2018 Building Performance Analysis Conference and SimBuild Co-Organized by ASHRAE and IBPSA-USA

SAND2018-9529C

Hybrid Session C5: Advanced Modeling: Calibration

Daniel Villa, P.E.
Sandia National Laboratories

SAND2017-XXXXC

dlvilla@sandia.gov
505-340-9162

Reducing Building Energy Modeling Workloads Through Automated Calibration

Sandia National Laboratories

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

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Acknowledgements

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

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

Present

Future site

2016

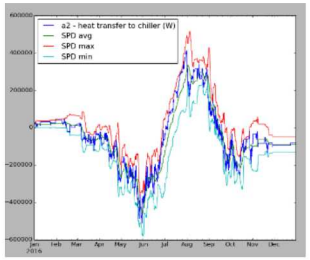
2017

2018

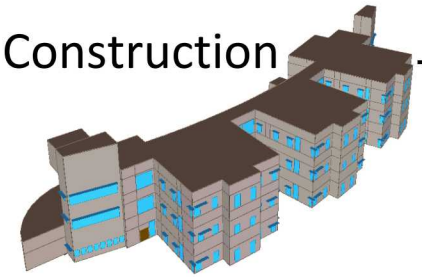
2019

2020

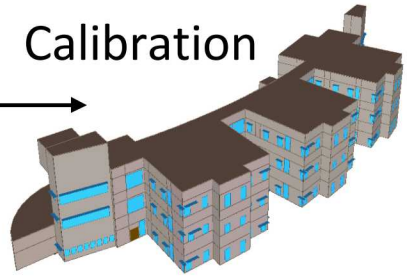
Historical data



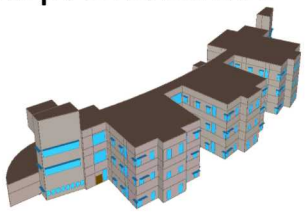
Construction



Calibration

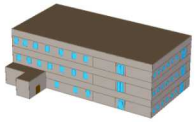


Future Representative

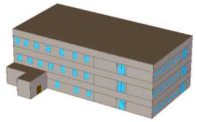


Assess site-wide energy future plan

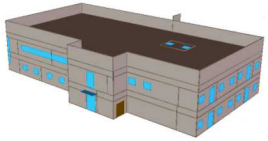
ECMs Evaluated no changes



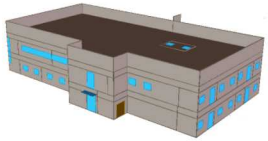
Recalibrate model



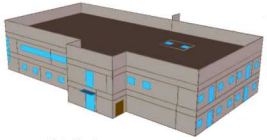
ECM Planned



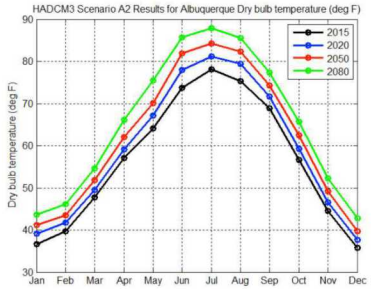
ECM Applied



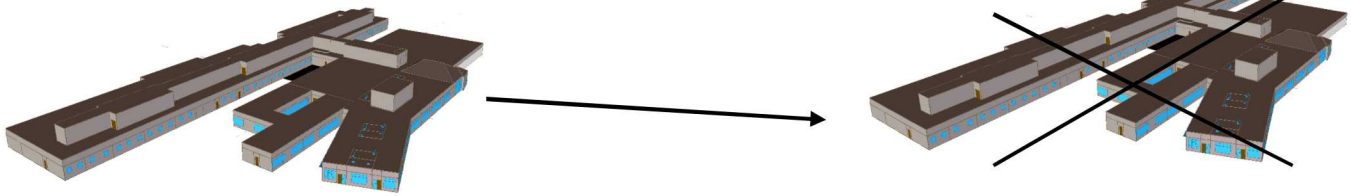
Updated Model with ECM



Climate change projections

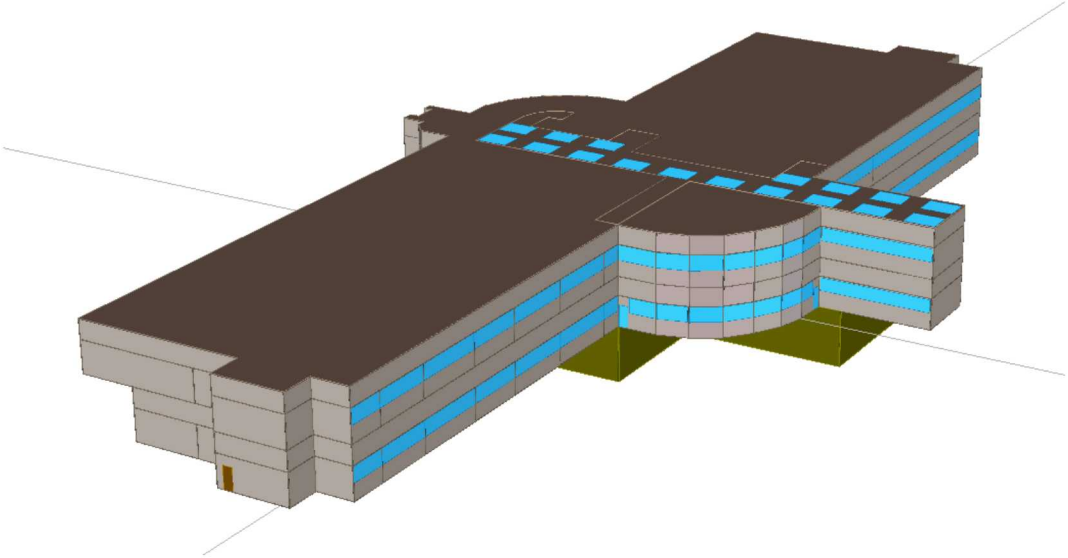


Demolition



Building #1

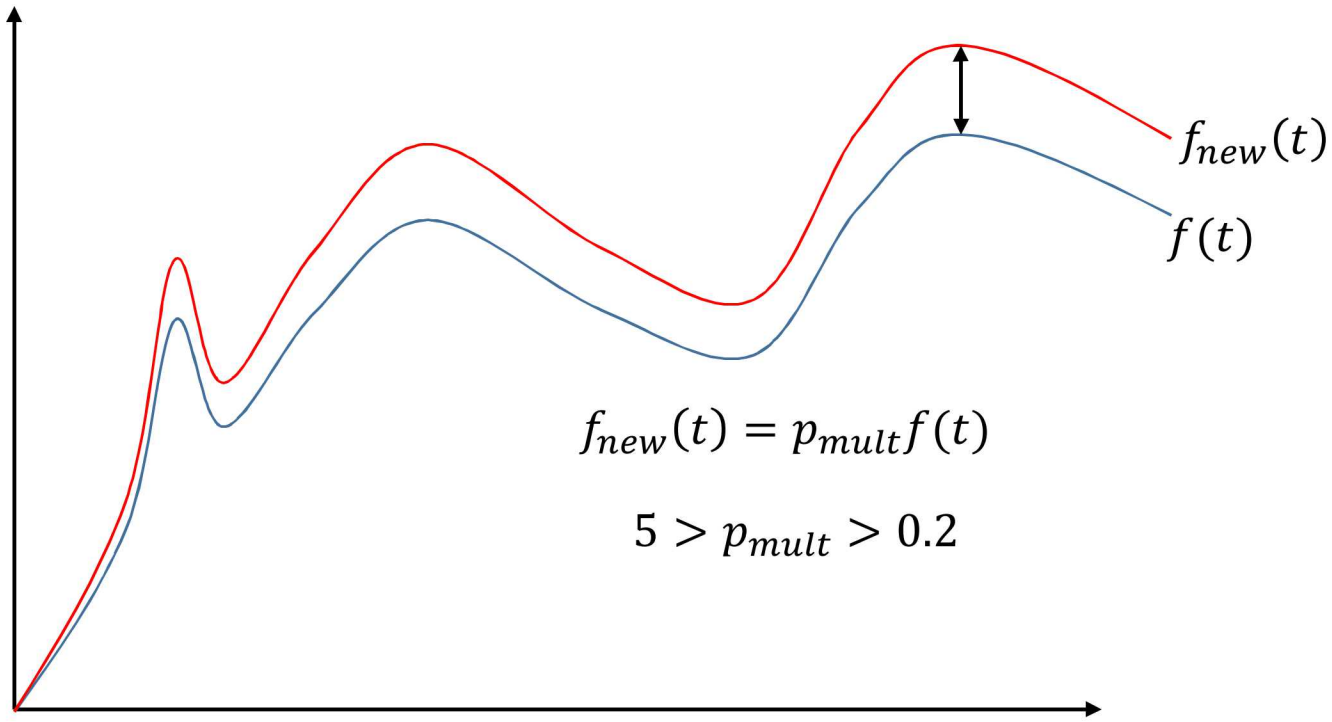
- 3 level 72,243ft^2 Light Lab with 2 24-7 operational exhaust systems
- Mixed single duct and dual duct on different HVAC systems
- Multiple additional lab air-handlers with independent operation modes
- Previously calibrated in 2014 to NMBE -2.92%, CV(RMSE) 5.41% - but falls outside of compliance for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



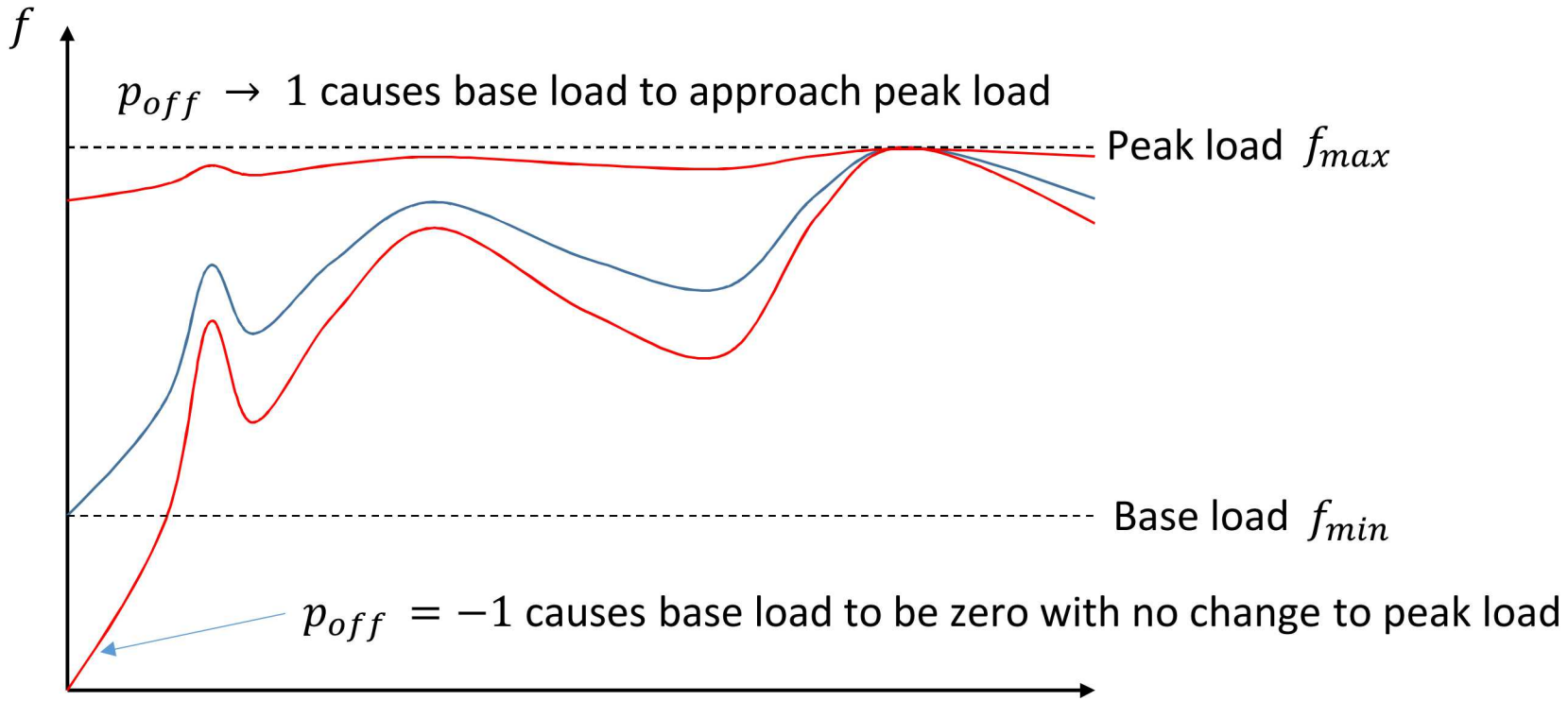
Insertion of Calibration Expressions

- ***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



Base load fraction offset effect



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

$$f_{new_{-1}}(t) = \frac{f_{max}}{f_{max} - f_{min}} f(t) - \frac{f_{max}f_{min}}{f_{max} - f_{min}}$$

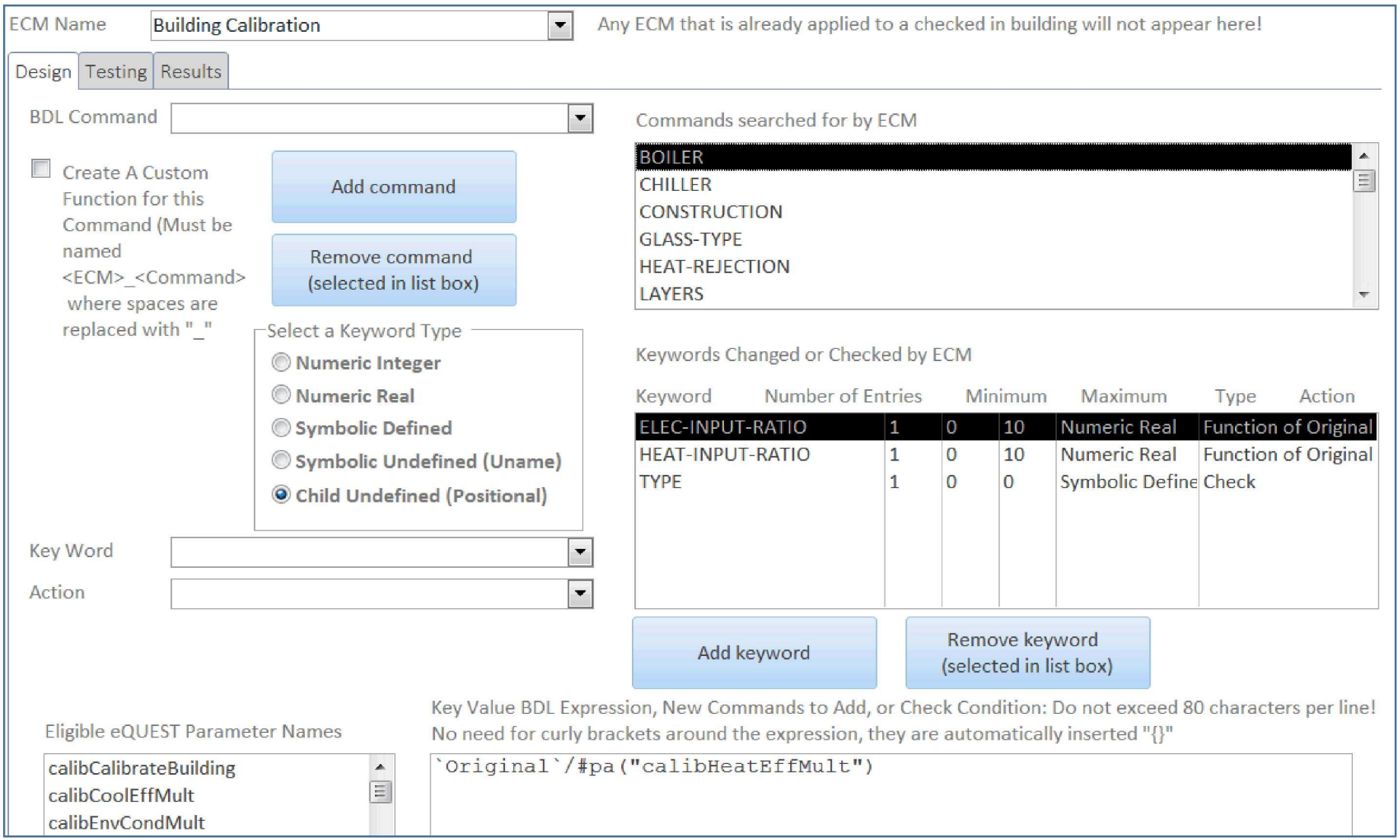
21 Parameter study sensitivity for Building #1

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

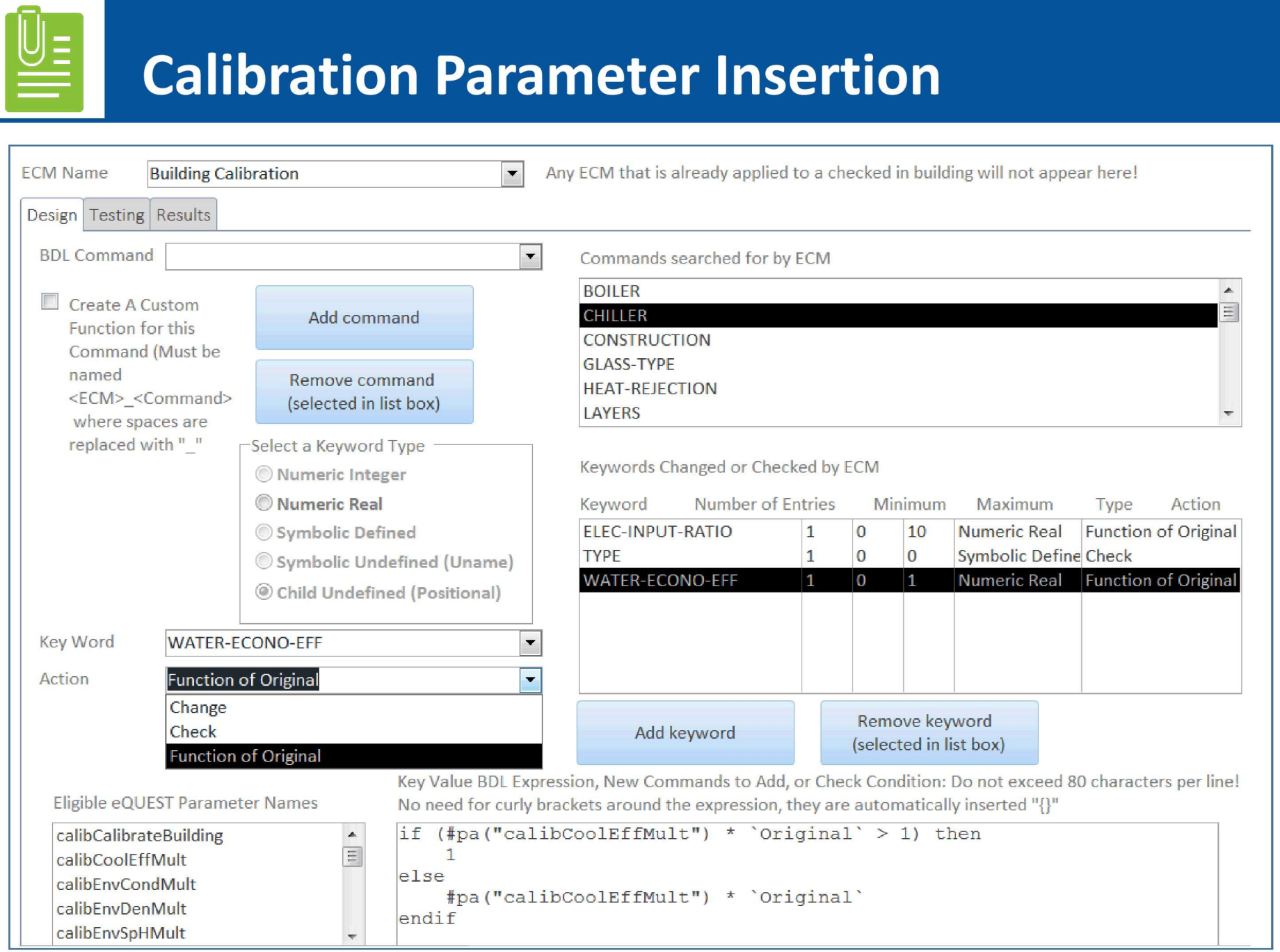
Parameter used in calibration

Parameter not used in calibration

Calibration Parameter Insertion



Calibration Parameter Insertion



Calibration Parameter Insertion

```
' testing of all of this is up to the user. BDL runs will show whether what you try works!
Public Function CUSTOM_ECM(FunctionName As String, BuildingFileObj As clsBuildingFile_shared, Keys() As clsKeys, Key As clsKeys, Prefix As
                                i As Long, c As Long, ECMCreate As clsECMCreate, _
                                KeyValuesInBuilding() As Variant, KeyValues() As Variant, KVIsExpression() As Boolean, KeyWords() As
                                CheckKeyValuesInBuilding() As Variant, CheckKeyValues() As Variant, CheckKeyWords() As String, _
                                MultKeyValuesInBuilding() As Variant, MultKeyValues() As Variant, MultKVIsExpression() As Boolean, M
    ' "i" is the index for the BDLCommandsInds for the current command i.e. BDLCommandsInds(i) is the command index for the current co
    ' "c" is the index for the current command Keys(c) = Key.
    Dim Dum As Double
    Dim FuncNoMinusName As String


    FuncNoMinusName = Replace(FunctionName, "-", "_")

    'YOU MUST MANUALLY PUT NEW FUNCTIONS INTO THIS LOCATION
    Select Case FuncNoMinusName

    Case "Building_Calibration_SPACE"
        CUSTOM_ECM = Building_Calibration_SPACE(BuildingFileObj, Keys, Key, Prefix, BDLCommandsInds, _
                                i, c, ECMCreate, _
                                KeyValuesInBuilding, KeyValues, KVIsExpression, KeyWords, _
                                CheckKeyValuesInBuilding, CheckKeyValues, CheckKeyWords, _
                                MultKeyValuesInBuilding, MultKeyValues, MultKVIsExpression, MultKeyWords)
    Case "Building_Calibration_CHILLER"
        CUSTOM_ECM = Building_Calibration_CHILLER(BuildingFileObj, Keys, Key, Prefix, BDLCommandsInds, _
                                i, c, ECMCreate, _
                                KeyValuesInBuilding, KeyValues, KVIsExpression, KeyWords, _
                                CheckKeyValuesInBuilding, CheckKeyValues, CheckKeyWords, _
                                MultKeyValuesInBuilding, MultKeyValues, MultKVIsExpression, MultKeyWords)
    Case "Building_Calibration_BOILER"
        CUSTOM_ECM = Building_Calibration_BOILER(BuildingFileObj, Keys, Key, Prefix, BDLCommandsInds, _
                                i, c, ECMCreate, _
                                KeyValuesInBuilding, KeyValues, KVIsExpression, KeyWords, _
                                CheckKeyValuesInBuilding, CheckKeyValues, CheckKeyWords, _
                                MultKeyValuesInBuilding, MultKeyValues, MultKVIsExpression, MultKeyWords)
```

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

KeyWords	BDLCommand	Action	KeyValueOrExpression
ELEC-INPUT-RATIO	BOILER	Function of Original	`Original`/#pa("calibHeatEffMult")
HEAT-INPUT-RATIO	BOILER	Function of Original	`Original`/#pa("calibHeatEffMult")
TYPE	BOILER	Check	-1
ELEC-INPUT-RATIO	CHILLER	Function of Original	`Original`/#pa("calibCoolEffMult")
TYPE	CHILLER	Check	-1
WATER-ECONO-EFF	CHILLER	Function of Original	if (#pa("calibCoolEffMult") * `Original` > 1) then
TYPE	CONSTRUCTION	Check	Iif("`TYPE`" = "U-VALUE",-1,0)
U-VALUE	CONSTRUCTION	Function of Original	#pa("calibEnvCondMult") * `Original`
GLASS-CONDUCT	GLASS-TYPE	Function of Original	#pa("calibEnvCondMult") * `Original`
TYPE	GLASS-TYPE	Check	iif("`TYPE`"="SHADING-COEF",-1,0)
FAN-KW-FSPEED	HEAT-REJECTION	Change	"Htrej-Fan-Pwr-fSpeed_calib" = CURVE-FIT
TYPE	HEAT-REJECTION	Check	-1
INSIDE-FILM-RES	LAYERS	Function of Original	`Original` /#pa("calibEnvCondMult")
CONDUCTIVITY	MATERIAL	Function of Original	#pa("calibEnvCondMult") * `Original`
DENSITY	MATERIAL	Function of Original	#pa("calibEnvDenMult") * `Original`
RESISTANCE	MATERIAL	Function of Original	`Original`/#pa("calibEnvCondMult")
SPECIFIC-HEAT	MATERIAL	Function of Original	#pa("calibEnvSpHMult") * `Original`

Calibration Parameter Insertion

55 keywords reference the 21 calibration parameters

PUMP-HP-FFLOW	PUMP	Change	"Pump-Power-fFlow_calib" = CURVE-FIT
AIR-CHANGES/HR	SPACE	Function of Original	#pa("calibInfiltrationMult") * `Original`
AREA/PERSON	SPACE	Function of Original	#pa("calibOccupMult") * `Original`
EQUIPMENT-KW	SPACE	Function of Original	#pa("calibPlugMult") * `Original`
EQUIPMENT-W/AREA	SPACE	Function of Original	#pa("calibPlugMult") * `Original`
EQUIP-SCHEDULE	SPACE	Check	-1
INF-FLOW/AREA	SPACE	Function of Original	#pa("calibInfiltrationMult") * `Original`
INF-METHOD	SPACE	Check	-1
LIGHTING-KW	SPACE	Function of Original	#pa("calibLightMult") * `Original`
LIGHTING-SCHEDUL	SPACE	Check	-1
LIGHTING-W/AREA	SPACE	Function of Original	#pa("calibLightMult") * `Original`
NUMBER-OF-PEOPLE	SPACE	Function of Original	#pa("calibOccupMult") * `Original`
PEOPLE-SCHEDULE	SPACE	Check	-1
SOURCE-POWER	SPACE	Function of Original	#pa("calibSourceMult") * `Original`
SOURCE-SCHEDULE	SPACE	Check	-1
ZONE-TYPE	SPACE	Check	-1

Calibration Parameter Insertion

55 keywords by the 21 calibration parameters

COIL-BF	SYSTEM	Function of Original	if (`Original` / #pa("calibCoolEffMult") > 1) then
COOLING-EIR	SYSTEM	Function of Original	`Original`/#pa("calibCoolEffMult")
DIRECT-EFF	SYSTEM	Function of Original	if (#pa("calibCoolEffMult") * `Original` > 1) then
HEATING-EIR	SYSTEM	Function of Original	#pa("calibHeatEffMult") * `Original`
HEAT-SOURCE	SYSTEM	Check	-1
INDIR-EFF	SYSTEM	Function of Original	if (#pa("calibCoolEffMult") * `Original` > 1) then
MIN-OUTSIDE-AIR	SYSTEM	Function of Original	if (#pa("calibOutAirMult") * `Original` > 1) then
RETURN-DELTA-T	SYSTEM	Function of Original	#pa("calibFanMult") * `Original`
RETURN-EFF	SYSTEM	Function of Original	if (#pa("calibFanMult") * `Original` > 1) then
RETURN-KW/FLOW	SYSTEM	Function of Original	`Original`/#pa("calibFanMult")
RETURN-STATIC	SYSTEM	Function of Original	if (`Original`/#pa("calibFanMult") > 10) then
SUPPLY-DELTA-T	SYSTEM	Function of Original	`Original`/#pa("calibFanMult")
SUPPLY-EFF	SYSTEM	Function of Original	if (#pa("calibFanMult") * `Original` > 1) then
SUPPLY-KW/FLOW	SYSTEM	Function of Original	`Original`/#pa("calibFanMult")
SUPPLY-STATIC	SYSTEM	Function of Original	if (`Original`/#pa("calibFanMult") > 15) then
TYPE	SYSTEM	Check	iif(0=0,-1,0)
EXHAUST-EFF	ZONE	Function of Original	if (#pa("calibExhaustMult") * `Original` > 1) then
EXHAUST-FLOW	ZONE	Function of Original	`Original`/ #pa("calibExhaustMult")
EXHAUST-KW/FLOW	ZONE	Function of Original	`Original`/#pa("calibExhaustMult")
EXHAUST-STATIC	ZONE	Function of Original	if (`Original`/#pa("calibExhaustMult") > 10) then
OA-FLOW/PER	ZONE	Function of Original	#pa("calibOutAirMult") * `Original`
OUTSIDE-AIR-FLOW	ZONE	Function of Original	#pa("calibOutAirMult") * `Original`

Calibration Parameter Insertion

Before:

```
909 "SEL1 UFMat (G.N9.U10.M1)" = MATERIAL
910   TYPE          = RESISTANCE
911   RESISTANCE    = 24.2076
```

After:

```
1020 "SEL1 UFMat (G.N9.U10.M1)" = MATERIAL
1021   TYPE          = RESISTANCE
1022   RESISTANCE    =
1023 {if(#pa("calibCalibrateBuilding")=1) 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)}
```

```
1550   GLASS-CONDUCT =
1551 {if(#pa("calibCalibrateBuilding")=1) then
1552 #pa("calibEnvCondMult") * (1/(1/#pa("Window U-Value W")
1553 else
1554 1/(1/#pa("Window U-Value W") - 0.2)
1555 endif}
```

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

```
1373   VALUES     = ( 0,&D,&D,&D,&D,&D,&D,0.35,0.7,0.45,0.4,0.45
1374 0.45,0.6,0.2,0.1,0.05,&D,0 )
```

```
1579   VALUES     = (
1580 {if(#pa("calibCalibrateBuilding")=1) then
1581 if(#pa("calibPlugBaseFrac")>0) then
1582     (1 - (0 + (1 - 0) * #pa("calibPlugBaseFrac")))/(1 - 0) *
1583 0) * #pa("calibPlugBaseFrac"))/(1 - 0)
1584 else
1585     (1 - (0 + (0-1) * #pa("calibPlugBaseFrac")))/(1 - 0) * (
1586 * #pa("calibPlugBaseFrac"))/(1 - 0)
1587 endif
1588 else
1589 0
1590 endif},
1591 {if(#pa("calibCalibrateBuilding")=1) then
1592 if(#pa("calibPlugBaseFrac")>0) then
1593     (1 - (0 + (1 - 0) * #pa("calibPlugBaseFrac")))/(1 - 0) *
1594 0) * #pa("calibPlugBaseFrac"))/(1 - 0)
1595 else
1596     (1 - (0 + (0-1) * #pa("calibPlugBaseFrac")))/(1 - 0) * (
1597 * #pa("calibPlugBaseFrac"))/(1 - 0)
1598 endif
1599 else
```

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

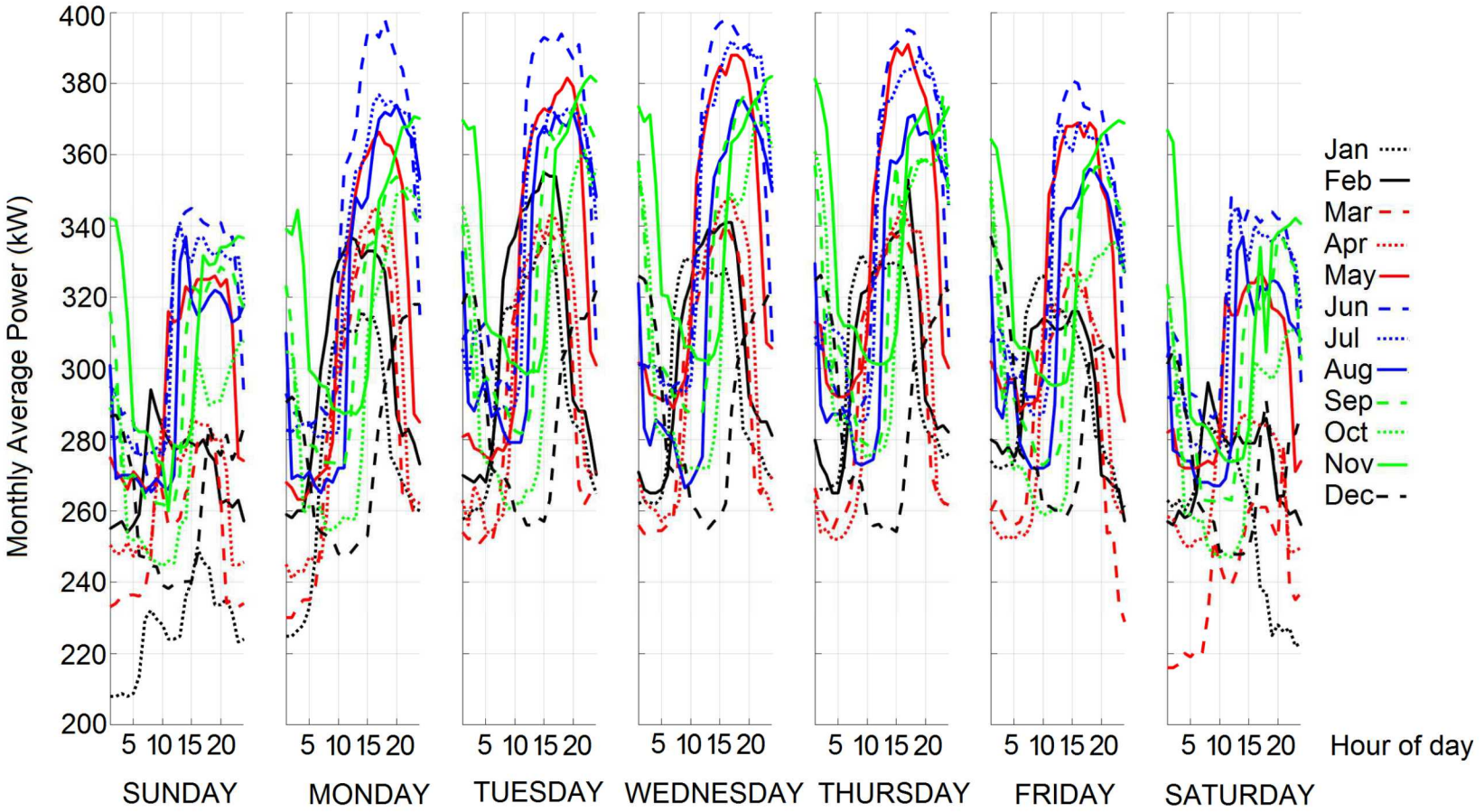
Quality Check Discoveries Building #1

- 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

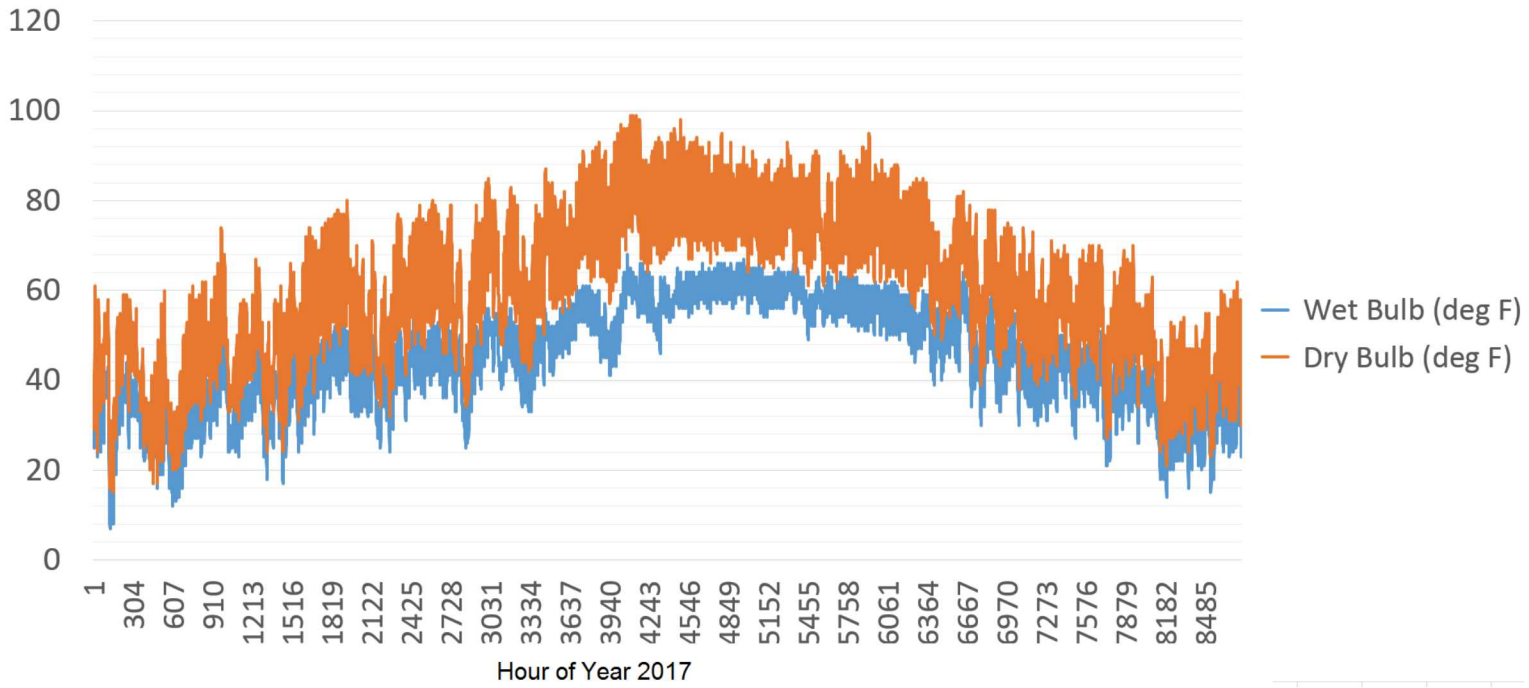
Quality Check Discoveries Building #1

- Base-load found to vary much less during weekends than original plug-loads/lighting and other schedules in model indicated



Weather File

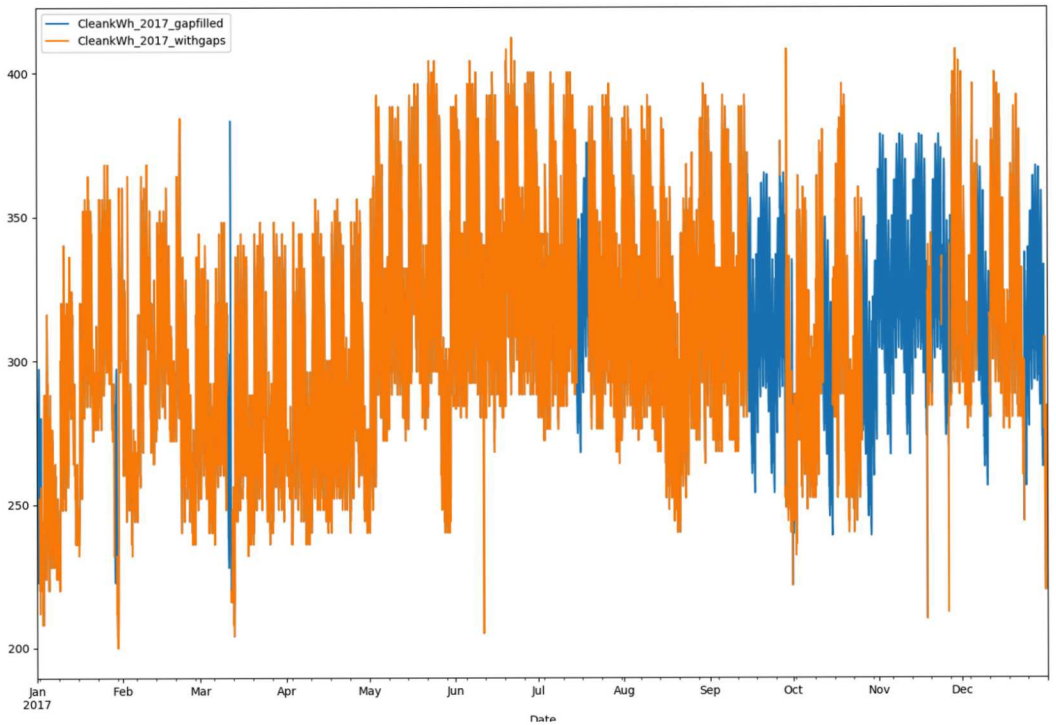
- Local data from SNL NM site for temperature, humidity, precipitation, pressure and solar radiation
- Cloud data filled in with TMY3



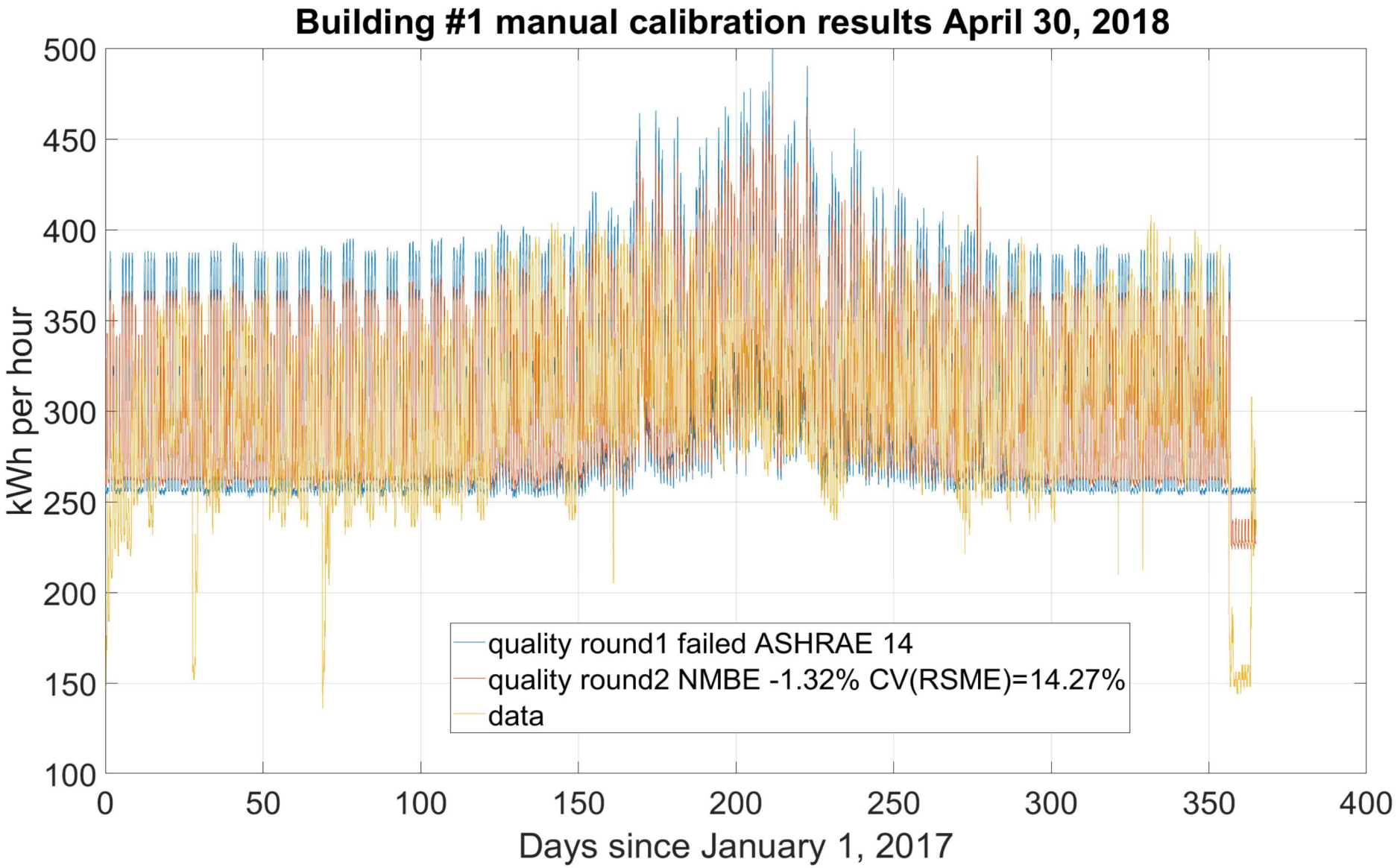
Electricity Data

- 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

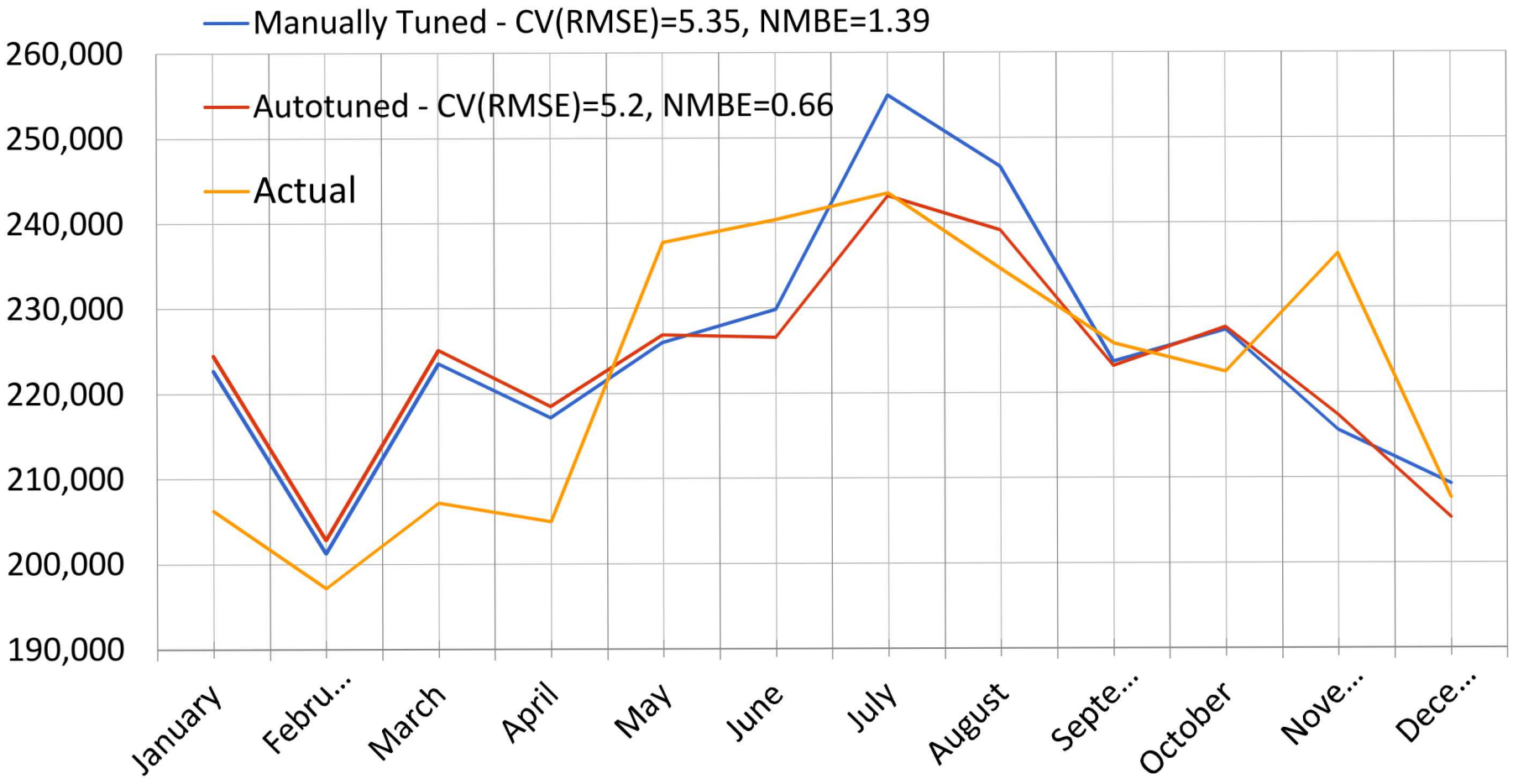
76% accuracy achieved from test portions of the data



Building #1 Manual Calibration



Auto-calibration results building #1

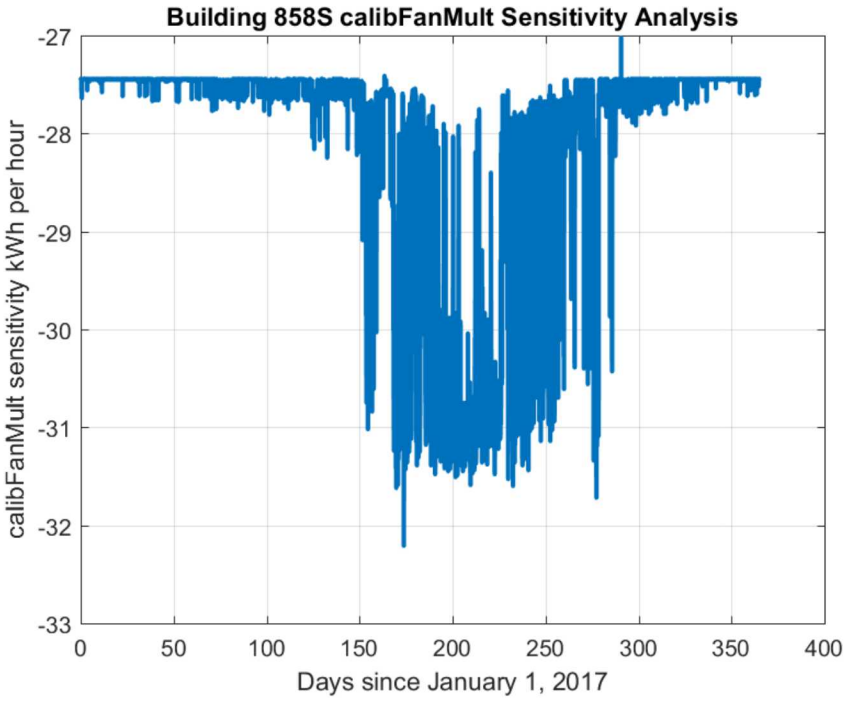


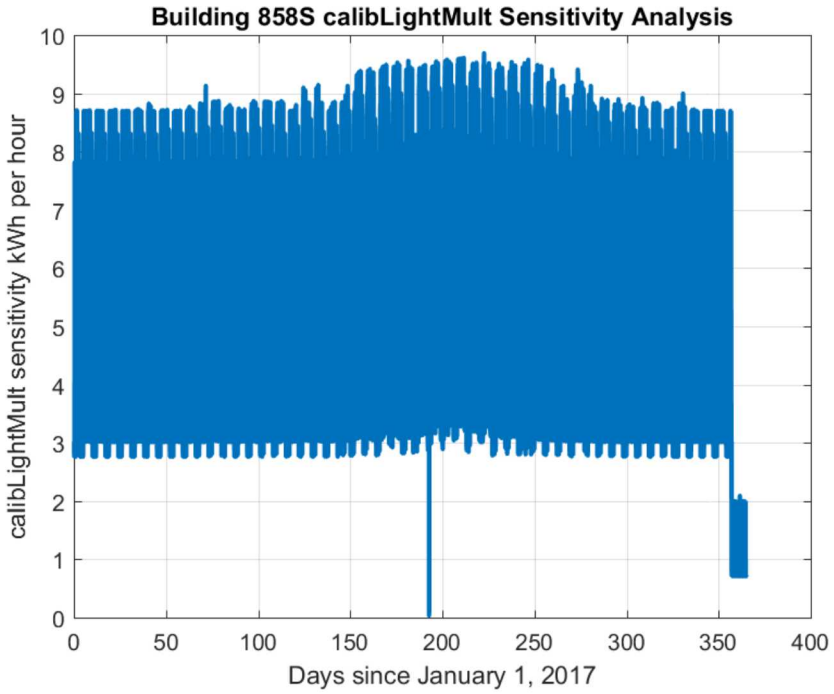
Auto-calibration results building #1

	Original Model	Autotune (from original)		Manual Calibration	Autotune (from manual)
Monthly utility data	8.4%	5.2%		5.2%	5.2%
	2.7%	0.2%		-1.4%	0.7%
Daily utility data	12.4%	9.1%		8.3%	7.5%
	2.7%	0.2%		-1.4%	-0.3%
Hourly utility data	19.5%	10.9%		11.5%	9.7%
	2.7%	0.2%		-1.4%	-0.3%
Cost		$2.50k		2.51k	$2.50k
Time		**15** hrs cpu		**27** hrs labor	**7** hrs cpu

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 requires 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

Bibliography

Villa, Daniel, Joshua New, Gerald Gallegos, Mark Adams, William Peplinski, Aaron Garrett, and Thushara Gunda. 2018. “Reducing Building Energy Modeling Workloads Through Automated Calibration.” Presented at the 2018 Building Performance Analysis Conference, Chicago, Illinois, September 26-28.

QUESTIONS?

Daniel Villa

dlvilla@sandia.gov

Joshua New, PhD.

JoshuaRNew@autotunemybuilding.com