Assessing the Impact of Cold Climate on Basement Temperatures

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Canadian Centre
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Assessing the Impact of Cold Climate on Basement Temperatures

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Report B-6042.2

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FINAL REPORT

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Canada

ASSESSMENT OF THE IMPACT OF COLD CLIMATE ON BASEMENT TEMPERATURES

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The Canadian Centre for Housing Technology (CCHT)

Built in 1998, the Canadian Centre for Housing Technology (CCHT) is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace.

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing. The twin houses offer an intensively monitored real-world environment with simulated occupancy to assess the performance of the residential energy technologies in secure premises. This facility was designed to provide a stepping-stone for manufacturers and developers to test innovative technologies prior to full field trials in occupied houses.

As well, CCHT has an information centre, the InfoCentre, which features a showroom, high-tech meeting room, and the CMHC award winning FlexHouse™ design, shown at CCHT as a demo home. The InfoCentre also features functioning state-of-the art equipment, and demo solar photovoltaic panels.

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Acknowledgements

The funding for this project was provided by Canada Mortgage and Housing Corporation (CMHC). Thank you for making this project possible and enabling us to mine the valuable data that has been collected at the facility over the years. Thanks are also extended to Wahid Maref and Hamed Saber for their helpful insights.

Executive Summary

Since 2001, a wealth of temperature data has been collected at the Canadian Centre for Housing Technology (CCHT) twin house facility. This report analyzes 7.5 years (January 2003 to August 2010) of basement foundation surface temperature and ground temperature data from the CCHT Reference House. The purpose of this analysis is to develop correlations between outdoor temperature and interior foundation wall surface temperature, and to identify conditions leading to the potential for condensation on the interior surface of the concrete foundation wall.

The Reference House features 200 mm poured concrete walls with RSI-3.5 (R-20) interior glass fibre batt insulation. Temperatures were measured at different depths and at four locations: buried in the ground 1.82 m (6 ft) from the foundation, on the exterior of the concrete wall, on the interior of the concrete wall, and on the interior of the insulated basement wall.

Basement wall surface temperatures and ground temperatures show a strong dependence on outdoor temperature. Temperatures near soil level react quickly to changes in outdoor temperature, while temperatures at greater depths depend on outdoor temperatures over a longer period of time. On the interior of the concrete foundation wall, surface temperature at soil level depends on the average outdoor temperature histories from the past 3 days, while surface temperature near the base of the wall depends on average outdoor temperature histories from the past 69 days. This can lead to cool conditions in the basement in the springtime, due to cold weather from the previous two months still impacting foundation temperatures.

The impact of snow on the foundation wall surface temperature is minimal compared to the relationship with outdoor temperature. Snow cover in excess of 60 cm was found to have some impact – keeping the interior surface temperature of the concrete foundation wall above freezing despite cold outdoor temperatures. However, the occurrence of this amount of snow cover was infrequent for the period studied, so no trends could be drawn from this data set.

Temperatures on the exterior of the basement foundation are usually warmer than the far field ground temperatures. This is particularly true in April, when the far ground is still in the process of thawing. The exterior temperature of the foundation wall was up to 10°C warmer than the ground surface temperature at this time of year.

Hourly outdoor and basement humidity levels were analyzed in detail for a one year period from July 2008 to June 2009 to determine the risk for condensation on the interior surface of the concrete wall. The Reference House basement air tended to be very dry, due to lack of humidification in winter, and the air conditioner removing moisture from the air in summer. As a result, the dew point of the basement air is almost always above the coldest measured surface temperature of the basement wall. However, 21°C house air would only have to be maintained at 20-30% relative humidity in winter to heighten the risk for condensation during this season. Additionally, if outdoor air was brought into the home unconditioned (e.g. through and open window), conditions were favourable for outdoor air to condense on the interior surface of the concrete wall ~17% of the year – particularly in summer. A properly installed air/vapour barrier on the interior of the basement wall assembly could help to prevent humid air from coming into contact with the cold concrete surface and minimize the potential for condensation.

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1 Introduction

The Canadian climate presents a challenge for residential construction. Throughout the year, the building envelope has to minimize energy losses while continuing to ensure occupant health and comfort. Surface temperatures of the foundation wall can be particularly problematic – since the foundation is often a location of thermal bridging, and the mass of concrete and the soil surrounding it are slow to respond to changes in outdoor conditions. If sufficiently humid air comes into contact with the cold surface of the foundation wall, there is opportunity for water vapour in the air to condense and the potential to cause moisture problems.

At the Canadian Centre for Housing Technology in Ottawa, Canada, a cross section of the Reference House North foundation wall (featuring interior glass fibre batt insulation) was instrumented at the time of construction in 1998. Since then, foundation surface temperatures and ground temperatures have been continuously monitored and collected. This valuable database is ideal for determining the interaction between the basement foundation wall and outdoor climate, and also for predicting the indoor humidity threshold for condensation.

This report analyzes over seven years of foundation temperature data in order to quantify relationships between outdoor temperature, snow cover and basement foundation temperatures, and to identify conditions where these temperatures may lead to the risk of condensation.

2 Background

2.1 CCHT Twin House Facility

Built in 1998, the Canadian Centre for Housing Technology (CCHT) (www.ccht-cctr.gc.ca) is jointly operated by National Research Council (NRC), Natural Resources Canada (NRCan), and Canada Mortgage and Housing Corporation (CMHC). CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace. Since its launch, CCHT has been the assessment site for more than 50 housing-related technologies, ranging from compact fluorescent light bulbs and high-performance windows to innovative natural gas-fired engines and a fuel cell.

The CCHT features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing (Figure 1). These houses were designed and built by a local builder to the R-2000 standard (NRCan, 2001) and were built with the same crews and techniques normally used by the builder.

The CCHT twin houses are fully instrumented and include a simulated occupancy system that simulates the daily water draws and electrical loads of a family of four. The internal heat gains from the occupants are also simulated, through the use of 60 W (adult) and 40 W (children) light bulbs. The CCHT twin houses feature over 300 sensors per house, including thermocouples and humidity sensors (Swinton, 2001).

The houses have a central forced air system to provide space heating and cooling. The system is controlled by a centrally located thermostat on the main floor. Three supply ducts and one return duct from this single zone system condition the air in the basement whenever there is a call for heat or cooling from the central thermostat. While the temperatures on the main floor are held within a tight band by the thermostat, temperatures on the basement are allowed to drift. This can lead to daily air temperature swings as discussed in Section 4.2.

Figure 1 - CCHT Twin-House Facility during winter (Reference House shown at right)

2.2 Basement construction

The data analyzed in this report was collected from the CCHT Reference House. The house features a full basement with interior-insulated 200 mm poured concrete walls (Figure 2). A full-height 2x4 stud wall with glass fibre batt insulation (RSI-3.4, R-19) sits on the interior side of the concrete, elevated from the basement slab by 2x4s, with a 25 mm (1 in) air gap between the stud wall assembly and the concrete. A spun-bonded polyolefin (SBPO) membrane wraps the entire stud wall assembly, attached to the interior side of the concrete and also to the interior side of the stud wall. The interior of the assembly is unfinished – the SBPO membrane is exposed to the basement air. The concrete foundation is exposed by approximately 30 cm (1 ft) above ground. The exposure at the time of construction was 15 cm (6 in), however, over time the soil around the foundation wall has settled. The exterior of the instrumented basement is shown in Figure 3. During construction, a drainpipe was laid around the footing of the foundation and covered in gravel. The area adjacent to the basement was then back filled with a mixture of excavated topsoil and clay (see Figure 4 and Figure 5).

A photo of the interior of the instrumented wall is shown in Figure 6. This is not a typical basement assembly, due to the breathable SBPO membrane on the interior side of the basement wall assembly. Typically an air/vapour barrier is required at this location (e.g. a polyethylene membrane). This experimental basement wall assembly without air/vapour barrier was shown to perform well in dry basement conditions such as those present in the research house. However, it would likely not be suitable for more humid interior environments.

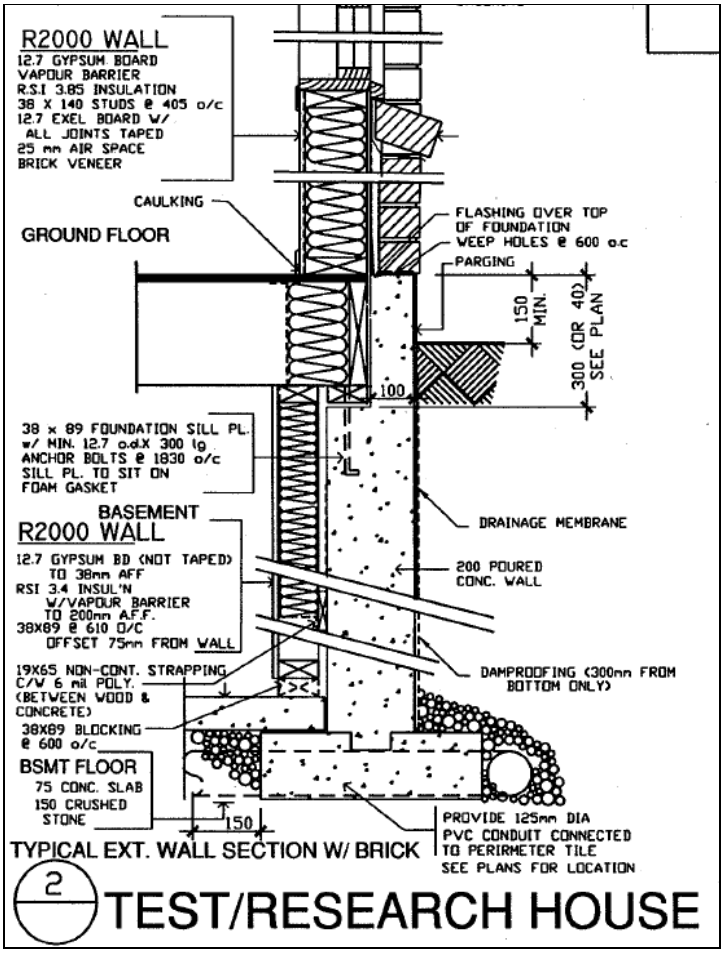

Figure 2 – As-built drawing of the CCHT Reference House Basement Section

Figure 3 - Photo of the exterior of the instrumented basement wall section

Figure 4 – Gravel covering a drain at the foot of the basement wall during construction (photo taken in 1998)

Figure 5 – Backfill used during construction, a mixture of excavated topsoil and clay (photo taken in 1998)

Figure 6 - Photo of the interior of the instrumented basement wall section (note: this is an experimental assembly with no interior air/vapour barrier)

3 Methodology

3.1 Analysis period

Data for this analysis was collected from the CCHT Reference House over a 7.5 year period from 02-Jan-03 to 03-Aug-10, including seven full heating seasons.

3.2 Data collection

Weather Data

Environment Canada weather data from the Ottawa International Airport, located approximately 15 km south of the twin house site, was used in this analysis (Environment Canada, 2011). Average daily temperature data from the airport was chosen over local temperature data since airport data was more complete. Temperatures from the Environment Canada data agreed closely with temperatures measured by thermocouples at the Reference House location. The total daily snow cover records from the airport were also used in the analysis. These give a general indication of the amount of snow likely to be found at the twin house facility, however, local snow effects including drifting and melting may result in different actual snow cover amounts at the Reference House location.

Hourly Outdoor and Indoor Conditions

One year of hourly temperature and relative humidity data from the basement and the exterior were analyzed in the detailed dew point temperature analysis in Section 4.7. For this analysis, the outdoor conditions were recorded locally at the twin house facility. The accuracy of relative humidity data is ± 2% RH.

Basement Wall Temperature Data

Ground temperatures, exterior foundation surface temperatures, interior foundation surface temperatures and interior basement wall temperatures were collected hourly. The monitored foundation cross section is located on the north side of the house. Ground and surface temperatures were measured by thermocouples at 5 depths (0 mm [0 in], 390 mm [15.5 in], 850 mm [33.5 in], 1460 mm [57.5 in], and 1990 mm [78.5 in]) below the ground surface at 4 locations: buried in the ground 1.82 m (6 ft) from the foundation; attached to the exterior surface of the foundation; attached to the interior surface of the foundation; and attached to the interior surface of the basement wall (fixed to the surface of the SBPO membrane). The accuracy of temperature measurements was +/-0.2°C. The numbered sensors and locations are presented in Figure 7. Thermocouples are numbered based on the numbering norm for the full house data acquisition system, which includes over 300 sensors.

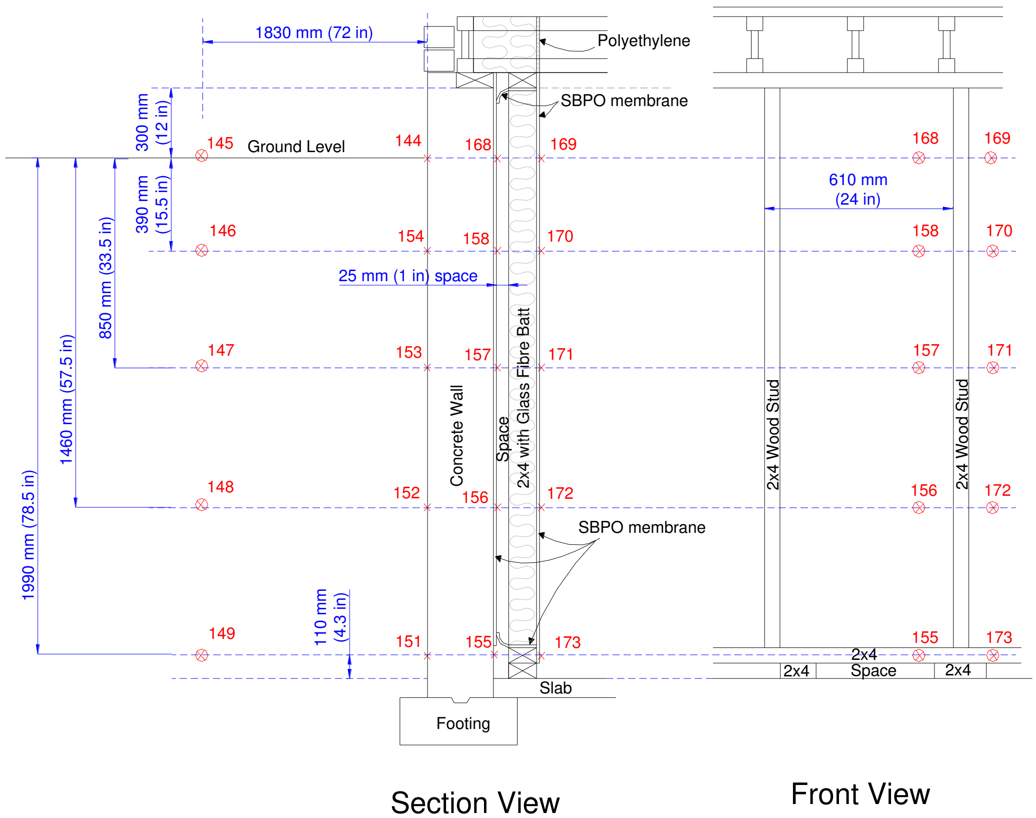

Figure 7 – Detailed basement wall section, showing thermocouple locations (note: the thermocouples on either side of the interior wood stud wall were not directly aligned and were separated by a stud as shown)

Thermocouples 169, 170, 171, 172 and 173 are located on the inner side of the inner spun bonded polyolefin membrane (SBPO). Thermocouples 168, 158, 157 and 156 are located on the inner side of the outer SBPO membrane. Thermocouple 155 is located on the inner side of the concrete wall. Thermocouples 144, 154, 153, 152, and 151 are located on the outer side of the concrete wall. Thermocouples 145, 146, 147, 148, and 149 are located in the ground, 1830 mm (72 in.) from the foundation wall. As shown in the above figure, the thermocouples on either side of the interior wood stud wall were not directly aligned and were separated by a stud.

4 Results

4.1 Weather

The basement assembly was exposed to a variety of weather conditions throughout the analysis period (see Table 1). Environment Canada data (1971-2000) indicates that the average Celsius heating degree days <18°C for Ottawa is 4602. Winter 2008-2009 is very close to this average. The remaining heating seasons in the analysis were warmer than average. 2009-2010 was the warmest of all, with 3983 HDD <18°C. Average daily temperatures ranged from -27.8°C to 29.3°C (Figure 8).

Table 1 – Heating degree days and snow cover for the analysis period

Year	HDD<18°C	Max snow cover (cm)	Average snow cover (cm)		
			Jan	Feb	Mar
2003-2004	4556	30	11	20	2
2004-2005	4522	40	16	12	20
2005-2006	4116	41	21	15	7
2006-2007	4327	24	7	18	10
2007-2008	4386	87	23	40	67
2008-2009	4600	69	40	40	3
2009-2010	3983	47	35	11	2

The maximum snow cover and the average monthly snow cover for January, February, and March are also shown in Table 1. 2007-2008 was by far the season with the highest snow cover, as shown in Figure 9. This winter experienced the second highest snowfall on record, with a total of 432 cm recorded.

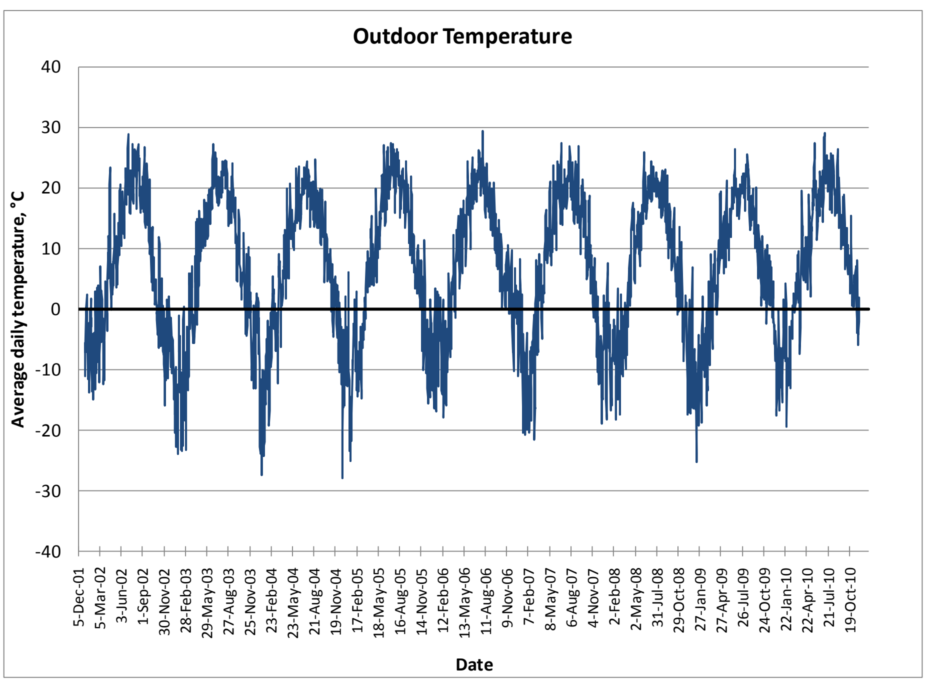

Figure 8 – Average daily outdoor temperature data for the analysis period (Environment Canada data from the Ottawa International Airport)

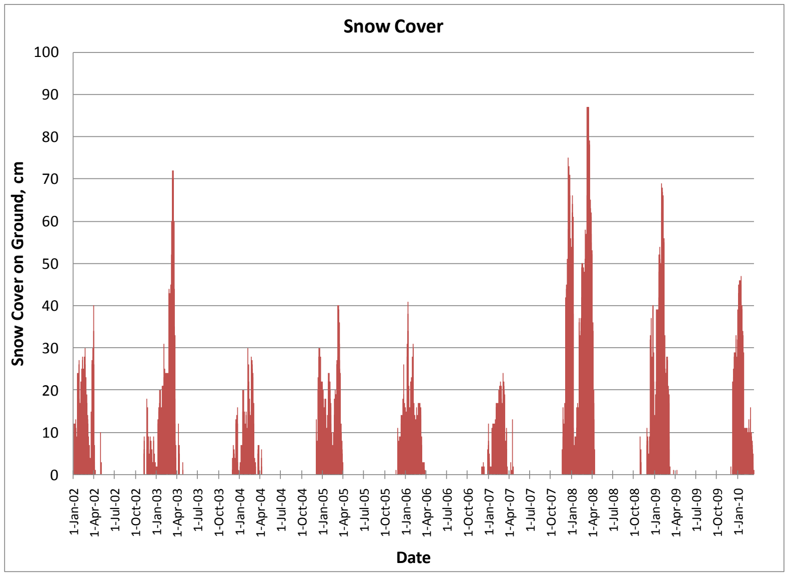

Figure 9 – Ground snow cover data for the analysis period (Environment Canada data from the Ottawa International Airport)

4.2 Interior Basement Air Temperature

In winter, the Reference House indoor temperature was maintained at approximately 21°C by a thermostat located on the main floor of the home that is set to 22°C. Summer temperature settings varied due to individual experiment requirements. The summer setting prior to 2006 was 22°C, in 2006 was 26°C, in 2007 was 22°C, and was 24°C in 2008 and 2009. Due to the central location of the thermostat, temperatures in the basement are free to drift (Figure 10).

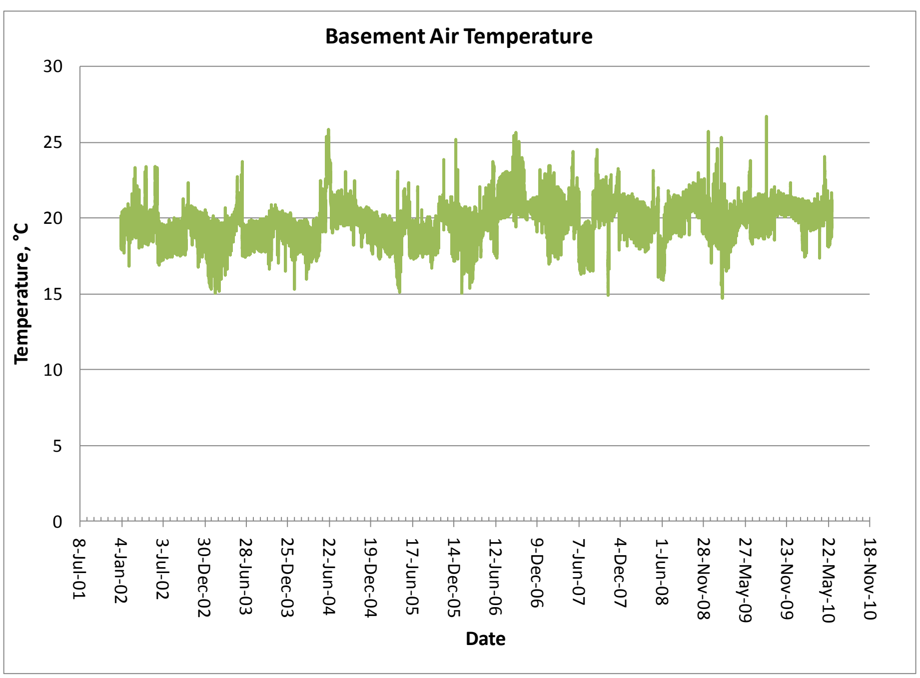

Figure 10 – Hourly basement air temperature

Sample temperatures from the winter are shown in Figure 11. The basement air temperature (green) and main floor air temperature (orange) are plotted on the left y-axis, and the outdoor air temperature is plotted in blue on the right y-axis. In winter, the basement air temperature dips down to 15°C on occasion. Even though there are three supply ducts for hot air and one return duct in the basement, if the temperature at the thermostat on the main floor is satisfied, the central heating system shuts off. This happens primarily on sunny days. This phenomenon is most evident in February (near the end of the plotted period): the outdoor temperatures dips daily below -10°C, while the basement temperature fluctuates between 17°C and 20°C. On these cold days, the thermostat calls for heat at night, and the basement receives the benefit of high amounts of heating. During the day, solar gains satisfy the thermostat on the main floor and the basement cools. The basement air temperature was measured just 30 cm (1 ft) below the basement ceiling. It is likely that temperatures at lower heights would be cooler. However, these were not measured.

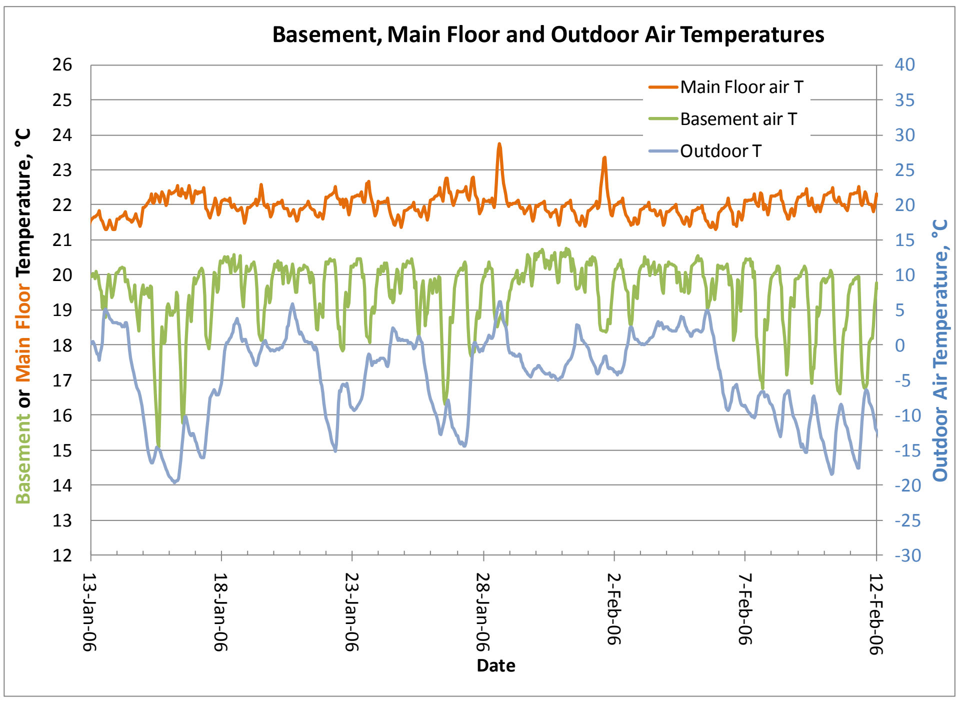

Figure 11 – Winter detail of hourly outdoor, main floor and basement air temperatures

A sample of summer basement air temperature is shown in Figure 12. This cooling season, the central thermostat setting was 24°C. Basement temperature fluctuates on a daily basis, in an inverse relationship with outdoor temperature. When the outdoor temperature is high, the central thermostat calls for cooling. While this cooling is needed on the main floor, it is not necessary for the basement. As a result, the basement cools to 19°C on occasion. At night, the outdoor air cools and the cooling system shuts off. The basement air then warms up to above 21°C.

In spring, basement temperatures drift more freely (Figure 13). This time of year, there is often overheating of the house on the main floor due to warm days and high solar gains. These houses are operated with closed windows year round, so heat can build up during the days and dissipate at night. The thermostat is satisfied the majority of the time, and does not call for heating. During the plotted period, the basement air temperature ~30 cm below the ceiling remains around 20°C. Again, air temperatures at lower heights in the basement may be cooler, but these were not measured.

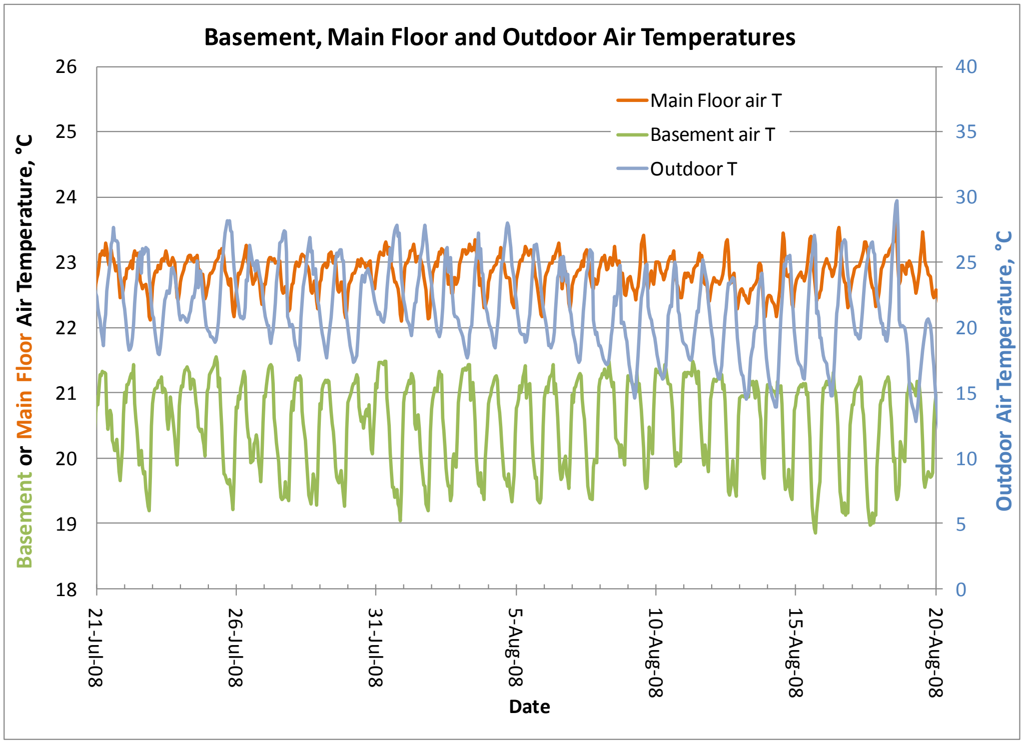

Figure 12 – Summer detail of hourly outdoor and basement air temperatures

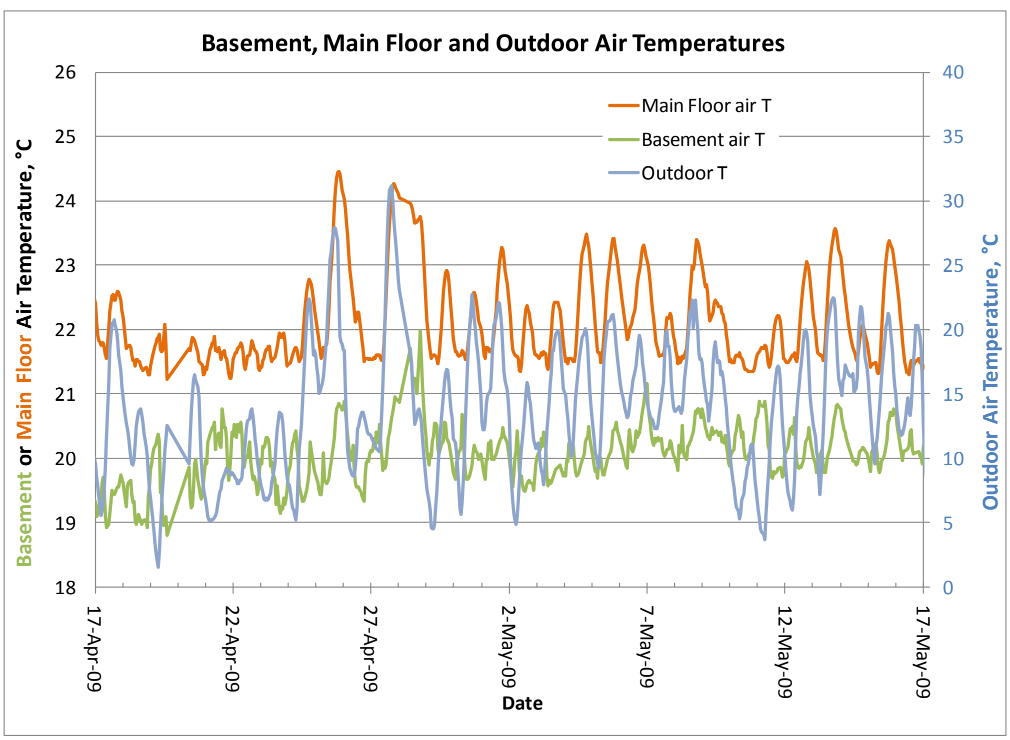

Figure 13 – Spring detail of hourly outdoor and basement air temperatures

4.3 Ground and Basement Wall Surface Temperatures

The average daily temperatures recorded by the thermocouples at the four different layers in the basement assembly are presented in Figure 14 through Figure 17.

The ground has a buffering effect. While temperatures at the surface of the soil fluctuate between -5°C and 23°C, temperatures deeper in the ground are steadier. At the deepest measured location, 1990 mm (78.5 in) below soil level, the temperature fluctuates between 6°C and 16°C. The peak occurs in September, and the minimum occurs in April (Figure 14). At the surface, the ground temperature follows the outdoor temperature closely: peaking above 20°C in July, and diving below 0°C in February. During the analysis period, the temperature never fell below freezing at the measurement location 850 mm (33.5 in) below soil level.

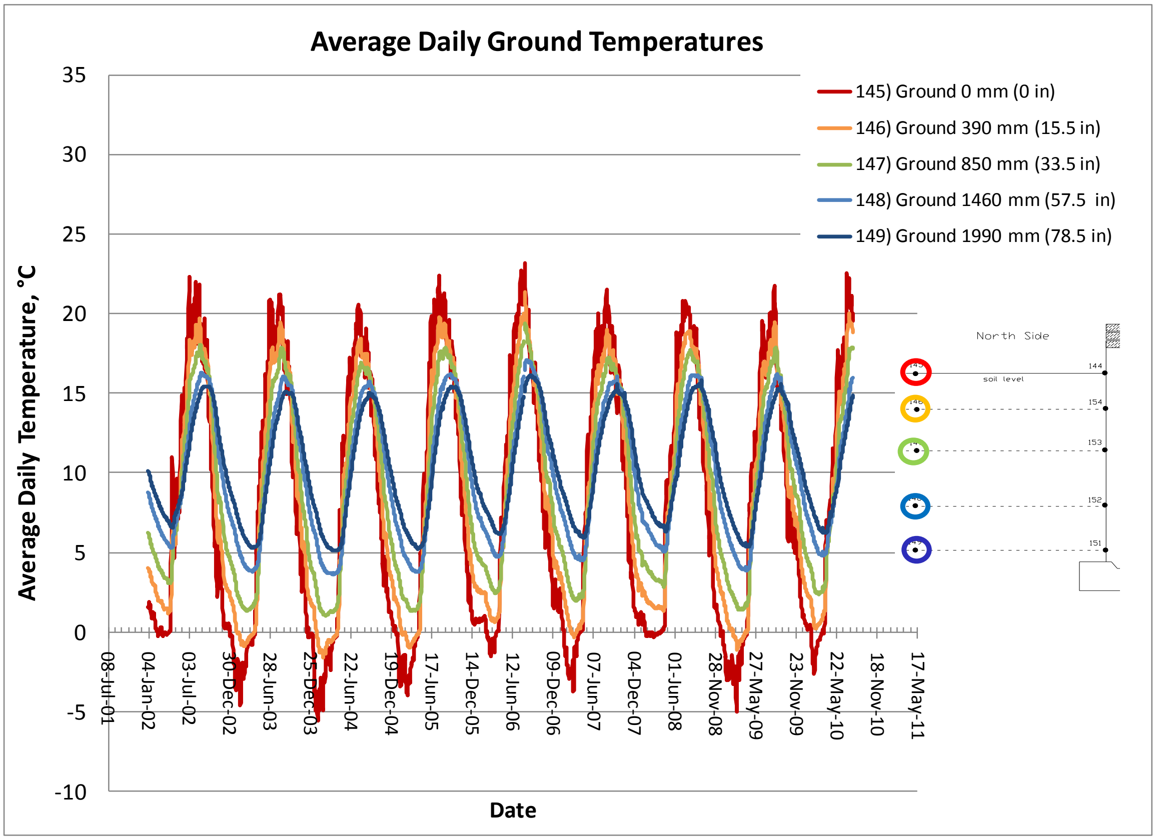

Figure 14 – Ground Temperatures

Temperatures from the exterior of the foundation are plotted in Figure 15. Temperatures at this location are influenced by ground temperatures, air temperatures and basement temperatures to varying degrees. Like the ground temperatures, the temperatures at the top of the foundation respond more rapidly to changes in outdoor temperature. This relationship is explored in Section 4.4. As a result, the coldest winter and warmest summer temperatures on the exterior foundation are recorded at ground level. By contrast, the temperatures near the base of the foundation wall relate most closely to ground temperatures. At the deepest location, the temperature fluctuates annually between 10°C and 17°C – slightly warmer than the temperatures at the same depth in the far ground location.

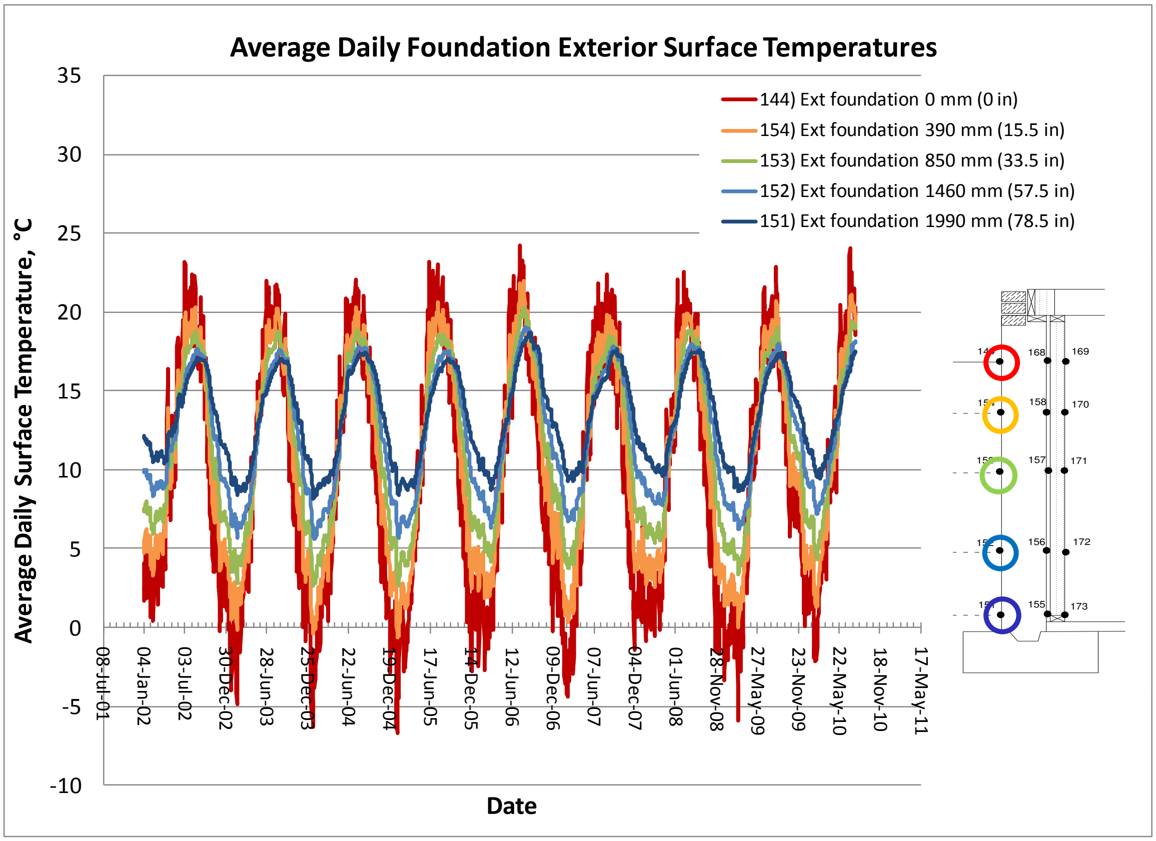

Figure 15 – Foundation Exterior Surface Temperatures

Temperatures at the interior surface of the concrete foundation wall behind the insulation layer follow similar trends as those on the exterior surface of the foundation (Figure 16). The coldest location in winter is again at soil level, and the coldest location during summer is at the base of the wall. Note: the thermocouple at the base of the wall is in direct contact with the concrete, unlike the four other thermocouples on this layer, which are adhered to the SBPO membrane (see Figure 7). Additionally, the thermocouple at the base of the wall is adjacent to the base plate of the interior insulated wall. This likely contributes to maintaining temperatures at this location above 9°C throughout the year.

The temperatures of the interior surface of the foundation wall are of particular interest in determining potential for condensation. If humid air were to find its way to this surface, cold temperatures could result in condensation. A full analysis of this phenomenon is presented in Section 4.7.

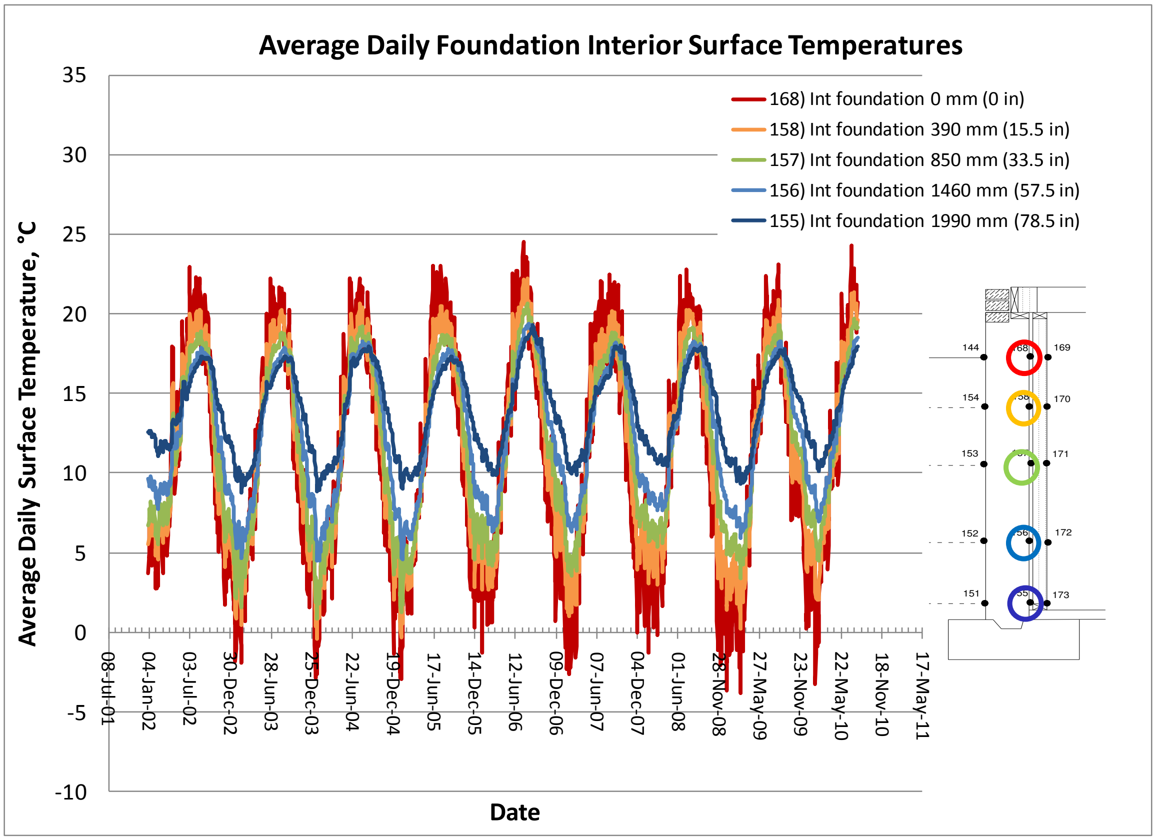

Figure 16 – Foundation Interior Surface Temperatures

Temperatures on the interior surface of the insulated basement wall are generally warmer than temperatures on the surface of the concrete, as they are most influenced by basement air temperature (Figure 17). Temperatures are coldest at the base of the wall, and warmest at the top of the wall. The gradation in temperature from the base to the top of the wall is likely influenced by the uninsulated slab and resultant basement air temperature stratification. Additionally, the thermocouple at the base of the wall is attached to the 2x4 base plate of the wood stud wall assembly. The wood frame creates a thermal bridge from the slab to the thermocouple location, causing this to be the coldest measured location on the interior surface of the wall year-round.

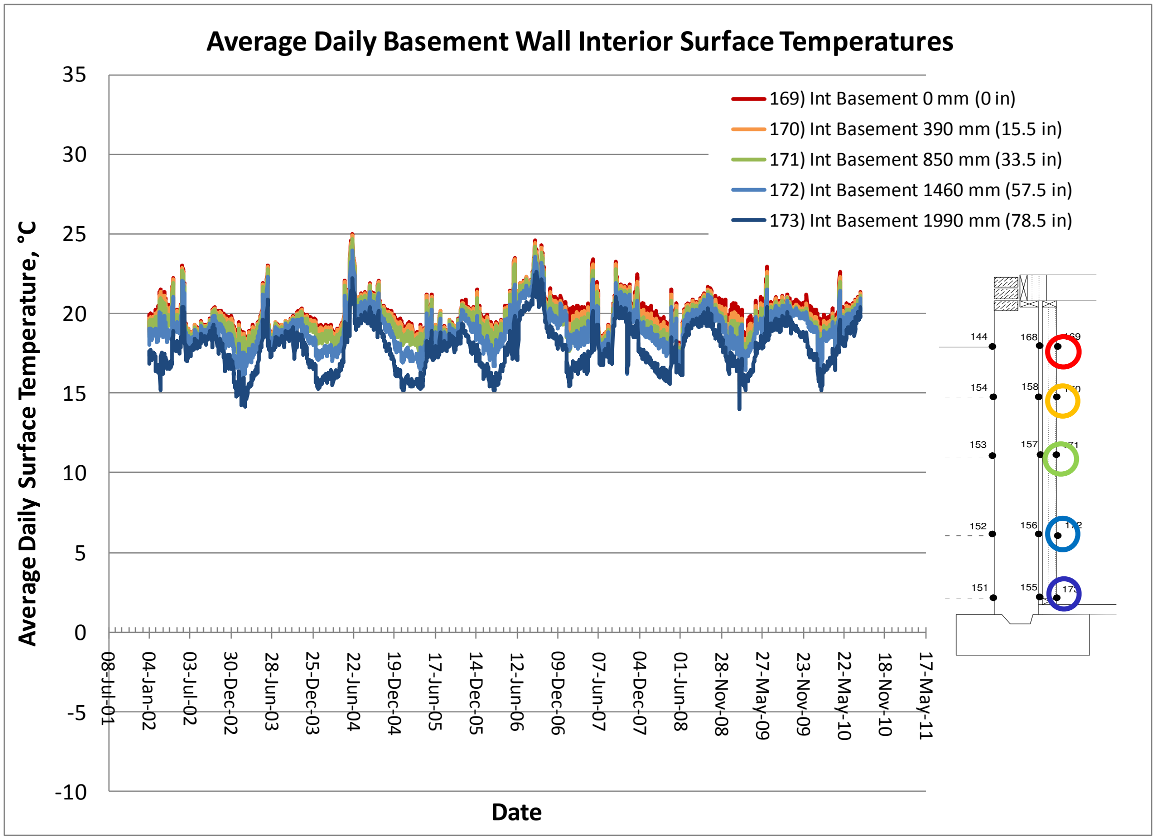

Figure 17 – Basement Wall Interior Surface Temperatures

4.4 Relationship with Outdoor Temperature

Ground temperatures and temperatures either side of the concrete foundation wall are strongly influenced by fluctuations in outdoor temperature. However, as shown in the previous section, the deeper the location, the longer the delay in temperature response. In order to determine the relationship between outdoor temperature and ground and foundation temperatures, the average daily measured temperature data was plotted against average outdoor temperature for all ground and foundation locations. The plot for thermocouple #168 (T168 - located at the top of the interior of the foundation wall, behind the insulation) is shown in Figure 18. Subsequently, the average temperature was plotted against a moving average of the outdoor temperature for the previous 2 days, 3 days, 4 days, etc., until the relationship with the strongest correlation was identified (with the highest R-squared value). For example, at T168 the relationship was strongest for a running average temperature from the past 3 days – as shown in Figure 19. This correlation has an R-squared value of 0.9712, the correlation with a moving average temperature for the past 2 days was 0.9654, and for the past 4 days was 0.9681. Thus, cold snaps 3 or more days in length will result in cold temperatures at the top of the foundation wall.

A second example is shown in Figure 20 and Figure 21. These plots are both for T155, the thermocouple near the base of the interior of the foundation wall, behind the insulation. In this location, the straight correlation between average daily surface temperature and average daily outdoor temperature is weaker than the correlation for T168 (Figure 18), with more scatter. However, when the average daily surface temperature at T155 is plotted against the running average temperature over the past 69 days, the correlation is strong (R-value: 0.959). Thus, the temperature at the base of the wall is dependent on the average outdoor temperature over the past 69 days.

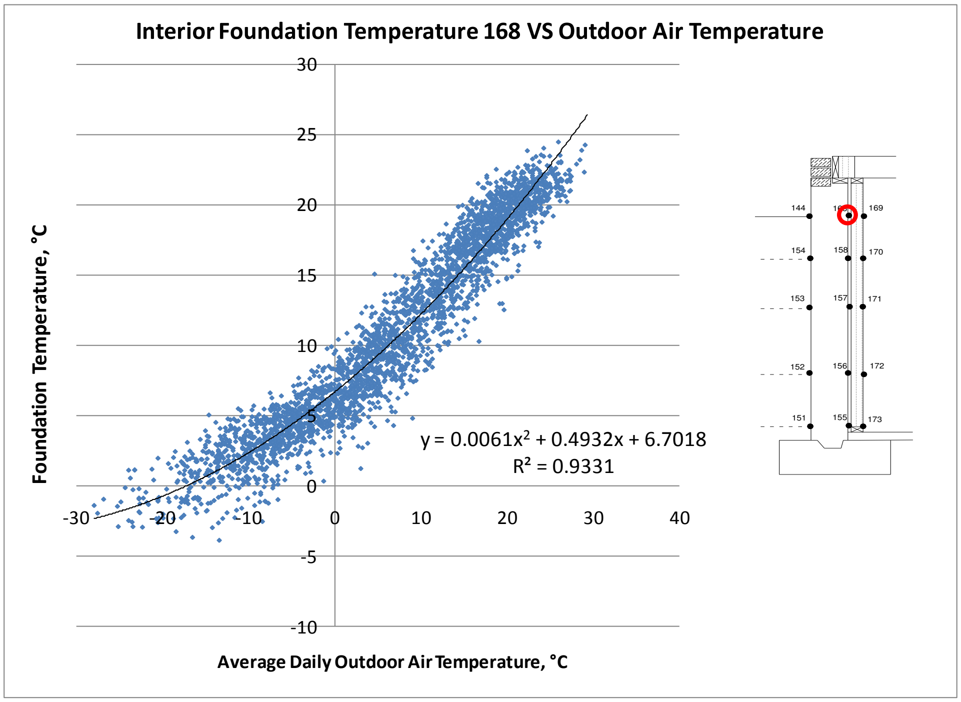

Figure 18 - Relationship between average daily foundation surface temperature T168 and average daily outdoor air temperature

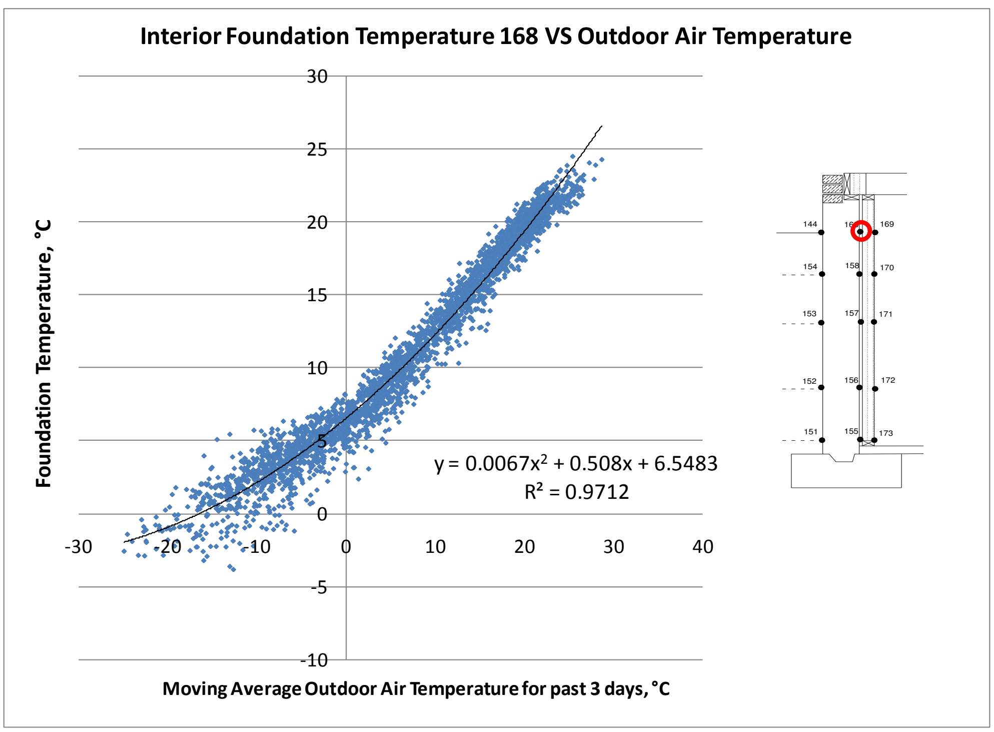

Figure 19 - Relationship between average daily foundation surface temperature T168 and moving 3 day average of outdoor air temperature

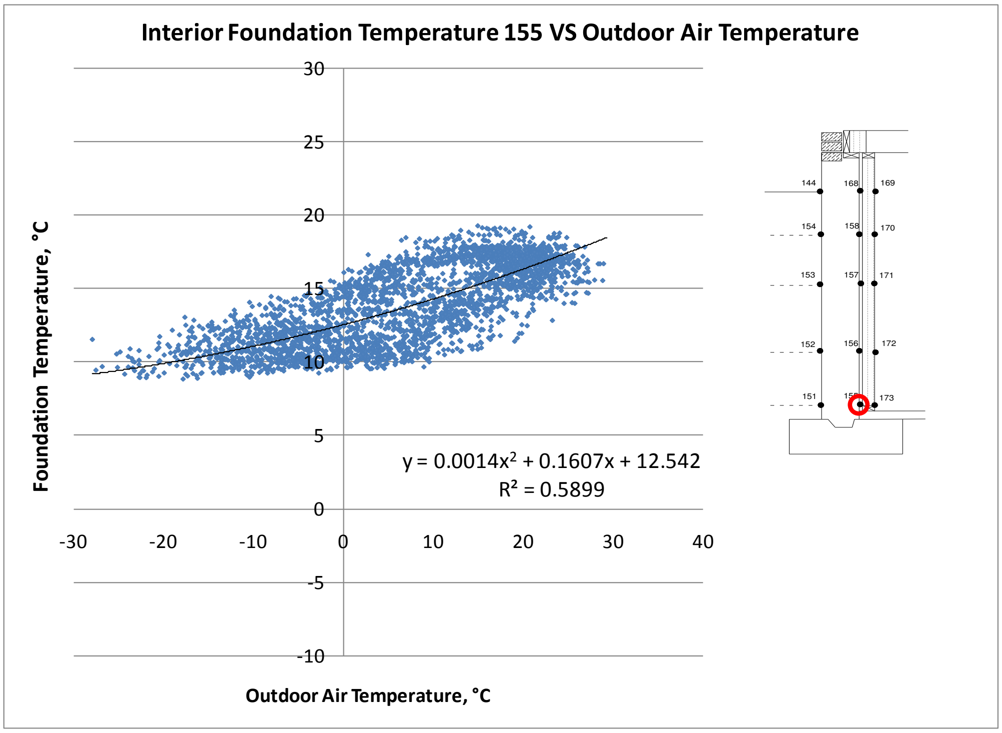

Figure 20 - Relationship between average daily foundation surface temperature T155 and average daily outdoor air temperature

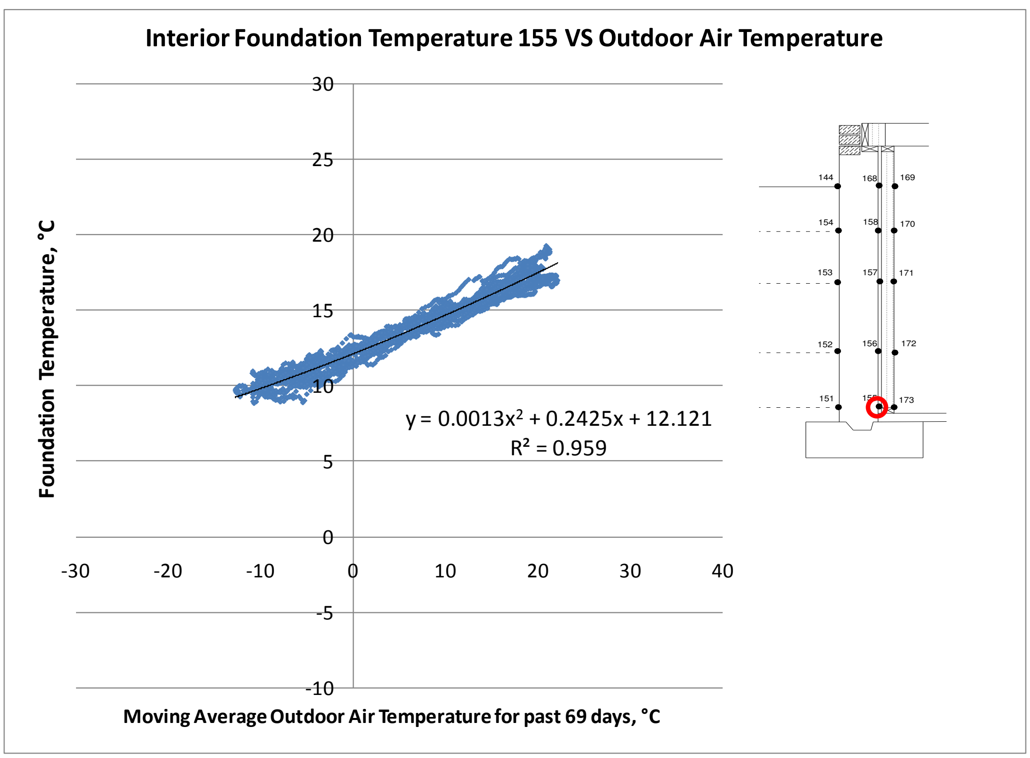

Figure 21 - Relationship between average daily foundation surface temperature T155 and moving 69 day average of outdoor air temperature

The same procedure was repeated for all the temperature measurement locations in the ground, on the exterior of the foundation wall, and on the interior of the foundation wall behind the insulation. The full set of resulting curves is included in Appendix A. The surface temperature at each location is dependent on the average outdoor temperature for the number of days listed in Figure 22. For example, the temperature measurement at location 149 (the deepest ground temperature location) is dependent on the average outdoor temperature from the previous 117 days. This figure shows the impact of the thermal conductivity of the foundation wall on the response to outdoor temperature. It is postulated that due to the conduction "fin" effect of the concrete in the foundation wall, temperatures on the interior of the wall react slightly faster to changes in outdoor temperature than the temperatures at the exterior of the wall (which are attenuated more by ground temperatures), and much faster than temperatures in the ground.

Even so, the temperatures at the base of the basement wall apparently depend on 69 days (over 2 months) of outdoor weather. This suggests that the temperature at this location in early April is dependent on the outdoor temperature histories of February and March.

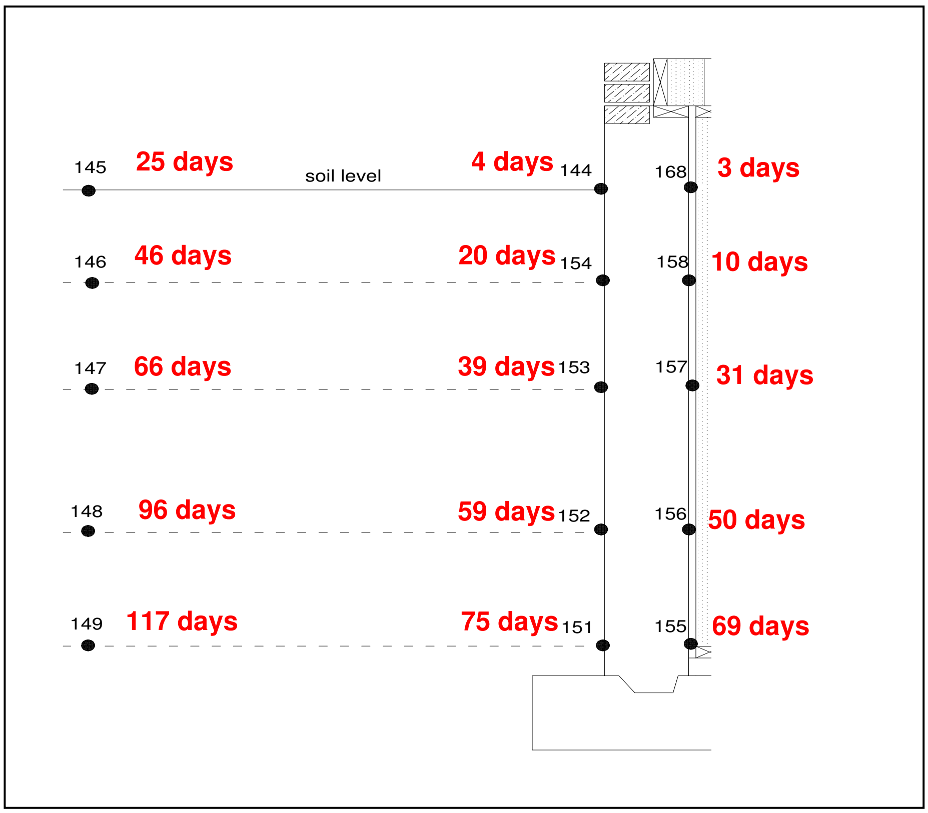

Figure 22 – Temperature is dependent on average outdoor temperature over previous x number of days

A snapshot of the wall assembly on the day with the coldest temperature on the interior of the foundation wall is shown in Figure 23. On this day, the interior surface of the concrete reached -4.8°C. At this same instant, the basement wall shows an apparent “fin effect”, whereby the concrete in the foundation wall is acting as a thermal bridge – conducting heat out of the basement wall assembly, to the top of the wall and to the exterior. The temperatures at the three middle locations (circled in green) are cooler than both the basement interior temperatures and the temperatures at the foundation/ground interface – an indication of heat being drawn out of the basement wall by the fin effect.

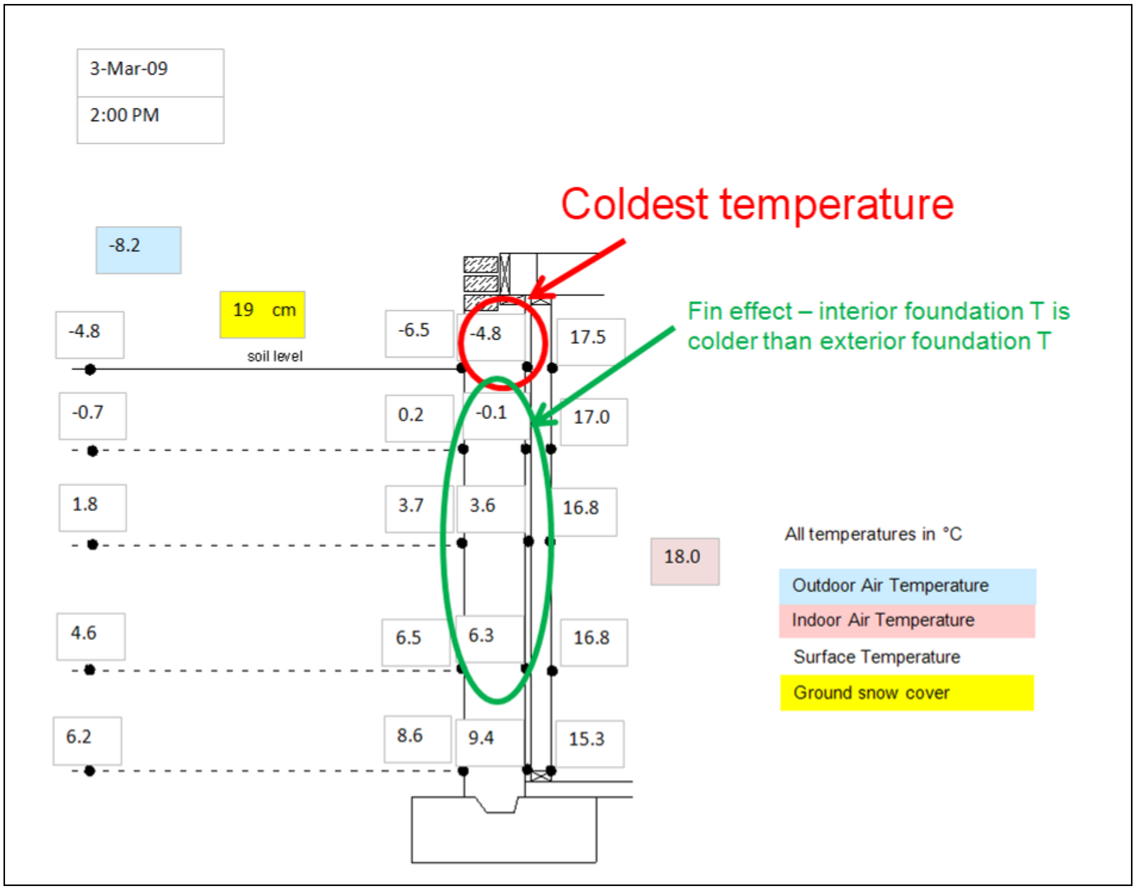

Figure 23 - Snapshot of temperatures on the day with the coldest surface temperature on the interior of the concrete foundation wall

4.5 Impact of Snow cover

The previous section described the relationship between the foundation interior surface temperatures and outdoor temperature histories. It is hypothesized that snow could help to insulate the foundation wall and increase interior foundation surface temperatures. The location at the top of the wall is of particular interest, since it responds the fastest to changes in outdoor conditions. To determine whether snow also affects foundation temperatures, the points in the foundation temperature VS moving average outdoor air temperature plot for T168 (Figure 19) were coloured based on degree of snow cover. The resulting graph is shown in Figure 24. As shown in this figure, there is no strong correlation with snow cover. Some of the coldest foundation temperatures still occur with some degree of snow cover. Even with more than 40 cm of snow, the interior surface temperature drops below 0°C on occasion.

With snow cover in excess of 50 cm, the interior basement foundation remained above freezing (Figure 25). However, during the analysis period this happened infrequently, resulting in limited data points: only 85 days with >50 cm snow, 49 days > 60 cm, and 19 days> 70 cm. Additionally - since the snow data is from the Ottawa International Airport and not measured locally, local effects such as drifting and melting away from the foundation wall are not captured. Therefore it is difficult to draw any useful relationships between surface temperature and snow cover from this data set.

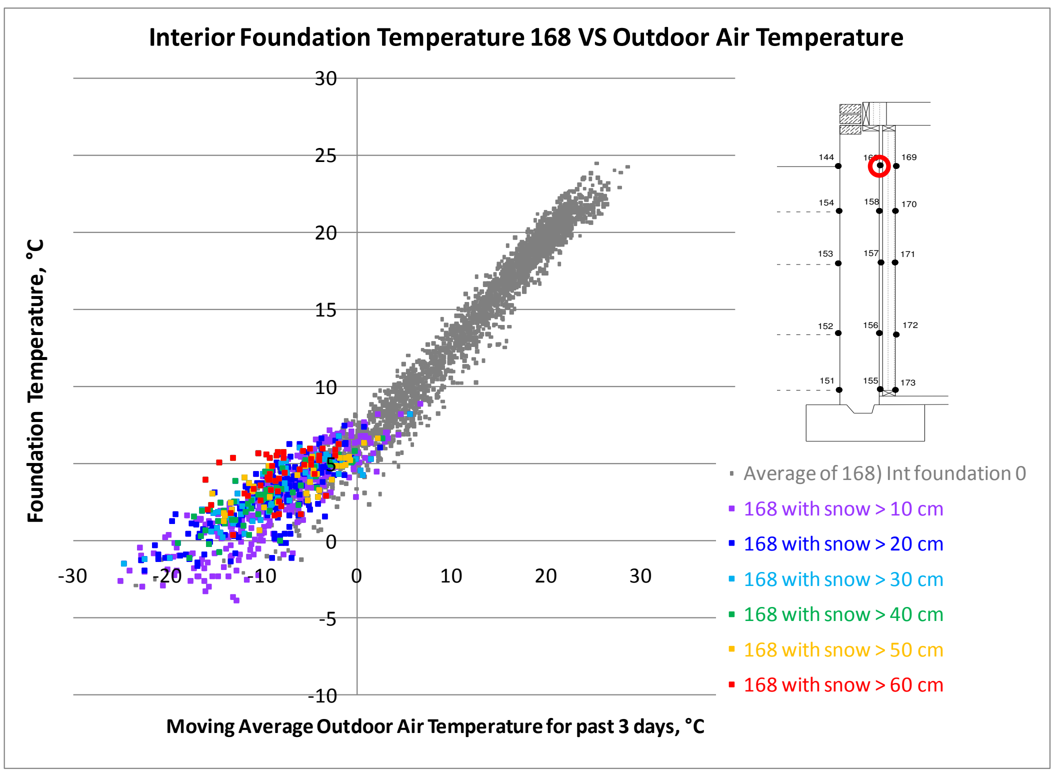

Figure 24 - T168 VS Average outdoor air temperature for past 3 days, coloured based on snow cover.

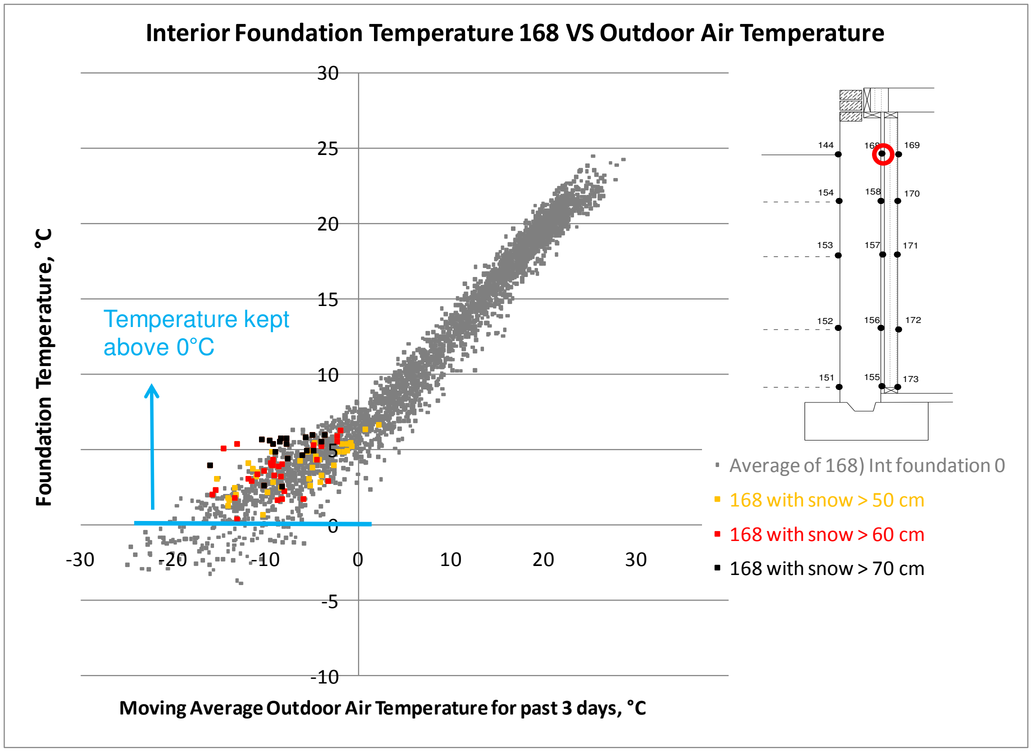

Figure 25 - T168 VS Average outdoor air temperature for past 3 days, coloured based on snow cover.

Example foundation and ground temperatures on a cold day with high amounts of snow cover are given in Figure 26. On this occasion, the outdoor temperature has dropped to -15.5°C, and the ground is covered by 72 cm of snow. The temperature at the top of the exterior of the foundation is 0.0°C. This indicates significant insulating effects from the snow, and potentially snow melting at the interface with the foundation wall. The lowest surface temperature on the interior side of the foundation (behind the insulation) is 2.4°C.

By contrast, sample data from a day with low snow accumulation and cold outdoor temperatures is presented in Figure 27. At the time shown, there is 12 cm of snow cover, and the outdoor temperature is -20.4°C. While the temperature at the surface of the ground is just below 0°C, the temperature at the top of the exterior of the foundation is -7.4°C. Without large amounts of snow cover, the exposed foundation wall and brick façade conducts heat out of the assembly, acting as a fin.

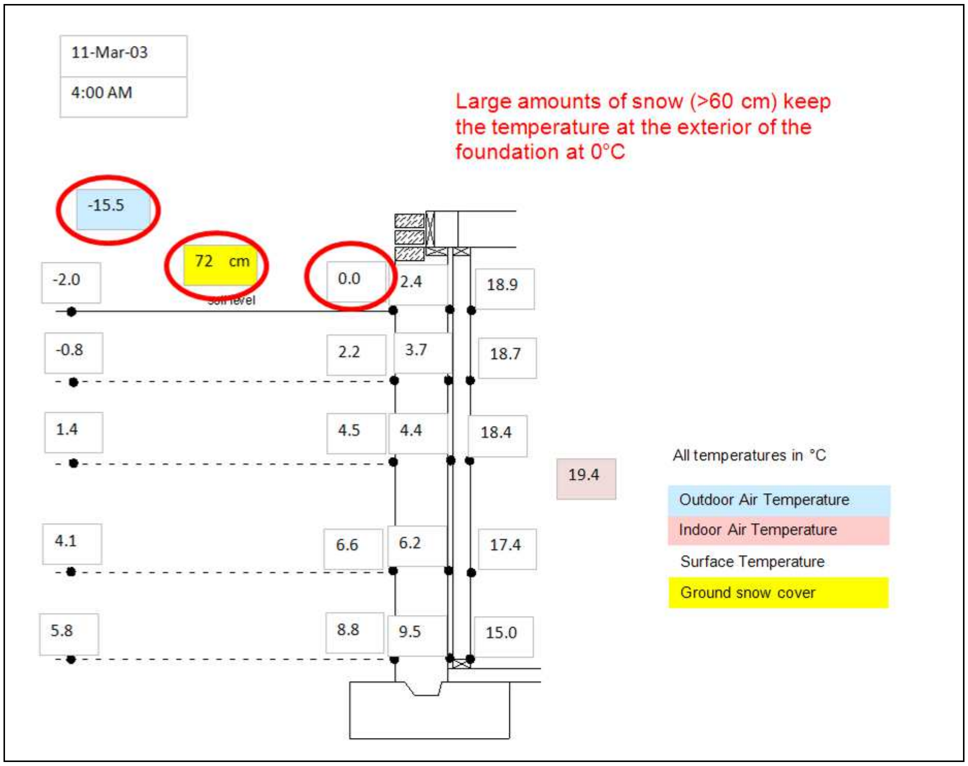

Figure 26 – Sample foundation temperatures on a cold day with high snow cover.

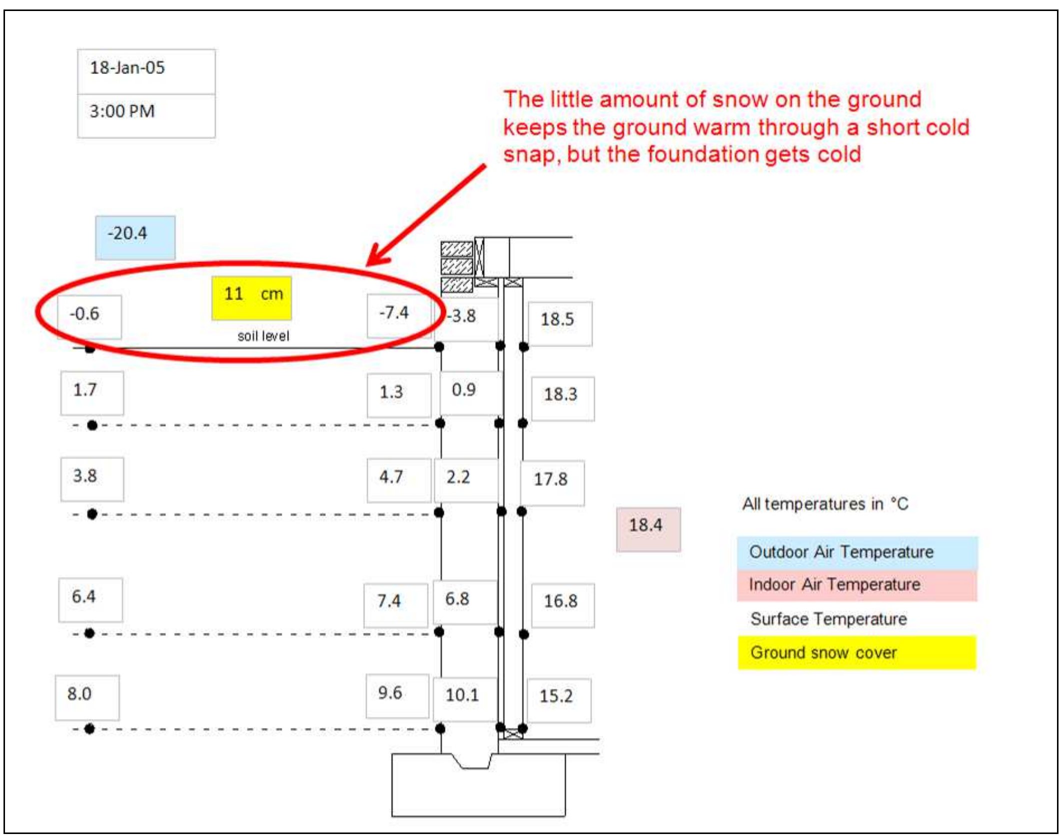

Figure 27 – Sample foundation temperatures on a cold day with low snow cover.

4.6 Spring trends and warming

In the spring, the foundation wall warms more rapidly than the soil in the far ground location. Sample temperatures from this time of year are shown in the cross section in Figure 28. In this instance, the temperature at the surface of the ground is just above freezing, while the exterior foundation temperature at soil level is 11°C. The ground is in the process of thawing, as shown by the sub-zero temperatures 390 mm (15.5 in) below soil level.

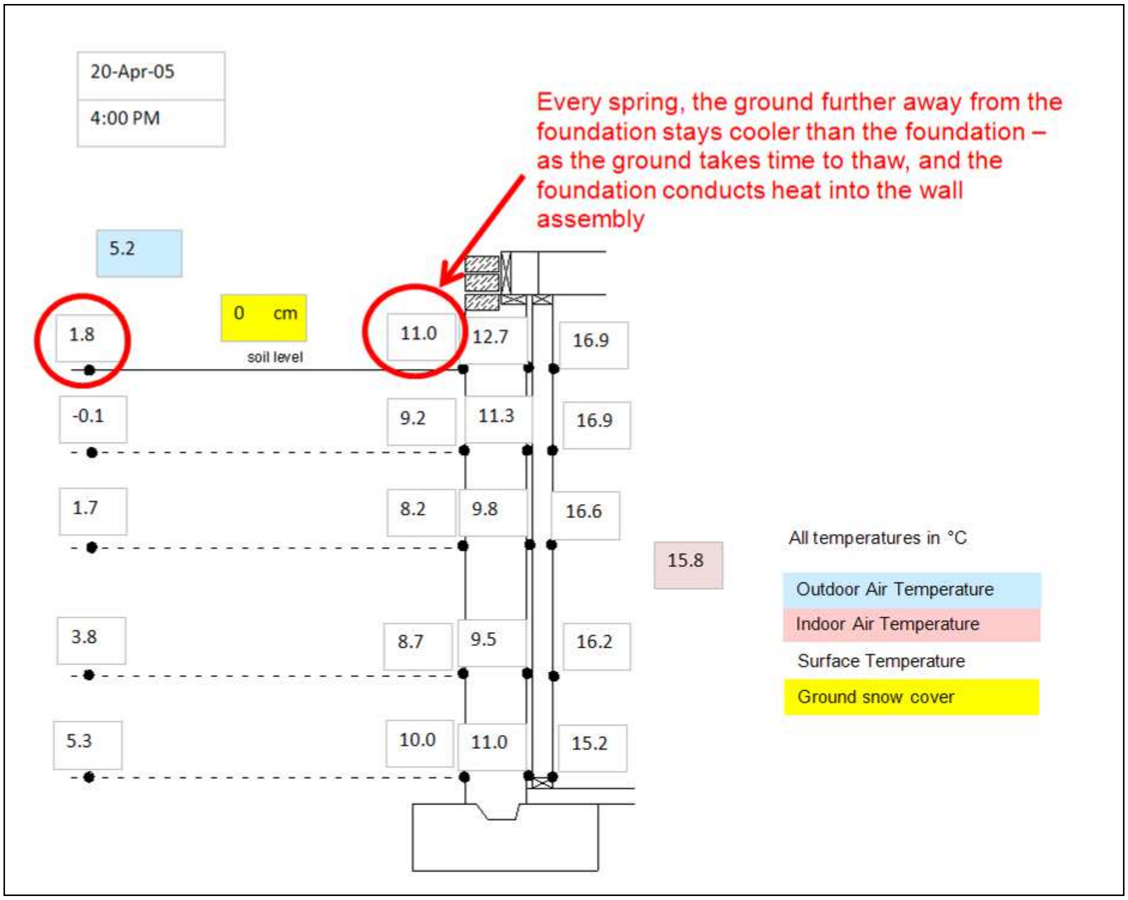

Figure 28 – Difference between the outdoor air dew point temperature and the minimum measured foundation temperature

The temperatures at the soil level in the ground (T144) and at the exterior of the foundation wall (T145) are compared for the full analysis period in Figure 29. The circled section on this graph is presented in more detail in Figure 30. Differences between the two temperatures are plotted in Figure 31. The spring temperature difference occurs annually and the peak difference occurs in mid April every year. This is evidence that on warm days the basement wall conducts heat into the ground from the basement and from the exposed above ground section of the foundation wall. This causes the ground around the foundation to thaw and heat up more rapidly than the soil in the far ground location. This can result in up to a 10°C temperature difference between these two locations in the spring.

The opposite phenomenon occurred once during the analysis period – on 18-Jan-05. On this day, a cold snap occurred with low amounts of snow on the ground. The foundation cooled rapidly, while the surface of the ground remained warm due to the small amount of snow cover and heat stored in the ground. Temperatures in the basement cross section for this occasion are shown in Figure 27.

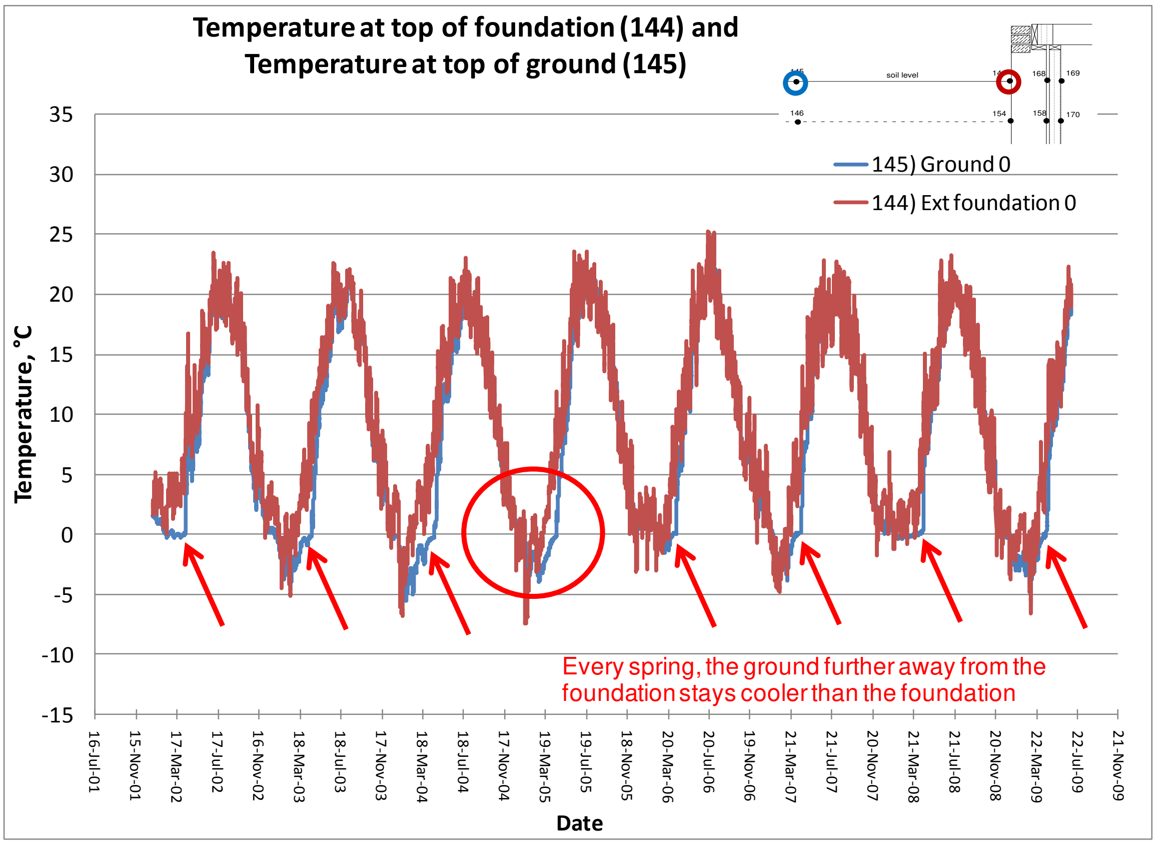

Figure 29 – Comparison between the temperature at the top of the foundation (T144) and the temperature at the surface of the ground (T145)

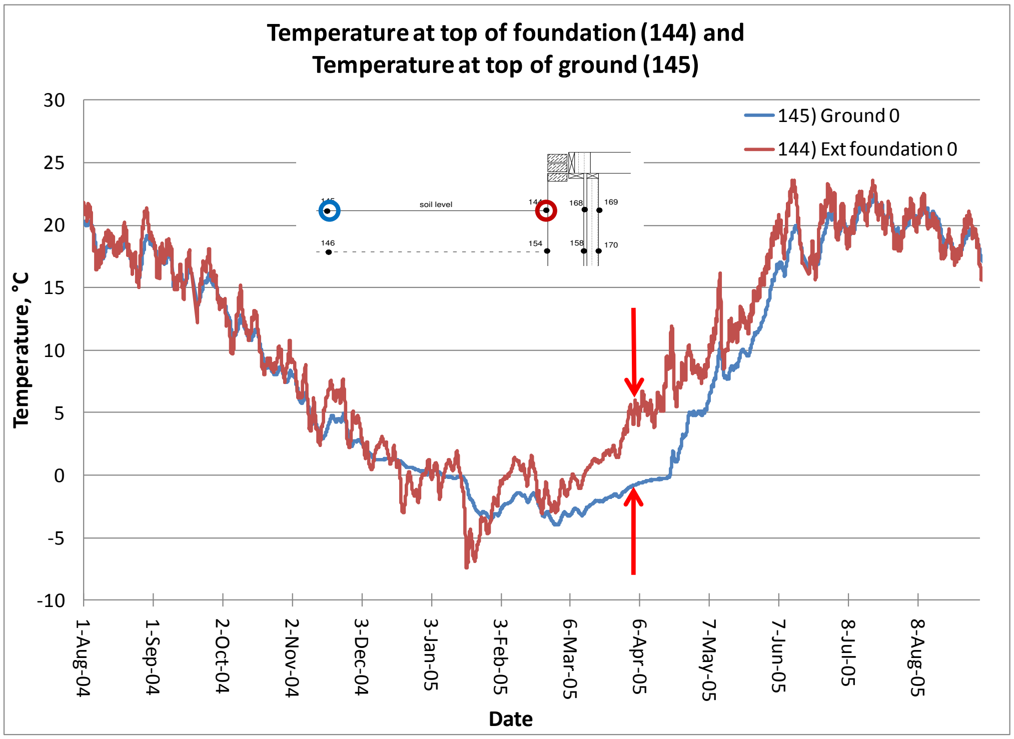

Figure 30 – One year detail (2004-2005) from the comparison between the temperature at the top of the foundation (T144) and the temperature at the surface of the ground (T145)

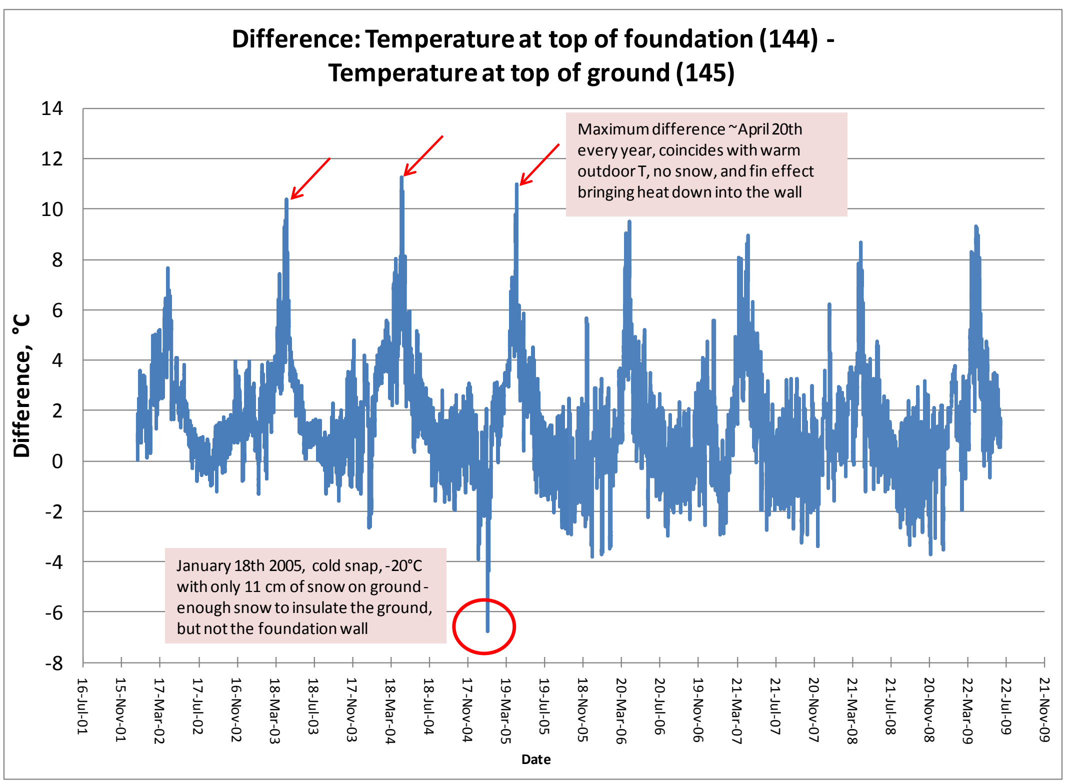

Figure 31 – Difference between the temperature at the top of the foundation (T144) and the temperature at the surface of the ground (T145)

Evidence for freezing and thawing of the ground is also apparent in the ground temperature VS air temperature history graphs in Appendix A. The graph for location T145 (at soil level in the far ground) is repeated in Figure 32. The temperature at this location shows dependence on the air temperature history from the past 25 days. In this graph, there is a scattering of points centered about 0°C ground temperature. A plausible explanation for this scattering is the freezing and thawing of the ground requiring additional energy to change phase, and delaying the response to changes in air temperature. This same effect is seen to a lesser extent in deeper ground temperature measurement locations (see Figure A-20 to Figure A-26). However, no freeze/thaw scatter is seen for the measurement locations adjacent to the foundation wall. This suggests that the foundation wall conducts heat into and out of the wall and surrounding ground, accelerating response to changes in outdoor temperature, and increasing the speed of freezing and thawing.

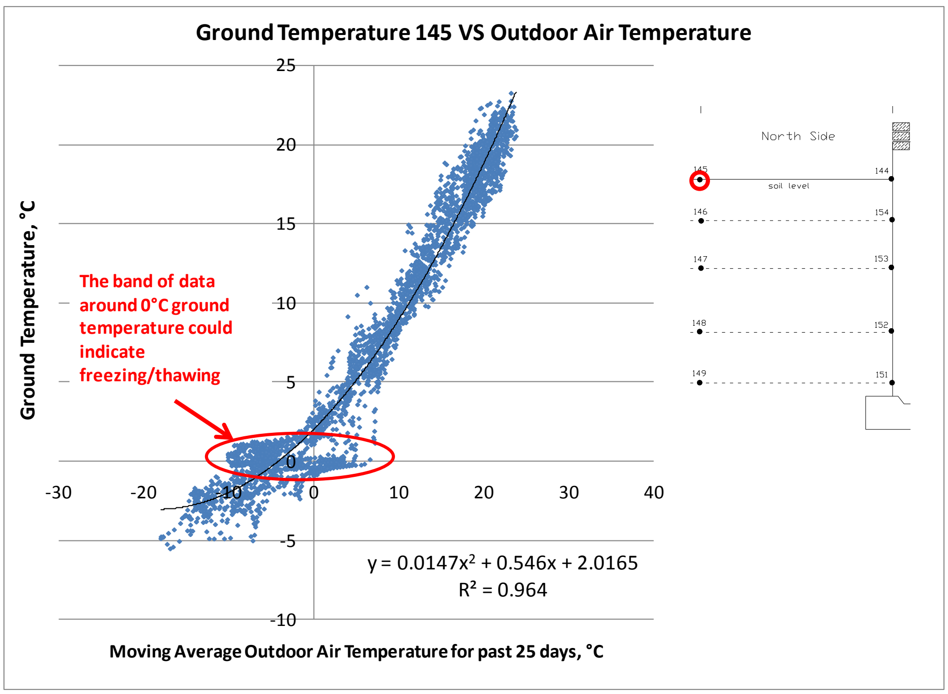

Figure 32 - Relationship between average daily foundation surface temperature T145 and moving 25 day average of outdoor air temperature

4.7 Potential for Condensation

Cold surface temperatures on the interior of the foundation wall have the potential to lead to condensation if: a) the surface temperature is below the dew point of room air, and b) there is a means for that air to come into contact with the surface.

One year of data, from 01-Jul-08 to 30-Jun-09, was selected for detailed analysis in order to determine the potential for conditions that could lead to condensation. 2008/2009 was chosen due to the fact that this year contained the coldest interior surface temperature event out of the whole analysis period, and recently calibrated relative humidity data was available for both the onsite exterior and basement conditions. Hourly temperature and humidity conditions for the 2008/2009 period are shown in Figure 33 and Figure 34 respectively. The indoor air temperature plotted for the basement was measured ~300 mm (1 ft) below the basement ceiling.

The large fluctuations in outdoor relative humidity (Figure 34) are due in large part to fluctuations in outdoor temperature. A plot of absolute humidity in grams of water vapour per kilogram dry air (gv/kg_{da}) provides a better comparison between indoor and outdoor humidity levels (Figure 35). In summer, the Reference House basement humidity is generally lower than outdoor conditions, due to the removal of humidity from indoor air by the air conditioning system. In winter, the absolute basement humidity is slightly higher than the outdoor humidity. This is due to some added moisture from the actions that are generated by the simulated occupancy system (such as showers, running the dishwasher, etc.). Despite this small amount of moisture generation, indoor winter humidity levels are still very low due to the lack of a humidification system. Health Canada (1987) recommends humidity levels be maintained between 30-55% in winter, unless constrained by window condensation.

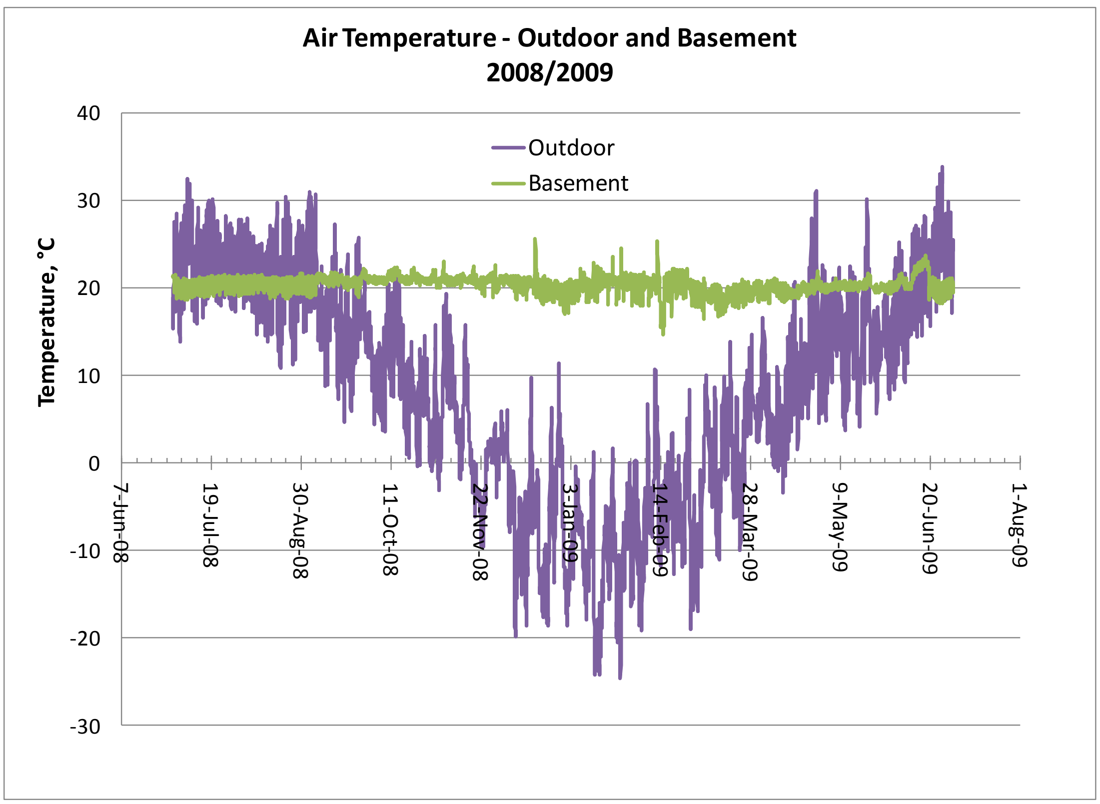

Figure 33 – Hourly outdoor and basement air temperatures for 2008/2009

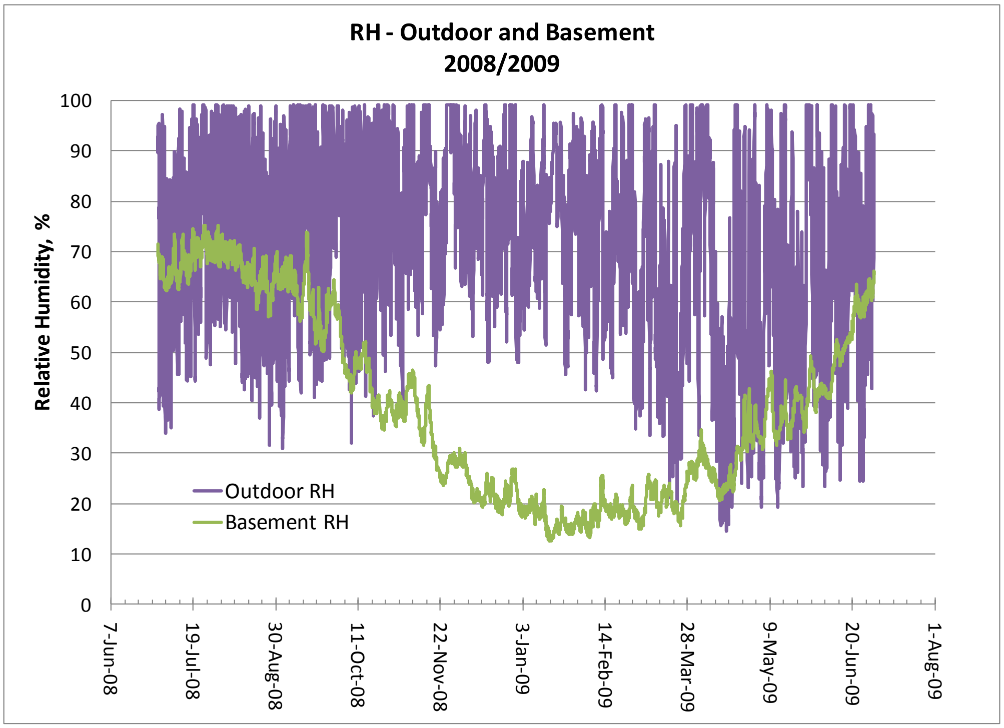

Figure 34 – Hourly outdoor and basement air relative humidity for 2008/2009

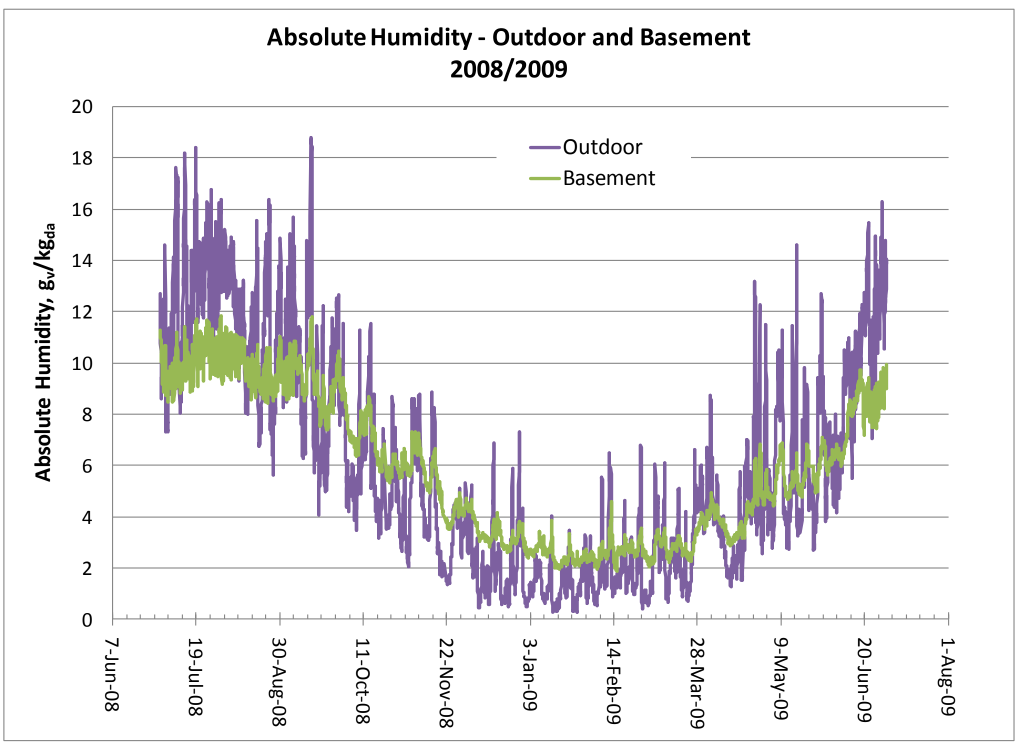

Figure 35 – Hourly outdoor and basement absolute humidity (in grams of water vapour per kg dry air) for 2008/2009

Hourly surface temperatures on the interior of the foundation wall, behind the insulation, are shown in Figure 36. The coldest locations have the greatest potential for condensation. In summer, the minimum measured temperature is at the base of the foundation wall (T155). Throughout fall, winter and spring, the minimum temperature is at the top of the foundation wall (T168). Temperatures may be lower at locations other than those measured. In winter, locations above ground level (higher up than the location of T168) or in the header area may be even colder.

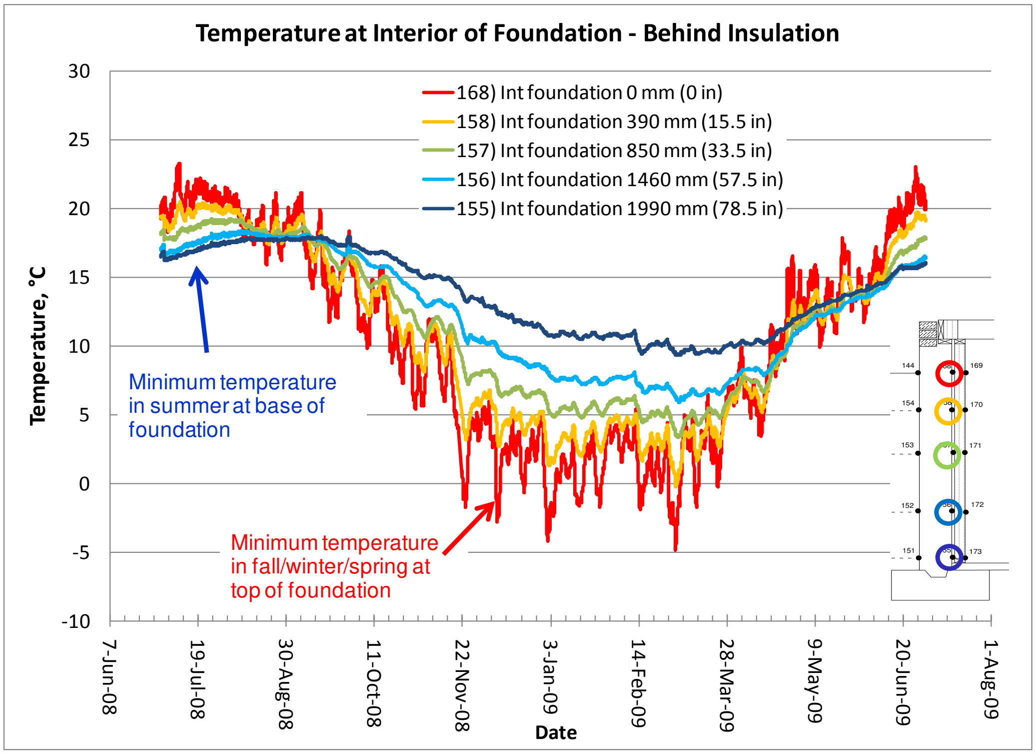

Figure 36 – Hourly surface temperatures at the interior of the foundation wall, behind the insulation

The coldest measured temperature on the foundation wall is plotted in multiple colours in Figure 37. The colours indicate the location where the coldest temperature occurs. Generally, this line follows the measured temperature at the base of the wall in summer (T155) and the top of the foundation wall in fall, winter and spring (T168). The calculated dew point temperature of the basement air (calculated from measured relative humidity and temperature) is plotted in black. When the minimum foundation temperature drops below the dew point temperature of basement air, there is the potential for condensation. The difference between these two temperatures is shown in Figure 38. A negative difference indicates that the minimum surface temperature is below the dew point temperature. This occurs rarely, for a total of 3.6 days during the 365 day period (~1.0%).

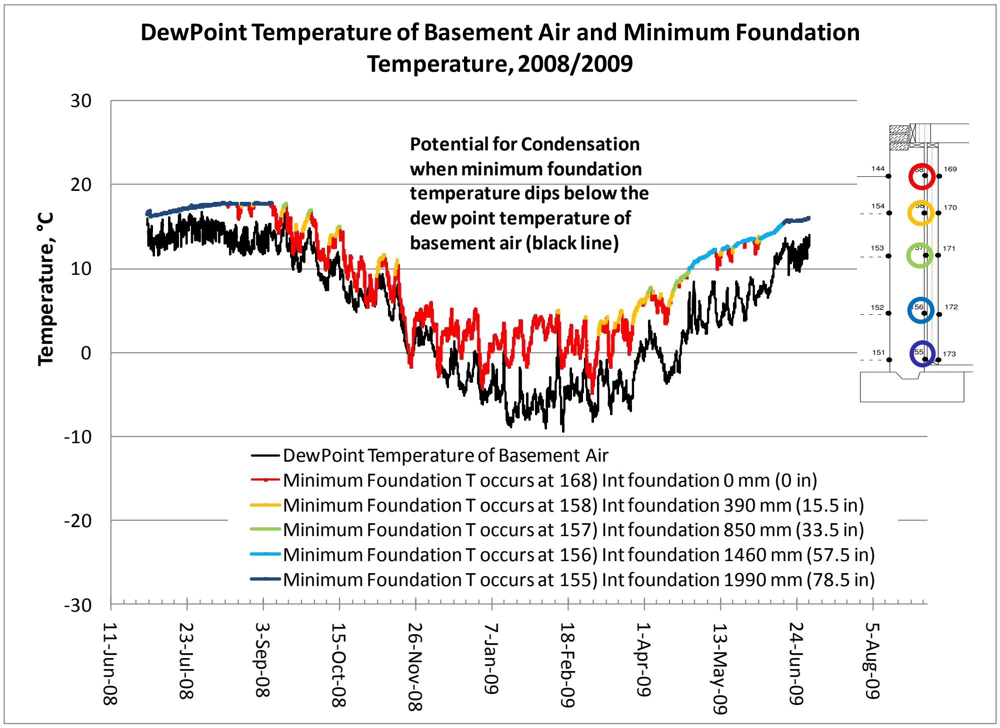

Figure 37 – Dew point temperature of basement air and minimum interior surface temperature of the foundation (behind the insulation), 2008/2009

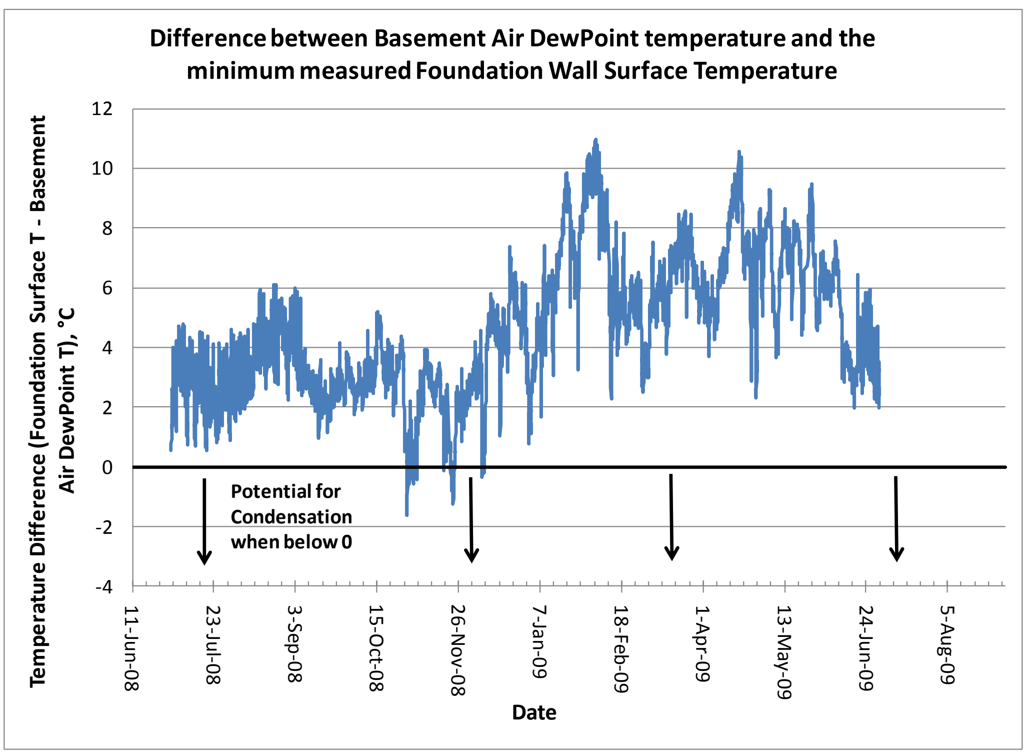

Figure 38 – Difference between basement air dew point temperature and the minimum measured foundation wall interior surface temperature (behind the insulation)

The research house was not humidified in winter, resulting in dry indoor conditions and low risk for condensation on the interior surface of the concrete foundation wall. However, as shown in Figure 39, the relative humidity of indoor air does not have to be very high in winter in order to have the potential for condensation on the interior of the basement foundation wall (behind the insulation). This figure shows the relative humidity of air at 21°C (the setting of a humidistat on the main floor of the home) that is likely to cause condensation at the coldest measured location on the basement foundation wall. This graph assumes the air from the main floor of the home is circulated to the basement, and could come into contact with the concrete surface of the basement foundation wall. Throughout the winter months, this threshold was mainly between 20 and 30% RH, dropping as low as 16%. This is below Health Canada's recommended indoor RH of 30%.

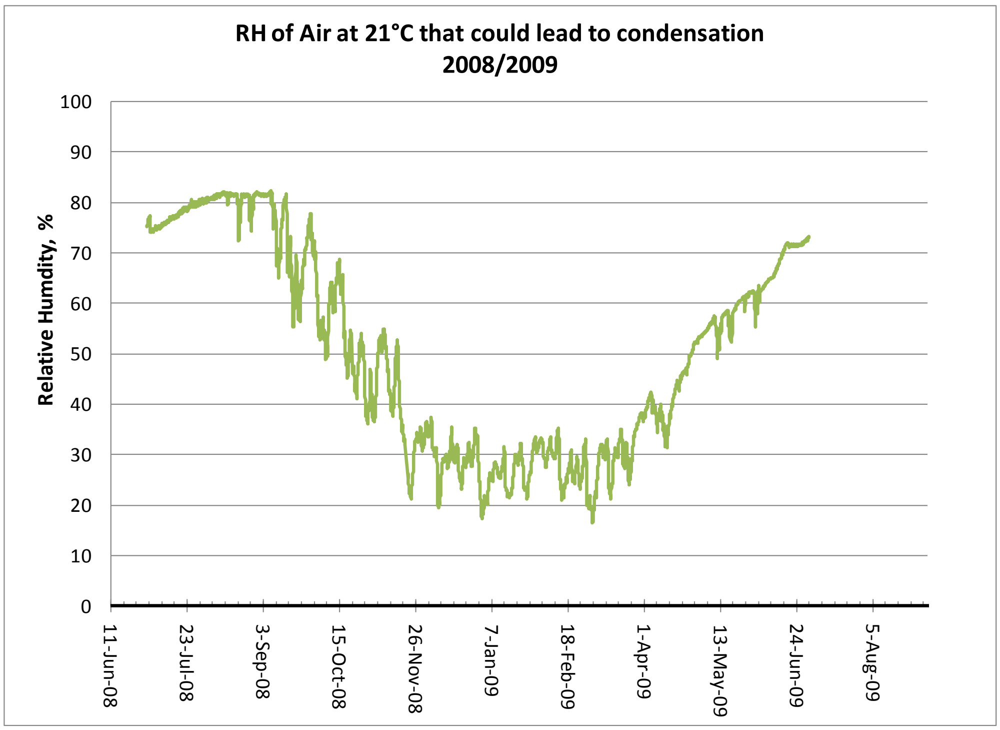

Figure 39 – Relative humidity of air at 21°C that could lead to condensation on the interior of the basement foundation wall (behind the insulation)

The calculated dew point temperature of the outdoor air is plotted in black alongside the minimum measured interior surface temperature of the foundation wall (behind the insulation) in Figure 40. The difference between the two curves is plotted in Figure 41. The minimum foundation temperature is below the dew point temperature of outdoor air ~45% of the summer, and ~8% of the time in the remaining months of the year (~17% of the analysis period in total). On these occasions, if the outdoor air entered the basement and came into contact with the surface of the foundation wall at the measurement location, there would be potential for condensation. For example, outdoor air could enter the basement through an open window, or could enter unconditioned through a ventilation system. In summer, the air conditioning system dehumidifies the air (moisture is removed as air conditioner condensate), lowering the dew point of interior air and reducing the potential for condensation.

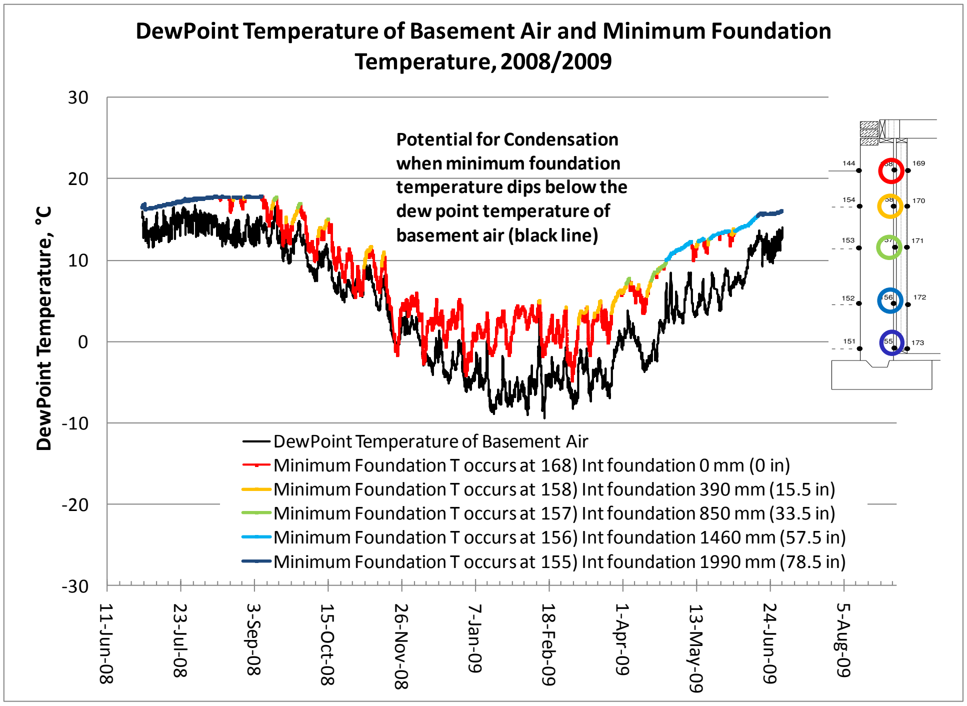

Figure 40 – Dew point temperature of outdoor air and minimum interior surface temperature of the foundation, 2008/2009

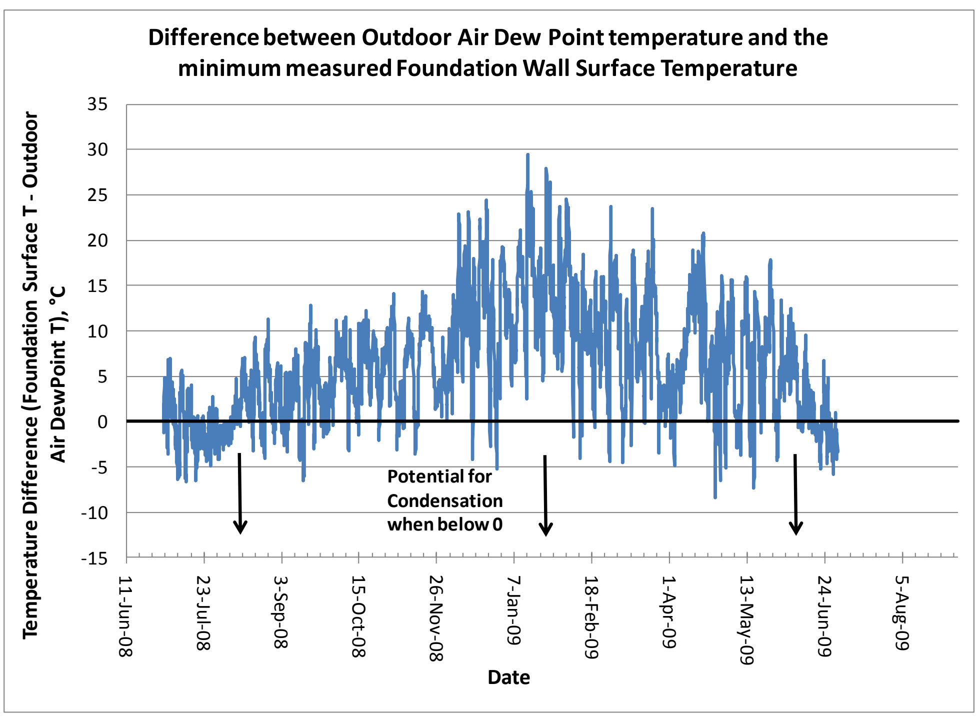

Figure 41 – Difference between the outdoor air dew point temperature and the minimum measured foundation wall interior surface temperature (behind the insulation)

5 Conclusions

The analysis of 7.5 years of foundation wall surface temperatures from the CCHT Reference House revealed strong correlations with outdoor temperature for all measured locations on the interior and exterior surface of the concrete foundation wall, and in the far ground.

Surface temperatures of the interior concrete foundation wall behind the insulation are highly dependent on outdoor temperature histories. At the top of the foundation (at ground level), surface temperature was shown to depend strongly on the average outdoor temperature from the past 3 days. At the base of the foundation, surface temperature was shown to depend strongly on the average outdoor temperature from the past 69 days. Also, due to the single-zone control of the central thermostat, on sunny days in spring, the main and second floor of the house may be warm enough to satisfy the central thermostat and shut off the heating system, while the basement surface temperatures may be at their coolest of the year. These combined factors could contribute to the basement being uncomfortably cool at this time of year.

The measured basement temperatures showed little discernable dependence on snow cover. For snow cover less than 60 cm, the impact was negligible compared to the relationship with outdoor temperature. While there is only ~30cm (1 ft) of exposed foundation, the brick façade may potentially add to the thermal fin effect of the concrete in the foundation – helping to draw heat out of the basement even when there is a large amount of snow cover. Since the main driving force for heat loss from the basement was shown to be outdoor temperature, snow cover appears to have negligible impact on heating loads in this type of home. Some impact on concrete surface temperature was seen for snow cover >60cm – where large amounts of snow cover were able to maintain foundation temperatures above freezing. However, there were few data points gathered over the past 7.5 years with high amounts of snow cover, so it is difficult to draw any meaningful trends from the data. Additionally, snow cover measurements were obtained from the Ottawa International Airport, and do not capture local effects such as drifting and melting near the foundation, so this analysis was inconclusive.

Outdoor and basement humidity levels were analyzed for a one year period from 01-Jul-08 to 30-Jun-09 to determine risk for condensation. The dew point temperature of the basement air exceeded the interior temperature of the concrete foundation wall, for 1% of the analysis period. These conditions favourable to condensation occurred primarily in autumn. However, conditions in the Reference House basement were generally very dry – due to lack of humidification in the winter, and the removal of humidity by the air conditioning system in summer. In the winter, the relative humidity threshold for condensation of 21°C air on the foundation surface was predominantly in the range of 20-30%, below Health Canada's recommended indoor RH of 30%. The threshold may be even lower at locations where surface temperatures were not measured, such as the header area or the corners of the foundation where heat loss is usually greater. This suggests that commonly maintained humidity levels could result in condensation on the interior of the foundation wall in this type of wall assembly.

Outdoor humidity levels were generally higher than basement humidity levels in the summer months. If the outdoor air entered the basement – for example through an open window – and came in contact with the foundation wall behind the insulation at the coldest point, condensation could potentially occur. Conditions were favourable for outdoor air to condense on the interior surface of the foundation wall behind the insulation ~17% of the time in the one year condensation analysis period.

In the Reference House basement wall assembly, the interior surface temperature of the concrete was of the greatest interest, due to the lack of air/vapour barrier and the air space between the stud wall assembly and the concrete wall. This construction does not prevent basement air from circulating in the wall assembly and for moist air to potentially come into contact with the cold concrete surface. While the experimental Reference House basement wall assembly has performed without any observed condensation problems through the period of analysis, the house is not humidified in winter, and runs air conditioning continuously throughout the summer – leading to dryer conditions than would be typically found in a home. The lack of air/vapour barrier could lead to moisture issues in homes with only a slightly more humid indoor environment – well within the operating humidity levels recommended by CMHC. The condensation analysis highlights the need for a continuous air/vapour barrier on the interior of the basement insulation – to prevent humid air from reaching cold foundation wall surfaces. With a proper air/vapour barrier on the interior finished wall surface to prevent interior moisture from getting in contact with the concrete, the cold temperatures of the concrete wall would not be a concern. In this situation, the interior surface temperatures of the finished wall would be the determining factor for potential for condensation.

The CCHT basement configuration features RSI-3.4 (R-19) insulation on the interior of the concrete foundation wall. Different amounts of insulation would result in different temperature profiles. Insulating on the exterior of the foundation wall should result in warmer concrete surface temperatures, depending on the detailing at grade, and thus reduce the potential for condensation. Similarly, different depths of basements would also result in different temperature profiles. The basement in this study only featured approximately 1 foot of exposed foundation above grade. Surface temperatures in a shallower basement or a basement with more exposure above grade would likely follow outdoor conditions even more closely – cooling more rapidly in winter, and heating more rapidly in summer.

The results from this study are for a single thermostat setting, 21°C in winter. Different operating conditions would likely result in different basement surface temperatures, and different potential for condensation.

While this report highlights the potential for cold basement wall surfaces to lead to condensation, this is only one of many causes of basement moisture-related issues. Other sources of moisture can include leaking windows, cracks in the foundation, improper grading of soil around the basement, and poor drainage system design (CMHC, 2008).

6 References

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Appendix A. Relationship with Outdoor Temperature

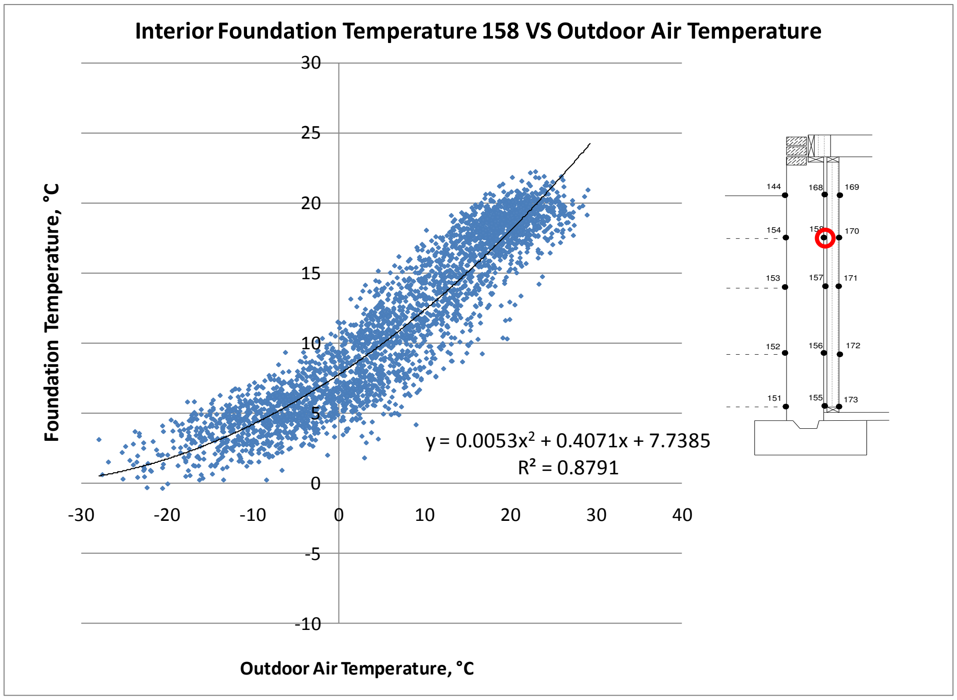

Figure A-1 - Relationship between average daily foundation surface temperature T158 and average daily outdoor air temperature

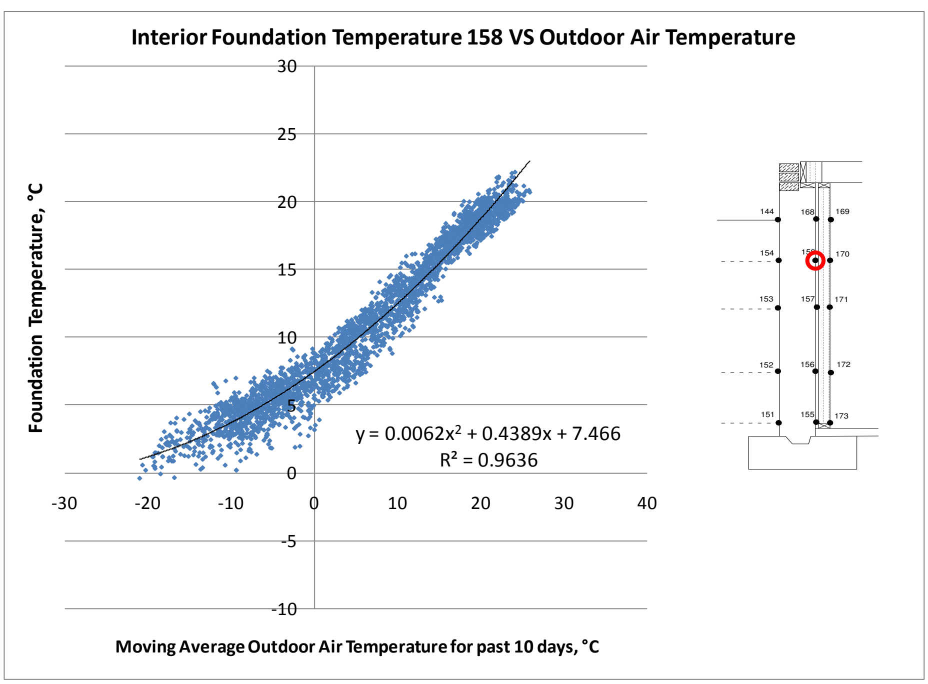

Figure A-2 - Relationship between average daily foundation surface temperature T158 and moving 10 day average of outdoor air temperature

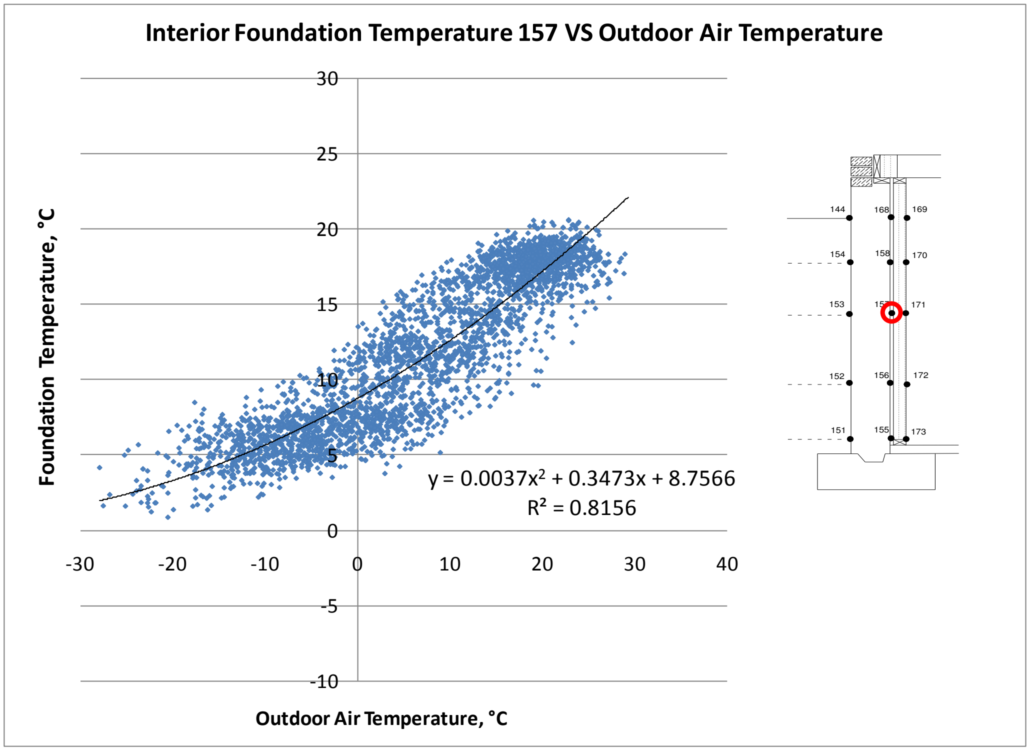

Figure A-3 - Relationship between average daily foundation surface temperature T157 and average daily outdoor air temperature

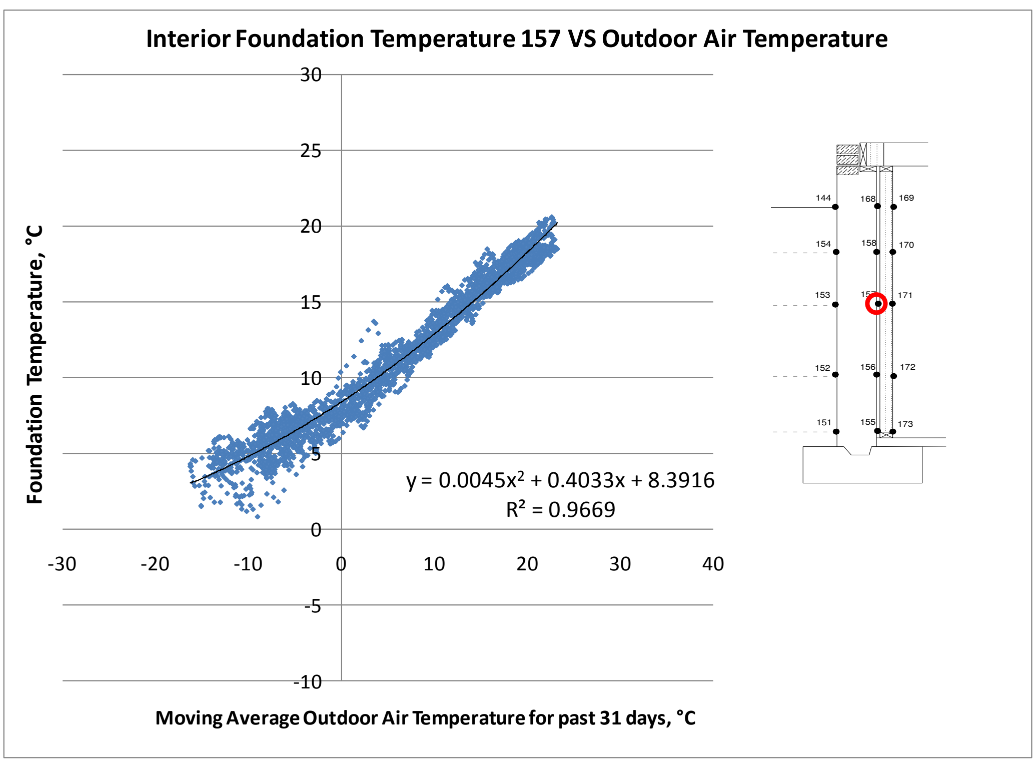

Figure A-4 - Relationship between average daily foundation surface temperature T157 and moving 31 day average of outdoor air temperature

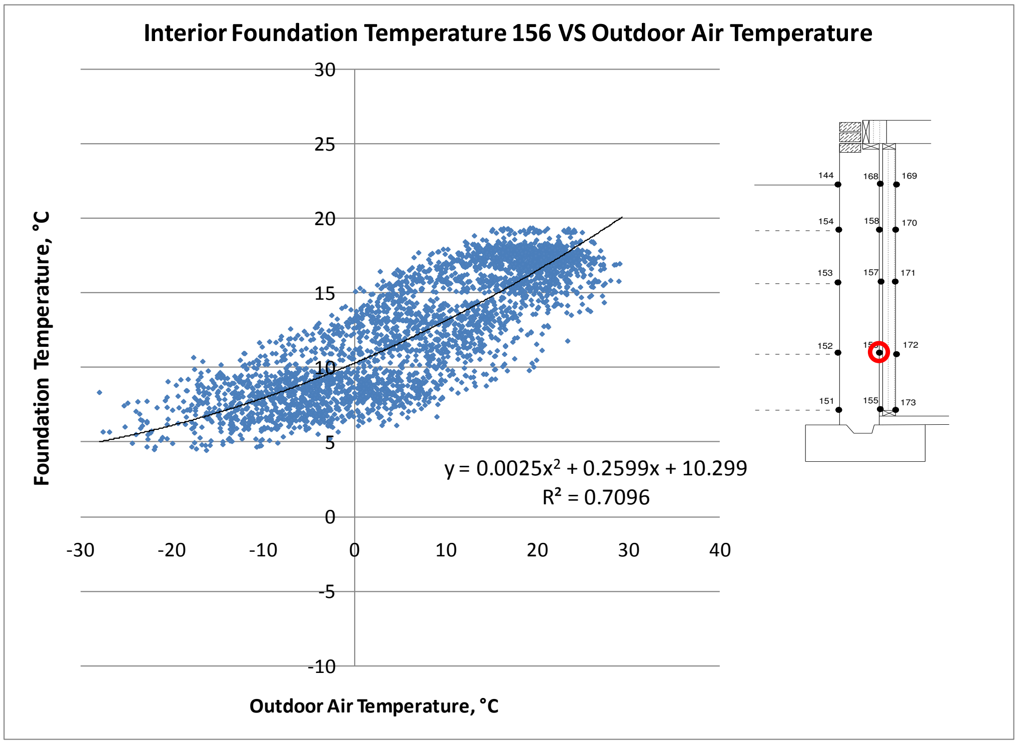

Figure A-5 - Relationship between average daily foundation surface temperature T156 and average daily outdoor air temperature

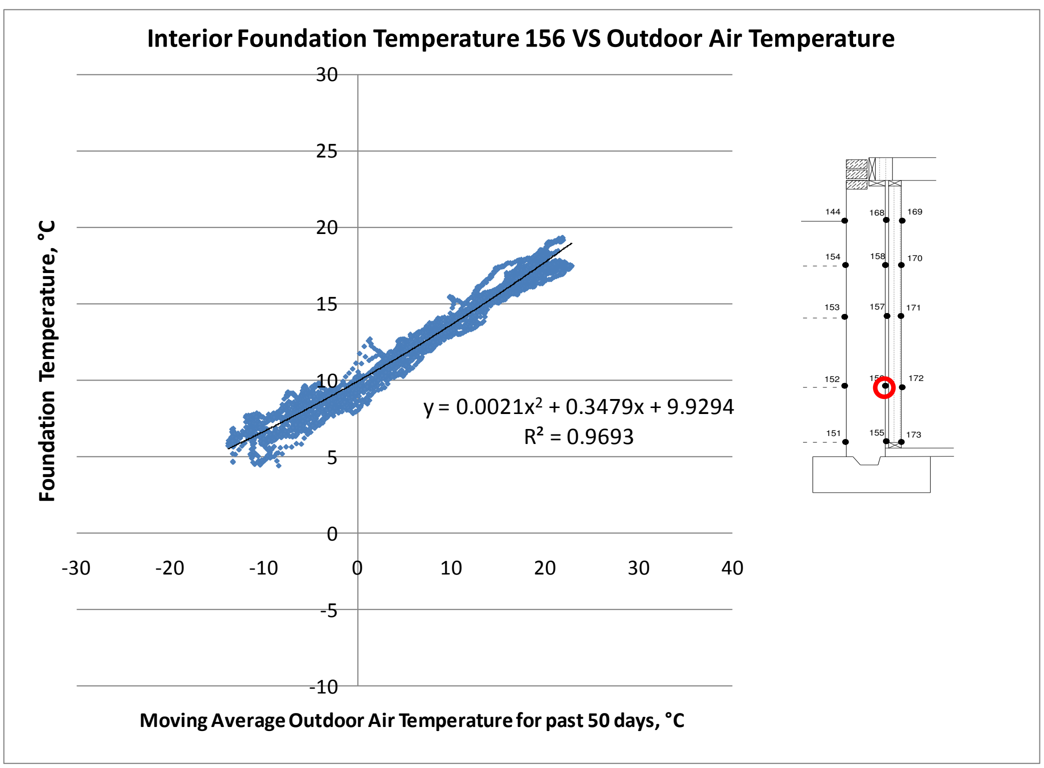

Figure A-6 - Relationship between average daily foundation surface temperature T156 and moving 50day average of outdoor air temperature

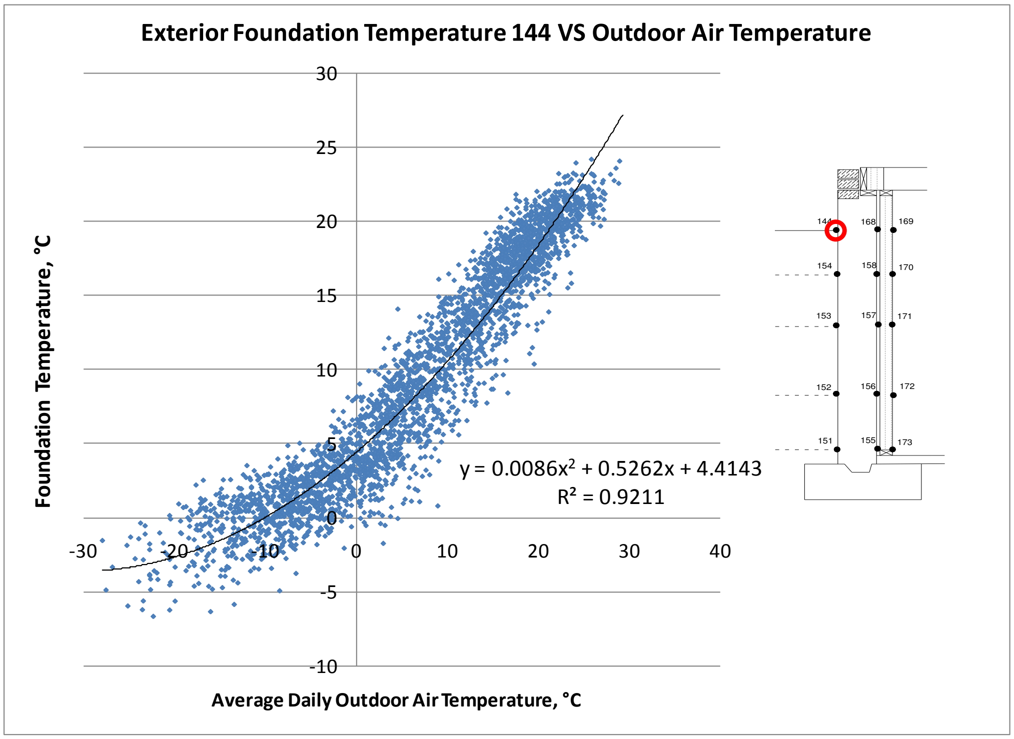

Figure A-7 - Relationship between average daily foundation surface temperature T144 and average daily outdoor air temperature

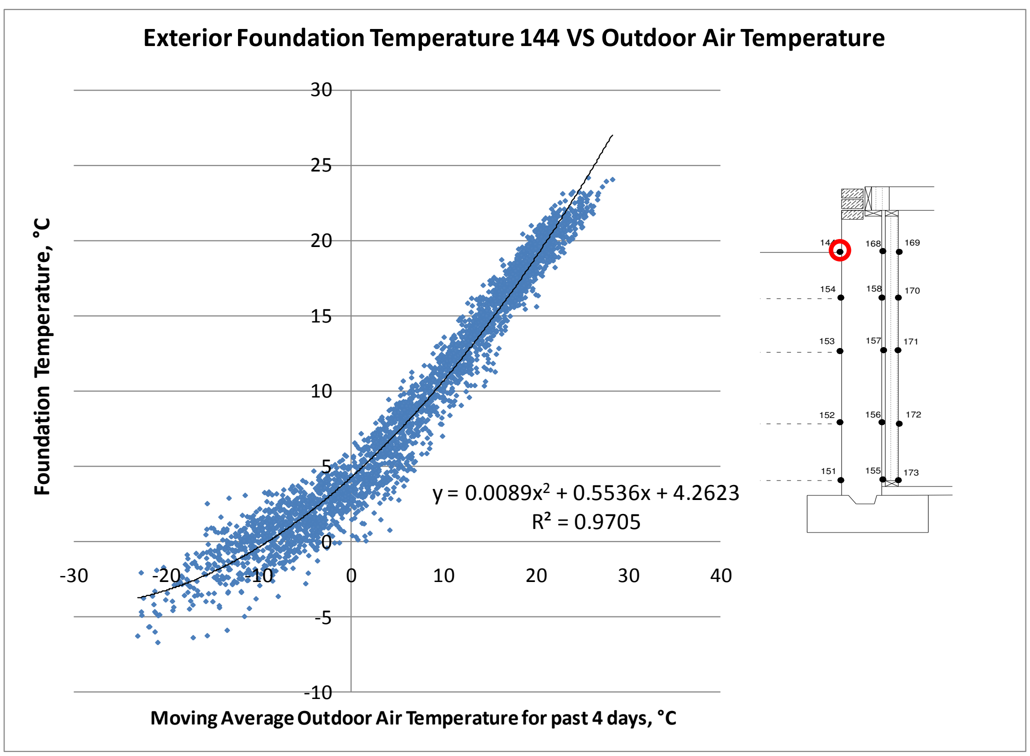

Figure A-8 - Relationship between average daily foundation surface temperature T144 and moving 4 day average of outdoor air temperature

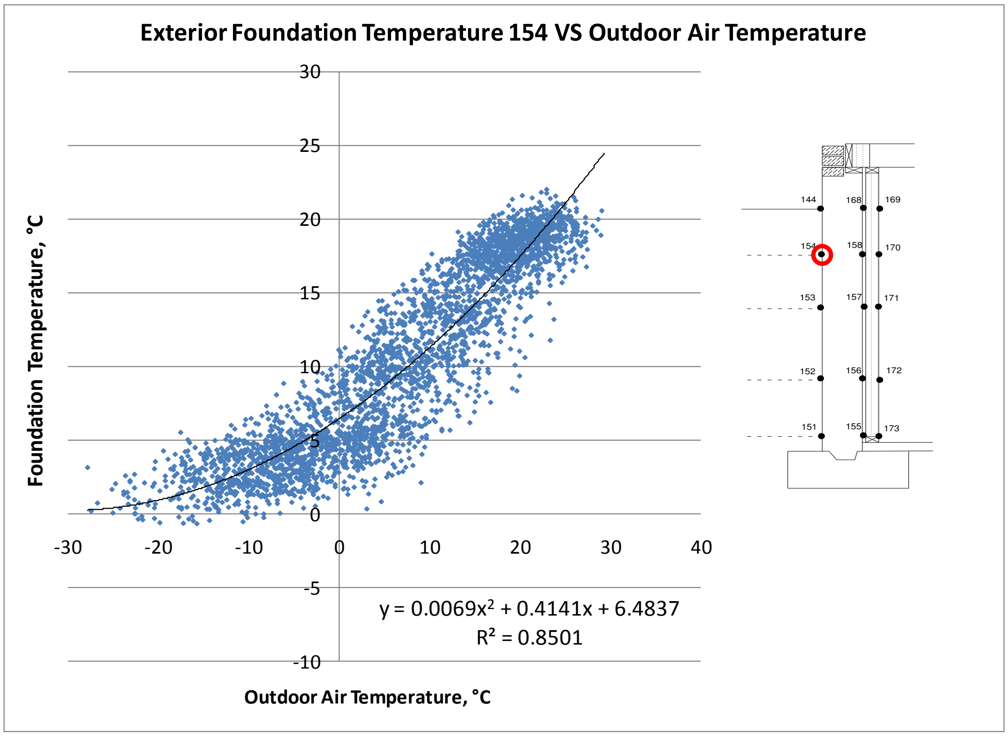

Figure A-9 - Relationship between average daily foundation surface temperature T154 and average daily outdoor air temperature

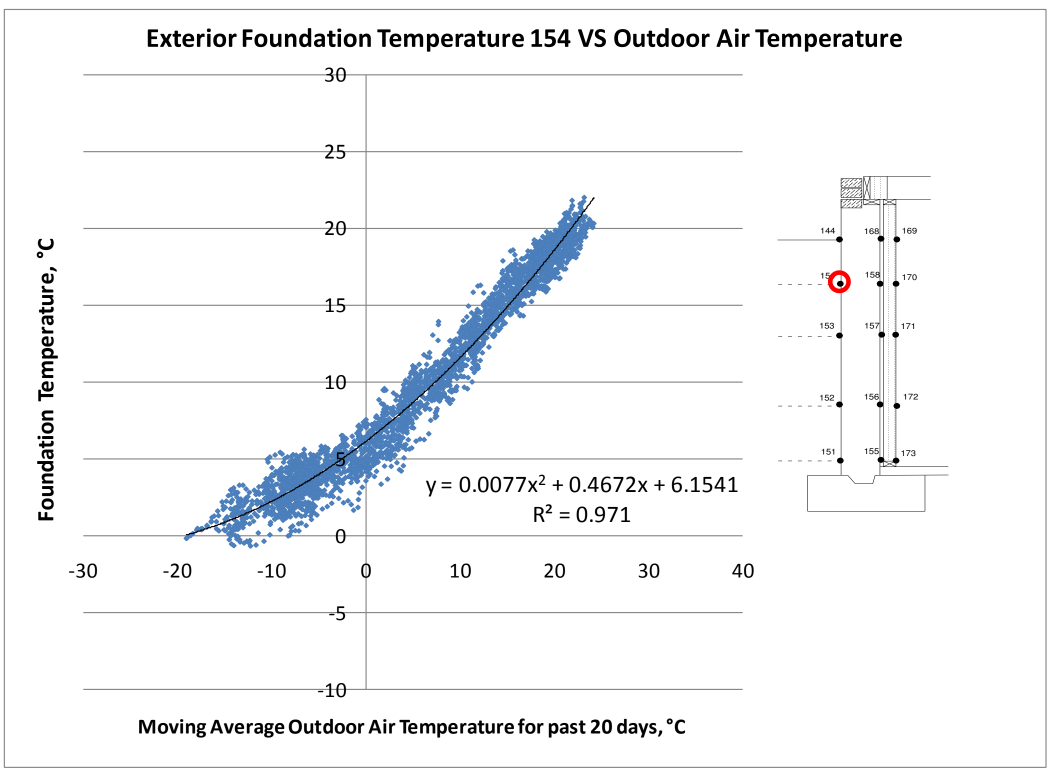

Figure A-10 - Relationship between average daily foundation surface temperature T154 and moving 20 day average of outdoor air temperature

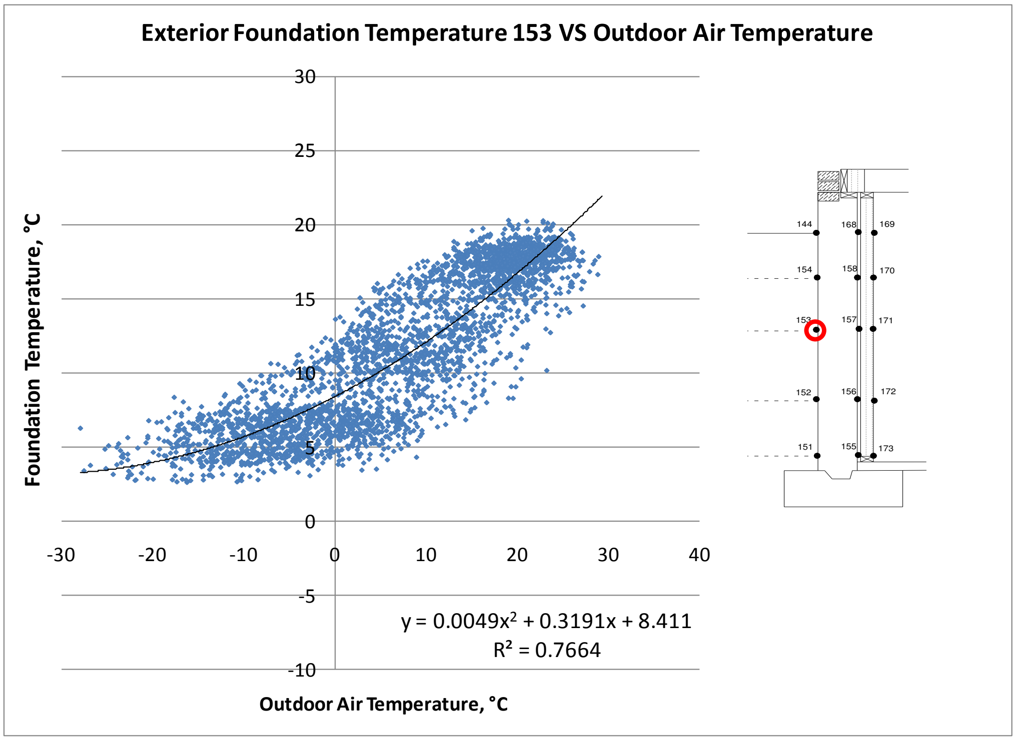

Figure A-11 - Relationship between average daily foundation surface temperature T153 and average daily outdoor air temperature

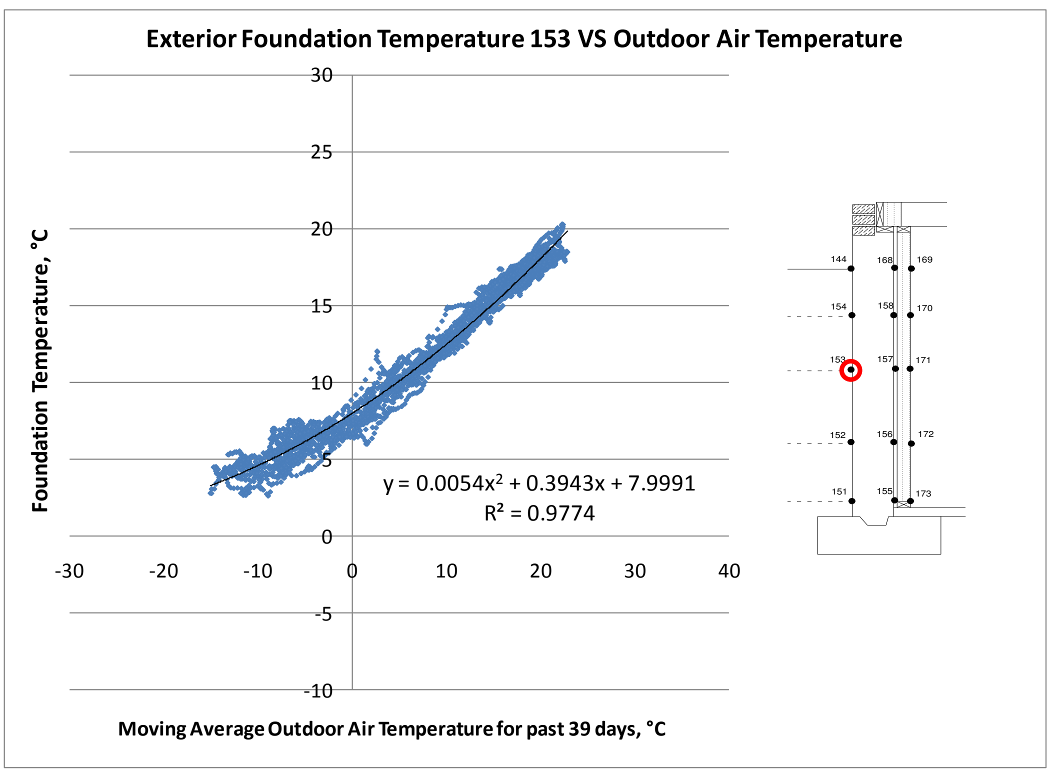

Figure A-12 - Relationship between average daily foundation surface temperature T153 and moving 39 day average of outdoor air temperature

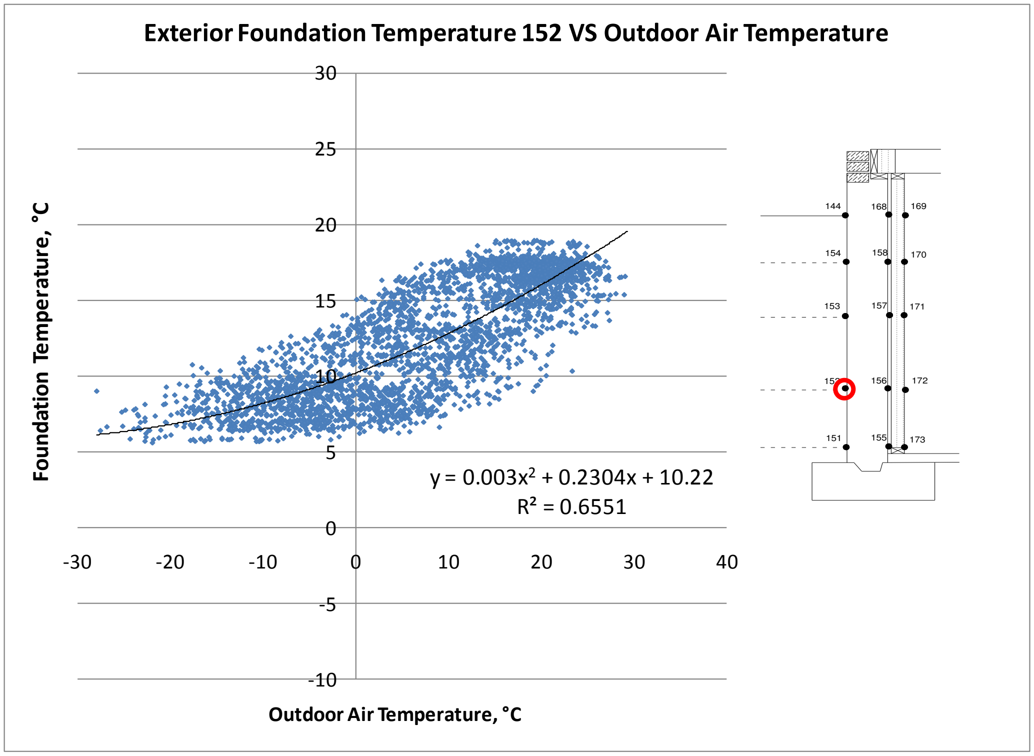

Figure A-13 - Relationship between average daily foundation surface temperature T152 and average daily outdoor air temperature

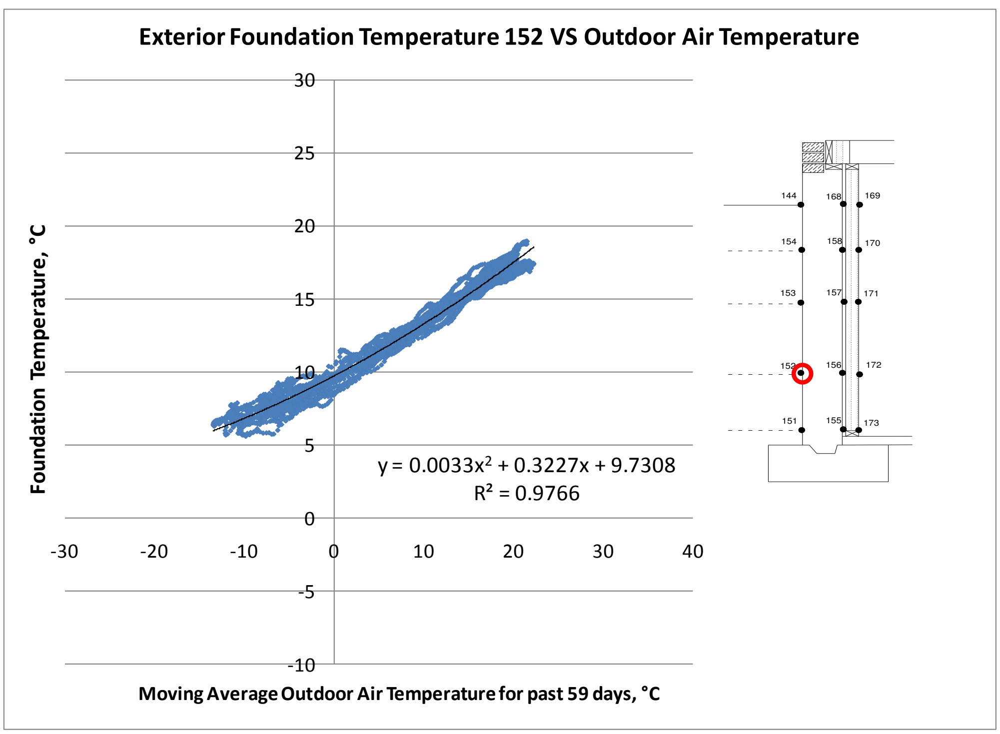

Figure A-14 - Relationship between average daily foundation surface temperature T152 and moving 59 day average of outdoor air temperature

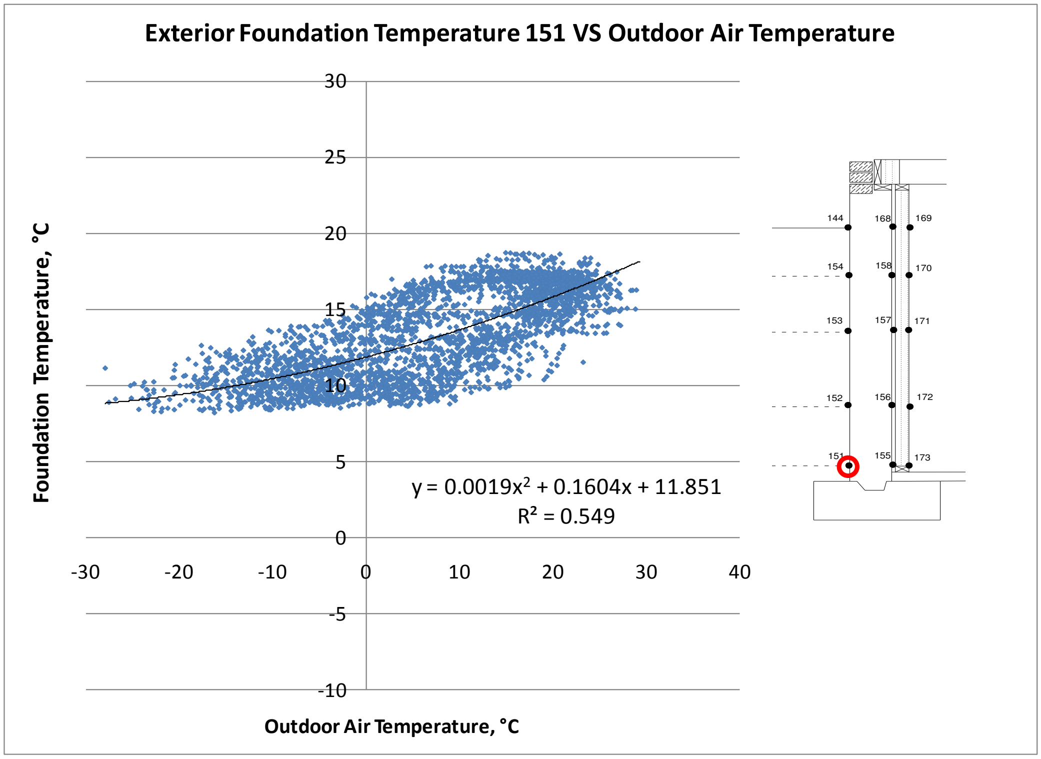

Figure A-15 - Relationship between average daily foundation surface temperature T151 and average daily outdoor air temperature

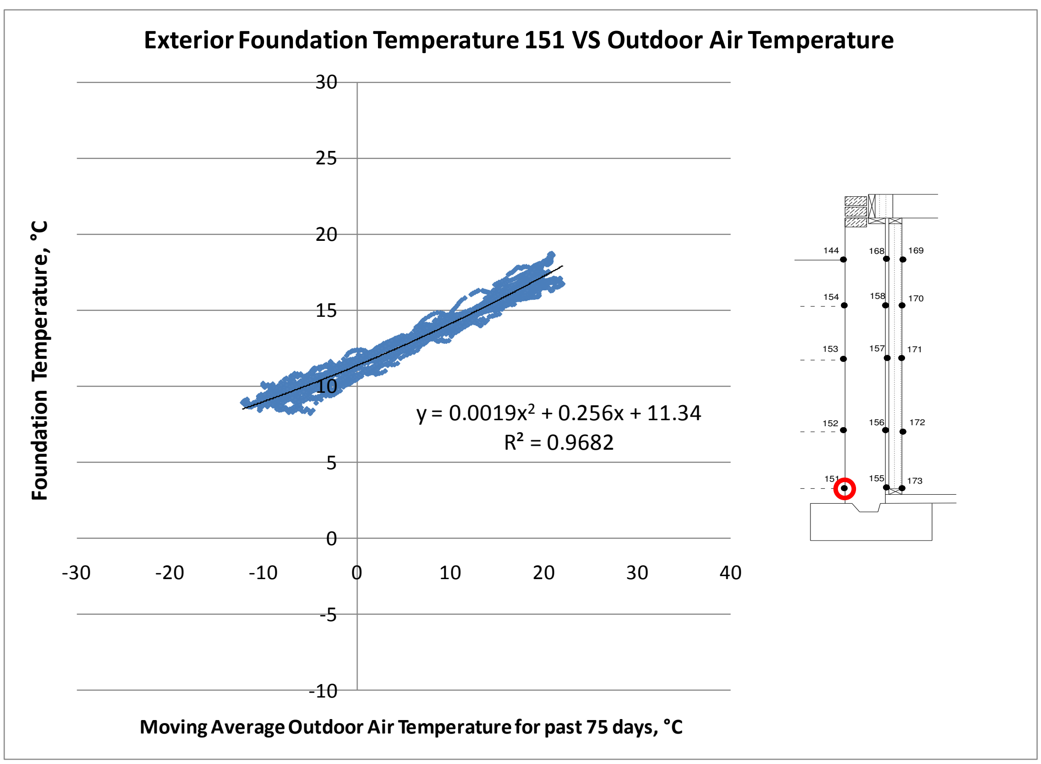

Figure A-16 - Relationship between average daily foundation surface temperature T151 and moving 75 day average of outdoor air temperature

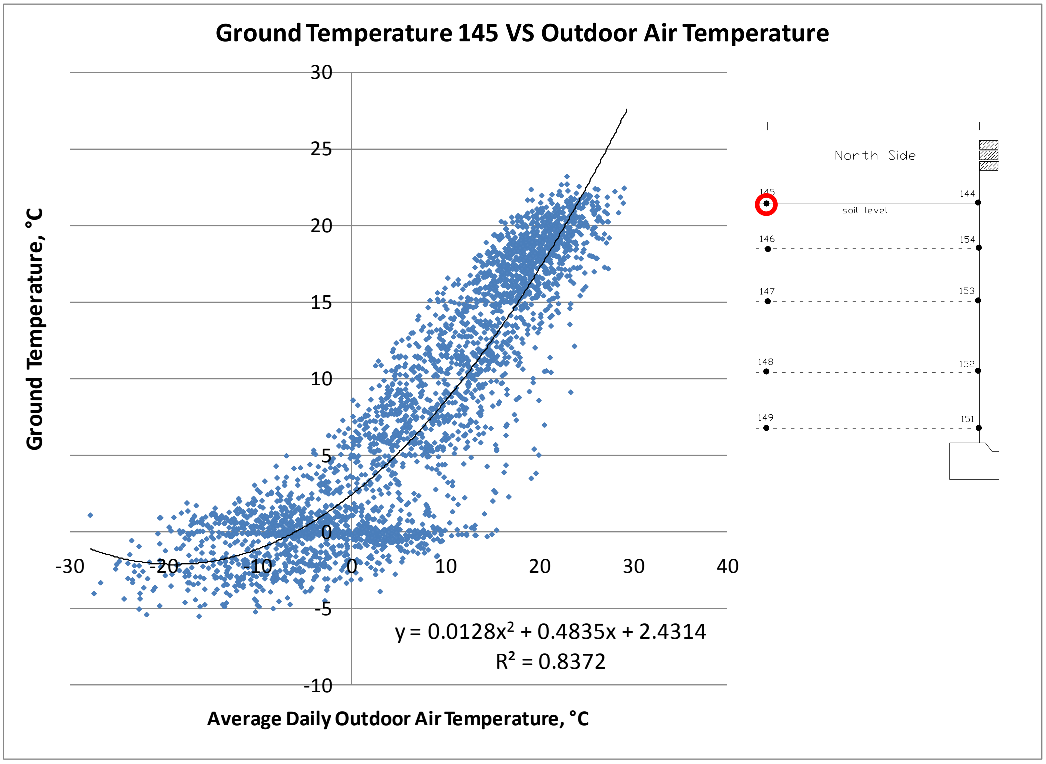

Figure A-17 - Relationship between average daily foundation surface temperature T145 and average daily outdoor air temperature

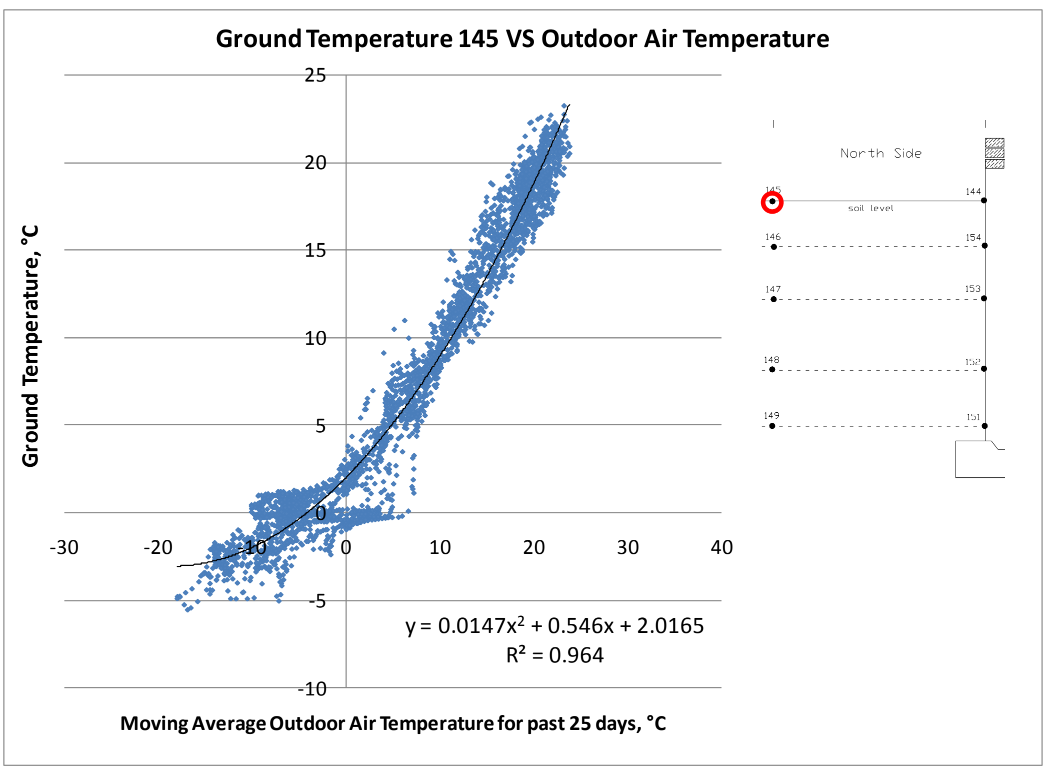

Figure A-18 - Relationship between average daily foundation surface temperature T145 and moving 25 day average of outdoor air temperature

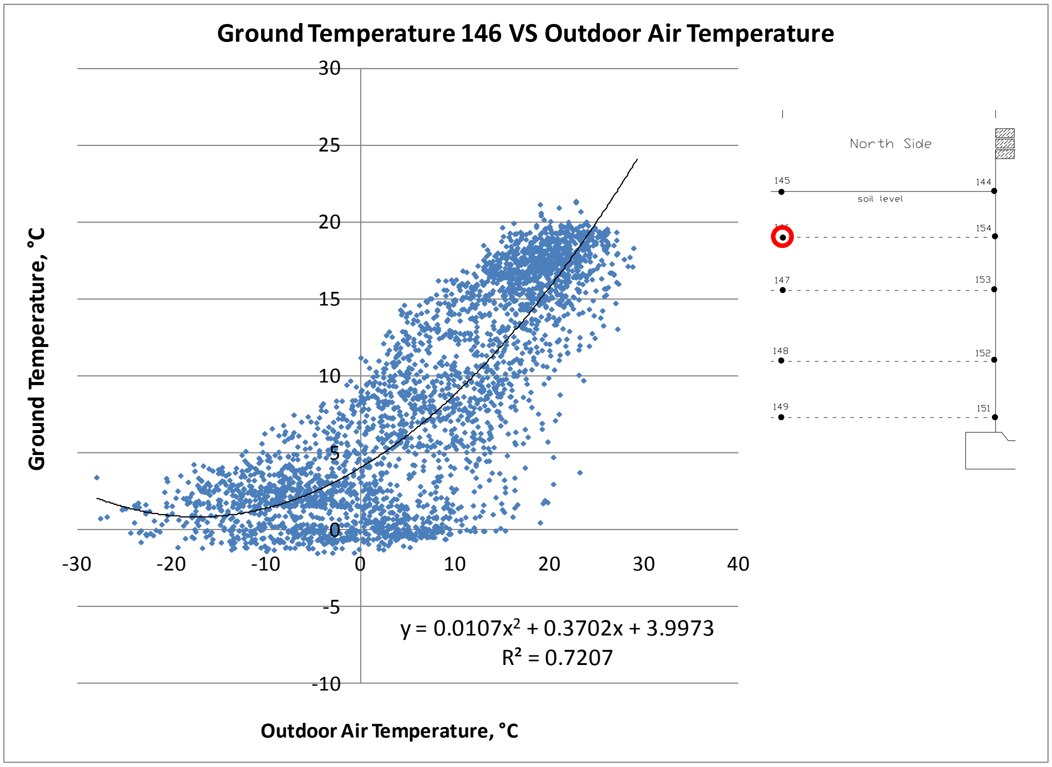

Figure A-19 - Relationship between average daily foundation surface temperature T146 and average daily outdoor air temperature

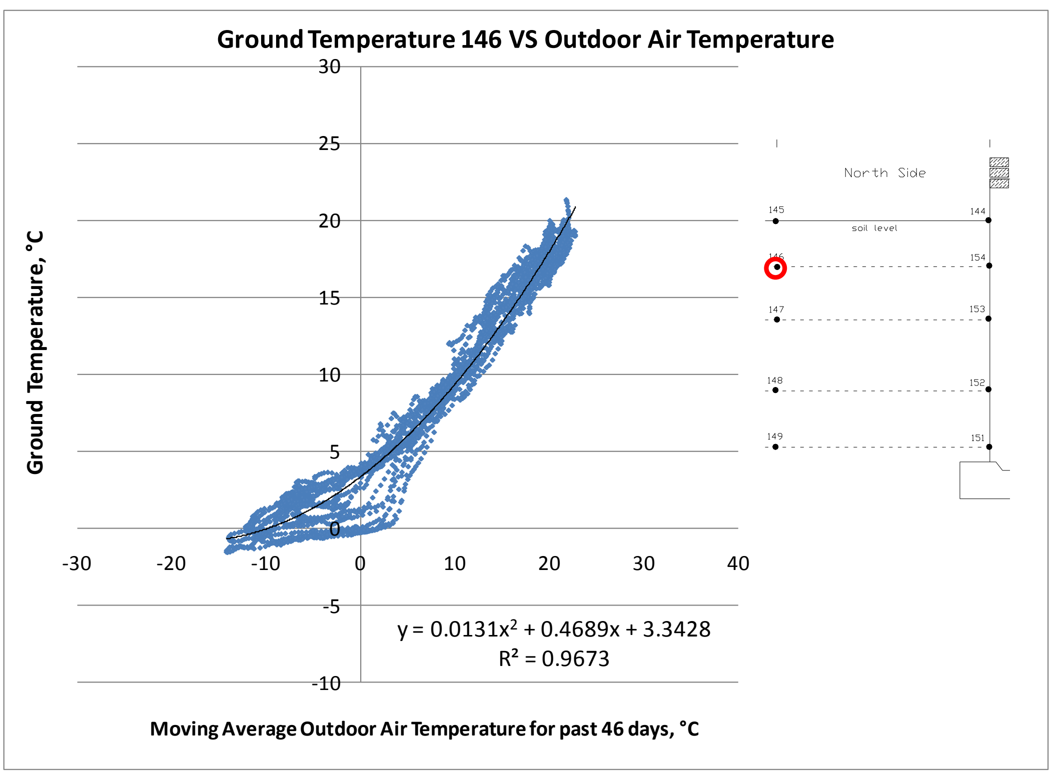

Figure A-20 - Relationship between average daily foundation surface temperature T146 and moving 46 day average of outdoor air temperature

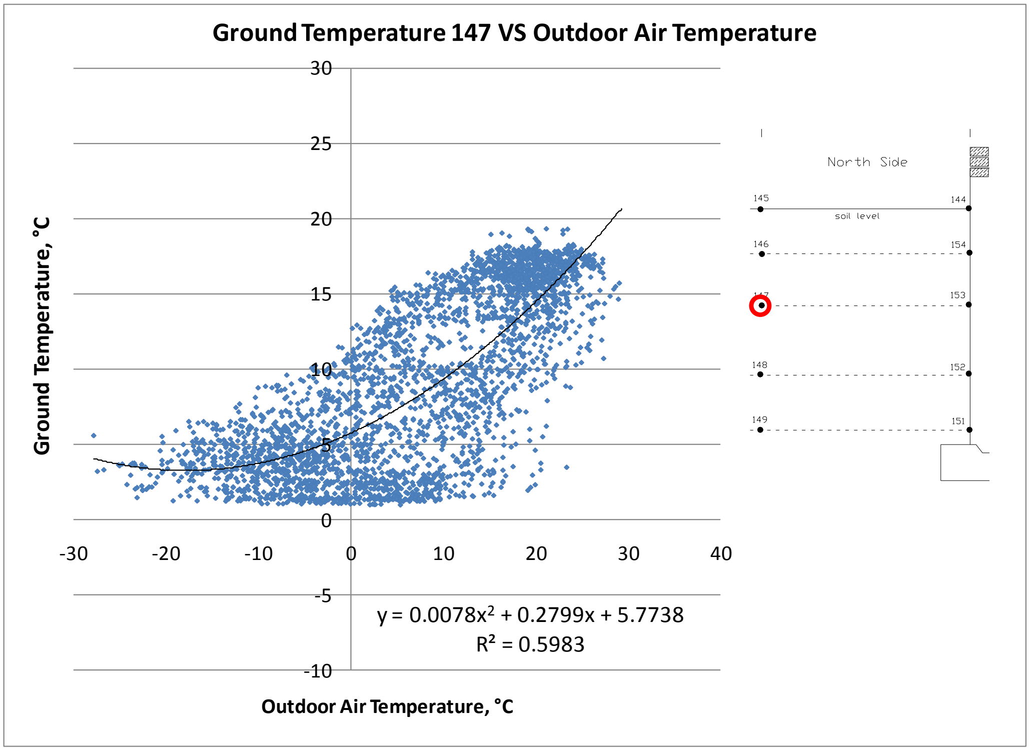

Figure A-21 - Relationship between average daily foundation surface temperature T147 and average daily outdoor air temperature

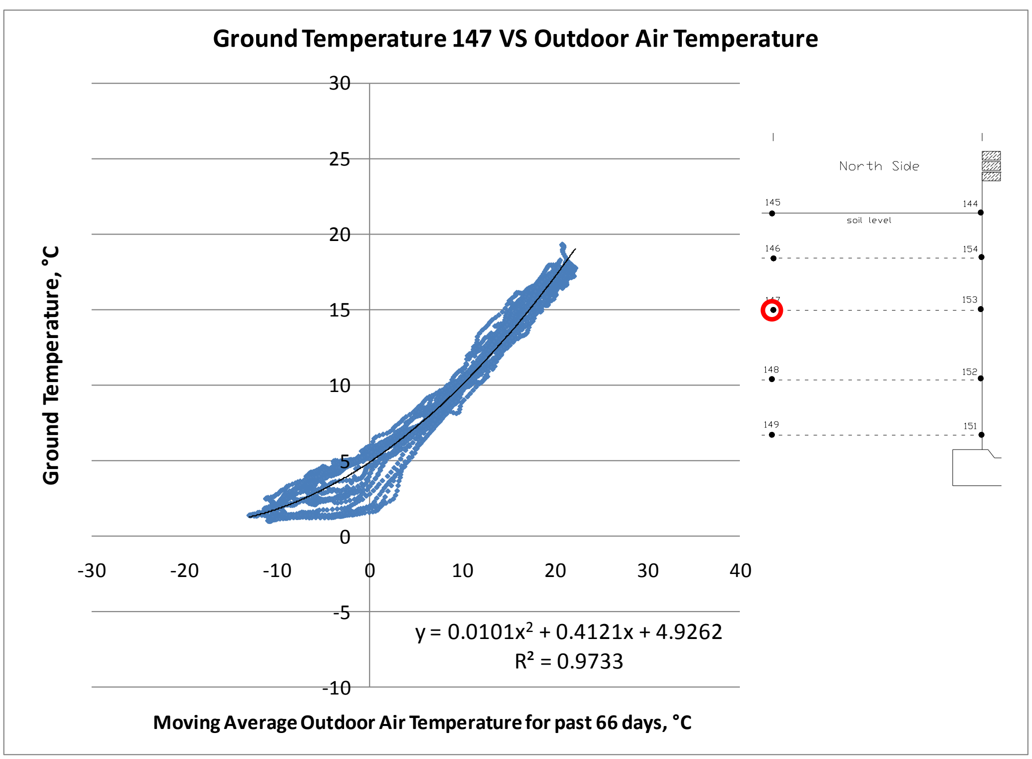

Figure A-22 - Relationship between average daily foundation surface temperature T147 and moving 66 day average of outdoor air temperature

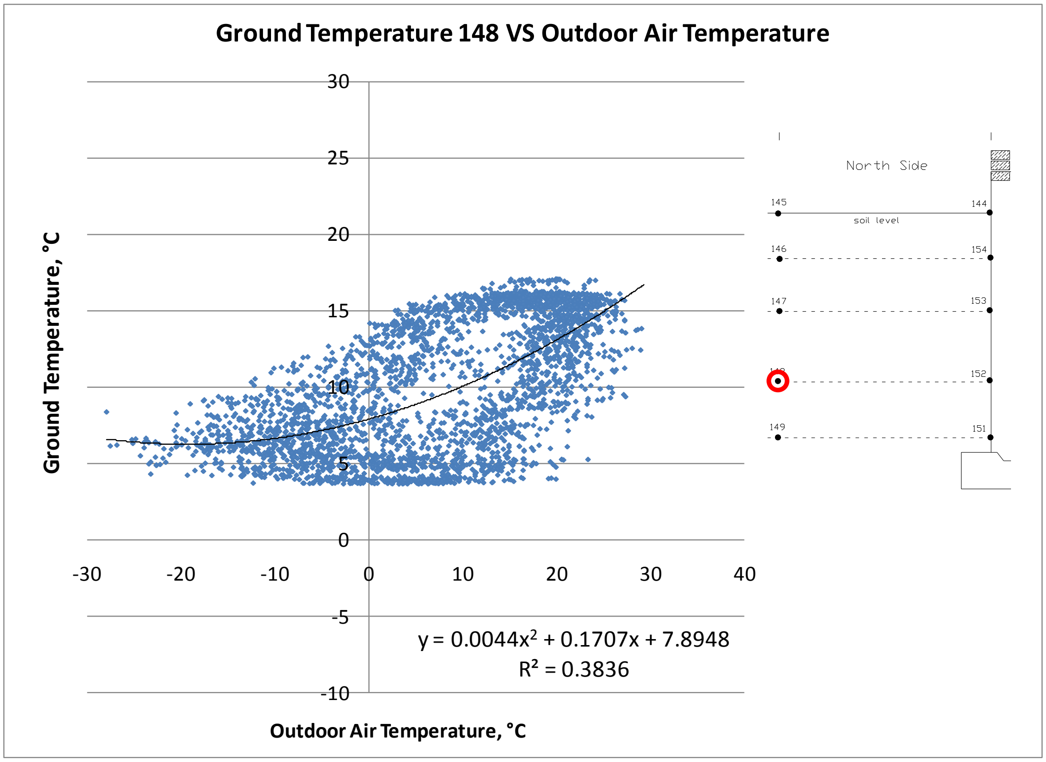

Figure A-23 - Relationship between average daily foundation surface temperature T148 and average daily outdoor air temperature

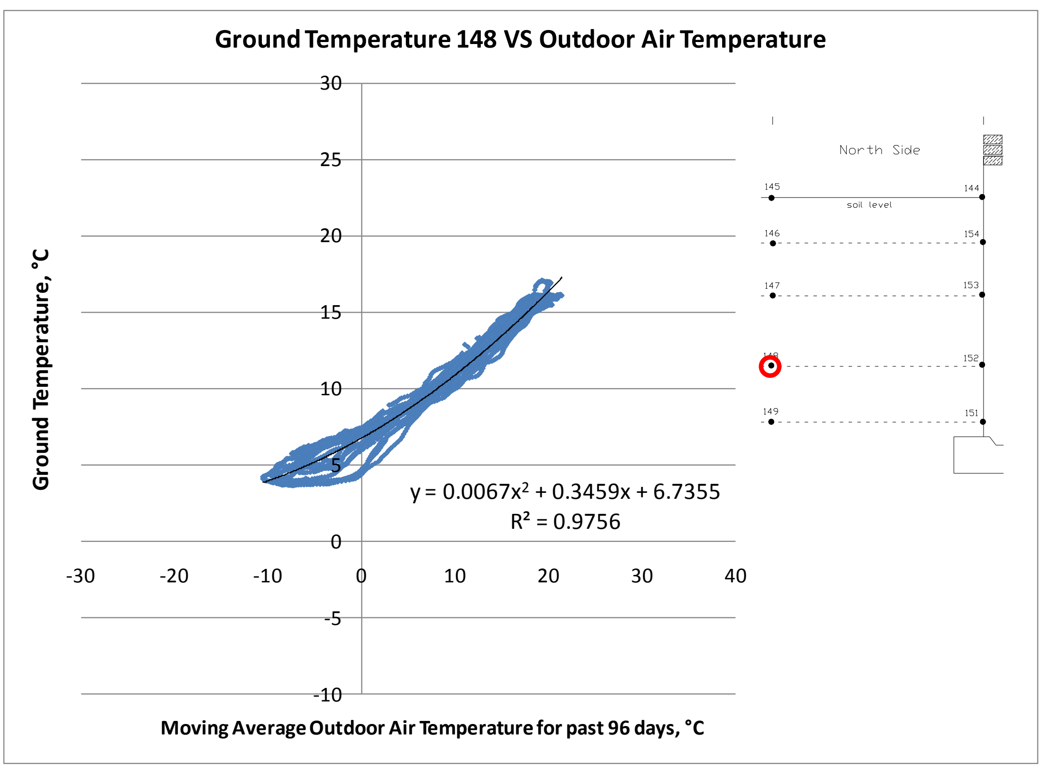

Figure A-24 - Relationship between average daily foundation surface temperature T148 and moving 96 day average of outdoor air temperature

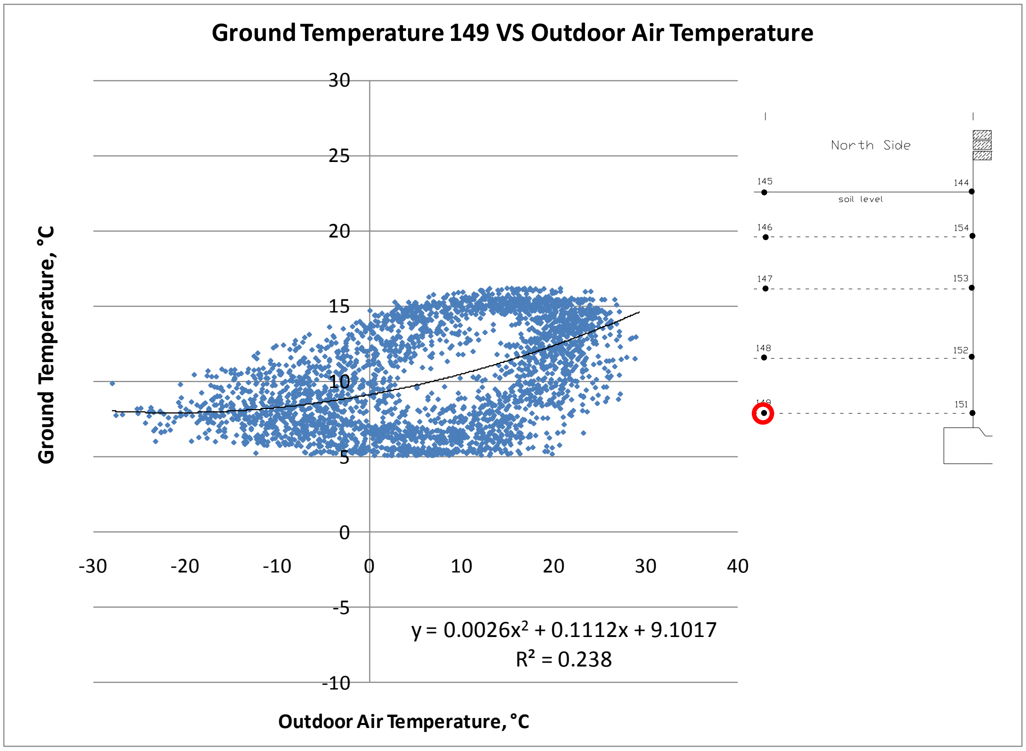

Figure A-25 - Relationship between average daily foundation surface temperature T149 and average daily outdoor air temperature

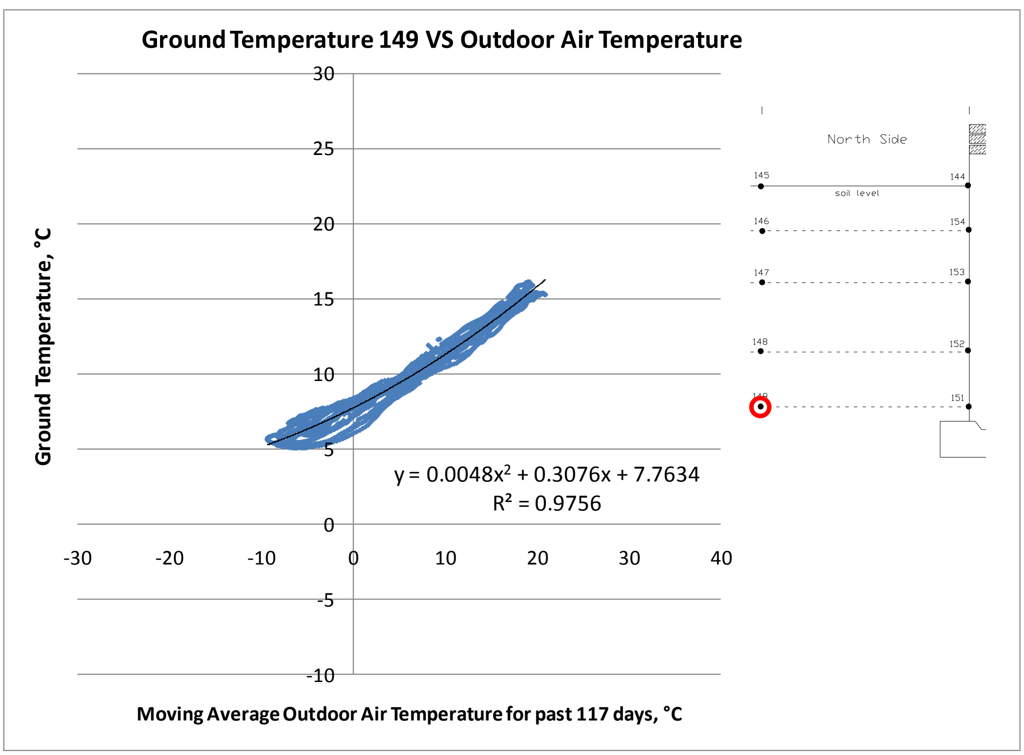

Figure A-26 - Relationship between average daily foundation surface temperature T149 and moving 117 day average of outdoor air temperature