Evaluation of Energy Efficiency of U.S. Army Hard Shelters

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Overview

- Background
- The huts
- Building energy modeling
- The huts modeling
- Model validations
- Final results

Background

Why this study

- *The Army uses a variety of soft shelters and semipermanent structures at Contingency Operating Bases (COBs) as barracks, dining halls, administrative offices, and maintenance shops*

- Efficient use of energy at COBs is critically important for the US DOD

  Avoid high rate of casualties on refueling convoys

  Fully burdened cost of fuel is very high

Efficient use of energy is critically important for the US DOD

- Avoid high rate of casualties on refueling convoys

During the wars in Iraq and Afghanistan

- 1 out of 8 US Army casualties was the result of protecting fuel convoys
- 1 in every 24 resupply convoys suffered a casualty
- Over 3000 American soldiers/contractors killed in fuel supply convoys between 2003 - 2007

PHOTO: KARIM SAHIB/AFP/GETTY IMAGES

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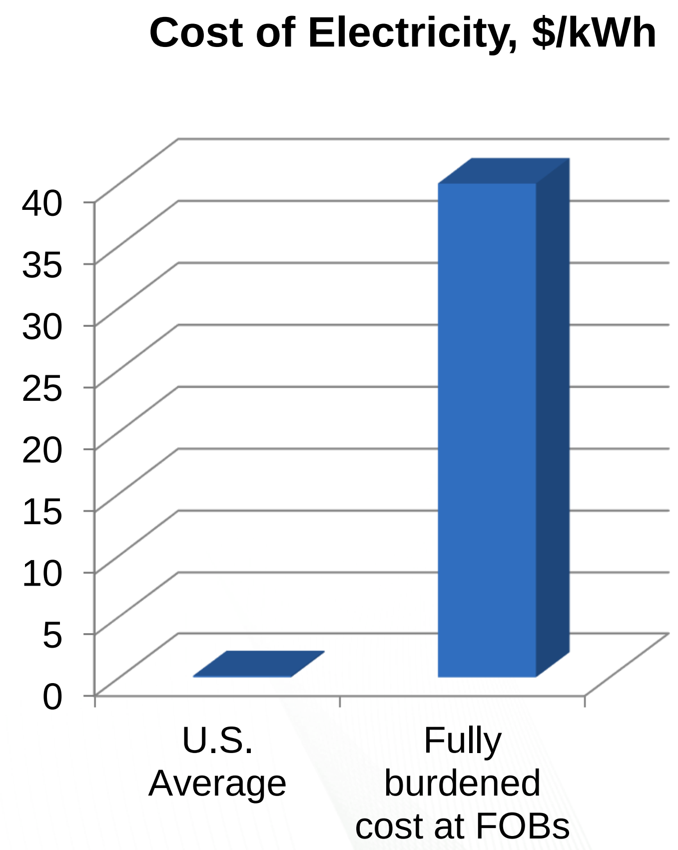
Efficient use of energy is critically important for the US DOD

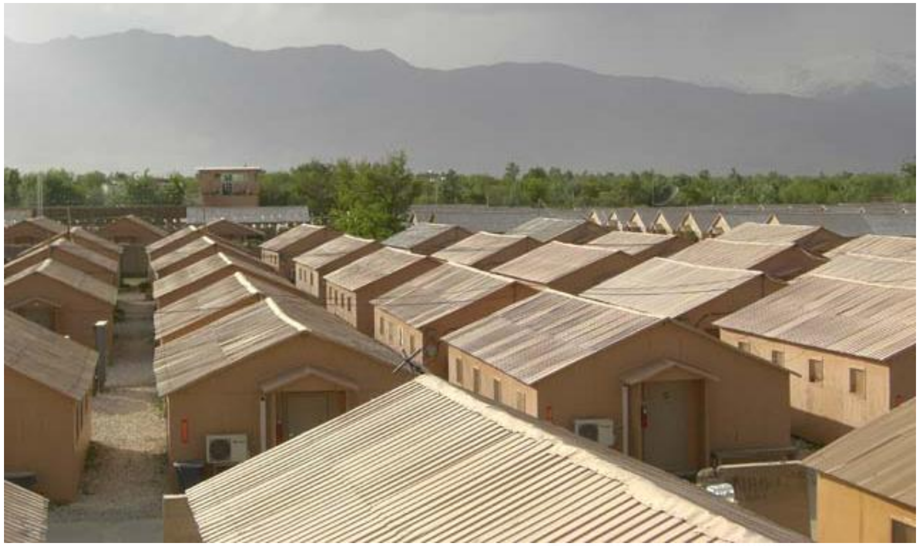
- Fully burdened cost of fuel: up to $400/gal or $40/kWh
- A typical 300-person camp use 400,000 gal fuel/year
- Over 50% energy is used to air condition shelters



The Huts

B-huts (barrack-huts) are commonly used at temporary Army bases

- Barracks Hut known as "B-huts" are commonly used at temporary Army bases
- B-huts are typically NOT energy efficient
- ORNL evaluated performance and feasibility of several technologies to improve energy efficiency of B-huts



http://www.bellport.com/slideshows/afghanistan/pages/B-Huts.htm

Three huts evaluated in Champaign, IL

Improved B-hut	Baseline B-hut	SIP hut (structural insulated panel)
Fiberglass insulation	No insulation	Foam insulation
Asphalt saturated felt and tape to reduce infiltration	No air barrier	Joints sealed to reduce infiltration

B-Huts construction




Photo credit: Dahtzen Chu, CERL

B-huts assembled in one week by professional construction crew

Building Energy Modeling

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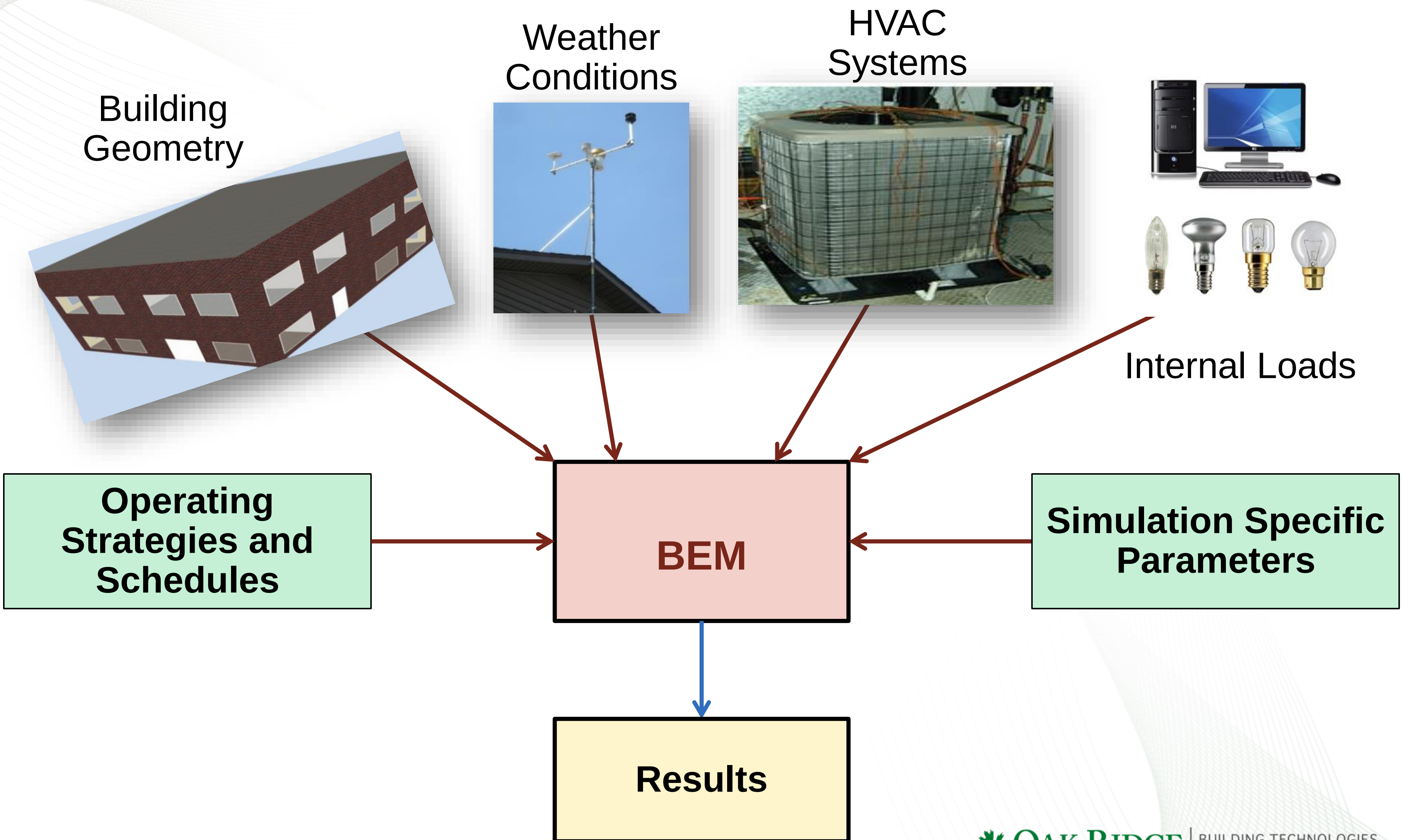
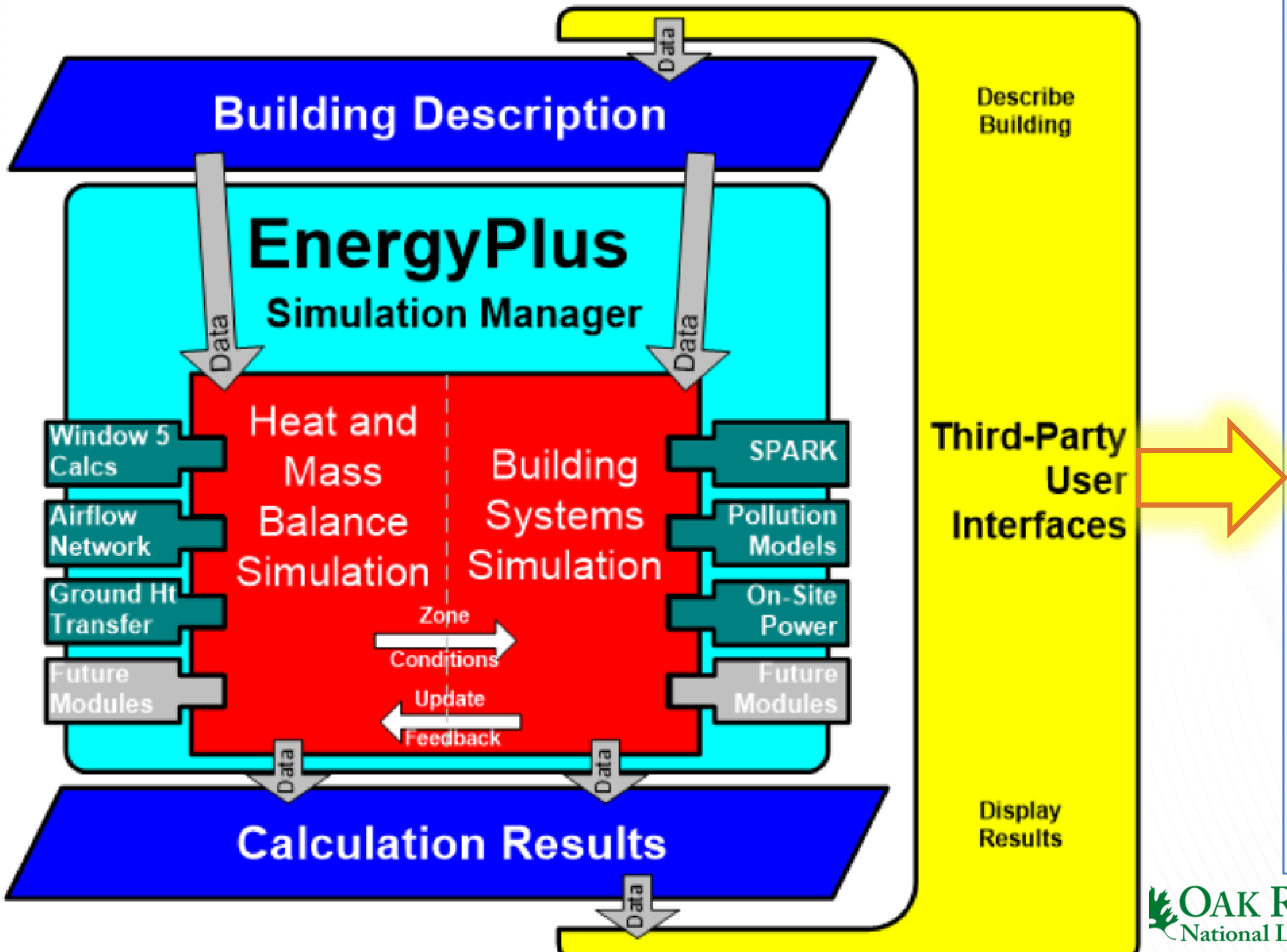
What is Building Energy Modeling (BEM)?

Dynamic Simulation



What is EnergyPlus (E+)?

- Collection of program modules
- Integrated, simultaneous solution
- Uses heat balance principle



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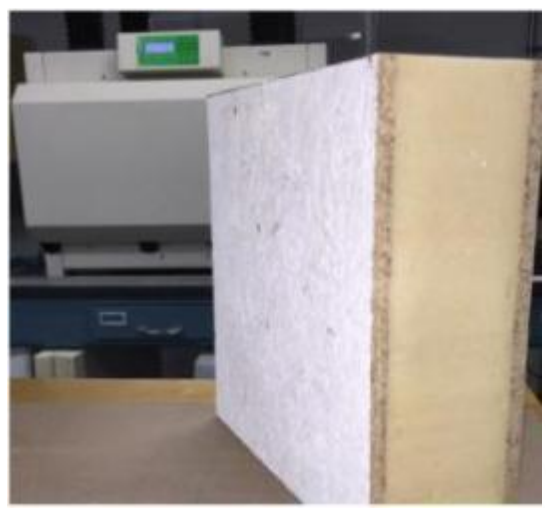
The Huts Modeling

Properties of materials evaluated to use in model

- Solar reflectance of exterior surfaces

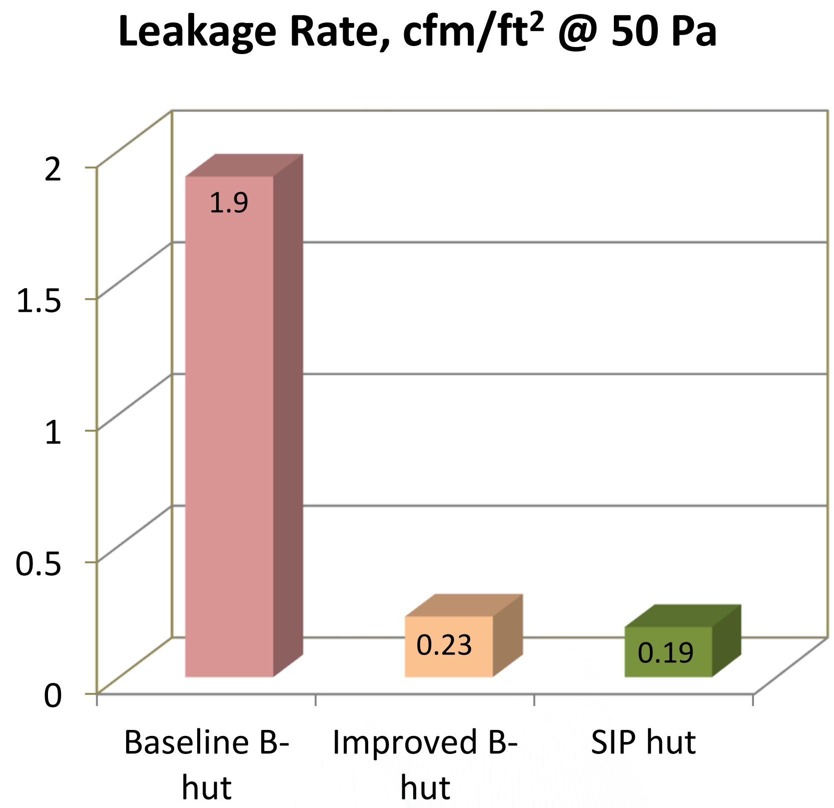
- Thermal conductivity as function of temperature



Air tightness measured to use in the models

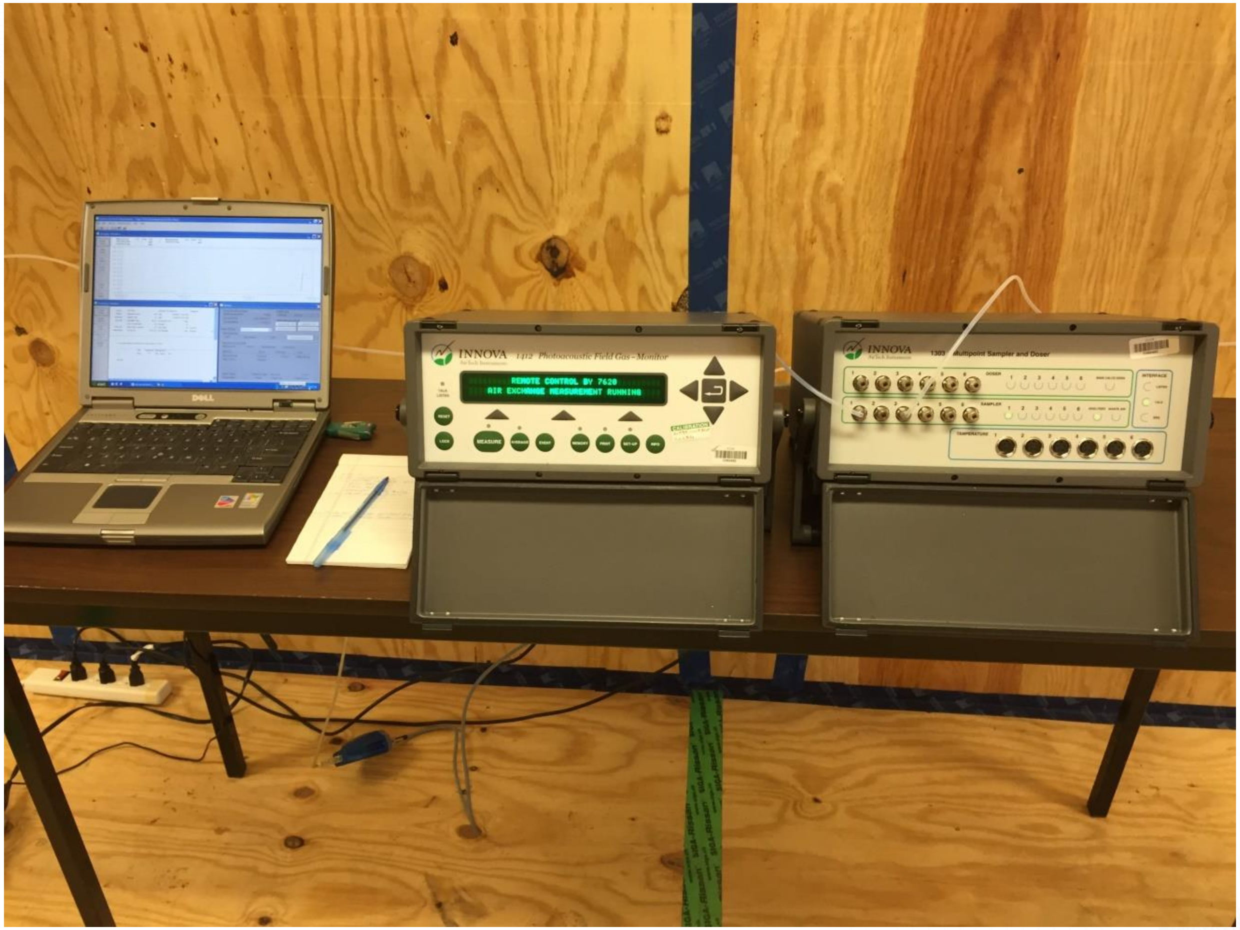
Test Results	Baseline B-hut	Improved B-hut
Date tested	8 July 14	2 September 14
Leakage rate (cfm/sf) at 50 Pa	1.909	0.232
Flow coefficient (cfm/Pa^n)	318.12	69.94
Pressure exponent	0.549	0.52

1 cfm/ft^2 ≈ 5 l/s/m^2



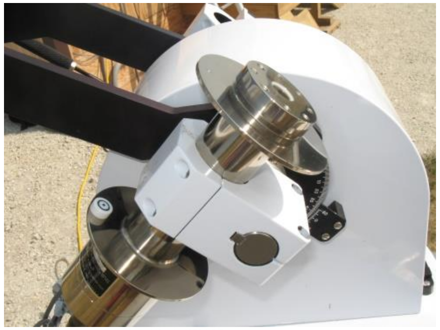
Improved B-hut and SIP hut are ≈10 times air tighter compared to the baseline B-hut

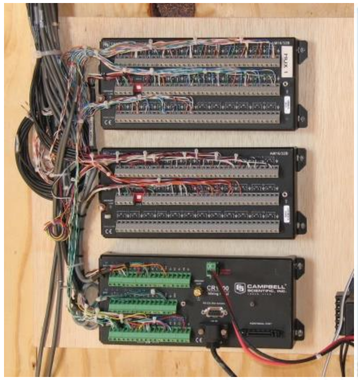
Tracer gas test to validate infiltration model



Huts were well-instrumented to validate EnergyPlus models

- 98 temperature sensors
- 8 humidity sensors
- 23 heat flux sensors
- 6 energy meters
- Complete weather station



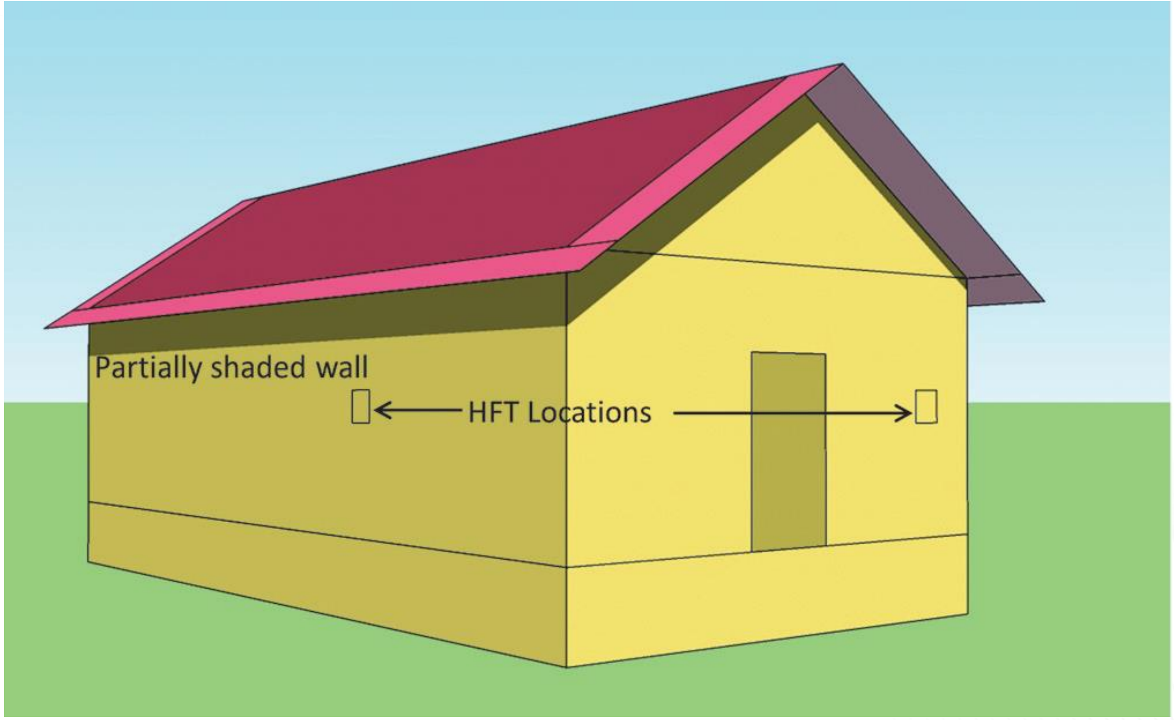


Commonly used mini-split heat pump

- Capacity 12 kBtu/h
- 2.6 lb refrigerant R-410A
- COP 3.4

Building energy models of the huts were developed

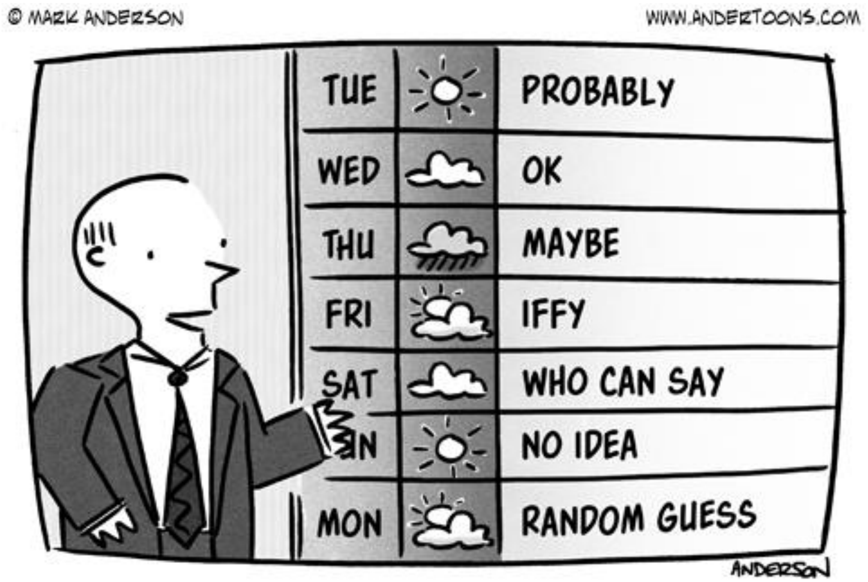
- Using as-built details
- Measured thermal properties
- Airtightness



Detailed modeling is important of validation

Temperature sensor and HFT location

Validation is essential to gain confidence that simulation results are meaningful



"And now the 7-day forecast..."

Model Validations using graphical and statistical methods

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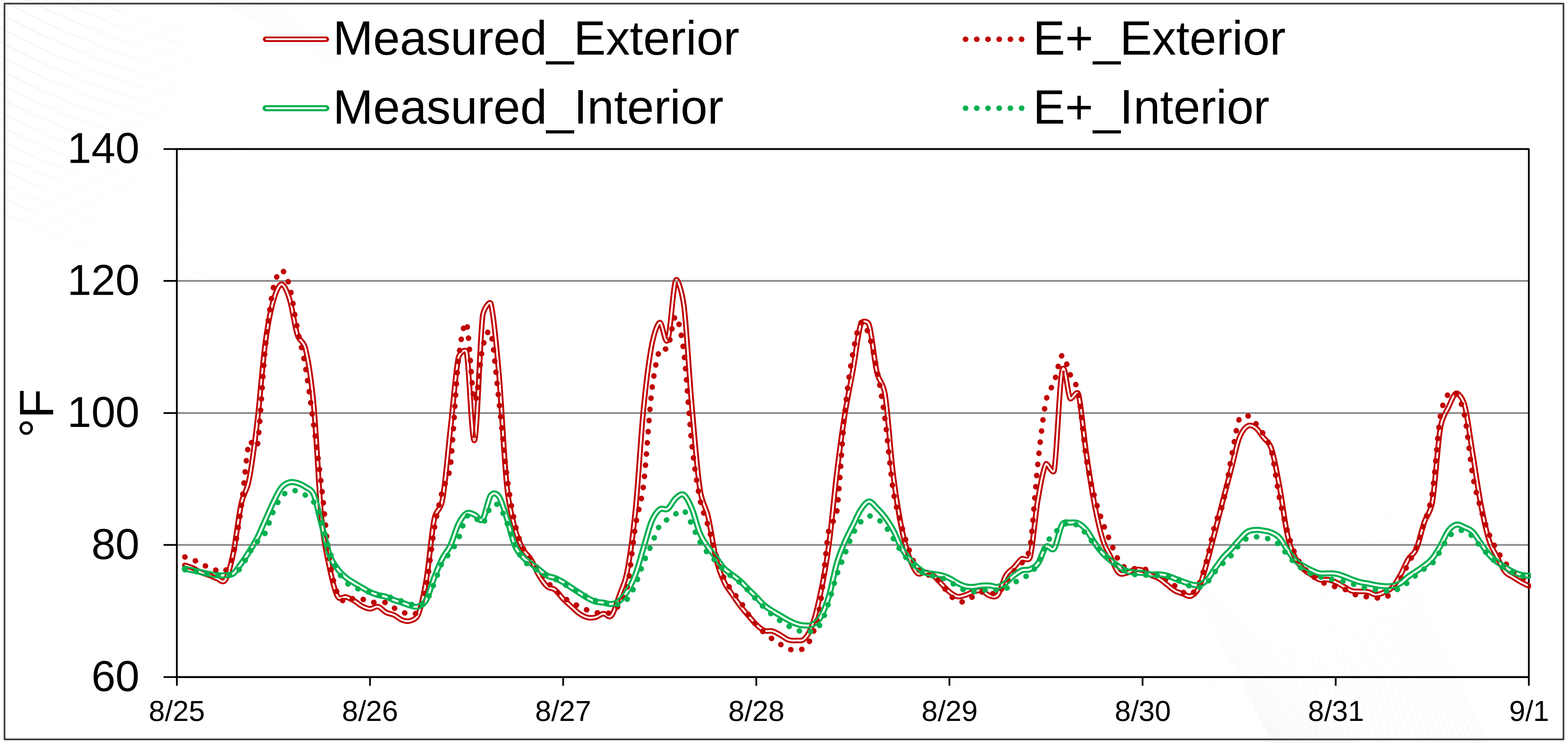
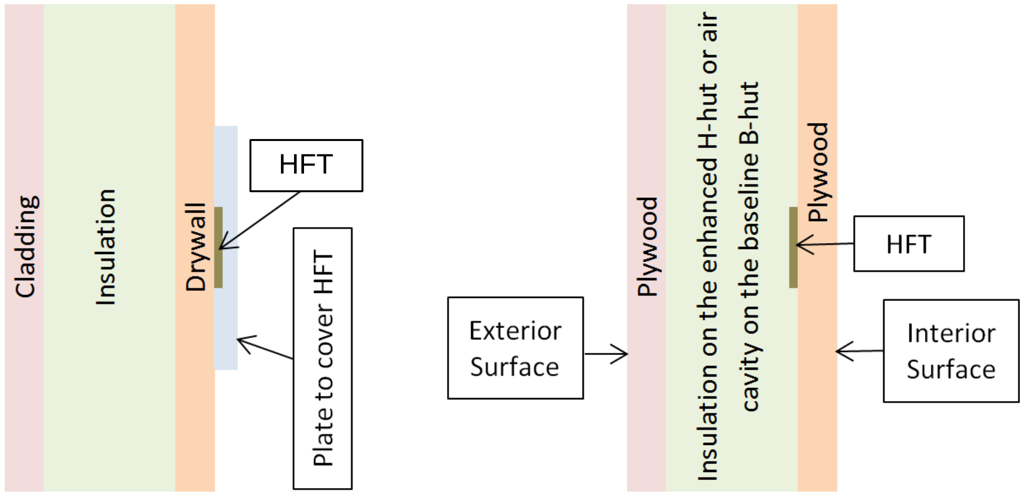
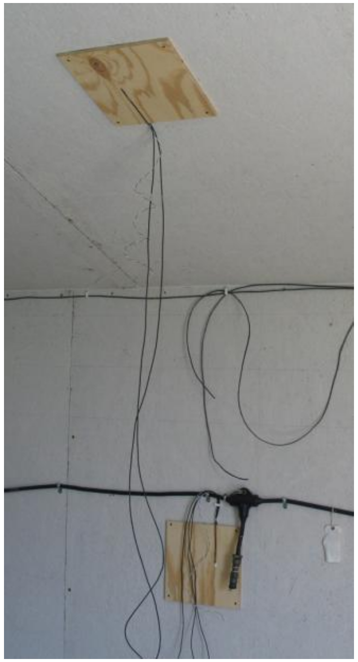
Model validation against surface temperature measurements



Model validation against heat flux measurement





- Typical placement of HFTs
- EnergyPlus was modified to calculate and report heat flux at interface between surfaces

CondFD Surface Heat Flux

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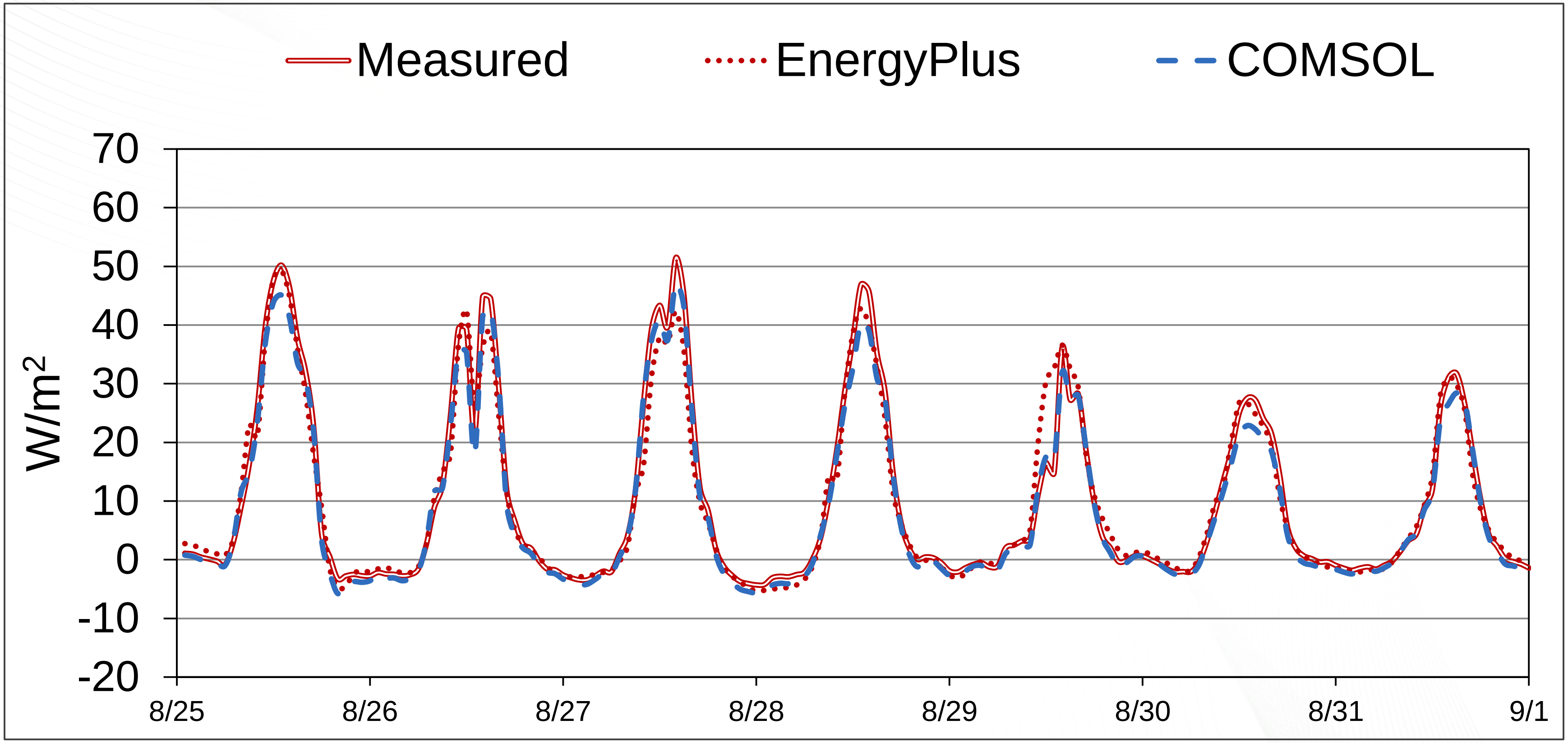
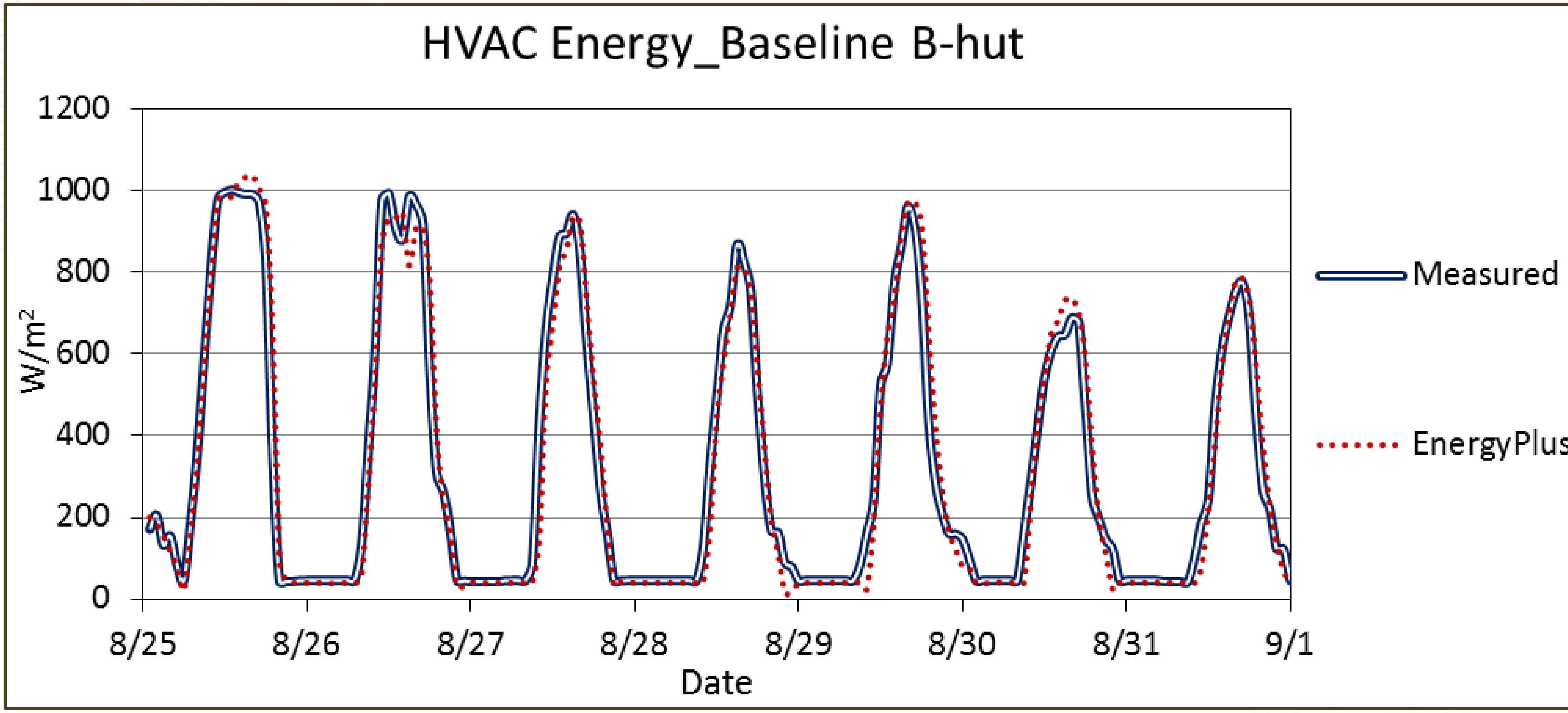
Model validation against heat flux measurements



Exterior surface temperatures match within 0.4°F, interior surface temperatures match within 1.0°F, and HF match within 0.35 Btu/h·ft²

		Baseline B-hut			Improved B-hut		
		Exterior Surface Temp, °F	Interior Surface Temp, °F	Heat Flux, Btu/h.ft²	Exterior Surface Temp, °F	Interior Surface Temp, °F	Heat Flux, Btu/h.ft²
South Wall	Measured	83.6	77.6	3.13	84.8	75.9	0.70
	EnergyPlus	83.6	76.6	3.02	85.1	75.3	0.68
	Difference	0.0	-1.0	-0.11	0.2	-0.6	-0.02
East Wall	Measured	80.1	76.6	1.61	81.3	75.6	0.40
	EnergyPlus	80.2	76.9	1.80	81.1	75.2	0.42
	Difference	0.1	0.4	0.19	-0.2	-0.4	0.01
West Wall	Measured	81.9	76.6	2.80	83.3	75.3	0.62
	EnergyPlus	82.0	75.8	2.45	83.3	75.2	0.54
	Difference	0.1	-0.7	-0.35	0.0	-0.1	-0.07
North Wall	Measured	78.7	76.0	1.21	79.6	75.4	0.28
	EnergyPlus	78.3	75.8	1.12	79.6	75.1	0.27
	Difference	-0.4	-0.2	-0.09	0.0	-0.4	-0.01

Model validation against HVAC energy use



Measured and EnergyPlus-calculated average cooling electricity use was in agreement within 3% for the baseline B-hut and within 8% for the improved B-hut

ASHRAE Guideline 14 requires using NMBE and CV-RMSE to determine compliance

$$\text{NMBE} = \frac{\sum_{i=1}^{N} \text{Meas}_i - \text{Sim}_i}{(N-1)*\overline{\text{Meas}}} * 100$$

$$\text{CV-RMSE} = \frac{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\text{Meas}_i - \text{Sim}_i)^2}}{\overline{\text{Meas}}} * 100$$

Where

Meas_i = measured value at hour i (for i from 1 to N hours

Sim_i = simulation predicted value at hour i

N = number of observation points

$\overline{\text{Meas}}$ = arithmetic mean of measured values

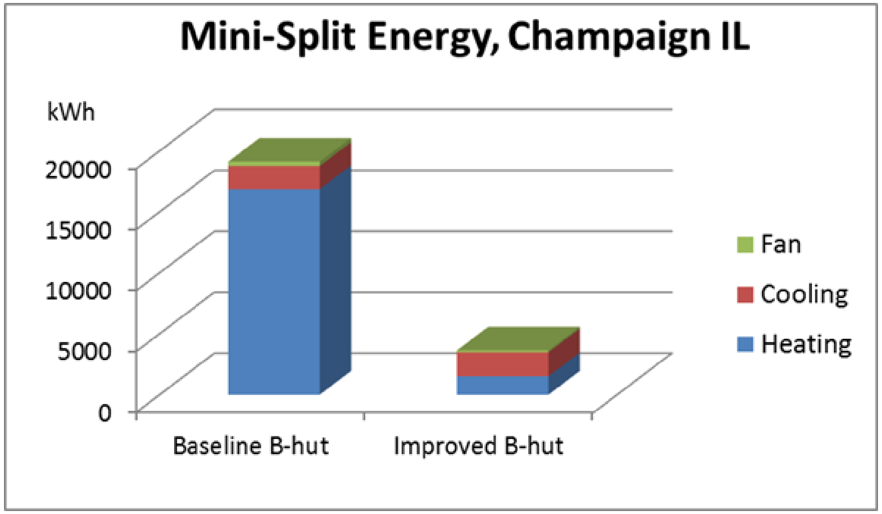
Acceptable Tolerances		
	Using hourly data	Using monthly data
NMBE	±10%	±5%
CV-RMSE	± 30%	±15%

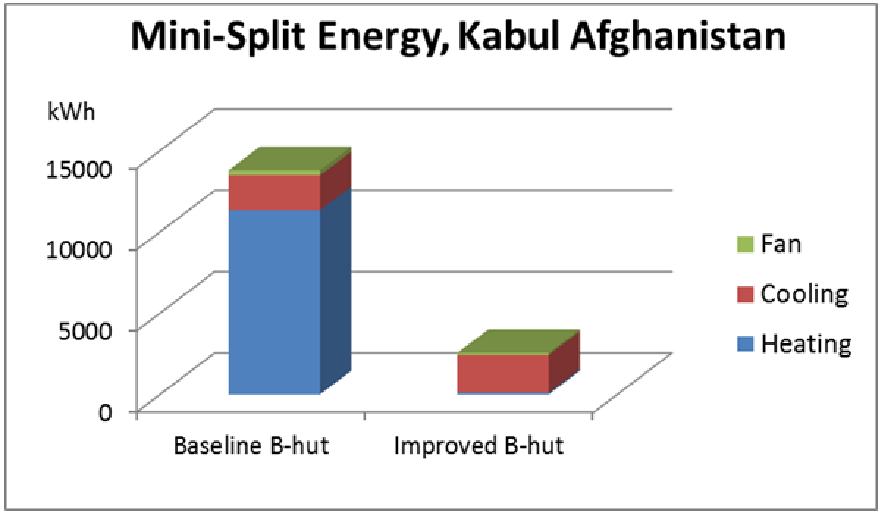
Model Validation using statistical methods

Model Validation using Combined Cooling and Heating Hourly Data			
	Baseline	Improved	ASHRAE 14 requirement
NMBE	-0.7%	5.7%	±10%
CV-RMSE	27.1%	21.3%	± 30%

Final Results

Annual simulation using TMY weather





- **Up to 80%** reduction in HVAC energy
- Potential to reduce upto **40%** of total energy use

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So what?

- Army is placing 20 SIP huts in Afghanistan as a pilot study
- SIP huts may become the new normal if successful
- Lessons learned from these projects may be widely adopted by the Army in the near future
- Energy Efficient Outposts Modeling Consortium is using these models for their study

Funding

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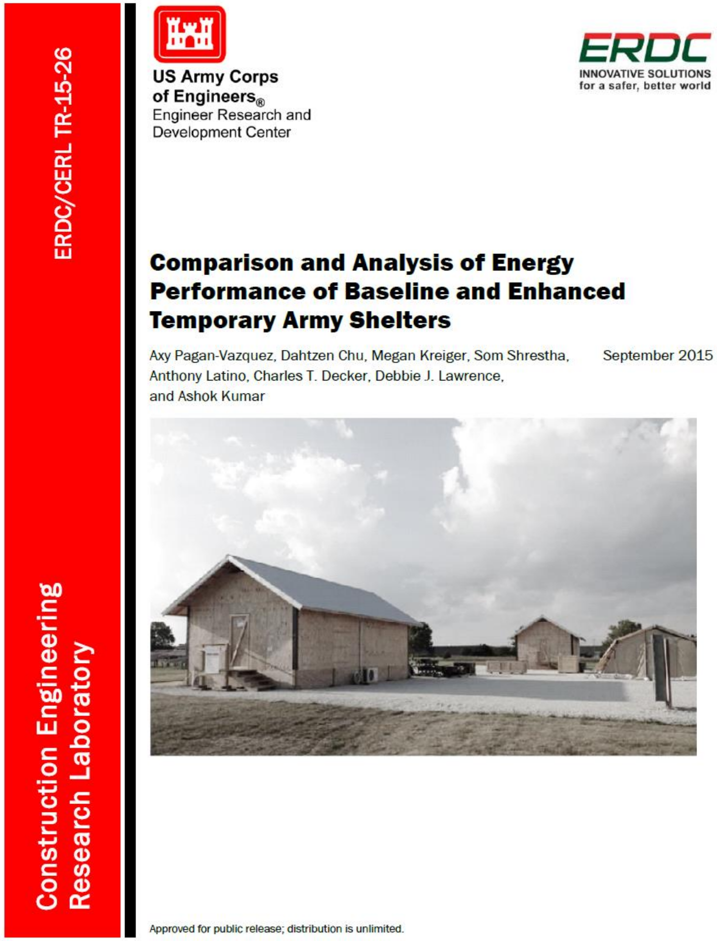
- Thanks to Amir Roth of DOE for proving fund to modify the EnergyPlus

For other details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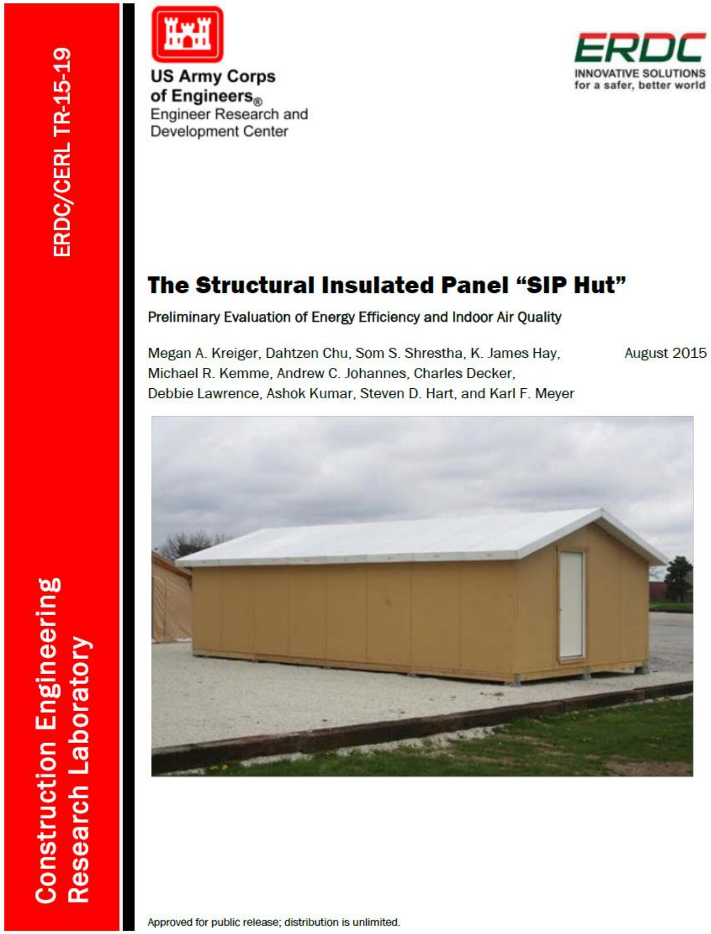
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The Structural Insulated Panel "SIP Hut"

Preliminary Evaluation of Energy Efficiency and Indoor Air Quality

Megan A. Kreiger, Dahtzen Chu, Som S. Shrestha, K. James Hay, Michael R. Kemme, Andrew C. Johannes, Charles Decker, Debbie Lawrence, Ashok Kumar, Steven D. Hart, and Karl F. Meyer

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Discussion

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