AC 2010-371: USING A LIVING-BUILDING LABORATORY (BUILDING AS A LABORATORY) AS A THERMODYNAMICS PROJECT IN THE ENGINEERING TECHNOLOGY CURRICULUM

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Using a Living-Building Laboratory (Building as a Laboratory) as a Thermodynamics Project in the Engineering Technology Curriculum

Abstract

This paper is written as a follow-up to a paper presented at the 2007 ASEE Annual Conference and Exposition. In that previous paper the concept of using the actual Engineering & Design building at our institution as a Living-Laboratory was proposed. This building is a relatively new building and construction was completed in the fall of 2005. During the early design stages provisions were made to allow students access to various types of data used in the operation of the building. The desire was that the building would be used by students as a Living Laboratory for such classes as thermodynamics, fluid mechanics, strength of materials, and HVAC. Students would be able to see how the theory that was taught in their classes was put into practical use throughout the building. Courses taught in the department could use the actual data from the building in laboratory assignments. Although provisions for installing all of the desired equipment were part of the final design, as the construction of the building progressed fiscal concerns caused a reduction in the number of Living-Building Laboratory components that were actually funded. Over the past two years members of the School of Computing & Engineering Sciences have been using resources provided through a National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement program (CCLI) grant to obtain and install some of this equipment and to make the data available for student use. This paper describes the use of the Living-Building Laboratory data in a thermodynamics course. Specifically, for this laboratory exercise the students applied their theoretical knowledge of mixing hot and cold fluids to analyze the Variable Air Volume (VAV) mixing box in the thermodynamics laboratory room using the actual data from the building. An assessment of the effect of using the actual building's data in place of an educational laboratory apparatus on the students' ability to understand the course material is also discussed.

Introduction

In the fall of 2005 the School of Computing & Engineering Sciences at our institution moved into a newly constructed building. During the early design stages provisions were made to allow students access to various types of data used in the operation of the building. The desire was to have the building used by students as a Living Laboratory. Students would be able to see how the theory that was taught in their classes was put into practical use throughout the building. Courses taught in the department could use the actual data from the building in laboratory assignments. Core mechanical engineering courses such as thermodynamics, fluid mechanics and strength of materials would be able to use this data for student lab work. Electrical engineering students would be able to observe the digital control and feedback processes as well as the power equipment used to drive various building functions. Both disciplines would be able to collaborate in collecting data from the building and making predictions as to how they might be able to improve the efficiency of its operation. Modifications were made to the original design in order to provide for this new use of the building. Modifications made to the building included making the HVAC/control room extra wide to provide access for students to observe equipment and take readings as well as leaving structural elements exposed to provide locations to mount strain gages to record the loads on the building's structure. Additional instrumentation was proposed that included valve position sensors, fan and pump speed sensors, humidity sensors, additional temperature readings, and so forth. Although the provisions for installing all of the desired equipment were built into the final building, as the construction of the building progressed fiscal concerns caused a reduction in the number of Living-Building Laboratory components that were actually funded ultimately resulting in little of the original concept existing in the completed building. A grant through the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement program (CCLI) was obtained in order to restore some of the benefits of the Living-Building Laboratory concept and this paper describes the use of some of this newly available building data in a thermodynamics laboratory exercise.

Introduction to the Living-Building Laboratory Concept

The idea of using the academic building as a laboratory is an easy concept to grasp. Students in the sciences (and really all disciplines) should be taught to examine the world around them; asking questions and seeking answers. Students majoring in technical disciplines should have a more personal connection with the technical details of building operations. Typical of many, our department saw ourselves purchasing educational laboratory demonstrators for such engineering processes as pipe flow, pump performance, heat exchanger operation, etc. All the while these same processes were taking place in real-time within the very building the students were in. Creating a method to access these actual processes that would allow the students to study them would take them from the realm of scaled-down, simplified educational models to the actual equipment they would be working with in industry. Exposing students to actual industrial equipment and processes they would see in industry is a worthy goal but ultimately the purpose of using the actual building should be to enhance the learning experience. To see where the Living-Building Laboratory concept fits into a student's educational experience it can be helpful to reference Bloom's Taxonomy.

One of the challenges in education today is trying to bridge the gap between students who often view education as an effort to try and push as many important facts into their brains as possible versus the understanding that we as educators have that students need to be able to synthesize that knowledge and be able to use it to make decisions (what we often call Design). Certainly, many courses that students take early in their program emphasize the learning of information and tools that are necessary foundations to making good engineering decisions. As they progress in their program of study they should be exposed to increasing levels of creative design. All of this is merely a discussion of an idea presented in 1956 by Benjamin Bloom in his Taxonomy.[1] Bloom identified three types of learning, one of which is the cognitive domain. Within his cognitive domain he identified six levels that most educators think of when referring to Bloom's Taxonomy. As a quick review, the original six levels of Bloom's cognitive domain are presented in Figure 1.0 below.

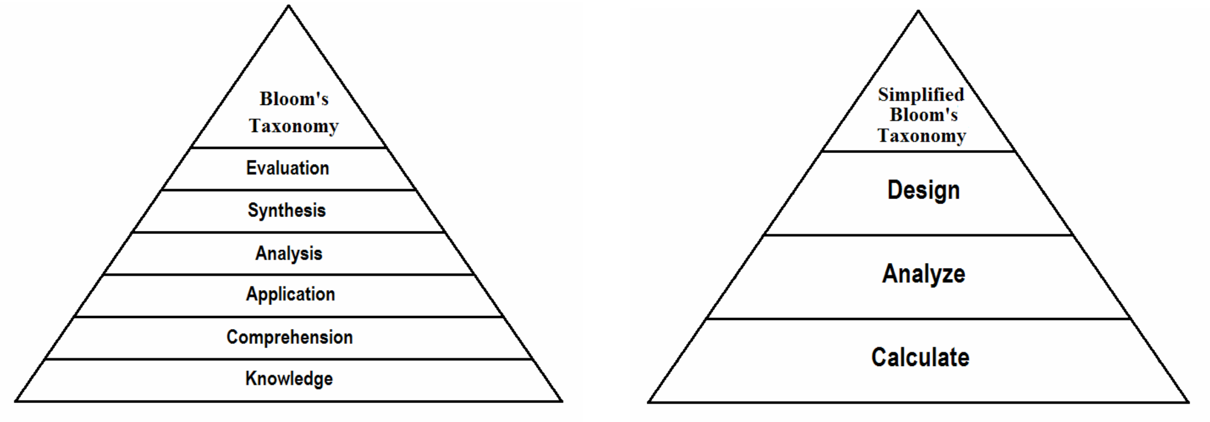

Figure 1.0, Bloom's Original Taxonomy and a Simplified Version of Bloom's Taxonomy

Educators are very familiar with the concept presented in Bloom's Taxonomy. The idea that students can learn at different levels is a driving force in how educators develop and construct their lessons. We know that students can learn at a lower level where all they are able to do is recognize the material; at a higher level they can repeat back what they have learned but at the highest levels they are able to synthesize their knowledge to analyze and draw conclusions. We all aspire to help students to reach the highest level which of course requires the greatest understanding of the topics and ideas.

As a simplification in teaching engineering technology the six levels can be collapsed into a three stage process that somewhat mimics the progression students go through in higher education: First we teach them how to Calculate; Second we teach them how to use their calculations to Analyze; and Third we teach them how to Design. Having only three levels is easier to remember and use in creating course materials.

Engineering Technology program classes in the freshman and sophomore years often emphasize the Calculate aspect as the students are still building their foundation of knowledge and tools. Senior level courses should be emphasizing the aspect of Design and decision making to prepare them for this final level before they graduate. In the middle is an often overlooked aspect that bridges the gap between Calculate and Design and that is Analysis. If students can become effective in analyzing an existing design they will improve their own design skills. Often times when students are given their first intensive Design problem they come up with unworkable solutions. Often the blame is noted as a failure to adequately teach design but in cases where the students did, in fact, design something and they were very creative in their approach it seems that the problem needs to be better defined. Where they likely had trouble was in attempting to bridge the gap between Calculate and Design. It is this skill that we set out to emphasize by using the building as a laboratory. This gives students the opportunity to analyze an existing design and then carry that forward to having them put forth recommendations for improvements to the design. Other research confirms the idea that having students analyze the building components provides similar benefits to engaging in research.

Students that have not faced open-ended design problems will find that their education is insufficient when they enter the workforce. There has been a great response to this need including accreditation requirements requiring students to work in a collaborative, team-oriented, capstone design project. Another avenue to expose students to this type of work is undergraduate research. But using an existing building as a laboratory lends itself more to analysis than it does to research. In other words, the students will be seeking data to answer questions posed to them by their instructor. The students will be studying questions that, in many cases, already have answers. This might lead to the thought that it will be of lesser value to the student. Some studies, however, indicate that when students are working on a large, complex, hands-on project, to them it is research and they derive many of the same benefits from such a project. ". . . the only difference between research and inquiry based learning is the prior state of knowledge of the broader community. In research it is unknown by all; in inquiry it is only unknown by the learner" (Fortenberry[5], 1998, p.54). To the student, the task of being assigned to analyze the complex workings of a building has much in common with research and the student will derive many of the same learning objectives from this approach.

Along these lines the same benefits provided to students in research should apply to the use of the Living-Building Laboratory. Some of these benefits as outlined by Malachowski[8] (1997), Karukstis[7] (2006) along with Goodwin and Hoagland[6] (1999) are: First, it can lead students to graduate school or a particular industry as students experience a particular type of work. Second, much of the monotony of school is absent in a project such as this. Third, students can feel a sense of accomplishment and confidence in their abilities. They will become more curious and inquisitive. Fourth, students might have to apply their knowledge in a different manner in order to understand or solve a problem. Fifth, all projects require reporting on the work completed. That is accomplished through verbal communication with a faculty member or in a formal paper or presentation. This will strengthen and enhance student communication skills and better prepare them to function in their future careers. Finally, even though this is not research it will require critical thinking and problem solving skills by the students. It has also been shown that student projects carried out with faculty mentoring results in increased student retention and achievement. This is important not only to our institution but to the local community as well since we are currently a net importer of employees to fill positions in the high-technology career fields (Regalado[9], Dec/Jan 2006, p.37).

It is also a concern that in the rush to satisfy this need for open-ended design work by students combined with the changing demographics of entering freshmen, engineering and technology students often end up skipping over the important skill of analysis and thus miss out on this important bridge between theory and design. In generations past engineering and technology students often came from work on farms and in industry that gave them a background in the operations of mechanical devices. They had some familiarity with the function and operation of technical equipment designed to perform a specific process. As the United States has become a more service-oriented economy more and more students enter technical majors without such a background (Egan[4], Feb 2007, p.36).

Problem solving has become a highly advocated skill that is being taught in courses ranging from English to mathematics and science and technology. This is occurring throughout the educational curriculum down into the elementary grades. The potential shortsightedness of this approach comes from the desire to teach students how to solve problems without first helping them obtain the tools necessary to complete the task. Teaching the students theory provides one important tool needed for effective design. The other important tool is analysis. Students need to spend some time analyzing the solutions of others in order to gain the necessary problem-solving skills they will need on the job.

We also negate some of a student's natural curiosity when we ignore the technical aspects of the world right around us. We want our students to be curious about their world. We want them to examine today's technology to see how others have achieved solutions to society's problems. It must be confusing to a student to come to a class encouraging them to explore their environment and then completely ignore the technology of the building in which that class is being held. A thermodynamics student is rigorously tested on his ability to understand the mixing of hot and cold air streams but he is never allowed to see that process going on right over his head. It's as if everyone is pretending that the process is not even there. Using the building as a lab illustrates to a student that technology can be anywhere and they should continue to be curious and look for it everywhere. It opens up their world of possibilities.

Gaining Access to the Data

As originally envisioned a large variety of data would be obtained from all over the building. It would be used in various courses in the Engineering & Technology curriculum. Students in thermodynamics would be able to study the mixing of hot and cold air streams, students in fluid mechanics courses could study the operation of pumps and the flow of water through pipes, strength of materials students could study the loads on the building's structure, and electrical engineering students could study the process of a feedback circuit to maintain the operating conditions of the building. The NSF grant allowed a revival of the Living-Building Laboratory concept but the cost of the equipment meant that the grant would not be able to fund all of the originally envisioned equipment but there would be a sufficient number to provide an enhanced laboratory experience for multiple courses. During the initial construction of the building, the decorative ceiling tiles in the Thermo-Fluids laboratory room were purposely omitted in order to expose the ventilation ducts and water pipes. Directly overhead is a large Variable Air Volume (VAV) mixing chamber that combines hot and cold air flows. The flow rate of the hot and cold air streams is controlled through a feedback circuit in order to maintain the desired temperature in the room. Data from the airflows entering and exiting the box are available through the commercial software that controls the building. The additional instrumentation is being integrated into this same control software making access easier and putting all of the data in a single location. The thermodynamics laboratory exercise that the students performed involved an analysis of this mixing box. A picture of this VAV box is shown below.

Figure 2.0, VAV Mixing Box suspended from ceiling.

Typical of modern construction, the building's operations are computer controlled and networked to a central physical plant facility. Process control software used for the new building is an ASHRAE/ANSI standard product known as BACnet®[2,3]. This makes much of the data desired for the Living-Building Laboratory concept already available. The latest version of this software was installed to run the building and it has a very user-friendly Webtalk graphic interface. A user ID and password are required to access the software and this involved some careful study in order to make certain that the security of the campus infrastructure would remain intact. Student and instructor accounts were set up that would not allow any control authority over the system. This was probably one of the biggest pieces of the puzzle to work through as it required the coordination of various departments on campus all with valid concerns about network security. With the account set up the students are able to access all of the data for the heating and ventilation operations across the entire building through an internet accessible web site. The first page they access allows them to select which floor they wish to view and then which room on that floor they wish to see the data for. A screen shot of this is shown in Figure 3.0 below.

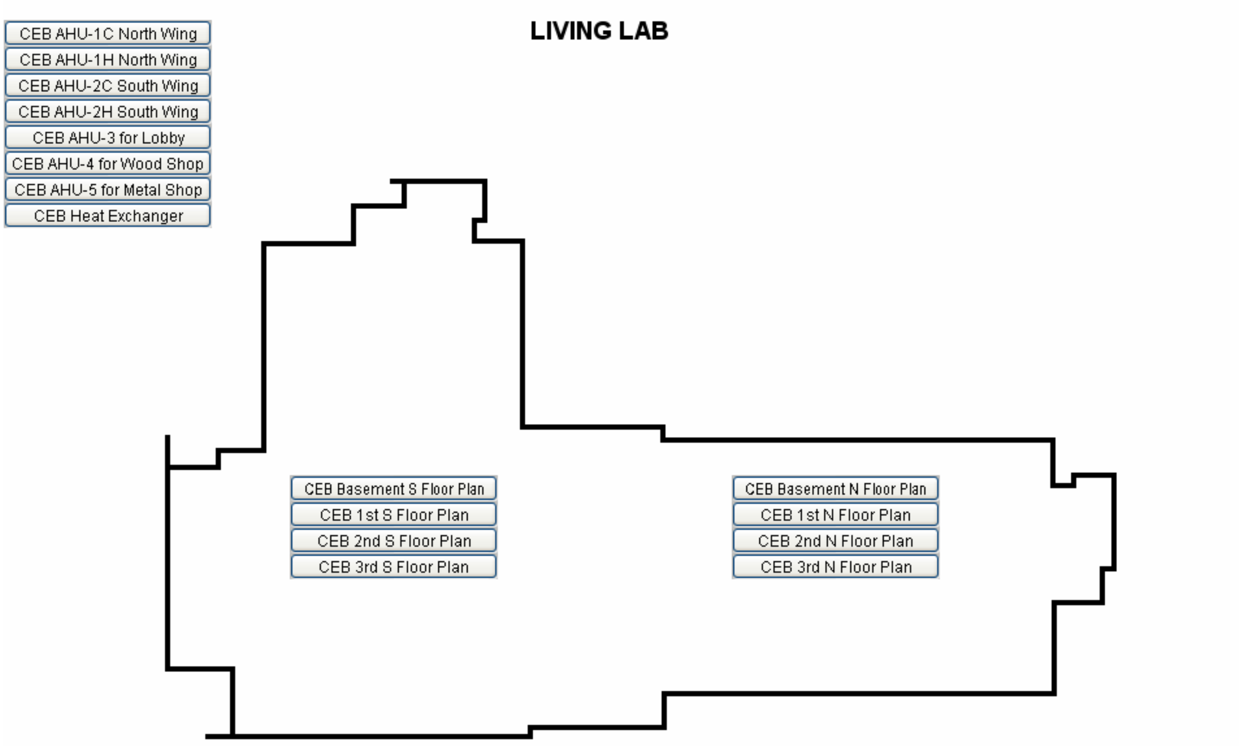

Figure 3.0, Webtalk display of building layout.

The Student Laboratory Exercise

The students were given access to the data for the VAV mixing box in the ceiling of the laboratory room. They were able to see both numerical data and a graphical representation of the mixing box. These two computer screens are shown in Figures 4.0 and 5.0.

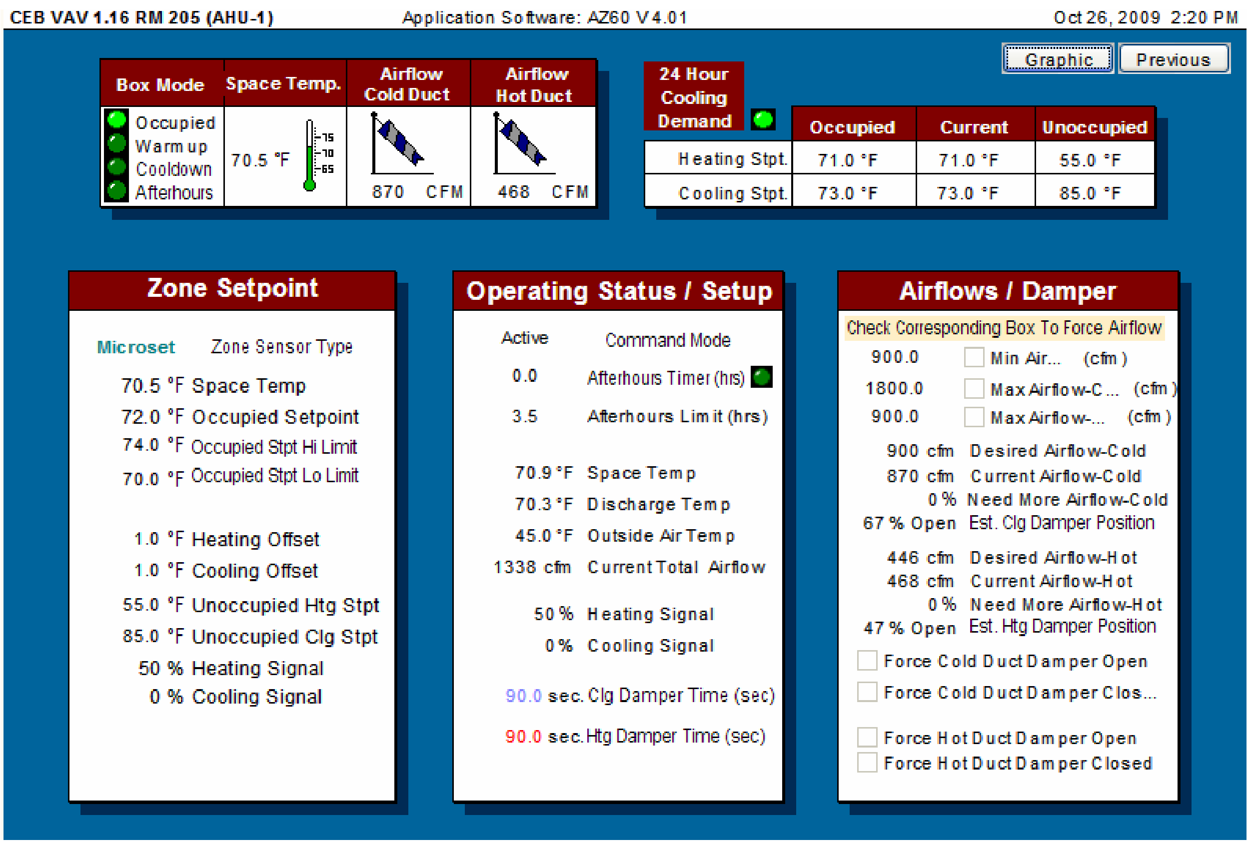

Figure 4.0, Numerical data for VAV mixing box.

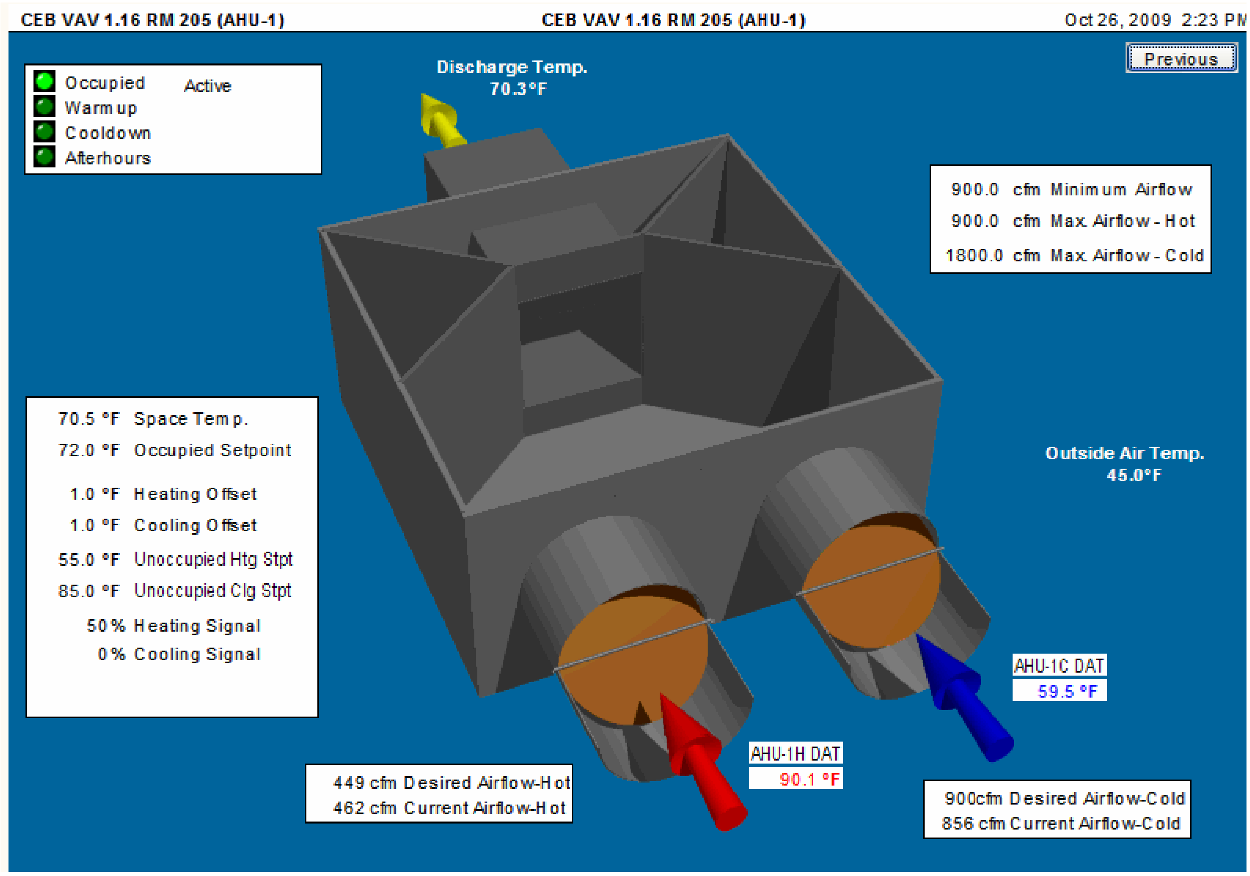

Figure 5.0, Graphical display of VAV mixing box.

The exercise was given to the students in the latter half of a one quarter thermodynamics course. Note that at the time that the students performed the laboratory exercise there had been some unforeseen delays and consequently the additional sensors had not yet been integrated into the software. Consequently, the laboratory exercise gave the students the benefit of using an actual device in the building that they could analyze but deeper analysis would not be possible until the following year.

The students were expected to be able to analyze the mixing box by applying a conservation of energy approach. Since not all of the students in the course had taken a fluid mechanics course they were given some help in first analyzing the mixing box using conservation of mass across a control volume:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \qquad \text{Eqn. 1}$$

Which for the mixing chamber can be written:

$$\dot{m}_{hot} + \dot{m}_{cold} = \dot{m}_{mixed} \qquad \text{Eqn. 2}$$

The students were reminded that massflow can be calculated as the air density times the average velocity times the cross-sectional area. The instructor then guided the students through a discussion of how to handle the density of the flow. If the students didn't eventually arrive at this point, then the instructor would suggest that they try assuming the flow has a constant density for their first calculations. The students would then apply conservation of energy across the mixing box. This would require an assumption that the process is adiabatic and has no work crossing the boundary of the control volume. Again, it is left for the students to work their way to these assumptions with the instructor guiding them as necessary.

$$\sum \dot{m}_{in} h_{in} = \sum \dot{m}_{out} h_{out} \quad \text{Eqn. 3}$$

Or, more simply:

$$\dot{m}_{hot} h_{hot} + \dot{m}_{cold} h_{cold} = \dot{m}_{mixed} h_{mixed} \quad \text{Eqn. 4}$$

With these assumptions, solving the equation is relatively simple. The next time the thermodynamics course is taught the data from the additional sensors will be available. These additional sensors will allow the students to perform a more rigorous analysis of the mixing box including such things as density variations as well as the air stream's humidity. More accurate temperature data will be available as well as improved accuracy on the volumetric flow rate. This additional data will allow more thermodynamic analysis to be done with the laboratory but the students should already be realizing the benefit of actually using the building and working with an actual mixing box used in commercial ventilation systems that is visible right above their heads. With the additional sensors the students should be better positioned to calculate the efficiency of the process. This will lead to a discussion of where the students see inefficiencies in the process and what might be done in order to make improvements. A dynamic analysis is also envisioned in the future where the students might track time-dependent operation of the system such as the increase in cooling load by having the empty room suddenly filled with students, computers and other heat-generating equipment.

Effectiveness of the Living-Building Laboratory

The overall score for the students in the thermodynamics course for the laboratory exercise that used the Living-Building Laboratory was 83%. The overall score of all 10 laboratory exercises for the entire thermodynamics course was 78%. This leads us to believe that the students were better able to understand the thermodynamic concept because they saw its use in an actual device and could easily relate to the device's purpose. Much of the laboratory equipment used in the thermodynamics course can be somewhat convoluted in its approach to present the thermodynamic problem. For example, our lab equipment used to teach refrigeration involves heating a large tank of water in order to create a requirement for cooling. This can feel artificial and confusing to the students. The need for heating and cooling a building is easy to understand and the purpose of the mixing box is very straightforward.

At the conclusion of the laboratory exercise the students were asked a series of questions in order to help assess whether the students felt that the use of the actual building improved their ability to understand the thermodynamic concepts. A simple, modified Likert scale question was asked as well as one that required the students to think and provide a paragraph on their impression of the experience. The Likert scale questions were intentionally very simple as we have found that the more involved the assessment tool, the more likely the students rush through it and don't pay attention. These questions are given below in Table 1.0 along with the percentage of student responses.

Table 1.0, Student responses on their laboratory experience.

	Definitely Yes	Somewhat	Not Really	Definitely No
Did the process of mixing air in order to achieve a desired temperature make more sense to you because you used an actual piece of building equipment rather than using a simplified lab experiment?	87%	13%		
The entire building heating and ventilation system is controlled by the network that we accessed to do this laboratory. Would you be interested in using more of the building data in future labs?	80%	20%		

The selection of the four point Likert scale forced the students to make either a positive or negative assessment of their experience. It can be seen from the results that there were no negative answers with the large majority being very positive about the experience.

In addition to these two questions, the students were also asked to write a short paragraph to answer the following question:

"Finally, what do you think was the most worthwhile aspect of using the building as a laboratory and how could the experience be improved?"

Here are some of the good and bad responses that students included from this section of their report write-up:

> "It provides a real world environment from which we are able to collect real world data."

> "Using the building as a whole brings more validity to experiments. . ."

"If more of this building was available as a laboratory as we walked the hall we could think and understand more concepts of the infrastructure."

"The experience could be improved if we could internally turn off the alarm and reset the system."

"It seems like it's easier to understand when using a real life situation."

"It's a good idea to use the building HVAC system as a lab experiment. It's two steps up from the book."

"With this laboratory I have a small taste of what I could be doing in my career."

"It could be improved by explaining more about how the automated system works."

"Maybe would have been cool if we also cooled the sensor and looked at the values given."

The answers were overall extremely positive. Most students wished they could have done more with the data. With the impending installation of the additional sensors it is believed that the students will find the laboratory experience even more useful and relevant.

Educational Outreach

As part of the grant a professor from the department of education that specializes in science and technical education was brought into the project in order to help expand the use of the Living-Building Laboratory to interest high school and middle-school aged children in pursuing a technical career. This resulted in the Engineering & Design department constructing portable table-top boxes that simulate the mixing of hot and cold airstreams similar to the VAV mixing box in the actual building. These boxes are currently being used by the education department and the MESA program to prepare the MESA teachers to use them with their classes. Middle school students will have a couple of weeks to conduct experiments with these simulated mixing boxes. The students will then be brought onto the campus and will be able to see the VAV box in the building and use the building data to relate how the processes they examined with the small box represents the implementation of the theory in the real building.

Additional Uses of the Building Data

The Thermodynamic Laboratory discussed is based entirely on real-time data obtained from the building. Additional insight can be obtained by examining historical data and other trended information. A member of the Computer Science department was part of the grant and his work involved taking historical data obtained from the BACnet ® software and storing it in files that can be accessed on the web and used for trending information. The BACnet® software already has provisions for taking historical data built in so, in theory, the data is already there ready to be accessed. However, the reality of trying to provide access while safeguarding access to the network made this job a little more difficult than expected. The website has been created with features to display historical data in many different formats including straight numerical data as well as plots and graphs. The website is located at http://livinglab.cslabs.ewu.edu. However, at the time this paper was written, the intricacies of securely passing the data out for student use were still being developed so there was limited data on the site to work with.

Additionally, permission was obtained in a prior year to create some access points in the ducting in order to insert a handheld temperature probe at various points along the ducting. As originally envisioned, the Living-Building Laboratory would replace these access holes with permanently installed temperature probes. This aspect of the project remains unfunded for now. These access holes were used before access to the building data was made available and allowed students to see how the temperature of the flow changed as it traveled from the air handler units in the basement up to the laboratory room on the second floor. It would be an interesting exercise for the students to combine the use of these access ports along with the more easily obtained networked building data to further understand what is going on in the ventilation system for the building.

Areas for Future Study

This paper examined the use of the Living-Building Laboratory data as it was applied in a single laboratory exercise for a thermodynamics course. When the equipment purchased through this grant is fully installed it will provide building data for use in our fluid mechanics course as well as our heat transfer and HVAC courses.

It was also envisioned from the beginning that the Living-Building Laboratory would serve as a link to the community. Information on the operation of the building would be available through the internet. Citizens who helped fund the building would have some access to observe its operation. With information available over the internet it would be readily available for use in elementary, middle and high school courses. Engineering & Design department faculty and students could have that information available and use it in outreach programs to community schools. This type of use of the building is still in the planning stages.

One desired but unfunded set of equipment was a weather station to be mounted on the roof of the building. By having access to current temperatures, wind speeds and directions the overall efficiency of the building could be assessed. Students could see how changes in the conditions outside affect the operation of the building inside. Students might also be able to assess the structural loads placed on the building from the wind.

Conclusions

Our institution is not the first to access building data in order to use the building as a laboratory. Initial assessment data from our institution seems to indicate that the students relate to the material taught in their thermodynamics class much better by using the building as a laboratory. Comments were favorable and the teaching experience was more enjoyable as well. Assessments from other institutions that have done something similar seem to all be positive. In spite of these favorable assessments it still remains a little-used approach to technical education. It is our goal to include more of the building data in future laboratory exercises in the hopes that it will further enhance the student learning experience in multiple classes over multiple content areas.

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Appendix:
Sample Living-Building Laboratory
Student handout

TECH 380
LABORATORY #10
Using the Computer & Engineering Building

TECH 380 Thermodynamics Lab 10, Using the Computer & Engineering Building

Introduction: In this lab instead of using some educational laboratory equipment we will be using actual real-time data from the Computer & Engineering Building. Like most everything these days, the Heating, Ventilation and Cooling (HVAC) system in this building is highly computerized. The system is run through a program called BACnet®. The university has allowed us access to the realtime data through the BACnet interface. Specifically we will be looking at the Variable Air Volume (VAV) Mixing Box located in the ceiling of the Themo-Fluids Laboratory room. The purpose of this device is to mix flows of hot and cold air in order to keep the room at the desired temperature. To get a feeling for what this box is doing, watch as your instructor displays the BACnet interface and shows you the data available regarding this VAV box.

Before starting the actual measurements, some interaction with the software is needed. After displaying the data for the laboratory room, check the data, namely, the set and actual temperature of the room both on screen and on the room sensor. Hot air from a hair dryer is then directed to the room sensor to simulate an increase in temperature. The result is an increase in the cold air flow to the room and can be seen on the screen. In this lab, actual data from the BACnet interface is used to predict the air flow temperature in the room. The theory behind the experiment is presented below

Performing an energy balance on the mixing box results in the following relationship:

$$\left(\dot{m}h\right)_{HOT} + \left(\dot{m}h\right)_{COLD} = \left(\dot{m}h\right)_{MIXTURE}$$

Before we can analyze the thermodynamics of this box we need to do some fluid dynamics analysis. We will invoke the conservation of mass law. Recall that for mass to be conserved, everything that goes into the box has to exit the box. This can be expressed in terms of massflow:

$$\sum\left(\dot{m}\right)_{IN} = \sum\left(\dot{m}\right)_{OUT}$$

We have two flows going in (hot air and cold air) and one coming out. So we can update the conservation of mass equation like this:

$$\left(\dot{m}\right)_{HOT} + \left(\dot{m}\right)_{COLD} = \left(\dot{m}\right)_{MIXTURE}$$

Remember that massflow is the product of the fluid density, the mean velocity, and the cross-section area:

$$\dot{m} = \rho VelocityA$$

Also, Velocity times the cross sectional area gives Volumetric flow rate, often given the symbol, Q or V dot:

$$\dot{V} = Q = \rho V$$

Volumetric flow rate happens to be one of the parameters that we can read directly from the instrumentation on the box through the BACnet interface. All we need now is the density of the air. For our first guess we will assume that the density is constant across the entire flow through the box. This allows us to cancel out density and then solve the conservation of mass equation strictly in terms of volumetric flowrate:

$$\dot{V}_{COLD} + \dot{V}_{HOT} = \dot{V}_{MIXTURE}$$

So now it is easy to find the Volumetric Flowrate of the exit flow from the mixing box. Knowing that we are treating density as a constant allows us to simplify the Energy Balance equation from above and get:

$$\left(\dot{V}h\right)_{HOT} + \left(\dot{V}h\right)_{COLD} = \left(\dot{V}h\right)_{MIXTURE}$$

Let's assume that we don't know what the temperature of the mixed gas exiting the box will be but we want to calculate it from this equation. Assuming standard air conditions you can find the enthalpy values from tables in your text based on the exit temperature of the airflow obtained from the software.

Now, we need to do our own calculation to try to predict the exit temperature. If one assumes a constant C, then (refer to laboratory one for the entire derivation) the temperature of the mix will be

$$T_{MIX} = T_H + \frac{m_C}{m_{MIX}}(T_C - T_H)$$

And if one assumes a constant density, then the previous equation can be written as

$$T_{MIX} = T_H + \frac{\dot{V}_C}{\dot{V}_{MIX}}(T_C - T_H)$$

Where the dot represent the rate with respect to time of the argument. So $\dot{V}_C$ is the volume flow rate. All of the parameters on the right hand side of the equation are obtained from the software, (except of course Tmix). Compare the value obtained from this calculation to the actual one obtained from the software.

How close did you get with your calculation?

What assumptions did we make in order to get this answer?

How reasonable are the assumptions that we made?

How might those assumptions affect the accuracy of the answer?

What other information would you need to know in order to analyze the mixing box using density as a variable?

Finally, I hope you can see that this laboratory is a little different from what we usually do. Most of the time we use a small piece of educational laboratory equipment to demonstrate a thermodynamic property. We wanted to make the laboratory experience more realistic for you and so we made it possible for you to see the actual data being used in the building itself and then use the building as your laboratory. Consequently, we want you to answer a couple of questions relating to the use of this building as a laboratory:

	Definitely Yes	Somewhat	Not Really	Definitely No
Did the process of mixing air in order to achieve a desired temperature make more sense to you because you used an actual piece of building equipment rather than using a simplified lab experiment?				
The entire building heating and ventilation system is controlled by the network that we accessed to do this laboratory. Would you be interested in using more of the building data in future labs?				

Finally, what do you think was to most worthwhile aspect of using the building as a laboratory and how could the experience be improved?