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Enhancing Student Learning through Extracurricular Energy Projects

Ms. Caitlyn Clark, University of Notre Dame

Caitlyn Clark is a first year graduate student pursuing a Ph.D. at the University of Notre Dame. Her research involves using particle image velocimetry techniques for various flow analyses. She is also a recent alumni of Western Kentucky University where she served as a thermo-fluids research assistant. During her undergraduate career she carried out multiple research projects funded through internal grants and industry sponsorships.

Prof. Robert E. Choate III, Western Kentucky University

Robert Choate teaches thermo-fluid and professional component courses in Mechanical Engineering, including Thermodynamics, Fluid Mechanics, Sophomore Design and the ME Senior Project Design course sequence. Prior his appointment at WKU, he was a principal engineer for CMAC Design Corporation, designing thermal management solutions for telecommunication, data communication and information technology equipment.

Mr. Jimmy Sandusky, Halton Company

Jimmy Sandusky is the Research and Development Manager at Halton Company located in Scottsville, KY. Halton is an international manufacturer of products that deliver comfortable and energy efficient indoor environments. Mr. Sandusky is a graduate of the Western Kentucky University Mechanical Engineering program.

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Caitlyn L. Clark, Robert E. Choate, Jimmy Sandusky
University of Notre Dame / Western Kentucky University / Halton Company

Abstract
During the 2014-2015 academic year, the Mechanical Engineering Program at Western Kentucky University has involved itself with better understanding how energy is being consumed in commercial, industrial and residential arenas. A WKU mechanical engineering student partnered with Halton Company, a manufacturer of kitchen ventilation systems, to create a platform utilizing the capabilities of aerodynamic assessment. This platform was designed to ensure that their products minimize energy consumption associated with ventilation of convective heat and effluent.

Secondly, an internal student grant was awarded to allow a student researcher to develop a relationship between leakage areas, pressures, and flow rates. Understanding how these elements correlate will provide an understanding of energy consumption in residential, commercial and industrial settings due to building envelope construction and maintenance/aging flaws.

Halton Company manufactures kitchen ventilation hoods, which are sized for commercial kitchen use. This being the case, it was impractical to obtain a hood sized for use in the university laboratory. Therefore, a scaled-down model was designed and built so that the results from laboratory research could be correlated to commercial sized applications. All kitchen ventilation systems require two main parts; an exhaust air moving device (AMD) and effluent collection hood. In order to recreate these items, before testing of the scaled–down hood could begin, an air flow bench was developed and characterized to replicate the exhaust AMD system, which was then coupled to the scaled down version of the kitchen ventilation hood.

To study the effects of leakage areas on energy consumption in building envelopes, a “blower door” simulation test bed was purchased with the grant funds. This test bed included “windows” or “apertures”, which allowed for various leakage geometries to be placed in the envelope of the structure. Along with this, the exterior structure and its cover included different pressure taps so that the internal static pressure within the structure may be determined at various locations. To complete the test bed, all of the instruments required to conduct a blower door test - an air moving device, differential and flow measuring device, blower door frame and covering - were included in the performance measure.

An important aspect of these projects was the ability of the ME Program to provide an undergraduate student valuable learning experiences by managing and executing these projects as an extracurricular activity. The learning experiences, present throughout the projects, consisted of both project management and technical aspects. Assessment of outcomes of student learning from these real world energy applications was also performed.

Keywords: Energy Efficiency and Conservation, Building Science

Introduction

Since at least 1950, the amount of energy consumed per year within the United States has steadily increased within all sectors.[1] New developments within each of the residential, commercial, industrial, and transportation sectors has placed additional strain on the amount of energy produced each year. Between January and July of 2014, the U.S. Energy Information Administration estimates, that 41% of the total energy consumed was within the residential and commercial sectors alone.[2]

Although the energy used within all sectors directly affects society, it is not always easy to make changes to reduce the amount used. It is difficult, as a consumer, to alter the processes used in manufacturing to lower the amount of energy used within industry. It is also difficult, as an individual, to reduce the amount of energy that the transportation sector as a whole consumes. However, it is not as difficult to make changes within the residential and commercial sectors because these are environments which we directly come in contact with. These two sectors focus on the energy that is consumed within homes and commercial buildings.

Halton Company focuses on the development of products to improve indoor environments within commercial settings. They also work to ensure that their company is creating the most energy efficient systems possible. They have made a name for themselves as a leading manufacturer of kitchen ventilation systems both within the United States and globally. Halton's engineers are more than capable of designing and building effective hood systems, which minimize the amount of energy consumed by customers while still maintaining comfort for kitchen personnel and restaurant diners. However, it is hard to qualitatively demonstrate this performance to perspective customers.

This being the case, Halton Company determined that a visual tool, similar to a Schlieren system but for field use, was necessary. This visual tool needed to provide images that clearly demonstrated that their systems were more energy efficient than competitors. Also, it was required that the tool could correctly verify the systems performance. Before this tool could be considered, a flow bench to simulate the air moving device (AMD), measurement and control of a commercial kitchen ventilation system needed to be designed, built and tested (DBT). The ME Program at Western Kentucky University has a significant history of incorporating this methodology into its sophomore, junior and senior capstone design course sequences.[3,4] Therefore, this project methodology, although extracurricular, was very familiar to student, faculty and industry participants.

Work on the Halton research project began in January 2014. During this work, an additional opportunity presented itself in the form of a Faculty-Undergraduate Student Engagement (FUSE) grant. FUSE grants are internal grants given by the Office of Sponsored Programs at WKU to support undergraduate students' intellectual development by fostering active engagement in the areas of independent and extracurricular research. This grant allowed for a further investigation into how energy is being consumed within the residential sector. Approximately one-third of the

energy a home owner purchases is lost through apertures in their homes building envelope.[5] The amount of air which escapes a home through cracks is governed by three factors: leakage area, differential pressure across the area, and the flow rate of the air. However, relationships between these three factors and how they relate to energy consumption vary considerably.
In order to study this phenomenon, a test bed was purchased which simulates a building environment. Once the leakage area is characterized, the variances in pressure and flow rates can be characterized based on the aperture geometry. After the factors are understood, it can be determined how these aerodynamic relationships relate to an overall energy loss and associated energy cost in residential, commercial and industrial structures.

An important aspect of these projects was the ability of the ME Program to provide an undergraduate student valuable learning experiences by managing and executing these projects as an extracurricular activity. The learning experiences, present throughout the projects, consisted of both project management and technical aspects. Assessment of outcomes of student learning from these real world energy applications was also performed.

Extracurricular Project: Design, Build and Test (DBT) of an Air Flow Bench

Western Kentucky University takes pride in adhering to a design, build, and test methodology[3,4], which is typically incorporated within the design sequence of the curriculum. Through this methodology, a student team is typically required to conduct research and learn essential skills before ever building or testing an experiment. Because Halton Company manufactures kitchen ventilation hoods, which are sized for commercial use, it was impossible to obtain a hood sized for laboratory use. It was determined that a scaled-down model must be created so that the results from laboratory research could correlate to the industrial sizes. All kitchen ventilation systems require two main parts; an exhaust fan – air moving device (AMD) – and a hood. In order to correctly model a field setup, the laboratory test bed would have to include these two elements. The test bed would also be required to produce flow patterns, which would be similar to those found in an industrial hood.

In order to correctly simulate the effect of the exhaust AMD on a system, it was determined that an air flow bench could deliver the optimum results. Air flow benches consist of an AMD and incorporate a means of determining air flow characteristics or volume flow rates. Several different flow measuring devices can be used for this characterization; common examples include Bernoulli Obstruction flow meters, such as orifices plates, nozzles, and Venturi tubes. Halton, however, developed their own product, the MSD, which utilizes Pitot tube measurements to determine volume flow rate.

In Figure 1, the internal structure of an MSD can be seen. Each MSD is composed of a Pitot array which contains pressure taps at specific locations. As the air passes through the cross section, it causes a velocity pressure to form in each tube, depending on location either stagnation (leading edge) or static (trailing edge). The air flow is then measured by combining this differential pressure, and a characteristic coefficient, *k*-factor, which is different depending on the diameter of the duct work or suitable MSD. Because the outcomes from this research would be incorporated into a Halton Company system, it was decided that an MSD would be the appropriate measuring device to incorporate into the air flow bench.

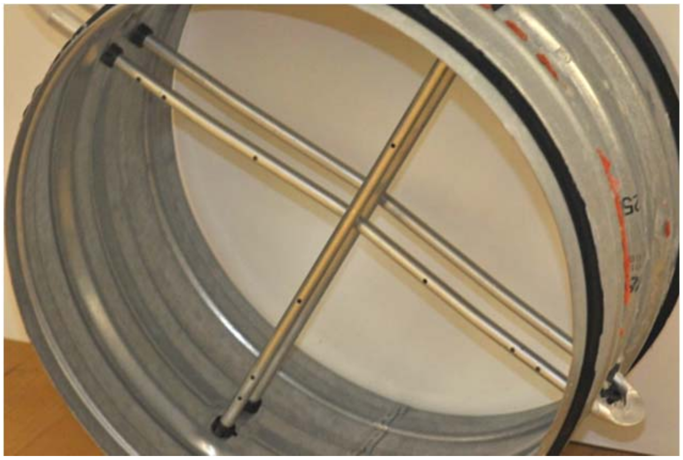
Figure 1 Pitot Tube Structure of the MSD.

The design of the air flow bench soon followed after the decision to use the MSD. At the time of design, two fans had previously been purchased for use within a prior research project, which had not come to fruition. Availability, therefore, determined their incorporation into the flow bench. The two AMD’s consisted of an M-6 and M-8 In-Line Duct Booster fans, produced by Tjernlund Products, Inc., which were meant for inline installation into 6-inch and 8-inch diameter ductwork.

The flow stream that was produced had a very circular pattern due to the fact that the fans being used were radial. This being the case, it was important that calculations concerning the entry length required to create fully developed turbulent flow be completed. Once finalized, it was determined that placing the MSD approximately ten diameters away from the fan would produce optimal results. For the best results, Halton engineers recommended that the MSD be placed at least a length of three diameters away from any obstructions. This suggested distance had been determined from field observations and was determined to be enough length to obtain an accurate measurement using the MSD. Because space constraints within the lab would not allow for ten diameters length of ductwork, the engineers suggested length was used instead.

The final completed air flow bench can be seen in Figure 2. The bench was constructed using 6-in and 8-in diameter PVC pipe which were intended for sewage drain pipes. Wood stands were created so that the bench was supported and the fans could be mounted to the cart. The bench was placed upon the cart as a space saver and to make moving the bench easier.

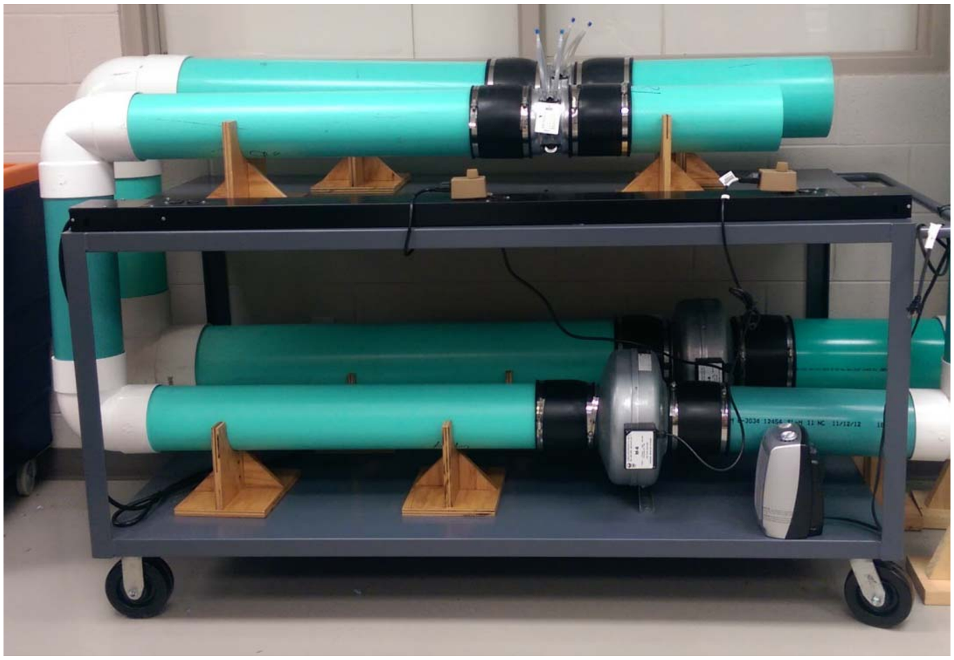

Figure 2 Air Flow Bench - 6-inch and 8-inch Diameter PVC Pipe Networks

The next step to this research consisted of characterizing the air flow bench, which had been created. This process would allow for a true understanding of how the assembled system performed. The system's impedance curve needed to be established so that the operating point could be determined. Knowing the operating point allows for an understanding of how losses within the system create a pressure which determines available air flow. Additionally, the true value of the volume flow rate versus the measurement being produced by the MSD needed to be characterized. By verifying the MSD's measurements it could be ensured that the flow bench was yielding measurements that could relate to a calibrated standard. Through both of these evaluations an understanding of what the bench's true performance was could be determined. After the performance was known, any improvements the bench might need would be apparent.

To establish the system's impedance curve minor and major losses within the system needed to be accounted for. Major losses are characterized based on the velocity of the fluid, the type of ductwork in which it is flowing in, as well as the length of the ductwork. In contrast, minor losses are caused by the inclusion of items such as valves, fittings and bends into the network, and the velocity of the fluid following through them. Every item within the system which created an obstruction to the flow resulted in additional impedance. Within the flow bench created, the only obstructions were the PVC elbows which curved the networks around the cart and the lengths of the individual pipes. It was determined that the impedance due to the MSD could be considered negligible because the tubes did not severely interfere with the flow of the air.

Figures 3 and 4 show the final impedance curves for the system. Because the effect of the losses depends on the velocity of the air, an equation was derived and various velocities, and corresponding volume flow rates, were used to populate the curve. Along with this, manufacture provided data concerning the fan's performance at certain amounts of pressure head were plotted. The data provided by the company resulted in the fan's curve. When the system curve was plotted against the fan curve, the point of intersection is referred to as the operating point. Within the 6-in diameter network this point occurred at approximately 390 cfm with 0.70 inches of water head pressure. Within the 8-inch diameter network the point was near 610 cfm with 0.50 inches of water head pressure. The operating points for both systems show the amount of pressure that is being placed on the fan due to the attached system and the resulting flow rate that is produced. It is important that these operating points fall within the midrange of the fan curve. If the system creates a large amount of a head pressure, the fan will reach its dead head point and no flow will be observed. In contrast, if the system does not provide very much head pressure on the fan, the fan could slip and this would also cause problems.

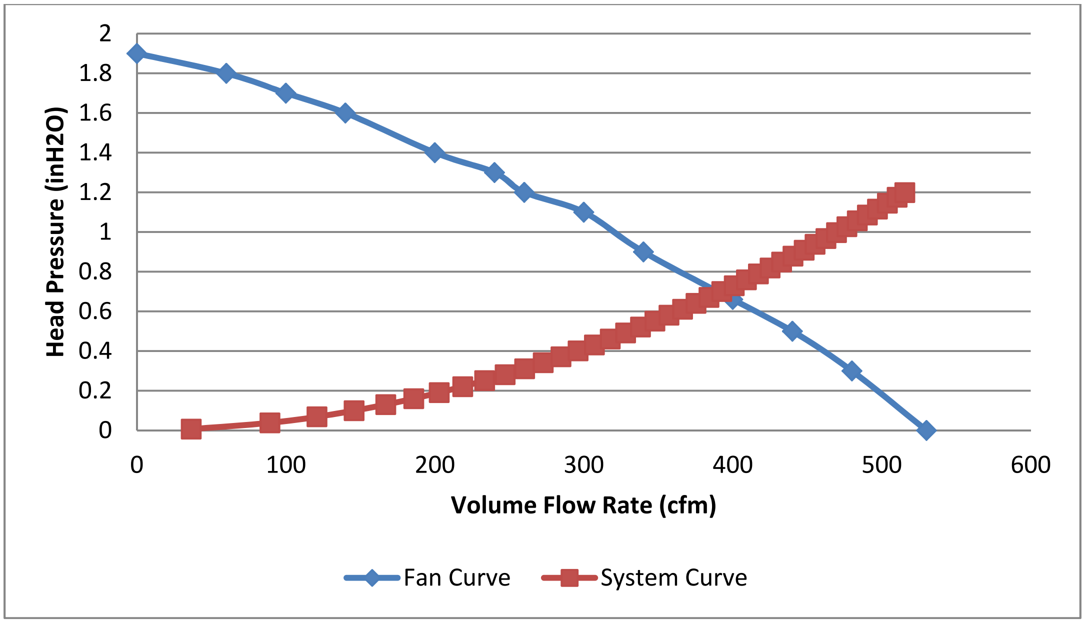

Figure 3 Impedance and Fan Curves for 6-inch Diameter Flow Bench

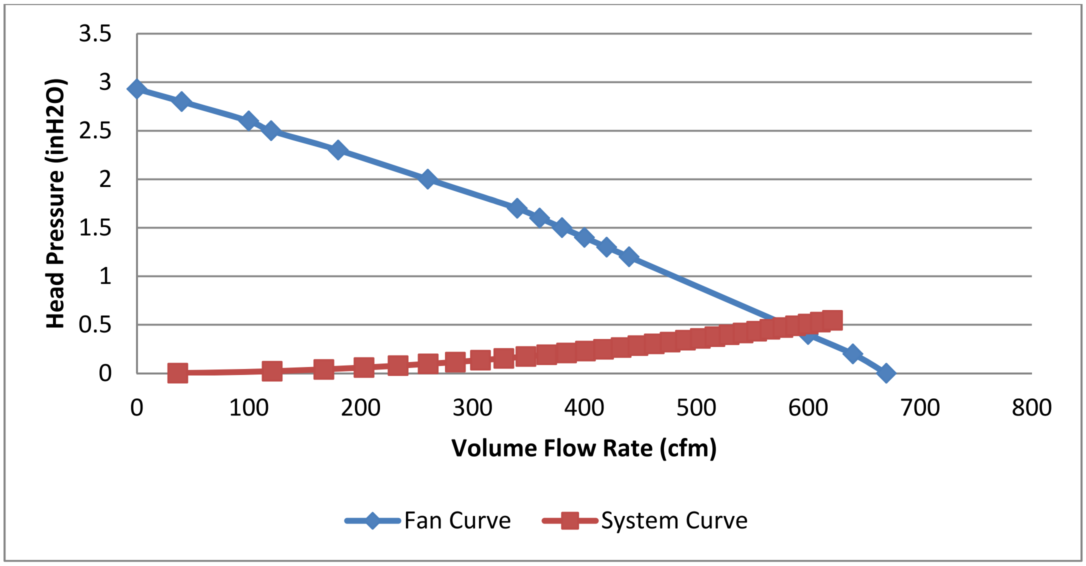

Figure 4 Impedance and Fan Curves for 8-inch Diameter Flow Bench

The second portion necessary to truly understanding the capabilities of the flow benches was characterizing their flow measuring abilities. In order to do this, a calibrated hot film anemometer was used as the standard measuring device. MSD measurements were compared to the measurements made using the hot film anemometer. Hot film traverses were conducted on both network systems. Measurements were taken in an annulus arrangement. A diagram of this arrangement can be seen in Figure 5. The cross section of the pipe was divided into three areas; A, B, and C. Within each area, four different measurements were taken at positions 1, 2, 3, and 4. In the center area, C, only one measurement was taken because this was the point where all four points converged. The velocities obtained from the hot film anemometer were then translated into volume flow rates using the area of each annulus in which the measurements were taken.

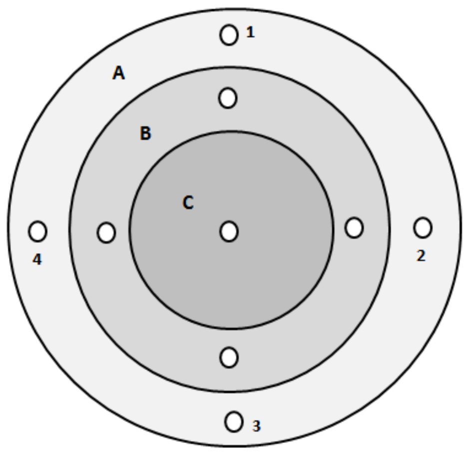

Figure 5 Annulus Traverse for Hot Film Anemometer Air Velocity Measurements

Table 1 shows a set of measurements collected comparing the MSD and hot film anemometer readings.

Table 1: Velocity Traverse Using Hot Film Anemometer Compared to MSD Measurement Taken at an MSD reading of **289.27 ft^3/min**

Area	Position 1 Velocity (ft/min)	Position 2 Velocity (ft/min)	Position 3 Velocity (ft/min)	Position 4 Velocity (ft/min)	Volume Flow Rate(ft^3/min)
A	1485	1655	1590	1505	198.80
B	1535	1625	1560	1530	117.56
C	1540	1540	1540	1540	33.60
				Total:	**305.897**
				% Difference:	**5.435%**

Discrepancies in MSD measurements were in comparison to hot film anemometer readings ranged from as high as 10% and as low as 5%. After determining this range it was decided that an air flow straightener incorporated into each network would improve readings. An air flow straightener functions as a device which helps to decrease the required length to develop a fully turbulent flow. This decrease in length would then allow for more accurate readings at the MSD.

The air flow straightener created consisted of plastic material which was composed of a honeycomb structure. This material had previously been used as a filtration material within a Halton Company product. The material allowed for air to flow through it easily and was capable of being cut to the correct dimensions. Each sheet of the filtration material was 1-inch thick. The Air Movement and Control Association (AMCA) state that a flow straightener must be 0.45 times the diameter of the pipe it is being inserted.[6] In order to stay compliant with these standards, multiple layers of the material would have to compose the straightener while ensuring that the holes were concentric. The finished product is shown in Figure 6. In this photograph, a backlight has been shined into the end of the air flow bench to better demonstrate the fact that honeycomb structure is concentric.

Figure 6 Honeycomb Air Flow Straightener

Extracurricular Project: Analyzing Leakage Effects in Building Envelopes

Within the FUSE grant proposal, a designed test bed which incorporated a differential pressure measuring device, an air moving device, volume flow meter, and a way of creating different leakage area geometries was determined to be necessary. This test bed would essentially be able to conduct blower door tests on a structure, which would fit within the confines of a laboratory space. Similar to the research project conducted with Halton, it is impossible to bring a full scale building into a laboratory environment to conduct research. Therefore, the structure that was to be created would once again have to be scaled-down appropriately.

Opportunity presented itself, however, in the form of The Energy Conservatory (TEC) Trainer™.[7,8] This device consists of a metal frame structure, which is covered with a nylon material. Nylon is less porous than most other materials and allows for a more airtight enclosure to be obtained. The design of this covering is made unique to the trainer. It includes “windows” which allow for various leakage geometries to be placed in the structures envelope. Each window consists of a Velcro pocket which can be attached over a hole placed into the outer nylon covering the structure. Each pocket has its center removed so the hole within the covering is still exposed.

The pocket allows for a piece of 11.5-inch x 5.75-inch, 1/16-inch thick ABS plastic to be inserted. The plastic pieces allow for the opening in the covering to be decreased depending on the amount it has been inserted. The ability to vary the depth of insertion allows for different geometries of leakage areas to be created. The covering also includes three different pressure taps so that the internal static pressure of the structure may be determined. The placement of the pressure taps was decided to be the best locations based on experiments conducted by The Energy Conservatory. The trainer itself consists of only 5 sides, leaving the front portion open so that a blower door frame can be placed within it.

To complete the test bed, all of the instruments required to conduct a blower door test were necessary. This equipment includes an air moving device (AMD) and differential and flow measuring device along with the blower door frame and covering. Additionally, the software, TECTITE™, was made available via web download to acquire and record data collected during the test. Because all of the blower door equipment was available within the Mechanical Engineering Program thermal Fluids Laboratory, and the trainer was able to accommodate all of the necessary requirements set forth, it was determined that purchasing the trainer would be more effective than creating a designing simulated building envelope system – a “buy” versus a “make” design decision. The completed test bed including the trainer and the blower door frame and components is shown in Figure 7.

Figure 7 TEC Trainer™ Structure with Blower Door Frame and AMD

Because the nylon material is not completely airtight and it is impossible to create a sealed perimeter around the area where the blower door frame is inserted into the trainer, there are naturally occurring leakages. These leaks must be accounted for so that when defined leakage areas are placed into the buildings envelope accurate readings can be extrapolated.

Several blower door tests were conducted on the trainer, which uses the Canadian General Standards Board standard test and the TECTITE™ software developed by The Energy Conservatory to perform data analysis. The software has the ability to conduct automated airtightness tests when used in conjunction with Minneapolis Blower Door equipment. During a test, the software varies the speed of the fan to establish and maintain a prescribed differential pressure. Values of both the airflow and the pressure are recorded and the software calculates and stores the test results.

Multiple tests have yielded approximate baseline leakages areas of 7-inch^2 Canadian equivalent leakage area (EqLA) and 4-inch^2 Lawrence- Berkley effective leakage area (ELA). Both of these values have been determined by using TECTITE™. Data collected from one of the multiple blower door tests shown in Figure 8.

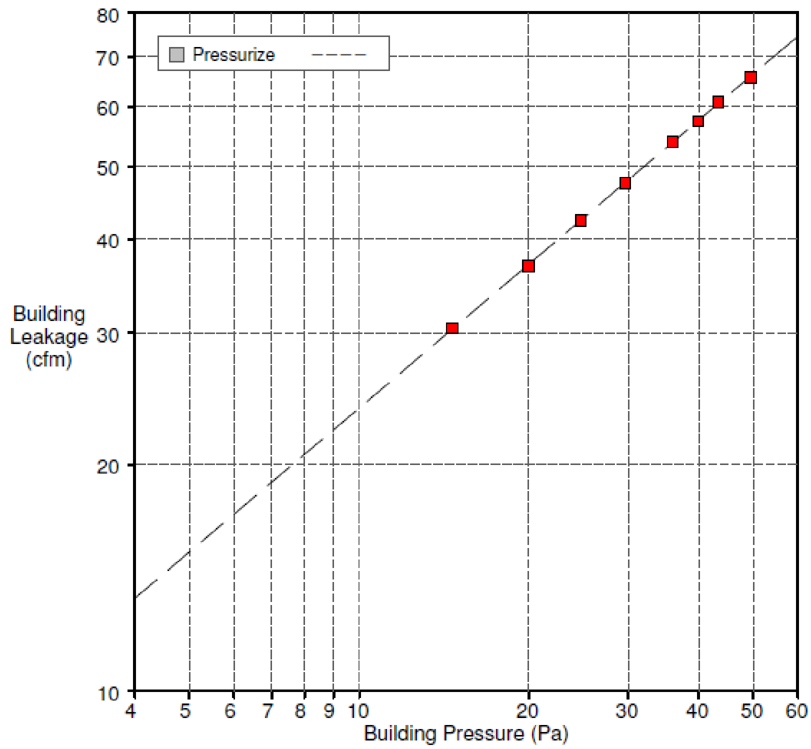

Figure 8 Baseline Leakage Rate for The Energy Conservatory TEC Trainer™

Assessment of the these Extracurricular Projects on Student Learning

An important aspect of these projects was the ability of the ME Program to provide an undergraduate student valuable learning experiences by managing and executing these projects as an extracurricular activity. The learning experiences, present throughout the projects, consisted of both project management and technical aspects. It is apparent that the depth and level of investigation in both of these projects far exceed what can be typically accomplished in a traditional Fluid Mechanics lecture and Instrumentation and Experimentation laboratory course.

The non-technical, but equally rewarding aspects, of these projects were the direct result of schedule, budget and fixed dates of delivery. The student researcher was given approximately 8 weeks to design, build, and test the air flow bench so that it could be incorporated in a scaled-downed evaluation of the Halton Company's Kitchen Ventilation Hood. On the grant based project, approximately 15 weeks was scheduled by the WKU's Office of Sponsored Programs and the Dean's Office for the student researcher to deliver tangible results and present the findings at the WKU's Student Research Conference.

The Halton Company project was needed for a real world application on a fixed timeline, and had only two possible outcomes: success (operational air flow bench) or failure (non-operational air flow bench). This provided a unique experience because most student projects are evaluated on degrees of success and failure (i.e., a grade) instead of an overall success or failure. The instructor's observation is the succeed/fail nature of these projects created a strong desire to accomplish the tasks at hand resulting in the necessary adoption of project management techniques such as detailed scheduling and organization and utilizing multiple resources to accomplish several tasks at once by the student researcher.

Along with the mentioned project management experiences, the project also provided valuable technical experiences. The student researcher had completed in the semester prior to project start our Instrumentation and Experimentation course. Expectations were high on performance on experimental planning, instrumentation uncertainty prediction and selection and the student researcher performed in an exemplary manner. Present throughout the design and build stages was the need for the student to learn about these various measurement techniques and instruments in order to select and design for the proper instruments needed for this particular project.

Because the student researcher had not yet taken Fluid Mechanics at the time the project was started, the most notable technical challenge was the recurring need to quickly learn about unfamiliar topics (i.e. fan characterization and air flow measurement techniques) in order to understand how to design, build, and test an effective flow bench. In class, we learn about fan performance and frictional losses, but in this application, these theoretical developments are applied through functional relationships for fans and blowers, flow and pressure measurement and piping networks, which often collapse to simple correlations between pressure or head (inches of water) and volume flow rate (SCFM).

Finally, the student learned the importance of looking to industry standards as a source to gain understanding in common testing and measurement procedures.[6] The standard proved to be a valuable resource in gaining a general understanding of testing methodology and terminology that guided the development of the experimental procedure used for this particular application. Once the test bed was built the technical challenges shifted to testing the test bed and developing the experiments. This gave the student the opportunity to learn about experimentation and verification techniques as well as experience in designing an experiment to accomplish a certain task.[9,10]

Conclusions and Future Work

In conclusion, these DBT projects were a valuable experience for Halton Company, Western Kentucky University and the student researcher in charge of the project. WKU’s ME Program gained an air flow bench at little monetary cost that provides an appropriate student learning experience for future research. Moreover, the adaptability of the bench makes it possible to use in a variety of laboratory experiments based on the specific needs and desired learning outcomes.

On the part of the student researcher, this extracurricular activity provided learning experiences that no single course could provide. As a result, the student worker has been able to add value to her undergraduate education by applying and refining a variety of engineering skills. Moreover, the rewards personally witnessed by the student have inspired her to continue to seek out ways to add value to future engineering education and career endeavors.

Both research projects require more development to create results which help to better understand energy conservation and efficiency. This work will be continued in future academic years possibly as a senior capstone project with the ME Program. During that time, the above list of objectives will be completed along with new requirements set forth by Halton engineers. This group of students, led by the second author of this paper, will apply the initial student researcher's findings to full-scale Halton Company Kitchen Ventilation Hoods.

A subsequent FUSE grant was awarded to another student researcher; therefore, further study concerning the effects of leakage areas will continue through December 2016. Multiple obstruction plates will be created which the same dimensions as those provided by The Energy Conservatory. Various rectangular holes of definite geometry will be placed in the newly created plates. Each plate will then be tested in the trainer and corresponding leakage areas will be determined. From these results, a correlation will be derived, which relates the pressure and flow rate to the prescribed leakage area. Additionally from these results and through the use of the TECTITE software, the amount of corresponding energy consumption will be determined.

As a final outcome of this project, it is hoped that the results can be correlated to full scale buildings. This would result in data that engineers and field technician would find beneficial in their work. Additionally, operating procedures on how to use the trainer as a learning tool for conducting blower door tests will be developed. These procedures could then possibly be incorporated into curriculum for an energy auditing course which would teach future engineers how to properly assess energy efficiency of buildings.

Overall, both projects take a unique approach to helping solve a very serious problem our society faces today. Energy efficiency and conservation will continue to remain a problem as the population grows and remains so heavily energy dependent. However, making small changes within our commercials environments or our homes will help to reduce this dependency. Realizing the effects a crack around a window sill has on the amount of energy we consume or how much energy goes into maintaining the air quality of the restaurant you eat in is a step forward in reducing our energy consumption.

Bibliography

1. http://www.eia.gov/totalenergy/data/monthly/pdf/sec2_3.pdf
2. http://www.eia.gov/consumption/
3. Schmaltz and Choate, “Improving Student Design Skills through Successive Design and Build Projects,”2006 ASME IMECE Conference Proceedings, Chicago, IL, November 2006.
4. Schmaltz, Byrne, Choate, and Lenoir, “Integrated Professional Component Plan from Freshmen Experience to Senior Project,” 2004 ASEE Annual Conference Proceedings, Salt Lake City, UT, June 2004.
5. Straube, John, “Air Leaks: How They Waste Energy and Rot Houses”, The Taunton Press, 2012, pg. 45
6. AMCA/ANSI/ASHRAE Standard 210-99, 1999, Laboratory Method of Testing Fans for Aerodynamic Performance Rating, AMCA and ASHRAE.
7. Minneapolis Blower Door™, Operation Manual for Model 3 and 4 Systems, The Energy Conservatory, August 2012.
8. TEC Trainer™, Assembly Instructions and User’s Guide, The Energy Conservatory, October 2011.
9. Holman, J.P., *Experimental Methods for Engineers*, McGraw-Hill, Boston, 2001.
10. Wheeler, A.J. and A.R. Ganji, *Introduction to Engineering Experimentation*, Prentice Hall, Englewood Cliffs, 1996.