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Demand Response Resource Quantification with Detailed Building Energy Models

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INFORMS Annual Meeting, Session MB09 – Development of Electricity Systems

November 14, 2016
Nashville, Tennessee

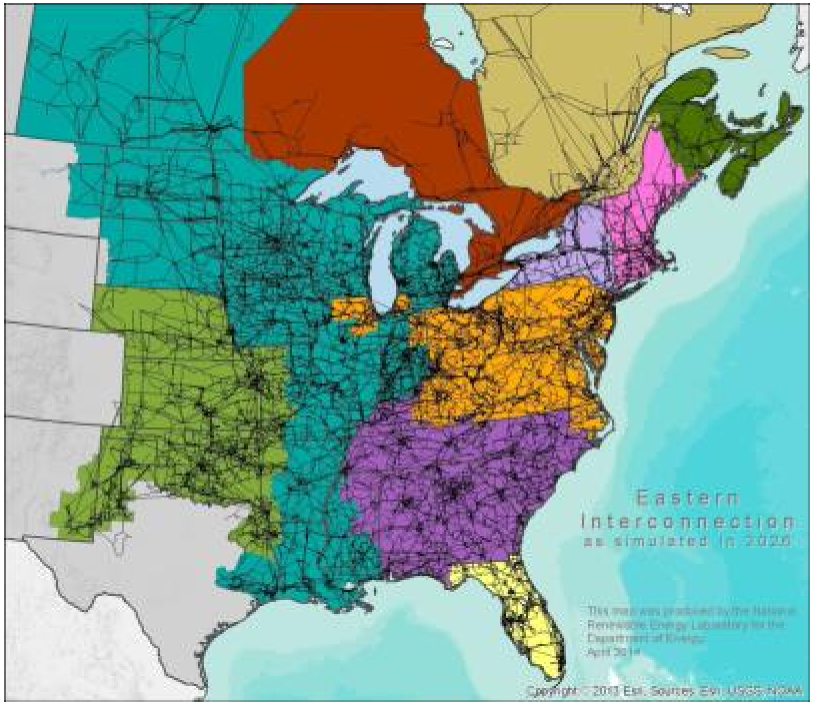
NREL/PR-6A20-67531

Overview

- Motivation
  - Grid integration studies
  - Emerging demand response technologies
  - Existing demand response resource data sets
- Approach & Preliminary Results
- Future Work

Motivation

Grid integration studies investigate particular potential issues with renewable integration to determine (1) if they are real and (2) mitigation options.

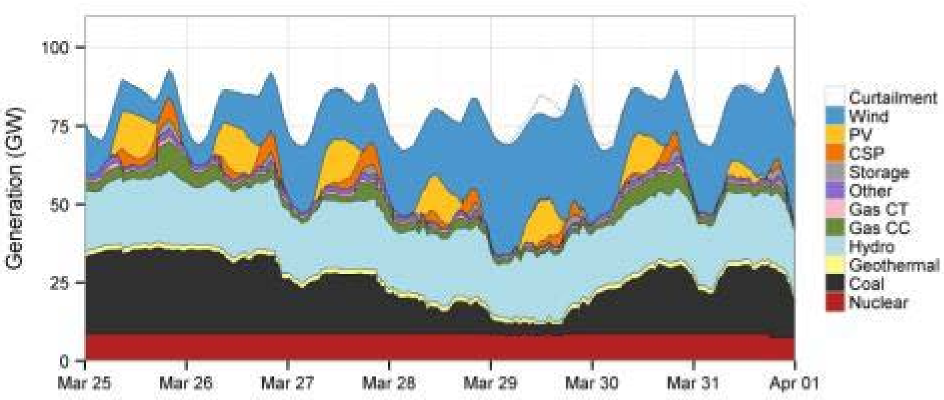


Studies

- Eastern Wind Integration and Transmission Study (EWITS)
- Renewable Electricity Futures (REF)
- Western Wind and Solar Integration Study (WWSIS)
- Eastern Renewable Grid Integration Study (ERGIS)

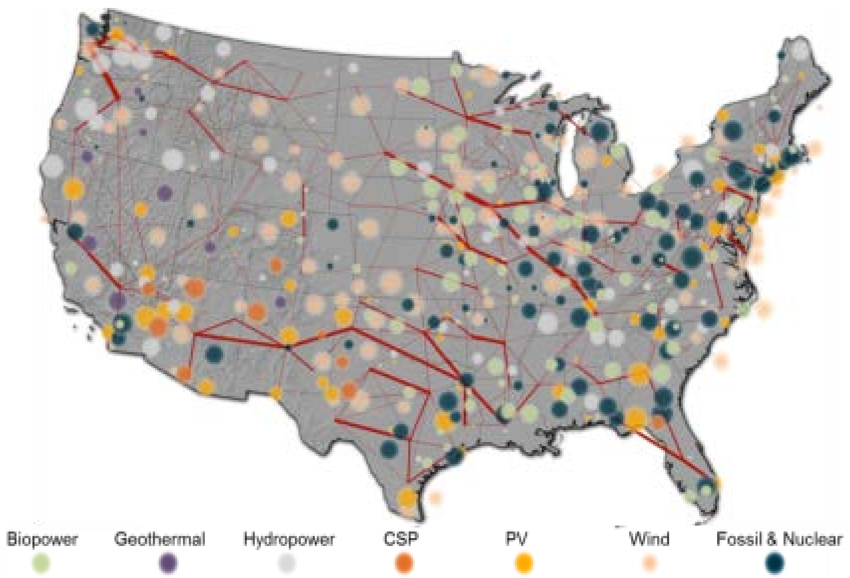
Features

- High resolution renewable resource data
- Investment decision models (capacity expansion)
- Operational models (hourly, sub-hourly, and dynamic)



For basic grid integration studies, a simple **approach to load modeling** is sufficient. For exploring deeper levels of change, deeper understanding of load are also needed.

Typical: Load from a historical weather year (the same one as wind and solar) is grown by a fixed percentage per year.

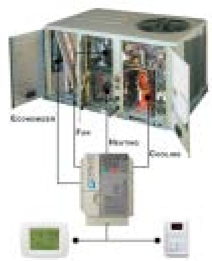


Current State-of-the-Art: Renewable Electricity Futures Study has a whole chapter on load modeling. Brackets low and high demand and adjusts load shapes.

Our Goal: Geospatially and temporally resolved load modeling done by sector modelers, with the ability to explore a number of future scenarios (efficiency, electrification, flexibility).

Emerging Demand Response Technologies

- Demand response start-ups are proliferating.
- Field demonstrations provide valuable data on what is possible but are very expensive per data point. Example: BPA-sponsored field demonstration



Roof Top Units (RTUs)

Lighting

Plug Loads

DR Signal

Electric Water Heaters

→ Use simulation to screen for best opportunities

Primary Research Questions

To what extent can demand-side resources help integrate renewable energy into power systems?

What demand-side resources make the most economic sense? Where and in what sorts of conditions?

To what extent can the energy economy be decarbonized through electrification? What role might demand-side flexibility play under those conditions?

Existing Demand Response Resource Data Sets

Existing data sets

- LBNL (Olsen et al. 2013)
- LBNL updated
- LBNL California (Alstone et al. 2016)
- The Brattle Group evaluation for FERC (FERC et al. 2009)
- European estimate (Gils 2014)

Remaining issues

- Geospatially resolved weather
- Building heterogeneity—physical and operational
- Headroom to absorb additional energy
- Other aspects of physical and operational realism, especially for energy shifting

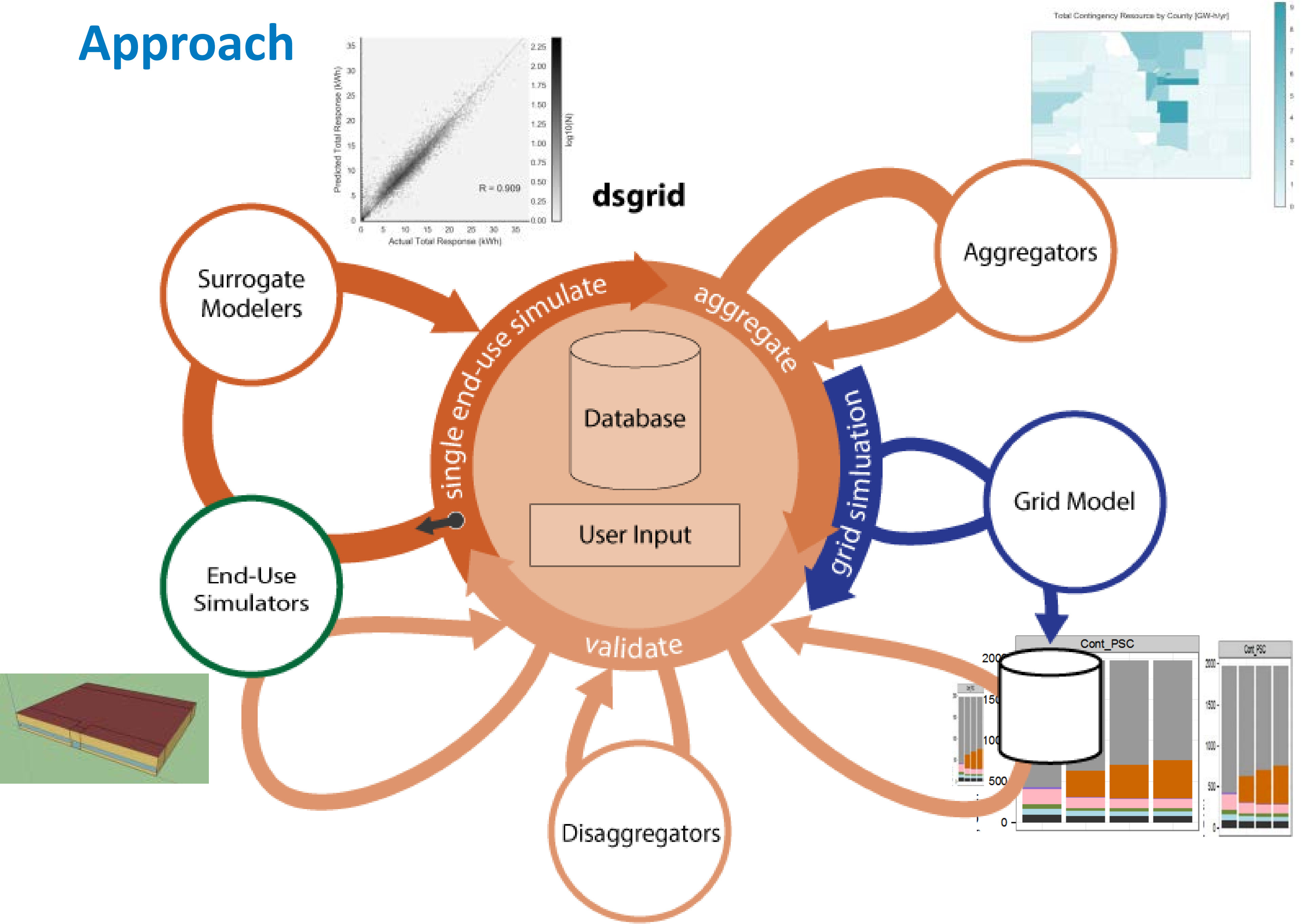
Approach & Preliminary Results

Estimate Capability of Buildings to Provide Particular Grid Services

DR Products (Hummon et al. 2013)

Products		Physical Requirements			
Product Type	General Description	How fast to respond	Length of response	Time to fully respond	How often called
Regulation	Response to random unscheduled deviations in scheduled net load (bidirectional)	30 seconds	Energy neutral in 15 minutes	5 minutes	Continuous within specified bid period
Flexibility	Additional load-following reserve for large un-forecasted wind/solar ramps (bidirectional)	5 minutes	1 hour	20 minutes	Continuous within specified bid period
Contingency	Rapid and immediate response to a loss in supply	1 minute	≤ 30 minutes	≤ 10 minutes	≤ Once per day
Energy	Shed or shift energy consumption over time	5 minutes	≥ 1 hour	10 minutes	1-2 times per day with 4-8 hour notification
Capacity	Ability to serve as an alternative to generation	Top 20 hours coincident with balancing authority area system peak			

Approach



Predicted Total Response (kWh)
Actual Total Response (kWh)
R = 0.909
log10(N)
dsgrid
Surrogate Modelers
Aggregators
single end-use simulate
aggregate
Database
User Input
grid simluation
Grid Model
End-Use Simulators
validate
Disaggregators
Cont_PSC

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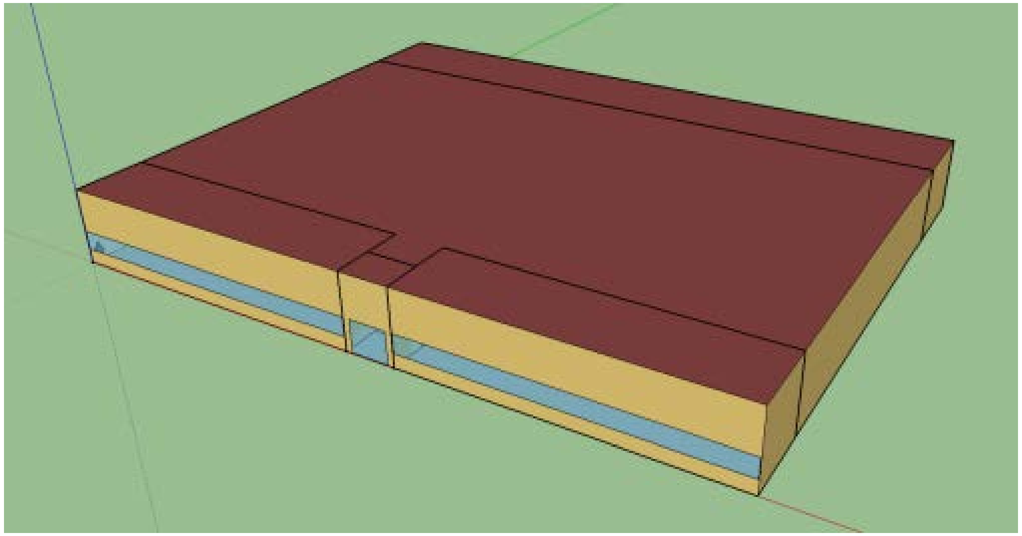
Retail Buildings within Colorado's Balancing Area (RMPP)

Methodology Overview

1. Define the OpenStudio prototype building
2. Apply demand response modeling measures
3. Sensitivity analysis
4. Large-scale sampling
5. Post-process to create database of responses
6. Surrogate modeling
7. Aggregate using surrogate models and building population data, including actual year weather and characteristics mapped to surrogate model inputs
8. Import data into grid operations simulation
9. Run grid simulation to calculate resource value

Step 1. Choose a Model*



Standalone Retail Reference Building

Floor Area: 24,692 ft^2
Vintages: 90.1-2013, 90.1-2010, 90.1-2007, 90.1-2004, 1980-2004, Pre 1980
Geography: 16 ASHRAE Climate Zones

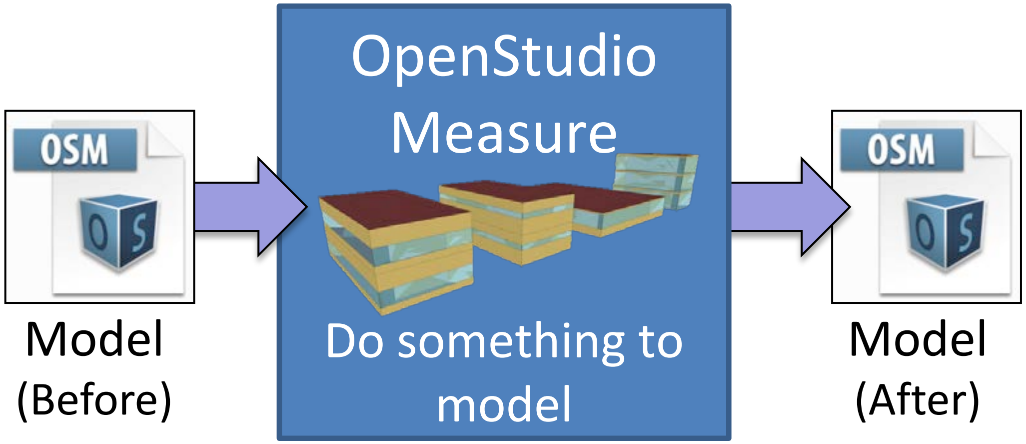
*DOE Reference/Prototype Building, see

https://github.com/NREL/openstudio-standards

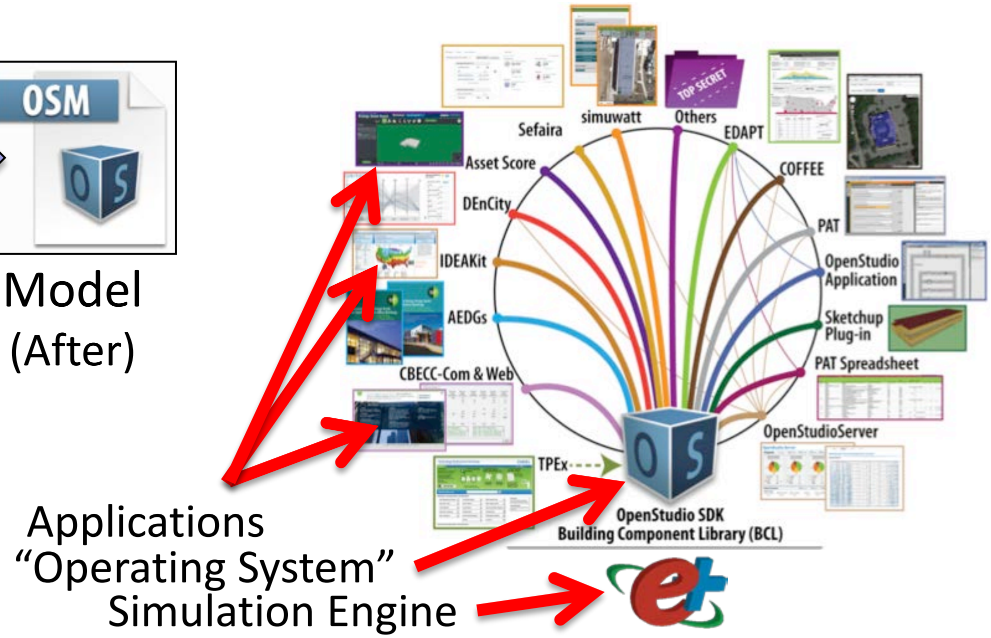
(16 building types, 7 vintages each)

Step 2. Apply DR Measures

OpenStudio Measures are small scripts that transform building models **quickly** and **easily**



DOE Energy Modeling Ecosystem



1. EnergyPlus measure to define the demand response event
2. EnergyPlus measure to define the actual response
3. Reporting measure to gather output data

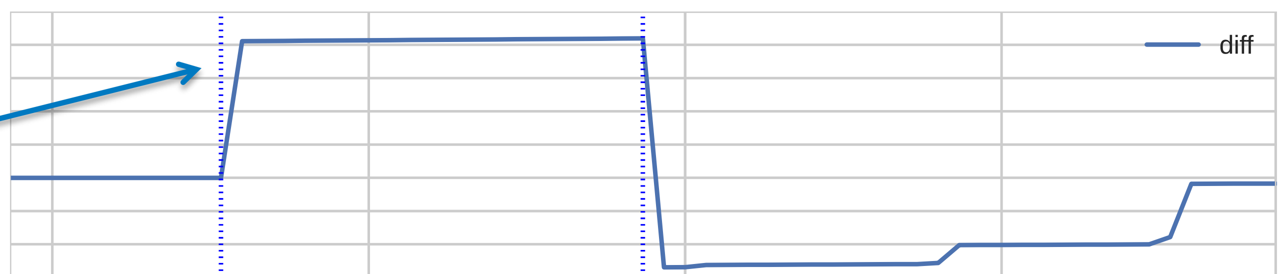
Step 2. Apply DR Measures (cont.)

`event_delta_t` = 5 degF, `start_time` = 13:40 hrs, `duration` = 20 minutes

Increased setpoint by `event_delta_t` at `start_time` for `duration` minutes

R Event

Reduce power use from Baseline By 40 kW for 20 minutes



Shed:
40 kW
[1.6 W/ft^2]

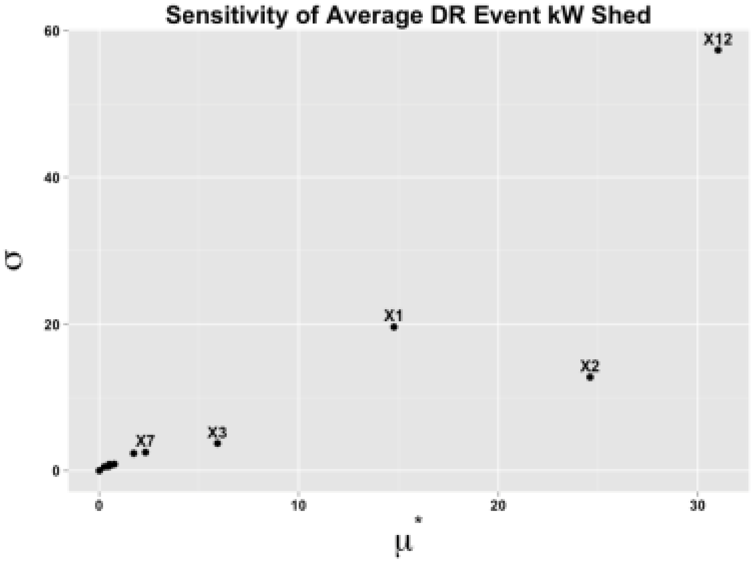
Step 3. Sensitivity Analysis

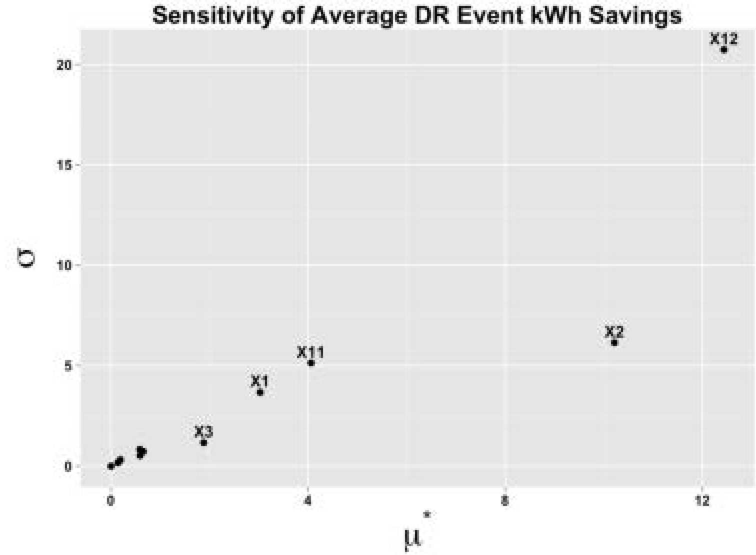
Quantify DR behavior for different:

- Times of the day (start time)
- Event lengths (duration)
- Event setpoint reductions (event delta T)
- Weather conditions
- Building envelope parameters (R value, mass, solar absorptance)
- Building HVAC parameters (fan belt efficiency)
- Building lighting parameters (internal LPD)
- Building schedule parameters (linear perturbation/24 hours for all schedules, weekday/Saturday/Sunday) (to do)

Step 3. Sensitivity Analysis (cont.)

Parameter Impact Using the Morris Method





Measure	Variable	ID	Units	min	max
Create DOE Prototype Building	Building Vintage	X1	NA	0	1
Set Weather File	Location	X2	NA	0	1
Reduce Lighting Loads	Reduction Percentage	X3	%	0	60
Change Exterior Wall Properties	R Multiplier	X4	NA	0.5	2
Change Exterior Wall Properties	Solar Absorptance Multiplier	X5	NA	0.5	2
Change Exterior Wall Properties	Thermal Mass Multiplier	X6	NA	0.5	2
Change Exterior Roof Properties	R Multiplier	X7	NA	0.5	2
Change Exterior Roof Properties	Solar Absorptance Multiplier	X8	NA	0.5	2
Change Exterior Roof Properties	Thermal Mass Multiplier	X9	NA	0.5	2
Improve Fan Belt Efficiency	Motor Efficiency Change	X10	%	-20	20
DR Schedule Maker	Event Duration	X11	Hours	0.25	0.5
DR Schedule Maker	Event Start Time	X12	Hours	8	20
DR Setpoint Modifier	Event Delta-T	X13	C	0	6

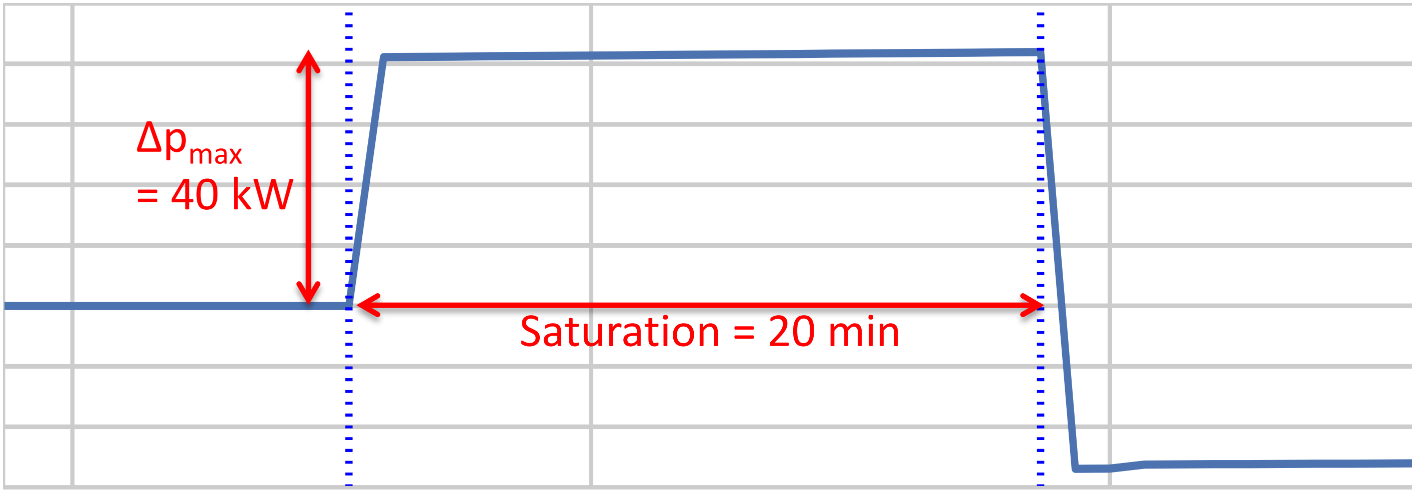
Step 4. Large-Scale Sampling Analysis

Quantify DR behavior for different:

- Times of the day (start time)
- Event lengths (duration)
- ~~Event setpoint reductions (event delta T)~~
- Weather conditions
- Building envelope parameters (R value, mass, solar absorptance) -- Subset
- ~~Building HVAC parameters (fan belt efficiency)~~
- Building lighting parameters (internal LPD)
- ~~Building schedule parameters (linear perturbation/24 hours for all schedules, weekday/Saturday/Sunday) (to do)~~

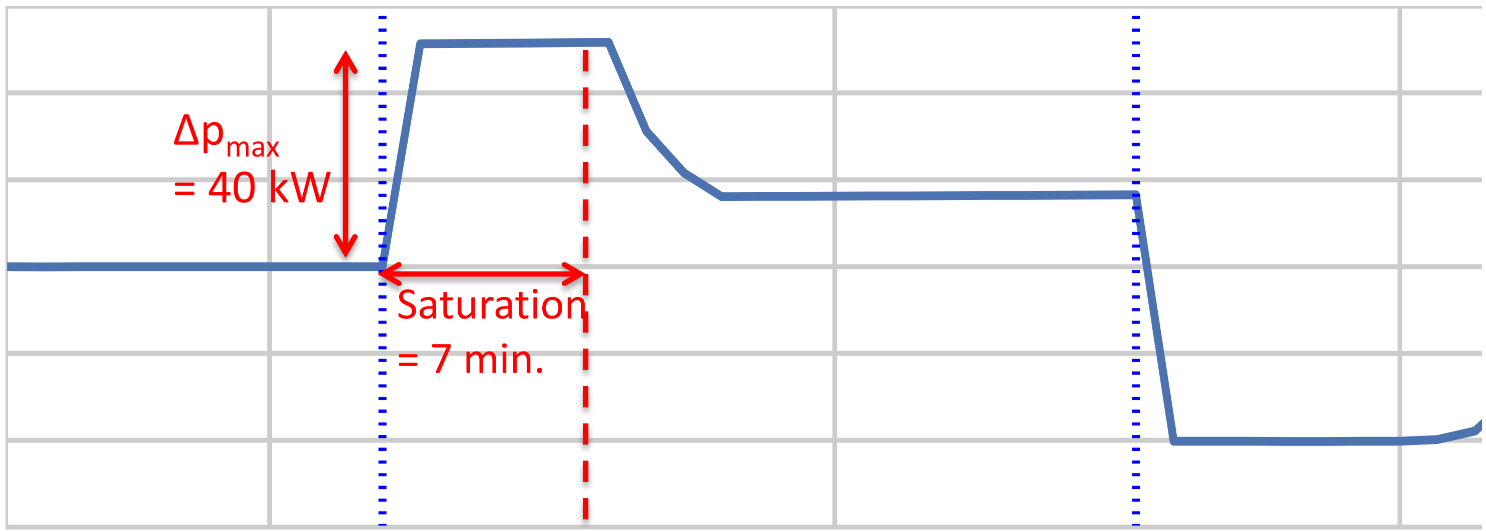
Step 5. Post-Process Simulations

- Calculate the Shed, "Δp_{max}"
- Calculate the "*Saturation Time*"

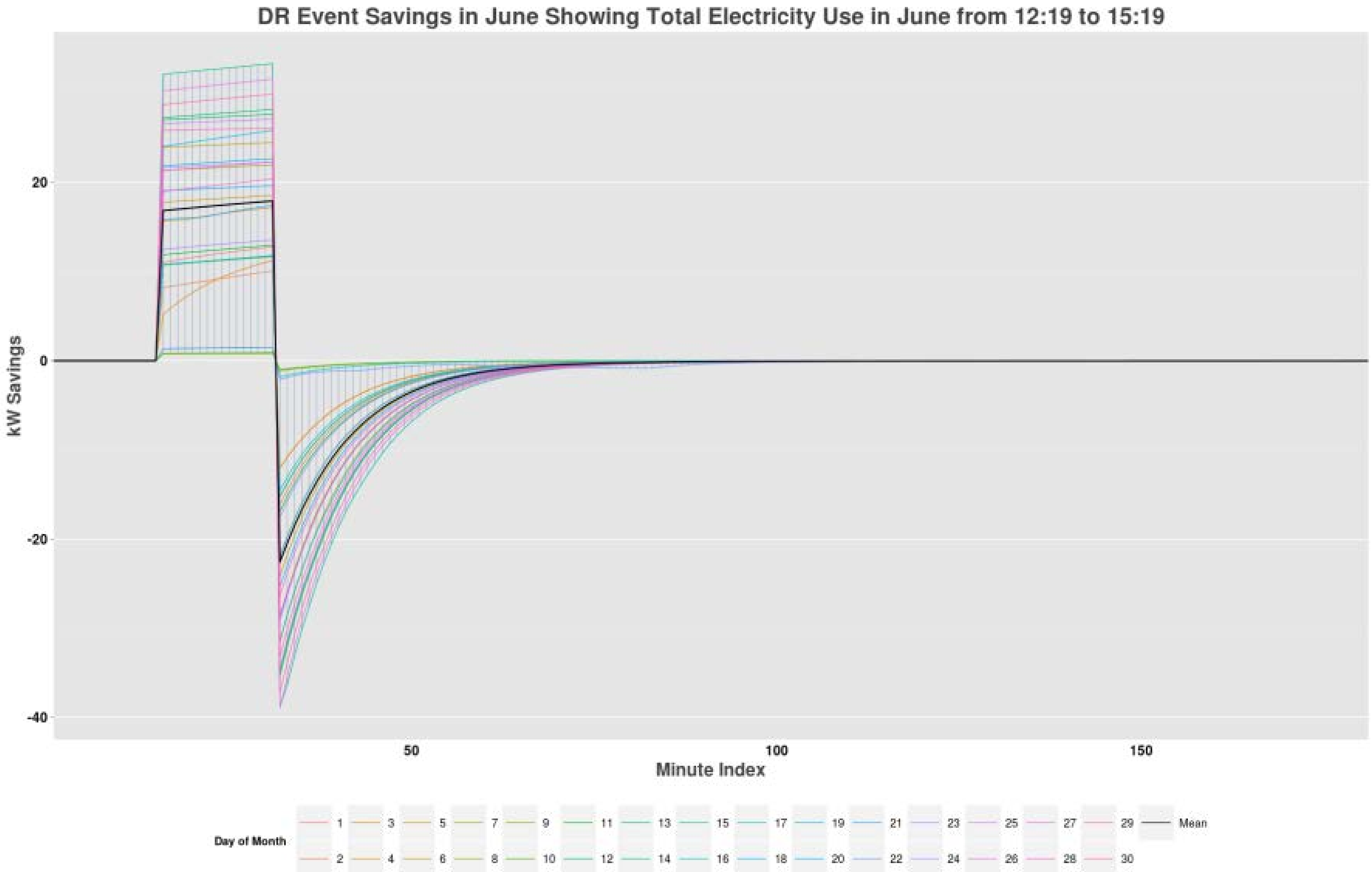


Step 5. Post-Process Simulations (cont.)

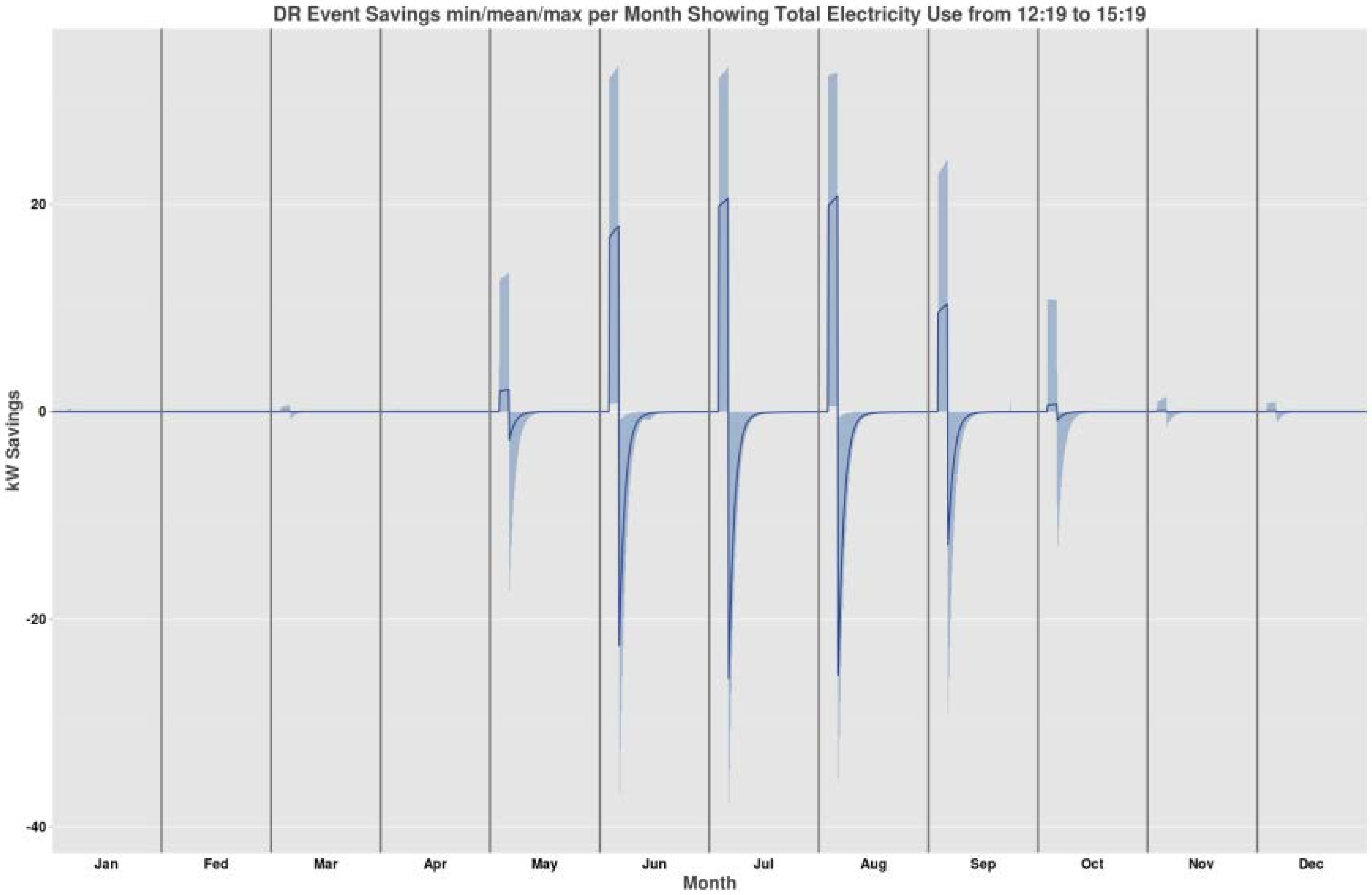
E+ captures when the building '*saturates*' prior to the end of the event.



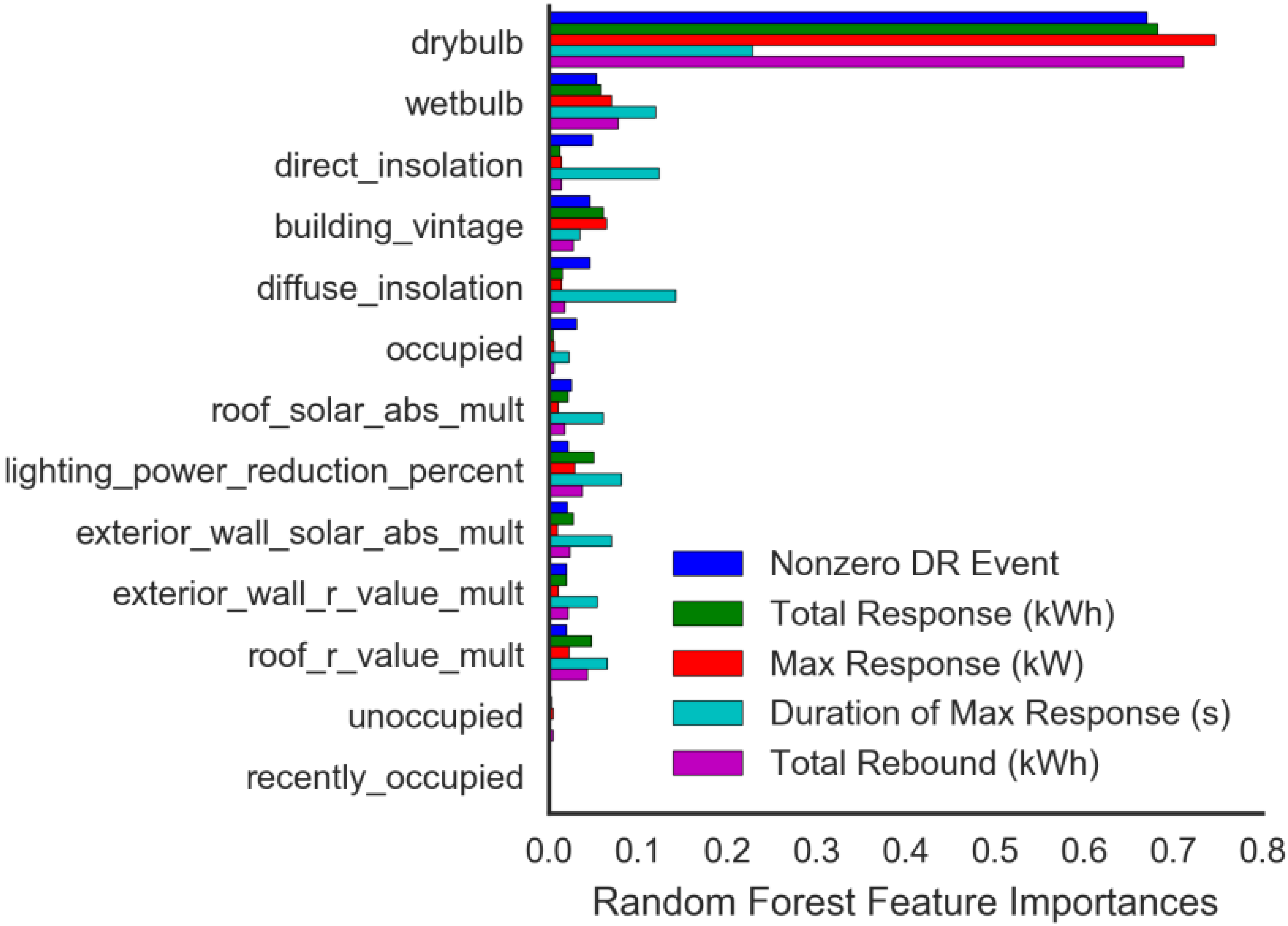
Step 5. … Into Database of Responses



Step 5. … Into Database of Responses (cont.)



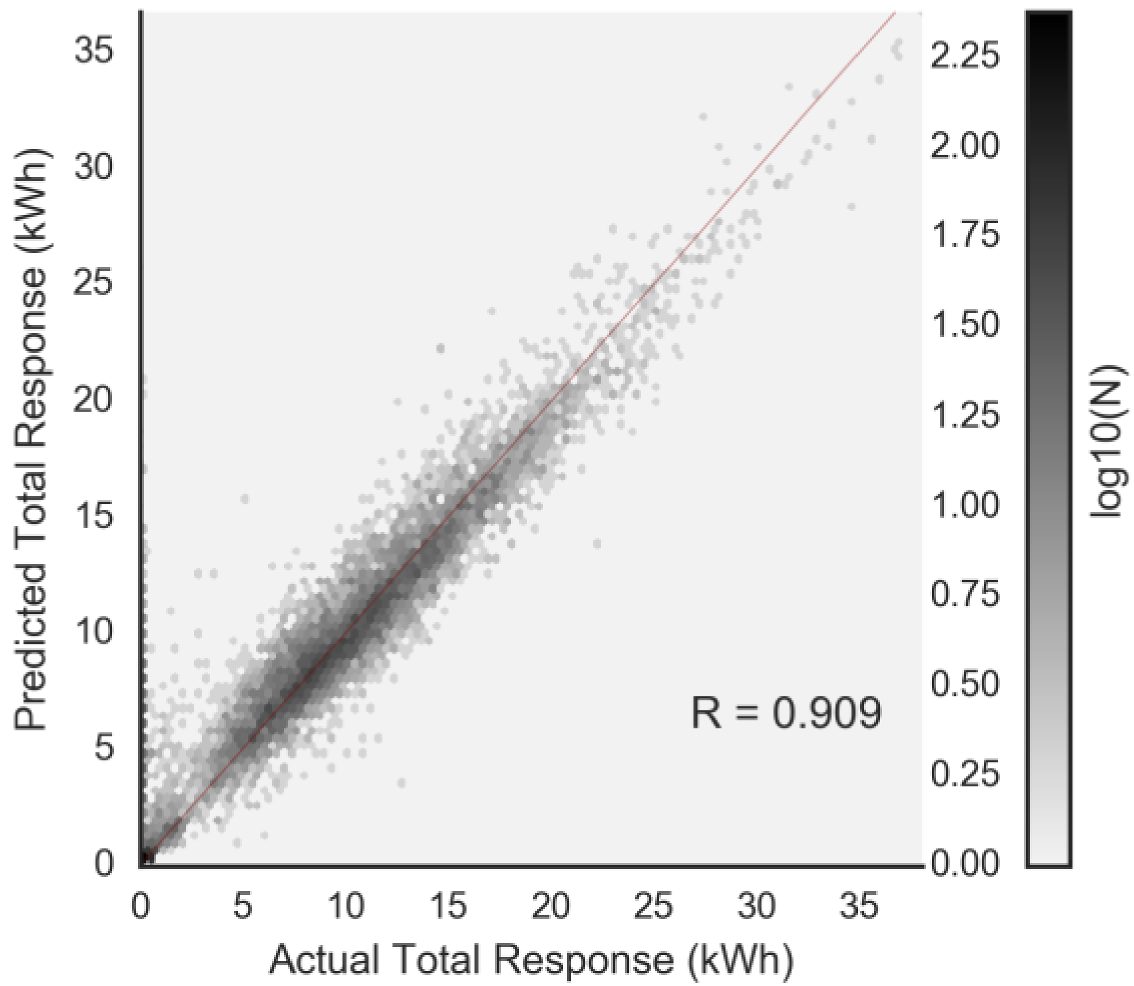
Step 6. Surrogate Modeling



Step 6. Surrogate Modeling

DR Resource in kWh per 20-min event

(Random Forest regression engine; 500 model runs; 45,404 test events)



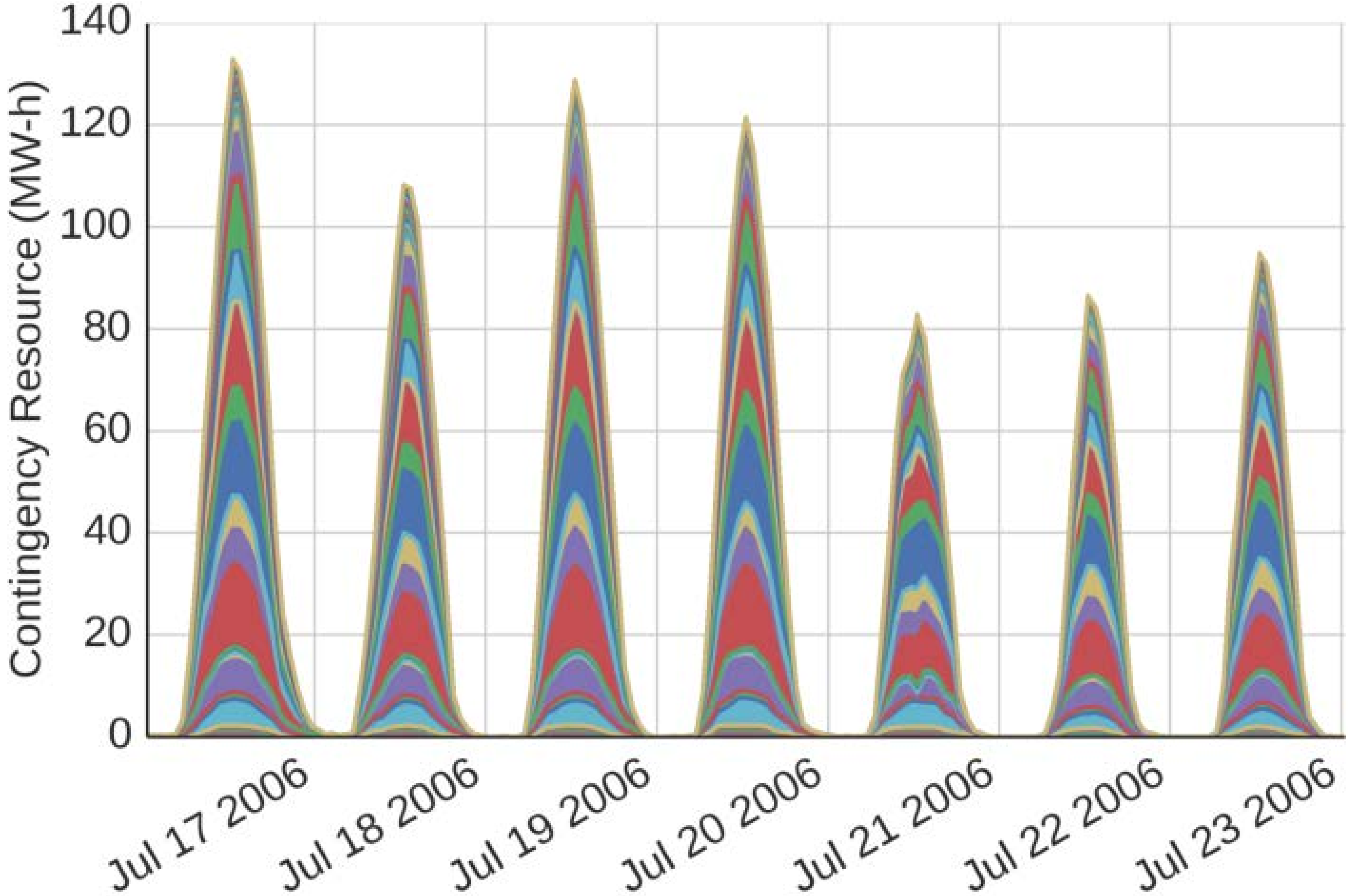
Step 7. Aggregate

Example Data Sources (results use those in blue)

	CBECS *(public)*	Commercial Business Patterns *(public)*	Commercial Building Inventory *(private)*	CoStar™ *(private)*
Source	EIA	Census	Tax Assessor Records	Direct Calls & Canvassing
Geographic Resolution	4 Census Regions 9 Census Divisions	3,007 Counties	Individual Parcels	Individual Buildings
Temporal Resolution	~10 years	1 year	>50 years	>50 years
Focus	Energy Use	Economic Activity	Direct Marketers	Real Estate Market
Building Information	Detailed	Minimal	Detailed	Detailed
Sample Size	~5,215 Buildings	NA http://www.census.gov/econ/cbp/methodology.htm	~14,353,645 Buildings (99% of Parcels) http://www.commbuildings.com/	~4.6 Million Properties (95 Billion sq ft) https://www.costar.com/

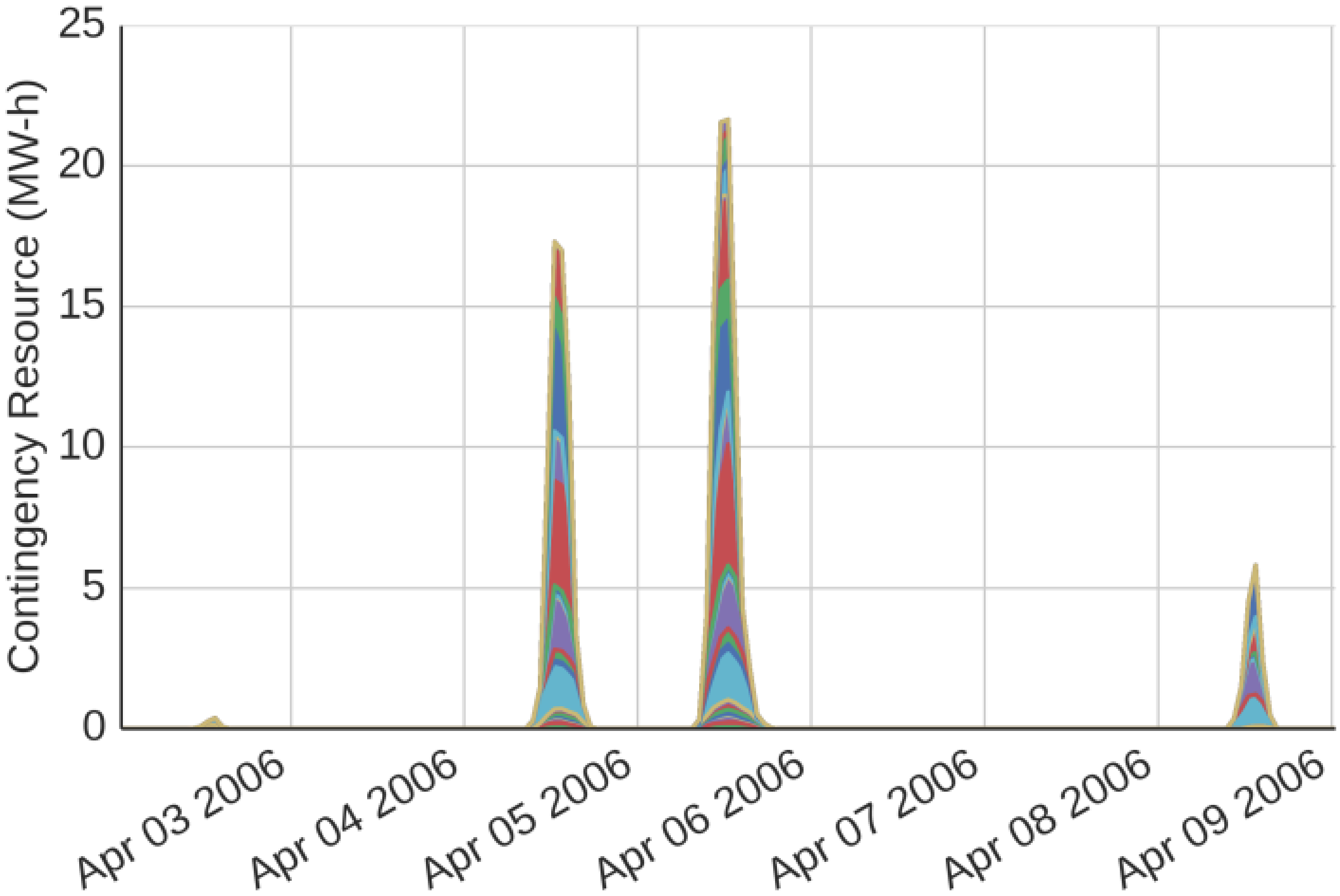
Step 7. Aggregate (cont.)

Standalone Retail Buildings in the United States Using CBECS and CBP Data: Summer Week



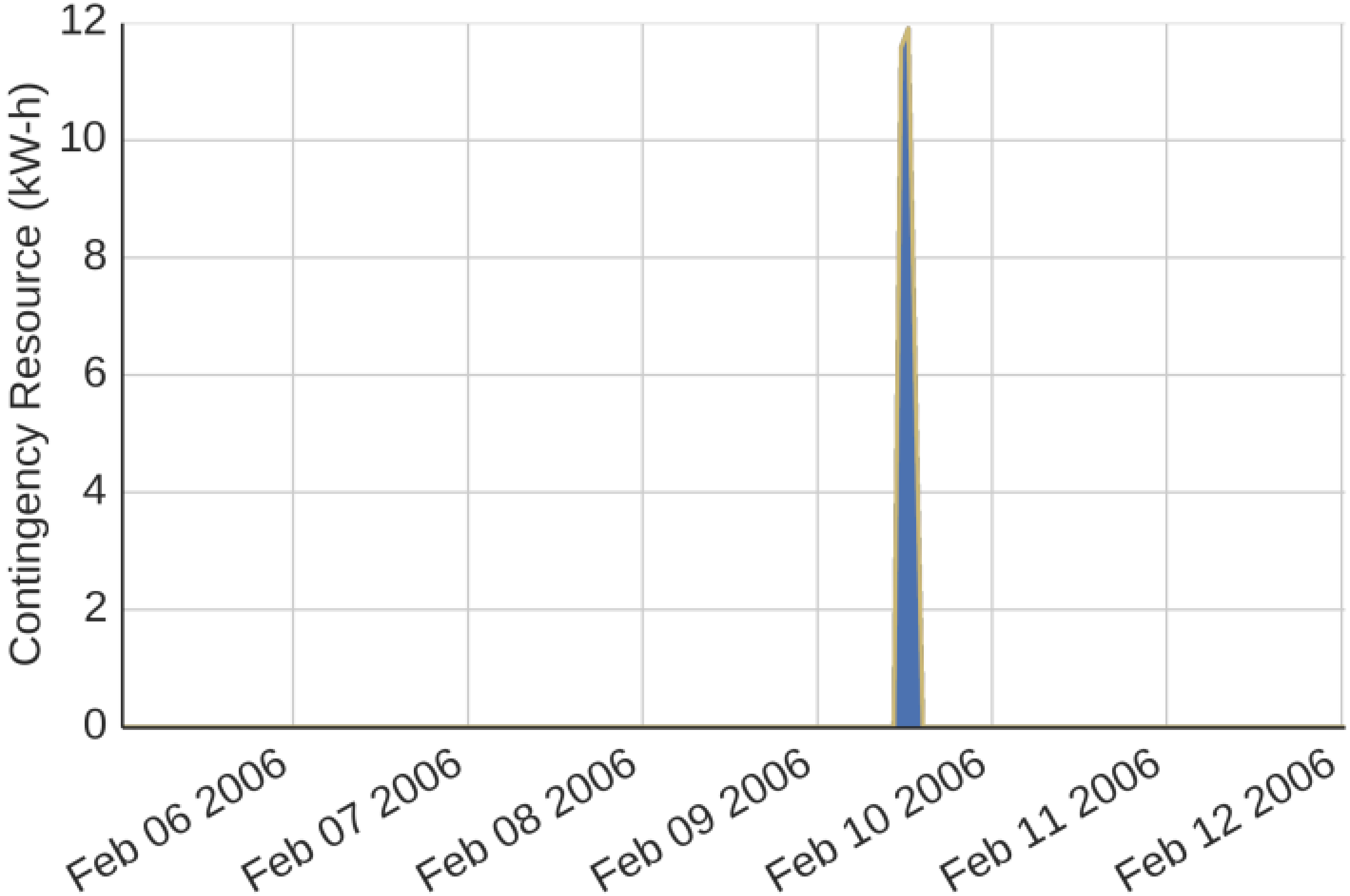
Step 7. Aggregate (cont.)

Standalone Retail Buildings in the United States Using CBECS and CBP Data: Spring Week

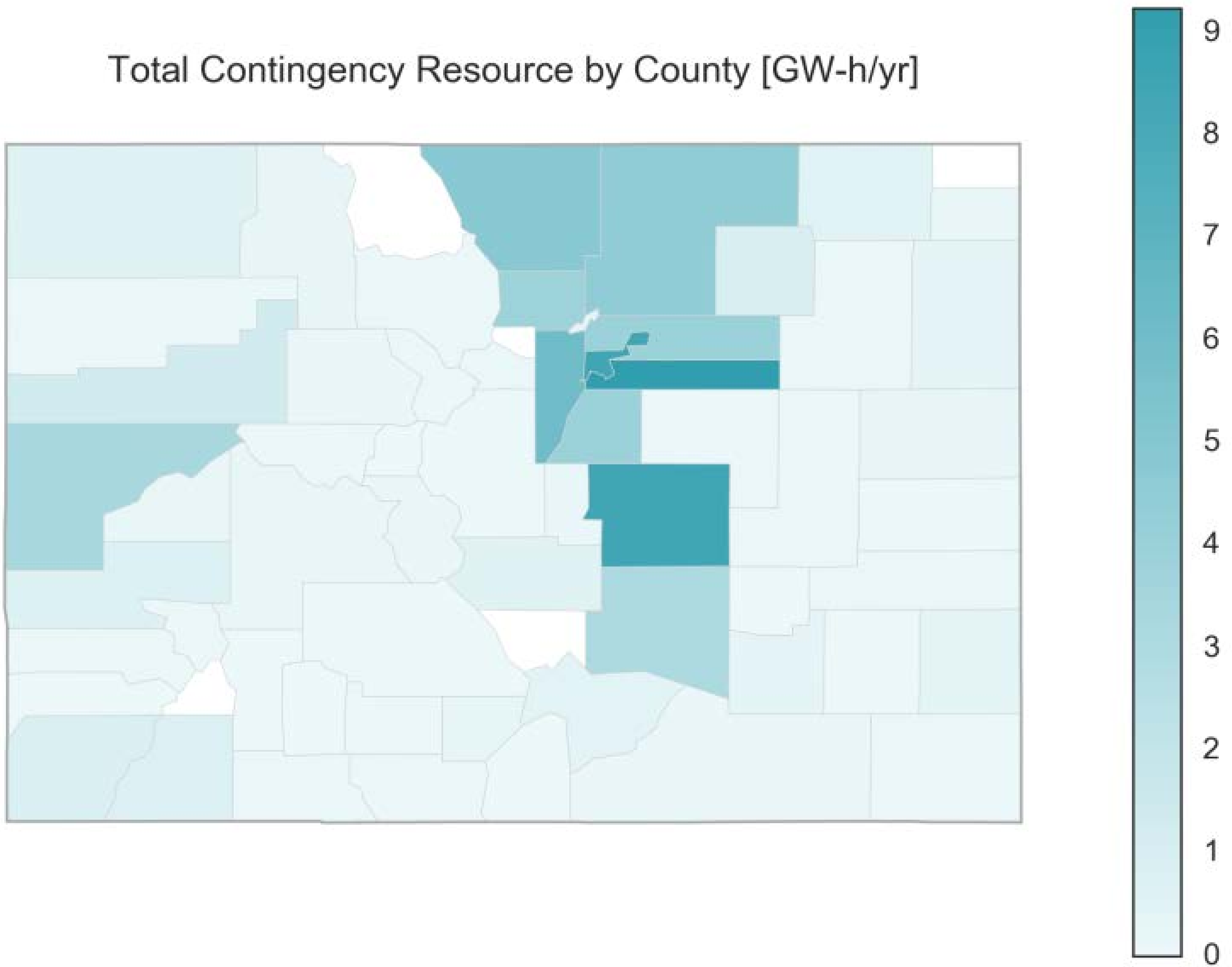


Step 7. Aggregate (cont.)

Standalone Retail Buildings in the United States Using CBECS and CBP Data: Winter Week



Step 7. Aggregate (cont.)



Step 8. Quantify DR Value with Grid Models

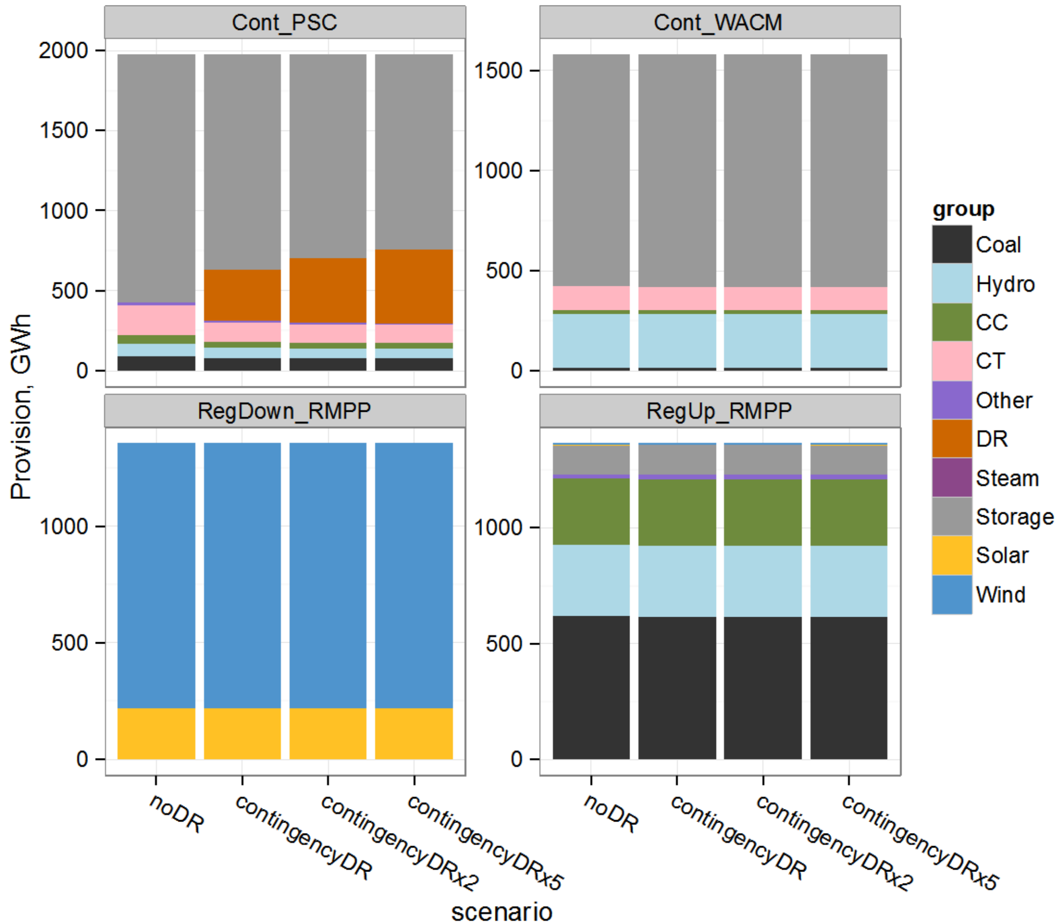
Use PLEXOS Cost Production Model:

Commercial software tool that provides energy market participants, system planners, investors, regulators, consultants, and analysts with a comprehensive range of features integrating electric, water, gas and heat production, transportation, and demand over simulated timeframes from minutes to 10s of years.

Table. Value of Retail DR in Colorado's RMPP for a 20-Minute Contingency Service

Market Penetration Scenarios	Installed Capacity of DR (MW)	Reduction in System Cost (million $)	Reduction of System Cost ($/MW of DR)	Revenue to DR providers ($/MW of DR)
#1	339	1.458	4,300	2.20
#2 (x2)	678	1.523	2,200	0.33
#3 (x5)	1,695	1.470	9,00	0.18

Changes in Generation Resources with Increasing Retail DR within Colorado's RMPP



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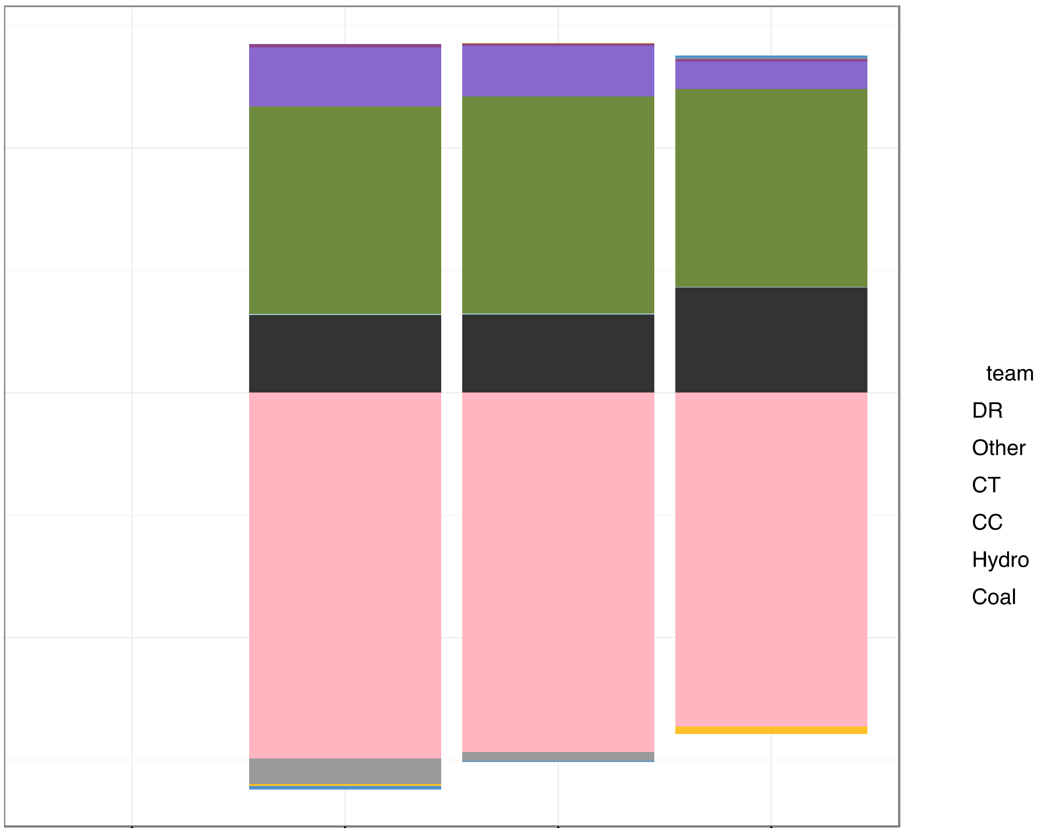
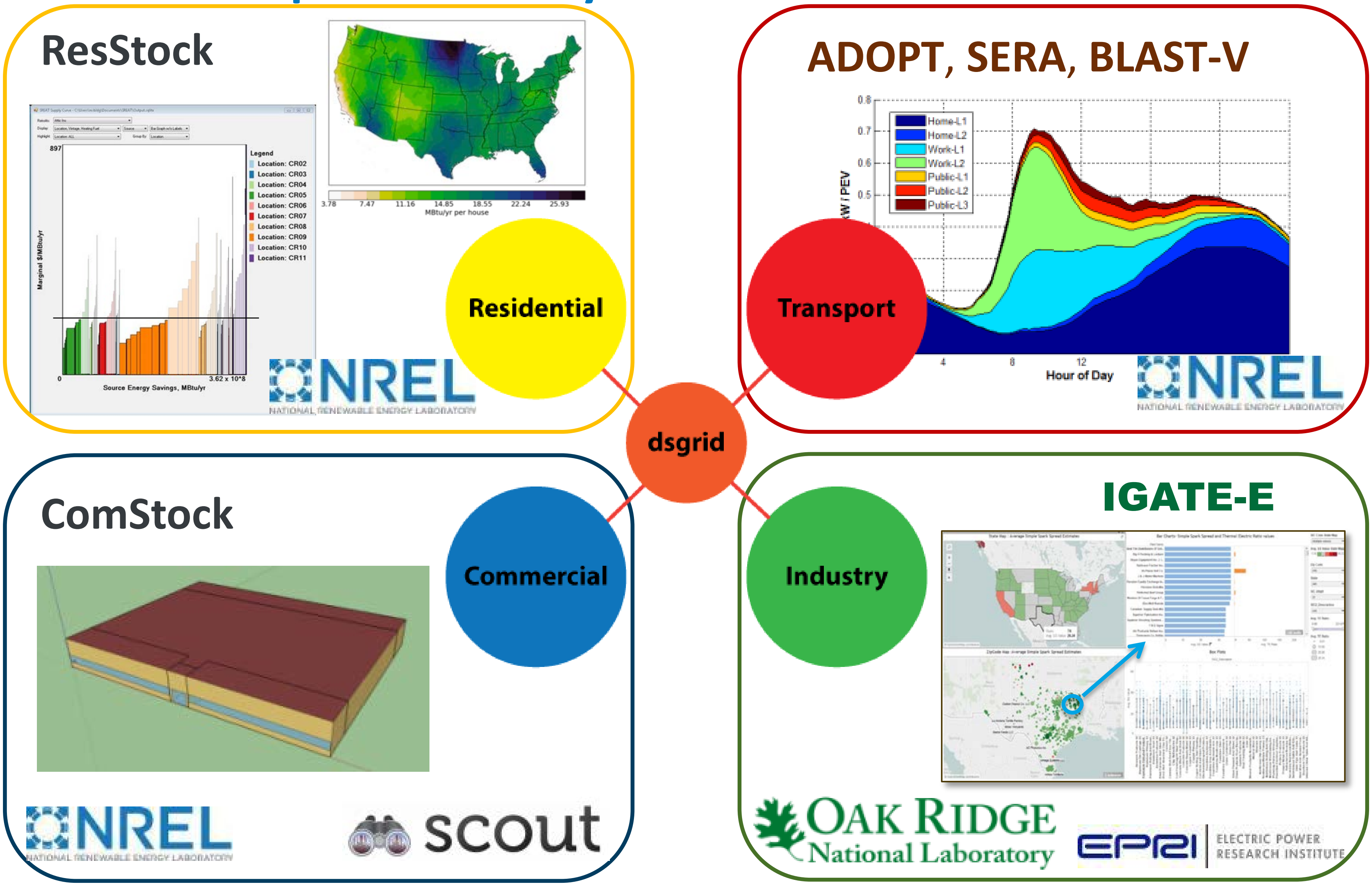


Future Work

We're bringing four energy modeling teams together to create an unprecedentedly detailed look at electrical load.



Thank you!

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