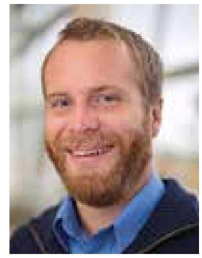
Lab Notes: Thermal Performance of ICF Walls



By Micah Garrett

The thermal performance of insulated concrete form (ICF) walls has been a long-debated topic amongst building industry leaders. ICF companies have touted their performance while cavity wall proponents have argued that their superior performance is purely anecdotal. In 2017, the Insulated Concrete Forms Manufacturing Association (ICFMA) chose to seek hard data behind anecdotes to explain the thermal performance of ICF wall assemblies.

To comprehend the full story, one must first understand the historical code transition for mass walls that transpired between the 2009 and 2018 code cycles. In the 2009 IRC/IBC, mass walls could use less overall insulation in comparison to cavity wall assemblies. This decision was made because mass walls contributed an enhanced benefit to the performance of the wall. This caveat in the code came out of research that was conducted in the 1990s and early 2000s.

One important study that the ICF industry cites was conducted at Oak Ridge National Laboratory called the *Dynamic Thermal Performance of Concrete and Masonry Walls*. The study modeled

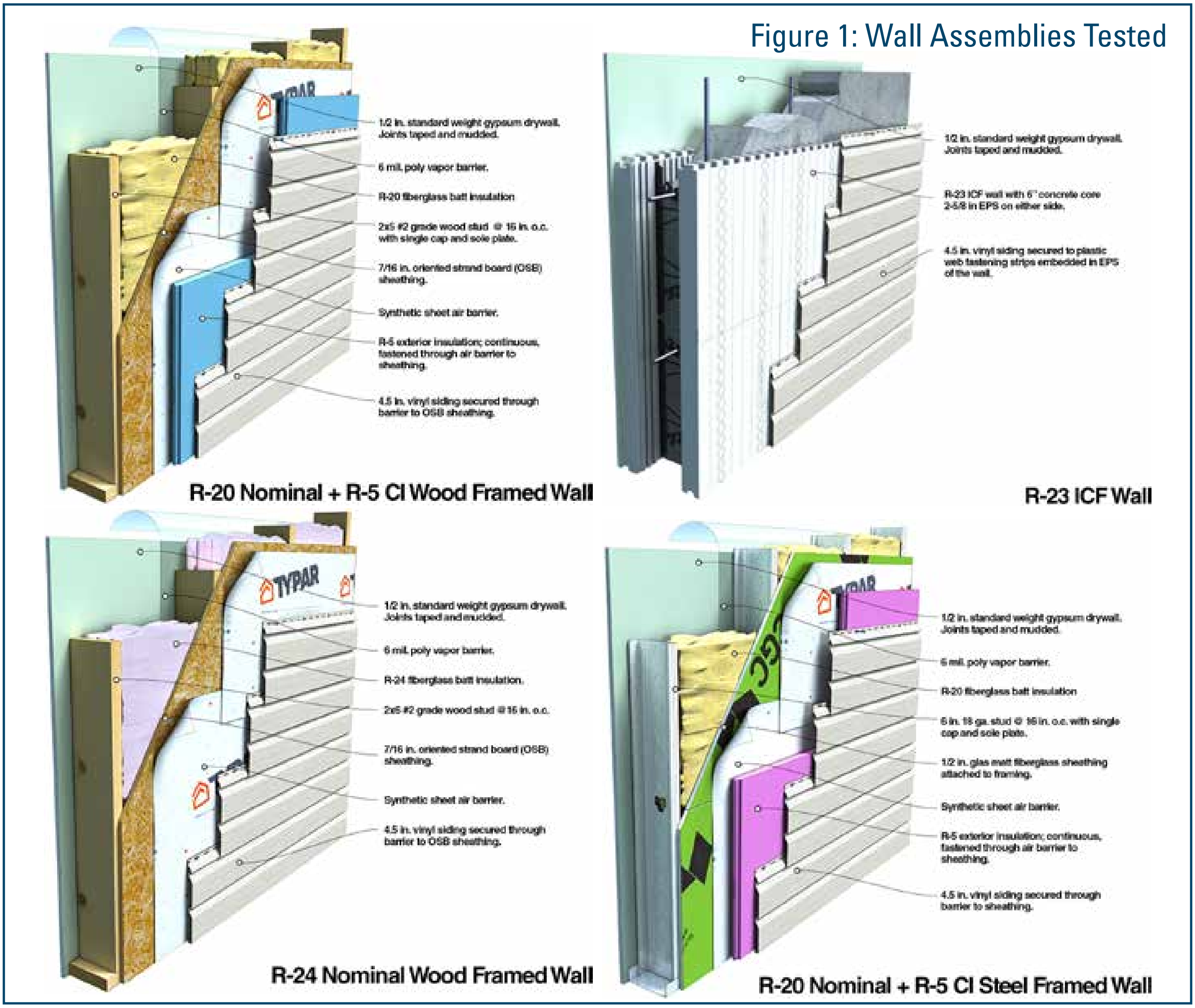


Figure 1: Wall Assemblies Tested

several uniform concrete structures with mass walls and four different insulation configurations—on the inside, outside, both sides and without insulation—in several different climate zones. Control groups were established and cross tested with modeled calculations used in the software against actual hot-box data collected from several of the assemblies. The results found that structures with insulation on the outside of the mass wall performed better than some of the other configurations.

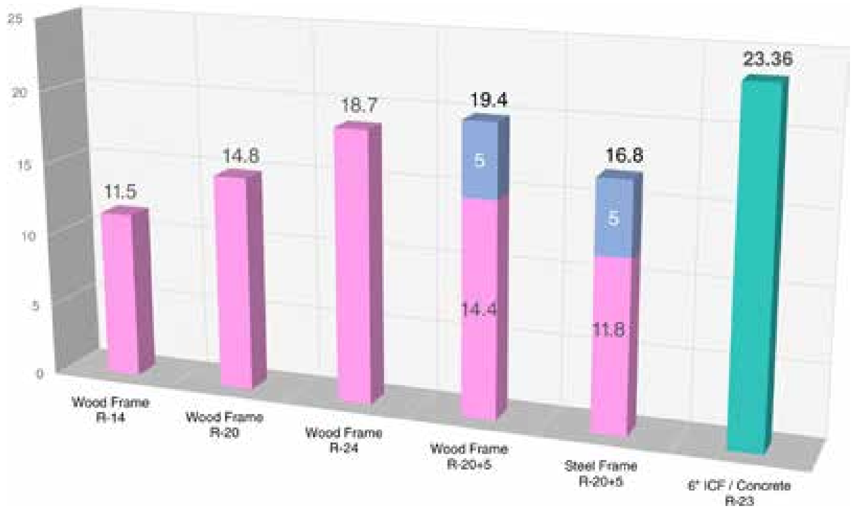
A later study at Oak Ridge National Laboratory confirmed these results and went further to compare the results to cavity wall performance. This study, *Influence of Building Design on Energy Benefit of Thermal Mass Compared to Prescriptive U-Factors*, confirmed the enhanced performance of mass walls with insulation on the outside and further validated that mass wall performance was superior to cavity wall construction.

Research such as these reaffirmed the 2009 ICC decision to allow less overall insulation for mass walls and demonstrated that continuous insulation on the outside of structures is one of the best ways to improve the energy performance of buildings, especially those in colder climate zones. Continuous insulation reduces the effects of thermal bridging. When looking at the 2012 and 2015 IRC/IBC, similar research was applied to cavity wall construction resulting in continuous exterior insulation along with air barriers becoming an acceptable practice to improve the performance of framed walls.

In recognition of this changing market dynamic, the members of the ICFMA joined to commission independent rigorous testing of ICF wall assemblies. The first study, called the CLEB Study, evaluated the performance of an ICF wall assembly compared to a code-compliant 2x6 cavity wall assembly. This study confirmed not only the performance contribution from continuous insulation, but demonstrated that mass walls performed significantly better than cavity walls with batt insulation. (See "New Study Quantifies Thermal Mass Benefits" in the May 2017 issue or online at *www.icfmag.com*.)

After evaluating these results, the ICF-MA commissioned two additional studies evaluating an ICF assembly in comparison to several different wood and steel-framed cavity assemblies; especially assemblies that use continuous insulation. The next study solicited CAN Best Laboratories in Ontario to conduct a series of guarded hot-box thermal tests to compare ICF wall performance with cavity wall assemblies that are currently in use and code compliant in both USA and Canada. The assemblies tested are shown in Figure 1. For the third study, ICFMA solicited RDH Building Science Laboratories to examine the airtightness of existing ICF structures using blower door technology to test the air changes per hour (ACH) performance of existing ICF structures in comparison to a large body of research conducted on structures built with wood-framed cavity walls.

Figure 2: Assembly Type & Nominal R-Value



CAN Best created a guarded hot box test by placing a wall section without windows inside a sealed chamber, with the wall assembly splitting the chamber into two distinct sides. One side of the chamber blows continuous hot or cold air, mimicking outdoor elements, while the other side with a calorimeter is kept at a constant controlled temperature, mimicking an occupied home. To test the performance of an assembly in cold weather, the blowing side has a temperature of -31° F and the controlled side has a controlled temperature of 72° F. To test the performance of an assembly in hot weather, the temperature on the blowing side is 131° F and the controlled side is 72° F. Temperature gauges were placed in the wall assembly to monitor any temperature fluctuation throughout the wall during the experiment.

Once the test is begun, air is blown at a continuous rate at the stated temperature and additional energy is added to the temperature-controlled side to keep it at a constant temperature of 72° F. The temperature in the wall is then continuously measured until it no longer changes temperature. The controlled side is also monitored to find a state of equilibrium where a fixed amount of energy can be applied to maintain the temperature of the chamber and wall. This point in the experiment is called steady state and allows for several calculations to be made. The first value is a calculation of R-value. The second is the amount of energy input that is needed to maintain equilibrium. The amount of time it takes for the experiment to arrive at steady state is also noted.

Five total assemblies were tested in heating mode, and a sixth data point was added from the prior CLEB study. Figure 2 shows the calculated results of the R-value of each assembly at steady state. Every cavity wall tested performed worse than the expected R-value based on the materials used in the assembly. For example, the cavity wall with R-20 batt insulation might have been expected to perform at or near an R-20. In reality it performed closer to an R-14.8. On a percentage basis this is nearly 25% less overall R-value. The ICF wall however, performed at or slightly better than its material basis. In the test case, the assembly performed at an R-23.36 when its actual R-Value is an R-23. This result shows that thermal bridging is still a significant problem for cavity walls. Even when continuous insulation is used on a cavity wall, it is still unable to achieve a comparable performance to an ICF wall. The study also confirms that the steel stud wall, which comprises a significant amount of commercial construction, performs worse than an equivalent wood wall.

At steady state, the total energy input into the controlled side of the wall was calculated. When an assembly can achieve a higher R-value, less overall energy is needed to maintain a stable temperature. Over the duration of the experiment, total energy usage is also calculated. Since the ICF wall slowly moves towards steady state, it consumes significantly less energy over the same time period. For the end customer, this translates into actual savings on heating or cooling bills, and additional cost savings such as allowing the reduction of the HVAC equipment used in the structure.

The last data set that can be pulled from the research is the amount of time it takes for a wall assembly to move towards steady state. See Figure 3. In heating mode, most assemblies move towards steady state in 12 hours or less. This means that when a cold front moves through a region, a wood or steel structure will quickly need energy to keep the building at a stable temperature. The structure becomes little more than a sophisticated tent. In contrast, an ICF wall dramatically resists temperature change, due to stored energy in its mass. While the best built cavity wall with continuous insulation was able to achieve a steady state time of 54 hours, it pales in comparison to the result of the ICF wall at 144 hours.

The time to steady state data confirms the enhanced benefit argument. The stored energy in a mass wall acts like a thermal battery. The wall temperature in the concrete trapped on both sides by EPS insulation changes its temperature very slowly. This partnership allows the wall to resist major temperature swings in the environment. Additionally, because of the ICF's airtightness, a structure will retain its warm or conditioned air much longer. In a power outage situation, an ICF structure will be significantly more resilient. Douglas Bennion, chair of the ICFMA technical committee suggests, "An ICF structure gives an 'ART,' advanced response time, which means you can shelter in place for longer periods of time during a power outage or extreme climate event."

The third study by RDH Laboratories examined the air tightness of 49 ICF structures in comparison to blower door data collected on nearly 230,000 wood

Figure 3: Hours to Reach Equilibrium

structures throughout the US and Canada. They additionally took data sets from a prior ORNL study and MIT study on the airtightness of ICF structures to compare with the new research results. In summary, they found that wood structures built between 2002 and 2012 had an average ACH rating of 4.8, while the ICF structures studied had an average ACH rating of 1.26. This performance confirms that a monolithic concrete wall with insulation on both sides significantly improves the air tightness of a structure. As building codes are evolving, the focus is shifting to the control of unregulated air flow through the building shell, rather than increasing the amount of insulation. Insulation in terms of contribution to the thermal envelope is considered less important than air intrusion. ICF walls have been shown to eliminate unregulated air flow in clear-wall areas, leaving only doors, windows and other connections to contend with.

When these studies are used in conjunction, they demonstrate the effectiveness of an insulated mass wall. As the building science community continues to search for more energy efficient building materials, it should be noted that ICF walls demonstrate a strong historical track record. They perform better than cavity walls, maintain their R-value over time, and consistently resist temperature fluctuation because of stored energy. ICF structures require less overall energy to heat or cool, and the longer time required to reach steady state "flattens the temperature curve" delivering safety, comfort and less cost to the end user.

Micah Garrett is chair of the ICFMA education committee and COO at BuildBlock Building Systems. ■

TEST REPORT

Thermal performance testing on
2x6 Wood Stud Wall (R24/RSI 4.22 Batts)

Performed in accordance with ASTM C1363-11

"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus".

Report No. L18-1248-5292-1H
Report Date: August 16, 2019

Prepared for:
ICFMA
(Insulating Concrete Forms Manufacturers Association)
www.icfma.org

Heating Load Test Results	***IMP***	**SI**
Exterior Ambient Temperature	*-31.0°F*	-35.0°C
Interior Ambient Temperature	*71.7°F*	22.1°C
Thermal Resistance (R-Value) *Btu/hr/ft²/°F* (W/m²/°K)	***18.67***	**3.29**

Respectfully submitted by:

CANADIAN BUILDING ENVELOPE Science and Technology (CAN-BEST)

Report Authorized by:

Elie Alkhoury, M.Eng.(Building Science), P.Eng.

- This report does not constitute certification of the test product. The reported test results refer only to the specimen tested. No representation is made that other samples of similar design will feature like performance.
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1 Introduction

Canadian Building Envelope Science and Technology (CAN-BEST) was retained by the Insulating Concrete Forms Manufacturers Association (ICFMA) to carry out thermal performance testing on one 2x6 wood stud wall with stud cavities insulated with friction fit R24 fiberglass batts.

Testing was carried out on one 8' by 8' (2440 mm x 2440 mm) panel in a Guarded Hot Box (GHB) in accordance with ASTM C1363-11 *"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus"*. Detailed description of CAN-BEST's GHB is found in Appendix (A).

As per Client request, the primary units used in this report are Imperial followed by SI.

Testing was carried out in a Heating Load mode at exterior and interior ambient nominal air temperatures of -31°F and 72°F (-35°C and 22°C) respectively.

2 Panel Description *(as provided by Client)*

Panel Designation: 2x6 Wood Stud Wall (R24/RSI 4.22 Batts)

Details of panel construction are provided in drawings found in Appendix (B), and summarized as follows (wall construction from interior to exterior):

- *½" (12.7 mm) thick standard weight gypsum board (CGC Brand) secured directly through vapor barrier to wood studs with No. 6 x 2" (3.6 mm x 50 mm) long coarse thread screws. Joints taped and mudded.*
- *6 mil (0.152 mm) polyethylene vapor barrier stapled to frame members with Standard C shaped metal staples*
- *2"x6" (38x140) #2 Grade Spruce Wood Stud Framing consisting of single cap plate and single sole plate c/w with studs installed at 16" (400 mm) o/c. (No window jack studs or headers).*
- *R24 (5 ½" (140mm) thick) John Mansville Brand (white) Fiberglas dense insulation batts friction fit in gaps between studs*
- *7/16" (11mm) thick std. OSB sheathing screwed/nailed to stud wall per code.*
- *Rona®/Typar® brand, polypropylene/spun bonded polyolefin fabric/sheet air barrier (ICC-ES/ESR-1404/CCMC No. 12884-R)*
- *Standard D4.5DL double 4.5 inch (114mm) Dutch lap white vinyl siding secured directly through air barrier to OSB sheathing with No. 6 x 2" (3.6mm x 50mm) long coarse thread screws.*

3 Panel Construction

The test panel was constructed by the Client at their facilities, and delivered fully assembled to CAN-BEST Laboratory in Brampton, Ontario.

Panel installation in test frame and instrumentation are performed by CAN-BEST staff members. Prior to testing, the test panel was conditioned at laboratory's environment for a minimum period of Two weeks.

4 Test Procedure

Testing is carried out in a Guarded Hot Box (GHB) that employs two full-scale environmental chambers simulating the required weather and room side test conditions.

Panel Preparation – The test panel was mounted in an opening made in a highly insulated 12" (300 mm) thick rigid EPS foam surrounding mask, held in a steel test frame that interfaces with both sides of the GHB’s environmental chambers. The panel’s perimeter was then sealed to the surrounding mask using expandable polyurethane foam and tape in order to eliminate through panel air leakage.

Panel Instrumentation - The surface temperatures of the test panel were measured using Gauge 30, Type "T" thermocouple temperature sensors. A total of 24 sensors were applied to the panel's interior and exterior surfaces (12 on each side).

All measurements of temperature, input energy, pressure difference across the panel, exterior wind speed and interior convective air speed were monitored continuously at the rate of once per second and their 600-second averages were logged once per 10 minutes.

5 Test Results

Detailed test results and calculation of thermal performance parameters such as Thermal Conductance (C-Value, surface to surface), Thermal Transmittance (U-Value, air to air) and Thermal Resistance (R-Value, air to air) are provided in Appendix (C), and summarized in Table (1).

The power input is measured in BTU/h (Watt), and demand for power is inversely proportional with the panel's Heat Flow Resistance (HFR). The panel's R-Value is in essence a measure of its HFR taken when the steady state condition has been met.

The panel's thermal resistance (R-Value) is derived from the following measurements, all taken at steady state condition, stabilized for both temperature and power:

- panel's interior and exterior surface temperatures,
- exterior and interior ambient test temperatures, and
- power input.

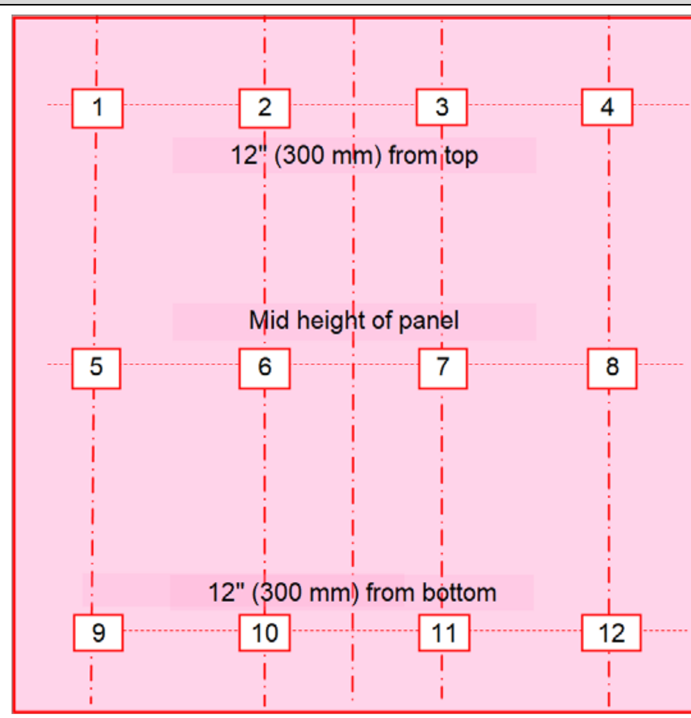
Plots of the power input, monitored over the entire duration of test period, and the panel's corresponding HFR are provided in Figures 1a/1b respectively (2a/2b for metric).

Table (1) Thermal Performance Test Results
Heating Load at -31°F and 72°F (-35°C and 22°C) Ext. and Int. Temperatures

Thermal Conductance/Transmittance		BTU/hr/ft²/°F	W/m²/°C
C	Specimen Surface to Surface Thermal Conductance	0.056	0.319
U_{st}^{*}	Standard Specimen Overall Thermal Transmittance	0.054	0.304
Thermal Resistance		°F.ft².hr/BTU	°C.m²/W
R_{st}^{*}	Standard Specimen Overall Thermal Resistance	18.67	3.29

TC #	Surface Temperatures			
	°F		°C	
	Int.	Ext.	Int.	Ext.
1	68.3	-28.9	20.2	-33.8
2	68.2	-29.3	20.1	-34.0
3	68.3	-29.1	20.2	-34.0
4	69.3	-29.3	20.7	-34.0
5	66.2	-29.2	19.0	-34.0
6	67.2	-29.7	19.5	-34.3
7	65.5	-29.8	18.6	-34.4
8	67.5	-29.2	19.7	-34.0
9	66.8	-28.7	19.3	-33.7
10	67.3	-29.7	19.6	-34.3
11	65.2	-30.1	18.4	-34.5
12	67.1	-30.4	19.5	-34.6
Avg.	67.2	-29.5	19.6	-34.1

Interior surface temperatures and thermocouple locations as viewed from interior side



* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/°K for cold and warm sides respectively.*

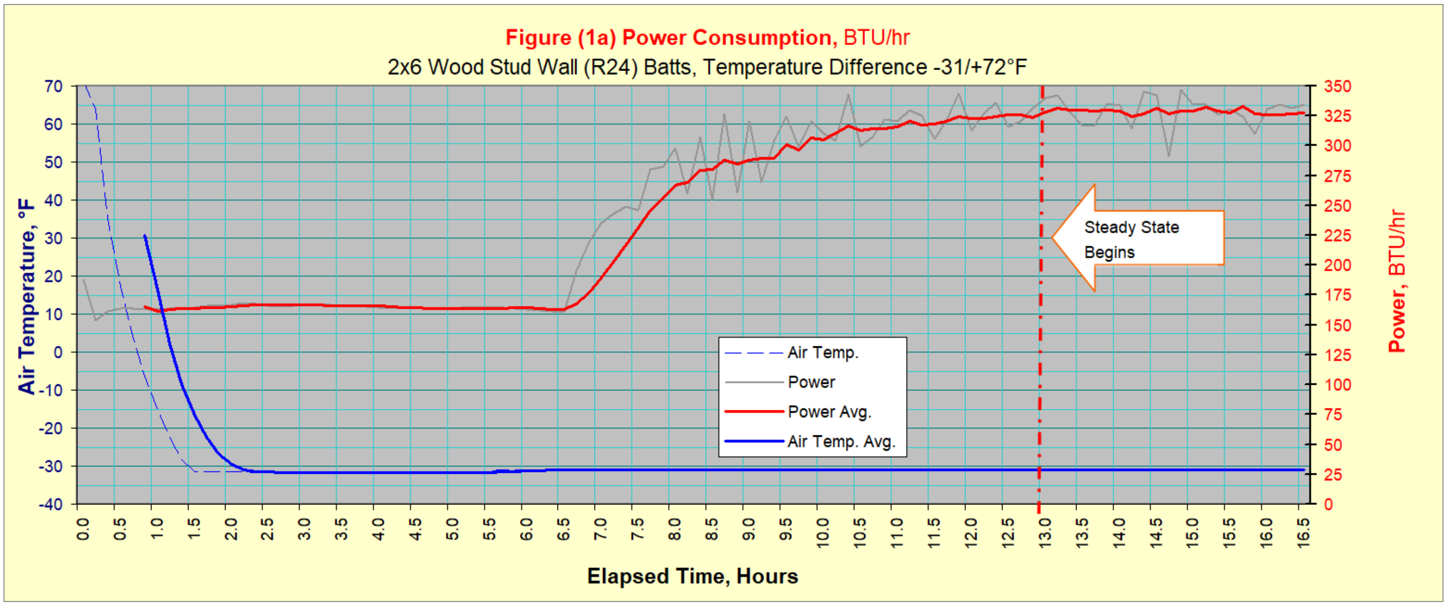


Figure (1a) Power Consumption, BTU/hr
2x6 Wood Stud Wall (R24) Batts, Temperature Difference -31/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
Steady State Begins
Air Temp.
Power
Power Avg.
Air Temp. Avg.

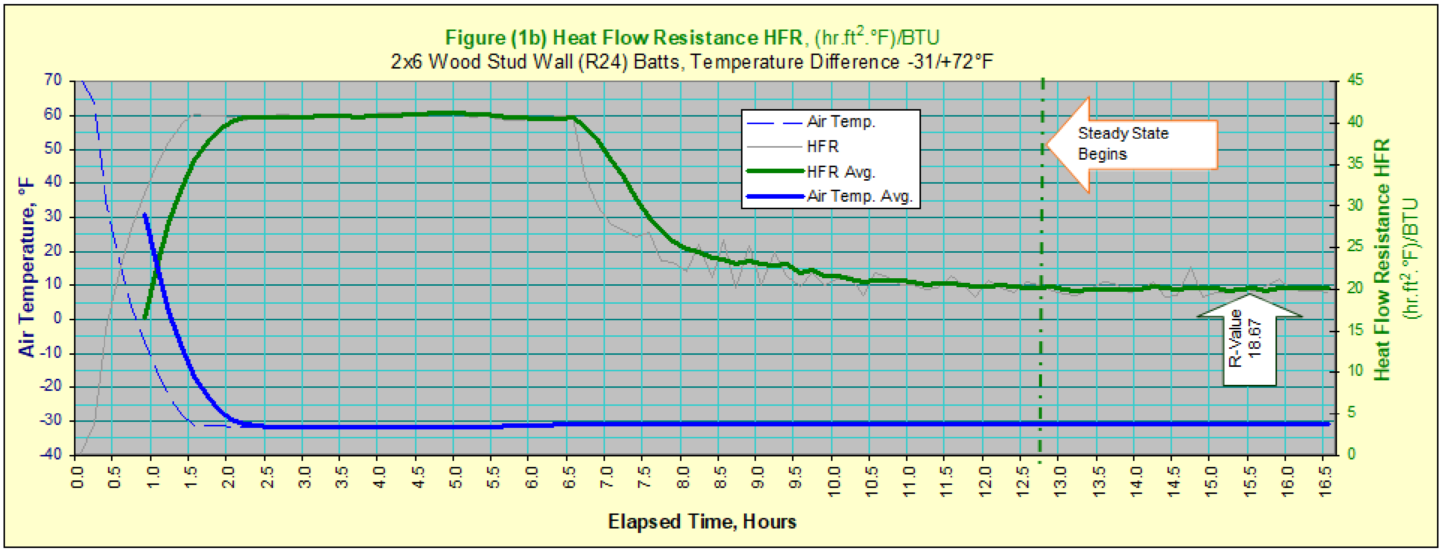


Figure (1b) Heat Flow Resistance HFR, (hr.ft2.°F)/BTU
2x6 Wood Stud Wall (R24) Batts, Temperature Difference -31/+72°F
Air Temperature, °F
Heat Flow Resistance HFR (hr.ft2.°F)/BTU
Elapsed Time, Hours
Steady State Begins
R-Value 18.67
Air Temp.
HFR
HFR Avg.
Air Temp. Avg.

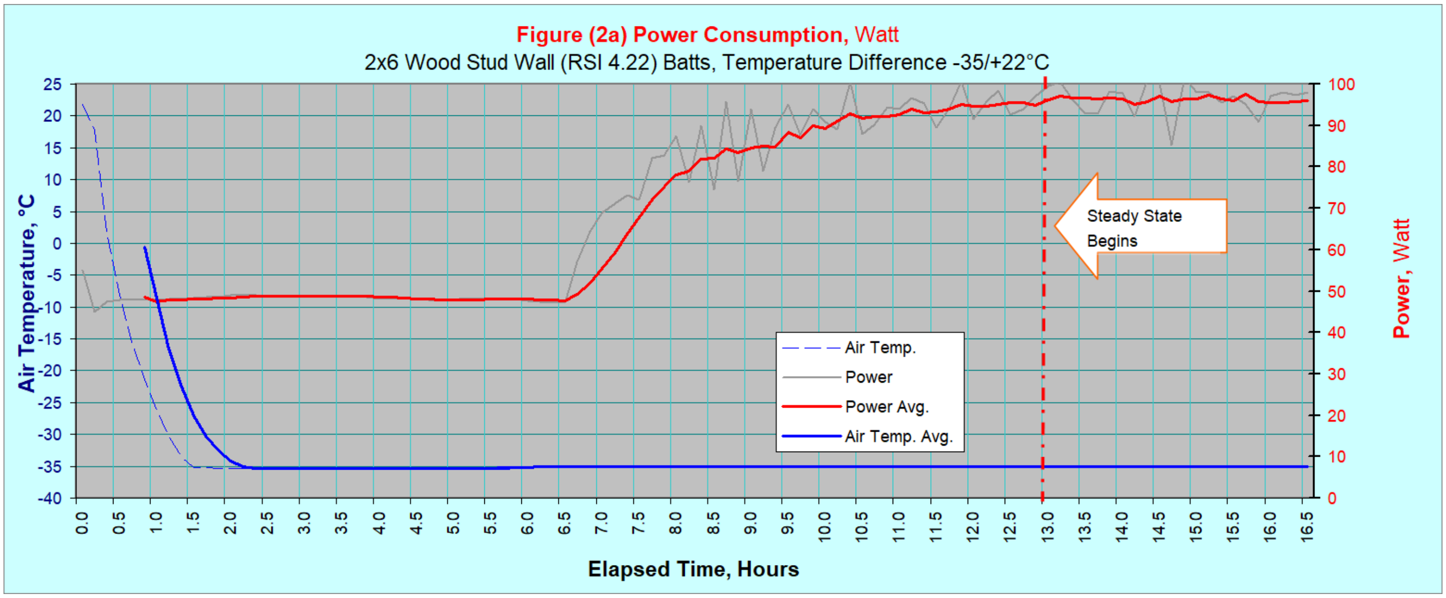


Figure (2a) Power Consumption, Watt
2x6 Wood Stud Wall (RSI 4.22) Batts, Temperature Difference -35/+22°C
Air Temperature, °C
Power, Watt
Elapsed Time, Hours
Steady State Begins
Air Temp.
Power
Power Avg.
Air Temp. Avg.

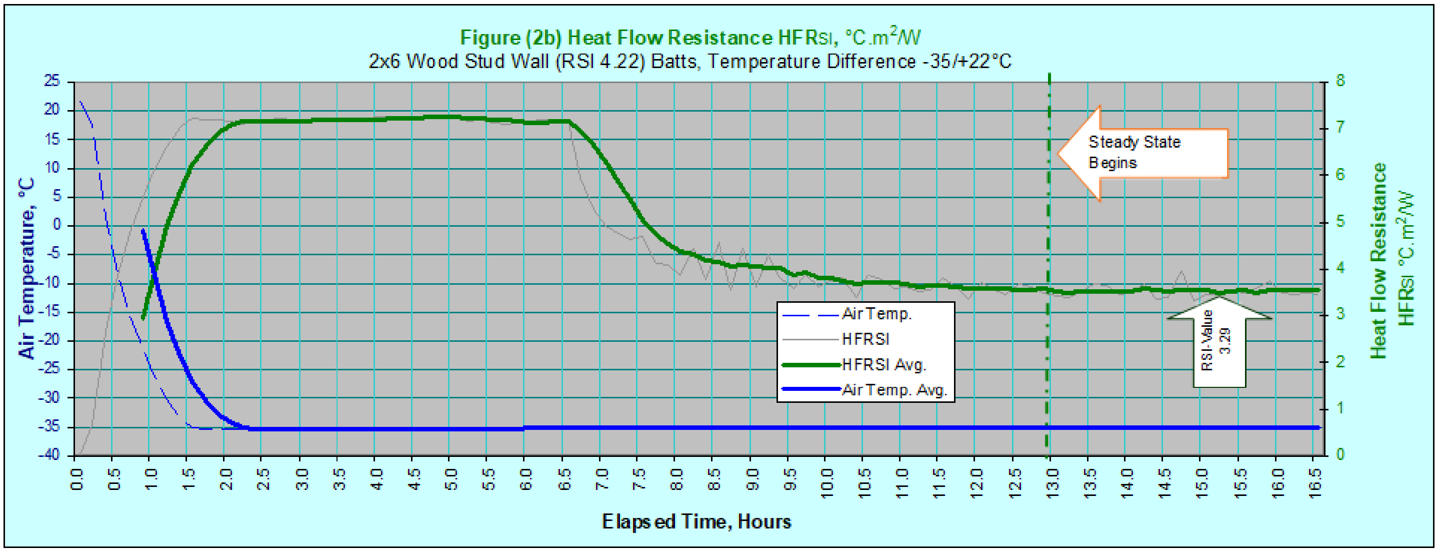


Figure (2b) Heat Flow Resistance HFRSI, °C.m²/W
2x6 Wood Stud Wall (RSI 4.22) Batts, Temperature Difference -35/+22°C
Air Temperature, °C
Heat Flow Resistance HFRSI °C.m²/W
Elapsed Time, Hours
Steady State Begins
RSI-Value 3.29
Air Temp.
HFRSI
HFRSI Avg.
Air Temp. Avg.

6 Conclusion

Based on the test results, the derived thermal resistance of test panel is:

R-Value: **18.67** ^{o}F.ft^{2}.h/BTU

RSI: 3.29 ^{o}C.m^{2}/W *(to convert RSI to R-Value, multiply by 5.678)*

Report History

Revision No.	Change	Date	Approved by
---	Original report issued	August 16, 2019	EA

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Appendix (A)

CAN-BEST's Guarded Hot Box

CAN-BEST operates an ISO 17025, SCC accredited full-scale Guarded Hot Box Facility (GHB) facility that lends itself suitably to perform all the testing required for the evaluation program. As shown in Figure (A.1), the facility comprises the following main components:

- Fixed weather-side environmental chamber fitted with a wind machine.
- A matching moveable room side environmental chamber fitted with a large-scale calorimeter (energy metering box),
- A test panel holding frame with a 3 m x 3 m opening that, during testing, would be sandwiched between the weather side and room side chambers of the GHB. The frame is fitted with a highly insulated perimeter mask that surrounds the test panel in order to eliminate undesirable lateral and flanking heat losses through its perimeter, and
- Instrumentation and computer software to monitor, control and log all measured temperatures, wind speeds, heat flow and other test parameters.

Weather-Side Environmental Chamber
The weather side (or exterior side) of CAN-BEST's GHB is a fixed environmental chamber fitted with a perpendicular wind machine as shown in Figure (A.1). The wind machine is capable of applying onto the test surface a perpendicular wind at various speed levels in a controlled and repeatable manner. Uniform wind delivery is achieved via adjustable tubes that are equally spaced over the entire test area. The wind machine is computer controlled to generate wind speeds of up to 8 m/s that can be varied in infinitesimal increments of 0.01 m/s (0.03 kph).

The generated wind speed is continuously monitored using permanently attached wind velocity sensors that are positioned onto the tip of strategically located wind delivery tubes. These sensors provide means of a closed feedback loop for controlling the wind machine's output in real time.

Room-Side Environmental Chamber
The room side (or interior side) of the GHB is a moveable environmental chamber that "Guards" a large-scale calorimeter (energy metering box). This calorimeter, being possibly the largest in Canada, has an effective metering area of up to 2440 mm wide by 2740 mm high (8' x 9').

The Guard Room maintains an ambient temperature surrounding the calorimeter constant and at the same level as its interior ambient test temperature. In order to minimize the extraneous heat loss/gain through the calorimeter, the Guard room temperature is controlled to limit the temperature difference across its walls to a minimum.

As shown in Figure (A.1), the calorimeter is fitted with a "Constant Temperature Baffle" with a known surface emissivity, positioned parallel to and facing the test panel. This provides means of heat loss/gain correction due to radiation exchange that may take place with the test wall.

Test Panel Holding Frame
The test panel holding frame is a mobile steel frame capable of holding a test panel up to 3124 mm square (123" square). As shown in Figure (A.2), the frame is fitted with a highly insulated perimeter mask (surround panel) required to minimize lateral and flanking heat losses through the test panel's perimeter. The mask is fitted with an opening that can accommodate the test panel, and with the panel installed, the frame is positioned "sandwiched" between the weather side and room side of the GHB.

GHB Instrumentation
The CAN-BEST GHB is fitted with state of the art instrumentation package that meet or exceed the performance requirements of ASTM C1363 standard as follows:

- Temperature sensors – Thermocouple wire, Gauge 30, Type T,
- Wind speed sensors placed at strategic locations to monitor and control both the applied wind speed in the weather side chamber and the natural convection developed in the room side chamber,
- Differential pressure sensor to monitor and control the static pressure difference across the test panel,
- RH sensor, placed inside the calorimeter to monitor and control the interior's ambient relative humidity,
- Means of de-humidification of the interior's ambient condition in order to prevent condensation from taking place on the temperature sensors that would interfere with their measurements, and
- Computerized monitoring and control software that allows changing any of the test parameters "on the fly" without interruption of the test progress. Data from all sensors are acquired continuously once every second, using 24 bit data acquisition system averaged over 600 seconds and logged every 10 minutes.

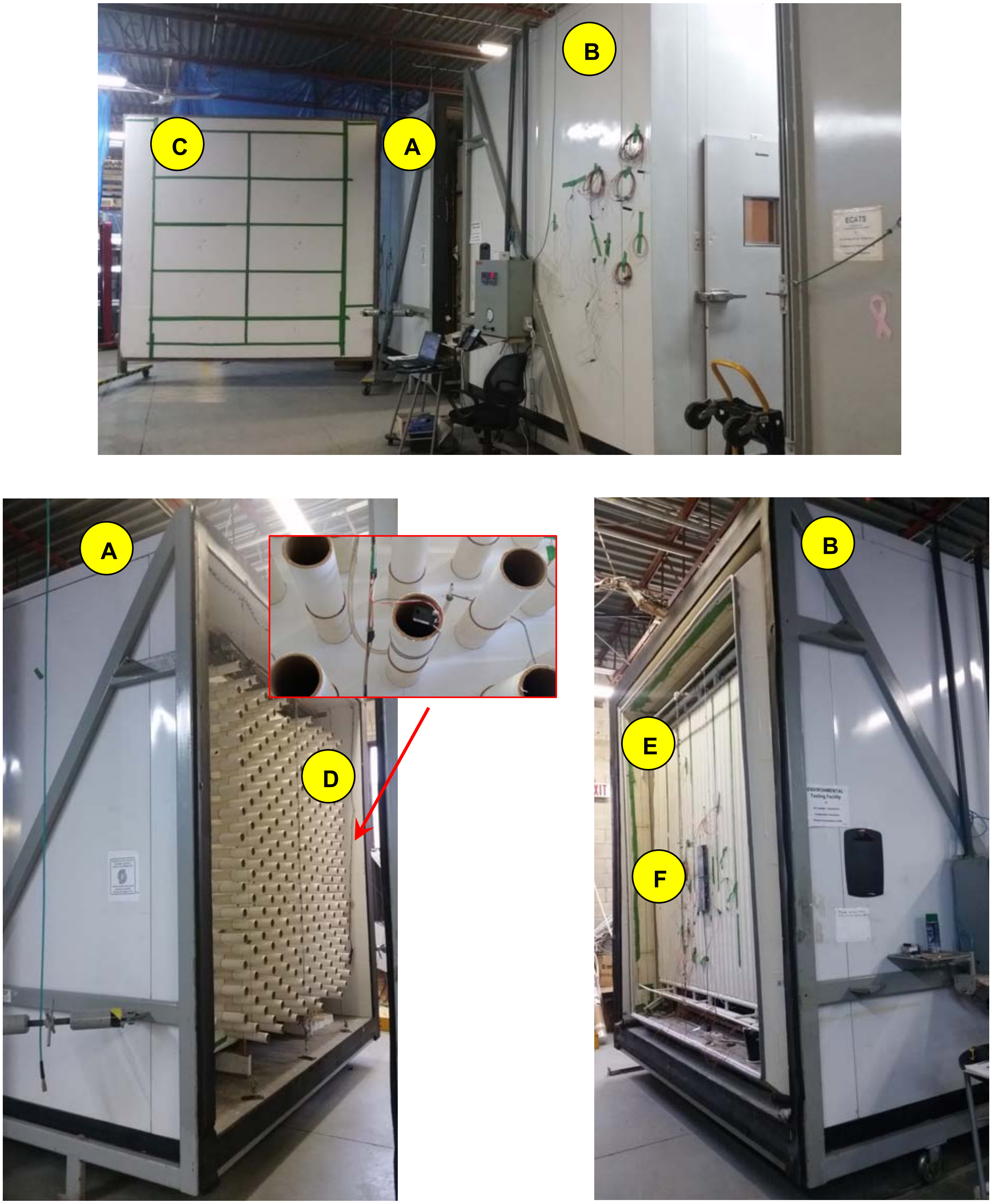
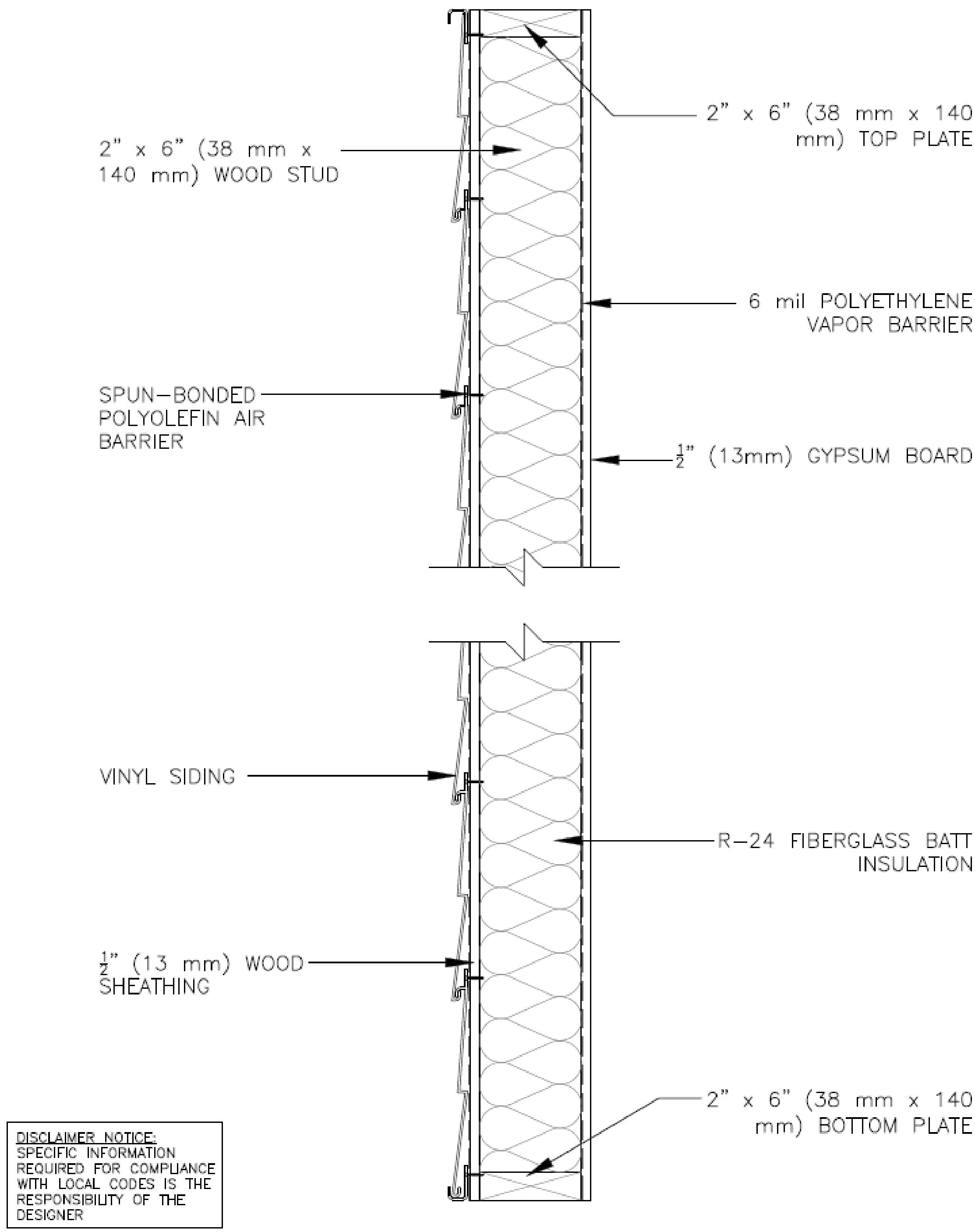


Figure (A.1): CAN-BEST Guarded Hot Box Setup
A – Weather Side Chambre, showing wind machine (D) with wind velocity sensor mounted (inset)
B – Room Side Chambre, showing Calorimeter (E) and Constant Temperature Baffle (F)
C – Test Frame, showing perimeter mask and installed calibration panel

Appendix (B) Drawing (1 Page)



INSULATING CONCRETE FORMS MANUFACTURERS ASSOCIATION

2" x 6" WOOD FRAME WALL c/w R–24 BATTS THERMAL RESISTANCE TESTING AT CAN–BEST BRAMPTON, ONTARIO

REV. NO. 000	DWG NO. TST008b
REV. DATE: FEB 2019	
DRAWN BY: K. STILL	SCALE: 1 : 8

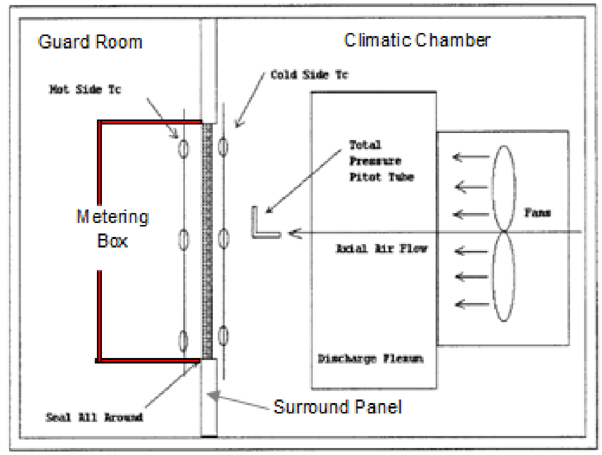
Appendix (C) CAN-BEST Thermal Performance Test, ASTM C1363-11, Guarded Hot Box (GHB)

Nudura - 2x6 (R24) Wood Stud Wall

Test Start Date: December 25, 2018
Test End Date: December 26, 2018

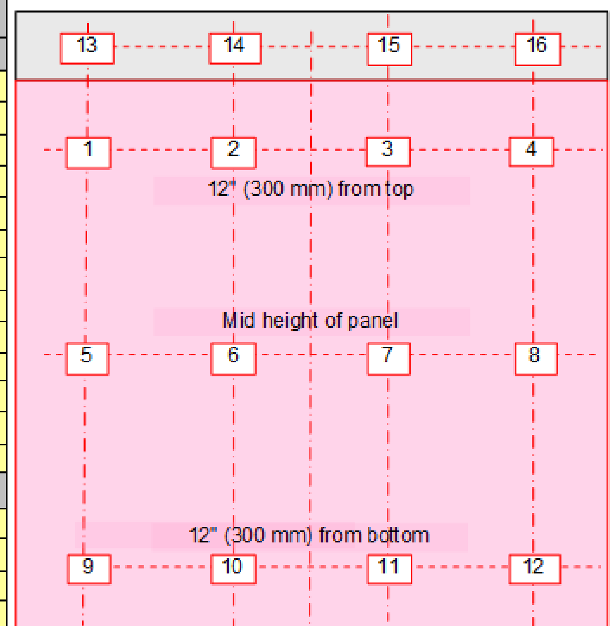
Specimen Dimensions:		*SI*	*Imp*
W_s	Width, m *(ft)*	2440	96.06
H_s	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:		*SI*	*Imp*
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°*	0.111	0.02
sp_{sp}	Width, m *(ft)*	2440	96.06
H_{sp}	Height, m *(ft)*	305	12.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	8.01
A_s	Sample Area, m² *(ft²)*	5.21	56.08

Job No.: 5292
Log File Name: Nudura 2018-09-25
Data Acquisition: One record per second
Data Logging Rate: One record per 10 minutes
Specimen ID: 5292-1
Metering Box ID: CAN-BEST 1003



Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side, °C *(°F)*	-35.00	*-31.0*
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.05	*71.7*
t_1	Surface Temperature - Room Side, °C *(°F)*	19.58	*67.2*
t_{sp1}	Surround Panel Temperature - Room Side, °C *(°F)*	21.25	*70.2*
t_2	Surface Temperature - Weather Side, °C *(°F)*	-34.10	*-29.4*
t_{sp2}	Surround Panel Temperature - Weather Side, °C *(°F)*	-33.78	*-28.8*
Q_f	Fan Heat Input, W *(Btu/h)*		
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	96.70	*330.0*
Q_{sp}	Surround Panel Correction, W *(Btu/h)*	4.55	15.54
E	Metering Box Thermopile Output, mV	8.50	8.50
Q_{mw}	Metering Box Walls Correction, W *(Btu/h)*	9.78	*33.4*
Q_s	Specimen Heat Flow, W *(Btu/h)*	101.93	*347.8*
Thermal Conductance/Transmittance, W/m²/°K *(Btu/h/ft²/°F)*		SI	IP
C	Specimen Surface to Surface Thermal Conductance	0.319	*0.056*
h_{henv}	Interior Surface to Environment Heat Transfer Coefficient	6.92	*1.22*
h_{cenv}	Exterior Surface to Environment Heat Transfer Coefficient	19.03	*3.35*
U	Specimen Air to Air Overall Thermal Transmittance	0.300	*0.053*
U_s *	Standard Specimen Overall Thermal Transmittance	**0.304**	***0.054***
Thermal Resistance, K.m²/W *(F.ft².h/Btu)*		SI	IP
R_{henv}	Interior Surface Film Resistance	0.14	*0.82*
R_{cenv}	Exterior Surface Film Resistance	0.05	*0.30*
R_u	Specimen Overall Thermal Resistance	3.33	*18.92*
R_s *	Standard Specimen Overall Thermal Resistance	**3.29**	***18.67***

TC #	Surface Temperatures°C	
	Int.	Ext.
1	20.2	-33.8
2	20.1	-34.0
3	20.2	-34.0
4	20.7	-34.0
5	19.0	-34.0
6	19.5	-34.3
7	18.6	-34.4
8	19.7	-34.0
9	19.3	-33.7
10	19.6	-34.3
11	18.4	-34.5
12	19.5	-34.6
Avg.	19.6	-34.1
Mask (Top 300 mm)		
13	21.5	-33.6
14	21.3	-34.1
15	21.0	-34.0
16	21.2	-33.4
Avg.	21.2	-33.8



Thermocouple locations as viewed from interior side

* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/° K for cold and warm sides respectively*

Canadian Building Envelope Science and Technology
38 Regan Road, Unit 4, Brampton, Ontario, Canada, L7A 1C6
Tel: (905) 840-2014 • *Fax: (905) 840-2847*

CAN-BEST
Established 1985

TEST REPORT

Thermal performance testing on
6" Steel Stud Wall (R20 Batts + R5 XPS)

Performed in accordance with ASTM C1363-11

"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus".

Report No. L18-1248-5292-3H
Report Date: August 16, 2019

Prepared for:
ICFMA
(Insulating Concrete Forms Manufacturers Association)
www.icfma.org

Heating Load Test Results	***IMP***	**SI**
Exterior Ambient Temperature	*-31.2°F*	-35.1°C
Interior Ambient Temperature	*72.0°F*	22.2°C
Thermal Resistance (R-Value) *Btu/hr/ft²/°F* (W/m²/°K)	***16.70***	**2.94**

Respectfully submitted by:

CANADIAN BUILDING ENVELOPE Science and Technology (CAN-BEST)

Report Authorized by:

Elie Alkhoury, M.Eng.(Building Science), P.Eng.

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Canadian Building Envelope Science and Technology (CAN-BEST) was retained by the Insulating Concrete Forms Manufacturers Association (ICFMA) to carry out thermal performance testing on one 6" steel stud wall with stud cavities insulated with friction fit R20 fiberglass batts and exterior R5 XPS boards.

Testing was carried out on one 8' by 8' (2440 mm x 2440 mm) panel in a Guarded Hot Box (GHB) in accordance with ASTM C1363-11 *"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus"*. Detailed description of CAN-BEST's GHB is found in Appendix (A).

As per Client request, the primary units used in this report are Imperial followed by SI.

Testing was carried out in a Heating Load mode at exterior and interior ambient nominal air temperatures of -31°F and 72°F (-35°C and 22°C) respectively.

2 Panel Description *(as provided by Client)*

Panel Designation: 6" Steel Stud Wall- R20 Batts in Cavity + R5 XPS Insulation on Exterior

Details of panel construction are provided in drawings found in Appendix (B), and summarized as follows (wall construction from interior to exterior):

- *½" (12.7 mm) thick standard weight gypsum board (CGC Brand) secured directly through vapor barrier to wood studs with No. 6 x 2" (3.6mm x 50mm) long coarse thread screws. Joints taped and mudded.*
- *6 mil (0.152 mm) polyethyene vapor barrier stapled to frame members with Std.C shaped metal staples*
- *6" x 1 5/8" (152 x 41mm) 18 Gauge (1.09mm thick) Clark Deitrich S162 (CSJ) Structural Steel Top and Bottom Plates & Studs @ 16" (400mm) o/c*
- *R20 (6" (152mm) thick John Mansville Brand (white/pink) Fiberglas insulation batts for steel framing, friction fit in gaps between studs*
- *½" (12.7mm) thick CGC SECUROCK® Brand UltraLight Glass -Matt (Fiberglas coated) Sheathing screw to framing with No. 6 x 2 1/2" (3.6mm x 63.5mm) long coarse thread screws.*
- *Rona®/Typar® brand, polypropylene/spun bonded polyolefin fabric/sheet air barrier (ICC-ES/ESR-1404/CCMC No. 12884-R)*
- *1" (25.4 mm) thick continuous Owns Corning Pink Extruded Polystyrene foam insulation mounted over air barrier and screwed in place with No 8 x 2 ½" (4mm x 63.5 mm) Hex head screws with washers.*
- *Standard D4.5DL double 4.5 inch (114mm) dutch lap white vinyl siding secured directly through XPS insulation and air barrier to OSB sheathing with No. 6 x 2 1/2" (3.6mm x 63.5mm) long coarse thread screws.*

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The test panel was constructed by the Client at their facilities, and delivered fully assembled to CAN-BEST Laboratory in Brampton, Ontario.

Panel installation in test frame and instrumentation are performed by CAN-BEST staff members. Prior to testing, the test panel was conditioned at laboratory's environment for a minimum period of Two weeks.

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Testing is carried out in a Guarded Hot Box (GHB) that employs two full-scale environmental chambers simulating the required weather and room side test conditions.

Panel Preparation – The test panel was mounted in an opening made in a highly insulated 12" (300 mm) thick rigid EPS foam surrounding mask, held in a steel test frame that interfaces with both sides of the GHB's environmental chambers. The panel's perimeter was then sealed to the surrounding mask using expandable polyurethane foam and tape in order to eliminate through panel air leakage.

Panel Instrumentation - The surface temperatures of the test panel were measured using Gauge 30, Type "T" thermocouple temperature sensors. A total of 24 sensors were applied to the panel's interior and exterior surfaces (12 on each side).

All measurements of temperature, input energy, pressure difference across the panel, exterior wind speed and interior convective air speed were monitored continuously at the rate of once per second and their 600-second averages were logged once per 10 minutes.

5 Test Results

Detailed test results and calculation of thermal performance parameters such as Thermal Conductance (C-Value, surface to surface), Thermal Transmittance (U-Value, air to air) and Thermal Resistance (R-Value, air to air) are provided in Appendix (C), and summarized in Table (1).

The power input is measured in BTU/h (Watt), and demand for power is inversely proportional with the panel's Heat Flow Resistance (HFR). The panel's R-Value is in essence a measure of its HFR taken when the steady state condition has been met.

The panel's thermal resistance (R-Value) is derived from the following measurements, all taken at steady state condition, stabilized for both temperature and power:

- panel's interior and exterior surface temperatures,
- exterior and interior ambient test temperatures, and
- power input.

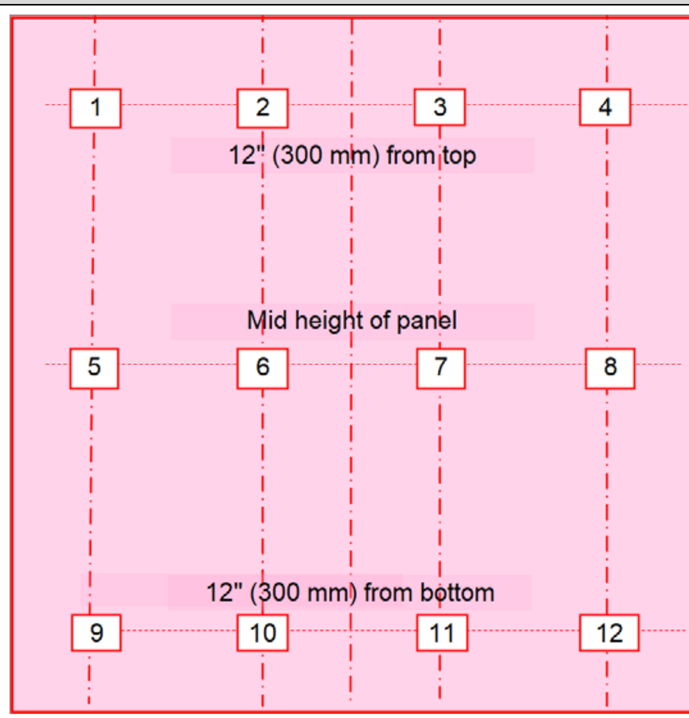
Plots of the power input, monitored over the entire duration of test period, and the panel's corresponding HFR are provided in Figures 1a/1b respectively (2a/2b for metric).

Table (1) Thermal Performance Test Results
Heating Load at -31°F and 72°F (-35°C and 22°C) Ext. and Int. Temperatures

Thermal Conductance/Transmittance		BTU/hr/ft^2/°F	W/m^2/°C
C	Specimen Surface to Surface Thermal Conductance	0.063	0.359
U_{st}^*	Standard Specimen Overall Thermal Transmittance	0.060	0.340
Thermal Resistance		°F.ft^2.hr/BTU	°C.m^2/W
R_{st}^*	Standard Specimen Overall Thermal Resistance	16.70	2.94

TC #	Surface Temperatures °F Int.	°F Ext.	°C Int.	°C Ext.
1	67.6	-29.5	19.8	-34.2
2	68.2	-29.9	20.1	-34.4
3	69.5	-30.2	20.8	-34.5
4	69.1	-30.2	20.6	-34.5
5	67.2	-29.4	19.6	-34.1
6	67.0	-29.7	19.5	-34.3
7	67.1	-30.4	19.5	-34.7
8	66.4	-30.5	19.1	-34.7
9	63.7	-29.4	17.6	-34.1
10	67.5	-30.2	19.7	-34.5
11	64.5	-30.8	18.1	-34.9
12	65.4	-30.8	18.6	-34.9
Avg.	66.9	-30.1	19.4	-34.5

Interior surface temperatures and thermocouple locations as viewed from interior side



* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m^2/°K for cold and warm sides respectively.*

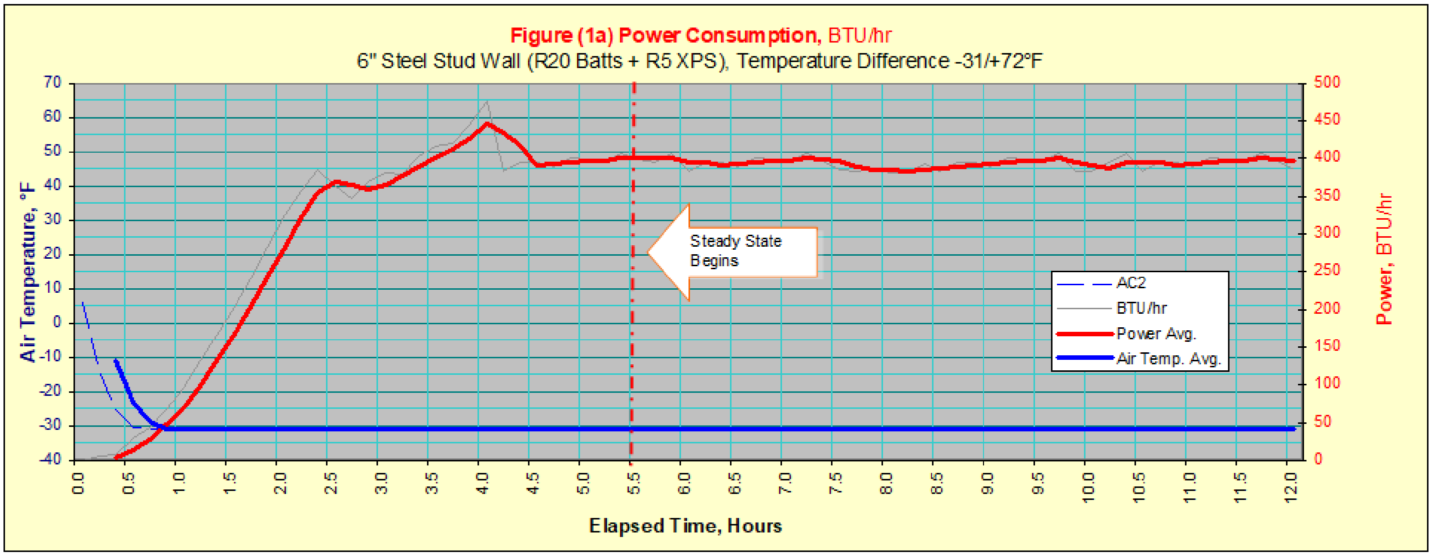


Figure (1a) Power Consumption, BTU/hr
6" Steel Stud Wall (R20 Batts + R5 XPS), Temperature Difference -31/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
Steady State Begins
AC2
BTU/hr
Power Avg.
Air Temp. Avg.

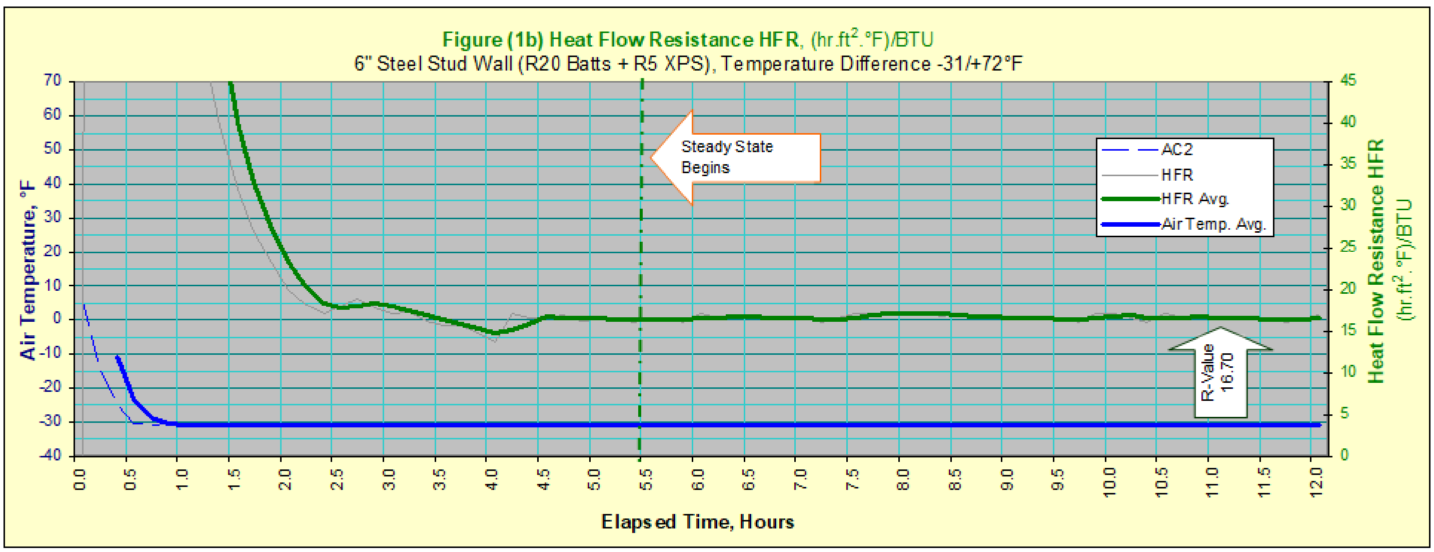


Figure (1b) Heat Flow Resistance HFR, (hr.ft².°F)/BTU
6" Steel Stud Wall (R20 Batts + R5 XPS), Temperature Difference -31/+72°F
Air Temperature, °F
Heat Flow Resistance HFR (hr.ft².°F)/BTU
Elapsed Time, Hours
Steady State Begins
R-Value 16.70
AC2
HFR
HFR Avg.
Air Temp. Avg.

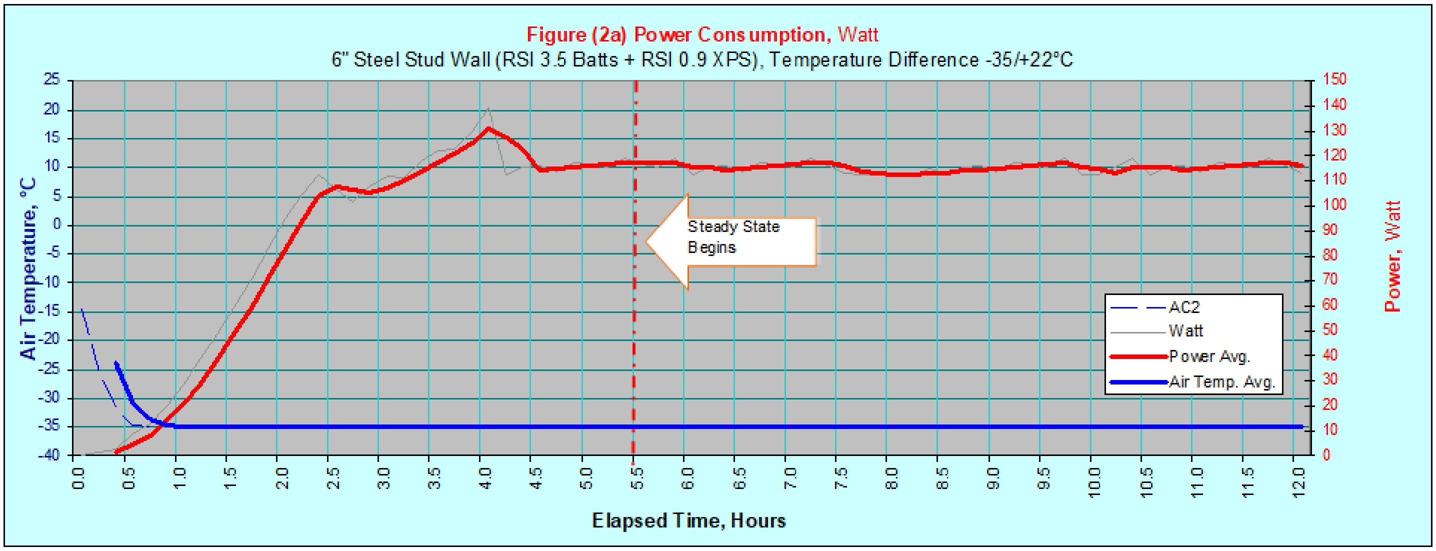


Figure (2a) Power Consumption, Watt
6" Steel Stud Wall (RSI 3.5 Batts + RSI 0.9 XPS), Temperature Difference -35/+22°C
Air Temperature, °C
Power, Watt
Steady State Begins
AC2
Watt
Power Avg.
Air Temp. Avg.
Elapsed Time, Hours

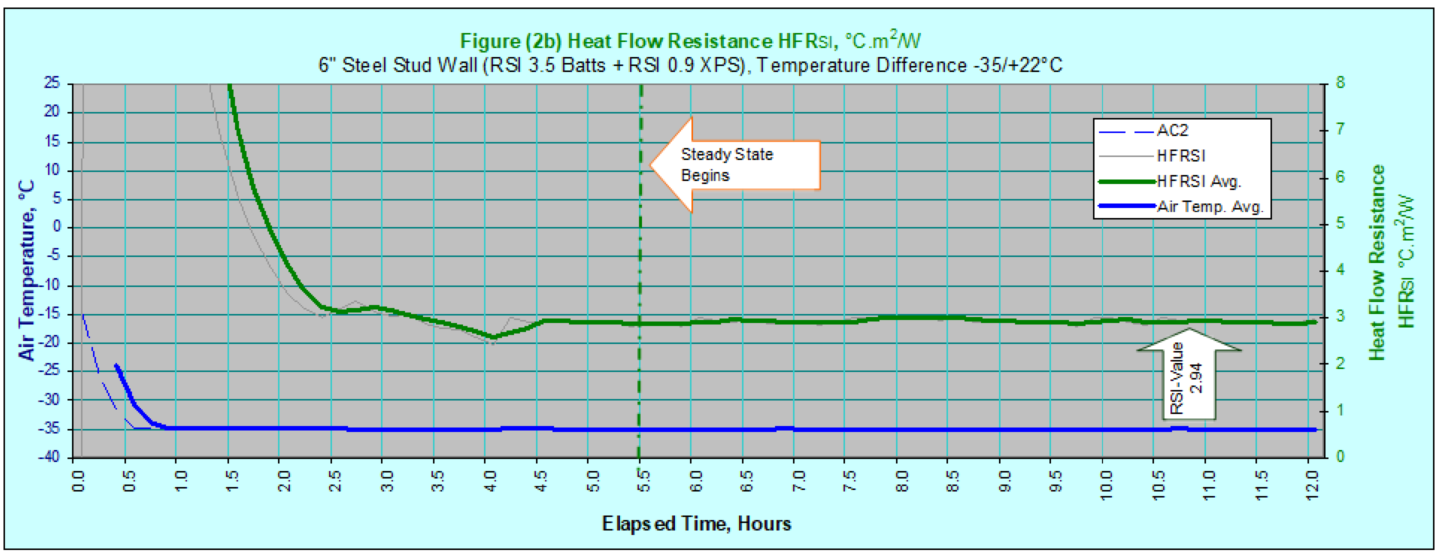


Figure (2b) Heat Flow Resistance HFRSI, °C.m2/W
6" Steel Stud Wall (RSI 3.5 Batts + RSI 0.9 XPS), Temperature Difference -35/+22°C
Air Temperature, °C
Heat Flow Resistance HFRSI °C.m2/W
Steady State Begins
RSI-Value 2.94
AC2
HFRSI
HFRSI Avg.
Air Temp. Avg.
Elapsed Time, Hours

6 Conclusion

Based on the test results, the derived thermal resistance of test panel is:

R-Value: **16.70** $^{o}F.ft^2.h/BTU$

RSI: 2.94 $^{o}C.m^2/W$ *(to convert RSI to R-Value, multiply by 5.678)*

Report History

Revision No.	Change	Date	Approved by
---	Original report issued	August 16, 2019	EA

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Appendix (A)

CAN-BEST's Guarded Hot Box

CAN-BEST operates an ISO 17025, SCC accredited full-scale Guarded Hot Box Facility (GHB) facility that lends itself suitably to perform all the testing required for the evaluation program. As shown in Figure (A.1), the facility comprises the following main components:

- Fixed weather-side environmental chamber fitted with a wind machine.
- A matching moveable room side environmental chamber fitted with a large-scale calorimeter (energy metering box),
- A test panel holding frame with a 3 m x 3 m opening that, during testing, would be sandwiched between the weather side and room side chambers of the GHB. The frame is fitted with a highly insulated perimeter mask that surrounds the test panel in order to eliminate undesirable lateral and flanking heat losses through its perimeter, and
- Instrumentation and computer software to monitor, control and log all measured temperatures, wind speeds, heat flow and other test parameters.

Weather-Side Environmental Chamber

The weather side (or exterior side) of CAN-BEST's GHB is a fixed environmental chamber fitted with a perpendicular wind machine as shown in Figure (A.1). The wind machine is capable of applying onto the test surface a perpendicular wind at various speed levels in a controlled and repeatable manner. Uniform wind delivery is achieved via adjustable tubes that are equally spaced over the entire test area. The wind machine is computer controlled to generate wind speeds of up to 8 m/s that can be varied in infinitesimal increments of 0.01 m/s (0.03 kph).

The generated wind speed is continuously monitored using permanently attached wind velocity sensors that are positioned onto the tip of strategically located wind delivery tubes. These sensors provide means of a closed feedback loop for controlling the wind machine's output in real time.

Room-Side Environmental Chamber

The room side (or interior side) of the GHB is a moveable environmental chamber that "Guards" a large-scale calorimeter (energy metering box). This calorimeter, being possibly the largest in Canada, has an effective metering area of up to 2440 mm wide by 2740 mm high (8' x 9').

The Guard Room maintains an ambient temperature surrounding the calorimeter constant and at the same level as its interior ambient test temperature. In order to minimize the extraneous heat loss/gain through the calorimeter, the Guard room temperature is controlled to limit the temperature difference across its walls to a minimum.

As shown in Figure (A.1), the calorimeter is fitted with a "Constant Temperature Baffle" with a known surface emissivity, positioned parallel to and facing the test panel. This provides means of heat loss/gain correction due to radiation exchange that may take place with the test wall.

Test Panel Holding Frame

The test panel holding frame is a mobile steel frame capable of holding a test panel up to 3124 mm square (123" square). As shown in Figure (A.2), the frame is fitted with a highly insulated perimeter mask (surround panel) required to minimize lateral and flanking heat losses through the test panel's perimeter. The mask is fitted with an opening that can accommodate the test panel, and with the panel installed, the frame is positioned "sandwiched" between the weather side and room side of the GHB.

GHB Instrumentation

The CAN-BEST GHB is fitted with state of the art instrumentation package that meet or exceed the performance requirements of ASTM C1363 standard as follows:

- Temperature sensors – Thermocouple wire, Gauge 30, Type T,
- Wind speed sensors placed at strategic locations to monitor and control both the applied wind speed in the weather side chamber and the natural convection developed in the room side chamber,
- Differential pressure sensor to monitor and control the static pressure difference across the test panel,
- RH sensor, placed inside the calorimeter to monitor and control the interior's ambient relative humidity,
- Means of de-humidification of the interior's ambient condition in order to prevent condensation from taking place on the temperature sensors that would interfere with their measurements, and
- Computerized monitoring and control software that allows changing any of the test parameters "on the fly" without interruption of the test progress. Data from all sensors are acquired continuously once every second, using 24 bit data acquisition system averaged over 600 seconds and logged every 10 minutes.

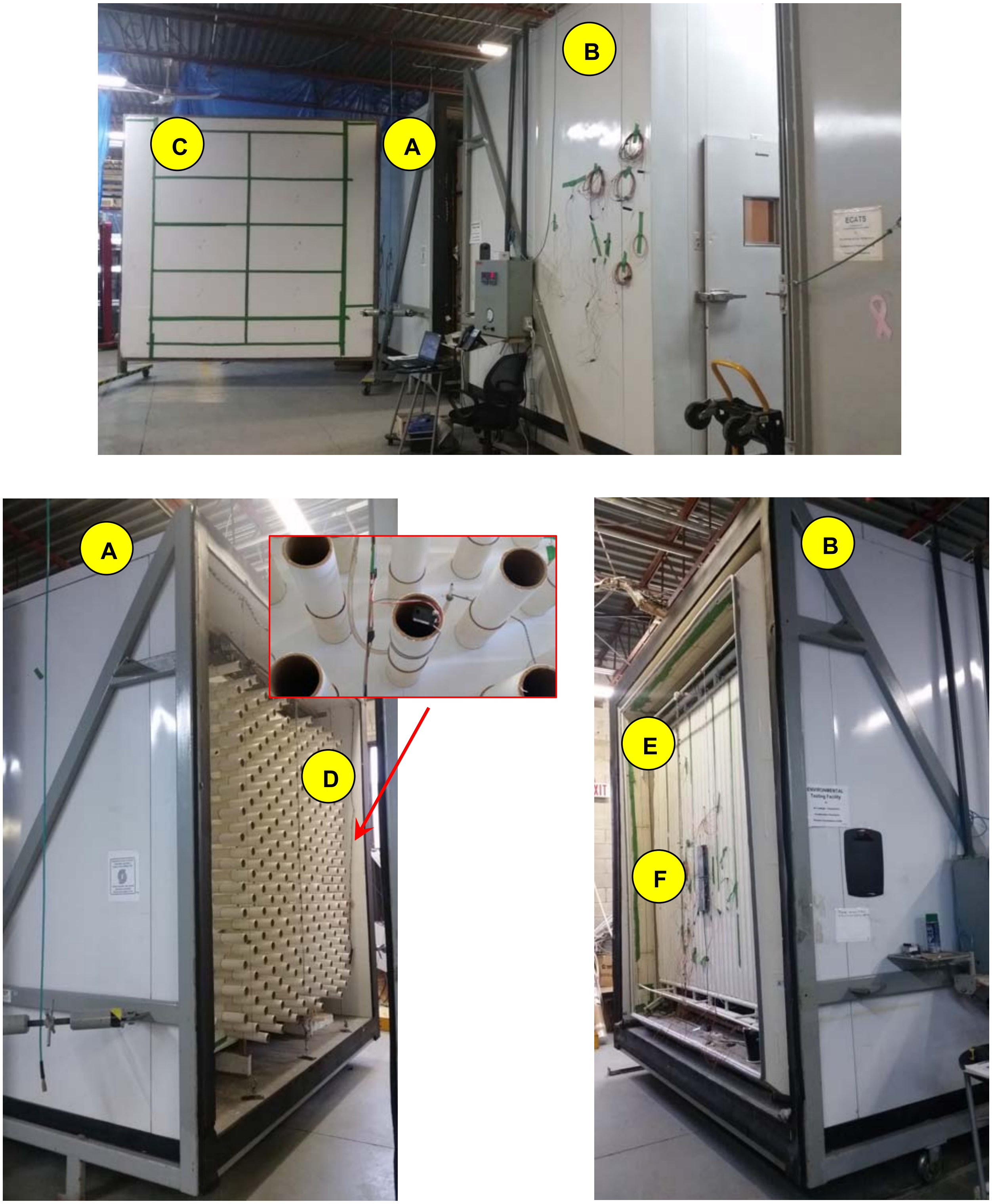
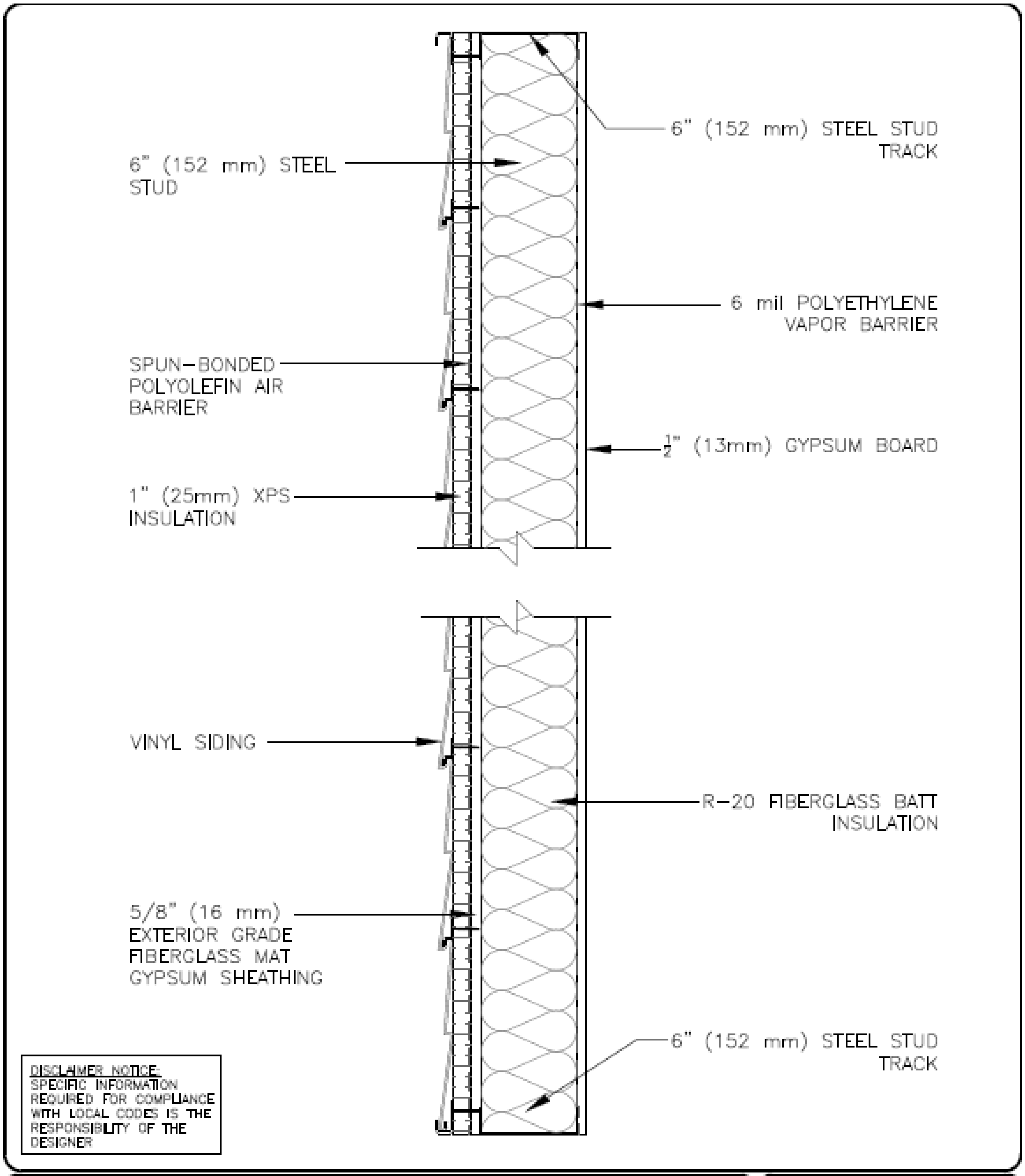


Figure (A.1): CAN-BEST Guarded Hot Box Setup
A – Weather Side Chambre, showing wind machine (D) with wind velocity sensor mounted (inset)
B – Room Side Chambre, showing Calorimeter (E) and Constant Temperature Baffle (F)
C – Test Frame, showing perimeter mask and installed calibration panel

Appendix (B) Drawing (1 Page)



6" (152mm) STEEL STUD WALL R–20 BATTS c/w 1" (25mm) XPS THERMAL RESISTANCE TESTING AT CAN–BEST BRAMPTON, ONTARIO	
REV. NO. 000	DWG NO. TST012b
REV. DATE: FEB 2019	
DRAWN BY: K. STILL	SCALE: 1 : 8

ICFMA
INSULATING CONCRETE FORMS MANUFACTURERS ASSOCIATION

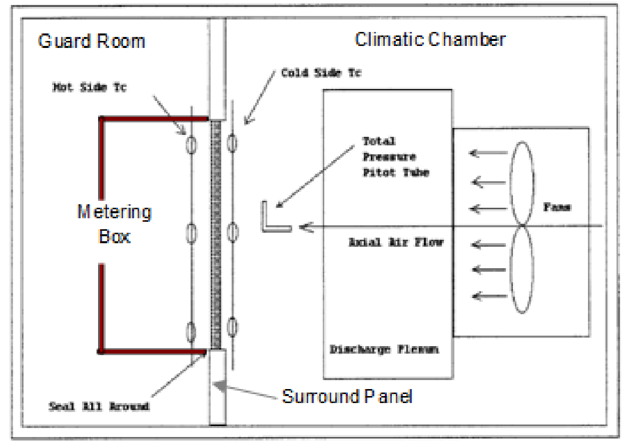
Appendix (C) CAN-BEST Thermal Performance Test, ASTM C1363-11, Guarded Hot Box (GHB)

Nudura - 6" Steel Stud Wall (R20 Batts + R5 XPS)

Test Start Date: November 2, 2018
Test End Date: November 3, 2018

Specimen Dimensions:		*SI*	*Imp*
W_s	Width, m *(ft)*	2440	96.06
H_s	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°*	0.111	0.02
sp_{sp}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	0.06
A_s	Sample Area, m² *(ft²)*	5.21	64.03

Job No.: 5292
Log File Name: Nudura 2018-11-02
Data Acquisition: One record per second
Data Logging Rate: One record per 10 minutes
Specimen ID: 5292-3
Metering Box ID: CAN-BEST 1003



Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side , °C *(°F)*	-35.12	-31.2
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.22	72.0
t_1	Surface Temperature - Room Side, °C *(°F)*	19.41	66.9
t_{sp1}	Surround Panel Temperature - Room Side, °C *(°F)*	20.99	69.8
t_2	Surface Temperature - Weather Side, °C *(°F)*	-34.45	-30.0
t_{sp2}	Surround Panel Temperature - Weather Side, °C *(°F)*	-34.17	-29.5
Q_f	Fan Heat Input, W *(Btu/h)*		
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	122.30	417.3
Q_{sp}	Surround Panel Correction, W *(Btu/h)*	4.56	0.11
E	Metering Box Thermopile Output, mV	-4.50	-4.50
Q_{mw}	Metering Box Walls Correction, W *(Btu/h)*	-2.66	-9.1
Q_s	Specimen Heat Flow, W *(Btu/h)*	115.07	392.7
Thermal Conductance/Transmittance, W/m²/°K *(Btu/h/ft²/°F)*			
C	Specimen Surface to Surface Thermal Conductance	0.359	0.063
h_{henv}	Interior Surface to Environment Heat Transfer Coefficient	6.88	1.21
h_{cenv}	Exterior Surface to Environment Heat Transfer Coefficient	28.81	5.07
U	Specimen Air to Air Overall Thermal Transmittance	0.337	0.059
U_s*	Standard Specimen Overall Thermal Transmittance	**0.340**	**0.060**
Thermal Resistance, K.m²/W *(F.ft².h/Btu)*			
R_{henv}	Interior Surface Film Resistance	0.15	0.83
R_{cenv}	Exterior Surface Film Resistance	0.03	0.20
R_u	Specimen Overall Thermal Resistance	2.97	16.84
R_s*	Standard Specimen Overall Thermal Resistance	**2.94**	**16.70**

TC #	Surface Temperatures°C	
	Warm	Cold
1	19.8	-34.2
2	20.1	-34.4
3	20.8	-34.5
4	20.6	-34.5
5	19.6	-34.1
6	19.5	-34.3
7	19.5	-34.7
8	19.1	-34.7
9	17.6	-34.1
10	19.7	-34.5
11	18.1	-34.9
12	18.6	-34.9
Avg.	19.4	-34.5
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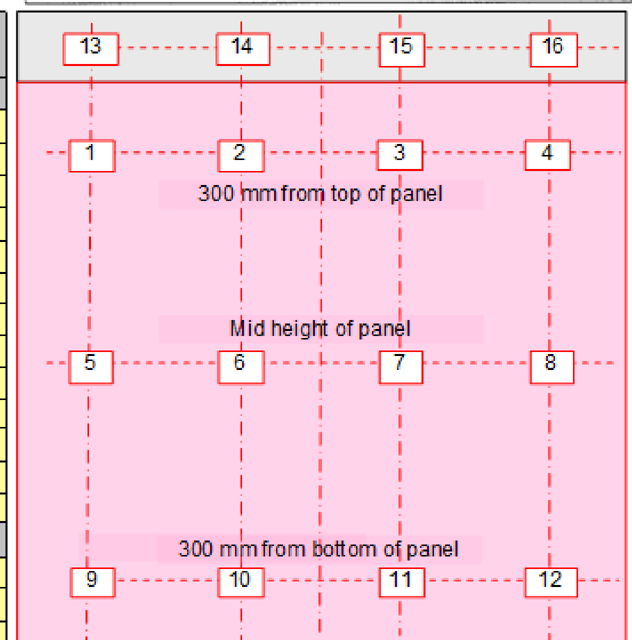

Thermocouple locations as viewed from interior side

* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/°K for cold and warm sides respectively*

TEST REPORT

Thermal performance testing on
2x6 Wood Stud Wall (R20 Batts + R5 XPS)

Performed in accordance with ASTM C1363-11

"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus".

Report No. L18-1248-5292-4H
Report Date: August 16, 2019

Prepared for:
ICFMA
(Insulating Concrete Forms Manufacturers Association)
www.icfma.org

Heating Load Test Results	*IMP*	SI
Exterior Ambient Temperature	*-31.1°F*	-35.1°C
Interior Ambient Temperature	*71.9°F*	22.1°C
Thermal Resistance (R-Value) *Btu/hr/ft²/°F* (W/m²/°K)	***19.43***	**3.42**

Respectfully submitted by:

CANADIAN BUILDING ENVELOPE Science and Technology (CAN-BEST)

Report Authorized by:

Elie Alkhoury, M.Eng.(Building Science), P.Eng.

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- *6 mil (0.152 mm) polyethyene vapor barrier stapled to frame members with Std.C shaped metal staples*
- *2”x6” (38x140) #2 Grade Spruce Wood Stud Framing consisting of single cap plate and single sole plate c/w with studs installed at 16” (400 mm) o/c. (No window jack studs or headers).*
- *R20 (5 ½” (140mm) thick) John Mansville Brand (white/pink) Fiberglas insulation batts friction fit in gaps between studs*
- *7/16” (11mm) thick std. OSB sheathing screwed/nailed to stud wall per code.*
- *Rona®/Typar® brand, polypropylene/spun bonded polyolefin fabric/sheet air barrier (ICC-ES/ESR-1404/CCMC No. 12884-R)*
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- exterior and interior ambient test temperatures, and
- power input.

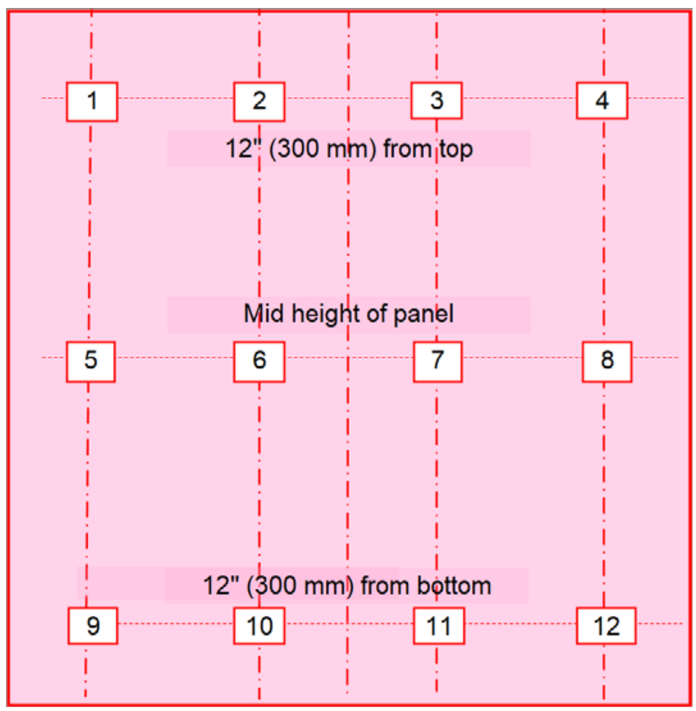
Plots of the power input, monitored over the entire duration of test period, and the panel's corresponding HFR are provided in Figures 1a/1b respectively (2a/2b for metric).

Table (1) Thermal Performance Test Results
Heating Load at -31°F and 72°F (-35°C and 22°C) Ext. and Int. Temperatures

Thermal Conductance/Transmittance		BTU/hr/ft^2/°F	W/m^2/°C
C	Specimen Surface to Surface Thermal Conductance	0.054	0.306
U_{st}*	Standard Specimen Overall Thermal Transmittance	0.051	0.2.92
Thermal Resistance		°F.ft^2.hr/BTU	°C.m^2/W
R_{st}*	Standard Specimen Overall Thermal Resistance	19.43	3.42

TC #	Surface Temperatures °F Int.	Surface Temperatures °F Ext.	Surface Temperatures °C Int.	Surface Temperatures °C Ext.
1	67.9	-29.2	19.9	-34.0
2	69.2	-29.3	20.7	-34.1
3	69.0	-29.3	20.6	-34.1
4	70.6	-29.6	21.5	-34.2
5	65.3	-29.2	18.5	-34.0
6	63.9	-29.6	17.7	-34.2
7	65.3	-30.0	18.5	-34.4
8	67.1	-30.3	19.5	-34.6
9	65.3	-29.3	18.5	-34.1
10	65.7	-30.1	18.7	-34.5
11	66.3	-30.5	19.1	-34.7
12	65.2	-30.6	18.4	-34.8
Avg.	66.7	-29.8	19.3	-34.3

Interior surface temperatures and thermocouple locations as viewed from interior side



* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m^2/°K for cold and warm sides respectively.*

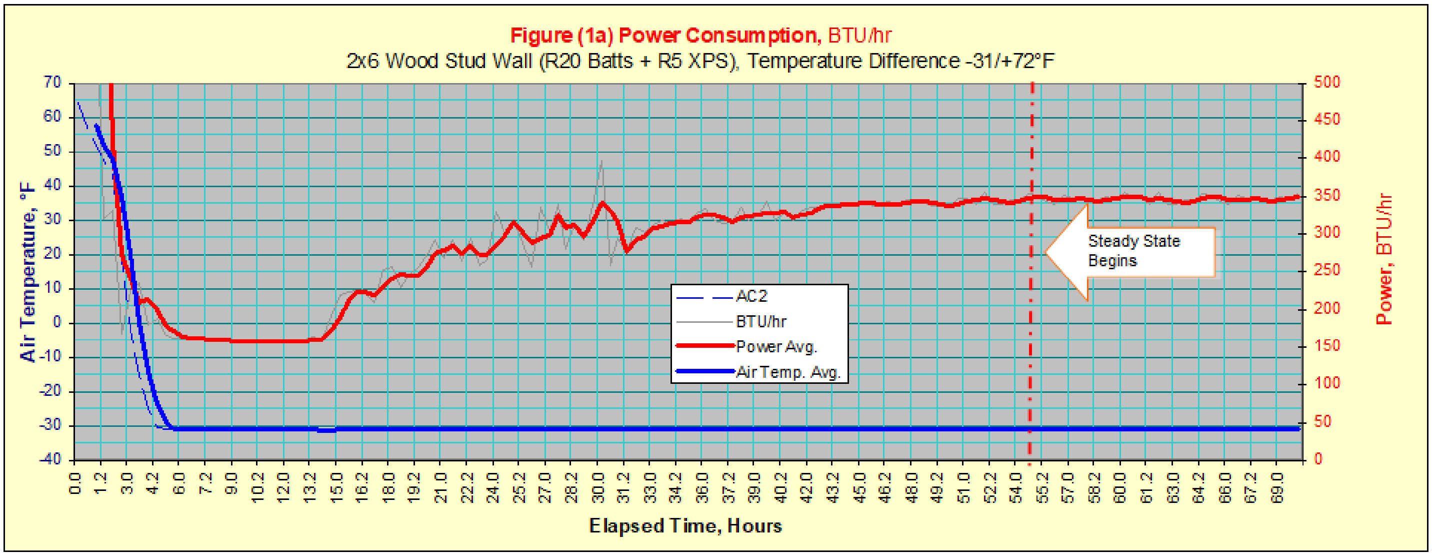


Figure (1a) Power Consumption, BTU/hr
2x6 Wood Stud Wall (R20 Batts + R5 XPS), Temperature Difference -31/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
AC2
BTU/hr
Power Avg.
Air Temp. Avg.
Steady State Begins

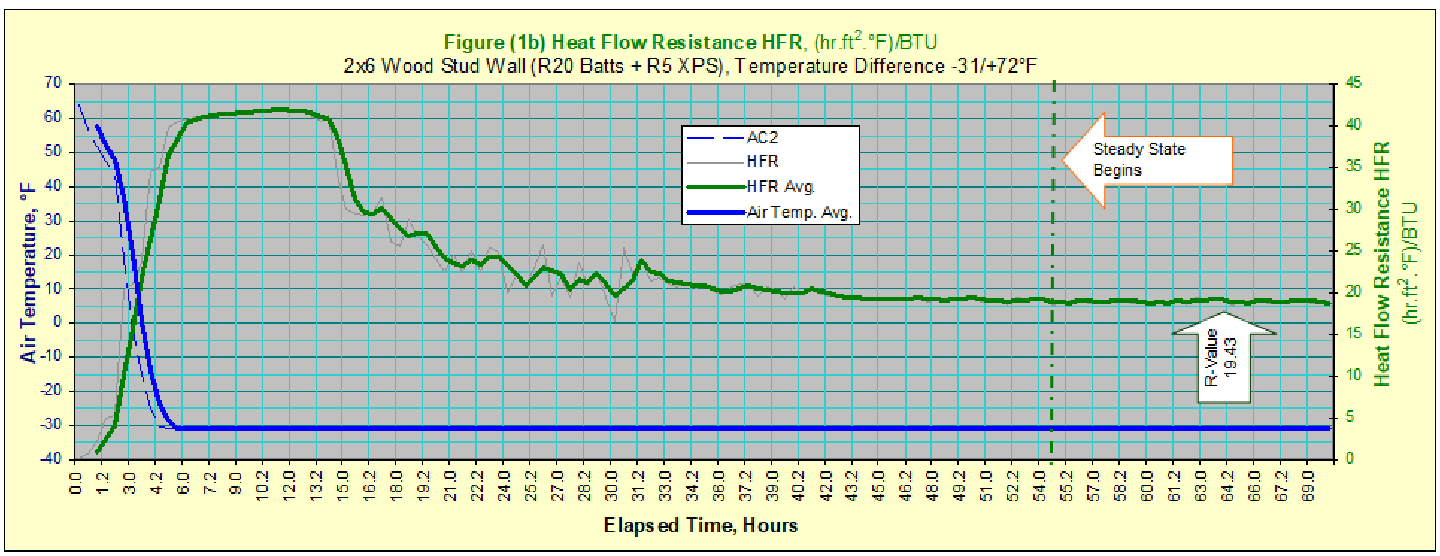


Figure (1b) Heat Flow Resistance HFR, (hr.ft².°F)/BTU
2x6 Wood Stud Wall (R20 Batts + R5 XPS), Temperature Difference -31/+72°F
Air Temperature, °F
Heat Flow Resistance HFR (hr.ft². °F)/BTU
Elapsed Time, Hours
AC2
HFR
HFR Avg.
Air Temp. Avg.
Steady State Begins
R-Value 19.43

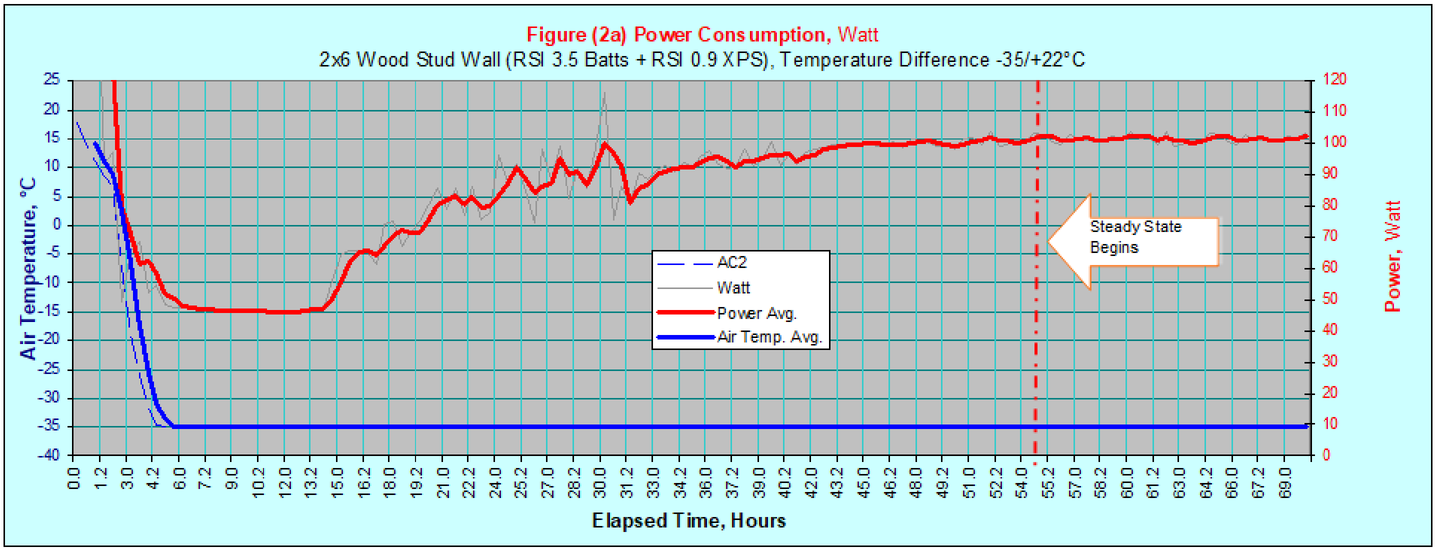


Figure (2a) Power Consumption, Watt
2x6 Wood Stud Wall (RSI 3.5 Batts + RSI 0.9 XPS), Temperature Difference -35/+22°C
Air Temperature, °C
Power, Watt
Elapsed Time, Hours
AC2
Watt
Power Avg.
Air Temp. Avg.
Steady State Begins

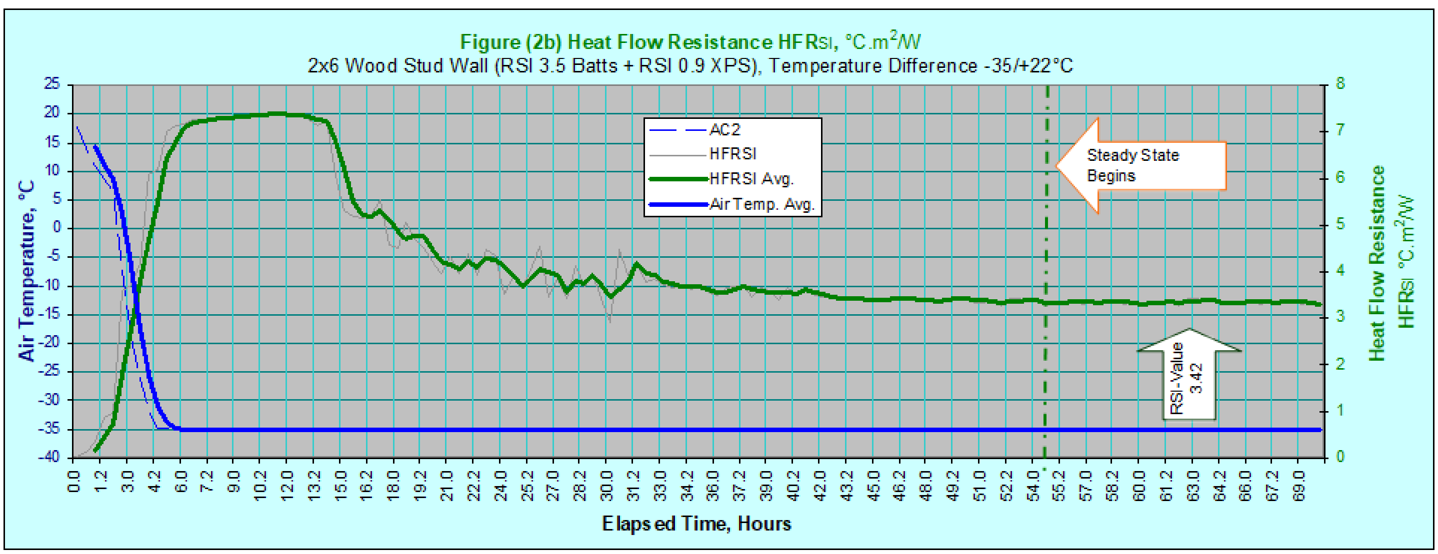


Figure (2b) Heat Flow Resistance HFRSI, °C.m²/W
2x6 Wood Stud Wall (RSI 3.5 Batts + RSI 0.9 XPS), Temperature Difference -35/+22°C
Air Temperature, °C
Heat Flow Resistance HFRSI °C.m²/W
Elapsed Time, Hours
AC2
HFRSI
HFRSI Avg.
Air Temp. Avg.
Steady State Begins
RSI-Value 3.42

6 Conclusion

Based on the test results, the derived thermal resistance of test panel is:

R-Value: **19.43** ^{o}F.ft^{2}.h/BTU

RSI: 3.42 ^{o}C.m^{2}/W *(to convert RSI to R-Value, multiply by 5.678)*

Report History

Revision No.	Change	Date	Approved by
---	Original report issued	August 16, 2019	EA

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Appendix (A)

CAN-BEST's Guarded Hot Box

CAN-BEST operates an ISO 17025, SCC accredited full-scale Guarded Hot Box Facility (GHB) facility that lends itself suitably to perform all the testing required for the evaluation program. As shown in Figure (A.1), the facility comprises the following main components:

- Fixed weather-side environmental chamber fitted with a wind machine.
- A matching moveable room side environmental chamber fitted with a large-scale calorimeter (energy metering box),
- A test panel holding frame with a 3 m x 3 m opening that, during testing, would be sandwiched between the weather side and room side chambers of the GHB. The frame is fitted with a highly insulated perimeter mask that surrounds the test panel in order to eliminate undesirable lateral and flanking heat losses through its perimeter, and
- Instrumentation and computer software to monitor, control and log all measured temperatures, wind speeds, heat flow and other test parameters.

Weather-Side Environmental Chamber
The weather side (or exterior side) of CAN-BEST's GHB is a fixed environmental chamber fitted with a perpendicular wind machine as shown in Figure (A.1). The wind machine is capable of applying onto the test surface a perpendicular wind at various speed levels in a controlled and repeatable manner. Uniform wind delivery is achieved via adjustable tubes that are equally spaced over the entire test area. The wind machine is computer controlled to generate wind speeds of up to 8 m/s that can be varied in infinitesimal increments of 0.01 m/s (0.03 kph).

The generated wind speed is continuously monitored using permanently attached wind velocity sensors that are positioned onto the tip of strategically located wind delivery tubes. These sensors provide means of a closed feedback loop for controlling the wind machine's output in real time.

Room-Side Environmental Chamber
The room side (or interior side) of the GHB is a moveable environmental chamber that "Guards" a large-scale calorimeter (energy metering box). This calorimeter, being possibly the largest in Canada, has an effective metering area of up to 2440 mm wide by 2740 mm high (8' x 9').

The Guard Room maintains an ambient temperature surrounding the calorimeter constant and at the same level as its interior ambient test temperature. In order to minimize the extraneous heat loss/gain through the calorimeter, the Guard room temperature is controlled to limit the temperature difference across its walls to a minimum.

As shown in Figure (A.1), the calorimeter is fitted with a "Constant Temperature Baffle" with a known surface emissivity, positioned parallel to and facing the test panel. This provides means of heat loss/gain correction due to radiation exchange that may take place with the test wall.

Test Panel Holding Frame
The test panel holding frame is a mobile steel frame capable of holding a test panel up to 3124 mm square (123" square). As shown in Figure (A.2), the frame is fitted with a highly insulated perimeter mask (surround panel) required to minimize lateral and flanking heat losses through the test panel's perimeter. The mask is fitted with an opening that can accommodate the test panel, and with the panel installed, the frame is positioned "sandwiched" between the weather side and room side of the GHB.

GHB Instrumentation
The CAN-BEST GHB is fitted with state of the art instrumentation package that meet or exceed the performance requirements of ASTM C1363 standard as follows:

- Temperature sensors – Thermocouple wire, Gauge 30, Type T,
- Wind speed sensors placed at strategic locations to monitor and control both the applied wind speed in the weather side chamber and the natural convection developed in the room side chamber,
- Differential pressure sensor to monitor and control the static pressure difference across the test panel,
- RH sensor, placed inside the calorimeter to monitor and control the interior's ambient relative humidity,
- Means of de-humidification of the interior's ambient condition in order to prevent condensation from taking place on the temperature sensors that would interfere with their measurements, and
- Computerized monitoring and control software that allows changing any of the test parameters "on the fly" without interruption of the test progress. Data from all sensors are acquired continuously once every second, using 24 bit data acquisition system averaged over 600 seconds and logged every 10 minutes.

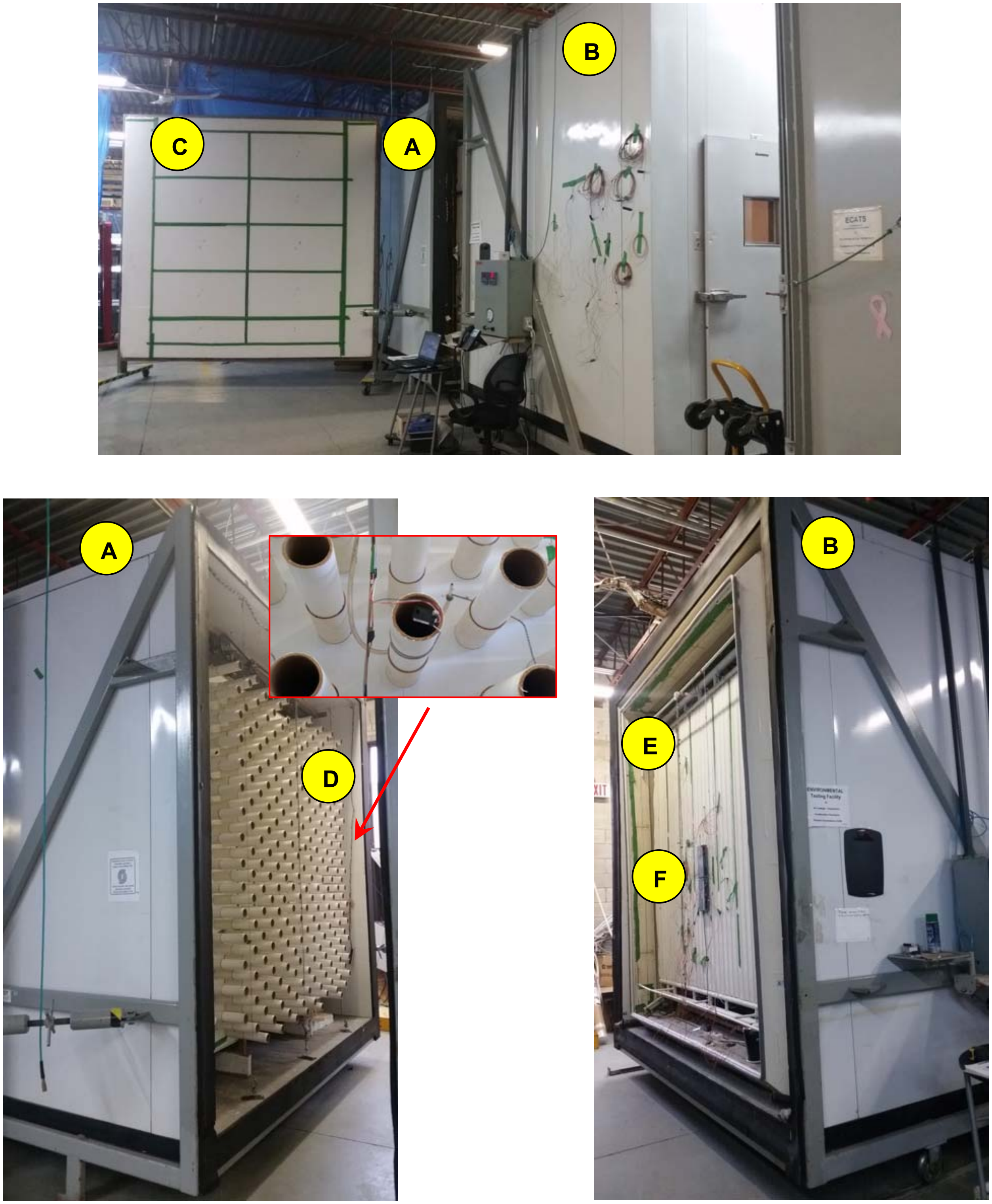
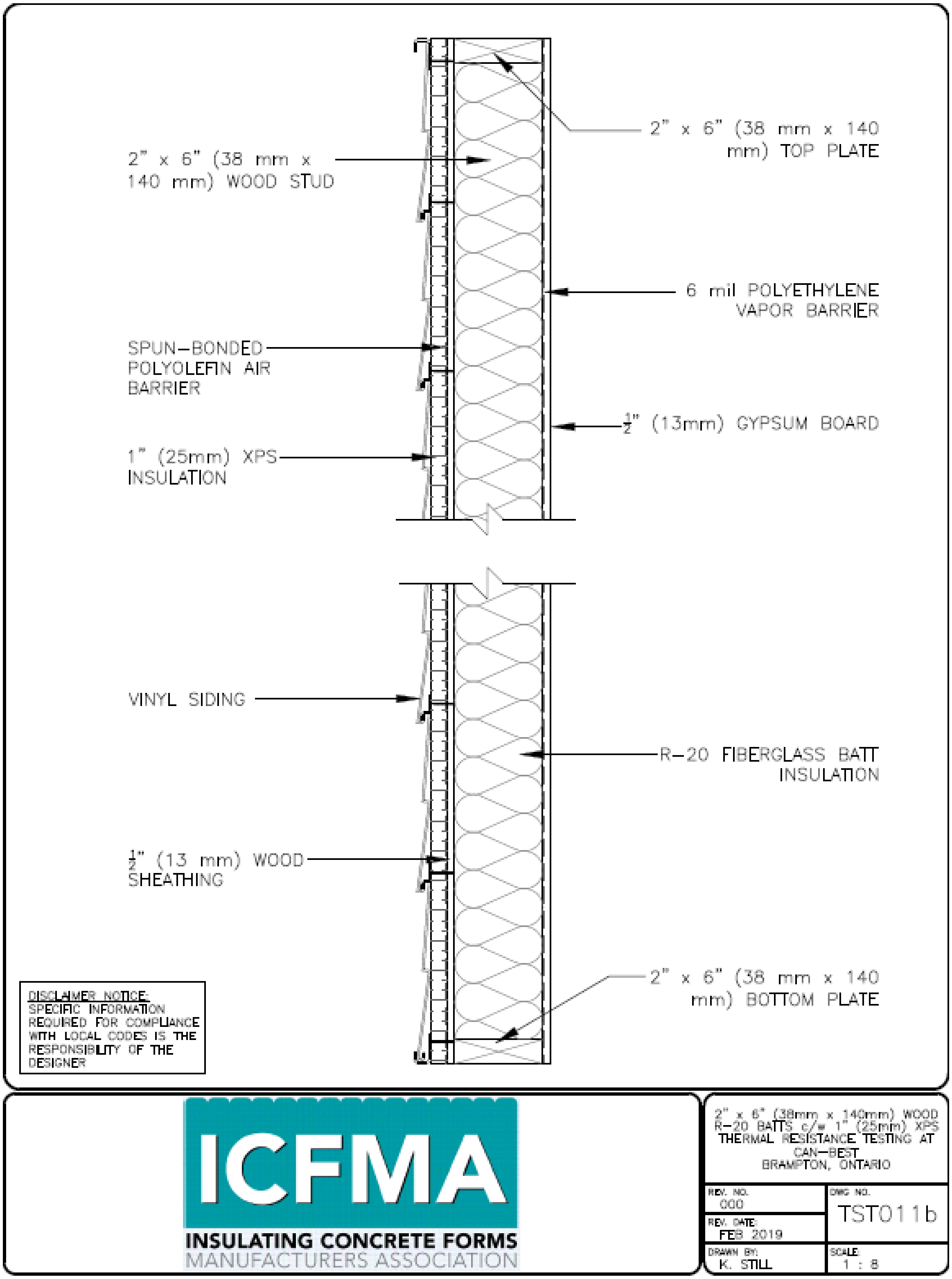


Figure (A.1): CAN-BEST Guarded Hot Box Setup

A – Weather Side Chambre, showing wind machine (D) with wind velocity sensor mounted (inset)
B – Room Side Chambre, showing Calorimeter (E) and Constant Temperature Baffle (F)
C – Test Frame, showing perimeter mask and installed calibration panel

Appendix (B) Drawing (1 Page)



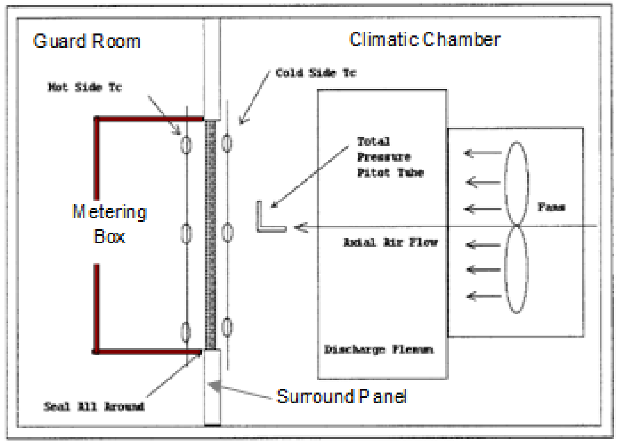
Appendix (C) CAN-BEST Thermal Performance Test, ASTM C1363-11, Guarded Hot Box (GHB)

Nudura - 2x6 (R20+5) Wood Stud Wall

Test Start Date: November 9, 2018
Test End Date: November 10, 2018

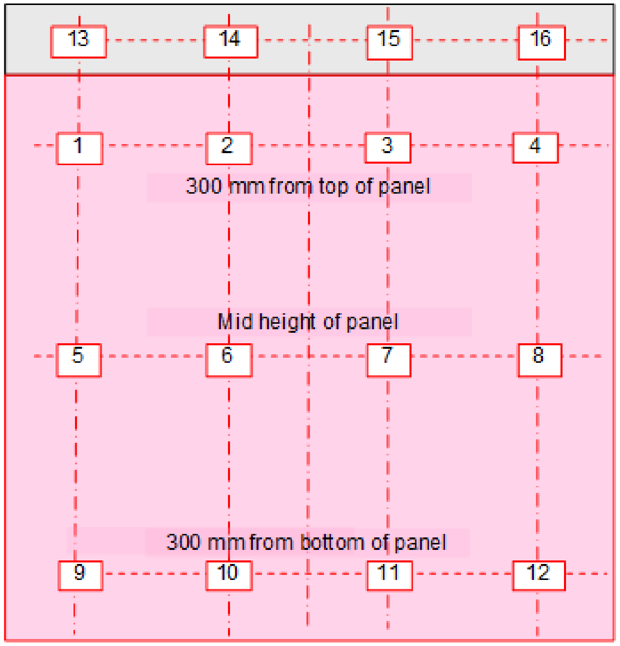
Specimen Dimensions:		*SI*	*Imp*
W_s	Width, m *(ft)*	2440	96.06
H_s	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°F)*	0.111	0.02
sp_{sp}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	0.06
A_s	Sample Area, m² *(ft²)*	5.21	64.03

Job No.: 5292
Log File Name: Nudura 2018-11-09
Data Acquisition: One record per second
Data Logging Rate: One record per 10 minutes
Specimen ID: 5292-4
Metering Box ID: CAN-BEST 1003



Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side, °C *(°F)*	-35.06	*-31.1*
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.14	*71.9*
t_1	Surface Temperature - Room Side, °C *(°F)*	19.29	*66.7*
t_{sp1}	Surround Panel Temperature - Room Side, °C *(°F)*	20.52	*68.9*
t_2	Surface Temperature - Weather Side, °C *(°F)*	-34.27	*-29.7*
t_{sp2}	Surround Panel Temperature - Weather Side, °C *(°F)*	-34.06	*-29.3*
Q_f	Fan Heat Input, W *(Btu/h)*		
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	101.48	*346.2*
Q_{sp}	Surround Panel Correction, W *(Btu/h)*	4.51	0.11
E	Metering Box Thermopile Output, mV	-1.06	-1.06
Q_{mw}	Metering Box Walls Correction, W *(Btu/h)*	0.64	*2.2*
Q_s	Specimen Heat Flow, W *(Btu/h)*	97.60	*333.0*
Thermal Conductance/Transmittance, W/m²/°K *(Btu/h/ft²/°F)*			
C	Specimen Surface to Surface Thermal Conductance	0.306	*0.054*
$h_{h,env}$	Interior Surface to Environment Heat Transfer Coefficient	5.76	*1.01*
$h_{c,env}$	Exterior Surface to Environment Heat Transfer Coefficient	20.80	*3.66*
U	Specimen Air to Air Overall Thermal Transmittance	0.287	*0.050*
U_s*	Standard Specimen Overall Thermal Transmittance	**0.292**	***0.051***
Thermal Resistance, K.m²/W *(F.ft².h/Btu)*			
$R_{h,env}$	Interior Surface Film Resistance	0.17	*0.99*
$R_{c,env}$	Exterior Surface Film Resistance	0.05	*0.27*
R_u	Specimen Overall Thermal Resistance	3.49	*19.81*
R_s*	Standard Specimen Overall Thermal Resistance	**3.42**	***19.43***

TC #	Surface Temperatures°C	
	Warm	Cold
1	19.9	-34.0
2	20.7	-34.1
3	20.6	-34.1
4	21.5	-34.2
5	18.5	-34.0
6	17.7	-34.2
7	18.5	-34.4
8	19.5	-34.6
9	18.5	-34.1
10	18.7	-34.5
11	19.1	-34.7
12	18.4	-34.8
Avg.	19.3	-34.3
Mask (Top 300 mm)		
13	21.8	-34.0
14	17.9	-34.3
15	21.2	-34.0
16	21.3	-33.9
Avg.	20.5	-34.1



Thermocouple locations as viewed from interior side

* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/°K for cold and warm sides respectively*

TEST REPORT

Thermal performance testing on
ICF Wall

Performed in accordance with ASTM C1363-11

"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus".

Report No. L18-1248-5292-5H
Report Date: August 16, 2019

Prepared for:
ICFMA
(Insulating Concrete Forms Manufacturers Association)
www.icfma.org

Heating Load Test Results	***IMP***	**SI**
Exterior Ambient Temperature	*-31.1°F*	-35.0°C
Interior Ambient Temperature	*72.1°F*	22.3°C
Thermal Resistance (R-Value) *Btu/hr/ft²/°F* (W/m²/°K)	***23.36***	**4.11**

Respectfully submitted by: **CANADIAN BUILDING ENVELOPE Science and Technology (CAN-BEST)**

Report Authorized by: Elie Alkhoury, M.Eng.(Building Science), P.Eng.

- This report does not constitute certification of the test product. The reported test results refer only to the specimen tested. No representation is made that other samples of similar design will feature like performance.
- This report was prepared for the consideration of the addressee only. It shall not be used by any other party without the written consent of CAN-BEST.
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1 Introduction

Canadian Building Envelope Science and Technology (CAN-BEST) was retained by the Insulating Concrete Forms Manufacturers Association (ICFMA) to carry out thermal performance testing on 6” core Concrete Insulated Concrete Form (ICF) wall panel.

Testing was carried out on one 8' by 8' (2440 mm x 2440 mm) panel in a Guarded Hot Box (GHB) in accordance with ASTM C1363-11 *"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus"*. Detailed description of CAN-BEST's GHB is found in Appendix (A).

As per Client request, the primary units used in this report are Imperial followed by SI.

Testing was carried out in a Heating Load mode at exterior and interior ambient nominal air temperatures of -31°F and 72°F (-35°C and 22°C) respectively.

2 Panel Description *(as provided by Client)*

Panel Designation: Nudura 6” Core Concrete Insulated Concrete Form (ICF) Wall

Details of panel construction are provided in drawings found in Appendix (B), and summarized as follows (wall construction from interior to exterior):

- *½” (12.7 mm) thick standard weight gypsum board (CGC Brand) secured directly through exterior surface if ICF foam to polypropylene web fastening strips within ICF with No. 6 x 2” (3.6mm x 50mm) long coarse thread screws. Joints taped and mudded.*
- *6” core uniform flat cavity ICF wall measuring 11 ¼” o/A thickness with 6 inch concrete core and 2 layers of Type II EPS foam each 2 5/8” in thickness. Standard siliceous based concrete mix and reinforced with No. 4 (10M) bar installed at 16” (400mm) o/c vertically and 16” to 18” (400 to 457mm) horizontally.*
- *Standard D4.5DL double 4.5 inch (114mm) dutch lap white vinyl siding secured directly through exterior surface if ICF foam to polypropylene web fastening strips within ICF with No. 6 x 2” (3.6mm x 50mm) long coarse thread screws.*

3 Panel Construction

The test panel was constructed by the Client at their facilities, and delivered fully assembled to CAN-BEST Laboratory in Brampton, Ontario.

Panel installation in test frame and instrumentation are performed by CAN-BEST staff members. Prior to testing, the test panel was conditioned at laboratory's environment for a minimum period of Two weeks.

4 Test Procedure

Testing is carried out in a Guarded Hot Box (GHB) that employs two full-scale environmental chambers simulating the required weather and room side test conditions.

Panel Preparation – The test panel was mounted in an opening made in a highly insulated 12" (300 mm) thick rigid EPS foam surrounding mask, held in a steel test frame that interfaces with both sides of the GHB's environmental chambers. The panel's perimeter was then sealed to the surrounding mask using expandable polyurethane foam and tape in order to eliminate through panel air leakage.

Panel Instrumentation **-** The surface temperatures of the test panel were measured using Gauge 30, Type "T" thermocouple temperature sensors. A total of 24 sensors were applied to the panel's interior and exterior surfaces (12 on each side).

All measurements of temperature, input energy, pressure difference across the panel, exterior wind speed and interior convective air speed were monitored continuously at the rate of once per second and their 600-second averages were logged once per 10 minutes.

5 Test Results

Detailed test results and calculation of thermal performance parameters such as Thermal Conductance (C-Value, surface to surface), Thermal Transmittance (U-Value, air to air) and Thermal Resistance (R-Value, air to air) are provided in Appendix (C), and summarized in Table (1).

The power input is measured in BTU/h (Watt), and demand for power is inversely proportional with the panel's Heat Flow Resistance (HFR). The panel's R-Value is in essence a measure of its HFR taken when the steady state condition has been met.

The panel's thermal resistance (R-Value) is derived from the following measurements, all taken at steady state condition, stabilized for both temperature and power:

- panel's interior and exterior surface temperatures,
- exterior and interior ambient test temperatures, and
- power input.

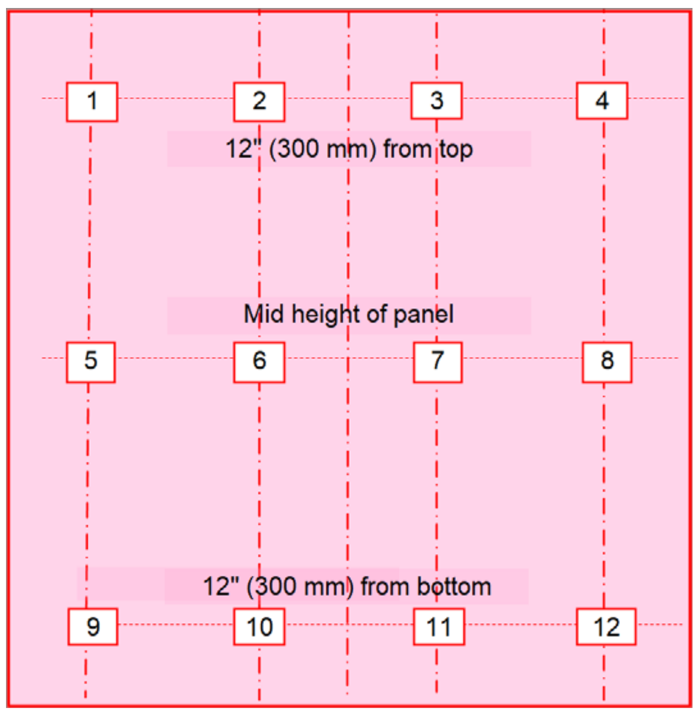
Plots of the power input, monitored over the entire duration of test period, and the panel's corresponding HFR are provided in Figures 1a/1b respectively (2a/2b for metric).

Table (1) Thermal Performance Test Results
Heating Load at -31°F and 72°F (-35°C and 22°C) Ext. and Int. Temperatures

Thermal Conductance/Transmittance		BTU/hr/ft²/°F	W/m²/°C
C	Specimen Surface to Surface Thermal Conductance	0.044	0.253
U_{st} *	Standard Specimen Overall Thermal Transmittance	0.043	0.243
Thermal Resistance		°F.ft².hr/BTU	°C.m²/W
R_{st} *	Standard Specimen Overall Thermal Resistance	23.36	4.11

TC #	Surface Temperatures °F		°C	
	Int.	Ext.	Int.	Ext.
1	69.0	-29.4	20.6	-34.1
2	69.1	-29.6	20.6	-34.2
3	70.5	-29.5	21.4	-34.2
4	70.0	-29.8	21.1	-34.3
5	69.1	-29.4	20.6	-34.1
6	69.1	34.5	20.6	1.4
7	69.4	-30.0	20.8	-34.5
8	69.6	-30.1	20.9	-34.5
9	69.3	-29.0	20.7	-33.9
10	69.7	-29.8	20.9	-34.3
11	69.5	-30.4	20.8	-34.6
12	69.3	-30.3	20.7	-34.6
Avg.	69.5	-24.4	20.8	-31.3

Interior surface temperatures and thermocouple locations as viewed from interior side



* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/°K for cold and warm sides respectively.*

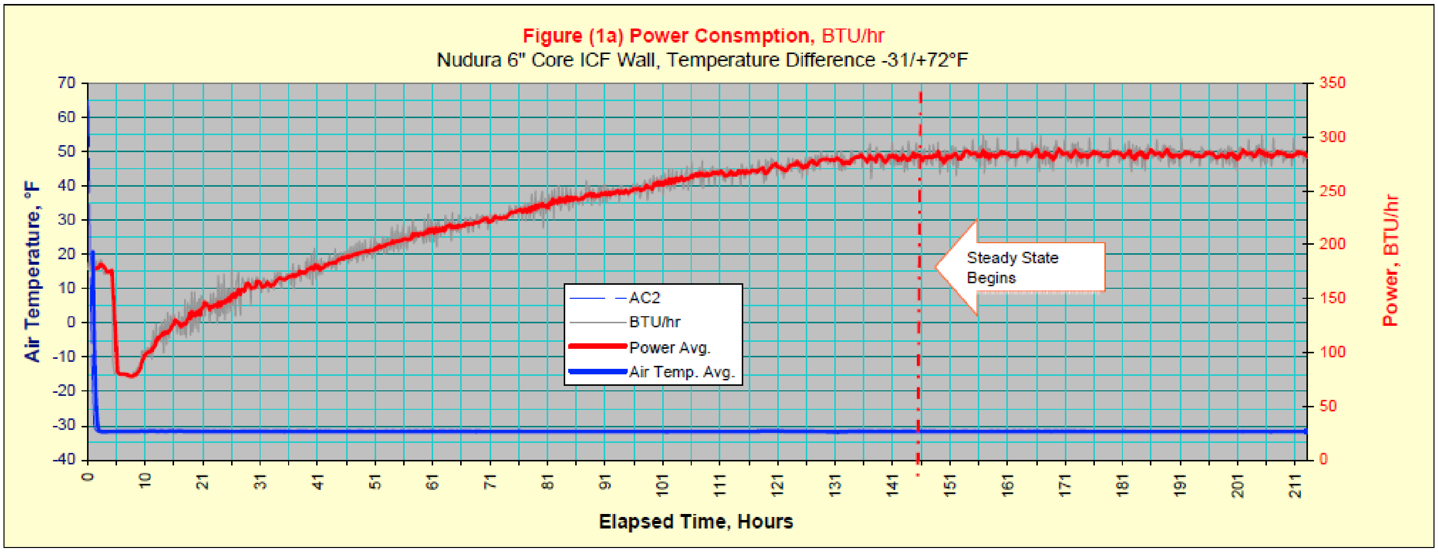


Figure (1a) Power Consmption, BTU/hr
Nudura 6" Core ICF Wall, Temperature Difference -31/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
Steady State Begins
AC2
BTU/hr
Power Avg.
Air Temp. Avg.

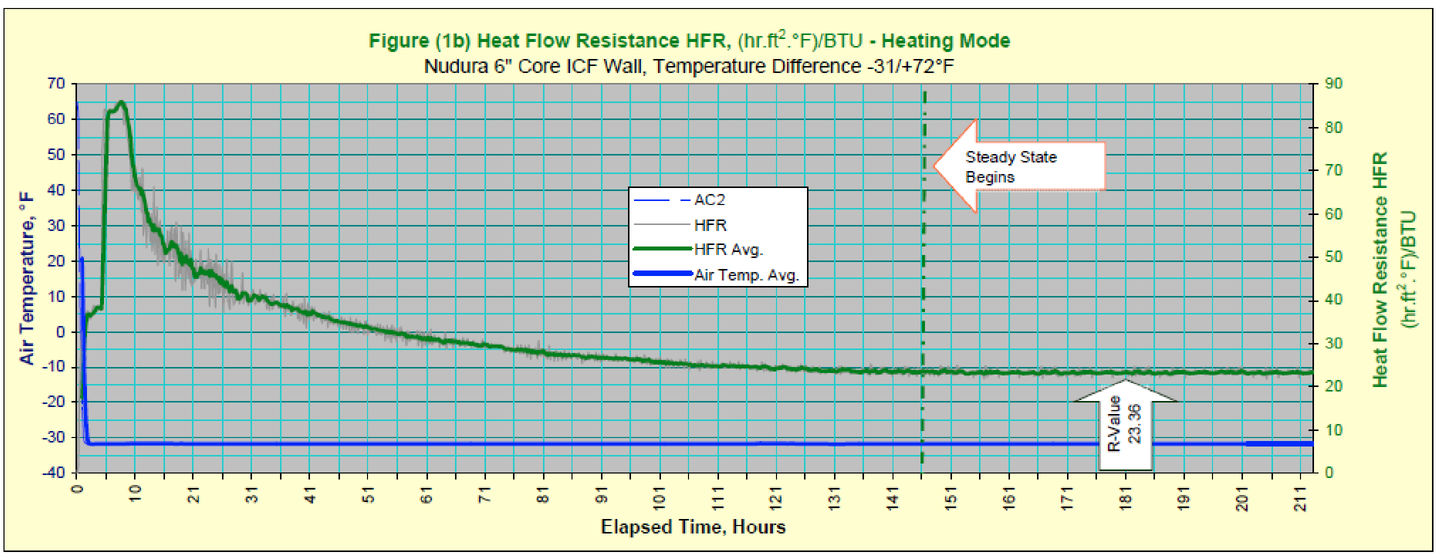


Figure (1b) Heat Flow Resistance HFR, (hr.ft².°F)/BTU - Heating Mode
Nudura 6" Core ICF Wall, Temperature Difference -31/+72°F
Air Temperature, °F
Heat Flow Resistance HFR (hr.ft².°F)/BTU
Elapsed Time, Hours
Steady State Begins
AC2
HFR
HFR Avg.
Air Temp. Avg.
R-Value 23.36

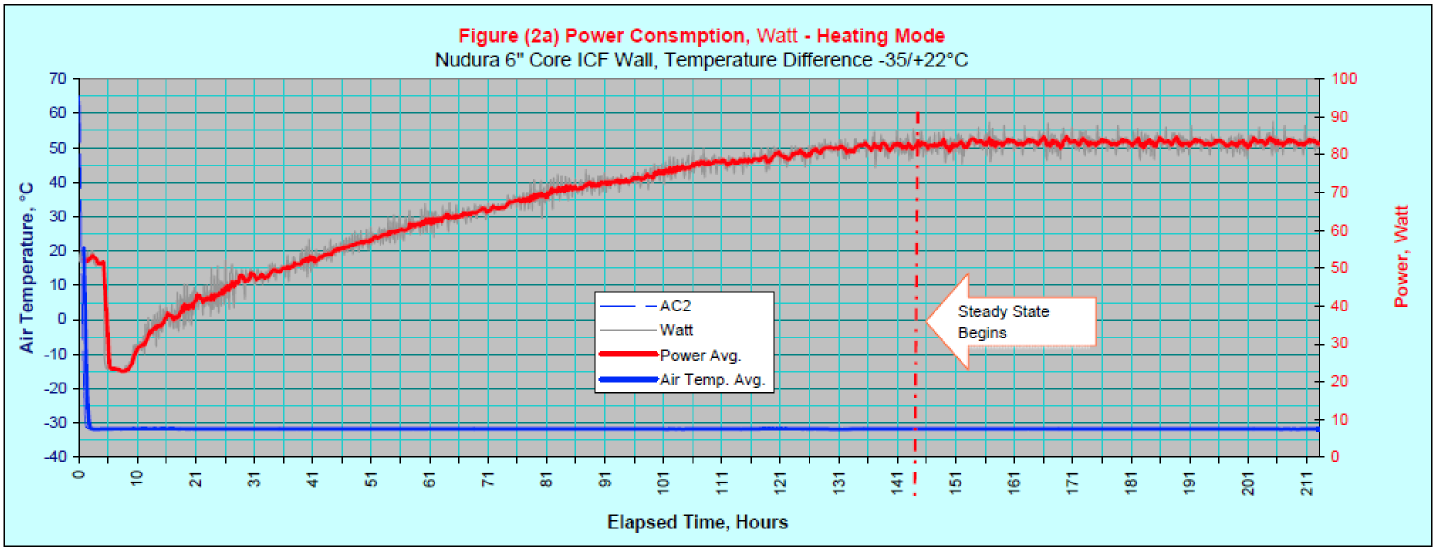


Figure (2a) Power Consmption, Watt - Heating Mode
Nudura 6" Core ICF Wall, Temperature Difference -35/+22°C
Air Temperature, °C
Power, Watt
AC2
Watt
Power Avg.
Air Temp. Avg.
Steady State Begins
Elapsed Time, Hours

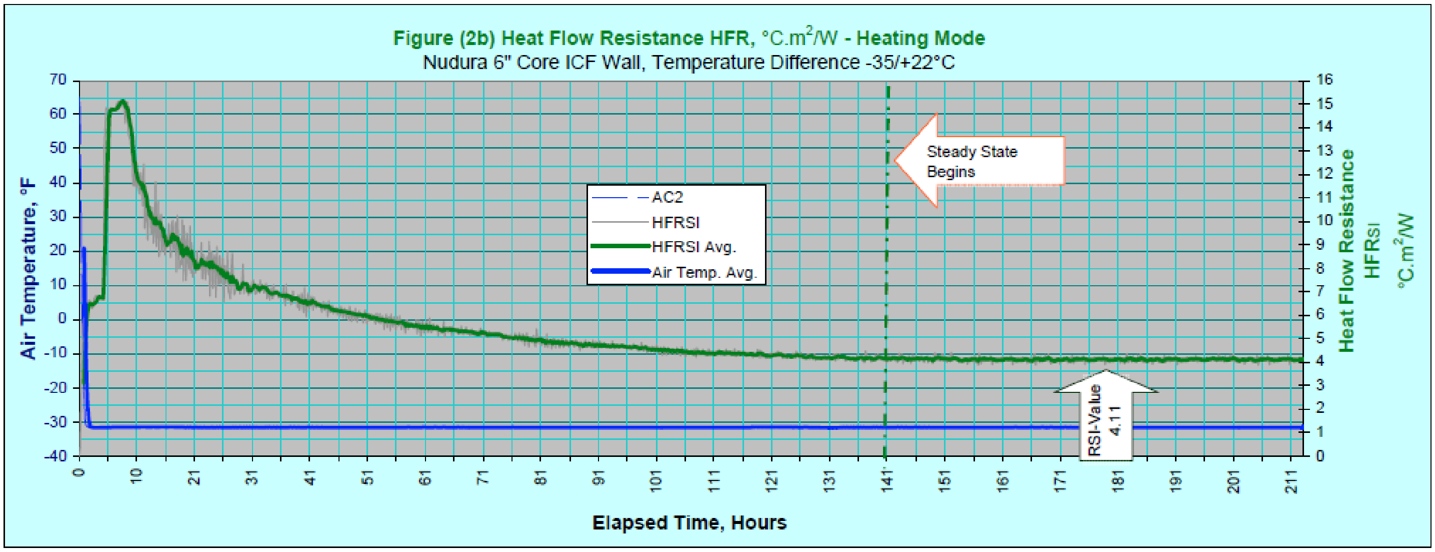


Figure (2b) Heat Flow Resistance HFR, °C.m2/W - Heating Mode
Nudura 6" Core ICF Wall, Temperature Difference -35/+22°C
Air Temperature, °F
Heat Flow Resistance HFRSI °C.m2/W
AC2
HFRSI
HFRSI Avg.
Air Temp. Avg.
Steady State Begins
RSI-Value 4.11
Elapsed Time, Hours

6 Conclusion

Based on the test results, the derived thermal resistance of test panel is:

R-Value: **23.36** $^{o}F.ft^{2}.h/BTU$
RSI: 4.11 $^{o}C.m^{2}/W$ *(to convert RSI to R-Value, multiply by 5.678)*

Report History

Revision No.	Change	Date	Approved by
---	Original report issued	August 16, 2019	EA

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Appendix (A)

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- Instrumentation and computer software to monitor, control and log all measured temperatures, wind speeds, heat flow and other test parameters.

Weather-Side Environmental Chamber

The weather side (or exterior side) of CAN-BEST's GHB is a fixed environmental chamber fitted with a perpendicular wind machine as shown in Figure (A.1). The wind machine is capable of applying onto the test surface a perpendicular wind at various speed levels in a controlled and repeatable manner. Uniform wind delivery is achieved via adjustable tubes that are equally spaced over the entire test area. The wind machine is computer controlled to generate wind speeds of up to 8 m/s that can be varied in infinitesimal increments of 0.01 m/s (0.03 kph).

The generated wind speed is continuously monitored using permanently attached wind velocity sensors that are positioned onto the tip of strategically located wind delivery tubes. These sensors provide means of a closed feedback loop for controlling the wind machine's output in real time.

Room-Side Environmental Chamber

The room side (or interior side) of the GHB is a moveable environmental chamber that "Guards" a large-scale calorimeter (energy metering box). This calorimeter, being possibly the largest in Canada, has an effective metering area of up to 2440 mm wide by 2740 mm high (8' x 9').

The Guard Room maintains an ambient temperature surrounding the calorimeter constant and at the same level as its interior ambient test temperature. In order to minimize the extraneous heat loss/gain through the calorimeter, the Guard room temperature is controlled to limit the temperature difference across its walls to a minimum.

As shown in Figure (A.1), the calorimeter is fitted with a "Constant Temperature Baffle" with a known surface emissivity, positioned parallel to and facing the test panel. This provides means of heat loss/gain correction due to radiation exchange that may take place with the test wall.

Test Panel Holding Frame

The test panel holding frame is a mobile steel frame capable of holding a test panel up to 3124 mm square (123" square). As shown in Figure (A.2), the frame is fitted with a highly insulated perimeter mask (surround panel) required to minimize lateral and flanking heat losses through the test panel's perimeter. The mask is fitted with an opening that can accommodate the test panel, and with the panel installed, the frame is positioned "sandwiched" between the weather side and room side of the GHB.

GHB Instrumentation

The CAN-BEST GHB is fitted with state of the art instrumentation package that meet or exceed the performance requirements of ASTM C1363 standard as follows:

- Temperature sensors – Thermocouple wire, Gauge 30, Type T,
- Wind speed sensors placed at strategic locations to monitor and control both the applied wind speed in the weather side chamber and the natural convection developed in the room side chamber,
- Differential pressure sensor to monitor and control the static pressure difference across the test panel,
- RH sensor, placed inside the calorimeter to monitor and control the interior's ambient relative humidity,
- Means of de-humidification of the interior's ambient condition in order to prevent condensation from taking place on the temperature sensors that would interfere with their measurements, and
- Computerized monitoring and control software that allows changing any of the test parameters "on the fly" without interruption of the test progress. Data from all sensors are acquired continuously once every second, using 24 bit data acquisition system averaged over 600 seconds and logged every 10 minutes.

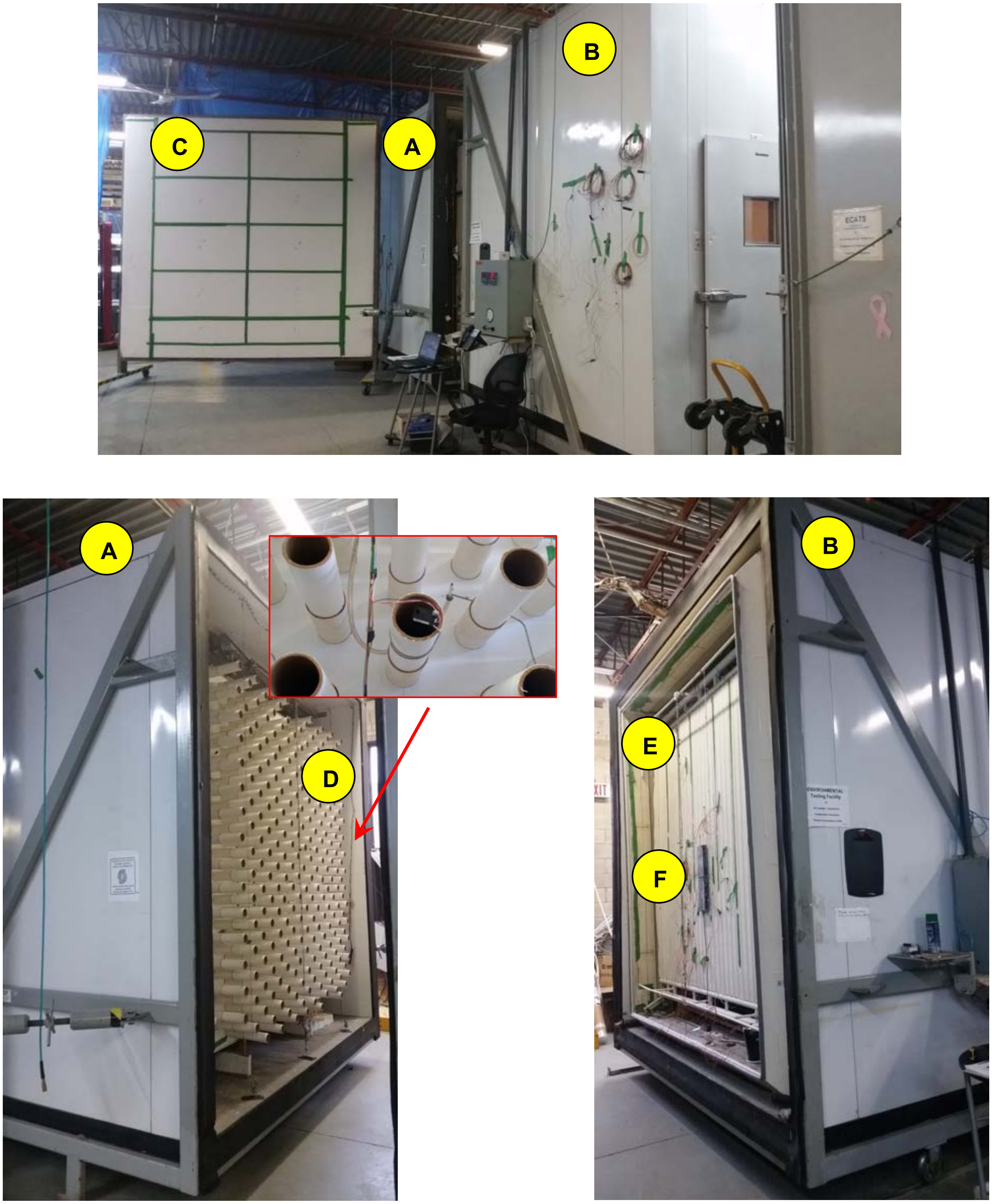
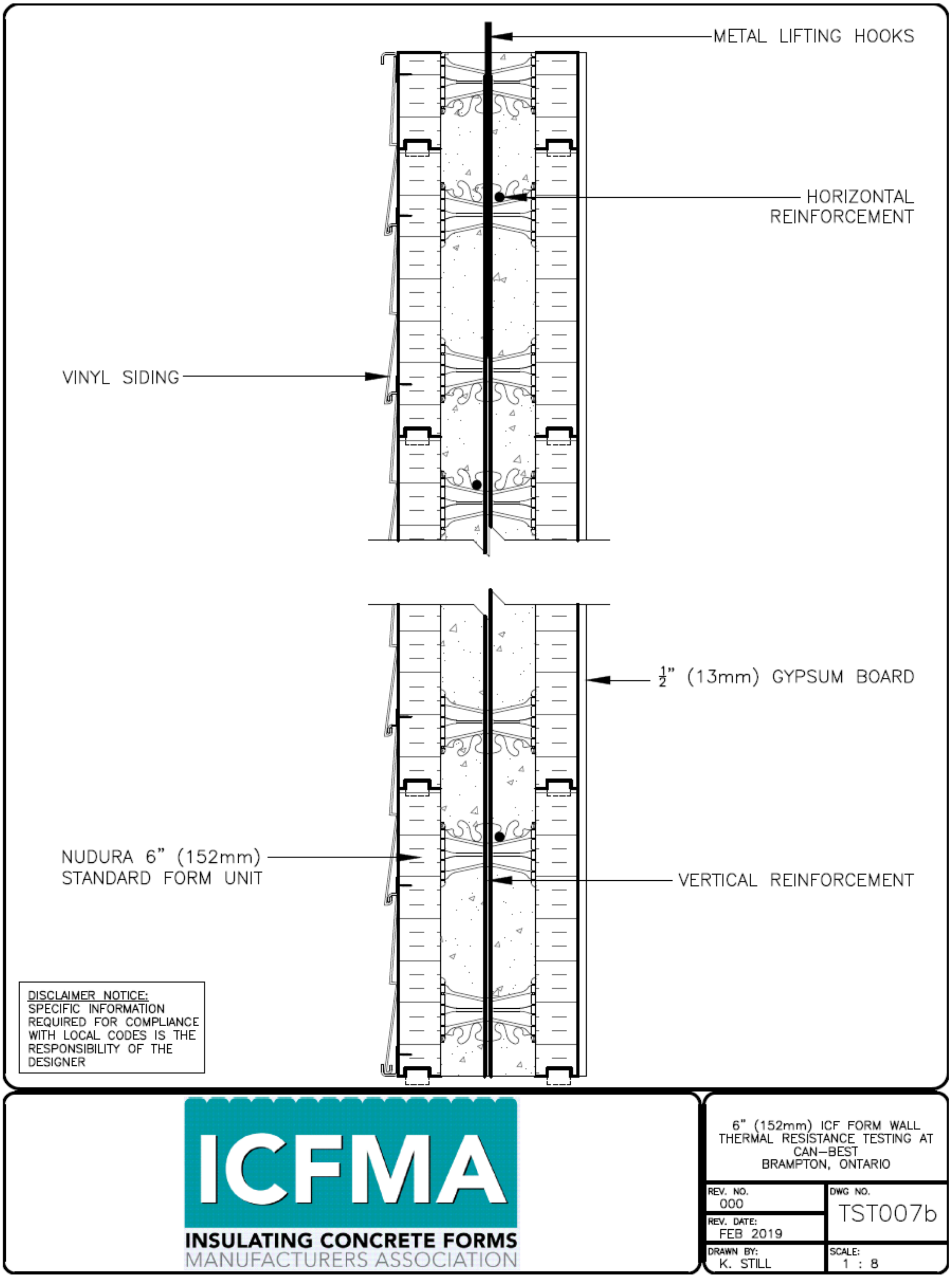


Figure (A.1): CAN-BEST Guarded Hot Box Setup

A – Weather Side Chambre, showing wind machine (D) with wind velocity sensor mounted (inset)
B – Room Side Chambre, showing Calorimeter (E) and Constant Temperature Baffle (F)
C – Test Frame, showing perimeter mask and installed calibration panel

Appendix (B) Drawing (1 Page)



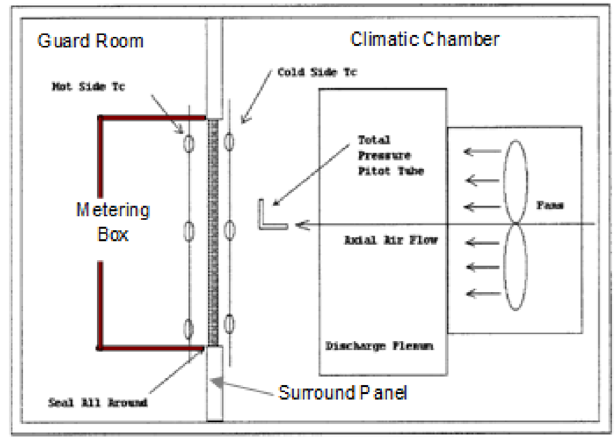
Appendix (C) CAN-BEST Thermal Performance Test, ASTM C1363-11, Guarded Hot Box (GHB)

Nudura - ICF Wall

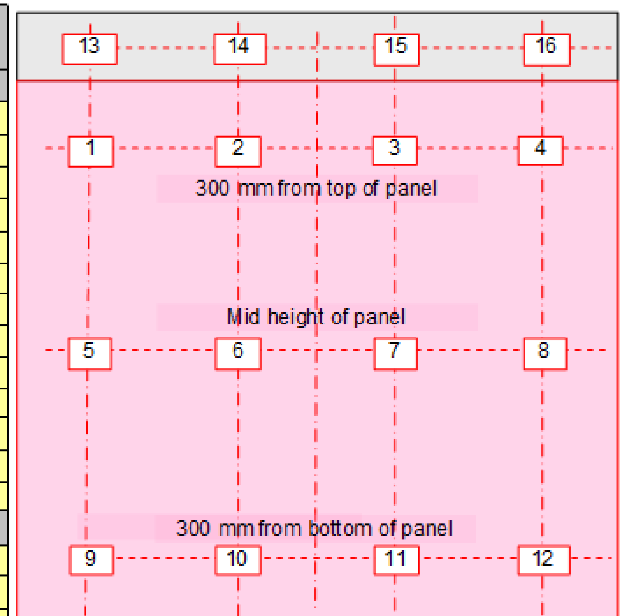
Test Start Date: December 18, 2018
Test End Date: December 20, 2018

Job No.:	5292		
Log File Name:	Nudura 2018-12-18		
Data Acquisition:	One record per second		
Data Logging Rate:	One record per 10 minutes		
Specimen ID:	5292-5		
Metering Box ID:	CAN-BEST 1003		

Specimen Dimensions:		SI	Imp
W_s	Width, m *(ft)*	2440	96.06
H_s	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°*	0.111	0.02
sp_{sp}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	0.06
A_s	Sample Area, m² *(ft²)*	5.21	64.03
Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side, °C *(°F)*	-35.03	*-31.1*
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.26	*72.1*
t_1	Surface Temperature - Room Side, °C *(°F)*	20.81	*69.5*
t_{sp1}	Surround Panel Temperature - Room Side, °C *(°F)*	21.47	*70.6*
t_2	Surface Temperature - Weather Side, °C *(°F)*	-31.04	*-23.9*
t_{sp2}	Surround Panel Temperature - Weather Side, °C *(°F)*	-34.10	*-29.4*
Q_f	Fan Heat Input, W *(Btu/h)*		
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	52.05	*177.6*
Q_{sp}	Surround Panel Correction, W *(Btu/h)*	4.60	0.11
E	Metering Box Thermopile Output, mV	30.12	30.12
Q_{mw}	Metering Box Walls Correction, W *(Btu/h)*	30.48	*104.0*
Q_s	Specimen Heat Flow, W *(Btu/h)*	77.94	*265.9*
Thermal Conductance/Transmittance, W/m²/°K *(Btu/h/ft²/°F)*		SI	IP
C	Specimen Surface to Surface Thermal Conductance	0.253	*0.044*
h_{henv}	Interior Surface to Environment Heat Transfer Coefficient	9.02	*1.59*
h_{cenv}	Exterior Surface to Environment Heat Transfer Coefficient	3.27	*0.58*
U	Specimen Air to Air Overall Thermal Transmittance	0.228	*0.040*
U_s*	Standard Specimen Overall Thermal Transmittance	**0.243**	***0.043***
Thermal Resistance, K.m²/W *(F.ft².h/Btu)*		SI	IP
R_{henv}	Interior Surface Film Resistance	0.11	*0.63*
R_{cenv}	Exterior Surface Film Resistance	0.31	*1.73*
R_u	Specimen Overall Thermal Resistance	4.38	*24.85*
R_s*	Standard Specimen Overall Thermal Resistance	**4.11**	***23.36***



TC #	Surface Temperatures°C	
	Warm	Cold
1	20.6	-34.1
2	20.6	-34.2
3	21.4	-34.2
4	21.1	-34.3
5	20.6	-34.1
6	20.6	1.4
7	20.8	-34.5
8	20.9	-34.5
9	20.7	-33.9
10	20.9	-34.3
11	20.8	-34.6
12	20.7	-34.6
Avg.	20.8	-31.3
Mask (Top 300 mm)		
13	21.7	-33.8
14	21.6	-34.4
15	21.2	-34.2
16	21.3	-34.1
Avg.	21.5	-34.1



Thermocouple locations as viewed from interior side

* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/° K for cold and warm sides respectively*

Canadian Building Envelope Science and Technology
38 Regan Road, Unit 4, Brampton, Ontario, Canada, L7A 1C6
Tel: (905) 840-2014 • *Fax: (905) 840-2847*

CAN-BEST
Established 1985

TEST REPORT

Thermal performance testing on
2x6 Wood Stud Wall (R20/RSI 3.5 Batts)

Performed in accordance with ASTM C1363-11

"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus".

Report No. L18-1248-5292-6H
Report Date: August 16, 2019

Prepared for:
ICFMA
(Insulating Concrete Forms Manufacturers Association)
www.icfma.org

Heating Load Test Results	***IMP***	**SI**
Exterior Ambient Temperature	*-31.0°F*	-35.0°C
Interior Ambient Temperature	*71.5°F*	22.0°C
Thermal Resistance (R-Value) *Btu/hr/ft^2/°F* (W/m^2/°K)	***14.84***	**2.61**

Respectfully submitted by:

CANADIAN BUILDING ENVELOPE Science and Technology (CAN-BEST)

Report Authorized by:

Elie Alkhoury, M.Eng.(Building Science), P.Eng.

- This report does not constitute certification of the test product. The reported test results refer only to the specimen tested. No representation is made that other samples of similar design will feature like performance.
- This report was prepared for the consideration of the addressee only. It shall not be used by any other party without the written consent of CAN-BEST.
- This report may not be reproduced or quoted in partial form without the approval of CAN-BEST.

1 Introduction

Canadian Building Envelope Science and Technology (CAN-BEST) was retained by the Insulating Concrete Forms Manufacturers Association (ICFMA) to carry out thermal performance testing on one 2x6 wood stud wall with stud cavities insulated with friction fit R20 fiberglass batts.

Testing was carried out on one 8' by 8' (2440 mm x 2440 mm) panel in a Guarded Hot Box (GHB) in accordance with ASTM C1363-11 *"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus"*. Detailed description of CAN-BEST's GHB is found in Appendix (A).

As per Client request, the primary units used in this report are Imperial followed by SI.

Testing was carried out in a Heating Load mode at exterior and interior ambient nominal air temperatures of -31°F and 72°F (-35°C and 22°C) respectively.

2 Panel Description *(as provided by Client)*

Panel Designation: 2x6 Wood Stud Wall (R20/RSI 3.5 Batts)

Details of panel construction are provided in drawings found in Appendix (B), and summarized as follows (wall construction from interior to exterior):

- *½" (12.7 mm) thick standard weight gypsum board (CGC Brand) secured directly through vapor barrier to wood studs with No. 6 x 2" (3.6mm x 50mm) long coarse thread screws. Joints taped and mudded.*
- *6 mil (0.152 mm) polyethyene vapor barrier stapled to frame members with Std.C shaped metal staples*
- *2"x6" (38x140) #2 Grade Spruce Wood Stud Framing consisting of single cap plate and single sole plate c/w with studs installed at 16" (400 mm) o/c. (No window jack studs or headers). (NOTE: Would like to discuss potential of implication if a double top plate had been used)*
- *R20 (5 ½" (140mm) thick) John Mansville Brand (white/pink) Fiberglas insulation batts friction fit in gaps between studs*
- *7/16" (11mm) thick std. OSB sheathing screwed/nailed to stud wall per code.*
- *Rona®/Typar® brand, polypropylene/spun bonded polyolefin fabric/sheet air barrier (ICC-ES/ESR-1404/CCMC No. 12884-R)*
- *Standard D4.5DL double 4.5 inch (114mm) dutch lap white vinyl siding secured directly through air barrier to OSB sheathing with No. 6 x 2" (3.6mm x 50mm) long coarse thread screws.*

3 Panel Construction

The test panel was constructed by the Client at their facilities, and delivered fully assembled to CAN-BEST Laboratory in Brampton, Ontario.

Panel installation in test frame and instrumentation are performed by CAN-BEST staff members. Prior to testing, the test panel was conditioned at laboratory's environment for a minimum period of Two weeks.

4 Test Procedure

Testing is carried out in a Guarded Hot Box (GHB) that employs two full-scale environmental chambers simulating the required weather and room side test conditions.

Panel Preparation – The test panel was mounted in an opening made in a highly insulated 12" (300 mm) thick rigid EPS foam surrounding mask, held in a steel test frame that interfaces with both sides of the GHB's environmental chambers. The panel's perimeter was then sealed to the surrounding mask using expandable polyurethane foam and tape in order to eliminate through panel air leakage.

Panel Instrumentation - The surface temperatures of the test panel were measured using Gauge 30, Type "T" thermocouple temperature sensors. A total of 24 sensors were applied to the panel's interior and exterior surfaces (12 on each side).

All measurements of temperature, input energy, pressure difference across the panel, exterior wind speed and interior convective air speed were monitored continuously at the rate of once per second and their 600-second averages were logged once per 10 minutes.

5 Test Results

Detailed test results and calculation of thermal performance parameters such as Thermal Conductance (C-Value, surface to surface), Thermal Transmittance (U-Value, air to air) and Thermal Resistance (R-Value, air to air) are provided in Appendix (C), and summarized in Table (1).

The power input is measured in BTU/h (Watt), and demand for power is inversely proportional with the panel's Heat Flow Resistance (HFR). The panel's R-Value is in essence a measure of its HFR taken when the steady state condition has been met.

The panel's thermal resistance (R-Value) is derived from the following measurements, all taken at steady state condition, stabilized for both temperature and power:

- panel's interior and exterior surface temperatures,
- exterior and interior ambient test temperatures, and
- power input.

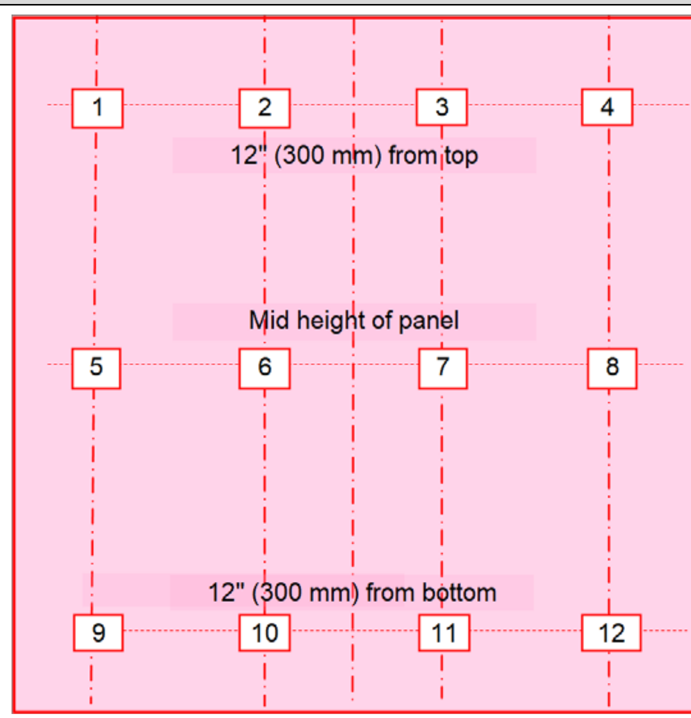
Plots of the power input, monitored over the entire duration of test period, and the panel's corresponding HFR are provided in Figures 1a/1b respectively (2a/2b for metric).

Table (1) Thermal Performance Test Results
Heating Load at -31°F and 72°F (-35°C and 22°C) Ext. and Int. Temperatures

Thermal Conductance/Transmittance		$BTU/hr/ft^2/^oF$	$W/m^2/^oC$
C	Specimen Surface to Surface Thermal Conductance	0.072	0.407
U_{st}^*	Standard Specimen Overall Thermal Transmittance	0.067	0.383
Thermal Resistance		$^oF.ft^2.hr/BTU$	$^oC.m^2/W$
R_{st}^*	Standard Specimen Overall Thermal Resistance	14.84	2.61

TC #	Surface Temperatures			
	°F		°C	
	Int.	Ext.	Int.	Ext.
1	67.5	-28.8	19.7	-33.8
2	68.8	-28.3	20.5	-33.5
3	67.5	-27.9	19.7	-33.3
4	70.4	-28.4	21.4	-33.5
5	62.8	-28.4	17.1	-33.5
6	59.8	-29.3	15.5	-34.1
7	62.3	-28.4	16.8	-33.5
8	65.3	-29.0	18.5	-33.9
9	64.7	-28.9	18.1	-33.8
10	64.5	-29.3	18.1	-34.1
11	65.3	-29.4	18.5	-34.1
12	64.1	-29.3	17.8	-34.0
Avg.	65.2	-28.8	18.5	-33.8

Interior surface temperatures and thermocouple locations as viewed from interior side



* Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 $W/m^2/^oK$ for cold and warm sides respectively.

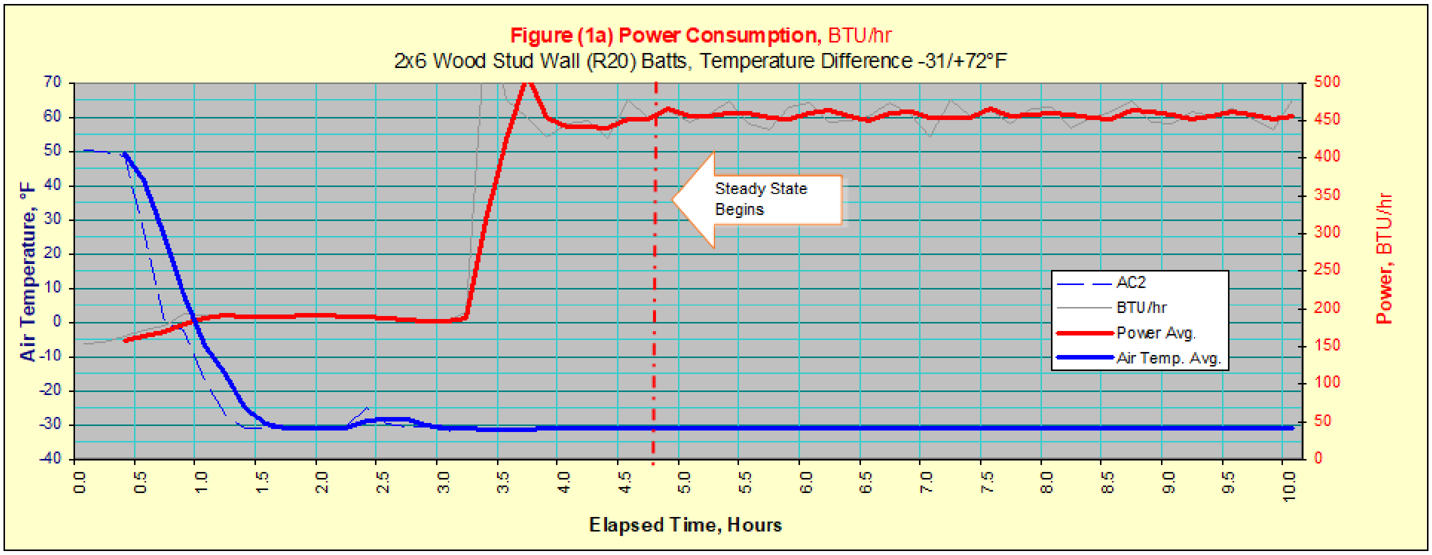


Figure (1a) Power Consumption, BTU/hr
2x6 Wood Stud Wall (R20) Batts, Temperature Difference -31/+72°F
Air Temperature, °F
Power, BTU/hr
Steady State Begins
AC2
BTU/hr
Power Avg.
Air Temp. Avg.
Elapsed Time, Hours

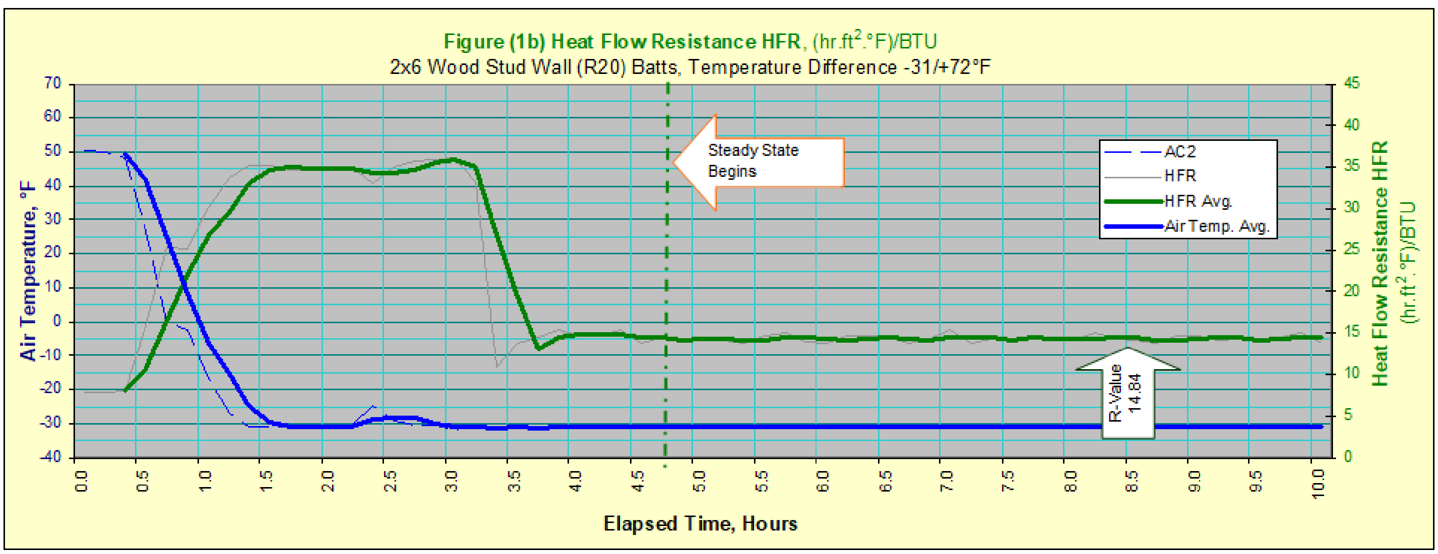


Figure (1b) Heat Flow Resistance HFR, (hr.ft2.°F)/BTU
2x6 Wood Stud Wall (R20) Batts, Temperature Difference -31/+72°F
Air Temperature, °F
Heat Flow Resistance HFR (hr.ft2.°F)/BTU
Steady State Begins
AC2
HFR
HFR Avg.
Air Temp. Avg.
R-Value 14.84
Elapsed Time, Hours

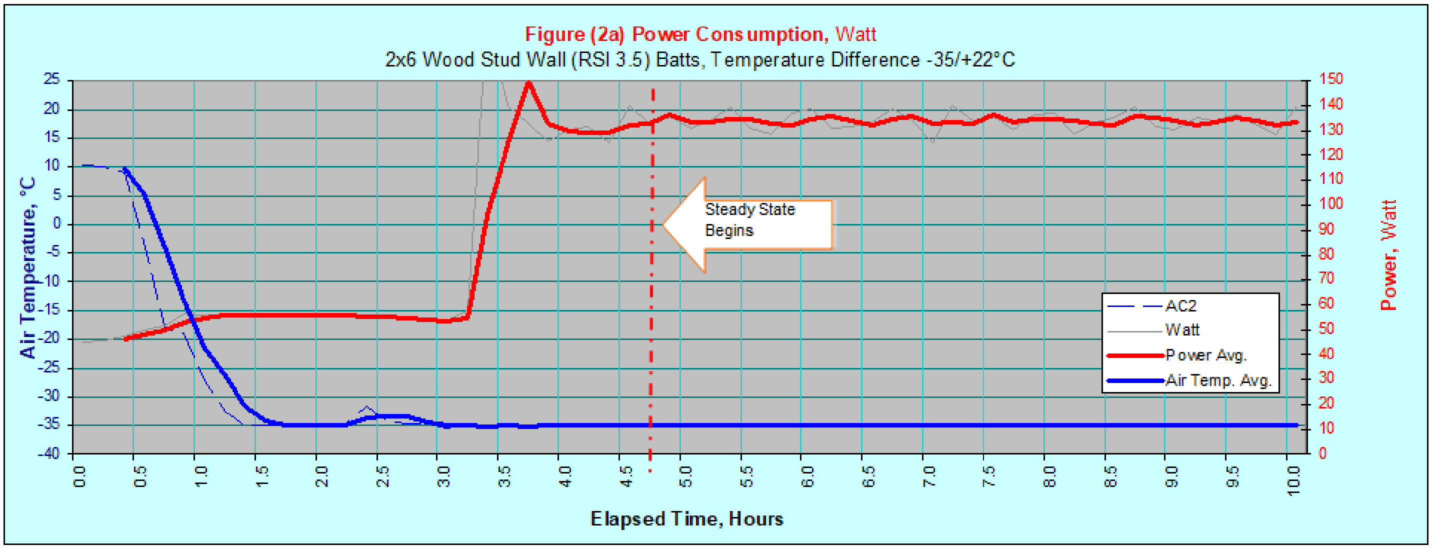


Figure (2a) Power Consumption, Watt
2x6 Wood Stud Wall (RSI 3.5) Batts, Temperature Difference -35/+22°C
Air Temperature, °C
Power, Watt
Steady State Begins
AC2
Watt
Power Avg.
Air Temp. Avg.
Elapsed Time, Hours

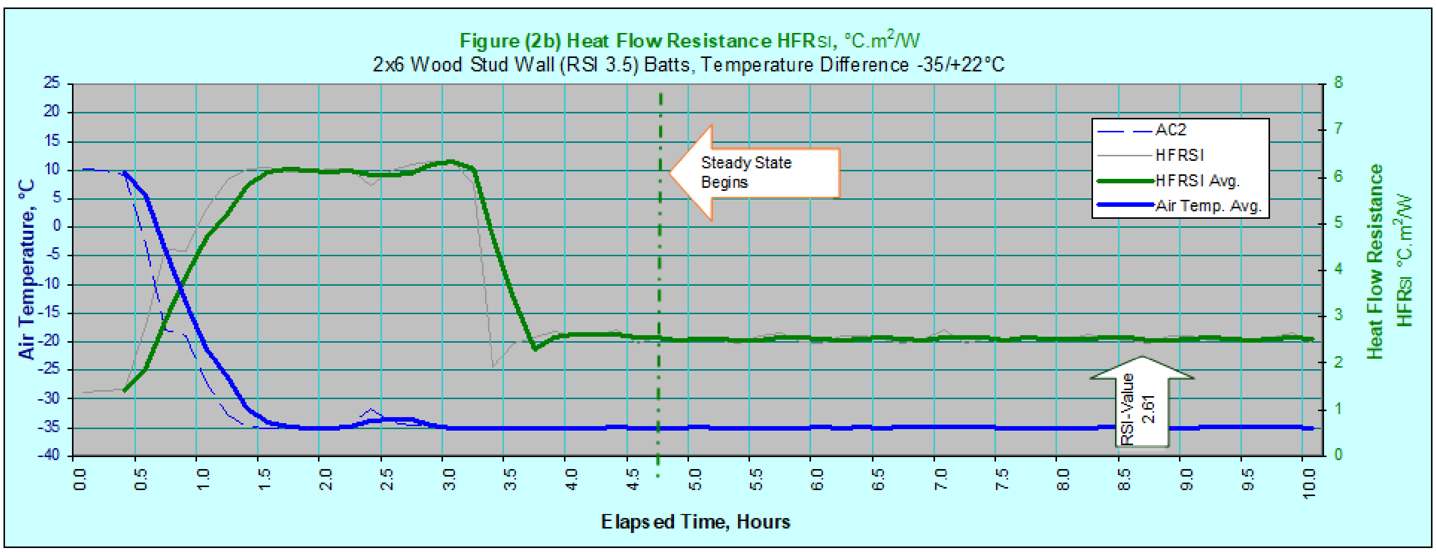


Figure (2b) Heat Flow Resistance HFRSI, °C.m²/W
2x6 Wood Stud Wall (RSI 3.5) Batts, Temperature Difference -35/+22°C
Air Temperature, °C
Heat Flow Resistance HFRSI °C.m²/W
Steady State Begins
AC2
HFRSI
HFRSI Avg.
Air Temp. Avg.
RSI-Value 2.61
Elapsed Time, Hours

6 Conclusion

Based on the test results, the derived thermal resistance of test panel is:

R-Value: **14.84** ^{o}F.ft^{2}.h/BTU

RSI: 2.61 ^{o}C.m^{2}/W *(to convert RSI to R-Value, multiply by 5.678)*

Report History

Revision No.	Change	Date	Approved by
---	Original report issued	August 16, 2019	EA

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Appendix (A)

CAN-BEST's Guarded Hot Box

CAN-BEST operates an ISO 17025, SCC accredited full-scale Guarded Hot Box Facility (GHB) facility that lends itself suitably to perform all the testing required for the evaluation program. As shown in Figure (A.1), the facility comprises the following main components:

- Fixed weather-side environmental chamber fitted with a wind machine.
- A matching moveable room side environmental chamber fitted with a large-scale calorimeter (energy metering box),
- A test panel holding frame with a 3 m x 3 m opening that, during testing, would be sandwiched between the weather side and room side chambers of the GHB. The frame is fitted with a highly insulated perimeter mask that surrounds the test panel in order to eliminate undesirable lateral and flanking heat losses through its perimeter, and
- Instrumentation and computer software to monitor, control and log all measured temperatures, wind speeds, heat flow and other test parameters.

Weather-Side Environmental Chamber
The weather side (or exterior side) of CAN-BEST's GHB is a fixed environmental chamber fitted with a perpendicular wind machine as shown in Figure (A.1). The wind machine is capable of applying onto the test surface a perpendicular wind at various speed levels in a controlled and repeatable manner. Uniform wind delivery is achieved via adjustable tubes that are equally spaced over the entire test area. The wind machine is computer controlled to generate wind speeds of up to 8 m/s that can be varied in infinitesimal increments of 0.01 m/s (0.03 kph).

The generated wind speed is continuously monitored using permanently attached wind velocity sensors that are positioned onto the tip of strategically located wind delivery tubes. These sensors provide means of a closed feedback loop for controlling the wind machine's output in real time.

Room-Side Environmental Chamber
The room side (or interior side) of the GHB is a moveable environmental chamber that "Guards" a large-scale calorimeter (energy metering box). This calorimeter, being possibly the largest in Canada, has an effective metering area of up to 2440 mm wide by 2740 mm high (8' x 9').

The Guard Room maintains an ambient temperature surrounding the calorimeter constant and at the same level as its interior ambient test temperature. In order to minimize the extraneous heat loss/gain through the calorimeter, the Guard room temperature is controlled to limit the temperature difference across its walls to a minimum.

As shown in Figure (A.1), the calorimeter is fitted with a "Constant Temperature Baffle" with a known surface emissivity, positioned parallel to and facing the test panel. This provides means of heat loss/gain correction due to radiation exchange that may take place with the test wall.

Test Panel Holding Frame
The test panel holding frame is a mobile steel frame capable of holding a test panel up to 3124 mm square (123" square). As shown in Figure (A.2), the frame is fitted with a highly insulated perimeter mask (surround panel) required to minimize lateral and flanking heat losses through the test panel's perimeter. The mask is fitted with an opening that can accommodate the test panel, and with the panel installed, the frame is positioned "sandwiched" between the weather side and room side of the GHB.

GHB Instrumentation
The CAN-BEST GHB is fitted with state of the art instrumentation package that meet or exceed the performance requirements of ASTM C1363 standard as follows:

- Temperature sensors – Thermocouple wire, Gauge 30, Type T,
- Wind speed sensors placed at strategic locations to monitor and control both the applied wind speed in the weather side chamber and the natural convection developed in the room side chamber,
- Differential pressure sensor to monitor and control the static pressure difference across the test panel,
- RH sensor, placed inside the calorimeter to monitor and control the interior's ambient relative humidity,
- Means of de-humidification of the interior's ambient condition in order to prevent condensation from taking place on the temperature sensors that would interfere with their measurements, and
- Computerized monitoring and control software that allows changing any of the test parameters "on the fly" without interruption of the test progress. Data from all sensors are acquired continuously once every second, using 24 bit data acquisition system averaged over 600 seconds and logged every 10 minutes.

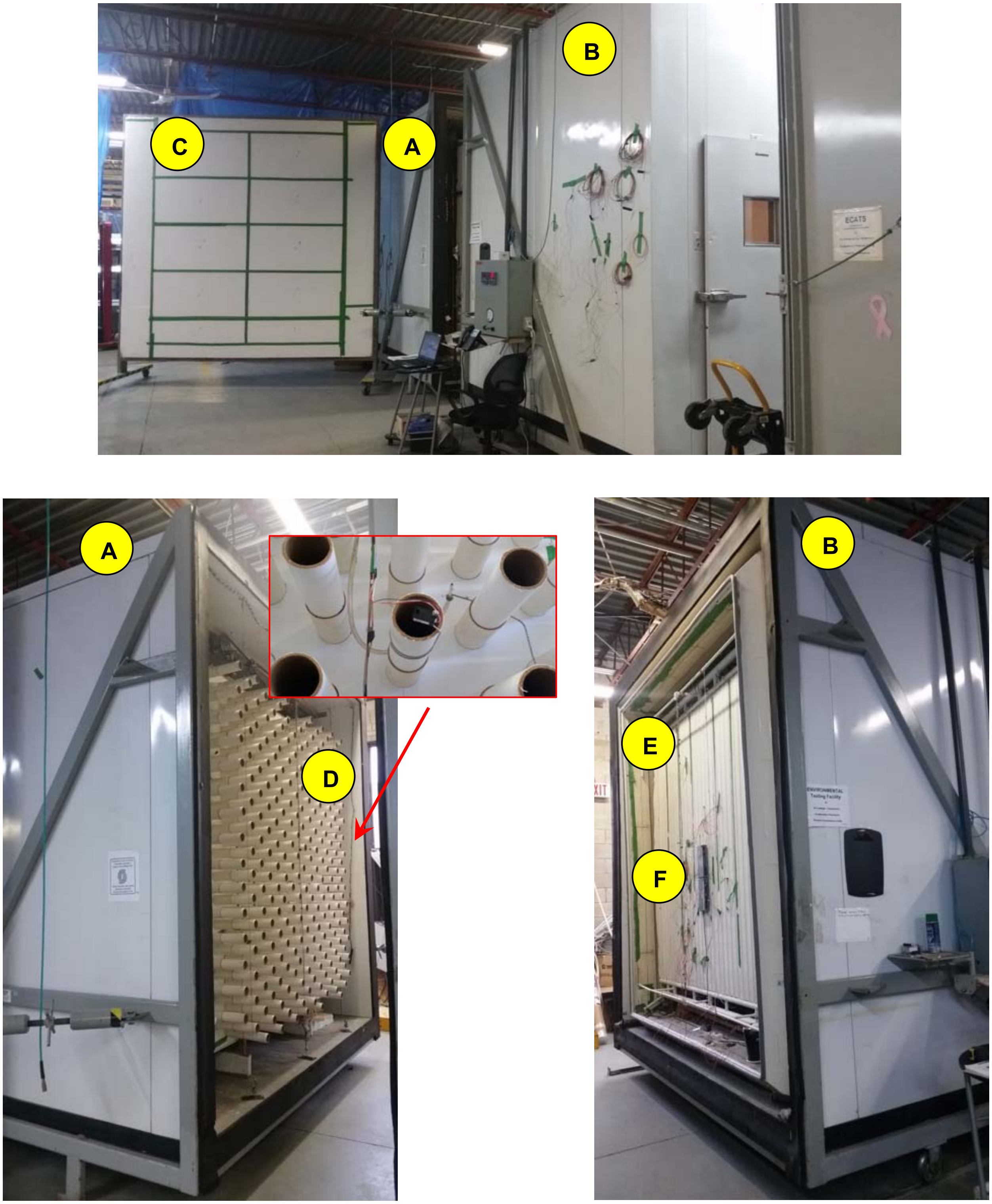
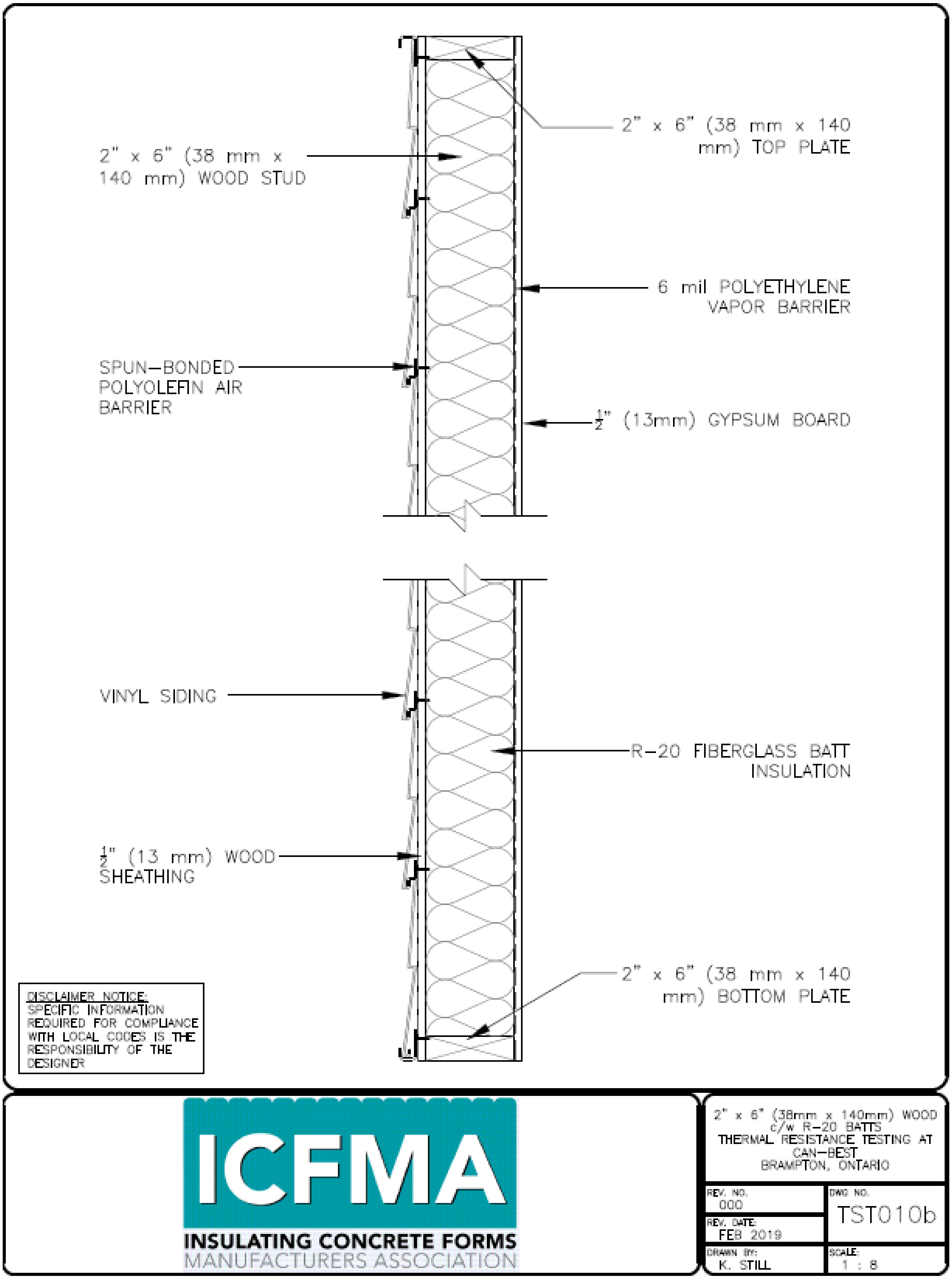


Figure (A.1): CAN-BEST Guarded Hot Box Setup

A – Weather Side Chambre, showing wind machine (D) with wind velocity sensor mounted (inset)
B – Room Side Chambre, showing Calorimeter (E) and Constant Temperature Baffle (F)
C – Test Frame, showing perimeter mask and installed calibration panel

Appendix (B) Drawing (1 Page)



Appendix (C) CAN-BEST Thermal Performance Test, ASTM C1363-11, Guarded Hot Box (GHB)

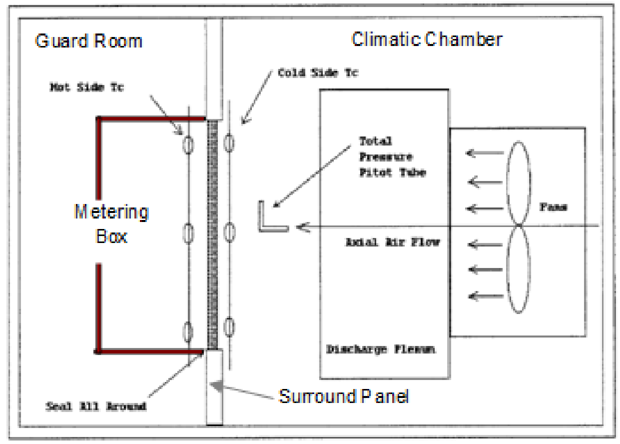
Nudura - 2x6 (R20) Wood Stud Wall

Test Start Date: January 10, 2019
Test End Date: January 12, 2019

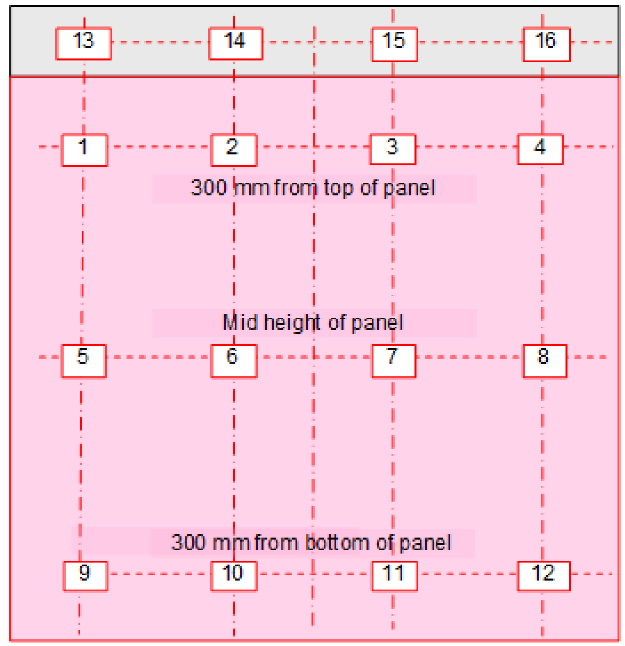
Job No.: 5292
Log File Name: Nudura 2019-01-10
Data Acquisition: One record per second
Data Logging Rate: One record per 10 minutes
Specimen ID: 5292-6
Metering Box ID: CAN-BEST 1003

Specimen Dimensions:		SI	Imp
W_s	Width, m *(ft)*	2440	96.06
H_s	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°F)*	0.111	0.02
sp_{sp}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	0.06
A_s	Sample Area, m² *(ft²)*	5.21	64.03

Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side, °C *(°F)*	-35.02	-31.0
t_h	Ambient Temperature - Room Side, °C *(°F)*	21.95	71.5
t_1	Surface Temperature - Room Side, °C *(°F)*	18.47	65.2
t_{sp1}	Surround Panel Temperature - Room Side, °C *(°F)*	20.98	69.8
t_2	Surface Temperature - Weather Side, °C *(°F)*	-33.74	-28.7
t_{sp2}	Surround Panel Temperature - Weather Side, °C *(°F)*	-34.04	-29.3
Q_f	Fan Heat Input, W *(Btu/h)*		
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	133.14	454.3
Q_{sp}	Surround Panel Correction, W *(Btu/h)*	4.55	0.11
E	Metering Box Thermopile Output, mV	-4.00	-4.00
Q_{mw}	Metering Box Walls Correction, W *(Btu/h)*	-2.18	-7.4
Q_s	Specimen Heat Flow, W *(Btu/h)*	126.40	431.3
Thermal Conductance/Transmittance, W/m²/°K *(Btu/h/ft²/°F)*			
C	Specimen Surface to Surface Thermal Conductance	0.407	0.072
h_{henv}	Interior Surface to Environment Heat Transfer Coefficient	6.10	1.07
h_{cenv}	Exterior Surface to Environment Heat Transfer Coefficient	16.61	2.93
U	Specimen Air to Air Overall Thermal Transmittance	0.373	0.066
U_s*	Standard Specimen Overall Thermal Transmittance	**0.383**	**0.067**
Thermal Resistance, K.m²/W *(F.ft².h/Btu)*			
R_{henv}	Interior Surface Film Resistance	0.16	0.93
R_{cenv}	Exterior Surface Film Resistance	0.06	0.34
R_u	Specimen Overall Thermal Resistance	2.68	15.24
R_s*	Standard Specimen Overall Thermal Resistance	**2.61**	**14.84**



TC #	Surface Temperatures°C	
	Warm	Cold
1	19.7	-33.8
2	20.5	-33.5
3	19.7	-33.3
4	21.4	-33.5
5	17.1	-33.5
6	15.5	-34.1
7	16.8	-33.5
8	18.5	-33.9
9	18.1	-33.8
10	18.1	-34.1
11	18.5	-34.1
12	17.8	-34.0
Avg.	18.5	-33.8
Mask (Top 300 mm)		
13	21.7	-33.8
14	19.4	-34.1
15	21.3	-34.2
16	21.6	-34.0
Avg.	21.0	-34.0



Thermocouple locations as viewed from interior side

* *Values normalized to Standard ASHRAE 90.1 Heat Transfer Coefficients of 30.0 and 8.3 W/m²/°K for cold and warm sides respectively*

2x4 (R14) Wood Stud Wall - Cooling Mode

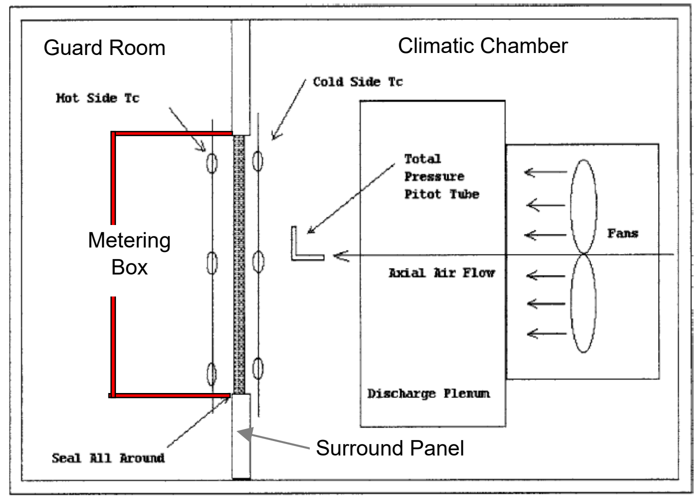
Test Start Date: October 1, 2018
Test End Date: October 2, 2018

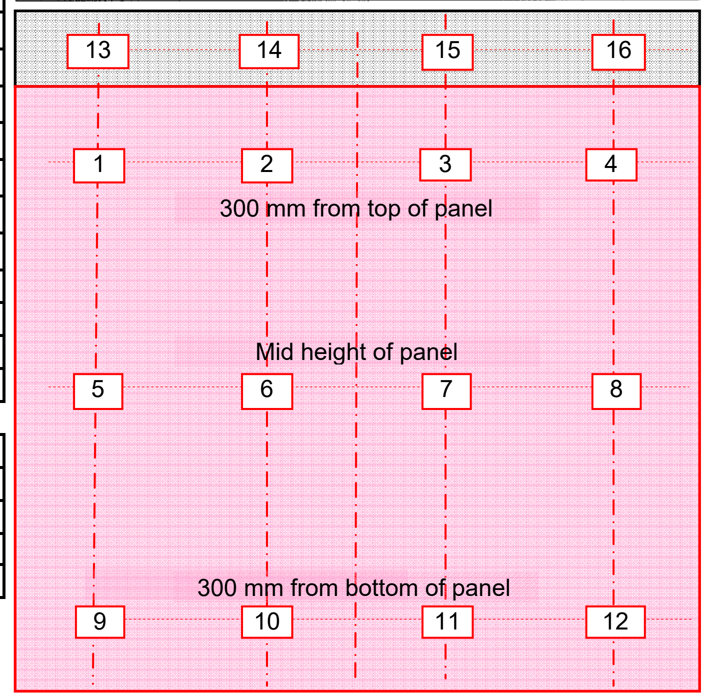
Specimen Dimensions:		SI	Imp
W_S	Width, m *(ft)*	2440	96.06
H_S	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m^2 *(ft^2)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, $W/m^2/^oK$ *($Btu/h/ft^2/^o$*	0.111	0.02
sp_{SP}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m^2 *(ft^2)*	0.74	0.06
A_s	Sample Area, m^2 *(ft^2)*	5.21	64.03

Job No.:	5292
Log File Name:	Nudura 2018-10-01
Data Acquisition:	One record per second
Data Logging Rate	One record per 10 minutes
Specimen ID:	5292-2
Metering Box ID:	CAN-BEST 1003

Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side , °C *(°F)*	54.97	*130.9*
t_h	Ambient Temperature - Room Side, °C *(°F)*	23.64	*74.5*
t_1	Surface Temperature - Room Side, °C *(°F)*	24.94	*76.9*
t_{SP1}	Surround Panel Temperature - Room Side, °C *(°F)*	24.48	*76.1*
t_2	Surface Temperature - Weather Side, °C *(°F)*	54.50	*130.1*
t_{SP2}	Surround Panel Temperature - Weather Side, °C *(°F)*	54.74	*130.5*
Q_f	Fan Heat Input, W *(Btu/h)*	49.00	
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	177.91	*607.1*

TC #	Surface Temperatures°C	
	Room	Weather
1	24.8	54.3
2	25.3	54.5
3	26.1	54.6
4	25.8	54.6
5	24.7	54.2
6	25.1	54.6
7	25.5	54.9
8	25.3	54.7
9	24.2	54.2
10	24.2	54.5
11	24.2	54.6
12	24.2	54.2
Avg.	24.9	54.5
Mask (Top 300 mm)		
13	24.5	54.6
14	24.6	54.8
15	24.5	54.9
16	24.4	54.7
Avg.	24.5	54.7





Thermocouple locations as viewed from interior side

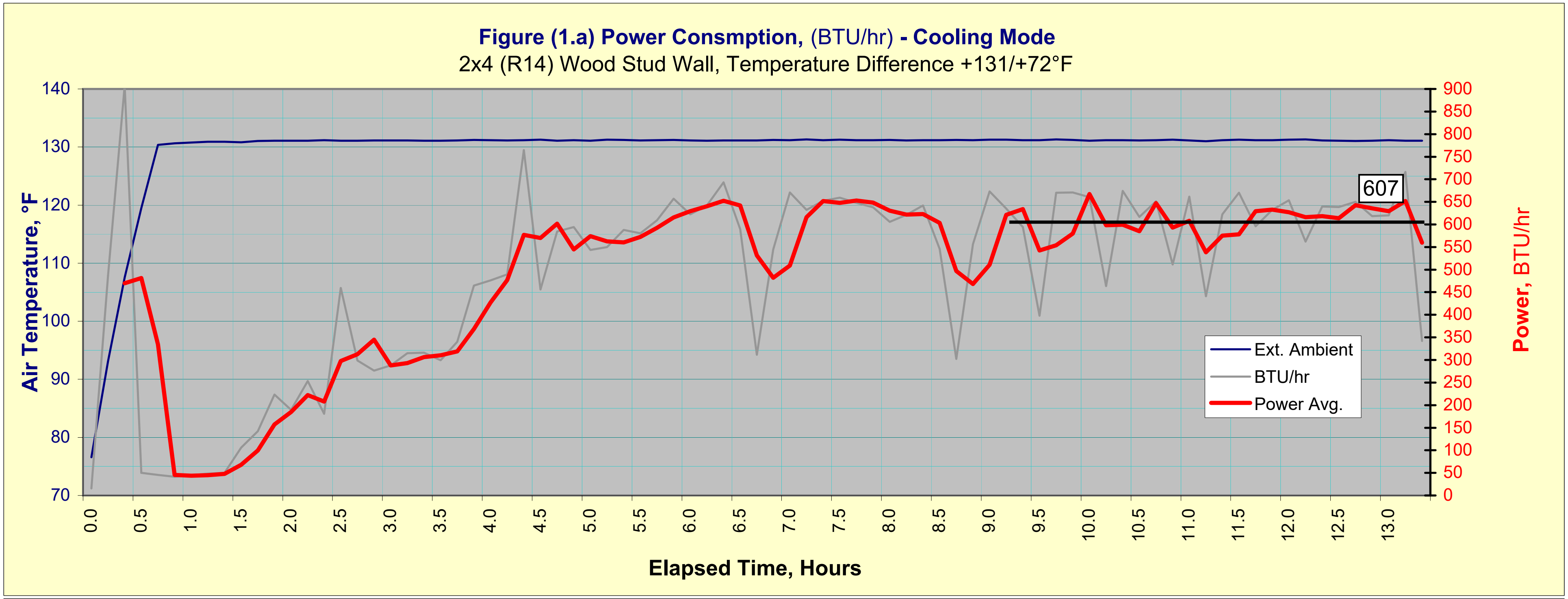


Figure (1.a) Power Consmption, (BTU/hr) - Cooling Mode
2x4 (R14) Wood Stud Wall, Temperature Difference +131/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
607
Ext. Ambient
BTU/hr
Power Avg.

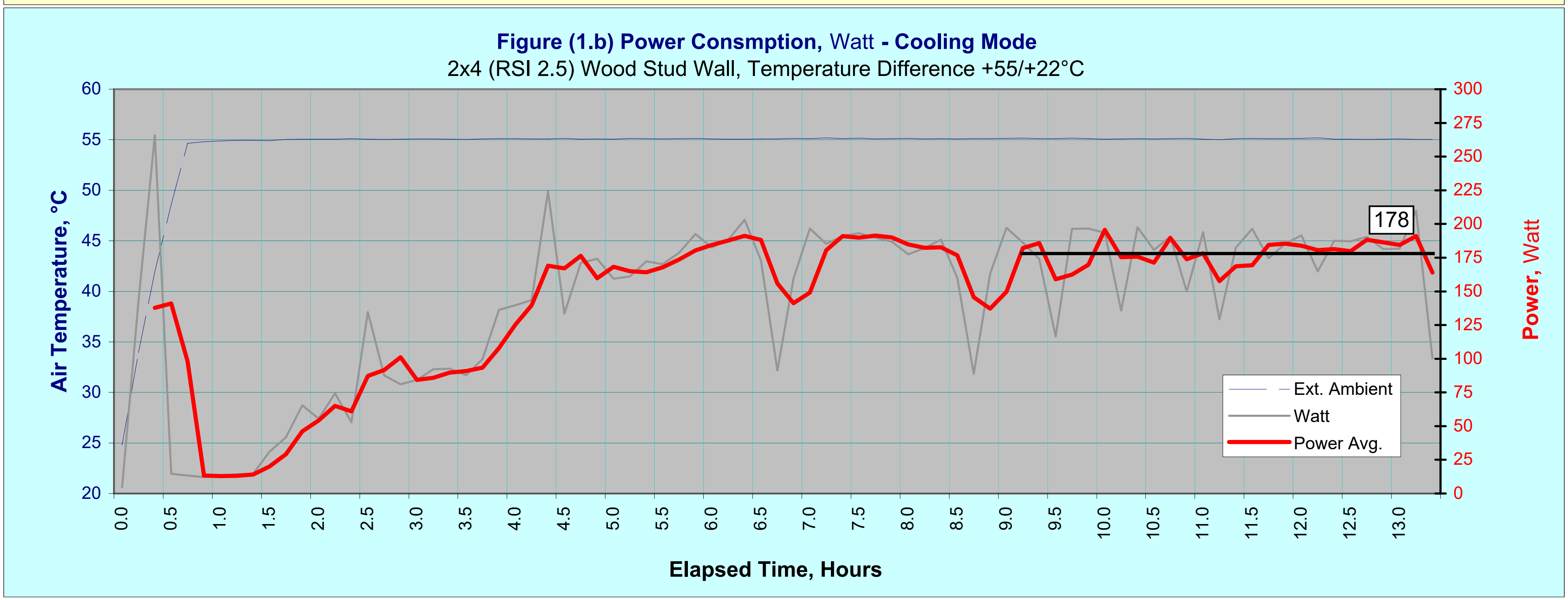


Figure (1.b) Power Consmption, Watt - Cooling Mode
2x4 (RSI 2.5) Wood Stud Wall, Temperature Difference +55/+22°C
Air Temperature, °C
Power, Watt
Elapsed Time, Hours
178
Ext. Ambient
Watt
Power Avg.

CAN-BEST Thermal Performance Test 8/20/2019

2x6 (R20+5) Wood Stud Wall - Cooling Mode

Test Start Date: November 12, 2018
Test End Date: November 13, 2018

Specimen Dimensions:		***SI***	***Imp***
W_S	Width, m *(ft)*	2440	96.06
H_S	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°*	0.111	0.02
sp_{SP}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	0.06
A_s	Sample Area, m² *(ft²)*	5.21	64.03

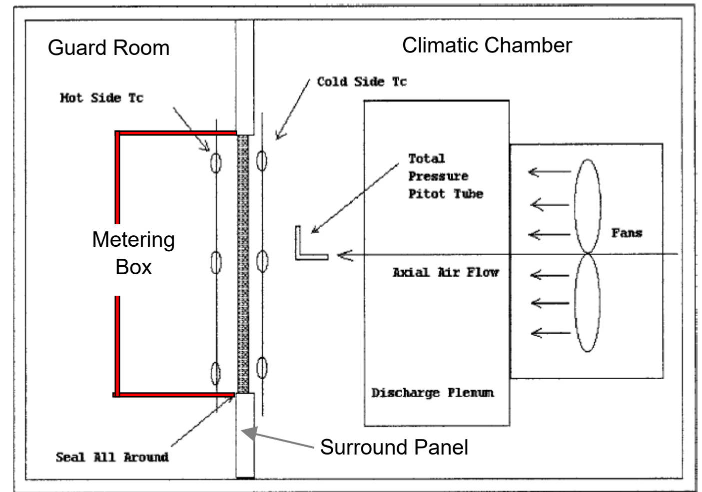
Job No.: 5292
Log File Name: Nudura 2018-11-12
Data Acquisition: One record per second
Data Logging Rate One record per 10 minutes
Specimen ID: 5292-4
Metering Box ID: CAN-BEST 1003

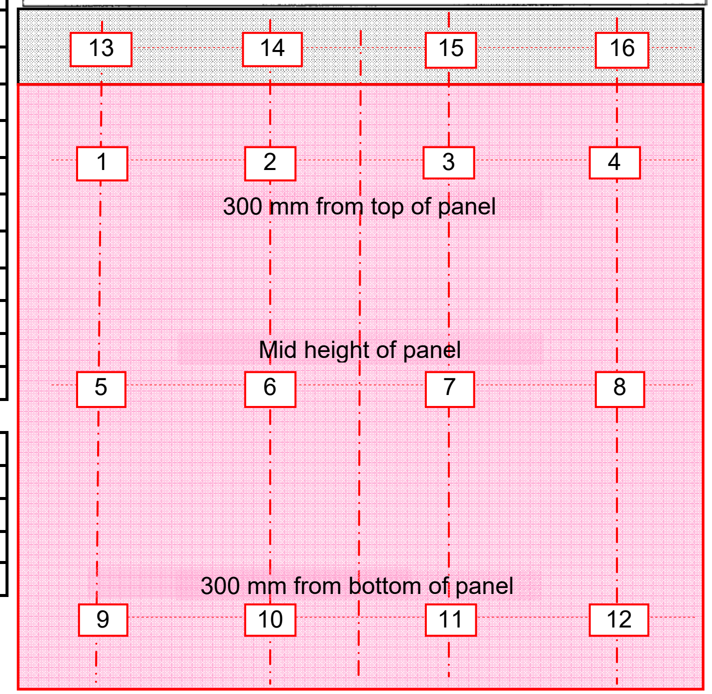
Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side , °C *(°F)*	55.16	*131.3*
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.83	*73.1*
t_1	Surface Temperature - Room Side, °C *(°F)*	23.56	*74.4*
t_{SP1}	Surround Panel Temperature - Room Side, °C *(°F)*	24.27	*75.7*
t_2	Surface Temperature - Weather Side, °C *(°F)*	55.14	*131.2*
t_{SP2}	Surround Panel Temperature - Weather Side, °C *(°F)*	55.13	*131.2*
Q_f	Fan Heat Input, W *(Btu/h)*	49.00	
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	128.50	*438.5*

TC #	Surface Temperatures°C	
	Room	Weather
1	24.4	55.1
2	24.6	55.2
3	26.0	55.2
4	24.9	55.2
5	23.5	55.1
6	23.7	55.1
7	24.0	55.3
8	24.0	55.3
9	18.9	54.9
10	23.1	55.1
11	23.0	55.2
12	22.7	54.9
Avg.	23.6	55.1

Mask (Top 300 mm)

TC #	Room	Weather
13	24.3	55.0
14	24.4	55.2
15	24.2	55.2
16	24.1	55.1
Avg.	24.3	55.1





Thermocouple locations as viewed from interior side

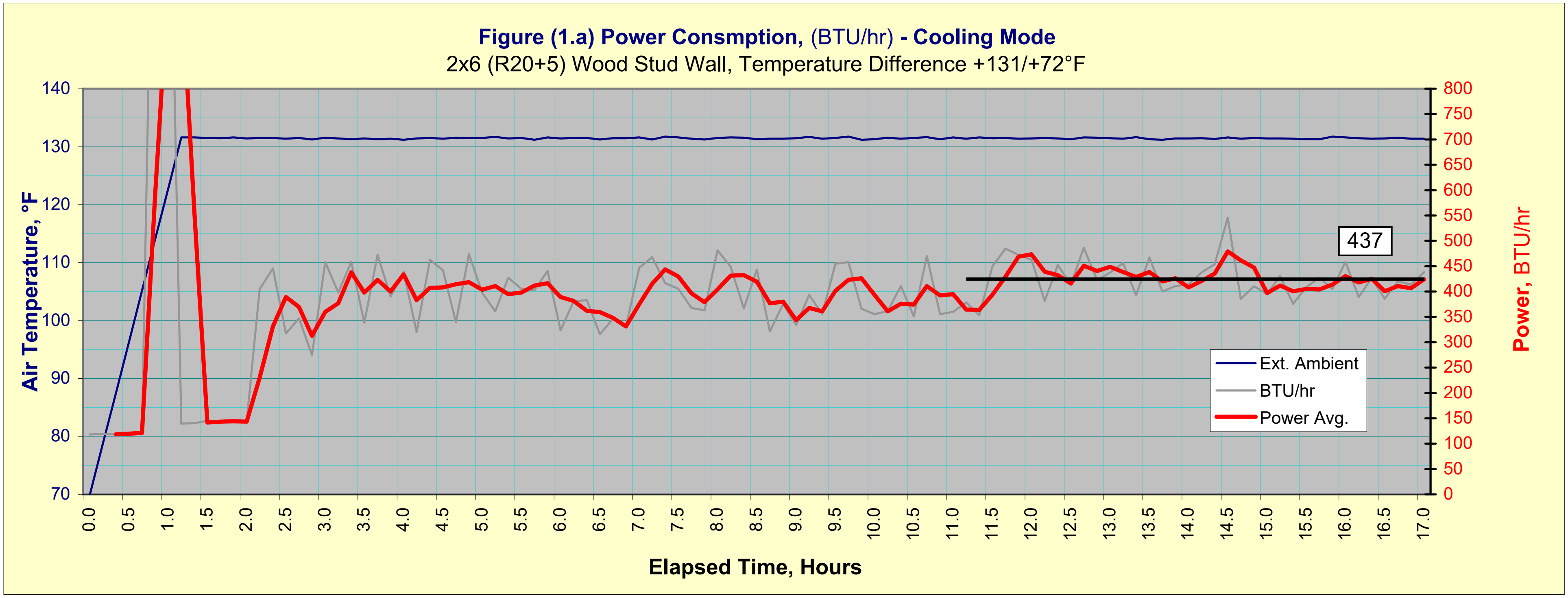


Figure (1.a) Power Consmption, (BTU/hr) - Cooling Mode
2x6 (R20+5) Wood Stud Wall, Temperature Difference +131/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
437
Ext. Ambient
BTU/hr
Power Avg.

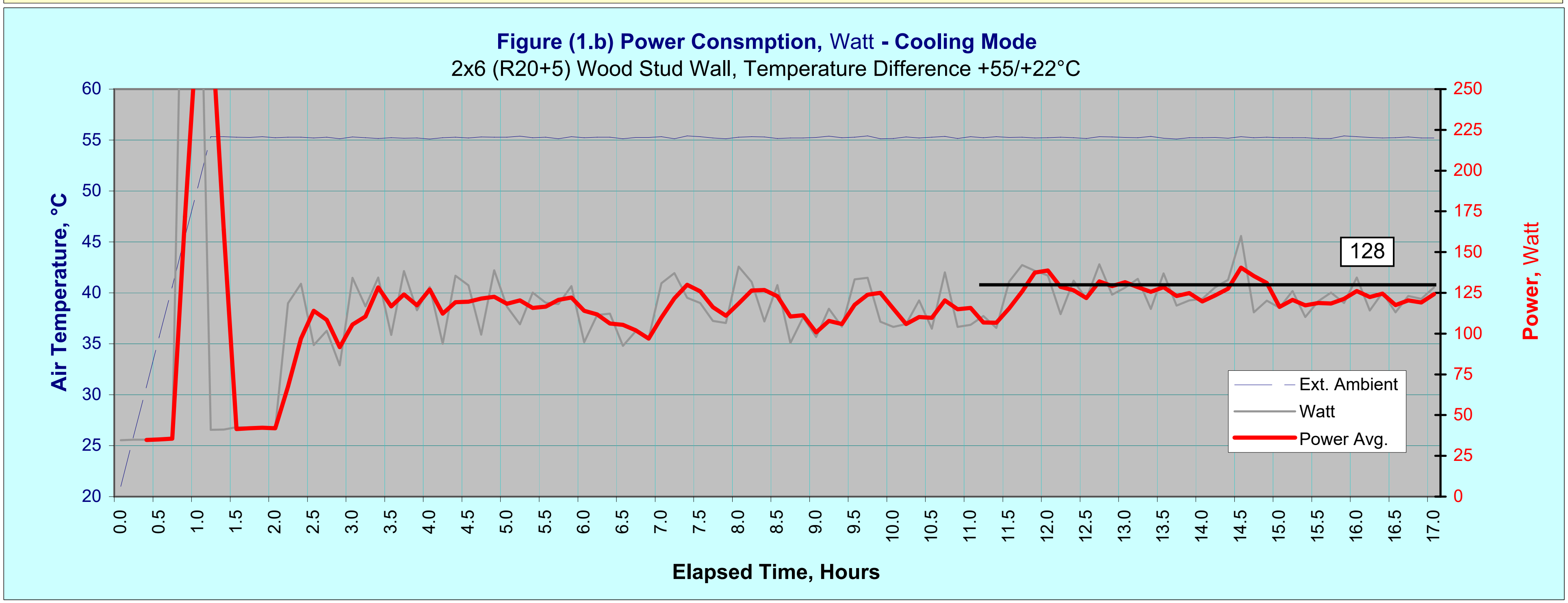


Figure (1.b) Power Consmption, Watt - Cooling Mode
2x6 (R20+5) Wood Stud Wall, Temperature Difference +55/+22°C
Air Temperature, °C
Power, Watt
Elapsed Time, Hours
128
Ext. Ambient
Watt
Power Avg.

Nudura - ICF Wall - Cooling Mode

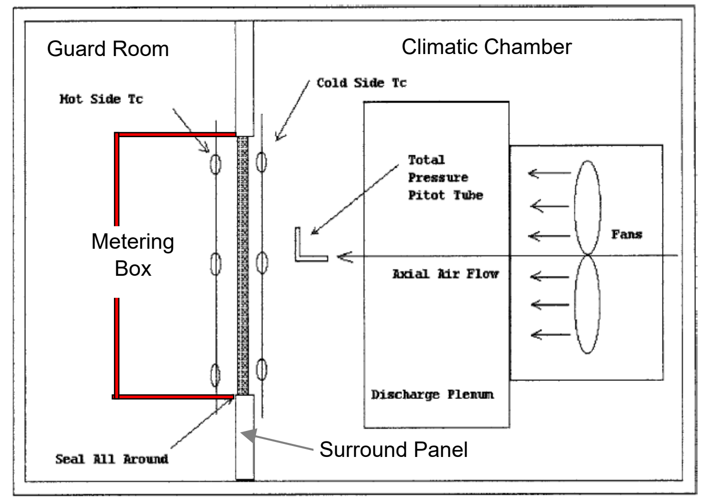
Test Start Date: March 11, 2019
Test End Date: April 5, 2019

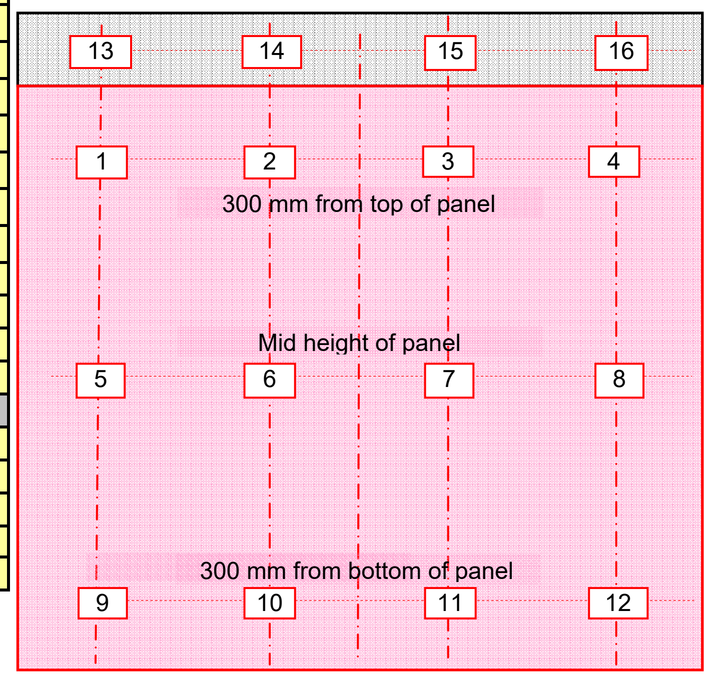
Job No.:	5292
Log File Name:	Nudura 2019-03-31
Data Acquisition:	One record per second
Data Logging Rate	One record per 10 minutes
Specimen ID:	5292-5
Metering Box ID:	CAN-BEST 1003

Specimen Dimensions:		*SI*	*Imp*
W_S	Width, m *(ft)*	2440	96.06
H_S	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m² *(ft²)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, W/m²/°K *(Btu/h/ft²/°*	0.111	0.02
sp_{SP}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m² *(ft²)*	0.74	0.06
A_s	Sample Area, m² *(ft²)*	5.21	64.03

Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side , °C *(°F)*	55.32	*131.6*
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.62	*72.7*
t_1	Surface Temperature - Room Side, °C *(°F)*	22.67	*72.8*
t_{SP1}	Surround Panel Temperature - Room Side, °C *(°F)*	23.38	*74.1*
t_2	Surface Temperature - Weather Side, °C *(°F)*	54.92	*130.9*
t_{SP2}	Surround Panel Temperature - Weather Side, °C *(°F)*	54.77	*130.6*
Q_f	Fan Heat Input, W *(Btu/h)*	49.00	
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	105.38	*359.6*

TC #	Surface Temperatures°C	
	Warm	Cold
1	22.6	54.8
2	22.9	54.9
3	23.2	54.9
4	23.9	54.8
5	23.5	54.9
6	22.8	55.1
7	23.0	55.1
8	23.1	55.0
9	23.1	54.8
10	23.1	54.9
11	23.0	54.9
12	22.7	54.7
Avg.	23.1	54.9
Mask (Top 300 mm)		
13	21.7	54.7
14	23.8	54.9
15	23.6	54.8
16	23.4	54.6
Avg.	23.1	54.7





Thermocouple locations as viewed from interior side

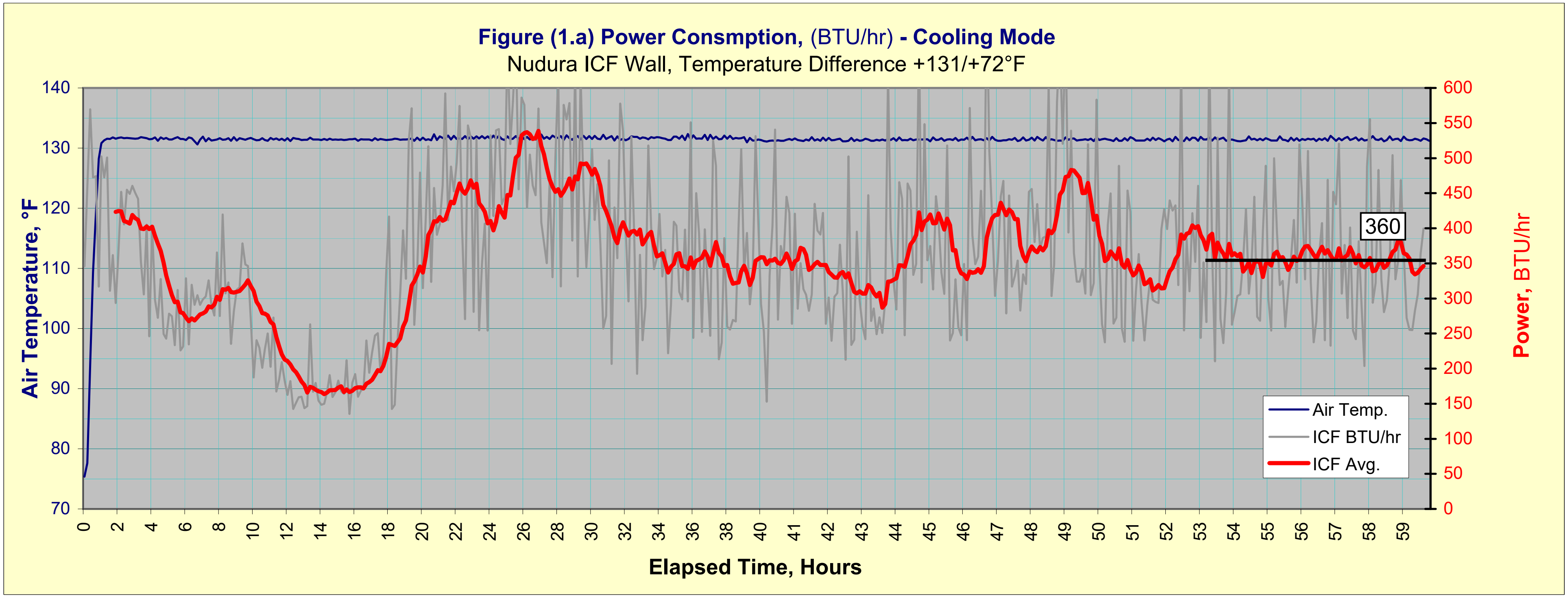


Figure (1.a) Power Consmption, (BTU/hr) - Cooling Mode
Nudura ICF Wall, Temperature Difference +131/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
Air Temp.
ICF BTU/hr
ICF Avg.
360

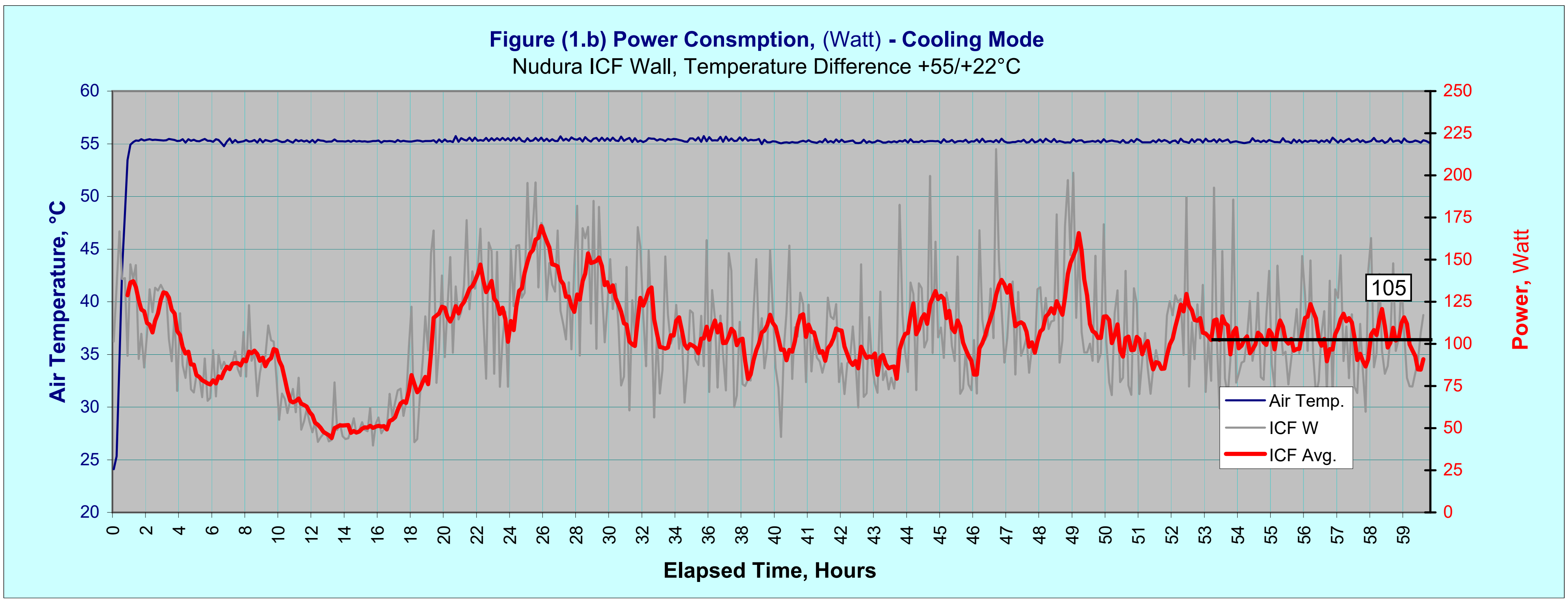


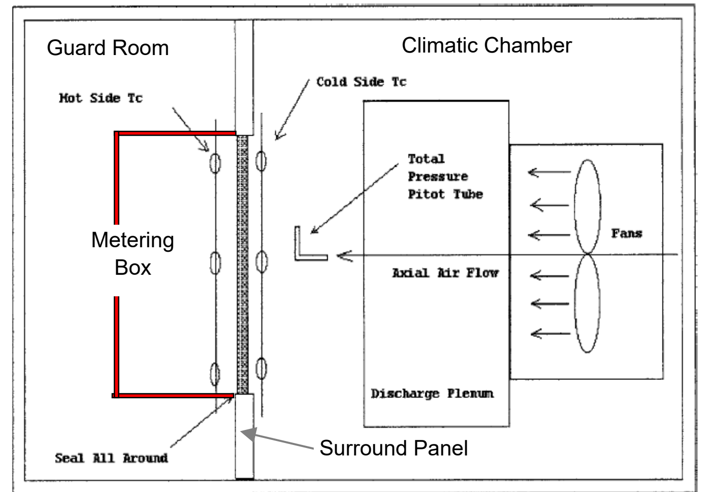
Figure (1.b) Power Consmption, (Watt) - Cooling Mode
Nudura ICF Wall, Temperature Difference +55/+22°C
Air Temperature, °C
Power, Watt
Elapsed Time, Hours
Air Temp.
ICF W
ICF Avg.
105

2x6 (R20) Wood Stud Wall - Cooling Mode

Test Start Date: January 15, 2019
Test End Date: January 16, 2019

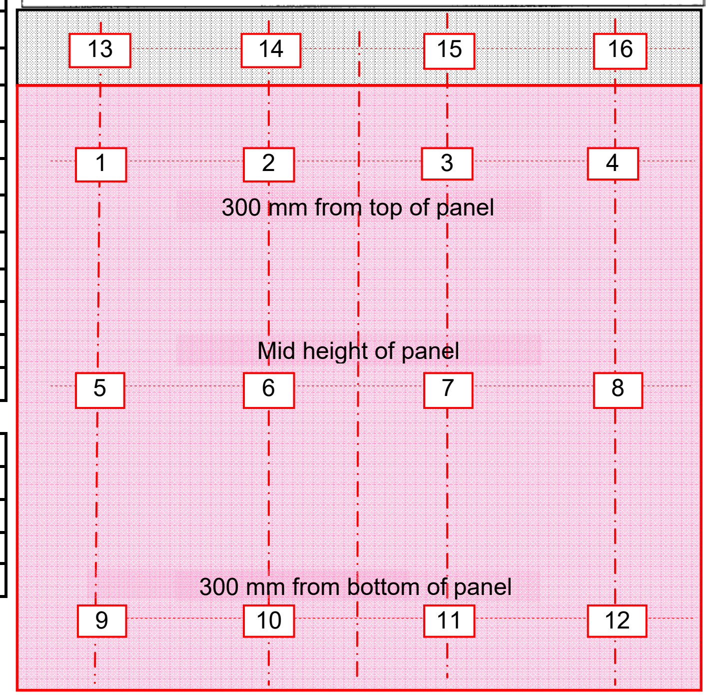
Specimen Dimensions:		*SI*	*Imp*
W_S	Width, m *(ft)*	2440	96.06
H_S	Height, m *(ft)*	2440	96.06
A_t	Surface Area, m^2 *(ft^2)*	5.95	64.08
W_{mb}	Width, m *(ft)*	2438	8.00
H_{mb}	Height, m *(ft)*	2743	9.00
Surround Panel:			
C_{sp}	Conductance, $W/m^2/^oK$ *($Btu/h/ft^2/^o$*	0.111	0.02
sp_{SP}	Width, m *(ft)*	2438	8.00
H_{sp}	Height, m *(ft)*	305	1.00
A_{sp}	Surround Panel Area, m^2 *(ft^2)*	0.74	0.06
A_s	Sample Area, m^2 *(ft^2)*	5.21	64.03

Job No.:	5292
Log File Name:	Nudura 2019-01-15
Data Acquisition:	One record per second
Data Logging Rate	One record per 10 minutes
Specimen ID:	5292-6
Metering Box ID:	CAN-BEST 1003



Measured Temperatures and Heat Input at Steady State		SI	IP
t_c	Ambient Temperature - Weather Side , °C *(°F)*	55.04	*131.1*
t_h	Ambient Temperature - Room Side, °C *(°F)*	22.10	*71.8*
t_1	Surface Temperature - Room Side, °C *(°F)*	24.58	*76.2*
t_{SP1}	Surround Panel Temperature - Room Side, °C *(°F)*	23.00	*73.4*
t_2	Surface Temperature - Weather Side, °C *(°F)*	46.52	*115.7*
t_{SP2}	Surround Panel Temperature - Weather Side, °C *(°F)*	55.15	*131.3*
Q_f	Fan Heat Input, W *(Btu/h)*	49.60	
Q_h	Heaters Heat Input, W *(Btu/h)*		
Q_{in}	Total Energy Input, W *(Btu/h)*	147.33	*502.7*

TC #	Surface Temperatures°C	
	Room	Weather
1	22.9	55.1
2	25.2	55.2
3	25.3	55.2
4	26.8	55.2
5	25.6	18.7
6	24.3	55.1
7	24.4	19.2
8	24.7	55.1
9	24.8	54.9
10	23.7	55.1
11	23.6	55.2
12	23.5	54.9
Avg.	24.6	49.1
Mask (Top 300 mm)		
13	23.4	55.1
14	24.3	55.3
15	19.9	55.3
16	24.4	55.3
Avg.	23.0	55.3



Thermocouple locations as viewed from interior side

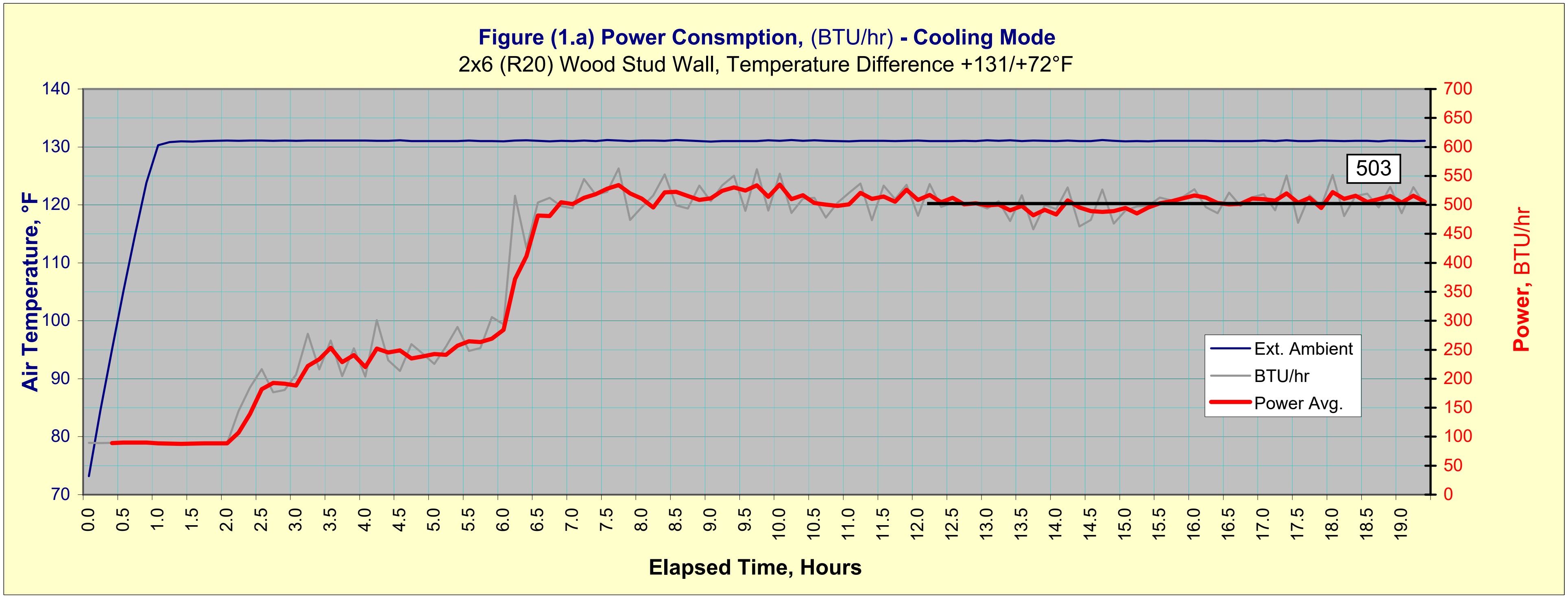


Figure (1.a) Power Consmption, (BTU/hr) - Cooling Mode
2x6 (R20) Wood Stud Wall, Temperature Difference +131/+72°F
Air Temperature, °F
Power, BTU/hr
Elapsed Time, Hours
503
Ext. Ambient
BTU/hr
Power Avg.

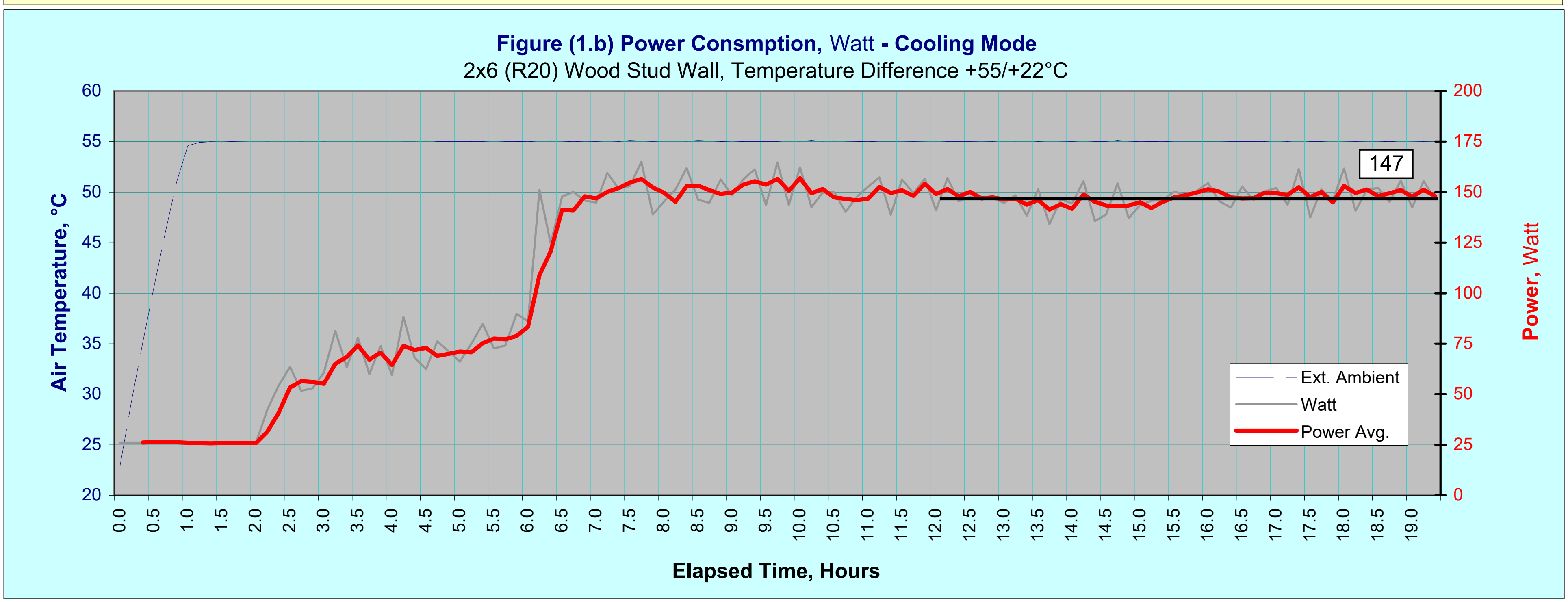


Figure (1.b) Power Consmption, Watt - Cooling Mode
2x6 (R20) Wood Stud Wall, Temperature Difference +55/+22°C
Air Temperature, °C
Power, Watt
Elapsed Time, Hours
147
Ext. Ambient
Watt
Power Avg.