Transforming Building Operation and Maintenance Practices through Interactive Building Re-tuning e-Learning

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ABSTRACT

Many problems that plague commercial buildings can be identified and corrected using a systematic, semi-automated approach called re-tuning, developed by Pacific Northwest National Laboratory (PNNL). PNNL has developed a Building Re-Tuning e-learning course to teach individuals how to use this approach to assess buildings' operations, identify opportunities for improvement, and implement no-cost and low-cost changes to reduce overall energy consumption.

Traditional approaches to training focus on memorizing facts and procedures rather than actively solving problems and identifying the root causes. In contrast, teaching by problem-solving uses real-world contexts that compel learners to actively apply knowledge. PNNL's approach to designing and developing web-based training systems is built upon fundamental cognitive learning concepts, sound instructional design principles, and innovative technical solutions to create virtual "hands-on" activities that facilitate learning.

The online course provides students the opportunity to not only learn but also practice the re-tuning process through a series of realistic interactive exercises. By the time learners complete the course, they will have already practiced gathering building information, trending building automation system data, responding to issues raised by building occupants, and re-tuning a variety of systems throughout a virtual building.

This paper will describe the PNNL methodology to developing the online building re-tuning training, including how interactive exercises are used to promote knowledge discovery and practice throughout the re-tuning process and how real-world contexts and challenges are designed into the instruction to provide learners meaningful, relevant activities that help them solidify the concepts and apply them in their workplaces.

Introduction

There is general agreement that the commercial building stock in the U.S. is not properly maintained and operated. There is also a general agreement that retro-commissioning (RCx) of these existing buildings saves energy in the range from a few percent to over 60%, with most reported savings in the range of 10% to 30% (U.S. DOE undated; Haasl and Sharp 1999; Claridge et al. 1996; 2000; Liu et al. 2002; 2003; Mills 2009). Despite all the benefits, there is a cost associated with commissioning (Cx) . A report on Cx in public buildings (Quantum Consulting 2003, pp. 1-3) states "While the concept of Cx is increasingly accepted, there are still barriers--particularly with regard to cost--to implementation of the kind of thorough, independent third-party Cx that is necessary for the full benefits of Cx to be realized." Only a small fraction of new construction and a very small fraction of existing buildings have been commissioned.

[1]Operated for the U.S. Department of Energy by Battelle Memorial Institute.

Even when performed, pressures exist to keep costs down, which in some cases limit the depth to which the Cx is performed.

There are two major reasons for lack of widespread adoption of RCx: cost and persistence. Although the payback associated with RCx in most cases can be less than 3 years (Mills 2009), there can be significant upfront cost – up to $0.6/sf. Because a number of measures that the RCx process corrects relate to our inability to control the building operations effectively, correcting these problems does not guarantee that these corrections will persist over time (more than 6 months). Therefore, a process is needed that is less costly and addresses the lack of persistence. In the long term, automation is the key to addressing both problems associated with the RCx, because it has the ability to identify operational problems as they occur. However, in the short term, because an automated process has not been developed and widely deployed, an alternate approach is needed.

To address the perception of high cost and the lack of persistence of RCx, Pacific Northwest National Laboratory (PNNL) has developed Building Re-tuning training, which teaches building operations staff how to detect inefficient operations and implement improvements that lead to reduced energy consumption and more reliable equipment operations. More recently, PNNL converted that training into an online interactive course.

This paper describes the PNNL methodology to building re-tuning instructions, including how interactive exercises are used to promote knowledge discovery, how a variety of presentation methods accommodate different learning styles by presenting key concepts multiple times in a variety of ways to improve retention leading to the ultimate goal to modify student's behavior as they transition from the e-learning course to real-world practice in their workplace.

Background

Periodic re-tuning of building controls and heating, ventilation and air conditioning (HVAC) systems helps eliminate inefficient and improper operations and improves building efficiency. Re-tuning, as it is practiced, is a systematic, semi-automated process of detecting, diagnosing and correcting operational problems with building systems and their controls (Katipamula and Brambley 2008; Brambley and Katipamula 2009). 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 for performing it. Small, low-cost repairs, such as calibrating and 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 re-tuning. The focus of re-tuning is identifying and achieving significant energy savings at little cost; it might be thought of as a scaled-down retro-commissioning (RCx) process. The process has been shown to identify operational problems that can be corrected with low- or no-cost – and the impact is immediate. Unlike the traditional RCx approach, which has a broader scope with significantly greater time and cost investments attached, re-tuning primarily targets HVAC systems and their controls (Katipamula and Brambley 2008; Brambley and Katipamula 2009). Because it is targeted and is less costly, it can be repeated periodically (every 3 to 4 months) to ensure persistence of operations.

The intended audience for this e-learning course is onsite employees responsible for day-to-day building operations; offsite contractors (retro-commissioning agents or control vendors) hired to improve a building's energy efficiency; and college students interested in entering this field. The focus is on large (100,000 sf) commercial buildings (offices, malls and schools), but the concepts and techniques presented can be applied to any type and size of facility that has a BAS.

One might wonder why anyone would deploy a scaled-down, less thorough, RCx process. The answer is that measurable improvements, with minimal capital investment and shorter payback period, are more readily approved by building management. Even though full RCx may be financially sound, it can be perceived as risky because of large 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 managerial scrutiny to gain approval. Re-tuning has shown 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 full RCx might face.

Furthermore, re-tuning provides practices and analytic tools that can be easily adapted to routine operation and maintenance of buildings with BASs. The re-tuning process was initially demonstrated in a pilot program in Washington State and then throughout the U.S. with an objective of transforming the practices of building operations staff by giving them the tools and knowledge to keep their buildings operating efficiently. The pilot program focused on training in-house and contracted building operation teams in performing re-tuning, so they could develop hands-on experience in the process. Training involves 1 day in the classroom, which is followed by up to 2 days of hands-on re-tuning of a building the team operates, all under the supervision of the trainers. Forms for logging, simple-to-use spreadsheet analytic tools, and reporting templates are provided as aids for performing re-tuning.

Over the past 5 years, PNNL has provided Building Re-tuning classroom instruction and field training to more than 300 building operators, engineers, and energy managers from more than 30 organizations. To reach a larger audience more quickly, PNNL developed a free interactive e-learning course, available to anyone interested in improving a building's energy and operational performance and the comfort of the building's occupants. However, the current classroom training approach has limitations because the building operations staff have to attend the classroom and field training in person. Therefore, PNNL has converted the building re-tuning training into an online interactive course that has a potential to reach a wider audience. Although online training may not be a complete substitute for classroom and field training, the approach that PNNL used to develop and present the training online has the potential to enhance the building operations capabilities of the people taking the course. After completing the online course, learners will have the tools and practice needed to identify opportunities for energy improvement in their own buildings and apply the re-tuning process.

Approach

Traditional approaches to e-learning focus on passively reading facts and procedures rather than actively practicing those procedures and solving meaningful challenges. In contrast, action-based learning, using real-world contexts and challenges compels learners to actively practice applying knowledge in realistic situations and, as a result, brings about modified behaviors in the workplace. By practicing relevant activities and thought processes, learners become more engaged with the training, are more motivated to learn, and can retain and apply their newly acquired knowledge and skills better (Allen 2003; Clark and Mayer 2008).Training effectiveness studies have shown that active learning (thinking and doing) results in much greater retention rates and behavioral modification than passive instruction (watching and listening) (Brown 2004; Clark and Mayer 2008; Horton 2006). PNNL's approach to designing and developing e-learning is built upon fundamental cognitive learning concepts, sound instructional design principles, and innovative technical solutions that use a variety of multimedia and interactive paradigms to facilitate learning. This approach is applied to the building re-tuning training to challenge learners in activities and environments that mimic those they will find in the workplace (Figure 1).

Figure 1. Example Scenario of What a Learner will Encounter

Within the online course, learners participate in virtual building inspections, performing the same activities and using the same tools they would see in their day-to-day jobs. In this example, the learner is checking temperature readings in an office by pointing a virtual infrared thermometer at various spaces around the room just like they would with a real thermometer.

PNNL began by designing and developing a virtual three-dimensional, two-story commercial building, as shown in Figure 2 This building includes a complete central plant containing chillers, boilers, pumps, an air handler, and supporting pipes, ducts, valves, and meters. Several office spaces, hallways, and conference rooms are also included, along with a roof area, complete with rooftop units, vents, and fans. Throughout the course, learners become familiar with this building as they work through inspection activities and re-tuning scenarios. They learn to gather and review information about the building (such as mechanical prints, electrical prints, current building use, occupancy type, etc.); set up and monitor trend graphs in a virtual BAS; examine equipment in and around the building; and get input from building occupants.

Instruction is presented using a variety of media. Introductory concepts are presented through text, animations, and graphics (Figure 3). The primary concepts are then reinforced and practiced through the interactive exercises. For each activity, the goal of presenting the learners with realistic contexts (both physical and intellectual) is a top priority. If learners can find relevance to their own work environments and activities, they are more likely to become engaged with the training, try their best to achieve success, and carry the learned behaviors back to their jobs (Allen 2003).

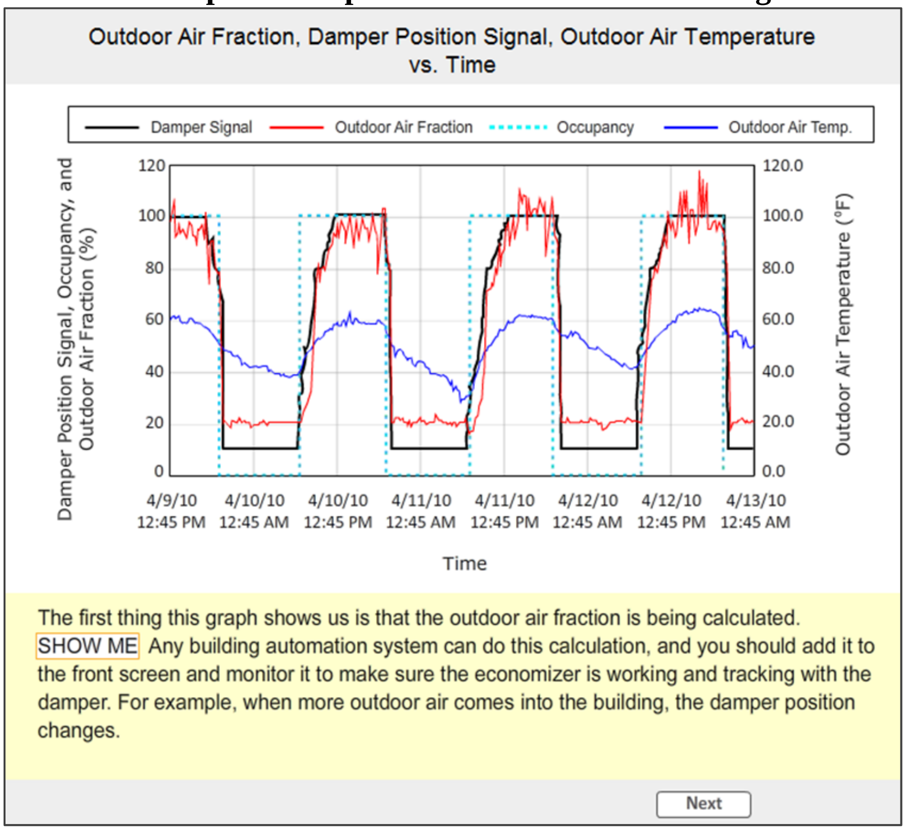
Figure 2. A Virtual, Three-Dimensional Commercial Building Serves as the Training Environment for Learners

Throughout the course, they have the opportunity to work outside, inside, and on top of this virtual building, performing field inspections, interacting with occupants, and practicing re-tuning activities.

In the initial practice activities, guidance is provided through hints and instructional feedback, based on the learner's decisions and actions. This instruction, which comes directly as a result of the learners' decisions, will help them achieve deeper levels of understanding and application. In the final re-tuning activities, learners apply everything they have learned about collecting and analyzing building information to complete over a dozen scenarios derived from real-world building operation experiences. For each scenario, a description of an operational issue occurring within the building is presented (Figure 4). Just as they would in the real world, learners must choose a course of action to identify the best solution for the particular issue. Solutions may be as simple as performing maintenance on a particular piece of HVAC equipment or as complex as setting up and trending building system data to discover opportunities to fine tune the systems and increase overall energy efficiency.

Because the primary goal of the building re-tuning process is to correctly identify opportunities for energy efficiency improvement and make the right decisions to correct operational efficiency issues, each of the interactive re-tuning scenarios demands a 100% success rate. Learners do not receive a score based on partially correct performance. Instead, incorrect solutions result in more opportunities to practice until the correct solutions are found. It is this repeated practice that builds new knowledge and skills into long-term memory that will enable learners to recall and perform the skills more readily on the job (Clark and Mayer 2008). More experienced learners who may have already acquired some of the required knowledge and skills can work through exercises more quickly, while those less experienced get the needed practice to help them solidify their understanding of the re-tuning process. In the end, everyone achieves 100% success. Instead of presenting multiple-choice quizzes, which usually test little more than short-term memory, PNNL's e-learning development team chose to provide more realistic and challenging activities to help engage learners and modify work practices.

Figure 3. An Example of Graphic Animation in the Training Environment



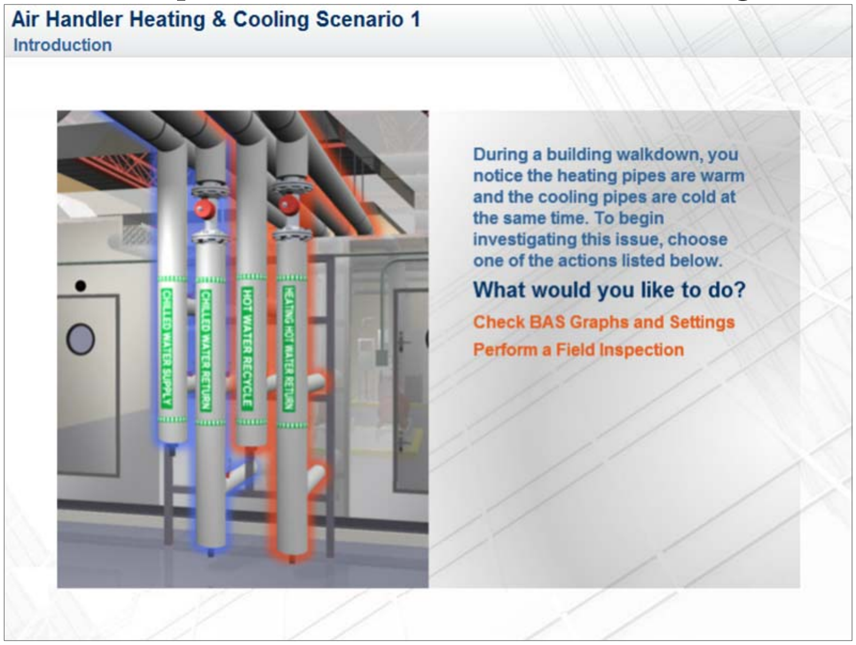
Animations, graphics, and interactive demonstrations are used to teach learners primary re-tuning concepts. Later, interactive exercises will help learners practice applying the information they have learned.

Example Scenario

In the final re-tuning scenarios, learners have the opportunity to walk through the re-tuning process to assess the current state of the building, listen to occupant concerns, investigate current system configurations and settings, and explore ways to correct problems and decrease energy use. One of the scenarios begins by informing the learner of an issue related to the BAS trend graphs. The learner must use all resources available to investigate and solve the problem. The learner may choose to explore the BAS graphs and settings, perform a field inspection to look for hardware configuration or maintenance issues, or do both (Figure 5).

Selecting the BAS path, the learner is presented with current system settings (set points, overrides, and alarms) as well as a trend graph with which the learner may plot an assortment of data points and look for anomalies (Figure 6). The learner may select any or all data points to plot on the trend graph. Relationships between the various data may help the learner find a solution (Figure 7).

Figure 4. An Example of Interactive Scenario in the Training Environment



In the final activities of the course, learners work through several interactive scenarios, with minimal guidance, to re-tune systems within the building and address issues reported by building occupants.

Figure 5. Options Presented at Beginning of Scenario

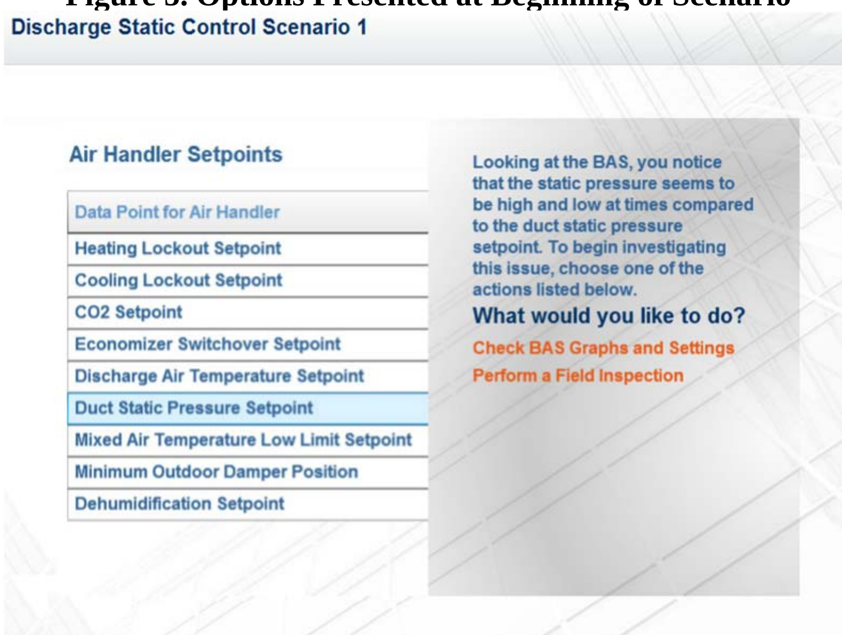
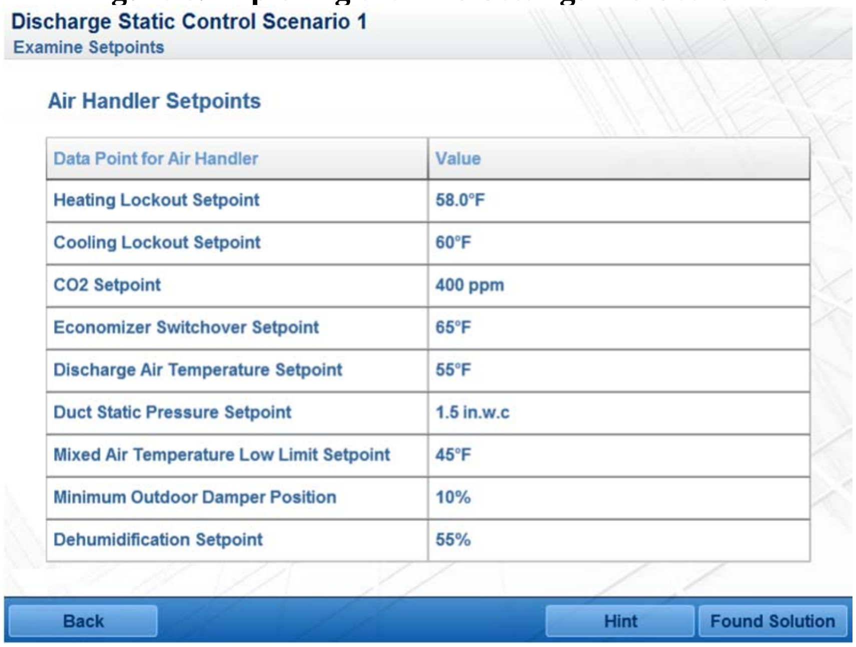


Figure 6. Exploring the BAS Settings in a Scenario



Data Point for Air Handler	Value
Heating Lockout Setpoint	58.0°F
Cooling Lockout Setpoint	60°F
CO2 Setpoint	400 ppm
Economizer Switchover Setpoint	65°F
Discharge Air Temperature Setpoint	55°F
Duct Static Pressure Setpoint	1.5 in.w.c
Mixed Air Temperature Low Limit Setpoint	45°F
Minimum Outdoor Damper Position	10%
Dehumidification Setpoint	55%

If the learner chooses to perform a field inspection, options to inspect various areas of the building are presented (Figure 8).

Figure 7. Plotting Trend Graphs at the BAS

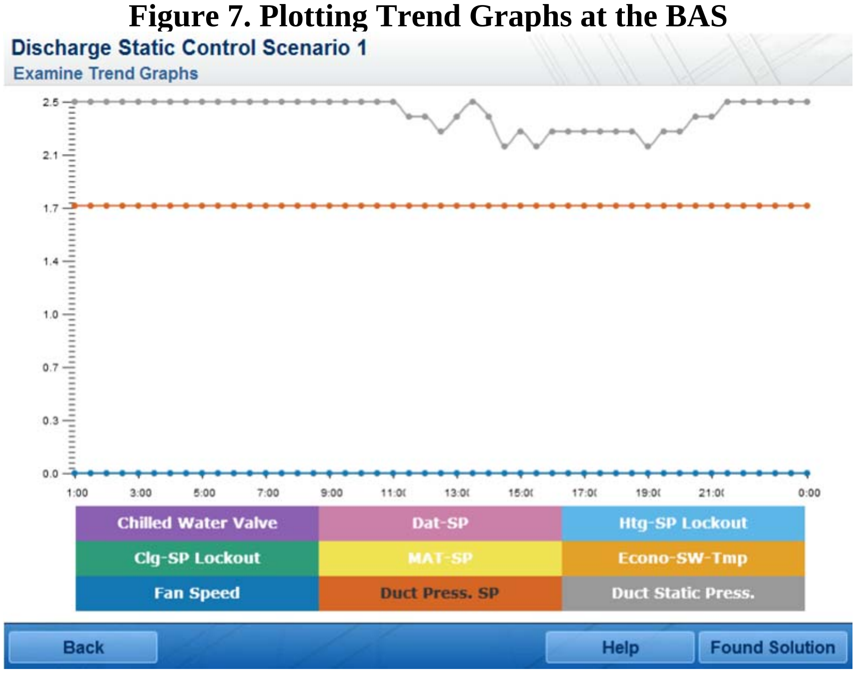
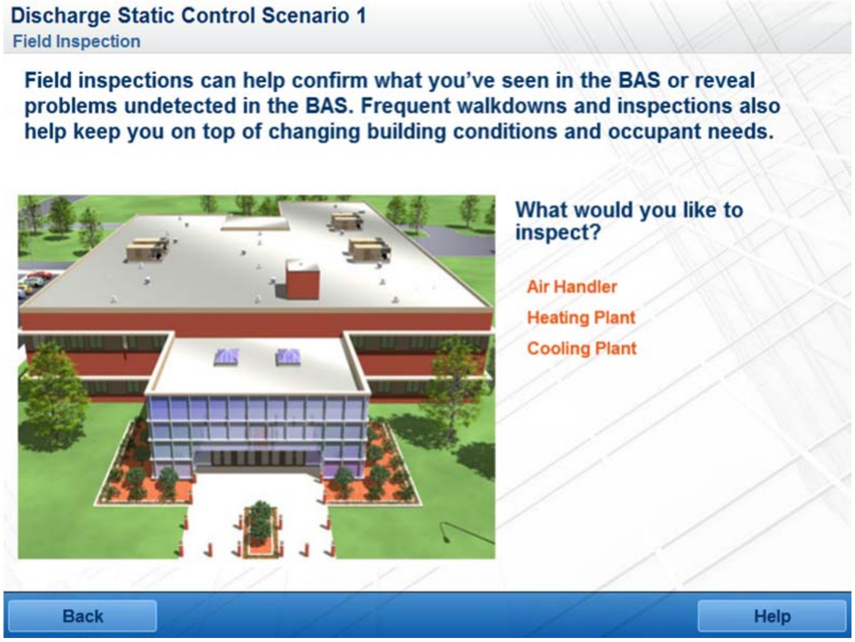


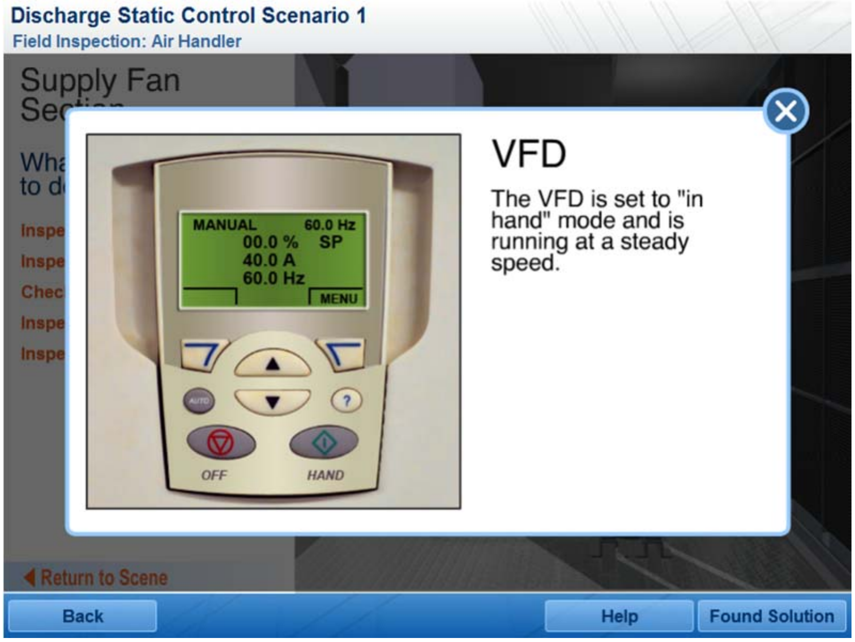
Figure 8. Example Field Inspection Options



Once at a particular location, the learner can drill down into the various pieces of equipment to review their current state (Figures 9 and 10). A maintenance issue may be discovered or perhaps a misconfiguration that is causing increased energy consumption. Some red herrings may be present at each step along the way, so if the learners choose to simply guess their way through a scenario, they may repeatedly find themselves at dead ends. They must carefully examine the information and keep the initial issue and goal in mind.

Figure 9. Exploring the Air Handler During a Field Inspection

Figure 10. Inspecting Individual Systems and Equipment During the Field Inspection



As soon as a potential solution is identified, the learner moves to the solution screen (Figure 11). Here, several possible solutions are presented, and the learner must choose the best one. If a wrong solution is selected, the learner is taken back to investigate further.

If a correct solution is selected, the learner is not off the hook. They must provide a justification as to why they chose a particular solution (Figures 12). Again, this reduces the likelihood that a learner simply guessed.

Figure 11. Selecting the Best Solution the Issue Presented in the Scenario

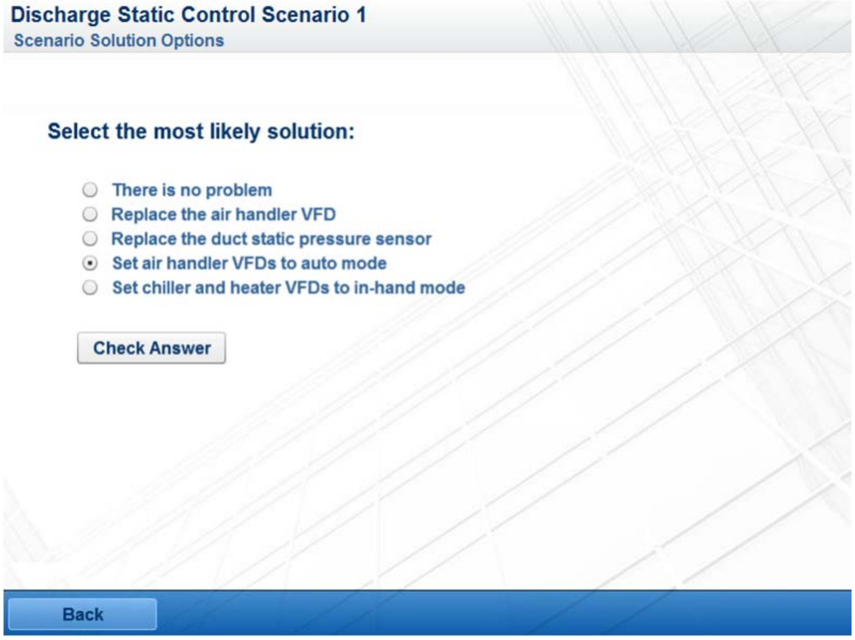
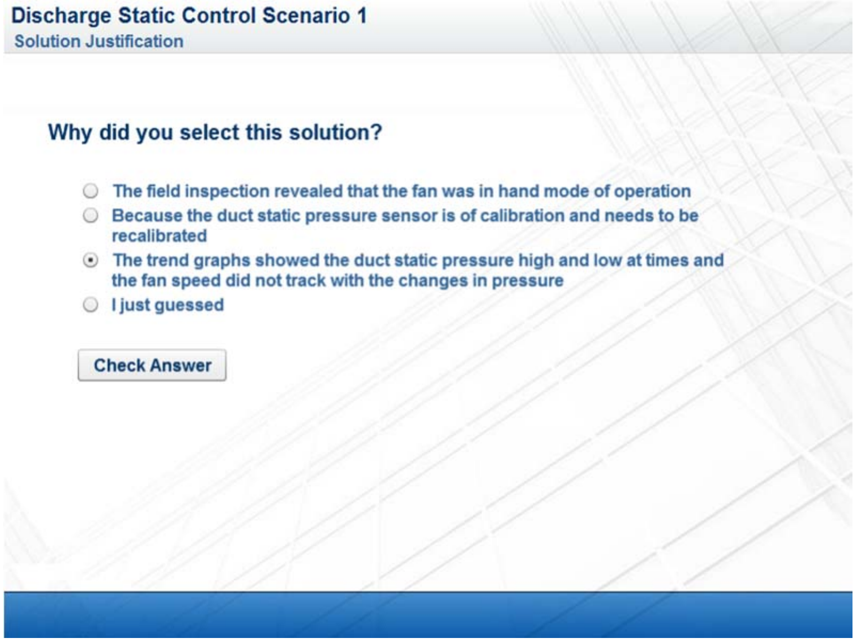


Figure 12. Learners must Provide Justification for the Solution They Have Selected



Current and Future Plans

The first version of the online training is currently available for free to anyone who would like to learn the building re-tuning process (http://retuningtraining.labworks.org). The course may be repeated as many times as desired or may be used for reference. Job aids, including tip sheets, checklists, monitoring plans, and templates are available to be downloaded, printed, and taken on the job site to facilitate the re-tuning process. A list of websites is also included to provide learners access to related building energy information. Work is currently underway to enhance the current course to provide more interactive exercises, practice scenarios, animations, and lessons.

Commercial buildings are not operated efficiently for a number of reasons, including lack of trained building operators. One of the ways to improve the operating efficiency of the buildings is to train the building operations staff on how to detect and correct operational problems as they occur. The building re-tuning e-learning training is a step in that direction to improve operator skills. After completing the online course, learners will have the tools and practice needed to identify opportunities for energy improvement in their own buildings and apply the re-tuning process, which will lead to more efficient commercial building stock.

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