Visualization and Software Simulations for Actualized Energy Savings

ASHRAE Local Chapter
Jan. 21, 2015

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40 Years: Energy and Quality of Life
A brief history of energy and life quality
Sustainability is the defining challenge

- **Buildings in the U.S.**
  - 41% of primary energy/carbon
  - 73% of electricity, 34% of gas

- **Buildings in China**
  - 60% of urban building floor space in 2030 has yet to be built

- **Buildings in India**
  - 67% of all building floor space in 2030 has yet to be built
Energy Consumption and Production

U.S. Primary Energy Consumption
- Residential Buildings: 28%
- Commercial Buildings: 22%
- Industrial: 31%
- Transportation: 19%

Commercial Site Energy Consumption by End Use
- HVAC 32%
- Lighting 25%
- Water heating 6%
- Refrigeration 4%
- Electronics & Computers 12%
- Other 13%

Energy Consumption and Production

The Role of Renewable Energy in the Nation’s Energy Supply, 2009
- Total = 94.578 Quadrillion Btu
- Renewable Energy 8%
- Petroleum 37%
- Natural Gas 25%
- Coal 21%
- Nuclear Electric Power 9%
- Geothermal 5%
- Biomass waste 6%
- Wind 9%
- Wood 24%
- Biofuels 20%

World Energy Production

TN 2012 Electric Bill - $1,533
Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work
- Autotune
- Publications
Presentation summary

- Scientific Paradigms (context)
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work
- Autotune
- Publications
4th Paradigm – The Science behind the Science

• Empirical – guided by experiment/observation
  – In use thousands of years ago, natural phenomena

• Theoretical – based on coherent group of principles and theorems
  – In use hundreds of years ago, generalizations

• Computational – simulating complex phenomena
  – In use for decades

• Data exploration (eScience) – unifies all 3
  – Data capture, curation, storage, analysis, and visualization
  – Jim Gray, free PDF from MS Research
Presentation summary

• Scientific Paradigms
• Roof Savings Calculator
• Visual Analytics
• Knowledge Work
• Autotune
Urban Heat Island Effect and Albedo Engineering

Image from Lawrence Berkeley National Laboratory
Computer tools for simulating cool roofs

Roof Savings Calculator (RSC)

Chris Scruton
CEC

R. Levinson,
H. Gilbert,
H. Akbari

Marc LaFrance
DOE BT

A. Desjarlais,
W. Miller,
J. New

INDUSTRY

COLLABORATIVE
R&D

LBNL

ORNL

WBT

Joe Huang,
Ender Erdem
Roof Savings Calculator

- Replaces:
  - EPA Roof Comparison Calc
  - DOE Cool Roof Calculator

- Minimal questions (<20)
  - Only location is required
  - Building America defaults
  - Help links for unknown information
RSC = AtticSim + DOE-2.1E

AtticSim - ASTM C 1340 Standard For Estimating Heat Gain or Loss Through Ceilings Under Attics
Commercial building types

Office  "Big Box" Retail  Warehouse

RoofCalc.com impact

100,000+ visitors, 200+ user feedback,

Average: ~81 visitors/day

30,752 visits came from 112 countries/territories

This country/territory sent 28,498 visits via 52 regions

United States
Canada
India
Australia
United Kingdom
South Korea
Italy
Nationwide results

Cost savings for offices - 14 cities, local utility prices, 22 roof types

<table>
<thead>
<tr>
<th>Description</th>
<th>Reflectance</th>
<th>Emisivity</th>
<th>SRI</th>
<th>Houston $ saved</th>
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<td>49</td>
<td>83</td>
<td>55</td>
<td>208</td>
<td>...13</td>
</tr>
</tbody>
</table>

Summer operation of HVAC duct in ASHRAE climate zone 3
Enhanced RSC Site

Input Parameter GUI

Result Output

Database

Total Savings: $178

These numbers represent our estimate of your energy costs. You can specify new values and re-calculate.

Electricity price (cents per kWh):
11.68

Natural gas price (dollars per 1000 ft$^3$):
11.65

Re-calculate savings

Heating
Cooling

User

Hyperion

RSC Engine

Inputs

Savings

Simulation

Exists?

Savings

RSC Engine

Database

Results
“We speak piously of ... making small studies that will add another brick to the temple of science. Most such bricks just lie around the brickyard.”
RSC Service Example (Python)

client = suds.client.Client('URL/TO/WEB/SERVICE/rsc.wsdl')
print(client)

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('..//examplemodel.xml', sm)
sr = client.service.simulate(sm)
print(sr)

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('..//examplemodel.xml', sm)
print(sm)
contents = client.service.test(sm)
with open('pytest.zip', 'wb') as outfile:
    outfile.write(base64.b64decode(contents))

...download example building and batch script from rsc.ornl.gov/web-service.shtml
Update 1 line of code to change servers

```python
import base64
import suds
import xml.dom.minidom
import logging

def loadSoapModelFromXml(xmlfilename, soapmodel):

def loadSoapResultsFromXml(xmlfilename, soapresults):

logging.basicConfig()

test_type = ['simulate', 'test', 'upload', 'download']

print("hello there, initializing client")
client = suds.client.Client('http://evenstar.ornl.gov/RSC/service/rsc.wsdl')
print("printing client")
print(client)
raw_input('Press Enter to continue...'+"\n")
```
Millions of simulations visualized for DOE’s Roof Savings Calculator and deployment of roof and attic technologies through leading industry partners

**DOE: Office of Science**  
**CEC & DOE EERE: BTO**  
**Industry & Building Owners**

Engine (AtticSim/DOE-2) debugged using HPC Science assets enabling visual analytics on 3x(10)^6 simulations

CentiMark, the largest nation-wide roofing contractor (installs 2500 roofs/mo), is integrating RSC into their proposal generating system (20+ companies now interested)

**AtticSim**

Roof Savings Calculator (RSC) web site/service developed and validated [estimates energy and cost savings from roof and attic technologies]

Leveraging HPC resources to facilitate deployment of building energy efficiency technologies
Personal story behind one of DOE’s RSC images

14. Radiant barrier present:
- Yes
- No

15. Attic insulation (ft²):
- R-50
- R-38
- R-19
- R-11
- R-7
- R-5
- R-3
- None

16. Duct location:
- Conditioned space
- Attic

17. Duct leakage:
- Inspected (4%)
- Uninspected (14%)

Duct Leakage
Leaky ducts in unconditioned spaces are effectively costing you money to condition the planet, not your house. Commercial buildings have typical leakage rates of 10–20%; likewise, residential buildings typically have duct leakage rates near 14%. The CEC’s Title 24 target leakage rate for insulated ducts is 4% and requires no greater than 6%. This calculator supports duct leakage rates of 4% and 14%.

Leaky Connection
Damaged Duct
Sealed Ducts
Presentation summary

• Scientific Paradigms
• Roof Savings Calculator
• Visual Analytics
• Knowledge Work
• Autotune
PCP - car data set
PCP bin rendering (data)

• Transfer function coloring:
  – Occupancy or leading axis
The power of “and” – linked views (info)

Multivariate Visualization of Large-Scale Parameter Sweeps

Parallel Coordinates Plots +

Time-variant Function Plots +

Category Charts +

Climate Zone Map =

Roof Savings Calculator
www.roofcalc.com
Dr. Joshua New (ORNL) and Chad Jones (UC-Davis)
Dr. William A. Miller (ORNL), A. Desjarlais (ORNL), Yu Joe Huang (WhiteBox), Ender Erdem (WhiteBox)
Large Data Visualization

Knowledge

Large Data Visualization
Outliers (wisdom)

• Selection of heating outliers
• Find all have box building type and in Miami
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McKinsey Global Institute Analysis

Exhibit E3
Estimated potential economic impact of technologies from sized applications in 2025, including consumer surplus
$ trillion, annual

- Mobile Internet: 3.7–10.8
- Automation of knowledge work: 5.2–6.7
- The Internet of Things: 2.7–6.2
- Cloud technology: 1.7–6.2
- Advanced robotics: 1.7–4.5

Source: McKinsey Global Institute analysis
$1000 machine helping meat machines
Humans and computers

- 3 lbs (2%), 20 watts (20%)
- 120-150 billion neurons
- 100 trillion synapses
  - Firing time ~milliseconds
- 11 million bits/second input
  - Consciousness - 40 bits/second
- Working memory – 4-9 words
- Long-term memory – 1-1k TB
- Complex, self-organizing

- PC – 40 lbs, 500 watts
- 4 cores
- 3 billion Hz
  - Firing time ~nanoseconds
- 100 million bits/second
  - Not yet
- 62,500,000 words
- Disk – 3TB, perfect recall
Learning associations

Full Results

Detailed Results
Presentation summary

• Scientific Paradigms
• Roof Savings Calculator
• Visual Analytics
• Knowledge Work (context)
• Autotune
Existing tools for retrofit optimization

Simulation Engine
DOE—$65M (1995–?)

API

OpenStudio
Business limitations for M&V

3,000+ building survey, 23-97% monthly error

<table>
<thead>
<tr>
<th></th>
<th>ASHRAE G14 Requires</th>
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<tbody>
<tr>
<td>Using Monthly utility data</td>
<td>CV(RMSE) 15%</td>
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<tr>
<td></td>
<td>NMBE 5%</td>
</tr>
<tr>
<td>Using Hourly utility data</td>
<td>CV(RMSE) 30%</td>
</tr>
<tr>
<td></td>
<td>NMBE 10%</td>
</tr>
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</table>
The Autotune Idea
Automatic calibration of software to data
The search problem

Problem/Opportunity:
~3000 parameters per E+ input file

2 minutes per simulation = 83 hours
ORNL High Performance Computing Resources

Titan:
299,008 CPU cores
18,688 GPU cores
710TB memory, distributed

Jaguar:
224,256 cores
360TB memory

Nautilus:
1024 cores
4TB shared-memory

Kraken:
112,896 cores

Gordon:
12,608 cores
SSD
HPC scalability for desktop software

- EnergyPlus desktop app
- Writes files during a run
- Uses RAMdisk
- Balances simulation memory vs. result storage
- Works from directory of input files & verifies result
- Bulk writes results to disk

Acknowledgment: Jibo Sanyal, ORNL R&D Staff
Computational complexity

Problems/Opportunities:
Domain experts chose to vary 156
Brute-force = $5 \times 10^{52}$ simulations

E+ parameters

LoKU
13.75 billion years

Need $4.1 \times 10^{28}$ LoKU
What is artificial intelligence?

• Give it (lots of) data
• It maps one set of data to another
• Paradigms
  – Unsupervised (clustering)
  – Reinforcement (don’t run into wall)
  – Supervised (this is the real answer)
• Methods for doing that... biologically motivated or not
MLSuite: HPC-enabled suite of machine learning algorithms

- Linear Regression
- Feedforward Neural Network
- Support Vector Machine Regression
- Non-Linear Regression
- K-Means with Local Models
- Gaussian Mixture Model with Local Models
- Self-Organizing Map with Local Models
- Regression Tree (using Information Gain)
- Time Modeling with Local Models
- Recurrent Neural Networks
- Genetic Algorithms
- Ensemble Learning

Acknowledgment: UTK computer science graduate Richard Edwards, Ph.D. (advisor Dr. Lynne Parker); now Amazon
MLSuite example

• EnergyPlus – 2-10 mins for an annual simulation

!- ALL OBJECTS IN CLASS
Version,
  7.0; !- Version

!- SIMULATION CONTROL
Simulation Control,
  No, !-Do Zone Sizing Calc
  No, !-Do System Sizing Calc
...

• ~E+ - 4 seconds AI agent as surrogate model, 90x speedup, small error, brittle
“the world is the best model of itself.”

–Rodney Brooks, 1990, Elephants and nouvelle AI

Nouvelle AI. A robot should sense and then move according to simple rules such as “Avoid collisions” or “Wander.”
Source of Input Data

- 3 Campbell Creek homes (TVA, ORNL, EPRI)
- ~144 sensors/home, 15-minute data:
  - Temperature (inside/outside)
  - Plugs
  - Lights
  - Range
  - Washer
  - Radiated heat
  - Dryer
  - Refrigerator
  - Dishwasher
  - Heat pump air flow
  - Shower water flow
  - Etc.
MLSuite Architecture

Data Preparation

30x LS-SVMs
validation folds 1-10
input orders 1-3
Applications of machine learning

• Linear Regression predicting whole building energy use

- House 1 (House 2 is similar)
- House 3
- House 3 Next hour

• Accuracy Metrics for best subset of sensors

- Root Mean Squared Error (RMSE):
  \[ RMSE = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (y_i - p_i)^2} \]

- Mean Absolute Percentage of Error (MAPE):
  \[ MAPE = \frac{1}{N} \sum_{i=1}^{N} \frac{|y_i - p_i|}{y_i} \]

- Coefficient of Variance (CV):
  \[ CV = \frac{RMSE}{y_{mean}} \times 100 \]

- Mean Bias Error (MBE):
  \[ MBE = \frac{1}{N-1} \sum_{i=1}^{N} (y_i - p_i) \times 100 \]

<table>
<thead>
<tr>
<th>HME FFNN</th>
<th>HME LS-SVM</th>
<th>SVR</th>
<th>FCM</th>
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<tbody>
<tr>
<td>RMSE (Watt-Hours)</td>
<td>569.96±50.13</td>
<td>582.61±33.97</td>
<td>603.85±40.55</td>
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<tr>
<td>MAPE(%)</td>
<td>17.07±1.19</td>
<td>15.94±0.92</td>
<td>15.48±0.87</td>
</tr>
<tr>
<td>CV(%)</td>
<td>20.14±1.65</td>
<td>20.59±1.12</td>
<td>21.32±1.32</td>
</tr>
<tr>
<td>MBE(%)</td>
<td>0.42±1.17</td>
<td>-0.07±0.89</td>
<td>-1.50±0.80</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Best Four Sensors</th>
<th>Best Model</th>
<th>Top 10 Sensors</th>
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</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>1127.88±33.00</td>
<td>942.25±26.14</td>
</tr>
<tr>
<td>MAPE</td>
<td>41.17±1.12</td>
<td>30.53±1.03</td>
</tr>
<tr>
<td>CV</td>
<td>39.76±1.02</td>
<td>33.21±0.73</td>
</tr>
<tr>
<td>MBE</td>
<td>-0.04±0.90</td>
<td>-0.06±0.92</td>
</tr>
<tr>
<td>ICOMP (IFIM)</td>
<td>2166.3±1.54</td>
<td>1845.88±21.25</td>
</tr>
</tbody>
</table>
MLSuite: HPC-enabled Suite of Machine Learning algorithms

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- K-means with local models
- Gaussian mixture model with local models
- Self-organizing map with local models
- Regression tree (using information gain)
- Time modeling with local models
- Recurrent neural networks
- Genetic algorithms
- Ensemble learning
Evolutionary computation

How are offspring produced?

<table>
<thead>
<tr>
<th></th>
<th>Thickness</th>
<th>Conductivity</th>
<th>Density</th>
<th>Specific Heat</th>
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<tr>
<td>Bldg1</td>
<td>0.022</td>
<td>0.031</td>
<td>29.2</td>
<td>1647.3</td>
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<tr>
<td>Bldg2</td>
<td>0.027</td>
<td>0.025</td>
<td>34.3</td>
<td>1402.5</td>
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<tr>
<td>(1+2)₁</td>
<td>0.0229</td>
<td>0.029</td>
<td>34.13</td>
<td>1494.7</td>
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<tr>
<td>(1+2)₂</td>
<td>0.0262</td>
<td>0.024</td>
<td>26.72</td>
<td>1502.9</td>
</tr>
</tbody>
</table>

- Average each component
- Add Gaussian noise
- … “AI inside of AI”
Getting more for less

• EnergyPlus is slow
  – Full-year schedule
  – 2 minutes per simulation

• Use abbreviated 4-day schedule instead
  – Jan 1, Apr 1, Aug 1, Nov 1
  – 10 – 20 seconds per simulation

Monthly Electrical Usage  
Hourly Electrical Usage

\[ r = 0.94 \]  
\[ r = 0.96 \]
Evolutionary combination

4 of 19 experiments
1. Surrogate Modeling
2. Sensor-based Energy Modeling (sBEM)
3. Abbreviated Schedule
4. Island-model evolution
Automated M&V process Autotune calibration of simulation to measurements

**Features:**
- Works with "any" software
- Tunes 100s of variables
- Customizable distributions
- Matches 1+ million points

**Commercial Buildings**
- Monthly utility data: CVR 15%, NMBE 5%
- Hourly utility data: CVR 30%, NMBE 10%

**Residential home**
- Tuned input avg. error: Within 30¢/day (actual use $4.97/day), Hourly – 8%
- Monthly – 15%

**Leveraging HPC resources to calibrate models for optimized building efficiency decisions**
HPC-informed algorithmic reduction... to commodity hardware

LoKU
13.75 billion years

Need $4.1 \times 10^{28}$ LoKU

1 hour
That’s great, but how can I use it?

**Autotune**

**Introduction to Autotune**

Autotune can save time, effort, and money in modeling a building. Autotune uses a rough estimate of the building and real data to create models that more closely represent the building. All you have to do is get started with one of the setups and you can soon have models of your building.

**About This Website**

Autotune is designed to make the modeling process easier. You can start designing your model through the basic or advanced setup. If you have already completed the setup, you can enter your tracking number into the tracking box to review the progress of your order or download models if any are available.

*Enjoy the simplistic power of Autotune!*

**Create a model for your building**

**Basic Setup**

The basic setup is designed with simplicity in mind. If you have only the basic knowledge of the building, this is the choice of setup for you.

**Advanced or Experienced Setup**

The advanced setup is for those who are very knowledgeable with the specifications of the building. This setup will provide the most customized model and will result in quicker, more accurate results.

![Image of Autotune interface](Image)

**IDF Generation**

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
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<td>Timestep</td>
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<tr>
<td>Run Number</td>
<td>1</td>
</tr>
<tr>
<td>Floor Height (meters)</td>
<td>3.9624</td>
</tr>
<tr>
<td>Plenums</td>
<td>True</td>
</tr>
<tr>
<td>Orientation</td>
<td>0.0</td>
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<tr>
<td>Geometry</td>
<td>Rectangle</td>
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<tr>
<td>Configuration</td>
<td>Five Zone</td>
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<tr>
<td>Zone Layout</td>
<td>Flat</td>
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<tr>
<td>Wall Type</td>
<td>Steel Frame Non Res</td>
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<tr>
<td>Roof Style</td>
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<td>Roof Type</td>
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<td>South WWR</td>
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<td>East WWR</td>
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<td>North WWR</td>
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<td>West WWR</td>
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<td>South Window Type</td>
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<td>East Window Type</td>
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<td>North Window Type</td>
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<td>West Window Type</td>
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<td>HVAC Type</td>
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<td>Has Reheat</td>
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<td>Reheat Coil</td>
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**60+ fields** (optional)
Determine inputs to calibrate

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<th></th>
<th>Restaurant</th>
<th>Hospital</th>
<th>Large Hotel</th>
<th>Large Office</th>
<th>Medium Office</th>
<th>Midrise Apartment</th>
<th>Primary School</th>
<th>Quick Service</th>
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<td>81</td>
<td>155</td>
<td>166</td>
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<tr>
<td>#Groups</td>
<td>49</td>
<td>146</td>
<td>71</td>
<td>45</td>
<td>38</td>
<td>82</td>
<td>113</td>
<td>54</td>
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<table>
<thead>
<tr>
<th></th>
<th>Secondary School</th>
<th>Small Hotel</th>
<th>Small Office</th>
<th>Stand-alone Retail</th>
<th>Strip Mall</th>
<th>Super Market</th>
<th>Warehouse</th>
<th>TOTAL</th>
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<tbody>
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<td>72</td>
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<td>113</td>
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<td>#Groups</td>
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<td>89</td>
<td>73</td>
<td>45</td>
<td>1143</td>
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<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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<td>1</td>
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<td>Object</td>
<td>Field</td>
<td>Default</td>
<td>Minimum</td>
<td>Maximum</td>
<td>Distribution</td>
<td>Type</td>
<td>Group</td>
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<td>20.28</td>
<td>uniform</td>
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</tbody>
</table>
Provide actual data

Select location
Current Selection: Chicago, IL

Input Data

Electricity
Have a file containing energy usage:
Choose File | No file chosen
Sample File: Monthly Sample, Hourly Sample
OR

Energy usage from previous months:

<table>
<thead>
<tr>
<th>Month</th>
<th>Energy Usage kWh</th>
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<tbody>
<tr>
<td>January</td>
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<tr>
<td>February</td>
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<td>June</td>
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<td>July</td>
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<td>November</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td></td>
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</tbody>
</table>

Gas

Temperature

Tune
You have completed all the steps of the wizard!
Click Tune below to Submit your Information

Email Address (optional):
### Autotune returns calibrated model

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<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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<tr>
<td>Input error average</td>
<td>24.38</td>
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<tr>
<td>Input error maximum</td>
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<td>Input error minimum</td>
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<tr>
<td>Input error variance</td>
<td>228.53</td>
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</tbody>
</table>

#### CV(RMSE)

- CH4:Facility [kg](Monthly): 9.95
- CO2:Facility [kg](Monthly): 15.42
- CO:Facility [kg](Monthly): 20.40
- Carbon Equivalent:Facility [kg](Monthly): 14.42
- Cooling:Electricity [J](Hourly): 1577.96
- Electricity:Facility [J](Hourly): 10.48

#### NMBE

- CH4:Facility [kg](Monthly): -9.57
- CO2:Facility [kg](Monthly): -14.78
- CO:Facility [kg](Monthly): -19.52
- Carbon Equivalent:Facility [kg](Monthly): -13.83
- Cooling:Electricity [J](Hourly): 592.77
- Electricity:Facility [J](Hourly): -9.52
- Electricity:Facility [J](Monthly): -9.52

143+ outputs

---

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  </Name>
  <Roughness>
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    tuneDistribution="uniform"
    tuneGroup="A"
    tuneConstraint="A+B<1">
    0.005
  </Thickness>
</Material>
```

IDF + CSV = XML
# Performance and availability

<table>
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<th>Autotune Results</th>
<th>ASHRAE G14 Requires</th>
<th>Autotune Results</th>
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<td>Monthly utility data</td>
<td>CVR 15%</td>
<td>0.32%</td>
<td>CVR 15%</td>
<td>1.20%</td>
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<tr>
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<td>NMBE 5%</td>
<td>0.06%</td>
<td>NMBE 5%</td>
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<tr>
<td>Hourly utility data</td>
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<td>0.07%</td>
<td>NMBE 10%</td>
<td>0.35%</td>
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</tbody>
</table>

Results from 24 Autotune calibrations (3 building types - 8, 34, 79 tuned inputs each)

Results from 20,000+ Autotune calibrations (15 types – 47-282 tuned inputs each)

FY15 project to begin integration of Autotune web service as an OpenStudio application
Free to use. Pay for cloud computing.
Discussion

Oak Ridge National Laboratory
EESD – Martin Keller
ETSD – Johney Green
BTRIC – Patrick Hughes & Ed Vineyard
WBCI – Melissa Lapsa

Joshua New, Ph.D.
newjr@ornl.gov