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R-stud Thermal Testing

DATE February 13, 2017

REGARDING **Thermal Performance Testing of the R-stud Steel Stud System**

Dear Mr. Lucas,

RDH Building Science Inc. (RDH) is pleased to provide you with this report for thermal performance testing of the R-stud system using a guarded hot plate apparatus.

1 Introduction

1.1 RDH Testing Overview

It is widely understood that industry standard steel studs significantly reduce the thermal performance of a wall system using insulation in the stud cavities. R-stud LLC has developed a new stud that has improved thermal performance.

RDH Building Science Inc. (RDH) was retained by R-stud LLC to perform physical thermal performance testing of the R-stud thermally improved steel stud system using our modified ASTM C177 compliant large scale guarded hot plate apparatus. The purpose of the testing was to quantitatively measure the thermal performance of the components of the R-stud system with relation to steel studs typically used in the industry.

R-stud's thermally improved stud and track were tested as part of a mock-up wall assembly comprising interior gypsum board, insulation, and exterior gypsum board. Testing was also conducted on an assembly without a stud and an assembly with a standard steel stud to allow for comparison against the R-stud system. The effect of using batt insulation versus using blown insulation was also evaluated.

1.2 Background

A steel stud penetrating the cavity insulation layer of a wall assembly creates a significant thermal bridge because steel is approximately one hundred times more thermally conductive than insulation. ASHRAE 90.1 estimates that the effective framing/cavity R-value with 6" steel studs and a 16" on center spacing is R-7.4 when used with R-21 insulation in the cavity.

The U-value of an assembly containing thermal bridges can, in a general sense, be predicted using the following equation (ISO 10211, ISO14683)

$$U = \frac{\Sigma(\Psi \cdot L) + \Sigma(\chi \cdot n)}{A_{Total}} + U_o$$

Where:

U is the thermal conductance in W/m^2°C, including thermal bridging;

U_0 is the “clear wall” thermal conductance assuming no systemic thermal bridging in W/m^2°C

A_{tot} is the area by which the heat flows through in m^2;

Ψ is the linear thermal bridge conductance value in W/m°C;

L is the length of linear thermal bridge in m;

χ_j is the point thermal conductance value in W/°C; and

n is the number of point thermal bridges.

Computer modelling of thermal bridges is often performed to estimate the □ and □$_i$ coefficients for linear and point thermal transmittances, respectively. It is also useful to extend measured results. However, it is important to note that models may not be an accurate representation of reality nor are they intended to be. For example, complex geometries and contact resistances between materials are often not included in models, leading to inaccuracies in the results produced. It is therefore important that physical measurement of thermal bridges be undertaken.

The thermal performance of materials for building science purposes has typically been measured using three devices; the heat flow meter, the guarded hot plate, and the guarded hot box. The heat flow meter (ASTM C518) is a comparative method whereby the device is calibrated based on a reference specimen of known thermal performance and then similar specimens can be measured. It generally measures small homogenous materials, for example, insulations measuring 12” by 12” with a maximum thickness of 4”. The guarded hot plate is an absolute method (ASTM C177) whereby the actual heat flow through a specimen is measured. Guarded hot plates often measure specimens of the same size or somewhat larger than the heat flow meter. The guarded hot box is an apparatus (currently described by ASTM C1363) that creates an environmentally controlled airspace on each side of a specimen and then measures the heat flow across the specimen to determine its conductance. The hot box is the most complicated and expensive to operate but it is the most representative of full multi-dimensional assemblies. The hot box is also the least accurate method because of the challenges of flanking losses and air movement. It does not allow users to investigate the influence of specific materials or details directly: two specimens must be built, with and without the detail of interest and the results can then be compared.

Multiple standards exist that regulate the design, construction, and operation of guarded hot plates but ASTM C177-13 “Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus” has achieved international acceptance for being the most accurate (Zarr, 2001). The ASTM standard guides design and procedure but of course does not provide sufficient design and construction details to construct a guarded hot plate without prior knowledge and experience in heat transfer, temperature measurement, temperature control, and mechanical design. It only provides general criteria based on experience that has shown to provide guarded hot plates with reliable and reproducible measurements (Jackson, 1976). For development and commissioning of the guarded hot plate used for this testing report, the reader may refer to the engineering master’s thesis by Joseph

Simonji (Simonji 2016). In addition, background information on guarded hot plates and our apparatus can be found in Appendix A.

Testing of non-homogenous specimens in guarded hot plate apparatuses such as those containing layers or thermal bridges is not typically performed. However, with a large apparatus and by making special provisions, accurate measurement of non-homogenous specimens is possible.

1.3 Test Specimens

Several mock-up wall assemblies were tested in the guarded hot plate apparatus. In these wall assemblies, relatively high thermally conductivity materials such as the gypsum board and steel stud provide an easy path for heat to escape or be gained from the meter plate area. Thus, it must be guarded from ambient temperatures. An 8" thick square ringed guard composed of medium density mineral wool insulation was chosen to protect the wall assembly, leaving a 32"x32" (0.82x0.82 m) core wall assembly. This same guard was used for all of the test specimens. A cross-section of a complete specimen with a standard steel stud is shown in Figure 1.

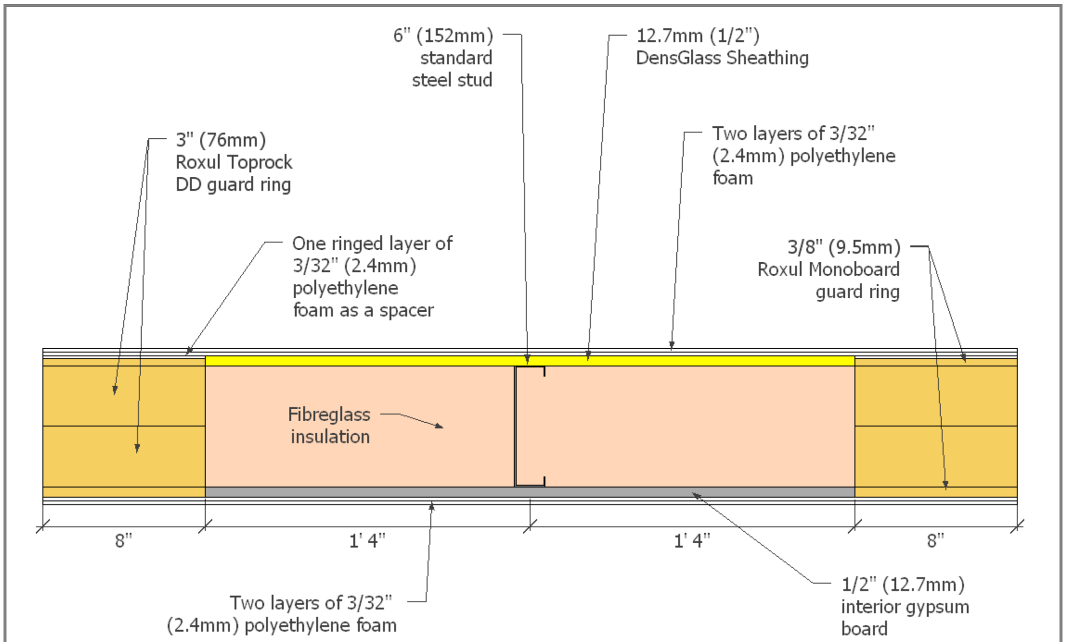

Figure 1 – Cross-section schematic of the guarded hot plate apparatus.

Nine separate specimens were tested as part of this project. All of the specimens resembled the mock-up wall assembly configuration shown in Figure 1 but with different stud and insulation substitutions. The heat flow through a standard steel stud, an R-stud stud, and an R-stud track were measured along with a base case without any stud or track. A steel stud of similar structural strength and span capacity to the R-stud stud was chosen for a fair comparison. The standard steel stud tested was a 600S162-68 and is shown in Figure 2. The corresponding R-stud track is shown in Figure 3.

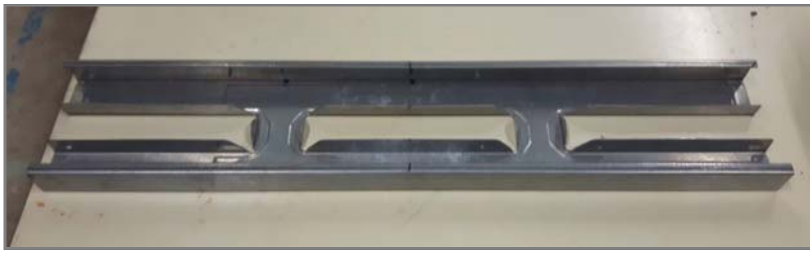

Figure 2 – One of the R-stud studs used in the assemblies.

Figure 3 – The R-stud track used in the assemblies.

The actual thickness and dimensions of the stud and track samples measured can be seen in Appendix B.

Because the R-stud stud has a 12” repeating pattern and the meter area has a 16” width, an additional test was undertaken to determine the effect of the stud geometry on the total heat flow in the meter area. Centering the R-stud stud on the meter plate about a punch-out hole in the stud means that two of the “legs” between the punch-outs are included in the meter area. The areas of the stud around the legs have a higher heat flow through them than through the areas where the punch-out holes are. Therefore, including more legs (stud centered about a hole) in the meter area could cause more heat flow and an underestimation in the conductance than if fewer legs were included (stud centered about a leg). The two stud configurations are shown in Figure 4.

Two types of insulation were evaluated in the mock-up wall assembly: fiberglass batt (Owens Corning PINK R-20, 6" thick) and blown fiberglass (Knauf Insulation Jet Stream Ultra packed to 1.8 lb/cu ft). Blown fiberglass is more difficult to install to the correct density but has the advantage of being able to fill in gaps more reliably.

A summary list of the specimens tested is shown in Table 1.

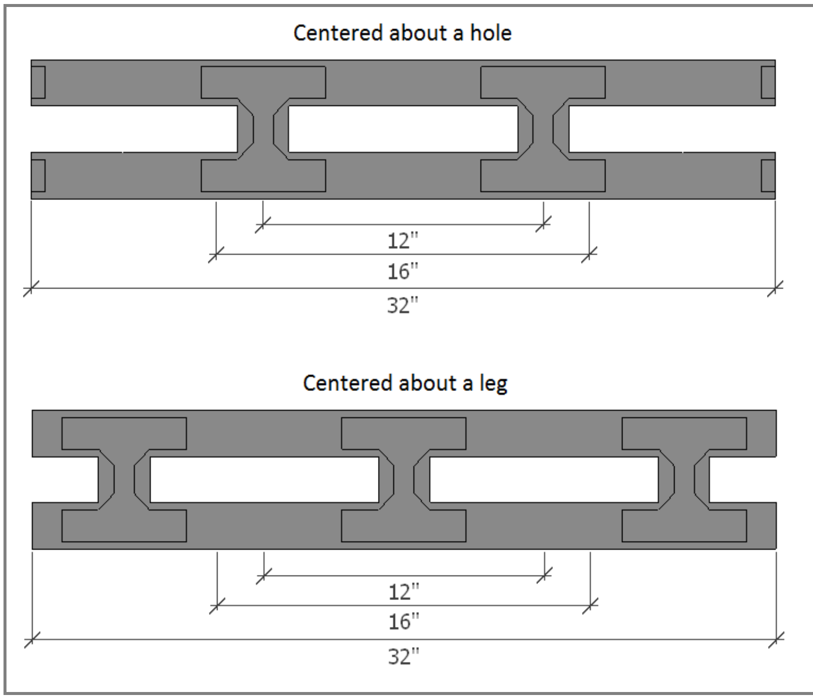

Figure 4 – The two R-stud configurations tested.

Table 1 – List of specimens.

Test #	Insulation and Stud Combination
1	Fiberglass batt only (6" depth)
2	Fiberglass batt and standard 6" steel stud
3	Fiberglass batt and 6" R-stud stud (centered about a hole)
4	Fiberglass batt and 6" R-stud stud (centered about a leg)
5	Fiberglass batt and 6" R-stud track (centered about a hole)
6	Blown fiberglass only (6" depth)
7	Blown fiberglass and standard 6" steel stud
8	Blown fiberglass and 6" R-stud stud (centered about a hole)
9	Blown fiberglass and 6" R-stud track (centered about a hole)

Photographs of the step-by-step installation of a steel stud specimen are shown in Figure 5 through Figure 16.

Figure 5 – The bottom two layers of polyethylene foam (representing an interior surface film).

Figure 6 –The bottom mineral wool guard for around the interior gypsum board layer.

Figure 7 – The mineral wool guard around the insulation and stud layer.

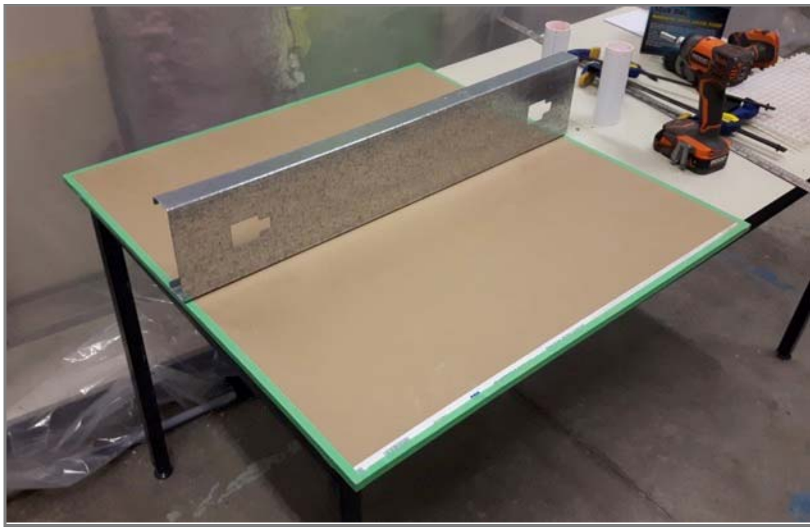

Figure 8 –Steel stud screwed to the interior gypsum board.

Figure 9 – Fiberglass batt insulation installed around the standard stud. Thin PVC pipe spacers are placed at the corners outside of the meter area to ensure the 6" stud cavity is maintained.

Figure 10 – Completed wall assembly.

Figure 11 – Wall assembly installed surrounded by mineral wool guard.

Figure 12 – Top mineral wool guard piece around the exterior gypsum wallboard.

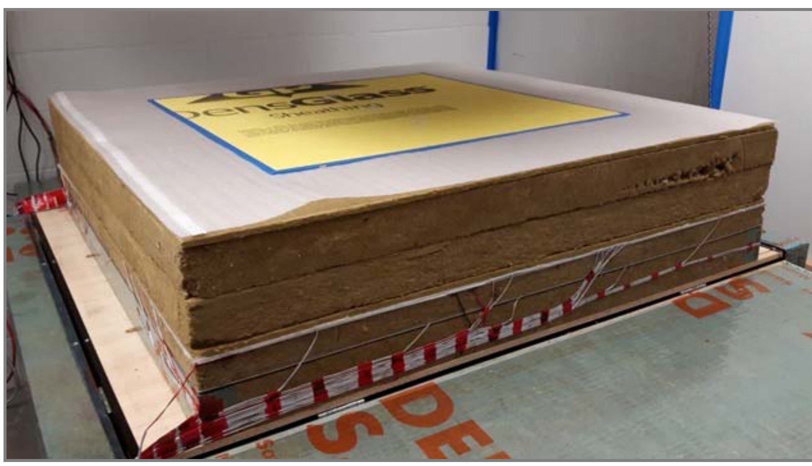

Figure 13 – Polyethylene foam spacer.

Figure 14 – Two polyethylene foam layers (representing an exterior surface film).

Figure 15 –Cold plate installed on top of specimen stack. The edge insulation panels fold up to guard the entire stack from ambient conditions.

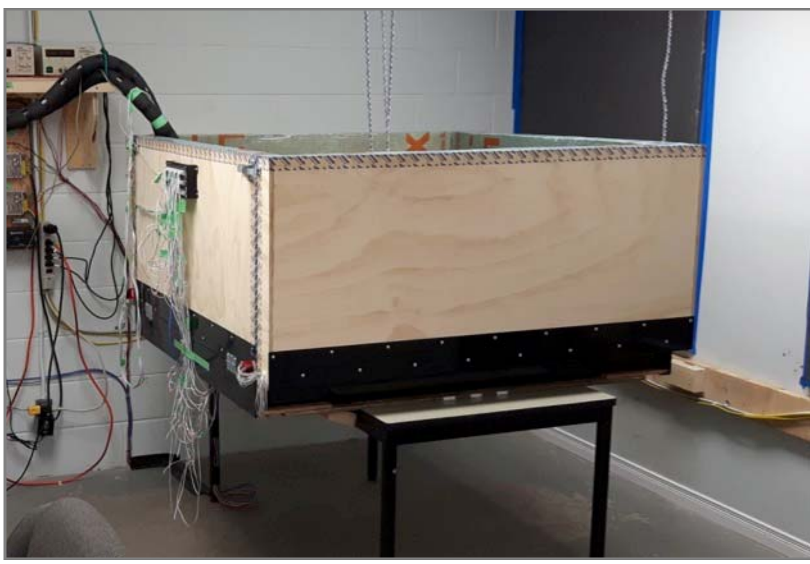

Figure 16 – Apparatus with the edge insulation panels closed around the specimen stack, ready for testing.

1.4 Testing Procedure

For each fiberglass batt specimen, the mock-up wall assembly core was constructed and inserted into the mineral wool guard. For each blown fiberglass specimen, the mock-up wall assembly was constructed in the mineral wool guard. The loose fiberglass was blown through an insulation blower into a large container to fluff it up. Then, the loose insulation was weighed and packed by hand into the assembly in layers to ensure the correct density was achieved. The result is shown in Figure 17.

Figure 17 –Blown fiberglass installed within the R-stud assembly.

For the R-stud stud and track, additional temperature sensors were placed on the stud/track to measure the temperature profile throughout the stud/track. The data from these sensors can later be used for validation and calibration of computer models. Figure 18 and Figure 19 show the additional sensors placed on the R-stud track. Sensors were placed on the R-stud stud in the same pattern.

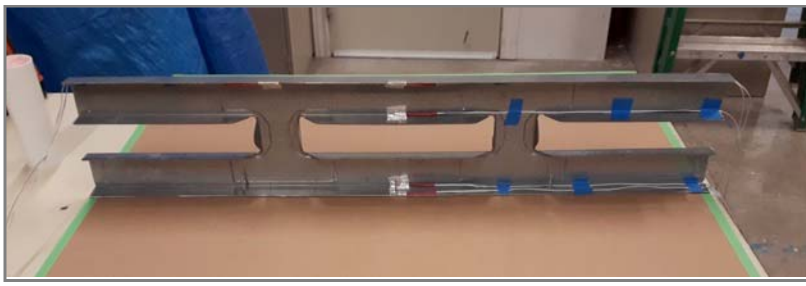

Figure 18 – Additional temperature sensors on the R-stud track.

Figure 19 – Close-up view of the additional sensors at the middle of the track.

After the wall assembly was installed, the top layers of the polyethylene foam and mineral wool guard were added to complete the specimen and then the cold plate was lowered onto the specimen stack. The edge insulation panels were folded up, the hot and cold plates powered on, and the apparatus left to reach equilibrium. Equilibrium was declared when the meter plate power reached a stable value (better than 1% of value) with no increasing or decreasing trends. Equilibrium was generally reached within 1 or 2 days.

Hot and cold plate target temperatures were generally reached within two to three hours from the beginning of each test and remained constant with a standard deviation of better than ±0.005˚C thereafter. An example of the temperature distribution of the hot and cold plates can be seen in Appendix C.

Average values for the power, hot plate temperature, and cold plate temperature at equilibrium over several hours were recorded. The meter area for the apparatus through which heat flow is measured is known to be 255.0 in^2 (164,516 mm^2).

The thickness of each specimen was measured with a ruler in multiple locations around the perimeter of the specimens.

Using the measured power, temperature difference, thickness, and area, the apparent conductance and other thermal performance metrics were calculated.

2 Results

The most important summary testing results are shown in Table 2. The R-value of the polyethylene foam, gypsum board, and Densglass sheathing were measured previously so that their R-value could be subtracted from the measured overall assembly. The R-value of these layers is shown in

Table 3 and the results from Table 2 modified by subtracting the R-value of the gypsum board and foam layers are shown in Table 4.

As can be seen, the fiberglass batt performed at an R-value of R-18.6, and the blown fiberglass at R-24.0. The impact of a standard stud can also clearly be seen: over half of the R-value is lost. The psi-factor (linear transmittance) is about 0.12 for the standard steel stud.

The R-stud results in a psi-factor of 0.040 to 0.044 Btu/hr•ft•˚F (0.070 to 0.076 W/mK): a 40% reduction in thermal bridging.

Table 2 – Thermal testing results for entire test assemblies.

Test #	Description	Thickness (in)	Hot Plate Temp. (°F)	Cold Plate Temp. (°F)	Temp. Diff. (°F)	Mean Temp. (°F)	Power (Btu/hr)	Heat Loss Coefficient (Btu/hr·°F)	Conductance (Btu/hr·ft2·°F)	R-value (hr·ft2·°F /Btu)	Ψ Factor (Btu/hr·ft·°F)
1	FG batt, no stud	7.31	100.0	49.9	82.1	75.0	6.92	0.084	0.048	21.0	-
2	FG batt, standard stud	7.32	100.0	50.1	81.9	75.1	14.44	0.176	0.100	10.0	0.069
3	FG batt, R-stud stud (centered on hole)	7.32	100.0	50.0	82.0	75.0	11.42	0.139	0.079	12.7	0.041
4	FG batt, R-stud stud (centered on leg)	7.32	100.0	50.1	82.0	75.0	11.60	0.141	0.080	12.5	0.043
5	FG batt, R-stud track (centered on hole)	7.32	100.0	50.1	82.0	75.0	11.30	0.138	0.078	12.8	0.040
6	Blown FG, no stud	7.28	100.0	49.9	82.2	75.0	5.51	0.067	0.038	26.4	-
7	Blown FG, standard stud	7.31	100.0	50.0	82.0	75.0	13.61	0.166	0.094	10.7	0.074
8	Blown FG, R-stud stud (centered on hole)	7.30	100.0	50.0	82.1	75.0	10.32	0.126	0.071	14.1	0.044
9	Blown FG, R-stud track (centered on hole)	7.30	100.0	49.9	82.1	75.0	9.90	0.121	0.068	14.7	0.040

Measurements shown in the table represent average values taken at steady state over several hours.

Table 3 – R-value of gypsum board and foam layers.

Assembly Layer	R-value (hr·ft²·°F/Btu)
Two layers of 3/32" thick polyethylene foam (hot side)	0.62
1/2" thick interior gypsum wallboard	0.50
1/2" thick Densglass exterior sheathing	0.56
Two layers of 3/32" thick polyethylene foam (cold side)	0.71

Table 4 – Measured results for cavity insulation (gypsum board and foam layers are subtracted).

Sample	RSI (m^2°C/W)	R-value (hr·ft²·°F/Btu)
Fibreglass batt	3.28	18.6
Blown Fibreglass	4.23	24.0

It is worth noting that because of the lips of the punch-outs in the R-stud system, the batt insulation did not perfectly fill the gaps around the stud which may reduce its thermal performance. Figure 20 shows the gaps created in the R-stud system when batt insulation is used and carefully installed. These gaps could potentially reduce the performance of the assembly slightly.

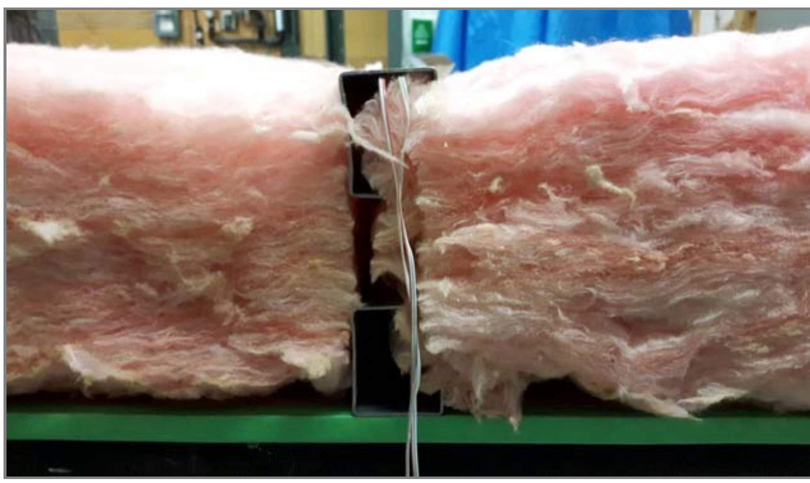

Figure 20 – Gaps around the R-stud stud when batt insulation is used.

3 Conclusions

The results confirmed that a standard steel stud will result in a significant reduction in thermal resistance. Heat flow through a 16" wide section will more than double, and the better the stud space insulation, the larger the percentage reduction.

The R-stud components provided about a 26% improvement in R-value over the standard steel stud when used with fiberglass batt insulation and about a 35% improvement in R-value over the standard stud when used with blown fiberglass insulation. The R-stud components still act as a thermal bridge but reduce the thermal bridging relative to a standard steel stud by about 40%. The Ψ-factor was found to be between 0.040 to 0.044 Btu/hr•ft•˚F (0.070 to 0.076 W/mK) for the R-stud components versus 0.069 and 0.074 Btu/hr•ft•˚F (0.120 and 0.128 W/mK) for the standard stud.

The R-stud stud and track performed similarly to each other.

These measurements did not show any appreciable difference in performance whether the stud was located with the hole or the leg centered over the meter plate.

Please feel free to contact the authors if you have any questions. We would be happy to arrange a conference call to discuss this report at your convenience.

Yours truly,

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Appendix A - Apparatus

A guarded hot plate apparatus is a device that measures the thermal performance of a material by imposing a temperature difference across the material and then by measuring the corresponding heat flow, a thermal conductivity or conductance is calculated. The material is placed between two metal isothermal plates of differing temperatures, called the hot and cold plates. It is called a "guarded" hot plate apparatus because the hot plate is divided into multiple plates and only the heat flow through the center plate, named the meter plate, is used for the thermal conductance calculation. The surrounding plates, named the side guard plates, are controlled to be the exact same temperature as the meter plate to guard the center heat flow from being influenced by ambient temperatures. Heat flow from the meter plate backwards away from the specimen is guarded through the use of a back guard plate controlled to the same temperature as the meter plate. This produces a situation where theoretically all of the heat flow should flow from the meter plate through the specimen towards the cold plate for an accurate measurement of thermal conductance. Figure 21 shows a schematic of the guarded hot plate apparatus in cross-section.

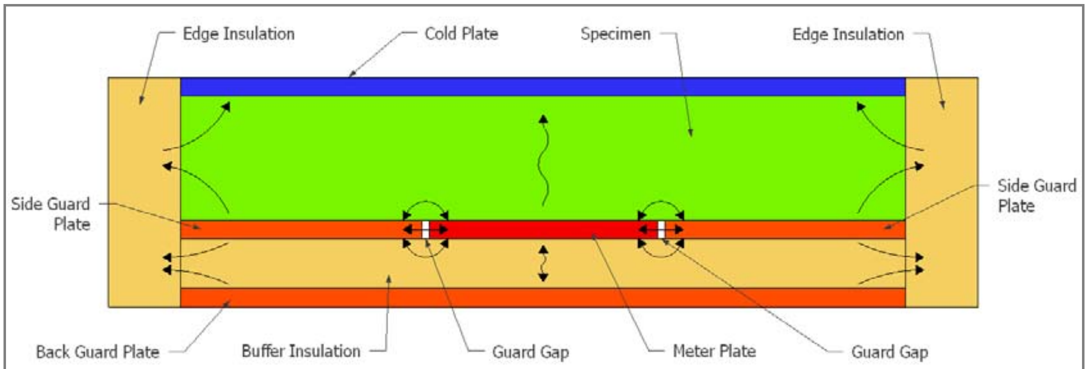

Figure 21 – Cross-section schematic of the guarded hot plate apparatus.

Our guarded hot plate apparatus can measure specimens measuring up to 48" square with a maximum thickness of 16". The meter plate measures 16"x16" which lends itself well to measuring steel stud systems with a 16" on-centre spacing. The meter plate and guards are shown in Figure 22 and the cold plate is shown in Figure 23.

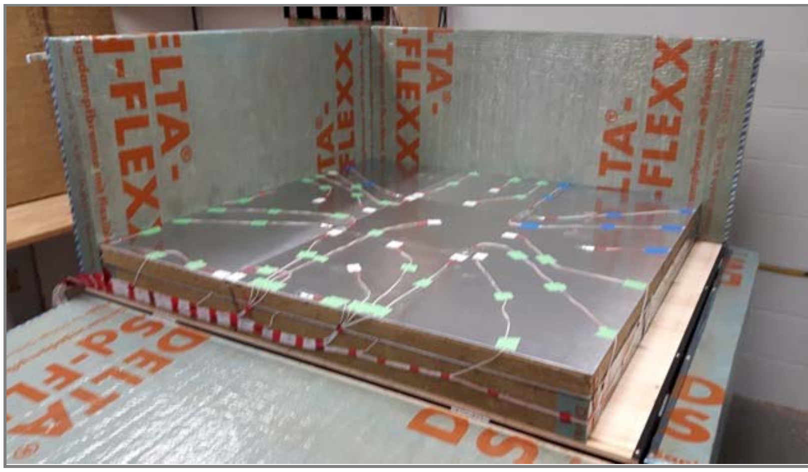

Figure 22 – Meter plate and guards.

Figure 23 – Cold plate.

The complete apparatus with a specimen included is shown in Figure 24 with the edge insulation panels open and in Figure 25 with the edge insulation panels closed.

Figure 24 – Apparatus with the perimeter insulation panels open.

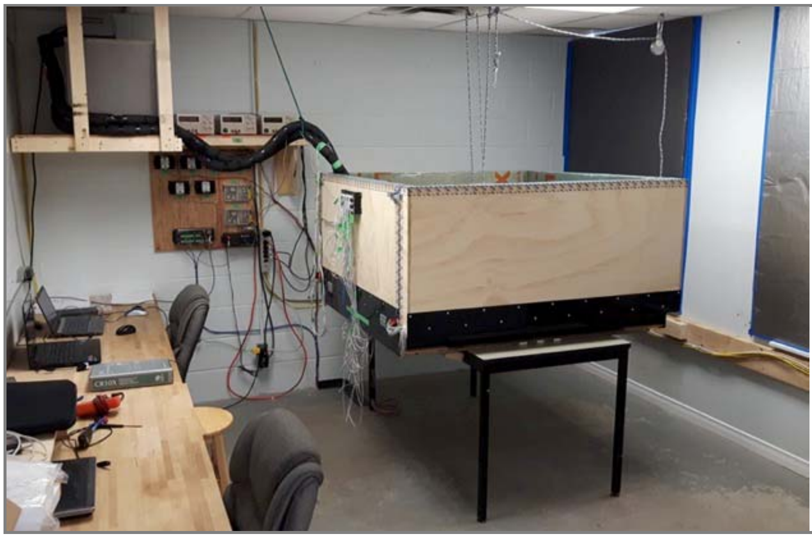

Figure 25 – Apparatus with the perimeter insulation panels closed and ready for testing.

Temperature sensors (thermistors) are placed in numerous locations throughout the apparatus. They are used for control and to check that isothermal conditions are met. The thermistor locations on the back guard, meter plate / side guards, and the cold plate, are shown in Figure 26, Figure 27, and Figure 28, respectively.

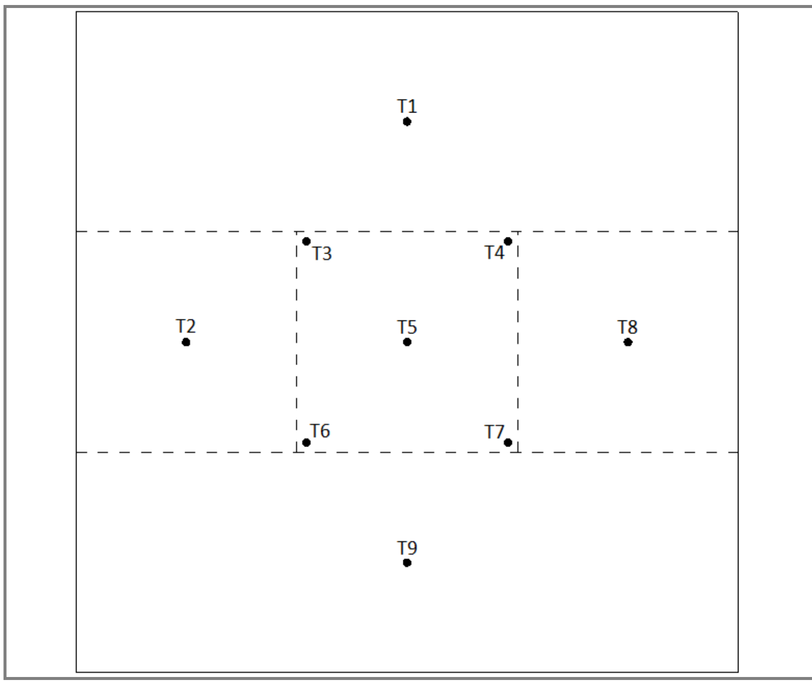

Figure 26 – Thermistor layout on the back guard.

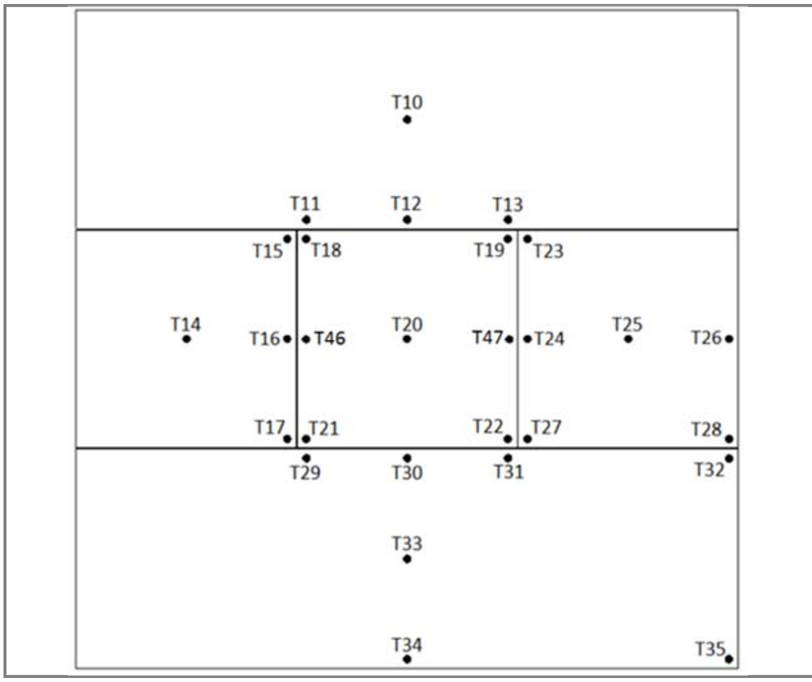

Figure 27 – Thermistor layout on the meter plate and side guards.

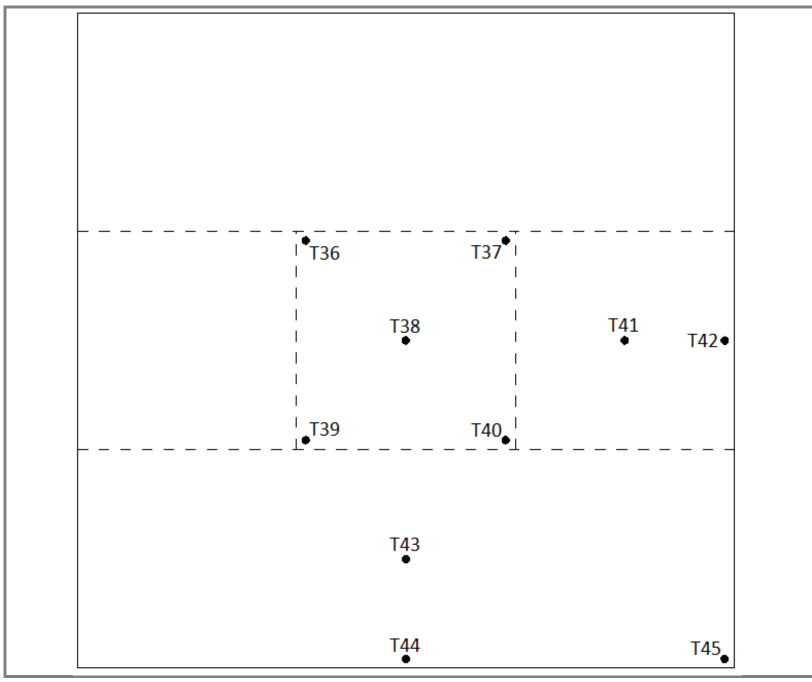

Figure 28 – Thermistor layout on the cold plate.

Temperature measurement of the plates is accurate to ±0.01˚C.

Appendix B – Stud and Track Measurements

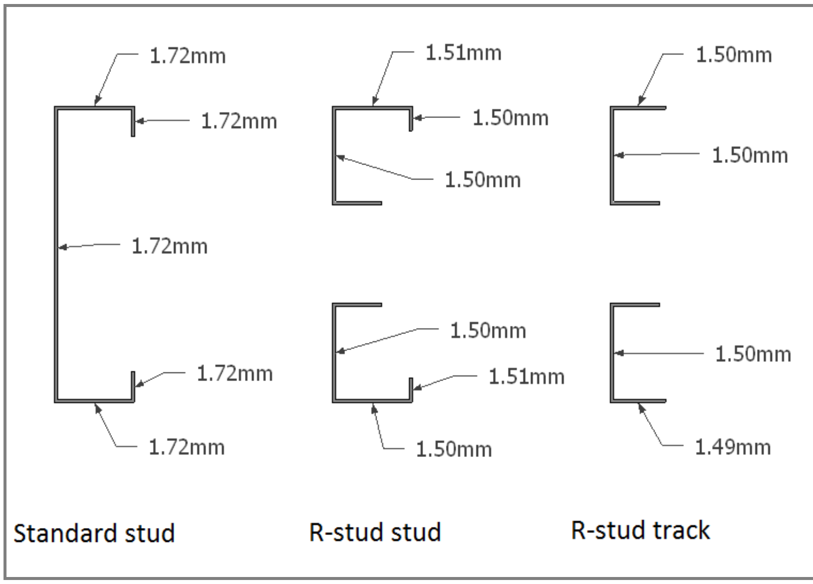

Figure 29 – Measured stud and track thicknesses (cross-sections shown).

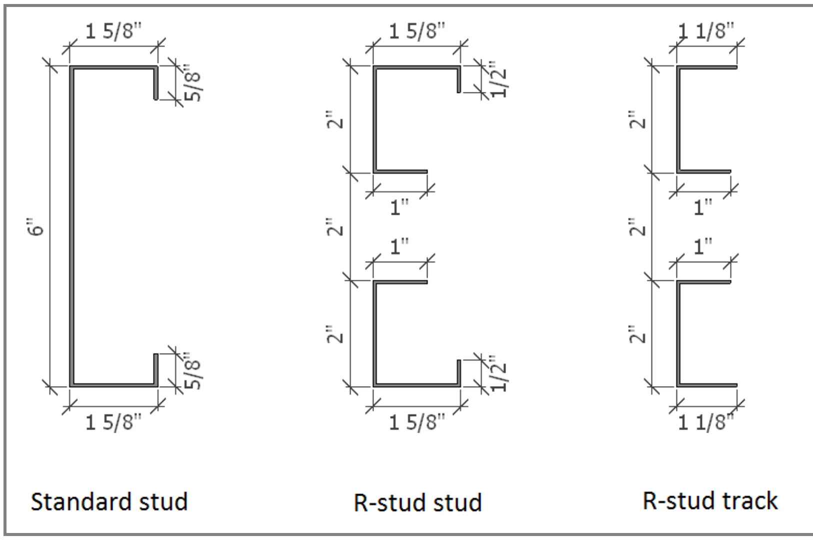

Figure 30 – Measured stud and track dimensions (cross-sections shown)

Appendix C – Temperature Distribution on the Plates

The temperature distribution of the hot and cold plates is shown in Figure 31, Figure 32 and Figure 33. Values shown in these figures are average temperatures at steady state in degrees Celsius.

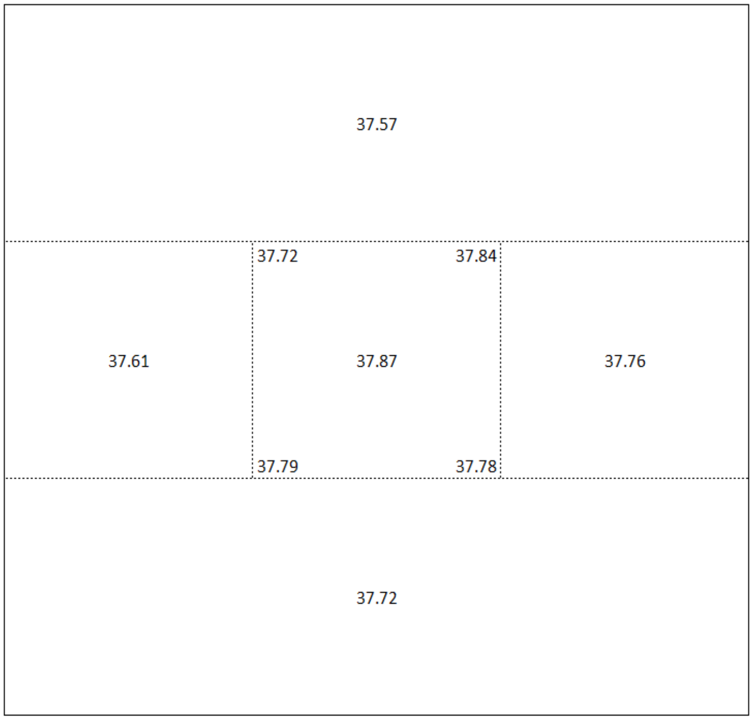

Figure 31 – Example temperature distribution (˚C) on the back guard.

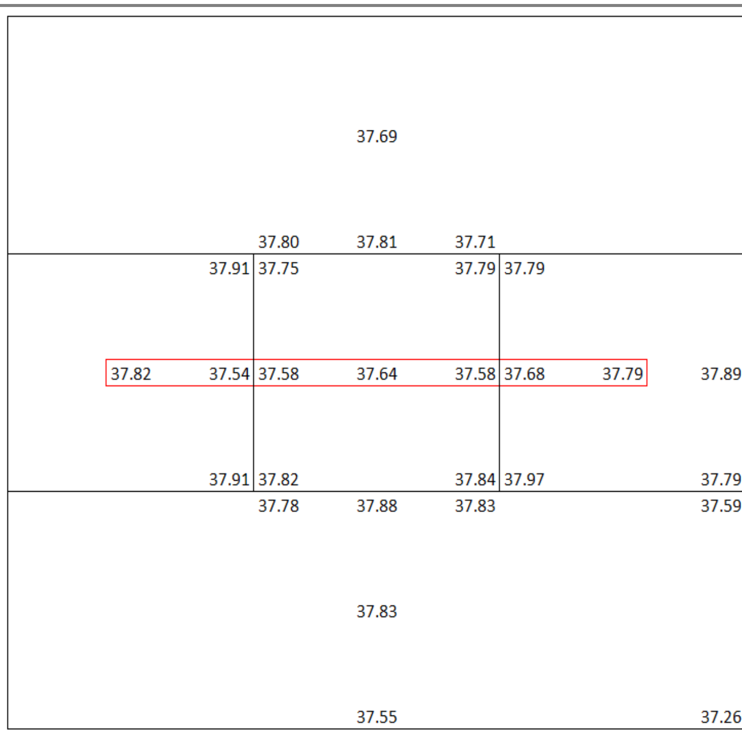

Figure 32 – Temperature distribution (˚C) on the meter plate and side guards. Stud location outlined in red.

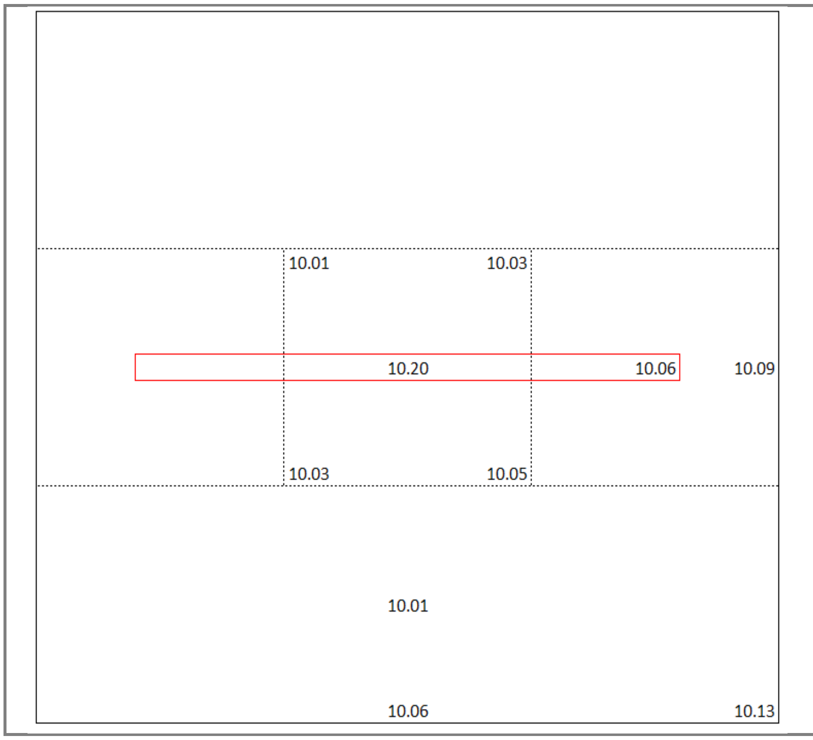

Figure 33 – Temperature distribution (°C) on the cold plate. Stud location outlined in red.