Ground-Coupled Heat Loss with WUFI® Plus and Common Standards: Methods to Analyze Designs for Different Climates

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Outline

- Introduction and Motivation
  - Why slab heat loss?
  - What is kind of breakthroughs are we looking for?
- Our “Slab Study”
  - Configurations; Conditions; Locations
- Losses from Different Methods and Summation Periods
  - Heat/Cooling Months; Heating/Cooling Periods
  - WUFI Plus and WUFI 3-D elements
  - Los Alamos and EN-ISO 13370
- Summary and Future Work

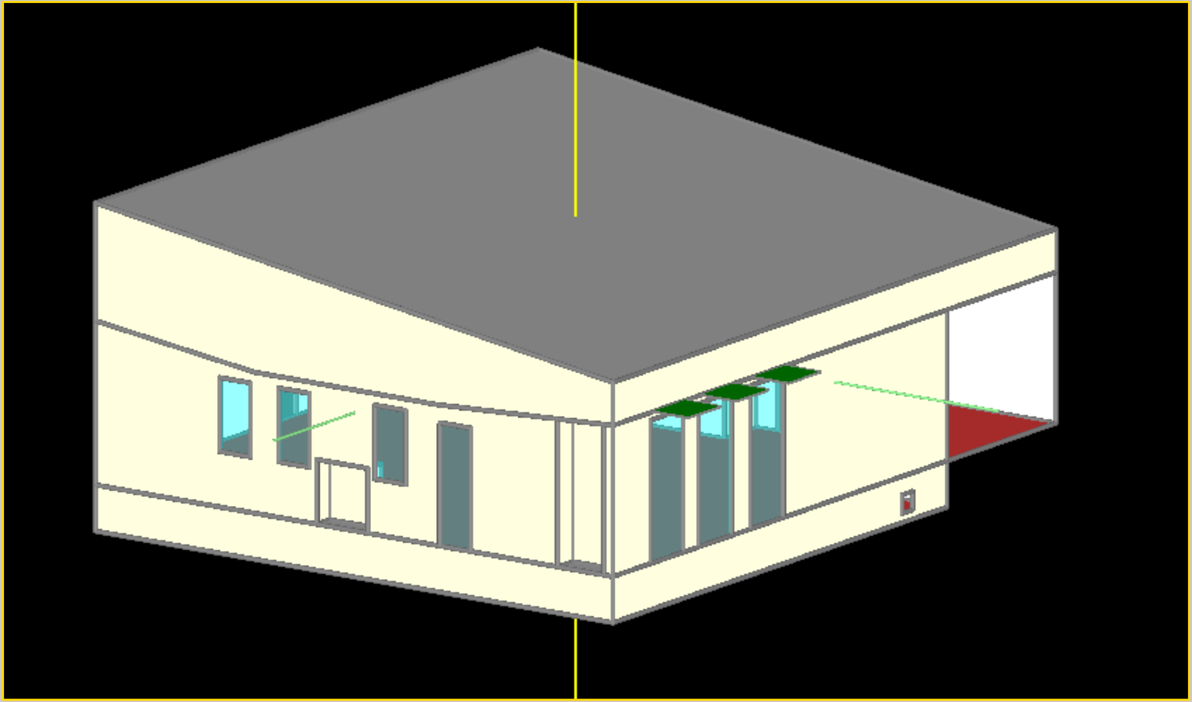
The not-so-great construction aspects of Solar Decathlon Competitions

Our enCORE was installed on our campus

Well built walls and roof with super-advanced systems ….

placed on concrete block piers with really great conditions for mold growth.

enCORE WUFI simulations were hijacked by ground temps



The crawlspace "floor" is a 20 mil vapor barrier/retarder on top of packed stone. For accurate humidity modeling, we needed better ground temperature,

but is a crawl space where "the value" is?

It became clear that studying ground-coupled heat loss was more important than the crawlspace of a fancy triple-wide in Ohio.

- 10% of the annual heat loss in a 1970s home to about 30-50% of the annual heat loss in 1990 code-compliant homes.
- What would the percent heat loss be in a current “standard-build” home? Next big place to save!
- Ground-coupled heat loss is especially important in buildings with high ratios of ground-coupled floor area to volume.
- The “**GBA Effect**:” Discussion of a 16” under-slab insulation requirement

Better knowledge of ground coupling can lead to much broader impact … but it ain’t easy.

Accurate **simulations** need large volumes

“Multi-Physics” **simulations** require specifying hard-to-determine and highly variable boundary conditions

- Unknown soil types
- Variable soil moisture
- Ground water
- Freezing
- Ground cover, including snow

Standards eliminate the need for large-scale simulations

- Inaccuracies
- Inability to answer detailed design questions

So what should be our goal?

A. Promote the perfect ground-contact insulation system (*à la* “The Perfect Wall”)
   - Not everyone is building the perfect wall
   - The perfect system might not exist

B. Develop guidelines
   - Rarely optimized

C. Develop tools that give users the power to make informed decisions for their system
   - Integrate with other tools
   - Push optimization

There are two main objectives for this second study

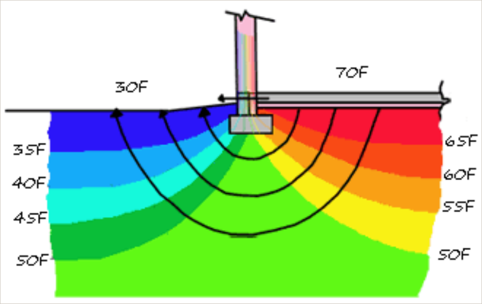
Compare Methods

- Static Calculations
  - Simplified transmission
  - EN ISO 13370
- Dynamic Simulations
  - WUFI Plus
  - 3-D

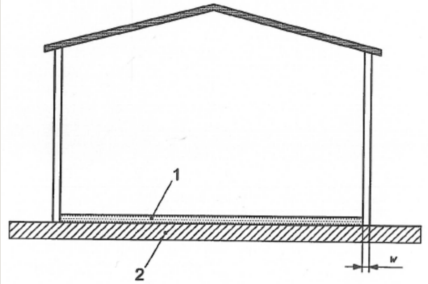
Compare Results

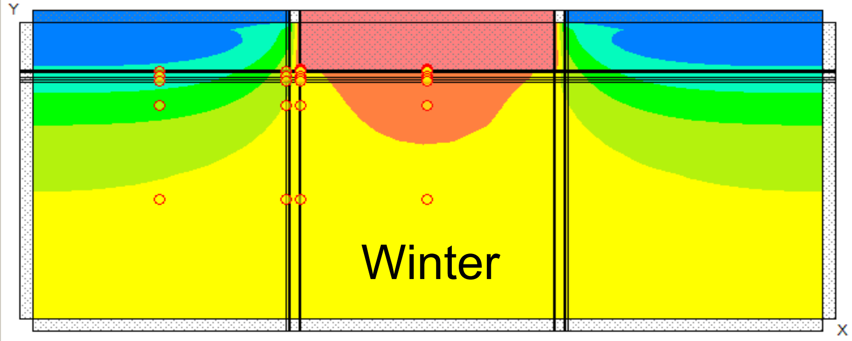
- Different climates
- Different designs
  - Insulation Schemes
  - Thicknesses (R-Values)

Assumptions for simple transmission



ISO13370 Diagram





3-D Results for heating dominated climate

More details on the approach

4 methods:

- Simplified (Los Alamos) Slab Transmission Heat Loss
- EN ISO 13370
- WUFI® 3-D elements
- WUFI® Plus

} Dynamic Methods

4 locations: Chicago (5), Seattle (4C), Phoenix (2), and New Orleans (2A)

Several insulation configurations: next slides

2 insulation thicknesses: 2" (R20) and 4" (R40)

The “standards” approaches

Simple Slab Heat Loss (Los Alamos, 1984):

- Based on perimeter (P) and perimeter insulation (R)

$$Q = 4.17\ P/(5+R)\ HDD \times 24$$

- Accounts for insulating property of soil
- Used heating degree days (HDD)
- Consider this to be uniform under-slab insulation

EN ISO 13370 (2007):

- Used by PHPP
- Heat loss quantity obtained by summing over heating months using monthly internal/external temperature averages
- Can Include horizontal or vertical perimeter insulation

More EN ISO 13370 calculation details

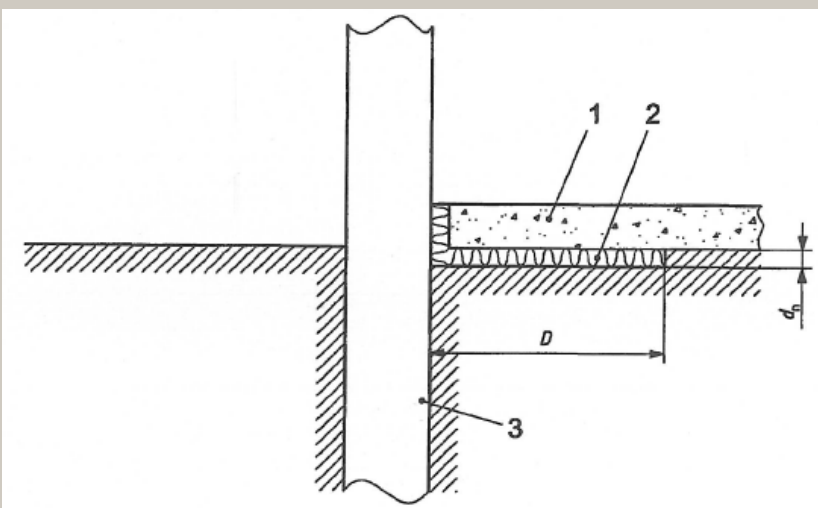
Steady state ground heat transfer coefficient (W/K)

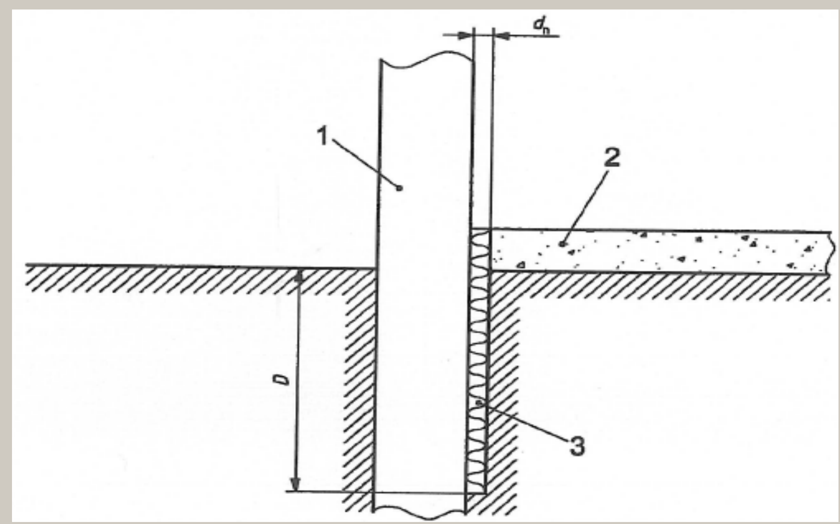
$H_g = AU + P(\psi_g + \psi_{g,e})$

$U = \frac{2\lambda}{\pi B' + d_t} \ln\left(\frac{\pi B'}{d_t} + 1\right)$ or $U = \frac{\lambda}{0.457 B' + d_t}$ (mod or well insulated)

$\psi_{g,e} = -\frac{\lambda}{\pi}\left[\ln\left(\frac{D}{d_t} + 1\right) - \ln\left(\frac{D}{d_t + d'} + 1\right)\right]$ (horizontal)

$\psi_{g,e} = -\frac{\lambda}{\pi}\left[\ln\left(\frac{2D}{d_t} + 1\right) - \ln\left(\frac{2D}{d_t + d'} + 1\right)\right]$ (vertical)





The two dynamic energy modeling approaches using WUFI

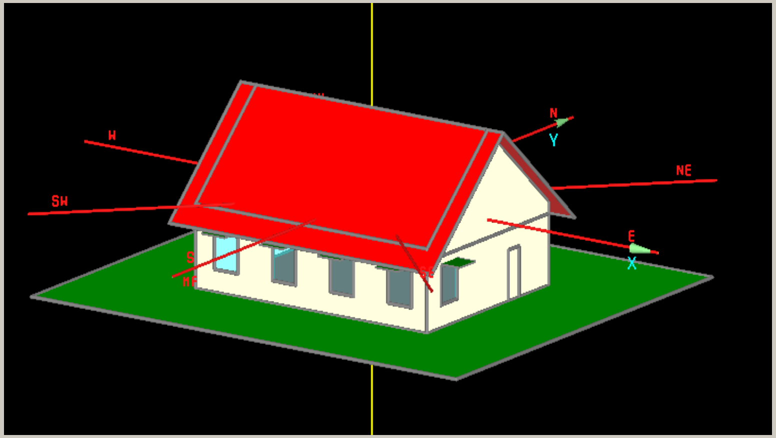
WUFI® Plus:

- No perimeter insulation
- 2 year initialization
- Artificial, location-dependent sine cure for temperature of ground-slab interface and no storage
- Transmission heat losses only (no radiative)
- Heat losses from slab-bottom heat flux summed over heating period

WUFI® 3-D elements:

- Simulated area 20 m beyond slab, 15 m deep, 2 year init
- Perimeter insulation
- User defined solar gains on inner surface
- No hygro- or radiation-effects for the slab
- Heat “Exchange with 3-D elements”

The WUFI models



- Relatively Small: 9m x 12 m
- R-60 Ceiling, R-36 Walls
- U=0.16 triple pane windows
- 0.53 window shading factor
- Constant loads: 2.8 occupants
- 0.41 constant ventilation

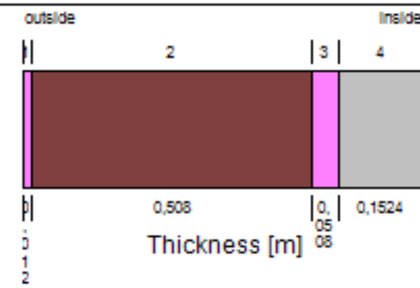
Case 1:
WUFI Plus
Slab
Component

Homogenous layers

Thermal resistance: 2.536 m²K/W (without Rsi, Rse)

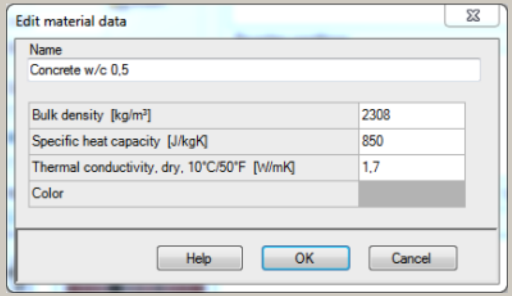
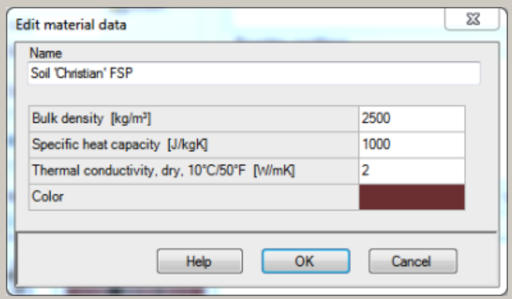
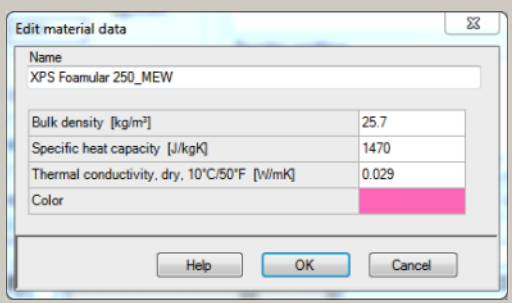
Heat transfer coefficient (U-value): 0.37 W/m²K

Thickness: 0.726 m



Nr.	Material/Layer (from outside to inside)	ρ [kg/m³]	c [J/kgK]	λ [W/mK]	Thickness [m]	Color
1	XPS Foamular 250_tc0	25.7	1469.99	0.029	0.013	
2	Soil 'Christian' FSP	2500	1000	2	0.508	
3	XPS Foamular 250_tc0	25.7	1469.99	0.029	0.051	
4	Concrete w/c 0,5	2308	850	1.7	0.152	
5	Linoleum carpet, untreated	1200	900	1	0.002	

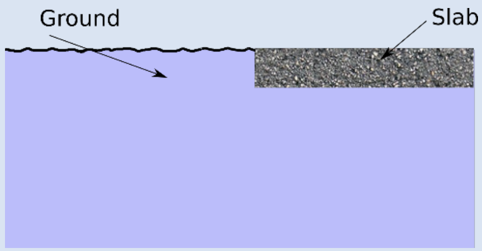
Dimensions, properties , and BCs for the 3-D element simulations

3-d Element Materials	Dimension	Properties	Boundary Conditions
Slab	6" (0.152m) thick	 Edit material data Name: Concrete w/c 0,5 Bulk density [kg/m³]: 2308 Specific heat capacity [J/kgK]: 850 Thermal conductivity, dry, 10°C/50°F [W/mK]: 1,7 Color Help OK Cancel	Top: simulated Zone 1 Bottom: soil elements Sides: soil or insulation elements
Soil	53.58 yard x 56.88 yard x 16.40 yard (49m x 52m x15m)	 Edit material data Name: Soil 'Christian' FSP Bulk density [kg/m³]: 2500 Specific heat capacity [J/kgK]: 1000 Thermal conductivity, dry, 10°C/50°F [W/mK]: 2 Color Help OK Cancel	Top: Insolation collector Bottom: average yearly outdoor temperature (constant); 99% RH Sides: adiabatic
Insulation	2" (0.0508m) or 4" (0.1016m) thick	 Edit material data Name: XPS Foamular 250_MEW Bulk density [kg/m³]: 25.7 Specific heat capacity [J/kgK]: 1470 Thermal conductivity, dry, 10°C/50°F [W/mK]: 0.029 Color Help OK Cancel	Top: slab elements Bottom Soil elements Sides: Soil elements

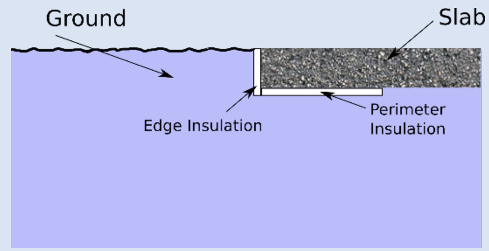
Chicago: 8.82 C
New Orleans: 19.4 C
Phoenix: 21.4 C
Seattle: 10.4 C

The insulation configurations for the 3-d element simulations

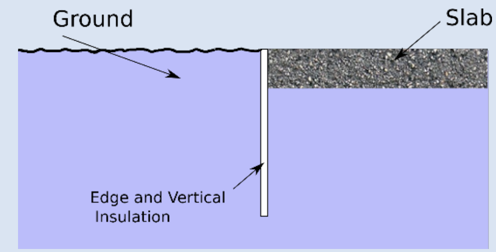
Case 2



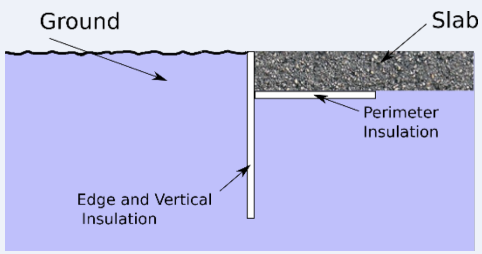
Case 3



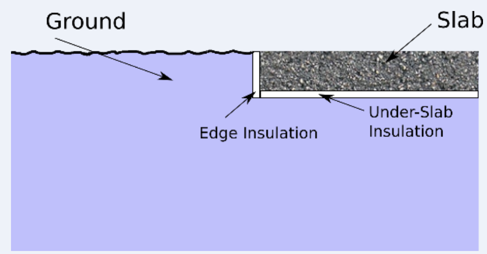
Case 4



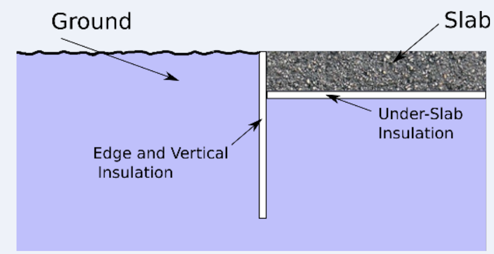
Case 5



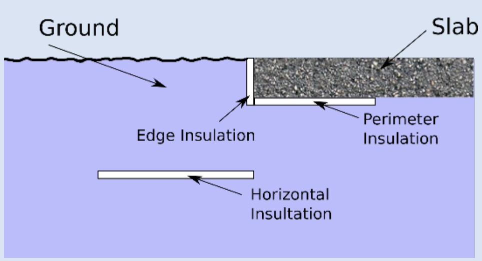
Case 6



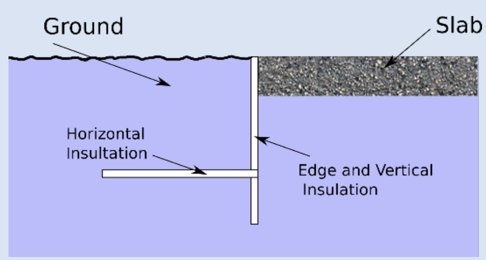
Case 7



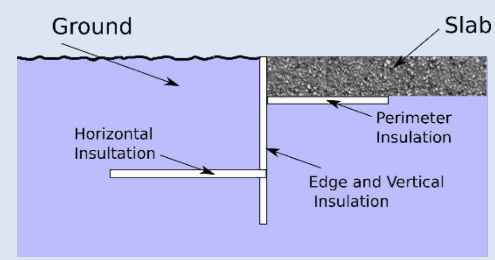
Case 8



Case 9



Case 10



The cases from the “standards” approaches

Case 11: IS0 13370, no insulation	Case 12: IS0 13370, uniform under-slab
Case 13: IS0 13370, 4’ vertical perimeter only	Case 14: IS0 13370, 2’ horizontal perimeter only
Case 15: IS0 13370, full under and 4’ vertical perimeter	Case 16: ISO 13370, full under and 2’ horizontal perimeter
Case 17: Los Alamos, uniform under-slab	

The 3 periods over which losses calculated

Heating Degree Day (HDD) from from WUFI Climate Data or on-line sources (see http://www.degreedays.net/)

- 65 deg. F (18.33 Deg. C) baseline temperature)
- insignificant differences

Heating Months (essentially from PHPP)

Chicago: October 1 – June 1	New Orleans: Dec 1 – Feb 1
Phoenix: Dec. 1 – Feb 1	Seattle: September 1 – July 1

Heating (and Cooling) Period in WUFI

- Sum over 1 hour time increments when heating (or cooling) power exceeds 0.1 kW

Results from the "standards" approach

	Chicago Thin	Chicago Thick	NewOrl Thin	NewOrl Thick	Phoenix Thin	Phoenix Thick	Seattle Thin	Seattle Thick
Case 11: ISO No Insulation	6053		1243		805		7232	
Case 12: ISO Uniform under-slab	2260	1439	390	241	237	145	2778	1775
Case 13: ISO 4' vertical perimeter	2113	1468	804	732	539	495	2236	1418
Case 14: ISO 2' horiz. perimeter	4076	3865	1023	999	671	657	4725	4458
Case 15: ISO uniform and 4' vert	1624	952	319	187	194	113	1973	1158
Case 16: ISO uniform and 2' horiz perimeter	2053	1250	367	220	223	133	2516	1535
Case 17: Los Alamos uniform	2024	1230	443	270	320	194	1487	904

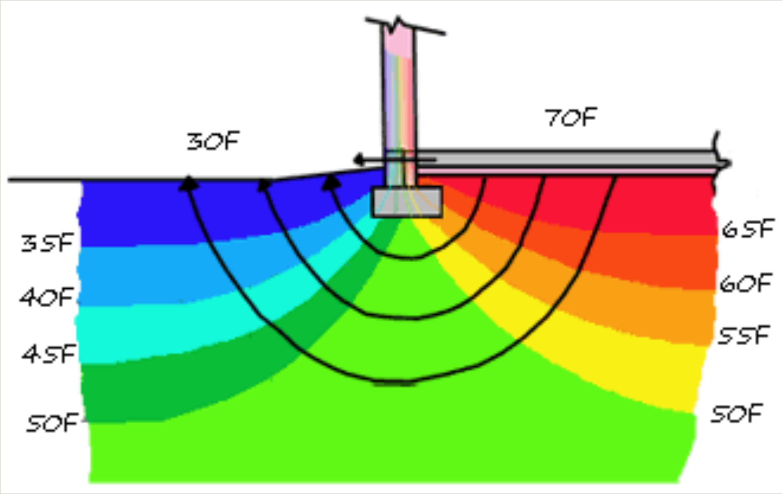
- Case 17 is in the ball park
- Case 15 is the best system
- 2' horizontal does not do much

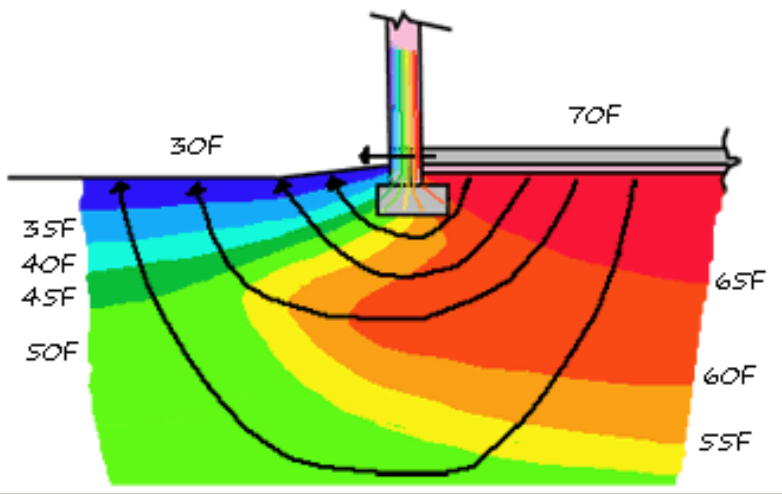
- Phoenix has lowest heating loads
- Best case in Seattle is Case 17?

WUFI results for the different configurations

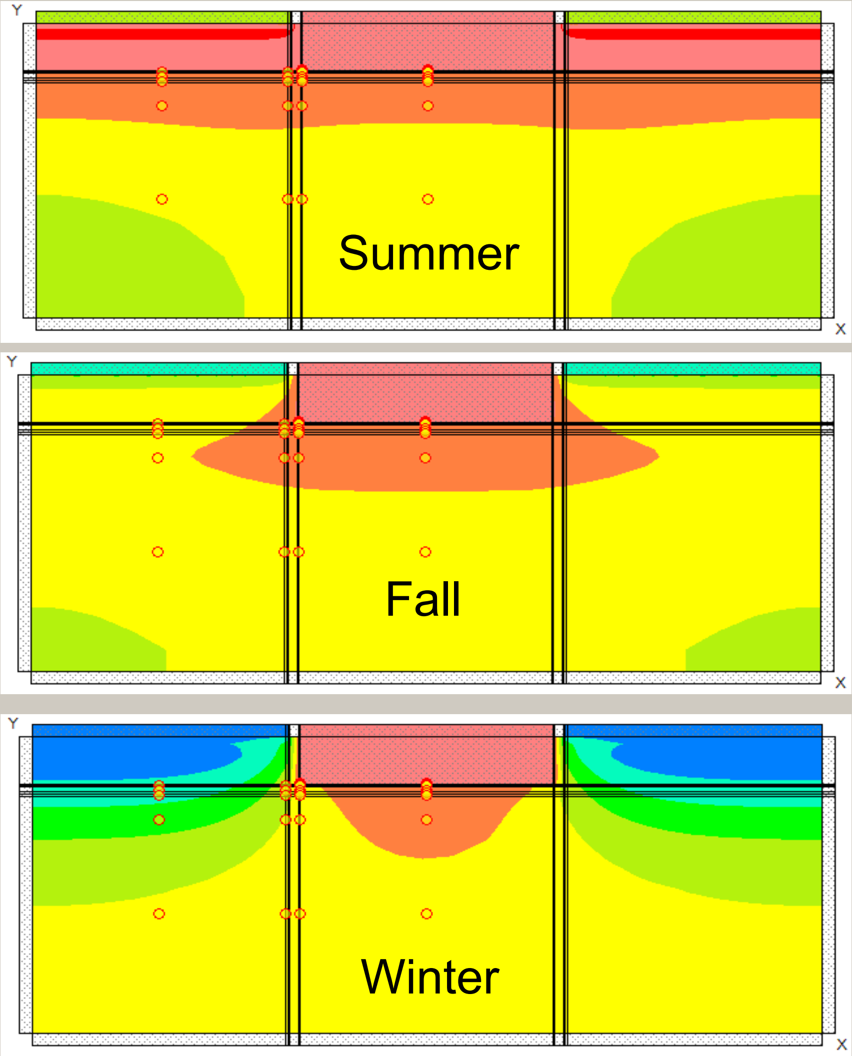
	Chic Thin	Chic Thick	NewOr Thin	NewOr Thick	Phoen Thin	Phoen Thick	Seat Thin	Seatt Thick
Case 1a: WUFI Slab	1831	1138	68	47	313	200	1767	1831
Case 1b: WUFI Slab No Insulation	9004	-	195	-	1396	-	8424	9004
Case 2: No Insulation	8267	8332	-86	-93	144	138	7326	8267
Case 3: 2' Perimeter	5113	4645	134	164	332	259	4919	5113
Case 4: 4' Vertical	4492	4004	225	254	416	439	4522	4492
Case 5: 2' Perim and 4' Vert	4492	3541	218	239	404	420	4094	4492
Case 6: Uniform under-slab	2893	1878	20	4.4	154	99	2802	2893
Case 7: Uniform under and 4' Vert	2415	1596	67	33	199	127	2490	2415
Case 8: 2' Outboard horizon	5322	-	-26	-	323	-	5198	5322
Case 9: 2' Outboard and 4' Vert	4474	-	53	-	412	-	4514	4474
Case 10: 2' Outboard and 2' of Perim	3882	-	65	-	405	-	4013	3882

What is really going on underground





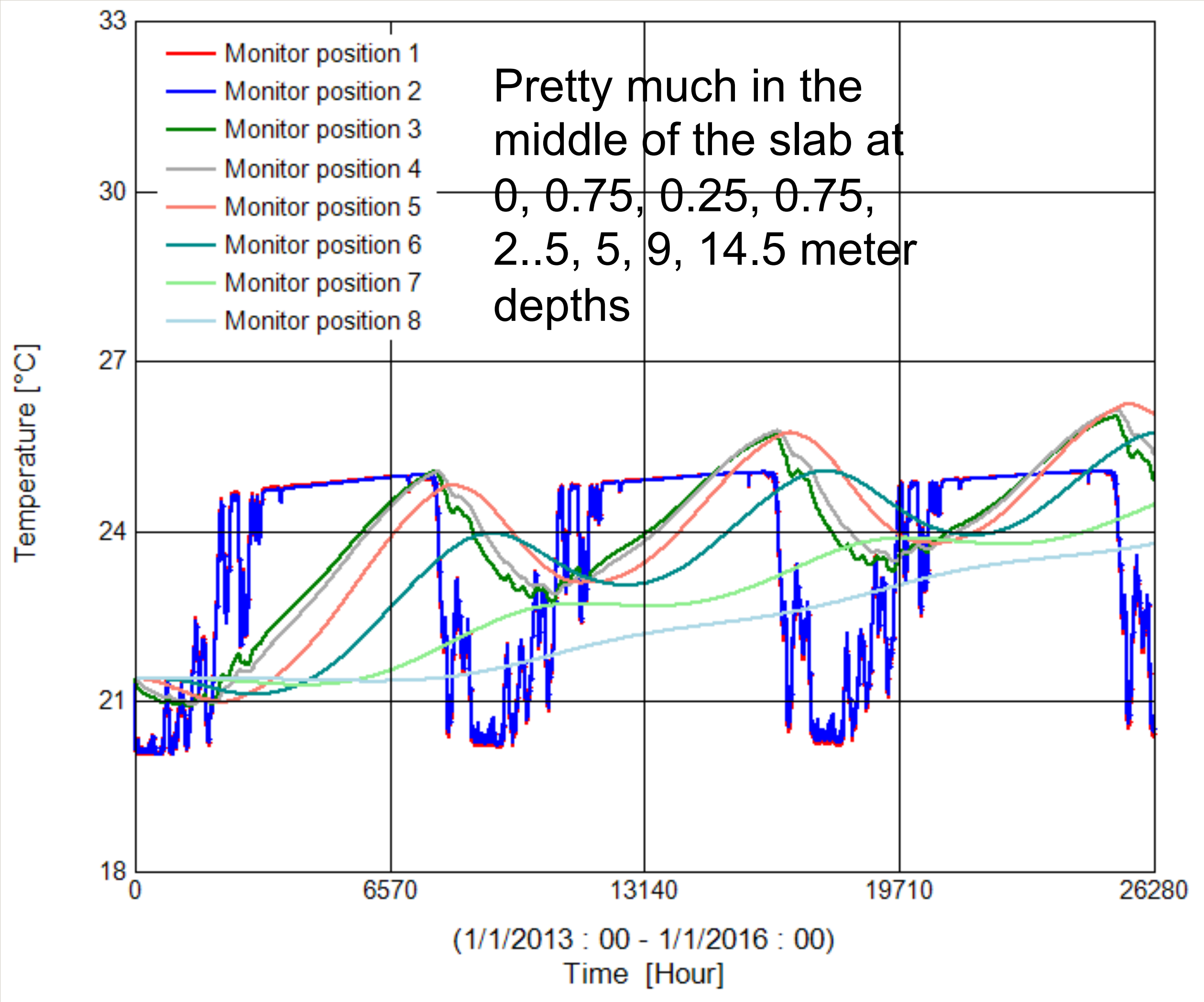
Shamelessly lifted from Bob Scheulen's Sensible House website (http://www.sensiblehouse.org)



3-D Results for heating dominated climate

Not all of the temperatures in the 3-d volume have stabilized

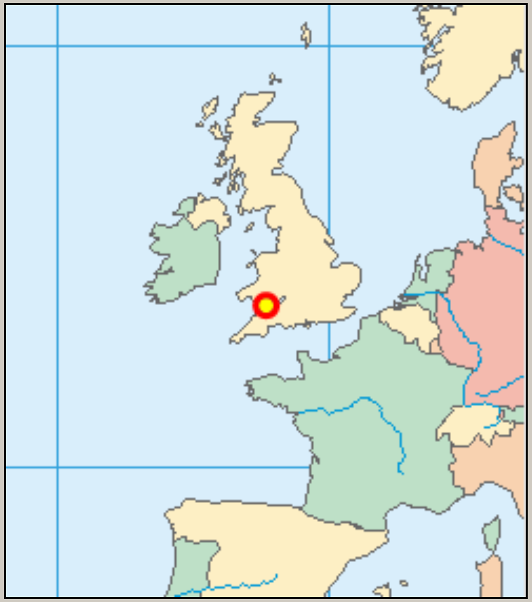
Simulated temperatures at depth in Phoenix

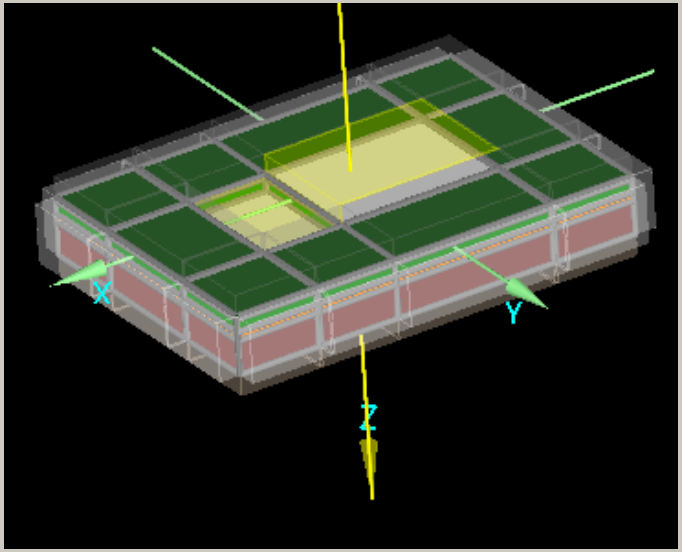


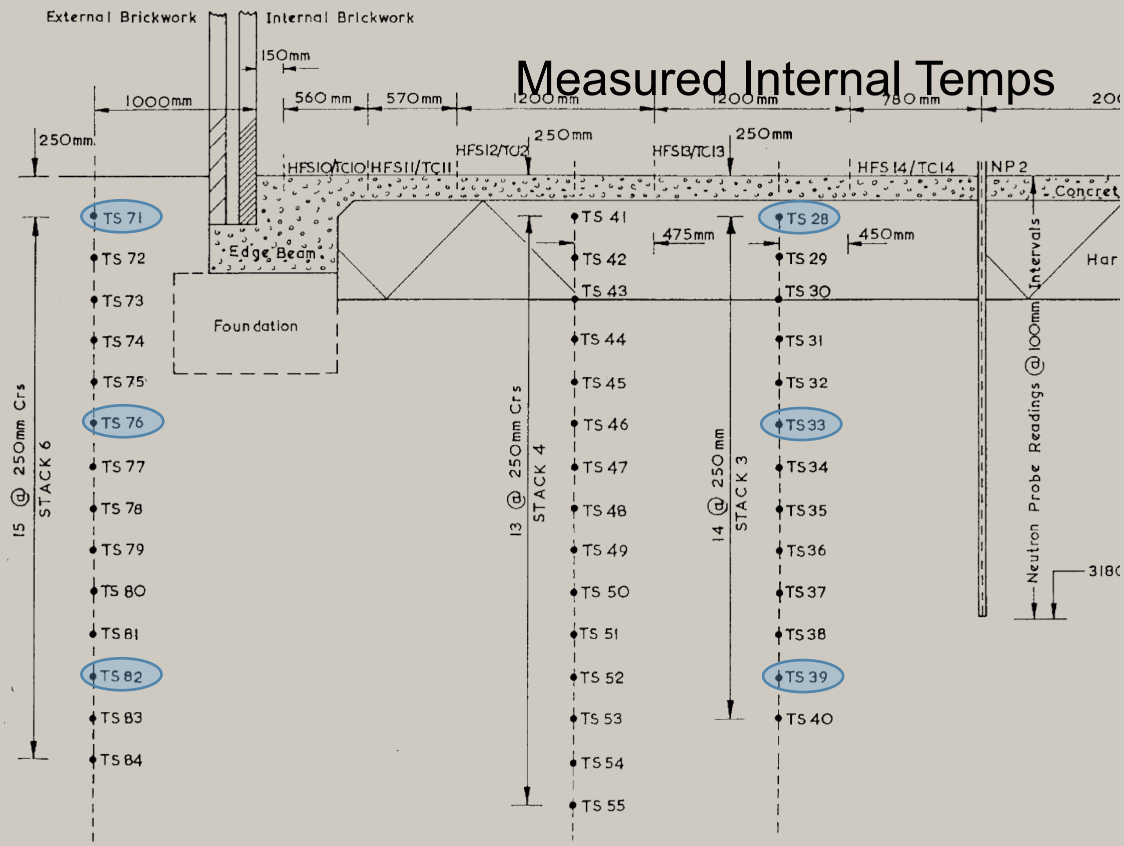
Which brings us back to the point about not knowing boundary conditions very well.

The Cardiff engineering building from the early 1990s

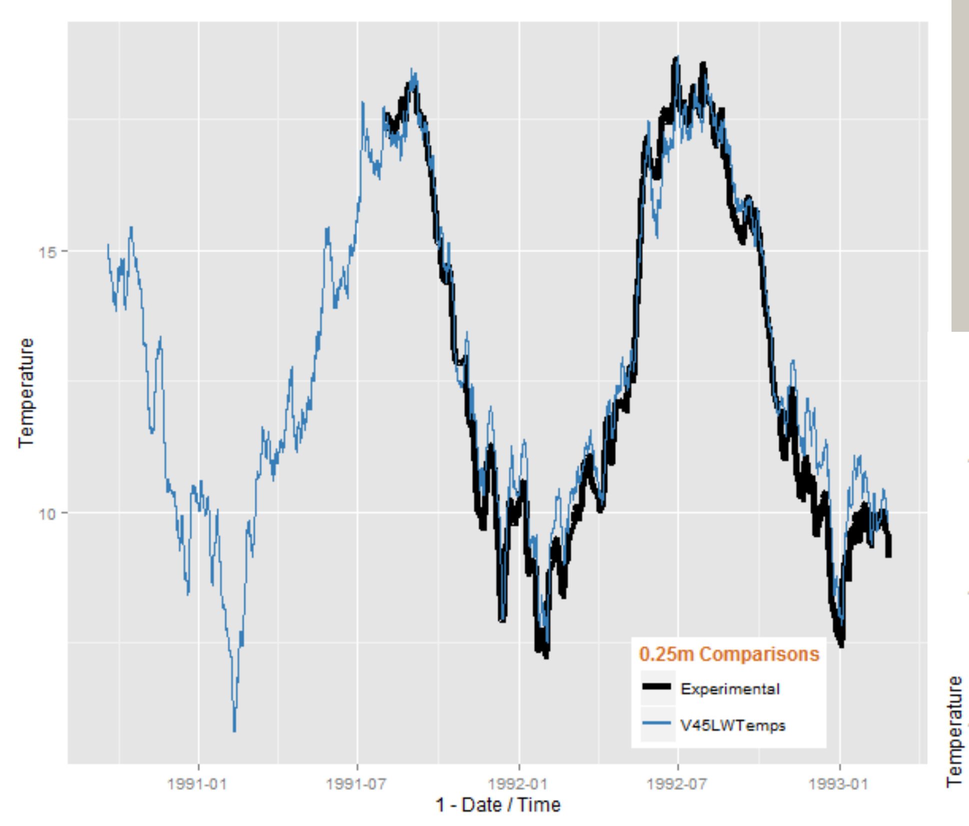
has internal temperature, ground temperature, and some heat flux data



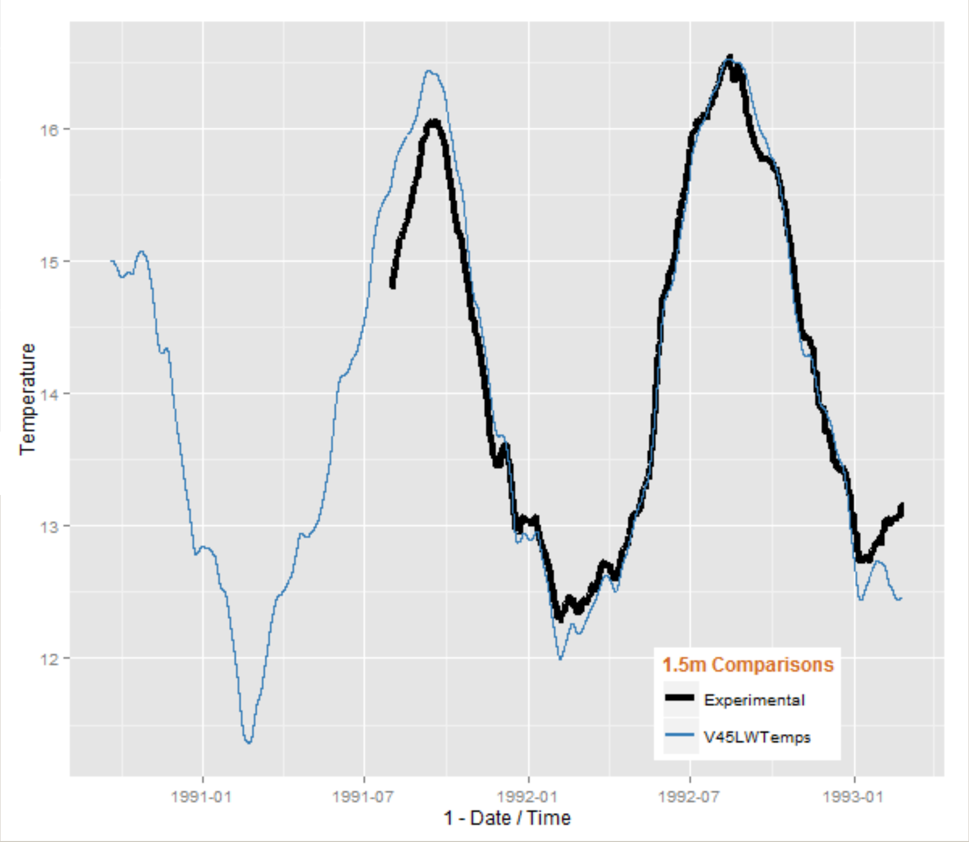




The data from the outside thermocouple stack

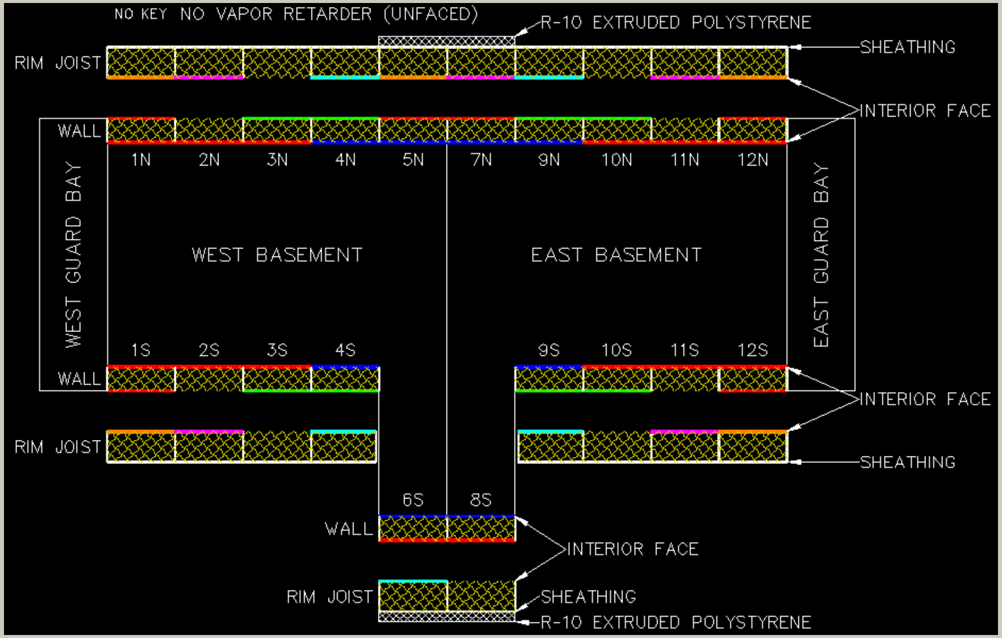


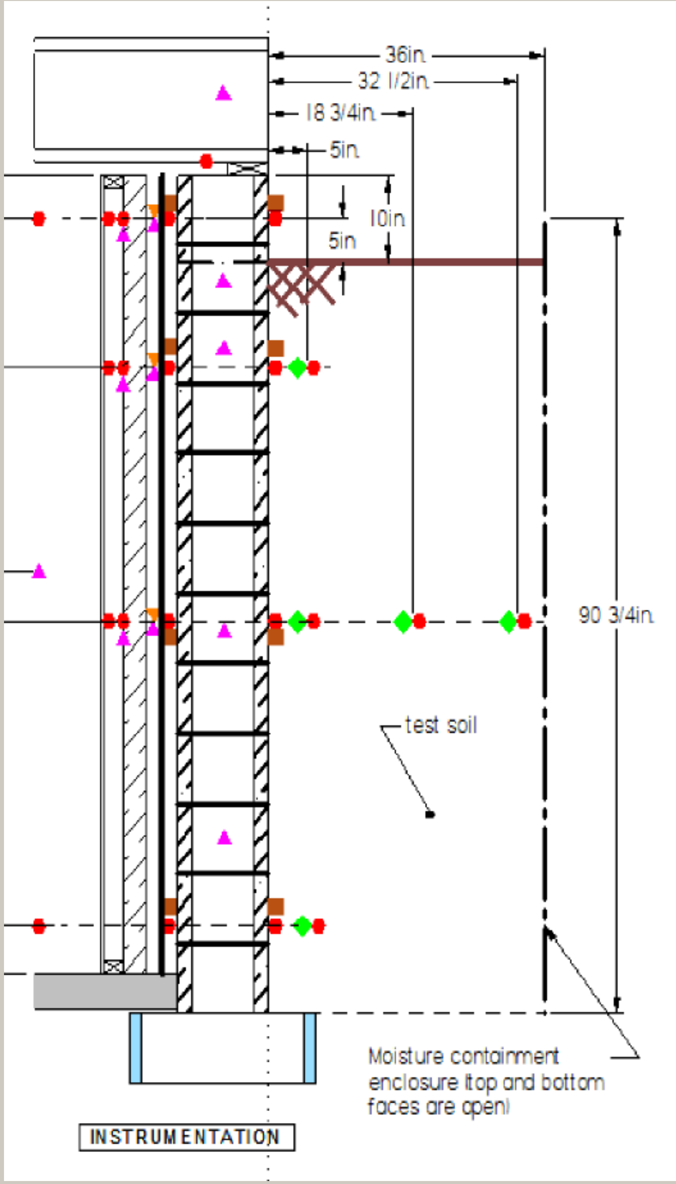
match really well, especially near surface.



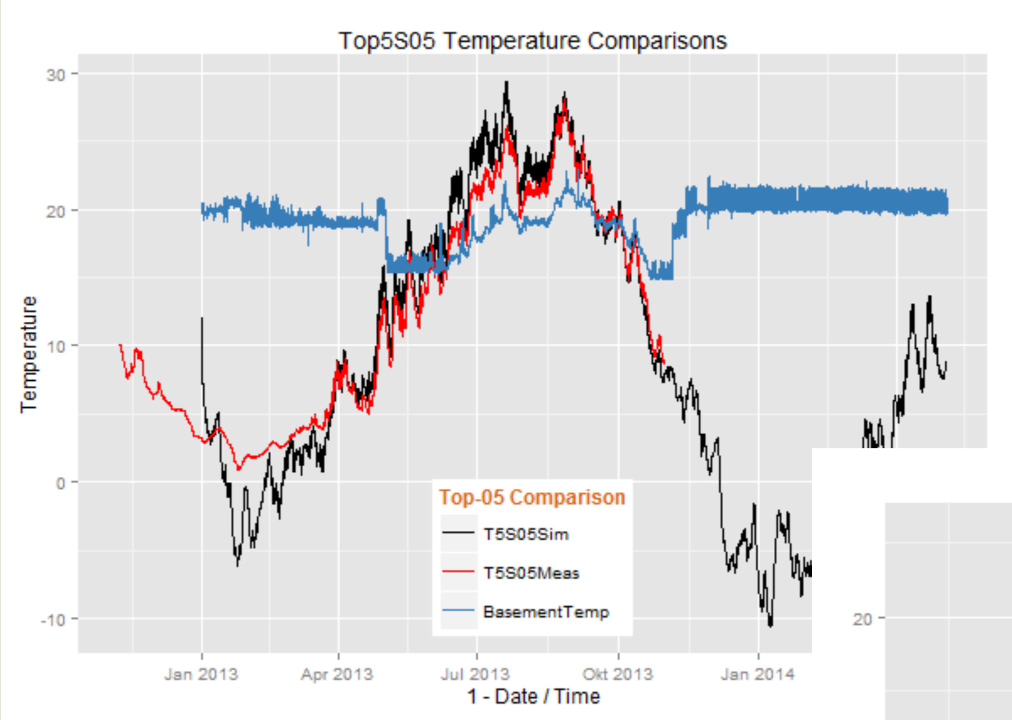
The disturbed soil may still be "initializing."

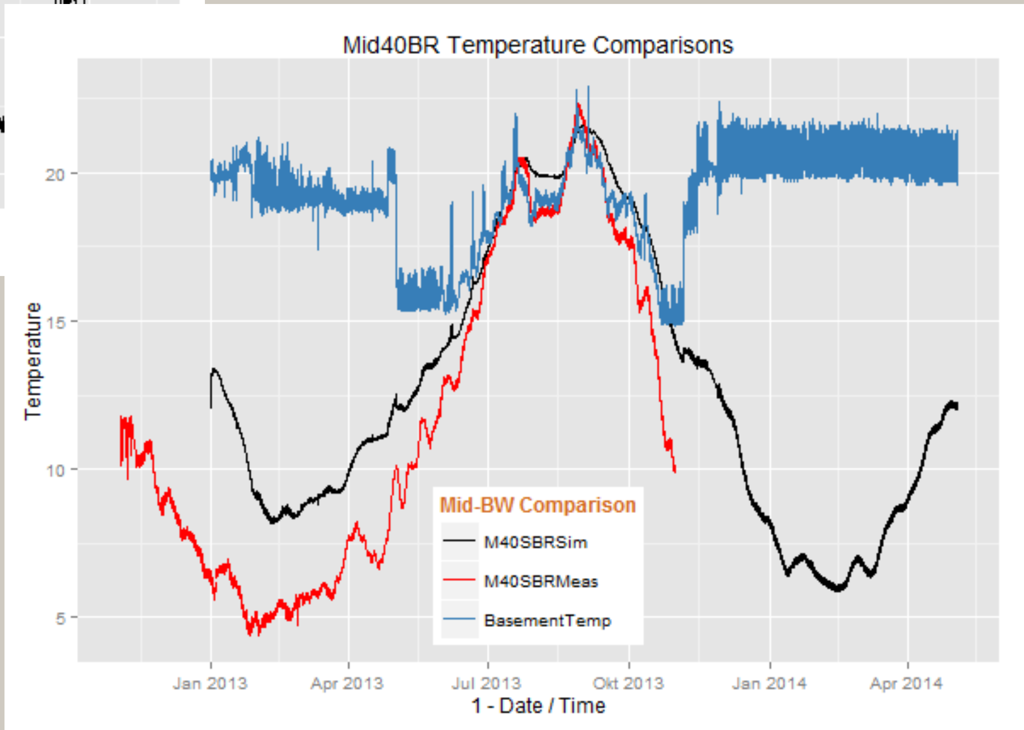
CRRF in Minnesota is for studying retrofit basement walls





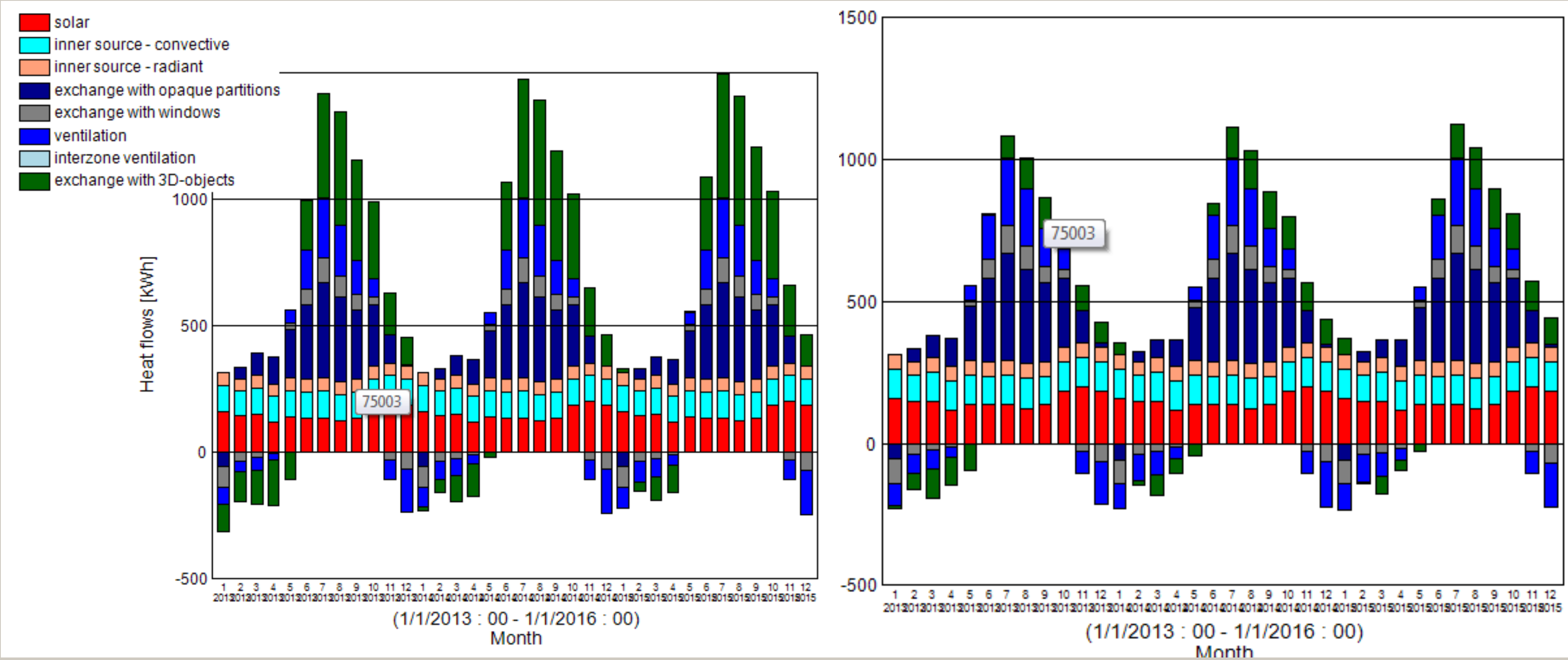
Near-surface, near wall results show excellent correlation





Lower depth at wall showing issues in the winter

Monthly heat flow data



Phoenix with no insulation (left) an uniform (2”) insulation

Summary: The number of cases and parameters is overwhelming

- Standards are not bad for heating climates
- For chosen parameters, full uniform insulation is best
- Horizontal perimeter insulation does *not* help too much
- Vertical perimeter insulation does help
- Cooling climate results indicate less insulation is better for heating periods ….
  … but heating period heat losses are not significant
- By definition dynamic 3-d simulations will have more information; heat flow depends on gradients
- Preliminary cooling period results indicate uniform insulation does not necessarily save the most energy

Overall comments about WUFI 3-D elements

There is relatively little overhead in implementing WUFI 3D elements

- The biggest challenge is the materials properties and initialization

WUFI 3D elements can add much of the necessary physics

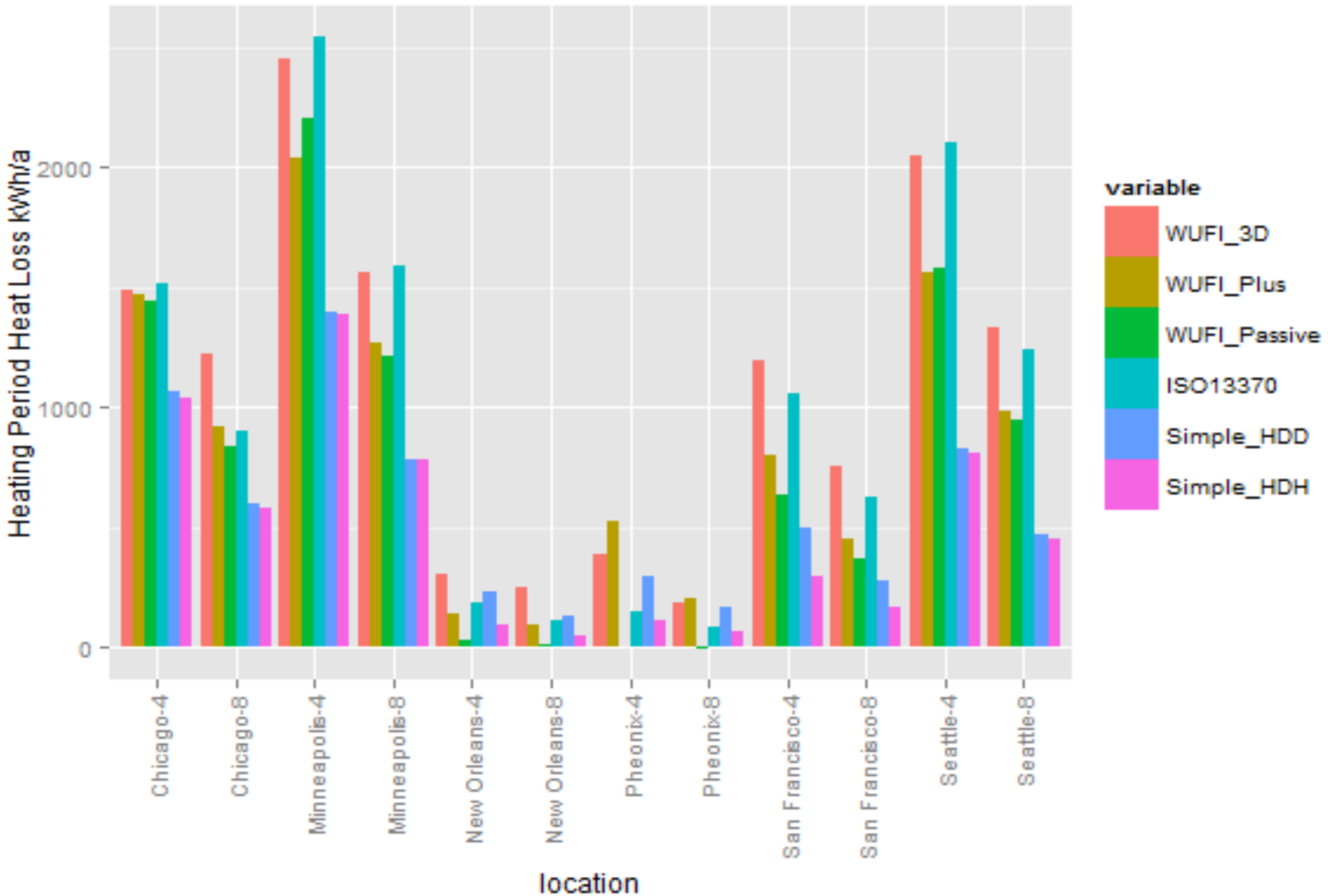
- Temperature distributions
- Different zones
- Model edge insulation
- Storage
- Climate specific and dynamic

On-Going Interests

- Work on cooling losses
- Confirm initialization effects
- Work on standardizing summation periods
- Best practices for using WUFI 3-d to simulate ground losses

  → Potentially develop and implement
- Focus and publish

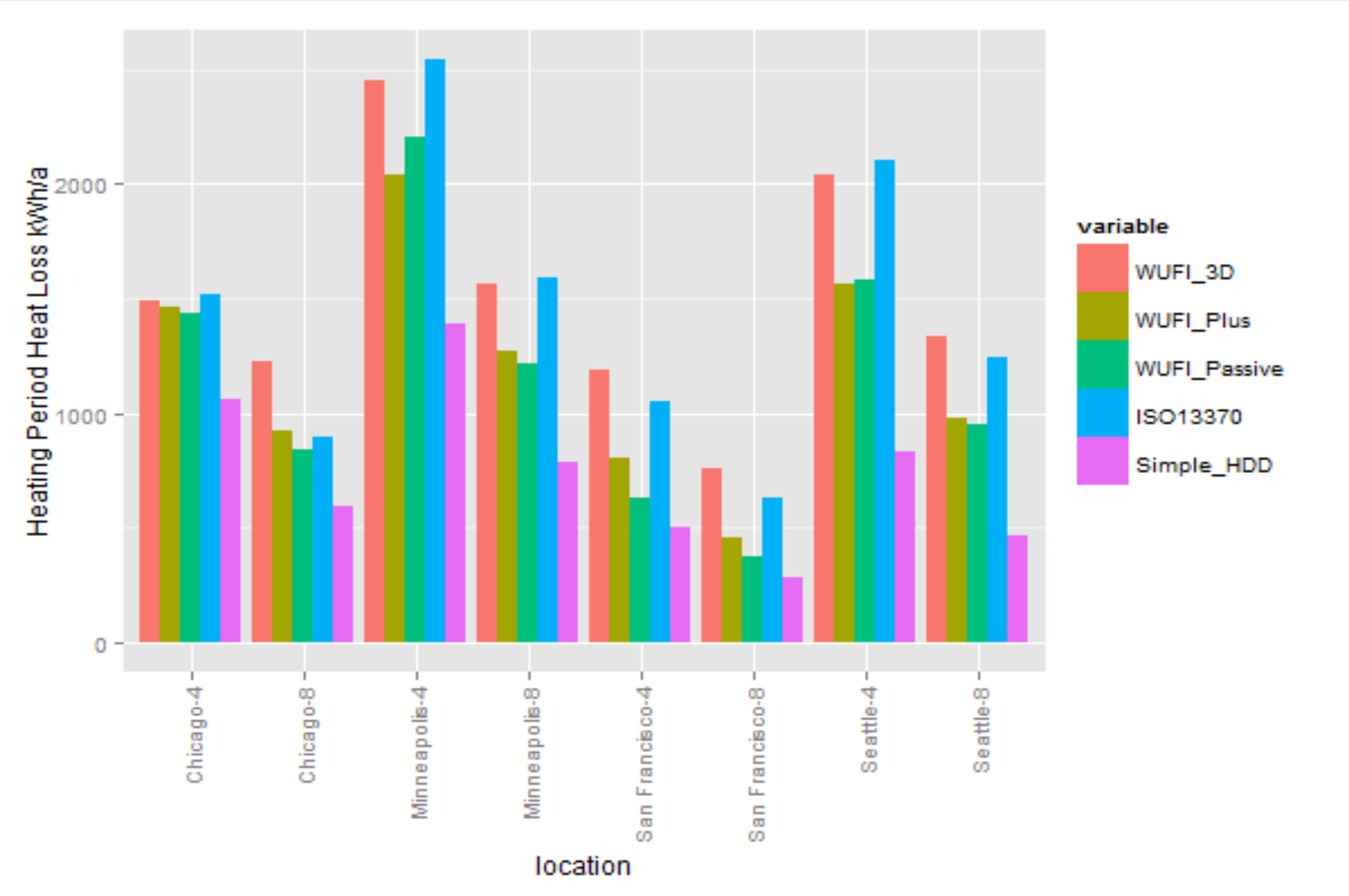
Overview of all results together is a little overwhelming



There are observations and there are questions

- Simple heat loss with HDD and HDR are the same and under-predict slab heat loss in heating climates
- Choices made in the ISO 13370 calculations gave results that are very similar to dynamic WUFI simulations
- For Chicago, a slab with 4” of XPS has about 45% of total heat loss
- For heating period, insulation thickness for New Orleans does not show any difference in heat loss
- Heat loss in Phoenix is surprisingly high and is reduced by about 50% by 8” insulation

Now only the cold and coastal climates are shown.



More observations and questions

- The slab heat loss in Seattle is just as high as in Chicago
- Going from 4” to 8” can reduces heat loss; the reduction is climate dependent
- The benefits of going from WUFI Plus (dynamic) and WUFI Passive (static) are essentially the same.
- WUFI 3D gives the highest heat losses in all cases

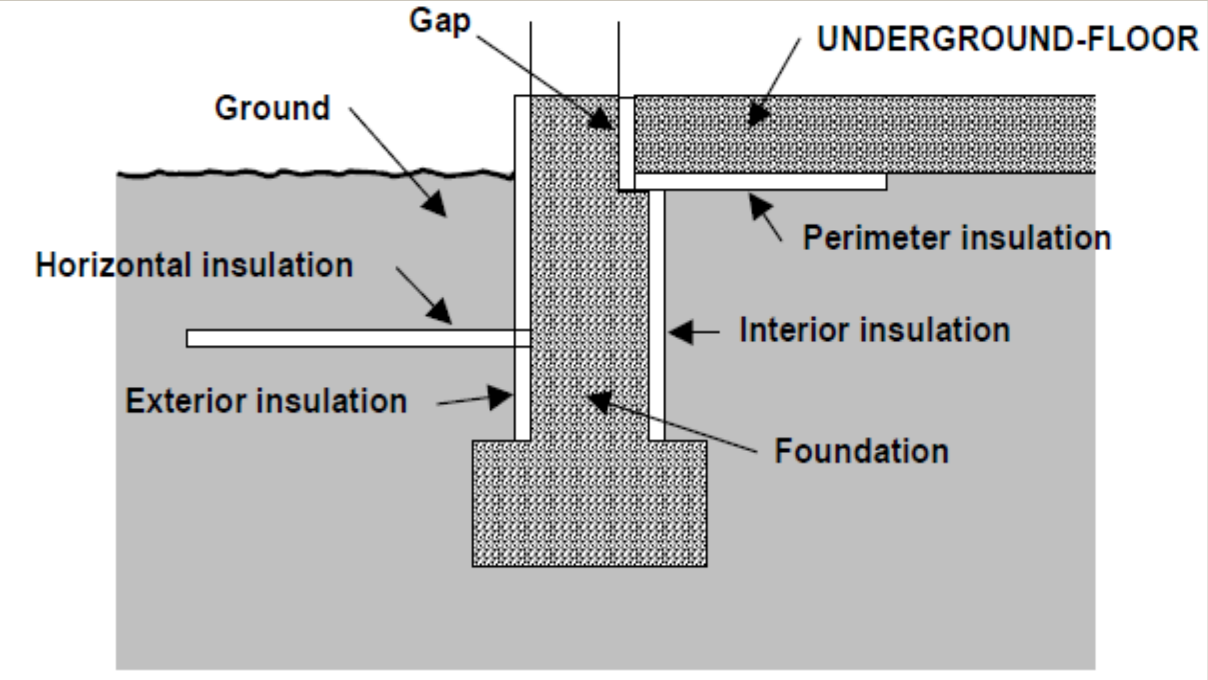
We are working to draw more valuable conclusions for you

Might have started with too much insulation. Go back to less.

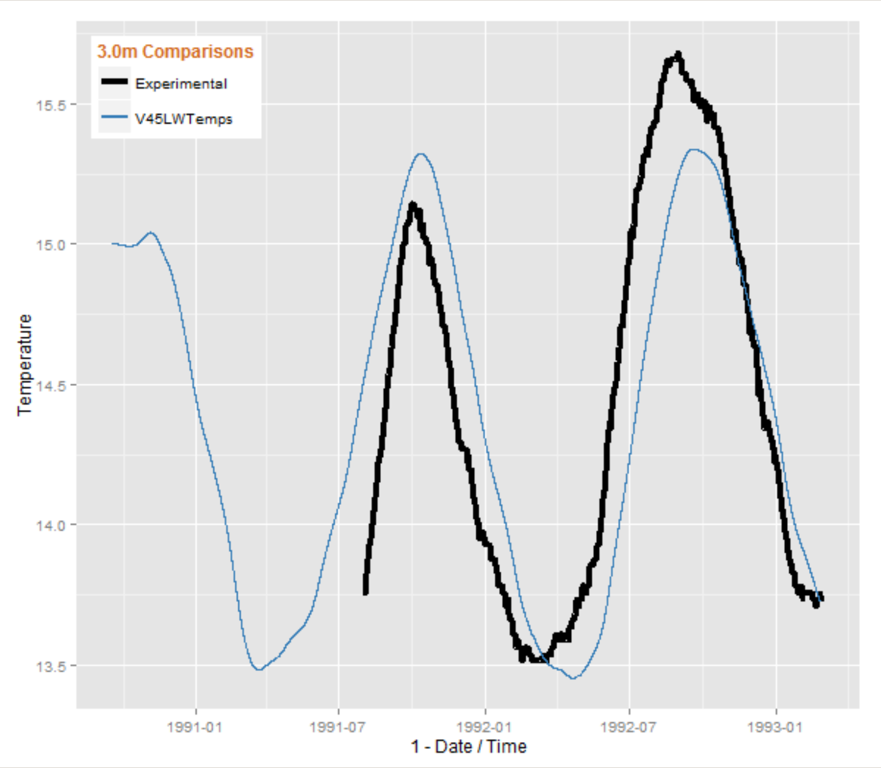
Region dependent soil types

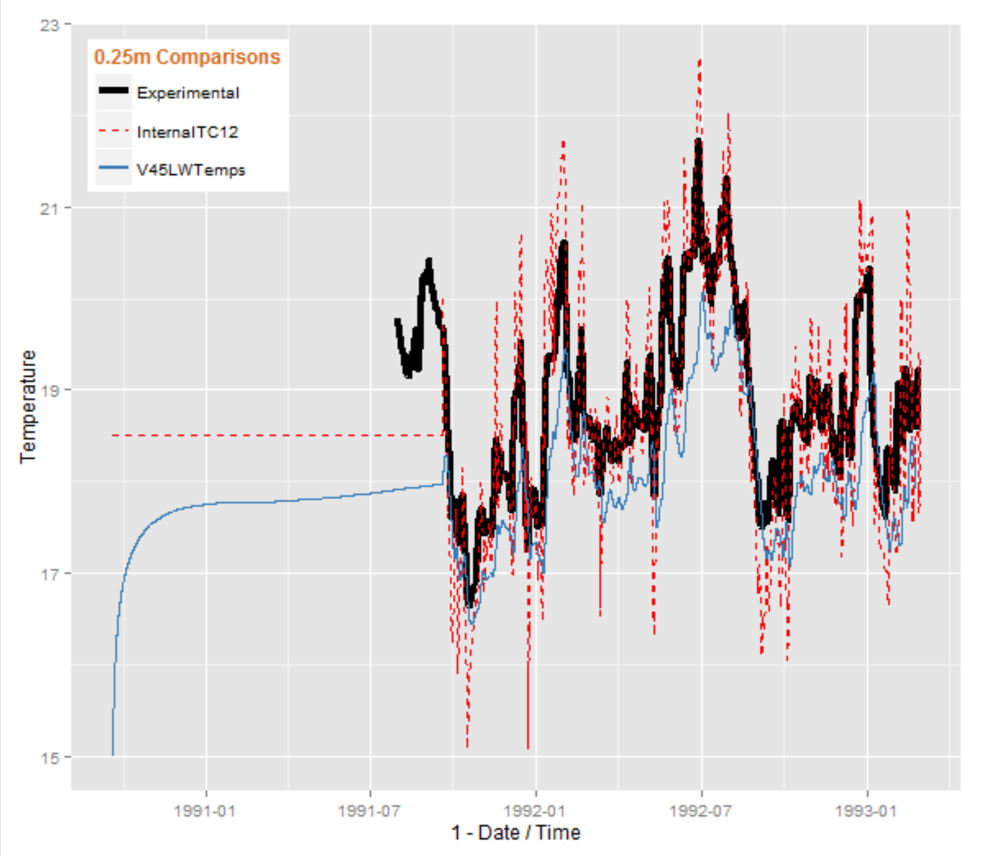
Add a soil layer component in WUFI Plus

Adding Horizontal Insulation and eliminating interior under-slab insulation



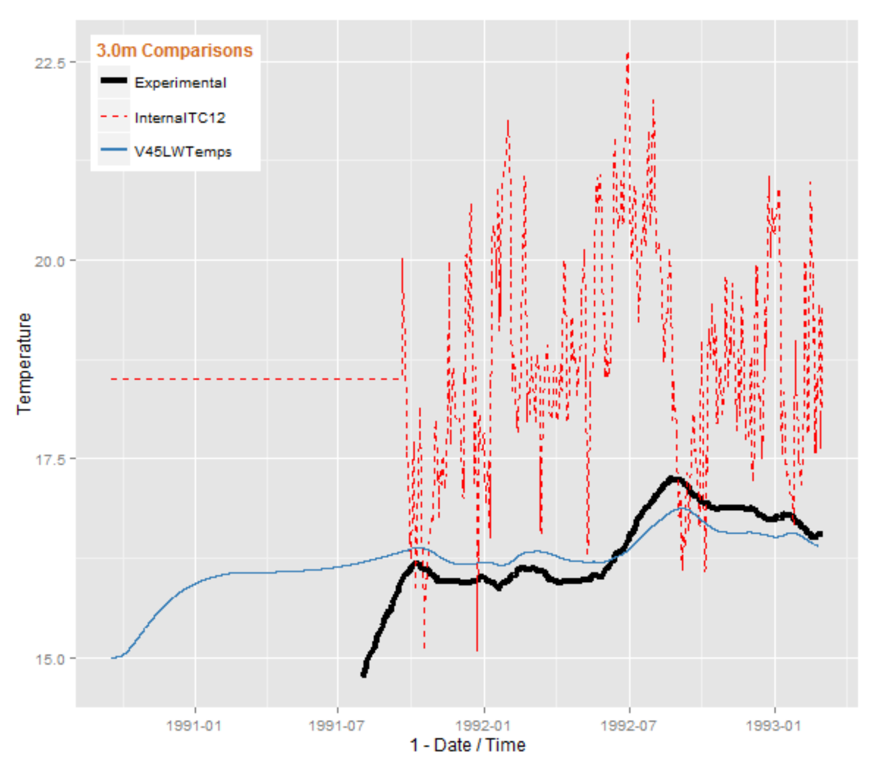
Outside comparisons at lower depths show more discrepancy



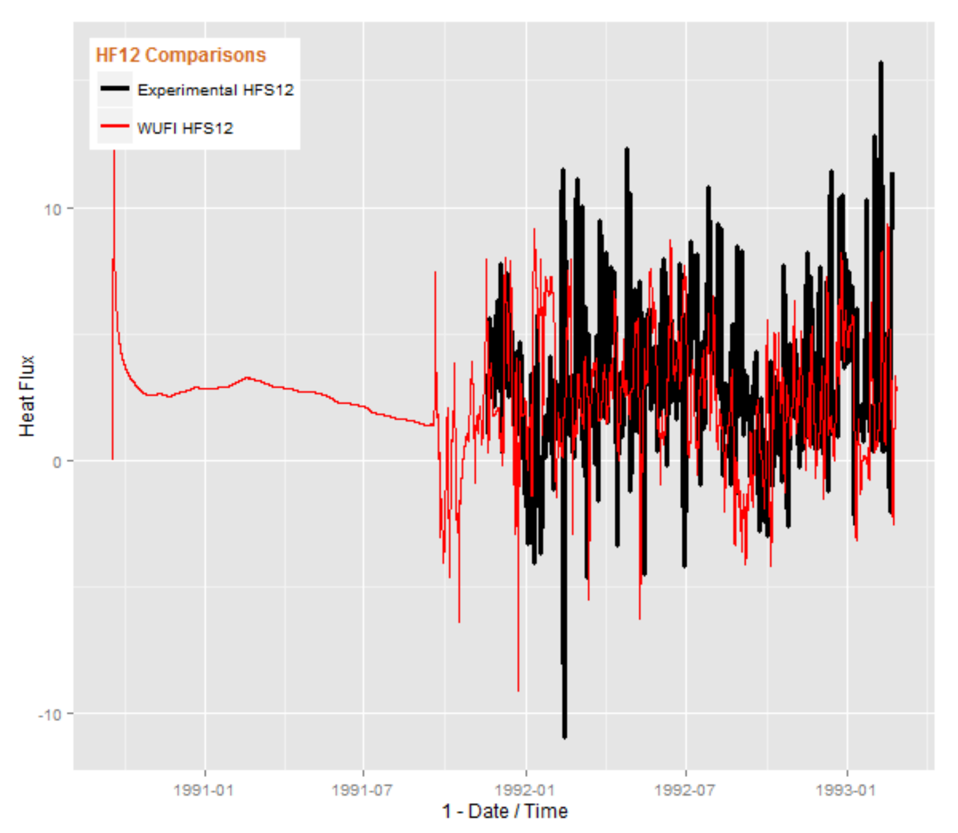


But the near-surface indoor correlations are very good, and the influence of indoor temperature is evident.

The match under the slab at the lowest depth is good

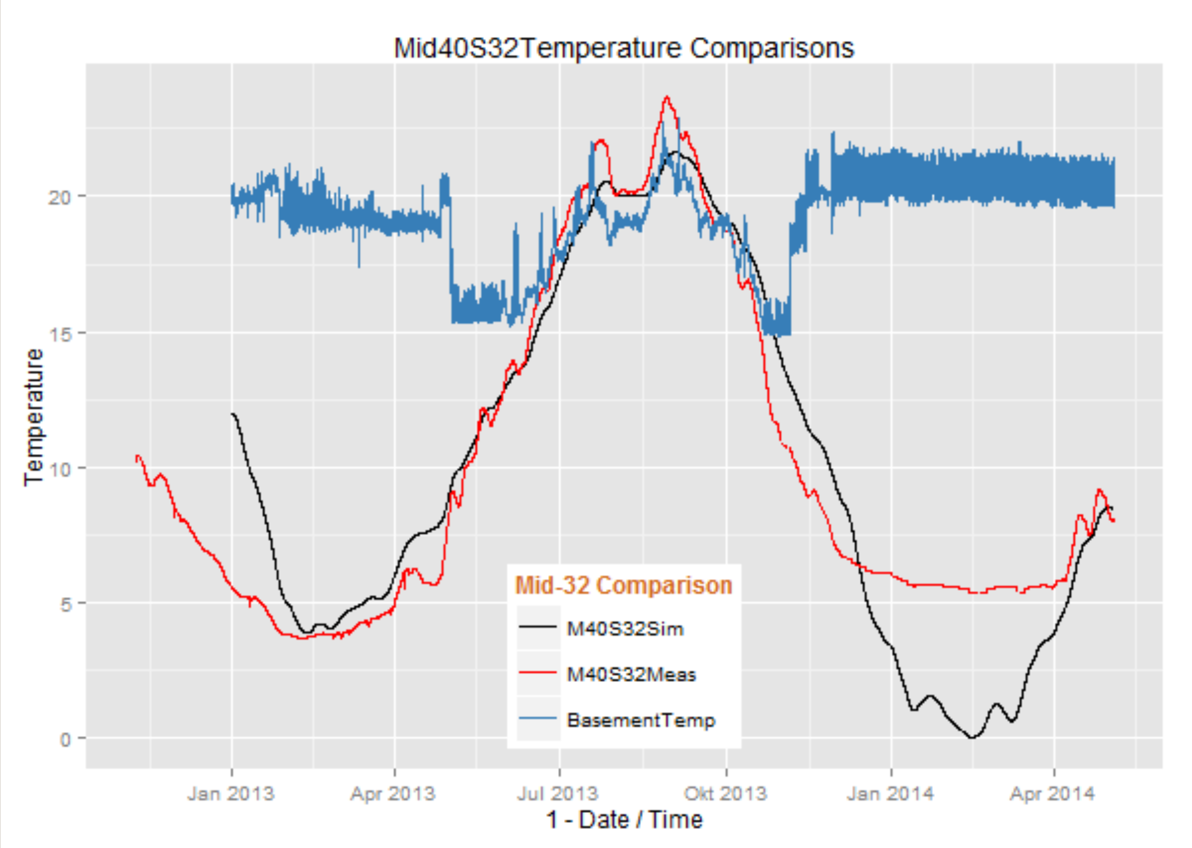


The effects of heat capacity on time-shifting are better for the inside.



Trends for heat flux are generally very good, despite strong external influences on measurements.

It appears that snow and ground freezing effects are missing



Snow will influence short wave absorption. Freezing is a phase change (latent heat) process and will drastically change surrounding temperatures