NRC-CNRC

Institute for Research in Construction

Demand Responsive Buildings: Reducing on-peak electricity use in offices and houses

Guy Newsham et al.

National Research Council Canada
Conseil national de recherches Canada

Canada

Overview

- Why demand response is important
- Commercial Building DR
  - Lighting
  - HVAC
- Residential DR
  - Air-conditioning

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Introduction

- Building energy use growing
- On-peak electricity growing faster
- Can supply meet demand?


TIMES ONLINE

The best of The Times and The Sunday Times, in real time

Times Online July 28, 2006

Thousands face second Central London blackout

BY ELSA MCLAREN AND AGENCIES

A second wave of power cuts could affect thousands of homes and businesses in Central London today, the energy supplier has warned.

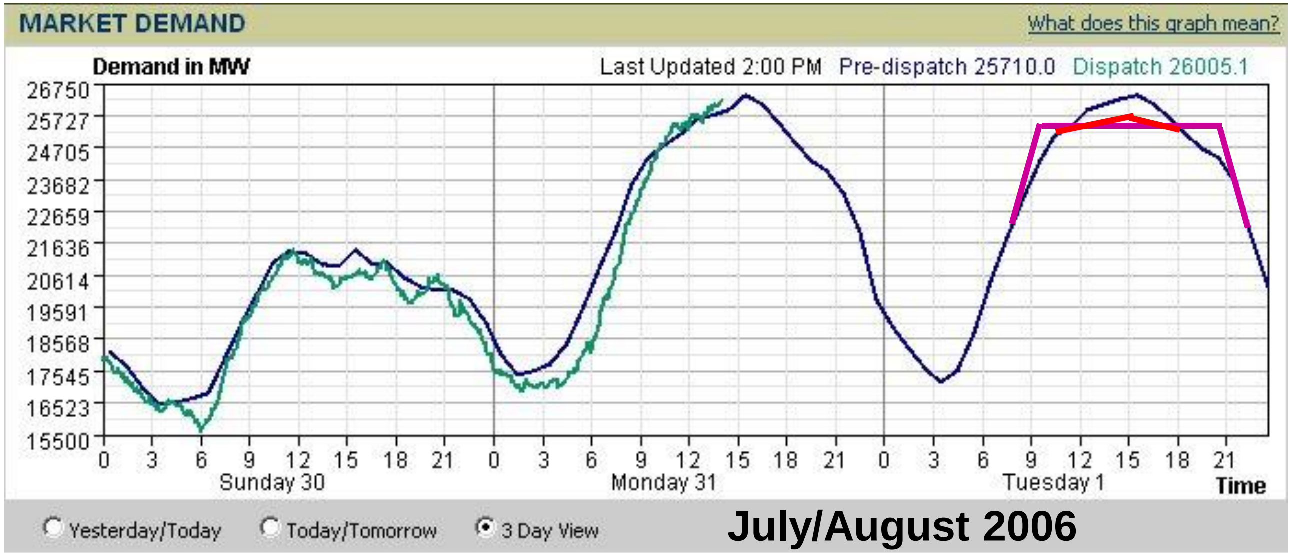

THE TAMPA TRIBUNE

OUT BUT NOT DOWN

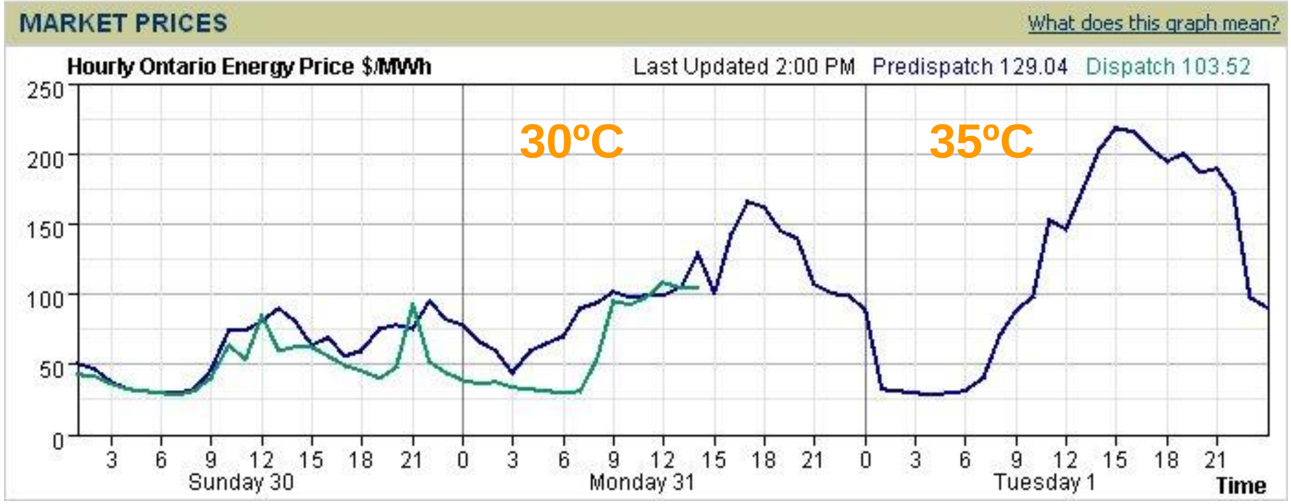
Millions Keep Composure As Massive Power Grid Collapses

Introduction

- Summer load profile, Ontario



- Load shifting
- Load shedding

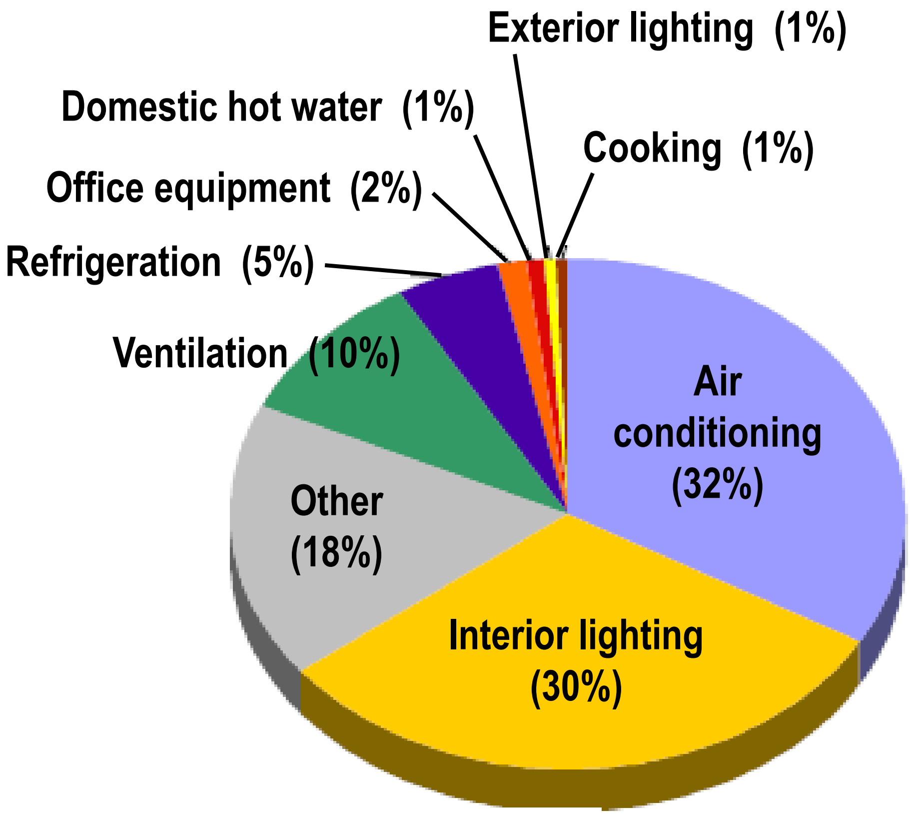


- 2-5% peak reduction can halve spot price

http://www.theimo.com/

Peak Use Profile in Buildings

- A/C and lighting are the obvious targets

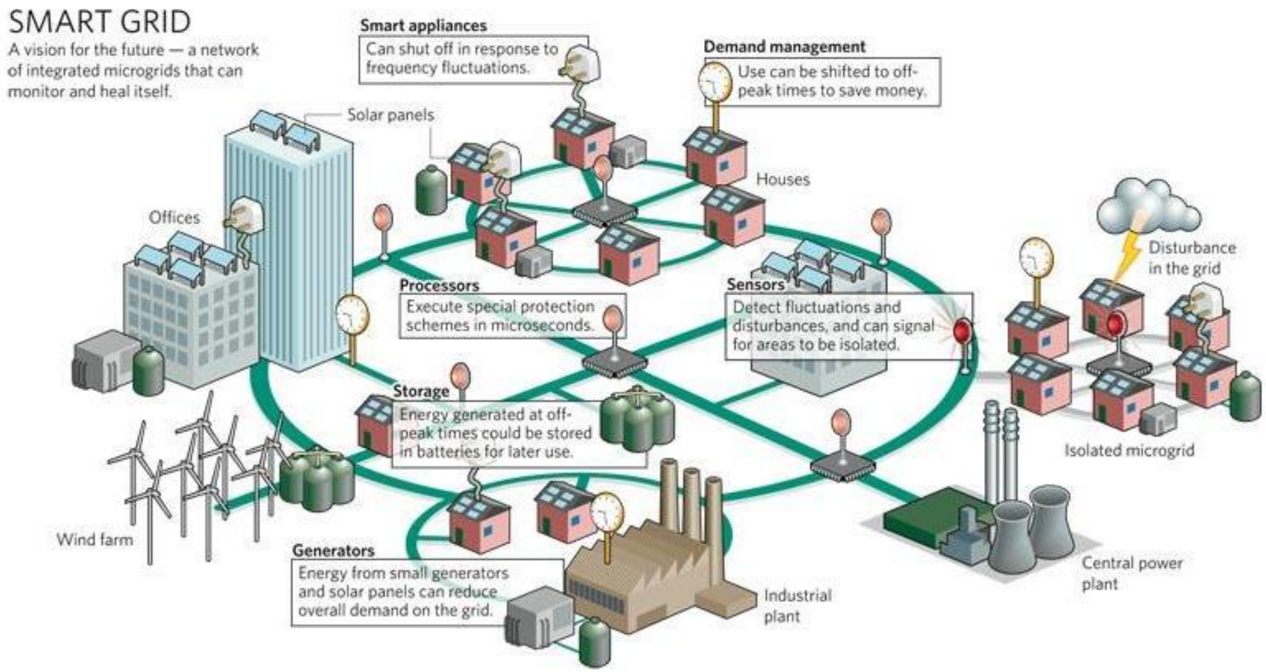


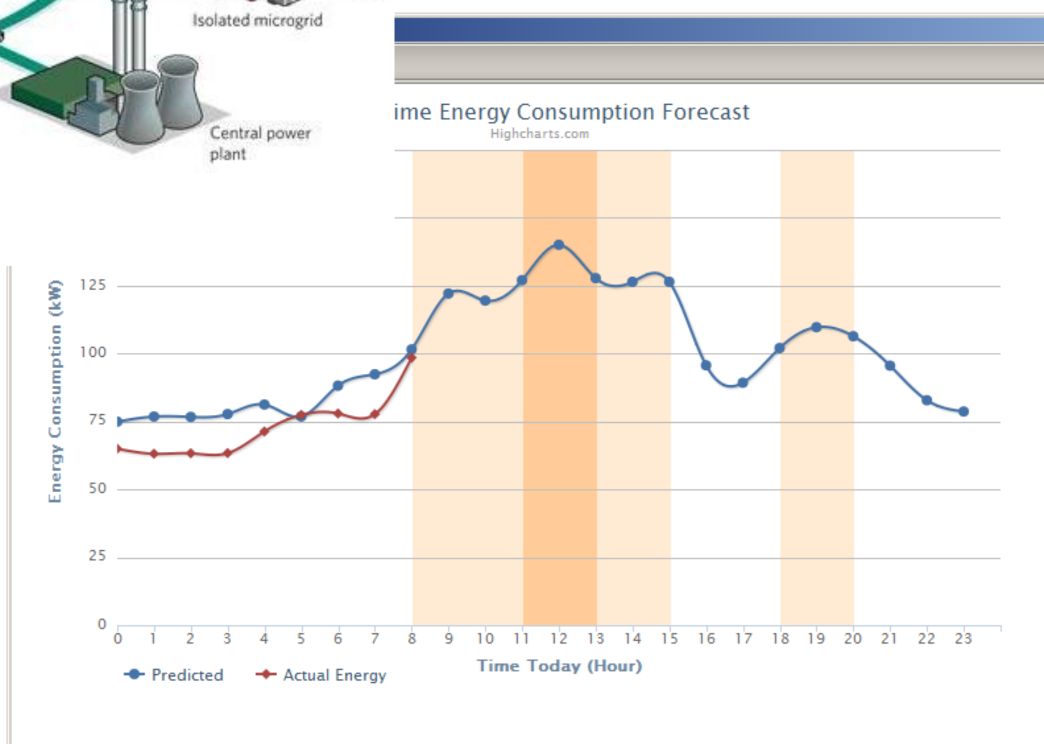
3 Hour Peak

Canada vs. California

- Summer vs. winter peaks
  - Most of Canada, winter is peak
  - Peaks at different times
  - Some strategies in common

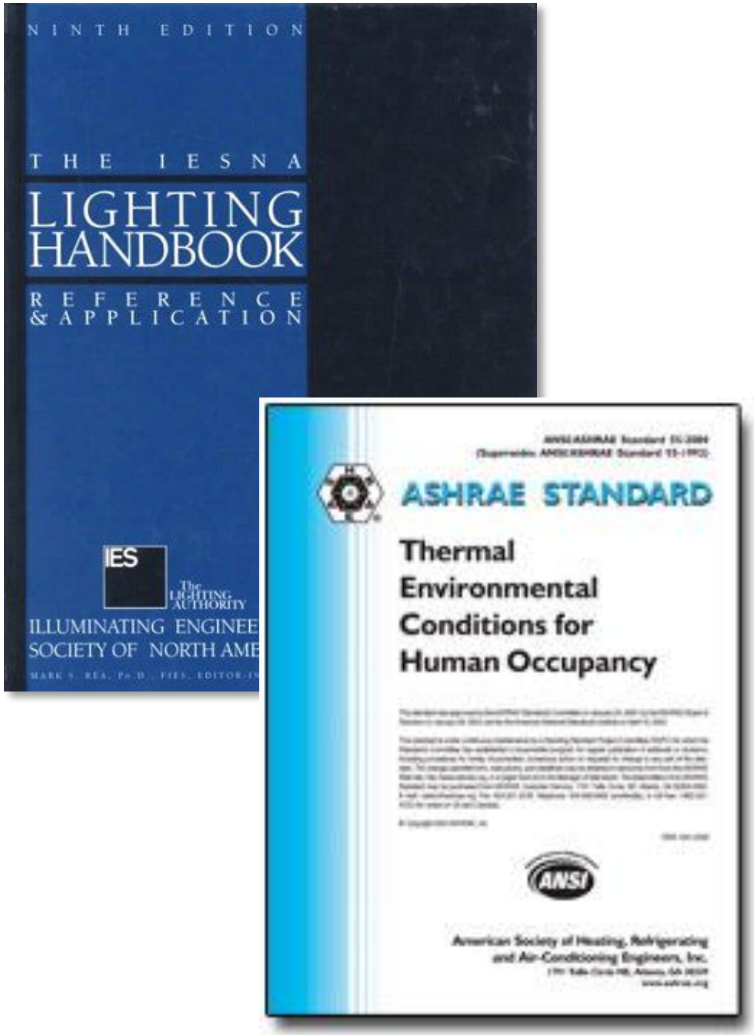
DR as a Smart Grid "app"





Comfort Effects?

- Usually set lighting and temperature levels to optimize comfort
- Not true with demand response



Laboratory Studies

- Electric lighting can be dimmed without hardship by:
  - 20% over 10 seconds, with no daylight
  - 40%+ over 30 minutes, with no daylight, or over 10 seconds with daylight
- Temperature can increase without hardship by:
  - 1.5ºC over 2½ hours

Details at: ***http://www.nrc-cnrc.gc.ca/eng/projects/irc/demand-responsive.html***

Field Study

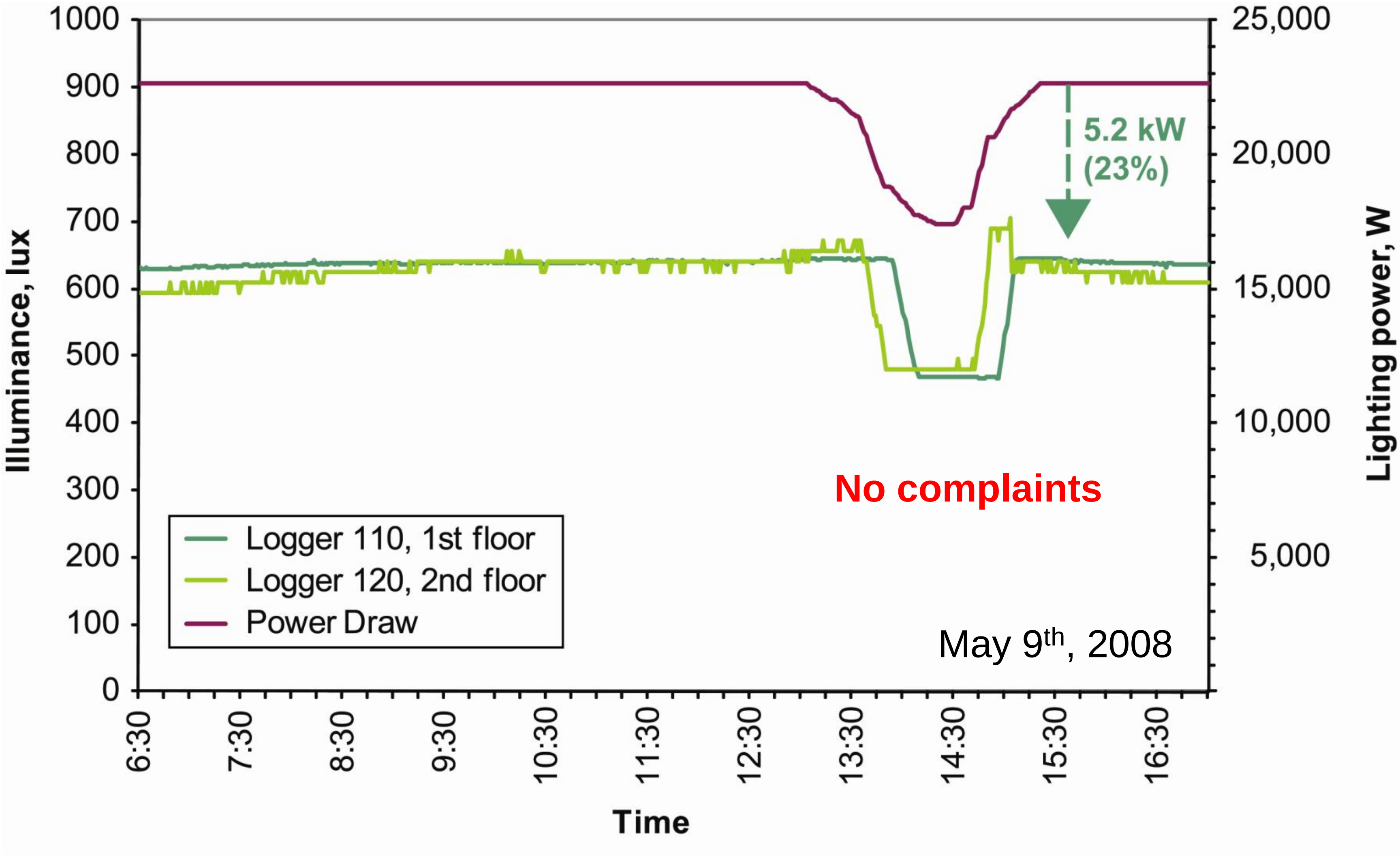
Federal office

Community college

Field Study

- Office building
  - 525 luminaires, 330 dimmed on load shed days

Field Study

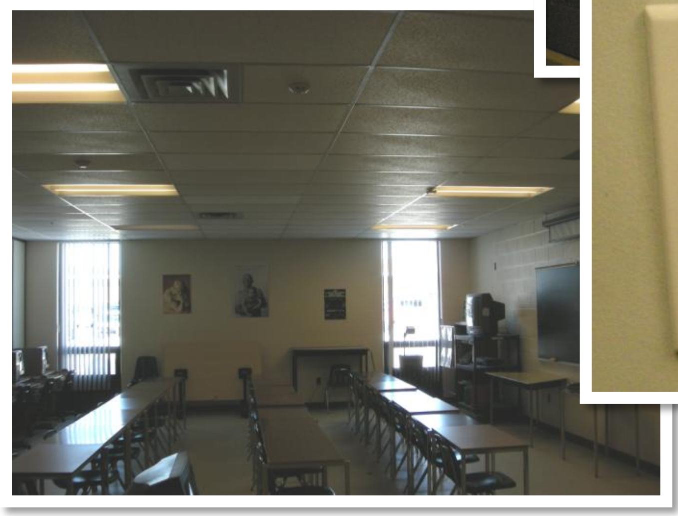


No complaints

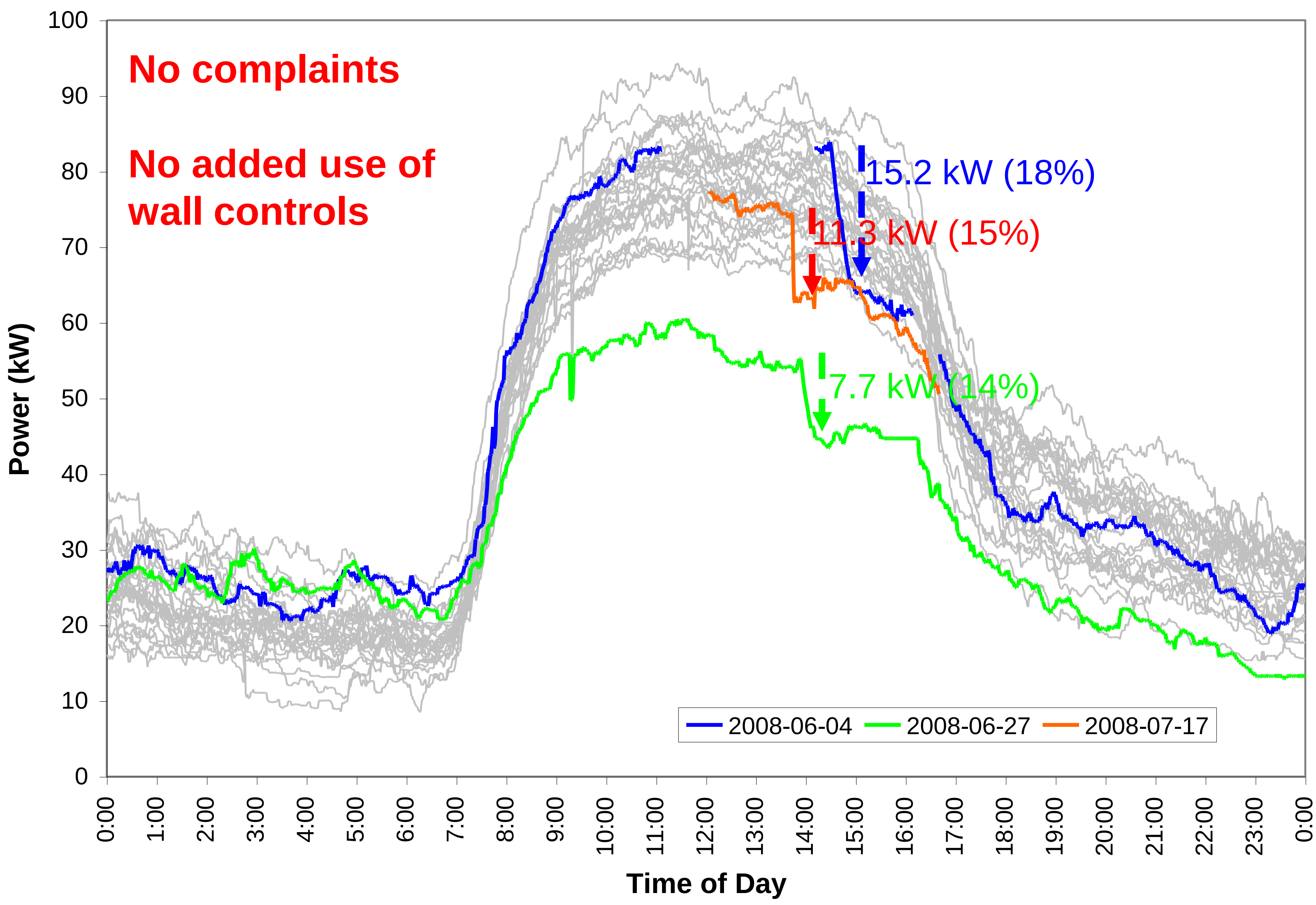
May 9th, 2008

Field Study

- College campus
  - Offices, classrooms, and corridors in 7 buildings
  - 2300 luminaires, 1852 dimmed on load shed days



Field Study



No complaints
No added use of wall controls
15.2 kW (18%)
11.3 kW (15%)
7.7 kW (14%)
Power (kW)
Time of Day
2008-06-04
2008-06-27
2008-07-17
100
90
80
70
60
50
40
30
20
10
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00

HVAC Field Trials

- California
  - Automated demand response trials in 2004
  - Mostly HVAC strategies
  - 18 sites, 36 buildings, >10 million ft^2 floor area

Piette et al., Findings from the 2004 Fully Automated Demand Response Tests in Large Facilities, LBNL/DRRC Report LBNL-58178 (2005). ***http://drrc.lbl.gov/pubs/58178.pdf***

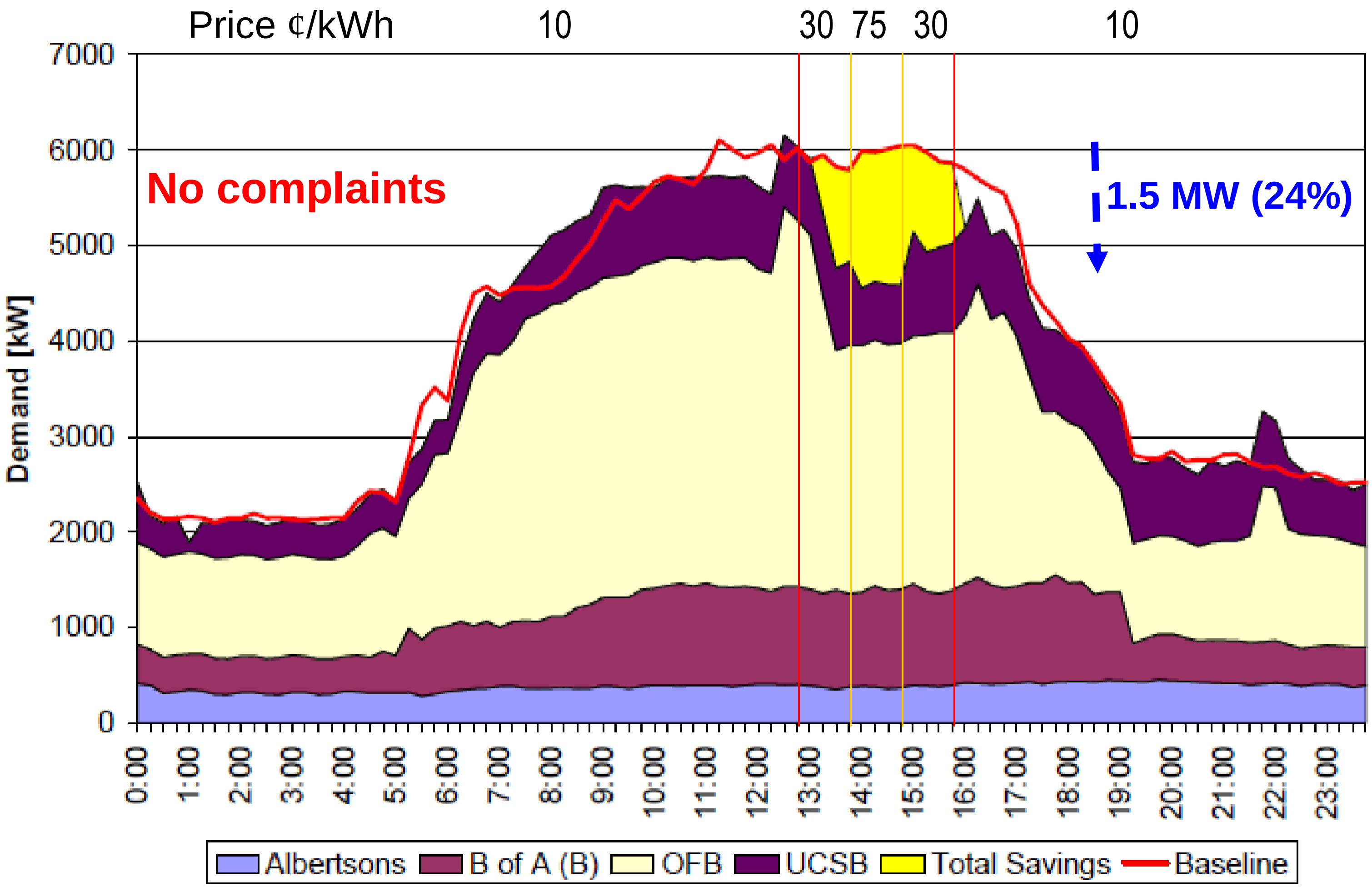
http://drrc.lbl.gov/drrc-pubsall.html

HVAC Field Trials

Site	30 ¢/kWh	75 ¢/kWh
Albertsons	Overhead light 35% off	Anti-sweat door heater night-mode
B of A	Supply air temp. reset 55°F → 59°F Duct static pressure 2.2 IWC → 1.8 IWC	Supply air temp. reset → 59°F Duct static pressure → 1.4 IWC
Cal EPA	Duct static pressure 1.0 IWC → 0.5 IWC	Turn off light where daylight is available
CETC	Unload chiller and cool with ice storage Two air handling units off Electric humidifier off	
Cisco	VAV zone setup 2°F Computer Room AH setup 2°F Boiler pump off & stairwell fan-coils off Sweep lighting where daylight is available Stairwell, lobby, and hallway lights off	
50 Douglas	Global zone setup 76°F → 78°F	Global zone setup → 80°F
Summit Ctr	Global zone setup 76°F → 78°F	Global zone setup → 80°F
Echelon	Zone set point increase Dim office lighting	2 of 3 rooftop units off Lobby, common area light off Hallway light 33~50% off
OFB	Global zone setup 72°F → 76°F Global zone setback 70°F → 68°F	Global zone setup → 78°F Global zone setback → 66°F
UCSB	Supply fan VFD 70% limit Economizer 100% open	Supply fan VFD 60% limit Duct static pressure reset 0.4 IWC (partial) Heating/cooling valve closed

HVAC Field Trials

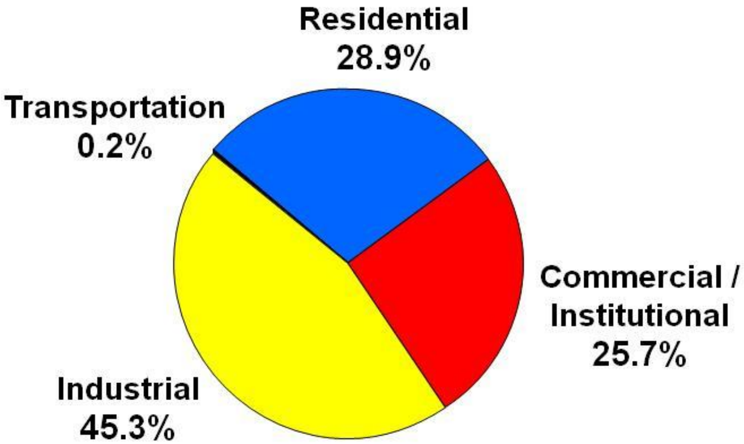
- Sept 8th, outdoor temperature 32ºC (90ºF)

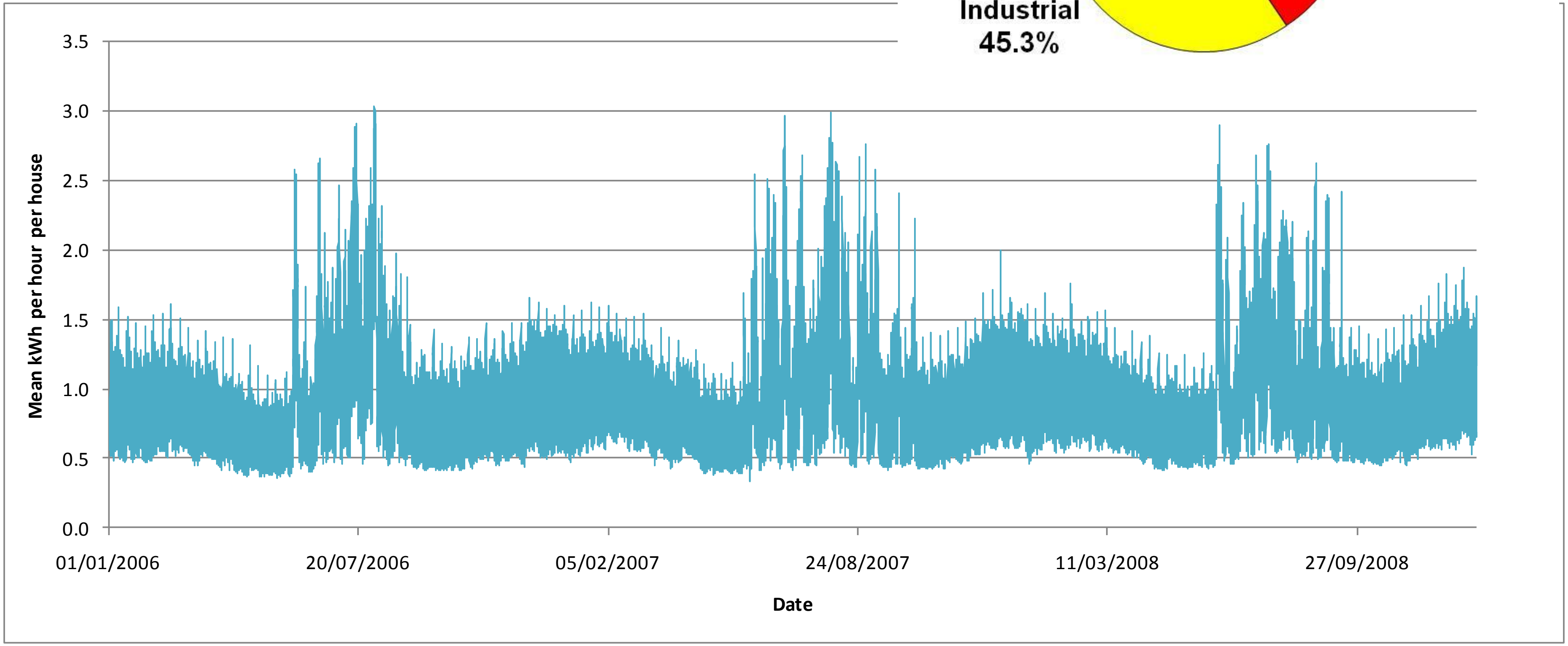


Commercial DR Summary

- Substantial peak reductions possible
- Little risk of substantial hardship, if guidelines followed, but …
- These are <u>TEMPORARY</u> measures in extreme circumstances NOT the new normal
- RP-1 and LEED now include DR

The Residential Problem





NRC-CNRC

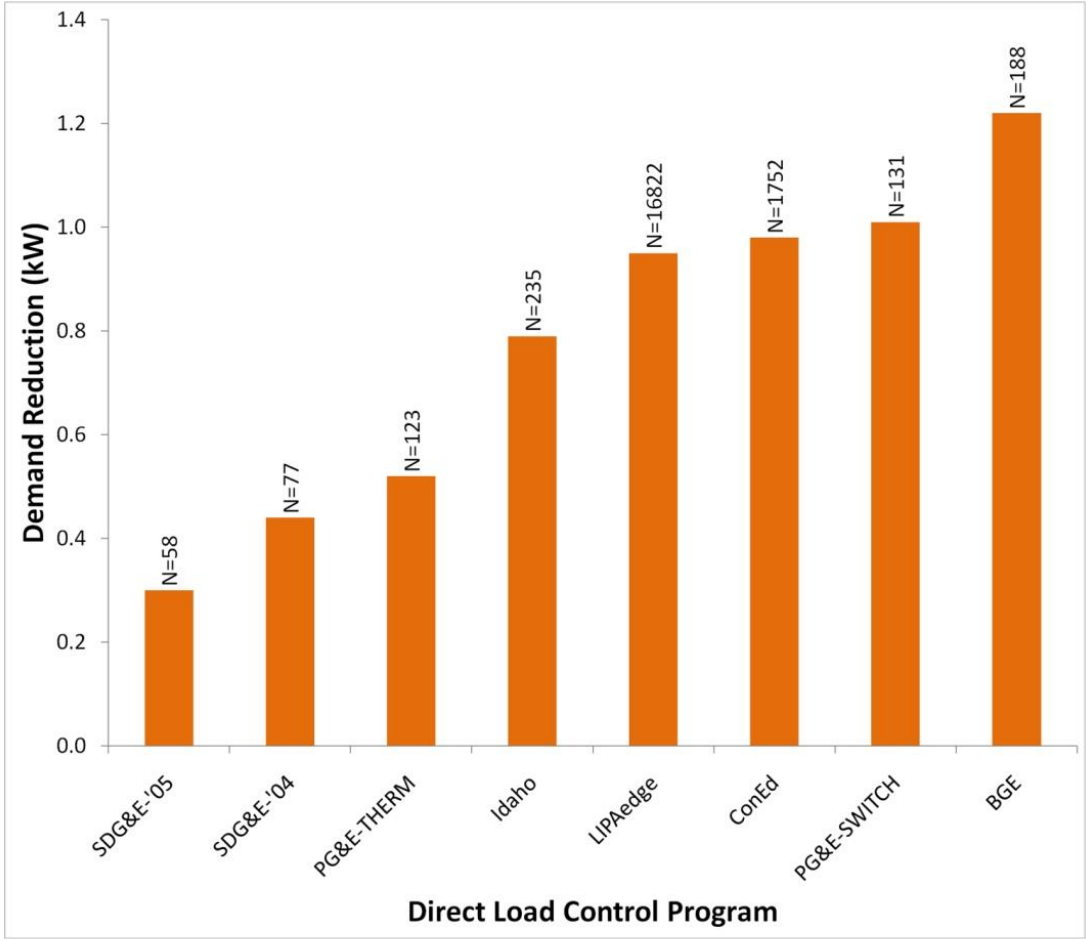
PeakSaver Program

- Voluntary province-wide program
- Direct load control of central a/c by utility
- Thermostat increased 2^{o}C during 4-hr on event days (expected to be high demand)
- Maximum of 10 events per year
- Occupant may opt out of an event

http://www.diamond-hvac.com/ac.php

Direct Load Control - Literature Review

- “The effect of utility time-varying pricing and load control strategies on residential summer peak electricity use: A review”
  Newsham & Bowker, *Energy Policy* Vol. 38 (2010), pp. 3289–3296



http://www.nrc-cnrc.gc.ca/eng/projects/irc/zero-peak.html

Data Set

- Consists of
  - 3 years of hourly data
    - Up to 1297 households (2006-2008)
    - Survey was conducted on 360 households in 2006
  - 2008 had
    - hourly data from all 1297 residential accounts
    - 205 households enrolled in the Ontario-wide PeakSaver program

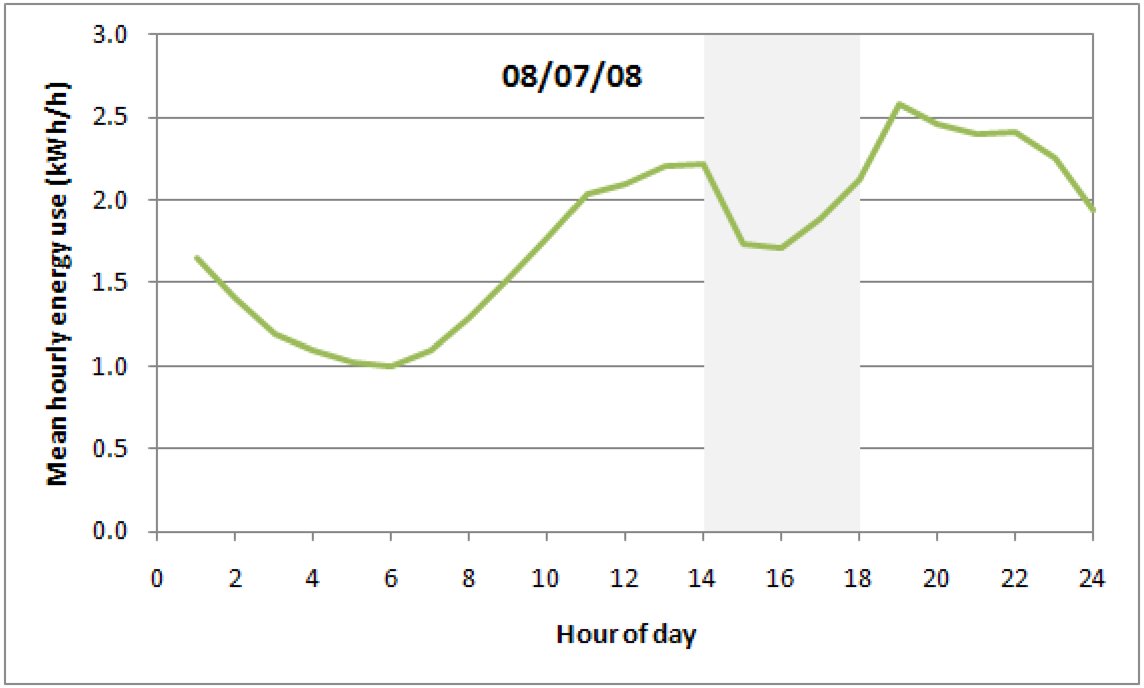
Household Characteristics

	N=320			
	Min.	Max.	Mean	S.D.
Total electrical energy used, kWh	1957	18165	8727	3456

N=320	Yes				No				
Use electricity to heat water?	32				288				
Use electricity to heat space?	26				294				
Own central air conditioner?	271				49				
Own window air conditioner?	13 (one=8; two=5)				307				
Is the house detached?	215				105				
Number of occupants	1	2	3	4	5	6	7	8	?
	15	101	71	90	32	8	0	1	2

	N	Min.	Max.	Mean	S.D.
Age of house, years	291	1	156	16.3	20.8
How old is central a/c? years	250	0	50	5.5	6.4
Finished living space, ft^2 (m^2)	310	1000 (93)	4500 (418)	2035 (189)	668 (62)

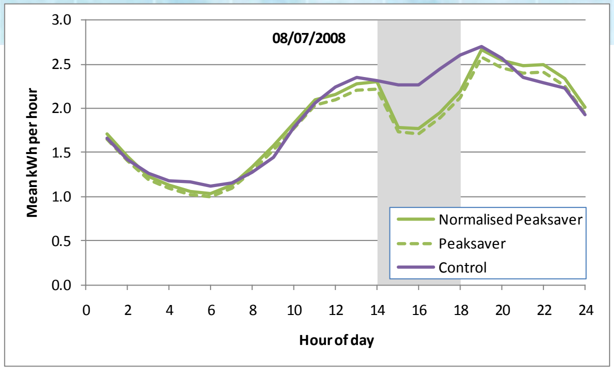
Measuring the Effect

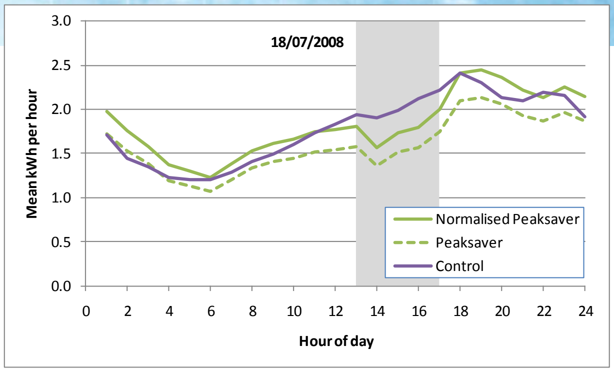


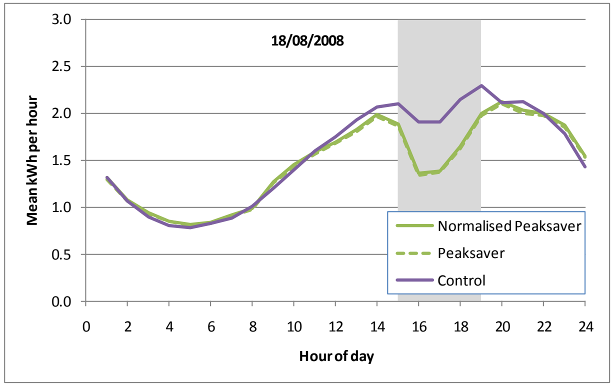
What would energy use have been without the event?

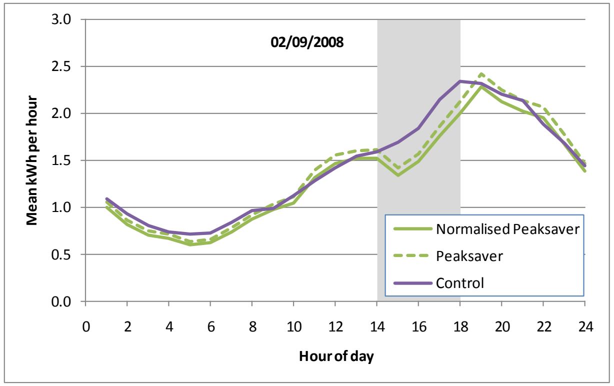
1. Participants on event day vs. Control group
2. Participants on event day vs Participants on equivalent non-event day
3. Participants only, multiple regression analysis
4. Participants only, time-series analysis

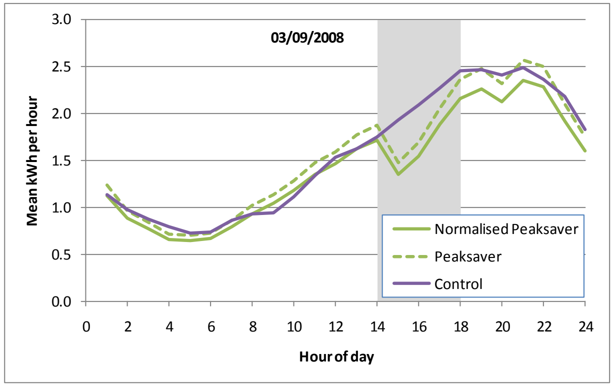
vs. Control Group (N=268)





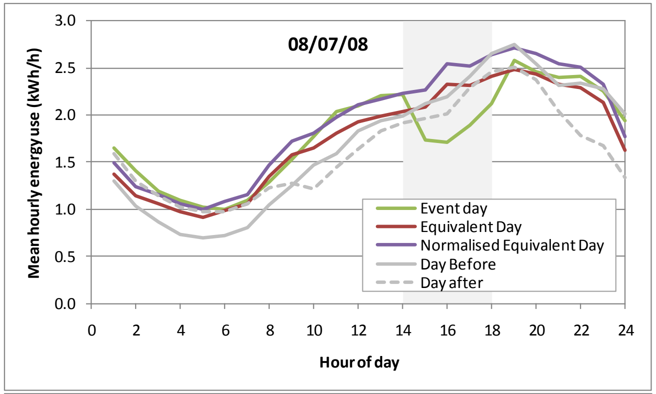


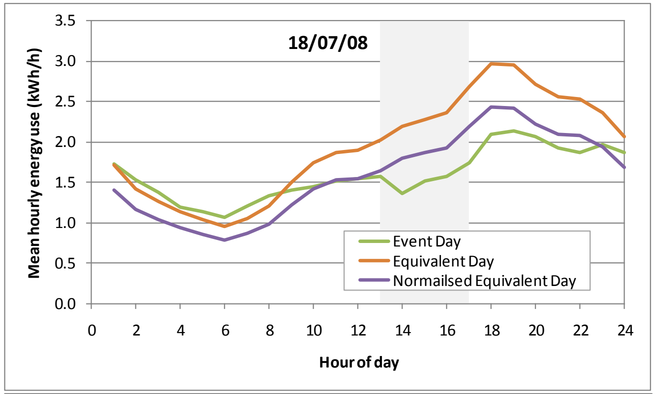


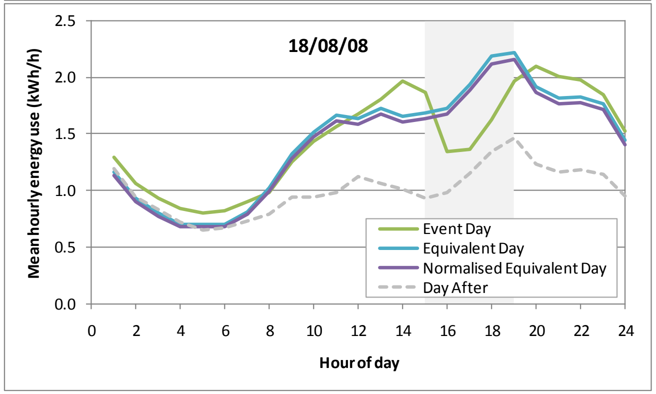


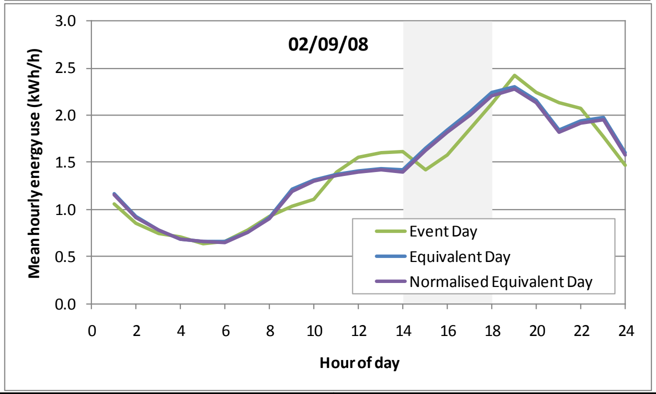
Event date	Normalisation factor
July 8th, 2008	1.03
July 18th, 2008	1.15
August 18th, 2008	1.01
September 2nd, 2008	0.95
September 3rd, 2008	0.92

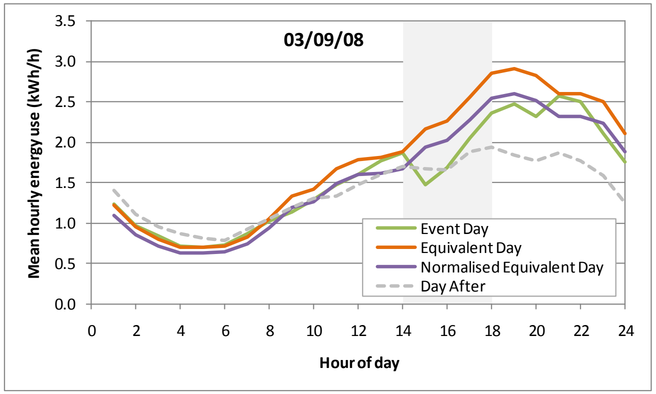
vs. Equivalent Day











Event date	Normalization factor
July 8, 2008	1.09
July 18, 2008	0.82
August 18, 2008	0.97
September 2, 2008	0.99
September 3, 2008	0.89

Multiple Regression

$$y_t = \sum_{l=0}^{6} \beta_{CDH24,l} CDH24_{t-l} + \sum_{l=0}^{6} \beta_{RH,l} RH_{t-l} + \beta_{NWD} NWD_t + \beta_{ST} ST_t +$$

$$\sum_{m=6}^{10} \beta_{MTH,m} MTH_{m,t} + \sum_{h=1}^{24} \beta_{HR,h} HR_{h,t} + \sum_{h=1}^{24} \beta_{E1,h} E1_{h,t} + \sum_{h=1}^{24} \beta_{E2,h} E2_{h,t} +$$

$$\sum_{h=1}^{24} \beta_{E3,h} E3_{h,t} + \sum_{h=1}^{24} \beta_{E4,h} E4_{h,t} + \sum_{h=1}^{24} \beta_{E5,h} E5_{h,t} + \varepsilon_t$$

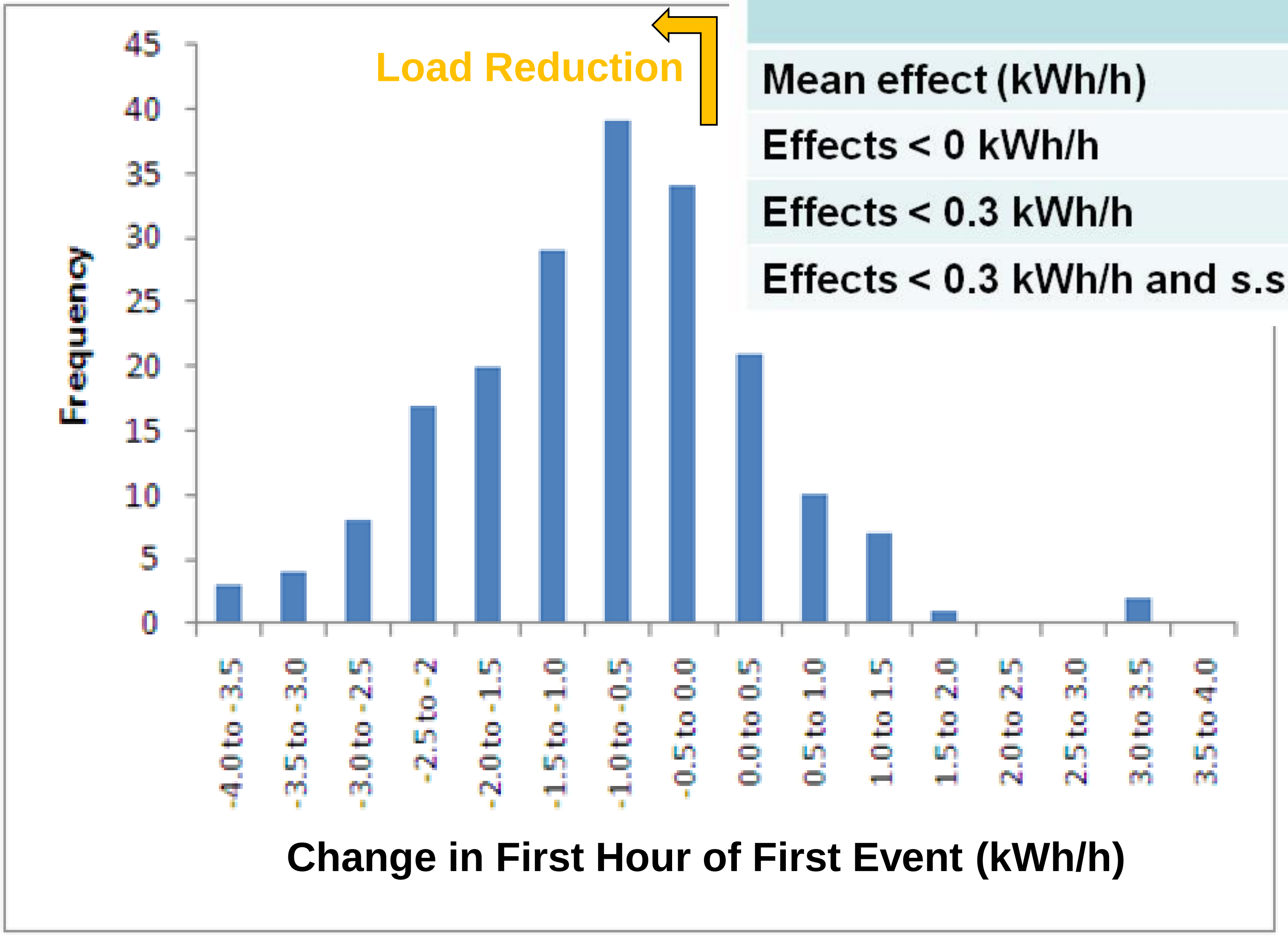
- Time-series regression is much more complex

Compare Results

- Different methods give different results

		Estimated effect, %			
		Method 1	Method 2	Method 3	Method 4
Event Date	Event-ending Hour	Cntrl. Grp.	Equiv. Day	Simp. Regr.	TS Regr.
July 8, 2008	15	21.0	23.8	**32.7**	**22.9**
	16	22.1	32.8	**35.2**	**24.9**
	17	20.0	25.0	**33.0**	**23.4**
	18	15.7	19.5	**28.9**	**19.9**
July 18, 2008	14	17.8	24.3	**30.8**	**12.3**
	15	12.4	18.9	**27.4**	
	16	15.4	18.8	**29.1**	
	17	9.6	20.3	**25.6**	
August 18, 2008	16	28.7	20.0	21.2	**26.3**
	17	27.4	27.4	**29.0**	**31.0**
	18	23.3	23.4	**21.4**	**25.4**
	19	13.2	8.5	6.7	**13.8**
September 2, 2008	15	20.5	12.9	(20.6)	**9.4**
	16	19.4	13.7	(13.1)	
	17	18.1	7.3	**(29.2)**	
	18	14.2	4.0	**(37.4)**	
September 3, 2008	15	30.1	23.8	**23.8**	**15.5**
	16	26.1	16.4	**23.5**	
	17	17.3	9.9	14.1	
	18	11.8	7.1	4.3	

Individual Household Participation



Mean effect (kWh/h)	-0.84 kWh/h
Effects < 0 kWh/h	79 %
Effects < 0.3 kWh/h	68 %
Effects < 0.3 kWh/h and s.s.	27 %

Reasons for Non-participation

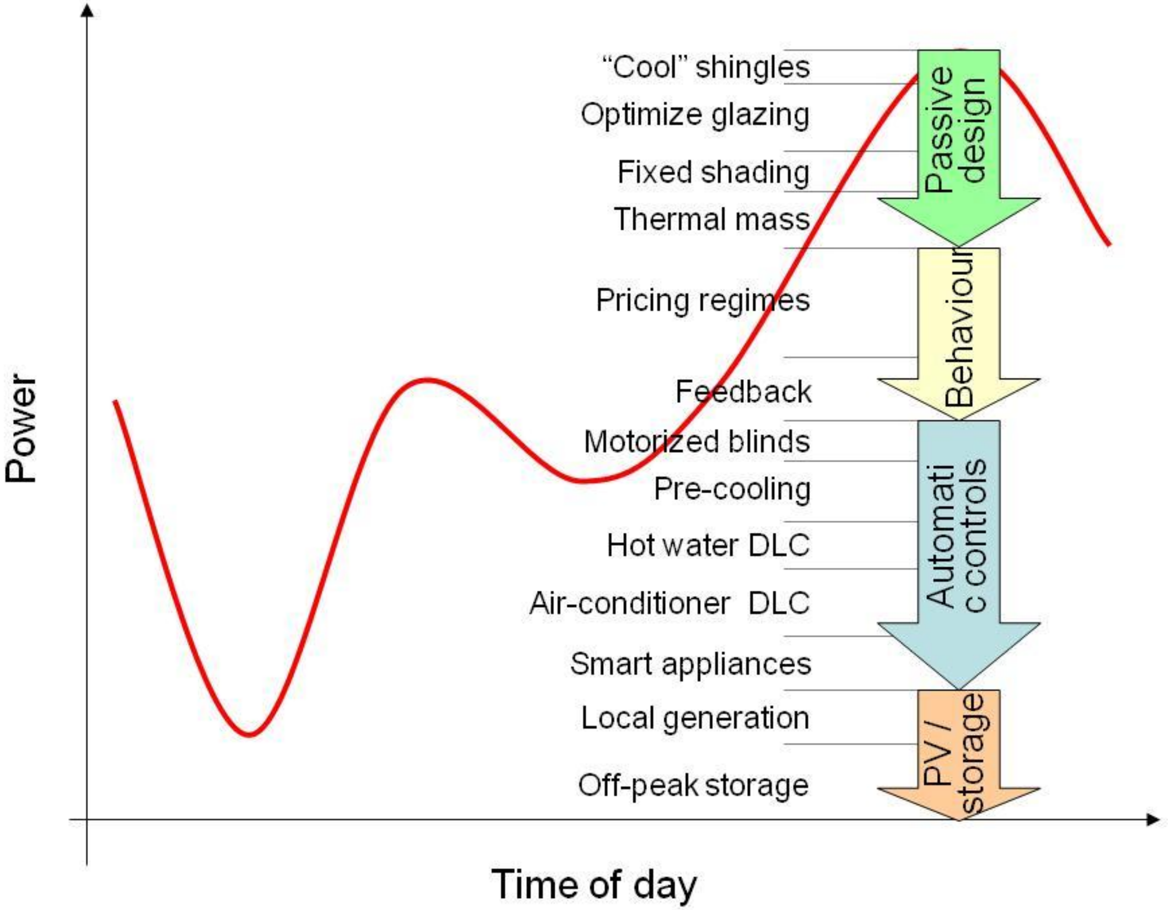
- Equipment failure: thermostat reset signal was not received or actuated
- Occupants overrode thermostat or opted out
- Household characteristics such that a/c would not have been used anyway
- Undersized a/c units with continuous operation even at higher setpoint
- Occupants used more electricity for other things

Individual Household Participation

- Which household characteristics predict participation?
- Help to target DSM programs
- Pursue in future studies …

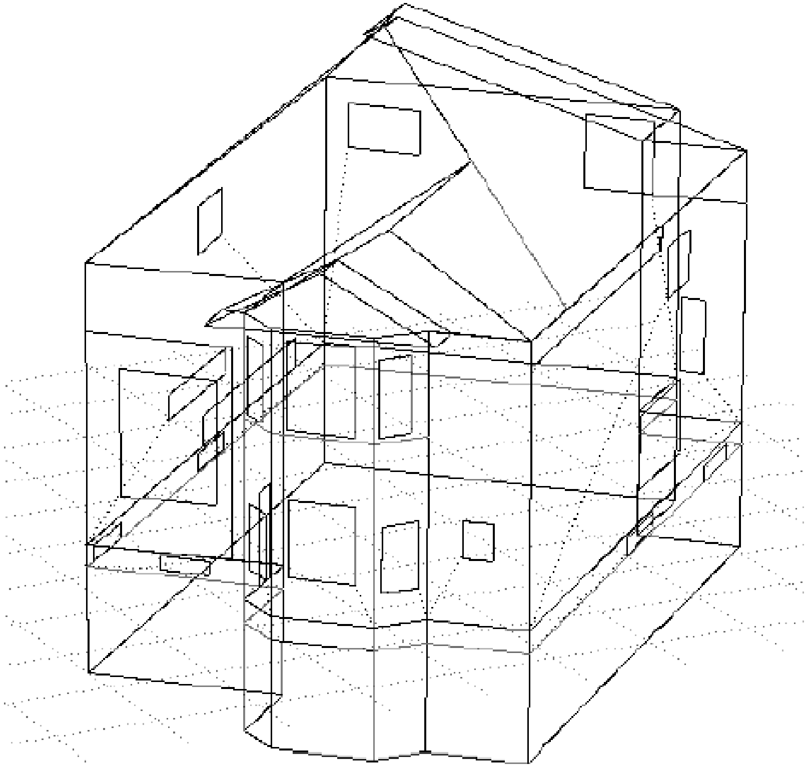
“Power Nap” Project

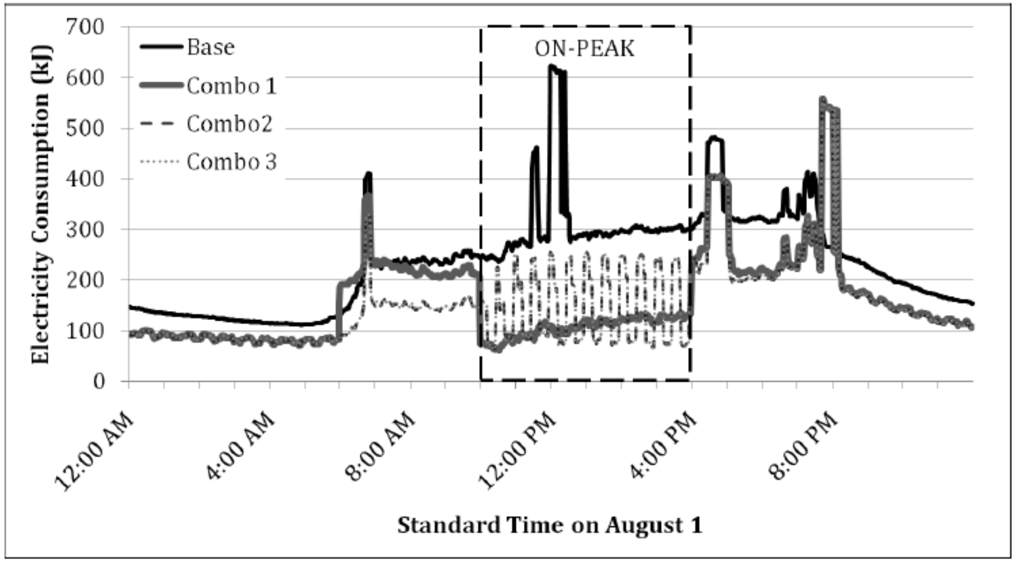
- What combination of measures could reduce grid power draw to zero during peak periods?



Carleton Univ. Simulations

- ESP-r model used to explore design and operation options to reduce peak load

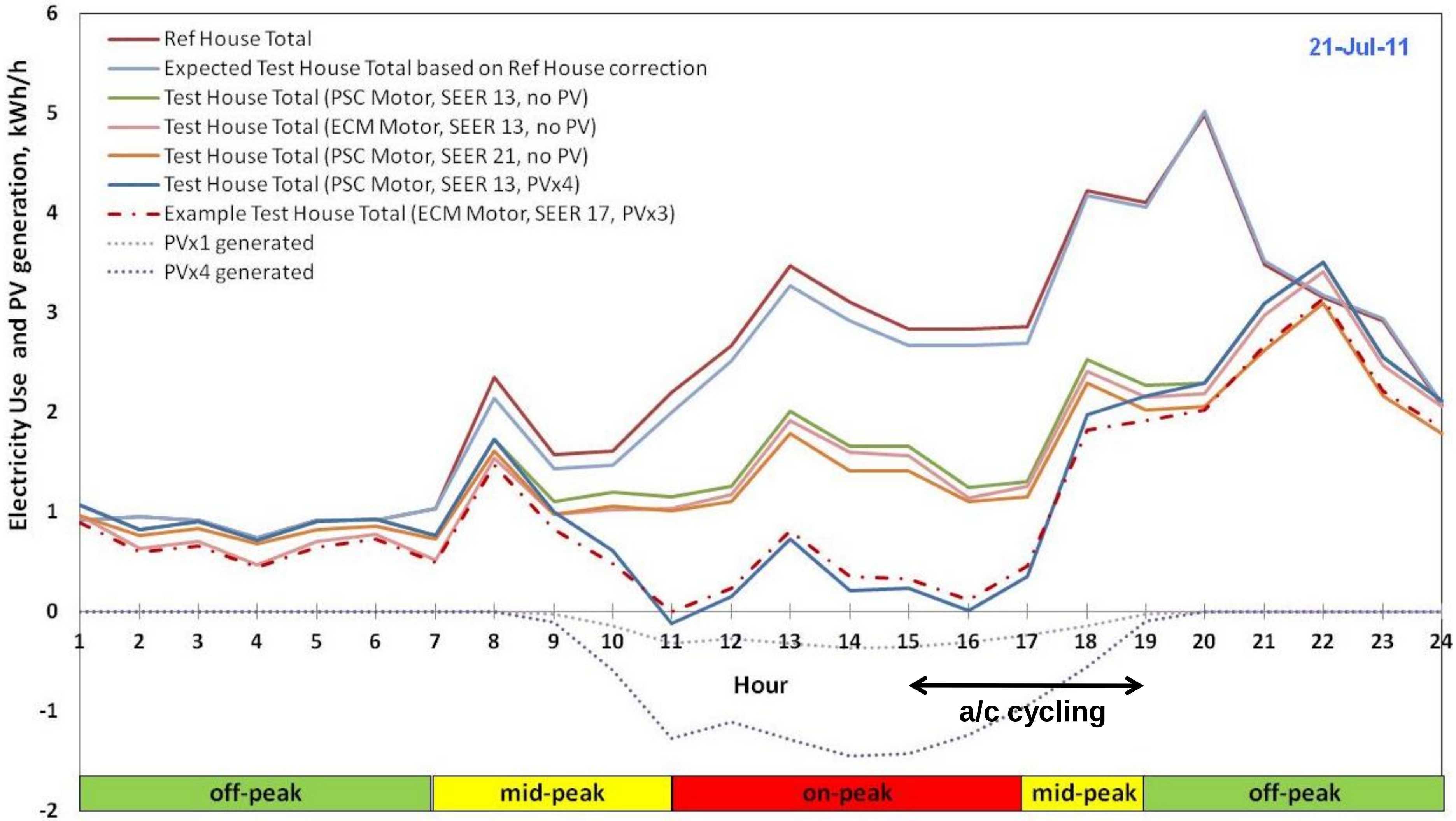




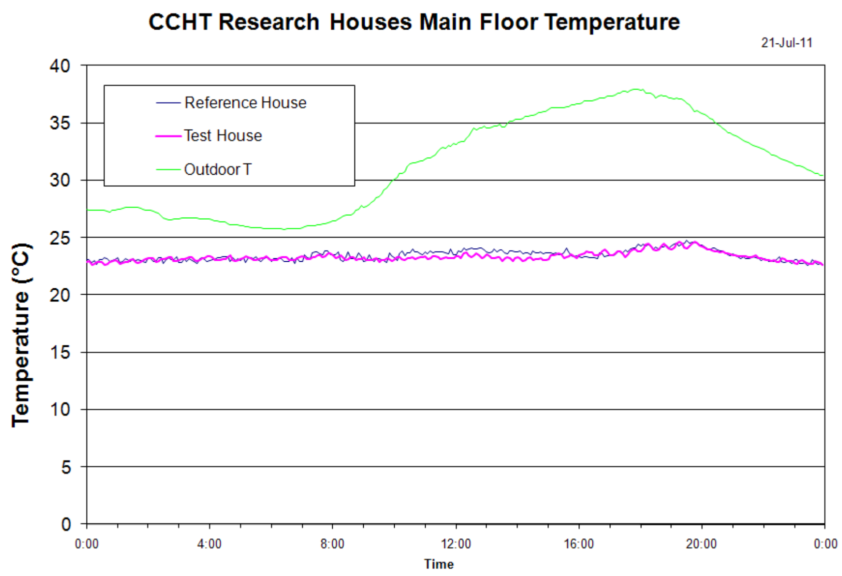
CCHT Trials, Summer 2011

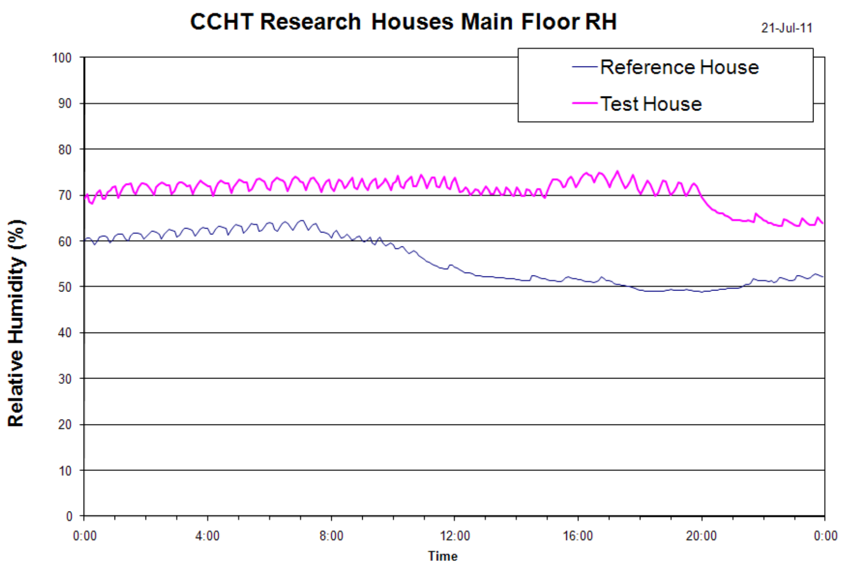
- a/c cycling
- External blinds
- CFL lighting
- Shift washer/dryer to later
- Close basement registers
- PV from Info Centre

The “worst day of the year”



The "worst day of the year"





Residential DR Summary

- Analysis of PeakSaver data revealed:
  - Average peak load reductions were 0.2 – 0.9 kW per household, varying by method of analysis
  - Recommend use of time-series regression
  - Perhaps only a minority of participant households contributed to a given event
- Zero peak in houses is achievable