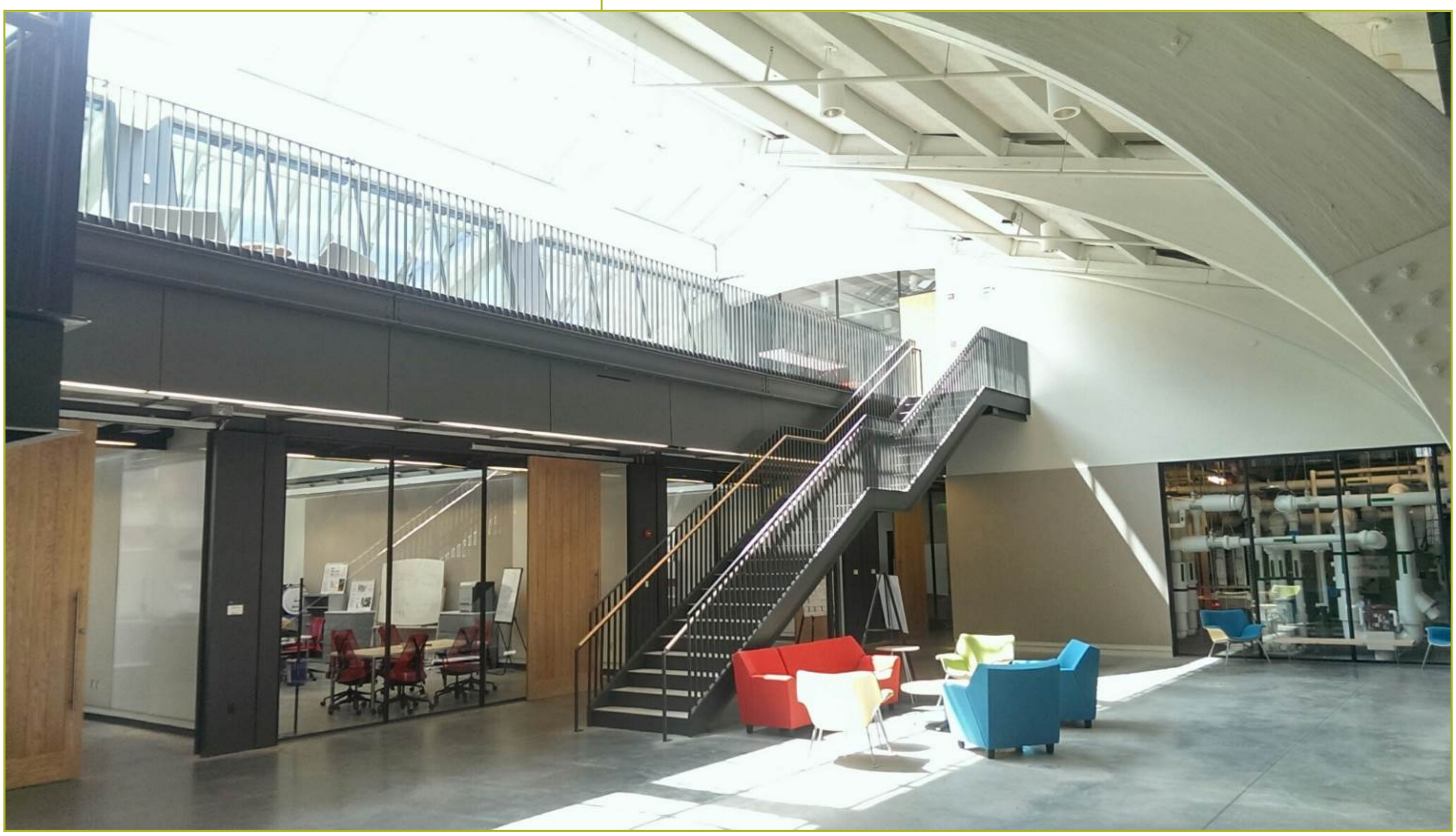
CONSORTIUM for BUILDING ENERGY INNOVATION

REPORT

Title: Building Re-Tuning Updated Case Studies

Report Date: April 30, 2016

Report Author: Lisa Shulock



Report Abstract

Project objectives.

Deliverable Requirement: Four updated case studies published on CBEI website and integrated into BRT with BAS curriculum

Deliverable report: Four BRT case studies have been updated: Parmenter's Las Colinas, GSA's Courthouse Annex and LBJ Education building (two in one combined document) and Georgia Tech's TSRB. The case studies are published on the CBEI website. DOE is determining the long term home for these case studies since the CBEI website will not be kept current. The case studies are also posted in the BRT training materials file share for use by BOMA and APPA. Additional content for the training from the case studies and material from CBEI's building 661 have been added to the training modules.

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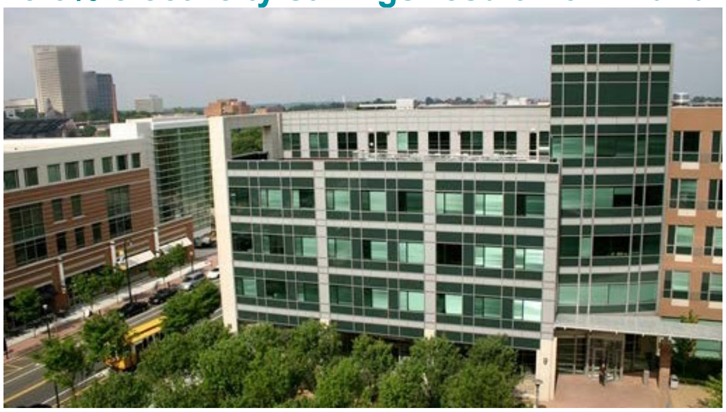
Four BRT case studies have been updated: Parmenter's Las Colinas, GSA's Courthouse Annex and LBJ Education building (two in one combined document) and Georgia Tech's TSRB. The case studies are published on the CBEI website. DOE is determining the long term home for these case studies since the CBEI website will not be kept current. The case studies are also posted in the BRT training materials file share for use by BOMA and APPA. Additional content for the training from the case studies and material from CBEI's building 661 have been added to the training modules.

The case studies are attached.

Re-tuning Case Study

GeorgiaTech Re-tunes Research Building and Saves 23.6% on Electricity. Atlanta, GA

23.6% electricity savings result from Building Re-tuning training.



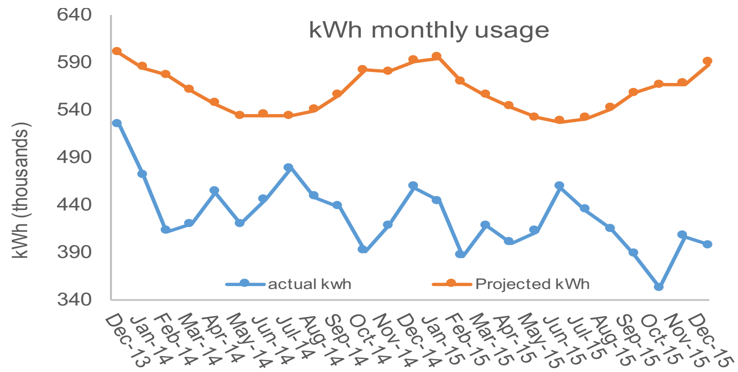


Figure 1. Projected kWh usage based on a year's monthly consumption prior to re-tuning and weather normalized.

Address: TSRB, 85 Fifth St NW, Atlanta, GA
Owner: The University Financing Foundation
Lease: Georgia Tech, Triple Net Lease
Size: 209,000 Square Feet

The Technology Square Research Building (TSRB) is an academic research center at the Georgia Institute of Technology, owned by The University Financing Foundation and managed by Gateway Facility Services. It houses five research centers with space for 500 researchers. TSRB also houses state-of-the-art conference facilities that accommodate several special events. The TSRB is part of the Better Buildings Challenge Atlanta, and has committed to reducing energy usage 20% by 2020 – total savings have surpassed the goal and reached 26.84% since its 2009 baseline. The building faces energy challenges such as variable occupancy, 24/7 operational lab spaces, and a data center.

In July 2013, experts from the Pacific Northwest National Lab conducted a re-tuning training with the property management staff. The building utilized its building automation system (BAS) to identify re-tuning opportunities in addition to the indoor and outdoor building walk-down. Following the training, five re- tuning measures were implemented which contributed to electricity savings of 23.6 % over 2 years compared to projected usage (Figure 1). Improvements were made to the building's envelope, cooling schedule, and the condensing water system. In addition to energy savings, the building's tenants have benefited from increased comfort due to optimizing the set points of the HVAC system.

Since its construction in 2002, the building has continually improved its energy performance, increasing its ENERGY STAR rating from 35 in 2009 to 67 in 2013. Re-tuning contributed to this improvement and the building's ongoing process of re-tuning should help increase the building's ENERGY STAR score further over time.

Example: BAS Trend Data Provides Retuning Opportunity in Overcooled Zone

Figure 2 shows the actual zone air temperature (blue line) for one of the zones in the TRSB building, compared to the zone's temperature set point (green line), and its damper position. The fact that the average temperature is consistently below the set point indicates that the zone is overcooled. A significant number of zones were observed to be at minimum temperature and damper position, confirming that many spaces were overcooled. Upon further analysis, the building staff determined that the cause was attributable to the zone's minimum CFM (cubic feet per minute) value being too high. This led the building to institute a re-tuning measure for CFM minimum reset, which led to energy savings as well as increased occupant comfort.

Conditions to spot in General Zone Data Analysis

Key conditions to identify while analyzing BAS graphs:

- No night time setback for air temperature or pressure
- Significant reheat for interior zone terminal box during occupied hours

Building re-tuning saves energy and money

From late 2013 to early 2015, PNNL helped identify re-tuning measures in 100 office buildings. Many, but not all, of the recommended measures were implemented by the building operations staff. Annual energy savings ranged between 2% to 26%, with a median savings of 15%. Annual normalized cost savings ranged between 0.0$/sf to 0.6$/sf, with a median savings of 0.12$/sf. If all re-tuning measures identified were implemented, the savings would have been even larger.

- Overcooling or overheating
- Significant reheat during summer/cooling season for exterior zone box
- Supply-air temperature too cool or too warm
- No use of supply-air reset
- Certain zones (e.g. corner offices) driving AHU operation
- Some zones out of control, oscillating between heating and cooling

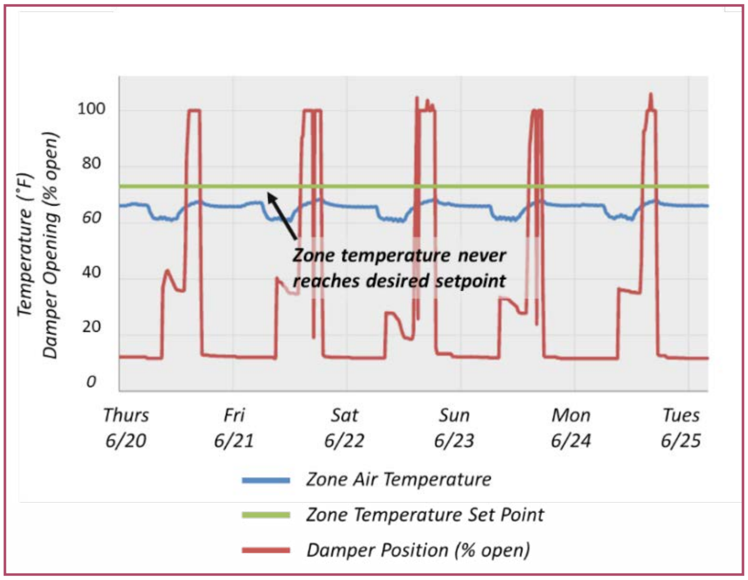


Figure 2. Trended Graph of Zone Temperature and Damper Position Reveals an Overcooled Zone.

Strategy for Success: Re-tuning on a Continuous or Periodic Basis

Re-tuning should be on a continuous or periodic basis. After the initial building re-tuning, follow-up actions should include:

1. All operation and maintenance (O&M) actions recommended from the initial re-tuning evaluation should be implemented to maximize energy saving, reduce energy costs, and improve the comfort of occupants.
2. For any recommendations that can only be partially implemented, take steps to fully implement these actions and capture the complete savings benefits.
3. Continue conducting re-tuning analyses to calibrate to any changes in the building's personality and uses, such as changes in tenants, schedules, remodels, etc.
4. O&M staff continually look for problems and opportunities that can be resolved with re-tuning.
5. Document plans for continuous re-tuning. Establish schedules for re-tuning activities and refer to them frequently to ensure that follow up continues.
6. Take re-tuning lessons learned and train colleagues, as a success measure for staff development and continuous improvement in building performance.

What is Re-tuning?

Building re-tuning is a systematic process to identify and correct building operational problems that lead to energy waste. Building Re-Tuning Training is a blend of building walk-throughs and classroom instruction that teaches building operations staff and service personnel how to save energy and increase occupant comfort through low and no-cost operational improvements. There are two versions of the training: Observation-driven re-tuning for buildings without a building automation system (BAS) and data-driven re-tuning for buildings with BAS. This case study utilized the data-driven protocol.

No- and low-cost savings opportunities include items such as replacing faulty sensors, adjusting set-points and inefficient schedules, utilizing variable speed fans and economizers, insulating pipes, adding CO_2 sensors, widening thermostat dead bands, and sealing building envelope leaks. This process can reduce building energy use up to 25%.

Since 2016, TSRB has been in a state of continuous commissioning. The chief engineer and the building engineer have participated in the retuning process. Two capital improvements that have impacted building energy consumption since July 2013 are:

- Demand ventilation in the first floor conference center in June 2014
- Tied laboratory exhaust fan into the automation in August 2014

The company has in-house personnel that make changes in the BAS and have done retuning work by directly accessing the BAS interface.

Why Invest in Building Re-Tuning Training?

Building Re-Tuning Training is a worthwhile investment because saving energy is not reliant on commissioning agents, energy auditors or professional engineers. Facility engineers and building operators - the people who are in the buildings regularly – learn to identify energy saving opportunities and act. The savings are regenerative because the trained building operator or facility engineer is able to continuously re-tune his/her building and maintain optimized conditions.

Table 1 shows the implemented recommendations and associated effort and energy savings in selective systems.

Table 1. Re-tuning Recommendations Implemented at Georgia Tech University TSRB

System	Recommendation	Effort	Savings
Envelope	Repaired discrepancies in exterior walls and installed weather strips on doors.	Low	Low
Scheduling	Programmed reset schedule for supply air temperature	Med	High
Scheduling	Programmed reset schedule for supply air pressure	Low	High
Terminal VAV Boxes	Reduced minimum CFMs on Terminal Units	Med	High
Condensing Water Loop	Reset condensing loop differential pressure set point based on building load and process load.	Med	High
Condensing Water Loop	Programmed cooling temperature control reset schedule	High	Med

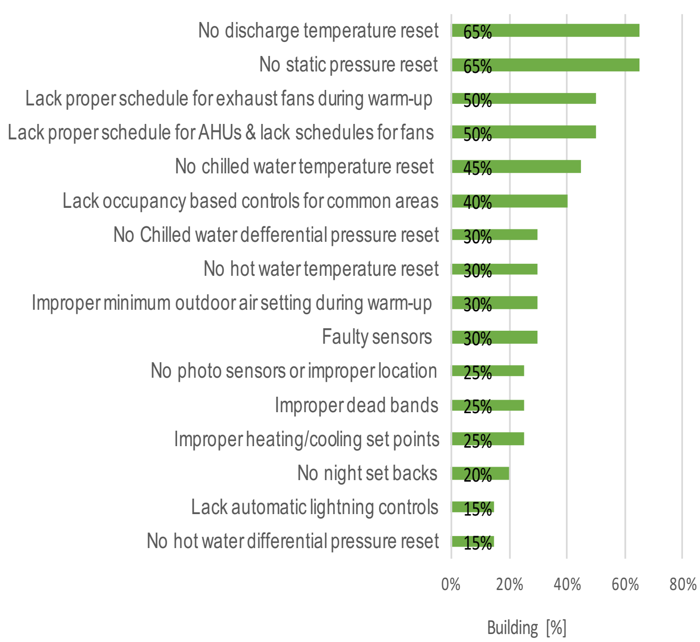


Figure 3. PNNL Meta-Analysis of 100 Commercial Office Buildings (2013-2015)

How to read this chart:

As many as 50% of the buildings in which re-tuning took place lack proper schedules for AHUs and/or lack schedules for exhaust fans or fans running during warm-up mode; over 65% of the buildings do not use static pressure or discharge temperature reset on AHUs; over 30% of the buildings have one or more faulty sensors and/or improper minimum outdoor-air setting during morning warm-up, etc.

Acknowledgements:

This case study and related work is funded by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Pacific Northwest National Laboratories created the building re-tuning training program and performed the building re-tunings for this case study. The Pennsylvania State University updated the results in 2016.

Re-tuning Training Opportunities and Online Resources

The Department of Energy funded Pacific Northwest National Labs (PNNL) to create the Building Re-Tuning Training program. Penn State led efforts for DOE to make Building Re-Tuning Training widely accessible. See https://www4.eere.energy.gov/workforce/projects/buildings-retuning-training for information about accessing the training. Classroom training material, training instructor manual and online re-tuning interactive training and energy charting and metrics tools are available at http://buildingretuning.pnnl.gov/

PENNSTATE

Re-tuning Case Study

GSA National Capital Region Re-tunes Office Building and Courthouse. Washington, D.C.

In two years since re-tuning the LBJ Dept. of Education Headquarters, facilities staff from GSA saved an impressive 14.2% on electricity usage.

What is Building Re-Tuning?

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No- and low-cost savings opportunities include items such as replacing faulty sensors, adjusting set-points and inefficient schedules, utilizing variable speed fans and economizers, insulating pipes, adding CO2 sensors, widening thermostat dead bands, and sealing building envelope leaks. This process can reduce building energy use up to 25%.

The U.S. General Services Administration (GSA), National Capital Region (NCR) is dedicated to providing superior support to the federal government in the Washington, D.C. metropolitan area. NCR's teams of property and energy management professionals help reduce energy consumption and costs in GSA-owned buildings.

In March of 2014, experts from the Pacific Northwest National Laboratory (PNNL) delivered re-tuning training to property managers, building engineers, and O&M contractor staff. The training consisted of a day in the classroom and a day of hands-on practical application in two buildings: Lyndon B. Johnson (LBJ) Department of Education Headquarters Building and William Bryant Courthouse Annex. The 550,800 rentable square feet (rsf) LBJ building was constructed in 1961, underwent a full modernization completed in 1996, and had its HVAC system commissioned in 2010. The 264,842 rsf Annex was constructed in 2005, and houses 9 courtrooms, 8 chambers for Court of Appeals judges, 11 chambers for District judges, and office space for court/federal functions.

Building engineers and operators identified a long list (see full list in Tables 1 and 2) of re-tuning efficiency measures in both buildings. GSA is now exploring ways in which the strategies and approach learned in the training can be shared with others within its organization.

Building re-tuning saves energy and money

From late 2013 to early 2015, PNNL helped identify re-tuning measures in 100 office buildings. Many, but not all, of the recommended measures were implemented by the building operations staff. Annual energy savings ranged between 2% to 26%, with a median savings of 15%. Annual normalized cost savings ranged between 0.0$/sf to 0.6$/sf, with a median savings of 0.12$/sf. If all re-tuning measures identified were implemented, the savings would have been even larger.

LBJ Office Building:

LBJ Department of Education Building
Address: 400 Maryland SW, Washington, DC 20202
Owner: U.S. General Services Administration
Size: 550,800 Rentable Square Feet

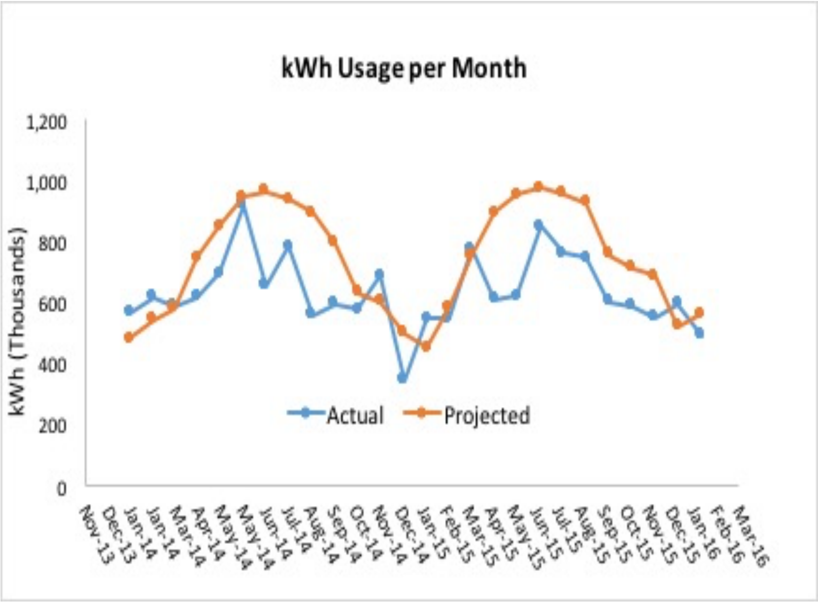

Figure 1. Projected kWh usage in LBJ Building based on monthly consumption prior to re-tuning

In two years post-retuning, the building has saved an average of 14.2% on its electricity usage due to a number of energy saving opportunities (Figure 1). GSA has continued building re-tuning by seasonal adjustment of set points and reevaluating them based on existing conditions.

Finding: Early morning Monday HVAC startups at the LBJ Building

Monday HVAC system schedules for the LBJ building were set to start at 3AM for many AHUs and delay by 1 hour (4AM start time) for the other days of the week. This schedule cooled the building earlier than necessary. During the re-tuning walk-through, operators realized the need to determine optimum schedules for the different HVAC systems and adjust accordingly to match the actual occupancy and loading requirements. Re-tuning measures to address this efficiency opportunity include:

- Consider using optimal start for AHUs. Optimal start allows for setting the BAS schedules for AHU occupancy to 6AM, although building operators selected earlier start-up times. This avoids the everyday start time of 3AM (Monday) to 4AM (other weekdays) and saves multiple hours of AHU energy usage daily.
- Tighten up schedules for systems that serve spaces with little to no perimeter impacts (basement, library, etc.) or non-office spaces (health club, etc.). They are not designed as "working" spaces that need to meet the same mandates for comfort level attainment by the start of the work day (6AM-7AM).
- Lighting schedules on the BAS should also be evaluated for further delay on startup and for earlier shut down (rather than the current 9PM turn off time).

Finding: Leaky valve and need for AHU temperature controls at LBJ Building

Overnight "baking" was found in the LBJ Building, in which building temperatures rose during cold winter evenings and the HVAC system needed to cool the building during startup the next morning. Building engineers can seal the leaky hot water control valve to temper this inefficient energy operation.

Figure 2 is the BAS trend data chart for the LBJ Building's AHU-1 system. The discharge air (black line) and mixed air (red line) temperatures on the AHU-1 rise from 90°F to almost 110°F during unoccupied periods. Valve is leaking, because the hot water control valve's signal (teal line) is indicating 0% open during the same time period in the charts.

Engineers remedied this situation on the spot by increasing the output signal to the valve from 8 psi to 12 psi, which closed it completely.

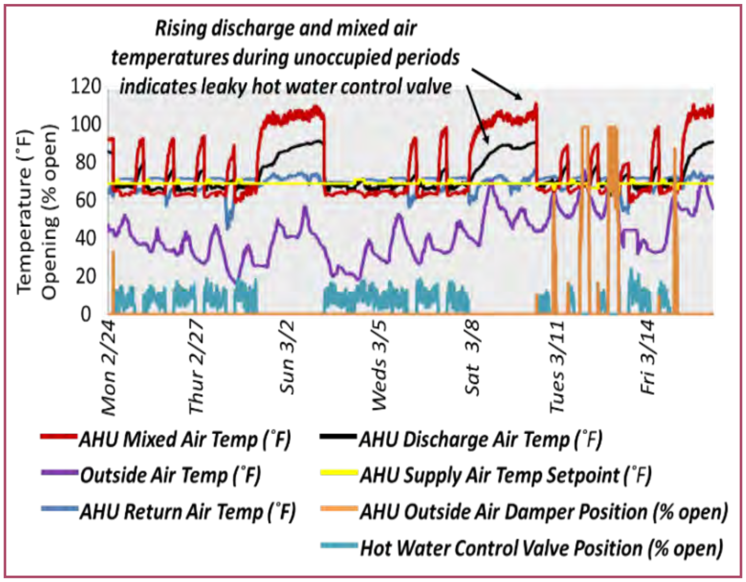

Figure 2. BAS trend data shows AHU-1 discharge air and mixed air temperature data

Recommendation: Utilize BAS Optimal Start Opportunities

BASs often have an "optimal start" function that automatically determines the optimum time to activate the HVAC system to return the space temperatures to within 1 to 2°F of desired set points just prior to scheduled occupancy. Over time, the system "learns" the optimum time (see Figure 3) to pre-start when conditions mandate. This saves energy when compared to thermostats that often start the HVAC system earlier than necessary. To keep the desired indoor

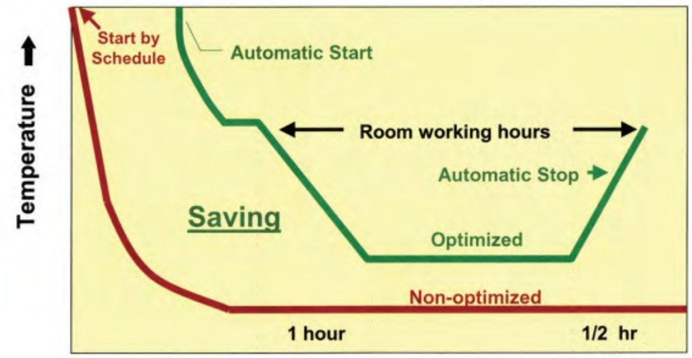

Figure 3. Energy savings over a workday using optimal start versus a BAS schedule

Table 1. No- to low-cost re-tuning measures implemented at the LBJ Building

System	Measure
Scheduling	Manually changed the start-up set points on the main equipment by one hour later. This gives us a new normal Monday morning start up at 4AM, and a Tuesday through Friday start-up of 5AM.
Set Points	For Monday morning startups, building staff manually start equipment. During warm periods, will run the building early to bring in free cooling from outside. Building operations are changed based on outside air temperature. Overall reduction in run time has not increased tenant complaints.
Set Points	Make micro adjustments to temperature and airflow in response to tenant complaints that allow optimal comfort, without distorting the building's airflow balance. Technicians check temperatures shown from the BAS sensors and actual conditions at the location, as well as air flow rates that are being shown compared to the design specs.
Cooling Towers	Lowered the condenser water temperature set point from 83°F to 80°F. The lower condenser water temperatures will improve the chiller performance.
Lighting	Changed primary lighting to LEDs in two large offices and a conference room on the 7th floor. The Department of Education plans to voluntarily incorporate LED lighting in all future interior alterations in the building.
Scheduling	The BAS has the capacity to "learn" optimal HVAC start up times to have the building reach occupied space conditions when it is required. The building's management plans to exercise this BAS option.
Scheduling	Reduced exhaust schedules (no longer 24 hours), and fixed the negative pressure in the building.
Lighting	For desk task lighting, building operators worked with the tenant to turn off lighting via motion sensors.

temperature, the BAS calculates and reads indoor and outdoor temperatures frequently in addition to other influencing variables. It then runs the specific apparatus for the minimum time required to reach the comfort zone at the beginning of the work shift. The LBJ Building would benefit from utilizing optimal start.

Finding: LBJ Building's BAS Reveals Area for Improved Return Fan Speed Control

Air Handling Unit (AHU) static pressure controls for all the AHUs appear to indicate that there may be room for improved return fan speed control. The BAS trend data chart (figure 4) for AHU-1 shows the supply fan speed (red line) and the return fan speed (green line) tracking with each other and never more than 10% (6 Hz) difference. Some AHUs are even tighter (5% or 3 Hz difference).

Generally, return fans are able to move significant amounts of air, even with smaller motors and slower fan speeds as a result of the much lower static pressure drops (no filters, no coils, and no ductwork) that these return fans are moving air through. If not controlled properly, they can contribute to negative building conditions.

Re-tuning measures to address this opportunity include

- Consider implementing a reset of the static pressure set point (adjust between 0.5 inches to up 1.0 inches.)
- Consider installing a sensor that monitors the building static pressure (referenced to outside). With a reliable and properly located building static pressure sensor, the return fan speed control can be better managed to prevent over-speed operations that result in negative pressure building conditions.

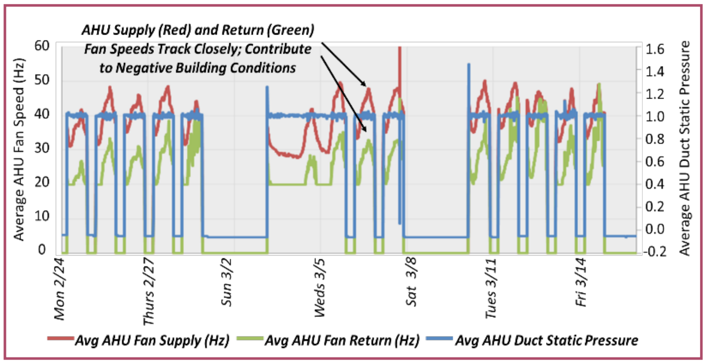

Figure 4. BAS trend data from LBJ AHU-1 system show supply static pressure and fan speed data

Courthouse Annex:

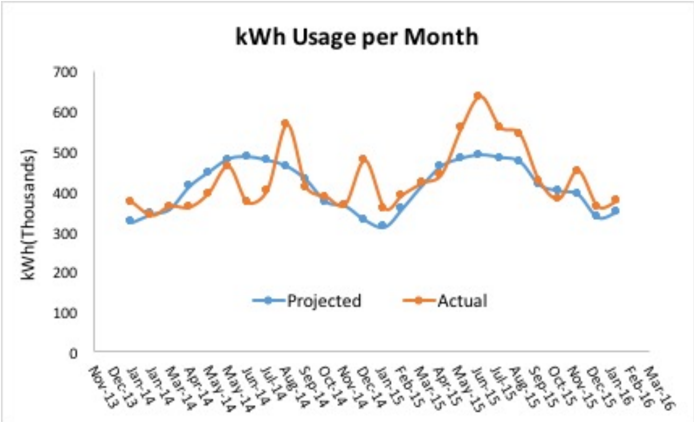

Figure 5. Projected kWh usage in Courthouse Annex based on monthly consumption prior to re-tuning.

In the two years post-retuning the electricity consumption has increased by 4% compared to the pre-retuning projected energy consumption. (figure 5). It should be pointed out that energy data was not normalized for occupancy.

Since 2014, set points and operation schedule adjustments have been evaluated periodically. Also, since January 2016 GSA has cut back the lighting schedule by 4 hours in the garage and the atrium.

Concurrent with the re-tuning period, the building was subject to capital improvements and until the impact of those improvements are fully measured and documented, the impact of building retuning cannot be accurately measured.

Finding: Automatic-Reset for Annex Heating Systems to Run at Design Specifications

The Annex reheat system and perimeter heating system are each designed with two pumps, yet only one pump is used to run each system. However, these are VFD-driven pumps, so additional energy savings could be achieved by running both pumps in tandem. The reheat loop temperature was observed to be ~148°F, which is considerably higher than necessary. To address this excess temperature, the set point for the reheat loop should be on an automatic reset algorithm. Building operators could implement an automatic set point reset algorithm based upon either the outdoor air temperature or based upon the average reheat valve position (demand-based). In either case, the reset algorithm should take advantage of the system design (steam heat exchanger), which allows for much lower set points than non-condensing boiler systems. Therefore, building operators could reset the reheat loop set points as low as 100°F to reduce steam consumption and minimize waste heat from leaking valves at terminal boxes.

It was not clear if the reheat system was configured to automatically lockout based upon increasing outdoor air temperatures. Building operators could evaluate this configuration and implement outdoor air lockouts for the reheat system to take advantage of warmer weather. If discharge temperatures are configured to de-humidify (overcool), ensure that this is done judiciously. If not, the reheat system may run when not needed.

Finding: Determine if Annex Economizers Are Working Efficiently

The BAS controls for AHU-6E, shown in Figure 6, indicate that the outdoor air temperature is 53°F while the mixed and preheat temperatures are indicating between 58.5°F and 58.9°F. The return air temperature indicates 73.8°F. The

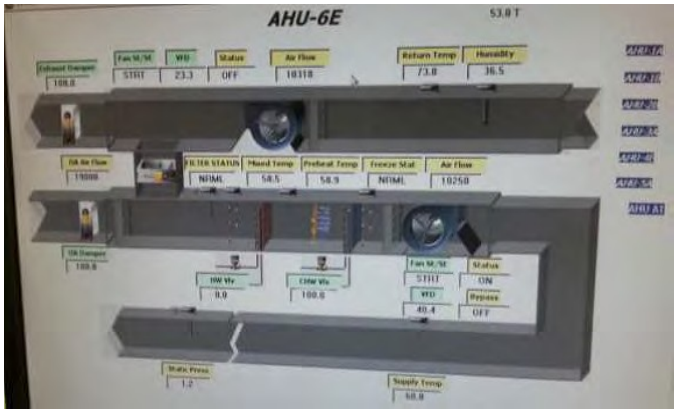

Figure 6.AHU economizer damper commands and temperature sensor data

Table 2. No- to Low-Cost Re-tuning Measures Implemented at the William Bryant Courthouse Annex

System	Measure
Garage Fans	Reduced garage fan operating runtime and frequency from 168 hours/week at 60 hertz to 55 hours/week at 25 hertz, using 7 fans with 40 hp motors and 3 fans with 25 hp motors.
Steam Supply	Shut off steam supply for the AHUs and VAV boxes for the summer months (June-September). The system was designed to both heat and cool during the summer months, GSA NCR has been able to shut the steam off by making constant changes to discharge air temperatures.
Steam	Shut off steam supply to the snow melt system for summer months.
Schedule	Changed building start up times from 3:30am to 6am unless there are extremely hot outside air temperatures for the day – this led to almost a 20% savings on start-up.
Set Points	Changed supply temperature set points from 55 to 58 degrees.
Lighting	Installed ~40 motion sensors in mechanical and electrical areas and public restrooms.
Schedule	Changed chillers shut down times from 6PM to 5:30PM.
Lighting	Changed outside lights that were on the emergency lighting circuit to be on the normal circuit.
Steam	Insulated steam heating lines in the Annex plant.
Chilled	Increased chilled water set point from 42° to 43-45° depending on outside air temperature.
Garage Lighting	Planning a lighting project to replace all garage lighting with LED bulbs using a time clock and motion sensor system. Garage lights were on 24/7, but the system will run 5 days a week (M-F) from 7AM to 6PM. This will reduce lighting time from 168 hours/week to 55 hours/week.
BAS	Planning a BAS upgrade in to enable further energy saving improvements and connect the building's BAS to the GSA network.

calculated outdoor air fraction is greater than 70% (not 100%, as indicated by the BAS data). This disparity indicates inefficient economizer usage.

Determine if economizers are working properly. Evaluations should include review of control code as well as mechanical linkage and actuators. The AHU in the BAS graphic appears to be leaking air from the return section, into the mixed air section, resulting in warmer discharge air temperatures.
Building engineers should verify that economizer linkages and dampers are working properly.

Finding: Reduce Annex Base Load by Turning off the Snowmelt Pump in Summer

The snow melt pump and heating system was found running while outdoor temperatures were > 50°F. Turning off the snow melt pump provides an opportunity to reduce non-essential base load. To implement this re-tuning measure, operators need to verify that the snow melt controls only activate the pump and heat exchanger when snow melting is really needed. This activation should only occur when the outside air temperatures are below freezing and when the dew point is low enough to cause sufficient freezing of moisture on the surface of the sidewalk or parking ramp (whatever surface is designed to have snow or ice automatically melted). Otherwise, this pump and heating energy are being wasted. Without the re-tuning, this pumping energy could have become part of the Annex's base load and been "missed" as an opportunity to reduce non-essential base load.

Recommendation: Conduct Building Walk through to Identify Over-lit Spaces

Building walk-throughs help identify efficiency opportunities such as over-lighting in mechanical spaces and garage areas. Figure 8 shows an over-lit mechanical room in the Annex.

Parking garages often have a significant number of metal-halide fixtures that are on 24/7. Building operators can implement parking garage lighting upgrades with occupancy controls and LEDs to increase efficiency. Mechanical rooms also offer an opportunity for reduced lighting system usage via manual shut-down or occupancy sensors. Sometimes hundreds of light fixtures may be optimized by increasing the amount of time they are turned off. Operators installed ~40 motion sensors in Annex mechanical and electrical areas.

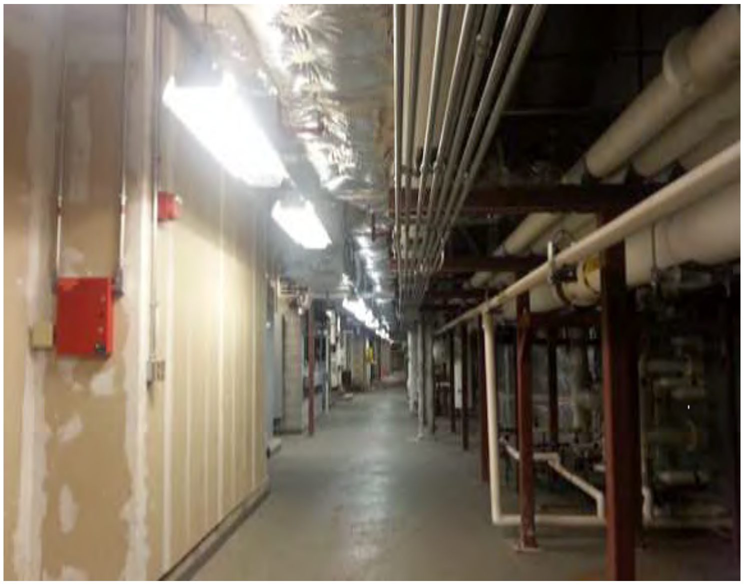

Figure 7. During the Annex Re-tuning building walk-through, operators found lighting in this mechanical room always on

Operators can also make improvements by de-lamping. Reductions can be confirmed by conducting light level measurements or by removing every other light fixture and running a test to determine if adequate light levels still exist. Removing every other fixture reduces energy use by 50% and creates spare lamps and fixtures for future lighting operations.

Summary of implemented capital improvements for LBJ and Courthouse annex:

LBJ: in demand flow project, the accurate differential pressure meters improve the matching of chilled water flow to load on chillers, and results in a 4-6 years payback which is approximately $400,000 in saving. As a result the LBJ building will further reduce energy use in the next operating season (Spring 2016).

Courthouse Annex: At the time of re-tuning, the BAS system was upgraded significantly. In January 2016, lighting was upgraded to LEDs in the parking and the Atrium. In addition, new chillers were installed and will be up and running starting May 2016.

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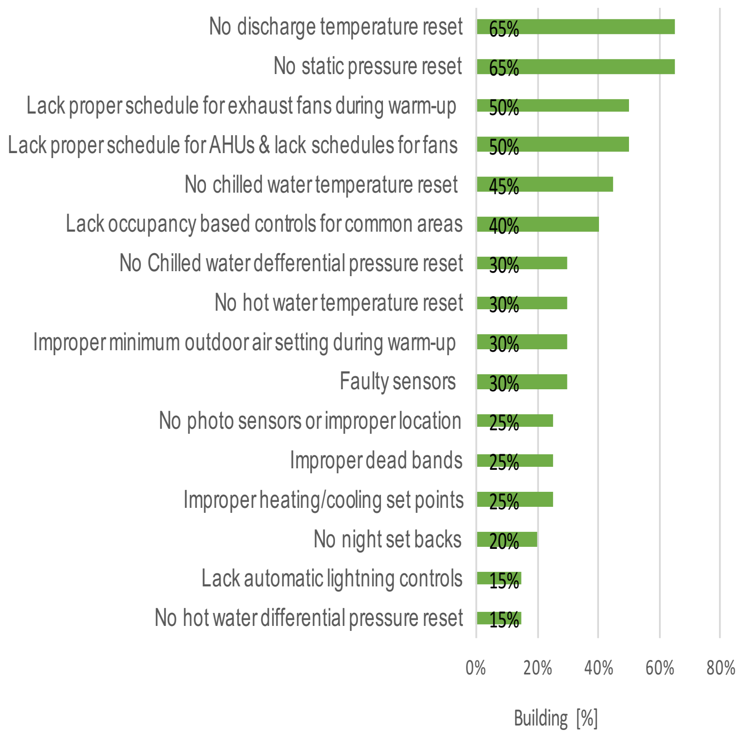

Figure 8. PNNL Meta-Analysis of 100 Commercial Office Buildings (2013-2015)

How to read this chart:

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Re-tuning Case Study

Parmenter Re-tunes Las Colinas Tower for Significant Energy Savings. Dallas, TX

Energy Star score improves by twenty-four points with Building Re-tuning training.

Address: 225 E. John Carpenter Frwy, Irving TX
Owner: Parmenter Realty Partners Size: 349,436 sq ft.

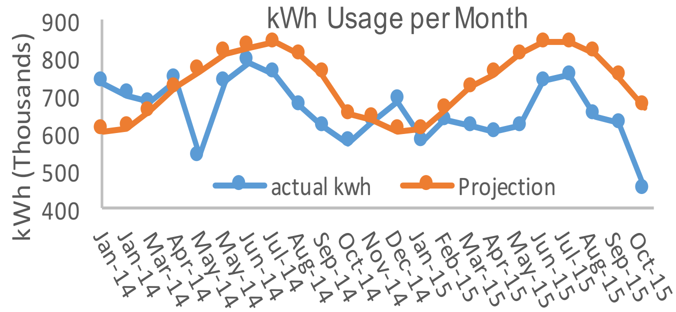


Figure1. Projected kWh usage based on a year's monthly consumption prior to re-tuning and weather normalization.

As a member of the Better Buildings Challenge, Parmenter Realty Partners is constantly looking for ways to improve their sustainability and reduce the impact their buildings have on the environment. Building re-tuning provides an opportunity to reduce energy consumption across the company's portfolio. In January 2014, with training experts from the Pacific Northwest National Laboratory (PNNL), Parmenter re-tuned its Las Colinas Tower II building in Irving, TX. Re-tuning provided the facilities management team with the ability to identify and understand building scheduling opportunities that drove significant, low-cost energy savings.

In the 2 years post-re-tuning, the building has saved an average of 9.7% on its electricity usage due to a long list of energy savings opportunities (details shown on following pages (Figure 1). Las Colinas Tower II also improved its ENERGY STAR score by 24 points from 55 to 79.

Initial implementation of re-tuning measures led to the discovery of additional efficiency opportunities. s First, Parmenter adjusted the outside air temperature sensor placement so it would read more accurately. Once the temperature sensor was calibrated, the operators realized that their BAS program contained numerous additional overrides. The more the Las Colinas building engineers investigated the root logic of BAS operations, the more opportunities they identified. Over the span of a few months, Parmenter implemented over two dozen no- to low-cost re-tuning measures and is continuing to re-tune Las Colinas II periodically for consistent savings.

What is Building Re-Tuning?

Building re-tuning is a systematic process to identify and correct building operational problems that lead to energy waste. Building Re-Tuning Training is a blend of building walk-throughs and classroom instruction that teaches building operations staff and service personnel how to save energy and increase occupant comfort through low and no-cost operational improvements. There are two versions of the training: Observation-driven re-tuning for buildings without a building automation system (BAS) and data-driven re-tuning for buildings with BAS. This case study utilized the data-driven protocol.

No- and low-cost savings opportunities include items such as replacing faulty sensors, adjusting set-points and inefficient schedules, utilizing variable speed fans and economizers, insulating pipes, adding CO2 sensors, widening thermostat dead bands, and sealing building envelope leaks. This process can reduce building energy use up to 25%.

Building re-tuning saves energy and money

From late 2013 to early 2015, PNNL helped identify re-tuning measures in 100 office buildings. Many, but not all, of the recommended measures were implemented by the building operations staff. Annual energy savings ranged between 2% to 26%, with a median savings of 15%. Annual normalized cost savings ranged between 0.0$/sf to 0.6$/sf, with a median savings of 0.12$/sf. If all re-tuning measures identified were implemented, the savings would have been even larger.

Example: Re-tuning Opportunity to Adjust Negative Building Pressure & Reheat Inefficiencies Found in BAS Trend Data

In Figure 2, the mixed air temperature (green line) and return air temperature (blue line) trended data readings both show patterns that may indicate the building is operating in a negative pressure condition at night (and perhaps even during the day). After the supply fan shuts down, both the mixed air and the return air temperature sensors immediately drop toward the outdoor air temperature value (teal line), in some cases dropping as low as almost 40 F.

It appears that during the 6-day period in November, the return air temperatures progressively got cooler (possibly indicating that this building also got cooler). Perhaps the reheat system is not working properly, or some other issue exists such as significant infiltration. There is a re-tuning efficiency opportunity to explore further and solve the root of the problem.

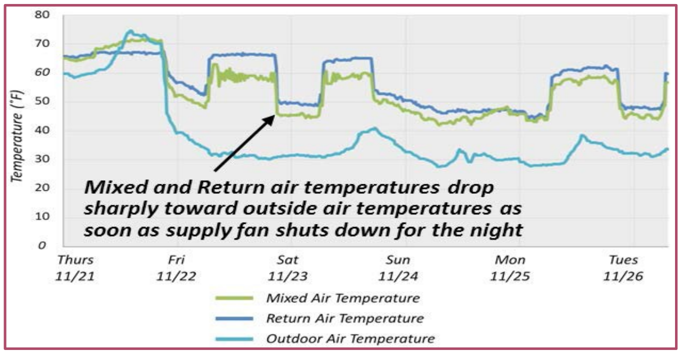


Figure 2. Trended Data Showing Return Air and Mixed Air Temperature Performance

Table 1. Sampling of Re-tuning Measures Implemented for the Las Colinas II

Issue Area	Finding	Solution	Cost
Limited interaction with BAS by Engineers	Engineers were not internally trained to make changes to the BAS, relying heavily on the BAS vendor	Staffing was not 100%; need to hire a chief engineer with strong BAS experience. Plan training for engineers to properly use the system and make adjustments.	Within the property budget
Trending setup and monitoring	Trended data is invaluable for proper operation of the building	Trained engineers and now expect them to trend regularly	$0
BAS Vendor evaluation	Existing BAS vendor was not qualified to re-program the system, only to make minor adjustments	Replaced vendor	$0
Reprogram BAS	BAS programming has been compromised over time and new vendor couldn't make small cost effective changes without effectively rewriting	New vendor completely wrote a new program; all conflicting program logic	$18,000
Airflow gaps around the chilled	During the BAS walk down, found air leakage program that allowed air to flow	Installed sheet metal at open gaps to funnel the air through coils	$4,000
Calibration of pneumatic devices	A large percentage of pneumatic devices were out of calibration and water had been introduced to the system; the filter for air dryer was stopped up.	Recalibrate all pneumatic devices, add gauges to the air dryer, add more monitoring points to BAS for pneumatic system, train engineers on new HVAC tracking form for hot/cold calls	$17,00
Preventive Maintenance of dampers	Found that most dampers were dirty, gaskets are either missing or worn out, operation needs to be verified	Perform preventive maintenance on dampers and make all identified repairs. Make sure they operate properly per BAS program	In-house

Example: When Window-to-Wall Ratio is Significant, Re-tuning Opportunities Exist in Solar Load Efficiencies

The window-to-wall ratio is significant (at least 80% or greater) in Las Colinas Tower II, meaning that solar loading significantly impacts the building. Using a thermal imaging camera (see Figure 3), a significant difference in window temperatures on the south and west sides of the building was identified. East, south and west-facing windows exhibit significant solar gains on cold, but clear days (morning low temperatures around 20 F, afternoon high temperatures around 45 F). This was creating interior temperatures between 75 F and 78 F at the perimeter spaces facing south. Re-tuning measures to consider for buildings to counter solar heat gain include:

- Send periodic messages to occupants via email to encourage the judicious use of window blinds during peak solar conditions.
- Turn perimeter lights off (where controls and switching allow) to reduce the heat gain from electric lighting loads (trade off the solar gain with the lighting heat gain or vice versa) or de- lamp where possible.
- Window tinting may be an effective investment, but should be carefully evaluated for correct tinting materials and installation methods to safeguard windows from damage

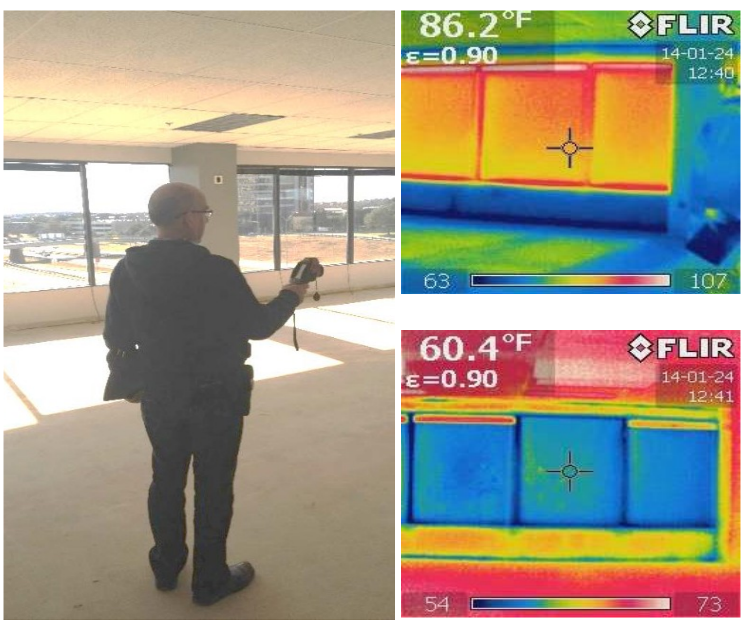


Figure 3. A thermal imaging camera is used to identify solar load for south-facing (top) and west-facing (bottom) windows

Strategy for Success: Don t Rely Solely on your BAS. Walk Down the Building Too

Building engineers sometimes rely too heavily on BAS alerts and not enough on in-person building walk-downs. While sophisticated BASs open up many possibilities for identifying efficiencies, some efficiency opportunities can only be identified from the physical act of walking through the building.

Building walk-downs help operators to get to know the building better and develop a general impression of the overall building condition, building systems, and HVAC system design.

The major steps of a building walk down include:

- Review electrical and mechanical prints
- Walk the outside of the building
- Walk the inside of the building
- Walk down the roof
- Walk down the air handlers
- Walk down the plant area
- Review the DDC system (BAS) front end

After the re-tuning training, the Las Colinas team decided to walk-down the building after hours. Operators found numerous inefficiencies: heat on after hours, task and break room lighting on while space was unoccupied, and terminal air fans running.

To solve this, they asked security to turn off all lights left on by tenants, and proposed installing electric to pneumatic (EP) switches on every floor to shut off all non-essential loads after hours.

Figure 4. Building walk-down included checking above the ceiling for duct condition, etc. (left) and reviewing electrical and mechanical prints (right)

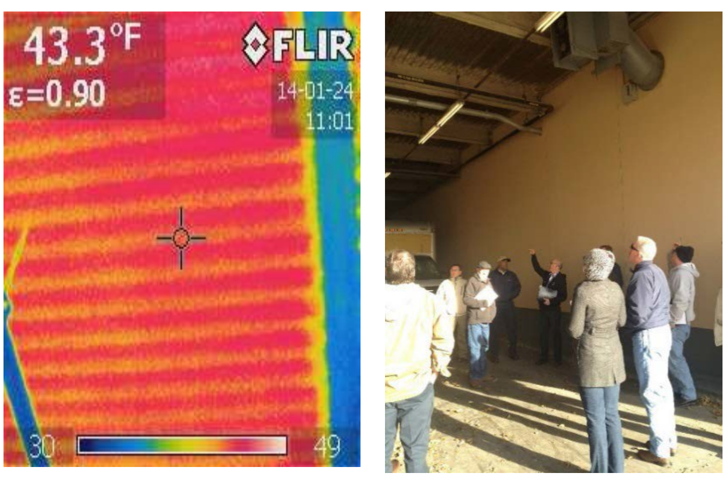
Example: Re-tuning Opportunity Identified in Las Colinas II Loading Dock Ceiling

Figure 5 shows an infrared image of the Parmenter Las Colinas II loading dock ceiling, just below office space. The outdoor air temperature is 30 F while the ceiling temperature was measured much higher at 43.3 F. During the re-tuning training building walk-down, it was noted that the loading dock ceiling insulation may be lacking. This likely has resulted in heat loss/gain to the office spaces above, which could contribute to tenant hot/cold calls and energy inefficiencies.

Re-tuning opportunities include evaluating areas of missing insulation or poorly insulated/sealed locations in loading docks, parking garages, and similar areas open to the outdoors.

Such measures include:

- Verify that initial garage parking lot area under office spaces is adequately insulated (hard ceiling with access panels). Suggest using an infrared camera image of the floor from above (looking down) if access issues are a problem.
- Seal penetrations of conduits and piping that route from loading dock areas into the building.
- Look for similar penetrations that may not be sealed on all perimeter sides of the building



. Figure 5. A thermal imaging camera is used to examine the loading deck ceiling

Example: Problem with Manual Override of a BAS and Re-tuning Solutions

In Figure 6, the AHU discharge air temperature set point (blue line) appears to be manually adjusted, based on the staggered stair-step flat lines. The discharge air temperature set point in the control code was found to be reset automatically from the return air temperature with a secondary reset based upon the outside air temperature. Figure 6 hints at manual overrides being used, so perhaps the automatic reset values are too low.

Retuning Solutions:

- Use a return air temperature reset only (remove the secondary outdoor air temperature reset). The current reset operation is currently between 70 F and 74 F return air temperatures, but the reset should be based upon the return air temperature operating between 72 F and 76 F. This schedule will lead to more comfortable conditions and will decrease the need for occupants/tenants to request overrides of the system s schedule
- Reset the discharge air temperature (blue line) to be between 53 F and 63 F, a 5 F increase. The current operation is between 48 F and 58 F. With this increase, the supply air should still be cool enough to provide adequate cooling at the warmest zones and provide adequate moisture removal at the cooling coils. The existing reset parameters result in higher energy costs for cooling and subsequent reheating at the terminal boxes

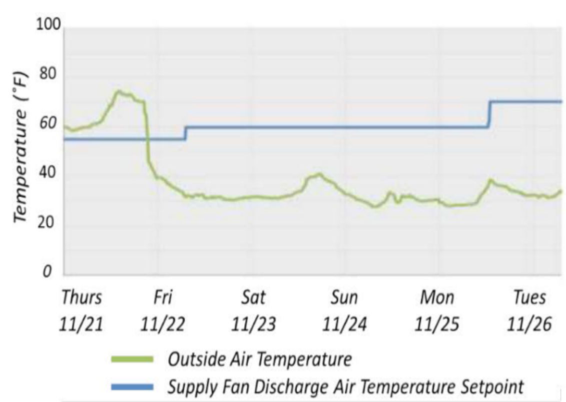


Figure 6. Manual Override on AHU Supply Fan Discharge Air Temperature Set Point

Why Invest in Building Re-Tuning Training?

Building Re-Tuning Training is a worthwhile investment because saving energy is not reliant on commissioning agents, energy auditors or professional engineers. Facility engineers and building operators - the people who are in the buildings regularly – learn to identify energy saving opportunities and act. The savings are regenerative because the trained building operator or facility engineer is able to continuously re-tune his/her building and maintain optimized conditions.

Summary of implementing re-tuning measures:

After the first re-tuning was completed by PNNL, Parmenter installed smart meters with Mach Energy so they can easily monitor how the building is performing in real time.

Capital improvements that have impacted building energy consumption since the original re-tuning are:

- Installed baffles around the chilled water coils where air was missing the surface of the coil to direct air across the coil
- Replaced defective chill water bypass valve
- Added inlet and outlet gauge on the pneumatic system and an alarm to notify the staff to clean the chilled water coils
- Cleaned the chilled water coils
- Rewrote the BAS program and completely retired the old program that was causing problems with the operation of the plant
- Monitored and adjusted the start times on the chiller, AHUs and other related equipment in the chiller plant
- Added/replaced door weather stripping
- Adjusted the statistic pressure in the building

Key actions the company took for re-tuning are:

- Purchased infrared cameras to help assess the envelope
- improve building operation
- Hired qualified engineers to run the building
- Applied building re-tuning training (BRT) to

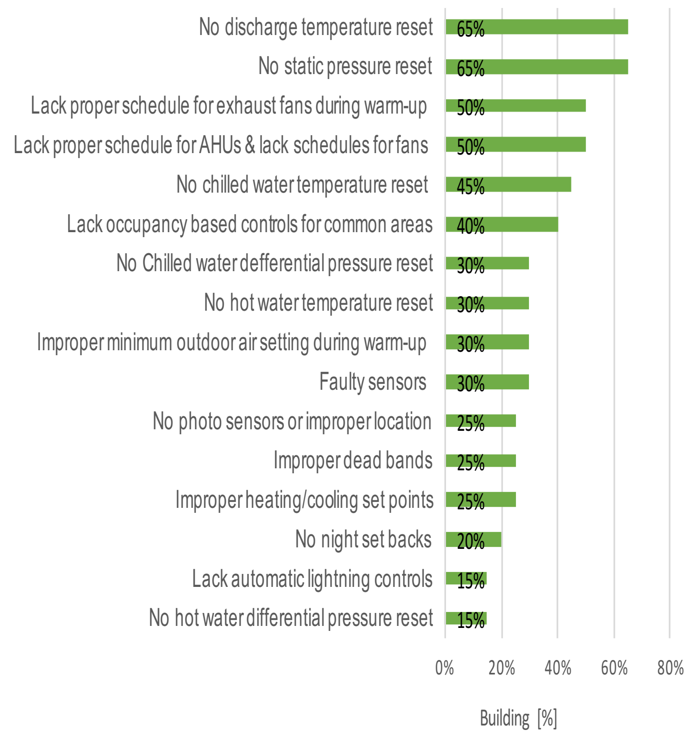


Figure 7. PNNL Meta-Analysis of 100 Commercial Office Buildings (2013-2015)

How to read this chart:

As many as 50% of the buildings in which re-tuning took place lack proper schedules for AHUs and/or lack schedules for exhaust fans or fans running during warm-up mode; over 65% of the buildings do not use static pressure or discharge temperature reset on AHUs; over 30% of the buildings have one or more faulty sensors and/or improper minimum outdoor-air setting during morning warm-up, etc.

Acknowledgements:

This case study and related work is funded by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Pacific Northwest National Laboratories created the building re-tuning training program and performed the building re-tunings for this case study. The Pennsylvania State University updated the results in 2016.

Re-tuning Training Opportunities and Online Resources

The Department of Energy funded Pacific Northwest National Labs (PNNL) to create the Building Re-Tuning Training program. Penn State led efforts for DOE to make Building Re-Tuning Training widely accessible. See https://www4.eere.energy.gov/workforce/projects/buildings-retuning-training for information about accessing the training. Classroom training material, training instructor manual and online re-tuning interactive training and energy charting and metrics tools are available at http://buildingretuning.pnnl.gov/