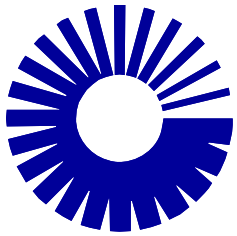


United Technologies Research Center

Validation of retrofit analysis simulation tool: Lessons learned

Marija Trčka (trckam@utrc.utc.com)
Stella Maris Oggianu
José Miguel Pasini

06/16/2014

This material is based upon work supported by :
the Energy Efficient Buildings Hub (EEB Hub), an energy innovation hub sponsored by the U.S. Department of Energy under Award Number DE-EE0004261 and by
U.S Department of Defense ESTCP Program ESTCP Program # 201257, contract number W912HQ-12-C-0051

OUTLINE

Introduction

Building model components

- Envelope — development and validation
- System — development and validation

Integrated model

- Inter-model validation
- Field tests

BUILDINGS ENERGY AUDIT AND RETROFIT ANALYSIS

A physics-based tool enabling 10x reduction in audit time in the assessment of energy conservation measures and package solutions

Individual Building Analysis (from weeks to less than 1 day)

Current State (expert based)

I: Energy baseline — 1-2 weeks*

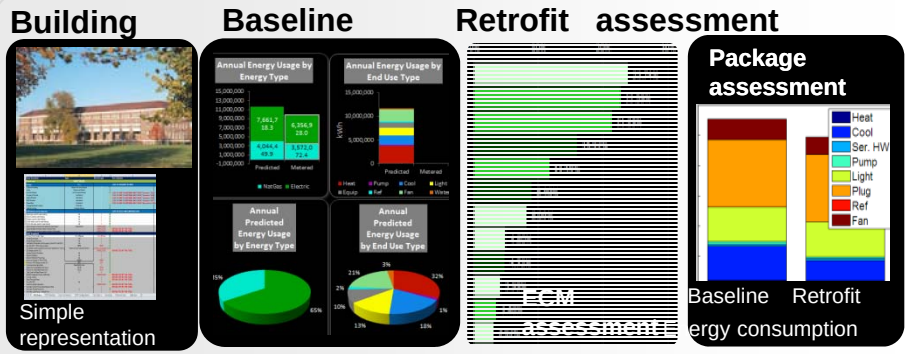
II: Detail assessment & retrofit evaluation — 2-3 weeks

III: Detailed modeling and verification — 3-4 weeks

Envisioned workflow

I – II — 1-2 days

III — ~1 week



Portfolio Assessment

Detailed portfolio: Capability to analyze in detail the buildings within a portfolio

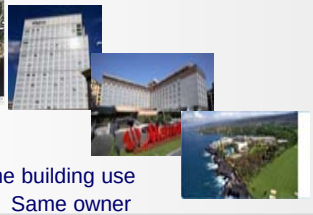
Policy making: New methodology to analyze at a portfolio level >200,000 buildings in 10 hours

Applications

Campus

Same location

National Accounts

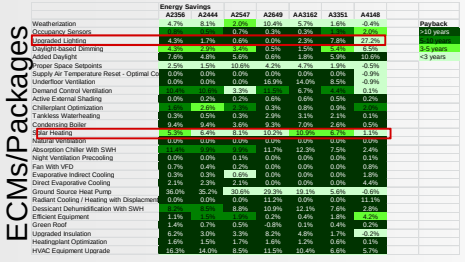


Same building use
Same owner

Government Agencies

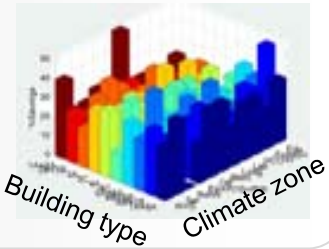
Portfolio Analysis

Performance track



Investment decisions

Savings (kWh, $)



OUTLINE

Introduction

Building model components

- Envelope — development and validation
- System — development and validation

Integrated model

- Inter-model validation
- Field tests

MODELING ASSUMPTIONS AND VALIDATION: BUILDING ENVELOPE MODEL

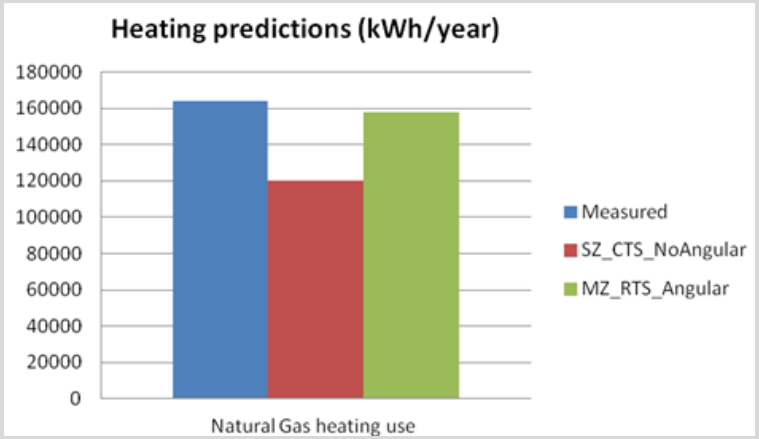
Simplified physics-based model, with multiple options for building models refinements that allow meeting the required accuracy

- Well mixed zone(s) (i.e. single inside air temperature node)
- 1D heat transfer through construction
- Thermal capacitance of internal mass and furnishings represented by a single lumped thermal mass
- Quasi-steady energy balance on the zone air node
- Load modeling assumptions:

$$\dot{Q}_{LOAD}(t) = \dot{Q}_{People\ sensible}(t) + \dot{Q}_{Equip\ sensible}(t) + \dot{Q}_{Fenestrati\ on}\left(T_{Sol-Air}, \dot{Q}_{Solar\ Radiation}, T_{Zone}\right) + \sum_{All\ Surfaces} \dot{Q}_{Conduction}\left(T_{Sol-Air}, T_{Zone}\right) + \dot{Q}_{Infiltrati\ on}\left(T_{Outside\ Air}, T_{Zone}\right) + \dot{Q}_{Internal\ Mass}\left(T_{Zone}, T_{Internal\ Mass}\right)$$

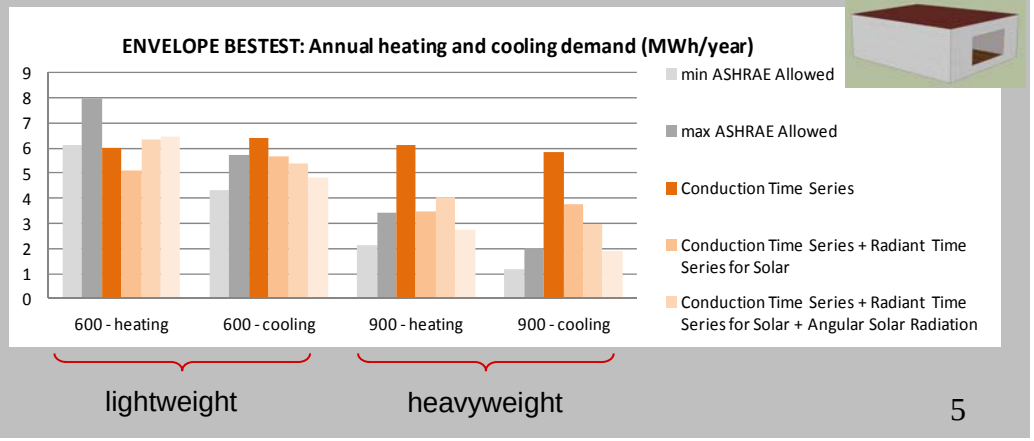
1. One-zone model, extended to five-zone

Localization of loads improves heating load predictions



2. Multiple options for heat transfer models

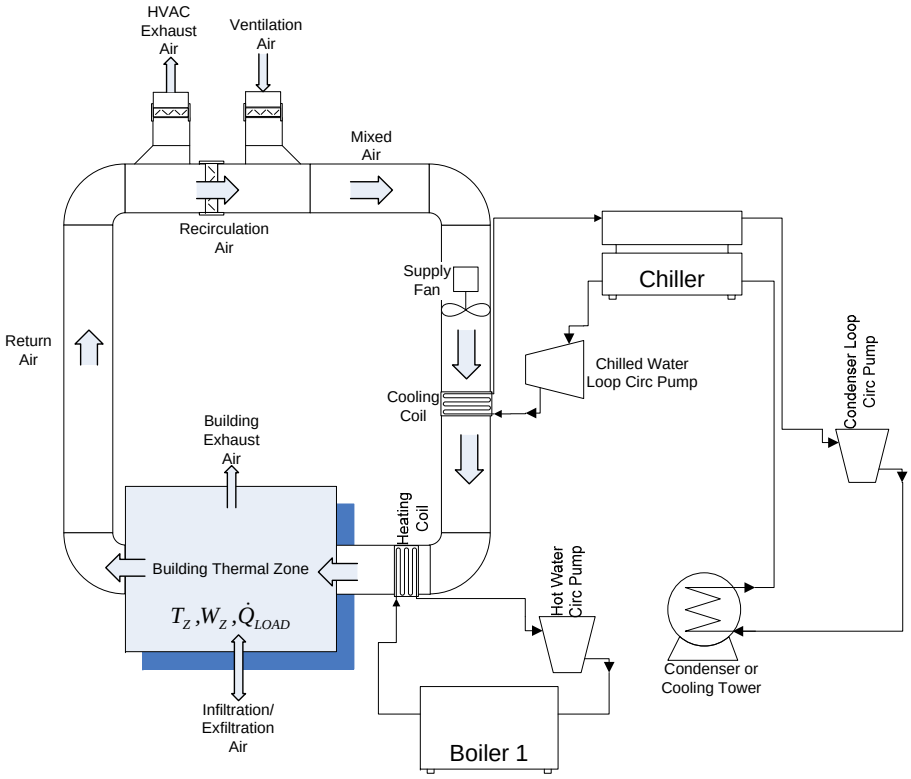
- Building demand side heat transfer mechanisms are validated against series of standardized tests (ASHRAE 140)
- Algorithm for heat transfer were improved and appended with more detailed algorithms
  - Full Radiant Time Series (RTS) method
  - Conduction Transfer function (CTF)

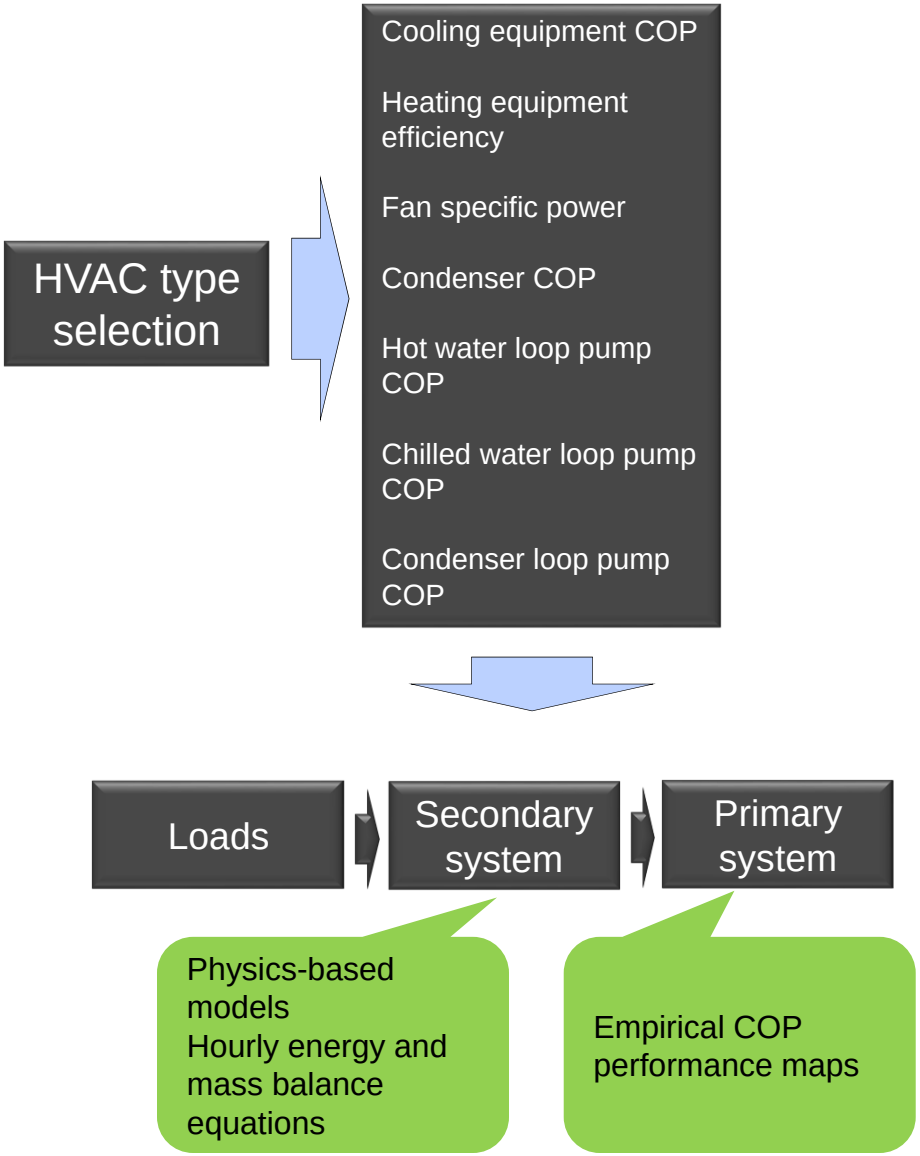


MODELING ASSUMPTIONS: HVAC SYSTEM MODEL

Simplified physics-based model

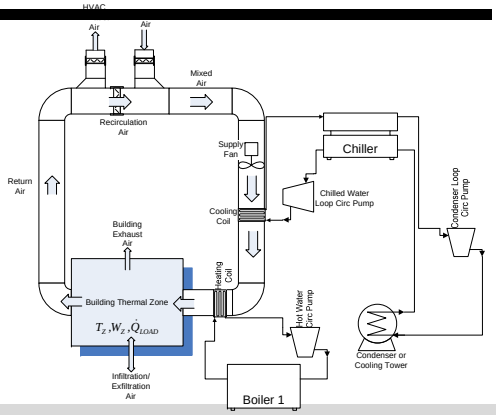
- One HVAC system per building
- System-based modeling approach
- COPs as a generic function of operating conditions
- Constant and variable air distribution systems
- Idealized control
- Sequential coupling from loads to energy supply





VALIDATION: HVAC SYSTEM MODEL

Deep Retro validated against standard inter-model validation procedures for building simulation software

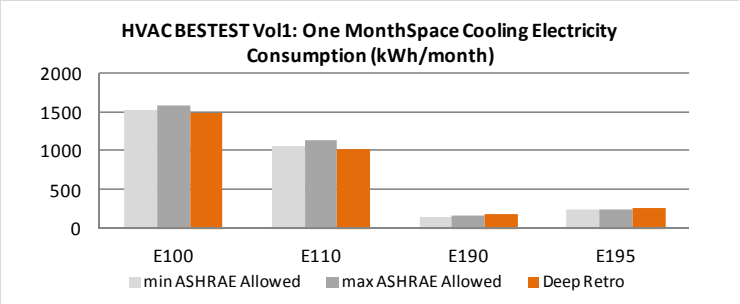


Loads → Secondary system → Primary system

STEADY STATE HVAC - VAV

Cooling energy demand for steady state condition for tested cases meet standard accuracy requirements
Deep Retro predicts well energy distribution among fans and compressor

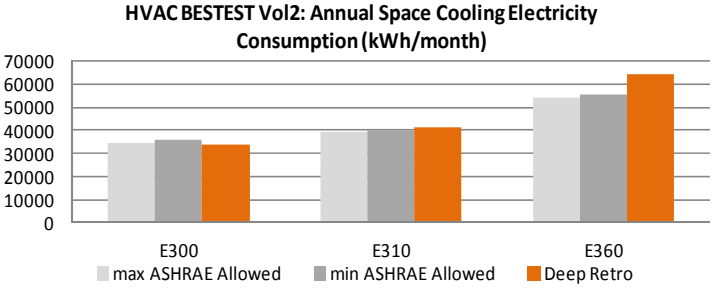
Case	Coil condition	Indoor temperature	Outdoor temperature
E100	dry	low	high
E110	dry	low	low
E190	wet loSHR	low	low
E195	wet loSHR	low	high



HVAC DYNAMICS - CAV

Deep Retro not flexible enough to test all dynamic cases
Deep Retro outside its validity region for undersized system
Cooling energy demand for transient conditions for tested cases without undersizing meet standard accuracy requirements

Case	Load
E300	Dynamics included low latent load
E310	Dynamics included high latent load
E360	Dynamics included undersized system



OUTLINE

Introduction

Building model components

- Envelope — development and validation
- System — development and validation

Integrated model

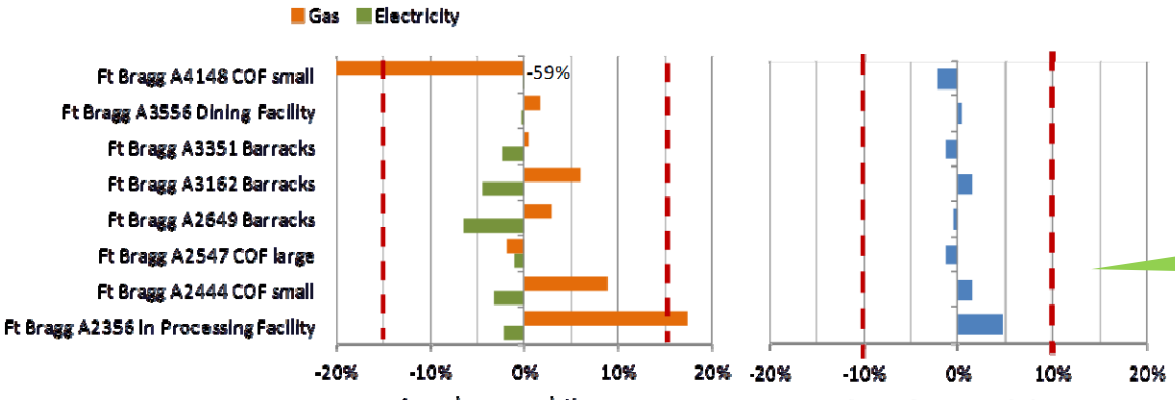
- Inter-model validation
- Field tests

VALIDATION: INTER-MODEL COMPARISON OF INTEGRATED BUILDING AND SYSTEM MODEL

Deep Retro validated against inter-model comparison against eQuest results for a real building model

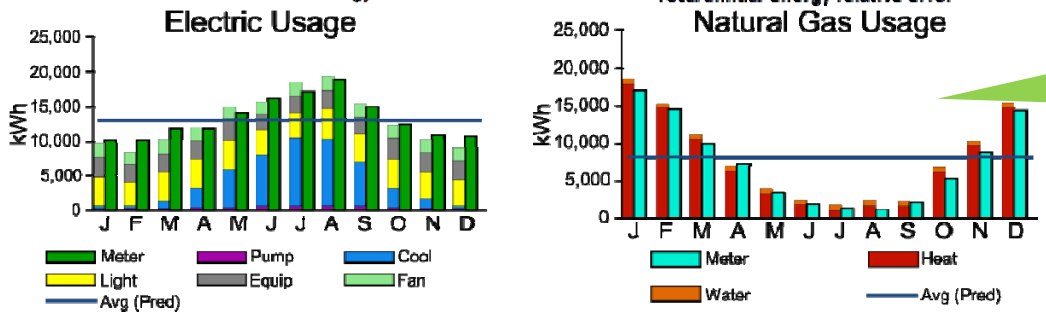
Building	Sq. ft.	Floors	Type/Purpose	Energy Sources	Annual electricity eQuest predicted [kWh]	Annual Natural Gas eQuest predicted [kWh]
A2356	11,664	1	In-processing facility	Electricity Natural Gas	157,150	86,292
A2444	20,096	2	COF		174,430	112,510
A2547	45,600	1	COF		555,040	380,523
A2649	37,904	4	Barracks		216,880	370,106
A3162	24,768	4	Barracks		217,410	304,120
A3351	52,624	4	Barracks		783,520	416,307
A3556*	29,247	1	Dining facility		1,189,400	545,604
A4148	17,128	2	COF		773,210	28,828
Total	239,031					

eQuest models had been developed and calibrated based on a short metering period for eight buildings by a third party ran retrocommissioning project



RTS modeling approach and single zone assumption used

Relative error in annual site energy by energy type (left) and in total (right)



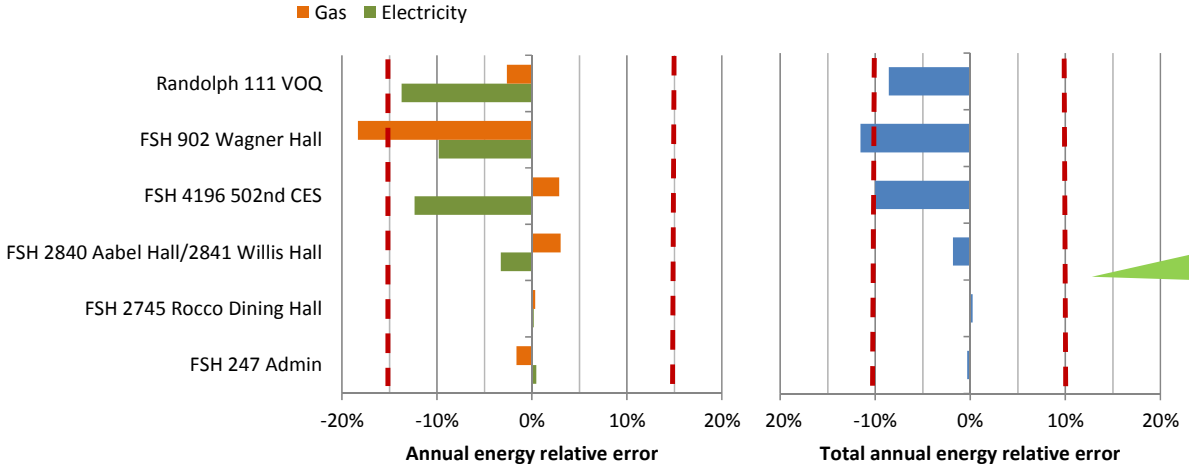
Comparison of monthly electricity and gas predictions from DeepRetro and provided eQuest model for building A2356

VALIDATION: FIELD TESTS

Deep Retro validated against real world data

- 25 buildings from Ft. Sam Houston, Randolph Air Force Base, and Lackland Air Force Base
- The models were built based on building walk-throughs by Building Intelligence Group (BIG) and UTRC
- Focus on 7 building for which metered data was reliable
- RTS modeling approach and single zone model used
  - Well insulated with low fenestration percentage

Building	Sq. ft.	Floors	Type/Purpose	Energy Sources
Randolph 111	45,597	1	Lodging	Natural gas / District CHW loop
FSH 902 Wagner Hall	24,000	1	Office	Natural gas / District CHW loop
FSH 4196 502nd CES	124,000	1	Office	Natural gas / Electricity
FSH 2840 Aabel Hall/2841 Willis Hall	460,000	4	Classroom / Office	Ditrict heating / Ditrict CHW loop
FSH 2745 Rocco Dining Hall	83,000	3	Dining facility	Natural gas / Electricity
FSH 247 Admin	24,074	2	Office	Natural gas / Electricity



RTS modeling approach and single zone assumption used

Relative error in annual site energy by energy type (left) and in total site energy (right) for JBSA buildings.

CONCLUSIONS

- Standard validation procedure required CTF modeling approach
- Field tests produce results with high accuracy even when using RTS modeling approach
  - All JBSA buildings demonstrated have low percentage of glass and are well insulated, so single-zone assumption was reasonable
  - Other factors (internal gains and ventilation) dominate the energy balance equation