Hybrid Session C5: Advanced Modeling: Calibration

Reducing Building Energy Modeling Workloads Through Automated Calibration

Daniel Villa, P.E.
Sandia National Laboratories

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dlvilla@sandia.gov
505-340-9162
Learning Objectives

- Understand one approach to application of auto-calibration to building energy models
- Understand some of the tradeoffs between automatic and manual methods for increasing the accuracy of building energy models
Acknowledgements

• For advocating and funding this work: Jerry Gallegos, Robin Jones, and Jack Mizner
• For the loving support of God and my family

• Potential Sources of Bias: Sandia National Laboratories, Tunation LLC, NTESS, Honeywell, Rice University, Purdue University, University of Texas Rio Grande Valley.
Outline

• Vision/Background
• Example building #1
• Automatic calibration measure design
• Manual quality checks
• Automated calibration
• Manual vs automated calibration time-resource comparison
• Conclusions
Vision/Background

• We aspire to build a site-wide framework for using building energy models (BEM) as the authorized configuration for a building’s energy performance
• We want to be able to use building energy models for multiple applications including:
  • Legal compliance to energy breakdown estimate requirements
  • Assessments of energy conservation measures on existing buildings
  • (Future) Combined BEM/data analytics
  • (Future) Model predictive control
• To accomplish our goals, BEM needs to progress to a higher level of efficiency in work flows to reduce costs and effort required to keep models up to date
• We are currently trying to learn how to efficiently maintain 121 BEM of existing buildings
Vision: Modeling site-wide evolution

- **Past site**
  - 2016: Historical data
  - 2017: ECMs Evaluated no changes
  - ECM Planned

- **Present**
  - 2018: ECM Applied
  - Construction
  - Calibration
  - Recalibrate model
  - Updated Model with ECM

- **Future site**
  - 2019: Demolition
  - 2020: Future Representative
  - Assess site-wide energy future plan
  - Climate change projections
  - Future

Vision: Modeling site-wide evolution

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- **Present**
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Vision: Modeling site-wide evolution
Building #1

- 3 level 72,243ft² Light Lab with 2 24-7 operational exhaust systems
- Mixed single duct and dual duct on different HVAC systems
- Multiple additional lab air-handlers with independent operation modes
- Previously calibrated in 2014 to NMBE -2.92%, CV(RMSE) 5.41% - but falls outside of compliance for 2017
- 5.42 GWh energy consumption 2017
Insertion of Calibration Expressions

• Once developed, automatic insertion of calibration parameters saves significant time and cost
  • Visual Basic for applications insertion by Building Design Language (BDL) parser
  • Parameters are designed to not interfere with the current state of the BEM
  • Two types of parameters:
    • Multiplier (default value = 1.0 range 0.2 to 5)
    • Base load fraction offset (default value = 0.0 range -1 to 1)
Multiplier Effect

\[ f_{new}(t) = p_{mult} f(t) \]

\[ 5 > p_{mult} > 0.2 \]
$p_{off} \rightarrow 1$ causes base load to approach peak load

$p_{off} = -1$ causes base load to be zero with no change to peak load

$$f_{new}(t) = \begin{cases} 
(1 - p_{off})f(t) + f_{max}p_{off} & 1 \geq p_{off} \geq 0 \\
-p_{off}f_{new-1}(t) + (p_{off} + 1)f(t) & -1 \leq p_{off} < 0 
\end{cases}$$

$$f_{new-1}(t) = \frac{f_{max}}{f_{max} - f_{min}} f(t) - \frac{f_{max}f_{min}}{f_{max} - f_{min}}$$
## 21 Parameter study sensitivity for Building #1

<table>
<thead>
<tr>
<th>10 % change in parameter</th>
<th>Total Energy 2017 (GWh)</th>
<th>ΔEnergy (GWh)</th>
<th>% Change</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td></td>
</tr>
<tr>
<td>calibCoolEffMult</td>
<td>5.3945</td>
<td>0.0267</td>
<td>0.492%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibEnvCondMult</td>
<td>5.4102</td>
<td>0.0110</td>
<td>0.203%</td>
<td>Multiplier</td>
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<tr>
<td>calibEnvDenMult</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibEnvSpHMult</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibEquipBaseFrac</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td>Baseload Offset</td>
</tr>
<tr>
<td>calibEquipmentMult</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibExhaustMult</td>
<td>5.4043</td>
<td>0.0169</td>
<td>0.311%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibFanMult</td>
<td>4.9280</td>
<td>0.4932</td>
<td>9.097%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibHeatEffMult</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibHeatRejectEffMult</td>
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<td>0.0000</td>
<td>0.000%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibInfiltrationMult</td>
<td>5.4213</td>
<td>-0.0001</td>
<td>-0.002%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibLightBaseFrac</td>
<td>5.4768</td>
<td>-0.0556</td>
<td>-1.025%</td>
<td>Baseload Offset</td>
</tr>
<tr>
<td>calibLightMult</td>
<td>5.5118</td>
<td>-0.0906</td>
<td>-1.672%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibOccupyBaseFrac</td>
<td>5.4094</td>
<td>0.0118</td>
<td>0.218%</td>
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<tr>
<td>calibOccupyMult</td>
<td>5.4093</td>
<td>0.0119</td>
<td>0.220%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibOutAirMult</td>
<td>5.4211</td>
<td>0.0001</td>
<td>0.002%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibPlugBaseFrac</td>
<td>5.4520</td>
<td>-0.0308</td>
<td>-0.568%</td>
<td>Baseload Offset</td>
</tr>
<tr>
<td>calibPlugMult</td>
<td>5.4761</td>
<td>-0.0549</td>
<td>-1.012%</td>
<td>Multiplier</td>
</tr>
<tr>
<td>calibPumpEffMult</td>
<td>5.3493</td>
<td>0.0719</td>
<td>1.326%</td>
<td>Multiplier</td>
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<td>calibSourceBaseFrac</td>
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<td>0.000%</td>
<td>Baseload Offset</td>
</tr>
<tr>
<td>calibSourceMult</td>
<td>5.4212</td>
<td>0.0000</td>
<td>0.000%</td>
<td>Multiplier</td>
</tr>
</tbody>
</table>
Calibration Parameter Insertion

- ECM Name: Building Calibration
- BDL Command
- Create A Custom Function for this Command (Must be named <ECM>_<Command> where spaces are replaced with "_"
- Add command
- Remove command (selected in list box)
- Select a Keyword Type
  - Numeric Integer
  - Numeric Real
  - Symbolic Defined
  - Symbolic Undefined (Unname)
  - Child Undefined (Positional)
- Key Word
- Action

- Commands searched for by ECM
  - BOILER
  - CHILLER
  - CONSTRUCTION
  - GLASS-TYPE
  - HEAT-REJECTION
  - LAYERS

- Keywords Changed or Checked by ECM
  - Keyword | Number of Entries | Minimum | Maximum | Type | Action
  - ELEC-INPUT-RATIO | 1 | 0 | 10 | Numeric Real | Function of Original
  - HEAT-INPUT-RATIO | 1 | 0 | 10 | Numeric Real | Function of Original
  - TYPE | 1 | 0 | 0 | Symbolic Define | Function of Original

- Add keyword
- Remove keyword (selected in list box)

Eligible eQUEST Parameter Names
- calibCalibrateBuilding
- calibCoolEffMult
- calibEnvCondMult

Key Value BDL Expression, New Commands to Add, or Check Condition: Do not exceed 80 characters per line!
No need for curly brackets around the expression, they are automatically inserted "{}"

`'Original'#/pa("calibHeatEffMult")`
Calibration Parameter Insertion

ECM Name: Building Calibration

Any ECM that is already applied to a checked in building will not appear here!

BDL Command

- Create A Custom Function for this Command (Must be named <ECM>_<Command> where spaces are replaced with "_")
- Add command
- Remove command (selected in list box)

Select a Keyword Type

- Numeric Integer
- Numeric Real
- Symbolic Defined
- Symbolic Undefined (Uname)
- Child Undefined (Positional)

Key Word: WATER-ECONO-EFF

Action: Function of Original

Keywords Changed or Checked by ECM

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Number of Entries</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Type</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEC-INPUT-RATIO</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>Numeric Real</td>
<td>Function of Original</td>
</tr>
<tr>
<td>TYPE</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>Symbolic Defined</td>
<td>Check</td>
</tr>
<tr>
<td>WATER-ECONO-EFF</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Numeric Real</td>
<td>Function of Original</td>
</tr>
</tbody>
</table>

Eligible eQUEST Parameter Names

- calibCalibrateBuilding
- calibCoolEffMult
- calibEnvCondMult
- calibEnvDenMult
- calibEnvSpHMult

Key Value BDL Expression, New Commands to Add, or Check Condition: Do not exceed 80 characters per line! No need for curly brackets around the expression, they are automatically inserted "{}"

```bash
if (#pa("calibCoolEffMult") * `Original` > 1) then
  1
else
  #pa("calibCoolEffMult") * `Original`
endif
```
Many operations to the BDL require custom functions that have not yet been incorporated into the user interface.
Calibration Parameter Insertion

55 keywords reference the 21 calibration parameters

<table>
<thead>
<tr>
<th>KeyWords</th>
<th>BDLCCommand</th>
<th>Action</th>
<th>KeyValueOrExpression</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEC-INPUT-RATIO</td>
<td>BOILER</td>
<td>Function of Original</td>
<td><code>Original</code>/#pa(&quot;calibHeatEffMult&quot;)</td>
</tr>
<tr>
<td>HEAT-INPUT-RATIO</td>
<td>BOILER</td>
<td>Function of Original</td>
<td><code>Original</code>/#pa(&quot;calibHeatEffMult&quot;)</td>
</tr>
<tr>
<td>TYPE</td>
<td>BOILER</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>ELEC-INPUT-RATIO</td>
<td>CHILLER</td>
<td>Function of Original</td>
<td><code>Original</code>/#pa(&quot;calibCoolEffMult&quot;)</td>
</tr>
<tr>
<td>TYPE</td>
<td>CHILLER</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>WATER-ECONO-EFF</td>
<td>CHILLER</td>
<td>Function of Original</td>
<td>if (#pa(&quot;calibCoolEffMult&quot;) * <code>Original</code> &gt; 1) then</td>
</tr>
<tr>
<td>TYPE</td>
<td>CONSTRUCTION</td>
<td>Check</td>
<td>l_if(`&quot;TYPE&quot;&quot; = &quot;U-VALUE&quot;,-1,0)</td>
</tr>
<tr>
<td>U-VALUE</td>
<td>CONSTRUCTION</td>
<td>Function of Original</td>
<td>#pa(&quot;calibEnvCondMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>GLASS-CONDUCT</td>
<td>GLASS-TYPE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibEnvCondMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>TYPE</td>
<td>GLASS-TYPE</td>
<td>Check</td>
<td>i_if(`&quot;TYPE&quot;&quot;=&quot;SHADING-COEFF&quot;,-1,0)</td>
</tr>
<tr>
<td>FAN-KW-FSPEED</td>
<td>HEAT-REJECTION</td>
<td>Change</td>
<td>&quot;Htrej-Fan-Pwr-fSpeed_calib&quot; = CURVE-FIT</td>
</tr>
<tr>
<td>TYPE</td>
<td>HEAT-REJECTION</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>INSIDE-FILM-RES</td>
<td>LAYERS</td>
<td>Function of Original</td>
<td><code>Original</code>/#pa(&quot;calibEnvCondMult&quot;)</td>
</tr>
<tr>
<td>CONDUCTIVITY</td>
<td>MATERIAL</td>
<td>Function of Original</td>
<td>#pa(&quot;calibEnvCondMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>DENSITY</td>
<td>MATERIAL</td>
<td>Function of Original</td>
<td>#pa(&quot;calibEnvDenMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>RESISTANCE</td>
<td>MATERIAL</td>
<td>Function of Original</td>
<td><code>Original</code>/#pa(&quot;calibEnvCondMult&quot;)</td>
</tr>
<tr>
<td>SPECIFIC-HEAT</td>
<td>MATERIAL</td>
<td>Function of Original</td>
<td>#pa(&quot;calibEnvSpHMult&quot;) * <code>Original</code></td>
</tr>
</tbody>
</table>
Calibration Parameter Insertion

55 keywords reference the 21 calibration parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Category</th>
<th>Change</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUMP-HP-FFLOW</td>
<td>PUMP</td>
<td>Change</td>
<td>&quot;Pump-Power-fFlow_calib&quot; = CURVE-FIT</td>
</tr>
<tr>
<td>AIR-CHANGES/HR</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibInfiltrationMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>AREA/PERSON</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibOccupMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>EQUIPMENT-KW</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibPlugMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>EQUIPMENT-W/AREA</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibPlugMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>EQUIP-SCHEDULE</td>
<td>SPACE</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>INF-FLOW/AREA</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibInfiltrationMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>INF-METHOD</td>
<td>SPACE</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>LIGHTING-KW</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibLightMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>LIGHTING-SCHEDUL</td>
<td>SPACE</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>LIGHTING-W/AREA</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibLightMult&quot;) * <code>Original</code></td>
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<tr>
<td>NUMBER-OF-PEOPLE</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibOccupMult&quot;) * <code>Original</code></td>
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<tr>
<td>PEOPLE-SCHEDULE</td>
<td>SPACE</td>
<td>Check</td>
<td>-1</td>
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<tr>
<td>SOURCE-POWER</td>
<td>SPACE</td>
<td>Function of Original</td>
<td>#pa(&quot;calibSourceMult&quot;) * <code>Original</code></td>
</tr>
<tr>
<td>SOURCE-SCHEDULE</td>
<td>SPACE</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>ZONE-TYPE</td>
<td>SPACE</td>
<td>Check</td>
<td>-1</td>
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</table>
## Calibration Parameter Insertion

55 keywords by the 21 calibration parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>Function of Original</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>COIL-BF</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>Original</code>/ <code>calibCoolEffMult</code>) &gt; 1 then</td>
</tr>
<tr>
<td>COOLING-EIR</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td><code>Original</code>/ <code>calibCoolEffMult</code></td>
</tr>
<tr>
<td>DIRECT-EFF</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>calibCoolEffMult</code>) * <code>Original</code> &gt; 1 then</td>
</tr>
<tr>
<td>HEATING-EIR</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td><code>calibHeatEffMult</code> * <code>Original</code></td>
</tr>
<tr>
<td>HEAT-SOURCE</td>
<td>SYSTEM</td>
<td>Check</td>
<td>-1</td>
</tr>
<tr>
<td>INDIR-EFF</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>calibCoolEffMult</code>) * <code>Original</code> &gt; 1 then</td>
</tr>
<tr>
<td>MIN-OUTSIDE-AIR</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>calibOutAirMult</code>) * <code>Original</code> &gt; 1 then</td>
</tr>
<tr>
<td>RETURN-DELTA-T</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td><code>calibFanMult</code> * <code>Original</code></td>
</tr>
<tr>
<td>RETURN-EFF</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>calibFanMult</code>) * <code>Original</code> &gt; 1 then</td>
</tr>
<tr>
<td>RETURN-KW/FLOW</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td><code>calibFanMult</code></td>
</tr>
<tr>
<td>RETURN-STATIC</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>Original</code>/ <code>calibFanMult</code>) &gt; 10 then</td>
</tr>
<tr>
<td>SUPPLY-DELTA-T</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td><code>calibFanMult</code></td>
</tr>
<tr>
<td>SUPPLY-EFF</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>calibFanMult</code>) * <code>Original</code> &gt; 1 then</td>
</tr>
<tr>
<td>SUPPLY-KW/FLOW</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td><code>calibFanMult</code></td>
</tr>
<tr>
<td>SUPPLY-STATIC</td>
<td>SYSTEM</td>
<td>Function of Original</td>
<td>if (<code>Original</code>/ <code>calibFanMult</code>) &gt; 15 then</td>
</tr>
<tr>
<td>TYPE</td>
<td>SYSTEM</td>
<td>Check</td>
<td><code>iif(0=0,-1,0)</code></td>
</tr>
<tr>
<td>EXHAUST-EFF</td>
<td>ZONE</td>
<td>Function of Original</td>
<td>if (<code>calibExhaustMult</code>) * <code>Original</code> &gt; 1 then</td>
</tr>
<tr>
<td>EXHAUST-FLOW</td>
<td>ZONE</td>
<td>Function of Original</td>
<td><code>Original</code>/ <code>calibExhaustMult</code></td>
</tr>
<tr>
<td>EXHAUST-KW/FLOW</td>
<td>ZONE</td>
<td>Function of Original</td>
<td><code>calibExhaustMult</code></td>
</tr>
<tr>
<td>EXHAUST-STATIC</td>
<td>ZONE</td>
<td>Function of Original</td>
<td>if (<code>Original</code>/ <code>calibExhaustMult</code>) &gt; 10 then</td>
</tr>
<tr>
<td>OA-FLOW/PER</td>
<td>ZONE</td>
<td>Function of Original</td>
<td><code>calibOutAirMult</code> * <code>Original</code></td>
</tr>
<tr>
<td>OUTSIDE-AIR-FLOW</td>
<td>ZONE</td>
<td>Function of Original</td>
<td><code>calibOutAirMult</code> * <code>Original</code></td>
</tr>
</tbody>
</table>
Calibration Parameter Insertion

Before:

910 .TYPE ........ := RESISTANCE.
911 .RESISTANCE := 24.2076

After:

1021 .TYPE ........ := RESISTANCE.
1022 .RESISTANCE :=
1023 \{if(#pa("calibCalibrateBuilding")=1) \cdot \text{then} \}
1024 (24.2076/#pa("calibEnvCondMult"))
1025 \{else \}
1026 24.2076
1027 \{endif}\}

Expressions are maintained:

-GLASS-CONDUCT = \{\}

\{1/(1/#pa("Window . U-Value . W") - 0.2)\}

Base-load fraction offset parameters lead to complex new expressions in schedules.
Quality Checks

• Auto-calibration only “tunes” parameters that change with time.

• 6-10 hours by trained professional
• Does not comprehensively check the model
• Assesses whether major changes in configuration have occurred
• Scour building automation system data and building audit reports for dissimilarities to the BEM
• Documents issues that cannot be fixed
• Rates readiness of the model for auto-calibration
Quality Check Requirements

• Review available information and verify whether it matches the model. In a spreadsheet note the following:
  • Information in the audit report that cannot be applied to the model with reason stated if the auditor is aware of the reason.
  • Information that is consistent with the model in the audit report
  • Information that is inconsistent and either:
    • Was corrected
    • Could not be corrected with reason why it could not be corrected—including insufficient time to correct the issue. Highlight rows with uncorrected issues in red.

• Reverify the corrected BEM can run in DOE2.2 and review the *.sim file for the “ATTN Simulation Messages” section. Place each message in a spreadsheet with the following notes:
  • List any warning that is a serious concern for the model’s accuracy and take corrective action if time allows.
  • Certify to the best knowledge of the reviewer that other Warning messages are either unimportant or that the reviewer did not have time to investigate them thoroughly.
Quality Check Requirements (continued)

• If applicable, create a to-do list of actions that still need to be taken to correct the model
• Rate the model (w/r to the information reviewed) as:
  A – ready for calibration,
  B – ready for calibration but with known issues,
  C – Known issues are serious and the auditor is unsure of whether the model should be calibrated,
  D – Calibrating the model is not recommended but known corrective actions in the to-do list may fix it.
  F – The model is fundamentally flawed and must be rebuilt or the building energy simulation tool is incapable of properly simulating the building.
Quality Check Requirements (continued)

• Provide a directory with the new model and run files
• Check-in of new model into our site-wide energy modeling database along with a link to the QC information above
Quality Check Discoveries Building #1

- 24-7 fans alternating and never run simultaneously

- Estimated total lab exhaust from flow data and added an air-handler that services a single lab
- Cut number of occupants in model by ½ based on personnel records in the building
- Baseboard source corrected to hot-water instead of electric
- Air handler unit #2 changed from incorrect dual duct to single duct system
Quality Check Discoveries Building #1

- Base-load found to vary much less during weekends than original plug-loads/lighting and other schedules in model indicated.
• Local data from SNL NM site for temperature, humidity, precipitation, pressure and solar radiation
• Cloud data filled in with TMY3
Electricity Data

• Hourly data with gap filling via linear regression with three predictors:
  1) average 2017 monthly kWh values,
  2) average 2017 day of the week values
  3) average 2017 day of the hour model of previous year’s data

76% accuracy achieved from test portions of the data
Building #1 Manual Calibration

Building #1 manual calibration results April 30, 2018

Days since January 1, 2017

quality round1 failed ASHRAE 14
quality round2 NMBE -1.32% CV(RSME)=14.27%
data

kWh per hour

0 50 100 150 200 250 300 350 400 450 500

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Auto-calibration results building #1

- Manually Tuned - CV(RMSE)=5.35, NMBE=1.39
- Autotuned - CV(RMSE)=5.2, NMBE=0.66
- Actual
## Auto-calibration results building #1

<table>
<thead>
<tr>
<th></th>
<th>Original Model</th>
<th>Autotune (from original)</th>
<th>Manual Calibration</th>
<th>Autotune (from manual)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monthly utility data</strong></td>
<td>8.4%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>5.2%</td>
</tr>
<tr>
<td></td>
<td>2.7%</td>
<td>0.2%</td>
<td>-1.4%</td>
<td>0.7%</td>
</tr>
<tr>
<td><strong>Daily utility data</strong></td>
<td>12.4%</td>
<td>9.1%</td>
<td>8.3%</td>
<td>7.5%</td>
</tr>
<tr>
<td></td>
<td>2.7%</td>
<td>0.2%</td>
<td>-1.4%</td>
<td>-0.3%</td>
</tr>
<tr>
<td><strong>Hourly utility data</strong></td>
<td>19.5%</td>
<td>10.9%</td>
<td>11.5%</td>
<td>9.7%</td>
</tr>
<tr>
<td></td>
<td>2.7%</td>
<td>0.2%</td>
<td>-1.4%</td>
<td>-0.3%</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$2.50k</td>
<td>2.51k</td>
<td>$2.50k</td>
<td></td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>15 hrs cpu</td>
<td>27 hrs labor</td>
<td>7 hrs cpu</td>
<td></td>
</tr>
</tbody>
</table>
Building #1 Auto Calibration

- Further refinement inhibited by seasonal variations not captured by calibration parameters
- Summer-Winter sensitivity but spring-summer-fall-winter needed!
Conclusions

- Auto-calibration methods require significant investment that is worth it for our case of establishing a repetitive process of calibrating 100’s of BEM.

- Cost is not significantly lower but trading compute hours for labor hours so that we have on-demand calibration is highly valuable.

- Further improvement is expected in the coming years as we refine this process including calibrations that look at more than just electricity data.
QUESTIONS?

Daniel Villa
dlvilla@sandia.gov

Joshua New, PhD.
JoshuaRNew@autotunemybuilding.com