2014 ASHRAE/IBPSA-USA
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Incorporating Uncertainty Analysis into a Building Retrofit Analysis Using OpenStudio and EnergyPlus

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Learning Objectives

- Describe the new Uncertainty Analysis capabilities of OpenStudio
- Identify features in OpenStudio relevant to uncertainty analysis
- Explain how to incorporate uncertainty analysis into deep retrofit project
- Describe the benefits of uncertainty analysis

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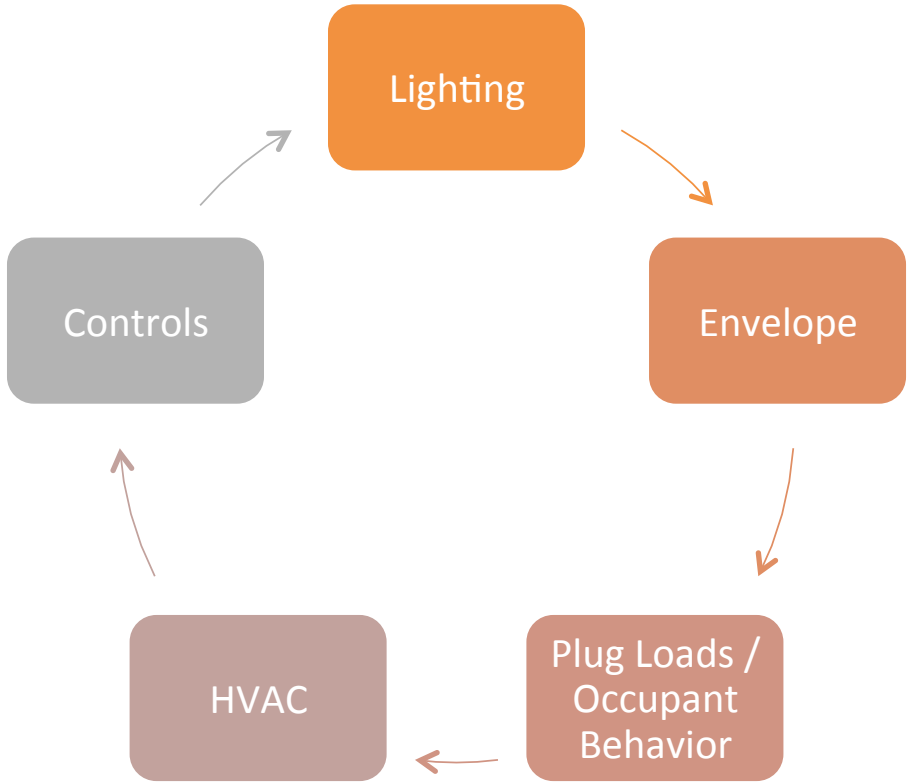
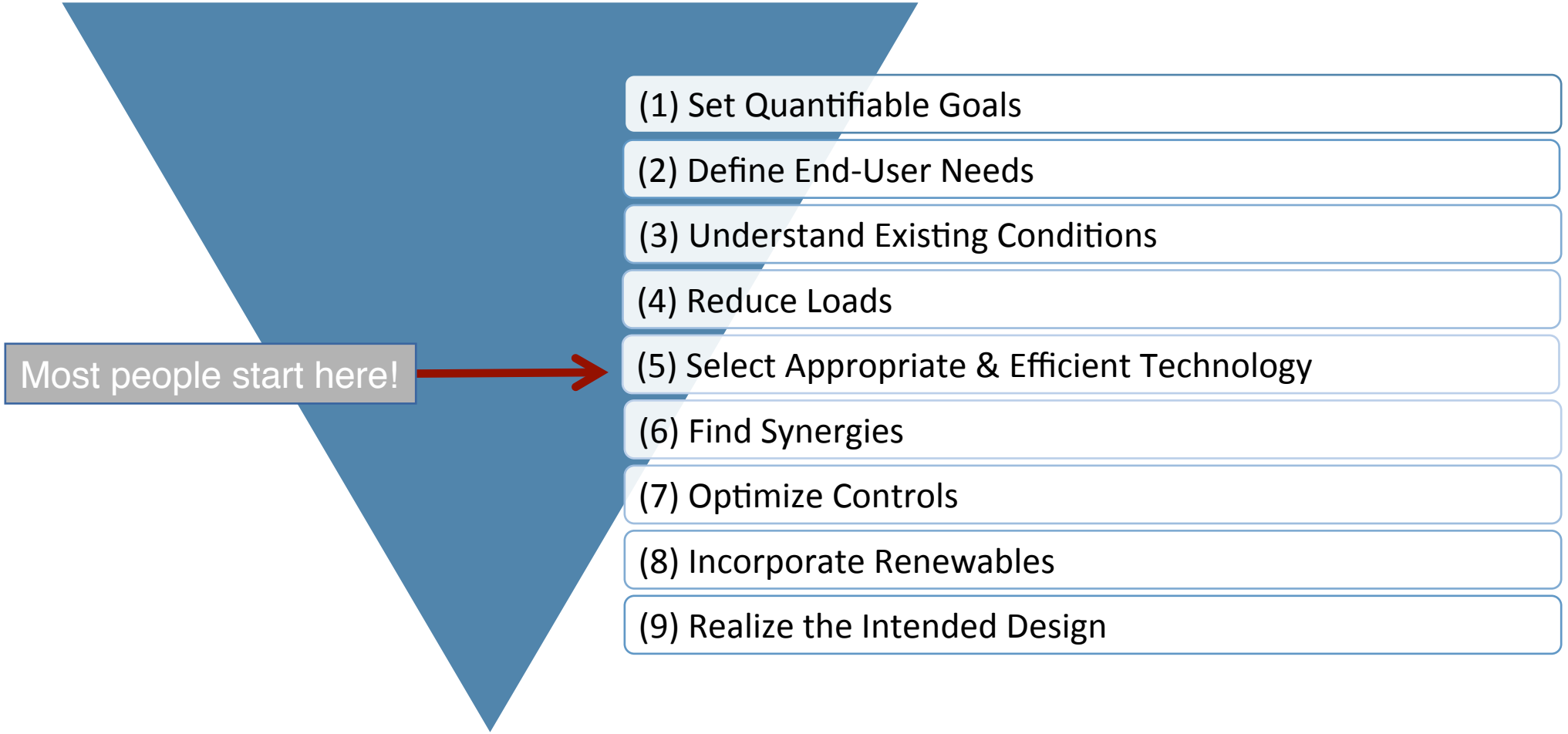
RMI's Approach to Deep Retrofits

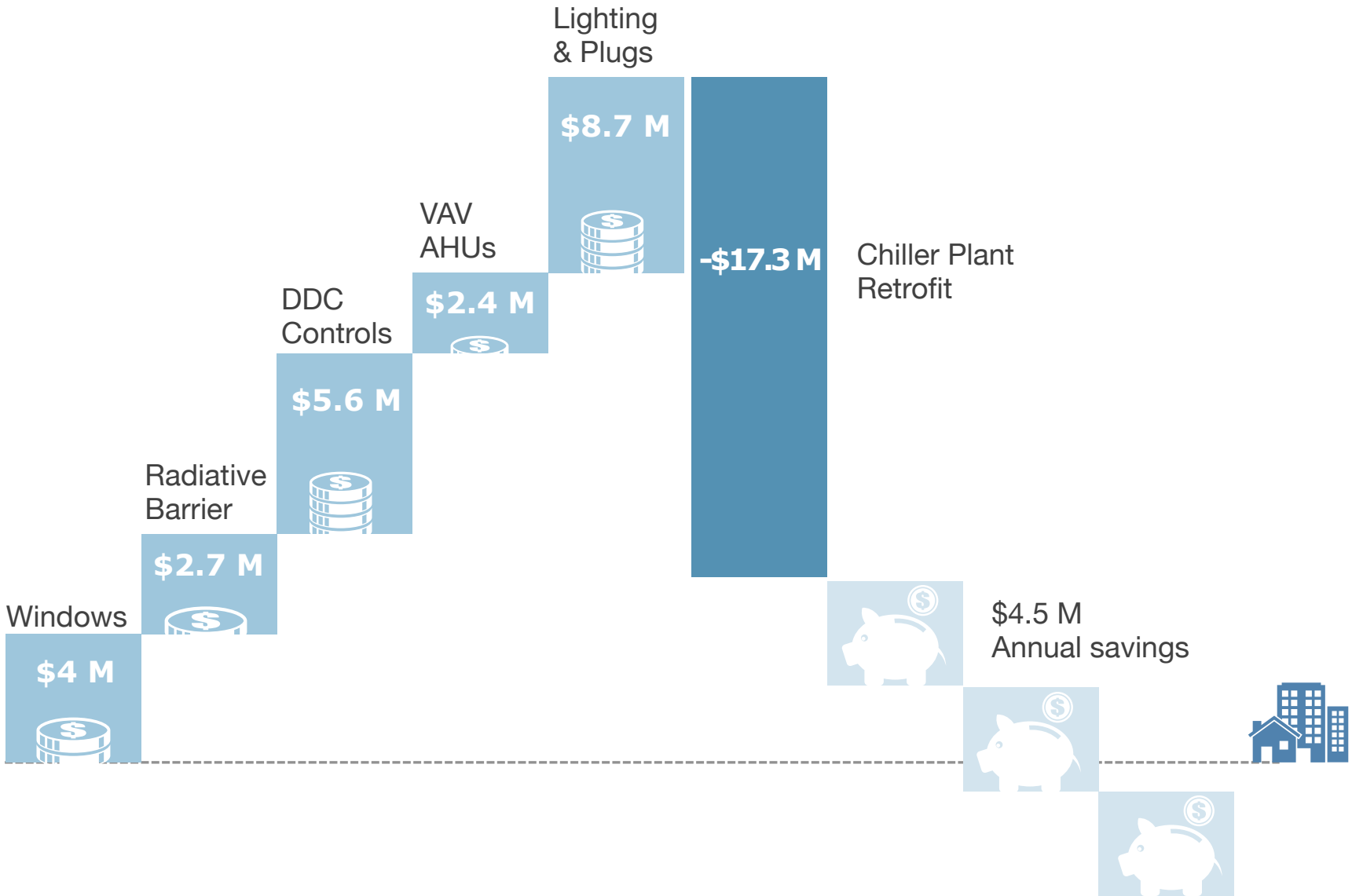
- Integrative design
- Whole building approach



Right Steps in the Right Order

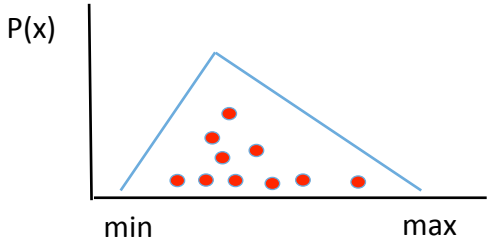


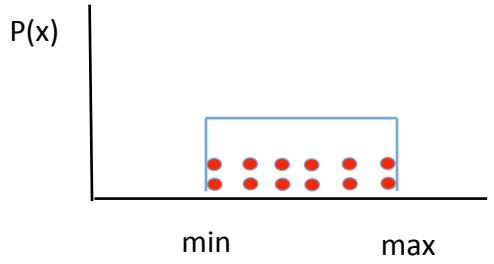
Right Timing & Tunneling Through the Cost Barrier

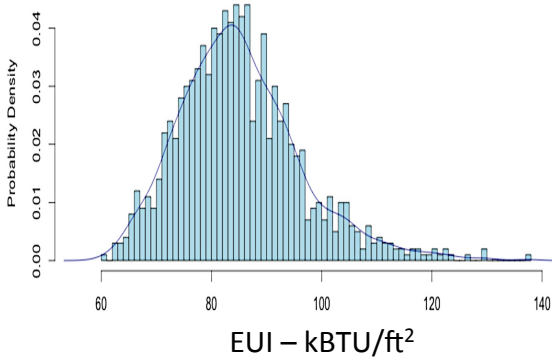


Uncertainty Analysis (UA) in OpenStudio

- Model inputs which are chosen for uncertainty analysis, are described:
  Min, max, standard deviation, distribution type
- Latin hypercube sampling (LHS) across parameters is used to generate statistically representative model runs (typically 1000s)
- Output can be expressed as a probability distribution
- Leverages cloud computing to facilitate large runs (Amazon Web Services, or local server)

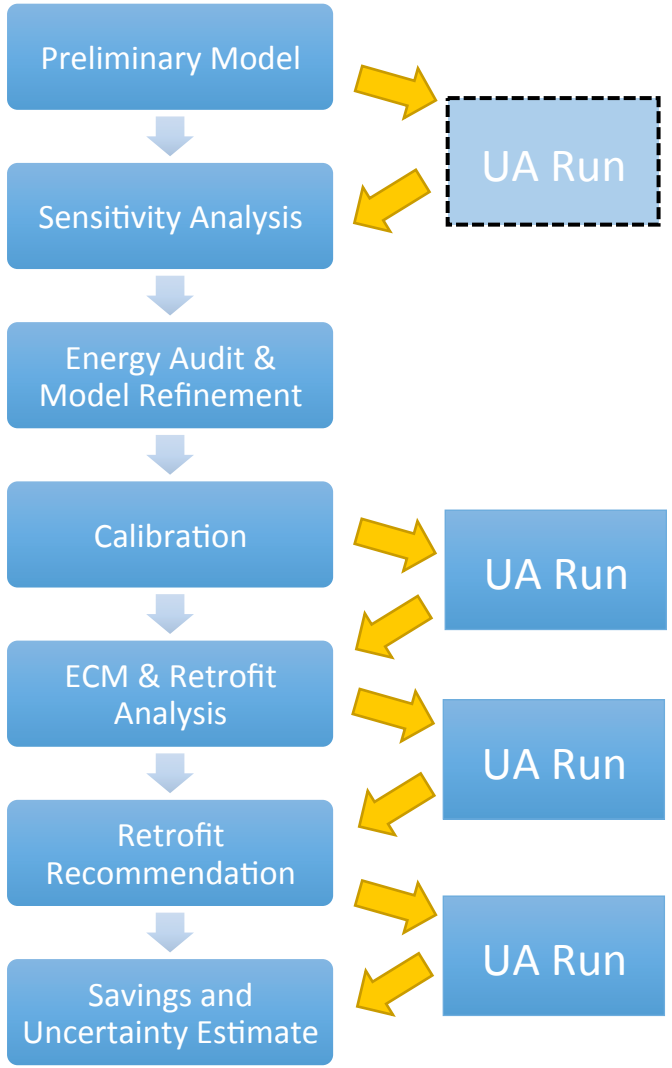






Incorporating UA into Retrofit Analysis

- Sensitivity analysis to inform audit & calibration
- UA informs ECM / Retrofit planning
- UA used to quantify final savings estimate as a probability distribution



Case Study Model

- Tested methodology on a hypothetical deep retrofit
- Based on DOE Reference, large office prototypical building model
- Created artificial utility data by perturbing model to use in calibration

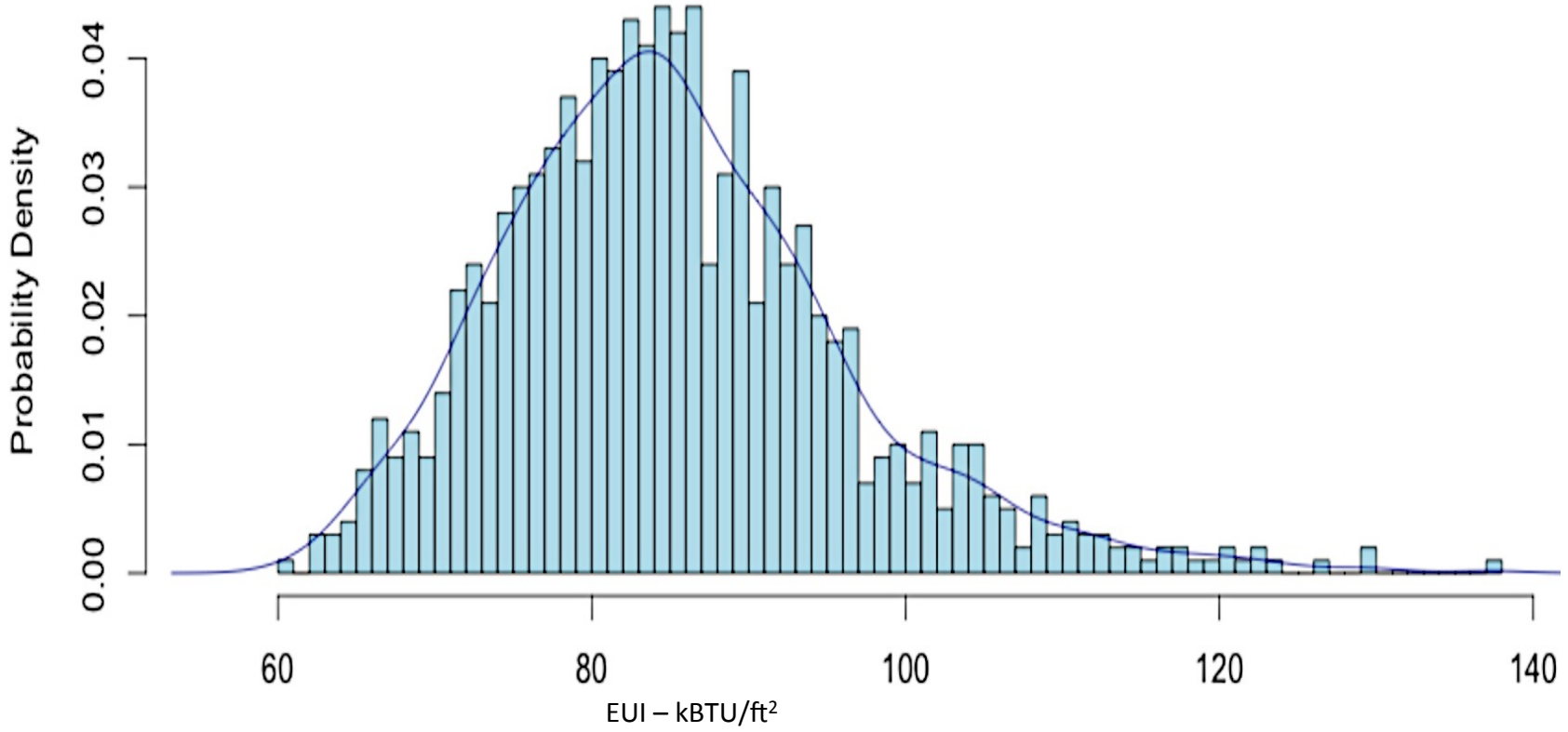
Model Characteristics:	
Area (ft^2)	500,000
Height (stories)	12 + basement
Aspect Ratio	1.5
Envelope	ASHRAE 90.1 1989 Zone 5B
Window to Wall Ratio	38%
HVAC	VAV with reheat, 2 central chillers & gas fired boiler
Outside Air	Economizers per 90.1
Internal Gains	Lights – 1.5 W/ft^2, plug loads – 1 W/ft^2

Sensitivity Analysis

- Identified parameters of interest
- Ran expected min and max for each using OpenStudio's Parametric Analysis Tool (PAT)
- Sorted results
- Parameters with <1% affect were treated as fixed, remaining carried forward for uncertainty runs

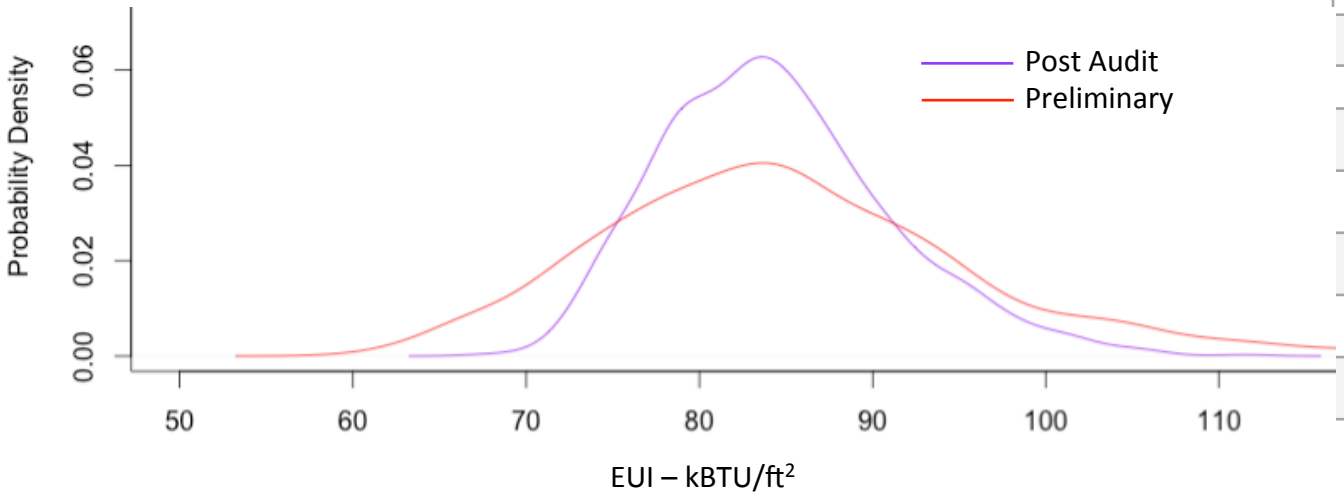
INPUT PARAMETER	MIN VALUE	MAX VALUE	Δ |EUI|
Min. VAV flow fraction	0%	60%	38%
Chiller COP	2.5	5.5	25%
Outside air	-90%	90%	17%
Boiler efficiency	50%	90%	17%
Heat/cool sizing factors	1	1.5	13%
Heat/cool setpoints	-2˚F	2˚F	8%
Start/end occupancy schd.	-2 hrs	+2 hrs	8%
Electric equipment load	-20%	30%	6%
Economizer max dry bulb	50˚F	100˚F	6%
Start/end cooling schd.	-2 hrs	+2 hrs	5%
Lighting load (LPD)	-20%	20%	3%
Infiltration	-30%	30%	3%
Night time lighting load	5%	50%	2%
Wall R value (BTU/(hr˚F ft^2)	1	5	2%
Night time equipment load	5%	50%	1%
Start/end cooling schd.	-2 hrs	+2 hrs	1%
Start/end lighting schd.	-2 hrs	+2 hrs	1%
Chilled water loop temp	35˚F	55˚F	1%
Exterior lights	10kW	20kW	<1%
Motor efficiency	85%	95%	<1%
Roof R value (BTU/(hr˚F ft^2)	10	20	<1%
Hot water loop temp	110˚F	160˚F	<1%
Orientation	0˚	45˚	<1%

Preliminary Model



Post Audit Uncertainty Input Refinement

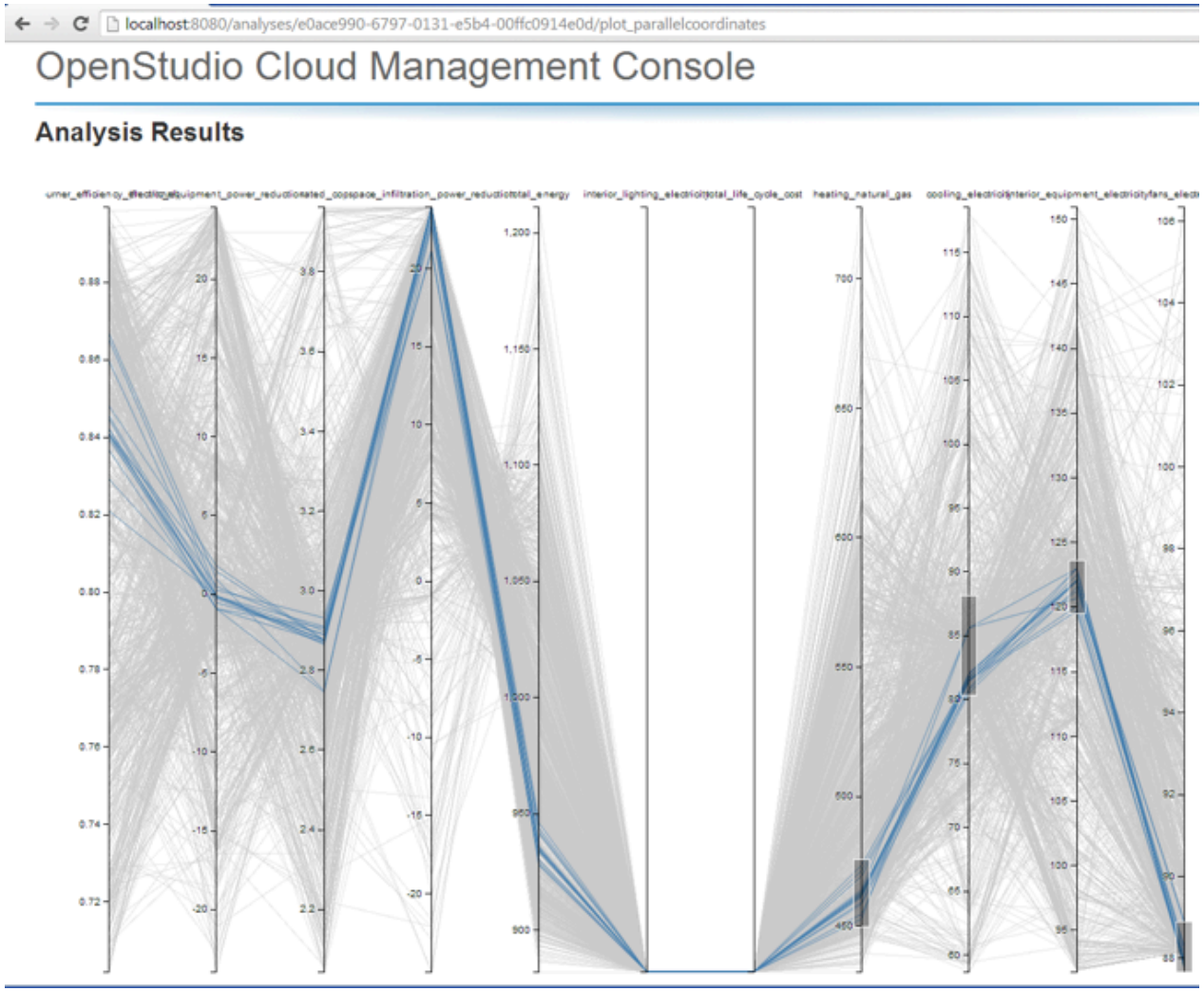
- Uncertainty reduced after targeted audit
- Some parameters become fixed, range and expected value revised for others



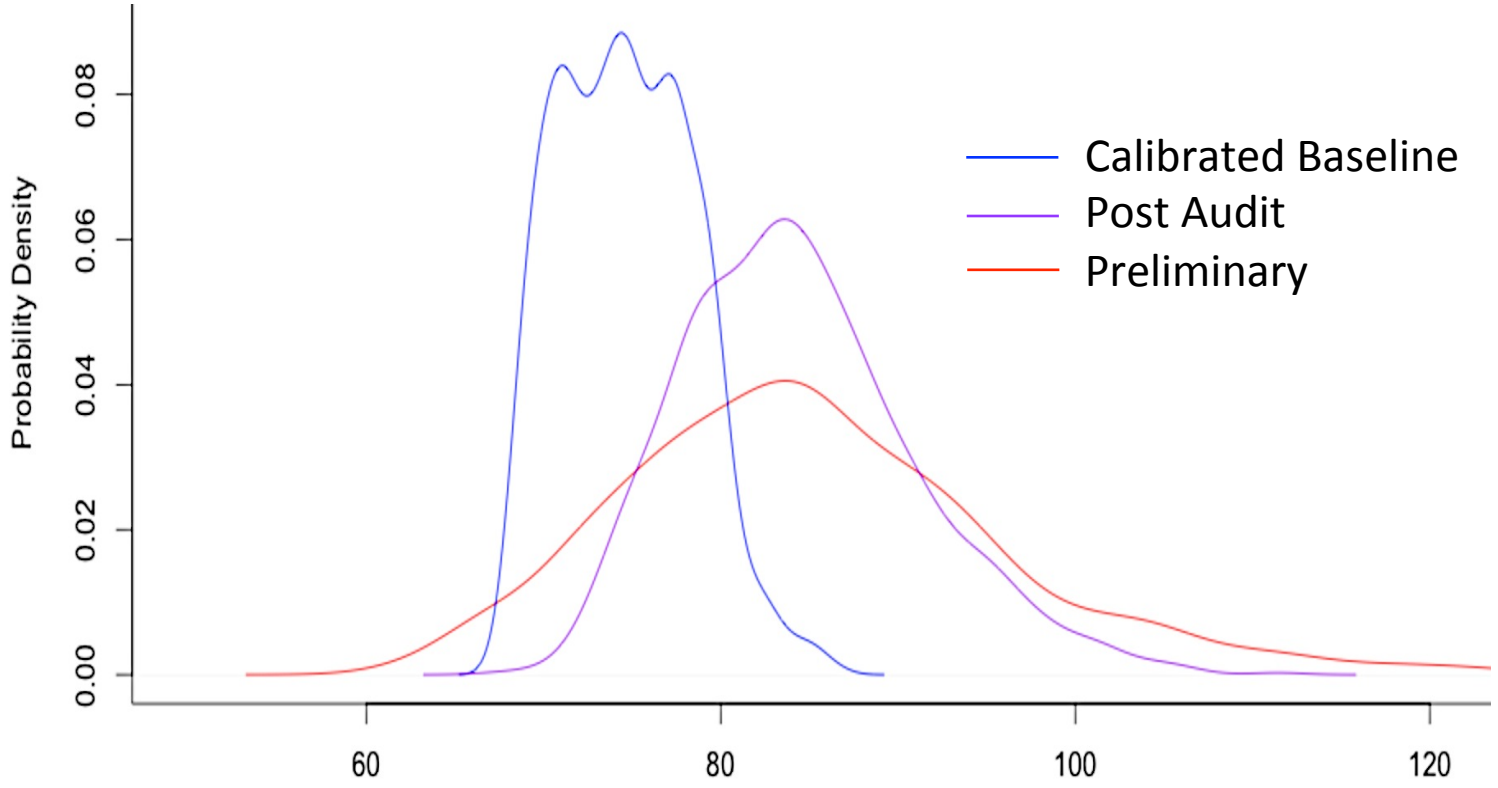
PARAMETER	RANGE	JUSTIFICATION
PARAMETER	**RANGE**	**JUSTIFICATION**
Lighting power density	-10% to +10%	Type of lights and quantity appear similar to drawings
Equipment load	-15% to +20%	Audit informs estimate (but operation remains uncertain)
Infiltration	-50 to 10%	Building envelope is in poor condition
Heat/cool setpoint	No change	This could vary due to operation
Ventilation (outdoor air)	-30 to +30%	Observation of outdoor air dampers
Exterior lights	0	No exterior lights found during audit
Economizer control	76˚F to 80˚F	Economizers appear to function
Schedule shifting	No change	Undetermined during audit, can change with operation
Fan pressure rise	No change	Hard to determine
Wall R value (BTU/(hr˚F ft^2)	No change	Hard to determine
Chiller COP	3 to 4	Audit reveals name plate rating
Boiler efficiency	0.6 to 0.8	Audit reveals name plate rating
Heat/cool sizing factors	Delete measure	Audit reveals name plate rating
Chilled water loop temp	45 +/-2˚F	Auditor observes permanent thermometer
Hot water loop temp	140 +/-2˚F	Auditor observes permanent thermometer
Min. VAV flow fraction	30 to 50%	Difficult to determine accurately

Calibration

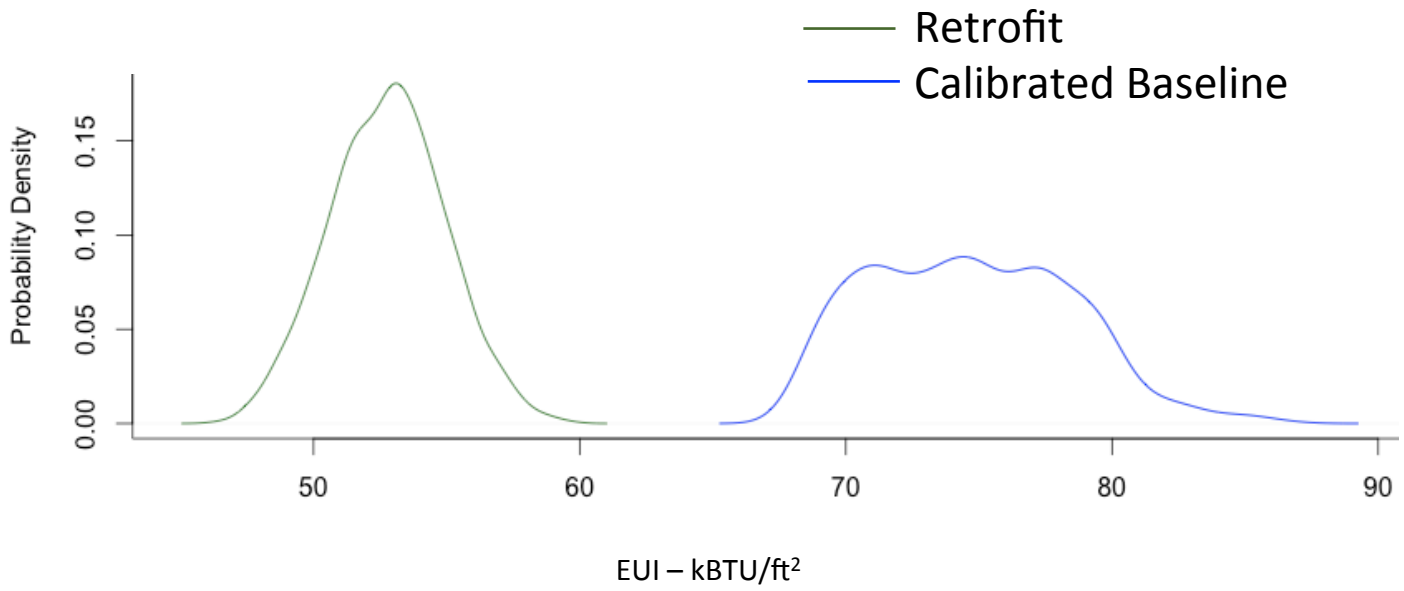
- OpenStudio auto calibration
- Results from sensitivity analysis / audit inform selection of calibration parameters
- ‘filter’ runs which lead to a calibrated solution
- Input variables treated as independent



Refinement of Preliminary Model



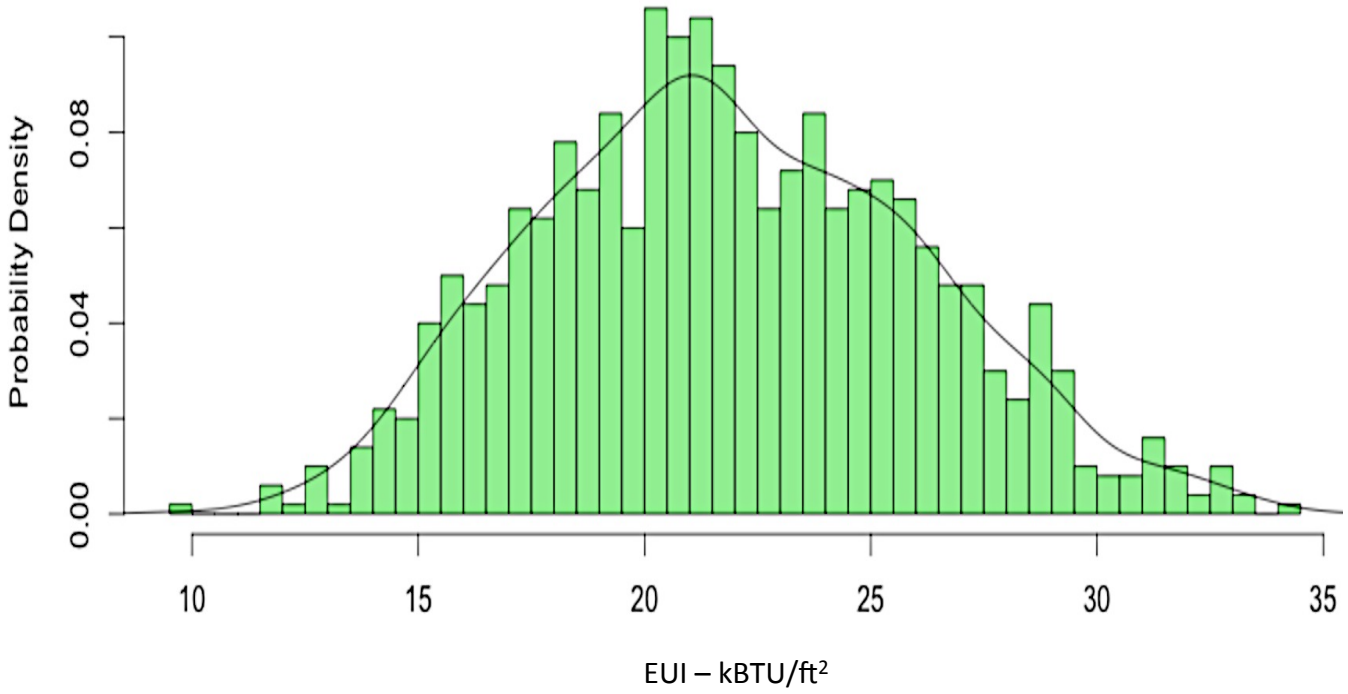
Retrofit Bundle Uncertainty Inputs



ECM	BASE VALUE	NEW VALUE	RANGE
Replace chiller (COP)	3.5	6	5.5 – 6.5
Lighting retrofit (LPD)	-	- 30%	-25% to -35%
Reduce Infiltration	-	- 30%	0% to -60%
Increase wall R (BTU/(hr˚F ft²)	1 to 5	12.5	11 to 15
Window upgrade	1x pane, reflective	3x pane, reflective	Not Analyzed
Outside air (m^3/s/ person)	0.12	0.11	-20% to +20%
Boiler efficiency	76%	95%	93% to 96%
Heating sizing factor	1.1	1	1 – 1.05

Energy Savings Estimate

- Calculating savings PDF:
  - Perfect correlation (array subtraction) or Convolution
- Perfect correlation would underestimate difference
- However preliminary PDF is an overestimate, due to inter-relationships between inputs in calibrated model



Simulation Time & Cloud Costs

5 uncertainty analysis runs, each with 1000 samples (individual model runs)

- 1.5 hours per UA run with only 4 core server & 4 core workers, whereas this would require approx. 12 hours to complete on a 4 core laptop
- approx. $6 per UA run
- total cost < $40, similar costs expected for most projects

Future Development

- Further resources needed for parameter value ranges
  - More actual performance values and guidance on distribution types
  - Ideally added to data libraries eg. BCL
- Integration between OS calibration tool & UA analysis (coming)
- Better accounting for interdependence of parameter values
- Refinement of approach to calculating energy savings PDF

Conclusion

- Outlined a methodology to incorporate uncertainty analysis into a retrofit analysis using existing open source software
- Power and low cost of cloud computing makes it feasible to incorporate UA into workflow
- Uncertainty analysis allows modelers to present a range of options distinguished by risk in addition to return on investment
- Expressing results as a probability distribution shows % chance of over performance

Questions?

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Download paper:

https://sites.google.com/a/rmi.org/building-energy-modeling/practitioners/best-practice-methods/uncertainty-analysis

Try it out:

https://github.com/NREL/OpenStudio-analysis-spreadsheet/releases/tag/0.3.0-pre4