Project Overcoat: Wall Insulation Upgrade Testing at the Cloquet Residential Research Facility

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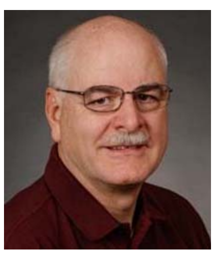
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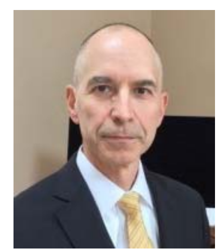

Dr. Antonio Aldykiewicz

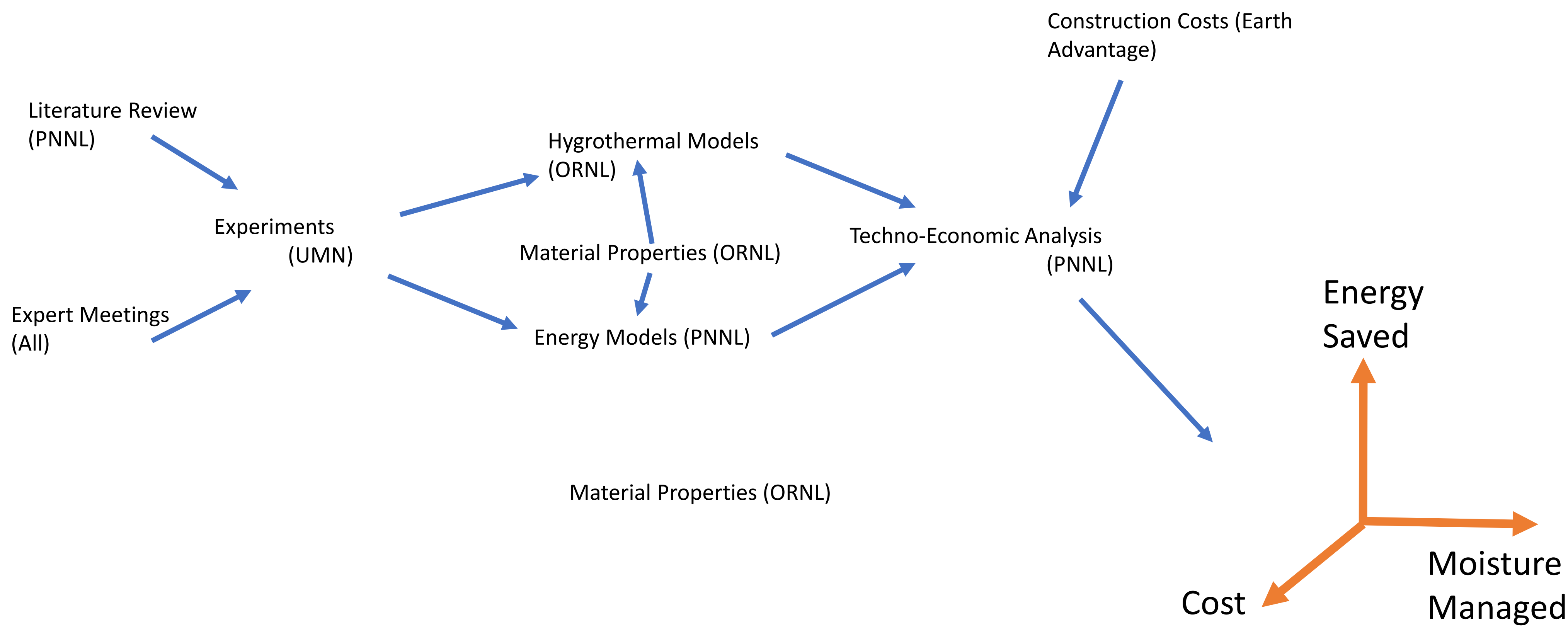

Jerry Atchley

Background and Scope

Project Goal

- Determine “the best” exterior wall retrofit system for the cold climate based on the walls studied and according to the following criteria:
  - low cost relative to the energy-efficient benefit
  - Moisture-durable
  - can be applied to a large portion of existing walls
  - “Fool Proof” construction

Major Project Components



Research Questions

The primary research questions associated with the experimental phase of this research are listed below:

- How can moisture risks be minimized or eliminated for each of these wall retrofit solutions?
- Does removing the cladding always improve the moisture, thermal and/or air leakage performance?
- Is there a clear path for reducing installation costs for any of these wall solutions?

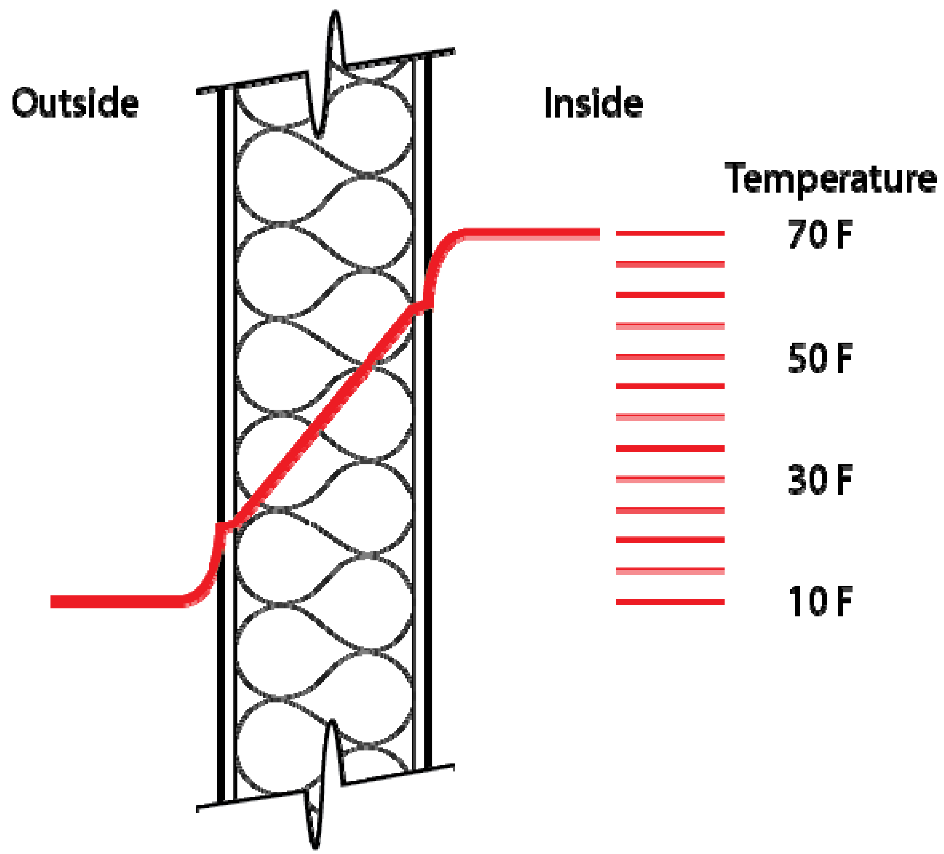
Some secondary research questions associated with the experimental research include:

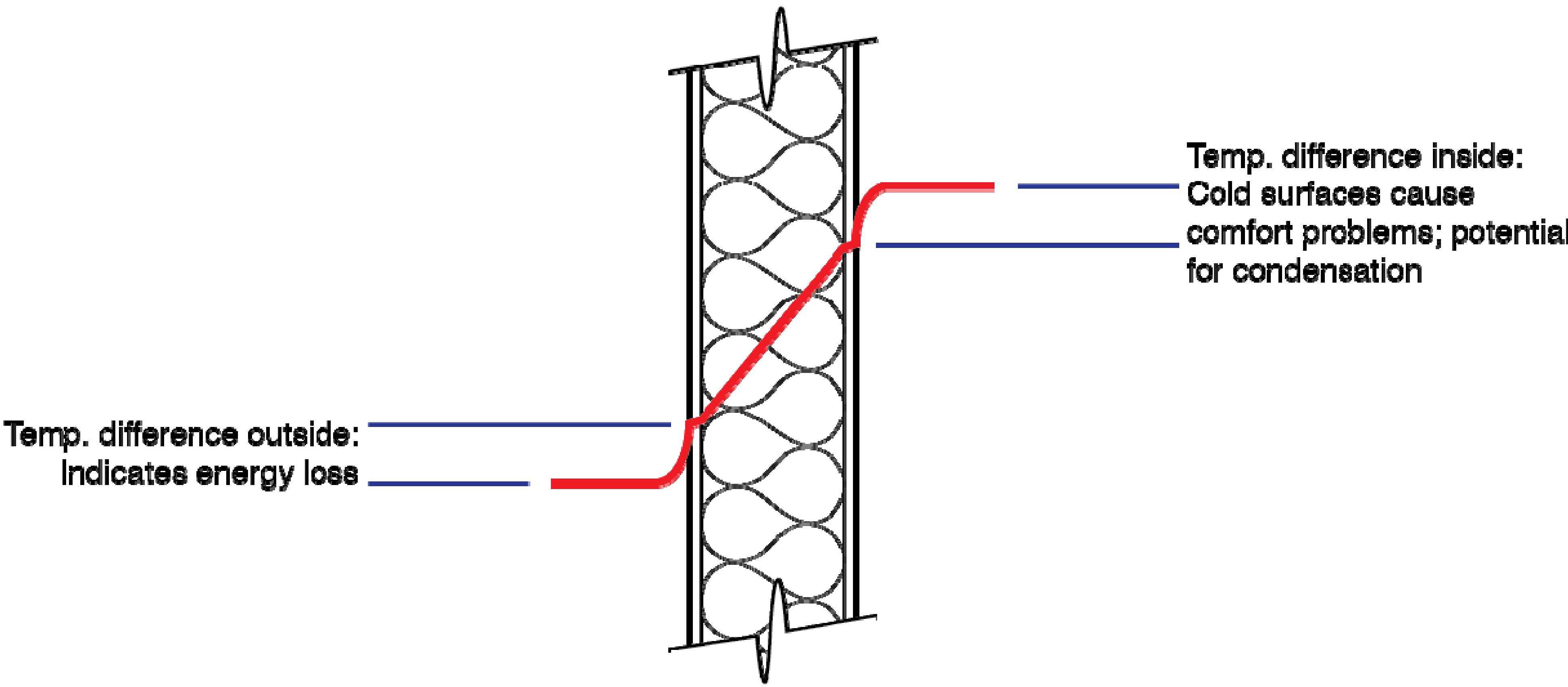
- Which of the chosen wall systems or components has the best thermal performance in the cold climate?
- Which of the chosen wall systems do not create a hygrothermal issue in the cold climate?
- Do any of the air control layers seem to work better than others?
- Which system is the easiest to install (based on lab team experience)?

Project Goal

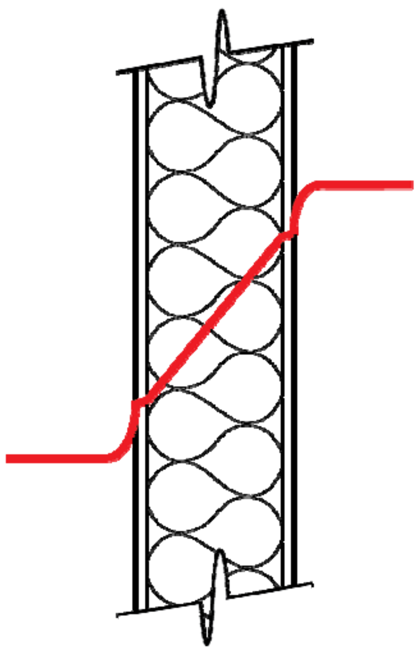
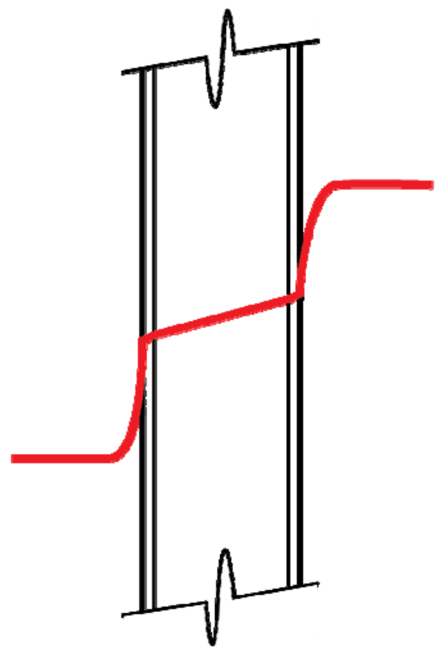
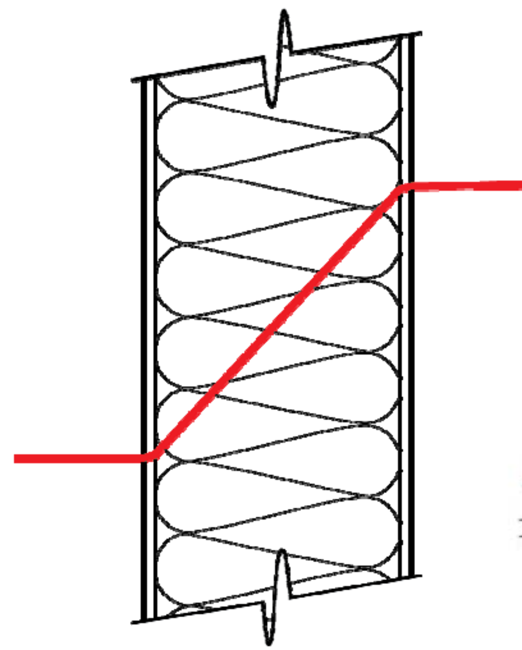
- Determine “the best” exterior wall retrofit system for the cold climate based on the walls studied and according to the following criteria:
  - low cost relative to the energy-efficient benefit –High R-value, airtight construction
  - Moisture-durable –Location of thermal control layer, airtight construction, vapor control strategy
  - can be applied to a large portion of existing walls
  - “Fool Proof” construction

Building Science Issues: Thermal Control





Temp. difference inside:
Cold surfaces cause
comfort problems; potential
for condensation
Temp. difference outside:
Indicates energy loss

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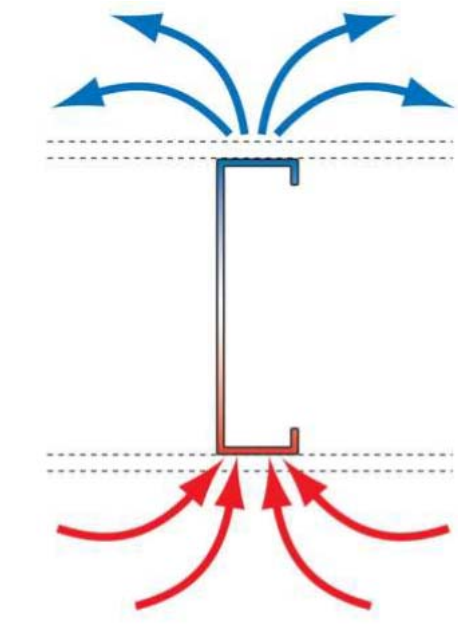
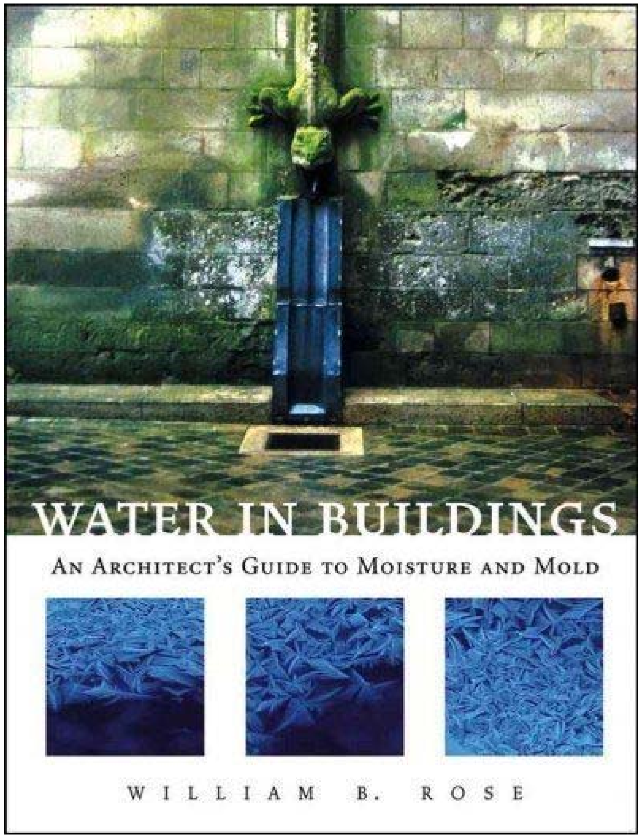
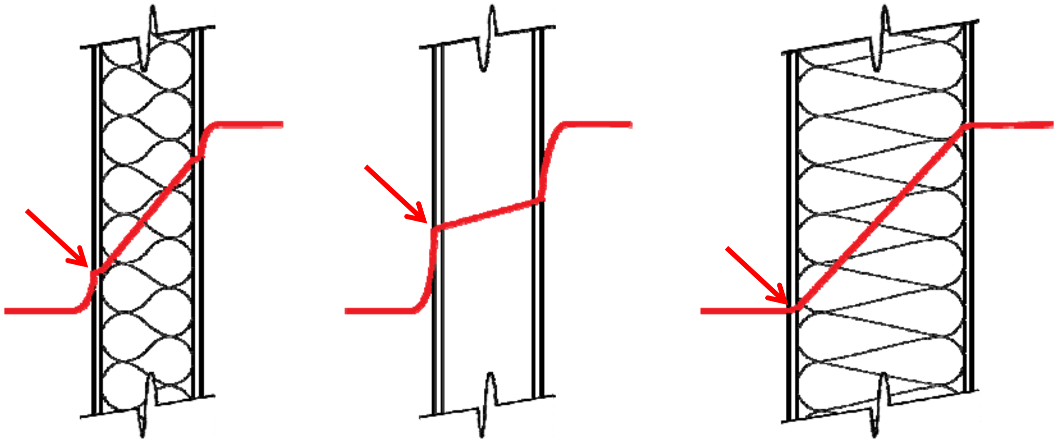


The relationship between insulation and moisture

As insulation levels increase, moisture risks are inherently magnified. This is due to what William Rose calls this the **Fundamental Rule of Material Wetness**: *Cold materials tend to be wet and warm materials tend to be dry.*





Building Science Issues: Air Control

A premium retrofit would include a dedicated air barrier which is:

-Continuous
-Structural (must not move under load)
-Impermeable (to air)
-Durable

However we are attempting to represent the real world, so some upgrades have one, some don't.

Air control integrity and air leakage calibration:

- Sheathing boards were not set tight, building paper was lapped and
- The entire panel perimeter was sealed before installation
- Used TEC Minneapolis Micro Leakage Meter @ 50 Pa across the wall
- Used a sealed electrical box with small hole to calibrate and equilibrate
- Final base wall measurements varied between 0.37 – 0.42 cfm @
- Post-treatment: cavity treatments were TLM (< 0.2 cfm); exterior

Building Science Issues: Vapor Control

As we all know, the vapor retarder goes on the inside…

But our basecase wall already has two: one on the interior, one on the exterior.

Treatments are designed so some ignore this fact, and some explicitly aim to accommodate this potential risk.

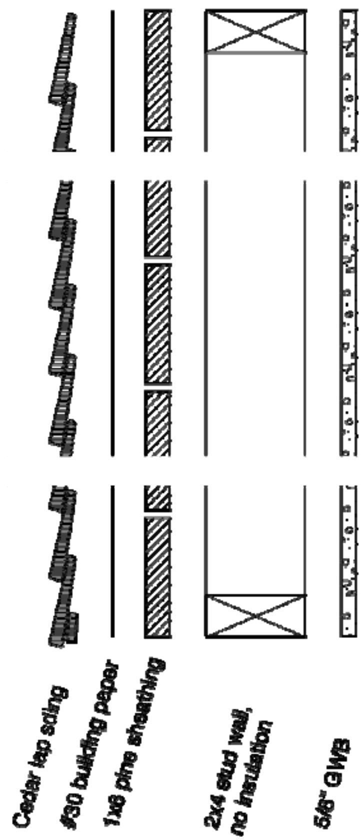
Building Science Issues: Water Control

The base case wall has an existing water control layer: #30 building paper.

Some treatments rely on this existing layer, while others add supplemental water control layers, or remove the siding and paper to add a new water control layer.

Wall A (B2 W1)
Base Case

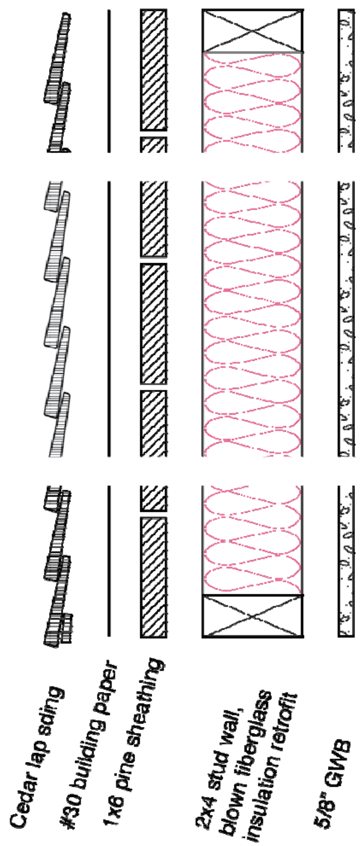
Oil primer
Vapor retarder primer (0.6 perm)
Latex paint



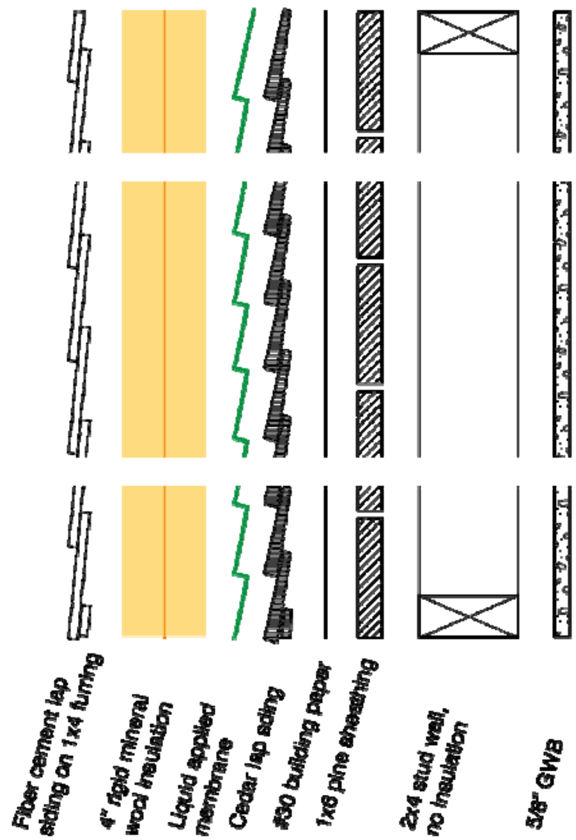
Vapor retarder primer (0.6 perm)

Potential insulation location strategies

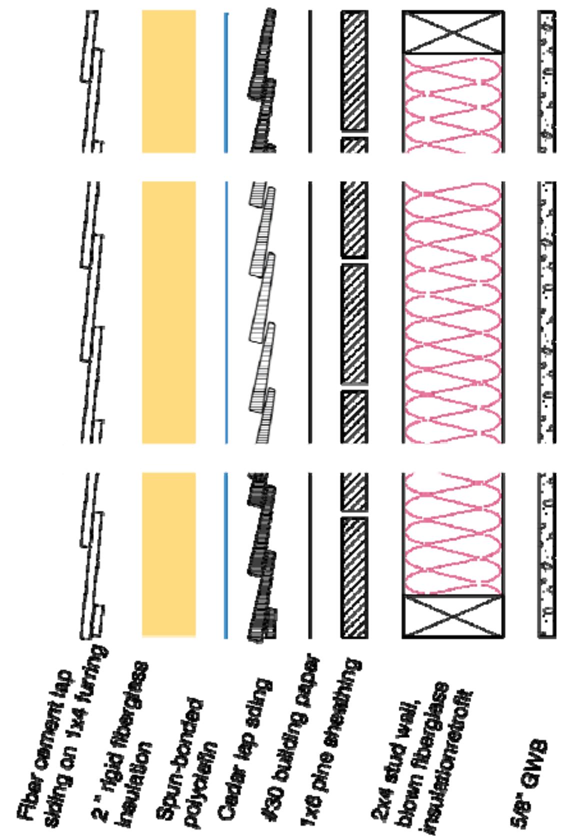
Cavity only

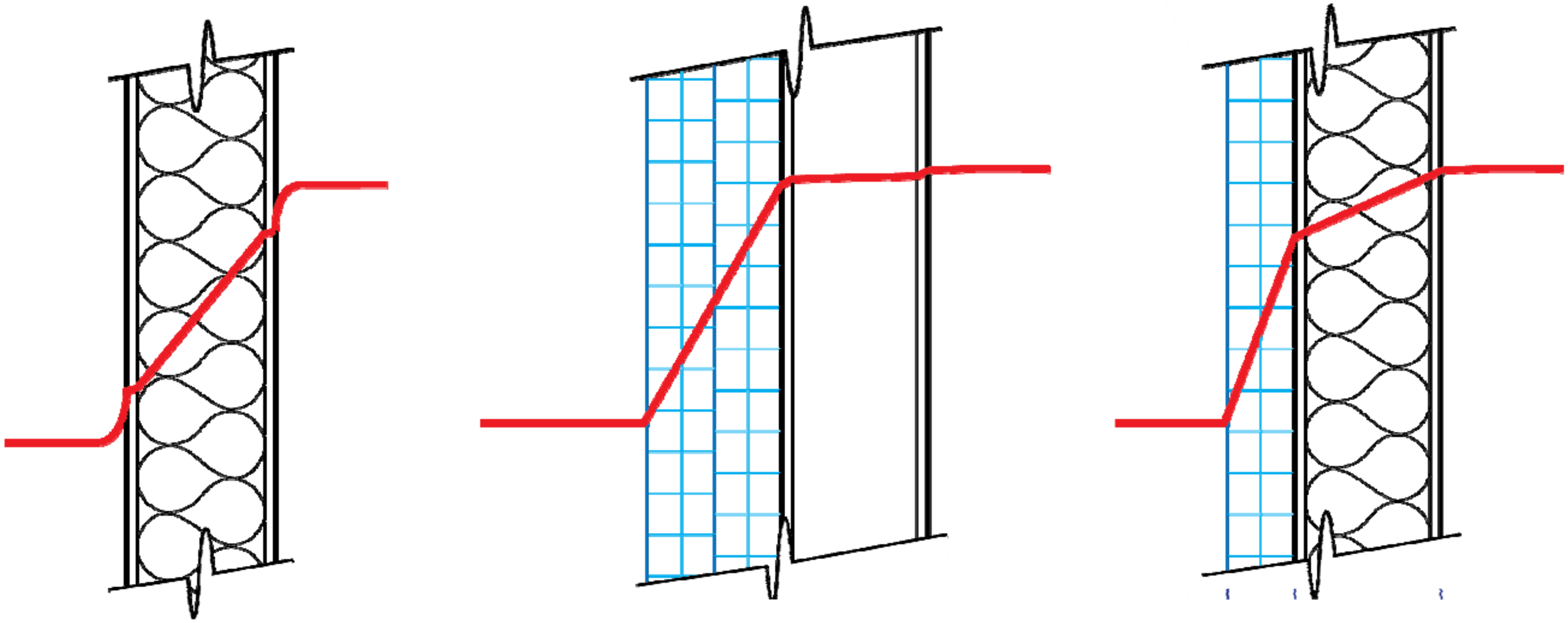


Exterior only

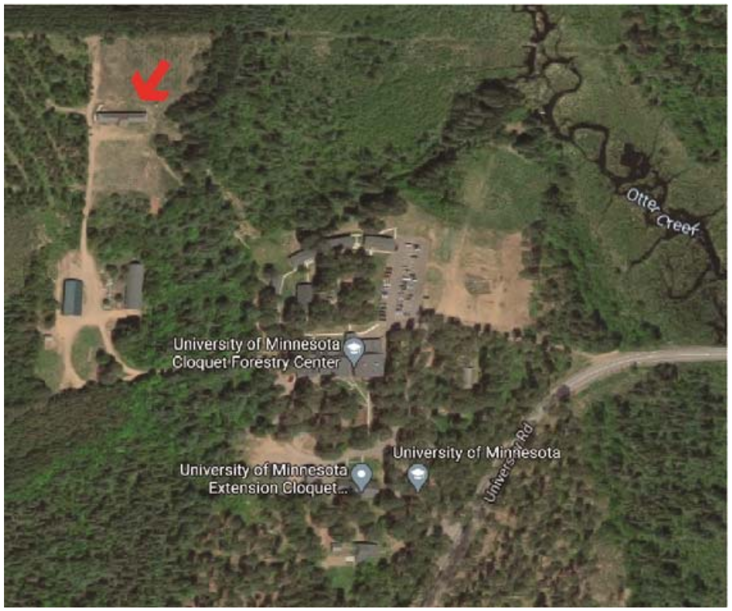


Hybrid (cavity + exterior)





Cloquet Residential Research Facility



PNNL – Wall Upgrades for Residential Deep Energy Renovation

In-situ Experimental Research

Cloquet Residential Research Facility
University of Minnesota

Research Team

Pat Huelman, Principal Investigator
Garrett Mosiman, CRRF Manager
Rolf Jacobson, Field Support
Fatih Evren, Graduate Assistant

Cloquet Residential Research Facility

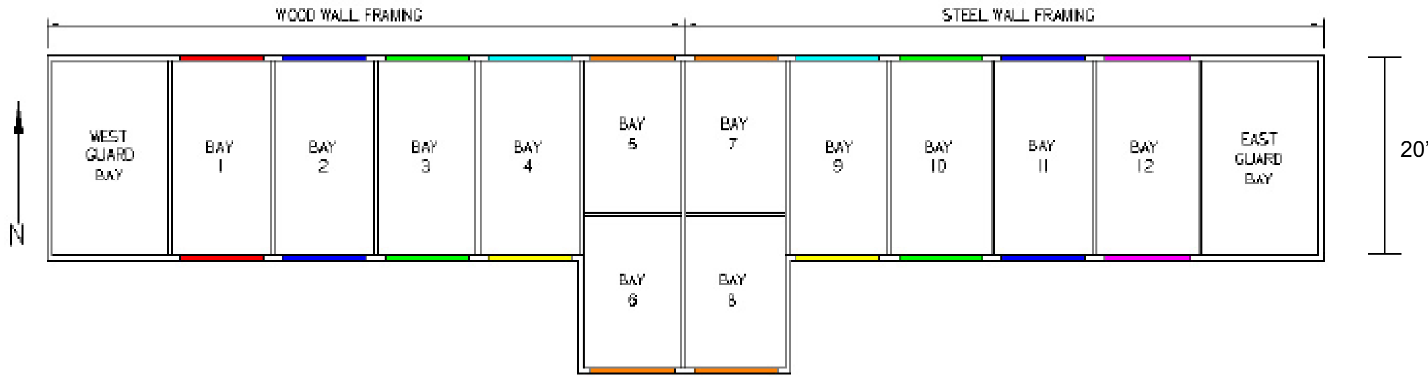
- Located at the University of Minnesota's Cloquet Forestry Center near Cloquet, MN
- Completed in 1997
  - original funding provided by CertainTeed Corp.
- Designed as a test bed to:

  evaluate long-term,

  cold-climate performance

  of full-scale building envelope components including:
    - foundations,
    - walls,
    - wall/window interface, and
    - roofing systems.

CRRF Building Design



Single-story building on a full basement

- West basement has hollow masonry block walls and I-joist floor trusses
- East basement has poured concrete walls with open web floor trusses

Divided into 10’ test bays along east/west axis

- 12 bays on main level with end guard bays
  - bays 1 to 6 framed in wood
  - bays 7 to 12 framed in metal
- 2 basement bays with end guard bays



Wall Selection

Results From 2019 Expert Meeting

- Most important wall selection criteria
  - air infiltration
  - constructability
  - cost
  - ease of control layer installation
  - time to install

Additional DOE Guidance

- After reviewing expert meeting results with DOE, additional guidance included:
  - Most impactful (most homes, most energy savings)
  - Removing OR leaving cladding in place
  - Does not necessarily need to be “deep”

Additional Criteria

- Cost (high, medium, low)
- Thermal Performance (good, better, best)
- Moisture Performance (possibly good, possibly problematic)
- Siding Removed (yes, no, ?)
- Supports DOE ABC Initiative
- Treatment Type (cavity, exterior, interior, combo)
- Insulation Type (material, form)
- Installation (site fabricated, offsite production, etc.)

Treatment Summary

- 8 types of insulation; fiberglass, cellulose, mineral fiber, EPS, XPS, Polyiso, PU, VIP
- 5 forms of insulation; batt, blown-in, panels, blocks, pourable/injected
- 12 combos of insulation type and form (more than one insulation is used in some treatments)
- 3 types of added water and/or air control layers (housewrap, peel and stick, LAM)

We ended up with:
- 9 wall treatments built on-site with existing building materials
- 1 wall treatments used prefabricated components
- 3 wall treatments used off-site produced systems
- 4 wall treatments of novel/emerging materials or systems

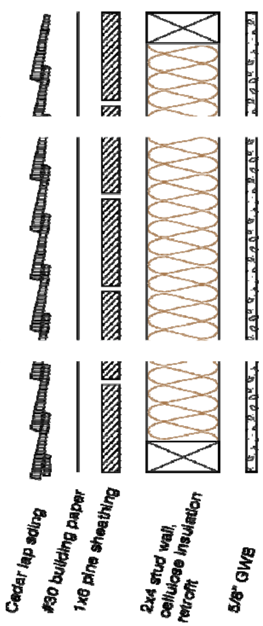
Wall Treatment Summary	Phase 1	Phase 2	Total
- Interior w/ cavity	0	1	1
- Cavity only	2	1	3
- Exterior w/ cavity	2	3	5
- Exterior only	3	2	5

Preparation of Base Case Walls:

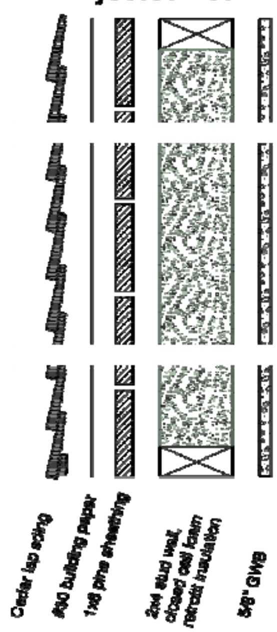
Interior Finish:	5/8” Drywall (with vapor retarder primer)
Framing:	2x4 SPF at 16” o.c.
Sheathing:	1x6 Pine
Water Control:	#30 Building paper
Cladding:	7 ¼”” Cedar Lap Siding (with oil primer, vapor retarder primer, and latex topcoat)

Test walls, Phase 1

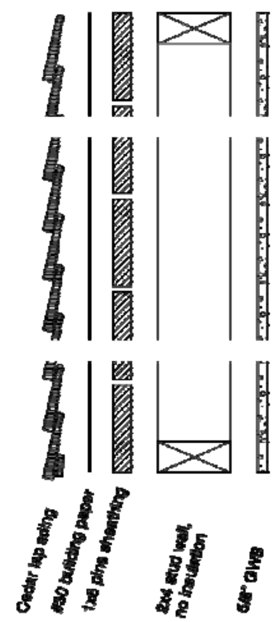
Wall B (B1 W1)
Cellulose



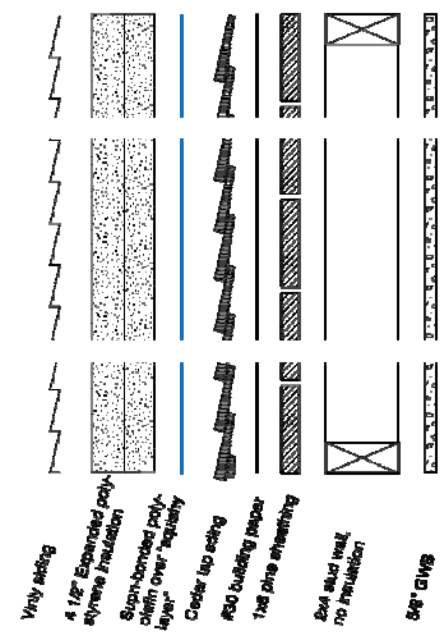
Wall C (B1 W2)
Injected Foam



Wall A (B2 W1)
Base Case

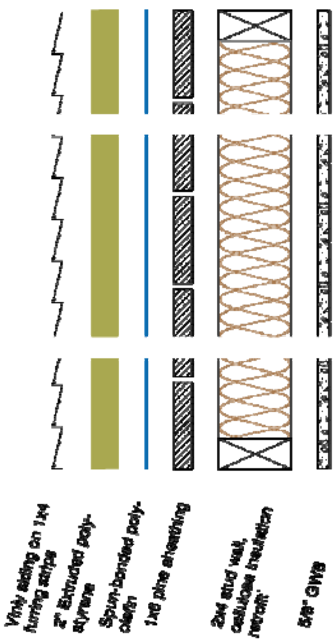


Wall D (B2 W2)
Exterior EPS

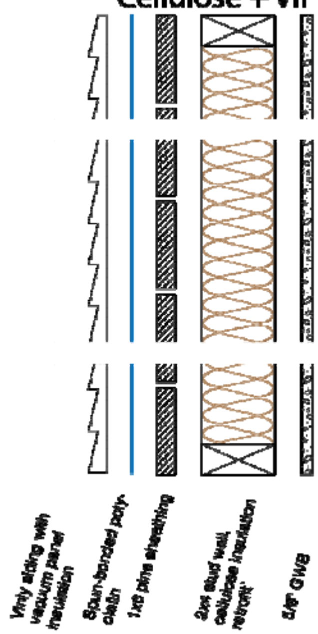


Test walls, Phase 1

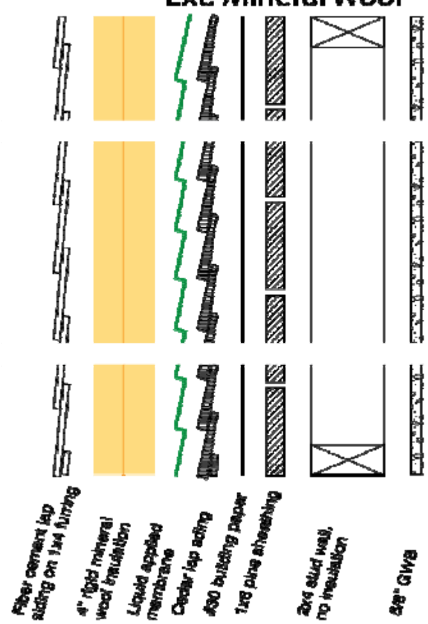
Wall E (B3 W1)
Cellulose + XPS



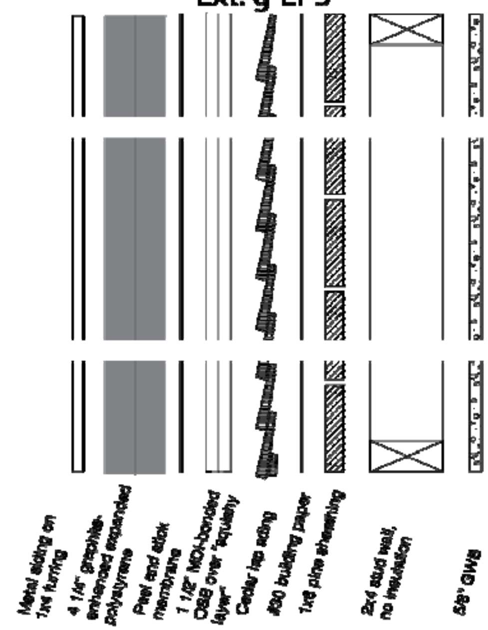
Wall F (B3 W2)
Cellulose + VIP



Wall G (B4 W1)
Ext. Mineral Wool

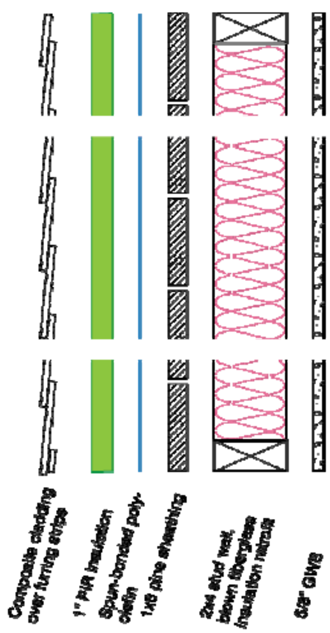


Wall H (B4 W2)
Ext. g-EPS

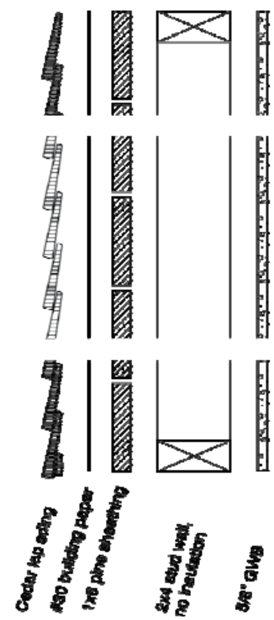


Test walls, Phase 2

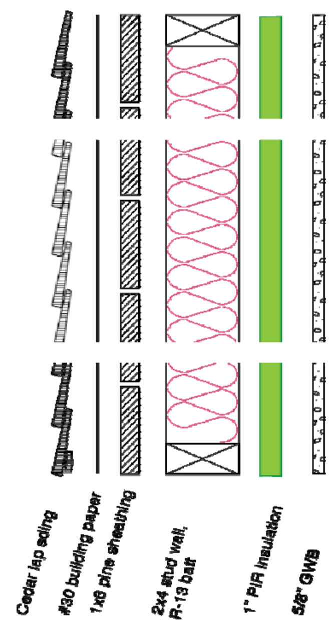
Wall L (B11 W1)
Exterior PIR



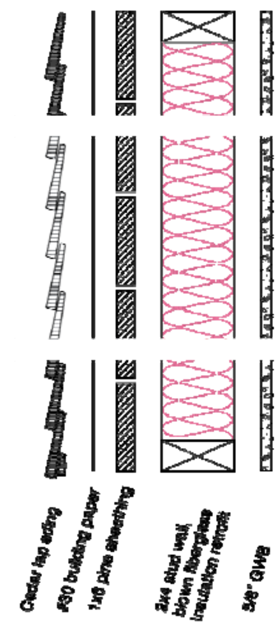
Wall I (B11 W2)
Base Case 2



Wall K (B12 W1)
Interior PIR

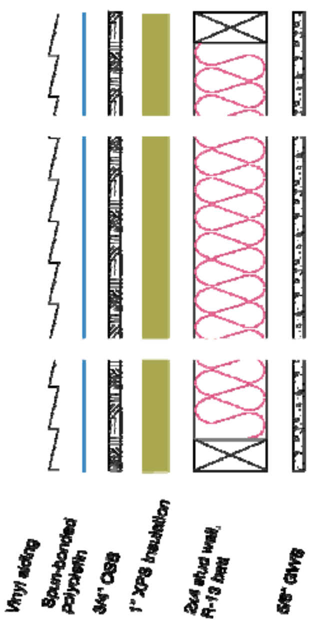


Wall J (B12 W2)
Fiberglass

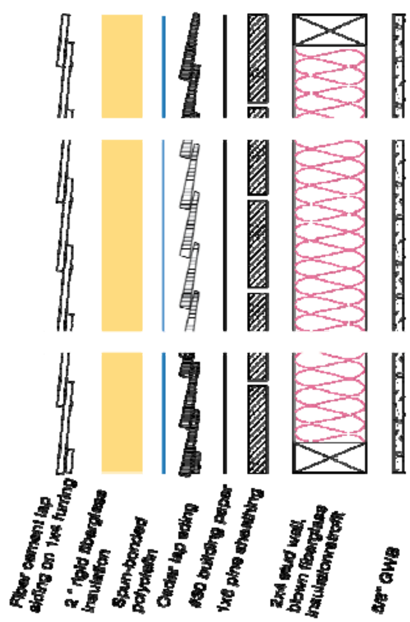


Test walls, Phase 2

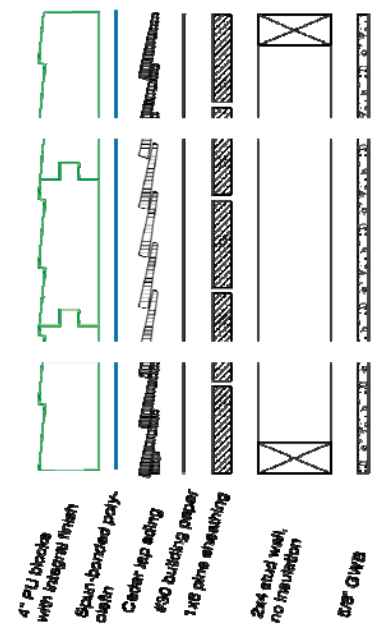
Wall P (B9 W1)
Thermal Break Shear



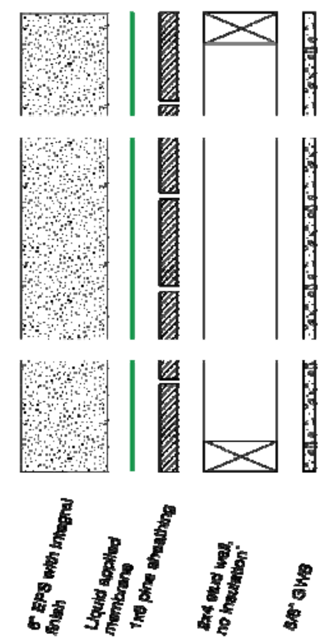
Wall O (B9 W2)
Exterior Fiberglass



Wall N (B10 W1)
ABC-Fraunhofer



Wall M (B10 W2)
REALIZE-EIFS



Instrumentation

Sensor Array

+/- 700 sensors

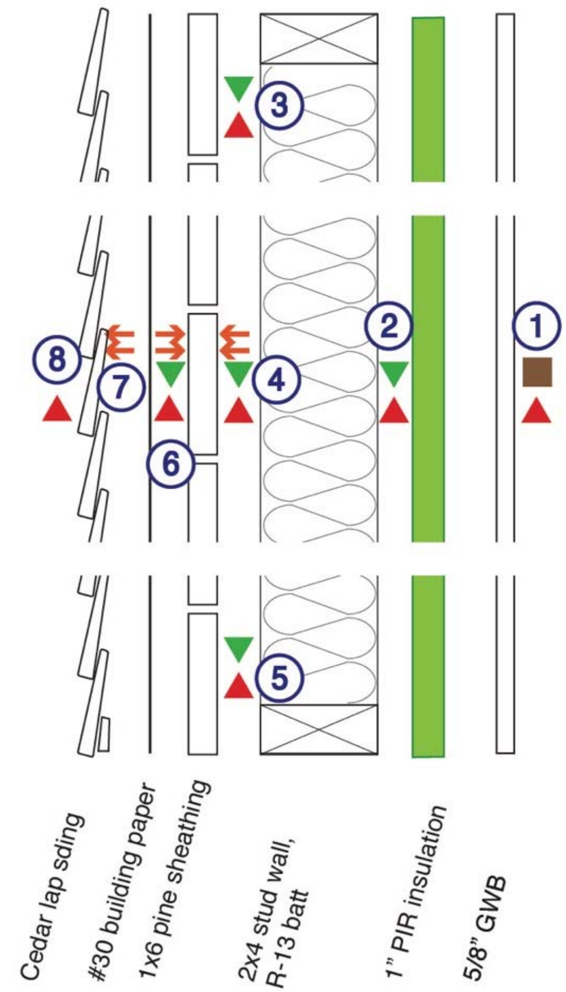
▲ TC-Thermocouple temperature sensor	Omega Type-T Thermocouple
▼ RH-Relative humidity sensor	Honeywell HIH-4000 Series
MP-Pin-type moisture content sensor	Brass nails + Enamel Paint
■ HF-Heat flux plate	FluxTeq PHFS-09e
(#) Sensor position number	

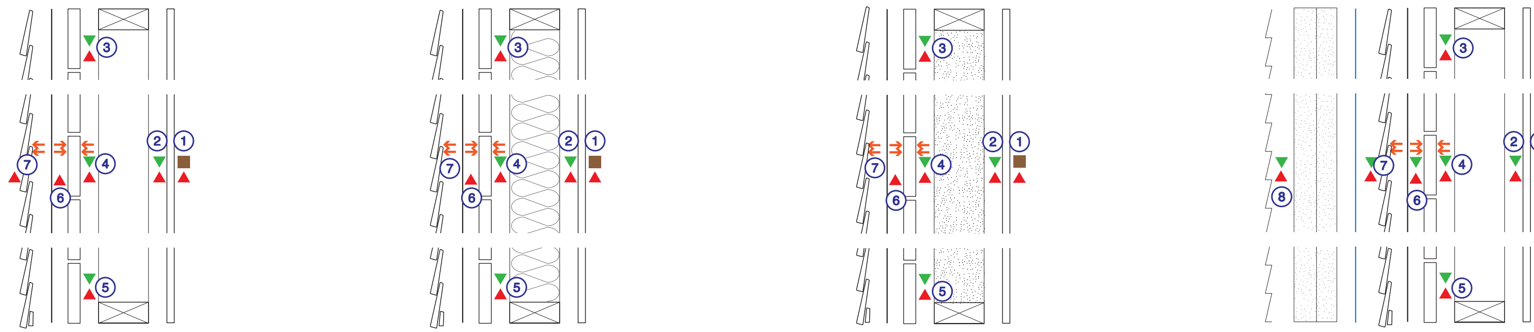
Pyronometers

- 6 Campbell Scientific CS320
- Vertical mount (4 south, 2 north)

Weather Station

- Wind speed / direction
- Temp / RH
- Horizontal pyronometer
- Rain gauge





Wall A

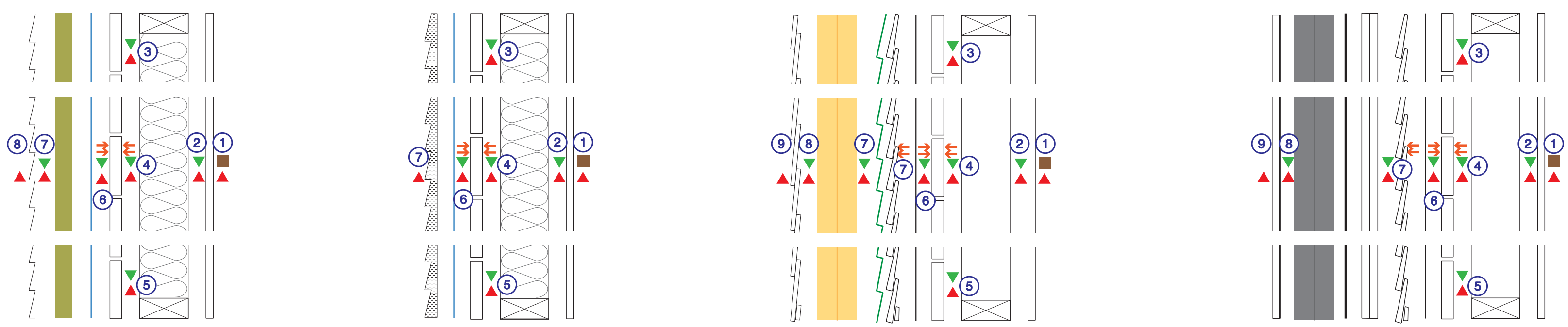
Wall B

Wall C

Wall D

Sensor Array

- ▲ TC-Thermocouple temperature sensor
- ▼ RH-Relative humidity sensor
- MP-Pin-type moisture content sensor
- ■ HF-Heat flux plate
- (#) Sensor position number

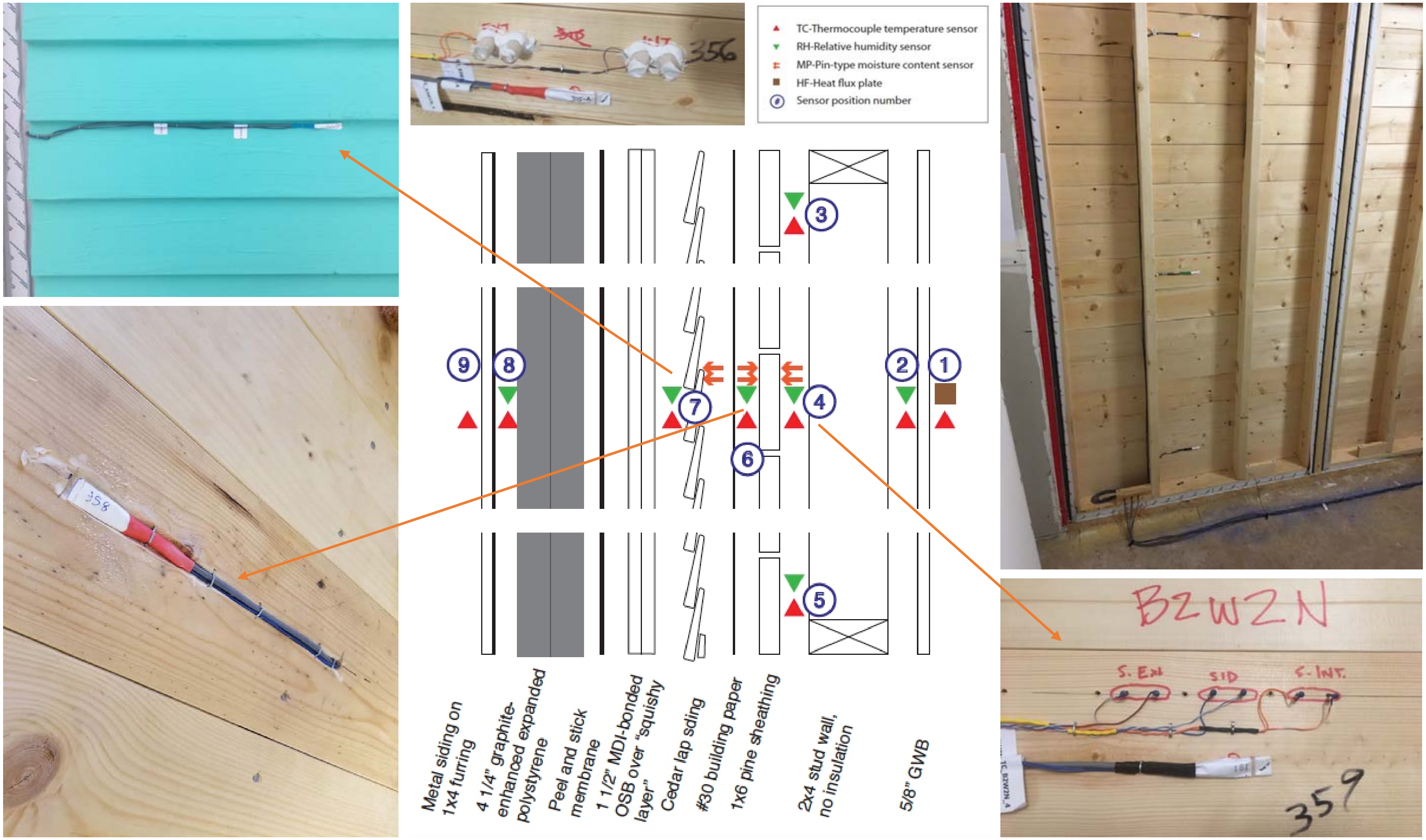


Wall E

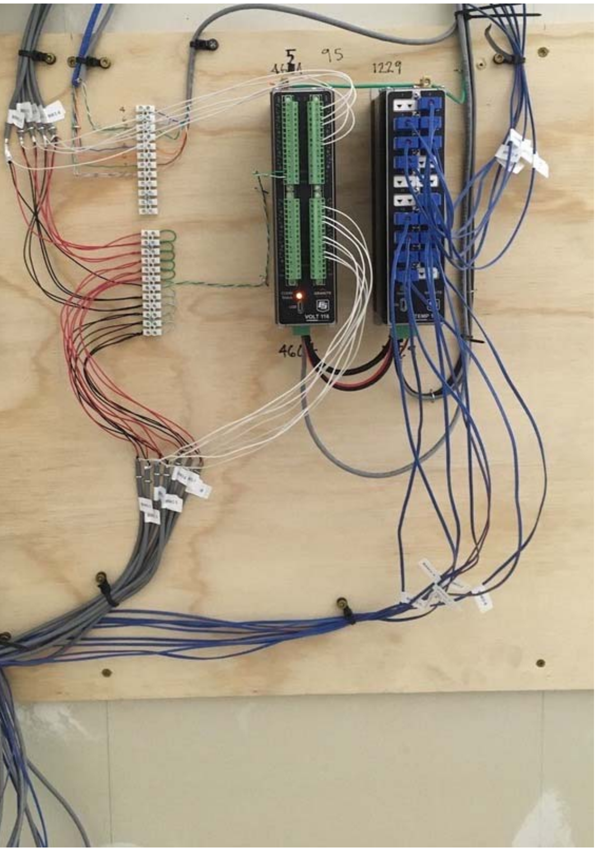
Wall F

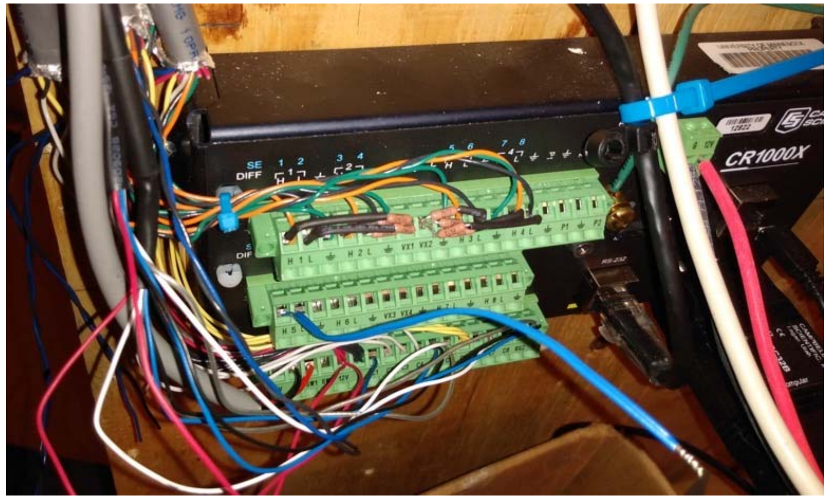
Wall G

Wall H



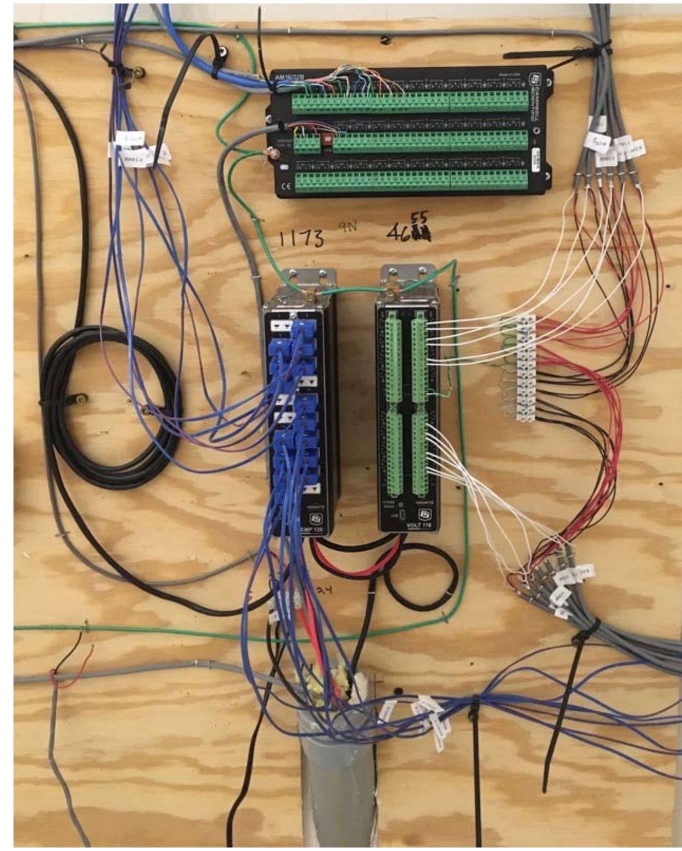
TC-Thermocouple temperature sensor
RH-Relative humidity sensor
MP-Pin-type moisture content sensor
HF-Heat flux plate
Sensor position number
356
B2W2N
359
358
1
2
3
4
5
6
7
8
9
Metal siding on 1x4 furring
4 1/4" graphite-enhanced expanded polystyrene
Peel and stick membrane
1 1/2" MDI-bonded OSB over "squishy layer"
Cedar lap sding
#30 building paper
1x6 pine sheathing
2x4 stud wall, no insulation
5/8" GWB





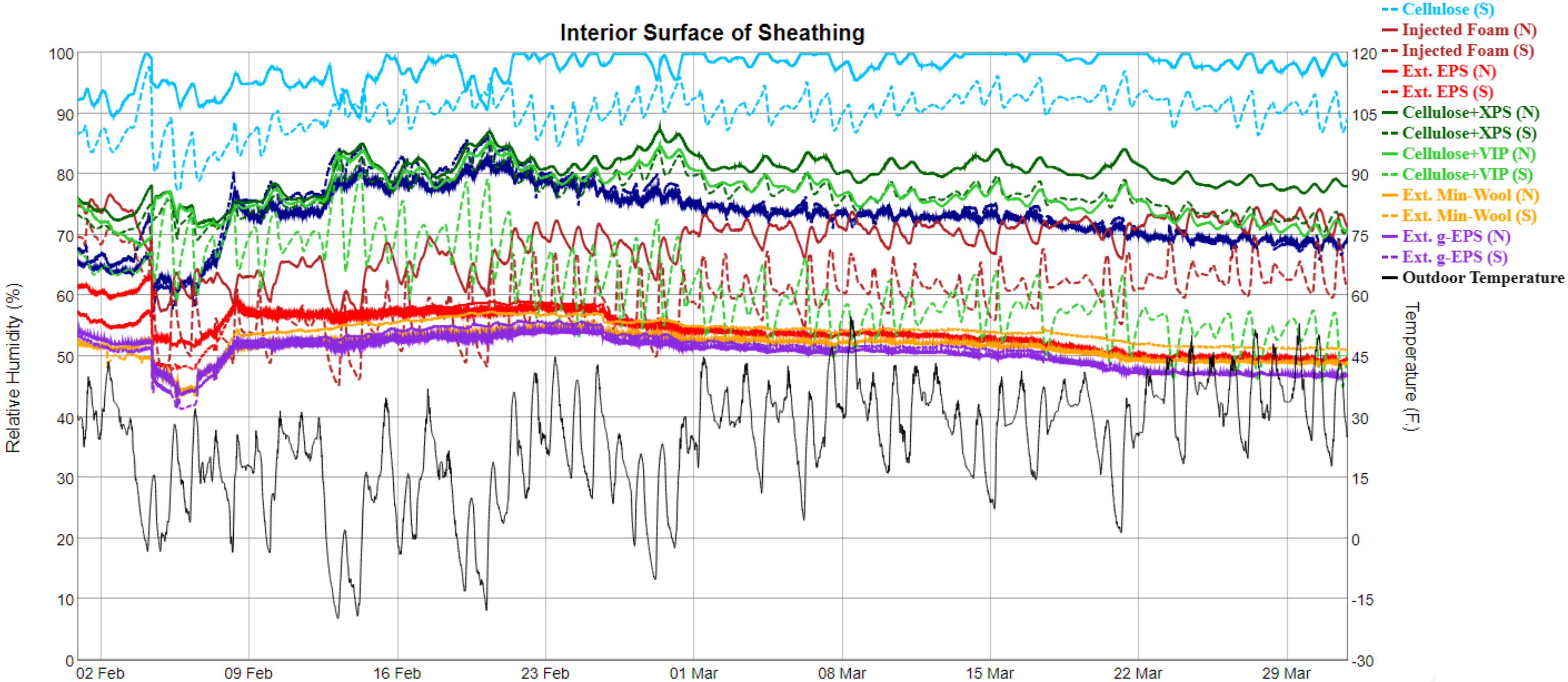
DAS Equipment by Campbell Scientific:

Datalogger	CR1000X (2)
Thermocouple Module	Temp 120 (16)
RH and Heat Flux	Volt 116 (16)
Moisture Content	AM 16/32 (8)
Communication	Sierra RV50X cellular modem

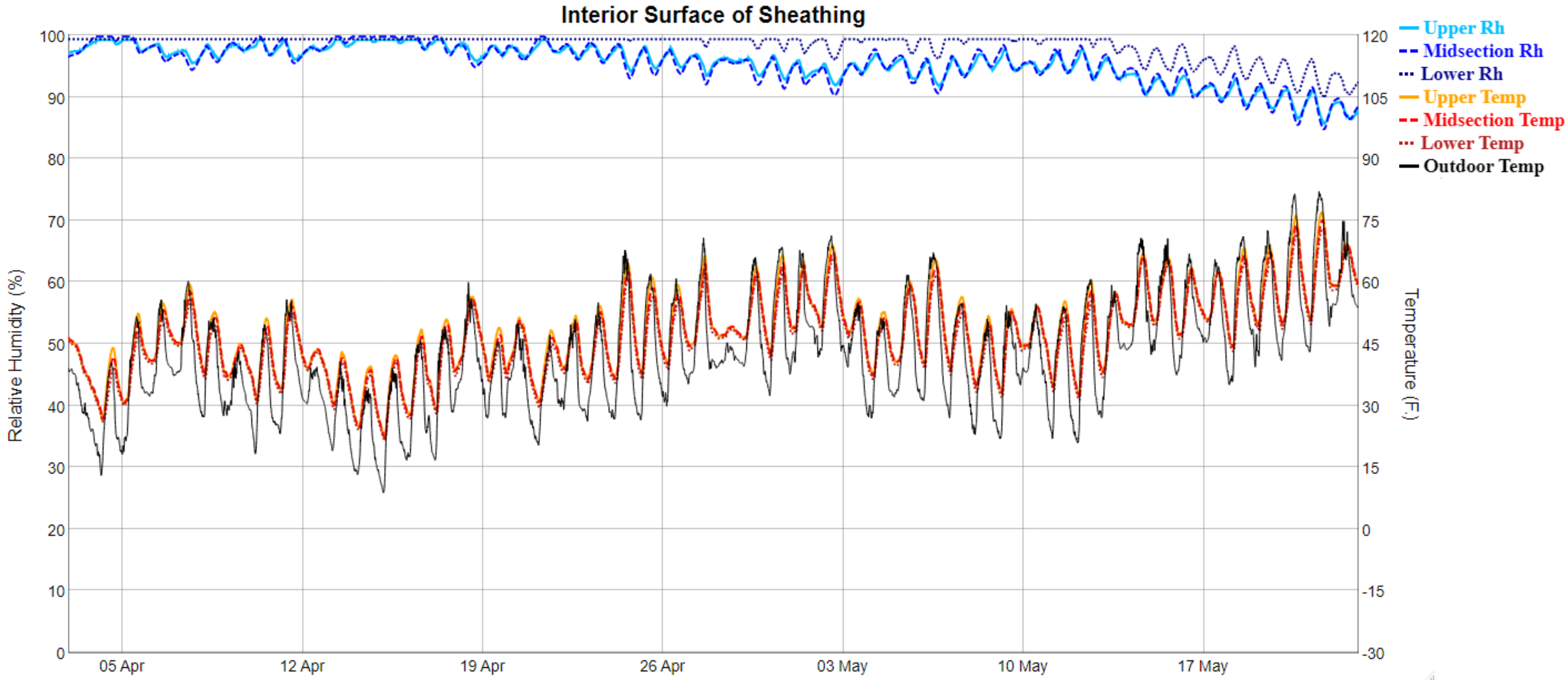


Initial Monitoring Results

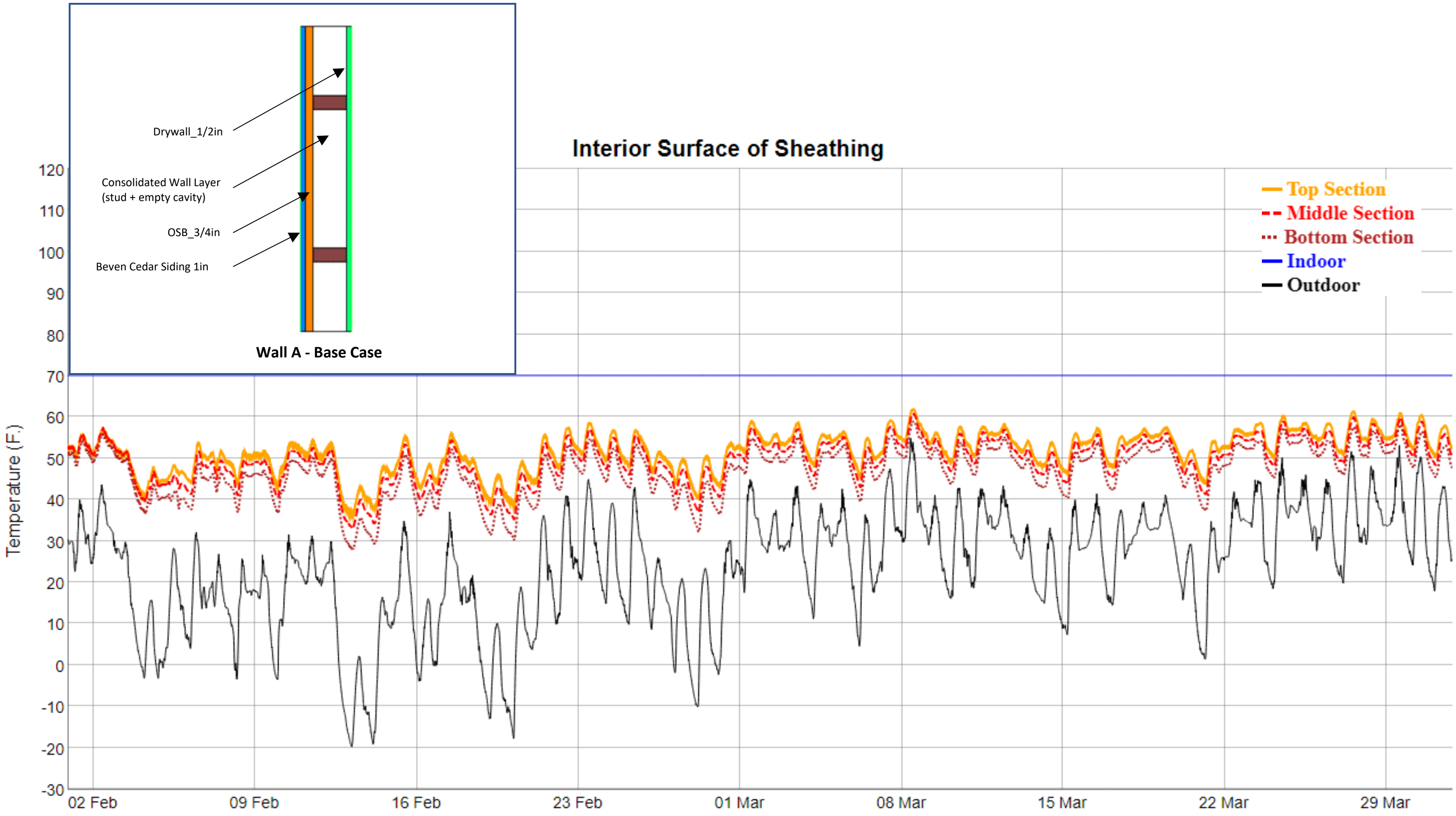
Relative Humidity For All Walls Over Time



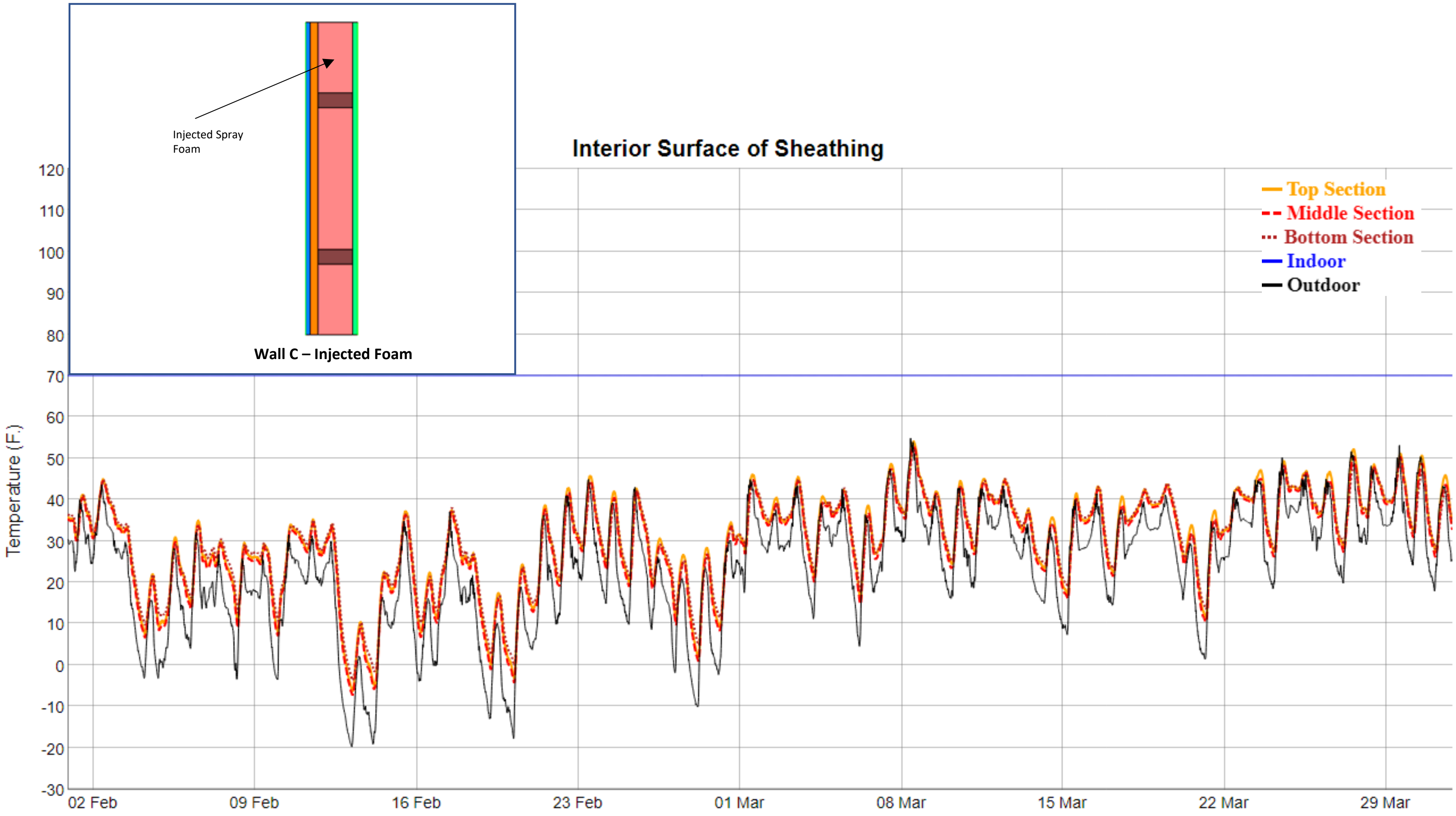
Cellulose Wall: RH and Temp at Interior Surface of Sheathing



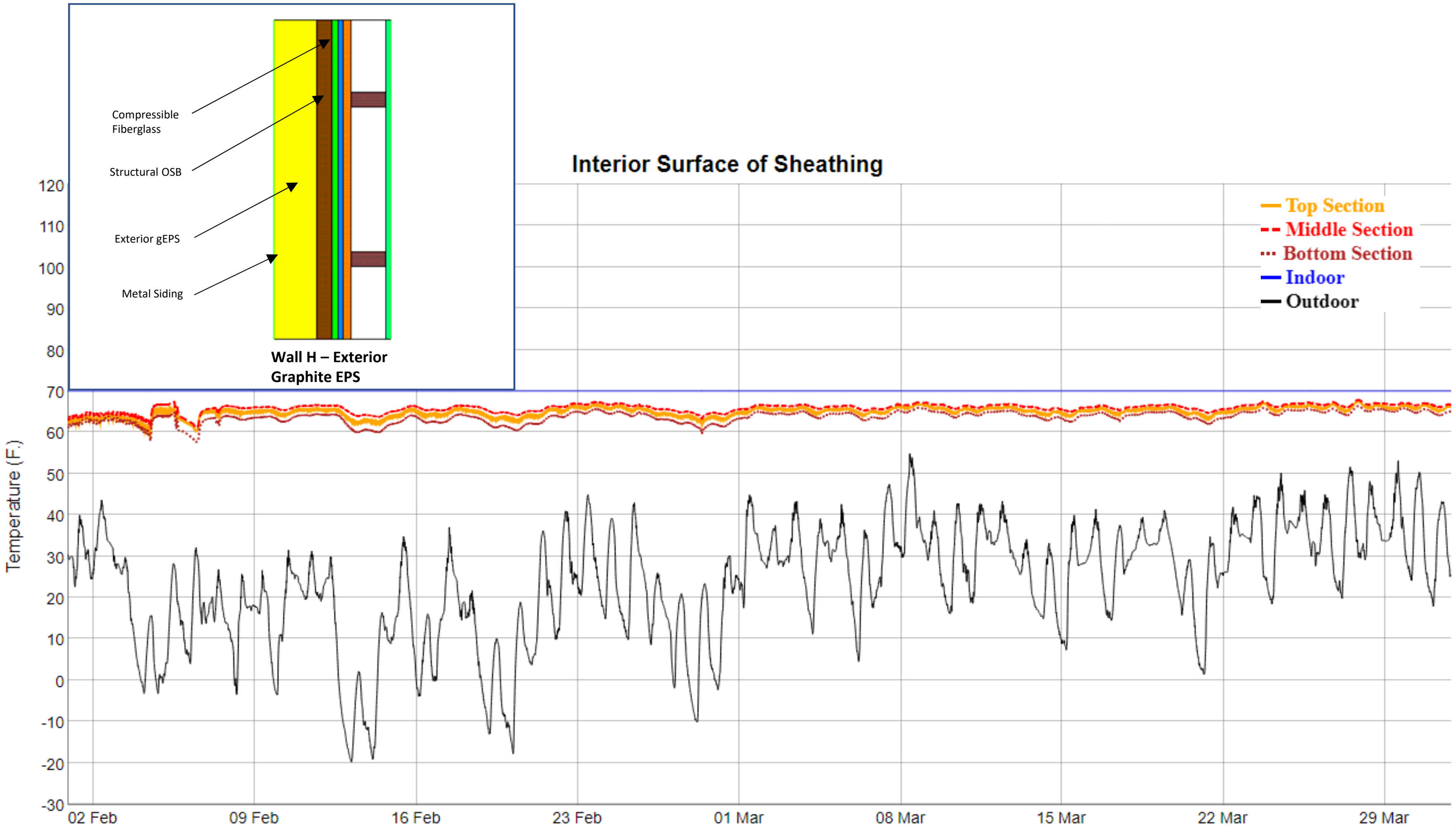
Baseline Wall Temperature



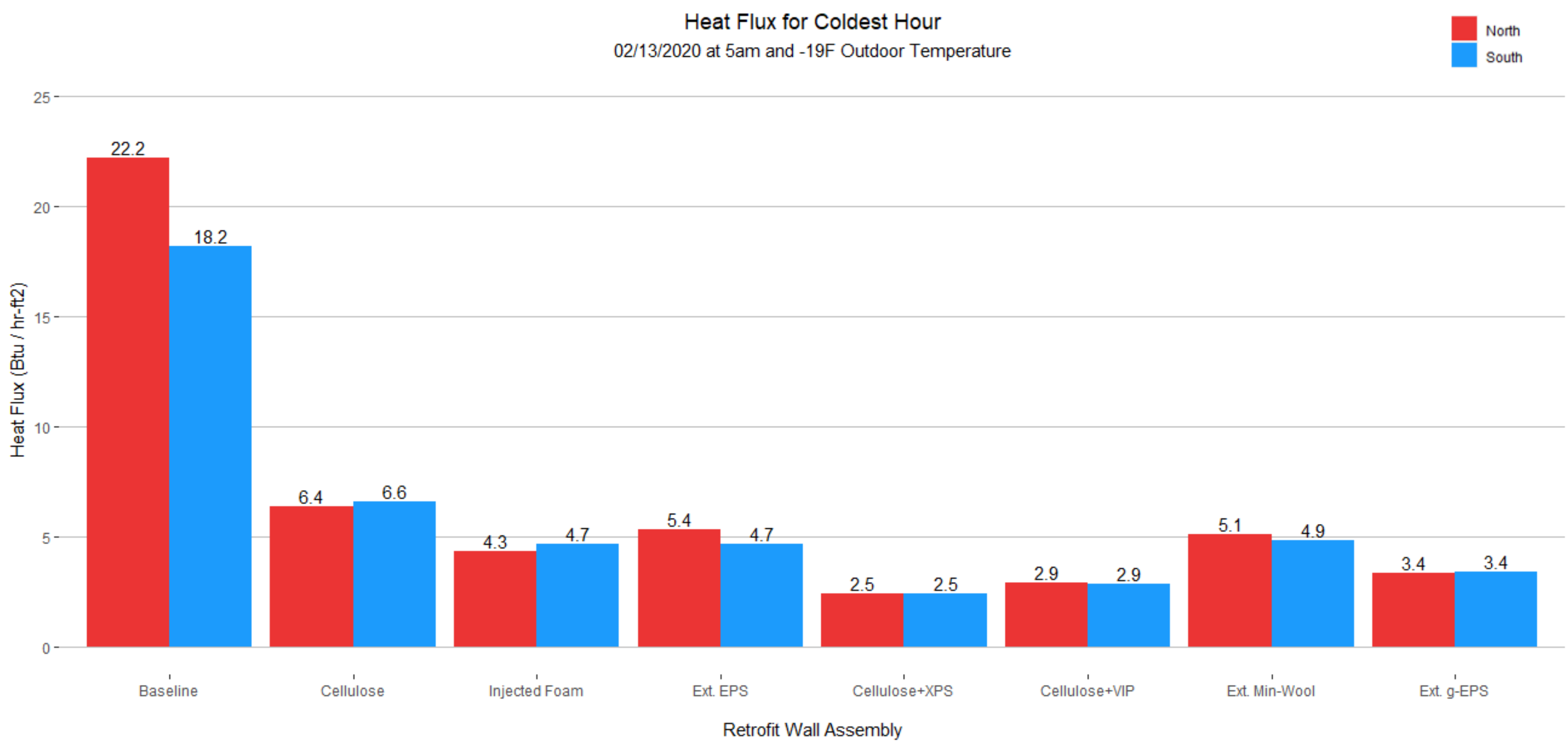
Injected Foam Wall Temperature



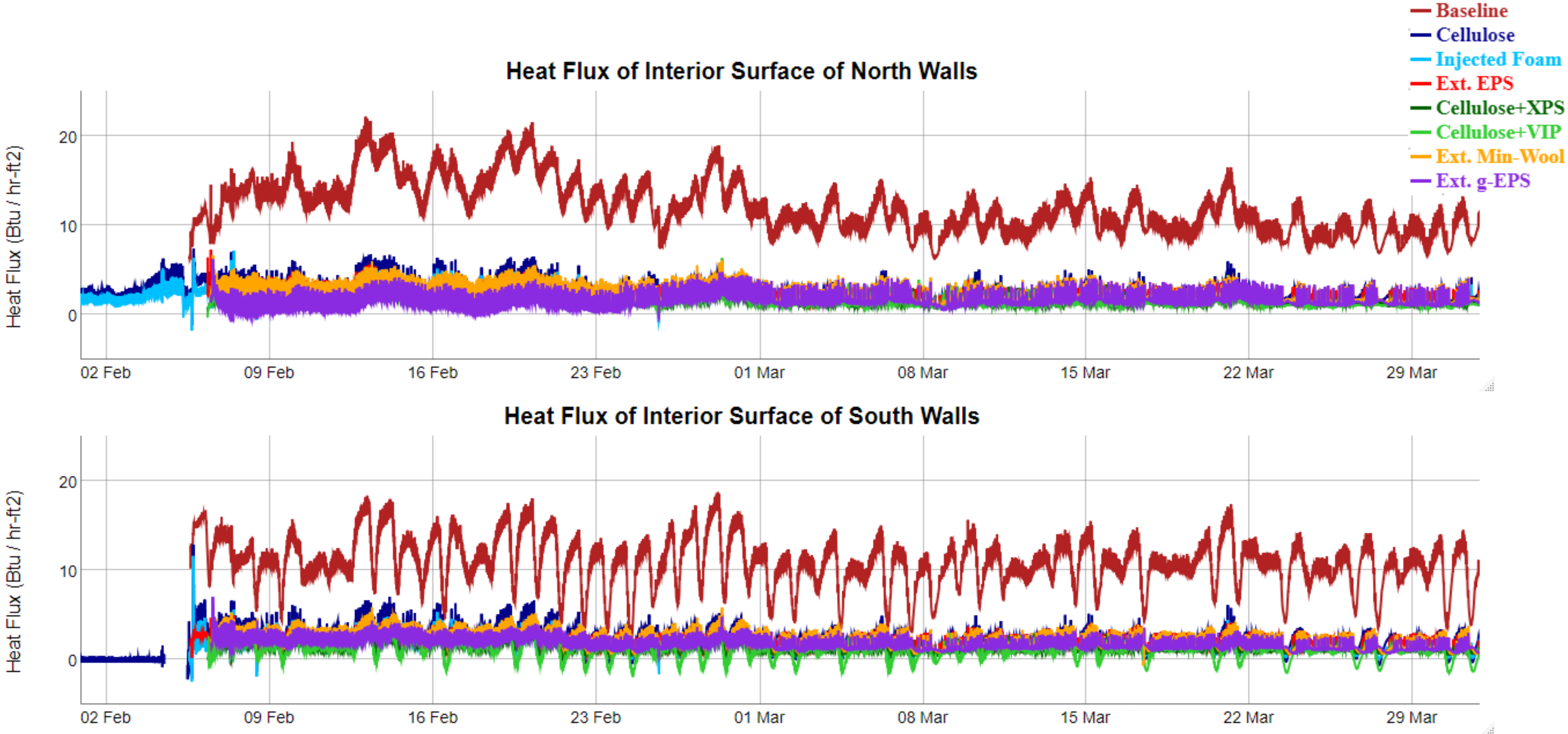
Exterior Graphite EPS Wall Temperature



Heat Flux For All Walls on Coldest Day



Heat Flux Over Time For All Walls



Hygrothermal testing and Modeling

Material property testing

Thermal properties

- ASTM C518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

Insulation	Thickness, in	Density, pcf	k, Btu-in/hr ft^2 F	R, hr ft^2 F/Btu-in
2-in. EPS	1.54	1.40	0.241	4.16
2.5-in. EPS	2.03	1.21	0.252	3.97
2-in. graphite-impregnated EPS	2.15	1.95	0.217	4.60
2-in. XPS	2.01	1.50	0.199	5.02
2-in. mineral wool	1.88	9.20	0.239	4.18
Dense-packed cellulose	3.50	3.50	0.286	3.50
Spray foam	2.01	1.58	0.174	5.76
1 by 6-in. wood siding	0.77	27.1	0.652	1.53
5/8-in. gypsum	0.62	43.7	0.513	2.81
3/4-in. OSB	0.71	40.5	0.407	2.46
Wood siding	0.80	26.0	0.588	1.79
Fiber cement siding	0.32	79.5	0.538	1.86
Fiberglass compression layer	0.50	3.83	0.221	4.52

Vapor permeance

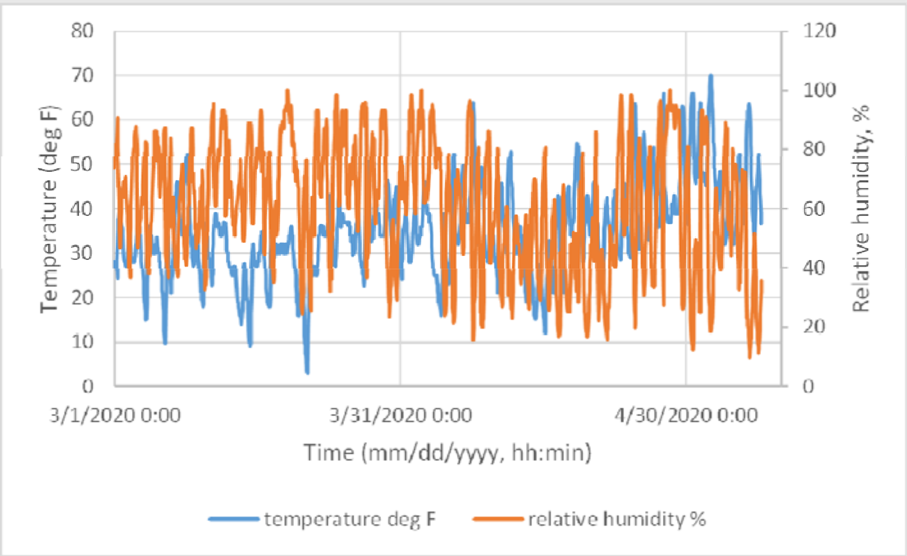
- ASTM E96, Standard Test Methods for Water Vapor Transmission of Materials

Materials	Water vapor transmission		Permeance		Permeability	
	g/h*m^2	grains/h*ft^2	g/s*Pa*m^2	perm	g/s*Pa*m	perm-in
1x6 wood siding	2.356	3.369	4.200×10^{-7}	7.735	8.411×10^{-9}	5.787
Gypsum board	10.659	15.243	2.000×10^{-6}	34.999	3.110×10^{-8}	21.394
Gyp board + paint	2.457	3.514	4.616×10^{-7}	8.068	7.120×10^{-9}	4.962
15# Felt	4.979	7.120	9.342×10^{-7}	16.348	6.202×10^{-10}	0.427
WRB	7.065	10.103	1.326×10^{-6}	23.199	1.189×10^{-10}	0.082
WRB + liquid AVB coating	3.227	4.615	6.056×10^{-7}	10.597	5.628×10^{-10}	0.387
AVB membrane	0.006	0.008	1.069×10^{-9}	0.019	8.380×10^{-13}	0.001

Validation study

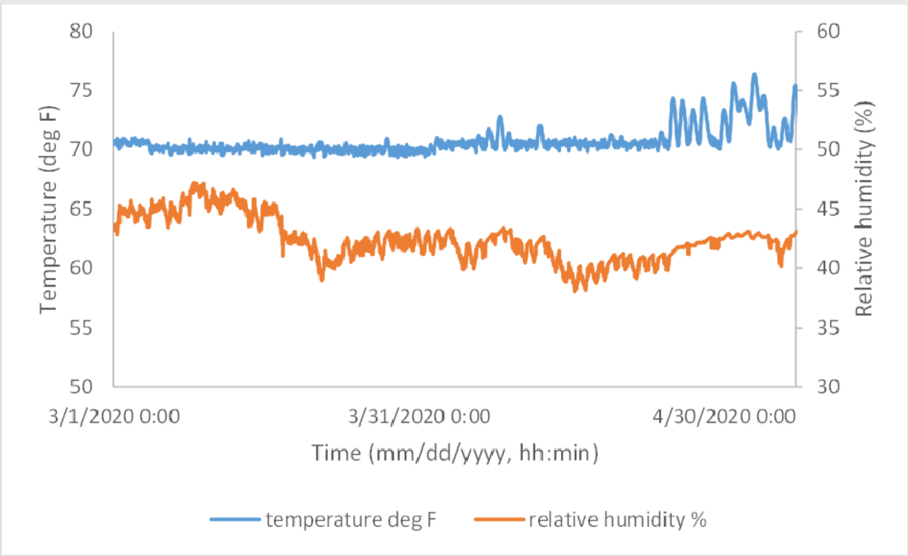
Exterior boundary condition

- Temperature and relative humidity

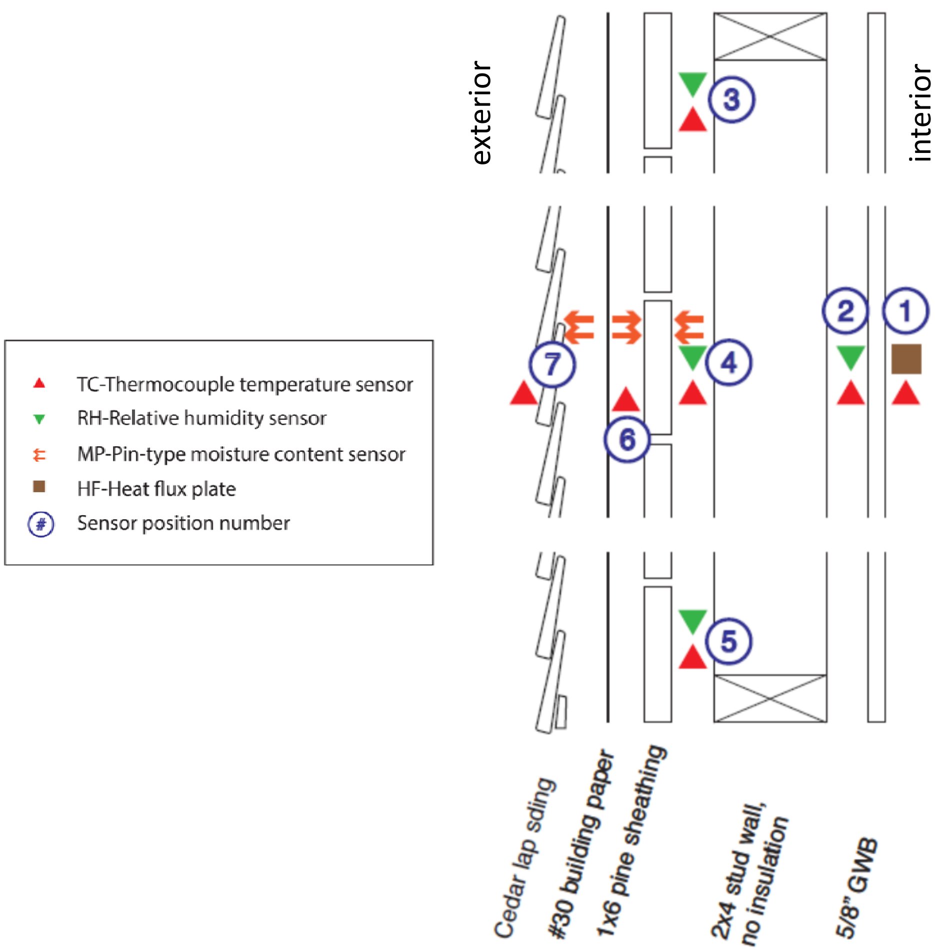


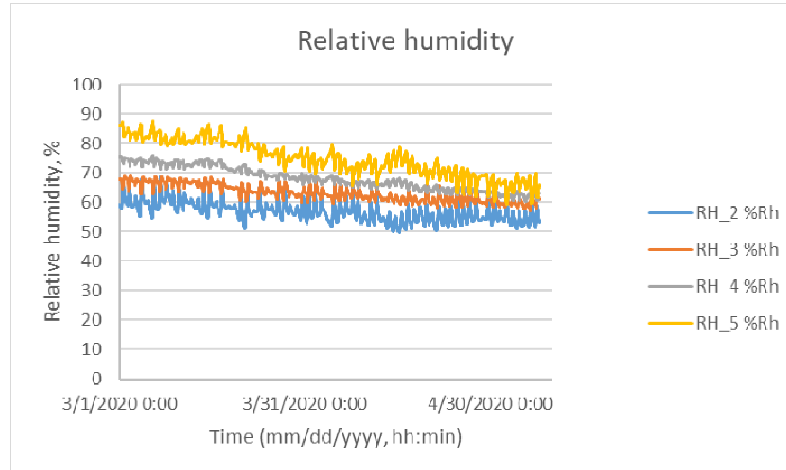
Interior boundary condition

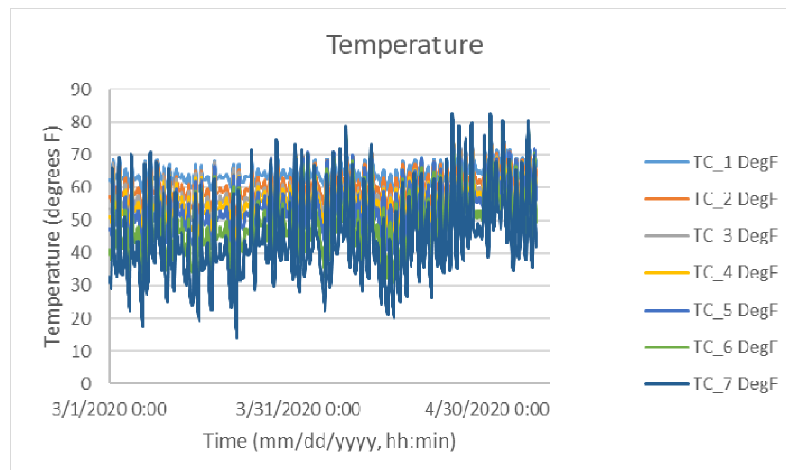
- Temperature and relative humidity



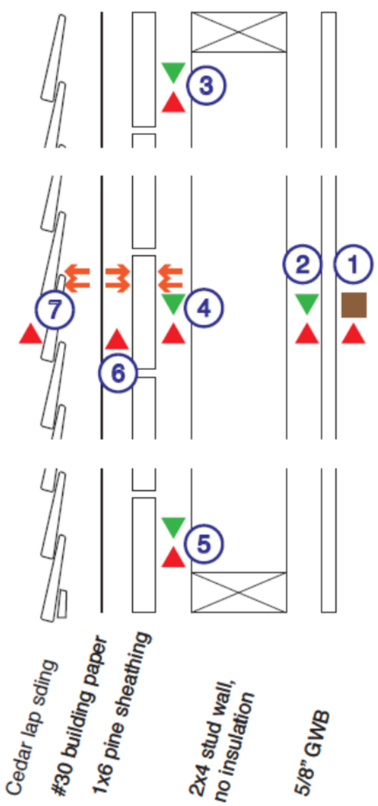
Wall A, base case, measured temp & RH, south facing orientation

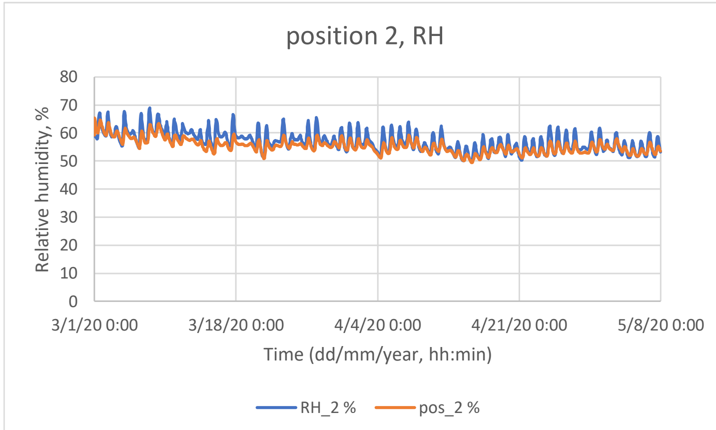


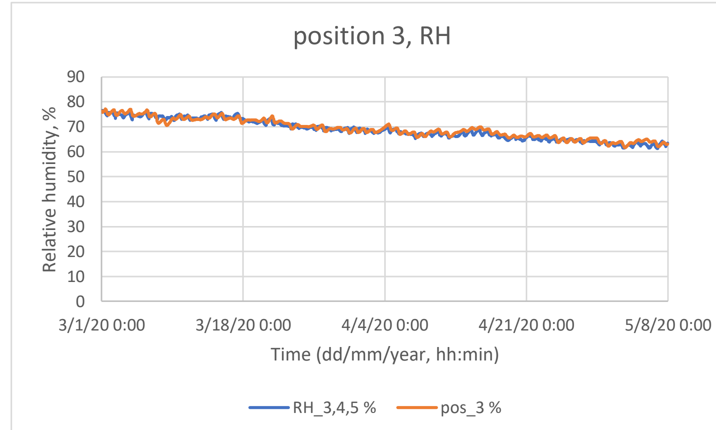


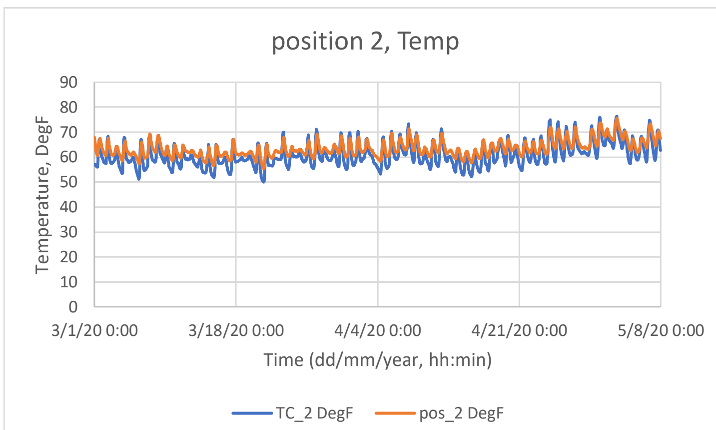


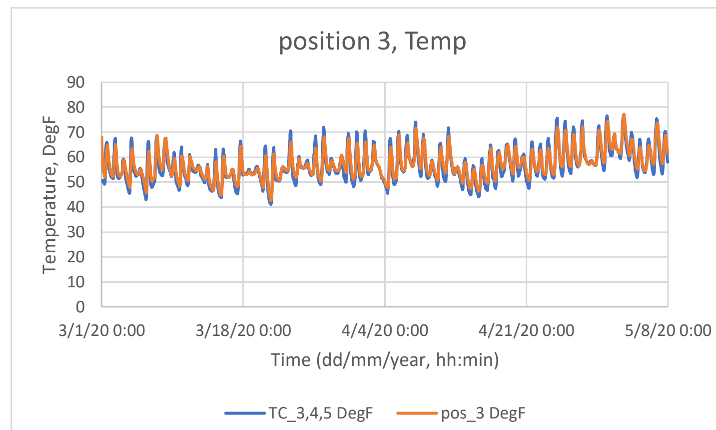
Wall A, base case, simulated & measured temp & RH, south facing orientation





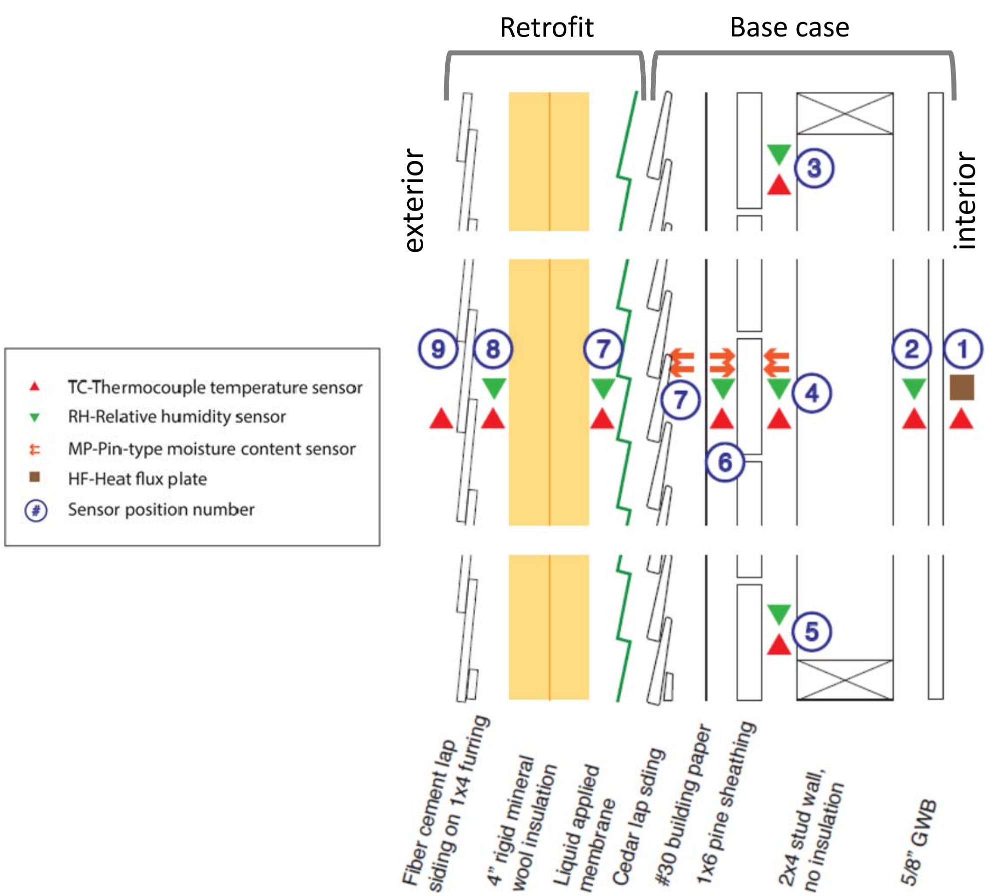


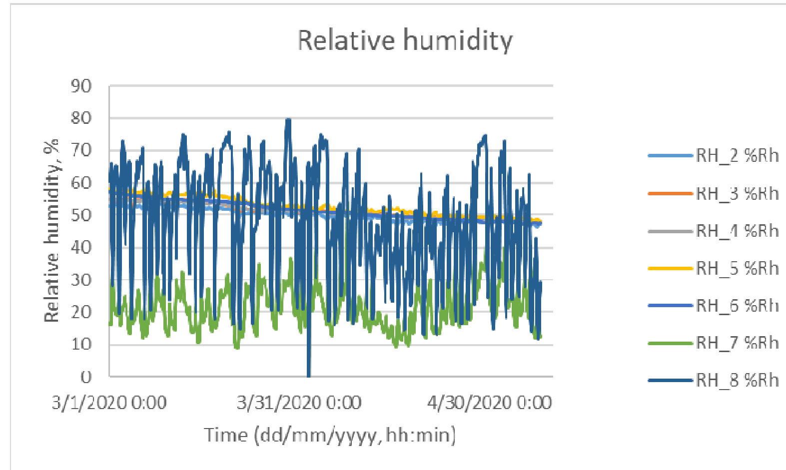


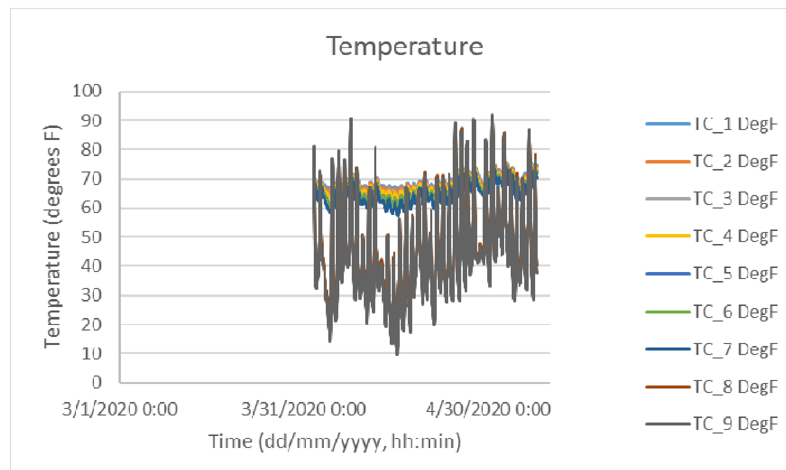


WUFI (pos_#) vs measured RH (RH_#) and Temperature (TC_#)

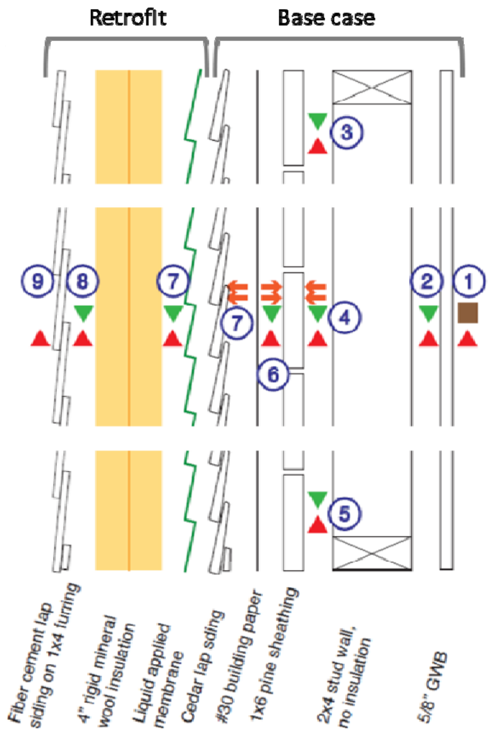
Wall G, measured temp & RH, south facing orientation

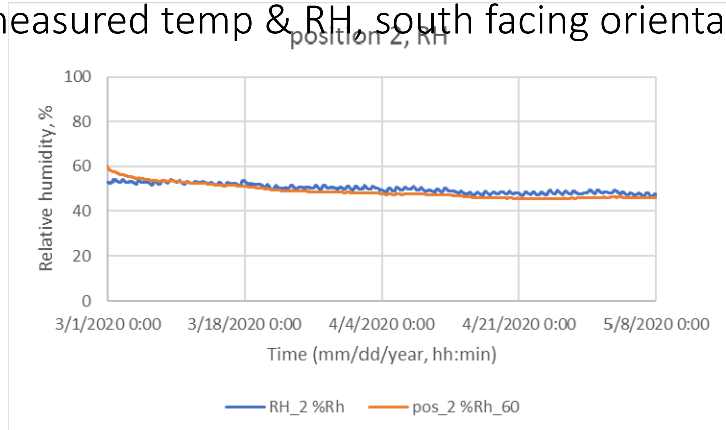


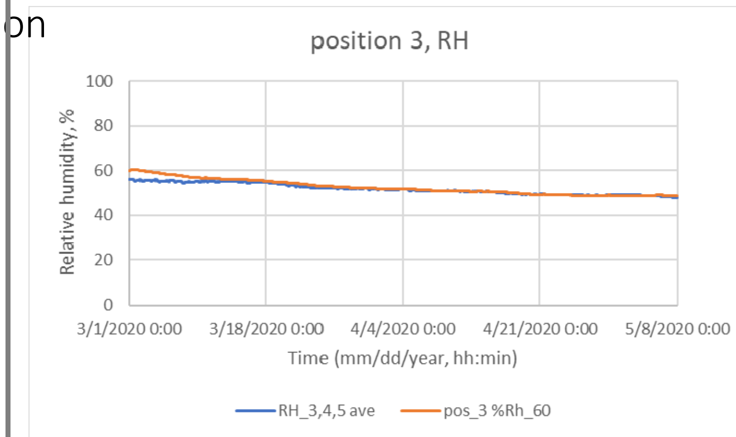


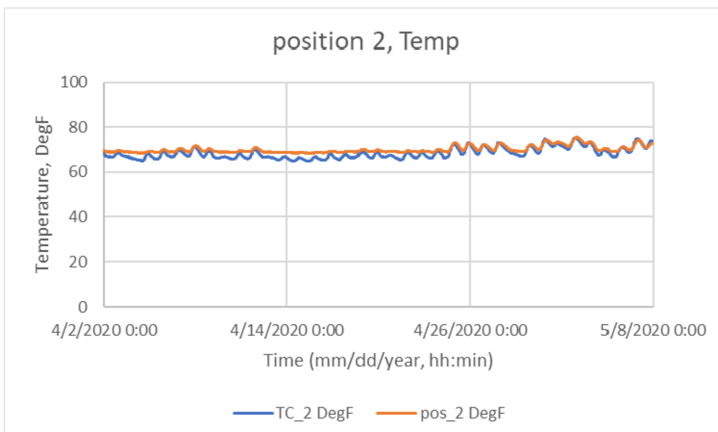


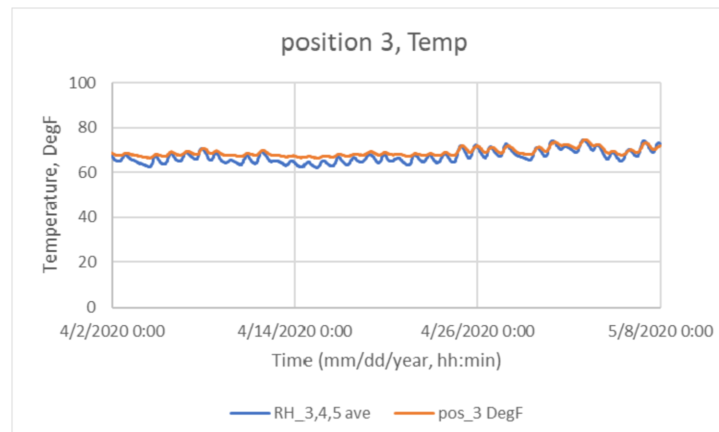
Wall G, simulated & measured temp & RH, south facing orientation





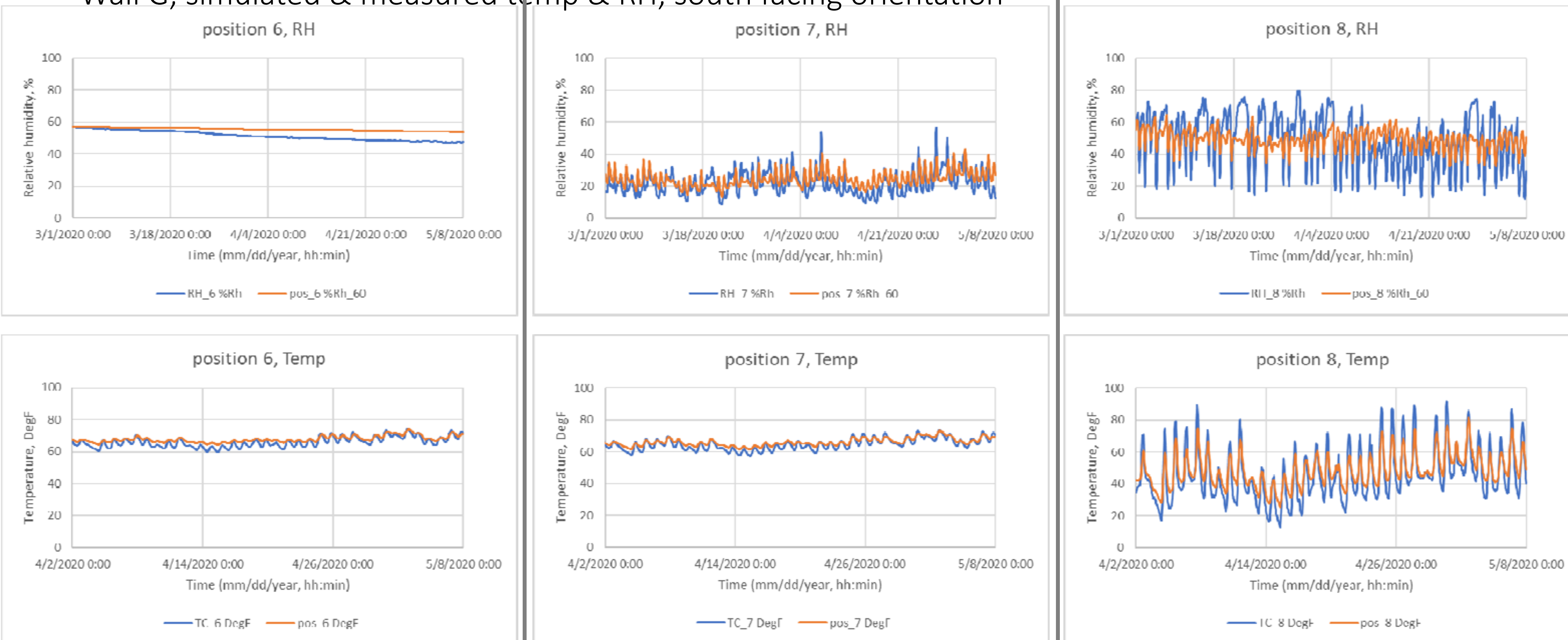






WUFI (pos_#) vs measured RH (RH_#) and Temperature (TC_#)

Wall G, simulated & measured temp & RH, south facing orientation



WUFI (pos_#) vs measured RH (RH_#) and Temperature (TC_#)

Simulation study

Simulations were carried out in accordance with standard ANSI/ASRHAE 160-2016, Criteria for Moisture-Control Design Analysis in Buildings.

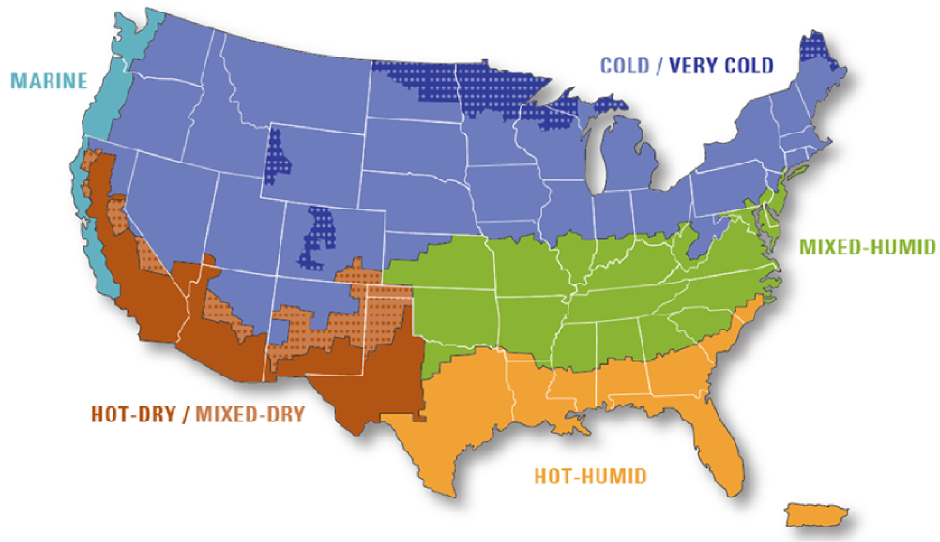
Eight climate zones specified by the Department of Energy:

- Fairbanks, Alaska (subarctic);
- International Falls, Minnesota (very cold);
- Boston, Massachusetts (cold);
- Charleston, South Carolina (mixed humid);
- Amarillo, Texas (mixed dry);
- Miami, Florida (hot humid);
- Tucson, Arizona (hot dry);
- Seattle, Washington (marine).

Duration: three years.

Calculated: moisture content; relative humidity; temperature; and heat flux across the wall assembly.

Performance metrics: the total moisture accumulation; energy consumption; number of consecutive days over 80 percent relative humidity; and mold index.

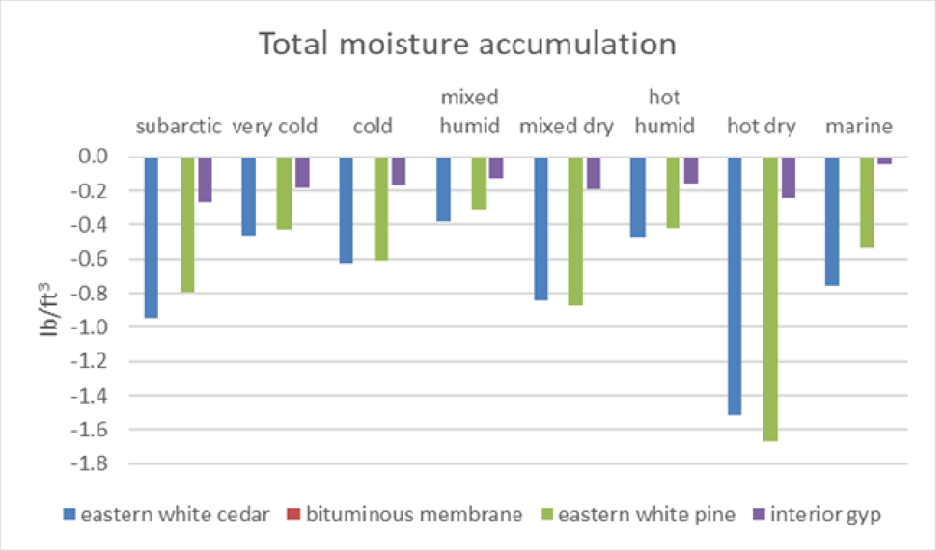


The figure shows 7 of the eight climate zones. The subarctic climate zone, not shown, is only in Alaska. Source: https://www.energy.gov/eere/buildings/climate-zones.

Wall A, Base case, hygrothermal simulation

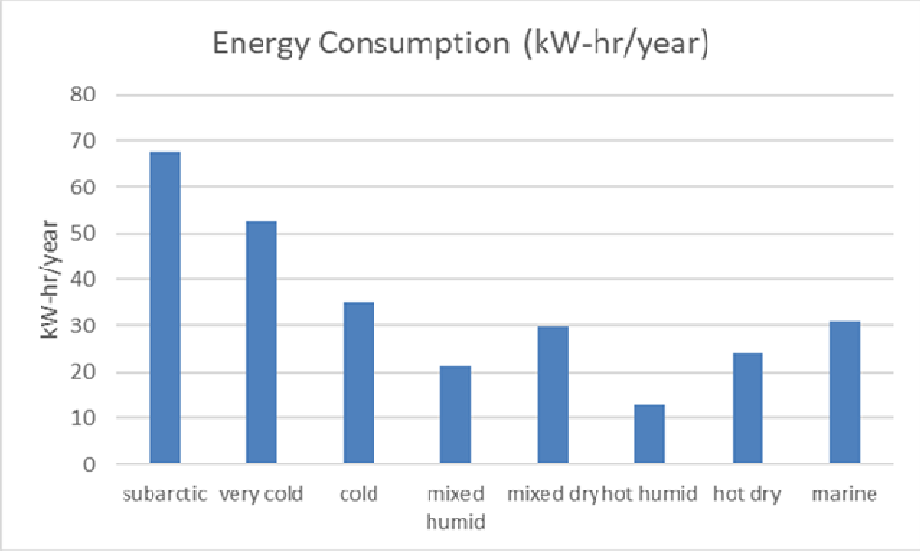
Total moisture accumulation

- Negative moisture accumulation indicates the assembly is drying during the simulation period



Energy consumption

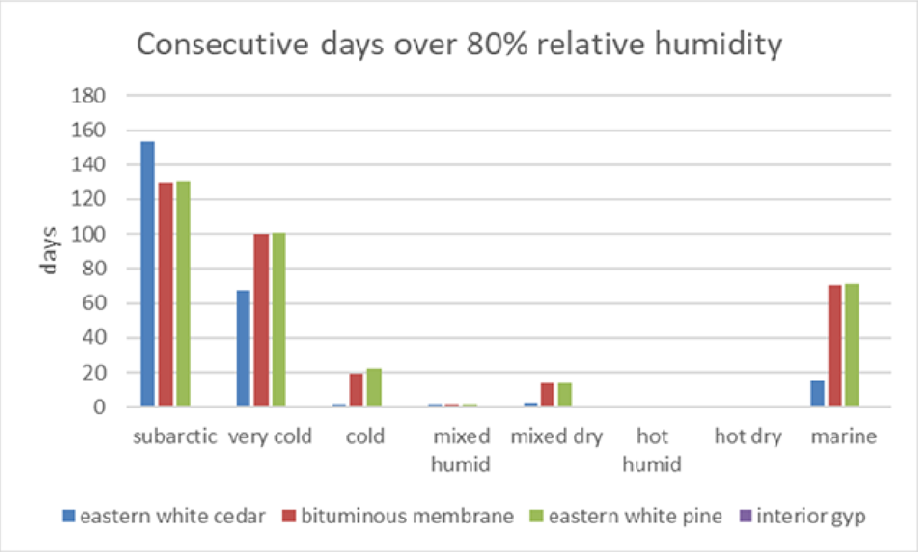
- Energy required to maintain the interior boundary condition



Wall A, Base case, susceptibility to mold growth

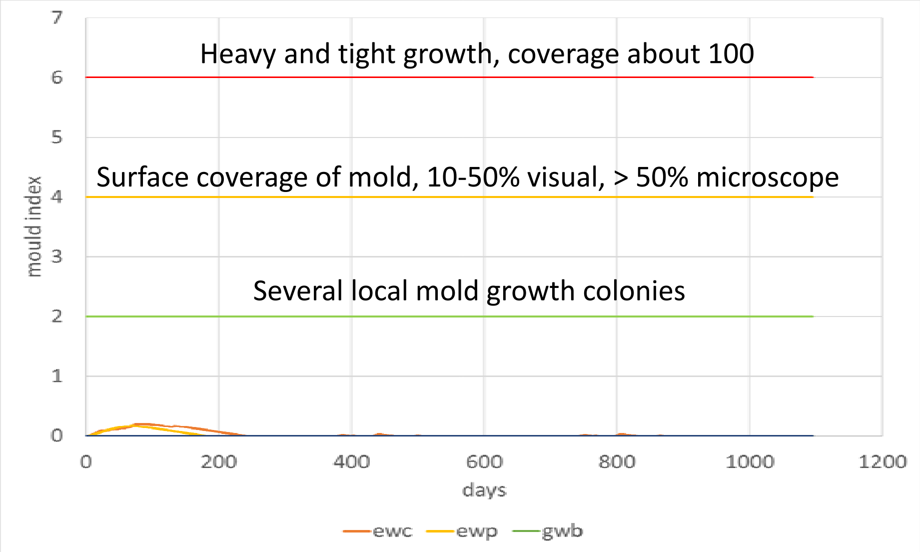
Consecutive days over 80% relative humidity

- The number of consecutive days over 80% relative humidity is used as a guide for the mold index calculation based on ASHRAE 160.



Mold index

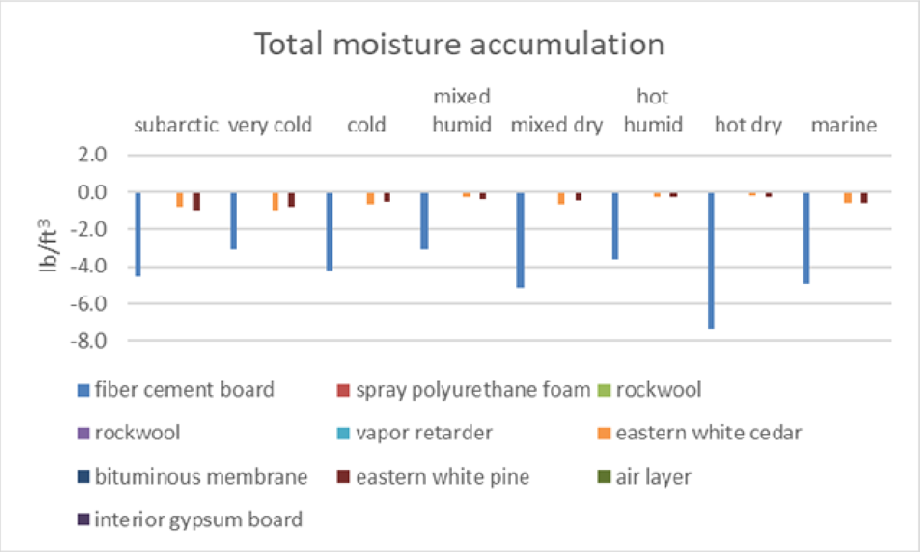
- Mold index accounts for the sensitivity of the material to mold growth, a value of 1 or less indicates no growth of mold.



Wall G, mineral wool, hygrothermal simulation

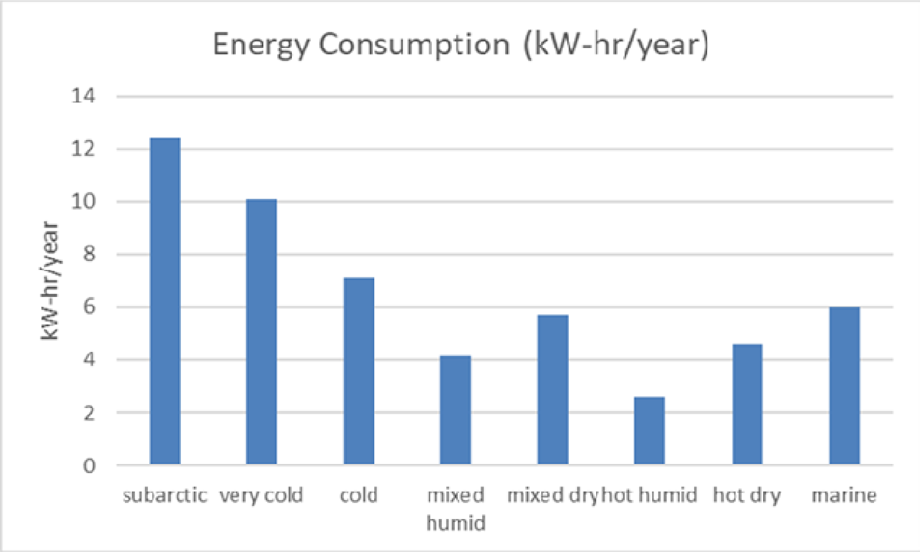
Total moisture accumulation

- Negative moisture accumulation indicates the assembly is drying during the simulation period.



Energy consumption

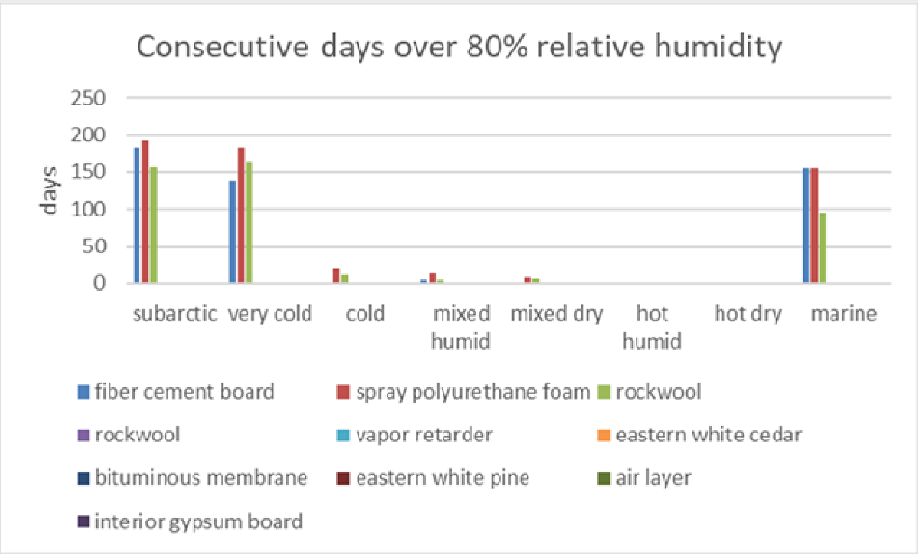
- Energy required to maintain the interior boundary conditions.



Wall G, mineral wool, Susceptibility to mold growth

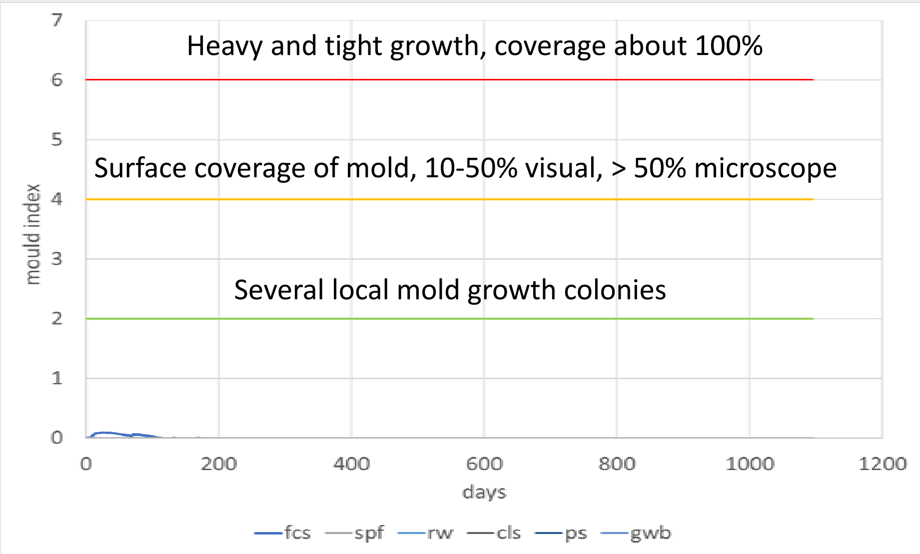
Consecutive days over 80% relative humidity

- The number of consecutive days over 80% relative humidity is used as a guide for the mold index calculation based on ASHRAE 160.



Mold index

- Mold index accounts for the sensitivity of the material to mold growth, a value of 1 or less indicates no growth of mold.



Phase 2 planned activities

- Support University of Minnesota with data acquisition setup.
- Measure required material properties for new products used in Phase 2 walls.
- Repeat model validation exercise with Phase 2 wall data.
- Repeat model generalizations with new wall assemblies.

Building Energy Modeling

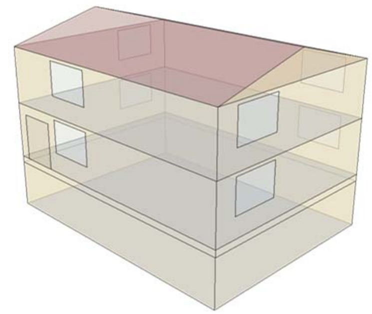
Objectives of the Energy Modeling

- Evaluate the performance of wall retrofits
- Support the selection of the candidate walls
- Estimate the energy and energy cost savings of the retrofits
- Conduct sensitivity analysis of savings due to improved insulations and air leakage

Energy Modeling Methodology

- Adopt the DOE Single-family Prototype Model to represent existing homes based on ResStock and other data sources
- Collect material properties and use THERM to calculate performance of the composite wall layers
- Develop EnergyPlus models for different wall configurations and climates to estimate energy and energy cost savings
- Feed the energy savings data to techno-economic analysis

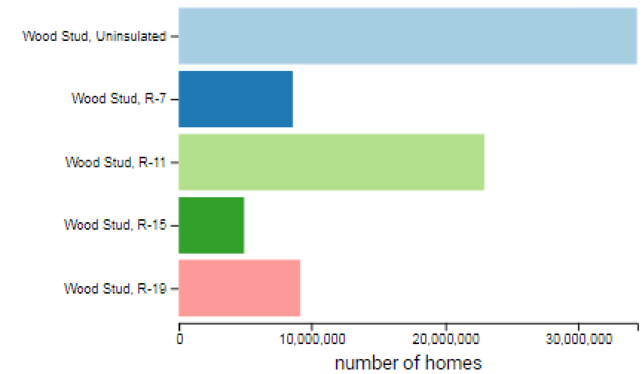
DOE Prototype Single-Family Building Model

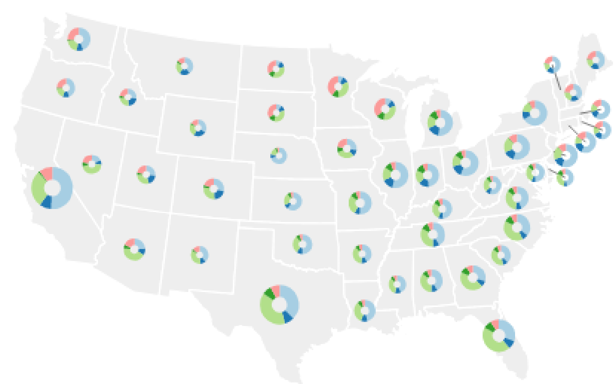


Item	Description	Data source
Total Floor Area (sq. feet)	3,600 (30' x 40' x 3 stories) including conditioned basement	DOE prototype
Aspect Ratio	1.33	DOE prototype
Window-to-Floor Ratio	15%	DOE prototype
Thermal Zoning	Single zone with living space, attic, and heated basement	DOE prototype
Attic	vented	DOE prototype
Basement	Conditioned and uninsulated	DOE prototype
Floor to ceiling height	8.5'	DOE prototype
Windows	Double pane U-factor of 0.55 Btu/h-ft2-F and SHGC of 0.76	ResStock
Roof insulation	Insulated at attic floor R30	ResStock
Wall insulation	Wood framed without insulation (or R0)	ResStock
Air infiltration	ACH50 of 15	ResStock
Heating	Gas furnace 80% AFUE	ResStock
Cooling	SEER 10	ResStock
Duct	In conditioned space	ResStock
Water heater	Gas storage water heater	DOE prototype

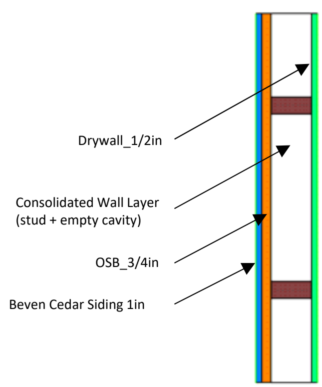
https://www.energycodes.gov/development/residential/iecc_models
https://www.nrel.gov/buildings/resstock.html

Baseline – Insulation wall

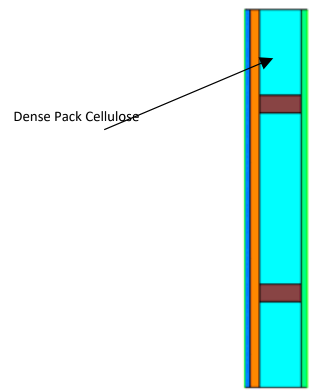




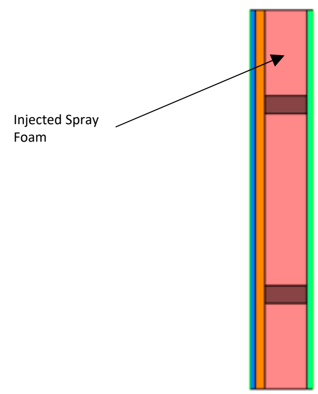
THERM Model of Baseline and Retrofit



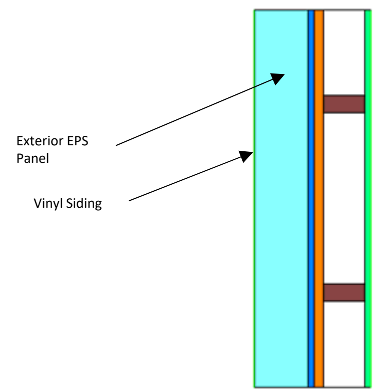
Wall A - Base Case



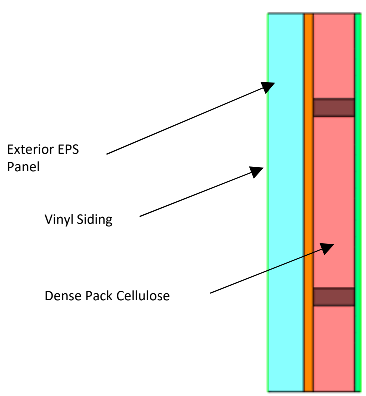
Wall B - Cellulose



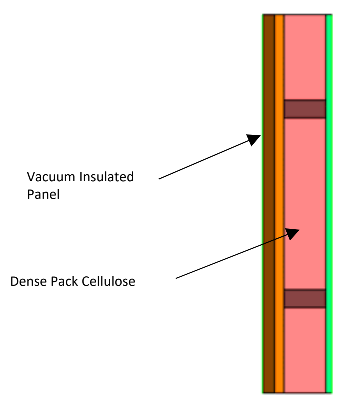
Wall C – Injected Foam



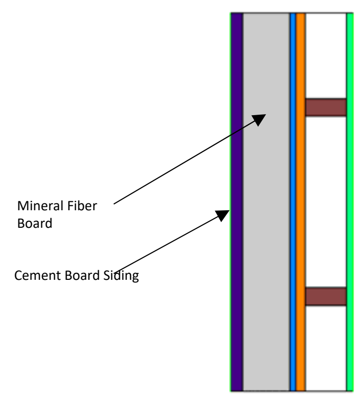
Wall D – Exterior EPS



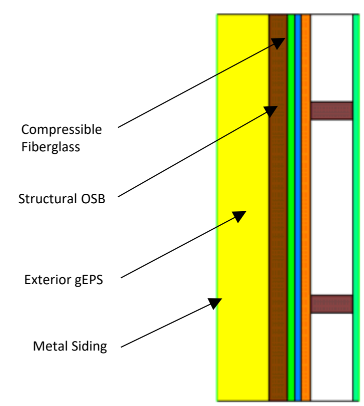
Wall E – Cellulose+XPS



Wall F – Cellulose+VIP



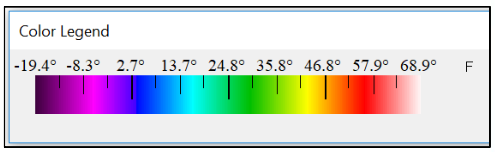
Wall G – Exterior Mineral Wool



Wall H – Exterior Graphite EPS

THERM Results of Walls in Isothermal View

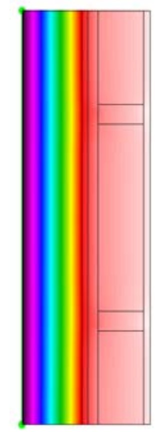
Winter design day
Outdoor air T: -20 deg F
Indoor air T: 70 deg F



Wall A - Base Case

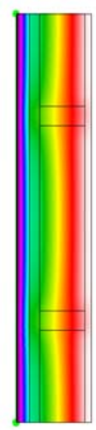
Wall B - Cellulose

Wall C – Injected Foam

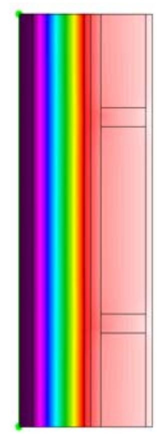


Wall D – Exterior EPS

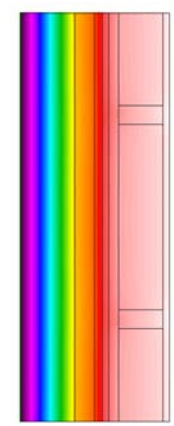
Wall E – Cellulose+XPS



Wall F – Cellulose+VIP



Wall G – Exterior Mineral Wool



Wall H – Exterior Graphite EPS

Calculated U-factor from THERM

Wall name	Cavity Insul. R-value	Continuous Insul. R-value	Effective R-value of entire wall	U-factor	ACH at 50Pa
A - Base Case	NA	NA	**3.9**	0.254	15
B - Cellulose	12.6	NA	**14.0**	0.071	14 Dense-pack cellulose
C - Injected Foam	21.0	NA	**16.8**	0.060	13 Sprayed foam
D - Exterior EPS	NA	18.9	**22.9**	0.044	10 Spun-bonded polyolefin
E - Cellulose+XPS*	12.6	11.5	**24.8**	0.040	10 Spun-bonded polyolefin
F - Cellulose+VIP	12.6	12.0	**24.2**	0.041	10 Spun-bonded polyolefin
G - Exterior Mineral Wool*	NA	20.0	**24.5**	0.041	10 Liquid-applied membrane
H - Exterior graphite-EPS	NA	23.2	**28.7**	0.035	10 Fully-adhered membrane

2018 IECC (CZ7): U-Factor of 0.045

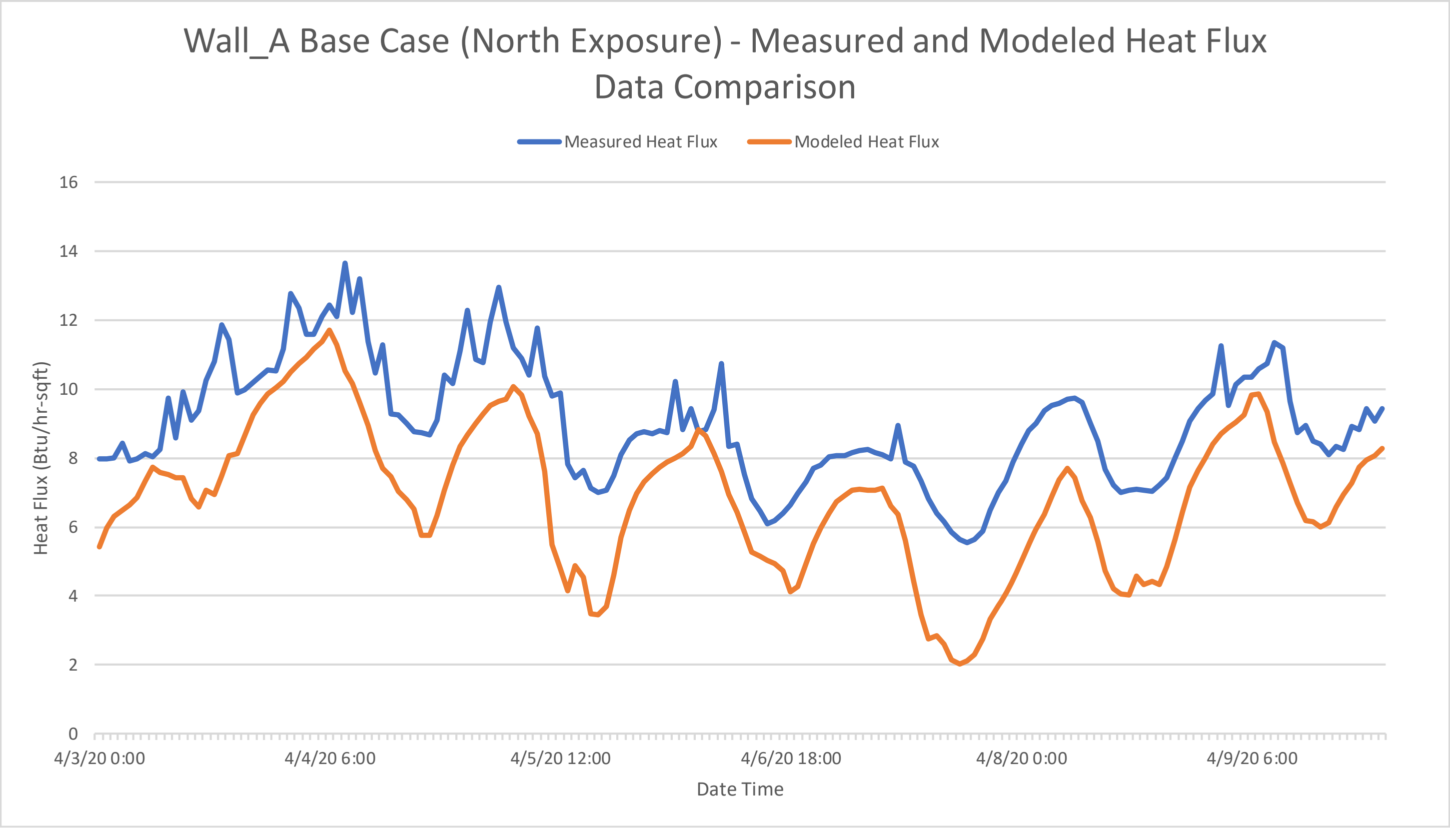
*Minor variations between the modeled and measured conductivity.
R-value in hr-ft2-F / Btu and U-factor is in Btu/hr-ft2-F

Wall Layers from THERM to EnergyPlus

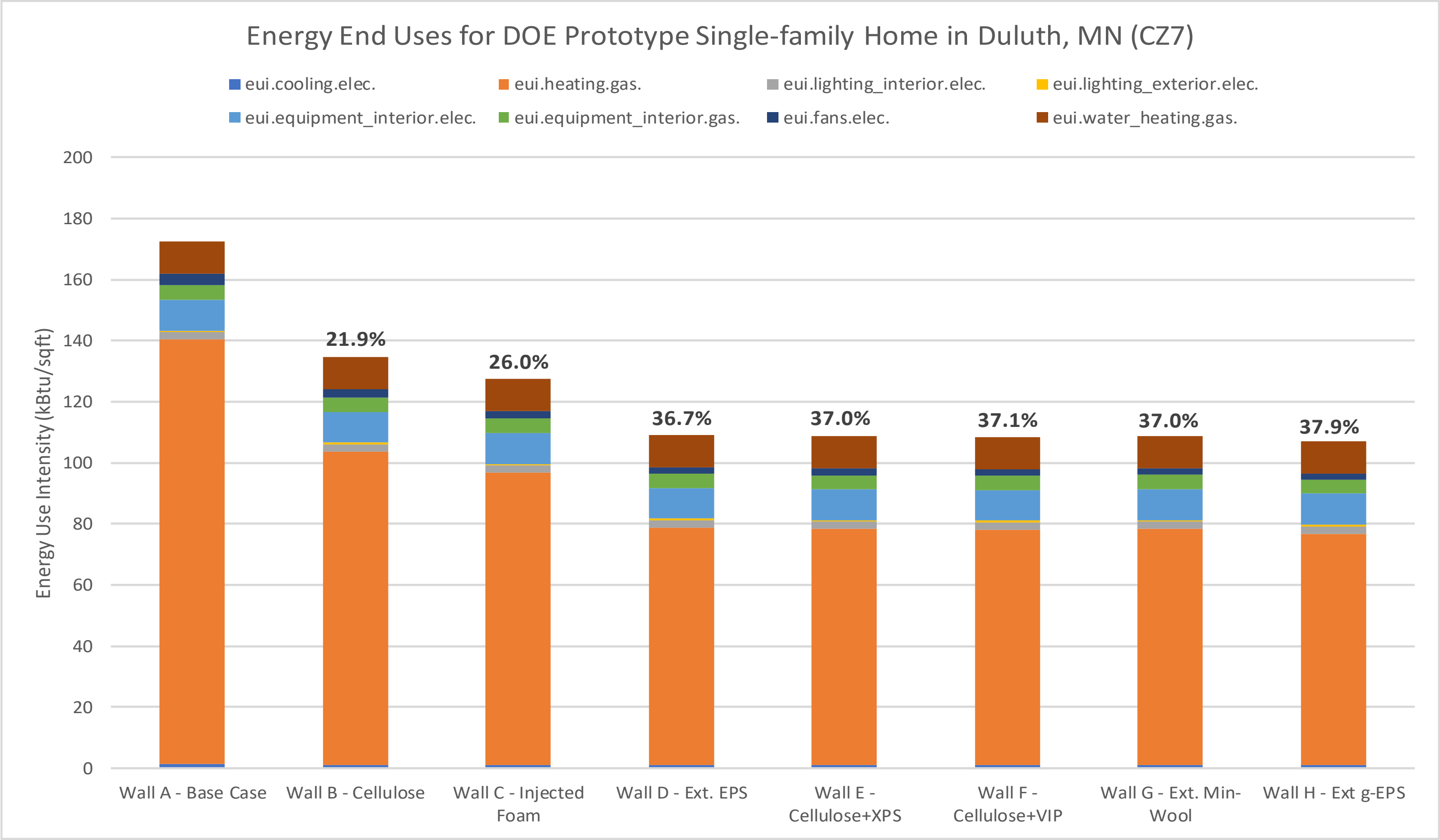
		Wall H - Exterior graphite-EPS						
	No.	**Material**	**Density (lbm/ft3)**	**Sp. Heat (Btu/lbm-F)**	**Thickness (in)**	**Conductivity (Btu-in/hr-ft2-F)**	**R-value (hr-ft2-F/Btu)**	**U-factor**
		Exterior airfilm					0.17	
Retrofit	1	Metal Siding	86.15	0.24	0.04	1.18	0.03	
Retrofit	2	graphite_impregnated_EPS	1.00	0.35	4.24	0.20	20.78	
Retrofit	3	Structural OSB panel	34.00	0.29	1.50	1.00	1.50	
Retrofit	4	Compressible Fibreglass	2.00	0.20	0.63	0.25	2.50	
Existing Wall	5	Bevel_cedar_siding_1in	22.00	0.39	0.50	0.60	0.83	
Existing Wall	6	Bldg_paper_felt (no_mass_mtrl)	NA	NA	NA	NA	0.01	
Existing Wall	7	OSB_3/4in	34.00	0.29	0.75	0.81	0.93	
Existing Wall	**8**	**wall_consol_layer_empty_cavity**	**4.01**	**0.39**	**3.50**	**4.09**	**0.86**	
	9	Drywall_1/2in	50.00	0.26	0.50	1.11	0.45	
		Interior airfilm					0.68	
		Wall assembly including air film					28.74	0.035

	Consolidated Wall Layer	Density (lbm/ft3)	Sp. Heat (Btu/lbm-F)	Thickness (in)	Conductivity (Btu-in/hr-ft2-F)		
8.1	Stud	28.0	0.39	3.50	0.80		
8.2	Air	0.08	0.40	3.50	5.67		
8	wall_consol_layer_empty_cavity	4.01	0.39	3.50	4.99		

Benchmark of Modeled Results with Measurement Heat Flux

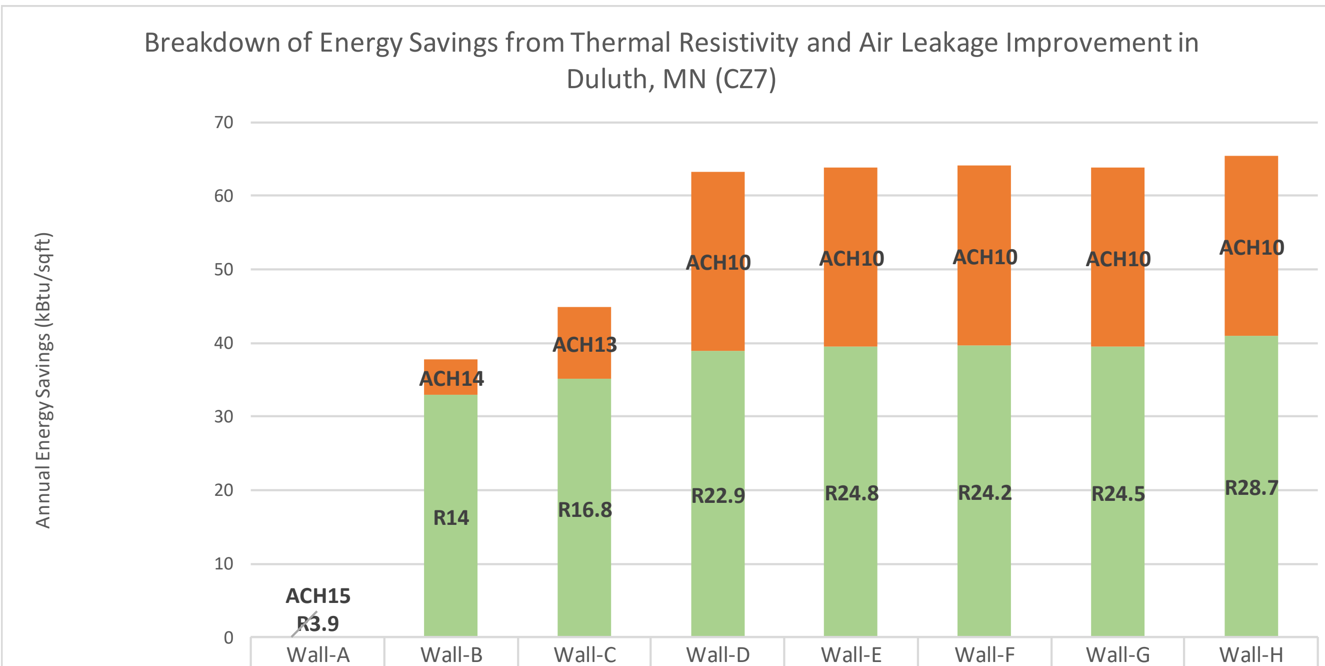


Annual Energy Consumption in Cold Climates



Sensitivity to Assumed Infiltration

- The baseline model was assumed to have ACH 15 per ResStock. The reduction in air infiltration for the retrofit walls was not characterized through the experiment yet.
- Sensitivity analyses were conducted to evaluate the impact of air leakage and insulation independently.



	Wall-A	Wall-B	Wall-C	Wall-D	Wall-E	Wall-F	Wall-G	Wall-H
Air Leakage	0	4.88	9.75	24.34	24.34	24.34	24.34	24.34
Thermal Resistivity	0	32.89	35.11	38.96	39.51	39.72	39.44	41.02

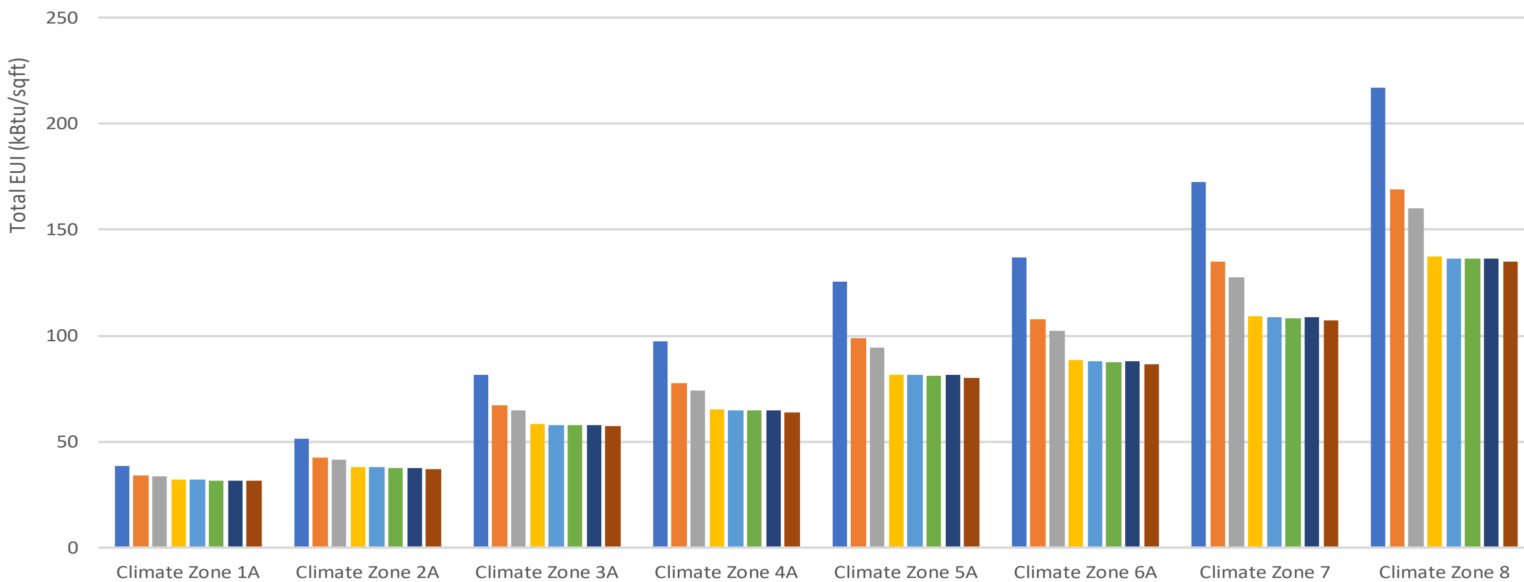
Annual Energy Use Comparison

Annual Energy Use Intensity for DOE Prototype Single-family Home

Wall A - Base Case; Wall B - Cellulose; Wall C - Injected Foam; Wall D - Ext. EPS; Wall E - Cellulose+XPS; Wall F - Cellulose+VIP; Wall G - Ext. Min-Wool; Wall H - Ext g-EPS

Percent Energy Savings compared to Wall-A Base Case

Wall-B	11.6%	16.7%	17.9%	20.4%	21.1%	21.4%	21.9%	22.0%
Wall-C	13.1%	19.1%	20.7%	23.9%	24.9%	25.3%	26.0%	26.1%
Wall-D	17.4%	26.1%	28.7%	33.2%	34.9%	35.5%	36.7%	36.6%
Wall-E	17.4%	26.1%	28.8%	33.5%	35.2%	35.8%	37.0%	37.0%
Wall-F	17.5%	26.3%	29.0%	33.6%	35.3%	35.9%	37.1%	37.1%
Wall-G	17.9%	26.6%	29.0%	33.5%	35.2%	35.8%	37.0%	37.0%
Wall-H	18.4%	27.5%	29.9%	34.5%	36.1%	36.7%	37.9%	37.8%



Summary

- An energy modeling methodology with THERM and EnergyPlus was implemented to evaluate the retrofit walls.
- For CZ7, two of the seven walls are less efficient than 2018 IECC. Others are equivalent or more efficient.
- The simulation results are benchmarked with the measurement results.
- Significant energy and energy cost savings (38% and 34%) can be found for cold climates using the most insulated walls. A third of the savings is from assumed air leakage reduction.
- The analysis results are sensitive to air leakage assumptions, especially in the colder climates.
- We recommend to study the infiltration in the future experiment work and air leakage reduction should be an important part of the retrofit technology.

Wall Study for Deep Energy Retrofits

Expert Meeting, January 20, 2021

Techno-Economic Study Update

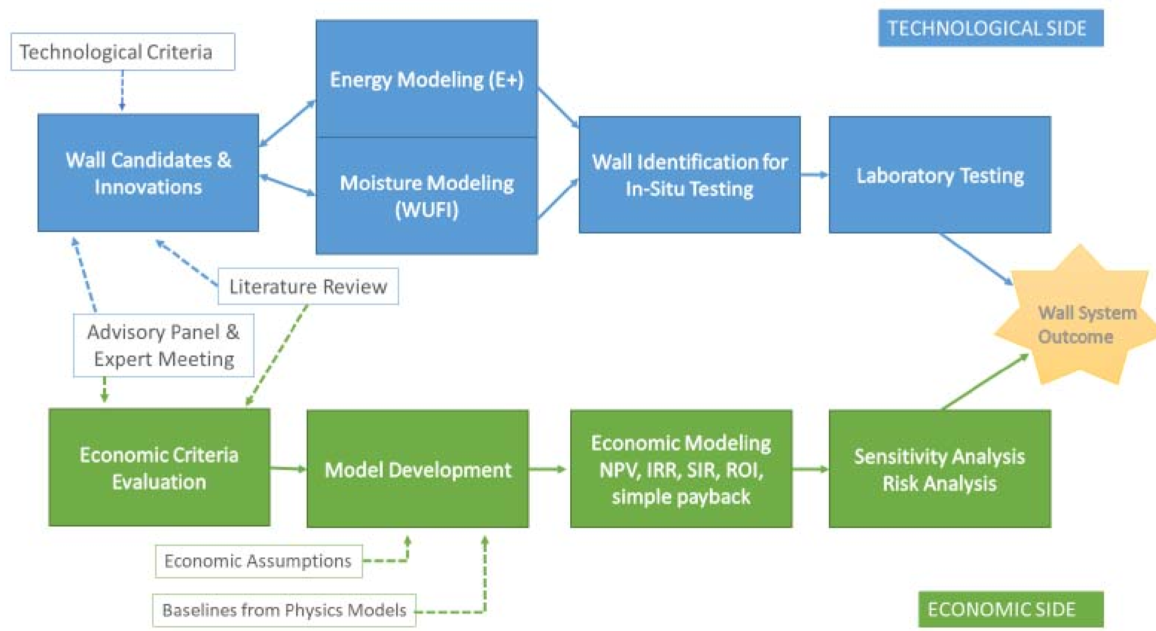
January 15, 2021

Chrissi Antonopoulos & Sumitrra Ganguli

Techno-Economic Analysis

Techno-Economic Study Objectives

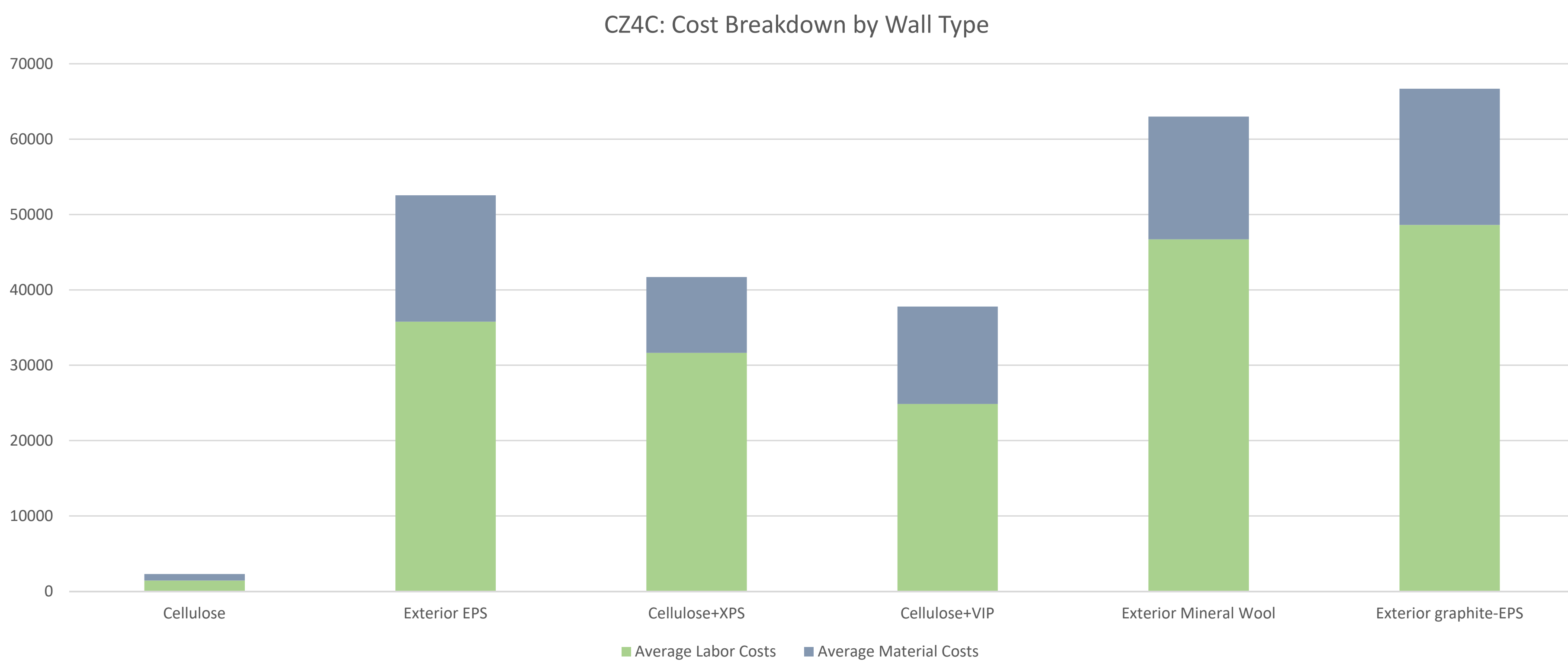
- Synthesize experimental data, model/simulations and economic data using a life-cycle approach to understand energy, cost and environmental impacts of wall systems.
- Goal: identify options that will save energy, be moisture durable, and promote residential building retrofits at scale.



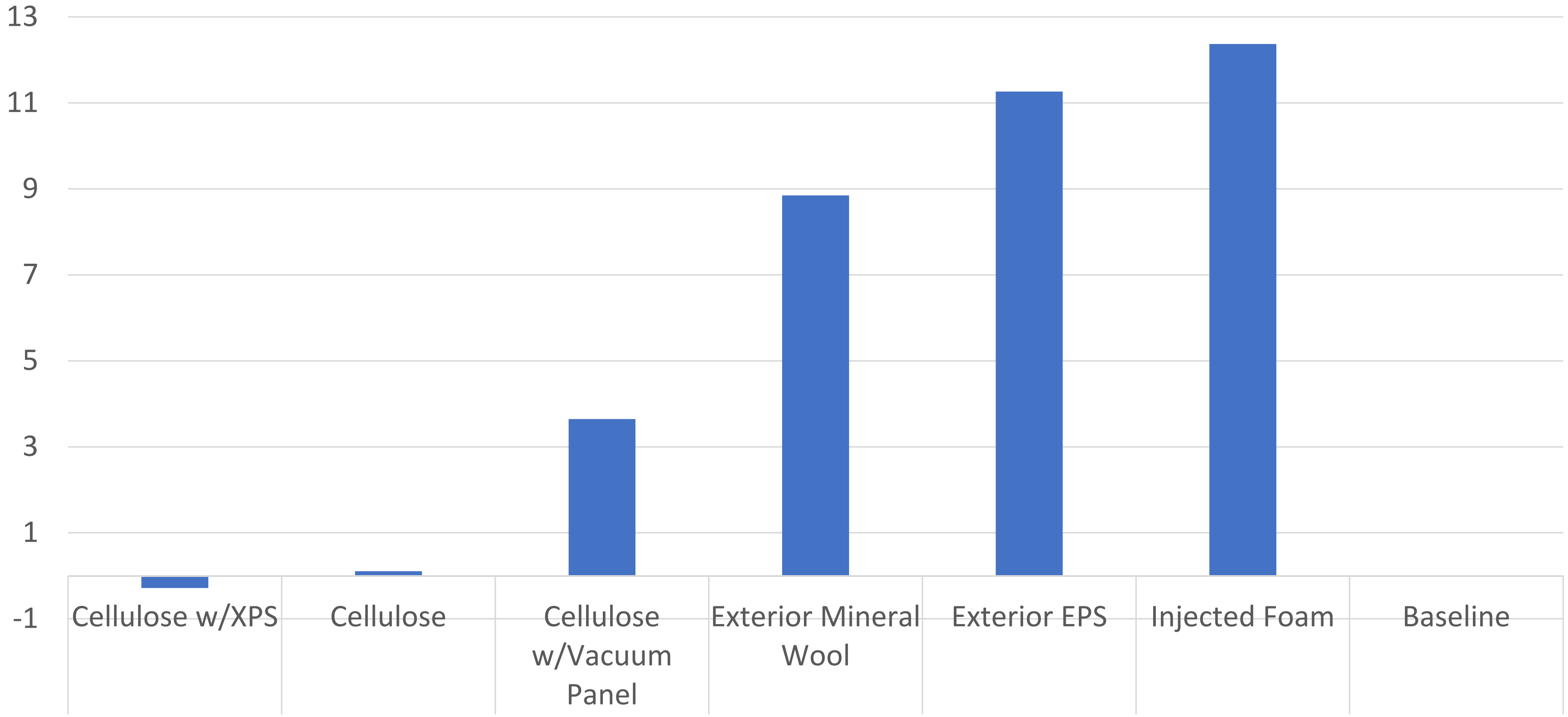
Cost Data

- Cost estimates provided by Earth Advantage:
  - Earth Advantage worked with three local retrofit contractors to determine:
    - ✓ Material cost
    - ✓ Labor cost
    - ✓ Additional overhead or miscellaneous costs if necessary.
  - Cost estimates include large and small local contractors.
- Three cost estimates for each wall was provided.
- Cost data from one local region (Portland, OR) will be extrapolated to other regions using RS Means regional indices. Costs will match the regional energy and moisture model analyses.
- Shows the performance of walls across the different climate zones (material, labor and energy cost savings over a 30-year period)
- All costs calculated as departures from the baseline wall (Delta Method)

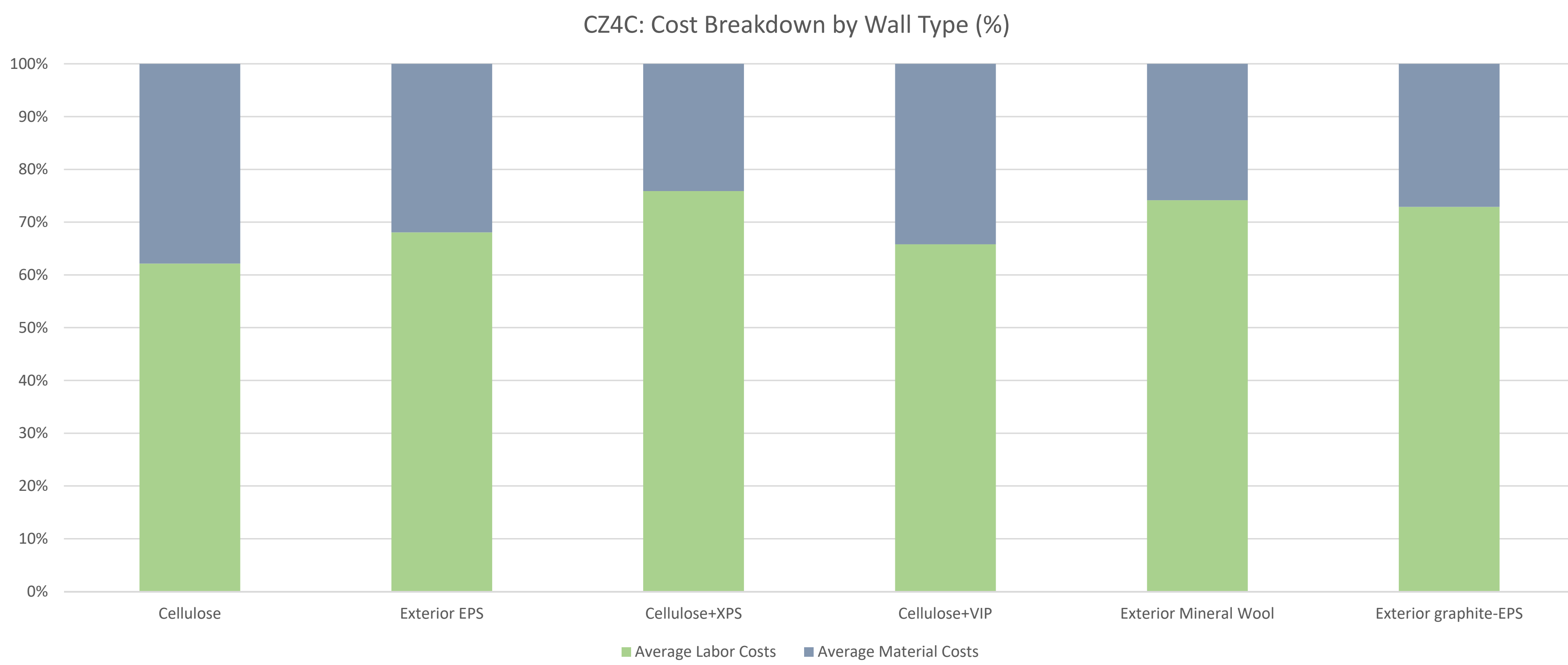
Labor and Material Costs, Portland, OR



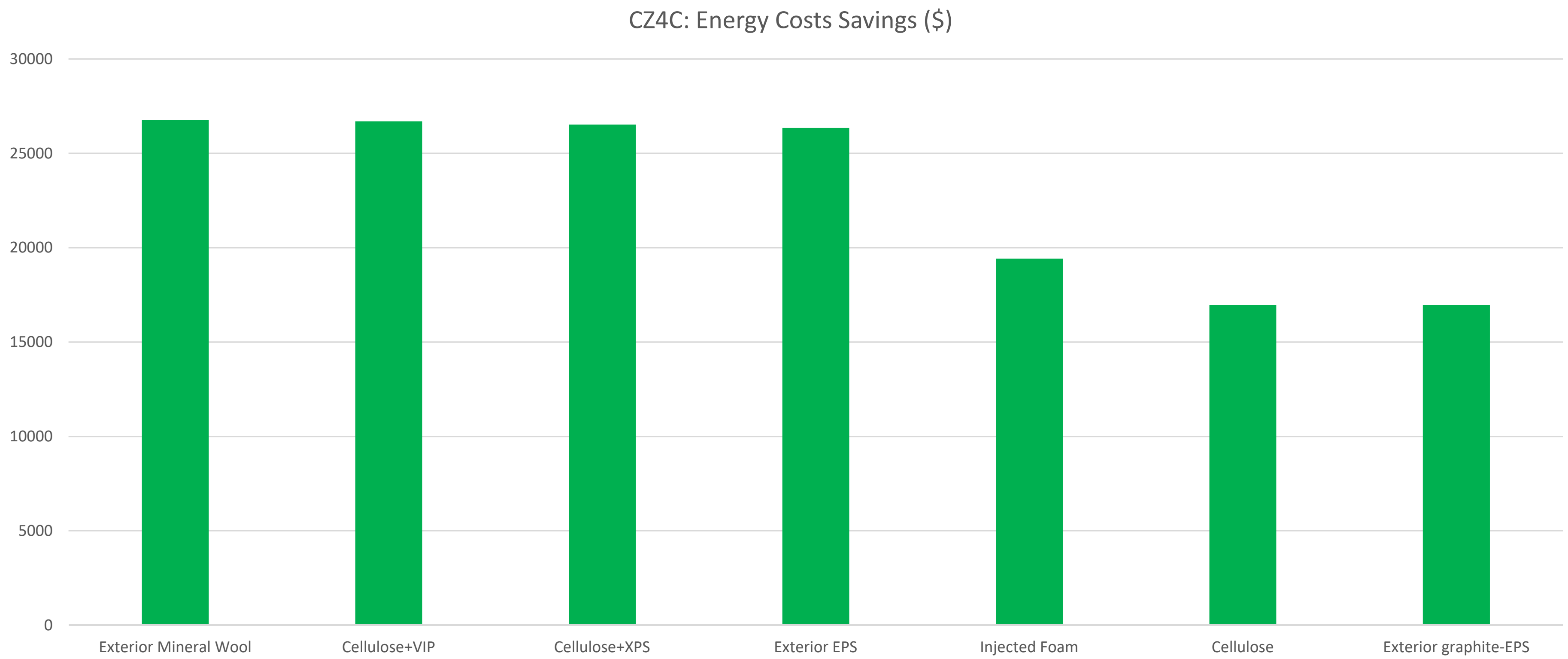
First Year Costs (Install Costs + Energy Cost Savings) Compared to Baseline (%)



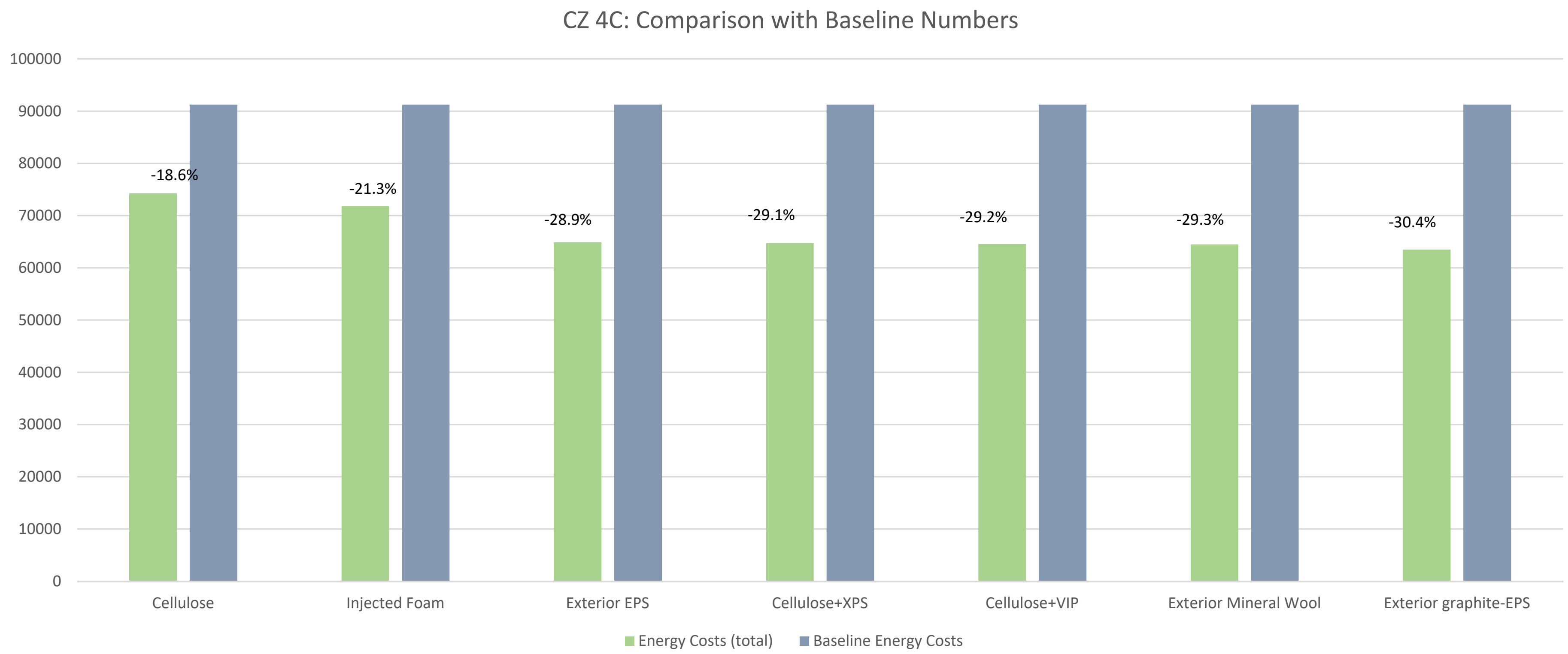
Labor & Material Percentage Breakdown



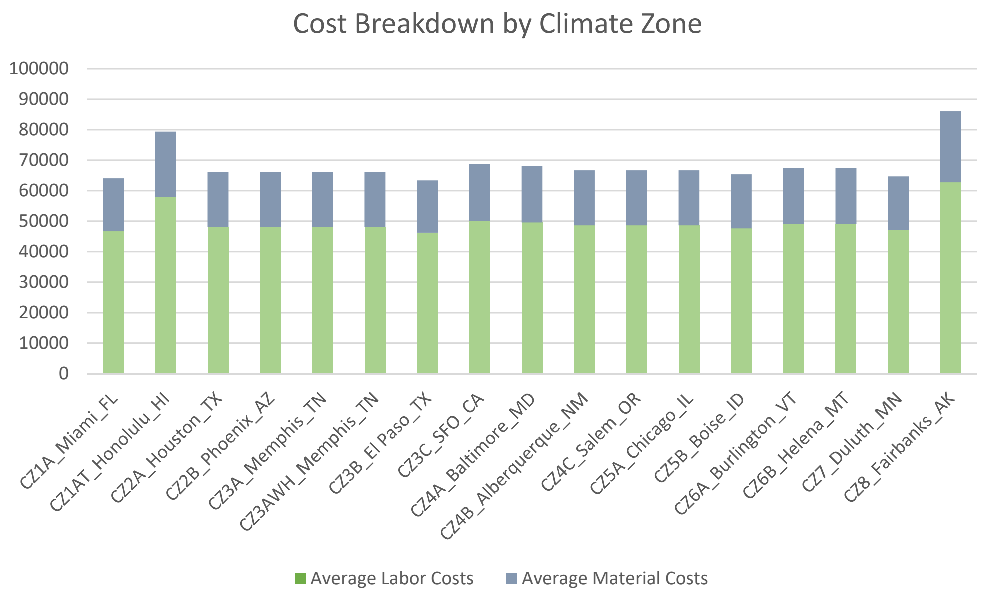
Energy Costs Savings over 30 Years

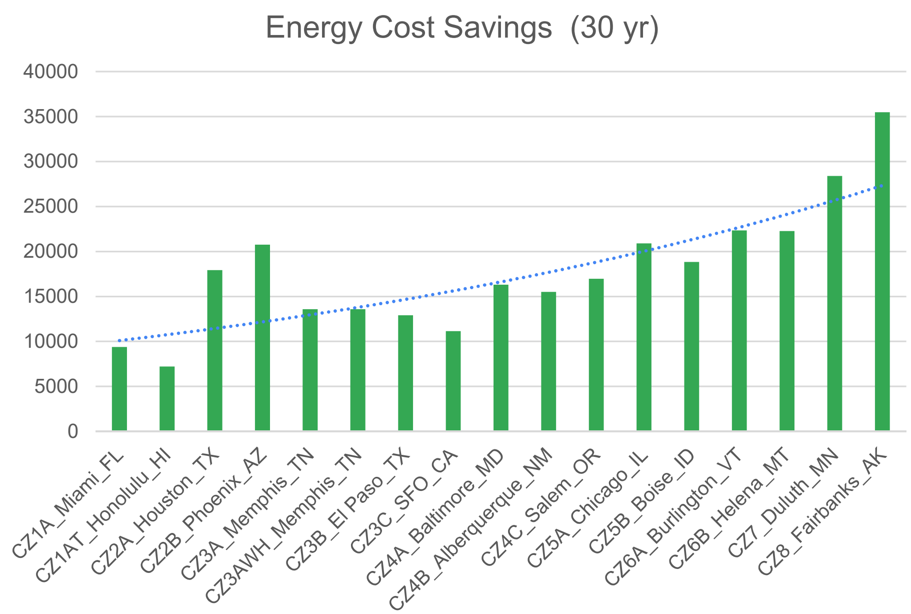


Energy Cost Savings Relative to Baseline



Wall H:Empty Cavity with Exterior graphite-EPS





Limitations to Cost Data

- Injected foam and VIP panels not commercially available. g-EPS “Energie Sprong” technology is not fully developed. Material and labor costs are estimates at this point. As such, Injected foam material/labor not included in the wall breakdowns at this juncture.
- Labor costs for emerging technologies are not well known. Contractors found it more difficult to bid labor for wall systems they weren’t familiar with.
- Significant variability in costs regionally
- Significant variability in costs depending on purchase power of the conractor
- Utility programs, WAP, and other EE programs around the country have impacts of final costs of materials.

Next Steps

- Develop metrics for moisture performance
- Develop metrics for sensor data
- Other metrics:
  - Simple payback
  - Reverse Payback
  - Risk Index associated with each wall

Whew.

Any questions?

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