Commercial Building Retuning

A Low-Cost Way to Improve Energy Performance

By **Michael R. Brambley, Ph.D.,** Fellow ASHRAE; and **Srinivas Katipamula, Ph.D.,** Fellow ASHRAE

Retrocommissioning has been slow to penetrate the market, as demonstrated by the small percentage of existing commercial buildings that have been retrocommissioned. In the cases where retrocommissioning studies have been completed, implementation of suggested actions to improve building performance and efficiency has been somewhat limited. The advent of LEED for Existing Buildings has promoted commissioning of existing commercial buildings, and yet the fraction of all buildings improved in this way still remains small.

An experiment under way in Washington is testing a scaled-down version of retrocommissioning, which the project team refers to as commercial building *retuning*. The focus of this process is to identify and correct building operational problems that lead to energy waste. The process is implemented primarily through building automation systems (BASs) at little or no cost other than the labor required to perform it.

Small, low-cost repairs, such as replacing faulty sensors, are included. Larger, more expensive energy-saving measures that require capital investment, such as retrofits or replacements of equipment, are not implemented as part of retuning. Although these larger measures may be identified, an analysis of their potential impacts is beyond the scope of the process. The focus of retuning is identifying and achieving significant energy savings at little cost; it might be thought of as a scaled-down retrocommissioning process.

Some readers might wonder why anyone would deploy a scaled-down, less thorough, retrocommissioning process. The answer is that measurable improvements, with minimal capital investment and shorter payback period, are more readily approved by building management. Although full retrocommissioning may be financially sound, it can be perceived as risky because of large capital investments and, in some cases, long payback periods. When faced with multiple options, near-term, low-cost alternatives tend to win out over long-term investments in the commercial real estate world. Larger investments receive greater

About the Authors

Michael R. Brambley, Ph.D., and **Srinivas Katipamula, Ph.D.,** are staff scientists at the Pacific Northwest National Laboratory, Richland, Wash.

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managerial scrutiny to gain approval. Retuning shows potential for serving as a vehicle to introduce building owners, managers, and operations staff to a low-cost process that enables them to make significant measurable improvements in the efficiency of their buildings, without the barriers in decision making that might occur with full retrocommissioning.

Retuning provides practices and analytic tools that can be adapted easily to routine operation and maintenance of buildings with BASs. The pilot program in Washington State has an objective of transforming the practices of building operations staff by giving them the tools and knowledge to keep their buildings operating efficiently. The program focuses on training in-house and contracted building operation teams in performing retuning, so they develop hands-on experience in the process.

Training involves one day in the classroom, which is followed by up to four days of hands-on retuning of a building the team operates, all under the supervision of the trainers. Most trained teams then apply the process on their own to five more buildings to develop additional experience and firmly ingrain the method and procedures in their minds. Forms for logging findings, simple-to-use analytic tools, and reporting templates are provided as aids for performing retuning. Trainers provide technical support for the additional buildings by e-mail and phone, and training materials and answers to frequently asked questions are available on a Web site as additional support.

Successful experiences with low-cost retuning also may increase the receptiveness of building staff, management and owners to full retrocommissioning in the future.

The Retuning Process

Retuning consists of seven primary steps:

1. Collection of basic building information;
2. Trend-data collection and analysis;
3. Building walk down;
4. Identification and implementation of retuning actions;
5. Report of findings, recommended actions and recommendations implemented;
6. Savings analysis; and
7. Continued use of retuning in operation and maintenance.

In the first step, **collection of basic building information,** data are documented for building shape, building size (total gross square feet, rental square feet, and number of stories), building uses, floor area devoted to each use, age, occupancy schedules, types of mechanical systems, information to uniquely identify the BAS (manufacturer, model and version), and other basic information important to characterize the specific building, its systems and its uses. Much of this information already may be known by some building operations staff, but it is documented in this stage to validate a common understanding by the operators, provide information for technical experts to use in assisting the team, and for future reference. Information not known by the staff frequently can be obtained from the building plans (ideally, as-built drawings), consultants (e.g., a controls consultant), or the control system.

Trend-data collection and analysis is central to the retuning process. It serves the critical function of revealing commonly occurring operation faults, such as operation of HVAC systems during times when the whole building or zones are unoccupied. Time series trend plots of operational parameters help in identifying problems that require time histories for detection, e.g., incorrect schedules, no use of setpoint setback (and set forward) during unoccupied modes of operation, and poor operation of economizers. These faults generally cannot be detected by observing operations at a single point in time or for a short time. Using trend plots is the best way to identify such faults.

A monitoring plan is developed before implementing trend logs. The plan documents what needs monitoring and how. Besides documenting the monitoring put in place, creating a plan helps ensure that adequate forethought is given to the logging before implementation. This prevents discovering after collecting data for a couple of weeks that it does not meet the needs of the analytic process. Information documented in the plan includes identification of the points to be monitored and for each point the planned trend start time, the end time, the length of the measurement period (two weeks is recommended), the time interval between logged measurements (30 minutes or less is recommended) and the measurement units (e.g., °F for temperature). The trend logs are then implemented in the BAS. Implementation procedures vary with the control system but all BASs in use today, even those dating back 20 years, have trending capabilities.

During the trending period, the logs should be checked periodically (e.g., once per day or every other day) to ensure that data are properly recording. After the trending period, the trend logs are downloaded (or exported) from the BAS to files (e.g., comma-separated variable [csv] files). The format of trend log files varies with BAS, even between BASs from the same vendor. These data files are prepared for use with spreadsheet-based analytic tools provided for retuning. There are specific formats, which are compatible with the spreadsheet tools. When a data file is opened in one of the spreadsheet tools, specific graphs are generated automatically. As part of training on the retuning process, trainees are taught how to interpret each data plot and detect specific common operational faults. All graphs are reviewed, and the operational issues found are recorded for reference during implementation of corrective actions later in the fourth step: **identification and implementation of retuning actions**.

After an initial set of operational faults has been identified by analysis of trend data, the on-site process begins with a **walk down of the building.** The walk down is a systematic process to develop familiarity with the building and its systems. The purpose of the walk down is to develop a general impression of the building design and overall building condition, to identify specific problems likely causing energy waste, and to uncover or verify the HVAC system design. Even staff, who operate the building on a daily basis, uncover details of which they were unaware during a systematic walk down. The major systems and sources of information inspected in the walk down include:

- Electrical and mechanical design prints;
- Building exterior;
- Inside the building;
- Roof and the equipment on the roof;
- Air handlers;
- Plant area; and
- Control system (BAS) front end.

Many of the faults identified in the trend log analysis are confirmed during the walk down. All information and significant observations are recorded. Forms are provided for logging the information while walking down the systems or onto which observations can be transcribed afterward.

The next step is **identification and implementation of retuning actions.** Using the BAS, schedules are corrected, discharge-air temperature and pressure setpoints are adjusted, air-handling unit (AHU) heating and cooling adjustments are implemented, AHU outdoor air makeup control settings are corrected, zone temperature setpoints and schedules are adjusted, terminal box control is corrected (if problems exist), and adjustments are made to the control of chiller and boiler plants. During review

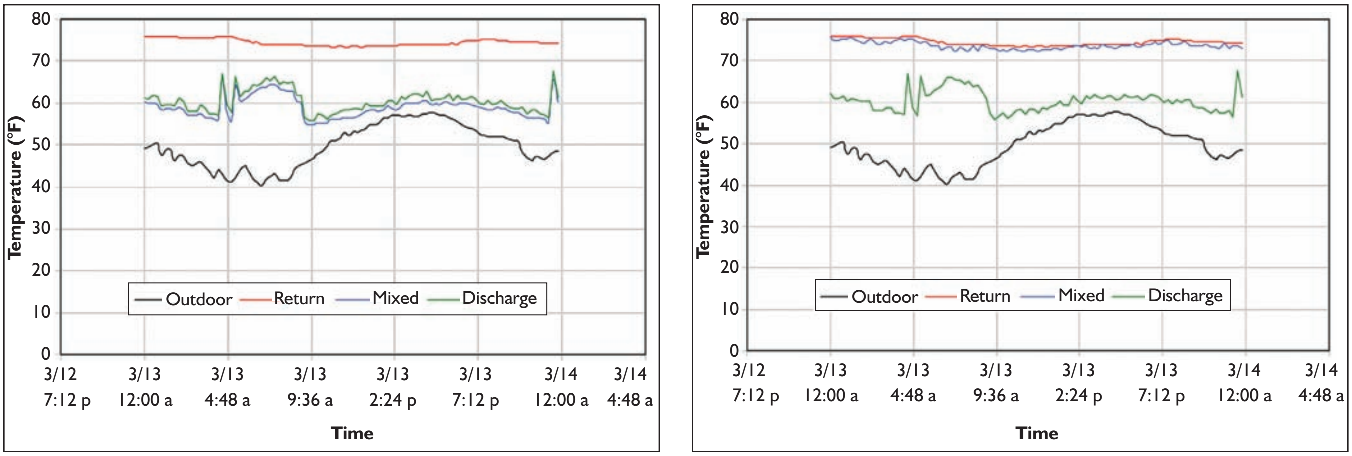

Figure 1a (left): Plots showing outdoor-air, return-air, mixed-air and discharge-air temperatures versus time for a properly controlled economizer. Figure 1b (right): An economizer with the outdoor-air damper stuck completely closed.

of the controls and making corrections, other problems with control code sequences and settings of fixed parameters can be detected. These are added to the list of faults detected and should be corrected.

Following implementation of corrective actions, all operation faults identified, actions taken to correct faults, and opportunities identified for further improving the operating efficiency through future retrofits are documented in the **post retuning report**. This report documents all opportunities identified in the retuning process and the status of each. The faults not corrected represent opportunities for additional low-cost energy savings through follow-up actions.

The **savings analysis** is critical to determining the degree to which retuning has succeeded in satisfying its objective of

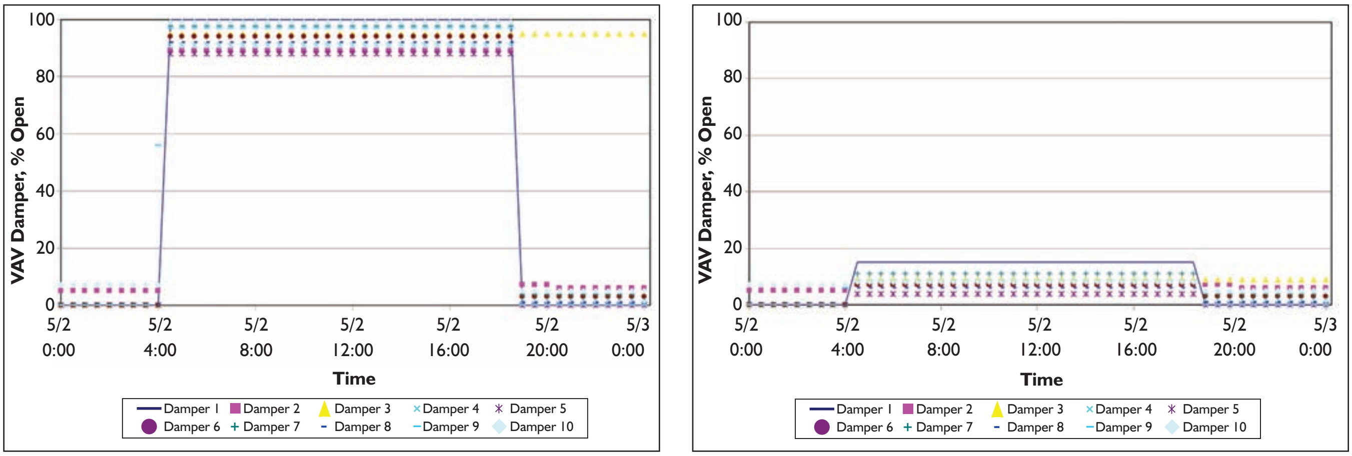

Figure 2a (left): Plots showing the damper positions for 10 VAV boxes, where the boxes are starved of air so the dampers are all nearly fully open. Figure 2b (right): Excess static pressure results in all dampers being nearly closed.

saving energy. The authors recommend evaluating savings on a 12-month annual basis. Annual savings ($E_{savings}$) are calculated as the difference between the actual energy use in the 12 months following completion of retuning (E_{actual}, e.g., the sum of the energy consumption shown on monthly utility bills) and the energy that would have been used during the same 12 months if the building had not been retuned (E_{base}), i.e.,

$$E_{savings} = E_{base} - E_{actual} \quad (1)$$

E_{base} should be determined from a model that captures the dependence of the building energy consumption on driving factors such as weather and building occupancy, which are sufficient to capture variations with time at the resolution of days or months for office buildings. For determination of an-

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nual savings, a model that provides monthly values of energy use can be used.

In this case,

$$E_{base} = \sum_{j=1}^{12} E_{base,j} \qquad (2)$$

Where, $E_{base,j}$ represents the energy consumption of the building in month j and the summation is over the 12 months following retuning. The model for $E_{base,j}$ can be determined from a regression of measured monthly energy consumption on terms that are functions of weather and occupancy (or other driving explanatory variables) for the data set of measured monthly energy consumption and values of the explanatory variables for each of the 12 months immediately prior to retuning of the building. The resulting regression model provides an equation from which the value of $E_{base,j}$ can be determined for each of the 12 months following retuning.[1]

Other methods and tools are available for determining energy savings from higher resolution data such as 15-minute interval electric data. At least one can be used to track energy savings on a daily basis.[2] Such tools can provide close tracking of energy savings after commissioning and a useful monitoring capability for quickly and easily detecting loss of energy savings, long before utility bill analysis would reveal such problems.

The seventh step to **continue use of retuning for operations and maintenance,** after the first six steps have been completed, is key to ensuring the persistence of the energy savings achieved from initial retuning. The key to ensuring continued savings is to continually or periodically trend the data (e.g., monthly or quarterly) as recommended for step 2, and analyze it using the spreadsheet tools provided or equivalent tools, such as those in the publically available Universal Translator.[3,4] Regular use of these tools will reveal when operating conditions have reverted to improper practices or may reveal new opportunities for improving operations, further increasing energy savings when implemented.

Analyzing Trend Logs

This section presents examples of how plots prepared automatically from BAS trend logs are used to detect operation problems that are easily corrected with changes in control parameters, control code, or disconnected components. Some of the faults that seem quite obvious cause the greatest wastage of energy—operating systems 24 hours per day when the building is occupied only a fraction of that (maybe 10 hours per day), no use of setback or set forward for unoccupied times, ventilating with outdoor air to cool down or warm up spaces before daily occupancy, and operating with automatic controls overridden. These problems can all be detected from simple trend-data plots. The following examples are more complex.

Air-side Economizer Operation

Air-side economizers are used to obtain free cooling with cool outdoor air used in place of, or to supplement, mechanical cooling when outdoor conditions are suitable for doing so. Unfortunately, economizers often do not work properly, causing energy-use penalties rather than savings.[5,6,7,8] Causes include incorrect initial installation of hardware or software, overrides of controls, and poor maintenance.

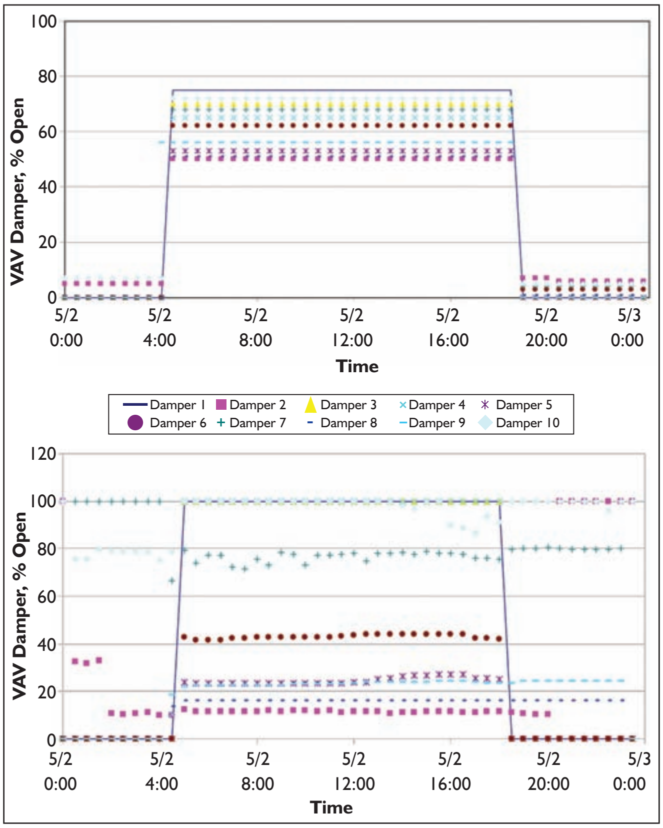

Figure 3a (top): Plots showing the damper positions versus time for 10 VAV boxes for a good distribution of damper positions with all between 50% and 75% open during occupied operation. Figure 3b (bottom): A marginally acceptable distribution of damper positions with more between 0% and 40% open than ideal.

Retuners are taught to look for several common incorrect behaviors of economizers, which result from incorrect control strategies, stuck dampers, disconnected or damaged damper linkages, failed damper actuators, disconnected wires, obstructions preventing damper movement, and failed and out-of-calibration sensors. A useful graph for detecting incorrectly operating economizers (with control based on dry-bulb temperature) includes plots of outdoor-air, return-air, mixed-air, and discharge-air temperatures versus time.

An example graph for a properly operating economizer is shown in *Figure 1a*. The outdoor-air temperature varies from nearly as low as 40°F (4°C) to as high as 57°F (14°C). All outdoor temperatures in this range are acceptable for economizing. The discharge air temperature tracks the mixed-air temperature closely, indicating that mechanical cooling is not being used and the outdoor-air flow rate is being modulated correctly. In contrast, *Figure 1b* shows time series for the same four variables for an economizer with the outdoor-air damper stuck fully closed. The mixed-air temperature tracks the return air temperature, indicating that no outdoor air is entering the mixing box even though the outdoor air temperature is in the same range as in

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Figure 1a. The outdoor air damper is not opening, which could be caused by any of the underlying faults that result in this condition, stuck dampers, disconnected linkages, failed actuators, or a disconnected actuator wire. Although only data for one day are shown in the two plots in *Figure 1*, the behavior would ordinarily be examined over many days to determine whether the underlying cause of the fault is intermittent or continuous.

Air-Handler Discharge Static Pressure

The second example relates to determining whether the discharge-air static pressure is reasonably controlled. In a variable-air-volume (VAV) system, if the static pressure is too low, most of the VAV terminal boxes served by the subject air handler will be starved of air and have their dampers nearly fully open during normal (nondesign condition) occupied operation (*Figure 2a*); if the static pressure is too great, the VAV boxes will have their dampers nearly completely closed to limit airflow into the zones (*Figure 2b*). For an air handler with a variable speed supply fan, the static pressure can be corrected by simply adjusting the static pressure setpoint.

Monitoring of the damper positions using the same trend data and plots initially used to detect the problem can be used to verify that the proper distribution of damper positions has been achieved or determine that further adjustment in the setpoint is required. When air is discharged at a good static pressure, most of the VAV box dampers will be operating between about 50% and 75% open (*Figures 3a* and *3b*) on days not close to design conditions.

Results from the Field

Interim results from retuning the first 30 buildings in the Washington pilot project reveal a few important observations:

- A number of operational problems have been found in many buildings. The three most common are: 1) systems running at times when they are not needed, 2) poor economizer operation, and 3) no reset used for chilled or hot water. Each of these problems was found in more than one-third of the buildings retuned so far.
- The reception to retuning training has been enthusiastic. Program participants see significant value in leveraging BASs to detect operational issues and graphically diagnosing their causes. Many positive comments on course content have been received from the managers and the technicians trained, and two organizations have asked for expanded offerings of the training.
- Despite the positive response to the training classes, many buildings staff are reluctant to make changes to systems for fear that anything changed could lead to occupant dissatisfaction and complaints. This reaction is common even for changes that can be implemented at little or no cost and have a high probability of significant energy savings and improved control of comfort conditions. This has limited the rate of implementation of corrective actions during initial retuning and required that many recommended actions be put on a list of actions deferred for future implementation.

In several cases, this issue has been discussed with organization management as a problem that might be corrected by clearly communicating to operations staff and subcontractors that they have the authority and are expected to make changes to system operations as part of the retuning process. In most buildings, progress is continuing in the desired direction, although in many cases slowly. This is an important issue that must be addressed to achieve the maximum energy savings and improvement in building operations.

Retuning is planned for about 26 more large commercial buildings under the pilot program for a total of 56 buildings and over 10 million ft^2 (929 000 m^2) of floor space. The energy savings evaluations will not be completed for several months. Preliminary estimates of energy savings for four buildings retuned by one service provider in Seattle show savings from 1% to 19%. The lower energy savings are for buildings where many of the potential improvements identified were not implemented because they required changes to parameters (e.g., setpoints) embedded in control code and not available through the control system's user interface. The higher energy savings portend significant benefits from the retuning process, provided the operational faults identified during retuning are corrected.

Future Dissemination

The Washington program is pilot testing retuning for large commercial buildings. The approach could be replicated in other locations or other approaches could be used for training and information dissemination. Widespread use of retuning could be supported and encouraged through government and utility programs similar to the Washington program or through education in community colleges, trade schools, and continuing-education programs are offered by professional and trade organizations. The tools developed to support the pilot program also could be made available more widely to building operators and engineers.

Work done to date has focused on developing the retuning process, delivering training to implementers, and testing the effectiveness of the process rather than on developing a business model for delivering retuning as a commercial service. Some service providers participating in the pilot program, however, have indicated that being a leader in offering such services keeps them at the forefront of their industry and differentiates them from their competition. Others see retuning as a way to effectively contribute to the sustainability of our planet. The authors envision creative entrepreneurs in this field developing ways to deliver retuning services as a product offering in the future.

Conclusions

Retuning focused on low-cost improvements to building operation provides a promising initial alternative to complete retrocommissioning of existing buildings. It can be implemented at little cost besides labor. Although energy-saving capital improvements are identified during retuning, their potential impacts are not analyzed in detail and they are not implemented as part of this process. They do, however, provide a starting point for evaluating future investments. Retuning emphasizes first getting

existing systems operating at their peak performance.

The reluctance of many building technical staff to implement changes relative to their status quo operational practices has been identified as the most significant barrier to reaching the full energy savings and performance improvements possible from retuning. Recognizing this, building owners and managers choosing to use this process and service providers offering it as a part of their services must take steps to address this impediment. They must ensure that technical staff feel fully empowered to make changes to correct the faults discovered during retuning and to make adjustments during the process that they might not ordinarily feel comfortable making. Clear communication of this authority to make changes without the risk of penalty is essential. Personal rewards to operations staff for achieving measurable improvements in building operation and energy efficiency might also be used to encourage staff to take actions beyond their normal comfort zone. By doing so, greater improvements will be achieved, and the staff will develop the confidence needed to continue to use the retuning tools and procedures as part of routine, day-to-day operations and maintenance, keeping their buildings operating efficiently and continually capturing new energy and cost savings.

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