Presentation Overview

- **NYC LL-87 – early experience,**
  Holly Savoia, NYC DOB

- **Case Study - 1500 Broadway,**
  Lou Rugulo, JCI

- **New Tools – UT, BASAT, LEAN, BRT**
  Taret Arafat, CUNY BPL and JCI Intern
  Marco Ascazubi, CUNY BPL and JCI Intern
  Michael Bobker, CUNY Building Performance Lab

Learning Objectives

- To be aware of issues in complying with the RCx portion of Local Law 87
- To be familiar with the typical procedures, data, and findings from RCx
- To understand the use of BAS in RCx
- To know how to use new public domain tools in RCx:
  - LEAN Energy Analysis, Building Automation System Assessment Tool (BASAT), Universal Translator (UT) and Building Re-Tuning (BRT)

Retro-Commissioning

The systematic investigation and adjustment of building systems to assure that they operating as per specifications and/or best efficiency.

Local Law 87 requires certain RCx procedures

- Investigation of major building systems
- Calibration of sensors that inform multiple systems

But much is left to the engineer's discretion in terms of what is investigated and how.

Retro-Commissioning (RCx)
Practices and New Tools

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Johnson Controls

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ASHRAE-NY and AEE-NY

4-22-14

RCx Case Study: 1500 Broadway

Objectives of the Case Study

- Procedures
- Findings
- Benefits
- Testing of new tools

1500 Broadway – Description

General Building Information

- Commercial/office high-rise built in 1972; renovated in 1995
- 34 floors, 2 mechanical floors
- Systems split into Low-Rise and High-Rise systems
- Con Ed Steam, Absorption Chillers

1500 Broadway – Description

HVAC System Information

- Two 900-ton steam-fired absorption chillers located on 15th Floor
- Perimeter induction units, core AHU originally constant volume
- Hot water converters for perimeter and interior reheat hot water
- One MP fan for perimeter induction units, one Constant volume core fan, and a common return fan located on each mechanical floor

BAS Information

- Manufacturer: Andover (now) Schneider Electric
- Software Product: Continuum; Pinpoint (graphical interface)

RCx Process

- Adapted from Commissioning procedure for new buildings. Purpose is verify the equipment condition and operation of buildings that have never been commissioned before. Looks for low-cost/no-cost improvements to comfort or efficiency.

- **Answers the following questions**:
  - Has there been a significant change of use or purpose?
  - Does the system currently function according to design intent (original or otherwise)?
  - Are key flows and sequences of operation what they should be?

- **Complicating factors**
  - Do we know the original design intent?
  - Do we have any drawings?
  - Is the design intent still the most efficient way to operate the building?

RCx Investigation & Testing

- Consists of 3 parts
  - Pre-functional tests
  - Functional Tests
  - Master Deficiency List

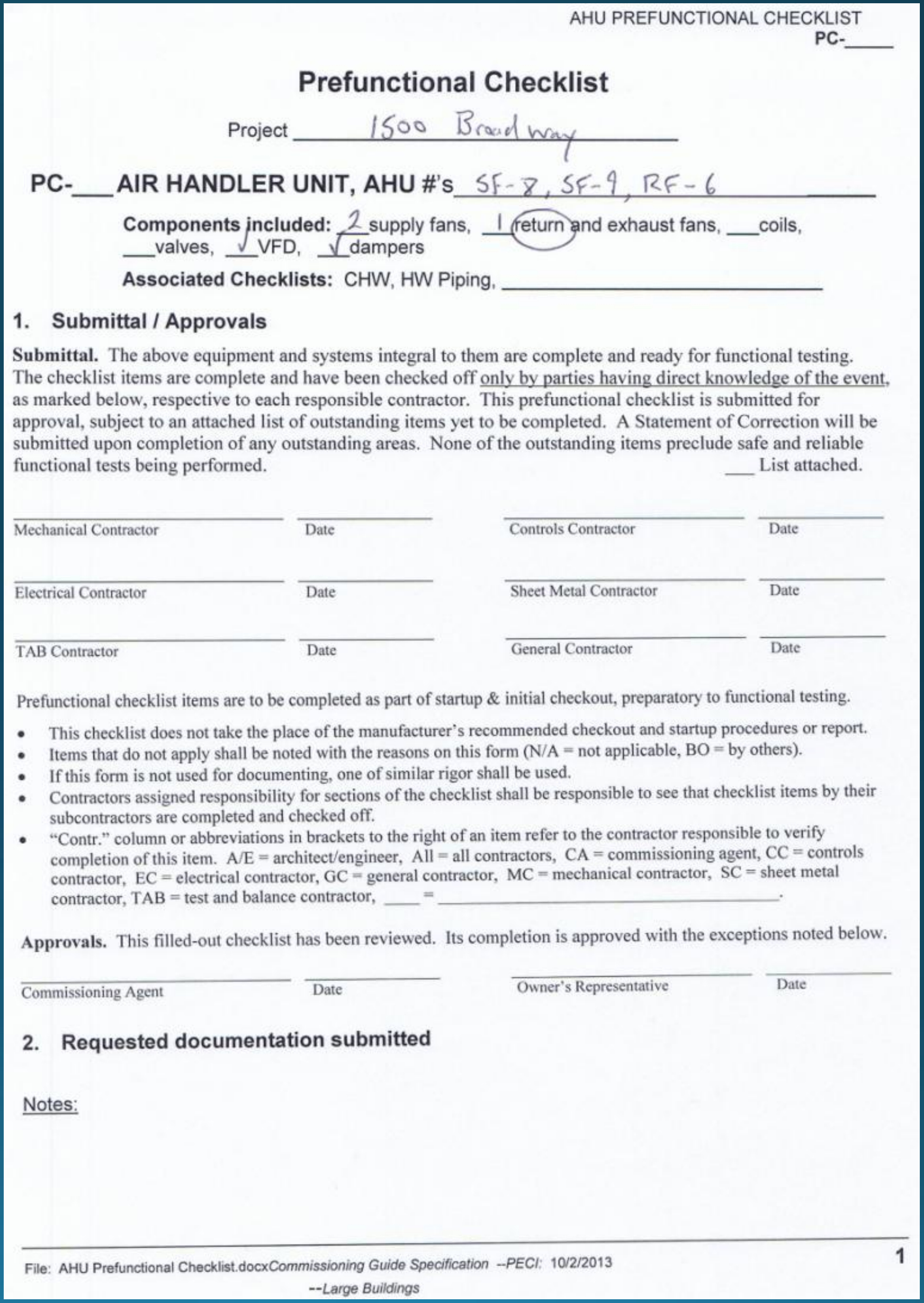
- Good source of Public Domain commissioning forms:
  - http://www.peci.org/model-commissioning-plans-guide-specifications
  - Documents used in the investigation are adapted from this source

RCx Investigation & Testing

- **Pre-functional test**
  - Generated for all major HVAC equipment
    - 2 Medium Pressure perimeter fans
    - 2 Low Pressure core fans
    - 2 Common return fans
    - 2 Chilled Water Pumps
    - 2 Condenser Water Pumps
  - Assesses equipment condition
    - Condition of sensors actuators, valves, and dampers
    - Installation and maintenance

Pre-functional Test Form 1

- What equipment are we covering in this procedure?
- Do we have documentation?



AHU PREFUNCTIONAL CHECKLIST
PC-____

Prefunctional Checklist

Project 1500 Broadway

PC-___AIR HANDLER UNIT, AHU #'s SF-8, SF-9, RF-6 _____

Components included: 2 supply fans, 1 return and exhaust fans, ___coils, ___valves, √ VFD, √ dampers

Associated Checklists: CHW, HW Piping, ______________________

1. Submittal / Approvals

Submittal. The above equipment and systems integral to them are complete and ready for functional testing. The checklist items are complete and have been checked off only by parties having direct knowledge of the event, as marked below, respective to each responsible contractor. This prefunctional checklist is submitted for approval, subject to an attached list of outstanding items yet to be completed. A Statement of Correction will be submitted upon completion of any outstanding areas. None of the outstanding items preclude safe and reliable functional tests being performed. ___ List attached.

Mechanical Contractor	Date	Controls Contractor	Date
Electrical Contractor	Date	Sheet Metal Contractor	Date
TAB Contractor	Date	General Contractor	Date

Prefunctional checklist items are to be completed as part of startup & initial checkout, preparatory to functional testing.

- This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report.
- Items that do not apply shall be noted with the reasons on this form (N/A = not applicable, BO = by others).
- If this form is not used for documenting, one of similar rigor shall be used.
- Contractors assigned responsibility for sections of the checklist shall be responsible to see that checklist items by their subcontractors are completed and checked off.
- "Contr." column or abbreviations in brackets to the right of an item refer to the contractor responsible to verify completion of this item. A/E = architect/engineer, All = all contractors, CA = commissioning agent, CC = controls contractor, EC = electrical contractor, GC = general contractor, MC = mechanical contractor, SC = sheet metal contractor, TAB = test and balance contractor, ____ = ______________________.

Approvals. This filled-out checklist has been reviewed. Its completion is approved with the exceptions noted below.

Commissioning Agent	Date	Owner's Representative	Date

2. Requested documentation submitted

Notes:

Pre-functional Test Form 2

Equipment "Background Checks"

- Is it what's expected from plans?
- Is it properly installed and maintained?

AHU PREFUNCTIONAL CHECKLIST

PC-____

Check if Okay. Enter comment or note number if deficient.

Check — Equip Tag->	SF-8	SF-9	RF-6			Contr.
Manufacturer's cut sheets	✓	✓	✓			
Performance data (fan curves, coil data, etc.)						
Installation and startup manual and plan	x	x	x			
Sequences and control strategies						
O&M manuals						

- ***Documentation complete as per contract documents for given trade........ ___ YES ___ NO***

3. Model verification

[Contr = ________]

1 = as specified, 2 = as submitted, 3 = as installed. Check if Okay. Enter note number if deficient.

Equip Tag--->						
Manuf.	1					
	2					
	3					
Model	1					
	2					
	3					
Serial #	3					
Capacity	1					
	2					
	3					
Volts/phase	1					
	2					
	3					

- ***The equipment installed matches the specifications for given trade.......... ___ YES ___ NO***

4. Installation Checks

Check if Okay. Enter comment or note number if deficient.

Check — Equip Tag->	SF-8	SF-9	RF-6			Contr.
Cabinet and General Installation						
Permanent labels affixed, including for fans	x	x	x			
Casing condition good: no dents, leaks, door gaskets installed	✓	✓	✓			
Access doors close tightly - no leaks	x	x	x			
Boot between duct and unit tight and in good condition	✓	✓	✓			
Vibration isolation equipment installed & released from shipping locks	✓	✓	✓			
Maintenance access acceptable for unit and components	✓	✓	✓			
Sound attenuation installed						
Thermal insulation properly installed and according to specification	✓	✓	✓	- some de-rusting due to age of		
Instrumentation installed according to specification (thermometers, pressure gages, flow meters, etc.)	x	x	x	- pneumatic differential sensors ur appear abandoned in place		
Clean up of equipment completed per contract documents	✓	✓	✓			

Notes:

Pre-functional Test Form 3

System conditions – installation + maintenance

AHU PREFUNCTIONAL CHECKLIST

PC-______

Check if Okay. Enter comment or note number if deficient.

Check Equip Tag->	SF-8	SF-9	RF-6			Contr.
Filters installed and replacement type and efficiency permanently affixed to housing--construction filters removed	√	√				
Valves, Piping and Coils (see full piping checklists)						
Pipe fittings complete and pipes properly supported	√	√	-			
Pipes properly labeled	√	√	-			
Pipes properly insulated	√	√	-			
Strainers in place and clean	√	√	-			
Piping system properly flushed	√	√	-			
No leaking apparent around fittings	√	√	-			
All coils are clean and fins are in good condition	√	√	-	Some dirt on the coils, but n		
All condensate drain pans clean and slope to drain, per spec	X	X	-	Standing water observed condensate pan		
Valves properly labeled	X	X	-			
Valves installed in proper direction	√	√	-			
OSAT, MAT, SAT, RAT, chilled water supply sensors properly located and secure (related OSAT sensor shielded)	X	X	X	Temp probes are too sh based on size of trun		
Sensors calibrated (See calibration section below)						
Motors: Premium efficiency verified, if spec'd?						
P/T plugs and isolation valves installed per drawings	√	√	-			
Fans and Dampers						
Supply fan and motor alignment correct	√	√	-			
Supply fan belt tension & condition good	√	√	-			
Supply fan protective shrouds for belts in place and secure	√	√	-			
Supply fan area clean	X	X	-	Debris observed inside un		
Supply fan and motor properly lubricated	√	√	-			
Return/exhaust fan and motor aligned	-	-	√			
Return/exhaust fan belt tension & condition good	-	-	√			
Return/exhaust fan protective shrouds for belts in place and secure	-	-	√			
Return/exhaust fan area clean	-	-	X			
Return/exhaust fan and motor lube lines installed and lubed	-	-	√			
Filters clean and tight fitting	X	X	-	filters were very dirt		
Filter pressure differential measuring device installed and functional (magnahelic, inclined manometer, etc.)	X	X	-	device is installed but appears abandoned in pl		
Smoke and fire dampers installed properly per contract docs (proper location, access doors, appropriate ratings verified)	√	√	-			
All dampers close tightly	X	X	-	Significant infiltration th dampers when closed		
All damper linkages have minimum play	√	√	-			
Low limit freeze stat sensor located to deal with stratification & bypass	X	X	-	Inadequate coverage of		
Ducts (preliminary check)						
Sound attenuators installed	√	√	√			

Notes:

Pre-functional Test Form 4

Calibration!

- When last calibrated
- Test against a test instrument

AHU PREFUNCTIONAL CHECKLIST
PC-_____

Check if Okay. Enter comment or note number if deficient.

Check	Equip Tag-> SF-8	SF-9	RF-6			Contr.
Specified sequences of operation and operating schedules have been implemented with all variations documented	X	X	X			
Specified point-to-point checks have been completed and documentation record submitted for this system	√	√	√			

- ***The checklist items of Part 5 are all successfully completed for given trade.___ YES ___ NO***

6. Sensor and Actuator Calibration [ ]

All field-installed temperature, relative humidity, CO, CO_2 and pressure sensors and gages, and all actuators (dampers and valves) on this piece of equipment shall be calibrated using the methods and tolerances given in the Calibration and Leak-by Test Procedures document. All test instruments shall have had a certified calibration within the last 12 months: Y/N______. Sensors installed *in* the unit at the factory with calibration certification provided need not be field calibrated.

Sensor or Actuator & Location	Loc-ation OK	1st Gage or BAS Value	Instr. Meas'd Value	Final Gage or BAS Value	Pass Y/N?

Sensor & Location	Loc-ation OK	1st Gage or BAS Value	Instr. Meas'd Value	Final Gage or BAS Value	Pass Y/N?

Gage reading = reading of the permanent gage on the equipment. BAS = building automation system. Instr. = testing instrument. Visual = actual observation. The Contractor's own sensor check-out sheets may be used in lieu of the above, if the same recording fields are included and the referenced procedures are followed.

- ***All sensors are calibrated within required tolerances*................................___ *YES* ___ *NO***

-- END OF CHECKLIST--

1500 Broadway
RCx Investigation & Testing

- **Functional Tests**
  - Developed from Sequence of Operations documents on-site
  - Verifies proper operation and system response
    - Key flows, temperatures, sequences
    - BAS as data source + test instrument

Functional Test Form 1

Detailed guide to and record of testing for each piece of equipment.

Functional Test

Project: 1500 Broadway Retrocommission

FT- 3 **COOLING AIR HANDLING UNIT AHU** SF-8

And Associated Equipment Including:

✓ **Return Fans, RF** RF-6

__ **Outside Air Handling Unit, AHU** ______

Related Tests: ______

1. Participants

Party	Participation
Isaac	
John Tecchio	
Nicholas Rugulo	

Party filling out this form & witnessing Nicholas Rugulo Date of test 10/9, 10/11

2. Prerequisite Checklist

a. The following have been started up and startup reports and prefunctional checklists submitted and approved ready for functional testing:

- __ Chilled Water System
- __ Connected Terminal Units
- __ Cooling towers
- __ Condenser water pumps
- __ Chilled water piping and valves
- __ Variable speed drives for pumps

b. __ All control system functions for this and all interlocking systems are programmed and operable per contract documents, including final setpoints and schedules with debugging, loop tuning and sensor calibrations completed.

______ Controls Contractor Signature or Verbal ______ Date

c. __ Piping system flushing complete and required reports approved.
d. __ Water treatment system complete and operational.
e. __ Vibration control report approved (if required).
f. __ Test and balance (TAB) completed and approved for the hydronic systems and terminal units connected.
g. __ All A/E punchlist items for this equipment corrected.
h. __ These functional test procedures reviewed and approved by installing contractor.
i. __ Safeties and operating ranges reviewed.
j. __ Test requirements and sequences of operation attached.
k. __ Schedules and setpoints attached.
l. __ False loading equipment, system and procedures ready (boilers, preheat or reheat coils, control loops, over-ride on OSA dampers, etc.)
m. __ Have all energy savings control strategies, setpoints and schedules been incorporated that this equipment and control system are capable of? If not, list recommendations below.

Functional Test Form 2

Control Program Review

Sensor & Device Calibration

Note use of BAS values

n. __ **Control Program Review.** Review the software control program(s) for this equipment. Parameters, setpoints and logic sequences appear to follow the specified written sequences.

o. __ Record of All Values for Current Setpoints (SP), Control Parameters, Limits, Delays, Lockouts, Schedules, Etc. Changed to Accommodate Testing:

Parameter	Pre-Test Values	Returned to Pre-Test Values √
Discharge air static pressure (SP)P	1.0	√
Discharge air temp.	65°	√
Static P. reset schedule	-	-
Discharge air reset schedule	-	-

Parameter	Pre-Test Values	Returned to Pre-Test Values √
Bldg. static P.	1.0	√
Dirty filter D.P.	-	
OSA CFM	-	

3. Sensor Calibration Checks. Check the sensors listed below for calibration and adequate location. This is a sampling check of calibrations done during prefunctional checklisting.

"In calibration" means making a reading with a calibrated test instrument within 6 inches of the site sensor. Verify that the sensor reading (via the permanent thermostat, gage or building automation system (BAS)) compared to the test instrument-measured value is within the tolerances specified in the prefunctional checklist requirements (________________). If not, install offset in BAS, calibrate or replace sensor. Use the same test instruments as used for the original calibration, if possible.

Sensor & Location	Location OK[1]	1st Gage or BAS Value	Instr. Meas'd Value	Final Gage or BAS Value	Pass Y/N?
DAT	X	65.3	64.8	65.3	No
RAT					
OSAT	X	64.5°	55°	64.5°	No

Sensor & Location	Location OK[1]	1st Gage or BAS Value	Instr. Meas'd Value	Final Gage or BAS Value	Pass Y/N?
Disch. SP	X	SP Transducer		located	No
		30 ft.	off fan		

[1]Sensor location is appropriate and away from causes of erratic operation.

4. Device Calibration Checks. The actuators or devices listed below checked for calibration. This is a spot check on a sample of the calibrations done during prefunctional checklisting and startup.

"In calibration" means observing a readout in the BAS and going to the actuator or controlled device and verifying that the BAS reading is correct. For items out of calibration or adjustment, fix now if easy, via an offset in the BAS, or a mechanical fix.

Device or Actuator & Location	Procedure / State	1st BAS Value	Site Observation	Final BAS Reading	Pass Y/N
Cooling coil valve (CCV) position or command and stroke*	1. Intermediate positions	25%-75%	25%-75%	25%-75%	Y
	2. Full open	100%	100%	100%	Y
	3. Increase pressure (open)	100%	100%	100%	Y
	4. Closed	0%	0%	0%	Y
	5. Remove power or air (closed)	0%	0%	0%	Y
Relief damper position **	1. Closed	0%	0%	0%	Y
	2. Full open	100%	80%	100%	No
Mixed air damper position **	1. Closed	0%	0%	0%	Y

Functional Test Form 3

Establish key flows
- water and air
- actual vs design

OA damper of major import.
- Position as commanded?
- Appropriate minimum?
- Leak-by when closed?

- **BAS as data source**

Device or Actuator & Location	Procedure / State	1st BAS Value	Site Observation	Final BAS Reading	Pass Y/N
	2. Full open	100%	75%	100%	No
Main OSA damper position**	1. Closed	0%	0%	0%	Y
	2. Full open	100%	75%	100%	No
Min. OSA damper position**	1. Closed	0%	0%	0%	Y
	2. Full open	100%	70%	100%	No
Inlet guide vane position***	1. Closed	-	-	-	-
	2. Full open	-	-	-	-
Variable fequency drive speed (VFD)***	1. Min.: 0 %	0%	0%	0%	Y
	2. Max.: 100 %	100%	100%	100%	Y

* Set pumps to normal mode. *Procedure 1.* Command valve to a few intermediate positions. Verify that readings in BAS reasonably correspond to the actual positions. For cooling coil valves (NC): *Procedure 2.* Lower space setpoint to 20F below space temperature. Verify BAS reading says CCV is 100% open. Visually verify valve is 100% open. *Procedure 3.* For

pressure to valve by 3 psi (do not exceed actuator rating). Verify valve

normal. *Procedure 4.* Set space setpoint to 20F above space temperature.

rify valve is closed. *Procedure 5.* Remove control air or electricity from

position do not change.

er is shut and BAS reads shut. 2. Do the same, commanding damper fully

ntrolling static pressure setpoint (duct or discharge) to be 1/4 of its

speed is at minimum for VFD *and* packaged controller reads the same.

ure 2. Lower the space temperature setpoint to be 20F below space

ng. Raise the static pressure setpoint as necessary to cause the

es are fully open or the fan speed is at its max. and verify that the

to normal.

onal Checks.

klist and startup reports completed successfully. Pass? Y / N Y

Functional Test Form
4-5 Specific Sequences

6. Functional Testing Record

Seq. ID From Specs[1]	Mode ID[2]	Test Procedure[3] (including special conditions)	Expected Response[4]	Pass Y/N	Note
1	FAN OFF	Standby Check. With Units Commanded off by BAS.	Verify by visual inspection that: Return Air Dampers in AHU 3&4 are Open Outside Air Dampers in AHU-3&4 are Closed Isolation Dampers on AHU-9&10 are Closed. Relief Dampers in RF-3 and RF-4 are Closed Cooling Coil Valves on Cooling Coils of AHU--3&4 are Closed	Y	
1	UNIT STARTUP	With Units Commanded on by BAS	Supply Fan Isolation Dampers Open in AHU-3&4(Both Supply Fans in each Unit) Supply Fan start through VSDs Supply Fan Isolation Dampers in AHU 9&10 Open AHU-9&10 Fans Start RF-3&4 Isolation Dampers Open RF-3&4 Fans start through VSDs Exhaust Fans EF-5,6,7,8,9&12 start.	Y	
2	RF VOLUME CONTROL	1. Verify RF Volume, utilizing air flow meters in Return Fans RF3&4, Supply Fans in AHU-3&4 and Garage Exhaust Fan EF-1, and TAB established CFMs for Exhaust Fans EF--5,6,7,8,9,12, TAB established Fixed Differential, make the following calculation: Return Air Flow=1/2{Supply Air Flow(AHU-3Flow+AHU-4 Flow) - EF5 Flow-EF6 Flow-EF7 Flow-EF8 Flow-EF9 Flow-EF-12 Flow--SF1 Flow-Fixed Differential} 2. Trend Log RF3&4, AHU 3&4, and SF-1 air flow rates at 5 min. intervals. Command off EF-5,6,7,8,9 and 12 sequentially at 5 min. Intervals.	Verify that RF air flow meter readings correspond to calculation. RF-6 not providing design CFM flow Verify that RF air flow meter readings continue to correspond to calculation	N	
3	TEMPERATURE CONTROL--ECONOMIZER	1. Utilizing BAS, Record OSA Temp. and OSA Dewpoint. 2. Calculate Enthalpy of OSA. 3. Utilizing Enthalpy calculations, reset DAT setpoint such that Enthalpy of OSA is less than Enthalpy of Supply Air at revised conditions.	Outdoor Air Dampers and Return Air Dampers should modulate in sequence to maintain DAT setpoint. Cooling Coil Valves should be closed.	N	

Dampers can modulate properly, however building operators were [illegible] dampers to position

Seq. ID From Specs[1]	Mode ID[2]	Test Procedure[3] (including special conditions)	Expected Response[4]	Pass Y/N	Note
3	TEMPERATURE CONTROL--ECONOMIZER	1. Utilizing Enthalpy calculations above, reset DAT setpoint such that the Enthalpy of Supply Air is less than that of OSA. 2. Return to normal operation. Utilizing BAS trend logging capabilities, record OSA temperature, Return Air Temperature, OSA Dewpoint, DAT setpoint and DAT at 15 min intervals for an 8 hr. period	OSA Dampers should close, Return Air Dampers should open, Chilled Water Coil Valves should modulate to maintain discharge Temp. Unit should attempt to utilize economizer cycle when possible for cooling.	Y	
4	DUCT STATIC PRESSURE CONTROL	Disable Duct Static Pressure Reset utilizing BAS Software. Adjust space temperature setpoint on significant quantity of zones to be well below observed reading.	Verify that VSD's modulate as required to maintain SP setpoint without hunting or overshooting setpoint	Y	
4	HIGH STATIC PRESSURE ALARM AND SHUTDOWN	With units running at low flow condition, utilizing a squeeze bulb, simulate an increase in discharge air static pressure.	Verify that BAS indicates an alarm condition at 3.6" WG and shuts fans down at 4"WG	N/A	
4	STATIC PRESSURE RESET	1. For PerimeterTerminal Units on floors 9-16, Reset space temperature setpoints to be below space temperatures. Utiliziing BAS trend logging capablilities, Record at 5 min. intervals, Discharge Air SP Spt, Perimeter TU Units in saturation. 2. Reset space temperature setpoints to be above space temperatures. Utilizing the same Trending as above, Record the same data points.	Verify that DA SP Spts increase by 0.10" WG at 5 min intervals until only one Perimeter TU remains in saturation. Verify that setpoints are met and maintained without excessive hunting. Verify that DA SP Spt decreases by 0.10"WG at 5 min intervals until one Perimeter TU reaches saturation.	N/A	
5	DISCHARGE TEMPERATURE RESET	1. For Perimeter Terminal Units Floors 9-16, Reset space sensor setpoints to be above space temperatures. Utilizing BAS Trend Logging, at 6 min intervals, record DAT setpoint, DAT, and perimeter TU cooling Flow rates. 2. For Perimeter Terminal Units Floors 9-16, Reset space sensor setpoints to be below space temperatures. Utilizing BAS Trend Logging, at 6 min intervals, record DAT setpoint, DAT, and perimeter TU cooling Flow rates.	Verify that Discharge Air Temperature Setpoint is reset upwards at 2 deg increments every 6 min to maintain design cooling CFM at 5 perimeter TUs to maintain design cooling CFM Verify that Discharge Air Temperature Setpoint is reset downwards at 2 deg increments every 6 min to reach design cooling CFM at only 5 perimeter Tus. Both should happen without excessive hunting.	N/A	
6	SMOKE CONDITIONS	Interfacing with EC, simulate a fire mode with the Fire Alarm System	Verify that AHU System returns to FAN OFF Status., with OSA and Relief Dampers in a Closed Position.	N/A	

Functional Test Form
6 - 7 More Specific Sequences

Seq. ID From Specs[1]	Mode ID[2]	Test Procedure[3] (including special conditions)	Expected Response[4]	Pass Y/N	Note
7	WARMUP CONTROL	Place Units BAS Control Mode into Warmup. Overwrite RAT Sensor Reading to be 65 Deg. F.	Verify that dampers assume a 100% Return Air Mode.	N/A	N = " warm progra into
7	WARMUP CONTROL	Place Units BAS Control Mode in Warmup. Overwrite RAT Sensor Reading to be 72 Deg. F.	Verify that unit returns to Normal Operation Mode	N/A	
11	FREEZE CONDITION	Overwrite Low Limit Detection Thermostat reading to be 38 Deg. F.	Verify that system alarms, fans stop, OSA Dampers close, Relief Dampers Close, and RA dampers open.	N	Freeze s not wired unit
13	RETURN FAN STATIC PRESSURE	With AHU Units 3&4 Units running at low air flow condition, Overwrite RF 3 or 4 return air fan inlet SP to a reading below -1.5" W.G.	Verify that system alarms and that all Fans are shut down.	N/A	
14	NIGHT PURGE	With Units in Night Low Limit Mode, Select a space temperature sensor at random and overwrite this value to be 82 Deg. F. Overwrite OSA temperature value to 63 Deg. F. Overwrite Relief Air Temp. Sensor to a value of 82 Deg. F., after 15 minutes, Overwrite Relief Air Temp Sensor to a Value of 75 Deg. F.	Verify that Unit Starts, Return Air Dampers Close, Heating Control Valves remain Closed, OSA Dampers open, flushing space with OSA, When Return Air Temperature reaches a value of 75 Deg. F., Purge Cycle should terminate,	N/A	
15	MANUAL SMOKE PRESSURIZ. SYSTEM	With Fire Alarm System in alarm, utilizing control panel in Fireman Control Center, select a floor and place floor into purge mode	Verify that Single Fan operates, Isolation dampers open only on selected Fans, Return Fans are off, Outside Air Handling Units are off, OSA dampers open, and return air dampers close.	N/A	
B1	MIN OSA UNIT FAN OFF	Command AHU-1&2 System off	Verify that AHU 9&10 isolation dampers are closed, and if OSA temperature is above 35 Deg. F, heating coil control valve is closed.	Y	
B1	MIN OSA UNIT FAN OFF	Simulate a OSA temperature below 35 Deg. F.	Verify that heating coil control valve opens	Y	
B2	MIN OSA UNIT TEMPERATURE CONTROL	Utilizing BAS software, reset discharge air setpoint to 80 Deg. F.	Verify that Face and Bypass Dampers and Heating Coil Control Valves modulate in sequence to maintain 80 Deg. F. Setpoint.	N/A	
B3	MIN OSA UNIT FREEZE CONDITION	Simulate a condition at low limit detection thermostat of below 40 Deg. F.	Verify that BAS system goes into alarm, AHU 7&8 Fans Shut Down, AHU-7&8 Isolation Dampers Close, and Heating Valve Opens.	N	No way trip free
	ON-FLOOR RETURN FAN OPERATION	Place AHU-3&4 in normal operating mode	Verify that RAF 9-1,9-2,10-1,10-2,11-1,11-2,12-1,12-2,13-1,13-2,14-1,14-2,15-1,15-2 Start and Run	Y	

Seq. ID From Specs[1]	Mode ID[2]	Test Procedure[3] (including special conditions)	Expected Response[4]	Pass Y/N	Note
	BUILDING STATIC PRESSURE	Trend log the supply fan speed, the relief fan speed, relief damper position and the building static pressure for 24 hrs at 5 min. intervals. During the trend, force, if necessary, the economizer damper to be full open and at minimum. Document these times.	Observe in the trends that the building static pressure is maintained within +/- 0.05" of setpoint without excessive hunting. Carefully examine during the extreme economizer damper positions. Observe that any relief dampers modulate as expected relative to relief fan operation and static pressure.	N	Operators hav no knowledge or ability t trend
	AHU FILTER DROP	Reset the Filter Differential Pressure to exceed the settting recommended by the filter manufacturer.	Verify that the BAS reports an alarm.	N	
-	CHILLED WATER VALVE CLOSING EFFICIENCY	1. Utilizing BAS, place AHU Units in WARMUP Mode. 2. Manually close isolation Valve in Chilled Water Supply to AHU Coil. 3. Place thermometer in Chilled Water Return Piping adjacent to AHU. Record temp. at 1 min. intervals for 15 min. 4. Manually open isolation Valve in Chilled Water Supply to AHU Coil. 5. Repeat Step 3. 6. Graph Results on Temperature-Time Basis.	Chilled Water Return Temp. should approach RAT. If significant divergence is noted, review specified performance requirements of Chilled Water Control Valves.	N/A	
--	SUPPLY FAN ISOLATION DAMPER	Utilizing BAS, Command AHU-1, SF-1 into the off position	Verify that AHU-1, SF-1 Isolation Dampers Close.	Y	
	REVIEW	Reveiw schedules, current setpoints and sequences with Specification Section 15950-3.3A and Control Drawings prepared by CC	Submit approved differences to be incorporated into as-builts.		

Record Foot Notes

[1]Sequences of operation specified in Contract Documents (attached).
[2]Mode or function ID being tested from testing requirements section of the project Specifications.
[3]Step-by-step procedures for manual testing, trend logging or data-logger monitoring.
[4]Include tolerances for a passing condition.
[5]Record any permanently changed parameter values and submit to Owner.

-- END OF TEST --

RCx Investigation & Testing

- **Master Deficiency List**
  - Documents all findings/repairs
  - Use to plan & track resolution

1500 Broadway Master Deficiency List

Unit	Category/Topic	Finding description and type*	Recommended solution or action	Date Added	Responsible Party	Status of implementation
	M	Two steam traps for the steam-HW heat exchanger system in the basement floor mechanical room are failed open	Replace or repair the traps	1/24/12	In-house	
RF-5	M	Insulation on interior of unit is de-nosing in some places	Repair insulation, apply mastic over degraded insulation to restore integrity.	10/7/13		
	O	Unit is not running based on Return Air requirements, currently operates off the same signal as SF-6.	Update control in BAS to allow Return Fan VFD to operate based on Return Air requirements.	10/14/13	T.M.Bier	
	O	Unit ramped down 15 Hz during SF-6 failure test, this is minimum programmed into VFD and is incorrect because SF-7 was still running and as a result, operating under further starved conditions.	Update controls in BAS to allow Return Fan to continue operating when SF-6 is not running. VFD controls should be updated to allow unit to modulate based on airflow requirements	10/14/13	T.M.Bier	
	M	Debris, both de-nosed insulation as well as foreign, found on floor inside unit.	Vacuum clean fan chamber, and check during cooling season to confirm that no moisture carryover wets insulation. If carryover exist, fan should be rebalanced to reduce coil velocity below 500 FPM.	10/7/13	In-house	
	O/M	Freezestat has inadequate coverage of coil surface, was also mounted incorrectly and laying in condensate pan of unit	Repair/Replace existing freeze stat as needed, mount additional freeze stats and wire them together in series to provide adequate coverage of the coil face. Tie the additional freezestats into the same alarm signal to the BAS to alert operators of a low-temp condition at the unit if any of the freezestats are tripped.	10/7/13		
	O	Freezestat was not wired into anything, it was mounted on the unit but not connected to the BAS or anything to allow it to shut the unit off in the event of a low-temp alarm	Repair and restore functionality of the freeze stat. Add a graphic in BAS to monitor freeze stat status and program a low-temp alarm that will shut down the unit and generate an alarm in the BAS.	10/22/13	T.M.Bier	

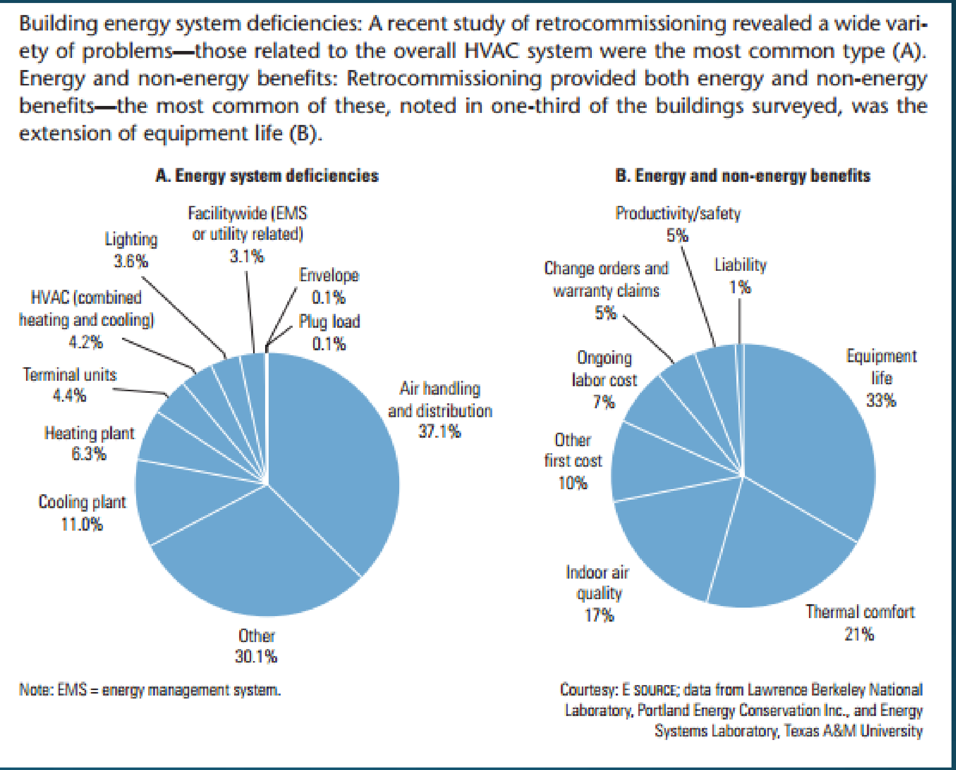
Master Deficiency List
Major findings identified for 1500

- Redundant Static Pressures on one fan
- **Pneumatic controls only partially operating**
- **Undersized return duct**
- Common return fan tracking only a single Supply fan
- Sequencing of common return fan upon failure of supply fan
- Core Reheat coils removed/abandoned
- **Excess Chilled water flow**
- **Deficient Condenser water flow**
- More recent tenant fit-outs are VAV, while older tenants still have Constant Volume systems

Benefit from RCx Findings

From MDL, we identify measures with particular energy savings potential

- Excess Outside Air due to undersized Return section
- CHW over-pumping



RCx shown to have many kinds of benefits

- Energy operating costs
- Equipment life extension
- Thermal comfort & IAQ
- Productivity & labor costs

Example of RCx Benefit
Correct Return Air Flow

- The original specifications required a minimum of 40% outdoor air for SF-7 and 25% outdoor air for SF-6. The return duct penetrations into the mixed air chamber are designed for the above OSA %, and are therefore undersized at present.
- "Under-sized Return Duct"
- Portion of return is under-sized for present load, requiring return-air spill and excessive amounts of Outside Air with associated energy cost.

- Improved OA Control is a common RCx finding with large energy savings

Example of RCx Benefit
Correct Return Air Flow

Savings from reduced OA result from less heating and cooling of OA air, calculated as approx. $39,000 per year

	Actual Airflow		**Design**				Annual Heating Savings			Annual Cooling Savings		
Fan	Mechanical Cooling	Economizer	**Airflow**	**Minimum Outside Air %**	Revised Outside Air %	Reduction in Outside Airflow	(MBtu)	Mlbs		(Ton/Hrs)	Mlbs	
SF-7 (Perimeter)	35,192	49,436	**61,000**	**40%**	20%	12,200	739174	762	$24,377.49	5270	44.8	$ 1,433.10
SF-6 (Core)	62,938	102,975	**123,618**	**25%**	20%	6,181	374488	386	$12,350.39	2670	22.7	$ 726.05
									$36,727.88			$ 2,159.15
			Winter	Summer								
Assumptions:	Average NYC Temp		38°	76°				Annual Savings		$	38,887.04	
	Average NYC Season Duration		27.5	20	Weeks							
	Blended Annual Steam Cost $31.99/Mlb											

Example of RCx Benefit
Chilled Water Pumping

- Based on testing via review of pump curves, CHWP-5 and CHWP-6 were found to have flows above their design
  - CHWP-5 19% over design and
  - CHWP-6 20 % over design.
  - Assuming the system was designed for a 15°F drop across the absorber, the current flow rates would only allow a 12.5°F temperature drop, affecting Latent cooling capacity as well as resulting in increased pumping HP
- Based on Pump Affinity laws,
  - 20% flow reduction yields a 43% HP reduction, which
  - results in a 35% reduction in kWh
  - **annual savings of 54,028 kWh (approx. $8,000)**

Table 3. Electricity End Use Analysis

System Component	Max On Peak kW	Average Annual kW	Annual Hours	Annual kWh	
Fans	385.00	327.25	5,148	1,684,683.00	
CW/CHW Pumps	220.00	145.20	2,112	306,662.40	
Tower	110.00	72.60	2,112	153,331.20	
Heating Pumps	33.00	21.78	3,696	80,498.88	
Lighting	418.65	418.65	4,290	1,796,012.79	
Office Loads	209.33	196.77	6,864	1,350,601.62	
Elevators	137.50	90.75	3,432	311,454.00	
Miscellaneous	84.50	41.66	5,760	239,956.36	
	1,598.0	1,314.7		5,923,200	
From Bills	1,598.0	1,314.7		5,923,200	From Bills

Based on the Energy Use Breakdown, the building uses 306,662 kWh for pumps. If we simplify, and assume the CW and CHW pumps are identical, then each uses 153,331 kWh.

New Tools (software)

Public domain products that can help focus and facilitate the RCx process

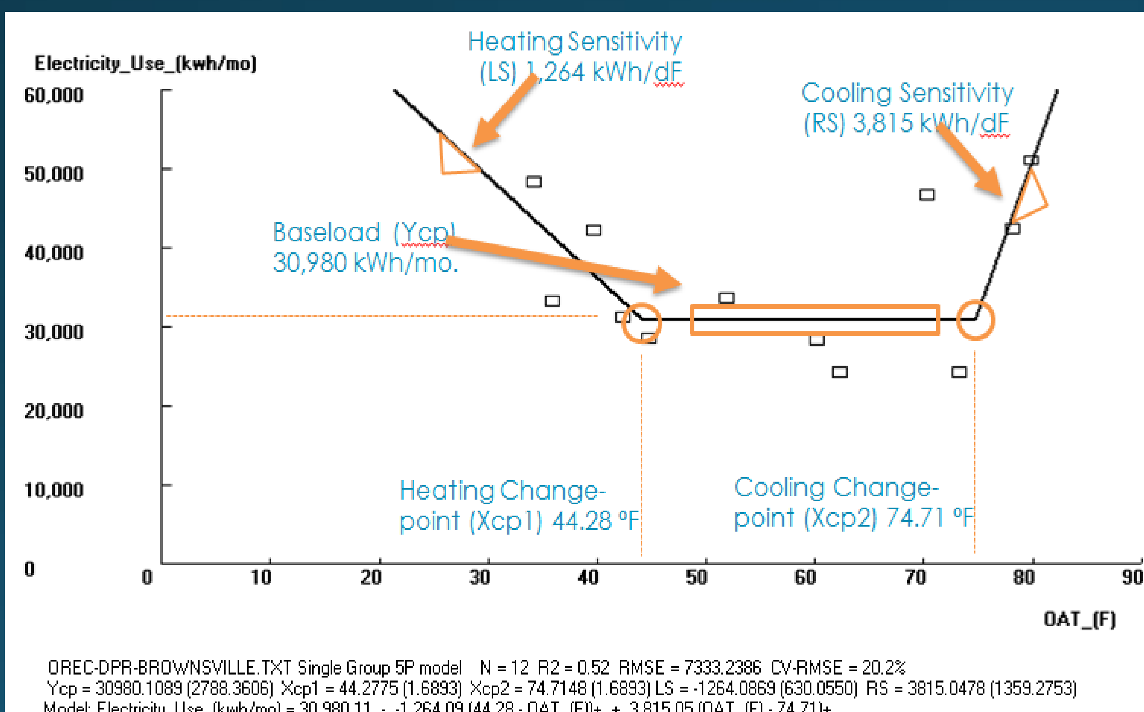
- LEAN Energy Analysis
- BASAT – Building Automation Assessment Tool
- Universal Translator
- Building Re-tuning Protocol

JCI has sponsored CUNY BPL in development and application trials under the NSF Center for Sustainably Integrated Buildings & Sites (SIBS)

New Tools – LEAN Energy Analysis

Inverse modeling based on monthly data

- Regression analysis of energy use against monthly average outdoor temperatures, originally for M&V use. Statistical validation.
- **ASHRAE Inverse Modeling Toolkit**, from work by Dr. Kelly Kissock
- Pre-site visit view of energy-use pattern without knowledge of building systems



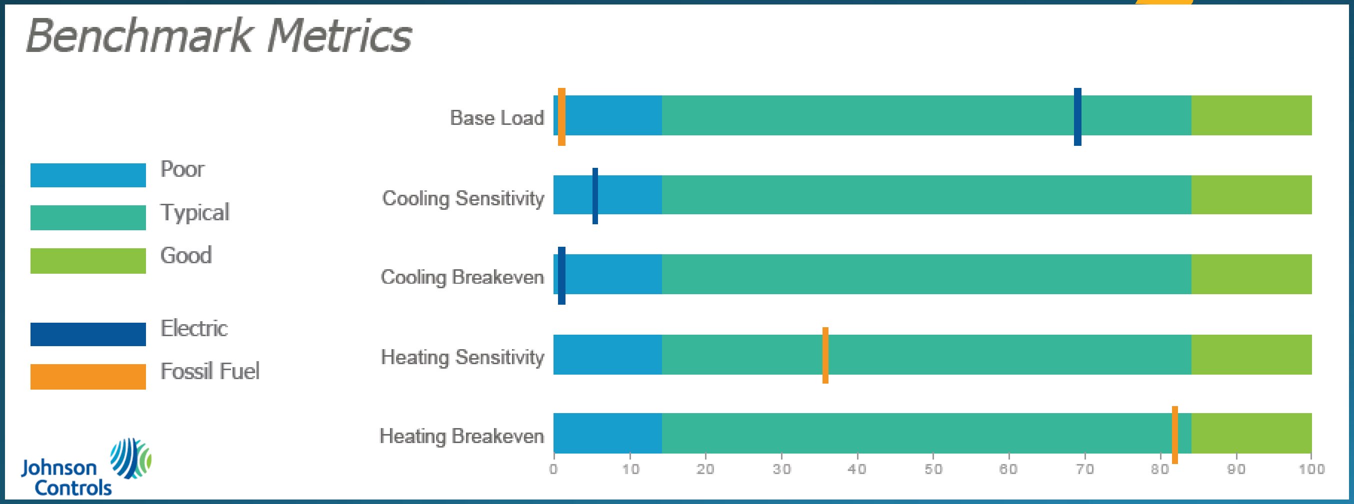
3-4-5 Parameter Change-Point Model

- Left slope shows heating
- Right slope shows cooling
- Change-points show balance temperatures
- Baseloads

Compare these across population to assess reduction opportunity

1500 Broadway: LEAN Energy Analysis JCI implementation

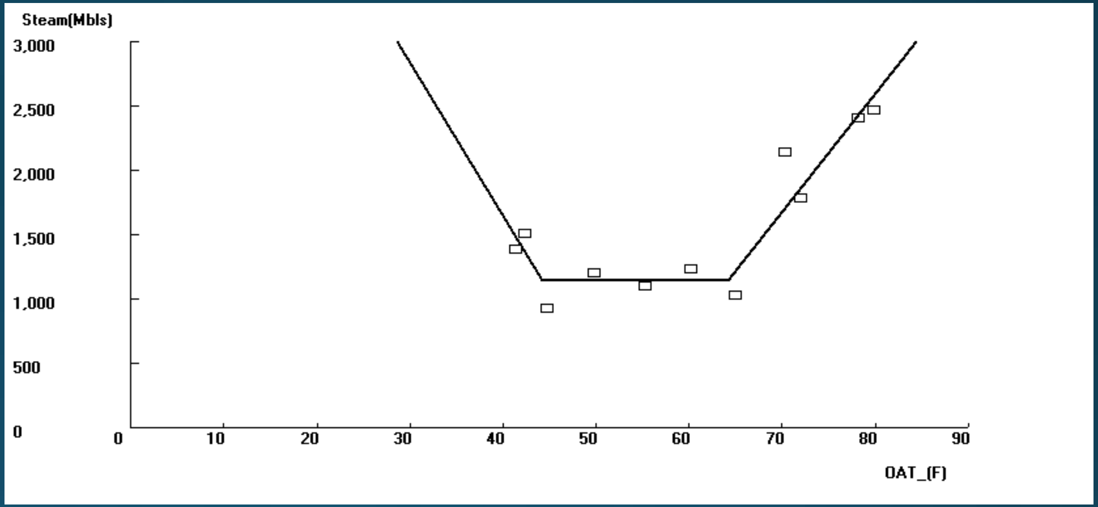
- JCI use of LEAN, based on a population of buildings in their databases, to provide broadly quantified recommendations
- Front-end tool, before going to field for any investigation
- Note the separate Electric and Fuel plots



New tools – LEAN Energy Analysis
How Can LEAN be used with RCx?

- Identify relative savings areas – heating, cooling, baseloads – and quantify savings opportunity
- Use this to focus effort
  - RCx is very detailed, can be a chase "down a rabbit hole" – so early savings potential quantification can guide effort

5-Parameter Model for Steam at 1500



<u>RCx Investigation Guidance</u>

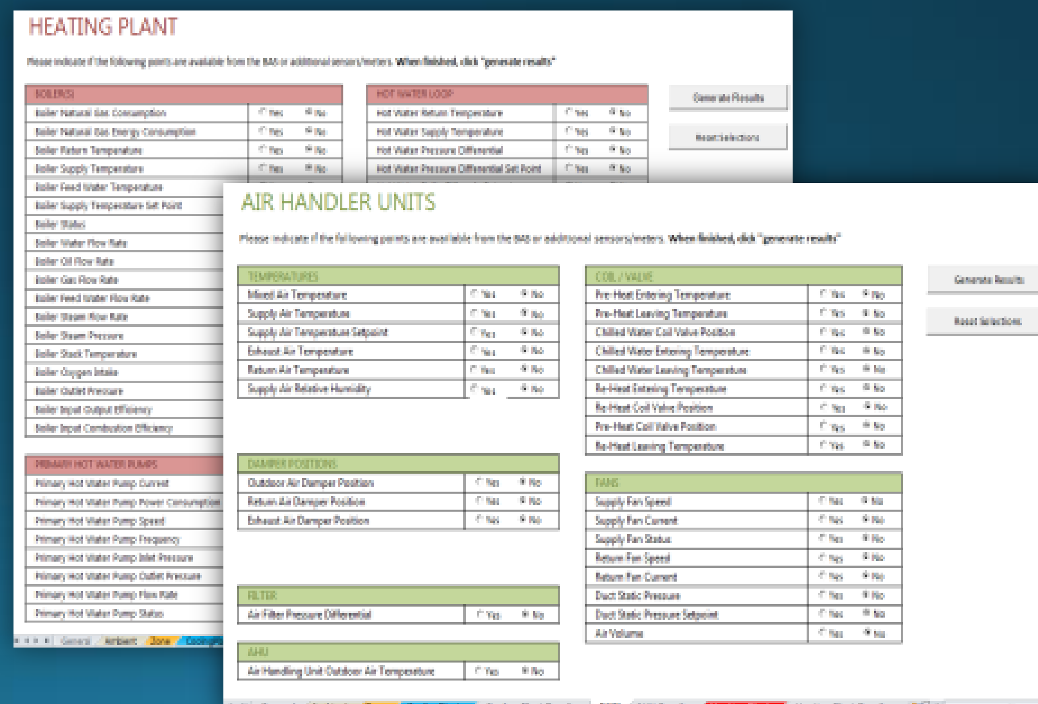
- Steam cooling dominates – focus
- High baseload and low heating change-point – simultaneous heating & cooling? **High ventilation**

New tools – Building Automation System Assessment Tool (BASAT)

- A programmed spreadsheet tool to assess available BAS functions based on installed sensors
- Initial development funded by NYSERDA

BASAT evaluates:

- AHU
- Cooling Plant
- Heating Plant
- Demand Response
- LEAN measures



BASAT – 1500 Broadway AHU Input Form

TEMPERATURES		
Mixed Air Temperature	○ Yes	◉ No
Supply Air Temperature	◉ Yes	○ No
Supply Air Temperature Setpoint	◉ Yes	○ No
Exhaust Air Temperature	◉ Yes	○ No
Return Air Temperature	◉ Yes	○ No
Supply Air Relative Humidity	○ Yes	◉ No

DAMPER POSITIONS		
Outside Air Damper Position	◉ Yes	○ No
Return Air Damper Position	◉ Yes	○ No
Exhaust Air Damper Position	◉ Yes	○ No

FANS		
Supply Fan Speed	◉ Yes	○ No
Supply Fan Current	○ Yes	◉ No
Supply Fan Status	◉ Yes	○ No
Return Fan Speed	◉ Yes	○ No
Return Fan Current	○ Yes	◉ No
Return Fan Status	◉ Yes	○ No
Duct Static Pressure	◉ Yes	○ No
Duct Static Pressure Setpoint	◉ Yes	○ No
Air Volume	○ Yes	◉ No

COILS / VALVES		
Pre-Heat Entering Temperature	○ Yes	◉ No
Pre-Heat Leaving Temperature	○ Yes	◉ No
Chilled Water Coil Valve Position	◉ Yes	○ No
Chilled Water Coil Valve Position Setpoint	◉ Yes	○ No
Chilled Water Entering Temperature	○ Yes	◉ No
Chilled Water Leaving Temperature	○ Yes	◉ No
Re-Heat Entering Temperature	○ Yes	◉ No
Re-Heat Leaving Temperature	○ Yes	◉ No
Heating Coil Valve Position	○ Yes	◉ No
Heating Coil Valve Position Setpoint	◉ Yes	○ No
Re-Heat Coil Valve Position	◉ Yes	○ No
Pre-Heat Coil Valve Position	○ Yes	◉ No

FILTER		
Air Filter Pressure Differential	○ Yes	◉ No

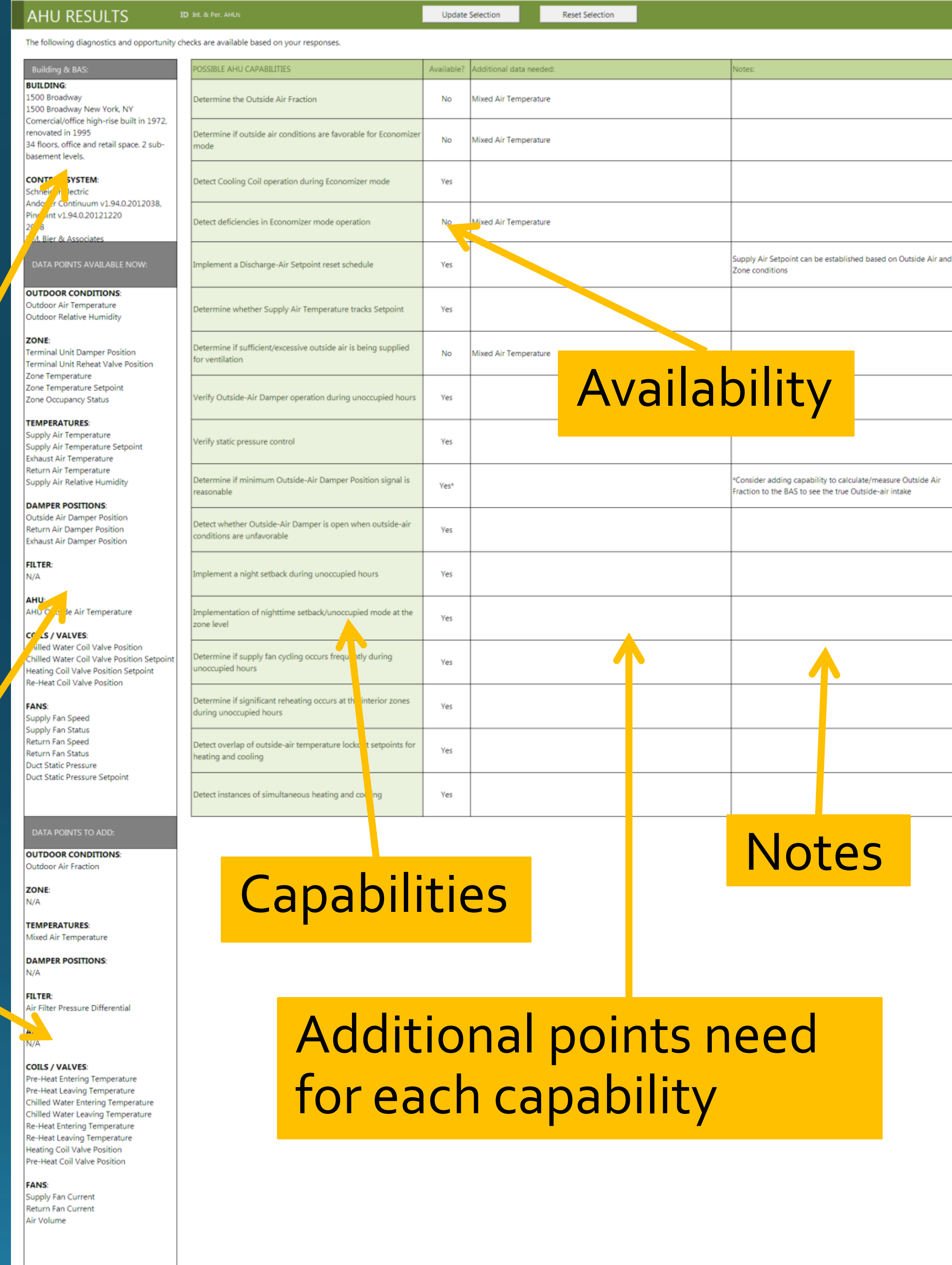
Checklist of sensors and actuators, completed in the field by reading off the BAS screens

BASAT – 1500 Broadway AHU OUTPUT Screen

Building Information

List of data points available

List of points to add



BASAT – 1500 Broadway AHU Results

BAS Capability:

Detect instances of simultaneous heating and cooling

Points Required:

- Chilled Water Coil Valve Position
- Re-Heat and/or Pre-Heat Coil Valve Position or Terminal Re-heat

POSSIBLE AHU DETECTION CAPABILITIES	Available?	Additional data needed for fault detection:
Detect instances of simultaneous heating and cooling	Yes	

BASAT – 1500 Broadway AHU Results

BAS Capability:

Evaluate Amount of Ventilation Air

Points Required:

Mixed Air Temp

Outdoor Air Temp

Return Air Temp

OR

Outside Air Fraction (calculated as a virtual point from MA, OA, RA)

POSSIBLE AHU DETECTION CAPABILITIES	Available?	Additional data needed for fault detection:
Determine the Outside Air Fraction	No	Mixed Air Temperature

BASAT – 1500 Broadway Findings/Recommendations

Air Handler Unit

- Mixed Air Temperature should be added (necessary for 4 out of 17 capabilities identified by BASAT)
- Can run trend logs for most RCx investigations at AHU

Cooling Plant

- Chillers are under-instrumented by current standards
  - Add ability to measure evaporator flow, return temperature and chiller power to track Chiller efficiency.
  - Add chilled water differential pressure – does system track set-point and chiller plant efficiency – is pumping optimized?

BASAT – RCx

How does it work with RCx?

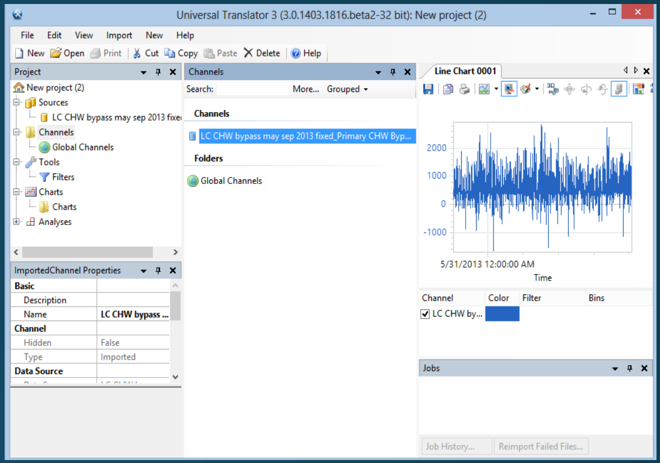
- **As front end to RCx –** BASAT provides overview of BAS status and capabilities for use in RCX investigation
- **Streamline RCx –** BASAT output provides list of available points & trend capabilities – benefits functional and pre-functional testing
- Consultants can utilize BASAT before they commit to a more in-depth project evaluation
- BASAT can be combined with LEAN to be included within a consultant or vendor’s typical “walk-through” evaluation of BAS infrastructure

New Tools – Universal Translator

What is UT?

UT is a software tool for the management and analysis of data from multiple loggers and trend data from BAS.

- Provides mathematical tools for data management of multiple sensors and data collection devices on different pieces of equipment
- Synchronizes varying time intervals between data sets
  - Example - Change between interval and state-change readings



UT User Interface

New Tools – Universal Translator

How did we use UT with RCx?

2 flows in a common system (total loop flow and by-pass flow)

- Different sampling formats
- Needed to make data comparable.

Change-of-state raw sensor readings

	A	B
1	Sample Time (Trend 2)	Primary CHW Bypsass loop Flow FT-03
2	5/1/2013 0:04	543.031
3	5/1/2013 0:05	492.83
4	5/1/2013 0:07	543.762
5	5/1/2013 0:08	493.445
6	5/1/2013 2:37	543.466
7	5/1/2013 2:37	491.709
8	5/1/2013 2:40	542.264
9	5/1/2013 2:42	491.366
10	5/1/2013 2:42	542.121
11	5/1/2013 2:43	491.584
12	5/1/2013 2:46	541.649
13	5/1/2013 2:48	490.954
14	5/1/2013 2:58	541.454
15	5/1/2013 2:58	491.317

NOTE ERRATIC TIME INTERVALS

Date converted to 5-minute interval

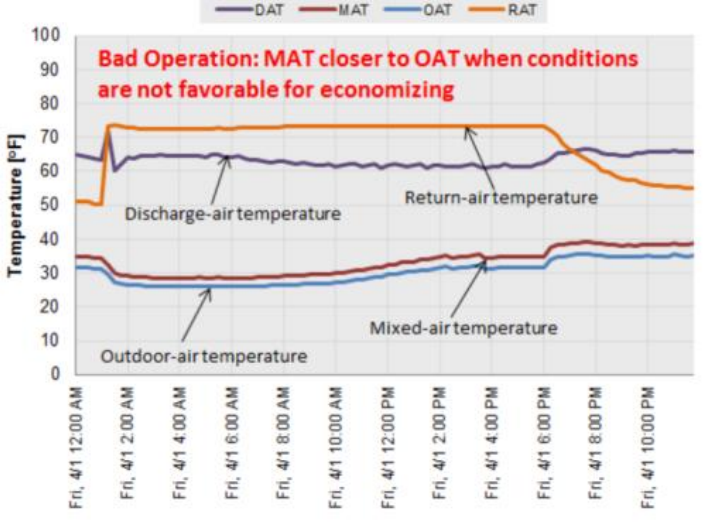
	A	B	C	D	E
1	Date/Time	CHW bypass may sep 2013 fixed_Primary CHW Bypsass loop Flow			
2	5/1/2013 0:05	492.83			
3	5/1/2013 0:10	512.8774			
4	5/1/2013 0:15	491.709			
5	5/1/2013 0:20	491.709			
6	5/1/2013 0:25	491.709			
7	5/1/2013 0:30	491.709			
8	5/1/2013 0:35	491.709			
9	5/1/2013 0:40	491.709			
10	5/1/2013 0:45	491.709			
11	5/1/2013 0:50	491.709			
12	5/1/2013 0:55	491.709			
13	5/1/2013 1:00	491.709			

EASY CONVERSION TO FIVE MINUTE INTERVAL, MATCHING OTHER FLOW DATA

New Tools – Building Re-Tuning

What is BRT?

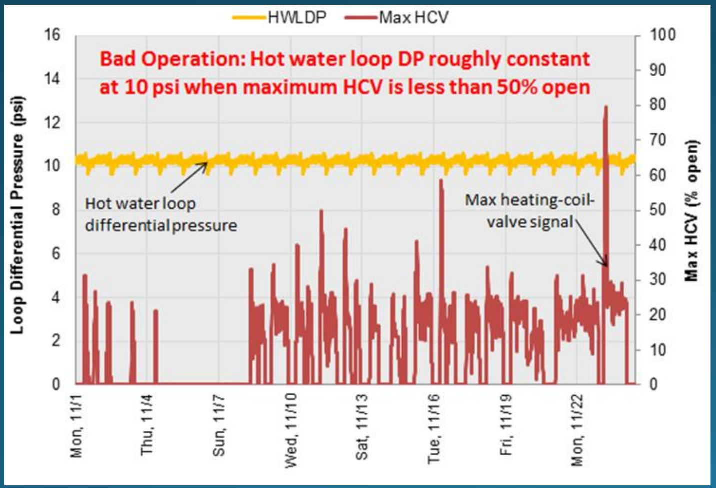
- Protocol developed by Pacific Northwest National Lab to use **trend data from BAS** to monitor system performance
  - FDD from data visualization
  - Emphasis on air systems
  - ***Training for building operators***

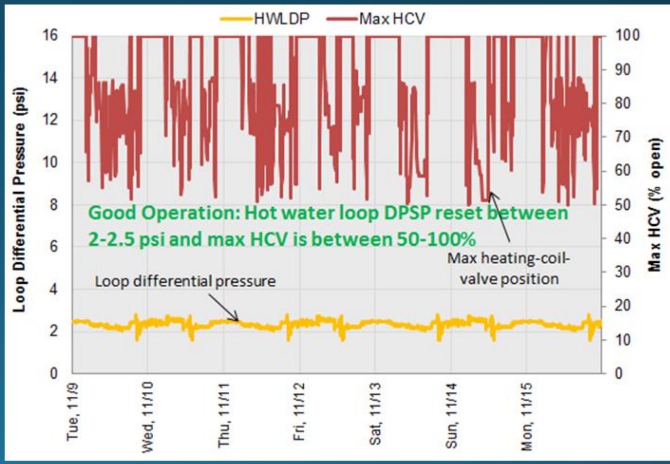


New Tools - Building Re-Tuning

How can BRT be used with RCx?

- Help operators understand RCx process and findings
  - (operator participation is required under LL87)
- Follow-up RCx with operator training
  - "on-going CX"





Conclusion

1. RCx is an established practice for investigating and tuning building systems, recognized by law in NYC
2. Can identify important sources of benefit to owner
3. Practices will continue to evolve with new tools, especially around the BAS, data acquisition and use
4. Building operating engineers can be effectively engaged in the process, turning “RCx” into “On-going Cx”
5. Puts engineers into formal engagement with how their systems operate

Q & A for CEU

1. What NYC Local Law requires retro-commissioning, for what buildings and on what schedule?

   A: NYC LL 87 requires RCx for all buildings of 50,000 sf and larger, on a 10-year cycle

2. What is investigated by the retro-commissioning process?

   A: Operation of major building systems for performance per specification and/or best possible efficiency.

3. How are Building Automation Systemsinvolved in RCx?

   A: As an object of evaluation for correct implementation of design intent and as a tool for observing and testing the operating sequences of equipment and systems.

4. What is LEAN Energy Analysis?

   A: A regression method for identifying areas of energy use and reduction opportunities based on monthly energy use data and outside air temperatures

5. What is Building Re-Tuning (BRT)?

   A: A protocol aimed at training building operators to implement on-going commissioning practices