Autotune Building Energy Models

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Purpose & Objectives

Problem Statement:

- "All (building energy) models are wrong, but some are useful"
  - 22%-97% different from utility data for 3,349 buildings
- More accurate models are more useful
  - Error from inputs and algorithms for practical reasons
  - Useful for cost-effective energy efficiency (EE) at speed and scale
- Calibration is required to be (legally) useful
  - ASHRAE G14 (NMBE<5/10% and CV(RMSE)<15/30% monthly/hourly)
- Manual calibration is risk/cost-prohibitive
  - Development costs 10-45% of federal ESPC projects <$1M
- Need robust and scalable automated calibration for market
  - Adjusts parameters in a physically realistic manner
  - Scales to any available data and model (audit)

Purpose & Objectives

Impact of Project:

- Reduces transaction cost of developing and selling EE improvement projects in existing buildings
- Enables the ESCO business model to reach smaller buildings and projects
- Enables speed and scale deployment approaches based on every building in served area having a continuously maintained calibrated model (audit)
- Enables tracked actual performance of implemented EE measures to improve model (audit) over time

Project endpoint is an automated calibration package that users of simulation tools can deploy as they choose.

Purpose & Objectives

Project Focus:

Objective: Develop a generalized, automated model (audit) tuning methodology that enables the model (audit) to reproduce measured data as best it can, by selecting best-match input parameters in a systematic, automated, and repeatable fashion.

BTO Goals: supports the BTO overarching goal of reducing building energy use 50% by 2030

BTO strategic programs: Autotune is listed as a “key service” within the BTO Strategic BEM Portfolio

Approach

Approach:

- Multi-objective optimization algorithms to minimize error between simulation output and measured data by intelligently adjusting building model inputs
- Sensitivity analysis and uncertainty quantification to determine importance of individual parameters
- Suite of machine learning algorithms to generate calibration functions based on building dynamics
- Quantify trade-off between tuning accuracy and amount of data available
- Creation of intuitive Autotune application on user's PC or website with database, software tools, and accelerated tuning agents in the background

Approach

Approach:

- Demonstrations of end-to-end Autotune prototype on:
  - ORNL's fleet of research houses and light commercial test buildings (flexible research platforms)
  - Weatherization and audit buildings "in the wild"

Key Issues:

- How well does it reproduce measured data?
- How long does it take?
- How well does this represent the actual building?

Approach

Distinctive Characteristics:

- Method scalable to available data
- Methods employed are model (audit) agnostic
- Can be used to speed up model (audit) runtime
- Capabilities in place for big data mining
- Interactive dashboard for Autotune progress
- Repeatable tuning results

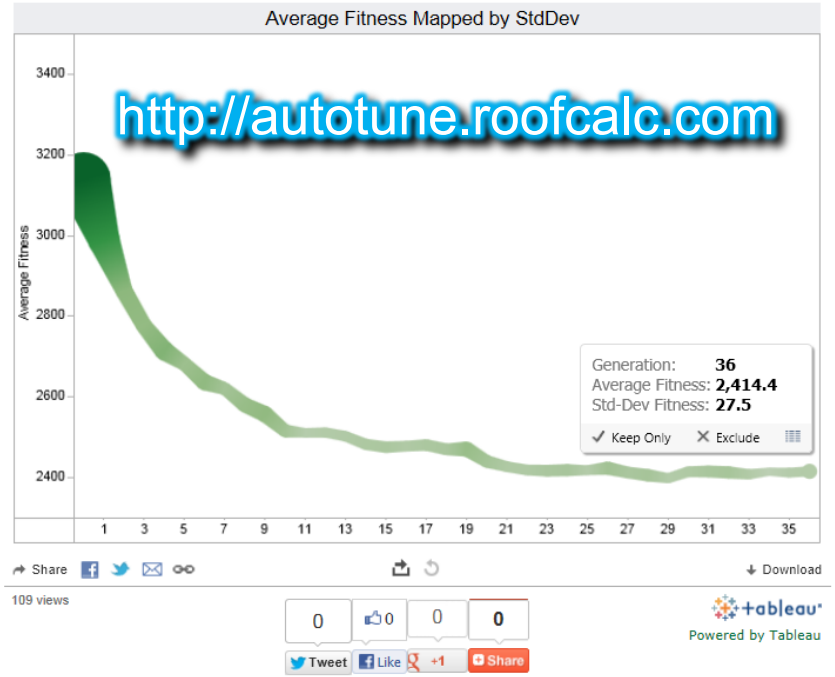
Accomplishments:

- End-to-end Windows desktop prototype created
- Overnight tuning of envelope-only parameters, 61% as accurate as 4 man-months of effort
- Autotune 156 EnergyPlus inputs in 3 hours on desktop was within 30¢/day (actual use $4.97/day)
- Autotune for National Energy Audit Tool (NEAT)
  - 15 inputs (±30%), reduced error 48%, 20mins on netbook
  - Experts would have tuned same way; 9,154 buildings
- Trinity test shows G14 compliance and realistic tuning
  - Outputs: CV(RMSE)<2.5%, NMBE<1% both hourly and monthly
  - Inputs: For 60% range, Autotune is close to real value (within 8% when tuning to hourly data, 15% when tuning to monthly data)

Accomplishments and Progress

Accomplishments:

- Titan scalability – 65k cores, 262,144 EnergyPlus (9TB), 44mins
- MLSuite allows easy use of software on supercomputers
- Tableau and Google Vis API interactive visualization and comparison of all Autotune experiments

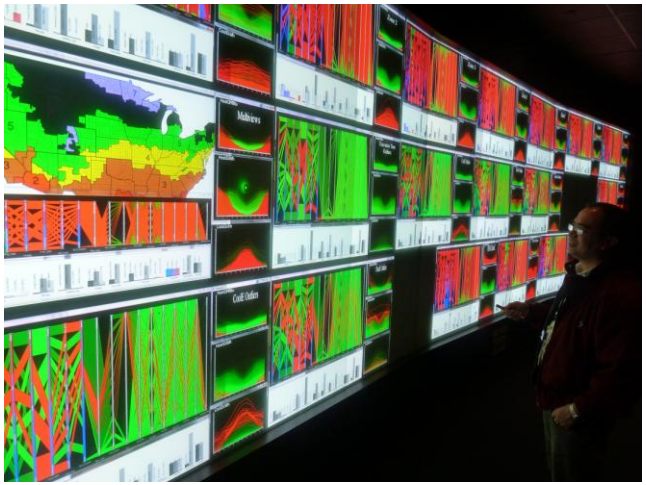


Progress on Goals:

- Tuning accuracy satisfies ASHRAE Guideline 14
- Less than 3 hours on standard computer
- Physically realistic results

Awards/Recognition:

- 2+ million core-hours, 4 competitive awards (free cost share)
- Extreme Science and Engineering Discovery Environment (XSEDE)
  - Nautilus 30k core-hours (CY11), 200k (CY12), 500k (CY13)
- Oak Ridge Leadership Computing Facility (OLCF)
  - Jaguar 500k core-hours (CY12), Titan 500k (CY13), Frost 200k (CY13), Lens/EVEREST (CY12&13)



Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project initiation date: Oct. 2011 (FY12)
Project planned completion date: Sept. 2014 (FY14)
Schedule and Milestones:

- FY12 – 10 DOE deliverables on time and budget
- FY13 – 7 of 14 DOE deliverables so far, all on time and budget

Summary	
WBS Number or Agreement Number	312856DC, 312856DF
Project Number	FY12-08, FY13-02
Agreement Number	BT0201, BT0305

Legend: Work completed; Active Task; Milestones & Deliverables (Original Pla; Milestones & Deliverables (Actual

Task / Event	FY2012 Q1 (Oct-De	Q2 (Jan-Ma	Q3 (Apr-Jur	Q4 (Jul-Sep	FY2013 Q1 (Oct-De	Q2 (Jan-Ma	Q3 (Apr-Jur	Q4 (Jul-Sep	FY2014 Q1 (Oct-De	Q2 (Jan-Ma	Q3 (Apr-Jur	Q4 (Jul-Sep
Project Name: Autotune E+ Building Models												
D1) Sensitivity analysis of ZEBRAlliance E+ building model												
D2) Mapping mechanism for E+ to sensor data												
D3) Heterogeneous learning systems for directed variable tuning												
D4) Initial Autotune status and performance report												
1) Autotune Reporting												
2) Monthly utility bill calibration												
3) Building templates												
4) Autotune capabilities												
5) Reporting and Travel												

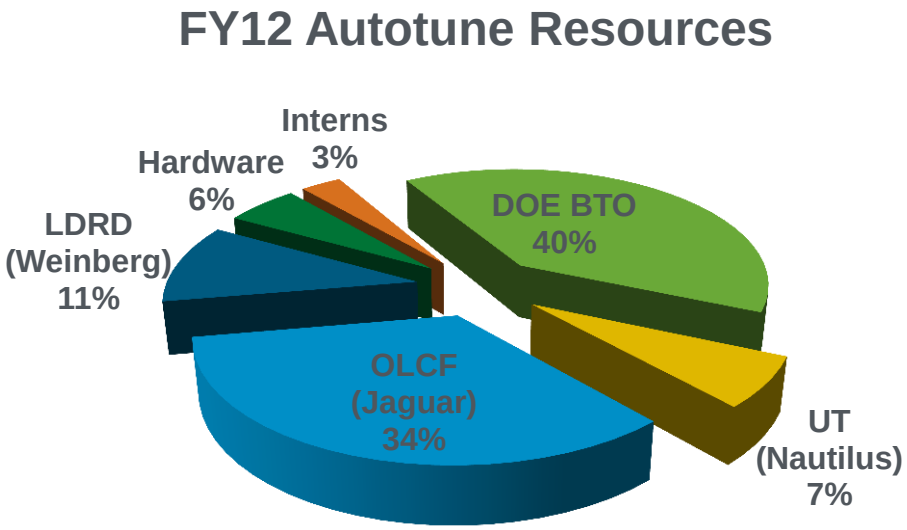
Project Budget

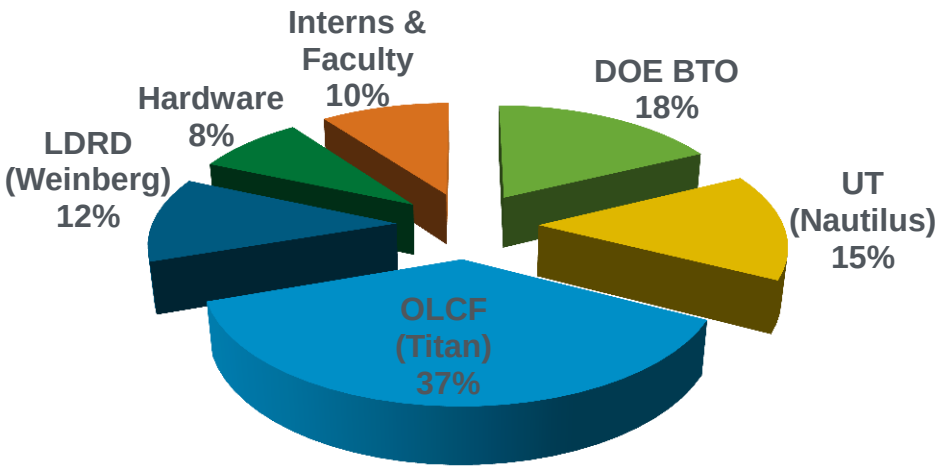
Cost to Date:

- FY12: fully costed
- FY13: $119k (45%)

Budget History			
FY2012		FY2013	
DOE	Cost-share	DOE	Cost-share
$650k	$980k	$264k	$1,225k

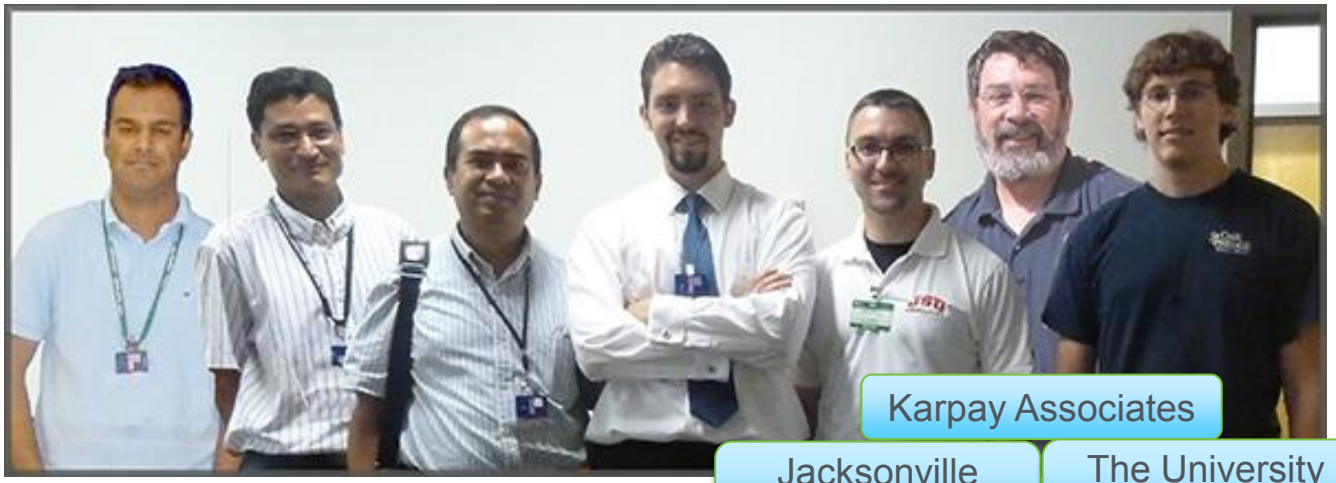
Funding Sources:





Project Integration, Collaboration & Market Impact

Partners, Subcontractors, and Collaborators:



Karpay Associates

Jacksonville State University

The University of Tennessee

Technology Transfer, Deployment, Market Impact:

- Autotune Invention Disclosure filed
- 5 software systems to copyright and release
- Plan to deploy Autotune in FY13

Communications (selected):

1 PhD Dissertation, 2 journals, 5 conference, 6 submitted soon, 5 internal reports (250+ pages)

Published:

- New, Joshua R., Sanyal, Jibonananda, Bhandari, Mahabir S., Shrestha, Som S. (2012). "Autotune EnergyPlus Building Energy Models." In *Proceedings of the 5th National SimBuild of IBPSA-USA*, International Building Performance Simulation Association (IBPSA), Aug. 1-3, 2012. [PDF pre-print]
- Sanyal, Jibonananda, Al-Wadei, Yusof H., Bhandari, Mahabir S., Shrestha, Som S., Karpay, Buzz, Garret, Aaron L., Edwards, Richard E., Parker, Lynne E., and New, Joshua R. (2012). "Poster: Building Energy Model Calibration using EnergyPlus, Machine Learning, and Supercomputing." In *Proceedings of the 5th National SimBuild of IBPSA-USA*, International Building Performance Simulation Association, Aug. 1-3, 2012. [PDF]

Accepted:

- Garrett, Aaron, New, Joshua R., and Chandler, Theodore. “Evolutionary Tuning of Building Models to Monthly Electrical Consumption”. ASHRAE Conference in Denver, CO, June 22-26, 2013.
- Sanyal, Jibonananda and New, Joshua R. “Simulation and Big Data Challenges in Tuning Building Energy Models”. IEEE Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, May 2013.

Planned/submitted:

- Edwards, Richard E., New, Joshua R., and Parker, Lynne E. “Constructing Large Scale EnergyPlus Surrogates from Big Data”. To be submitted to Energy & Buildings Journal, 2013.
- Garrett, Aaron and New, Joshua R. “Scalable Evolutionary Tuning of Building Models to Multiple Channels of Sub-Hourly Data”. To be submitted to ASHRAE, New York City, NY, Jan. 18-22, 2014.

Internal:

- Edwards, Richard E., and Parker, Lynne E. (2013). “MLSuite - FY2012 Final Report”. 68 pages
- Garrett, Aaron and New, Joshua R. (2012). “An Evolutionary Approach to Parameter Tuning of Building Models”. 68 pages
- Edwards, Richard E., New, Joshua R., and Parker, Lynne E. (2012) “Approximate l-fold cross-validation with Least Squares SVM and Kernel Ridge Regression”. 9 pages

Next Steps and Future Plans

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- BTO – finish Autotune project as detailed
- BTO – deploy in residential and commercial building integration program elements
- Weatherization – Autotune NEAT comparison of human vs. computer calibration
- Federal Energy Management Program – ESPC ENABLE program