A Public Domain, Transient, Experimental Database on the Hygrothermal Performance of Durable, Energy-Efficient Full Basement Foundation Walls in a Cold Climate

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Thermal Performance of the Exterior
Envelopes of Whole Buildings XIII
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OBJECTIVES

- To experimentally evaluate the energy and hygrothermal performance of retrofit foundation wall insulation systems compliant with the insulation requirements of the 2012 IECC and the hygrothermal performance standards of the 2009 MN Energy Code over a continuous two-year monitoring period.

- Develop and publish in the public domain a transient experimental database of cold climate foundation hygrothermal performance.

- Demonstrate the effectiveness of the database in assessing the accuracy and validity of an arbitrary building foundation system thermal simulation.

COLD CLIMATE DESIGN BASIS

MN DEPT. OF LABOR AND INDUSTRY RESIDENTIAL ENERGY CODE CHAPTER 1322-2015

R402.1.1.8 Foundation wall insulation performance option:

- The foundation shall be designed and built to have a continuous water separation plane (WSP) between the interior and exterior.

  A *water separation plane* (WSP) is a single component or a system of components creating a plane that effectively resists capillary water flow and water flow caused by hydrostatic pressure and provides a water vapor permeance of 0.1 perms (5.75 ng/s.m2.Pa) or less to retard water vapor flow by diffusion.

COLD CLIMATE DESIGN BASIS

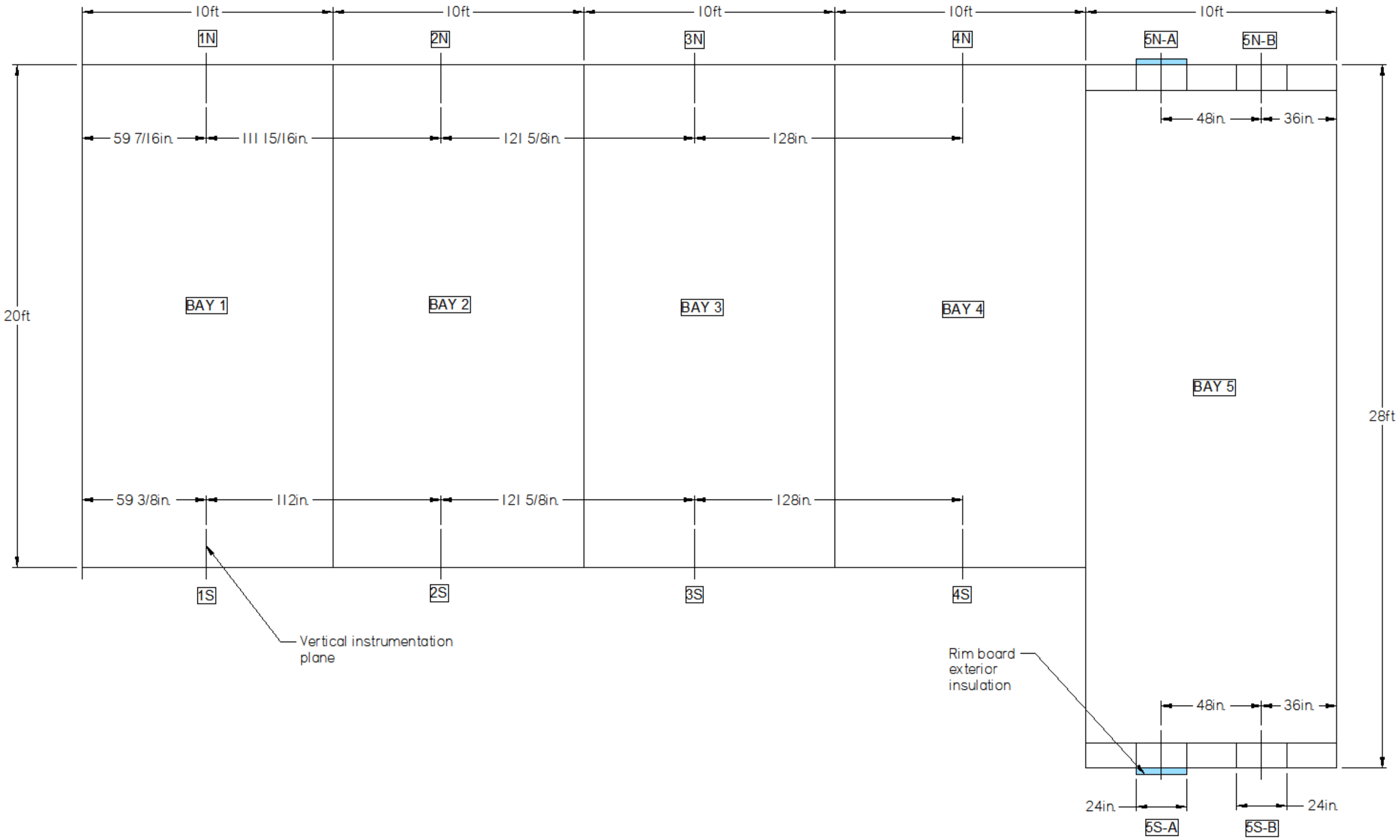
The interior side of the water separation plane shall:

a. have a stable annual wetting and drying cycle whereby foundation wall system water (solid, liquid, and vapor) transport processes produce no net accumulation of ice or water over a full calendar year and the foundation wall system is free of absorbed water for at least 4 months over a full calendar year;

b. prevent conditions of moisture and temperature to prevail for a time period favorable to mold growth for the material used; and

c. prevent liquid water from the foundation wall system from reaching the foundation floor system at any time during a full calendar year.

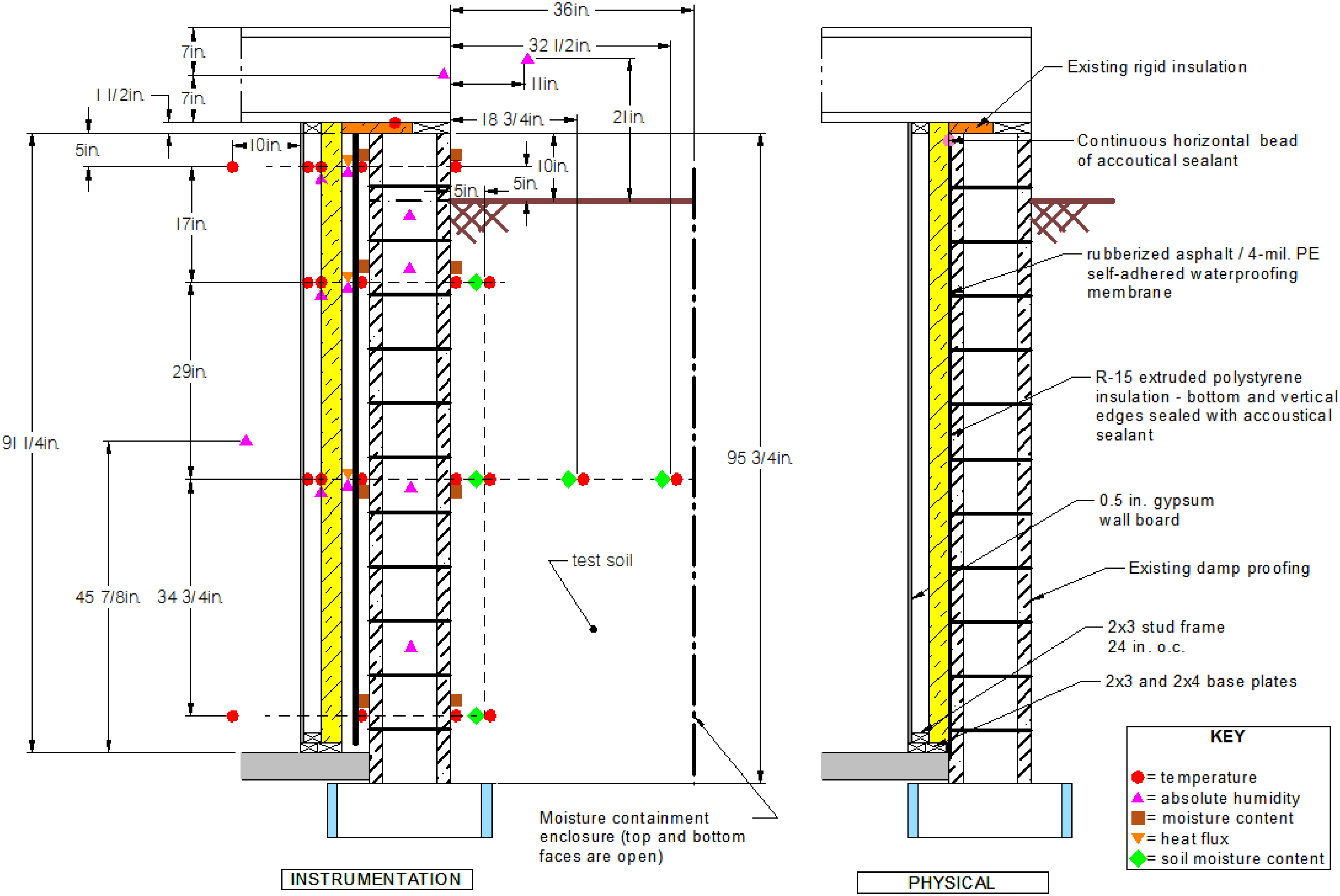
COLD CLIMATE RESIDENTIAL RESEARCH LABORATORY, CLOQUET, MN



Wall System Construction Details

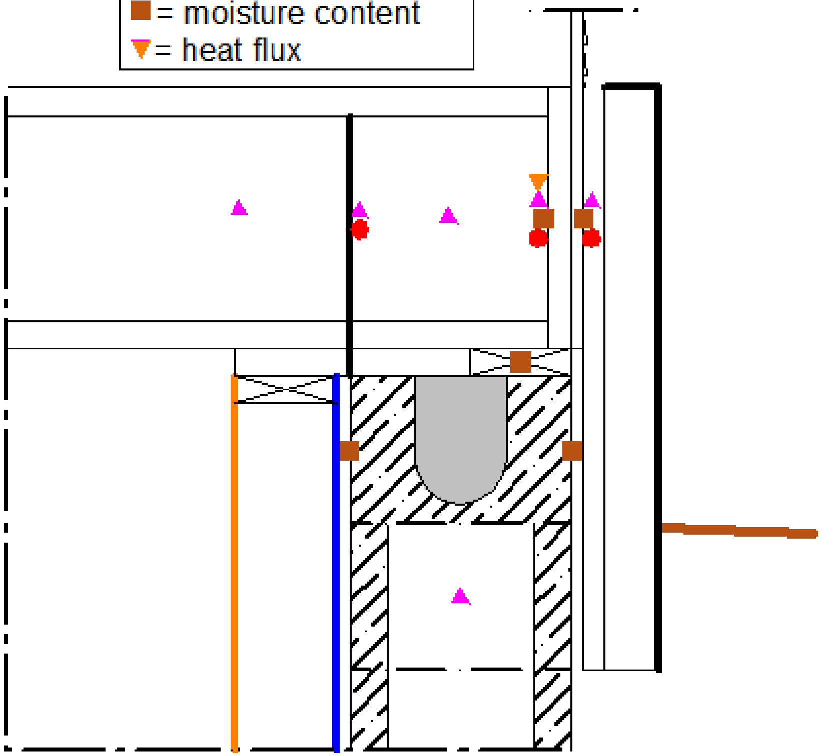
Bay	Water Separation Plane (WSP)	Insulation	Soil Classification (USDA Soil triangle/USC)
1	Adhered (rubberized asphalt / 4-mil PE)	Interior, Full-height, 3 in. XPS	loam/sandy-silt (ML)
2	Adhered (rubberized asphalt / 4-mil PE)	Interior, Full-height, 3 in. XPS	sand/sand (SP)
3	Non-adhered (dimpled HDPE membrane)	Interior, Full-height, 3 in. XPS	sand/sand with silt (SP-SM)
4	Adhered (rubberized asphalt / 4-mil PE)	Exterior, Half-height, 3 in. XPS	sand/sand with silt (SP-SM)
5	Non-adhered (6-mil PE)	Interior, R-11 batt	sand/sand with silt (SP-SM)

INSTRUMENTATION AND PHYSICAL LAYOUT FOR BAYS 1 AND 2

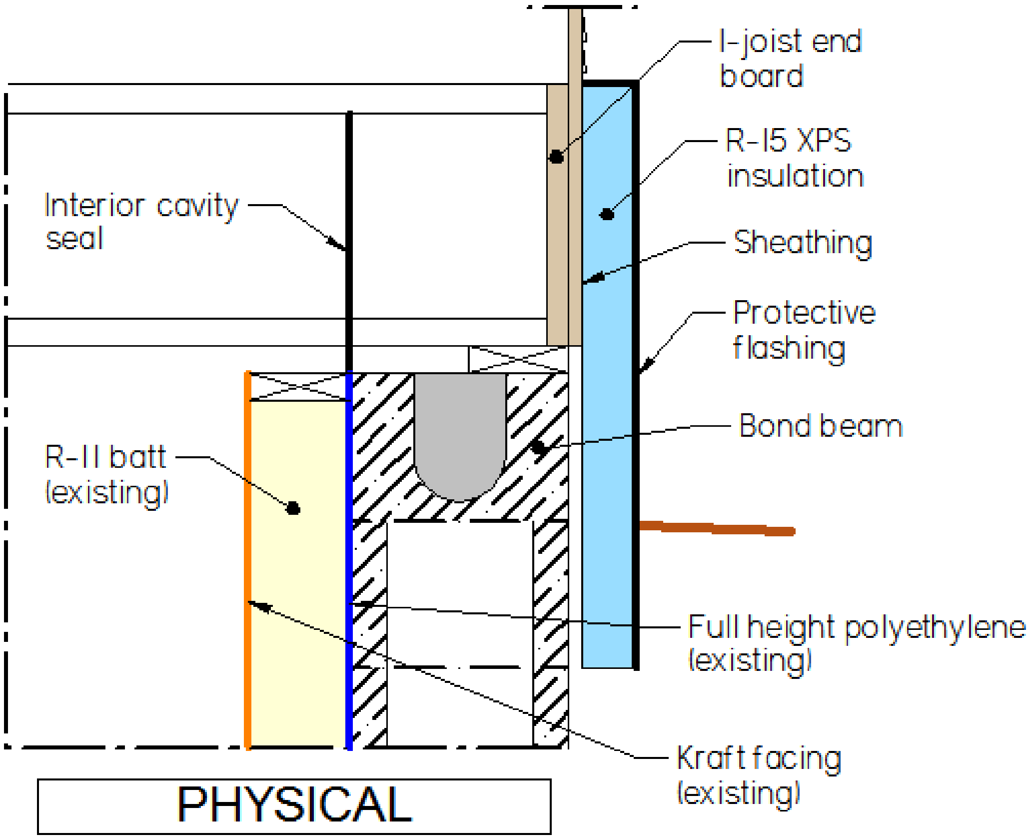


INSTRUMENTATION AND PHYSICAL LAYOUT FOR BAY 5

KEY
● = temperature
▲ = absolute humidity
■ = moisture content
▼ = heat flux



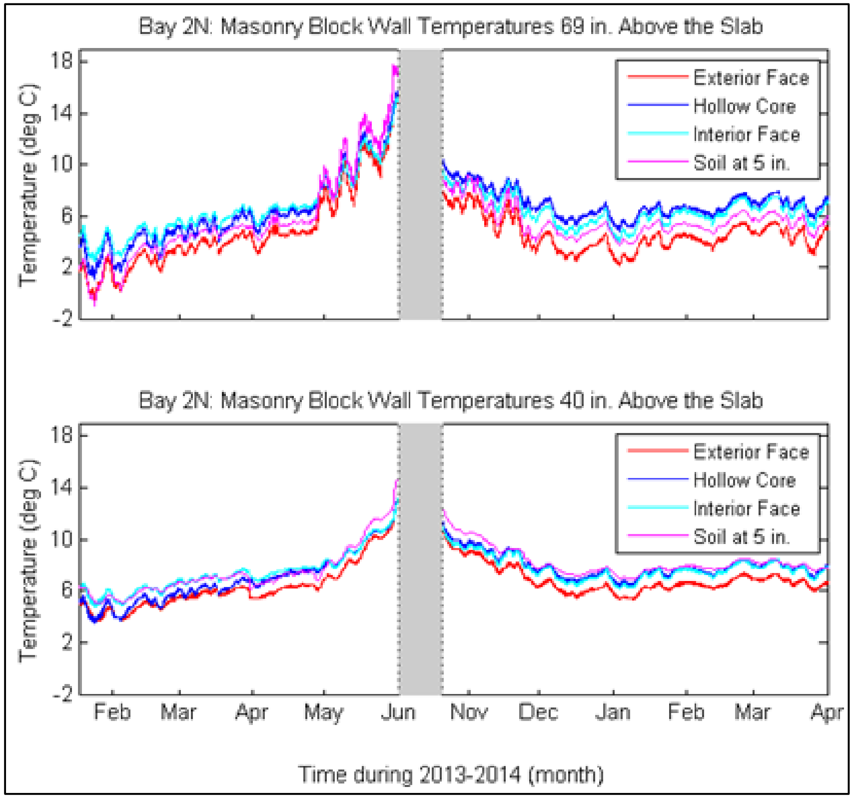
INSTRUMENTATION

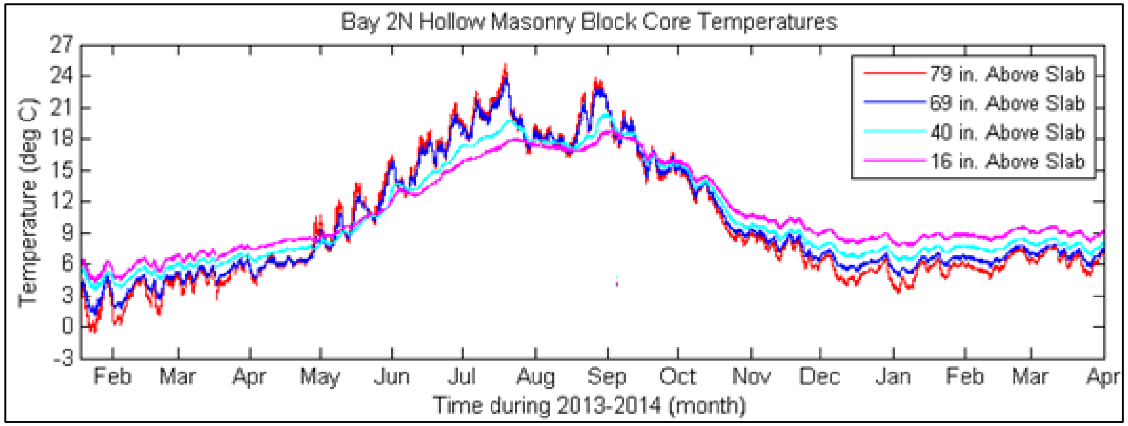


PHYSICAL

Heating season wall temperatures for Bay 2N at 69 in. and 40 in. above the slab

CMU BUOYANT CAVITY FLOW

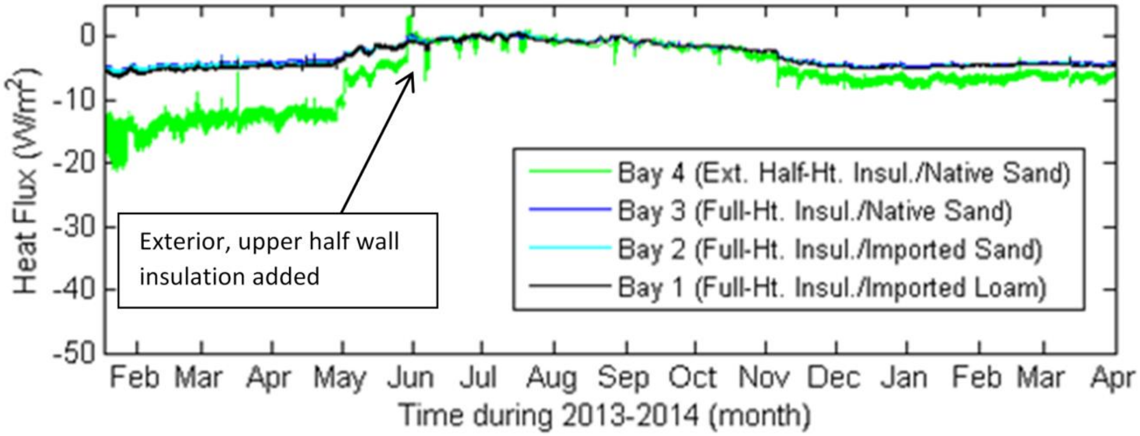




Impact of Exterior/Interior Insulation Placement on Wall Heat Loss

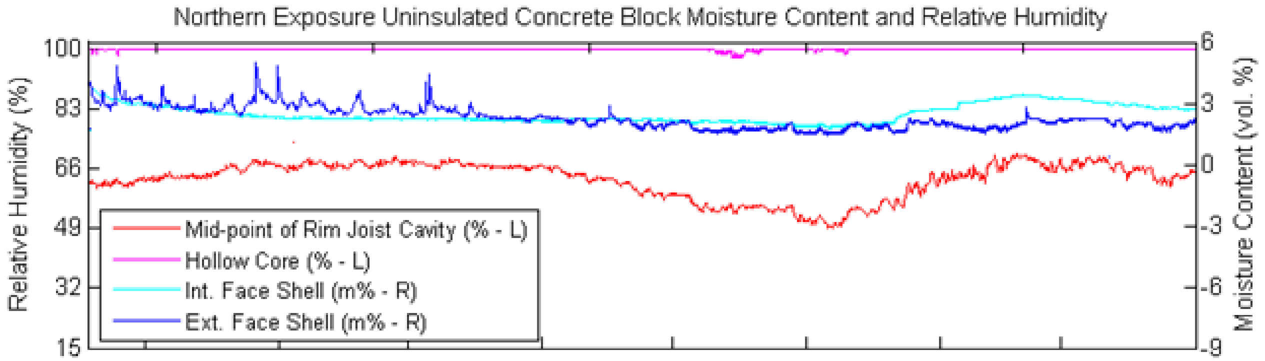
- Bay 4 insulation
  - 1st heating season: uninsulated
  - 2nd heating season: exterior R-15 XPS to 38 in. below grade
- 1st heating season at 12 in. BG:
  - Uninsulated (Bay 4): ~15 W/m^2.K
  - Full-wall, interior, R-15 continuous insulation (Bay 1-3): ~5 W/m^2.K
- 2nd heating season at 12 in. BG:
  - Half-wall exterior insulation (Bay 4): ~7 W/m^2.K
  - Full-wall, interior, R-15 continuous insulation (Bay 1-3): ~4.5 W/m2.K

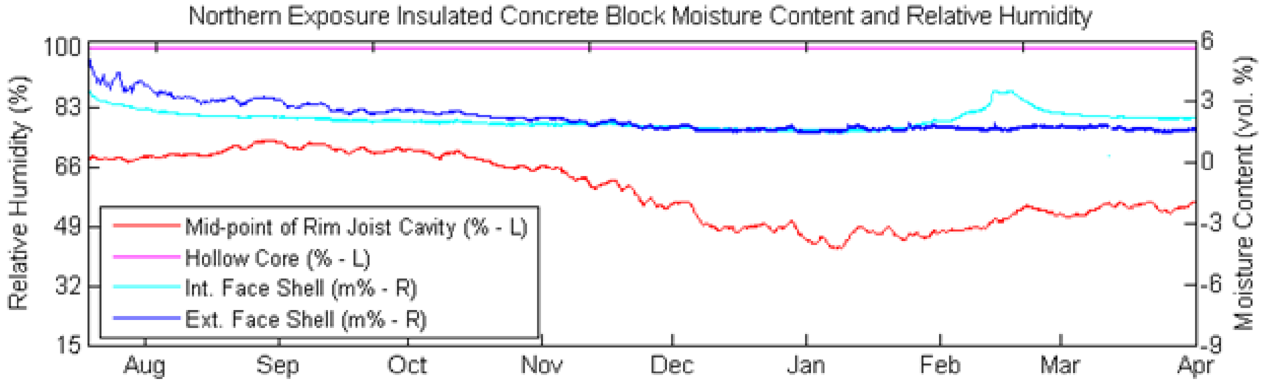
North exposure wall heat flux comparison (12 in. below grade)



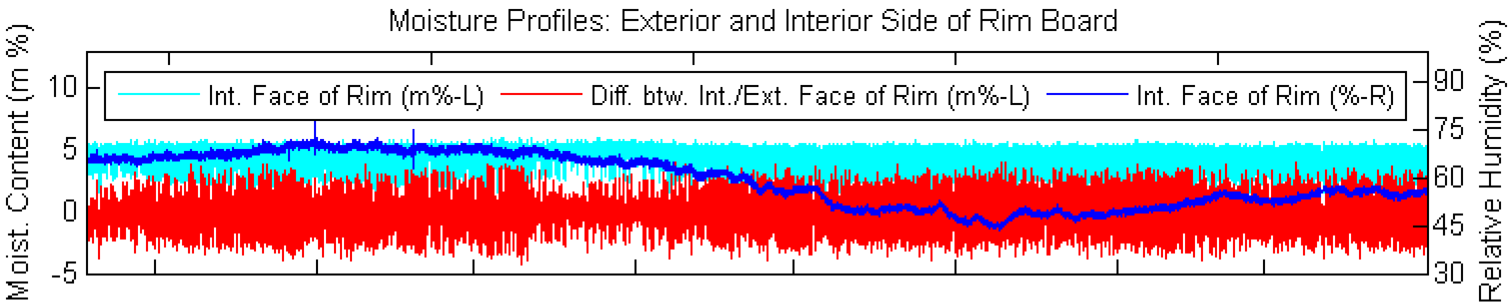
Exterior, upper half wall insulation added

Rim Joist Cavity /CMU Core Vapor Coupling

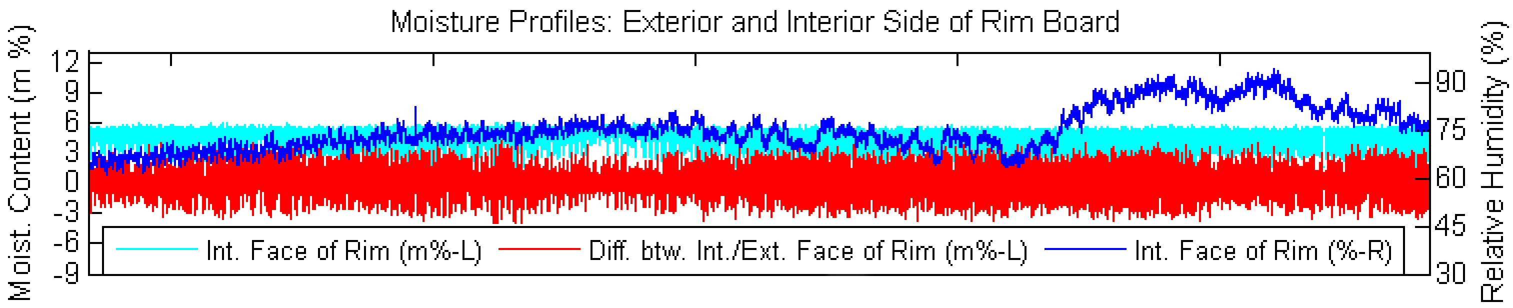




Bay 5N Insulated Rim Board



Bay 5N Uninsulated Rim Board

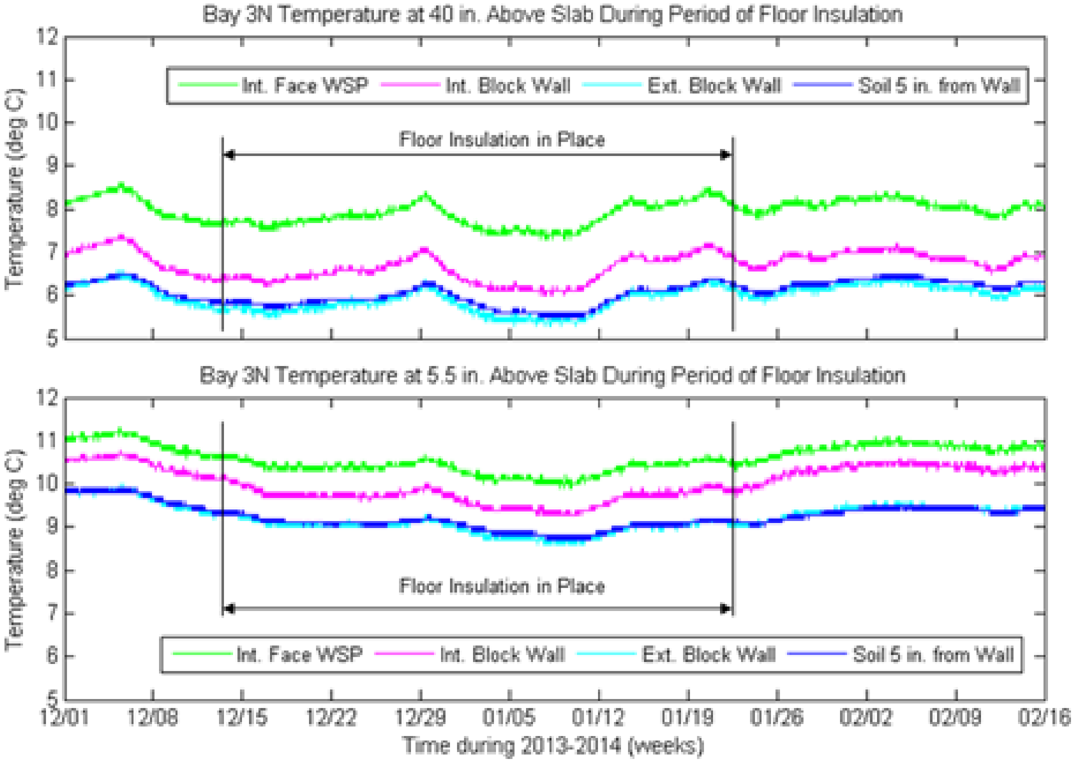


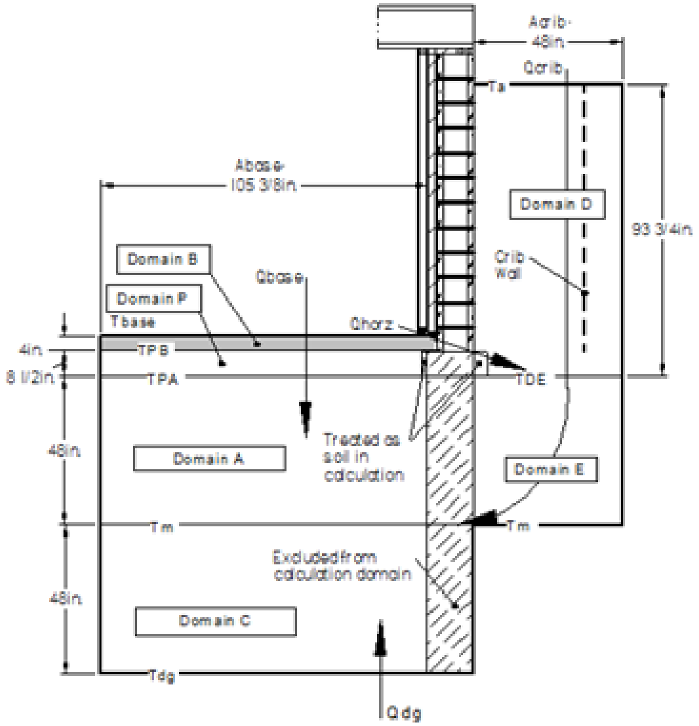
<u>Note</u>:

No condensation occurred on the rim board interior surface (dry bulb temperature greater than dew point temperature) over the monitoring period in both the insulated and uninsulated cases.

Influence of Sub-slab Soil Domain on the Soil Heat Transfer

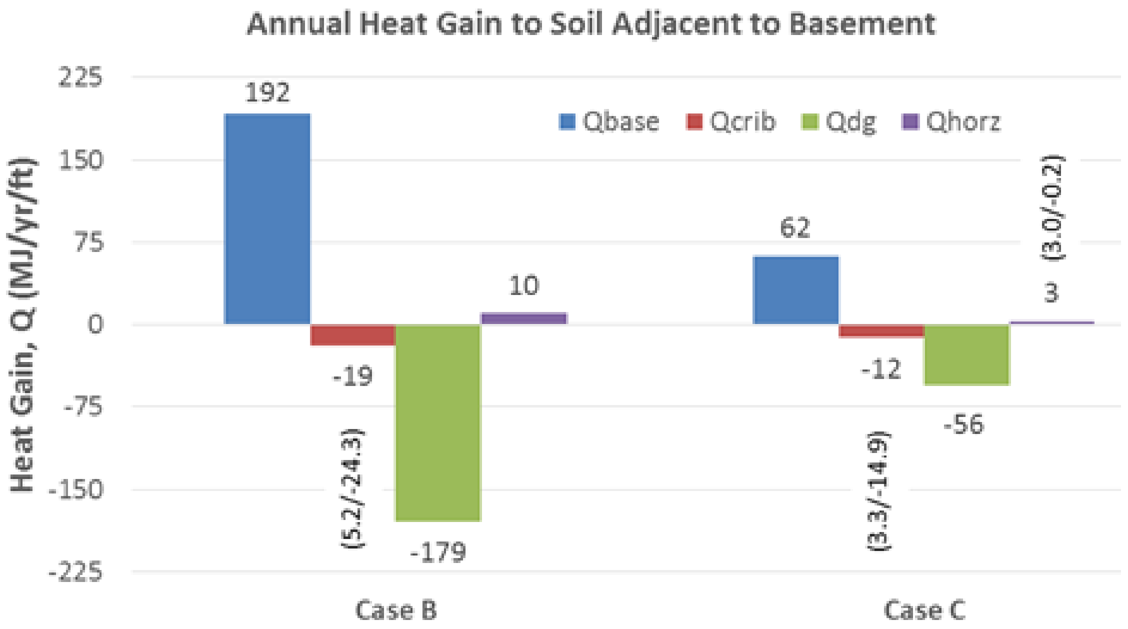
- Bay 3N temperature profiles were very similar to the corresponding profiles for Bay 2N with no floor insulation.





Soil domain and heat flows for heat transfer calculations in a minimalist model

- Case B: top of the water table located at the bottom of the footing
- Case C: top of the water table located at the bottom of the soil domain (8 ft. below the bottom of the footing).



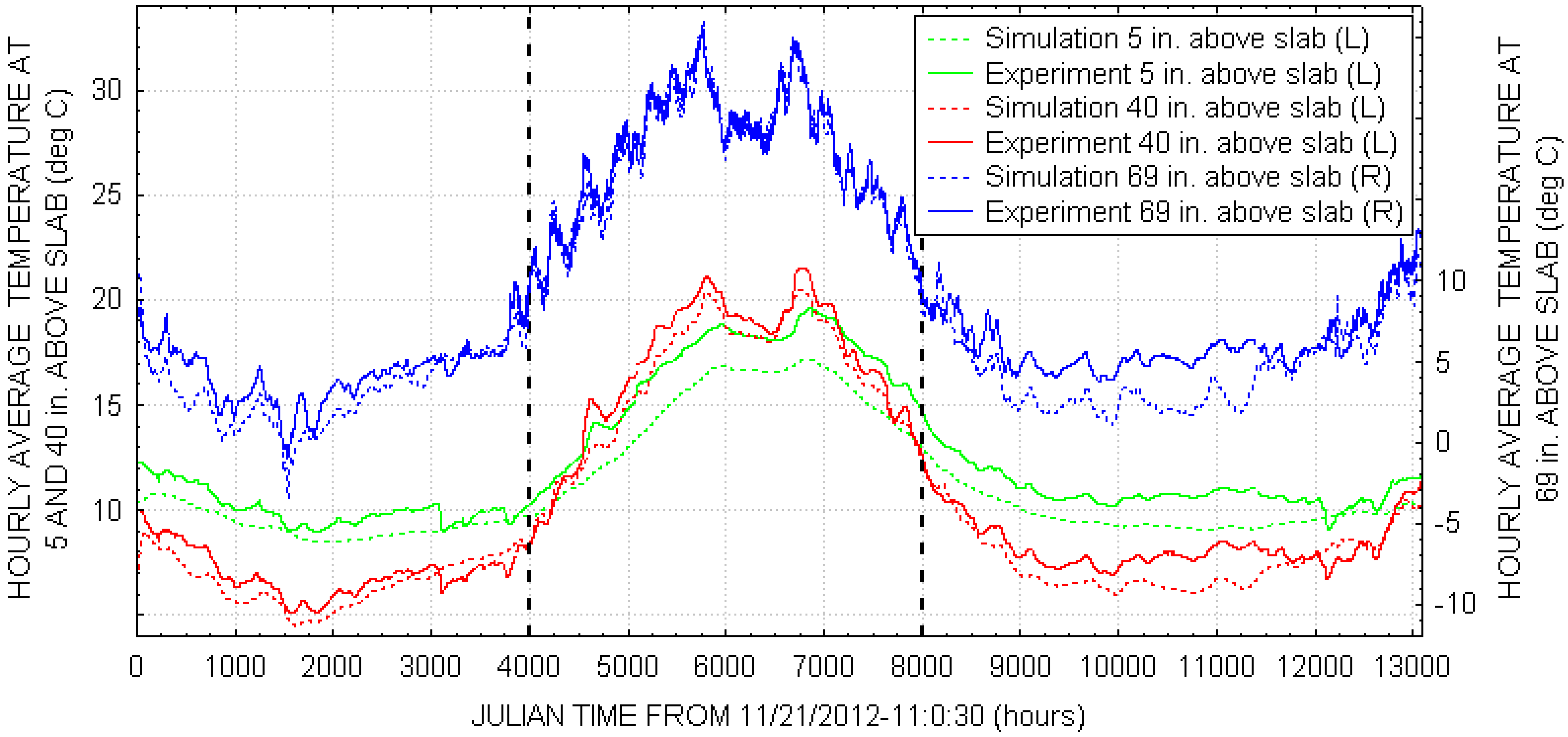
Note
A minimalist model is just complex enough to demonstrate that the essence of the observations are correctly understood.

Simulation/Experiment Result Comparisons

Simulation program: BUFETS (BUilding Foundation Energy Transport Simulation)[1]

- Based on a rigorous application of the continuum mechanics energy conservation balance that includes a jump energy balance across the frost front for describing solid/liquid phase change.
- Air and moisture (vapor and liquid) transport are not included in the simulation but their energy impacts may be represented by temperature and moisture dependent models or by measured data.
- Successfully tested[2] against the analytic IEA BESTEST case GC10a[3].

1. Goldberg, L.F., A.C. Harmon. 2015a. Cold Climate Foundation Retrofit Experimental Hygrothermal Performance: Cloquet Residential Research Facility Laboratory Results, National Renewable Energy Laboratory, U.S. Dept. of Energy, prepared under subcontract no. KNDJ-0-40338-04, http://www.nrel.gov/docs/fy15osti/63319.pdf.
2. Goldberg, L.F. and G. Mosiman. 2015. The Energy Savings Potential of Optimized Slab-on-Grade Foundation Insulation Retrofits, J. Green Buildings, v. 10(3), pp. 116-136.
3. Neymark, J. and R. Judkoff. 2008. International Energy Agency Building Energy Simulation Test and Diagnostic Method (IEA BESTEST), In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-On-Grade Construction, NREL Technical Report no. NREL/TP-550-43388.



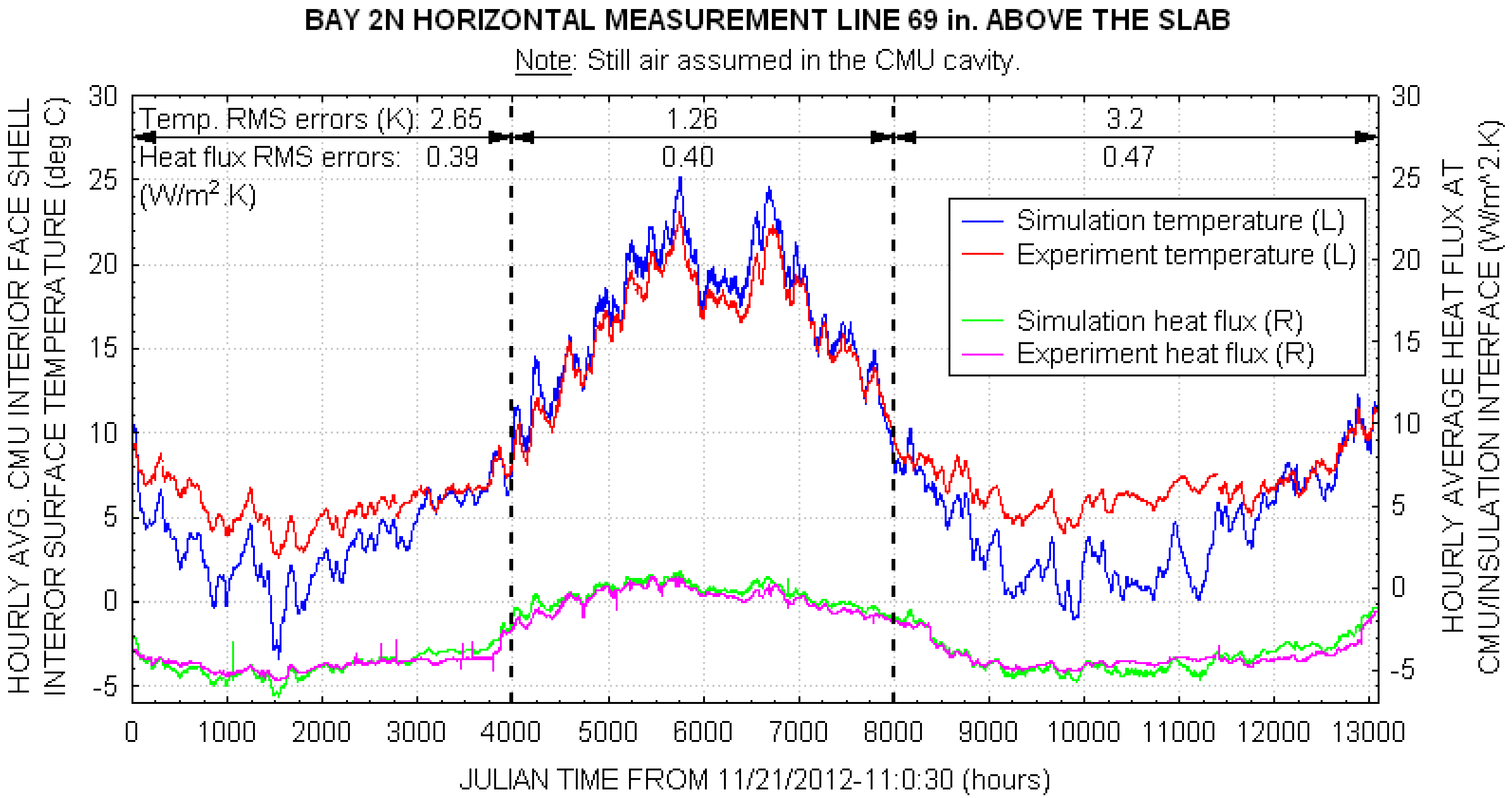
BAY 2N SOIL TEMPERATURES 5 in. AWAY FROM WALL

Note: Still air assumed in the CMU cavity.

Soil Temperature Simulation/Experiment Profile Root Mean Square Errors

Time Period (h)	5 in. above the slab - 75 ¾ in. below grade (K)	40 in. above the slab - 41 in. below grade (K)	69 in. above the slab - 12 in. below grade (K)
0 – 4000 (heating season)	0.85	0.79	1.46
4000 – 8000 (cooling season)	1.91	0.89	0.74
8000 – 13091 (heating season)	1.24	1.03	2.11

Note: Simulation “validity” requires that RMSE ≤ experimental uncertainty (for temperatures in this experiment ~ 0.6 K).



Bay 2N CMU wall interior surface heat flux and temperature profiles

Note:

The absolute heat flux error is ~15 % relative to the monitoring period average heat flux of 3.26 W/m².K.

Key boundary conditions for reducing root mean square errors (RMSE)

Baseline simulation conditions:

- water table at the base of the soil domain, ~ 96 in. below the slab
- convection/long wave radiation ambient snow cover boundary conditions

Key boundary condition changes:

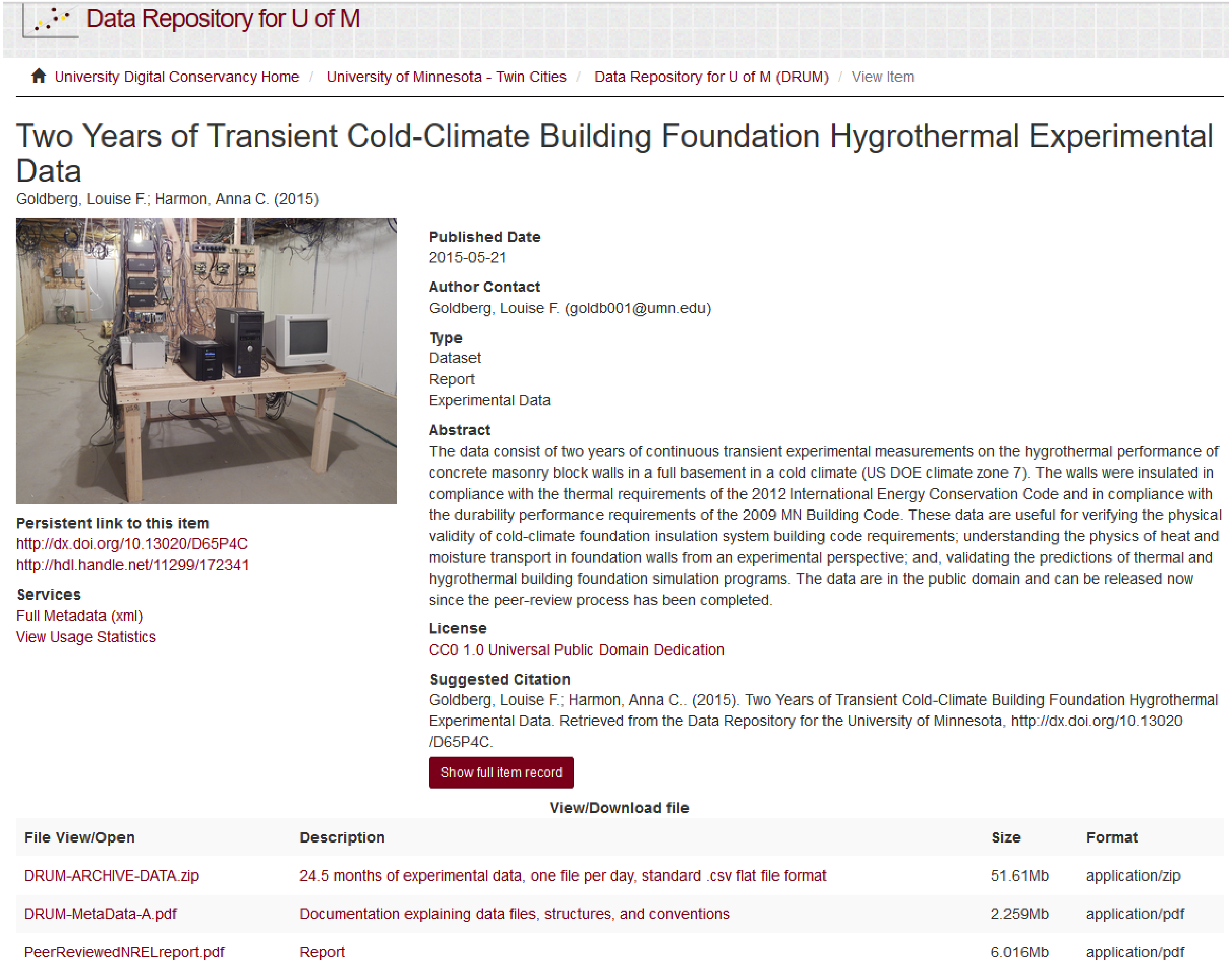
1. Inclusion of a subsoil water table model corresponding to Case B above.

   This reduced the baseline heating season simulation/experiment discrepancy at the base of the wall from **3 °C and 5 °C** to RMS errors of **1.24 °C (or less) and 1.91 °C** in the heating and cooling seasons respectively. Thus the simple analysis described above was supported by the simulation results.

Key boundary conditions for reducing root mean square errors (RMSE) (continued)

2. Invocation of a phase change model to describe the thermal impact of the snow cover in the heating season based on measured snow depth, diffuse, direct and long-wave surface radiation.

   This model approximates the effect of sublimation and melting at the snow surface and melting at grade. During the first and second heating seasons, the baseline RMS errors 12 in. below grade were **4.2 and 4.5 °C** respectively. With the phase change model in place, the RMS errors were reduced to **1.5 and 2.1 °C** respectively.



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Two Years of Transient Cold-Climate Building Foundation Hygrothermal Experimental Data

Goldberg, Louise F.; Harmon, Anna C. (2015)

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2015-05-21

Author Contact

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Type

Dataset

Report

Experimental Data

Abstract

The data consist of two years of continuous transient experimental measurements on the hygrothermal performance of concrete masonry block walls in a full basement in a cold climate (US DOE climate zone 7). The walls were insulated in compliance with the thermal requirements of the 2012 International Energy Conservation Code and in compliance with the durability performance requirements of the 2009 MN Building Code. These data are useful for verifying the physical validity of cold-climate foundation insulation system building code requirements; understanding the physics of heat and moisture transport in foundation walls from an experimental perspective; and, validating the predictions of thermal and hygrothermal building foundation simulation programs. The data are in the public domain and can be released now since the peer-review process has been completed.

License

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Suggested Citation

Goldberg, Louise F.; Harmon, Anna C.. (2015). Two Years of Transient Cold-Climate Building Foundation Hygrothermal Experimental Data. Retrieved from the Data Repository for the University of Minnesota, http://dx.doi.org/10.13020/D65P4C.

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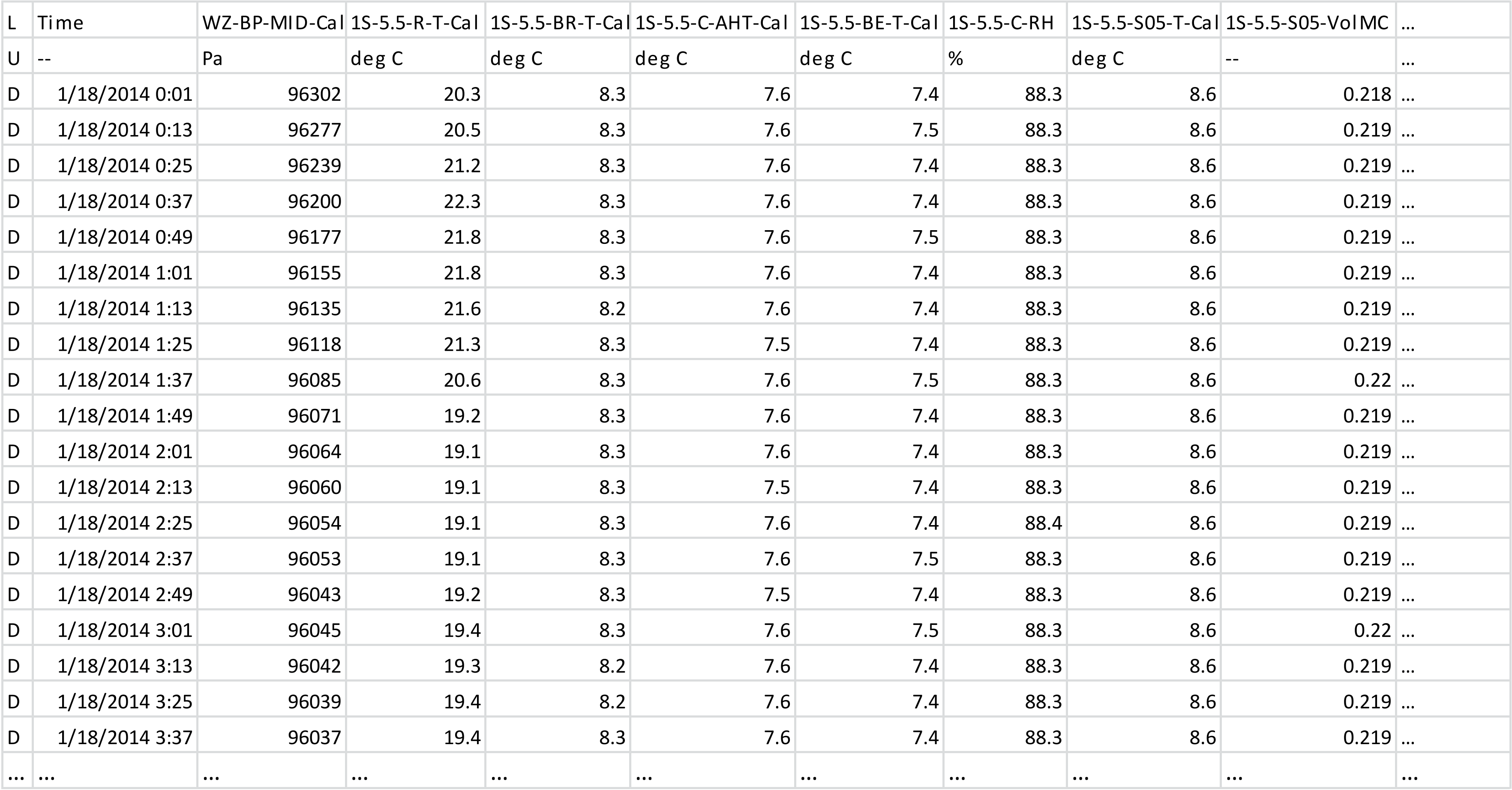
File View/Open	Description	Size	Format
DRUM-ARCHIVE-DATA.zip	24.5 months of experimental data, one file per day, standard .csv flat file format	51.61Mb	application/zip
DRUM-MetaData-A.pdf	Documentation explaining data files, structures, and conventions	2.259Mb	application/pdf
PeerReviewedNRELreport.pdf	Report	6.016Mb	application/pdf

DATA FILE SAMPLE – EXTRACT FROM SINGLE DAY .CSV FILE



L	Time	WZ-BP-MID-Cal	1S-5.5-R-T-Cal	1S-5.5-BR-T-Cal	1S-5.5-C-AHT-Cal	1S-5.5-BE-T-Cal	1S-5.5-C-RH	1S-5.5-S05-T-Cal	1S-5.5-S05-VolMC	…
U	--	Pa	deg C	deg C	deg C	deg C	%	deg C	--	…
D	1/18/2014 0:01	96302	20.3	8.3	7.6	7.4	88.3	8.6	0.218	…
D	1/18/2014 0:13	96277	20.5	8.3	7.6	7.5	88.3	8.6	0.219	…
D	1/18/2014 0:25	96239	21.2	8.3	7.6	7.4	88.3	8.6	0.219	…
D	1/18/2014 0:37	96200	22.3	8.3	7.6	7.4	88.3	8.6	0.219	…
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…	…	…	…	…	…	…	…	…	…	…

CONCLUSIONS

- The database is useful as it provides **experimental data for assessing the accuracy of thermal simulation programs** and it enables an **insightful understanding of the dominant thermal transport mechanics observed experimentally**.

- The experimental data demonstrate that **buoyant cavity flow exists in a CMU wall with interior insulation**. **This flow needs to be adequately accounted for in thermal simulations** of CMU walls to reduce heat flux and temperature RMSE's in and near the walls.

- IECC 2012 compliant RUS-15 interior insulation **reduces the heat flow through the upper half of a hollow CMU foundation wall by a factor of 3** compared with the same wall when uninsulated in a cold climate.

CONCLUSIONS (continued)

- On a hollow CMU wall, **upper half-wall** IECC 2012 compliant **RUS-15 exterior insulation yields a 55 % larger heat flow 12 in. below grade** than **full-wall interior RUS-15 insulation in a cold climate**. Thus, in this climate, half-wall exterior insulation does not offer any thermal performance advantages over full-wall interior insulation.

- In a vapor-sealed rim joist cavity, **a solid CMU wall bond beam** (vapor permeance of 0.1 to 1 US perms –Class II) **provides sufficient vapor isolation** from saturated hollow CMU cores so that condensation on the rim board interior face does not occur with or without exterior insulation.

- On a hollow CMU wall with RUS-15 full-height, interior insulation, **the heat transport through the footing and wall below the insulation** relative to the heat transport from the liquid-saturated soil beneath the basement **has a negligible measured impact on the soil temperatures adjacent to the wall** in a cold climate under pseudo-steady-state conditions.

CONCLUSIONS (continued)

- If a **water table** exists beneath the slab, **its depth and the proximity of its surface to the slab are critical for accurately calculating** the basement foundation thermal transport in a cold climate.

- **A simple heat transport model** that captures the essence of experimentally observed thermal phenomena in a full basement **can offer the same insight as a detailed, 3-dimensional thermal transient simulation**.

- A snow model that includes **phase change at the ambient and ground interfaces is necessary for accurately simulating** basement heat transport during the heating season in a cold climate.

- Heating season simulation/experiment CMU wall **heat flux errors of about 15 % arise from ignoring buoyant cavity flows** in the hollow cores of CMU foundation walls with full-wall interior insulation.

ACKNOWLEDGMENT

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