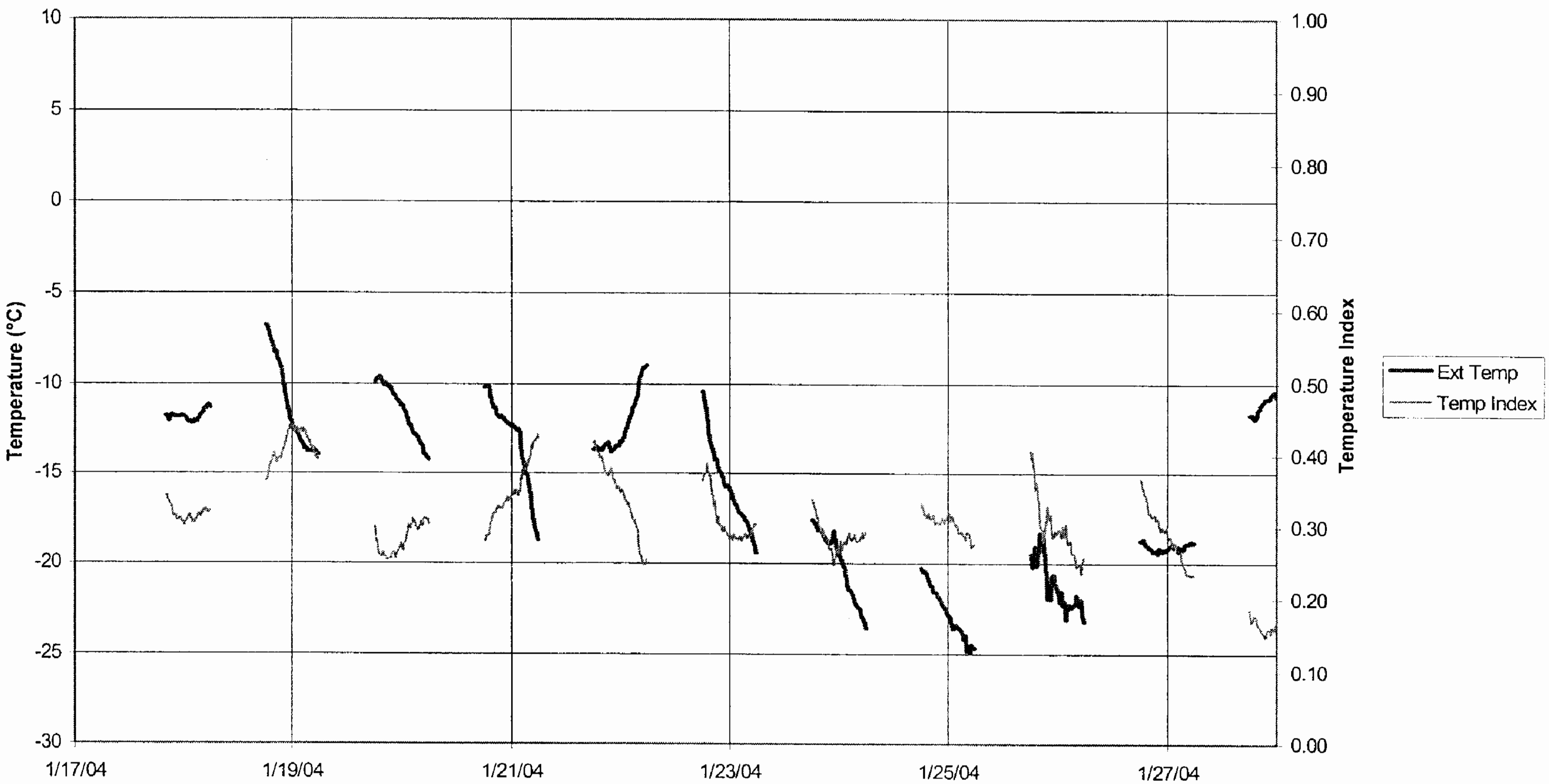


Figure 42: Manotick House, Post Repair Temperature Indices – Night Data Only

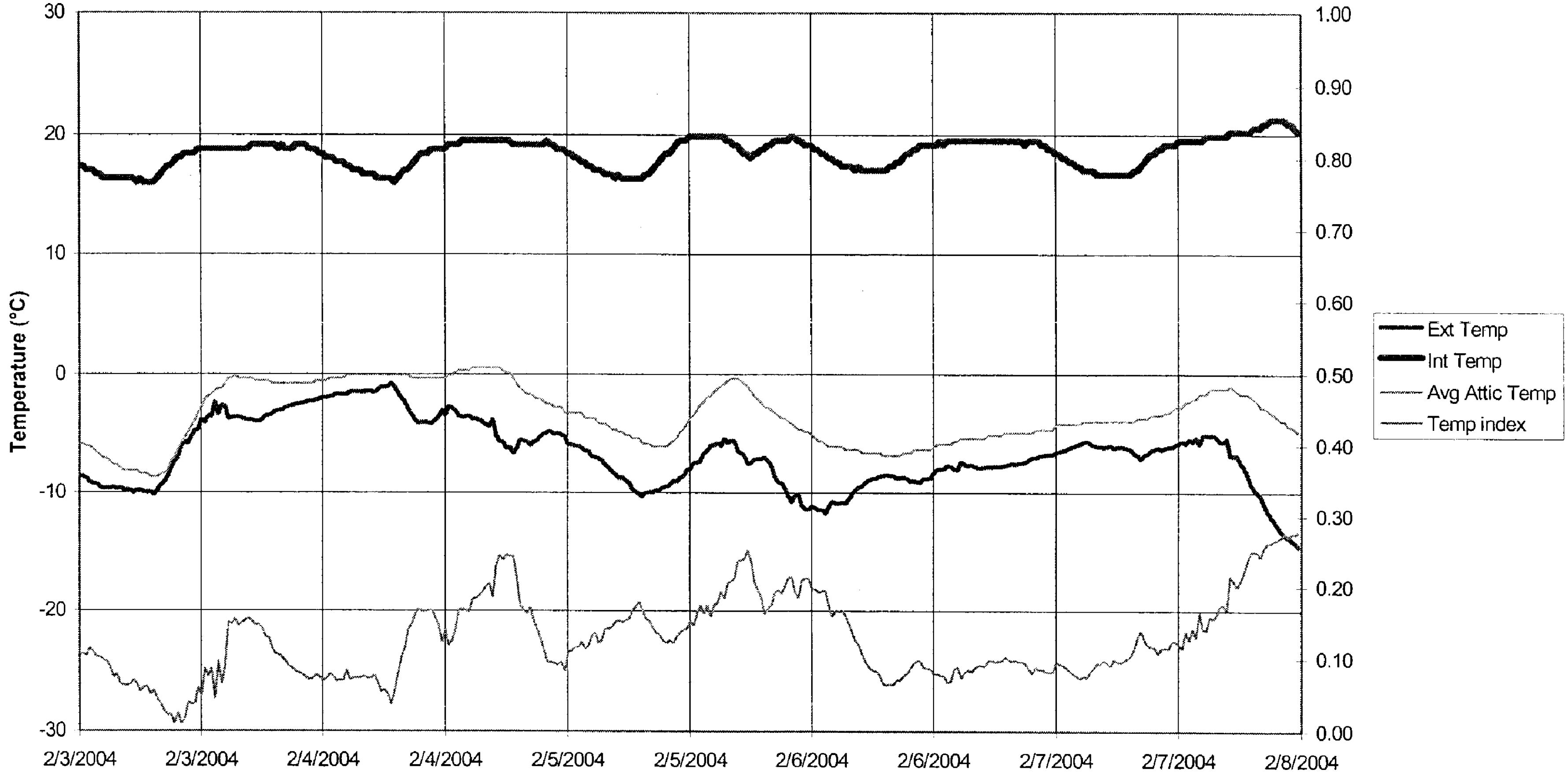


Figure 43: Manotick House, Temperature/Temperature index Data After Addition of Insulation