End-to-End Impact of Building Systems Response and Load Flexibility

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Energy Systems Integration 102
Research Challenges

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NREL | Golden, Colorado

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B2G Integration for Grid Flexibility

- Fundamental operation of electricity grid has changed relatively little over almost one hundred years.
- No grid-scale nor distributed storage at scale imminent
- RES generation increasing component in generation mix
- How best to enable flexible participation of building sited electricity consumers given a mix of traditional and renewable generation?
- Historically, DSR have played a inflexible role in energy markets, requiring grid balancing through modulation of generators.
- However, buildings can create additional grid flexibility to aid in absorbing intermittency of variable generation resources.

New Role of Buildings Emerging

- Significant peak electric demand reductions can be achieved through active TES systems and by utilizing passive building mass.
- Buildings may also provide ancillary services, including spinning and non-spinning reserve.
- Recent work has considered controllable building electric loads for economic dispatch in energy markets, including transmission constraints.
- As an example, researchers recently demonstrated that chilled water supply temperature could be modified to create DR.
- Frequency regulation in commercial buildings has also recently been investigated.

Energy Use Profiles

What is going on in buildings today?

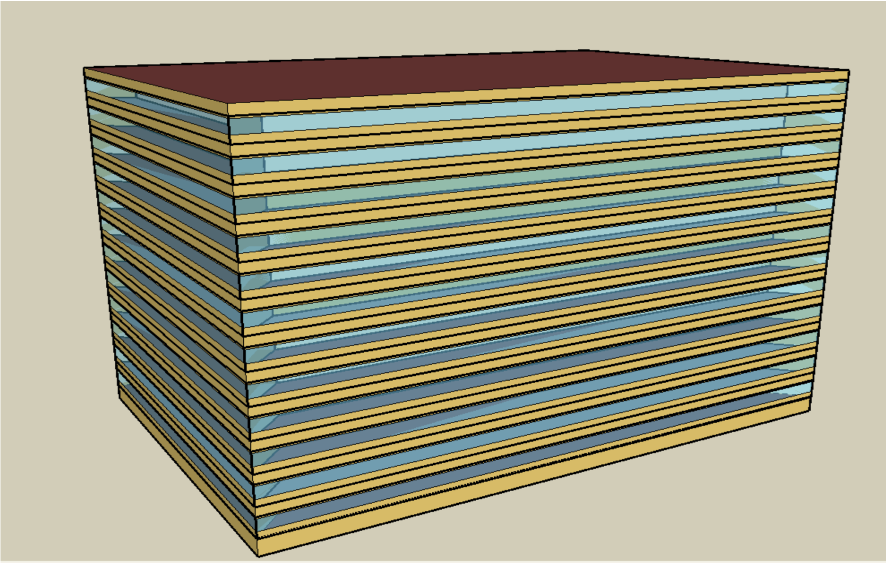
Energy Use Variability

- Energy consumption varies widely among different building types
- Location affects HVAC energy consumption
- Interactions with electrical grid involve temporal mapping of supply and demand
  - Seasonally
  - Hourly
  - Second-by-second
- Explore time-variations of building energy use…

- Consider prototypical buildings
  - Large and medium office
  - Standalone retail store
  - Midrise apartment building
  - Primary school
- Examine temporal energy use profiles
  - Monthly end use consumption of gas and electricity
  - Weekly load profiles in summer and winter
  - Daily load profiles in summer and winter
- What are opportunities to shape these demand profiles?

Large Office Building

- Twelve stories, 46,320 m^2
- 38% window to wall ratio
- Concrete and steel construction
- Insulation and window performance comply with ASHRAE Standard 90.1-2004
- Occupancy 19 m^2/person
- 16 W/m^2 lighting
- 11 W/m^2 equipment
- Central HVAC with gas boiler and electric chiller, VAV air distribution



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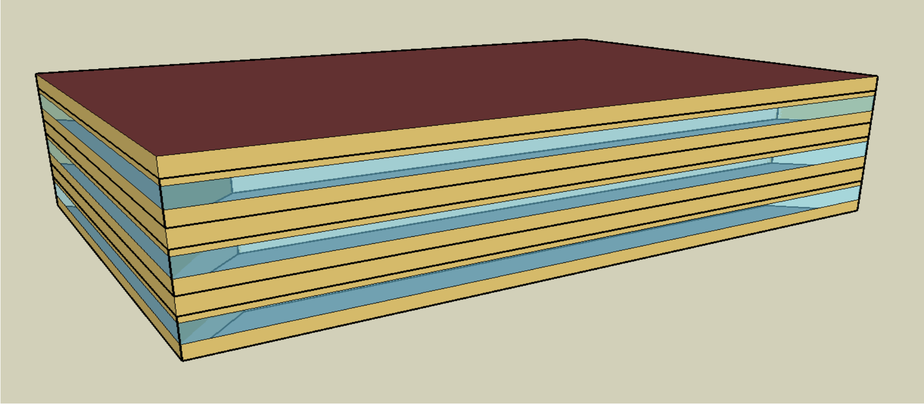
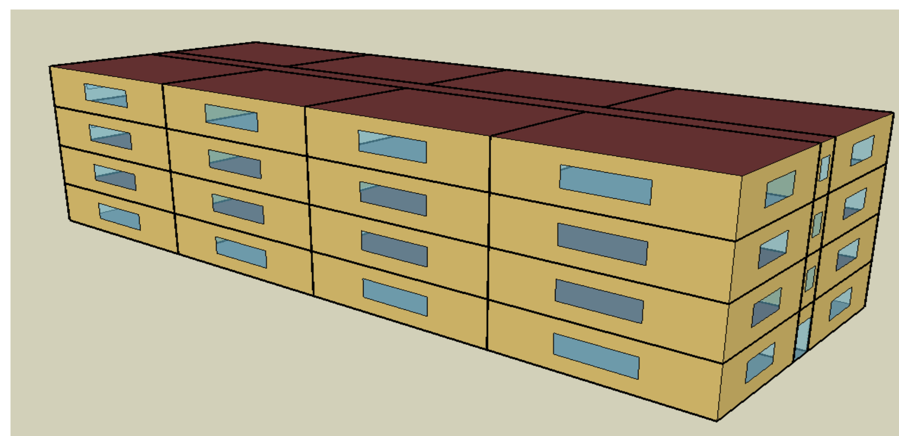
Medium Office Building

- Three stories, 4950 m^2
- 33% window to wall ratio
- Steel frame construction with stucco exterior
- Insulation and window performance comply with ASHRAE Standard 90.1-2004
- Occupancy 19 m^2/person
- 17 W/m^2 lighting
- 11 W/m^2 equipment
- Packaged gas and electric HVAC with multizone VAV and electric reheat



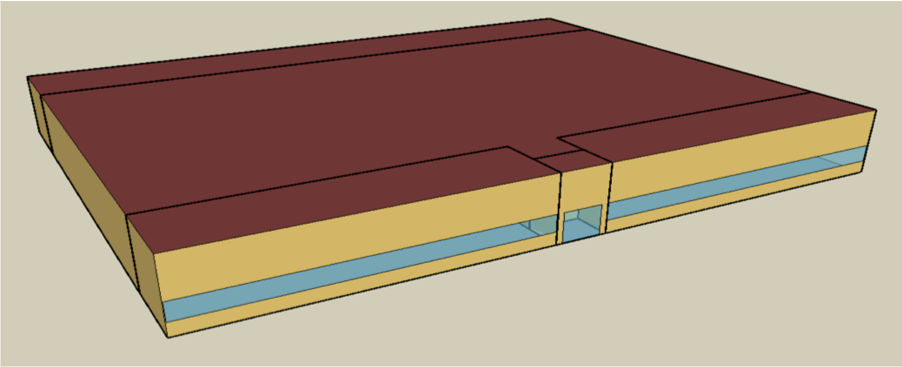
Midrise Apartment Building

- Four stories, 3135 m^2
- 15% window to wall ratio
- Steel frame construction with stucco exterior
- Insulation and window performance comply with ASHRAE Standard 90.1-2004
- Occupancy 35 m^2/person
- 3.9 W/m^2 lighting
- 5.4 W/m^2 equipment
- Gas furnace and split-system AC for each unit



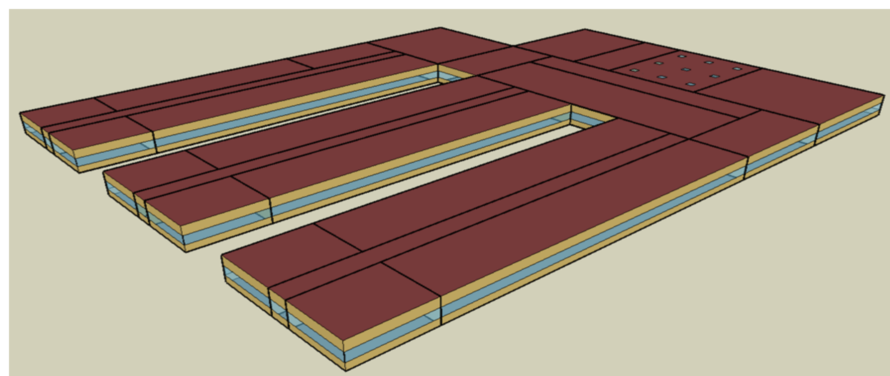
Stand-Alone Retail Store

- One story, 2300 m^2
- 7% window to wall ratio
- Concrete masonry unit construction
- Insulation and window performance comply with ASHRAE Standard 90.1-2004
- Occupancy 6.2 m^2/person
- 37 W/m^2 lighting
- 3.2 W/m^2 equipment
- Packaged gas and electric rooftop HVAC



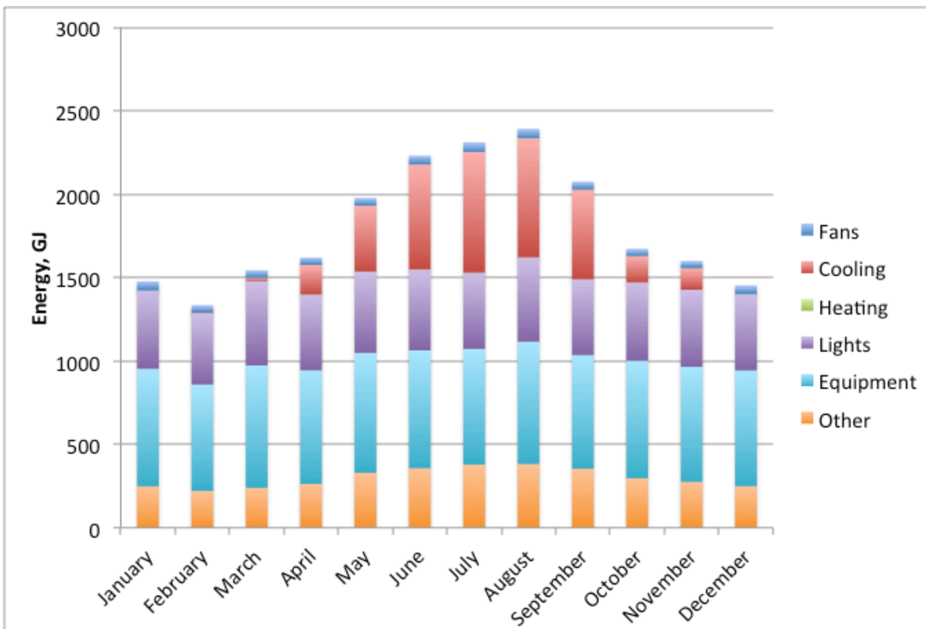
Primary School

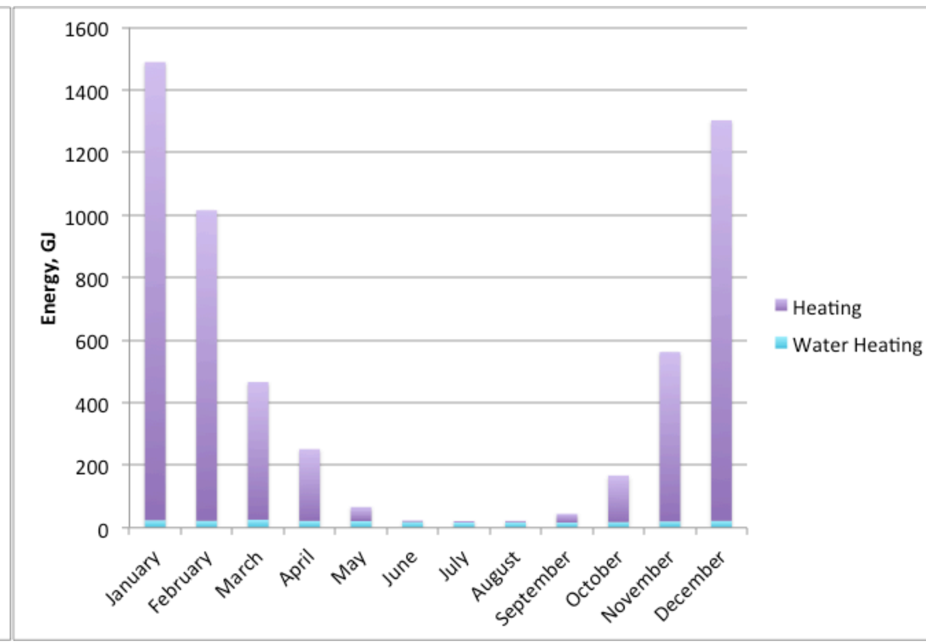
- Single story, 6870 m^2
- 35% window to wall ratio
- Steel frame construction with stucco exterior
- Insulation and window performance comply with ASHRAE Standard 90.1-2004
- Occupancy 4.8 m^2/person
- 21 W/m^2 lighting
- 15 W/m^2 equipment
- Packaged gas and electric HVAC



Large Office, Chicago

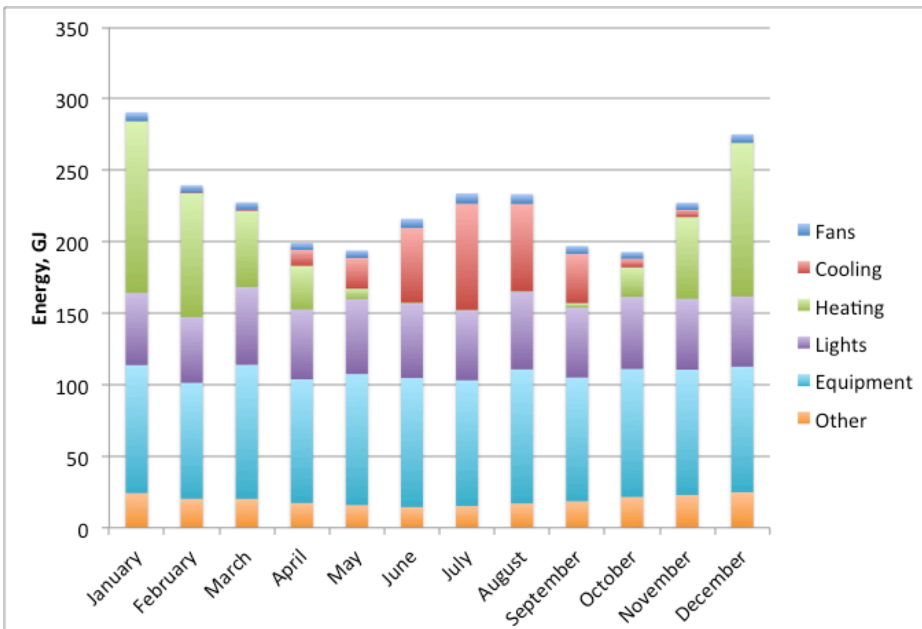
- Peak electricity use greater than gas use
- Miscellaneous electrical loads (equipment) and lighting main uses
- Other includes pumps, elevators, and exterior lighting
- No electric heating in winter

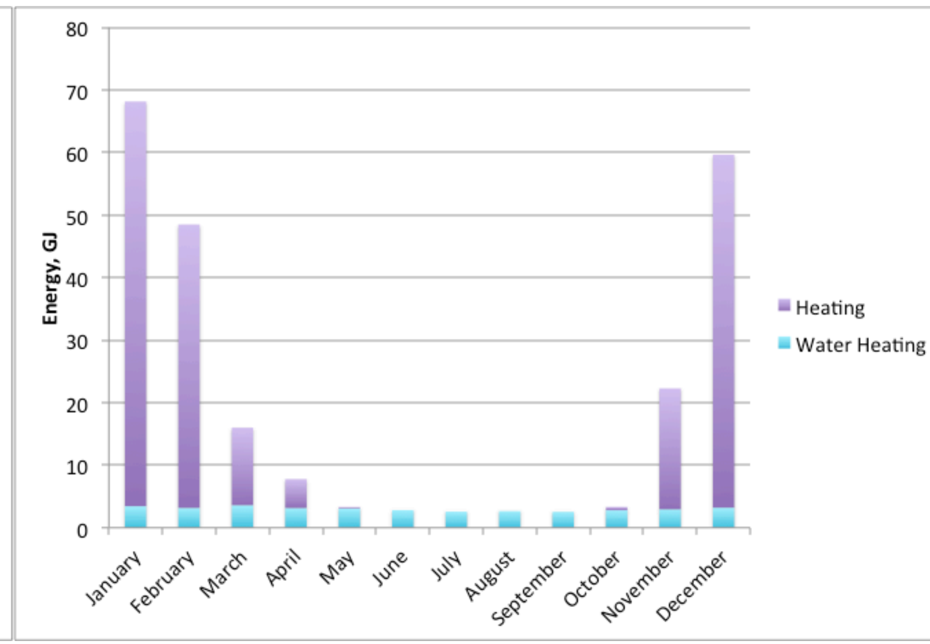




Medium Office, Chicago

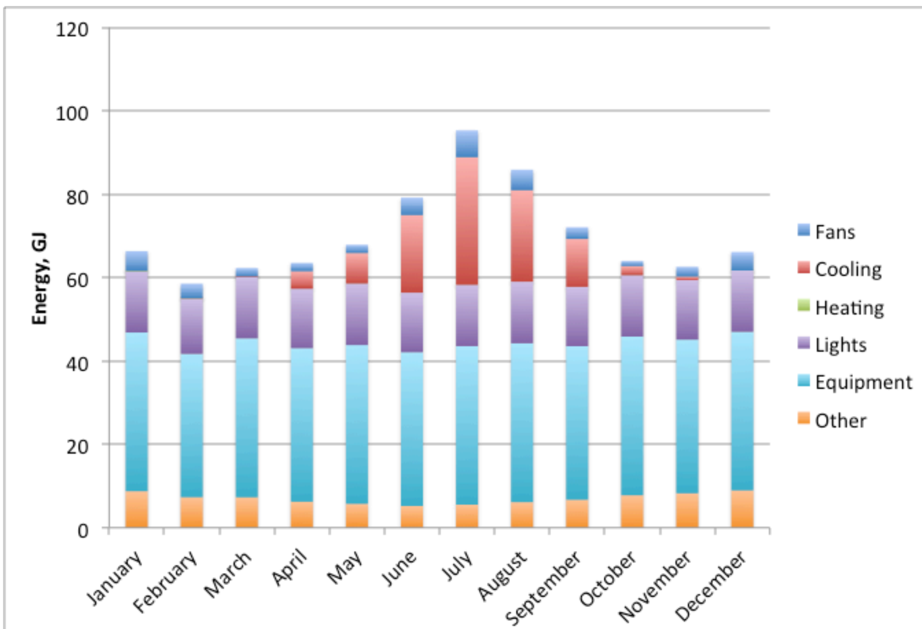
- Electricity dominate gas use
- Miscellaneous electrical loads (equipment) and lighting main uses
- Significant electric heating in winter due to zone reheat

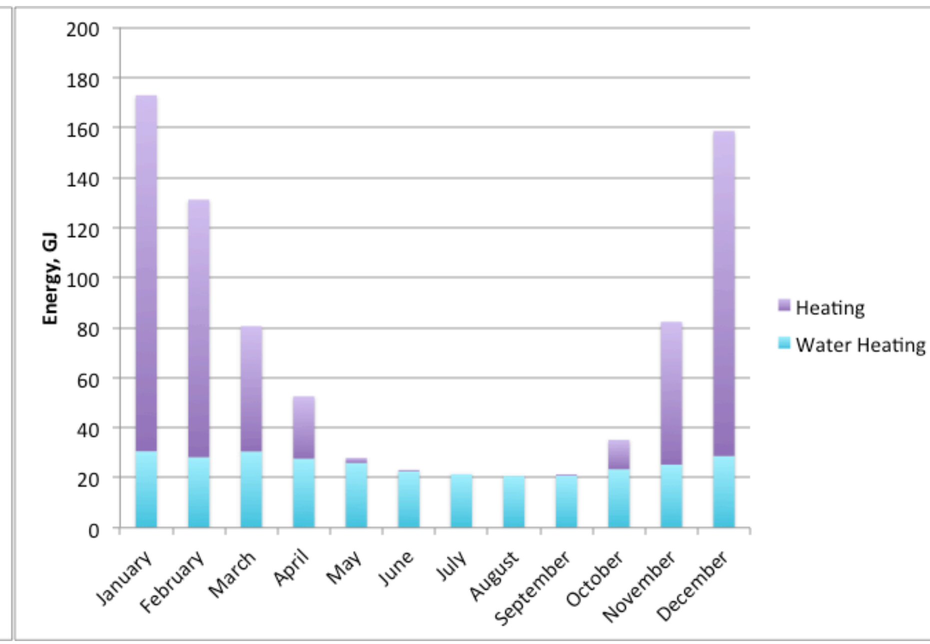




Midrise Apartment, Chicago

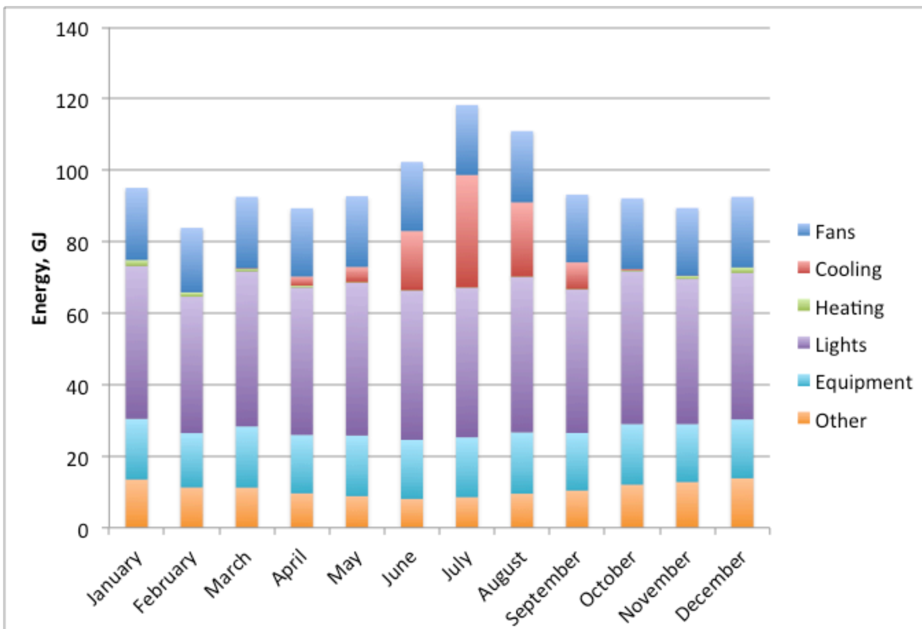
- Peak gas use greater than peak electricity use
- Miscellaneous electrical loads (equipment) main electricity use

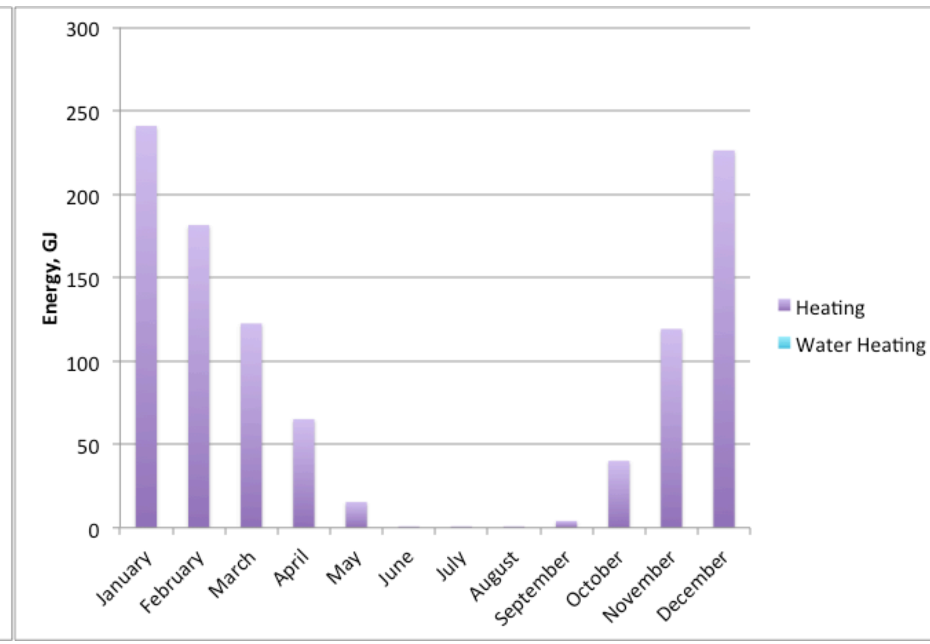




Retail Store, Chicago

- Peak gas use greater than peak electricity use
- Lighting is main electricity use
- Fans more significant due to ventilation requirements





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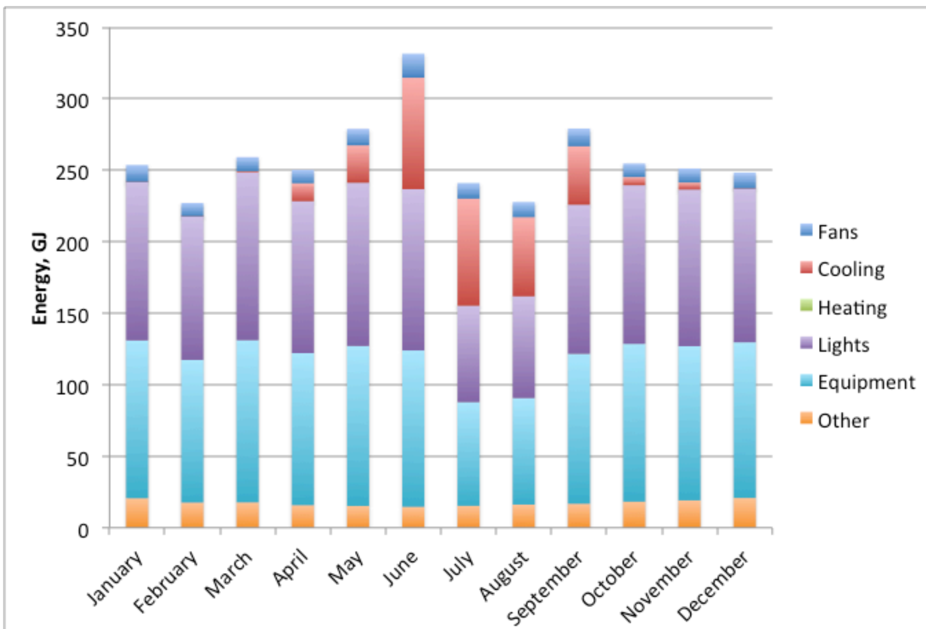
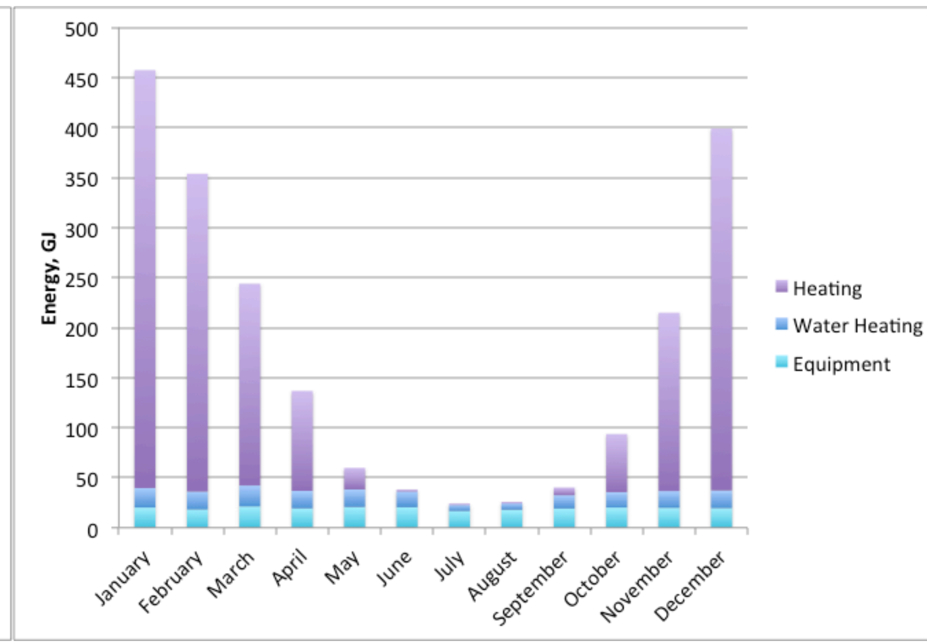
Primary School, Chicago

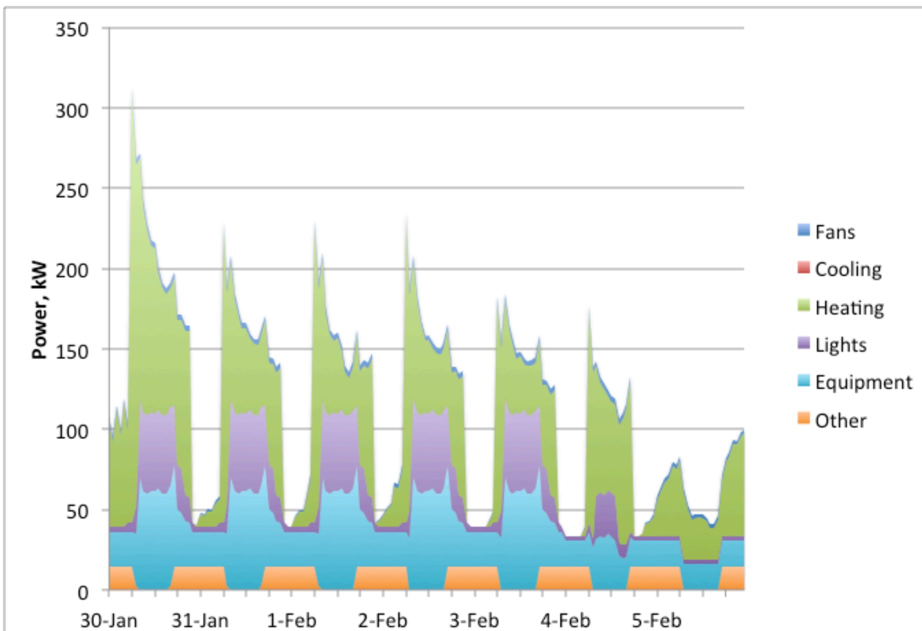
- Peak gas use greater than peak electricity use
- Lighting and equipment are main electricity uses
- Summer vacation affects consumption

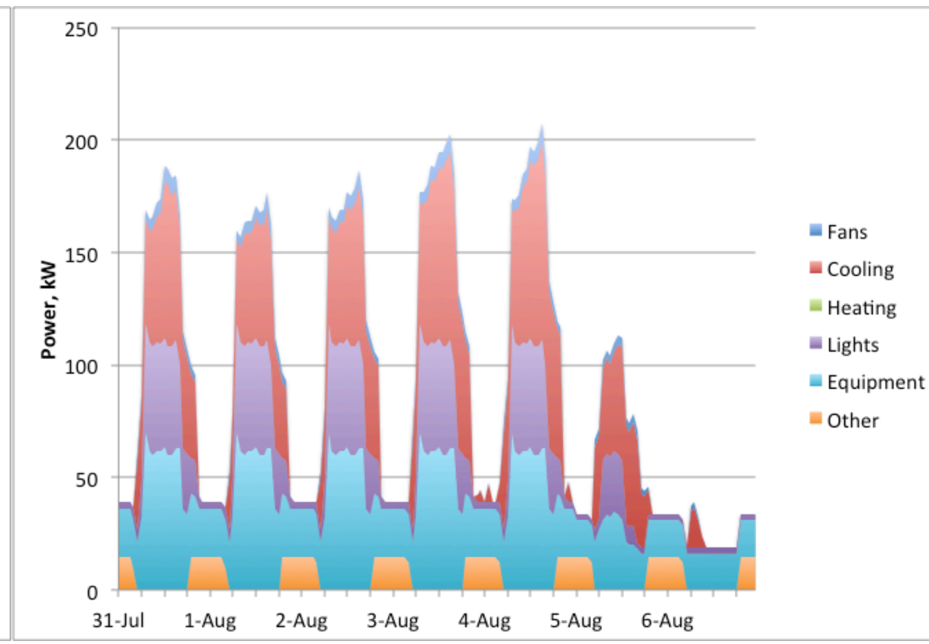




Medium Office, Chicago, Weekly Electricity

- Electric reheat can dominate demand
- Weekends significantly lower demand
- 5:1 factor between day and night summer demand





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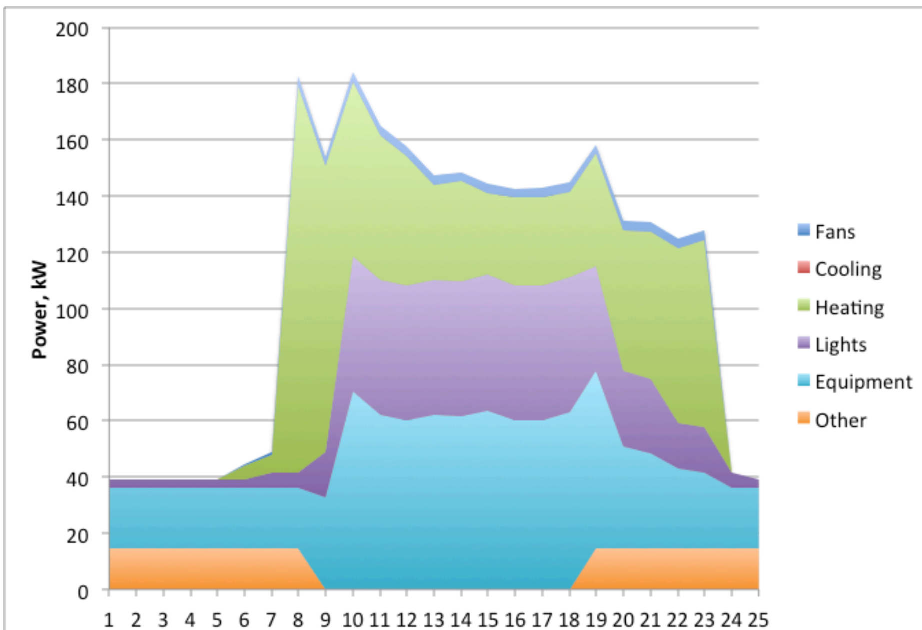
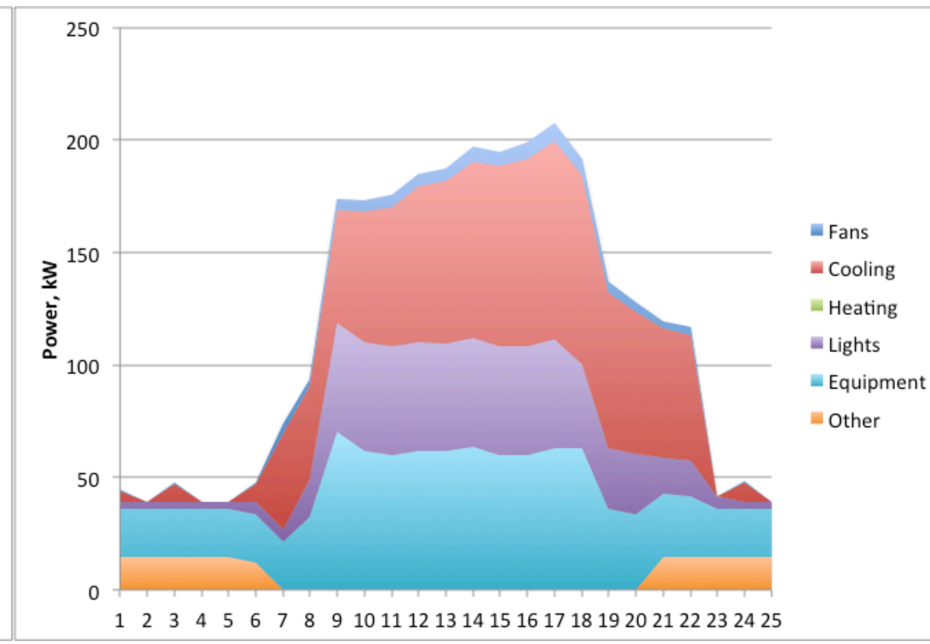
Medium Office, Chicago, Daily Electricity

- Electric reheat can dominate winter demand peak
- Summer demand driven by cooling
- 5:1 factor between day and night summer demand





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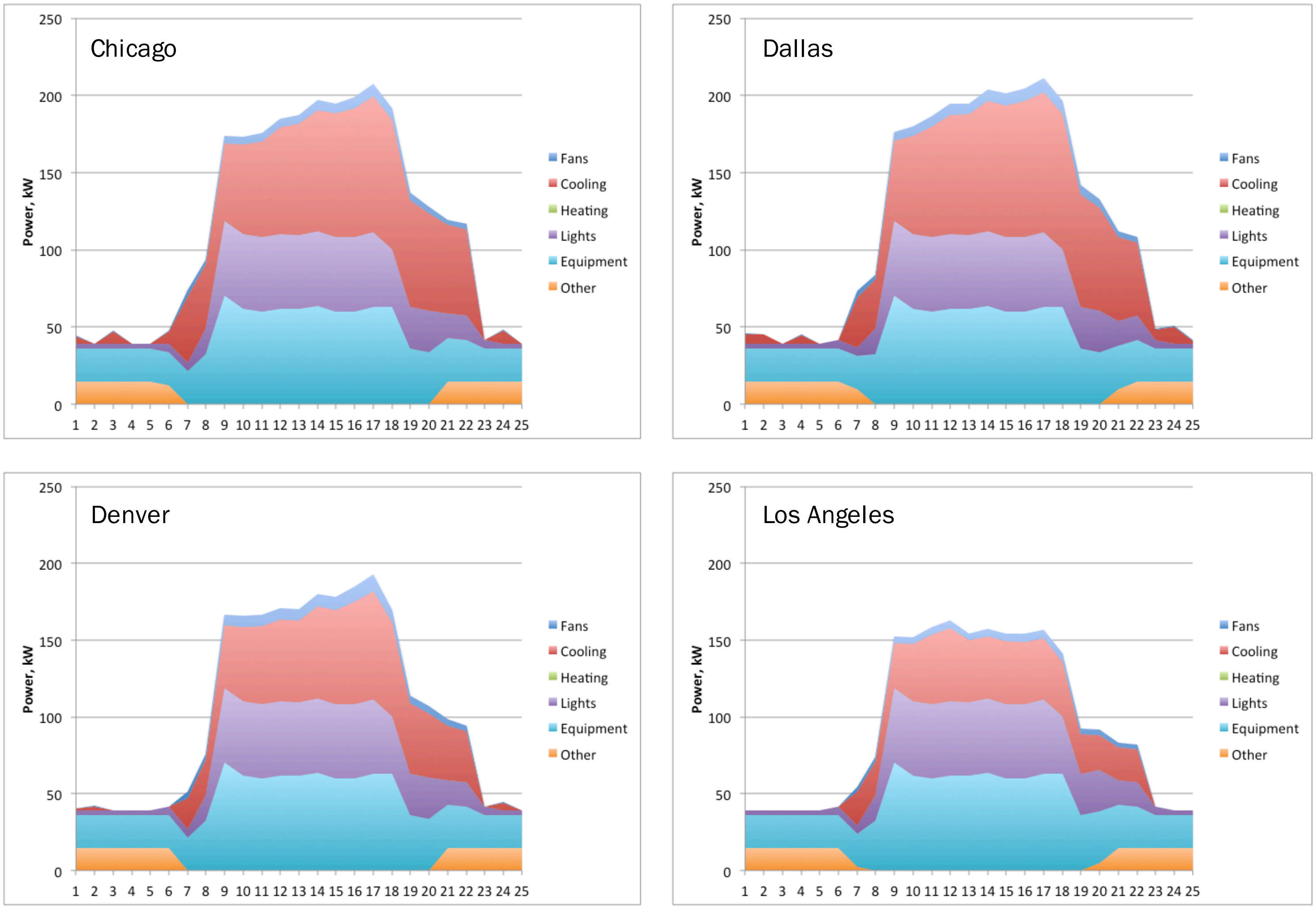
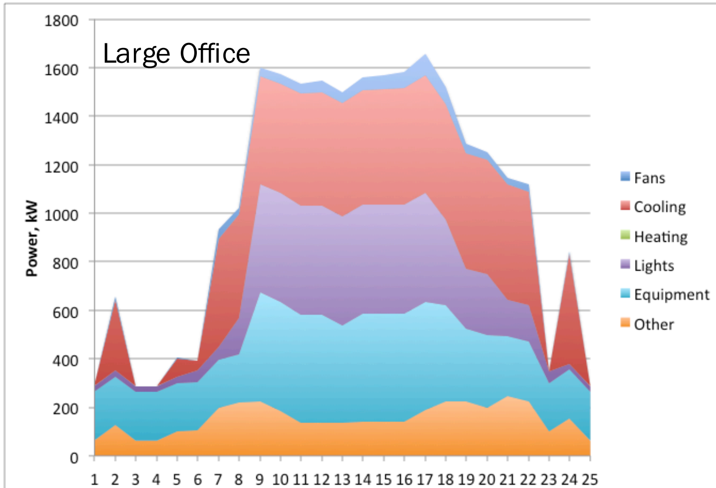
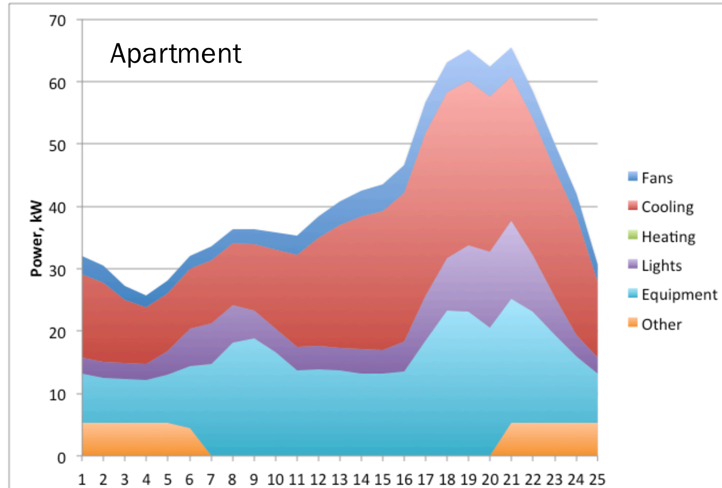
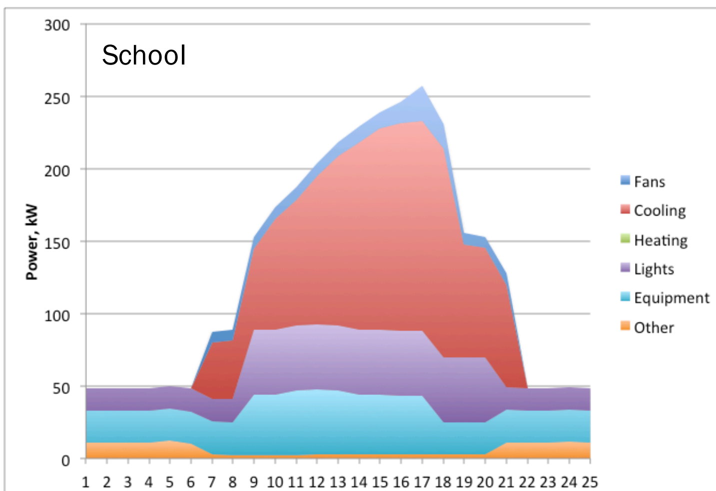
Medium Office, Summer Day

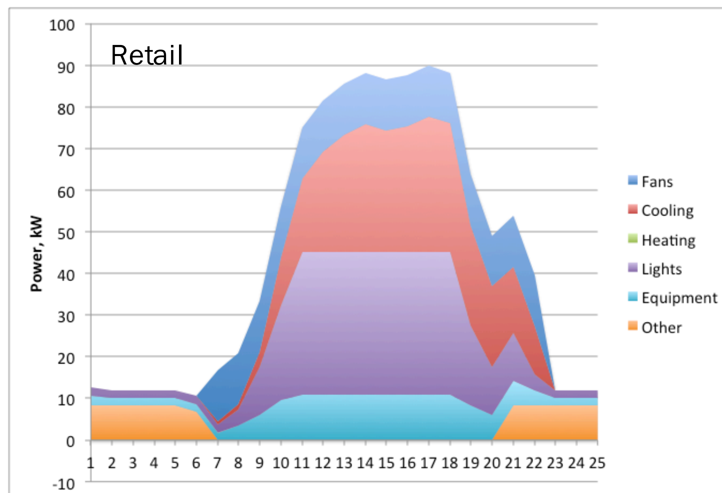


Summer Day, Chicago









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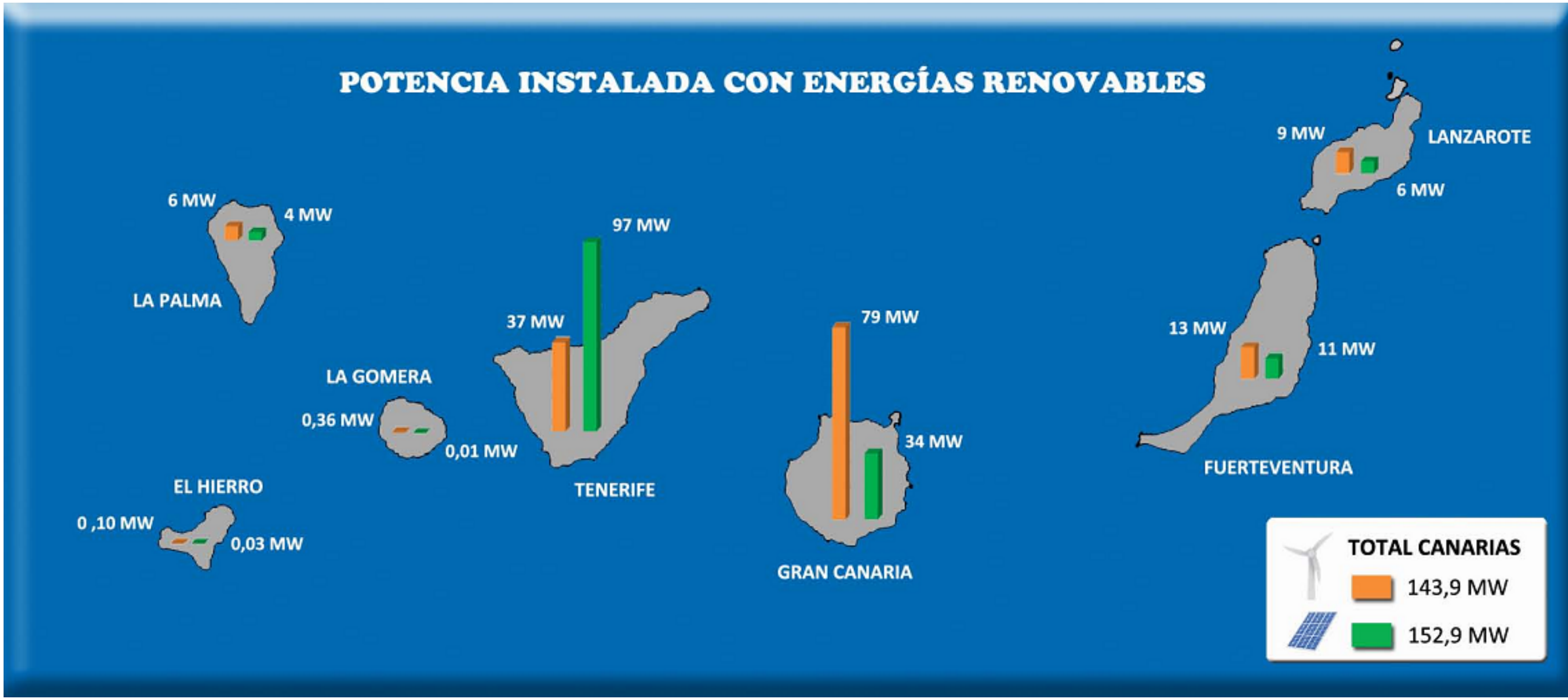
Summary of Energy Demand Profiles

- Heating demand dominates energy consumption in most building types and climates
  - Typically natural gas in US
  - If electric, heating will determine peak demand in most buildings
- While cooling may not be largest energy consumption, it is often largest contributor to peak summer electrical demand
- Large reduction of electrical demand at night and weekends
- Residential summer demand is short and late
- Fans can be significant component for high occupancy buildings with constant airflow

Fossil Power in the Canary Islands

Renewable Energy in the Canary Islands



Island of Tenerife Generation Sites

Island of Tenerife Thermal Power System

TENERIFE

C.T. Candelaria

Imagen: Ayuntamiento de Candelaria

Tecnología	Nº	Pot. Bruta unitaria (kW)	Pot. Bruta total (kW)
Turbina Vapor	4	40.000	160.000
Motor Diesel	3	12.000	36.000
Turbina Gas	2	37.500	75.000
Turbina Gas	1	17.200	17.200
		TOTAL	288.200

C.T. Granadilla

Imagen: Libro Energía. 2007.

Tecnología	Nº	Pot. Bruta unitaria (kW)	Pot. Bruta total (kW)
Turbina Vapor	2	80.000	160.000
Motor Diesel	2	24.000	48.000
Turbina Gas	1	42.000	42.000
Turbina Gas	1	37.500	37.500
Turbina Gas (CC1)	2	75.000	150.000
Turbina Vapor (CC1)	1	75.000	75.000
Turbina Gas (CC2)	2	76.700	153.400
Turbina Vapor (CC2)	1	78.400	78.400
		TOTAL	744.300

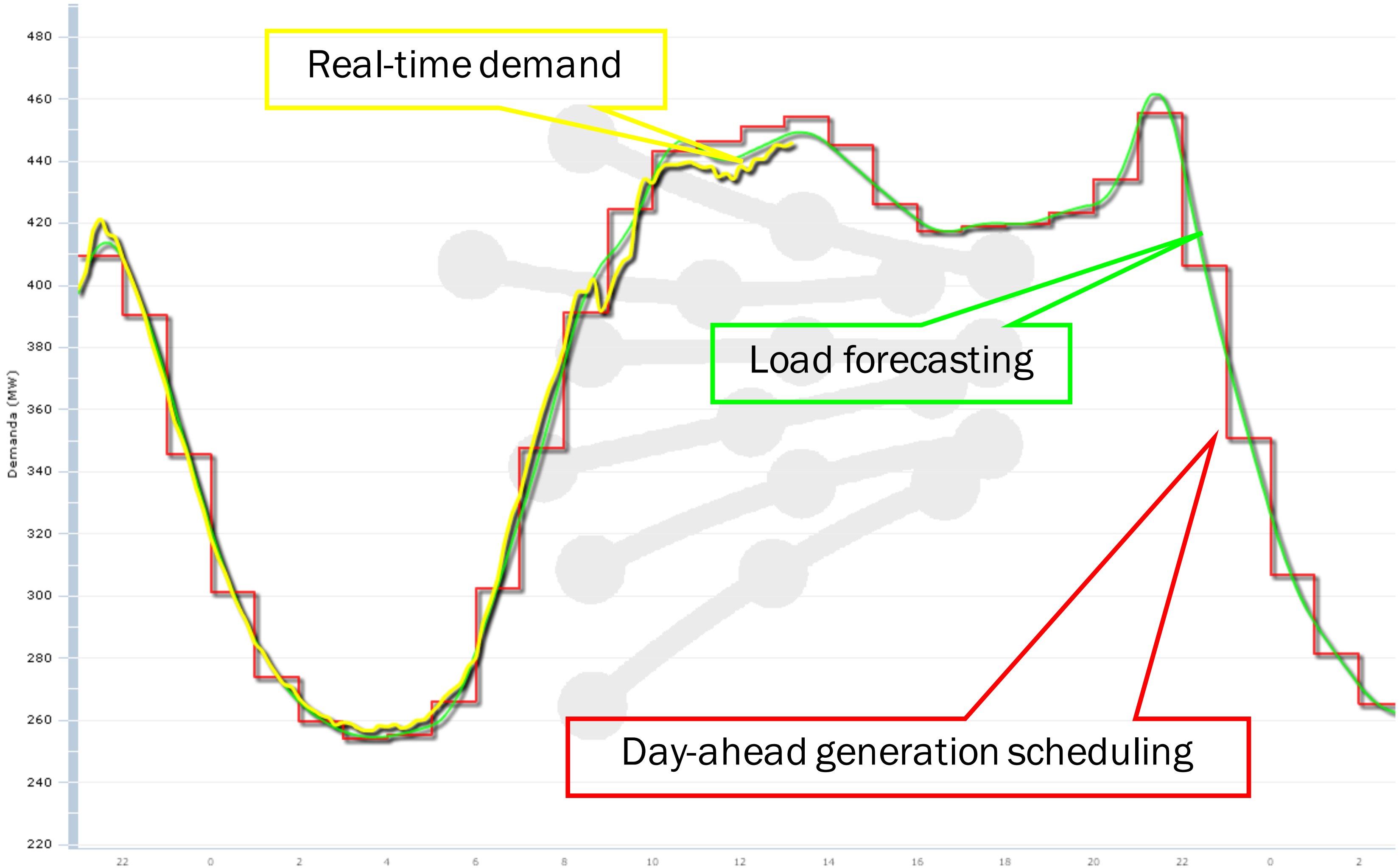
Subestación Arona

Tecnología	Nº	Pot. Bruta unitaria (kW)	Pot. Bruta total (kW)
Turbina Gas	2	25.000	50.000
		TOTAL	50.000

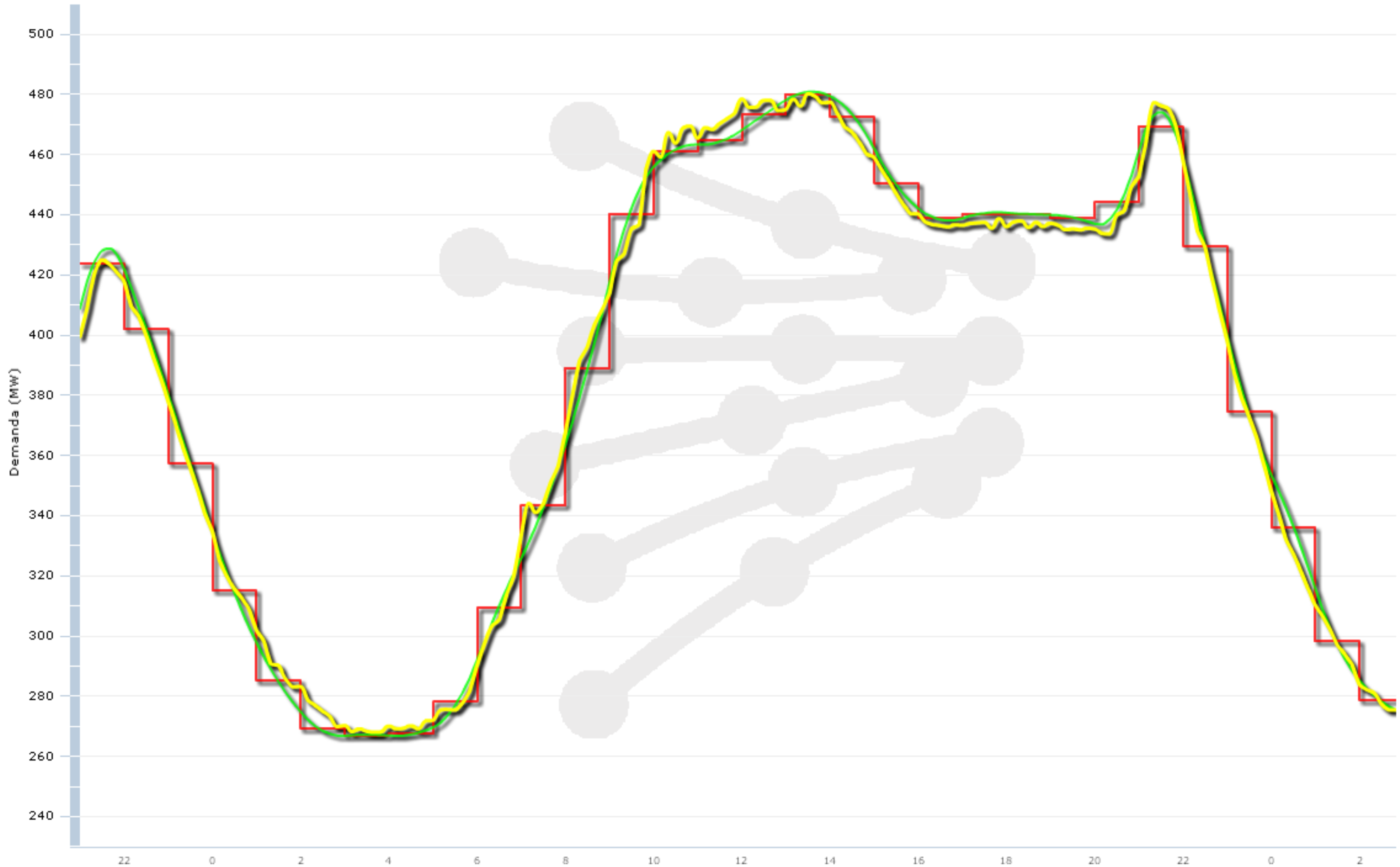
Subestación Guía de Isora

Tecnología	Nº	Pot. Bruta unitaria (kW)	Pot. Bruta total (kW)
Turbina Gas	1	48.600	48.600
		TOTAL	48.600

Load Profile June 24, 2015



Tenerife Summer Day (July 28, 2014)



Unit Commitment Model

$$\text{Minimizar} \quad \sum_{g=1}^{n_g} \left\{ A_g + \sum_{t=1}^{24} C_{g,t}(P_{g,t}) \right\}$$

$$P_{D_t} = \sum_{g=1}^{n_g} P_{g,t} \qquad t = 1, \ldots, 24$$

$$P_g^{\text{mín}} \cdot U_{g,t} \leq P_{g,t} \leq P_g^{\text{máx}} \cdot U_{g,t}$$

$$t = 1, \ldots, 24$$

Binary variables $U_{g,t}$ required to model the status on-off of generators and startup decisions (startup costs, A_g)

Unit Commitment Model

Additional constraints

- Spinning reserve

$$P_{D_t} + R_t \leq \sum_{g=1}^{n_g} P_g^{\text{máx}} \cdot U_{g,t} \qquad t = 1, \ldots, 24$$

- Ramp constraints

$$-\Delta P_g^{\text{bajar}} \leq P_{g,t} - P_{g,t-1} \leq \Delta P_g^{\text{subir}}$$

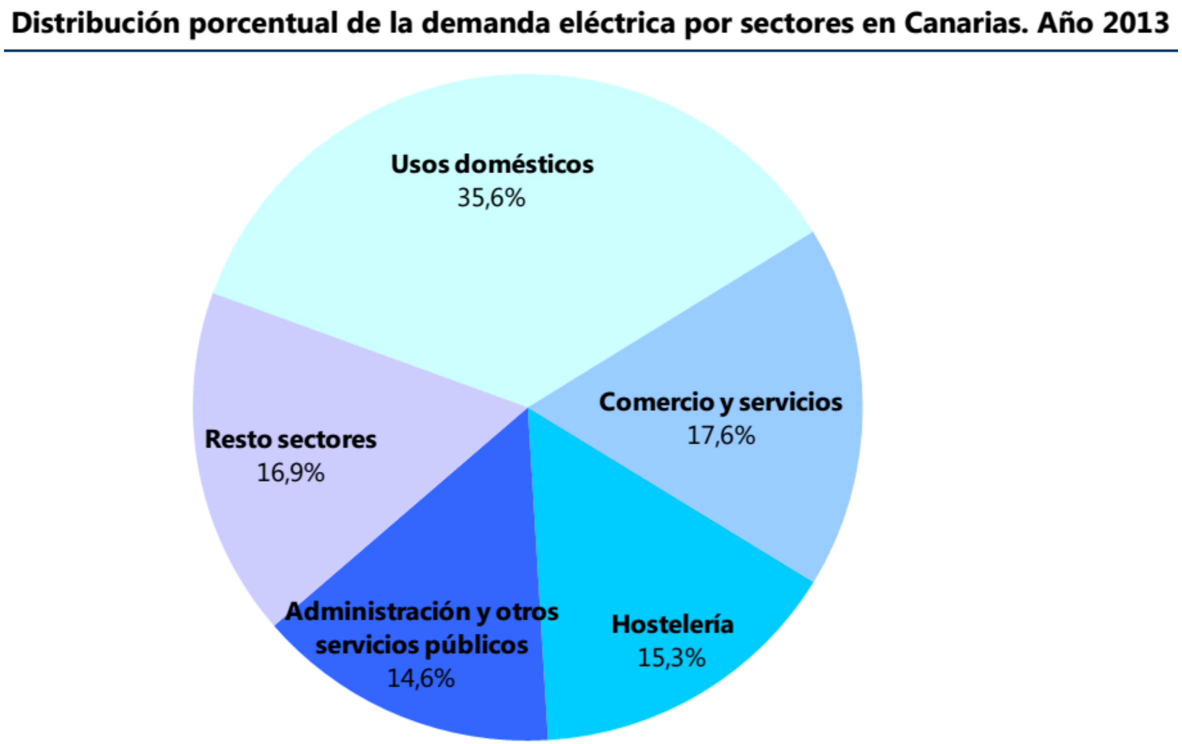
$$t = 1, \ldots, 24$$

- Limits on CO_2 emissions

$$E_g \geq \sum_{t=1}^{24} E_{g,t}(P_{g,t})$$

Case Studies

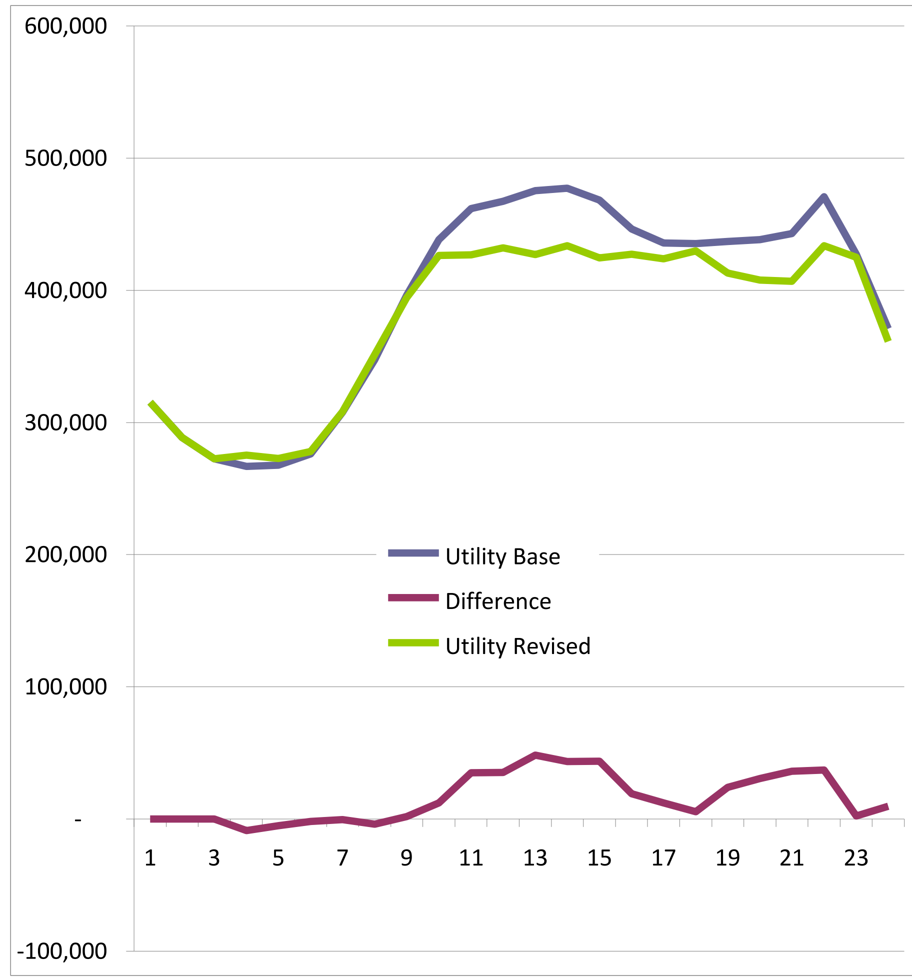
1. Unit Commitment without additional constraints
2. Unit Commitment including spinning reserve constraint
3. Modify Case 1 or 2 to reflect load flexibility



Demand Reduction

Electricity Meter (kW)
28-jul

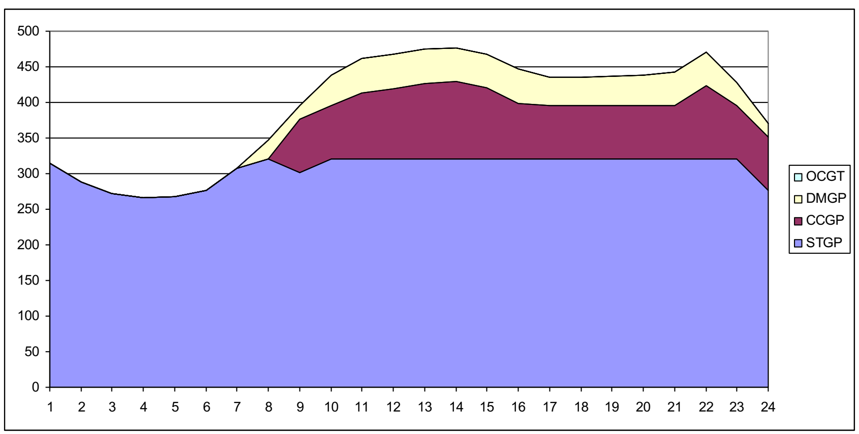
Hour	Utility Base	Difference	Utility Revised
1	315,259	24	315,235
2	288,553	- 0	288,553
3	272,444	- 0	272,444
4	266,769	- 8,634	275,403
5	267,661	- 5,075	272,736
6	276,129	- 1,853	277,982
7	307,653	- 442	308,095
8	347,550	- 3,880	351,430
9	396,157	1,797	394,360
10	438,418	12,140	426,278
11	461,857	35,049	426,808
12	467,296	35,115	432,181
13	475,248	48,290	426,958
14	477,123	43,488	433,635
15	468,213	43,623	424,590
16	446,441	19,134	427,307
17	435,905	12,119	423,786
18	435,400	5,630	429,770
19	436,891	23,874	413,017
20	438,384	30,574	407,810
21	442,902	36,173	406,729
22	470,767	37,071	433,696
23	427,273	2,380	424,893
24	370,920	9,707	361,213

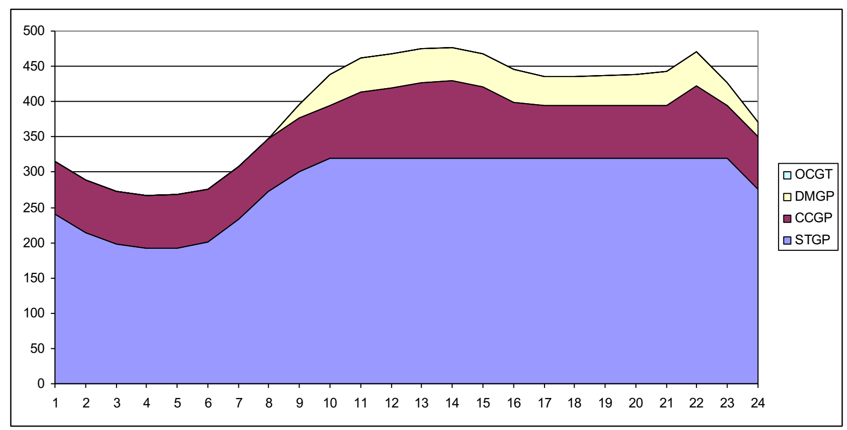


Examples

1. **Unit Commitment without additional constraints**
2. **Unit Commitment including spinning reserve constraint**

- Reserve constraint increases total cost (1.18%)
- CO_2 emissions are reduced (2.0%)





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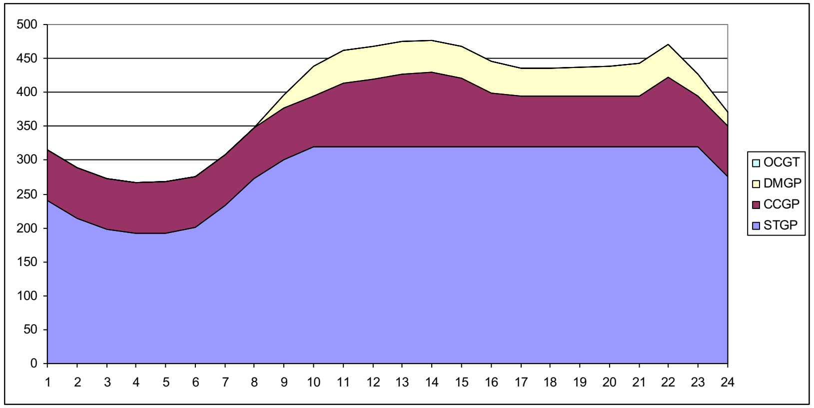
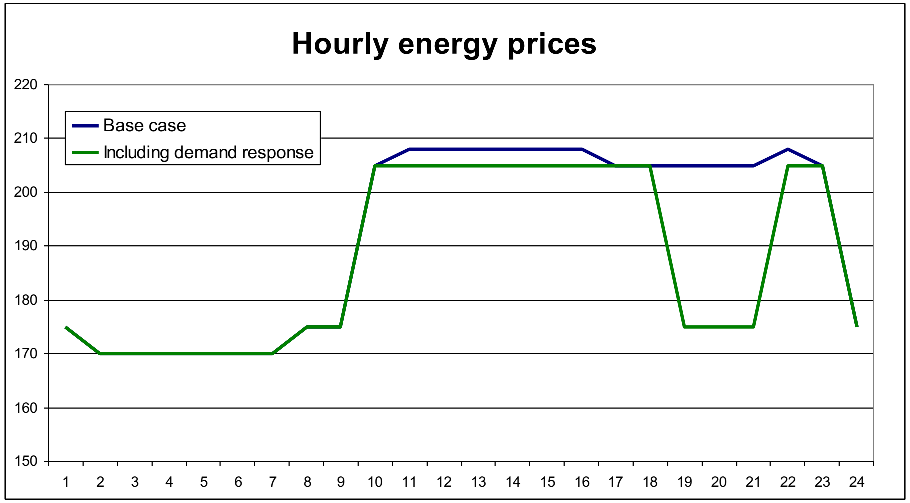
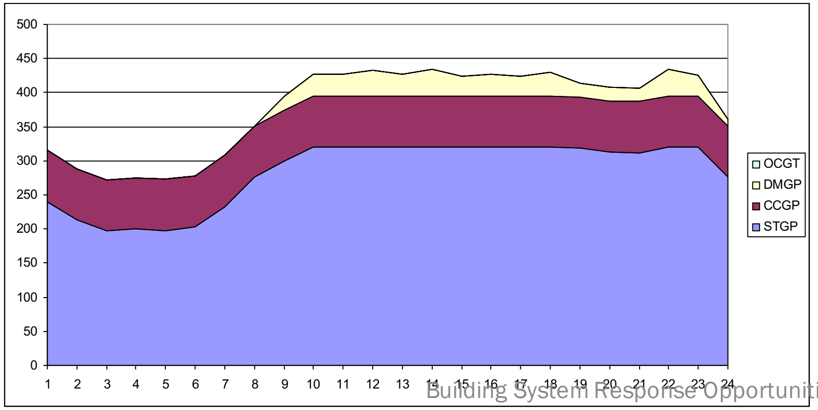
Examples

Unit Commitment including spinning reserve & load flexibility

- Reduction of total cost (4.5%)
- Reduction of CO_2 emissions (3.4%)







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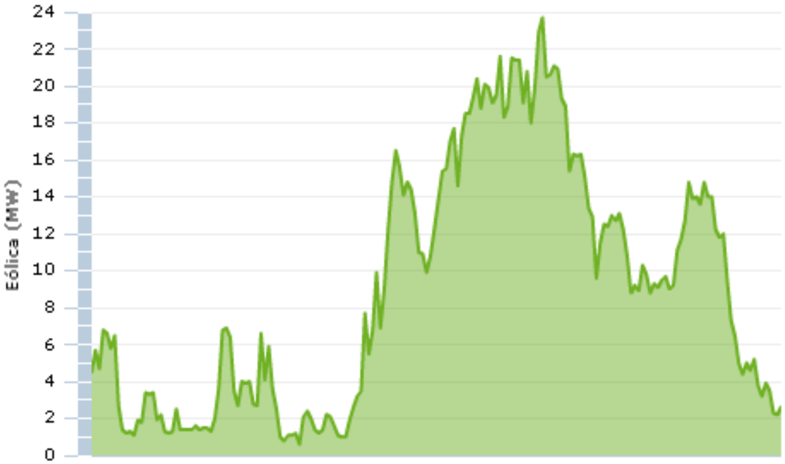
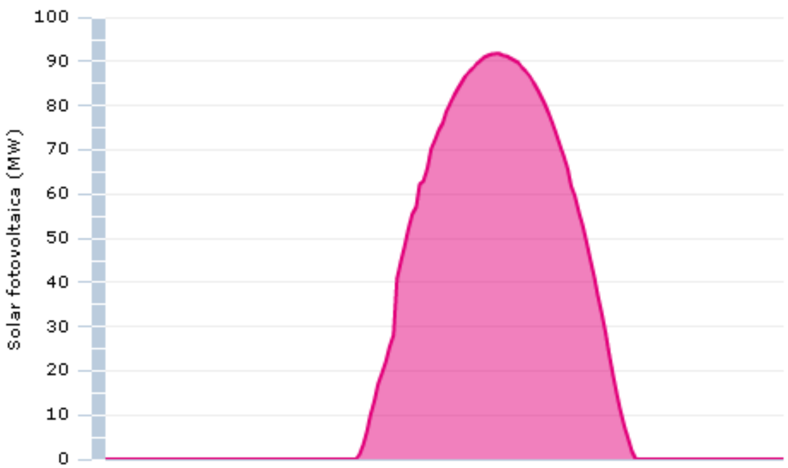
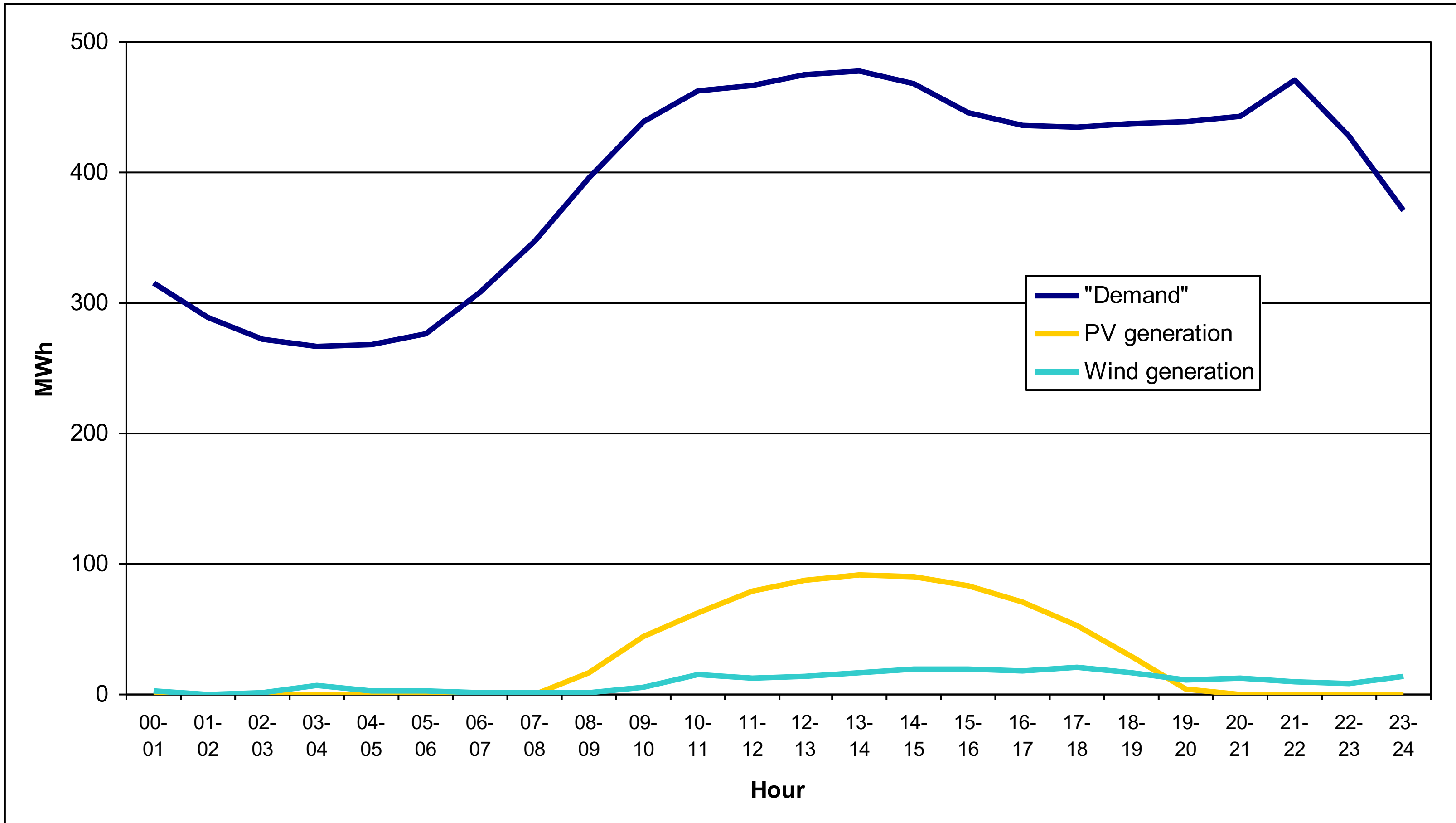
Renewable generation – 28 July 2014



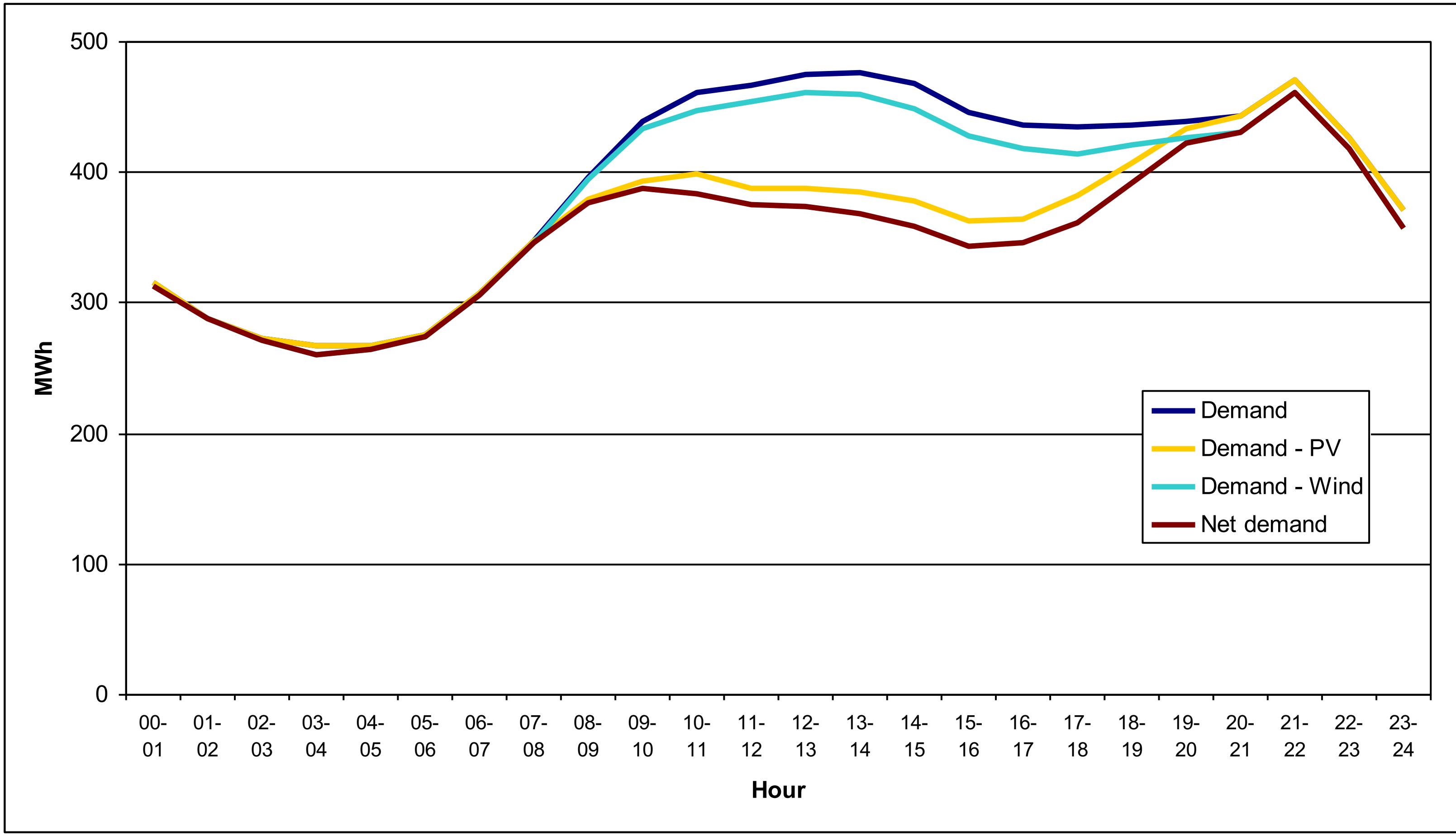


Subsistema	Tenerife	Fotovoltaica	Eólica
00-01	315.3	0.0	2.2
01-02	288.6	0.0	0.0
02-03	272.4	0.0	1.4
03-04	266.8	0.0	6.4
04-05	267.7	0.0	2.8
05-06	276.1	0.0	2.5
06-07	307.7	0.0	1.2
07-08	347.6	0.0	1.4
08-09	396.2	17.1	1.9
09-10	438.4	45.0	5.5
10-11	461.9	63.0	14.8
11-12	467.3	79.0	13.1
12-13	475.2	88.0	13.9
13-14	477.1	92.0	17.3
14-15	468.2	90.0	20.1
15-16	446.4	84.0	18.9
16-17	435.9	71.0	18.0
17-18	435.4	53.0	21.1
18-19	436.9	29.0	16.2
19-20	438.4	4.7	11.5
20-21	442.9	0.0	12.2
21-22	470.8	0.0	9.8
22-23	427.3	0.0	9.0
23-24	370.9	0.0	13.9
Total	9,431.2	715.8	235.1

Demand vs Wind and Solar– 28 July 2014



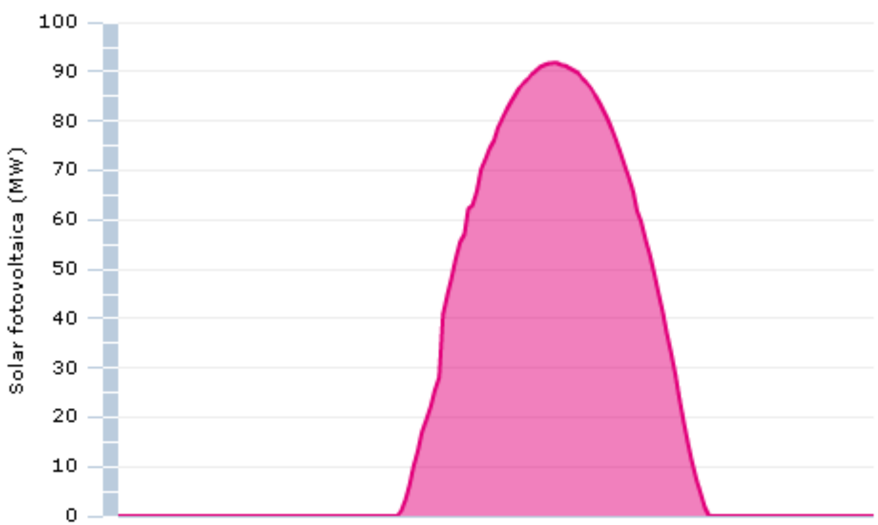
Net demand – 28 July 2014

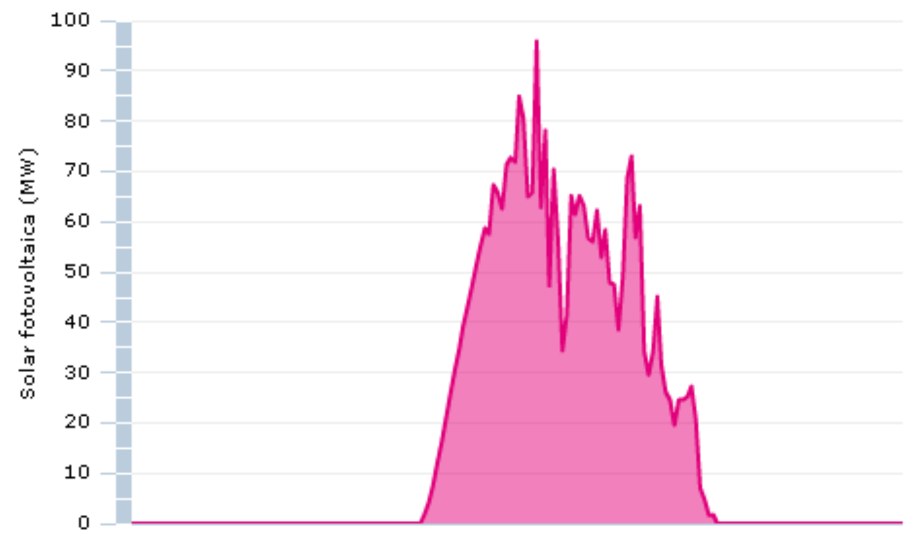


Unit Commitment with RG included

Additional constraints must be included:

- Ramping capability
- Fast-response generation reserve



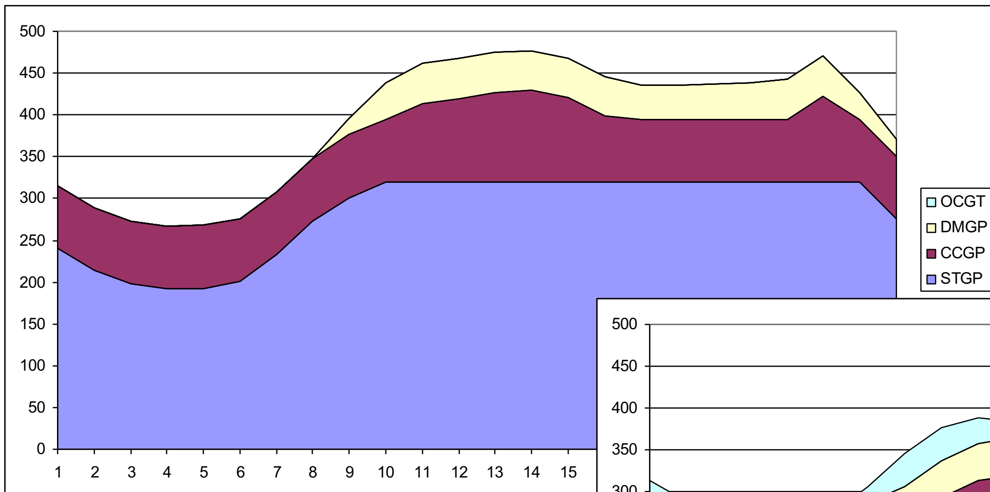


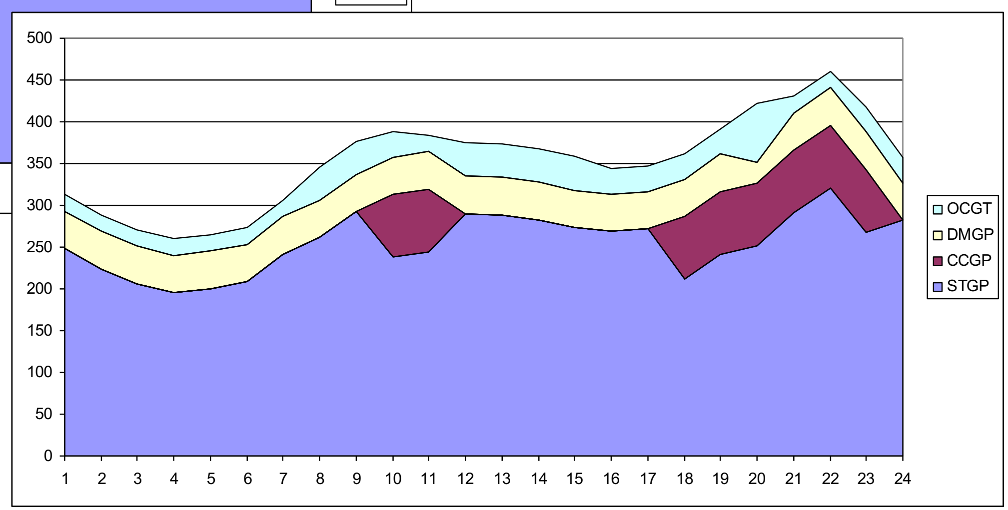
Case Studies

4. Unit Commitment including PV & WG and fast-response reserve constraints
5. Modify Case 4 to reflect load flexibility
6. Solve Case 4 or Case 5 minimizing CO2 emissions

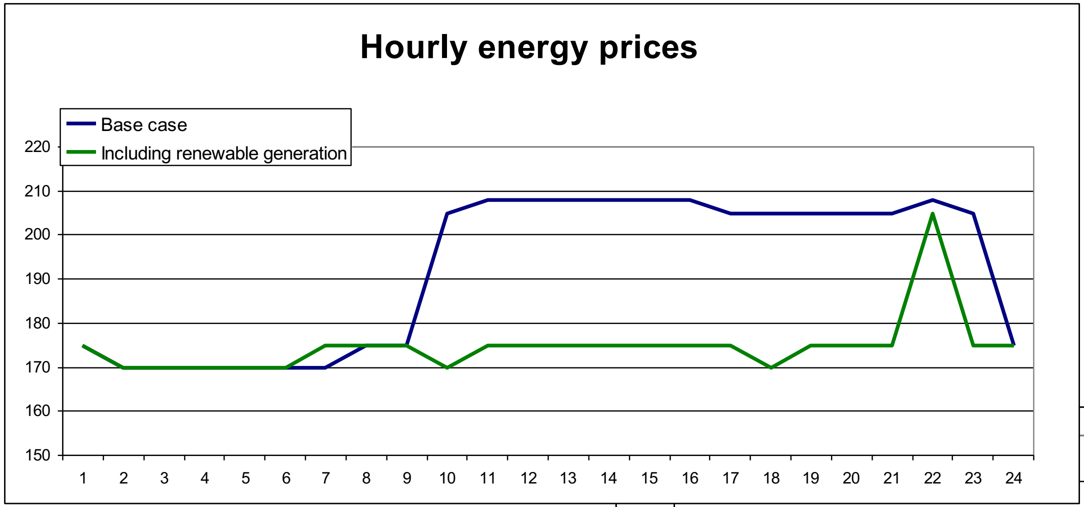
UC Including PV & Wind Generation

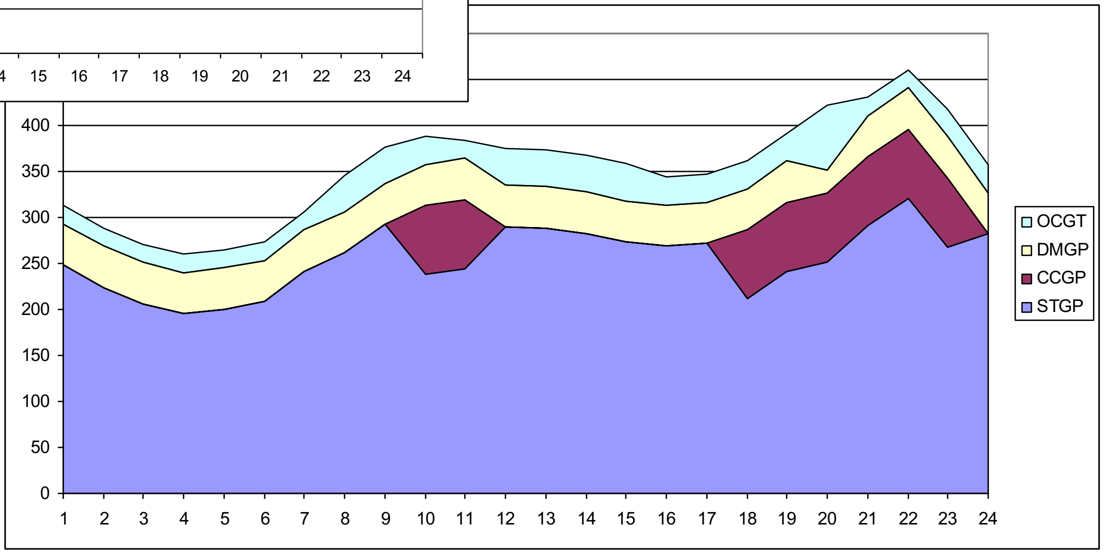
- Daily cost reduction of 9.2% due to PV and WG
- CO_2 emissions reduced by a 6.3%
- “Flexibility” becomes a critical issue in generation scheduling





UC Including PV & Wind Generation





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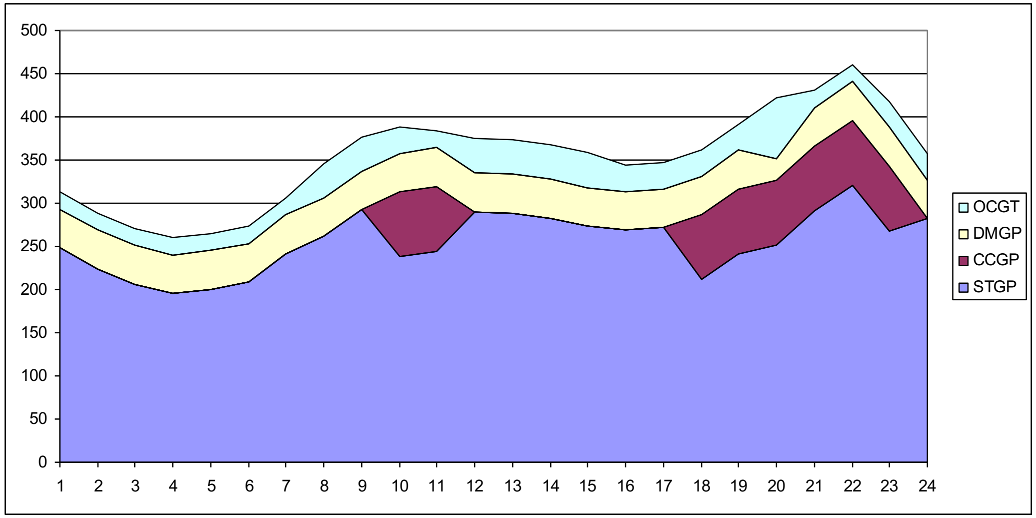
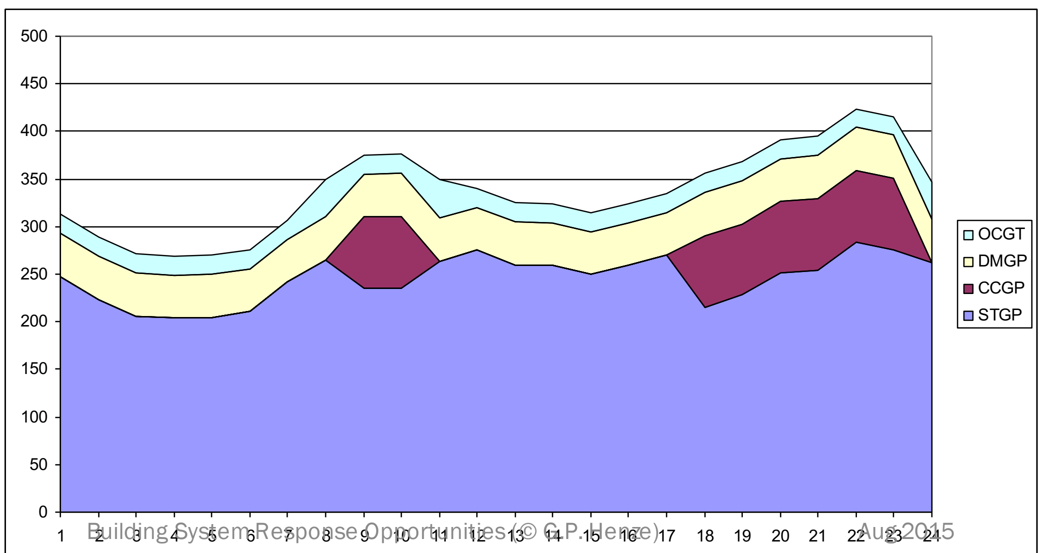
Unit Commitment Including RG & DR

- Additional cost (4.90%) and CO_2 (4.62%) reduction due to DR





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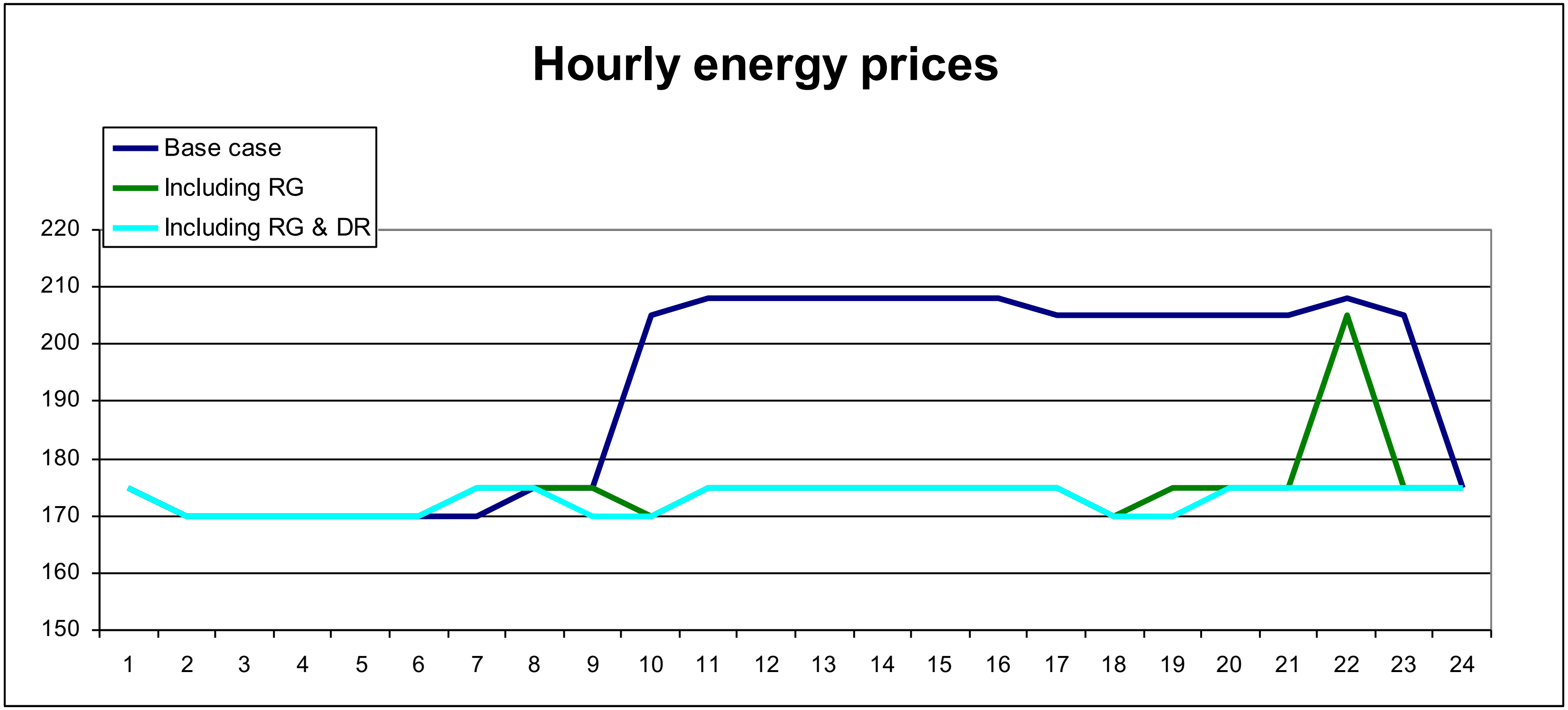
Unit Commitment Including RG & DR

- High prices at peak hours are avoided by avoiding the need to start small, peaking generators of high cost

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Thank you for your interest!