AC 2007-879: PLANNING A LIVING-BUILDING LABORATORY (BUILDING AS A LABORATORY) THAT WILL INTEGRATE WITH ENGINEERING TECHNOLOGY CURRICULUM

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Abstract

In the fall of 2005 the Engineering & Design Department at Eastern Washington University 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. Both disciplines would be able to collaborate in collecting operating data for the building and making predictions as to how they might be able to improve the efficiency of the operation. Modifications were made to the original design in order to provide for this new use of the building. These modifications included: making the HVAC/control room extra wide to provide access for students to observe equipment and take readings, exposing cable trays and ducting, instrumenting valves and pumps in order to obtain valve position and pump speed information, and leaving structural elements exposed to provide locations to mount strain gages to record the loads on the building's structure. 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. This paper describes efforts that have been undertaken in order to obtain the necessary equipment, functionality and course objectives to complete the Living-Building Laboratory concept.

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. A few years ago when approval was granted for the construction of a new Computing & Engineering Building, faculty members of the Engineering & Design department at Eastern Washington University devoted their efforts to working with the architectural firm and modifying the building's design to create access to the technical equipment located within the building. Additional instrumentation was also requested that would provide the complete picture of the daily operation of the building. Examples of these modifications include increased working area around flow handlers to allow student access, instrumentation of valves, pumps and fans to obtain valve positions, pump and fan speeds as well as temperature and pressure data. Various parts of the underlying structure were left accessible for the mounting of strain gages to obtain data on the changing loads experienced by the building throughout a day of use by students and from forces applied to the structure by external winds. Within the room that is the "Thermo-Fluids Laboratory" the cosmetic ceiling tiles were purposely omitted to allow students to view the components of the heating, ventilation, and air conditioning system as well as the various pipes involved in the water and vacuum systems installed in the building. With the ceiling tiles removed students would also be able to see the location of some of the sensors being used to gather the building data. All of this was done with the specific goal of using the building as a 'living' laboratory.

As originally envisioned the data obtained from the building would be used in various courses in the Engineering & Technology curriculum. For example, students in Thermodynamics would be able to study the mixing of hot and cold air streams. Directly overhead in the Thermo-Fluids laboratory room is a large air 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. The bare minimum data that is used to run the building's daily operation already takes readings of the incoming hot air temperature, the incoming cold air temperature, the incoming humidity level, and the outgoing mixed-air temperature. Fluid mechanics and thermodynamics students are taught about the conservation of mass principle using a control volume approach. They would be able to deduce that the sum of the massflow coming into the mixing chamber must equal the sum of the massflow leaving the mixing chamber. Or in equation form:

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

Which for the mixing chamber can be written:

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

The thermodynamic students would be able to further analyze this using a conservation of energy approach. This would require an assumption that the process is adiabatic and has no work crossing the boundary of the control volume in which case the governing energy equation simplifies such that the sum of the product of enthalpy and massflow coming into the mixing chamber must equal the sum of the product of enthalpy and massflow leaving the mixing chamber.

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

Or, more simply:

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

In order to solve this theoretical equation, students would need data from additional sensors that would provide information on the mixed air stream's humidity level as well as volumetric flow rate information. These sensors are above the standard data that is used for day-to-day regulation of the building's airflow. The small extra expense to add these additional sensors would be worth the effort as the students would now be able to solve this equation using the building data and then compare their answer with theoretical calculations learned in their academic course. It would lead them to question why they did or did not achieve the results predicted by the thermodynamic theory. They would also be able to calculate the efficiency of the theoretical process and of the actual process. It would lead them to question the inefficiencies of the operation and begin a quest for knowledge on how to improve upon the process. Because this is a dynamic process, the students would also be able to see how the presence of students alters the heating/cooling load within a room. Students would be able to calculate the actual impact upon the building load for each student that enters the building. This same approach could be taken for other pieces of equipment within the system including such things as heat exchangers and throttling valves.

Students within the Fluid Mechanics course would likewise be using actual data to determine pressure drop due to viscous friction losses and minor losses from fittings and fixtures in a piping system. They would be able to compare their theoretically derived answer with the actual data from the building. They would be able to form opinions on the accuracy of standard minor loss values as provided in the text with the actual data from the building. This would require additional instrumentation to provide pressure values at known positions along different lengths of pipes. If additional instrumentation is added to the buildings pumps the students would be able to create pump performance curves. To do this the students would need to know pump inlet pressure, outlet pressure, volumetric flow rate of the water through the pump and the pump rotor speed.

Solid Mechanics/Strength of Materials students would be able to relate changing wind loads on the building with changes in the stresses of the underlying structure. They would be able to attempt to correlate student movement within the building with changing loads on the building's structure. This would require the addition of strain gage data to analyze the stresses within the underlying building structure.

In addition, all of these courses would be able to access the aspect of diurnal variations in these values. Archived data from the course of a day/week/month/or year could allow students to see the variance in these values as a function of time. This could affect their solutions for the most efficient design as the design must operate efficiently at both low and high usage rates.

Another aspect of using the building involves group dynamics. The scope of many of these analysis projects would require that students learn to work effectively in teams. It would require them to take their basic understanding of theoretical concepts to then collectively decide what kind of data they would need in order to analyze the building components. They would then create a plan to gather that data, analyze the results, draw conclusions and make recommendations. This process covers a number of educational objectives. First, the students further develop their teamwork skills. Second, the students see the actual implementation of their theoretical studies. Third, the students set their schedule and have control over the success of their project. Fourth, the students are engaged in hands-on work with real-world equipment.

From all aspects, the Living-Building Laboratory concept would be a great enhancement to a student's education.

As the concept of a Living-Building Laboratory made its way around the college additional departments became excited about the possibilities of including its use into their courses. Proposals were made from the Physics department about the possibility of using the building to track dispersion of particles in public structures. Even the possibility of monitoring student movement within the building and the sociological implications this might demonstrate was also brought up. Faculty within the Computer Science department saw the project as an opportunity to have their students create 3-dimensional 'fly-throughs' of the building that would show anyone accessing the data through an internet sight exactly where the component and sensor was located within the building. They also saw the usefulness of having extensive amounts of archived building data that could be used by computer science students to develop software to analyze and effectively present the information.

It was also envisioned 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.

Research, Design and the Analysis Piece of Technical Education

It wasn't that long ago that a need was recognized within the engineering and technology education system for students to be exposed to open-ended design problems. The concern was that students were graduating from these programs based primarily on a student's ability to master homework-style problems that always had a 'correct' answer. This made their education insufficient when they faced open-ended, design problems on the job. 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[4], 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[7] (1997), Karukstis[6] (2006) along with Goodwin and Hoagland[5] (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 Eastern Washington University but to the local community as Washington is currently a net importer of employees to fill positions in the high-technology career fields (Regalado[8], 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, that engineering and technology students often end up skipping over an important bridge between theory and design. That overlooked link is analysis. 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[3], 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.

The EWU Living Lab thus far

The new Computing & Engineering Building at EWU has been in use since Fall of 2005 and is shown in the following figure.

Figure 1, Computing and Engineering Building at EWU

As the planning and construction of the new building progressed it became obvious that all aspects of the Living-Building Laboratory concept would not be funded as money earmarked for this was needed in more fundamental aspects of the construction. Areas that were designed to accommodate students have been built to that standard but certain elements of the instrumentation were not completed.

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®[1,2]. This makes much of the data desired for the Living Lab concept already available. But deciding how to grant access has become an important issue.

Grant Activity Update

One avenue that is being pursued in order to complete the funding of the Living-Building Laboratory is through grants. A grant through the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement program (CCLI) was applied for during the spring of 2006. This initial effort proved unsuccessful. This grant focused on improvements and innovations in education and therefore required either a repeatability aspect or perhaps a foundation or spring-board positioning of the project. The NSF committee decided that repeatability would be difficult to defend since many of the aspects of the Living-Building Laboratory as planned for in our building have to be designed in prior to the start of construction. From the NSF point of view this didn't make the Living-Building Laboratory as useful to other institutions wanting to implement the concept. The other possible avenue was that of a foundational or spring-board position for the concept that would allow others to take what has been done and then build upon that concept. Again, the grant committee decided that others may have difficulty building upon this concept as it was presented.

However this is not entirely the case. As the project is envisioned, data from the Living-Building Laboratory will be available through the internet. This means that anyone interested in the concept doesn't have to build their own building but can use this one. Additionally, older buildings periodically go through renovations to extend their lives and make them more efficient. Eastern Washington University has had and will continue to have ongoing building renovation projects. As these buildings are updated, more often than not, their heating, ventilation and air condition systems are installed using BACnet® or a similar networked control system. Thus a renovation project may be all that is needed in order to create a Living-Building Laboratory project.

What has already been done

Using data from a building isn't a new or novel idea however few models for using an entire building as a lab exist nationally. As an example, The University of Colorado at Boulder has a very robust example of such a building that they call the Building as a Learning Tool (BLT). Through their website you can gain access to large amounts of information on their building. You can see temperatures at many different places along the service ducts. In addition, you can access drawings of the specific location of that particular probe. They had the foresight to install windows into an elevator shaft allowing students to see the live operation of the various mechanical devices involved in the function of an elevator. The BLT is a great resource and well worth a visit to the website. Where the Living-Building Laboratory concept at Eastern Washington University hopes to expand upon what has been done at UCB and a few other locations is with the addition of additional sensors, such as flow rate sensors, to allow a complete thermodynamic analysis of the building. Other shortcomings communicated from UCB faculty will be addressed. In addition, utilizing strain gages for building loads will take the laboratory concept beyond the usual Fluids/Thermo realm and allow some structural analysis and even data relating to external wind loading.

The University of Colorado at Boulder has created a fantastic showpiece and does invite many people to tour the building and see many of the building-as-a-laboratory aspects that are in place. I would recommend that anyone interested in this concept look at their website: http://itll.colorado.edu. EWU looks to make greater use of the building than has been seen at other institutions by making it an integral part of the student's academic/laboratory experience. Additionally, EWU looks to utilize the combined, networked data as a complete picture of the building beyond just individual sensor-provided data. The usefulness of creating the Living-Building Laboratory is easily seen by the efforts of one professor in the department who decided he couldn't wait for the final Living-Building Laboratory installation so he obtained approval to put a few holes in the ventilation system in order to place temporary sensors within the airflow and provide some rudimentary data for the students to work with.

Conclusions and Looking to the Future

As mentioned earlier, certain aspects of the Living-Building Laboratory do currently exist within the infrastructure of our building and some are being put to use by the Engineering & Design department. The newness of the building has assured that the heating, ventilation, and air conditioning controls are all electronically controlled and networked to a single control location. This should make obtaining much of this information relatively simple. The problem lies in assuring access without granting control. The prevalence of malicious computer hackers requires caution in setting up the pathway to allow access to this data by the general public. At the present time operators who are authorized access have readily shown the Engineering & Design faculty the data available through BACnet. However, the search for how to open this data up for regular student use without compromising the operation of the building has not been resolved. Resolving this issue to the satisfaction of all parties is still on-going. Because of this roadblock the department hasn't gathered any usable data from the building as of yet. This is not seen as a show-stopper but the solution to this problem will need to be carefully constructed.

Additional data is also being sought to determine the magnitude of the extra cost that would be added-on to an already planned renovation project to extend it to function along the lines of a Living-Building Laboratory. Although the initial assessment by the NSF was that this project wasn't as repeatable as they would like, I believe that it actually is and that we just did not present it correctly. Any building that was constructed within the last few years is most likely running its heating and ventilation systems using networked data. Not only that, because of the prevalence of the BACnet standard, it is likely that BACnet is the protocol being used to run the building. Additionally, any recent building renovations would most likely also be upgraded to run a networked control protocol such as BACnet. This means that what we hope to do to the Computing & Engineering Building at EWU could be very repeatable at just about any other public building. Efforts are underway at EWU to assess the additional costs above and beyond the basic installation of networked heating and ventilation components of providing the additional sensors to make any building a Living-Building Laboratory. Providing this information with some lessons learned during the installation and use, along with courseware and assessment ideas are the major thrust of our current approach. We hope to be able to secure the necessary additional funding and support to make the Living-Building Laboratory a reality and then provide that information to any and all who wish to do the same.

Finally, looking into the larger future there is a hope to make the building data available through the internet. The ability to access the building data from the internet makes this an excellent tool to take into elementary, middle, and high school classrooms. This information could be used by a visiting faculty member to introduce technology into the classroom. Lesson plans could be made available so that elementary through high school science teachers can use the building as a science project in their classes. In addition to the obvious science and technology aspects of the Living-Building Laboratory, students today are very interested in the future and what changes global warming and the depletion of energy supplies might bring about. The Living-Building

Laboratory is a great resource to expose students to just how much energy is required to run a building, how that energy gets used, and what possibilities there are for future improvements. It could be a great vehicle to use with students of all interests to discuss the carbon cycle and how humans are influencing their environment through the use of non-renewable energy supplies. All-in-all, the concept of a Living-Building Laboratory has great potential and will continue to be pursued within the department of Engineering & Design at Eastern Washington University.

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