



2010.07.26

Dan Clayton
Polyurethane Foam Systems Inc.
440 Conestogo Road
Waterloo, Ontario, N2L 4E2

Via email: dclayton@on.aibn.com

Re: Final Report

**Field Investigation of Heating Energy Consumption of Test Huts Insulated with
Spray Foam and Fiberglass Batt**

Mr. Clayton,

BSCI designed and constructed a pair of identical test huts on the outskirts of Waterloo, Ontario Canada to allow the comparison of real-world heating energy performance when different insulation types are used. One of the two identical huts was insulated with fiberglass batt insulation and the other with closed cell spray polyurethane foam (Polarfoam Soya) with the same target R-value. The heating energy consumption of the two huts over the winter has been collected and analyzed. The purpose of this report is to provide a summary documentation of the construction details, to present and analyse the infrared imaging, and to record the analysis of the heating energy use of the two huts.

The data used for this report was from February and March 2010. The 2009/2010 winter was warmer than normal and the testing did not commence until after the coldest parts of winter had occurred. The limited data analyzed in this report shows clear heating energy savings if SPUF insulation of the same R-value as fiberglass batt is used, even if the buildings have the same airtightness. Long-term data could provide continued evidence of the savings and comparison in colder periods could provide evidence of a larger difference in energy performance. It is not clear what the reasons for the reduced heating energy requirements are: numerous mechanisms and reasons are possible, but none could be proven definitively given the data available.

Please feel free to contact me if you have any questions or would like to discuss this report.

Thanks,

A handwritten signature in black ink, appearing to read 'A. Grin'.

Aaron Grin M.A.Sc., P.Eng.

A handwritten signature in black ink, appearing to read 'John Straube'.

Dr. John Straube Ph.D., P.Eng.

Building Science Consulting
167 Lexington Court, Unit 5
Waterloo ON, N2J 4R9
phone: 519.342.4731

PFSI TWO HUT FIELD EXPOSURE COMPARISON

Final Report

July 26, 2010

Prepared for Polyurethane Foam Systems Inc.
440 Conestogo Road
Waterloo, Ontario, N2L 4E2

Prepared by



Building Science Consulting Inc.

167 Lexington Court, Unit 5
Waterloo, Ontario
Canada N2J 4R9

www.buildingscience.com

Introduction

This report documents a field study of the heating energy consumption of two structurally identical huts exposed to real Waterloo winter weather conditions

The purpose of the comparison is to determine the difference in space-heating energy consumption between two structurally identical huts exposed to real winter weather conditions. One hut is insulated with fiberglass batt and air-sealed with polyethylene sheet, and one is insulated with Polarfoam Soya 2.0 pcf Spray Polyurethane Foam (SPUF). The insulation levels were both the minimum required by the 2009 Ontario Building Code (OBC Part 9). Both huts are located in an exposed field on Berlett's Road outside of Waterloo, Ontario. The huts were positioned offset and far enough apart that one will not affect the solar or wind influences on the other.

Design and Specifications

The huts were designed to represent normal wood-frame housing construction practices in Ontario. Each building has a roughly rectangular plan shape encompassing 92 square feet of interior space and a ceiling height of 8 feet. The huts are raised on a wood frame to a height of 3 feet above the surrounding grade to ensure full exposure of the floor to the weather. Framing is 2x6 at 16" on centre, with double top plates and single bottom plates. The roof is a ventilated gable style at an 8:12 pitch. There is a door on the south side and windows on the north and west sides. The north window is an operable casement window and the west-facing window is fixed. All windows are OBC compliant double-glazed Low-E units. The walls were insulated to nominal R19 and the floors were insulated to R28 with either fiberglass batt or SPURF insulation. The ceilings of both huts were insulated with blown cellulose insulation to R40 through a gable access.

To ensure that the huts were built in accordance with standard construction practices a local builder was chosen to construct the huts. Way-Mar Incorporated was chosen in conjunction with PFSI during the planning stages of the project. Figures 1 and 2 were submitted to Way-Mar as construction drawings.

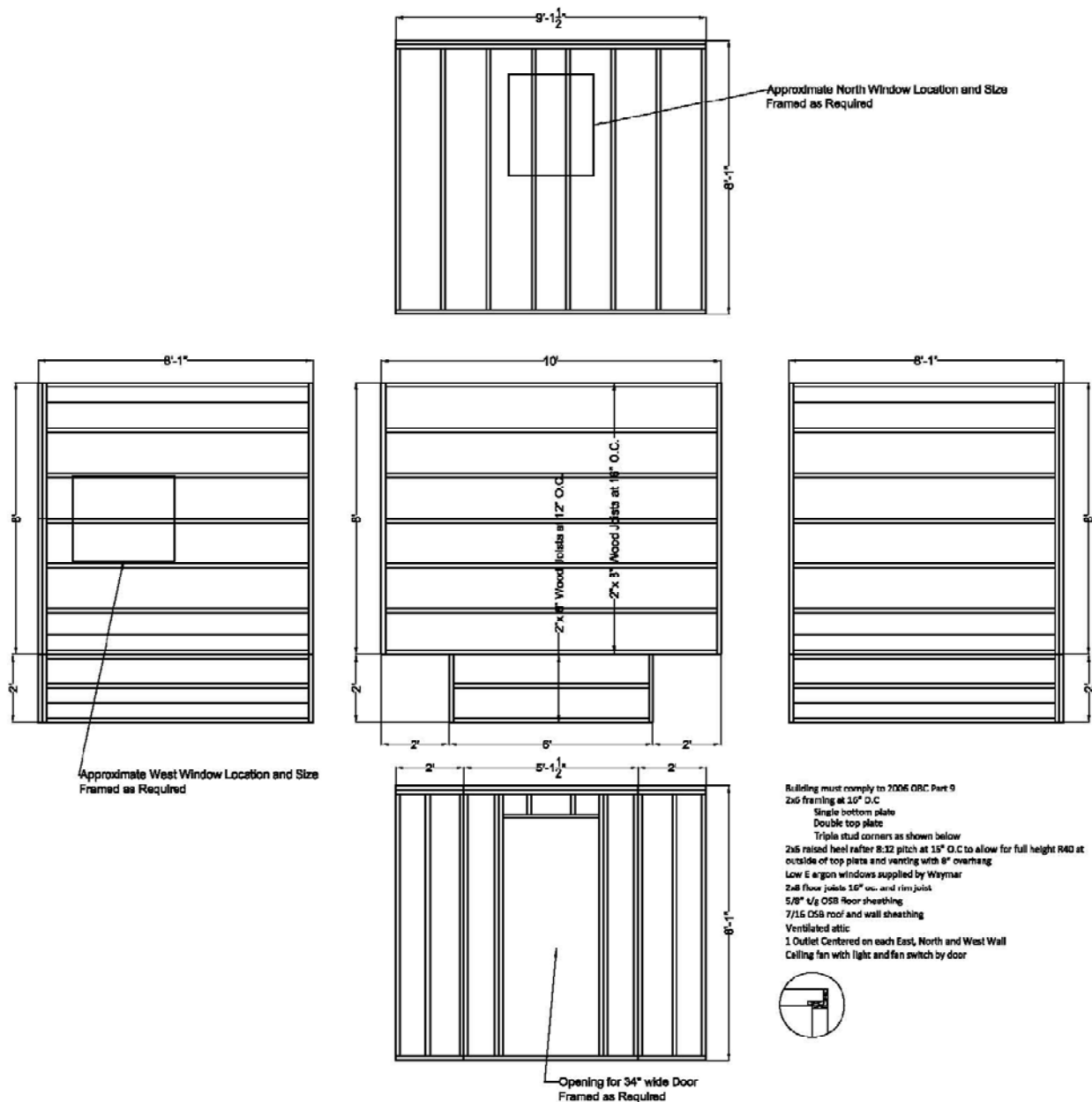


Figure 1 - Wall and Floor Framing Plan

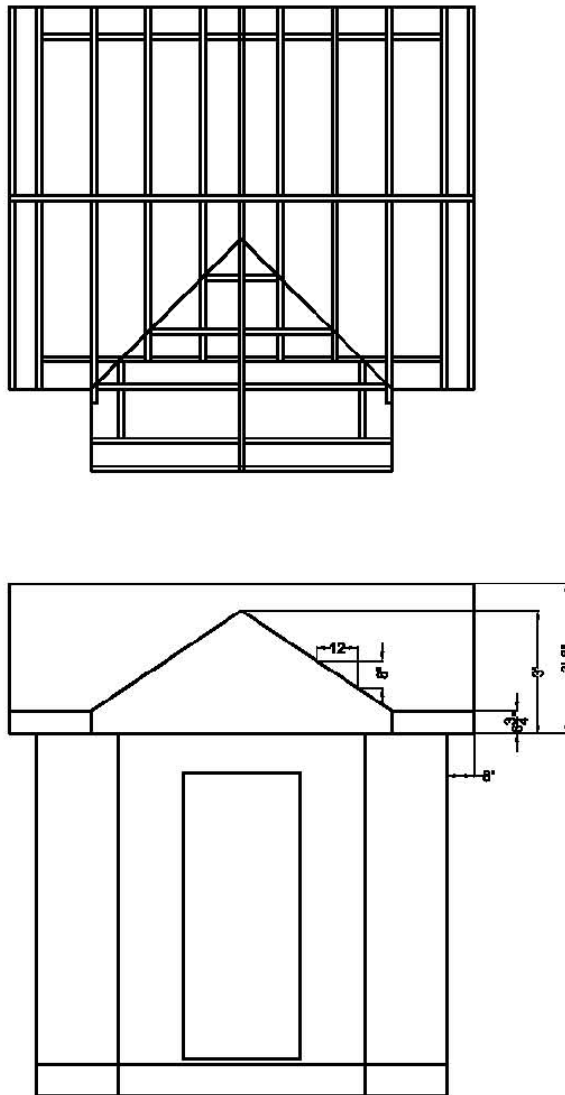


Figure 2 - Roof Framing Plan

Construction and Instrumentation

A detailed Construction and Instrumentation report was submitted on March 1st, 2010. Refer to this report for further information.

The two huts were constructed in an exposed field on Berlett's Road outside of Waterloo, Ontario. The location is mapped in Figure 3 below.

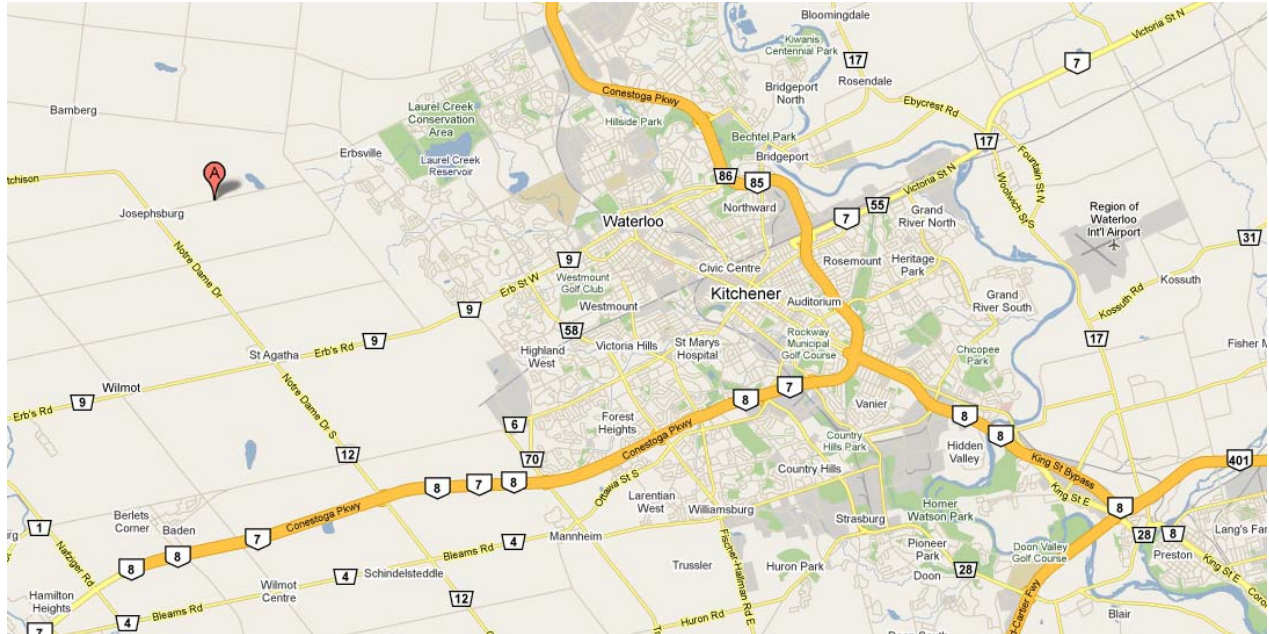


Figure 3 - Location of Testing Site

The electrical supply for the huts was trenched in December 2009, and construction of the panelized wall construction began in the Way-Mar warehouse on January 16th, 2010. The walls were completely framed and sheathed then loaded onto a trailer for transport to the site. Panelized walls were used to simplify construction and limit the amount of time outdoors for the labourers. The construction process was as follows:

- The level gravel pads were placed and the raised wood platforms were built by BSC staff.
- Southerly orientation of the bases was verified with a compass.
- Floors were sheathed onsite
- Walls were placed and fastened
- Roofs were framed then sheathed and shingled
- Tyvek was applied
- Windows and doors were installed
- Siding and soffit were then applied
- Fiberglass insulation was installed in the west hut
- SPURF insulation was installed in the east hut
- OSB was installed beneath the floors
- Drywall was installed, taped and mudded.
- Primer, paint and trim were installed over the next week.
- The installation of the data acquisition system was completed on February 23rd

Figure 4 through Figure 9 show a summary of photos in chronological order through the construction of the two huts. Where possible, photos of the two huts are shown side by side for comparison.



Figure 4 - East and West Hut Raised Base Orientation Verification



Figure 5 - East and West Hut Floor Framing and Sheathing



Figure 6 - East and West Hut Completed Floors and Walls



Figure 7 - East and West Hut 2-Stud Corners



Figure 8 - East and West Hut West Facing Window Framing



Figure 9 - Two Huts with Siding Complete (seen from South)

Data Acquisition System

The interior temperature of the huts is measured by two precision NTC thermistors (accurate to ± 0.2 C) and recorded by a Campbell Scientific CR500 data logger. The data logger compares the interior temperature to the 21°C set point and controls a relay to turn on an electric heater when required. The air within the hut is constantly mixed by a ceiling fan to ensure a uniform temperature throughout the space. An on-site weather station monitors outdoor climatic conditions.

To monitor the energy use the main power is monitored with an EKM¹ Model EKM-15IDS-N power meter (accurate to 2%) and the total used is stored by the data logger at one hour intervals. The EKM also has its own totaling function which can be used for comparison and backup. Monitoring the main power line to the huts allows the energy input to the heater, fan, lights and data acquisition system to be included in the total measured energy input. Figure 10 shows the data collection and control systems for each of the huts.

¹ www.ekmmetering.com - Model EKM-15IDS-N V.2



Figure 10 - East and West Hut Data Acquisition Systems

Infrared Imaging

Infrared photography was used to visually determine any differences in the thermal signatures of the two buildings. The air temperature on the morning of March 30th, 2010 was -4°C and conditions were optimal for photography. A Flir B50 infrared camera (specification details in appendix A) was used to collect the following images. Thermal images of the interior of the building did not reveal any significant differences in huts. Images of the exterior did show differences. The exterior surfaces between the framing members on the ccSPF appear in the images to be colder than the fiberglass hut. It appears as though the thermal bridging is more prominent on the ccSPF hut. Analysis shows that the stud locations are slightly warmer (0.5°C to 0.7°C) on the ccSPF hut and the bay locations have very similar temperatures to the fiberglass hut. This was seen on all orientations of the huts.

The warmer studs in the ccSPF walls are likely due to the fact that the stud space insulation in the ccSPF hut only fills approximately ½ of the depth of the stud bay. This leaves a larger surface area of the stud exposed to essentially the indoor environment at room temperature. Because there is more surface area exposed to room temperature there is slightly more energy loss through the studs. Computer heat flow analysis (described latter in this report) confirmed this hypothesis.

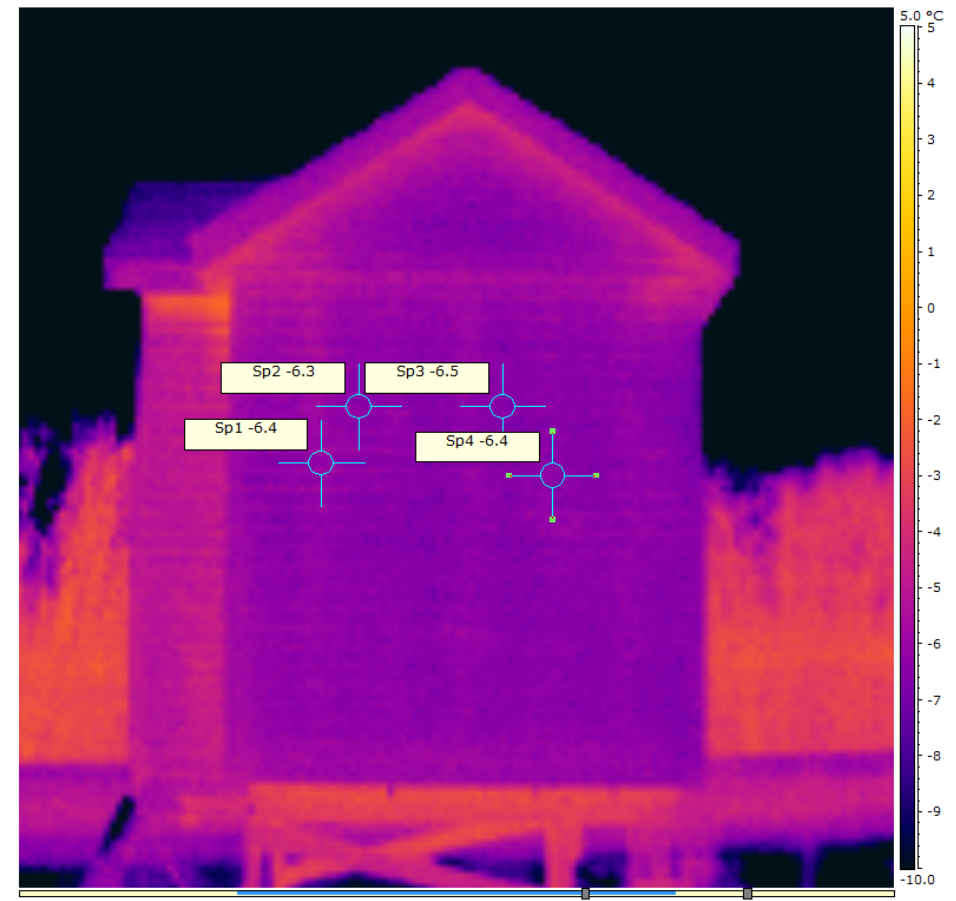


Figure 11 - Fiberglass Hut East Orientation Thermal Image

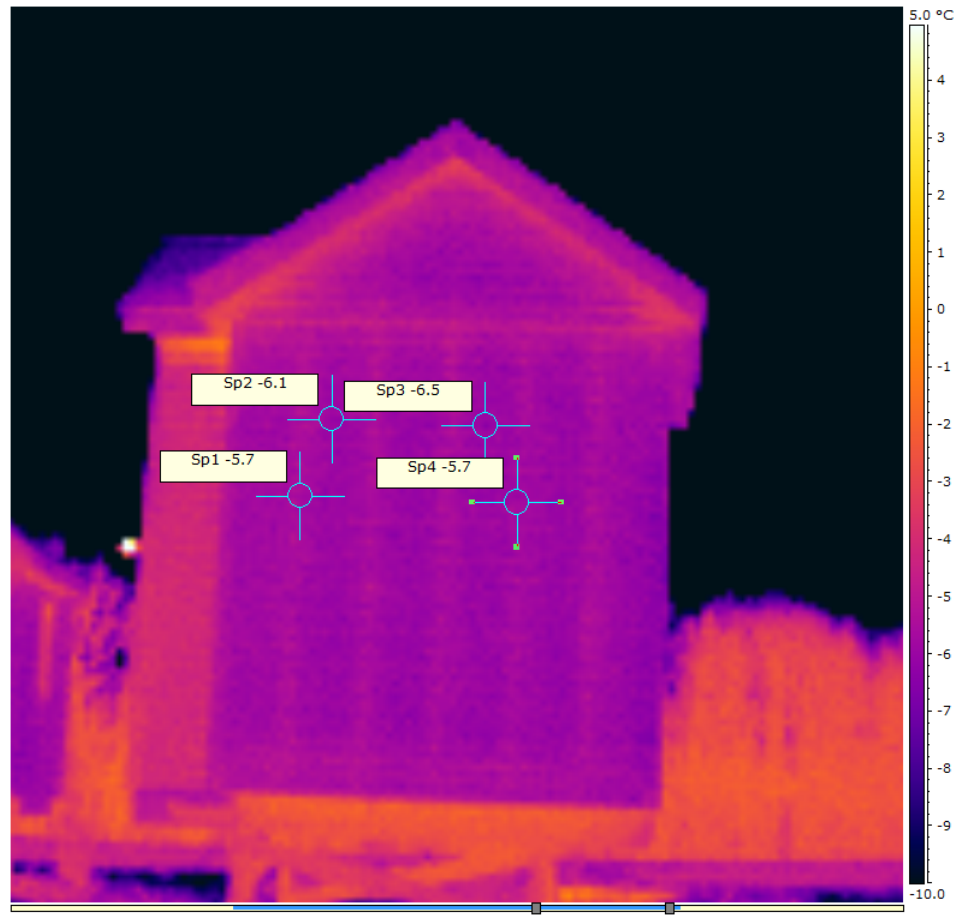


Figure 12 - CCSPF Hut East Orientation Thermal Image

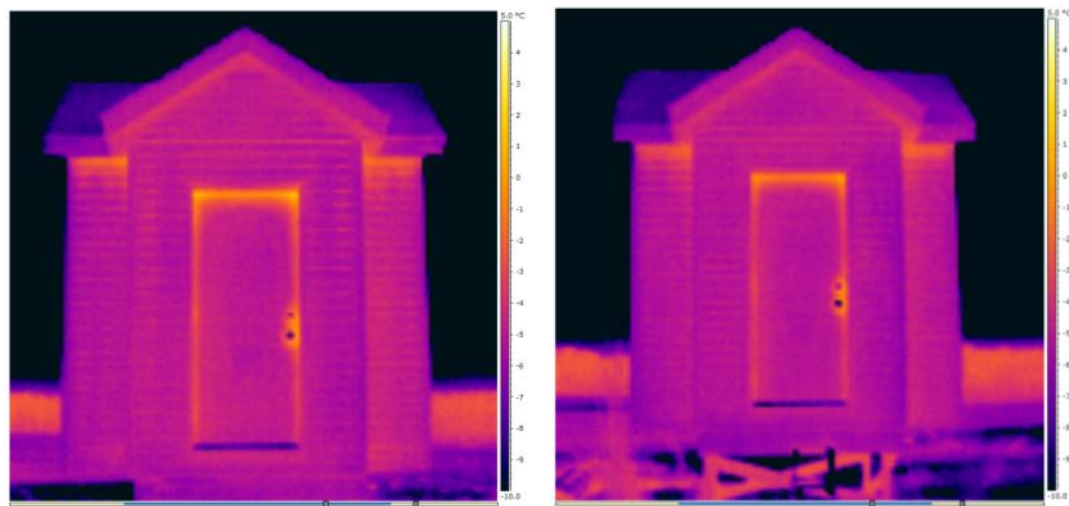


Figure 13 – CCSPF and Fiberglass South Orientation Thermal Images

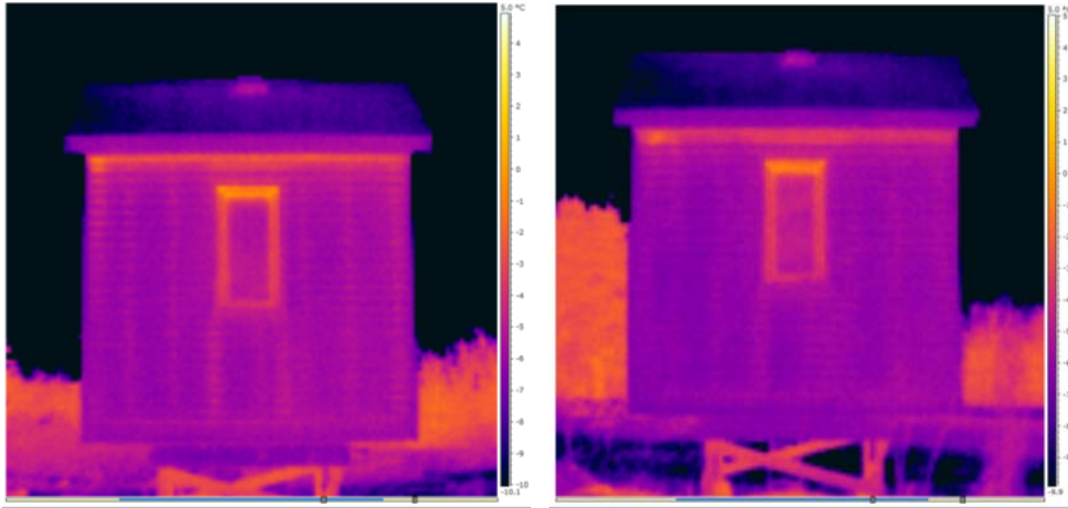


Figure 14 – CCSPF and Fiberglass North Orientation Thermal Images

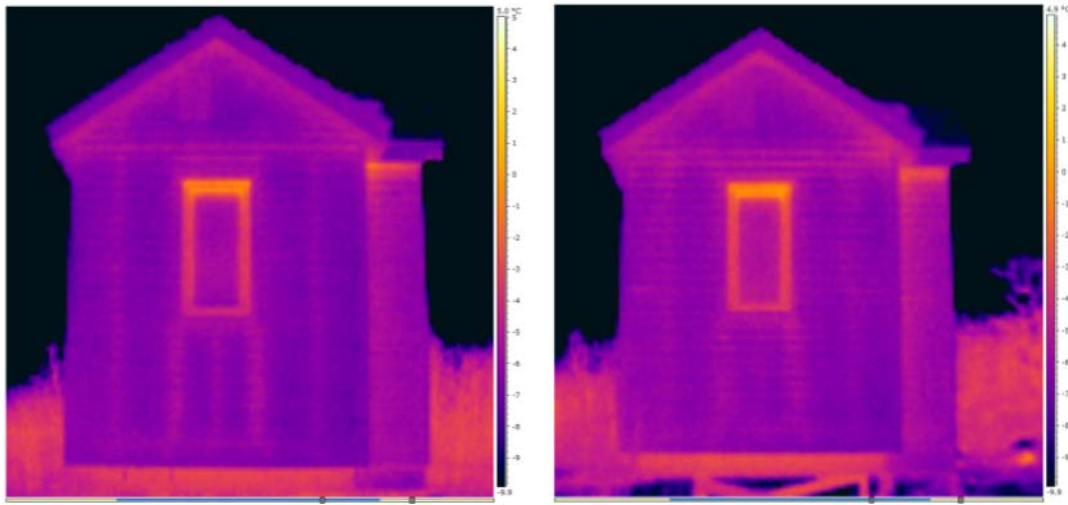


Figure 15 – CCSPF and Fiberglass West Orientation Thermal Images

Predicted Heating Energy Use

To understand the energy consumption data collected, the heat loss predicted using measured material property data and standard heat flow theory is described below.

Thermal conductivity of ccSPF varies with time immediately after spraying. The decay in conductivity was tracked by measuring samples collected at the test huts in the lab. Lab testing was conducted to ASTM C518 standards (lab equipment specifications are attached in Appendix A).

The contractor installed the ccSPF insulation in multiple passes while using a marked depth gauge made of 1/8" metal rod to ensure the required thickness of ccSPF were installed to achieve the code specified R19 for the walls and R28 for the floor. The depths that were installed assume the insulation had a cured R-Value of R6.6 per inch.

The conductivity testing was undertaken on three samples tested at 4 different times at the industry standard 24°C (75°F) mean temperature. The results are graphed in Figure 16. The results show that the insulation installed in the ccSPF hut is, on average, providing R6.2/inch rather than the assumed R6.6/inch. This is 7% less insulation value than anticipated. This means that the R19 walls are actually only insulated to R17.6 and the R28 floor is only insulated to R25.9 on average (Table 1.)

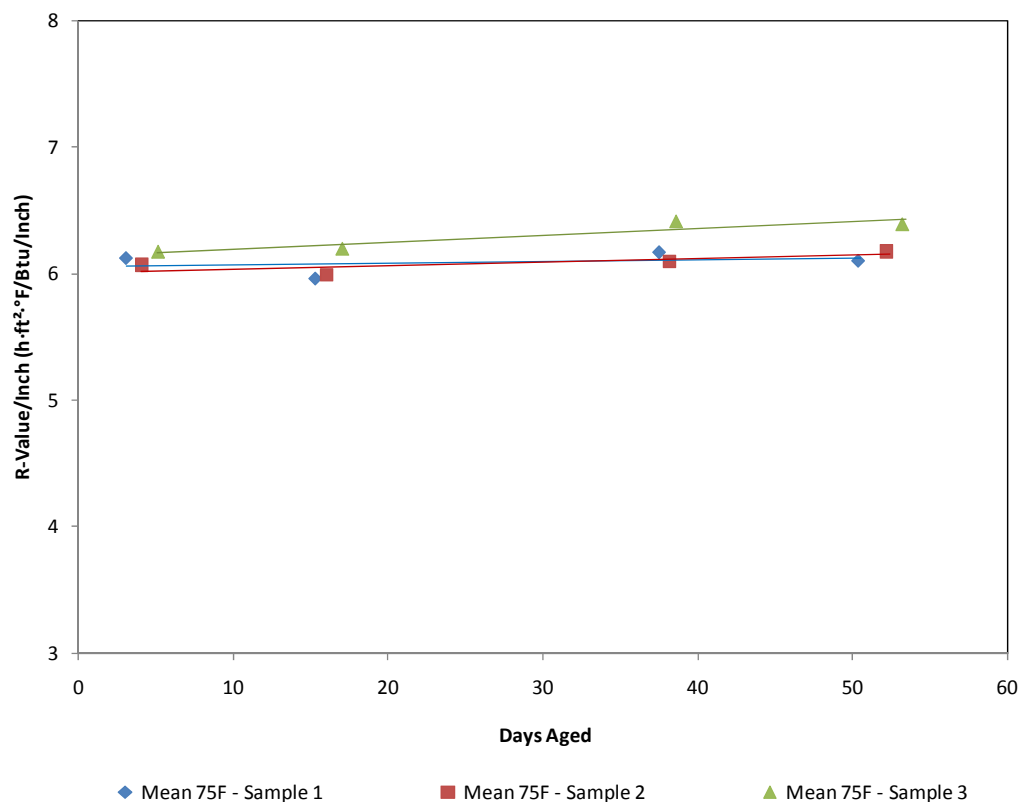


Figure 16 - CCSPF C518 R-Value Testing Results at Mean Temperature of 24°C

Table 1 – Target vs Installed R-Value in ccSPF Hut Tested at Mean Temperature of 24°C

Mean Temperature of 24°C	Walls	Floor
Aged R Value / Inch (h·ft²·°F/Btu)	6.6	6.6
R Value Goal (h·ft²·°F/Btu)	19	28
Thickness Installed (inches)	2.9	4.2
Actual R-Value/Inch (h·ft²·°F/Btu)	6.2	6.2
Actual R Value Installed (h·ft²·°F/Btu)	17.6	25.9
Reduction in R-Value	7%	7%

The R-value of insulations in service depend somewhat on the mean of the temperatures acting on either side. Table 2 shows the R-Value at a mean temperature of 10°C, which is a temperature more representative of the testing conditions considered in this report. The actual installed R-Value of the ccSPF at the realistic mean temperature is about R6.8. Using the insulation R-values

from Table 2, the hut's heat loss can be calculated while accounting for air films, OSB sheathing, drywall, and the thermal bridging of the framing. The actual heat loss predicted, including temperature effects and thermal bridging is 319 Watts when it is 0 °C outdoors and 21°C indoors.

Table 2 - Reduction of Installed R-Value in ccSPF Hut tested at Mean Temperature of 10°C

Mean Temperature of 10°C	Walls	Floor
Aged R Value / Inch (h·ft ² ·°F/Btu)	6.6	6.6
R Value Goal (h·ft ² ·°F/Btu)	19	28
Thickness Installed (inches)	2.9	4.2
Actual R-Value/Inch (h·ft ² ·°F/Btu)	6.8	6.8
Actual R Value Installed (h·ft ² ·°F/Btu)	19.6	28.9
Increase in R-Value	3%	3%

Table 3 - Heat Loss compared to Installed R-Values in ccSPF Hut

Insulation	Heat Loss at 0°C Ambient (Watts)	Percent Change in Heating Load
Assumed R 6.6/inch (at 24°C Mean)	323	
As Installed and Tested R 6.2/inch (at 24°C Mean)	331	2.5%
As Installed and Tested R 6.8/inch (at 10°C Mean)	319	-1.3%

The R-value of the fiberglass batts in the wall cavity were reduced from their nominal value due to the fact that they are compressed during installation into 5.5" deep stud bays. The reduction in mean temperature in service resulted in an increase in performance (as for the SPF). The ccSPF was installed at R6.2 per inch, but the mean temperature reduction showed an effective R6.8 per inch. The installed insulation R-values at a mean temperature of 10°C were used to calculate the heat losses shown in Table 4 and Table 5.

Table 4 - Heat Loss Tabulation for ccSPF Hut (21°C Inside, 0°C Outside)

	Area (ft ²)	R-Value h·ft ² ·°F/Btu	U-Value Btu/h·ft ² ·°F	Heat Loss (watts)
Windows	13.8	2.9	0.35	53.30
Door	20.5	8.0	0.13	28.38
Wall Stud Space	196.9	21.9	0.046	99.64
Wall Framing	60.7	7.9	0.127	85.22
Ceiling	74.5	39.9	0.025	20.68
Floor Stud Space	65.3	32.3	0.031	22.39
Floor Framing	9.2	11.3	0.089	9.07
Total				318.7

Table 5 - Heat Loss Tabulation for Fiberglass Hut (21°C Inside, 0°C Outside)

	Area (ft ²)	R-Value h·ft ² ·°F/Btu	U-Value Btu/h·ft ² ·°F	Heat Loss (watts)
Windows	13.8	2.9	0.35	53.30
Door	20.5	8.0	0.13	28.38
Wall Stud Space	196.9	22.6	0.044	96.41
Wall Framing	60.7	11.5	0.087	58.58
Ceiling	74.5	39.9	0.025	20.68
Floor Stud Space	65.3	30.2	0.033	23.95
Floor Framing	9.2	15.5	0.065	6.59
Total				287.9

Comparing Table 4 and 5, shows that as designed the hut insulated with fiberglass should have a heat loss of 288 W when it is 0°C outside, whereas the hut insulated with ccSPF is predicted to have a heat loss of 319 W under the same conditions. Hence, as designed with the materials used, we would expect the ccSPF hut to use more than 10% heating energy.

Note that the thermal bridging is more prominent for the ccSPF hut because of the fact that the stud space insulation only fills roughly 1/2 of the stud cavity. The inside surface of the foam as well as the inside surface of the stud where the foam ends will be close to indoor temperatures. This creates a shorter distance through the stud to the OSB, and hence outdoor conditions, which transfers more energy than the longer path associated with full stud depth fiberglass insulation which would force the heat to transfer through the full depth of the stud. Figure 17 and Figure 18 show the horizontal section of computer modeled isotherms (using THERM 5.0) of the two walls used in this comparison. Figure 18 shows the significantly tighter isotherms on the stud and shorter thermal bypass length of the framing of the ccSPF insulated wall.

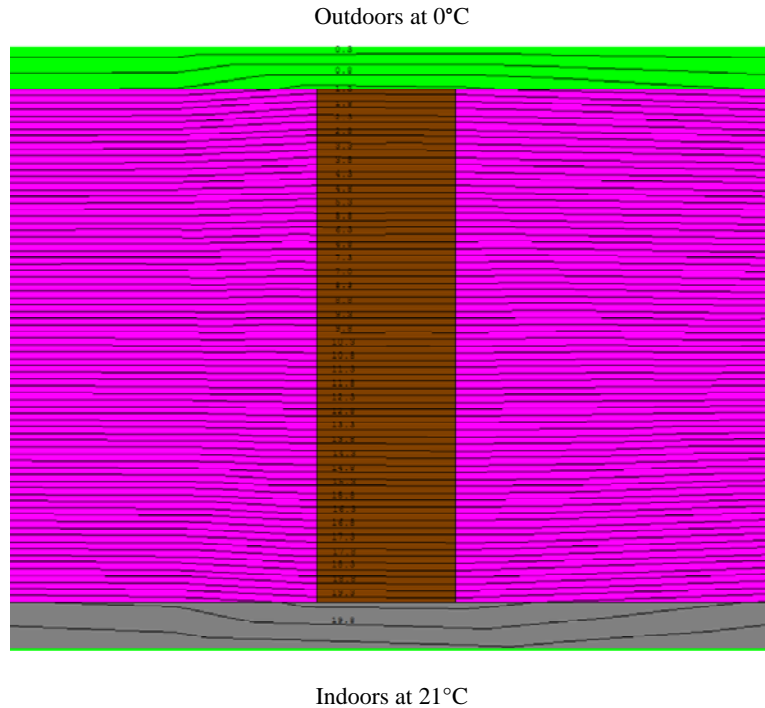


Figure 17 - Thermal Gradients of Fiberglass Insulated Wall

Because thermal bridging of the ccSPF hut is a significant portion of the heating load, the thermal bypass path length (and hence resistance to heat flow) is important. To determine the path length, a THERM model was created and the path length was estimated based on the thermal gradients through the wall. The location was chosen as the point where the gradients start more prominently and was measured from the face of the ccSPF. The length was found to be approximately 0.5" in front of the finished ccSPF insulation. To confirm that the path length chosen for the heat load calculations was logical, another THERM model was created and the clear wall R-value was compared to a parallel path calculated R-value using the assumed path length through the stud. The two calculations coincided and the thermal bypass length was used for the heat load calculations.

The thermal bridging identified by the infrared photography reported earlier was confirmed by the THERM modeling. The results are presented in Table 6. The ccSPF insulated hut shows significantly warmer exterior stud temperatures, while it showed warmer drywall interface temperatures on the interior.

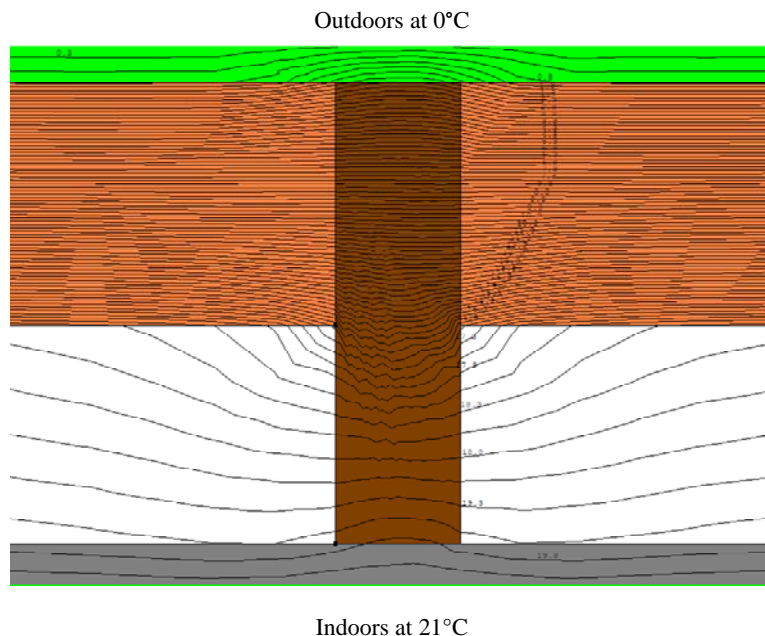


Figure 18 - Thermal Gradients of ccSPF Insulated Wall

The fiberglass batt R-Values were also adjusted for the fact that at lower testing temperatures the batts also perform at a higher R-value. The fiberglass batt R-values were determined from ASTM C518 testing as for the ccSPF values.

Table 6 - Installed R-Value and Surface Temperatures in THERM Modeling

	Installed R-value	U-Value Clear Wall W/m ² K	R-Value Clear Wall h·ft ² ·°F/Btu	Interior Stud Temp at Drywall (°C)	Exterior Stud Temp at OSB (°C)
As Built Fiberglass Batt at Mean 10°C	20.5	0.2805	20.2	19.3	1.1
As Built ccSPF at R6.8/inch and Mean 10°C	19.7	0.2955	19.2	19.8	2.0

Air tightness tests were completed to verify that the huts have similar air leakage characteristics. Ensuring the huts have similar air leakage characteristics removes the possibility that either hut has more or less heating requirements due to the air leakage. The test results show that the air leakage at 50Pa pressure difference of the two huts is within 2% of one another. The ccSPF tested at 54 CFM 50 with 99.99% correlation while the fiberglass hut tested at 55 CFM50 with 99.99% correlation. At the test pressure, the air leakage values correlate to 0.11 CFM per ft² for the CCSPF hut and 0.12 CFM per ft² for the fiberglass hut. The huts were both very well air sealed: the Canadian *ENERGY STAR for Homes* requirement for air tightness is 0.2 CFM per ft², meaning these huts are almost twice as airtight as a Canadian ENERGY STAR single detached home. The heating load due to air leakage, at a more realistic estimated in-service pressure gradient of approximately 1Pa, is 39 watts for the fiberglass hut and 38 watts for the ccSPF hut as shown in Table 7, a 1.8% difference. Note that air leakage comprises about 12.5% of the heat loss of the huts.

Table 7 – Sensitivity of Heating Load due to Air Leakage

	SPUF	Fiberglass	Percent Difference in Heating Load
Air Leakage at 50Pa (CFM)	54	55	
Heat Loss Due to Air Leakage at 50Pa (Watts)	642	654	1.8%
Natural Air Leakage (CFM)	3.23	3.29	
Heat Loss Due to Natural Air Leakage (Watts)	38	39	1.8%

A ccSPF installation does not yield a perfectly flat surface and hence it will not yield a perfectly uniform R-value over the surface of the wall. If the ccSPF installed was ½” thicker than specified, there would be a decrease in heating load of 8%, and if the ccSPF installed was ½” thinner than specified there would be an increase in heating load of 10%. The analysis in Table 8 assumes the insulation installed attains the rated R 6.6 per inch. Assuming the areas where the foam is ½” thinner is approximately equal to the areas where the foam is ½” thicker, the overall calculated heat loss of the ccSPF hut should be very close to the as specified R19 walls and R28 floor, this also relied on the foam that was installed being at the manufacturers claimed R-values per inch.

Table 8 - Sensitivity of Installed ccSPF Depth on Heating Load of ccSPF Hut

Insulation	Heat Loss at 0°C Ambient (Watts)	Percent Change in Heating Load
As Specified (R19 walls, R28 floor)	323	
Additional 1/2" (R22 walls, R31 floor)	298	-8%
Reduction of 1/2" (R16 walls, R25 floor)	356	10%

Measured Energy Use

The measured energy use was analyzed over several different periods using several methods.

Figure 19 plots the energy use and outdoor temperatures during a representative cold weather spell lasting 19 days (from Feb 24th to March 14th, 2010). The coldest day during this period was an average of -7.5°C, while the warmest was an average of +7°C. Table 9 summarizes the average measured daily total heating energy in kilowatts. Ambient conditions were measured at the University of Waterloo’s Class A weather station located 10 km’s East of the test site.

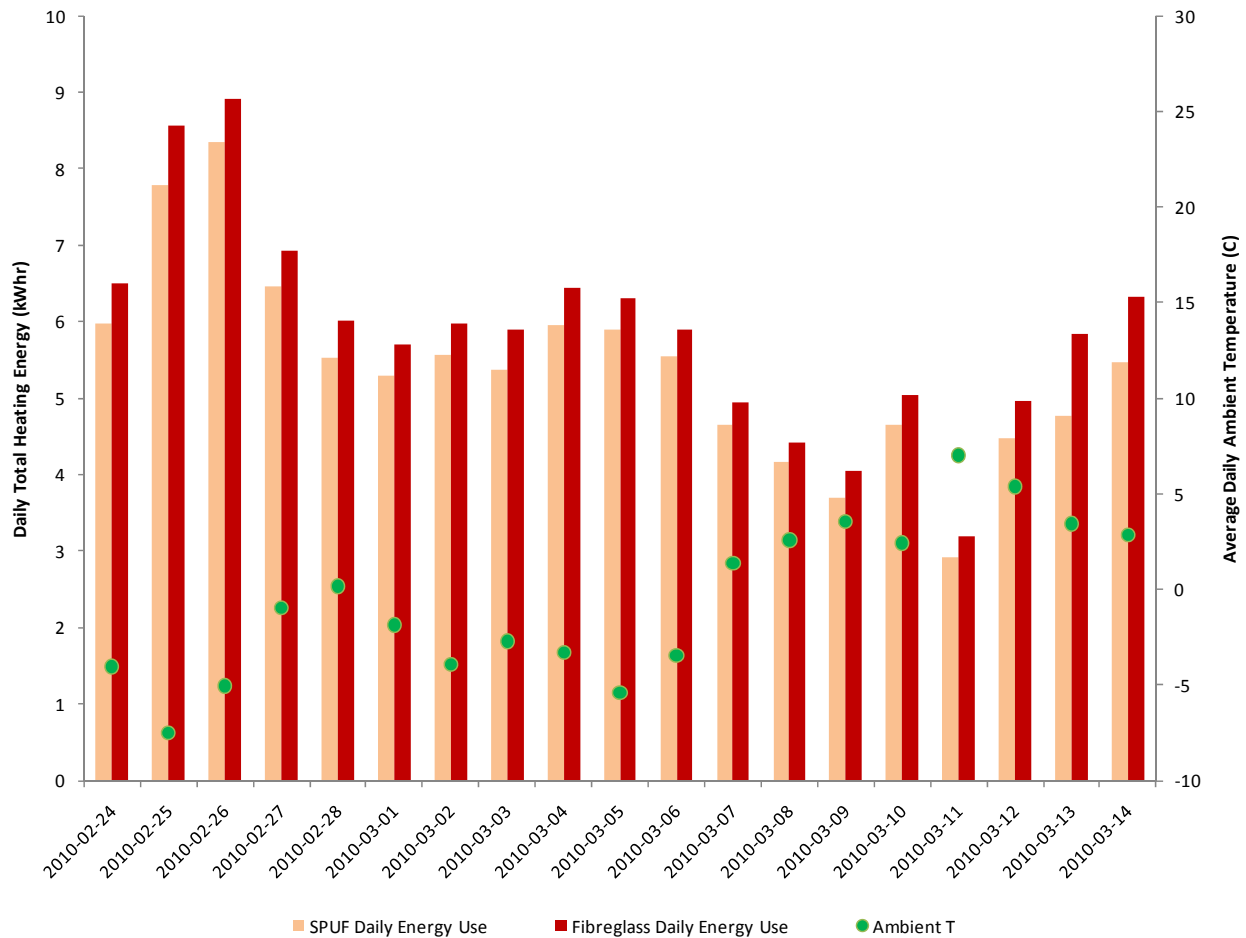


Figure 19 - Daily Total Heating Energy Comparison February 24th to March 14th

Over this entire 19 day period, the energy consumption of the huts was 101.2 kWh and 110.2 kWh. The fiberglass insulated hut used 9% more heating energy.

Table 9 - Daily Total Heating Energy Comparison February 24th to March 14th

	ccSPF Hut	Fiberglass Hut
Average Measured Daily Total Heating Energy (kWh) (Feb 24th - Mar 14th, Avg Outdoor T of -0.6°C)	101.2	110.2

When considering a longer analysis period, including the entire month of March, heating the fiberglass hut required 10% more energy than the ccSPF hut. This is shown in Table 10.

Table 10- Daily Total Heating Energy Comparison February 24th to March 31st

	ccSPF Hut	Fiberglass Hut
Average Measured Daily Total Heating Energy (kWh) (Feb 24th - Mar 31st, Avg Outdoor T of +1.5°C)	171.7	190.3

Solar gain through the windows in the huts contributed to heating during the daylight hours. In general, the heat demand by the electric heaters showed significant drops during the daylight hours on sunny days. This solar gain should benefit each of the huts identically, and such solar gains also provide a benefit in real buildings. However, to compare measured results to the predictions made in the previous section, it is necessary to eliminate the impact of solar heating.

To achieve this goal, only the heating need during the hours between midnight and 6 am were considered (this should avoid any stored solar heat from the daytime, and eliminate any solar gain from the sun in the morning).

Table 11 shows the results of this type of analysis over more than a one month period. The Fiberglass hut had an average heating demand 331 W vs 288 W for the ccSPF: the fiberglass hut used over 6% *more* energy than was predicted using standard methods and the ccSPF used 17% *less*. This analysis approach is, in our opinion, the best metric of real insulating performance.

Table 11 – Midnight to 6am Heating Load Comparison February 24th to March 31st

	ccSPF Hut	Fiberglass Hut
Measured Heating Load (Watts) (Feb 24th - Mar 31st, Avg Outdoor T of -1.6°C)	288	331
Predicted Heating Load	347	311
Predicted versus Measured Heating Load	83%	106%

The calculated heating load of the ccSPF hut, including air leakage, thermal bridging (with associated path length) and installed R-value was 15.4 watts for each degree Celsius difference from the indoor to outdoor. This is termed the heat loss coefficient. The fiberglass hut, including air leakage, thermal bridging and adjusted R-values due to compression of the fiberglass batts in the wall cavities, had a calculated heating load of 14.0 watts/°C. The measured values over all hours show that the ccSPF performed 27.4% better than predicted and the fiberglass hut performed 8.0% better than predicted. These energy values include the solar gain received by the huts through windows, walls, and roof. This is shown in Table 12 and Figure 20.

Table 12 - Calculated versus Measured Heat Loss Coefficients

	ccSPF Hut	Fiberglass Hut
Calculated Heat Loss Due Through Enclosure at 0°C Ambient with Specified R-Values (Watts/°C)	15.4	14.0
Heat Loss Due to Natural Air Leakage (Watts/°C)	1.83	1.87
Increase in Heat Loss due to Installed and Tested R-Values (Watts/°C)	0.39	0.28
Decrease in Heat Loss due to R-Value at Mean 10°C (Watts/°C)	-0.20	-0.28
Calculated As-Built Heat Loss (Watts/°C)	17.4	15.9
Measured Heating Load (Watts/°C) (Feb 24th - Mar 31st, Avg Outdoor T of -1.6°C)	12.6	14.6
Percent Difference in Calculated vs Measured Heat Loss (Watts)	-27.4%	-8.0%

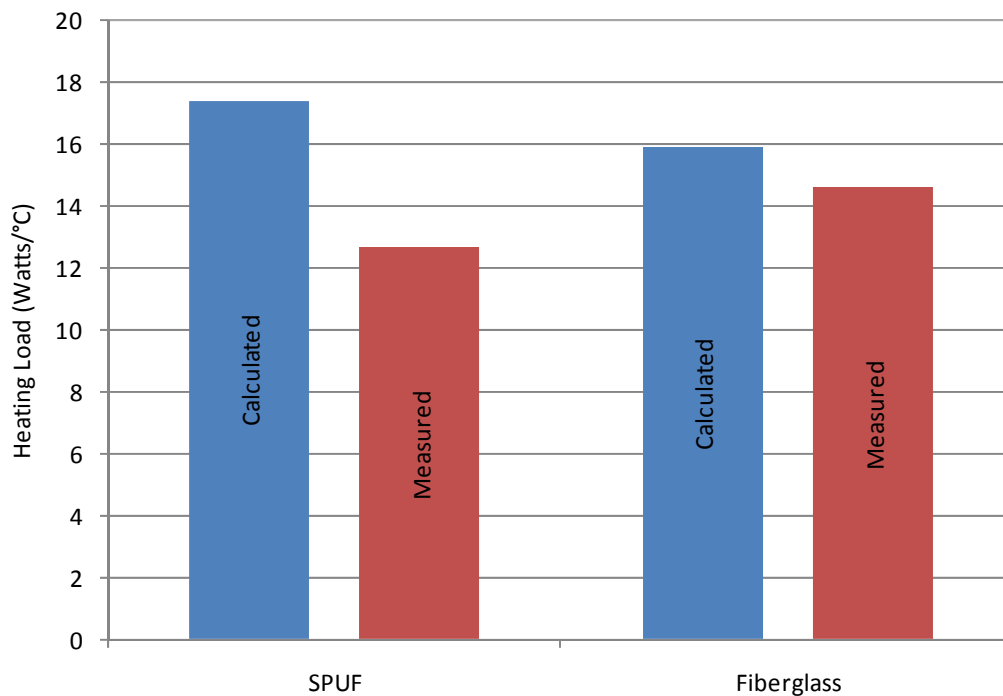


Figure 20 - Calculated versus Measured Heat Loss Coefficient (Watts/°C)

Both huts performed consumed less energy than predicted because of the free solar gain not accounted for in the analysis. It is evident in the actual measured data that the ccSPF hut used less heating energy than the fiberglass insulated hut, even though its installed true R-Value was calculated to be less.

The differences in performance may be due to windwashing, wind pumping, installation defects in the fiberglass, over thickness of the SPF, and different air leakage paths. It is not clear if these, singly or together, or some other mechanism explains the rather significant difference in heating energy use.

As a final sensitivity analysis, the impact of the variation in indoor temperature was assessed. During the testing period the interior conditions of the huts were maintained according to thermistor measurements which exhibited daily averages within 0.25% of one another. The thermistors are accurate to within +/- 0.2°C. This represents a possible variance of less than 1% heating energy use at 0°C outdoor temperature.

Table 13 - Thermistor Measurement Variation on Heating Load

Thermistor Measurement Variance	Heat Loss at 0°C Ambient (Watts)	Percent Change in Heating Load
21°C	322.8	
21.2°C	325.9	-0.95%
20.8°C	319.8	0.95%

Conclusions and Recommendations

Two structurally identical test huts were constructed with details typical of residential wood frame construction in Ontario. One of the huts was insulated with fiberglass batt insulation and the other with ccSPF. The huts were tested and shown to have almost identical air leakage characteristics, and were accurately maintained at the same temperature during the winter test period while the heating energy consumption was monitored.

Thermal images of the exterior of the huts showed differences in thermal signatures. Thermal bridging is more prominent on the ccSPF hut because the foam does not fill the stud bay. This leaves a larger surface area of the stud exposed to essentially the indoor environment at room temperature. Because there is more surface area exposed, and the thermal bypass length is shorter, there is slightly more energy loss through the studs.

Laboratory C518 thermal conductivity testing showed that the insulation installed in the ccSPF hut is (averaged over three samples), providing R6.2/inch, which is 7% less insulation value than anticipated (R6.6/inch) at the industry standard 24°C (75°F) mean temperature. This means that the planned R19 wall insulation layer is actually R17.6 in the hut and the R28 floor insulation layer is actually R25.9.

Both huts were framed identically, had nearly identical tested air leakage rates, and the same attic insulation material and quantity. The ccSPF insulated hut with R17.6 ccSPF in the walls and R25.9 ccSPF in the floor consumed 9.7% less heating energy than the otherwise-identical fiberglass batt insulated hut with R19 batt in the walls and R28 batt in the floor over a cold weather period lasting 35 days. The measured heating energy values show that the ccSPF consumed 27.4% less heating energy than predicted (when the actual installed R-values are considered) and the fiberglass hut consumed 8.0% less than predicted. The predicted heating energy comparison used measured material R-values for mean temperatures of 10°C for both the ccSPF and the fiberglass insulation, and included all thermal bridging effects. Solar heat gain through windows and on hut surfaces provided some free heat and helped explain the deviations from theory.

To remove the effect of solar gain, the heating energy consumption patterns was analyzed using data from nighttime periods only. Using this method, the fiberglass hut had an average heating demand of 331 W vs 288 W for the ccSPF: the fiberglass hut used almost 6% *more* energy than was predicted using standard prediction methods and the ccSPF used 17% *less*. This analysis approach is, in our opinion, the best metric of real insulating performance.

The evidence from these carefully controlled real field exposure test huts is that ccSPF exceeds its expected performance (when the installed R-value is known). The reasons for the improved performance are uncertain: it may be because of less convective looping and/or less wind washing, the impact of temperature, or some other cause. However, the experimental approach taken did aim to eliminate the impact of thermal bridging and air leakage, the two largest causes of performance variation in real houses. Further research would be necessary to identify the reasons.

Appendix A


FLIR Specifications

C518 Testing Equipment Specification

FLIR b50

FLIR b50 a lightweight, competent infrared camera. Li Ion batteries allow work for 5 hours without interruption of charging. The FLIR LED lights make it possible to work even in dark environments. Insulation alarm and Dew point alarm are perfect in a building site. The visual 2.3 Mpixel digital camera and three step Fusion Picture in Picture functionality helps produce radiometric JPEG images in a professional way. FLIR QuickReport™ software makes it possible to analyze IR and visual pictures captured in field back in the office.

-  *IR resolution 140 x 140 pixels*
-  *Digital camera 1536 x 1536 pixels*
-  *Lightweight 600 g*
-  *Laser Pointer*
-  *Copy to USB*
-  *Fusion (3 steps Picture in Picture)*

-  *5 hours battery*
-  *LED lights*
-  *21 languages*
-  *Dew point & Insulation alarm*
-  *NETD 90 mK*

FLIR b50 Features

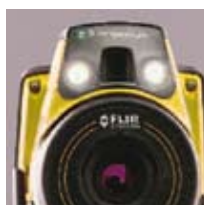
- **Digital Camera** — 2.3 Megapixels with built-in LED lights provides sharp images regardless of lighting conditions
- **Picture in Picture (PiP)** — Displays resizable IR image super-imposed over a digital image
- **Wide Temperature Range** — Measures from -20 °C to +120 °C targeting building applications
- **± 2% Accuracy** — Reliable temperature measurement
- **Insulation alarm** — Shows the insulation performance of the building structure
- **Dew point alarm** — Alerts you to the areas where there is a risk of condensation
- **Thumbnail Image Gallery** — Allows quick search of stored images
- **Laser Pointer** — Pinpoints the hot spot on the IR image with the real physical target
- **Micro SD Card** — Stores more than 2000 radiometric JPEG images



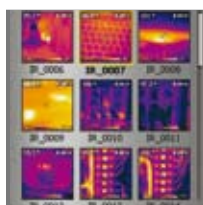
140 x 140 pixel resolution



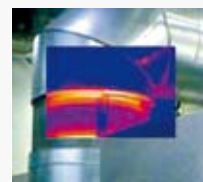
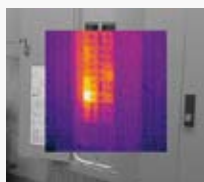
Fusion (3 steps PiP)



Built-in LED lights



Thumbnail Image Gallery



Fusion (3 steps Picture in Picture)

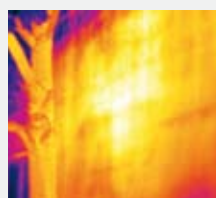
Allows for easier identification and interpretation of infrared images. This advanced technology enhances the value of an infrared image by allowing you to overlay it directly over the corresponding visible image. This functionality combines the benefits of both the infrared image and visual picture at the push of a button.

FLIR b50 Specifications

Imaging and optical data	
Field of view (FOV) /	25° × 25° / 0.10 m (0.33 ft.)
Minimum focus distance	
Spatial resolution (IFOV)	3.12 mrad
Thermal sensitivity/NETD	<0.09 °C (<0.16 °F) @ +25 °C (+77 °F) / 90 mK
Image frequency	9 Hz
Focus	Manual
Focal Plane Array (FPA) /	Uncooled microbolometer / 7.5–13 µm
Spectral range	
IR resolution	140 × 140 pixels
Image presentation	
Display	Built-in 3.5 in. LCD, 256k colors, 240 × 320 pixels
Image modes	IR image, visual image, Picture in Picture, thumbnail gallery
Picture in Picture	IR area (in three steps) on visual image
Measurement	
Object temperature range	–20 to +120°C (–4 to +248°F)
Accuracy	±2°C (±3.6°F) or ±2% of reading
Measurement analysis	
Spotmeter	Center spot
Area	1 box with min./max.
Emissivity correction	Variable from 0.1 to 1.0 or selected from list of materials
Reflected apparent temperature correction	Automatic, based on input of reflected temperature
Isotherm	1 with above/below
Dew point alarm	Yes
Insulation alarm	Yes
Set-up	
Menu commands	Palettes (Black and White, Iron and Rainbow), image adjustment (auto/manual)
Set-up commands	Local adaptation of units, language, date and time formats; automatic shutdown, display intensity
Storage of images	
Image storage	Standard JPEG, including measurement data, on memory card
Digital camera	
Built-in digital camera	2.3 Mpixels (1536 × 1536 pixels), and two LED lights
Digital camera, focus	Minimum focus distance 0.4 m (1.3 ft.)

Laser pointer	
Laser	Semiconductor AlGaInP diode laser, Class 2
Data communication interfaces	
Interfaces	USB-mini, USB-A
Power system	
Battery	Li Ion (field replaceable), 5 hours operating time
Charging system	In camera, AC adapter, 2-bay charger or 12 V from a vehicle
Power management	Automatic shutdown (user selectable)
AC operation	AC adapter, 90–260 VAC, 50/60 Hz, 12 V output to camera
Environmental data	
Operating temperature range	–15 to +50 °C (+5 to +122°F)
Storage temperature range	–40 to +70 °C (–40 to +158°F)
Humidity (operating and storage)	IEC 68-2-30/24 h 95% relative humidity +25 °C to +40 °C (+77°F to +104°F)
Encapsulation	IP 54 (IEC 60529)
Bump	25 g (IEC 60068-2-29)
Vibration	2 g (IEC 60068-2-6)
Physical data	
Camera weight, incl. battery	0.60 kg (1.32 lb)
Camera size (L × W × H)	235 × 81 × 175 mm (9.3 × 3.2 × 6.9 in.)
Scope of delivery	
Packaging, contents: Hard transport case, Infrared camera with lens, Battery, Calibration certificate, FLIR QuickReport™ PC software CD-ROM, Memory card with adapter, Power supply, Printed Getting Started Guide, USB cable, User documentation CD-ROM, Warranty extension card or Registration card	
Optional software	
FLIR Reporter Standard/ Professional	A powerful yet easy-to-use tool to generate comprehensive and professional infrared inspection reports.
FLIR BuildIR™	A powerful yet easy-to-use software designed to visualise and quantify building related issues

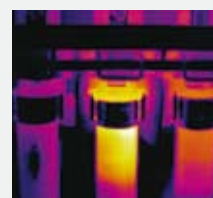
Applications



Building: Water and mildew in wall



Building: Heat Loss



Electrical: Hot Fuses



Specifications and prices subject to change without notice.

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FLIR Systems Co Ltd.
Headquarters Asia Pacific
Room 1613 – 15, Tower 2,
Grand Central Plaza,
138 Shatin Rural Committee Road,
N.T. Hong Kong
Tel: +852 2792 8955
Fax: +852 2792 8952
Email: flir@flir.com.hk

FLIR Systems (Shanghai) Co., Ltd
Head Office China
Tel: +86 21 5169 7628
Email: info@flir.cn

FLIR Systems Japan KK
Tel: +81 3 6277 5681
Email: info@flir.jp

FLIR Systems Australia Pty Ltd
Head office Australia
Tel: +61 3 9550 2800
Email: info@flir.com.au

FLIR Systems Korea Co., Ltd
Tel: +82 2 541 1834
Email: flir@flirkorea.com

FLIR Systems Taiwan
Representative Office
Tel: +886 2 2757 9662
Email: flir@flir.com.hk

FLIR Systems India Pvt Limited
C/o Swedish Trade Council
Tel: +91-11-46067100
Email: flir@flir.com.hk



www.flir.com/thg

THERMAL CONDUCTIVITY INSTRUMENT

- ☐ Conforms to ASTM C 518 & ISO 8301
- ☐ Specimen size 300 mm sq. (12")
- ☐ Thickness Range from 0 to 102 mm (4")
- ☐ Compact size
- ☐ Accuracy better than 1%
- ☐ Easy to use, rapid operation
- ☐ Microprocessor based
- ☐ Stand alone operation
- ☐ Solid state cooling\heating
- ☐ Operation from -30°C to 95°C (plate)
- ☐ Digital Thickness readout to 0.001"
- ☐ Powerful 24 Bit A/D Converter
- ☐ Two Thin-Film Heat Flux Transducers
- ☐ Temperature Control to 0.01°C
- ☐ Interfaces to a computer
- ☐ Ideal for slices of Cellular Plastics
- ☐ No need to calibrate for years
- ☐ Full One Year Parts and Labor Warranty
- ☐ Suitable for R&D and QC testing
- ☐ Win_Therm Software extends flexibility
- ☐ Extremely energy efficient



Simplicity of use:

Place the specimen in the test chamber, close the door and answer several prompts displayed on a clear 4 line alphanumeric LCD display. The Instrument does the rest.

The plate spacing is adjusted automatically to the desired specimen thickness (accurate to 0.001"). The sophisticated digital temperature control algorithm monitors the plate temperatures 20 times per second and rapidly brings the system to the selected equilibrium test condition. Tests can be performed repeatedly at one temperature or at up to 9 user selected temperatures between -30°C and 95°C. The test results can be output to the host computer.

Instrument Description and Procedure

The FOX314 instrument consists of two basic sections: the top section and the base. All the electronics are housed in the base section. The top section of the instrument is the actual test chamber. Once the door is opened, the sample can be placed between the two plates in the test stack. The upper plate is stationary. The lower plate can move up and down. It is powered by four independently controlled motors. The position of each corner of the bottom plate is monitored and controlled by a sophisticated digital thickness readout system with 0.025 mm (0.001") precision. Two options for thickness are available. Auto Thickness will cause the lower plate to raise and close on the sample, displaying thickness. User Defined Thickness will allow the user to enter the desired sample test thickness. This mode is used for compressible samples. The instrument will attain the specified sample thickness, specimen permitting. In either case the displayed results will be accurate to within 0.025mm (0.001"). Pressing ENT will initiate the test at the first setpoint. The instrument automatically advances to the next setpoints if more than one were entered. The results are displayed at the end of the test.

Transducers and Thermocouples

A high output Thin Film Heat Flux Transducer, developed by LaserComp, is permanently bonded to the surface of each plate. The transducers are of the integrating type with a 4"(101mm) square active area in the center. Overall thickness is only 0.040", precluding heat flow distortion. A type E thermocouple is bonded in the center of each transducer and both are sealed to insure consistent precision over time. Because each is within 0.005" of the sample's surface they provide accurate readings of the sample's surface temperature and heat flux. The same thermocouple is used for control of the plate temperature.

Electronic Power and Control

At the heart of the FOX314 instrument is a very powerful Digital Signal Processor and a 24 Bit Analog to Digital Converter. The A/D Converter converts the signals from the thermocouples and heat flow transducers to the digital domain. The resolution on the conversion is 0.6 μ V. This translates to a resolution of 0.01°C for temperature. For typical samples the resolution of transducer readings is 0.05%.

The DSP controls all aspects of the instrument's operation, from the user interface to sending data to the host computer and calculating the results. The DSP's most important task is to monitor the

fox314

Specimen Size:	305mm (12") square 0 to 102mm (4") thick
Temperature range:	-20°C to 95°C (-4°F to 203°F)
Absolute accuracy:	+/- 1%
Reproducibility:	+/-0.5%
Conductivity range:	0.005 to 0.35 W/mK (0.035 to 2.4 BTU in/hr ft ² °F)
Conductance:	should not exceed:12W/m ² °C (2.0 BTU/h ft ² °F)
Utility requirements:	110/220V 50/60 Hz switchable at 600VA cooling water at 18°C or less

temperatures of the plates and to perform a multistage PID algorithm to control the plates at +/- 0.01°C of the test setpoint temperature. Based on the outcome of the algorithm, new control signals are sent to the Power Output Board in each acquisition cycle (every 0.5 sec.). The Power Output Board provides the power to the solid state heating/cooling system in each plate. Both plates can be heated and cooled allowing for testing with heat flow up or down. The low thermal mass design of the plates combined with the power of the DSP and Power Output Board enable extremely fast attainment of setpoints.

Win_Therm Software

WIN_THERM Software package operating under Microsoft Windows allows for connection of FOX instruments to an IBM compatible computer through a standard RS 232 interface. Through a series of windows all the test parameters and format of outputs can be setup and changed at any time during the test. The software provides complete control of the instrument at all times. All selected data is automatically stored on a hard disk. Once the test conditions have been set and the test started, the computer can be used to display any desired outputs in a series of windows. Two FOX (and as many as 8 with modest additional hardware) instruments can be run simultaneously on one host computer.