Centrally Managed Room Air Conditioners for Load Control and Demand Response

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INTRODUCTION

Project Summary

- Overview: Installed 230 internet-connected room ACs in a 190-unit building and implemented demand management and demand response capabilities
- Funder: New York State Energy Research and Development Authority (NYSERDA) buildings research group
- Participants: The Levy Partnership, Inc. project lead; Herbert Hirschfield, P.E. consultant; Intech 21, technology vendor; Jefferson Towers, Inc. demonstration site

Purpose of the Project

- Demonstrate, test and evaluate the benefits of room air conditioner (RAC) load control in NYC master metered multifamily building
- Research questions:
  - How can peak demand reduction (kW) of master-metered multifamily buildings be achieved through dynamic control of individual RACs without sacrificing comfort?
  - How much kW reduction can be achieved?
  - What is the value proposition of such a system?

Intended Benefits

- Demand response: provide demand response capability and payments to building
- Load management: reduce peak monthly electric demand charge
- Controls: offer remote access to AC units

BACKGROUND

Peak Demand

- Demand charges are about 1/3 of electric bill for master-metered multifamily buildings in NYC
- Jefferson Towers demand charges ~$70,000 per year
- New York City experiences approximately 3 to 5 demand response events per summer

Month	2012	2011	2010	2009	2008	2007
May	284	316	268	164	156	204
June	316	312	348	168	360	296
July	336	348	380	252	340	340
August	292	296	320	320	268	352
September	252	216	332	164	264	260

Manhattan Plaza

- 1,690 unit all-electric complex in Manhattan.
- Hirschfeld study 1979 to 1982
- Demonstrated EMS controlling 3,000 thru-wall heating/AC units via one-way PLC
- Separate control of fan and compressor
- No command receipt verification
- Demonstrated energy reduction and demand response

Waterside Plaza

- 1,460 unit all-electric complex in Manhattan
- Hirschfeld, 1997
- Demonstrated EMS/submetering system to control 3,000 thru-wall heat pumps
- Two-way PLC to apartments enabled issuing commands via apartment heat pump circuits and the ability to retrieve apartment submetering data
- No separate control of fan and compressor

Jefferson Towers

- Combines features of both previous installations
- Two-way wireless radio communications inherent in existing submeter system
- Superior control and feedback on apartment conditions
- Controls the RACs with a device internal to the RAC chassis
  - separate control of the compressor and fan
  - time delay to avoid compressor short cycling
  - tamper-proof
  - standard RAC units

Candidates

- Master metered residential buildings
  - Coops, condos or rentals
  - Sub-metered or not
- Any building with many independent cooling loads on a single meter



Market

New York

- 400,000 living units in master metered buildings in New York[1]
- 745,000 apartments in NY with electricity included in rent (in bldgs with 5+ units) (RECS 2005)
- 1.5 million apartments in NYS with 2.2 million window ACs (in buildings with 5+ units) (RECS 2005)

National

- 8.1 million window ACs in 6 million apartments (in buildings with 5+ units) (RECS 2005)

[1] 105,000 units constructed under the Mitchell-Lama program (New York State Division of Housing and Urban Renewal; http://www.dhcr.state.ny.us/Programs/Mitchell-Lama/); approximately 180,000 master metered units under management of the New York City Housing Authority (NYC Housing Authority Fact Sheet; http://www.nyc.gov/html/nycha/html/about/factsheet.shtml); plus additional Section 213 buildings and others.

DEMONSTRATION

PROJECT

Site Description - Jefferson Towers

- 190 apartments
- 20 stories
- Cooperative
- Built 1968
- Upper West Side of Manhattan
- Two through-wall A/C sleeves per apartment
- Approximately 400 sleeves (not all contain A/Cs)
- Master metered

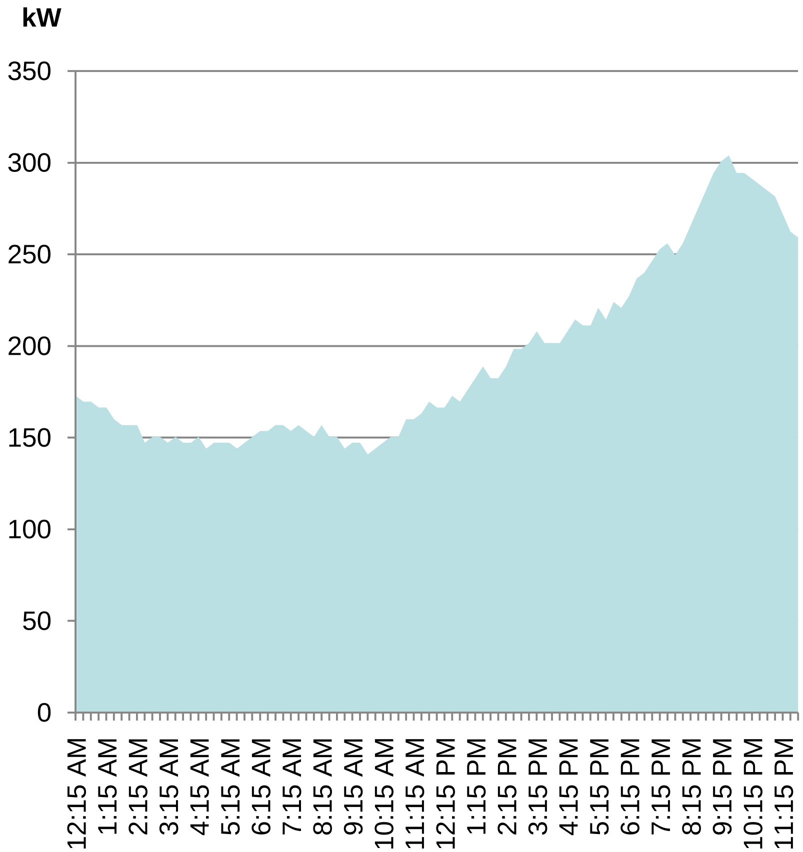
Jefferson Towers – Electric Use

- 1,100,000 kWh per year
- 30-35% for common spaces
- $220,000 per year
- 25-35% based on demand
- ~360 kW maximum summer peak
- 150 kW typical shoulder peak
- 90-100 kW minimum daily non-cooling demand

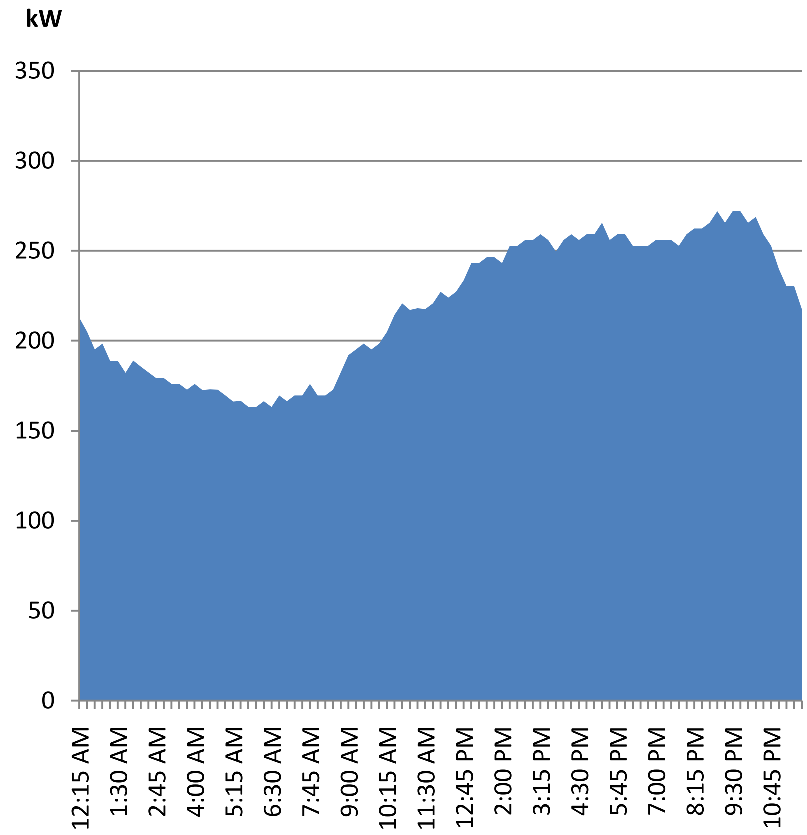
Submetering

- Submetered in 2003 with Intech 21 wireless mesh network submeters
- The year prior to submetering the peak load was 468 kW
- As a result of submetering, electric usage and peak demand declined ~25%

Typical Demand Profiles



weekday (8/6/07)
high temperature of 82.9°F



weekend (8/4/07)
high temperature of 89.1°F

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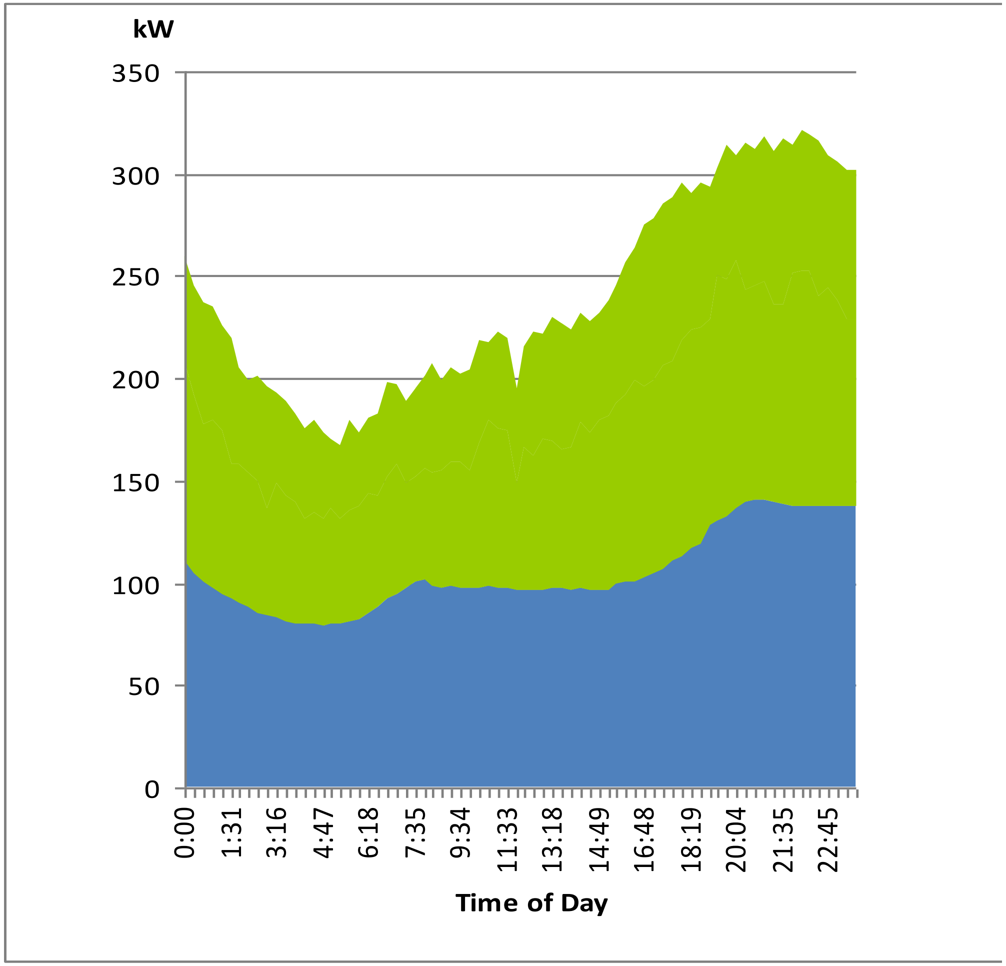
Cooling Drives Peak

- Cooling drives peak demand
- Peak 9-10pm



New Controllable RACs

- Pre-retrofit: ~300 RACs
- Added 230 new RACs with EER 9.4
  - 98 - 9,000 Btu/hr bedroom units
  - 132 -12,000 Btu/hr living room units
- Replaced 175 old units, added 55 RACs
- Removed units average EER 8.77
- Removed units average capacity 8,308 Btu/hr (bedroom) and 12,862 Btu/hr (living room)

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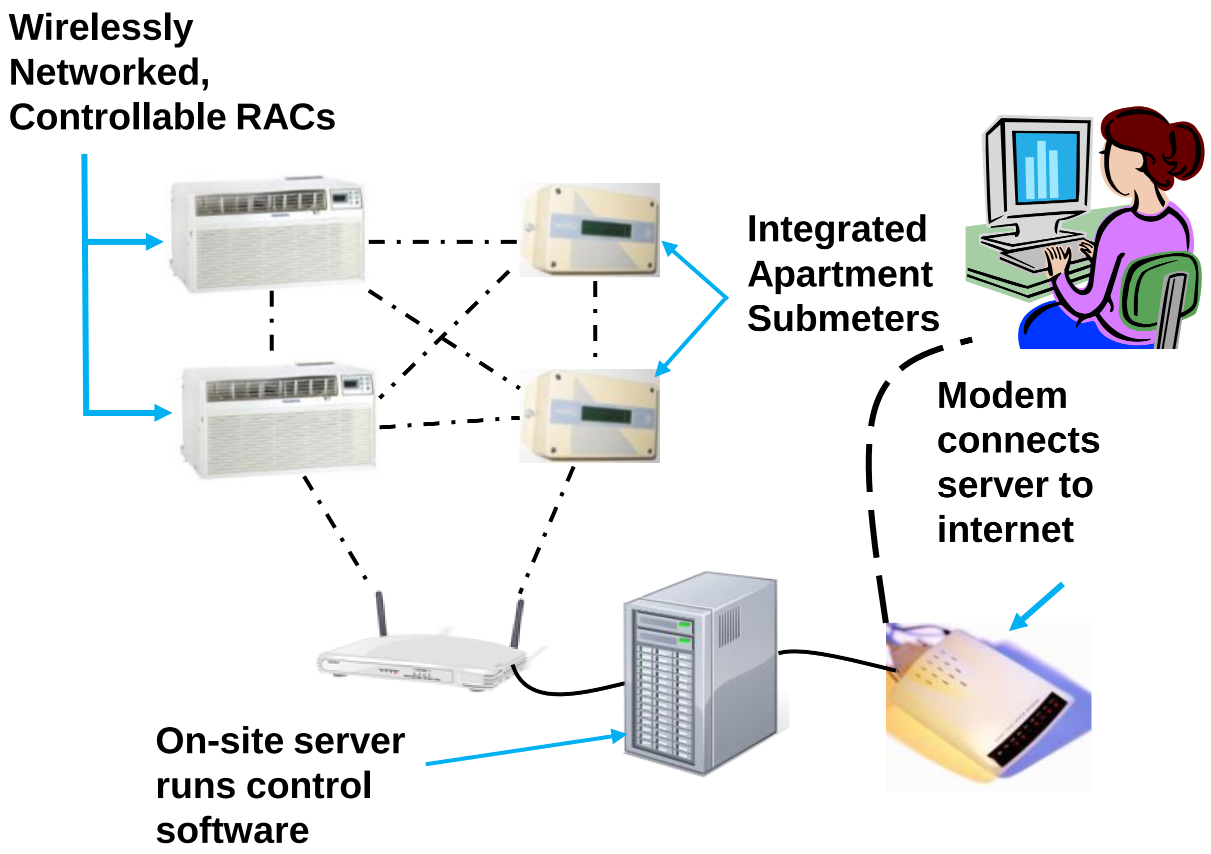
New Controllable RACs

- Off-the-shelf units
- Each RAC retrofit with control board, radio transceiver and temperature sensor
- Through-wall sleeve installation
- New control board can override original controller
- Wireless network node
- Communicate operational information about the RAC:
  - return air temperature
  - thermostat mode
  - fan speed
  - compressor operation

System Components

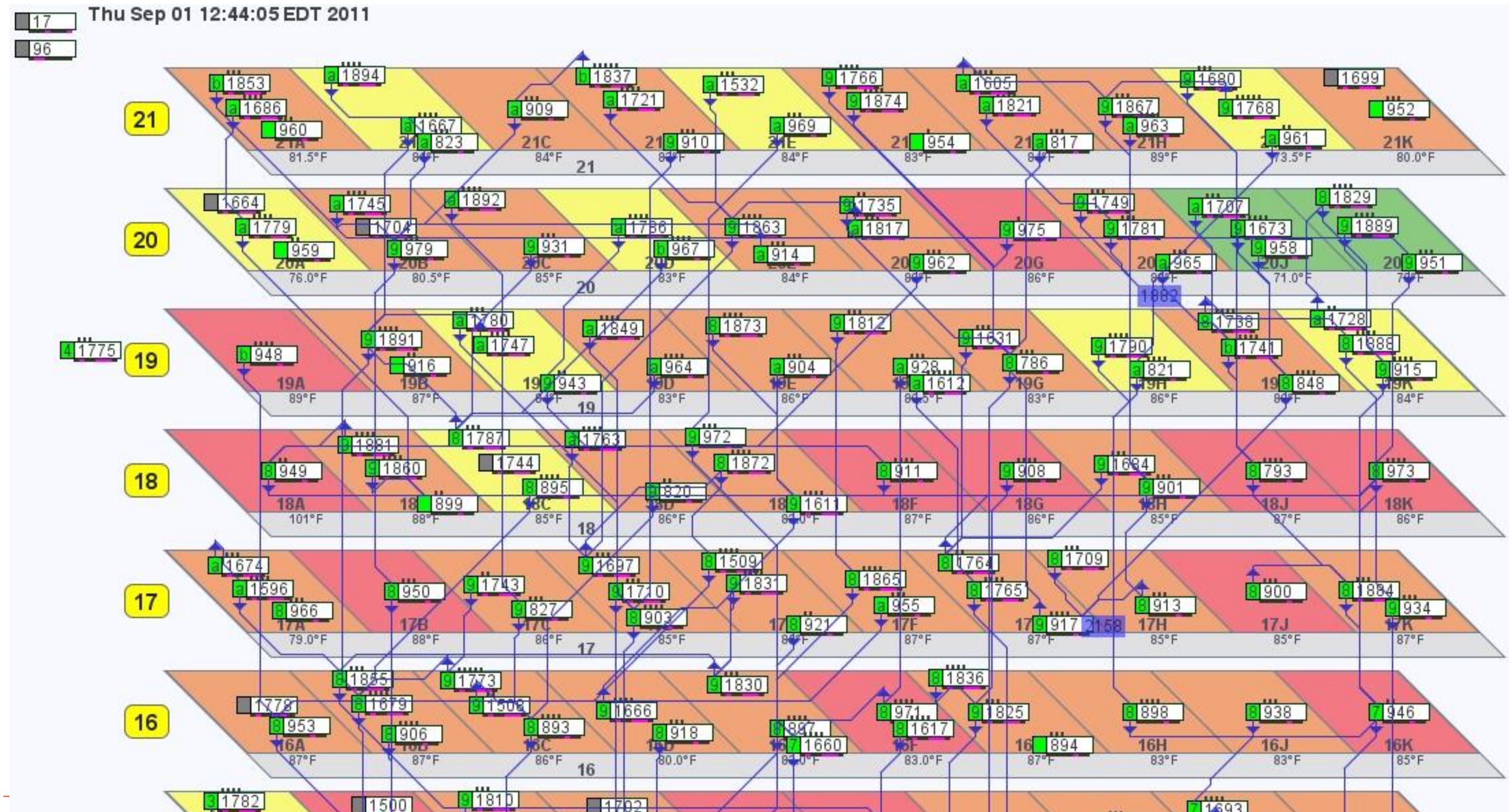


- RACs with integral wireless controller
- Building area network built on existing apartment electric submeters
- Central internet-connected computer
- RAC control software

Building Area Network

- Each submeter and RAC a node in self-healing wireless mesh network
- Each node a relay for other nodes
- Three receivers: each end of the building on the ground floor; one on 12th floor
- Receivers hard wired to computer

Wireless Network



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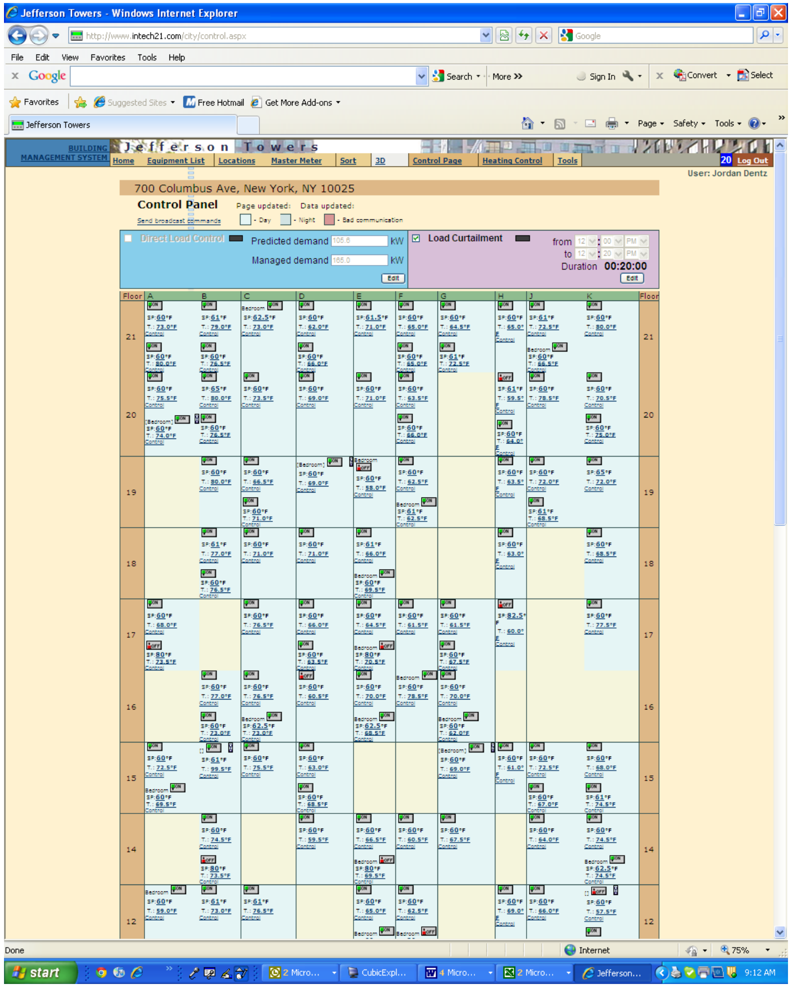
RAC Control System

- Each RAC has a unique ID number
- Can be grouped by any predetermined characteristic:
  - Room
  - Location
  - Operational variable



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RAC Web Interface

Device type

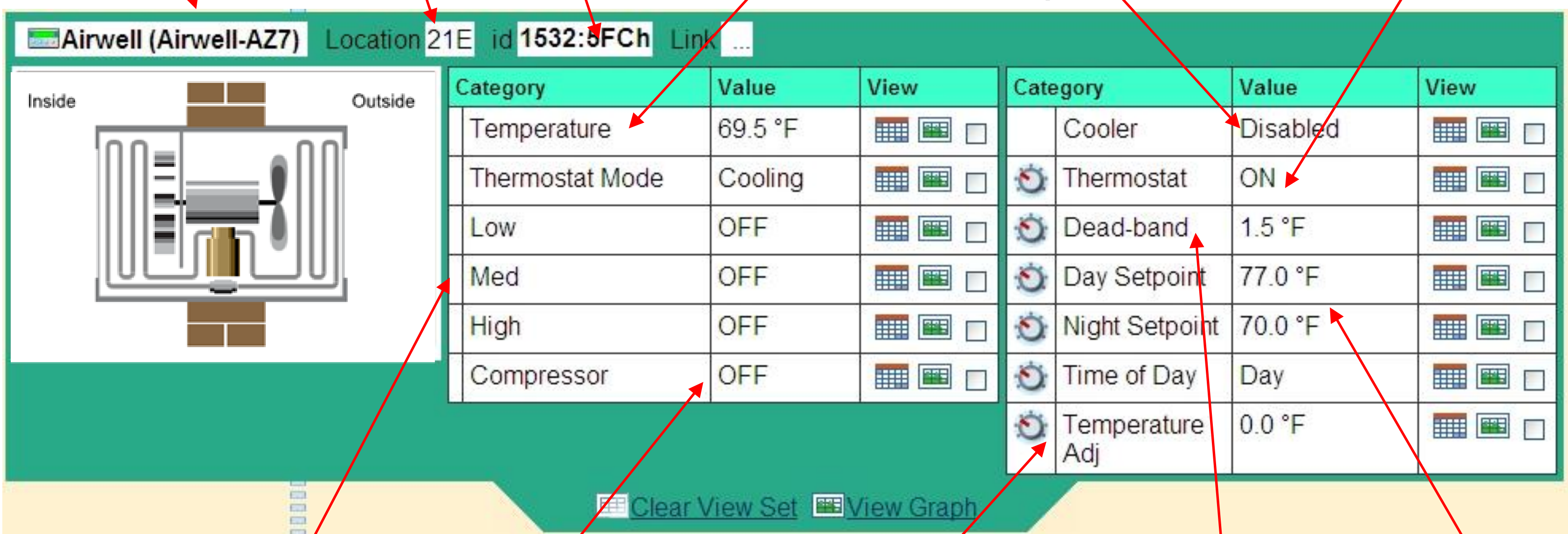
Apt. #

Device ID

RAT @ coil

Enable or disable comp.

What controls comp.



Fan speed

Comp. status

Manual adjuster to Temp. value

0-16 deg. dead-band

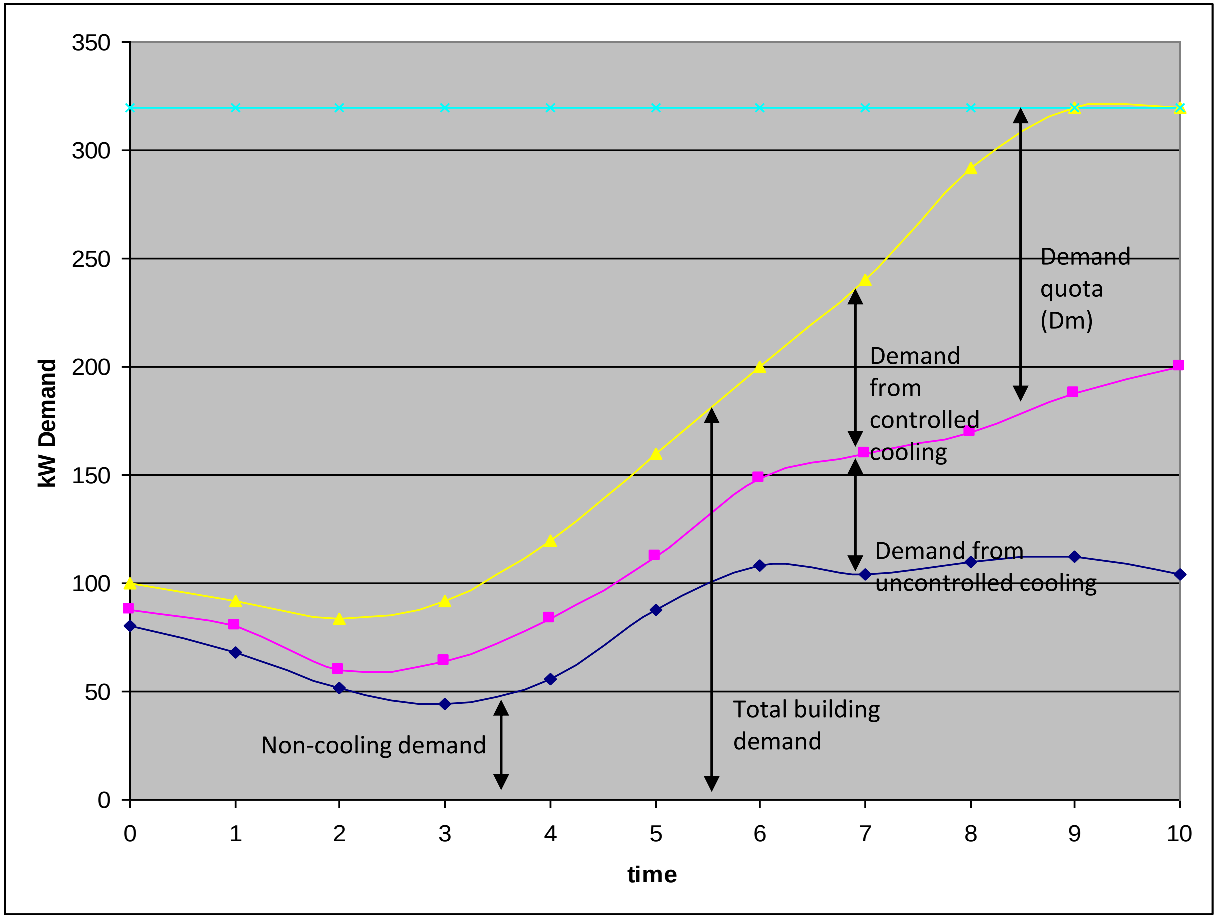
Control system set points

Highest Set Point Controls

Demand Management

- All networked RACs participate
- kW demand rationed by giving permission for a certain number of compressors to be on at any one time

Demand Management



Sample building demand graph

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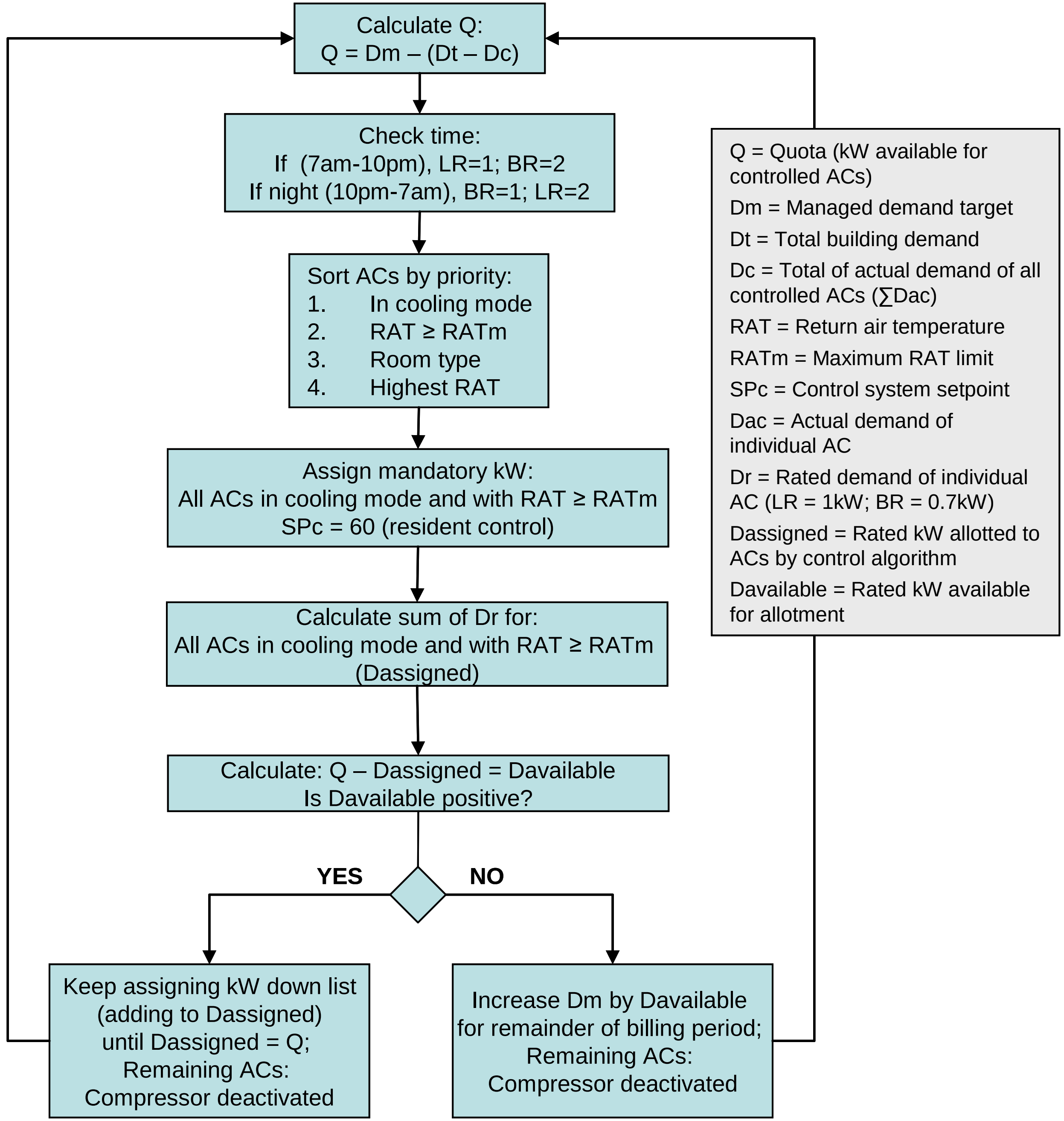
Control Strategy Flow Chart



Demand Management - Prioritization

- RACs sorted according to priorities:
  - In cooling mode
  - Where return air temperature is equal to or greater than the maximum allowable
  - Living room ranked above bedroom during daytime and vice versa
- Sorted by RAT within these groups

700 Columbus Ave, New York, NY 10025

Page updated: **9/6/2011 2:12:24 PM** Data updated: **9/6/2011 2:07:00 PM** Graph

Managed Demand (original): 194.00 kW Submit RATm: 77.0 F Submit SP-on: 72.0 F Submit

Managed Demand (Dm): 214.40 kW Submit SP-off: 77.0 F Submit

Current Demand (Dt): **105.60 kW** LR Dc: **9.12 kW** BR Dc: **2.31 kW**

Q=Dm-(Dt-Dc)= **120.23 kW** Dmdt: **0.00 kW** C_on= **1.91 kW**

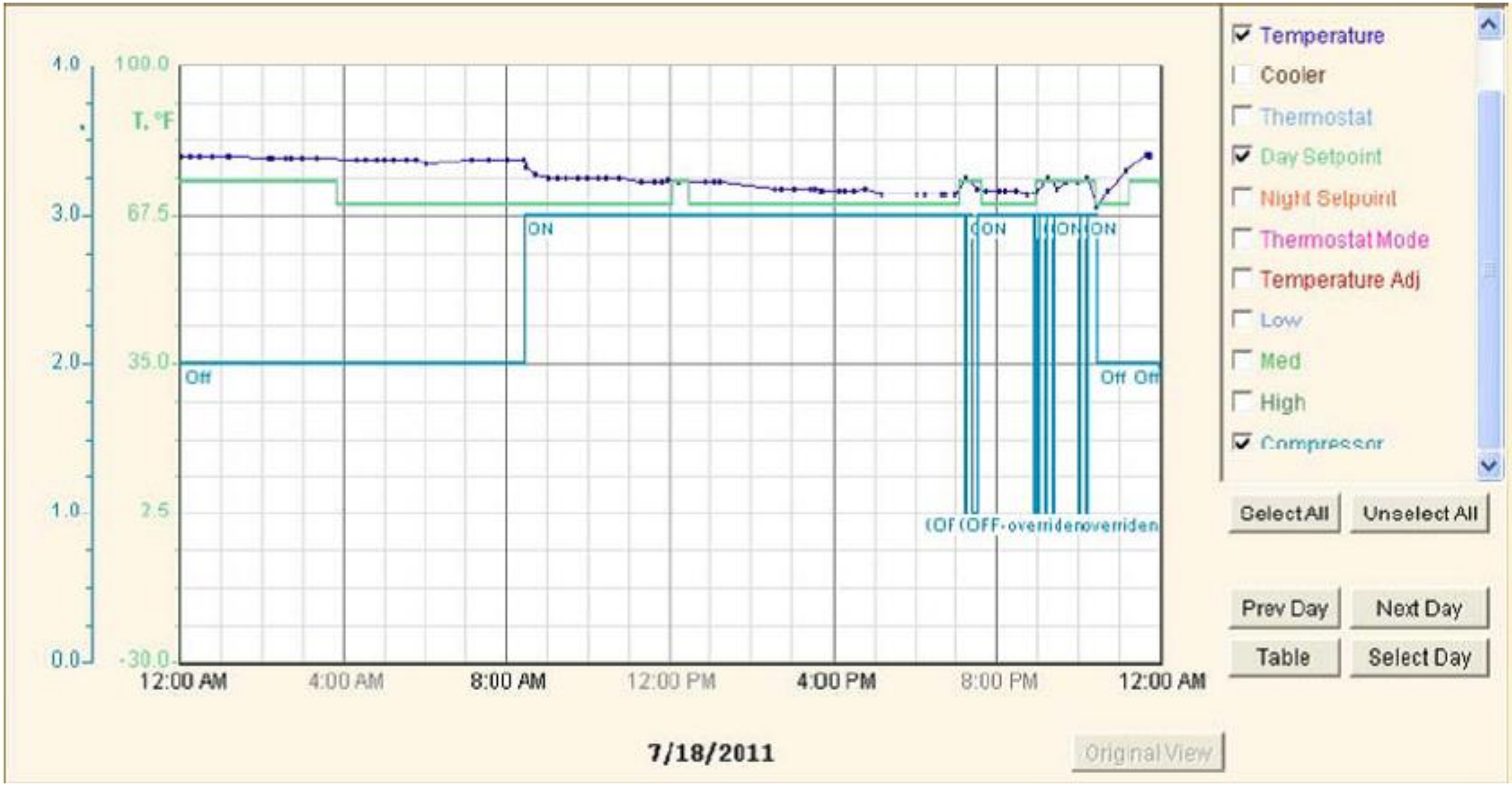
- devices allowed to run - devices will be turned off Control Page Curtailmen

	ACID	APT	Compressor Status	RAT ≥ RATm	Room	RAT	kW rating (compressor only)	SPc
1	69F	8G	1	no	LR	76.0	1.14	72.0
2	714	19F	1	no	LR	73.0	1.14	72.0
3	64C	19F	1	no	LR	73.0	1.14	72.0
4	743	4A	1	no	LR	73.0	1.14	72.0

Disabling RACs - Setpoints

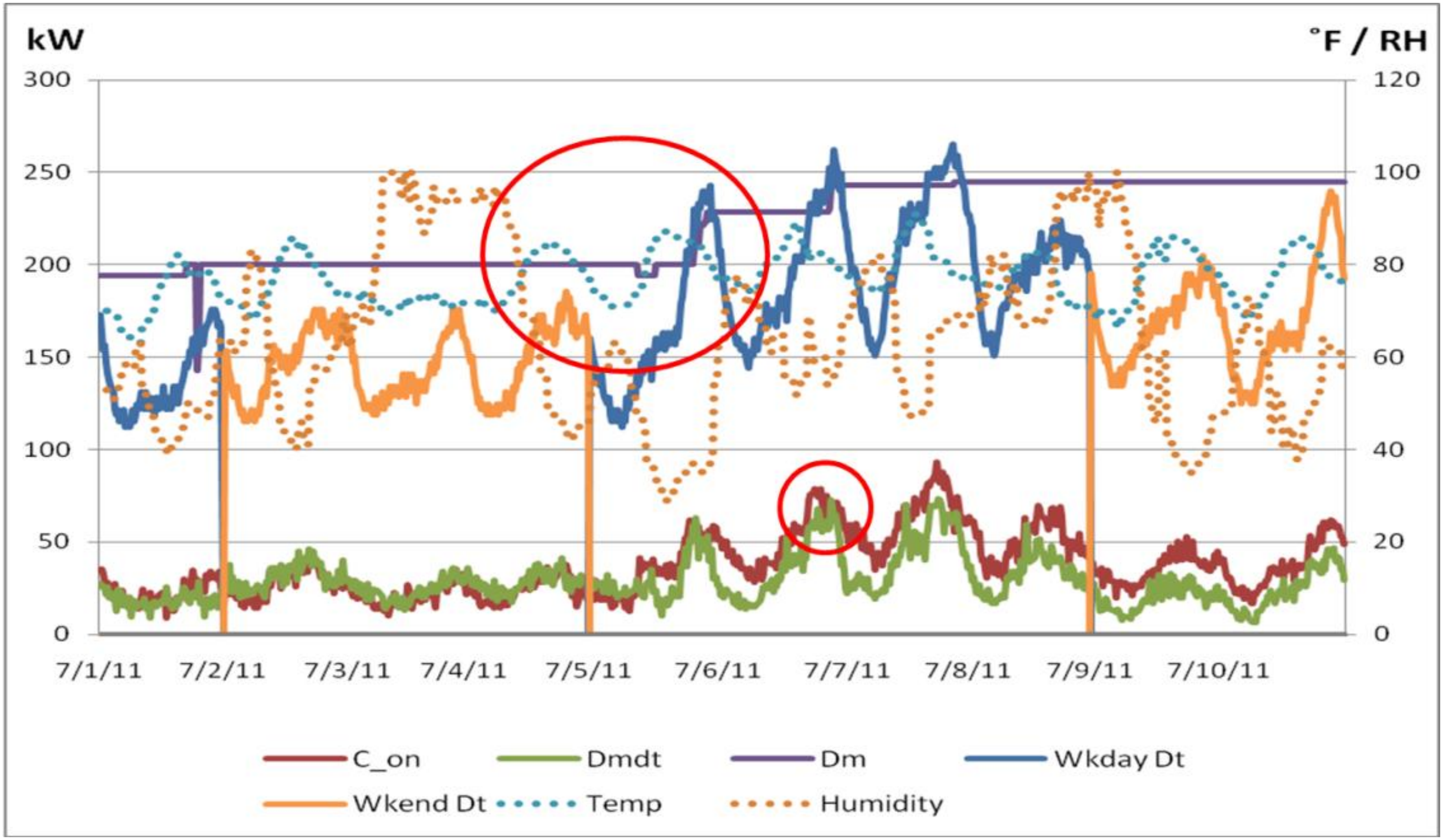
- Each RAC has two independent cooling setpoints:
  - local setpoint input by the resident
  - control system setpoint established by the software
- Compressor responds to the higher setpoint
- RAC compressors, (90% of the A/C load) can be disabled by raising the setpoint above the return air temperature
- The fan continues to operate

Example RAC Operation



Example RAC Operation

Example System Operation



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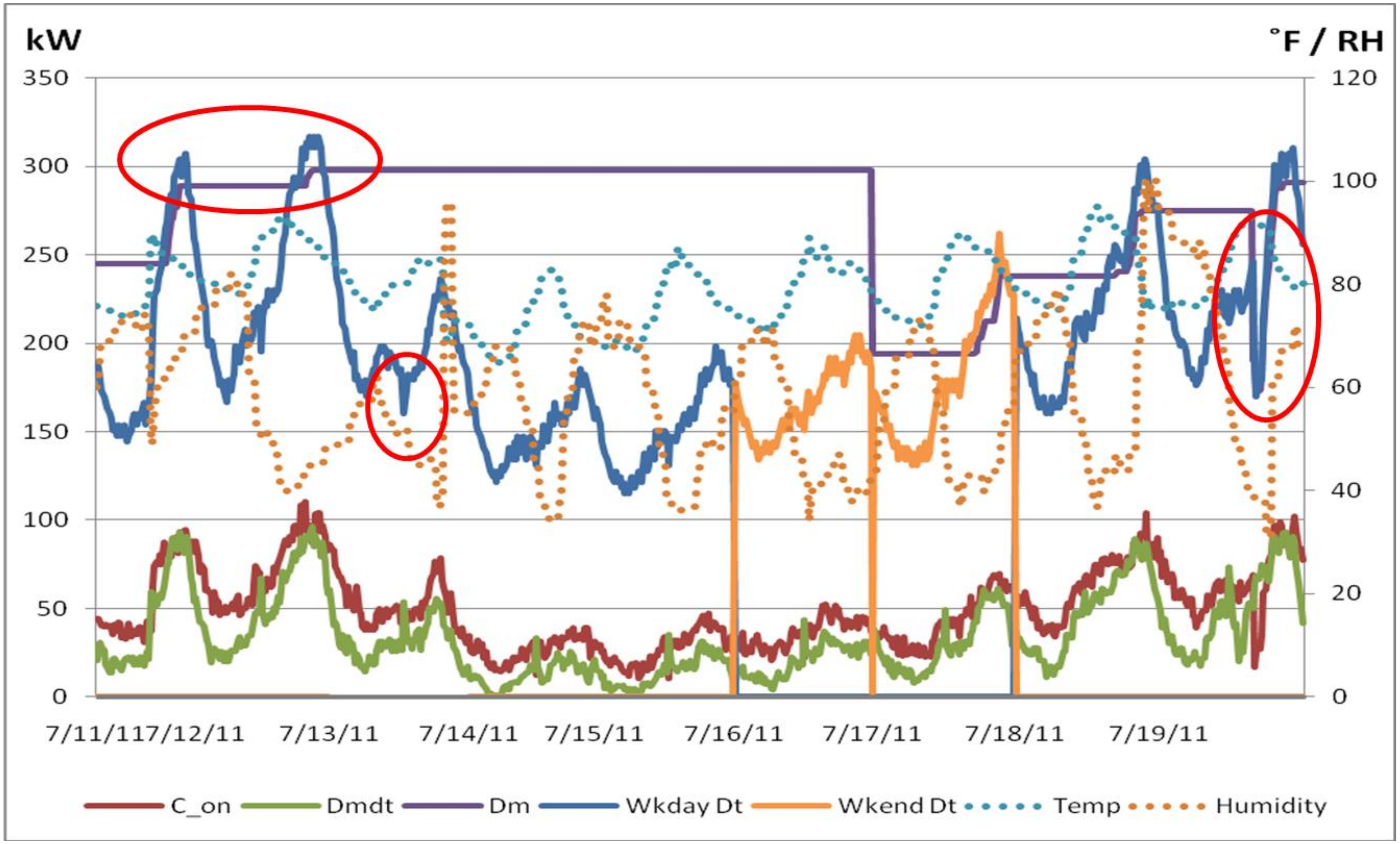
Example System Operation



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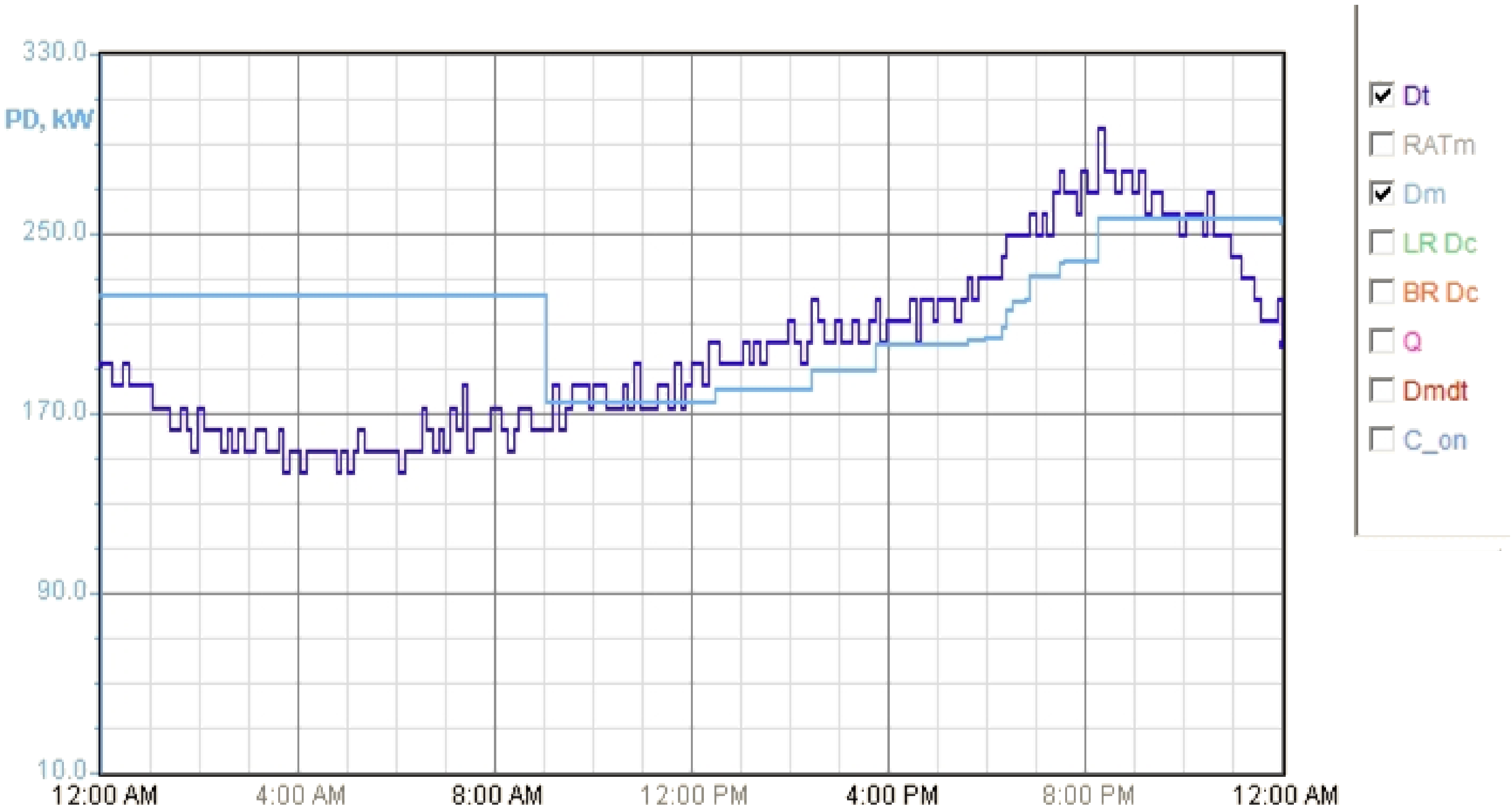
Demand Management



5/29/2012

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Demand Response

- Participation optional
- Enrolled RACs compressor disabled during curtailment
- Participants received share of earnings ($20 per RAC in 2011, $15 in 2012)
  - 2011: 71 units in 49 apartments
  - 2012: 66 units in 42 apartments
- Non-enrolled RAC setpoint increased to 75°F

Demand Response Scheduling

☑ **Load Curtailment**

Scheduled Date: 08/08/2013

Submit

from 2 : 30 PM
to 4 : 00 PM
Duration **01:30:00**

Edit

SP-off: 78.0 **F**

Submit

Page updated: **3/4/2014 10:04:26 AM**

- Bad communication

Curtailment List

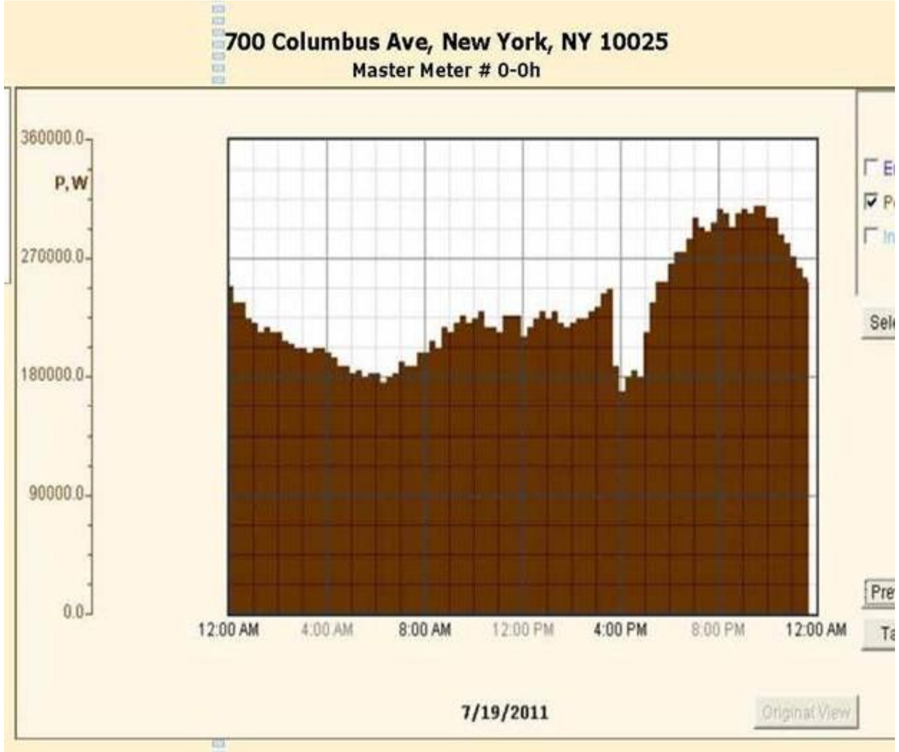
◉ Enrolled ○ Not Enrolled

Control Page Control List

	ACID	APT	Compressor Status	RAT ≥ RATm	Room	RAT	kW rating (compressor only)	SPc	APT
1	1745	20B	2	no	BR	45.5	0.77	68.0	20B Disenroll
2	1741	19J	2	no	BR	43.5	0.77	68.0	19J Disenroll
3	1735	20F	2	no	BR	38.5	0.77	68.0	20F Disenroll
4	1598	14K	2	no	BR	33.0	0.77	75.0	14K Disenroll
5	1837	21D	2	no	BR	32.5	0.77	68.0	21D Disenroll
6	1674	17A	2	no	BR	30.0	0.77	68.0	17A Disenroll
7	1711	11C	2	no	BR	28.5	0.77	75.0	11C Disenroll
8	1835	3K	2	no	BR	27.5	0.77	75.0	3K Disenroll
9	1749	20H	2	no	BR	26.5	0.77	68.0	20H Disenroll
10	1504	3D	2	no	BR	23.5	0.77	75.0	3D Disenroll
11	1594	7F	2	no	BR	23.0	0.77	75.0	7F Disenroll
12	1644	5K	2	no	BR	22.0	0.77	75.0	5K Disenroll
13	1830	16E	2	no	LR	63.0	1.14	68.0	16E Disenroll

Test: July 19, 2011

- 4pm-5pm
- Temp at start/end: 92/90
- Demand at start: 246 kW with 60 RACs running
- Reduced 66 kW
- Maintained demand below 200 Kw (170 to 189 kW)
- Following the test demand rapidly climbed to 250 kW and then continued to the peak of 315 kW at 9:00-10:00 pm
- No complaints recorded



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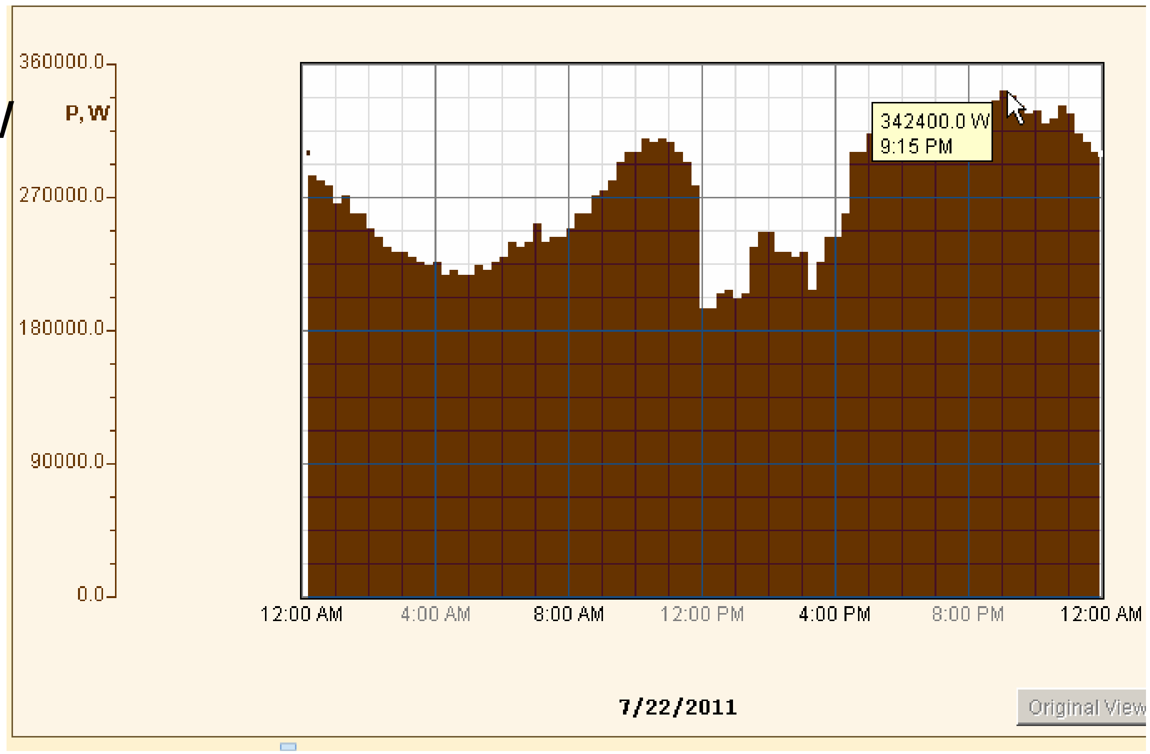
Event: July 22, 2011

- 12pm-4pm
- High temp: 103 deg @ 2pm
- Demand at start: 310 kW with 95 RACs running
- Peak: 342 kW
- Communications lags resulted in mid-event bump
- Otherwise demand reduced by about 100 kW



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Demand Response

Date	Time	Daily high OAT (°F)	Demand at event start (kW)	Average demand during event (kW)	Target demand during event (kW)	Peak demand for the day (kW)	Time of peak demand
July 19, 2011	4:00pm – 5:00pm	94	247	180	200	315	9:30pm
July 21, 2011	2:00pm – 6:00pm	96	262	220	200	337	10:00pm
July 22, 2011	12:00pm – 4:00pm	103	278	215	200	342	9:15pm
June 20, 2012	2:00pm – 6:00pm	94	172	175	230	298	7:57pm, 9:42pm
June 21, 2012	1:00pm – 5:00pm	93	200	201	230	336	8:32pm, 10:52pm
June 22, 2012	1:00pm – 5:00pm	90	248	204	230	250	5:44pm, 6:54pm, 9:00pm
July 18, 2012	1:00pm – 5:00pm	100	298	232	230	307	12:01pm

Results - Energy

- Weather normalized savings of 5,000 kWh over two years in cooling energy use (about 2%)
- When adjusted for the additional cooling equipment it results in a savings of 76,000 kWh and 66 kW demand
- Cost savings of $14,400 over two years ($0.115/kWh supply, $0.057/kWh delivery, $21.20/kW demand)
- Not accounting for increase in fresh air ventilation

Results - Demand

Day	Day of Heat Wave	Highest OAT of the Day (F)	RH at Time of PD (%)	Time of PD (PM)	Peak Demand (kW)	Peak Demand Savings
May 29*	4th	88	97	8:18	297.6	17.78
June 29	2nd	93	47	9:35	307.2	12.73
July 1	4th	93	40	10:23	297.6	15.68
Aug 5*	4th	89	66	7:57	297.6	13.25
Aug 17	1st	87	79	9:42	230.4	13.12
Sep 1*	3rd	90	68	8:32	220.8	9.68

Results - Demand

	2012	2011
Cooling season	May-Sep	May-Sep
Demand Rate	$21.20	$21.20
kW saved due to control system	71.1	71.5
Demand Savings due to control system	$1,508	$1,516

Economics – Jefferson Towers

Item	Quantity	Each	Total
New RAC units	230	$500	$115,000
Wireless control modules installed in RACs	230	$90	$20,700
Installation and disposal	230	$50	$11,500
Smart RAC system set-up and programming (estimated)			$5,000
Total implementation cost (assumes existing communication infrastructure)			$152,200

Economics – Jefferson Towers

- ROI of 21% and an estimated payback of less than five years
- Without factoring in subsidies, ROI and payback would be 7% and 15 years respectively

Economics – Jefferson Towers

Item	2011	2012	Avg. per year
Utility costs avoided – consumption (kWh) based on utility bill analysis	$6,539	$6,475	$6,507
Utility costs avoided – demand (kW) attributable to improved RAC EER	$705	$697	$701
Utility costs avoided – demand (kW) attributable to control system	$1,516	$1,508	$1,512
Demand response payments	$1,833	$1,800	$1,817
Total savings/income	$10,593	$10,480	$10,537
ROI / Simple Payback (based on Net cost)	21% / 4.8 years		
ROI / Simple Payback (based on Total cost)	7% / 14.4 years		

Economics – Ownership Costs

- 10-year ownership costs of two scenarios with no subsidies
- Choice: purchase new smart RAC or retain existing unit
- The "Retain old RAC" case includes the cost of establishing a sinking fund for eventual replacement
- Over ten year lifespan, costs similar
- A new smart RAC becomes more cost advantageous when the existing unit is older and less efficient

Economics – Ownership Costs

Item	Retain old RAC	Purchase smart RAC
New RAC	$250 (1)	$590 (2)
RAC installation	$25 (3)	$50
Utility costs	$920 (4)	$673 (5)
Demand response payments	N/A	-$80 (6)
Total ten-year cost of ownership	$1,195	$1,233

1. Assuming a room RAC lasts ten years on average, the existing units are on average half way through their lifespan, and a comparable new standard through-wall RAC costs $500.
2. Actual per unit costs for retrofit RAC.
3. Assuming a RAC lasts ten years on average, the existing units are on average half way through their lifespan after which a new unit must be installed, and actual per unit installation costs of $50.
4. Cooling energy costs for the baseline year divided by 350 RACs
5. Cooling energy costs for the baseline year (4) multiplied by 0.75 for improved unit EER (based on the average recorded EER of removed units multiplied by a 15% degradation factor for age), less demand charge savings of 2.5% of total bill.
6. $1833 per year divided over 230 RACs for ten years

Economics – 100% Replacement

- Marginal costs and benefits for a smart RAC system for 100% RAC replacement program (assuming costs and benefits of Jefferson Towers)
- Because in both of the scenarios all RACs are replaced, there are no efficiency benefits
- Financial benefits for demand response income and peak reduction
- ROI is 13%

Economics – 100% Replacement

Item	Total
Incremental cost of smart RAC at $90 per RAC x 350 units	$31,500
Smart RAC system set-up and programming	$5,000
Total incremental costs for smart RAC system	$36,500
Estimated annual demand response income	$2,500
Estimated annual peak demand charge savings due to control system	$2,250
Estimated annual savings/income due to smart RAC system	$4,750
ROI	13%
Simple Payback	7.7 years

Question	Response	
Type of smart RAC in apartment	**% all respondents**	
With living room smart RAC	84%	
With bedroom smart RAC	57%	
None	13%	
Did you curtail non-cooling electric usage during demand response events?	**% all respondents**	
Yes	83%	
No	10%	
Did not answer	8%	
Would you like the ability to program your RAC via the internet?	**% all respondents**	
Yes	28%	
No	58%	
Did not answer	14%	
Were the new smart RACs easy to use?	**% respondents with smart RAC**	
1 (hard to use)	5%	
2	1%	
3	22%	
4	20%	
5 (easy to use)	51%	
Would you enroll next year in automatic RAC curtailment (demand response)?	**% respondents with smart RACs**	
Yes	59%	
No	40%	
Were you as cool as you expected to be with the new smart RAC?	**In the living room**	**In the bedroom**
Yes	49%	75%
Sometimes	27%	11%
No	24%	17%

CONCLUSION

Conclusions – Demand Management

- Reduced peak demand 6-9%, if all RACs were included
- Sacrifice was slightly higher cooling set point (75°F) during evening peak demand period
- Less than five complaints during the summer of 2012 (system was operated 74 of 140 days)
- Greater demand reduction may be possible:
  - By increasing maximum setpoint to 78°F
  - By more precisely targeting when controls are activated to limit duration
  - In buildings with better thermal envelope (smaller windows)

Conclusions – Demand Response

- Demonstrated ability to automatically curtail cooling load
- System performance uneven in 2011
  - poor communications speed
  - internet connection failures
- If not for communications problems, target was met, suggesting that the commitment calculation method was appropriate
- Demand response events in 2012 operated smoothly with a more conservative commitment

Conclusions – Demand Response

- Baseline calculation methods makes demand response challenging for multifamily in NYC
- Averaging 20 peak hours underestimates likely load during event, which occurs on extreme weather days
- Outside temperatures (and demand) higher than that envisioned by the baseline calculation method
- Multifamily peaks in evening – out of synch with the afternoon grid peak – so system has less cooling load to work with
- Only ~25-35% RACs active at the onset of events
- Curtailment service providers hesitant to enroll mid-size multifamily because of moderate kW commitments and risk of penalties

Conclusions - Efficiency

- Weather normalized cooling energy consumption for the 2011 and 2012 cooling seasons was slightly lower than for the baseline pre-implementation year (2008)
- When adjusted for an additional 55 RACs and additional lobby cooling system added in 2010/2011, the consumption was about 26% lower – yielding a projected $6,500 in annual savings

Conclusions - Commercialization

- The control strategy and hardware close to market ready
- Integration of electrical submetering with both heating and cooling control unique
- Obtaining RACs incorporating required custom modifications is a challenge – difficult to justify for limited numbers
- Advantage to not depend on plugged-in wall device, residents' access to computer/Internet or installing software
- For master-metered buildings, tying RAC control system into a wireless submetering system makes sense

More Information:
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THANK YOU

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