Diagnostics for Monitoring-Based Commissioning

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Monitoring-Based Commissioning (MBCx)

- Uses energy-consumption and system performance monitoring to guide commissioning and verify energy savings for existing buildings
- Permanently installed monitoring is also used to:
  - Provide performance data continuously during operation
  - Detect performance degradation
  - Ensure persistence of savings
- Prime example:
  - MBCx Program implemented across state university campuses in California

(**Brown, K. and M. Anderson**, "Monitoring-Based Commissioning: Early Results from a Portfolio of University Campus Projects," *Proceedings of the 13th National Conference on Building Commissioning*. Available online: http://www.peci.org/ncbc/proceedings/2006/author.htm, PECI, Portland, Oregon, 2006.)

Role for Automated Fault Detection and Diagnostic (AFDD) Tools

- AFDD tools: Use measured data to detect, determine causes, and estimate impacts of operational faults
  - Physical faults in equipment
  - Incorrect control parameters and code
  - Poor use of scheduling
- Perform these functions at a point in time or continuously in real time
- Identify opportunities to save energy
- Detect sources of lost savings over time (performance degradation)
- Reduce time, effort, cost and knowledge required to acquire and analyze data revealing savings opportunities

Other Roles for AFDD Tools

- Enable timely correction of faults
- Automatically measure/track energy and cost savings

Potential result ⟶ Persistent savings

EXAMPLES

Example 1: Guiding Commercial Building Re-Tuning with Measured Data

- *Re-tuning* = a systematic, semi-automated process of detecting, diagnosing and correcting operational problems with building systems and controls
- Targets HVAC systems and controls with high-impact energy efficiency measures that can be delivered immediately, at low or no cost
- Uses monitored data to assess building operations and to identify energy saving opportunities
- Data analysis is supplemented by a building walk through and controls system review.
- Trends logs are implemented in control system for 1 to 2 weeks, prior to onsite re-tuning visit

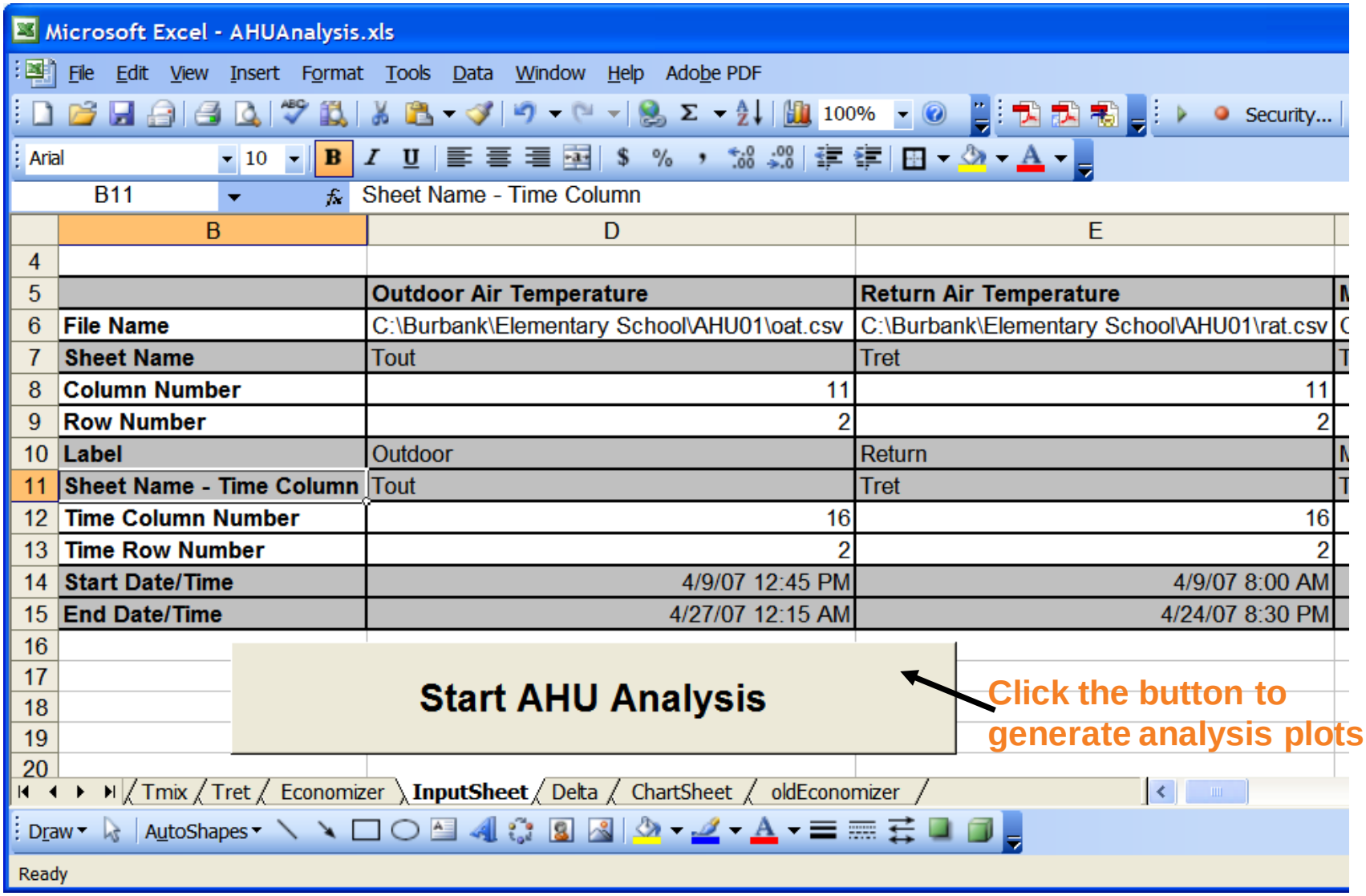
Guiding Commercial Building Re-Tuning with Measured Data

- Semi-automated spreadsheet tools are used to automatically produce specific data plots
  - AHU Analysis Tool: Plots time series for set points, economizer operations, ventilation, etc.
  - Zone Analysis Tool: Plots time series of set points and damper modulation.
  - Central Plant Tool: Plots temperature changes across coils for hot water and chilled water; assists with assessing condenser and cooling tower operation
- Trainees are taught to interpret these plots to identify energy saving opportunities

Re-Tuning Spreadsheet Tool

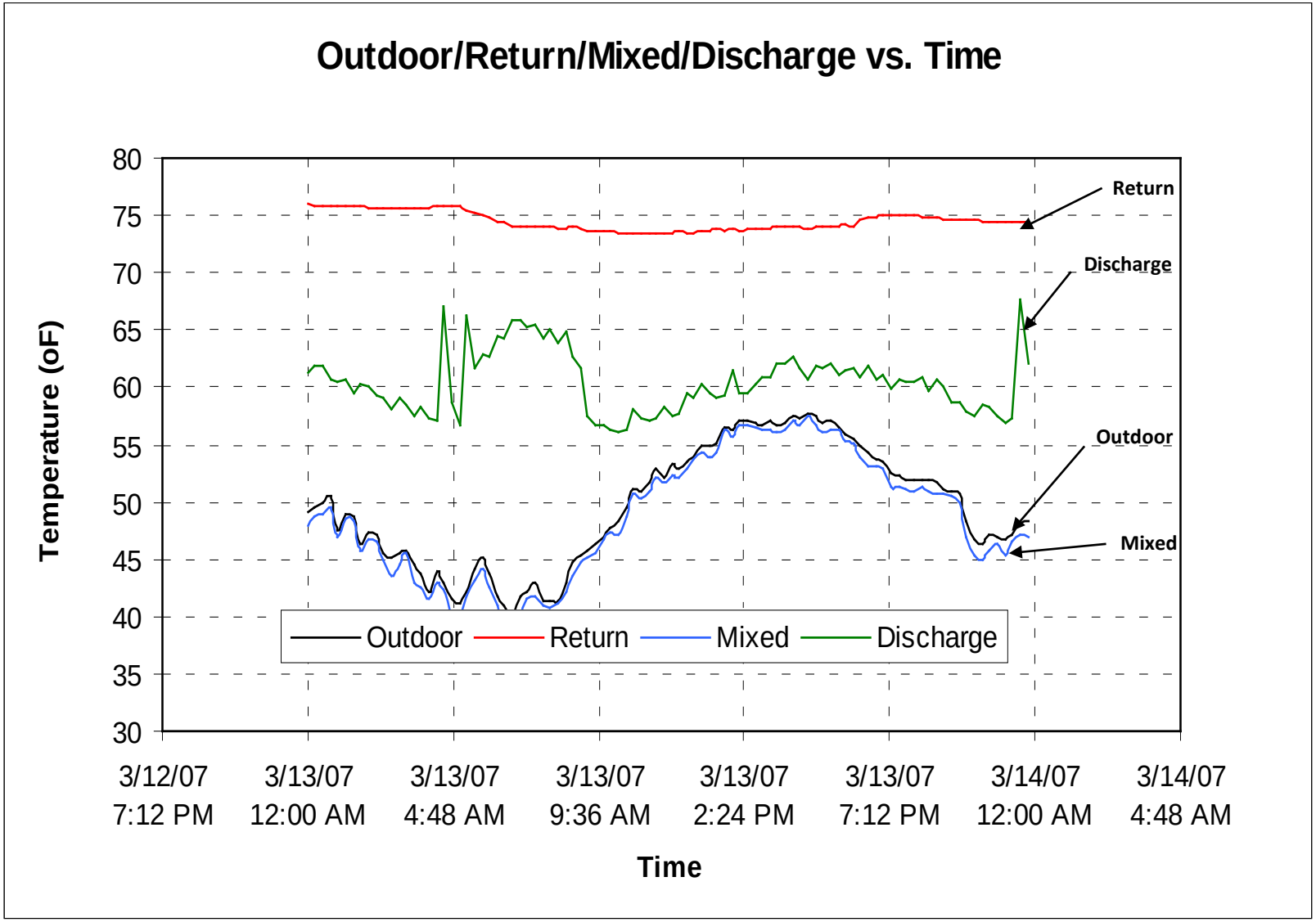
- Most building control systems can trend and export data to files, but the formats of trend logs vary from one EMCS to another
- Spreadsheets work with many formats but not all
- Spreadsheet tools are tailored to analyze and produce graphs that provide information on:
  - Air-handling units
    - Outdoor-air makeup
    - Economizer operation
    - Discharge temperature control
    - Discharge static pressure control
    - Simultaneous heating and cooling
  - Occupancy-based scheduling
  - Zone variable-air-volume boxes
  - Chiller and boiler plant operations

Spreadsheet Input Setup Screen

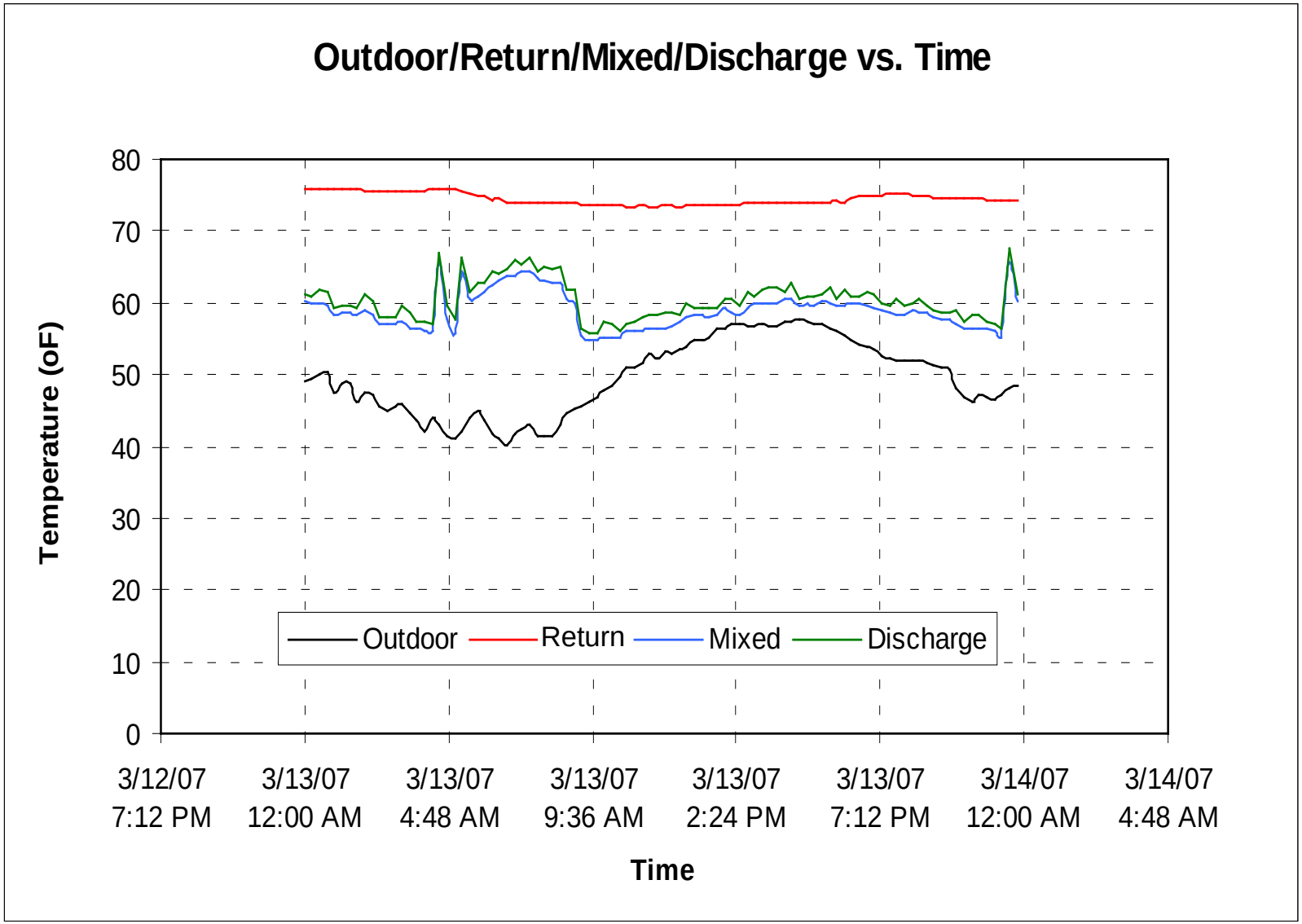


	B	D	E
4			
5		Outdoor Air Temperature	Return Air Temperature
6	File Name	C:\Burbank\Elementary School\AHU01\oat.csv	C:\Burbank\Elementary School\AHU01\rat.csv
7	Sheet Name	Tout	Tret
8	Column Number	11	11
9	Row Number	2	2
10	Label	Outdoor	Return
11	Sheet Name - Time Column	Tout	Tret
12	Time Column Number	16	16
13	Time Row Number	2	2
14	Start Date/Time	4/9/07 12:45 PM	4/9/07 8:00 AM
15	End Date/Time	4/27/07 12:15 AM	4/24/07 8:30 PM
16			
17			
18			
19			
20			

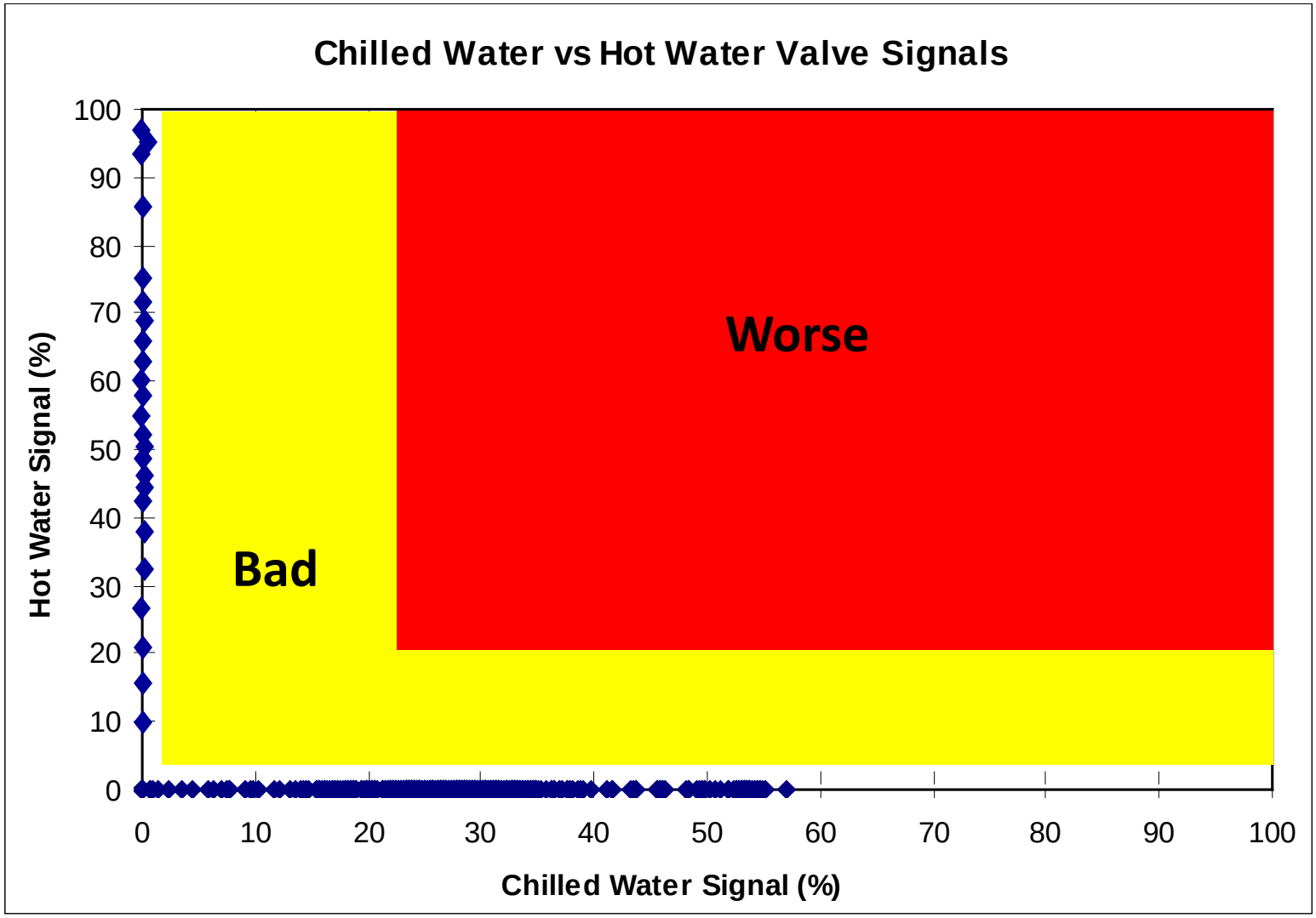
Improperly Operating Economizer



Properly Operating Economizer



Properly Operating Chilled- and Hot-Water Valves



Example 2: Tracking Energy Savings

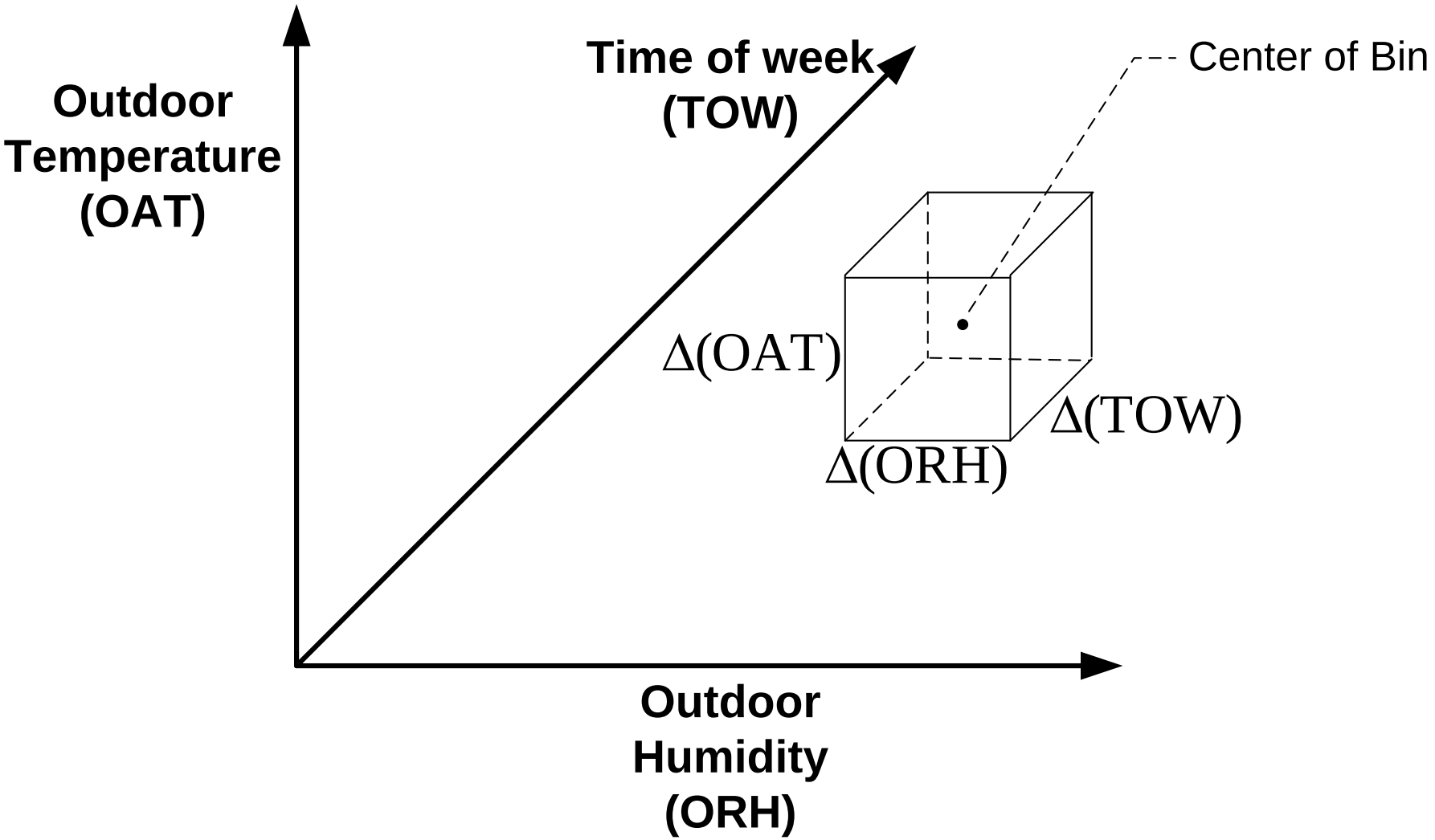
- Helps ensure that benefits of commissioning persist over time
- Empirical model used to represent energy using behavior of building before commissioning

Energy savings = Energy use of building for time period after Cx, if it had not been commissioned

- Actual energy use of the building for same time period after Cx

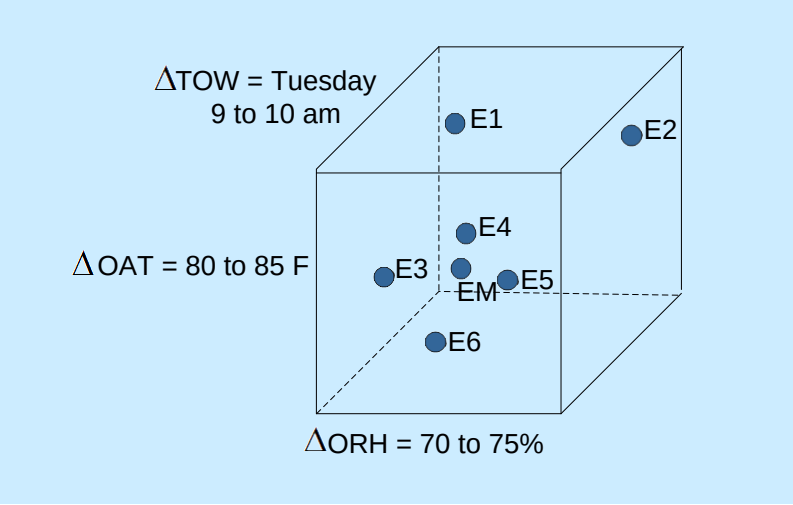
- The model controls for differences in driving (explanatory) variables:
  - Outdoor-air temperature
  - Occupancy schedules
  - Others

Bin-Based Model
Three-dimensional Binning Scenario



Bin-Based Model: Three-dimensional Binning Scenario

- Data points: (E_i, $x_{1,i}$, $x_{2,i}$, $x_{3,i}$)
  - E_i is the ith value of energy consumption
  - $x_{1,i}$, $x_{2,i}$, $x_{3,i}$ are the values of the three independent variables OAT, ORH and TOW corresponding to E_i
- A training period is defined, e.g., the year before Cx
- Each data point is assigned to a bin
- The median of the values of the E_is assigned to a bin is assigned as the value of energy consumption for the conditions represented by the bin



Bin-Based Model: Three-dimensional Binning Scenario

- For post-Cx time periods, the expected energy consumption of the building if it had not been commissioned is determined by the value of energy consumption for the bin corresponding to the specific measured values of the independent variables for that time period
- The energy savings for each time period can then be calculated

Energy savings = Energy use of building for time period after Cx, if it had not been commissioned

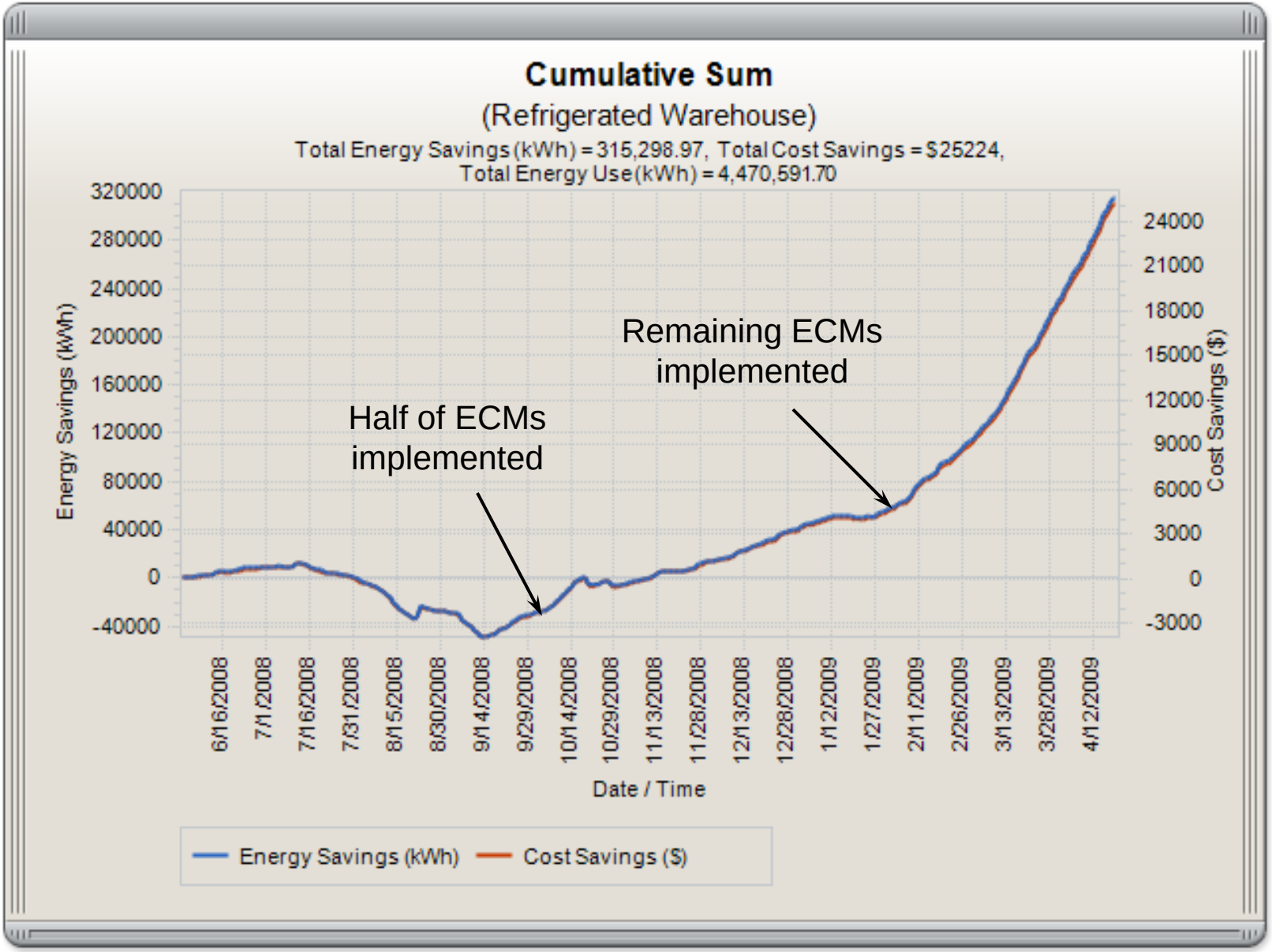
- Actual energy use of the building for same time period after Cx

- Capability embedded as diagnostic engine in web-based energy tool/service Energy Expert

Refrigerated Distribution Center

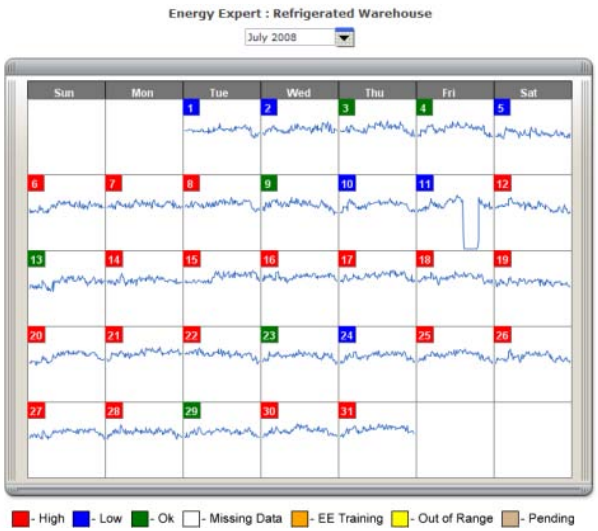
- Large refrigerated distribution center located in southwestern Canada
- About 500,000 sf
- 30 energy savings measures identified
- Half of the measures were implemented in October 2008
- Remaining measures implemented in early 2009

Refrigerated Distribution Center

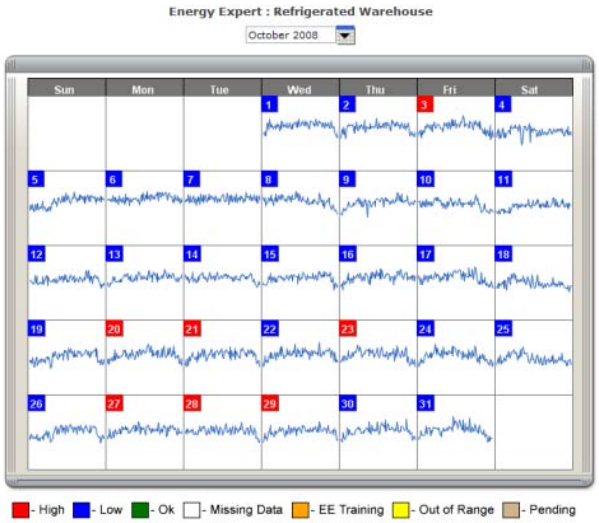


Refrigerated Distribution Center Calendar View of Energy Impacts

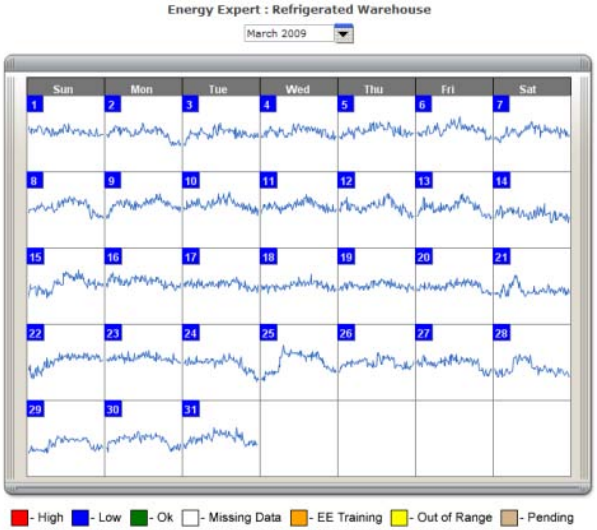
July 2008
Before Cx



October 2008
Initial Cx



March 2009
After All Cx

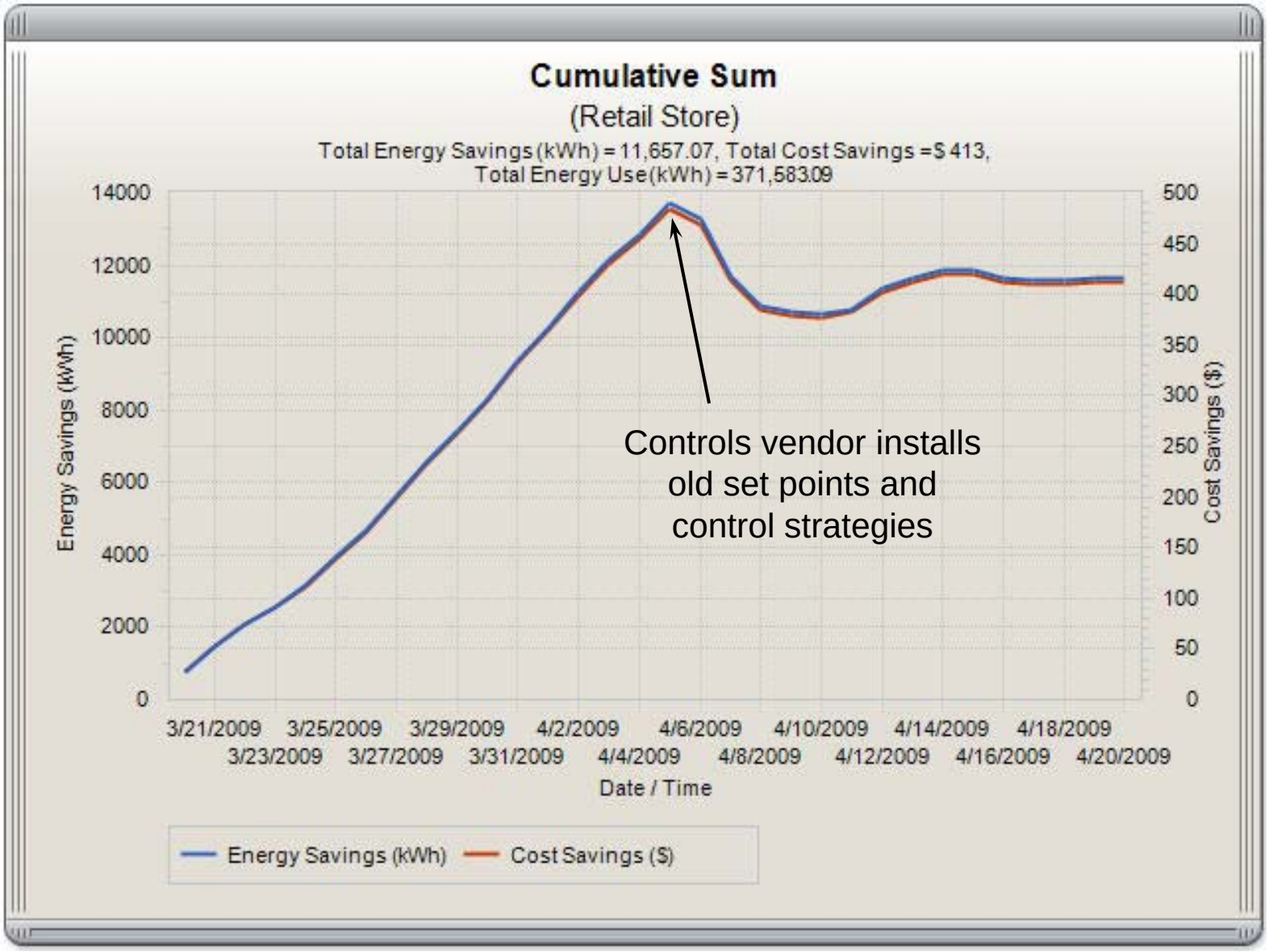


Red = High energy use
Blue = Lower energy use
Green = No change in energy use

Retail Store

- Located in southwestern Canada
- About 30,000 sf
- Significant savings after Cx measure implementation—approximately 28,000 kWh/month worth about $1000
- April 2009 – controls vendor upgraded software and overrode the tuning by resetting set points and control strategies to earlier archived versions
- The savings rate was reduced to zero
- The Energy Expert automatic tracking tool revealed the problem so it could be corrected

Retail Store

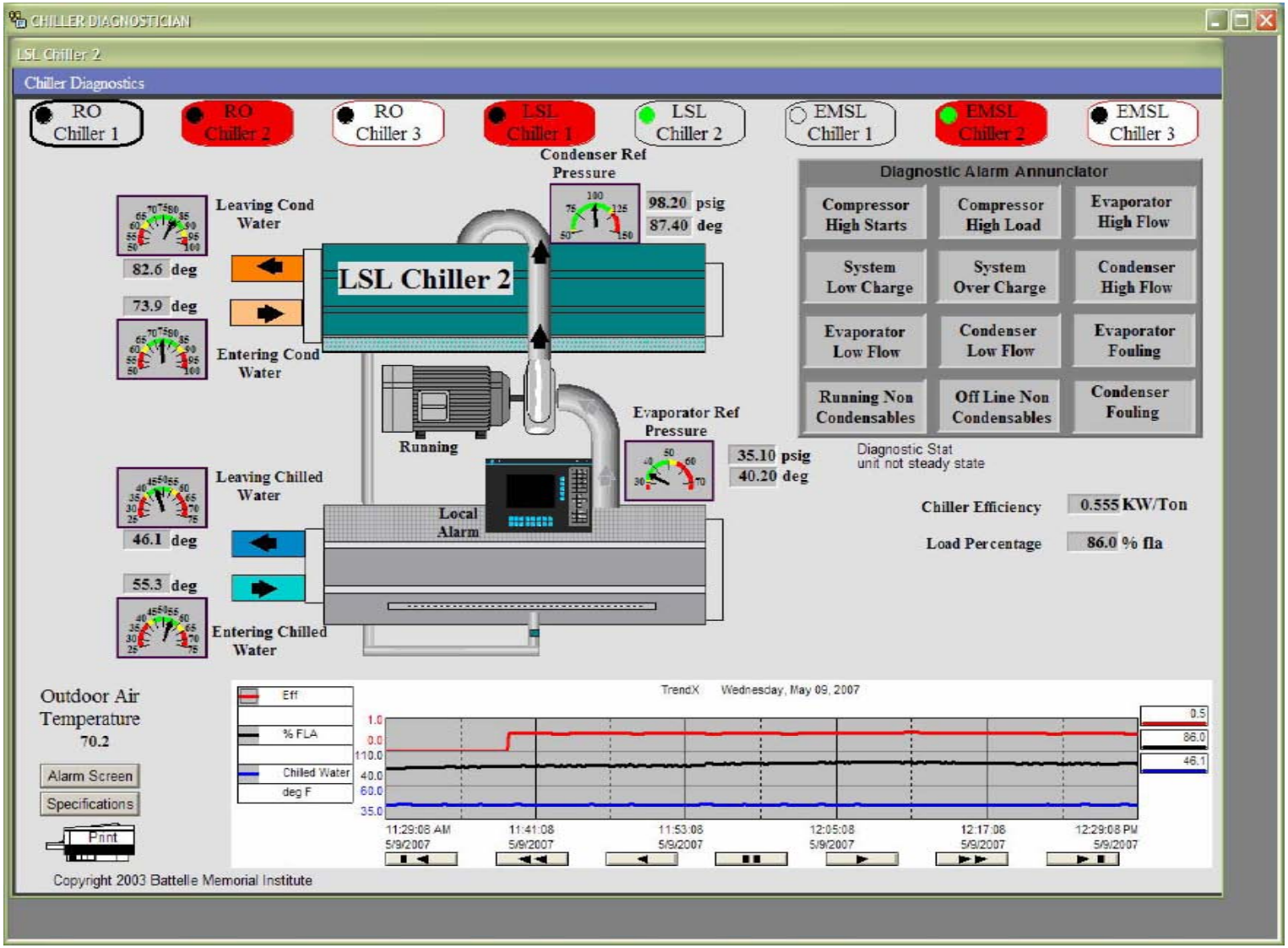


Enterprise Roll-Up Report for Owner/Manager of Many Facilities

Energy Expert Results for: Jan 1, 2009 - Apr 20, 2009

	High Demand	Actual Consumption	Expected Consumption	Consumption Δ	Savings ($)	Low	OK	High
Office Bldg. 1	120	178,573	287,911	109,338	8,747	110	0	0
Office Bldg. 2	206	265,015	321,088	56,073	4,486	100	6	4
Office Bldg. 3	770	777,083	860,868	83,785	6,703	73	12	24
Office Bldg. 4	331	376,728	419,051	42,324	3,386	89	13	8
Office Bldg. 5	323	251,769	303,499	51,730	4,138	105	5	0
Office Bldg. 6	294	418,752	454,795	36,043	2,883	86	15	9
Office Bldg. 7	169	280,683	317,090	36,407	2,913	109	1	0
Office Bldg. 8	801	1,083,433	1,023,492	-59,941	-4,795	34	13	63
Office Bldg. 9	303	434,943	477,023	42,081	3,366	79	22	9
Total		4,066,979	4,464,817	397,838	31,827	785	87	117

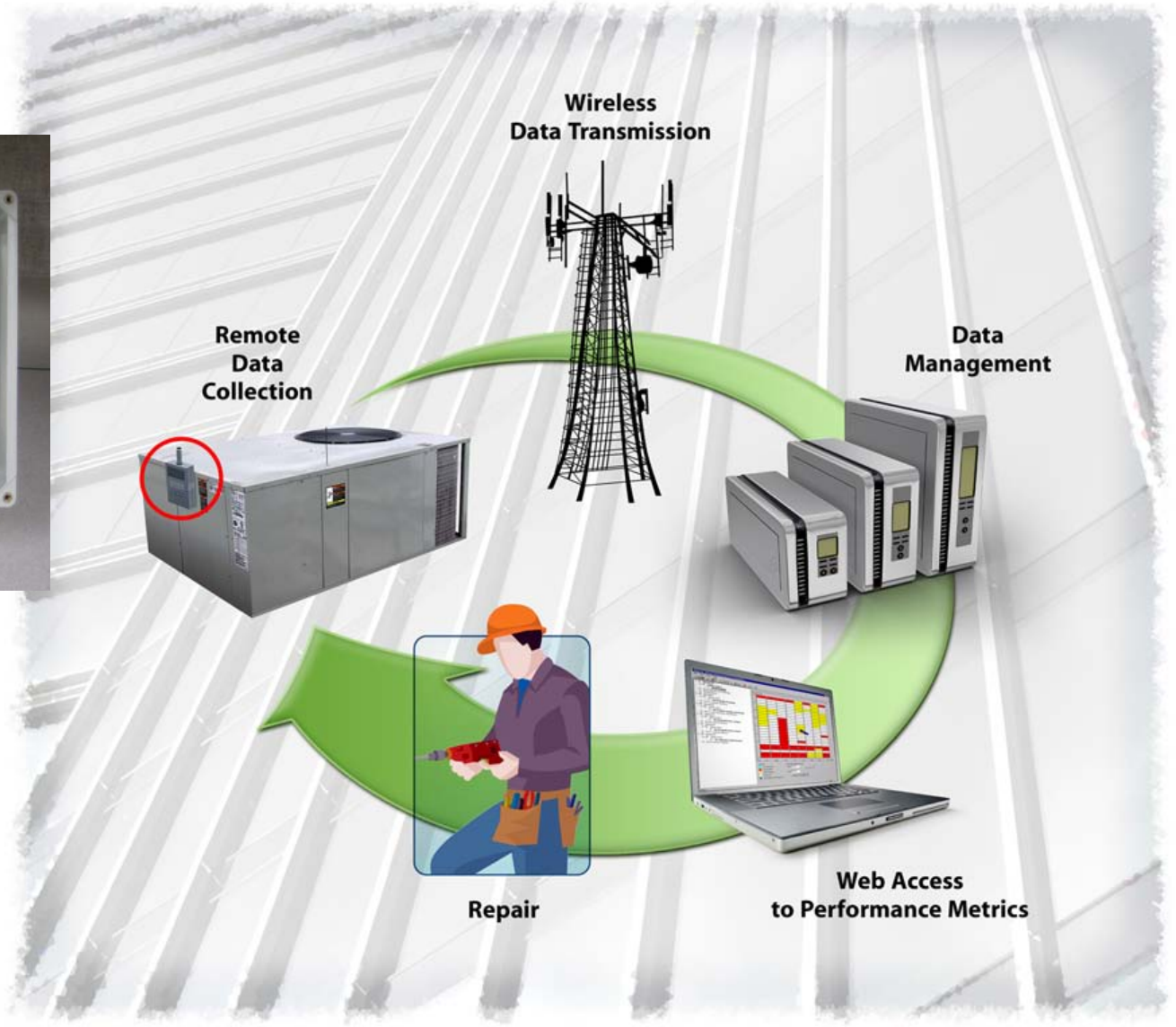
Example 3: Automated Centrifugal Chiller Diagnostician



Automated Centrifugal Chiller Diagnostician – MBCx Uses

- Detection of chiller operation problems during initial commissioning
- Chiller performance monitoring and fault detection during operation to guide operation and maintenance and maintain persistent savings
- Benefits:
  - Higher efficiency and better performance through
    - optimization of operation
    - timely maintenance and fault correction
  - Life extension

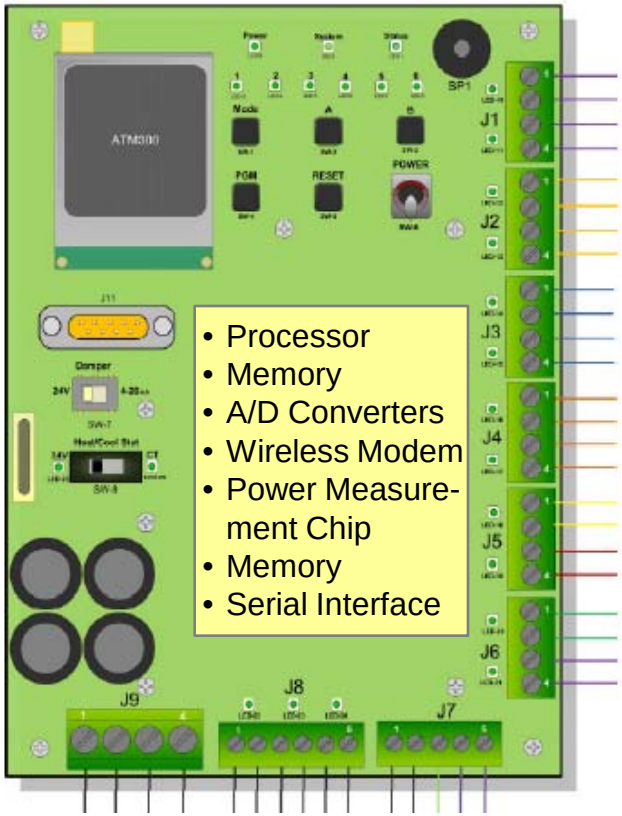
Example 4: Smart Monitoring and Diagnostic System (SMDS)



Smart Monitoring and Diagnostic System (SMDS)

- Monitors condition and performance of packaged heat pumps and air conditioners
- Detects and diagnoses faults with sensors, dampers/economizer, set points, control parameters and control logic
- Future – could implement refrigerant-side fault detection and diagnostics

Smart Monitoring and Diagnostic System (SMDS)



Voltage taps and ground

- Direct connections

Current transformers

Thermistors

- outdoor air
- return air

Thermistors & humidity sensors

- mixed air
- supply air

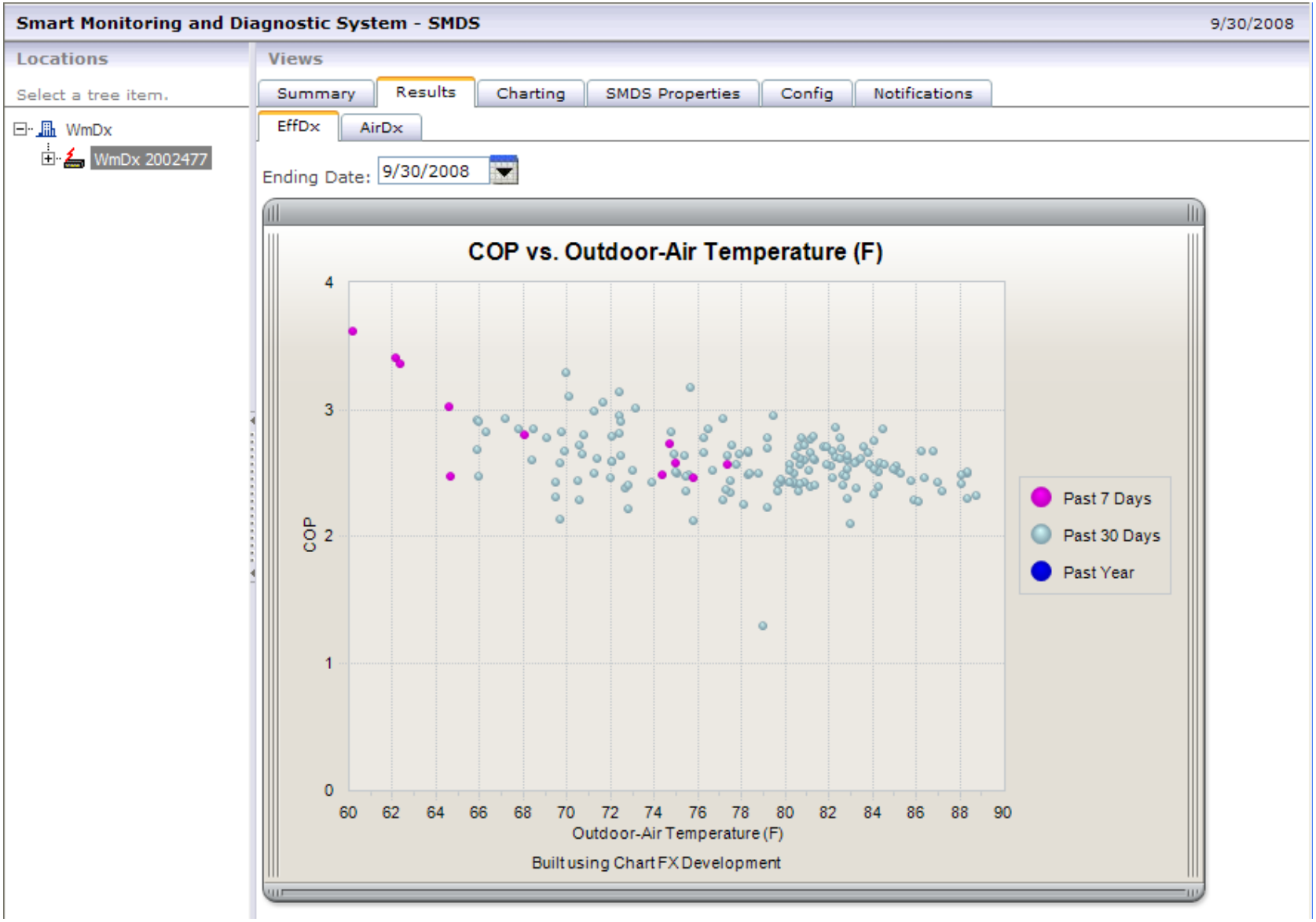
Current switch

- supply fan status

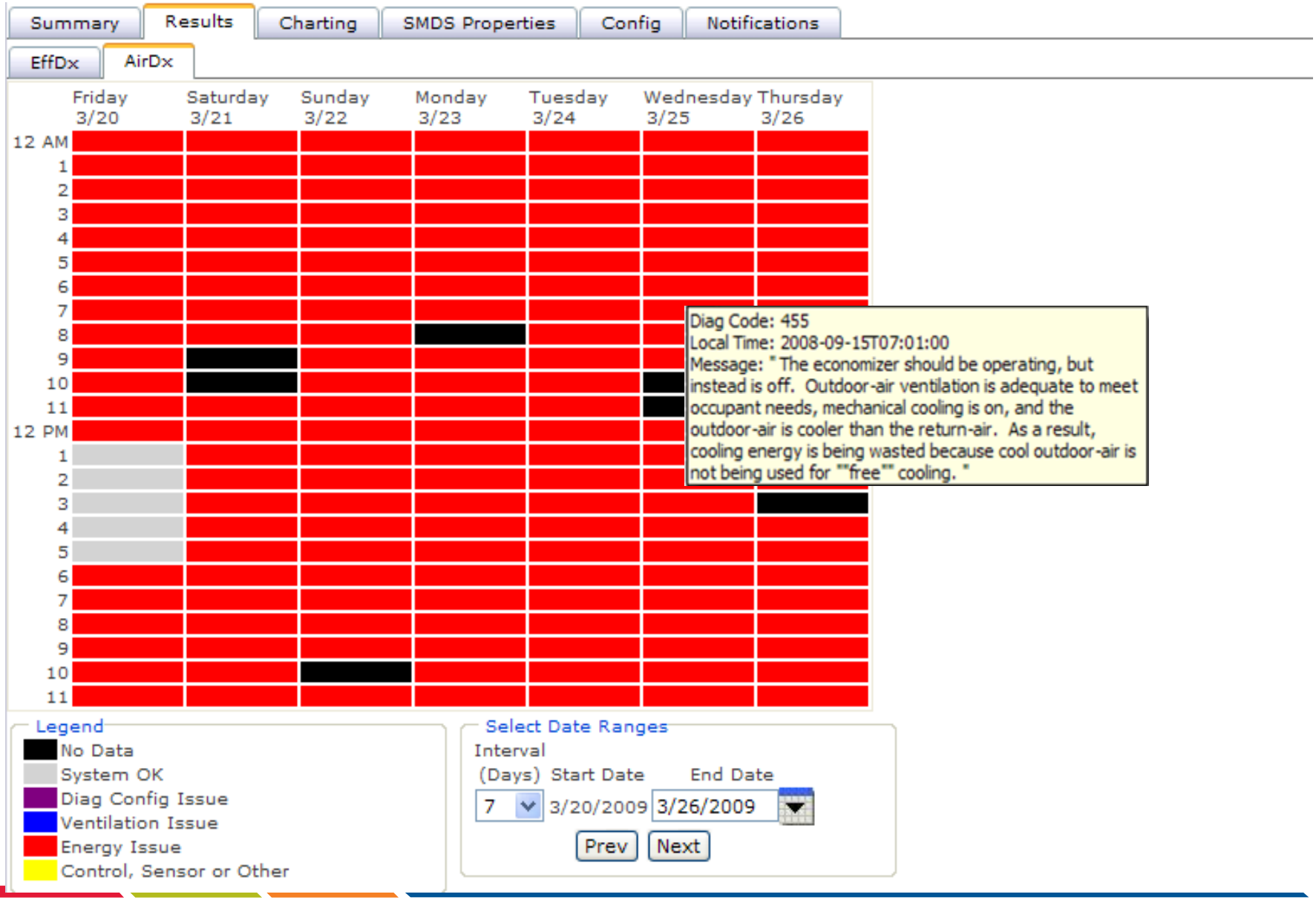
Direct connections

- heating/cooling status
- damper signal

Air-Conditioning COP Monitoring



Air-Side Diagnostics User Interface



Value of SMDS in MBCx

- Initial application to detect operational faults
- Quantify improvement in COP from commissioning
- Monitor performance and detect faults in real time during operation after commissioning – support persistent savings

Potential Impacts of Automated Monitoring and Diagnostics in MBCx

- Benefits
  - time savings in collection and analysis of data compared to temporary monitoring using data loggers, manual performance of functional tests, and manual offline data analysis
  - greater consistency across MBCx projects and potentially higher quality commissioning
  - better detection of performance degradation and detection and diagnosis of faults, helping ensure the persistence of savings after initial commissioning

Potential Impacts

- Costs
  - Cost of additional instrumentation
    - End-use sub-metering
    - Sensors not part of EMCS
  - Time for technicians to learn diagnostic tools
  - Small buildings not likely candidates – issue not unique to MBCx or use of automated diagnostic tools
- Measurement of Impacts
  - Re-tuning project is quantitatively evaluating impacts
  - Demonstration of SMDS is quantifying impacts
  - Results not yet available - will be reported in the future

Summary/Conclusions

- Examples provided for use of monitoring and diagnostic tools as part of MBCx
  - Identification of operational improvement opportunities
  - Savings measurement and monitoring
  - Detection of performance (savings) deterioration
  - Automated detection and diagnosis of faults in equipment and systems
- Benefits appear promising relative to costs but measured results are not available yet

Thank you!

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