
AC 2012-3436: CHALLENGES AND SUCCESSES OF CREATING A LIVING-BUILDING LABORATORY (BUILDING AS A LABORATORY) FOR USE IN THE ENGINEERING TECHNOLOGY CURRICULUM

Mr. Jason K. Durfee, Eastern Washington University

Jason Durfee received his B.S. and M.S. degrees in mechanical engineering from Brigham Young University. He holds a professional engineer certification. Prior to teaching at Eastern Washington University, he was a military pilot, an engineering instructor at West Point, and an airline pilot. His interests include aerospace, aviation, professional ethics, and piano technology.

Challenges and Successes of Creating a Living-Building Laboratory (Building as a Laboratory) For Use in the Engineering Technology Curriculum

Abstract

In the fall of 2005 the Engineering & Design department 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 that the building would be 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. Modifications were made to the original design in order to provide for this new use of the building. However, 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. In 2008 our department secured a National Science Foundation grant (NSF 07-543, CCLI Phase 1: Exploratory) in order to install some components of the original concept into the building. This paper constitutes the lessons learned from this effort as well as information on how the data was used to enhance program courses and the impact it had on student learning. Additionally, the information in this paper should serve to assist anyone desiring to attempt such a project in the future.

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. Students would be able to collect data from the building and make 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. 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 (NSF 07-543, CCLI Phase 1: Exploratory) was obtained in order to restore some of the benefits of the Living-Building Laboratory concept. At this point equipment installed as part of this grant has been used in thermodynamic and fluid mechanics courses. How this equipment was used in these two courses has been discussed in previous papers but will be briefly reviewed in this paper as well.

Introduction to the Living-Building Laboratory Concept^{4,5}

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.

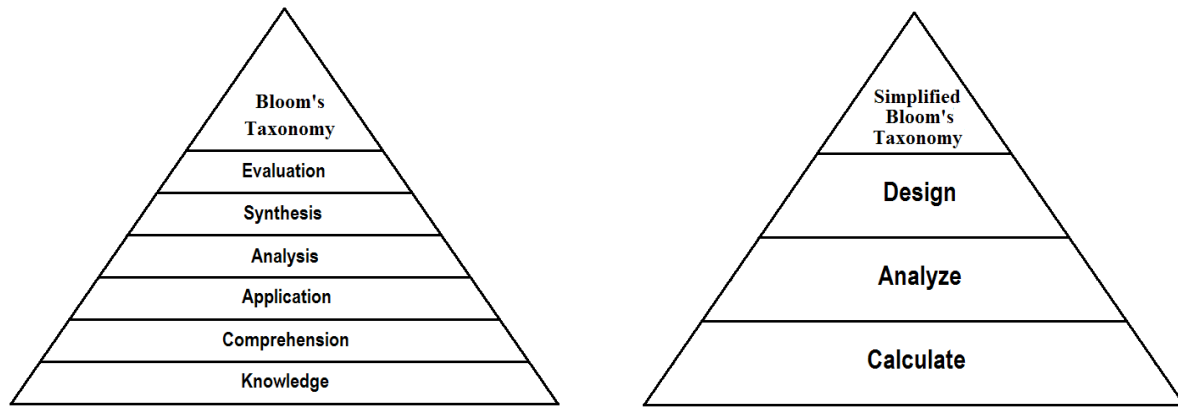


Figure 1.0, Bloom's Original Taxonomy and a Simplified Version of Bloom's Taxonomy

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” (Fortenberry⁷, 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 Malachowski¹¹ (1997), Karukstis¹⁰ (2006) along with Goodwin and Hoagland⁸ (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 (Regalado¹², 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 (Egan⁶, 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

Instructors have been accessing building data for many years in various creative ways. We followed such an approach earlier by gaining approval to drill a few holes in order to insert a thermocouple probe in various locations along a heating duct in our building. This kind of approach can be relatively cheap but requires expertise on the part of the instructor and creates a custom setup that often requires lots of equipment maintenance or human intervention to keep the data flowing. We went a different route than this for a couple of reasons. First we wanted to create a solution that would be easily repeatable by other institutions without requiring expertise in instrumentation and engineering. Also, in order to satisfy the requirements of the university, the concerns of the physical plant staff, and the owners of the building (government), it was determined that we would utilize the contractor that designed and installed the original HVAC system in the building. We would purchase our equipment through them and work with them to connect any newly installed equipment through the system already in place to run the building's HVAC.

A large amount of data from the Heating, Ventilation and Air Conditioning (HVAC) systems was already available prior to the implementation of this grant. The Computer and Engineering Building is typical of most newer or newly remodeled structures in that its operation is computerized and networked to the university's physical plant. This is done through a networking protocol known as BACnet®. This process control software is an ASHRAE/ANSI standard and it makes much of the data desired for the Living-Building Laboratory concept already available. Whereas BACnet® controls the exchange of the data with the building systems, accessing the data is possible in two different ways. The real time BACnet® data is accessible at our institution through a very user-friendly Webtalk® graphic interface. Additionally, the system creates archival records of system parameters and these are stored on the server controlling the entire university. At our institution the system is programmed to take archival data every 15 minutes. The real time data can be accessed from any internet-capable computer and requires a user ID and password. Each individual user ID for the system has permissions associated with it that allow a range of control from only being able to view the data

to having complete control to make changes to the operation of the building. The archival data requires access to the server itself and is not designed to be accessed over the internet.

It was this access that created one of the biggest problems in attempting to view the data. Since gaining access to the Computer and Engineering Building (CEB) data required gaining access to the network that controlled the entire university there were concerns about security. We had to be certain that if we opened the door for viewing the data we wouldn't also be opening a possible route for hacking into the system and allowing someone to gain control of the entire university's HVAC let alone gaining control of the CEB. In order to avoid opening up potential access one of the approaches looked at for both the real time and archival data was that of creating an entirely new webpage format that would make viewing and interpreting the data very easy. Data would flow only one direction from the server and this would minimize the potential for unintended access. It soon became apparent that this approach would require untold amounts of work and oversight. In fact, later in this paper it will be discussed how this approach doomed access to the archival data.

The approach that was finally agreed upon to at least gain access to the real-time data was to create a user identification and password to the Webtalk® interface that would allow access to the same system used by the facility operators, but to restrict access to only allow viewing of the data without the ability to make any changes. This still created a portal into the facility network and necessitated that this be used only by students currently taking a related course while they are supervised by the instructor. This was not a method that could be used to allow open public access to anyone as was originally envisioned at the start of the project.

Access to the archival data would not be as simple. This would require connecting to the server that stores the data. This had the potential to open up an even less secure path into the facility network. The solution that was decided upon was to set up a separate server. A software link was created that would access the archived data at various times (in our case, once a day) and retrieve that data. Data would only be allowed to flow one direction from the physical plant server to the separate server for this project. This data would then be used to populate a public website that would allow anyone to view the data used in the operation of the Computer and Engineering Building. Additionally, to make this even more useful to our students and to anyone in general that visited the website, additional data beyond that coming from the building was added. Data from the local National Weather Service station was also imported and made part of the website. At the same time you are viewing the past heating and cooling loads of the building you could reference that to the temperature and wind data surrounding the building. The home page of the public website is shown below as Figure 2.0.

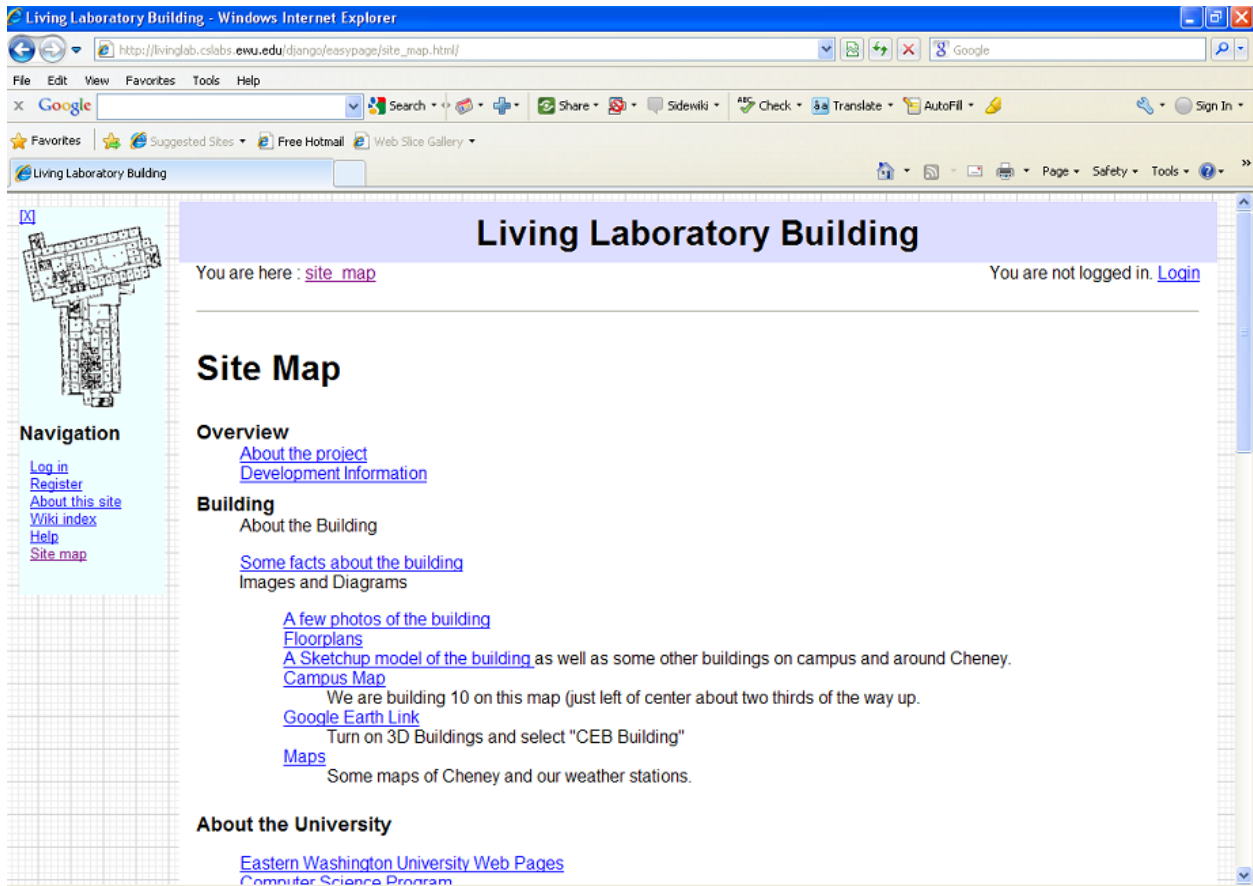


Figure 2.0, Public Website home page

The website was setup so that you could select whatever types of data you want to view. You then select the timeframe for the data selected and then you can easily create plots and graphs. An example of one of these user-created plots is shown as Figure 3.0.

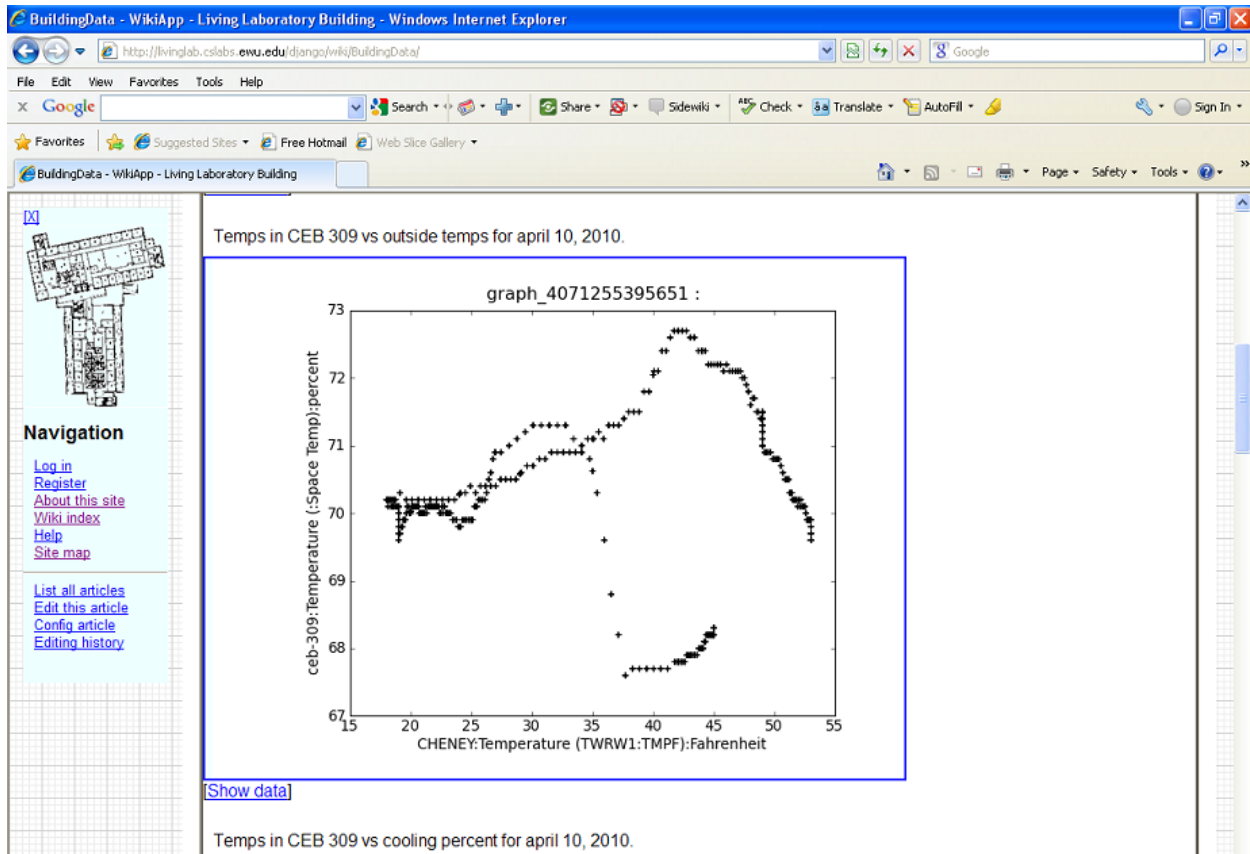


Figure 3.0, Sample plot

Additional information was added to this public website to include photos of the building, floor plans of the building, a campus map, and a Google Earth link for satellite photos of the building. This gave added value to the data by being able to see the surrounding structures and landscapes that might affect the wind flow around the building. Links were created to educational documents to explain in simple terms what the data was telling the viewer.

Using the Data in Laboratory Courses

As mentioned previously, data for all of the heating and cooling operations for the building is available through BACnet®. This data is accessed through a graphical Webtalk® interface. In addition to the data already utilized for the normal operation of the building, instrumentation was added to a Variable Air Volume mixing box and to a length of potable water pipe. The output from this additional instrumentation was added to this same graphical interface so that the data could be accessed from a common site. Student and instructor accounts were set up that would not allow any control authority over the system. This required coordination between various departments on campus all with valid concerns about network security. 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. The Variable Air Volume mixing box data and the pipe flow data

are accessed by selecting either of the two items at the bottom of the list at the top left of the screen shown in Figure 4.0 below.

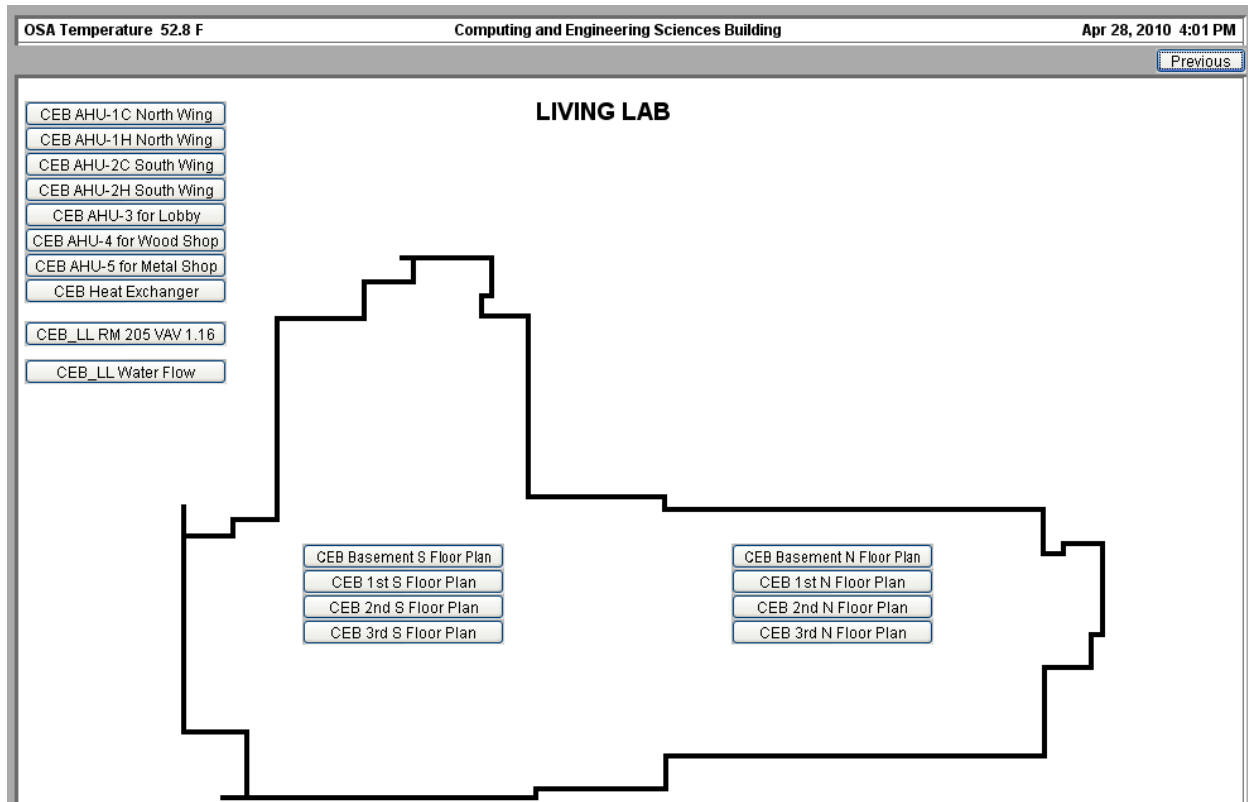


Figure 4.0, Webtalk® display of building layout.

The Variable Air Volume Mixing Duct Student Laboratory Exercise

One system that was instrumented as part of this grant was a Variable Air Volume mixing box that is mounted in to the ceiling of our thermo/fluids laboratory room. During the initial construction of the building, the decorative ceiling tiles in this 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. Instrumentation beyond that required to operate the building was added in order to provide humidity of the airstreams entering and exiting the box as well as more accurate readings of the speed of the airflows and the temperatures of the hot and cold airstreams. This additional data was wired through the same system as the data that is utilized to control the building and readout of the data was added to the same webpage display as the control data. This required the purchase of an additional data card because the card already installed did not have enough open channels to add all of the data from the additional instrumentation. This additional data card was mounted next to the original one

and both of them easily fit inside the original casing mounted on the side of the VAV mixing box. This was a fairly simple installation that was completed by our physical plant personnel. The thermodynamics laboratory exercise that the students performed involved an analysis of this mixing box. A picture of this VAV box is shown as Figure 5.0 below.



Figure 5.0, VAV Mixing Box suspended from ceiling.

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 6.0 and 7.0. Additional data from instrumentation added by the grant is shown in the box at the right of the screenshot in figure 6.0. Data from the additional instrumentation is shown in the boxes with headers in red letters for figure 7.0.

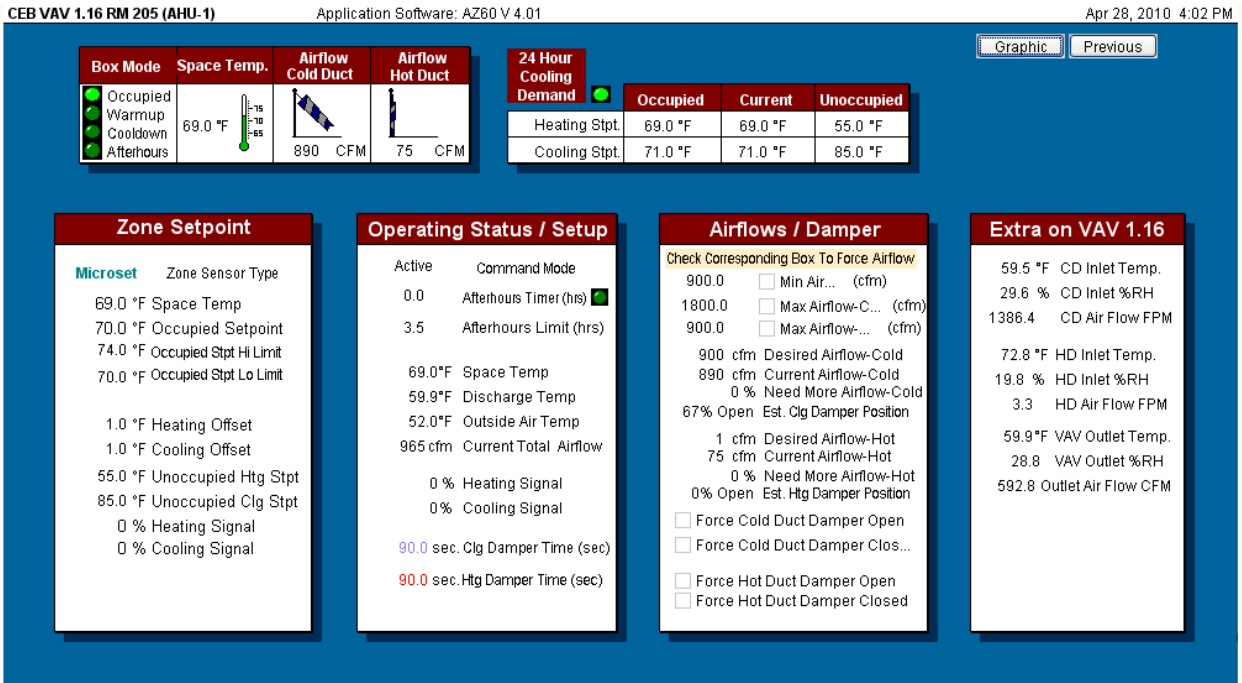


Figure 6.0, Numerical data for VAV mixing box.

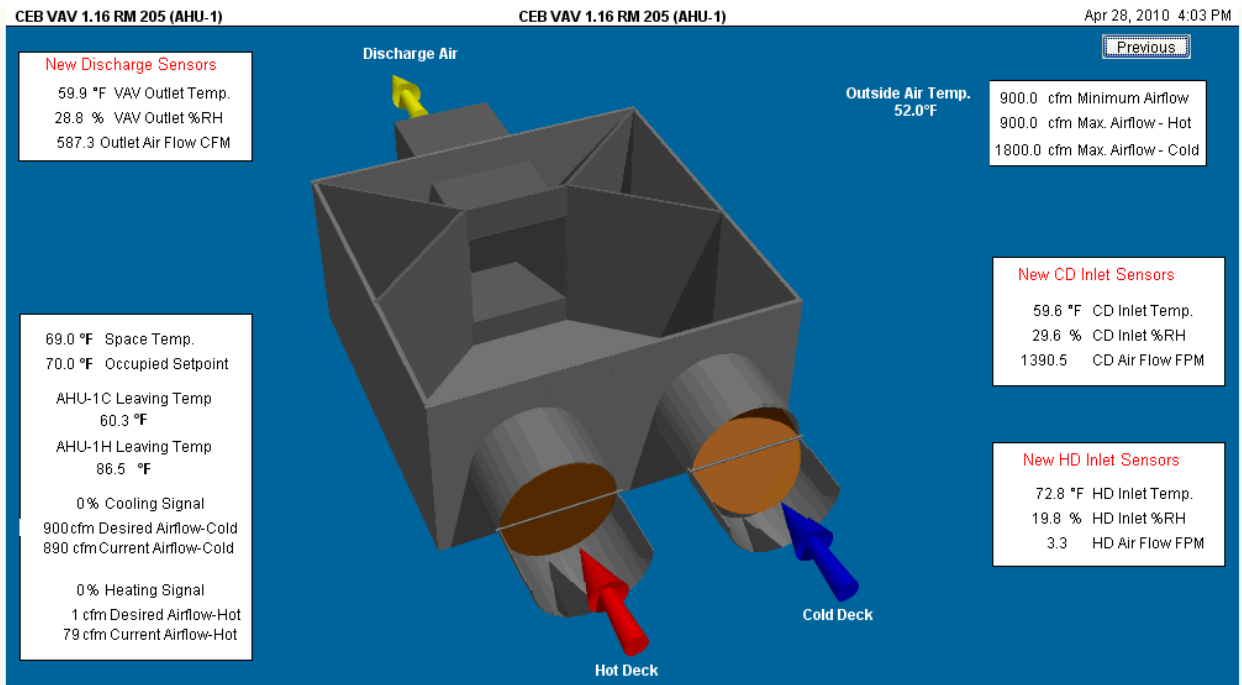


Figure 7.0, Graphical display of VAV mixing box.

The exercise was given to the students in the latter half of a one quarter thermodynamics course. 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, and additional assessment data, leads me 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. Additional information on this exercise is given in the paper presented at the 2010 ASEE Annual Conference and Exposition⁵.

The Pipe Flow Student Laboratory Exercise

Instrumentation was also added to a length of pipe in the lower floor of the building. The basement of the Computer and Engineering Building is divided into three major sections: a metallics lab, a non-metallics lab, and a material testing lab. Because of the nature of the equipment installed in these basement areas there are no ceiling tiles and so all of the plumbing is visible. That made this an ideal region to add instrumentation to a length of piping for the students to use as a lab exercise. The question then came about of how to best present and make this data available to the students. Although data from the flow of water in the pipe wasn't part of the heating, ventilation and cooling system, based on our previous experience in adding instrumentation to the HVAC system we were able to utilize the same system to display the data for this water pipe. A picture of a portion of the instrumented pipe is shown below as Figure 8.0.



Figure 8.0, Portion of Instrumented Pipe

The amount of instrumentation that could be installed was limited by the cost and so the decision was made to make the lab from a series flow and not a more complicated parallel flow portion of the piping system. This length of piping is completely visible to the students in the ceiling of our non-metallics lab as it passes through a wall and then terminates in a faucet in the materials testing laboratory. Students are able to vary the flow rate in the pipe through the faucet at the termination point of the pipe. There are various branching tees along the instrumented pipe but the flow in these branches is turned off during the lab exercise so that there is only a single series flow. In addition to these tees, the length of instrumented pipe also includes some diameter changes, some elbows and elevation changes. The students were given access to the data for the pipe through an internet connection on a computer that resides in the vicinity of the actual pipe. They were able to see the numerical data presented on a graphical representation of the instruments on the pipe. The computer screen that displays the data is shown in Figure 9.0.

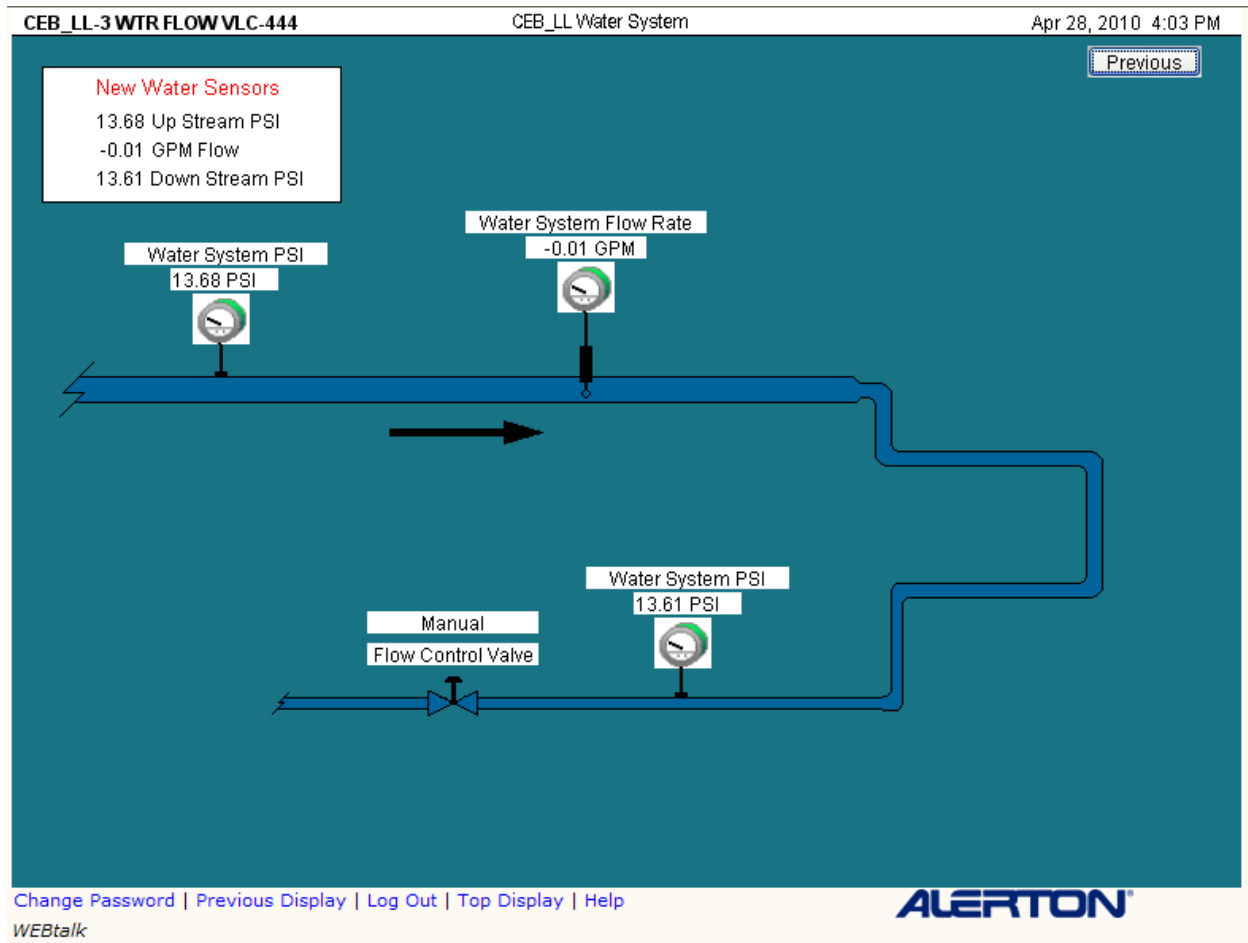


Figure 9.0, Graphical display of the instrumented pipe.

The exercise was given to the students in the latter half of a one quarter fluid mechanics course. The overall score for the students in the fluid mechanics course for the laboratory exercise that used the Living-Building Laboratory was 90%. The overall score of all 10 laboratory exercises for the entire fluid mechanics course was 82%. This, and other assessment data, leads me to believe that the students were better able to understand the fluid concept because they saw its use in an actual device and could easily relate to the device's purpose. Additional information on the Pipe Flow fluid laboratory is given in a paper presented at the 2011 ASEE Annual Conference and Exposition⁴.

Educational Outreach

As originally envisioned the Living-Building Laboratory would also serve as an element of educational outreach for visitors to our campus. This aspect of the building grew as the project progressed. A faculty member in the education department worked with engineering and technology faculty to design table-top sized mixing boxes that were constructed by one of our technology instructors. A picture of one of these boxes is shown as Figure 10.0 below.



Figure 10.0, Table-top mixing box

Teachers in various local middle school MESA classes were given training on how to use these devices in their science curriculum. After the middle school students had spent numerous weeks conducting and designing experiments with this table-top device, they were then brought to campus and introduced to the full-size mixing box and participated in calculations on the heating and ventilation flow in one of the classrooms. A smoke generator was used to display flow patterns from the air vents. This use of the building became one of the more engaging and enjoyable aspects of the project.

A further aspect of utilizing the data in the local public school system comes from the ability for professors visiting local schools to log into the real-time data network through any internet connection and utilize that information in their presentation to students.

Lessons Learned

We were not the first to implement some degree of transparency to the operation of our building. We will not be the last. A development known as Dockside Green, a \$1.2 billion development, seeks to become a net-zero energy use planned community. They intend to do this by providing

visual access to energy, water and electrical usage.¹³ Interest by other education institutions validates the relevance of this approach as applied to student learning. Currently, Saint Martin's University in Lacey, Washington is in the early stages of constructing their new engineering facility that proposes to also be a "building as a lab."⁹ This is a concept that is proving to be very popular among engineering and technology educators. Because of this, it was envisioned from the beginning of our project that we would publish our experiences so that others may learn from our efforts. Here's what should be of interest to anyone wishing to attempt such a project.

First of all, one aspect of this project is that the idea should be very transportable to other buildings. Most buildings built or remodeled in the last decade or two are likely being run through a networked system like our Computer and Engineering Building. It is also very likely that the networking system that is used on that building is the standard BACnet®. This makes the work that we did on our project very similar to what would be encountered in doing this on another building.

The second item to be aware of is that gaining access to the data will likely be the most difficult piece of the puzzle. Security issues make this a very difficult problem to solve. Security was an issue with our setup because we chose to access the data through the BACnet® system that was already running the building. This had advantages in that it provided data from sensors that were already installed in the building for its normal operation. It had the added advantage in that we were able to route any additional equipment installed in the building through this same system. Even the fluid piping data that was completely unrelated to the operation of the building was able to be added to the WEBtalk® webpage that already existed for the normal operation of the building. This approach was selected because a BACnet® approach would make this idea applicable to a large number of buildings. It also caused our issues related to network security. There have been other examples of buildings that have been instrumented to provide data that have done this completely outside of any of the systems required for the normal operation of the building. A good example of this is the engineering building at the University of Colorado at Boulder. Systems like these work independently of the system used to operate the building and minimize or eliminate security issues. The problem with that kind of setup is that there is duplication of sensors and increases in cost. We were trying for a more general approach that others could easily mimic.

Also be aware that our approach of working with the HVAC contractor, purchasing equipment through them and running it through their established network added to the cost of getting the data. Money had to be spent for consulting services as well as time for programming the control system to accept the additional instruments for display of the data.

Another lesson learned was in regards to the website created for public use. It was always envisioned that the public would have access to this building. This is a public building and we desired the taxpaying public to have access to the operation of their building. Making the data public would make this building an educational tool for anyone that logs on to the website and not just for the students in residence in our programs. Since the real-time data was accessed through the system that also operated the building a separate, public, website had to be created to allow general use. This website used archived data that was copied over from the server in the physical plant to a separate computer server hosting the copied data and the web programming.

The link between these two servers was programmed and monitored by a professor in the Computer Science department along with a graduate student. The website was readily useable and provided a very convenient method to access any and all of the historical data from the building. Screen shots from this website were shown in Figures 2.0 and 3.0.

The fact that it was necessary to create this website to allow public access to the data shows that it would take more than just an individual with a passing interest to recreate this aspect of our project on another building. Accessing the real-time networked data for local use was not very difficult but creating and maintaining a separate server and a website link would require more effort and expense. Maintaining this public website required large amounts of time. This is made manifest in the fact that this website is currently not operational. The link between the physical plant server and the website server needed constant monitoring by the Computer Science faculty member. The link would often go down. At one point the server in the physical plant crashed and was replaced. This information was not passed to the members of the research team and it took a few days of not being able to access data before it was discovered that a different server with a different server name was being used and the link had to be re-established. The graduate student working on the project has graduated and the Computer Science faculty member that oversaw the project has left the university and so this element of the project is not currently functional.

Closely related to the loss of function of the public website was the idea of providing public access to the building. The building is a public building paid for by public funds. It was felt that opening up the data from the building to the public would fulfill an obligation to the taxpayers to see how their money is used to run this building. It was hoped that it would provide greater understanding among the population of how a building functions, how much energy it takes to run a building, and where that energy goes. Unfortunately, this concept is currently left unfulfilled.

The successes of the project come in two areas. First, the educational outreach to local area middle school students was very successful. We have had two years of visits from groups of students averaging about 45 per year. Working with a faculty member in our education department allowed us to create an excellent hands-on tool that allows these students to understand and benefit when they visit the campus and view the mixing box and air ventilation system.

The other success comes from the direct application of building data to program courses. It can be seen from the data from the students who used the building instrumentation in their laboratory work that this project can be considered an educational success. The students felt that the learning experience was better, more relevant and contributed to greater understanding of the principles when they used the building as a lab rather than a piece of laboratory equipment.

Areas for Future Study

In the years since the initial grant was submitted our department has started teaching a course in HVAC. It is envisioned that the majority of the student work with the instrumented mixing box will transition from the thermodynamics course to this HVAC course.

Building data is currently available for use in our thermodynamics course, our fluid mechanics course, and soon to be introduced into our HVAC course. Equipment has been purchased to install strain gauges on some structural elements of the building and add this data to our solid mechanics course.

Weather data was accessed for the location of the building and made available on the public website however this data was not taken at the building but interpolated from weather stations in the surrounding area. It was always a desire to mount a small weather station to the roof of the building. This would provide even more accurate temperature and wind data and allow better calculations of the overall building efficiency. Once the structural aspect is finally installed it would also allow a better correlation between wind speeds/directions and 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 and fluid mechanics classes 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. Being able to show off the workings of the building to visiting middle and high school students generates excitement and interest in engineering and technical topics. 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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