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ECM Comments Supporting Section 140.9(c)4 - Fume Hood Auto-sashes

Nov 10, 2017

California Energy Commission
Dockets Office, MS-4
Re: Docket No. 17-BSTD-01
1516 Ninth Street
Sacramento, CA 95814-5512

ECM Holding Groupâ€™s Comments on Draft 2019 Building Energy Efficiency Standards

OUR BACKGROUND: Our team at ECM began marketing auto-sashes in 2010 and have installed well over 200 units. Our customers have included the Californian facilities of several major pharmaceutical firms and at least one other SoCal high-tech Fortune 500 company. Three of our clients (Burnham Institute, Life Technologies, and Takeda) also participated in a New Tech brand auto-sash study for SDG&E (attached), but more recently, weâ€™ve mostly installed TEL auto-sashes.

SITUATION: Over the course of auditing several hundred labs, weâ€™ve found that sashes are usually open â€“ perhaps 80% of the fume hoods have open sashes as I write this, but probably more.
In fact, lab staff sometimes think this is a best practice. For a 2017 example, we recently worked with a Fortune 500 client who operates 14 fume hoods. Each hood had a sticker instructing the operators to keep sashes 12 inches open when not in use. Thatâ€™s a problem. A clear Title 24 standard will help people figure out what is needed for health, safety, and our planet.

CEC PROPOSAL: ECM supports the October 2017 proposal to improve energy efficiency in laboratory fume hood installations (Section 140.9(c)4).

Laboratories use an enormous amount of energy due in part to ventilating a high volume of conditioned air through fume hoods. The proposed code sets the bar where it should be to save energy and improve lab safety.
The way the CEC structured the proposed code makes sense. We need a clear and simple standard, so it provides a prescriptive approach for lab designers. At the same time, ECM does not always install auto-sashes. We need performance benchmarks which allow us to communicate with customers, and deploy the diverse measures that work best for safety and appropriate energy savings in each particular space.

BEST PRACTICES: The best way to manage air flow is to develop a customized lab air strategy because each laboratory space has unique needs:
â€¢ How many exhausts and how many supplies for how many square feet?
â€¢ Does the lab space include snorkels or mixing cabinets?
(If so, does some equipment have manual dampers?)
â€¢ How are the mechanical systems engineered?
â€¢ Does heat from lab equipment impact the optimal air change solution?
The list goes onâ€¦ but that only makes a strong energy savings standard more important.

ENERGY SAVINGS: Energy savings with this technology can be phenomenal â€“ often in the 70-85% range â€“

but payback depends on a lot of factors. The basic concept of a VAV fume hood with an auto-sash system is to make sure the hood is exhausting hundreds instead of thousands of cfm. Savings are often an order of magnitude.

VAV lab controls are about balancing air supplies and exhausts, but where should lab designers put the set-point? This is why there must be clearer benchmarks, and why the proposed Title 24, Part 6 language is needed: to set a better-informed standard.

RELIABILITY: Weâ€™ve found auto-sashes to be a very reliable technology based on customer support experience. We donâ€™t recall a single site visit for repairs (this includes the 27 we installed in 2010). At another client, new and untrained staff took the auto-sashes off-line, and that require recommissioning. We found all the equipment in good working condition at that site. Bottom line: tech support calls have been infrequent and often turn-over related. We are able to handle auto-sash customer support by phone with very few exceptions.

SAFETY: Auto-sashes increase safety. By managing hood airflow with auto-sashes, face velocity is less impacted by random turbulence. Safety is also improved because the sash is much more likely to be closed in the event of a chemical reaction.

We strongly support the 10/4/17 CEC proposal language to reduce the energy wasted by fume hoods operations.

Sincerely,

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Additional submitted attachment is included below.

Engineering Measurement & Verification Study:

Laboratory Fume Control Hood

Automatic Sash Positioning System

Prepared by:
Information & Energy Services, Inc.

IES
Information & Energy Services, Inc.

Prepared for:

SDGE
A Sempra Energy utility®

Prepared For: SDG&E Emerging Technology Program

PROJECT TRACKING NUMBER:

ET11SDGE0018

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San Diego, 9/20/2012

This report file, named "ASPS Report Combined Rev 9.docx", and titled "Engineering Measurement & Verification Study: Laboratory Fume Control Hood Automatic Sash Positioning System" has been peer reviewed by us, and our suggestions for improvement have been incorporated. Based on the information available, we believe that the research was conducted in a sound and rigorous manner, and that the results are accurate and complete as presented.

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Marc Esser
President of NegaWatt Consulting, Inc.

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EXECUTIVE SUMMARY

This report contains the results of a study on the efficacy of one specific laboratory fume hood automatic sash positioning system (ASPS). This technology was evaluated to ensure that it performs as intended, and creates sufficient energy savings. To assess the performance of the ASPS, Information & Energy Services, Inc. (IES) analyzed data provided by three companies who use fume hoods, and had test systems installed for this study. Two of the test sites were in the La Jolla area and one was in the Carlsbad area (greater San Diego, CA area).

The ASPS being studied here is an energy savings device for laboratory fume hoods that works by closing the hood sash when the hood is not in active use. Energy usage is optimized by keeping the fume hood sash at its minimum required level, thus minimizing airflow which must be moved, heated and/or cooled.

From the airflow and building parameter data collected for this study, IES was able to conclude that the ASPS does significantly reduce the amount of airflow through the hood and therefore energy consumed by the building when installed as directed at the fume hood in a variable air volume system.

This study has found the following primary results, which are summarized in Table 1 on the following page:

- **Energy savings are gained via: Modulation of Supply and Exhaust Fans speed to provide reduced required by a closed hood thus yielding large savings (Affinity Law). In addition the Central Plant is required to condition less air, since less air is being exhausted through the hood.**
- **On average the airflow was found to be reduced by 54% simply by automatically keeping the sash closed when not in active use.**
- **Use of the ASPS is expected to save approximately 6,956 kWh and 134 therms per 62" wide hood per year on average, however many factors affect the savings; for example, central plant efficiency and pre-existing operator habits.**
- **Based on an estimated 85,000 fume hoods and a 5% market penetration, the statewide energy savings could be estimated at over 32,000 MWh**
- **Using a price of $5,800 per hood retrofitted; the expected typical payback period without rebates is 5 years at the average test facility blended rate of $0.131/kWh and $0.77/therm. The measure pricing information was provided by distributor to represent typical measure cost.**

Table 1: Energy Savings Summary

ENERGY AND FINANCIAL SUMMARY - 62" WIDE HOODS		
	6,956	kWh Saved per Year (Average 62" Hood)
$	936	kWh $ Saved per Year (Average 62" Hood)
	134	Therms Saved per Year (Average 62" Hood)
$	103	Gas $ Saved per Year (Average 62" Hood)
$	1,039	Total $ Saved per Year (Average 62" Hood)
$	5,800	Measure Cost (without rebates)
	5.6	Simple Payback (years)

ENERGY AND FINANCIAL SUMMARY - ALL HOODS IN STUDY		
	38,713	kWh Saved per Year (Total, All 5 Hoods)
$	5,055	kWh $ Saved per Year (Total, All 5 Hoods)
	1,022	Therms Saved per Year (Total, All 5 Hoods)
$	791	Gas $ Saved per Year (Total, All 5 Hoods)
$	5,846	Total $ Saved per Year (Total, All 5 Hoods)
$	29,000	Measure Cost (without rebates) (Total, All 5 Hoods)
	5.0	Simple Payback (years)

PROJECT OBJECTIVE

The objective of this study is to evaluate the energy savings potential of the particular type of Automatic Fume Hood Positioning System (ASPS). This emerging technology will be evaluated by comparing it to the pre-existing (completely manual sash height positioning) fume hood air flow at the test sites. The technology was tested on five fume hoods at three companies in the greater San Diego area.

Information & Energy Services, Inc. (IES) under contract with San Diego Gas & Electric Company Emerging Technologies Program was contracted to verify the effectiveness and potential for energy savings resulting from installation of the ASPS on a typical fume hood in a building with VAV supply and exhaust fan systems.

PROJECT SETTING AND METHODOLOGY

TECHNOLOGY OVERVIEW

An effort to become more energy efficient has led many building owners to consider automatic laboratory fume hood sash positioning systems. In addition to conserving energy, automatic sash positioning systems help to create a safer working environment as required by the National Fire Protection Agency (NFPA). Please see Figure 1 below showing the Components of the ASPS.

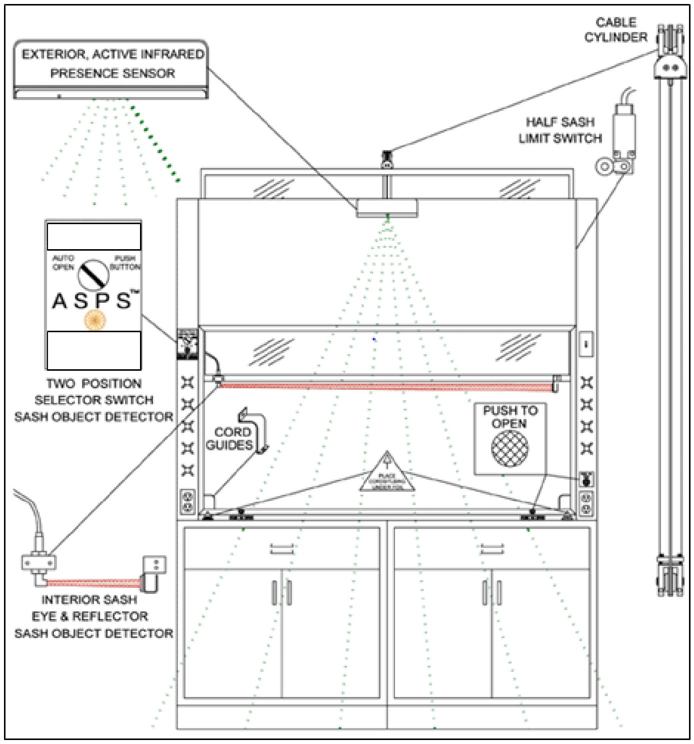

Figure 1: ASPS Component Details

The ASPS uses a cable and pneumatic cylinder system to raise and lower the sash automatically. An active infrared (IR) sensor is used to detect the presence of a person in front of the hood opening and will always automatically close the hood after a delay when no user is detected. The user can select if the sash should open automatically when a person is detected, of if the opening should be at the press of the button. The user can set the height at which the sash stays open, and operators can manually adjust this height during use. There are many options available from the manufacturer to customize operation of the ASPS, e.g. multiple height presets, time delay, travel rate, etc. An obstruction sensor on the inner edge of the sash is used to prevent the closing sash from striking an obstructing object, such as a piece of glass.

The ASPS helps to save energy by reducing airflow through the VAV fume hood. Unless personnel manually close the fume hood the VAV exhaust valves usually remain 80-100% open with face velocity controlled to approximately 100 ft/min in order to remain in compliance with OSHA required levels.

STATEWIDE MARKET POTENTIAL

Based on the number of fume hoods estimated to be in use in California shown on the LLNL website of 85,000 fume hoods, we can make certain market potential estimates[1]. PG&E estimates that there are 28,000 fume hoods in use within its service territory[2]. These estimates are shown to provide an example of how one might perform market potential calculations; several assumptions are made as shown below:

- **85,000 Fume Hoods total.**
- **Market Penetration rate of 5% assumed, this excludes all non-eligible systems.**
- **Average energy savings from this study assumed to be valid at other sites**

$$\underline{\boldsymbol{Statewide\ Savings}} \\ \underline{= \boldsymbol{Per\ Hood\ Savings} \times \boldsymbol{Total\ Hoods\ in\ CA} \times \boldsymbol{Market\ Penetration\ Rate}}$$

Table 2 **Error! Reference source not found.**below shows the estimated statewide California energy and financial savings potential.

Table 2: Statewide Market Potential Example

CALIFORNIA MARKET POTENTIAL	
85,000	Total Number of Fume Hoods (From LLNL)
5%	Market Penetration Rate
7,743	Average Annual Per Hood kWh Savings
204	Average Annual Per Hood therms Savings
32,905,707	Est. Statewide Annual kWh Savings
868,733	Est. Statewide Annual therms NG Savings

[1] http://www.lbl.gov/Science-Articles/Archive/fume-hood-elec-movie.html

[2] http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/biotech/fume_hood_qa.pdf

Market Overview

A full market survey was outside the scope of this study. The analysis performed herein depends on specific features of the technology evaluated; these distinguishing features are listed below:

- **Occupancy sensor to determine if user is present in front of the hood.**
- **Automatically lowers sash when user is not detected.**
- **Exhaust system not modified, responds to same static pressure set point.**

Without these three features, the system in question should be considered substantially different from those evaluated for this study.

A brief outline of the two systems commonly available is as follows:

- **New-Tech™ ASPS**
- **Phoenix Controls™**

The New-Tech™ ASPS works as described above. The New-Tech™ ASPS detects user presence in front of the hood and *automatically* closes the sash when there is no user present. The un-modified exhaust system is then required to move less air.

The Phoenix Controls™ system uses a different principle of operation. The Phoenix Controls™ system senses the position of the sash, and uses this information to adjust a damper installed in the exhaust duct whereby the airflow is reduced while still maintaining a safe face velocity (code states that 70 FPM is acceptable when un-occupied). The Phoenix Controls™ system is designed to optimize the exhaust airflow throughout the day responding to sash position. It does not *automatically* adjust the sash position based on occupancy; therefore these two systems should be considered fundamentally different. <u>The results of this study apply only to fume hood systems that *automatically* respond to occupancy.</u>

The type of system studied for this report has several advantages for energy savings:

- **Since the sash is lowered automatically, the user is not relied upon to remember to close hood sashes.**
- **No modification to the exhaust system means a lower installation cost, since no re-certification is required.**

HOST SITE 1 OVERVIEW

The first test site building located in the La Jolla area of San Diego, CA is a typical pharmaceutical research company with a larger number of fume hoods (over 50). The central plant efficiency was reported to be 1.2 kW/ton by the facilities staff. 82% efficiency was used natural gas calculations. Data was collected electronically and recorded at 5 minute intervals over both a baseline period and a post-retrofit period. The baseline period was 10.6 days. The post-retrofit period was 31.3 days. The following data points were collected: outside air temperature, hood face velocity, and sash height; for baseline measurements exhaust and supply fan speed and CFM were also able to be recorded. All data collection relied upon the building's existing control system capabilities. Since CFM at the hood was not available, vertical sash height and face velocity were used instead to calculate airflow through the hood.

At site #1 there were two (2) 20 horsepower exhaust fans and one (1) 50 horsepower supply fan serving the area with the test retrofit hood. A typical 62 inch wide fume hood number 2-80 was retrofitted with the ASPS device. For the 62 inch wide hood being studied here, baseline exhaust levels can be as high as 1,000 CFM with the sash fully open. Average baseline airflow on our test hood was 483 CFM. The baseline time period consists of data collected from 5/9/2011 to 5/19/2011. Using the ASPS, the sash will automatically close after personnel walk away from the fume hood, lowering the exhaust airflow. In the post-retrofit data set from 7/4/2011 to 8/4/2011 an average of 312 CFM was recorded. The savings are the difference between the average baseline exhaust airflow and the post-retrofit airflow, with a corresponding reduction in heating and cooling demand on the central plant and reduction in direct fan load on the supply and exhaust fans.

HOST SITE 2 OVERVIEW

The second test site building, also located in the La Jolla area of San Diego, CA is a typical pharmaceutical research company with a smaller number of fume hoods (less than 10 on this AHU system). The central plant efficiency was reported to be 0.6 kW/ton by the facilities staff. 82% efficiency was used natural gas calculations. Data was collected electronically and recorded at 5 minute intervals over both a baseline period and a post-retrofit period. The baseline period was 16.9 days. The post-retrofit period was 150 days. The following data points were collected: outside air temperature, hood CFM, hood sash position, hood face velocity, heating valve position, cooling valve position, Supply air temperature, Supply air fan CFM and Hz, Exhaust fan CFM and Hz, and static pressure set-points. All data collection relied upon the building's control system capabilities, between the baseline and post-retrofit periods the control system underwent an upgrade unrelated to the ASPS system but it resulted in a time period without data collection.

At site #2 there was one (1) three (3) horsepower exhaust fan and one (1) eleven (11) horsepower supply fan serving the area with the test retrofit hood. A typical 62 inch wide fume hood number 5 was retrofitted with the ASPS device on 6/14/2011. For the 62-inch wide hood studied here, exhaust levels can be as high as 850 CFM with the sash fully open. Average baseline airflow on our test hood was 457 CFM. The baseline time period consists of data collected from 5/7/2011 to 5/21/2011 with an additional data set provided which includes data from 6/11/2011 up to the installation date. Using the ASPS, the sash will automatically close after personnel walk away from the fume hood, lowering the exhaust airflow. In the post-retrofit data set from 6/15/2011 to 11/15/2011 an average of 216 CFM was recorded. The savings are the difference between the average baseline exhaust airflow and the post-retrofit airflow, with a corresponding reduction in heating and cooling demand on the central plant and reduction in direct fan load on the supply and exhaust fans.

HOST SITE 3 OVERVIEW

The third test site building, located in the Carlsbad, CA area is a typical pharmaceutical research company with a larger number of fume hoods (over 50). The central plant efficiency was reported to be 0.7 kW/ton by the facilities staff. 82% efficiency was used natural gas calculations. Data was collected electronically and recorded at 30 minute and 5 minute intervals for both the post-retrofit hoods as well as baseline hoods. The baseline data was collected using hood #16, #17, and #18 from 2/14/12 to 2/20/12. The following data points were collected for the post-retrofit set: outside air temperature, hood CFM, hood face velocity, cooling valve position, supply air temperature, AHU Fan Hz, exhaust fan CFM and Hz. All data collection relied upon the building's control system capabilities.

At site #3 there were two (2) constant speed exhaust fans and one (1) 50 horsepower supply fan serving the area with the test retrofit hood. The break horsepower of the exhaust fans is calculated based on the amount of air moved and the static pressure differential being maintained. Within the area served by the supply AHU, there are five exhaust fans, only two of which serve the same area as the test hoods. For the two 62.5-inch wide and one 86 inch wide hoods studied here, exhaust levels can be as high as 1979 CFM with the sash fully open. Average airflow on our 62.5" baseline test hoods was 1220 CFM. The baseline time period consists of data collected from 2/14/2012 to 2/20/2012 using un-modified 62.5" hoods #16, #17, and #18. Using the ASPS, the sash will automatically close after personnel walk away from the fume hood, lowering the exhaust airflow. In the post-retrofit data set from 1/16/2012 to 1/24/2012 an average of 479 CFM and 494 CFM was recorded on hoods #3 and #5, respectively. Hood #8 recorded an average of 839 CFM. The opening on hoods #3 and #5 are 62.5 inches wide, while the opening on hood #8 is 86 inches wide. To find a point of comparison, the CFM is divided by the width. The average CFM/inch of the baseline hoods is 19.5 CFM/inch, while the post-retrofit hoods recorded a value of only 9.4 CFM/inch. This translates into an average estimated savings of 1,954 CFM over the three hoods. The savings are the difference between the average baseline CFM/inch and the post-retrofit CFM/inch times the total width of all three test hoods. The financial savings will be resultant from the speed reduction in the supply and exhaust fans, as well as the corresponding reduction in heating and cooling demands on the central plant and reduction in direct fan load on the supply and exhaust fans.

MEASUREMENT & VERIFICATION PLAN OVERVIEW

The M&V protocol for this emerging technology is based on the recommendations of IPMVP Option B combined with Option D. Option B involves directly sub-metering the system values (CFM, Sash Height, Fan Hz, etc.) over a pre and post retrofit time period. Option D involves use of engineering calculations and software to simulate the energy savings based on the measured airflow reduction and other values.

Under this measurement plan, the retrofitting party assumes performance risk for the operation of the ASPS. Equipment was monitored for more than two weeks for each scenario.

APPLICABLE CODES & STANDARDS

California Code of Regulations, Title 24 covers minimum ventilation requirements for non-residential occupied spaces. Title 24 §121.a(1) states that:

- **"Within a building all enclosed spaces that are normally used by humans must be continuously ventilated during occupied hours with outdoor air using either natural or mechanical ventilation." The minimum required ventilation rate of outside air is 15 cfm per occupant.**

In the case of laboratory fume hoods, Title 24 is superseded by the higher ventilation requirements specified in Title 8 regarding workplace safety and fume hoods specifically.

In California, workplace safety is administered through the Department of Industrial Relations. Title 8 of the California Code of Regulations (Cal/OSHA regulations) covers workplace health and safety, including ventilation requirements for fume control hoods. These ventilation requirements are codified under §5154.1 (Ventilation Requirements for Laboratory Type Hood Operations) of Article 107 (Dusts, Fumes, Mists, Vapors, and Gasses) of Group 16 (Control of Hazardous Substances) of Subchapter 7 (General Industry Safety Orders) of Title 8. Pertinent selections from §5154.1 are quoted below:

- **(a) Scope. When laboratory-type hoods, also known as laboratory fume hoods, as defined below are used to prevent harmful exposure to hazardous substances, such hoods shall conform to all applicable provisions of Article 107, and shall conform to provisions of this section.**
- **(b) Definitions. Laboratory-Type Hood. A device enclosed except for necessary exhaust purposes on three sides and top and bottom, designed to draw air inward by means of mechanical ventilation, operated with insertion of only the hands and arms of the user, and used to control exposure to hazardous substances. These devices are also known as laboratory fume hoods.**
- **(c) Ventilation Rates.**
    - **(1) Laboratory-type hood face velocities shall be sufficient to maintain an inward flow of air at all openings into the hood under operating conditions. The hood shall provide confinement of the possible hazards and protection of the employees for the work that is performed. The exhaust system shall provide an average face velocity of at least 100 feet per minute with a minimum of 70 fpm at any point, except where more stringent special requirements are prescribed in other sections of the General Industry Safety Orders, such as Section 5209. The minimum velocity requirement excludes those measurements made within 1 inch of the perimeter of the work opening.**
    - **(2) When a laboratory-type hood is in use to contain airborne hazardous substances and no employee is in the immediate area of the hood opening, the ventilation rate may be reduced from the minimum average face velocity of at least 100 feet per minute to a minimum average face velocity of 60 feet per minute if the following conditions are met:**
        - **(A) The reduction in face velocity is controlled by an automatic system which does not require manual intervention. The automatic system shall increase the airflow to the flow required by (c)(1) when the hood is accessed.**
    - **(3) In addition to being tested as required by Section 5143(a)(5), hoods shall meet the following requirements:**
        - **(A) By January 1, 2008, hoods shall be equipped with a quantitative airflow monitor that continuously indicates whether air is flowing into the exhaust system during operation. The quantitative airflow monitor shall measure either the exact rate of inward airflow or the relative amount of inward airflow. Examples of acceptable devices that measure the relative amount of inward airflow include: diaphragm pressure gauges, inclined manometers, and vane**

gauges. The requirement for a quantitative airflow monitor may also be met by an airflow alarm system if the system provides an audible or visual alarm when the airflow decreases to less than 80% of the airflow required by subsection (c).

Please note that this ASPS system automatically closes the sash, the exhaust system then reduces airflow to meet the same face velocity requirement (greater than 100 fpm) at all times.

In addition to conserving energy, automatic sash positioning systems help to create a safer working environment as required by the National Fire Protection Agency (NFPA). The following NFPA standards apply to using and closing fume or chemical exhaust hoods:

- **NFPA Standard 45-6.8.3**
    - **Laboratory Hood Sash Closure: Laboratory hood sashes shall be kept closed whenever possible. When a fume hood is unattended, its sash shall remain fully closed.**
- **NFPA Standard 45A-6.8.3**
    - **Users should be instructed and periodically reminded not to open sashes rapidly and to allow hood to be open only when needed and only as much as necessary.**

PROJECT RESULTS & DISCUSSION

SYSTEM COST AND COST INFLUENCING FACTORS

There was no market survey or cost analysis performed under the scope of this work. For the purposes of this study the distributor set a cost of $5,800 per fume hood, this cost was intended to represent a typical cost in retrofit application and is inclusive of professional installation. The main factor influencing the cost would be quantity of hoods retrofitted, with a price discount possible if a large number of hoods were to be retrofitted by a single customer. Payback will be affected by the utility rate which the customer pays. For the purposes of this study the site's actual blended utility cost was used in all calculations, since the sites were selected to be representative of the customer base, it is presumed that the rates will also be representative. Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

VERIFICATION OF SYSTEM OPERATION & DESIGN

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #1 & Site #2

The data collected was analyzed by IES to determine the overall performance of the ASPS. Specifically, the analysis involved averaging the airflow in the baseline portion of the test and then comparing to the average airflow measured in the post-retrofit portion. The difference between the average baseline airflow through the test hood and the average post-retrofit airflow in CFM through the test hood is termed Average CFM Reduction. For calculation Details regarding methodology please see Appendix C.

Calculating the airflow reductions for the test hood are simple enough, but to be sure an accurate baseline is used, other hoods in the same location are also tested. Those results are presented on the following pages in the results section.

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #3

The data collected was analyzed by IES to determine the overall performance of the ASPS. Specifically, the analysis involved averaging the airflow in the baseline (un-modified) hoods and then comparing to the average airflow measured in the post-retrofit (ASPS optimized) hoods. The difference between the average baseline airflow and the average post-retrofit airflow in CFM through the combined test hoods is termed Average CFM Reduction. For calculation Details regarding methodology please see Appendix C.

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #1 & Site #2

Using the airflow savings calculated in the previous section as well as baseline data collected from the building supply and exhaust fan systems, IES analyzed the potential energy savings in terms of reduced fan load, reduced cooling load, and reduced heating load. The calculations used to determine the energy savings are shown below in terms of electric savings and natural gas savings. An electric rate based on 12 months of billing information is used to determine financial savings. A natural gas rate based on 12 months of billing history was used to estimate financial savings from natural gas pre-heat reduction. Actual rates used are shown in Appendix D, Utility Information. For calculation Details regarding methodology of determining the energy savings, please see Appendix C.

Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #3

Using the airflow savings calculated in the previous section as well as baseline data collected from the building supply and exhaust fan systems, IES analyzed the potential energy savings in terms of reduced fan load, reduced cooling load, and reduced pre-heat load. The calculations used to determine the energy savings are shown below in terms of electric savings and natural gas savings. For the heating and cooling savings, the central plant meters were used. The central plant meters showed an electric rate of $0.145/kWh and gas rate of $0.778/therm, based on 12 months of blended cost data. For the Fan savings, the estimated electric cost was based on a blend of the other non-central plant meters. The blended rate of $0.124/kWh was used, based on 12 months of billing data. A natural gas rate of $0.778 per therm was used to estimate financial savings from natural gas pre-heat reduction. A blended rate was used for each, in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible. For calculation details regarding methodology of determining the energy savings, please see Appendix C.

RESULTS

In general energy savings were estimated as the difference between the energy consumption at the baseline airflow rate and the energy consumption at the post-retrofit airflow rate, averaged over their respective test periods. This section will present the results of the study in two parts: airflow savings and energy savings. Calculations were performed using the equations presented in the previous section. All interval data were provided by the building automation system, other information comes from site visit and interviews with site facilities personnel. Table 3 below shows the average per hood annual electricity savings estimated for use of the ASPS.

Table 3: Average Annual Energy Savings per Hood

	Est. Avg. Tot. kWh Saved per hood (per year)
Site #1 – 62" Sash Width	6,888 kWh
Site #2 – 62" Sash Width	6,469 kWh
Site #3 – 62.5" Sash Width	7,511 kWh
Site #3 – 86" Sash Width	10,335 kWh
Average (62" Only)	6,956 kWh

The airflow parameters averaged over the three test sites and five test hoods are summarized below in Table 4.

Table 4: Combined CFM Study Summary

COMBINED CFM SUMMARY - ALL SITES	
720	Average 62" Hood Baseline CFM
355	Average 62" Hood Post-Retrofit CFM
365	Average 62" Hood CFM Reduction
51%	Average 62" Hood CFM Reduction (% of Baseline)
5,058	Five Hood Total Combined Average Baseline CFM
2,341	Five Hood Total Combined Average Post-Retrofit CFM
2,717	Five Hood Total CFM Reduction
54%	Five Hood Total CFM Reduction (% of Baseline)

The average airflow reduction was 54%, depending on pre-retrofit user habits. The energy and financial savings were estimated for the 62" sash width hoods and the results are shown on the following page in Table 5.

Table 5: 62" Sash Width Findings Summary

ENERGY AND FINANCIAL SUMMARY - 62" WIDE HOODS	
6,956	kWh Saved per Year (Average 62" Hood)
$ 936	kWh $ Saved per Year (Average 62" Hood)
134	Therms Saved per Year (Average 62" Hood)
$ 103	Gas $ Saved per Year (Average 62" Hood)
$ 1,039	Total $ Saved per Year (Average 62" Hood)
$ 5,800	Measure Cost (without rebates)
5.6	Simple Payback (years)

The energy and financial savings were estimated for all five of the hoods retrofitted for this study, the results are shown below in Table 6.

Table 6: All Hoods Summary

ENERGY AND FINANCIAL SUMMARY - ALL HOODS IN STUDY	
38,713	kWh Saved per Year (Total, All 5 Hoods)
$ 5,055	kWh $ Saved per Year (Total, All 5 Hoods)
1,022	Therms Saved per Year (Total, All 5 Hoods)
$ 791	Gas $ Saved per Year (Total, All 5 Hoods)
$ 5,846	Total $ Saved per Year (Total, All 5 Hoods)
$ 29,000	Measure Cost (without rebates) (Total, All 5 Hoods)
5.0	Simple Payback (years)

Detailed results discussion for each individual site can be found in Appendix E.

RESULTS – Site #1

The summarized results from Test Site #1 are shown in the Tables below.

Table 7 shows the airflow reductions, Table 8 shows the direct load fan kWh savings, and shows the financial savings and estimated simple payback period for the single hood retrofit.

Table 7: Site #1 Savings Summary

	FUME HOOD 2-80		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	483	312	172
Cooling kWh	1,654	1,066	588
Pre-Heat therms	101	65	36

Table 8: Site #1 Fan Savings Summary

Direct Load Fan kWh Savings													
Equipment	HP LF%	HP	Eff %	Annual Hours	Baseline EF/SF CFM	EF/SF Avg. Baseline Hz	Avg CFM Redution	CFM Reduction	EF/SF Hz Post	Post Avg. CFM	Fan kWh Pre	Fan kWh Post	**Fan kWh Saved**
Exhaust Fan 1	85%	20	93%	8760	16,931	55.1	86	0.5%	54.8	16,845	97,179	95,894	1,285
Exhaust Fan 2	85%	20	93%	8760	16,928	55.0	86	0.5%	54.7	16,843	97,149	95,864	1,285
Supply Fan	85%	75	94.5%	8760	33,727	46.3	172	0.5%	46.0	33,555	236,408	232,678	3,730
TOTALS		115					172				430,737	424,437	**6,300**

Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

Table 9 below shows the financial summary information, including typical unit cost provided by distributor, inclusive of installation. Energy costs were derived from 12 months of consumption and billing data ending in September 2011. A calculated natural gas cost of \$0.746/therm and electric cost of \$0.135/kWh were used for financial calculations. The electrical unit cost is a good representation of medium sized 24/7 company on a time-of-use rate tariff in California. The natural gas unit cost is a good representation of current natural gas market prices, but will fluctuate with the natural gas commodity market for delivery to the California market.

Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

Table 9: Site #1 Financial Summary

FINANCIAL SUMMARY		
kWh Saved		6,888
Electric Rate	$	0.135
Electric $ Saved	$	930
Gas Saved		36
Gas Rate	$	0.75
Gas $ Saved	$	27
Total $ Saved	$	957
Cost/CFM	$	5.57
Measure Price	$	5,800
Simple Payback (yrs)		6.1

Using the airflow calculations to compare the test hood at Site #1 (fume control hood number 2-80) baseline conditions to post retrofit conditions, we show the difference of (483.4 - 311.5) = 171.8 CFM in

Table 7 on the previous page and Table 10 below. Please note that the maximum CFM recorded was actually after the retrofit, indicating that the ASPS does not affect the potential to remove fumes but instead shuts the sash when the operator leaves the area.

Table 10: Site #1 hood 2-80 CFM Summary

	FUME HOOD 2-80		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	483	312	172
Min. CFM	85	40	n/a
Max. CFM	1,108	1,301	n/a

Using the airflow savings and the calculation methods presented in the previous section, the energy savings are estimated. Energy savings come in three parts: Direct (fan load) electricity savings, central plant cooling electricity savings, and central plant heating natural gas reductions. Please refer to

Table 7 through Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

Table 9 for summarized energy savings results.

The direct load electric savings are attributable to the supply and exhaust fans running at a reduced speed. It was found that in the baseline data the pair of 20 hp exhaust fans ran at 55.0 Hz and 55.1 Hz respectively. The 75 hp supply fan was found to run at an average speed of 46.3 Hz. Baseline Exhaust Fan and Supply Fan CFM data was also available. For post-retrofit calculations the supply and exhaust airflows were reduced by 172 CFM and the electric load was re-estimated at the reduced airflow. Please see Figure 2 below, showing the study findings at test site #1.

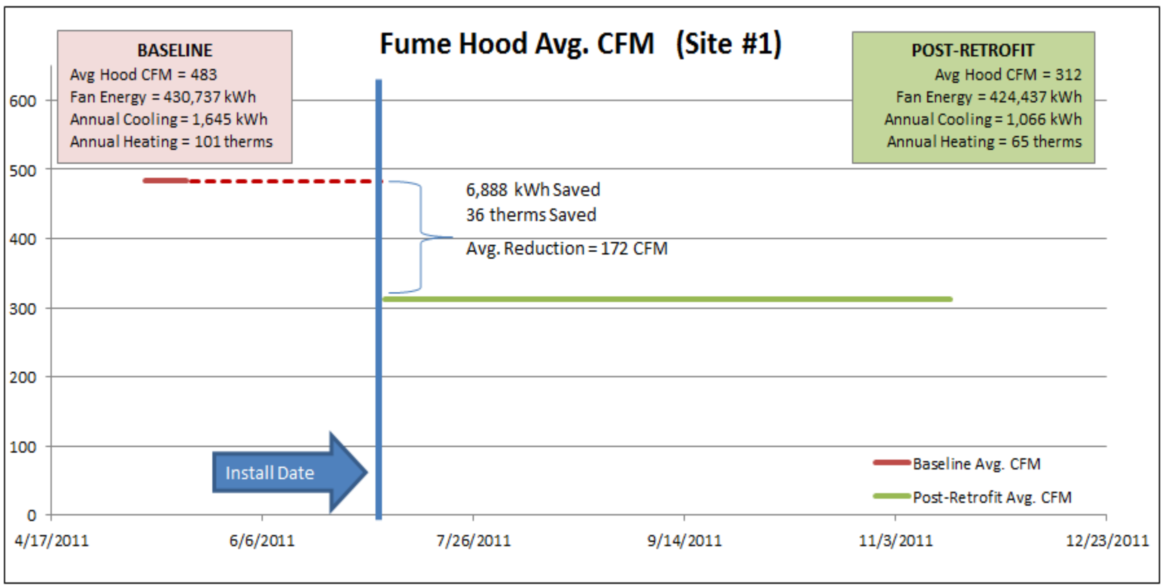

Figure 2: Site #1 Findings

The central plant energy reductions are calculated according to the methodology presented in the previous section. Based on staff interviews, the discharge air is maintained at a constant 55ºF. Since this space is a laboratory 100% outside air is used. Cooling energy is estimated as the energy needed to bring the ambient outside air down to 55ºF. When outside air is colder than discharge air the energy to pre-heat the air to 55ºF is estimated. Natural gas is used for heating. A heating efficiency of 82% is estimated. Based on the facility provided value, a central plant efficiency of 1.2 kW/ton is used in energy calculations. Financial calculations use an electric rate of $0.135/kWh and natural gas rate of $0.746/therm from the facility's previous 12 months of billing statements.

In general, savings can be expected to vary widely, depending entirely on the pre-existing manual sash management practices. This study found that the sash in question was already being managed very well with only moderate room for improvement. At this site, airflow through the test hood was reduced by 36% compared to the baseline conditions. Based on engineering calculations, this translates to an estimated annual savings of 6,888 kWh and 36 therms of natural gas for the single-hood retrofit that was undertaken. The avoided cost per CFM was calculated to be $5.57, with a simple payback of 6.1 years.

RESULTS – Site #2

The summarized results from Test Site #2 are shown in the Tables below. Table 11 shows the airflow reductions, Table 12 shows the direct load fan kWh savings, and

Table 13 shows the financial savings and estimated simple payback period for the single hood retrofit.

Table 11: Site #2 Savings Summary

	FUME HOOD #5		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	457	216	241
Cooling kWh	456	215	240
Pre-Heat therms	201	95	106

Table 12: Site #2 Fan Savings Summary

Direct Load Fan kWh Savings													
Equipment	Base Load Factor %	HP	Eff %	Annual Hours	Baseline EF/SF CFM	EF/SF Avg. Baseline Hz	Single Hood Avg CFM Redution	EF/SF % CFM Reduction	EF/SF Hz Post	EF/SF Post Avg. CFM	Fan kWh Pre	Fan kWh Post	**Fan kWh Saved**
Exhaust Fan	85%	3	89.5%	8,760	3,214	40.7	241	7.5%	36.2	2,973	7,345	5,544	**1,801**
Supply Fan	85%	7.5	91%	8,760	3,214	40.7	241	7.5%	36.2	2,973	18,060	13,633	**4,428**
TOTALS		11					241				25,406	19,177	**6,228**

Energy costs were estimated from 12 months of consumption and billing data ending in September 2011. The electrical unit cost is a good representation of medium sized 24/7 company on a time-of-use rate tariff in California. The natural gas unit cost is a good representation of current natural gas market prices, but will fluctuate with the natural gas commodity market for delivery to the California market. Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

Table 13

Table 13 below shows the financial summary information, including unit cost from distributor inclusive of installation.

Table 13: Site #2 Financial Summary

FINANCIAL SUMMARY		
kWh Saved		6,469
Electric Rate	$	0.144
Electric $ Saved	$	931
Gas Saved		106
Gas Rate	$	0.751
Gas $ Saved	$	80
Total $ Saved	$	1,011
Cost/CFM	$	4.19
Measure Price	$	5,800
Simple Payback (yrs)	5.7	

Using the airflow calculations to compare the test hood at Site #2 (fume control hood #5) baseline conditions to post retrofit conditions, we show the difference of (457 - 216) = 241 CFM in

Table 13 above and Table 14 below.

Table 14: Site #2 hood #5 CFM Summary

	FUME HOOD #5		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	457	216	241
Min. CFM	200	121	n/a
Max. CFM	824	850	n/a

The baseline data was used to put together an estimate of the average airflow through hoods 1, 2, 3, 4, 5, & 6. This was done to determine if the baseline airflow estimate from hood 5 used in the calculations was typical of the baseline of the other hoods.

Table 15 below summarizes this estimate:

Table 15: Site #2 non-modified hood CFM Summary

FUME HOOD AVG. BASELINE CFM	
5/7 to 5/21 & 6/11 to 6/13	
#1	669.6
#2	528.0
#3	539.0
#4	457.5
#5	457.2
#6	563.0
AVERAGE	**535.7**

FUME HOOD AVG. BASELINE CFM	
5/7 to 5/21 & 6/11 to 6/13	
#1	669.6
#2	528.0
#3	539.0
#4	457.5
#6	563.0
AVERAGE	**551.4**

As we see in

Table 15, there is some variation regarding airflow through each hood. The hoods have varied usage which accounts for the variations in airflow. The trended CFM data through each hood shows that Hood #1 through #5 vary frequently, with sash levels that are raised and lowered often; while hood #6 has slightly more consistent (but high) airflow indicating that the sash is adjusted slightly less frequently and left in a mostly open position much of the time. The CFM data trended for hoods 1 through 6 is shown in Appendix E, Site #2 Detailed Results. Please note ASPS technology was installed on hood #5 only, which took place on 6/14/2011. The average baseline airflow from hood #5 (test hood) was measured as 457 CFM, while the average from all other hoods measured was 551 CFM, indicating that the baseline airflow at the test hood is similar to, but significantly lower than the average airflow of the other hoods in the room over that same time period.

Using the airflow savings and the calculation methods presented in the previous section and detailed in Appendix C, the energy savings are estimated. Energy savings come in three parts: Direct (fan load) electricity savings, central plant cooling electricity savings, and central plant heating natural gas reductions. Please refer to Table 11 through

Table 13 for summarized energy savings results.

The direct load electric savings are attributable to the supply and exhaust fans running at a reduced speed. It was found that in the baseline data the 3 hp exhaust fan ran at an average speed of 40.7 Hz. The 11 hp supply fan was estimated to run at the same average speed because baseline data on the supply fan was not available for the majority of the baseline time period due to building control system loss of communication. Baseline CFM data was also available for the exhaust fan only for the majority of the time period. For post-retrofit calculations the supply and exhaust airflows were reduced by 241 CFM and the electric load was re-estimated at the reduced airflow, using an affinity law exponent of 2.4. Please see Figure 3 for the results of the study on the test hood at test site #2.

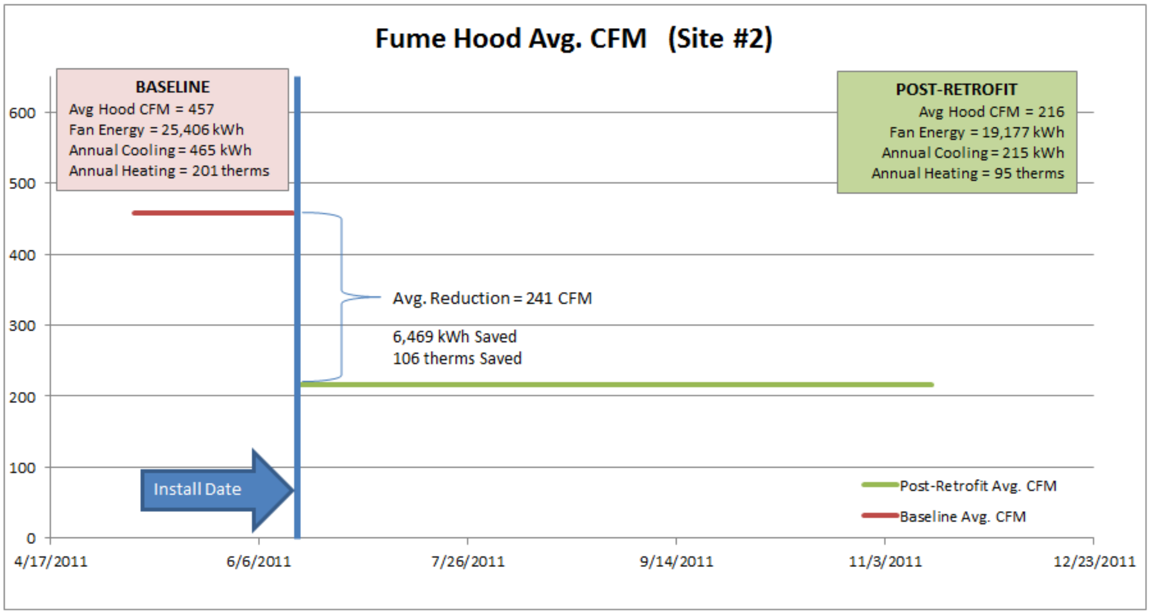

Figure 3: Site #2 Findings

The central plant energy reductions are calculated according to the equations and methodology presented in the previous section. The supply air temperature is estimated at a constant 59ºF based on the average supply air temperature in the provided data. Since this space is a laboratory 100% outside air is used. Cooling energy is estimated as the energy needed to bring the ambient outside air down to 59ºF. When outside air is colder than discharge air the energy to pre-heat the air to 59ºF is estimated. Humidity control is not a priority in this space. Natural gas is used for heating. A heating efficiency of 82% is estimated. Based on the facility provided information, a central plant efficiency of 0.60 kW/ton is used in all energy calculations. Financial calculations use an electric rate of $0.144/kWh and natural gas rate of $0.751/therm from the facility's previous 12 months of billing statements.

In general, savings can be expected to be much higher or much lower than they were at this test site, depending entirely on the pre-existing manual sash management practices. At this site, airflow through the test hood was reduced by 53% compared to the baseline conditions. Based on engineering calculations, this translates to an estimated annual savings of 6,469 kWh and 106 therms of natural gas for the single-hood retrofit that was undertaken. The avoided cost per CFM was calculated to be $4.19, with a simple payback of 5.7 years.

RESULTS – Site #3

The summarized results from Test Site #3 are shown in the Tables below. Table 16 shows the airflow reductions, Table 17 and

Table 18 show the direct load fan kWh savings on the supply and exhaust fans respectively, and Table 19 shows the financial savings and estimated simple payback period for the three hood retrofit.

Table 16: Site #3 Savings Summary

	Averaged Findings			
	BASELINE	*OPTIMIZED*	*SAVINGS*	*% SAVINGS*
Avg. CFM per Inch Width	19.5	8.6	10.9	56%
Cooling kWh	3,513	1,547	1,966	56%
Pre-Heat therms	1,572	692	880	56%

Table 17: Site #3 Supply Fan Savings Summary

Direct Load Supply Fan kWh Savings													
Equipment	Base Load Factor %	HP	Eff %	Annual Hours	Est. Baseline SF CFM	Est. SF Avg. Baseline Hz	Three Hood Avg CFM Redution	SF % CFM Reduction	Measured SF Hz Post	SF Post Avg. CFM	SF kWh Pre	SF kWh Post	**SF kWh Saved**
Supply Fan 09	85%	50	91%	8,760	34,219	40.5	2304	7%	37.8	31,915	118,876	100,562	**18,314**
TOTALS		50									**118,876**	**100,562**	**18,314**

The exhaust fans serving the same area as AHU 09 (shown below in

Table 18) all ran at constant speed in the data collection; therefore, the direct fan savings from those motors will resemble the results of an inlet guide vane system if the ASPS were installed. The motors will not save as much as if they were VFD controlled, but by virtue of moving less air a reduced power load is required. The load experienced by the exhaust fans is calculated using design CFM and static pressure set-points provided by the building maintenance staff.

Table 18: Site #3 Exhaust Fan Savings Summary

Direct Load Exhaust Fan kWh Savings						
Equipment	SP (" H2O)	Eff %	Annual Hours	Change in Load (Δ HP)	Three Hood Avg CFM Redution	**EF kWh Saved**
Exhaust Fan 34	1.5	70%	8760	0	0	0
Exhaust Fan 36	1.5	70%	8760	0	0	0
Exhaust Fan 37	1.5	70%	8760	0.2	605	1,333
Exhaust Fan 38	1.5	70%	8760	0.6	1,699	3,744
Exhaust Fan 39	1.5	70%	8760	0	0	0
TOTALS				**0.8**	**2,304**	**5,077**

It was found that the supply fan can modulate up and down as required, and ran at an average speed of 38 Hz in the post-retrofit data. The static pressure set-point and CFM for AHU 09 were provided by the building maintenance staff.

As shown in

Table 18, no energy savings were calculated for Exhaust Fans 34, 36, or 39 even though they serve the same area as AHU 09. Only Exhaust Fans 37 and 38 serve the area with the retrofit hoods; the airflow reduction was pro-rated between them. The exhaust fans serving the same area as AHU 09 are all constant speed; however there will be a load reduction experienced by the exhaust fans since less air being moved will require a reduced power load. The load is calculated using design CFM and static pressure set-points provided by the building maintenance staff.

Table 19 on the following page shows the financial summary information, including the unit cost provided by the distributor. The price shown is inclusive of installation. Energy costs were estimated from 12 months of consumption and billing data ending in December 2011. At the building in question, there is one meter that serves the central plant exclusively; over the 12 months the blended rate for this meter was $0.145/kWh which is used to compute the cooling kWh contribution to the total savings. To compute the contribution to the total savings by the Supply and Exhaust Fans, the 12 month average of all other electric meters serving the building was used. The fan kWh was assessed at $0.124/kWh. An estimated natural gas cost of $0.778/therm was used based on the blended rate from the single gas meter. The electrical unit cost is a good representation of medium sized 24/7 company on a time-of-use rate tariff in California. The slight differences between the rates reflect central plant being on an electric meter with a higher on-peak time-of use relative to the fans being served by a meter with a very flat load profile. The natural gas unit cost is a good representation of current natural gas market prices, but will fluctuate with the natural gas commodity market for delivery to the California market.

Table 19: Site #3 Financial Summary

FINANCIAL SUMMARY		
kWh Saved		25,356
Electric $ Saved	$	3,194
Gas Saved		880
Gas $ Saved	$	684
Total $ Saved	$	3,878
Cost/CFM	$	1.68
Measure Price	$	17,400
Simple Payback (yrs)		4.5

Using the airflow calculations shown in the previous section to compare the test hoods at Site #3 to the non-modified hoods, we show the difference of 2,304 CFM in Table 20.

Table 20: Site #3 Test Hood Summary

	Totalized Findings		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Hood #3, #5, #8 Total CFM	4,118	1,813	2,304
Fan kWh	237,906	214,515	23,390
Cooling kWh	3,513	1,547	1,966
Pre-Heat therms	1,572	692	880

The baseline data from hoods #16, #17, and #18 was used to put together an estimate of the average airflow through hoods #3, #5, and #8. This was done to determine the baseline airflow estimate for the post-retrofit hoods because the data recording capabilities necessary were only implemented after the ASPS were installed.

Table 21 summarizes this estimate in two parts:

Table 21: Site #3 Baseline CFM Summary

FUME HOOD AVG. BASELINE CFM			
Hoods 16, 17, 18			
Hood	Avg. CFM	inches width	CFM/in
#16	1231	62.5	19.7
#17	1313	62.5	21.0
#18	1115	62.5	17.8
AVERAGE	**1220**	**62.5**	**19.5**

FUME HOOD EST. BASELINE CFM			
Hoods 3, 5, 8			
Hood	CFM/in	inches width	Avg CFM
#3	19.5	62.5	1220
#5	19.5	62.5	1220
#8	19.5	86.0	1678
TOTAL	**19.5**	**211.0**	**4118**

As we see in the left part of the Table above, there is some variation regarding airflow through each hood. The hoods have varied usage which accounts for the variations in airflow. Table 22 below shows the average optimized CFM from hoods #3, #5, and #8.

Table 22: Site #3 Optimized CFM Summary

FUME HOOD AVG. OPTIMIZED CFM			
Hoods 3, 5, 8			
Hood	Avg. CFM	inches width	CFM/in
#3	479.3	62.5	7.7
#5	494.6	62.5	7.9
#8	839.6	86.0	9.8
TOTAL	**1813.4**	**211.0**	**8.6**

The average baseline airflow from the test hoods is shown to be on average much less than the non-modified hoods. Please see Appendix E for the trended CFM data for non-modified hoods #16, #17, and #18 as well as the modified hoods #3, #5, and #8. The average baseline airflow from the 62.5" optimized test hoods was measured as 487 CFM, while the average from all other baseline 62.5" test hoods measured was 1,220 CFM, indicating that the ASPS has had a significant effect on the lab airflow.

Using the airflow savings and the calculation methods presented in the previous section (and Methodology details in Appendix C), the energy savings are estimated. Energy savings come in three parts: Direct (fan load) electricity savings, central plant cooling electricity savings, and central plant heating natural gas reductions. Please refer to Table 16 through Table 19 for summarized energy savings results.

The direct load electric savings are attributable to the 50 hp supply fan running at a reduced speed. In addition, the constant speed exhaust fans serving the area with the test hoods will experience a reduced airflow and therefore less power load.

The central plant energy reductions are calculated according to the equations and methodology presented in the previous section. The supply air temperature is estimated at a constant 62ºF based on the average supply air temperature in the data; this is higher than the other two sites which will impact energy savings. Since this space is a laboratory, 100% outside air is used. Cooling energy is estimated as the energy needed to bring the ambient outside air down to 62ºF. When outside air is colder than discharge air the energy to pre-heat the air to 62ºF is estimated. According to facility staff, humidity control is not a priority in this space. Natural gas is used for heating. A heating efficiency of 82% is estimated. Based on the information to IES, a central plant efficiency of 0.70 kW/ton is used in all energy calculations. Financial calculations at the central plant use an electric rate of $0.145/kWh and natural gas rate of $0.778/therm from the facility's previous 12 months of billing statements ending in December, 2011. Non-Central Plant blended electric rate is calculated as $0.124/kWh based on 12 months of data. A distributor provided pricing of $5,800 each was used for the ASPS, and includes professional installation in a retrofit application. This price was intended by the distributor to be representative of a typical installation.

CUSTOMER FEEDBACK

For the most part, the customers (building operators) at all three test sites have been pleased with the performance of the ASPS. One customer purchased more units to further reduce their carbon footprint. The second customer removed the test unit, but it was not due to performance issues. The customer removed the test unit because the simple payback of 5.7 years was higher than their internal criteria of 2 to 3 years. The third customer is considering more units, pending the results of this study.

SAVINGS INFLUENCING FACTORS

The primary factor influencing potential savings is the behavior of the staff before installation. Both the supply and exhaust fans should be on VFDs with properly operating and responsive control systems capable of reducing fan speed while maintaining a consistent air velocity at the hood face as the sash is closed. Other factors include:

- **Supply Air temperature is an influencing factor on savings**
- **Whether or not the facility requires humidity control is an influencing factor on savings**

- **Central Plant kW/ton and heating efficiency is an influencing factor on savings**
- **Energy rates paid by the facility are factors influencing savings**

APPLICIBILITY OF FUTURE REBATE/INCENTIVE PROGRAMS

This study finds that rebate or incentive programs designed to increase proliferation of this technology in the commercial market would be appropriate. In the SDG&E territory where this study was conducted, rebates under the EEBR program or customized incentives under the EEBI program would both be examples of appropriate market encouragement. Currently in the SCE territory there is a Customized Solution (AC-59483) of $0.09 per kWh and $100 per kW being offered which is applied to the technology. Please see Table 23 below.

Table 23: SCE Customized Incentive

Customized Solution			
SOLUTION CODE	SOLUTION DESCRIPTION FOR HVAC CONTROLS	INCENTIVE	
		$/kWh	$/kW
AC-59483	Automatic sash closer controls	$0.09	$100

PROJECT ERROR ANALYSIS

PROJECT PLAN DEVIATION

It was necessary to deviate from the project plan at Site #3 because the installation of the test hoods was performed before the building control system could record data reliably. Data collection was believed to have commenced for a period of two weeks prior to retrofit installation, however this data was never provided to IES due to its loss by the building control system. As an alternate means of comparison, three other hoods were selected in another part of the building to use as a comparison to the ASPS hoods. The baseline hoods were selected because they were in use as a primary workstation; the selection which three workstations to use was done at random.

ANOMALOUS DATA AND TREATMENT

All data was provided to IES by the respective test site building maintenance departments. The test sites were responsible for measuring and recording all data points, and then transmitting them to IES technicians in electronic format (MS Excel). All data were used as delivered with no additional treatment needed. Data were checked for gross errors or omissions with additional data requests sometimes necessary if crucial parameters were discovered to have been accidentally omitted from a file. Sash height output on the BMS was physically verified with a tape measure. Calibrated face velocity meters verified that airflow requirements were met at all hoods at all times. Since all measurement equipment was consistent across the pre and post retrofit data collection period, it is presumed that any errors were consistent and therefore the relative percent change would not vary. Due to the verified spot checking we feel the collected data is accurate and represents valid data from which to make calculations. In addition the annually verified face velocity measurements provide additional support of accurate data collection.

CONCLUSIONS

After reviewing all of the variables in this study, it is clear that the ASPS is able to save energy in laboratory VAV systems for which it is designed. The major factor determining the amount of savings is the sash management practices of the operators before the automatic closer is installed. If the staff already keep the fume hoods closed much of the time, than an automated closer will only be able to provide limited additional closed time. Conversely, if staff does not strictly manage fume hood height, as is typical in most settings, than the automated sash closer will provide more dramatic changes in average airflow. The ASPS helps to reduce airflow to the required minimum levels; closed sash heights are pre-set to a safe minimum. Building central plant energy is saved by reduction in the amount of outside air that is fed through the building.

In order to predict the amount of savings that can be estimated from installation of the ASPS in future applications, information on the sash management practices of that building is helpful. Helpful information to be trended beforehand includes:

- **Exhaust fan CFM**
- **Each Hood CFM or Sash Height and face velocity**

- **Supply Fan CFM**
- **Central Plant kW/Ton & heating efficiency should be determined already**

BENEFITS OF EVALUATED TECHNOLOGY

The ASPS saves energy in a VAV system and improves user safety at the same time by closing the fume hood sash whenever possible. An ASPS allows the VAV system to reduce airflow and thereby save energy because of the following:

- **All air that is exhausted through the hood(s) must first be pulled in from the outside, filtered, cooled and heated, then pushed out again (single pass air), which all uses energy.**
- **If the hood is closed, then the amount of air that must be moved by the supply and exhaust fans is reduced, allowing the shaft speed and therefore the electrical demands of the motors to be reduced.**
    - **Due to the Affinity law, even small reductions in shaft speed result in large reductions to energy requirements (energy demand is reduced by a factor of X^3)**
- **In addition, less air must be heated and cooled, reducing the load on the chillers and boilers.**

POSSIBLE DRAWBACKS & RISKS OF EVALUATED TECHNOLOGY

No risks were discovered during the course of the study. Operator safety is improved by keeping the sash closed more of the time.

TECHNOLOGY IMPROVEMENT OPPORTUNITIES

No changes to the device or technology are recommended or needed, the technology functions as intended.

Market penetration could be improved if the cost of the technology were reduced. This could potentially be achieved through higher volume manufacturing lowering the per hood materials cost.

APPLICABILITY OF FINDINGS TO OTHER LOAD TYPES AND SECTORS

The findings of this study (and the equipment evaluated) could be applicable in any fume hood where the ASPS is installed or potentially would be installed. The average CFM reduction levels can be used to determine potential energy savings at a different building. The building's parameters and location can then be used to estimate the potential savings in terms of energy.

CONSIDERATIONS FOR LARGE SCALE PERSISTANT MARKET IMPLIMENTATION

Large scale implementation would save energy over the manual sash control that is common practice today.

POSSIBLE FUTURE STUDY

The authors do not find a need for future study based on the encouraging and consistent results of this study.

GLOSSARY AND ACRONYMS

Affinity Law- Fluid flow is proportional to shaft speed. Head pressure is proportional to the square of shaft speed. Power is proportional to the cube of shaft speed.

ASPS - Automatic Sash Positioning System

CFM- Cubic Feet per Minute

FPM- Feet per Minute

RPM- Revolutions per Minute

IR- Infrared

ECM- Energy Conservation Measure

VS- Variable Speed

VFD- Variable Frequency Drive

SCE- Southern California Edison

SDG&E- San Diego Gas & Electric Company

PG&E- Pacific Gas & Electric Company

NFPA- National Fire Protection Administration

OSHA- Occupational Health and Safety Administration

LLNL- Lawrence Livermore National Laboratory

APPENDIX A: PROJECT PLAN

TECHNOLOGY UNDER INVESTIGATION: Laboratory Fume Control Hood Automatic Sash Positioning System (ASPS)

INCUMBENT TECHNOLOGY BEING REPLACED: Prevailing practice is completely manual fume hood sash positioning, i.e. sash is moved up and down by operator.

GOALS OF ASSESSMENT PROJECT: The objective of this study is to evaluate the energy savings potential of the ASPS. This emerging technology will be evaluated by comparing it to the pre-existing energy consumption at the test sites. The technology was tested at three laboratories in the San Diego area. Results will be applicable to other similar retrofit applications. The results of this study will be presented in terms of kWh and therms saved and % airflow reduction.

M&V PLAN: Please see APPENDIX B – M&V PLAN

TEST SITE SELECTION: Test sites were selected by the Distributor, and approved by IES based on their willingness to have the ASPS installed and share their building's data.

TEST SITE INFORMATION: Three test sites were used. All test sites do bio-tech research and two are located very close to each other in the La Jolla / San Diego area, with the third located in the Carlsbad area. One to three fume hoods were retrofitted per site for the study. Baseline conditions were no sash positioning system (manual control). The user was asked not to change their behavior. More information on the test sites is presented in the body of this report.

CPUC PROJECT TRACKING NUMBER: ET11SDGE0018

APENDIX B: M&V PLAN

The long-term success of any comprehensive energy efficiency program depends on the development of an accurate, successful Measurement & Verification (M&V) plan. The main objective is to develop a cost effective plan that quantifies and verifies the performance results of the emerging technology. IES subscribes to using industry standard M&V protocols that have been developed in response to the need for reliable and consistent measurement practices.

MEASUREMENT & VERIFICATION OPTIONS

The M&V protocols have defined four M&V options (Options A through D) that meet the needs of a wide range of performance contracts and provide suggested procedures for baseline development and post-retrofit verification. These M&V options are flexible and reflect the considerations previously mentioned. The options are summarized in the following table.

Table 24: Measurement and Verification Options

M&V Option	How Savings are Calculated	Typical Applications
Option A: Partially Measured Retrofit Isolation		
Option B: Retrofit Isolation		
Savings are determined by field measurement of the energy use of the systems to which the ECM was applied; separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.	Engineering calculations using short term or continuous measurements	Application of controls to vary the load on a constant speed pump using a variable speed drive. Electricity use is measured by a kWh meter installed on the electrical supply to the pump motor. In the base year this meter is in place for a week to verify constant loading. The meter is in place throughout the post-retrofit period to track variations in energy use.
Option C: Whole Facility (Bill Comparison)		
Option D: Calibrated Simulation (Calibrated Building Modeling)		
Savings are determined through simulation of the energy use of components or the whole facility.	Energy use simulation, calibrated with hourly or monthly utility billing data and/or end- use metering.	Multifaceted energy management program affecting many systems in a building but where no base year data are available. Post-retrofit period energy use is measured.

IES selected a combination of Option B and Option D in order to most accurately quantify the energy load from both the typical baseline practice and retrofit equipment. Short term continuous airflow measurements will be taken at 15 minute intervals for both the baseline and retrofit equipment. Duration will be such that the load can be accurately extrapolated. In addition to measurement of the airflow parameters, the Fan Speed will be recorded. These measurements will be used with engineering calculations to simulate the central plant energy consumption savings. The following table summarizes the methods IES recommends for the project based on past experience and the scope of the M&V being requested.

Table 25: M&V Option Selected

#	ECM Description	Option A	Option B	Option C	Option D
1	Fume Hood Automatic Sash Positioning System		X		X

M&V PLAN—Install Automatic Fume Hood Positioning System

MEASUREMENT & VERIFICATION OVERVIEW

The intent of the ASPS is to save energy by reducing airflow through the VAV fume hood, thereby reducing fan energy and central plant energy use. The M&V protocol selected for this emerging technology is based on the recommendations of IPMVP Option B combined with Option D. Option B involves directly sub-metering the system loads for the baseline practice and energy saving equipment in order to verify that the measure has the potential to perform and to generate savings. This verification was done by measuring the airflow through the hood in question as well as the total airflow through the supply/exhaust system. Option D was used to estimate the effects on the energy consumption at the central plant. Performance verification techniques include engineering calculations with short-term metered values, resulting in measured verification of airflow reduction performance.

Under this measurement plan, the retrofitting party assumes performance risk for the operation of the ASPS. IES will collect short term trended data logging by the facility's building management system. This will be established by trending the CFM in the baseline and then again after installation of the measure. Data collection will persist for two weeks or as needed in each scenario.

TEST LOCATIONS

Three test sites to be used. All test sites do bio-tech research and two are located very close to each other in the La Jolla / San Diego area, with the third located in the Carlsbad area. One to three fume hoods were retrofitted for the study. Baseline conditions are no sash positioning system. The user will be asked not to change their behavior.

Testing Sites were selected by the distributor based diversity, existing configurations, usage, criteria of targeted customers, and on their willingness to participate. Sites were then approved by IES. The sites are qualified based on their locations and the fact that the fume hoods used to test are typical of what is found at most laboratories.

Energy Savings Calculation Methodology (Example used, others similar):

HOOD CFM SAVINGS EXAMPLE CALCULATION

- **CuFt per 5 min =** $\boldsymbol{Width \times sash\ ht \times face\ velocity \times 5}$
- **Where sash ht & face velocity are given in 5 min intervals**
- **Total CuFt =** $\boldsymbol{\sum CuFt\ per\ 5\ minute\ data\ points}$
- **Avg CFM =** $\boldsymbol{\frac{Total\ CuFt}{Total\ \#\ of\ minutes\ in\ data\ set}}$
- **CFM Reduced =** $\boldsymbol{Avg\ CFM_{pre} - Avg\ CFM_{post}}$
- **% CFM Reduced =** $\boldsymbol{\frac{CFM\ Reduced}{Avg\ CFM_{pre}}}$

FAN kWh SAVINGS EXAMPLE CALCULATION

- **Fan kWh Saved =** $\boldsymbol{fan\ kWh_{pre} - fan\ kWh_{post}}$
  - **Same for supply and exhaust fans**

- Fan kWh pre = $hp \times 0.746 \times LF\% \times 8760\ hours \times \frac{1}{eff\%} \times \left(\frac{Hz_{pre}}{60}\right)^{2.4}$
- Where Hz pre is the average logged speed of the fan before retrofit

- Supply Fan kWh pre = $75hp \times 0.746 \times 85\% \times 8760\ hours \times \frac{1}{94.5\%} \times \left(\frac{46.3}{60}\right)^{2.4}$
- Supply Fan kWh pre = $236,408\ kWh$
  - Exhaust Fan kWh calculation similar.
  - Hood CFM reduction calculated previously
  - Fan kWh post = $hp \times 0.746 \times LF\% \times 8760\ hours \times \frac{1}{eff\%} \times \left(\frac{Hz_{post}}{60}\right)^{2.4}$
- Hz post = $Hz_{pre} - (60 \times \%\ fan\ CFM\ reduction)$
  - Because shaft speed and flow have a linear relationship
  - Where Hz pre is the average logged speed of the fan before retrofit
- Hz post = $46.3Hz - (60 \times 0.5\%)$
- Hz post = $46.3Hz - 0.3Hz = 46.0Hz$
- Fan kWh post = $hp \times 0.746 \times LF\% \times 8760\ hours \times \frac{1}{eff\%} \times \left(\frac{Hz_{post}}{60}\right)^{2.4}$
- Sup. Fan kWh post = $75hp \times 0.746 \times 85\% \times 8760\ hours \times \frac{1}{94.5\%} \times \left(\frac{46.0}{60}\right)^{2.4}$
- Supply Fan kWh post = $232,678\ kWh$
  - Exhaust Fan kWh calculation similar.
- Fan kWh Saved = $fan\ kWh_{pre} - fan\ kWh_{post}$
  - Same for supply and exhaust fans
- Supply Fan kWh Saved = $236,408 - 232,678$
- Supply Fan kWh Saved = $3,730\ kWh$

FAN CFM SAVINGS EXAMPLE CALCULATION

- % fan CFM reduction = $\frac{Hood\ CFM\ Reduced}{baseline\ fan\ CFM}$
  - Where baseline fan CFM is the average of the logged values

- **% fan CFM reduction =** $\frac{172\ CFM\ Reduced\ @\ Test\ Hood}{33{,}727\ CFM\ @\ AHU}\%$

- **% fan CFM reduction = 0.5%**

COOLING kWh SAVINGS EXAMPLE CALCULATION

- **Cooling kWh Saved =** $\boldsymbol{Cooling\ kWh_{pre} - Cooling\ kWh_{post}}$
  - **Cooling kWh =** $\boldsymbol{\sum_{55}^{92} cooling\ kWh\ per\ temperature\ bin}$
  - **Same calculation pre and post with the difference being in the CFM used to calc.**
  - **Based on a discharge air temperature of 55F per facility staff interview (Site #1, Site #2 similar)**
  - **Cooling kWh per temp bin =** $\boldsymbol{Avg\ CFM \times 1.08 \times 1.2\frac{kW}{ton} \times \frac{1\ ton}{12{,}000Btu} \times degreehours\ in\ each\ bin}$
  - **Same calculation pre & post with the average CFM being different pre & post**
- **Degree hours / bin =** $\boldsymbol{\Delta T \times hours\ in\ temperature\ bin}$
  - **Where ΔT =** $\boldsymbol{outside\ air\ temperature - discharge\ air\ temperature}$
- **Therms Gas Saved =** $\boldsymbol{therms_{pre} - therms_{post}}$
  - **therms =** $\boldsymbol{\sum_{35}^{55} pre - heat\ therms\ per\ temperature\ bin}$
  - **Same calculation pre and post with the difference being in the CFM used to calc.**
- **Therms / temp bin =** $\boldsymbol{Avg\ CFM \times 1.08 \times \Delta T \times \frac{1\ therm}{100{,}000Btu} \times \frac{1}{eff} \times hours\ in\ each\ bin}$
  - **Same calculation pre & post with the average CFM being different pre & post**
  - **Where ΔT =** $\boldsymbol{discharge\ air\ temperature - outside\ air\ temperature}$

METERING PLAN

IES will measure the airflow through the hood and through the supply / exhaust for the entire space both in the baseline and after the measure has been installed. Supply / exhaust fan speed is also important. The airflow reduction will be calculated based on the difference between the pre and post retrofit data. The central plant energy savings will be calculated based on engineering equations simulating the loads based on building parameters and local TMY3 weather data.

All data collection will be performed at 15-minute intervals using the capabilities of whatever building automation system is in use at the test site.

All or some of the following data points will be collected on a 15 minute interval basis:

- **Time/date (of each data point)**
- **Hood Exhaust CFM or hood sash height & face velocity**
- **Fan Speed (Hz)**
- **Supply Air Temperature**
- **Supply Air CFM**
- **Exhaust Air CFM (should match)**

EXPECTED ACCURACY

The M&V plan for this study allows for an accurate calculation of savings, while limiting the length of time involved and the costs of verification. Full RCx to calibrate all the building sensors and systems the at the three test sites were well beyond the scope of this study, however we can be confident in the reliability of the results due each site's required face velocity sensors at each fume hood. Per Cal/OSHA requirements the face velocity must be above a certain safe threshold (100 FPM) and is continually monitored. These sensors are verified and calibrated annually. If the fume hoods face velocity had dropped below the required threshold verification of data would have detected this change. While face velocity was not used directly it did allow IES to verify that minimum safe airflow conditions were being met at all times using the ASPS device.

Central plant kW/ton was provided to IES by others, and was not investigated as such.

APPENDIX C: Methodology

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #1 & Site #2

The data collected was analyzed by IES to determine the overall performance of the ASPS. Specifically, the analysis involved averaging the airflow in the baseline portion of the test and then comparing to the average airflow measured in the post-retrofit portion. The difference between the average baseline airflow through the test hood and the average post-retrofit airflow in CFM through the test hood is termed Average CFM Reduction. The calculations below show how the Average CFM Reduction was arrived at.

1. $\boldsymbol{Average\ CFM\ Reduction = Baseline\ Average\ CFM_{pre} - Average\ CFM_{post}}$
2. $\boldsymbol{Baseline\ Average\ CFM_{pre} = \frac{total\ cubic\ feet\ of\ air\ thru\ hood\ in\ entire\ study\ period}{total\ minutes\ in\ study\ period}}$
3. $\boldsymbol{Average\ CFM_{post} = \frac{total\ cubic\ feet\ of\ air\ thru\ hood\ in\ entire\ study\ period}{total\ minutes\ in\ study\ period}}$
4. $\boldsymbol{total\ cubic\ feet\ of\ air\ thru\ hood\ in\ entire\ study\ period = total\ CF}$
5. $\boldsymbol{total\ CF = \sum CF_{5\ min}}$
6. $\boldsymbol{CF_{5min} = total\ cubic\ feet\ of\ air\ thru\ hood\ in\ each\ 5\ minute\ interval}$
7. $\boldsymbol{CF_{5min} = hood\ width \times sash\ height \times face\ velocity \times 5\ min}$

Where:

- **Sash height = data provided from building control system feedback (in ft)**
- **Face velocity = data provided from building control system feedback (in ft/min)**
- **There are 5 minutes in each interval (data was provided in 5 minute intervals)**

In addition to calculating Average CFM Reduction, the percentage of its baseline airflow was also calculated according to the formula shown below:

8. $\boldsymbol{Average\ \%\ CFM\ Reduced = \frac{Average\ CFM\ Reduction}{Baseline\ Average\ CFM}\ \%}$

Calculating the airflow reductions for the test hood are simple enough, but to be sure an accurate baseline is used, other hoods in the same location are also tested. Those results are presented on the following pages in Appendix E.

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #3

The data collected was analyzed by IES to determine the overall performance of the ASPS. Specifically, the analysis involved averaging the airflow in the baseline (un-modified) hoods and then comparing to the average airflow measured in the post-retrofit (ASPS optimized) hoods. The difference between the average baseline airflow and the average post-retrofit airflow in CFM through the combined test hoods is termed Average CFM Reduction. The calculations below show how the Average CFM Reduction was arrived at.

9. $\boldsymbol{Average\ CFM\ Reduction = test\ hoods\ total\ width\ \times \left(Avg\ Baseline\ \frac{CFM}{inch} - Avg\ Optimized\ \frac{CFM}{inch}\right)}$
10. $\boldsymbol{test\ hoods\ total\ width = 62.5" + 62.5" + 86" = 211\ inches}$
11. $\boldsymbol{Avg\ Optimized \frac{CFM}{inch} = \frac{total\ cubic\ feet\ of\ air\ thru\ hood\ \#3+\#5+\#8\ in\ entire\ study\ period}{total\ minutes \times test\ hoods\ total\ width}}$
12. $\boldsymbol{Avg\ Baseline \frac{CFM}{inch} = \frac{Baseline\ Avg\ CFM\ per\ hood}{62.5"}}$
13. $\boldsymbol{Avg\ Baseline\ CFM\ per\ hood = \frac{total\ cubic\ feet\ of\ air\ thru\ hood\ \#16+\#17+\#18\ in\ entire\ study\ period}{3\ hoods \times (total\ minutes\ in\ study\ period)}}$
14. $\boldsymbol{total\ cubic\ feet\ of\ air\ thru\ hood\ X\ in\ entire\ study\ period = total\ CF}$
15. $\boldsymbol{total\ CF = \sum CF_{5\ min}}$
16. $\boldsymbol{CF_{5min} = total\ cubic\ feet\ of\ air\ thru\ hood\ in\ each\ 5\ minute\ interval}$
17. $\boldsymbol{CF_{5min} = instantaneous\ CFM \times 5min}$

Where:

- **Instantaneous CFM is recorded by the building control system and there are 5 minutes in each interval (data was provided in 5 minute intervals)**

In addition to calculating Average CFM Reduction, the percentage of its baseline airflow was also calculated according to the formula shown below:

18. $\boldsymbol{Average\ \%\ CFM\ Reduced = \frac{Average\ CFM\ Reduction}{Estimated\ Baseline\ Average\ CFM}\ \%}$
19. $\boldsymbol{Estimated\ Baseline\ Avg\ CFM\ = Avg\ Baseline\ \frac{CFM}{inch} \times test\ hoods\ total\ width}$

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #1 & Site #2

Using the airflow savings calculated in the previous section as well as baseline data collected from the building supply and exhaust fan systems, IES analyzed the potential energy savings in terms of reduced fan load, reduced cooling load, and reduced heating load. The calculations used to determine the energy savings are shown below in terms of electric savings and natural gas savings. An electric rate based on 12 months of billing information is used to determine financial savings. Actual rates used are shown in the Utility section of the Appendix. The calculations below show how electric, gas, and financial savings were arrived at.

20. $\boldsymbol{Annual\ kWh\ Saved = Annual\ kWh_{pre} - Annual\ kWh_{post}}$

21. $\boldsymbol{Annual\ kWh_{pre} = Annual\ cooling\ kWh_{pre} + Annual\ fan\ kWh_{pre}}$

22. $\boldsymbol{Annual\ kWh_{post} = Annual\ cooling\ kWh_{post} + Annual\ fan\ kWh_{post}}$

23. $\boldsymbol{Annual\ cooling\ kWh = \sum_{55}^{92} cooling\ kWh\ per\ temperature\ bin}$

- **Based on a discharge temperature of 55F (59F at Site #2).**

24. $\boldsymbol{Annual\ cooling\ kWh\ per\ temperature\ bin =}$
$\boldsymbol{average\ CFM \times 1.08 \times \frac{kW}{ton} \times \frac{ton}{12{,}000Btu} \times degree\ hours\ per\ year\ in\ each\ bin}$

Where:

kW/ton = central plant efficiency was **provided by facility**.

25. $\boldsymbol{degree\ hours\ per\ year = \Delta T \times hours\ per\ year\ in\ temperature\ bin}$

26. $\boldsymbol{\Delta T = outside\ air\ temperature - discharge\ air\ temperature}$

Where:

- **System uses 100% outside air.**
- **TMY3 data divided into 2 degree temperature bins (MCAS Miramar data used for Site #1 and Site #2, Palomar Airport data used for Site #3).**
- **Constant 55F discharge air temp. per facility staff interview. (59F at Site #2)**
- **No cooling kWh calculated below outside air temperature of 55F.**

27. $\boldsymbol{Annual\ fan\ kWh = hp \times base\ LF\% \times annual\ hours \times 0.746 \times \frac{1}{motor\ effciency} \times \left(\frac{Hz}{60}\right)^{2.4}}$

Where:

- **Base Load Factor of 85% used on horsepower.**

- **Annual hours of 8,760 used (always enabled 24/7).**
- **NEMA nominal motor efficiency based on horsepower was used.**
- **Hz is speed of motor, different pre and post. Affinity law exponent of 2.4 was used.**

28. $\boldsymbol{Hz_{pre} = average\ of\ baseline\ data\ reported}$
29. $\boldsymbol{Hz_{post} = Hz_{pre} - (60 \times AHU\ CFM\ \%\ reduced)}$
30. $\boldsymbol{AHU\ CFM\ \%\ reduced = \frac{Avg\ CFM\ Reduction}{baseline\ AHU\ total\ CFM}\ \%}$
31. $\boldsymbol{baseline\ AHU\ total\ CFM = average\ of\ baseline\ data\ reported}$

Where:

- **Baseline AHU total CFM = averaged CFM values from building control system feedback.**

A natural gas rate based on 12 months of billing history was used to estimate financial savings from natural gas pre-heat reduction. The calculations below show how the natural gas savings were arrived at.

32. $\boldsymbol{Annual\ Therms\ Gas\ Saved = Annual\ therms_{pre} - Annual\ therms_{post}}$

Where:

- **Pre-heat is calculated for outside air temperature bins less than 55F**

33. $\boldsymbol{therms_{pre} = \sum_{35F}^{55F} pre\ heat\ therms\ per\ OSA\ temp\ bin}$
34. $\boldsymbol{therms_{post} = \sum_{35F}^{55F} pre\ heat\ therms\ per\ OSA\ temp\ bin}$
35. $\boldsymbol{pre\ heat\ therms\ per\ bin = (Discharge\ Air\ temp - OSA\ temp) \times Avg\ CFM \times 1.08 \times \frac{1\ therm}{100{,}000\ Btu} \times \frac{1}{thermal\ efficiency} \times hours\ in\ bin}$

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #3

Using the airflow savings calculated in the previous section as well as baseline data collected from the building supply and exhaust fan systems, IES analyzed the potential energy savings in terms of reduced fan load, reduced cooling load, and reduced pre-heat load. The calculations used to determine the energy savings are shown below in terms of electric savings and natural gas savings. For the heating and cooling savings, the central plant meters were used. The central plant meters showed an electric rate of $0.145/kWh and gas rate of $0.778/therm, based on 12 months of blended cost data. For the Fan savings, the estimated electric cost was based on a blend of the other non-central plant meters. The blended rate of $0.124/kWh was used, based on 12 months of billing data. The calculations below show how electric savings were arrived at.

36. $\boldsymbol{kWh\ Saved = kWh_{pre} - kWh_{post}}$
37. $\boldsymbol{kWh_{pre} = cooling\ kWh_{pre} + fan\ kWh_{pre}}$
38. $\boldsymbol{kWh_{post} = cooling\ kWh_{post} + fan\ kWh_{post}}$
39. $\boldsymbol{cooling\ kWh = \sum_{55}^{88} cooling\ kWh\ per\ temperature\ bin}$

- **Based on a discharge temperature of 62F**

40. $\boldsymbol{cooling\ kWh\ per\ temperature\ bin =}$
$\boldsymbol{average\ CFM \times 1.08 \times kW/ton \times \frac{ton}{12{,}000Btu} \times degree\ hours\ in\ each\ bin}$

Where: kW/ton = central plant efficiency of 0.70 kW/ton provided by facility.

41. $\boldsymbol{degree\ hours = \Delta T \times hours\ in\ temperature\ bin}$
42. $\boldsymbol{\Delta T = outside\ air\ temperature - discharge\ air\ temperature}$

Where:

- **System uses 100% outside air.**
- **TMY3 data divided into 2 degree temperature bins (Palomar Airport data used).**
- **Average 62F discharge air temperature per facility data.**
- **No cooling kWh calculated below outside air temperature of 55F.**

43. $\boldsymbol{Annual\ Supply\ fan\ kWh = hp \times base\ LF\% \times annual\ hours \times 0.746 \times \frac{1}{motor\ effciency} \times \left(\frac{Hz}{60}\right)^{2.4}}$

Where:

- **Base Load Factor of 85% used on horsepower.**
- **Annual hours of 8,760 used (always enabled 24/7).**
- **NEMA nominal motor efficiency (maximum) based on horsepower was used.**
- **Hz is speed of motor, different pre and post. Affinity law exponent of 2.4 was used.**

44. $Hz_{pre} = Hz_{post} \times \frac{Estimated\ Baseline\ CFM}{post\ CFM}$
45. $Estimated\ baseline\ CFM = \ post\ CFM + CFM\ reduced$
46. $Hz_{post} = average\ of\ post\ retrofit\ data\ reported$
47. $post\ AHU\ total\ CFM = provided\ by\ bldg.maint.$
48. $Annual\ Exhaust\ Fan\ kWh = \frac{CFM \times SP}{6356 \times Efficiency} \times annual\ hours$

Where:

- **CFM & Static Pressure (SP) provided by building maintenance staff**
- **Annual hours of 8,760 used (always enabled 24/7).**
- **Efficiency of 70% used to cover fan and motor efficiency, conservative estimate.**

A natural gas rate of $0.778 per therm was used to estimate financial savings from natural gas pre-heat reduction. The calculations below show how the natural gas savings were arrived at.

49. $Annual\ Therms\ Gas\ Saved = Annual\ therms_{pre} - Annual\ therms_{post}$

Where:

- **Pre-heat is calculated for outside air temperature bins less than 62F**

50. $Annual\ therms_{pre} = \sum_{35F}^{62F} pre\ heat\ therms\ per\ OSA\ temp\ bin$
51. $Annual\ therms_{post} = \sum_{35F}^{62F} pre\ heat\ therms\ per\ OSA\ temp\ bin$
52. $pre\ heat\ therms\ per\ bin = (DA\ temp - OSA\ temp) \times Avg\ CFM \times 1.08 \times \frac{1\ therm}{100{,}000\ Btu} \times \frac{1}{thermal\ efficiency} \times hours\ per\ year\ in\ bin$

APPENDIX D: UTILITY DATA

Please note: Energy costs were estimated from 12 months of consumption and billing data. Due to variety of rate tariffs offered to commercial customers throughout California, and the fact that fume hoods can be found in many various businesses, no single tariff was evaluated as a one size fits all solution. Actual energy rates for the test sites were used in calculations performed for this study. A blended rate was used in preference to time of use rates because the energy savings from the ASPS occur both at night and during the day as well. Blended rates are more appropriate because the time of day that the savings occur depends entirely on the baseline habits of the operator. Baseline habits were determined to vary widely. Accordingly a blended rate is the most faithful representation of the savings energy rate possible.

TEST SITE #1

Blended actual utility rates are used in all calculations.

Table 26: Site #1 Electric Utility Summary

Site #1: Electric Utility Information October 2010-September 2011													
	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Total
kWh	283,025	278,681	262,534	260,922	244,525	238,820	241,208	272,741	261,780	310,604	284,078	291,914	3,230,831
Cost ($)	$40,790	$37,071	$34,502	$33,498	$30,552	$30,370	$31,982	$36,724	$36,200	$41,651	$40,481	$42,589	$436,410
Blended Rate ($/kWh)	0.14	0.13	0.13	0.13	0.12	0.13	0.13	0.13	0.14	0.13	0.14	0.15	0.13

Notes

1. Average consumption and cost of all Site #1 meters

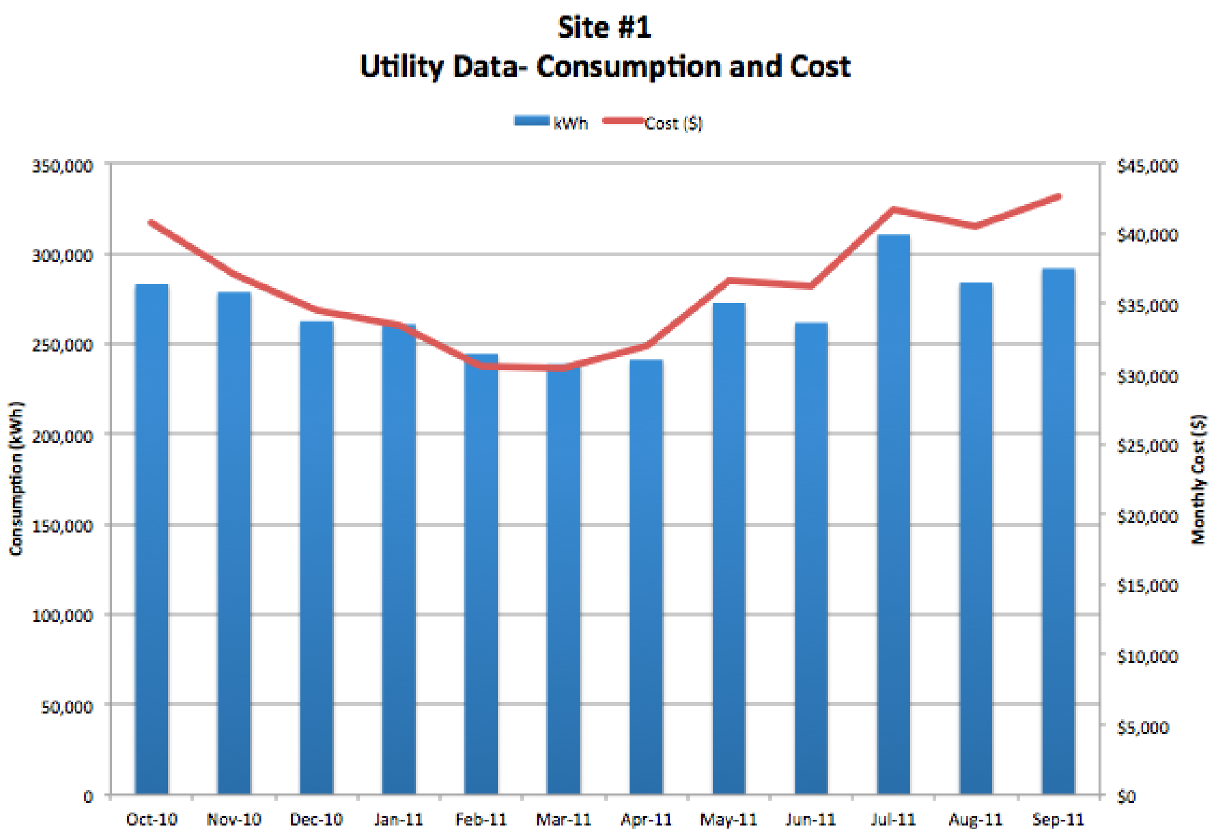

Figure 4: Site #1 Electric Consumption History

Table 27: Site #1: Natural Gas Utility Summary

Site #1: Gas Utility Information October 2010-September 2011													
	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Total
therms	15,505	18,157	21,238	23,492	20,550	18,744	16,602	16,545	15,455	14,110	13,541	13,548	207,487
Cost ($)	$10,987	$12,276	$15,502	$16,872	$15,757	$13,812	$12,638	$12,699	$12,199	$11,006	$10,868	$10,156	$154,772
Blended Rate ($/therm)	0.71	0.68	0.73	0.72	0.77	0.74	0.76	0.77	0.79	0.78	0.80	0.75	0.75

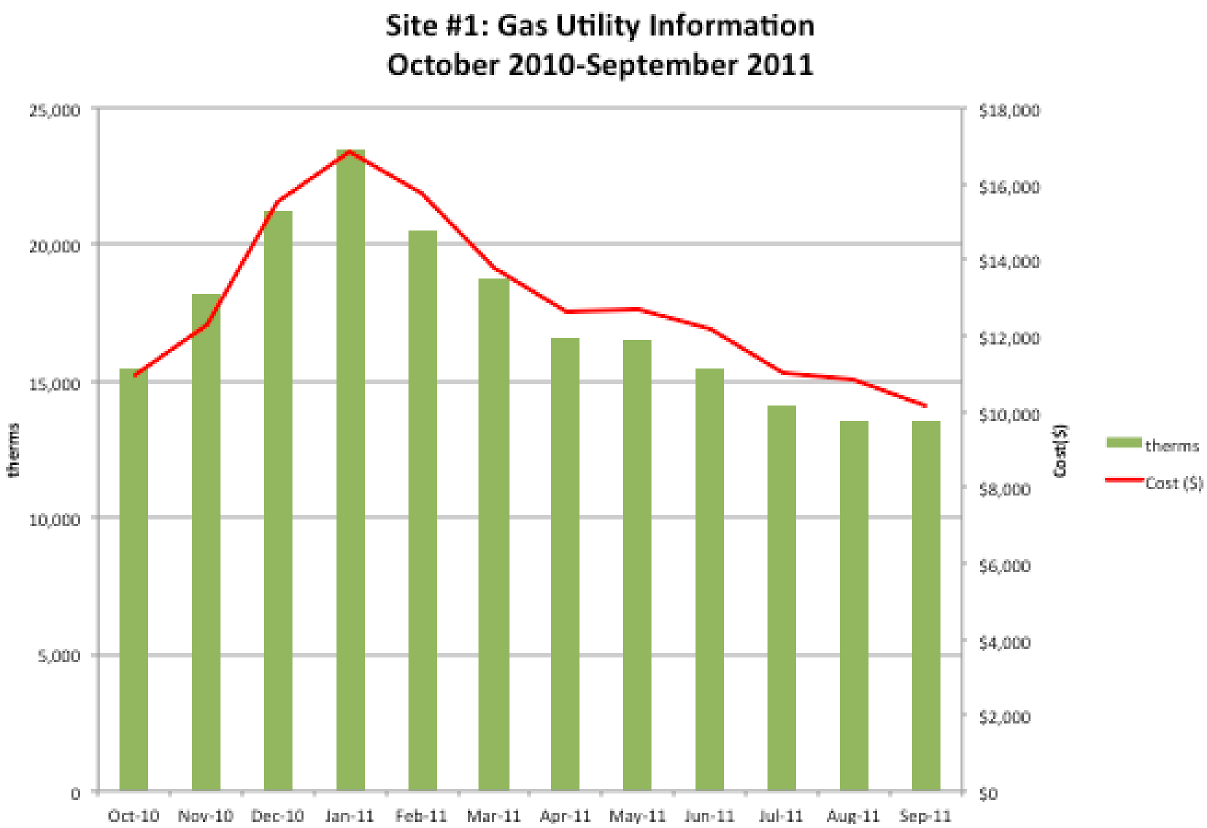

Figure 5: Site #1 Natural Gas Consumption History

TEST SITE #2

Blended actual utility rates are used in all calculations.

Table 28: Site #2 Electric Utility Summary

Site #2: Electric Utility Information Oct. 2010- Sept. 2011													
	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Total
kWh	120,607	118,700	105,688	115,073	107,655	104,540	109,015	120,572	114,355	139,000	124,037	126,648	1,405,889
Cost ($)	$20,710	$16,853	$14,865	$15,381	$14,527	$13,958	$14,604	$16,336	$15,509	$19,263	$18,112	$22,176	$202,293
Blended Rate ($/kWh)	0.17	0.14	0.14	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.18	0.14

Notes

1. Average consumption and cost of all Site #2 meters

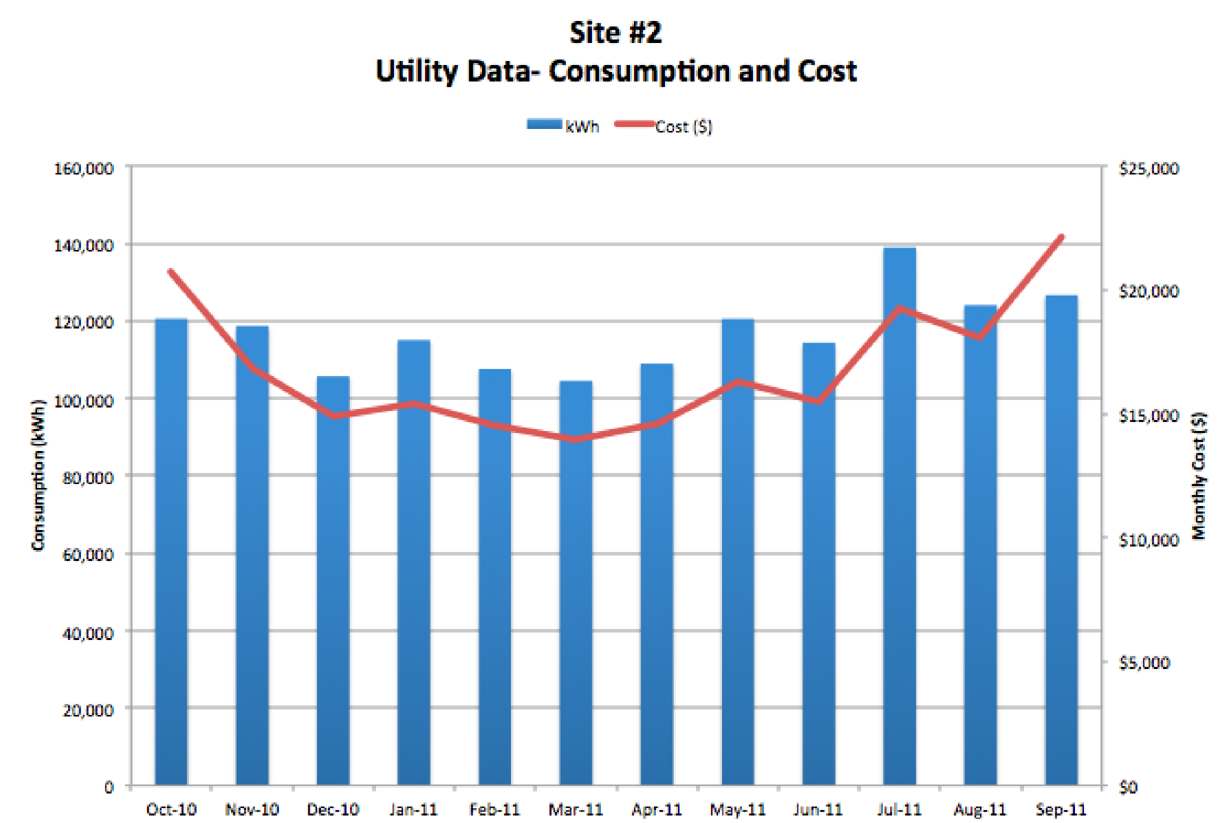

Figure 6: Site #2 Electric Consumption History

Table 29: Site #2 Natural Gas Utility Summary

Site #2: Gas Utility Information October 2010-September 2011													
	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Total
therms	9,219	11,475	12,565	12,959	18,287	17,554	16,645	11,893	11,333	10,826	9,884	9,480	152,118
Cost ($)	$6,592	$7,811	$9,235	$9,427	$13,926	$12,851	$12,577	$9,171	$8,985	$8,479	$7,973	$7,152	$114,179
Blended Rate ($/therm)	0.71	0.68	0.74	0.73	0.76	0.73	0.76	0.77	0.79	0.78	0.81	0.75	0.75

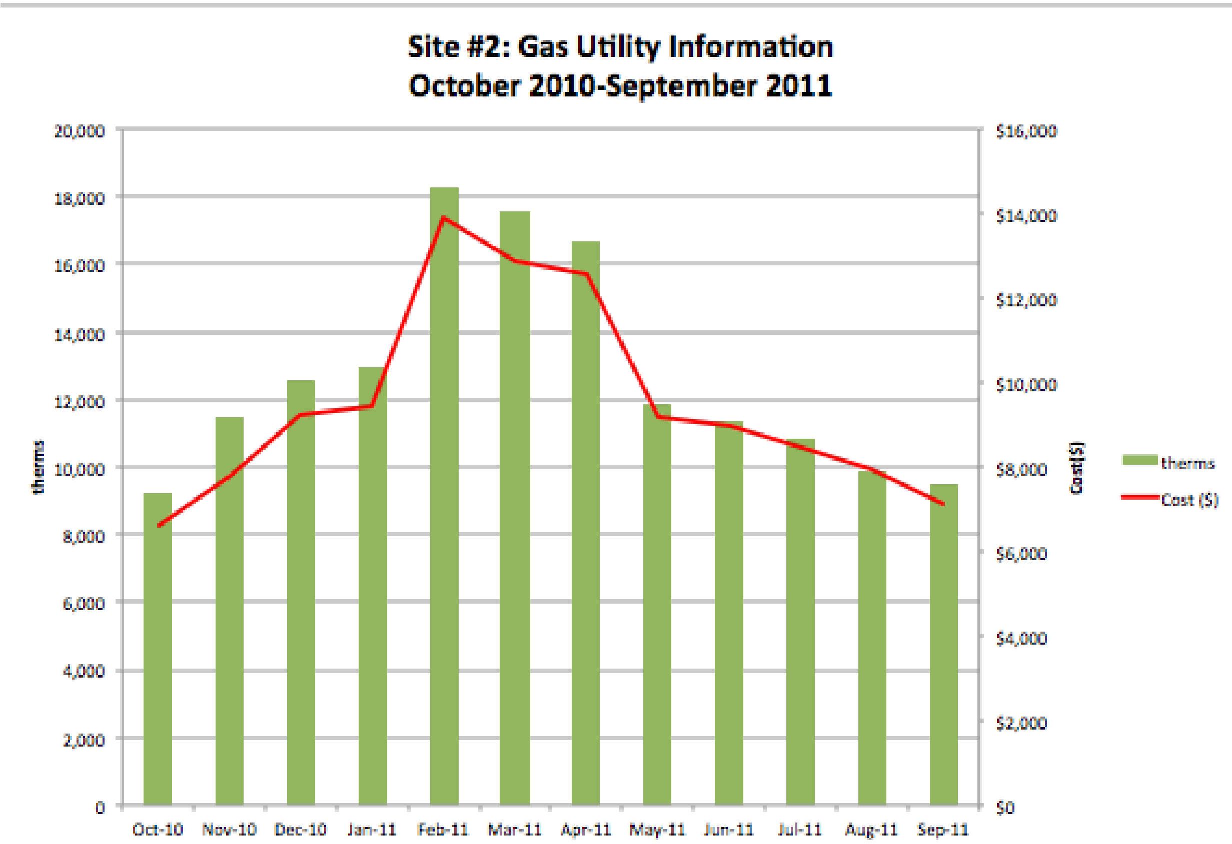

Figure 7: Site #2 Natural Gas Consumption History

TEST-SITE #3

Blended actual utility rates are used in all calculations.

Table 30: Site #3 Central Plant Electric Utility Summary

Site #3, Central Plant: Electric Utility Information 2011													
	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Total
kWh	193,364	161,426	159,598	199,097	202,828	200,941	302,057	302,474	306,514	251,417	177,563	190,190	2,647,469
Cost ($)	$28,254	$24,911	$25,021	$30,300	$30,926	$29,023	$40,751	$40,605	$48,004	$35,308	$25,602	$25,344	$384,048
Blended Rate ($/kWh)	0.15	0.15	0.16	0.15	0.15	0.14	0.13	0.13	0.16	0.14	0.14	0.13	0.15

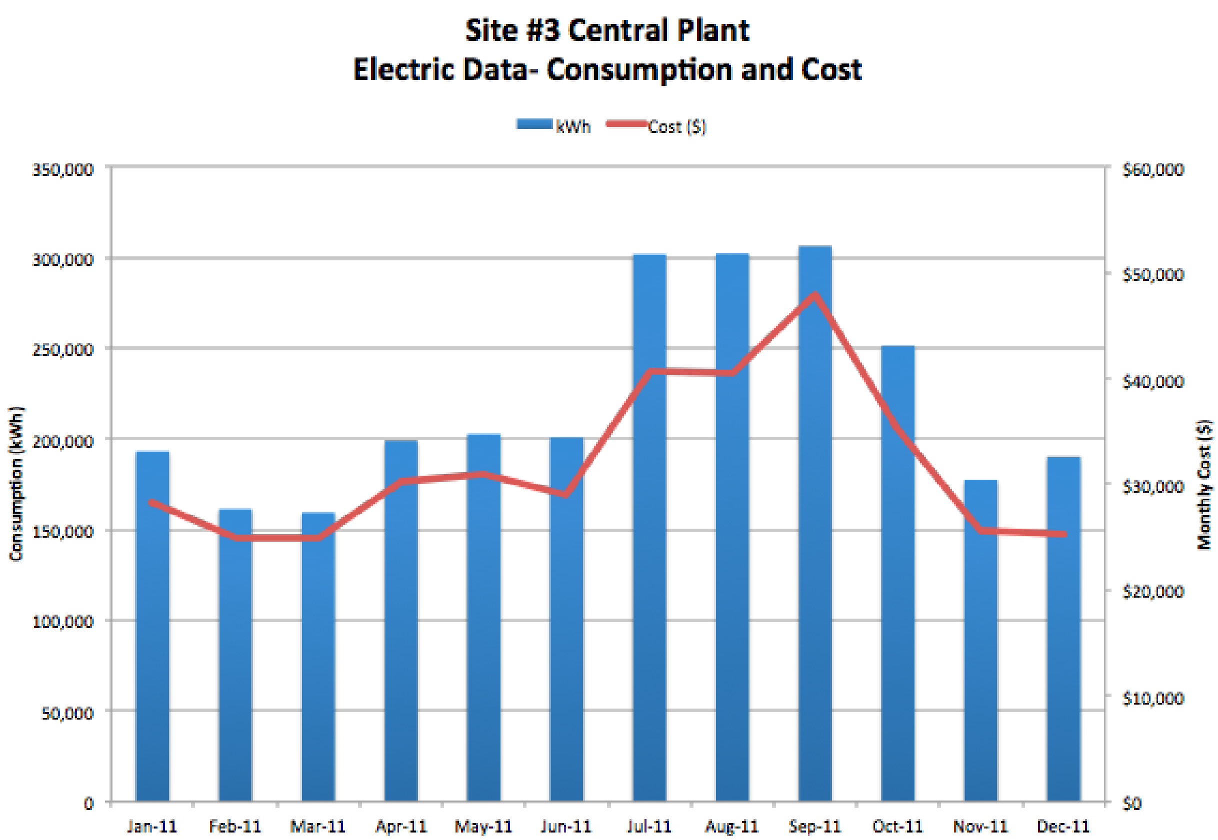

Figure 8: Site #3 Central Plant Electric Consumption History

Table 31: Site #3 Non-Central Plant Meters Electric Utility Summary

Site #3, Non-CP Meters: Electric Utility Information 2011													
	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Total
kWh	179,730	168,367	173,893	179,595	176,370	173,535	187,146	167,378	170,569	175,031	162,327	165,477	2,079,419
Cost ($)	$22,033	$20,713	$21,021	$21,607	$22,158	$21,686	$23,135	$21,444	$23,161	$21,599	$19,921	$20,106	$258,585
Blended Rate ($/kWh)	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.13	0.14	0.12	0.12	0.12	0.12

Notes

1. Average consumption and cost of all non-central plant meters

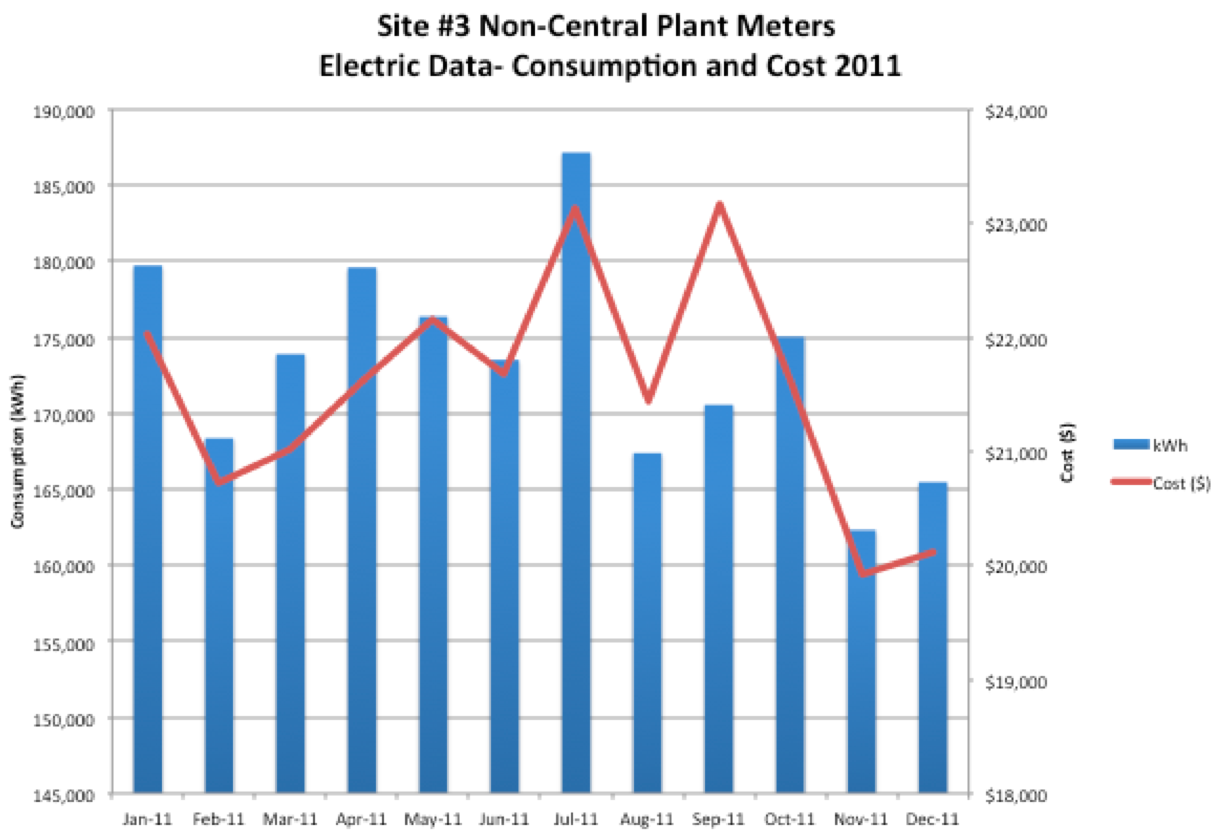

Figure 9: Site #3 Non-Central Plant Meters Electric Consumption History

Table 32: Site #3 Natural Gas Utility Summary

Site #3: Gas Utility Information 2011													
	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Total
therms	4,971	4,295	4,910	4,528	3,738	3,375	2,989	1,686	1,430	2,138	2,675	3,280	40,015
Cost ($)	$3,716	$3,316	$3,761	$3,491	$2,963	$2,738	$2,441	$1,460	$1,219	$1,665	$2,003	$2,362	$31,134
Blended Rate ($/therm)	0.75	0.77	0.77	0.77	0.79	0.81	0.82	0.87	0.85	0.78	0.75	0.72	0.79

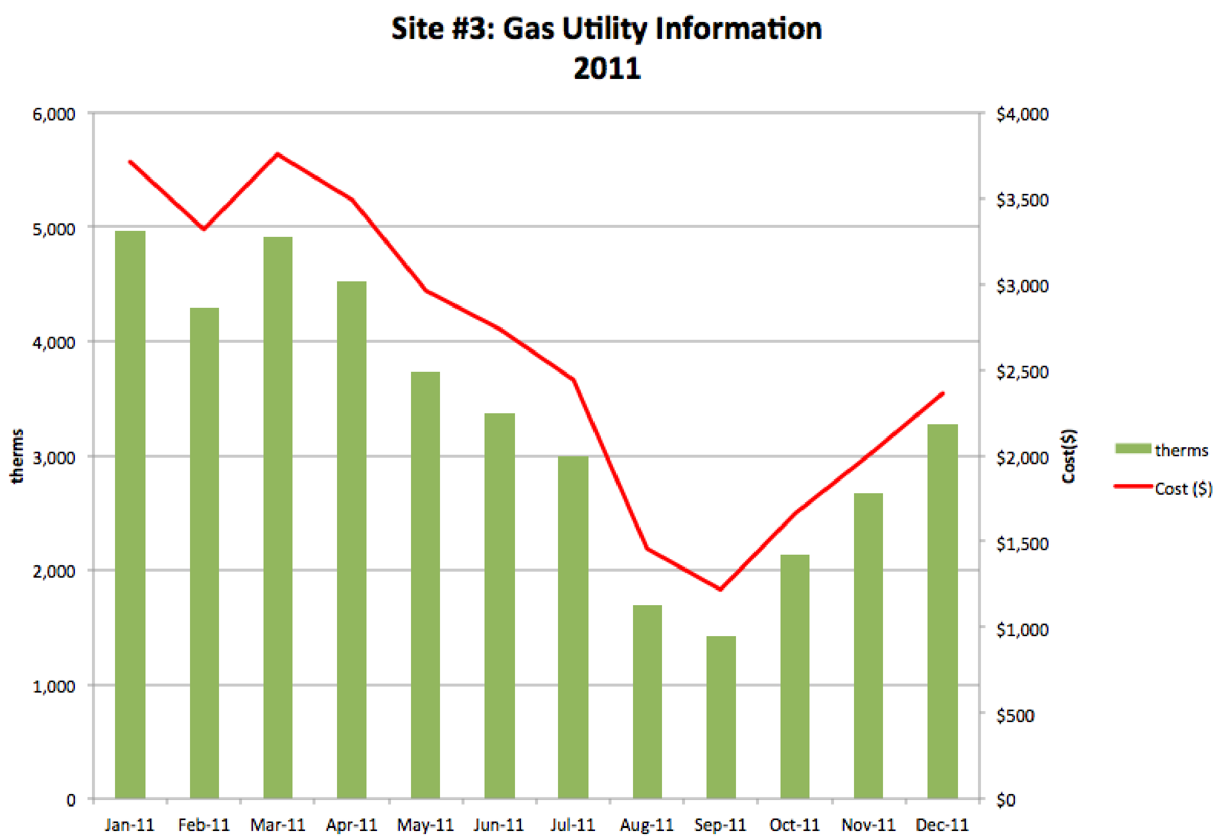

Figure 10: Site #3 Natural Gas Consumption History

APPENDIX E: Detailed Results by Site

DETAILED RESULTS – Site #1

The summarized results from Test Site #1 are shown in the Tables below.

Table 7Table 33 shows the airflow reductions, Table 34 shows the direct load fan kWh savings, and shows the financial savings and estimated simple payback period for the single hood retrofit.

Table 33: Site #1 Savings Summary

	FUME HOOD 2-80		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	483	312	172
Cooling kWh	1,654	1,066	588
Pre-Heat therms	101	65	36

Table 34: Site #1 Fan Savings Summary

Direct Load Fan kWh Savings													
Equipment	HP LF%	HP	Eff %	Annual Hours	Baseline EF/SF CFM	EF/SF Avg. Baseline Hz	Avg CFM Redution	CFM Reduction	EF/SF Hz Post	Post Avg. CFM	Fan kWh Pre	Fan kWh Post	**Fan kWh Saved**
Exhaust Fan 1	85%	20	93%	8760	16,931	55.1	86	0.5%	54.8	16,845	97,179	95,894	1,285
Exhaust Fan 2	85%	20	93%	8760	16,928	55.0	86	0.5%	54.7	16,843	97,149	95,864	1,285
Supply Fan	85%	75	94.5%	8760	33,727	46.3	172	0.5%	46.0	33,555	236,408	232,678	3,730
TOTALS		115					172				430,737	424,437	**6,300**

Table 35 below shows the financial summary information, including unit cost from distributor inclusive of installation. Energy costs were estimated from 12 months of consumption and billing data ending in September 2011. An estimated natural gas cost of $0.746/therm and electric cost of $0.135/kWh were used for financial calculations.

Table 35: Site #1 Financial Summary

FINANCIAL SUMMARY		
kWh Saved		6,888
Electric Rate	$	0.135
Electric $ Saved	$	930
Gas Saved		36
Gas Rate	$	0.75
Gas $ Saved	$	27
Total $ Saved	$	957
Cost/CFM	$	5.57
Measure Price	$	5,800
Simple Payback (yrs)	6.1	

Using the airflow calculations to compare the test hood at Site #1 (fume control hood number 2-80) baseline conditions to post retrofit conditions, we show the difference of (483.4 - 311.5) = 171.8 CFM in Table 36 below. Please note that the maximum CFM recorded was actually after the retrofit, indicating that the ASPS does not affect the potential to remove fumes but instead shuts the sash when the operator leaves the area.

Table 36: Site #1 hood 2-80 CFM Summary

	FUME HOOD 2-80		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	483	312	172
Min. CFM	85	40	n/a
Max. CFM	1,108	1,301	n/a

The baseline data was used to put together an estimate of the average airflow through hoods 2-30 through 2-85. This was done to determine if the baseline airflow estimate from hood 2-80 used in the calculations was typical of the baseline of the other (non-modified) hoods. Table 37 on the following page summarizes this estimate:

Table 37: Site #1 non-modified hood CFM Summary

FUME HOOD AVG. BASELINE CFM				
FHC2-30	455		FHC2-61	320
FHC2-31	194		FHC2-62	480
FHC2-33	489		FHC2-64	458
FHC2-34	313		FHC2-66	517
FHC2-35	403		FHC2-67	621
FHC2-39	475		FHC2-68	490
FHC2-40	318		FHC2-70	376
FHC2-42	368		FHC2-71	598
FHC2-44	373		FHC2-72	461
FHC2-46	413		FHC2-73	398
FHC2-47	517		FHC2-74	347
FHC2-48	234		FHC2-75	285
FHC2-50	609		FHC2-77	315
FHC2-52	562		FHC2-78	322
FHC2-53	379		FHC2-79	511
FHC2-55	649		FHC2-81	295
FHC2-56	506		FHC2-83	301
FHC2-57	358		FHC2-84	308
FHC2-58	444		FHC2-85	495
FHC2-60	470		**AVERAGE**	**421**

As we see in Table 37 above, there is some variation regarding airflow through each hood. The hoods have varied usage which accounts for the variations in airflow. The trended sash height data shows that some hoods are opened and closed frequently, while the sash of others was only adjusted once or twice in a 10 day period. The CFM data trended for hood 2-80 is shown in Figure 11 on the following page. There is data for 5/9/2011 through 5/19/2011 and 7/4/2011 through 8/4/2011, unfortunately the time period between 5/20 and 7/3 was not available. The average baseline airflow from hood 2-80 (test hood) was measured to be 483 CFM, while the average from all other hoods measured was 421 CFM, indicating that the baseline airflow at the test hood is similar to but slightly higher than the overall baseline of the other hoods in the room over the same time period. Our test hood (2-80) had a baseline average airflow of 483 CFM which is typical of the other hoods, especially those that are used as workstations.

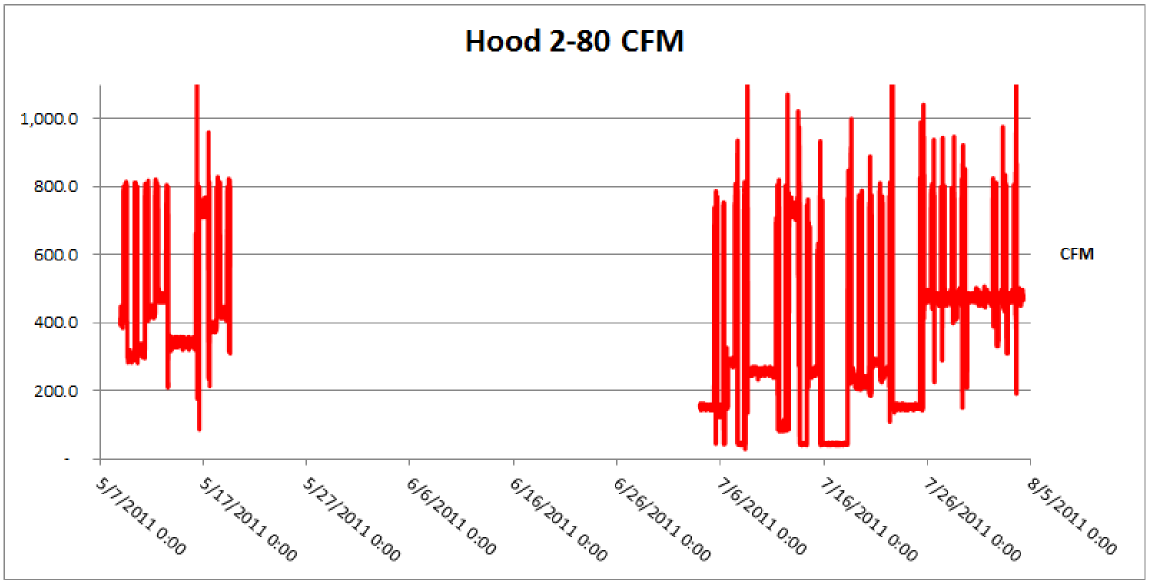

Figure 11: Site #1 Test Hood CFM Profile

Using the airflow savings and the calculation methods presented in the previous section, the energy savings are estimated. Energy savings come in three parts: Direct (fan load) electricity savings, central plant cooling electricity savings, and central plant heating natural gas reductions. Please refer to Table 33 through Table 35 for summarized energy savings results.

The direct load electric savings are attributable to the supply and exhaust fans running at a reduced speed. It was found that in the baseline data the pair of 20 hp exhaust fans ran at 55.0 Hz and 55.1 Hz respectively. The 75 hp supply fan was found to run at an average speed of 46.3 Hz. Baseline Exhaust Fan and Supply Fan CFM data was also available. For post-retrofit calculations the supply and exhaust airflows were reduced by 172 CFM and the electric load was re-estimated at the reduced airflow. Please see Figure 12 on the following page, showing the study findings at test site #1.

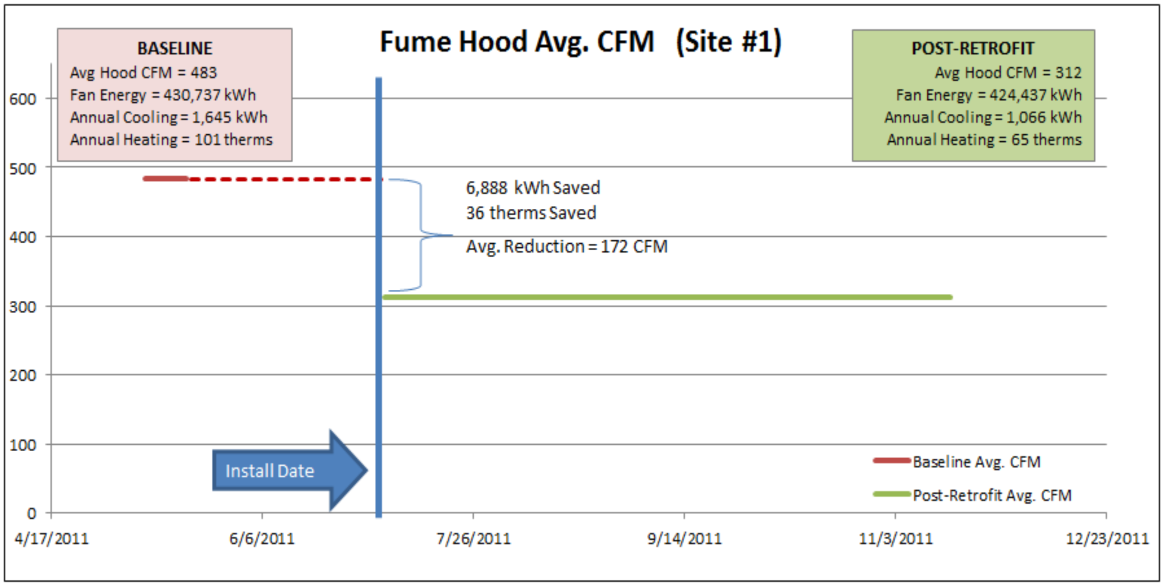

Figure 12: Site #1 Findings

The central plant energy reductions are calculated according to the equations and methodology presented in the previous section. Based on staff interviews, the discharge air is maintained at a constant 55ºF. Since this space is a laboratory 100% outside air is used. Cooling energy is estimated as the energy needed to bring the ambient outside air down to 55ºF. When outside air is colder than discharge air the energy to pre-heat the air to 55ºF is estimated. Natural gas is used for heating. A heating efficiency of 82% is estimated. Based on the facility provided value, a central plant efficiency of 1.2 kW/ton is used in energy calculations. Financial calculations use an electric rate of $0.135/kWh and natural gas rate of $0.746/therm from the facility's previous 12 months of billing statements.

In general, savings can be expected to vary widely, depending entirely on the pre-existing manual sash management practices. This study found that the sash in question was already being managed very well with only moderate room for improvement. At this site, airflow through the test hood was reduced by 36% compared to the baseline conditions. Based on engineering calculations, this translates to an estimated annual savings of 6,888 kWh and 36 therms of natural gas for the single-hood retrofit that was undertaken. The avoided cost per CFM was calculated to be $5.57, with a simple payback of 6.1 years.

DETAILED RESULTS – Site #2

The summarized results from Test Site #2 are shown in the Tables below. Table 38 shows the airflow reductions, Table 39 shows the direct load fan kWh savings, and Table 40 shows the financial savings and estimated simple payback period for the single hood retrofit.

Table 38: Site #2 Savings Summary

	FUME HOOD #5		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	457	216	241
Cooling kWh	456	215	240
Pre-Heat therms	201	95	106

Table 39: Site #2 Fan Savings Summary

Direct Load Fan kWh Savings													
Equipment	Base Load Factor %	HP	Eff %	Annual Hours	Baseline EF/SF CFM	EF/SF Avg. Baseline Hz	Single Hood Avg CFM Redution	EF/SF % CFM Reduction	EF/SF Hz Post	EF/SF Post Avg. CFM	Fan kWh Pre	Fan kWh Post	**Fan kWh Saved**
Exhaust Fan	85%	3	89.5%	8,760	3,214	40.7	241	7.5%	36.2	2,973	7,345	5,544	**1,801**
Supply Fan	85%	7.5	91%	8,760	3,214	40.7	241	7.5%	36.2	2,973	18,060	13,633	**4,428**
TOTALS		11					241				25,406	19,177	**6,228**

Table 13

Table 40 on the following page shows the financial summary information, including unit cost from distributor inclusive of installation. Energy costs were estimated from 12 months of consumption and billing data ending in September 2011.

Table 40: Site #2 Financial Summary

FINANCIAL SUMMARY		
kWh Saved		6,469
Electric Rate	$	0.144
Electric $ Saved	$	931
Gas Saved		106
Gas Rate	$	0.751
Gas $ Saved	$	80
Total $ Saved	$	1,011
Cost/CFM	$	4.19
Measure Price	$	5,800
Simple Payback (yrs)	5.7	

Using the airflow calculations to compare the test hood at Site #2 (fume control hood #5) baseline conditions to post retrofit conditions, we show the difference of (457 - 216) = 241 CFM in Table 41 below.

Table 41: Site #2 hood #5 CFM Summary

	FUME HOOD #5		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Avg. CFM	457	216	241
Min. CFM	200	121	n/a
Max. CFM	824	850	n/a

The baseline data was used to put together an estimate of the average airflow through hoods 1, 2, 3, 4, 5, & 6. This was done to determine if the baseline airflow estimate from hood 5 used in the calculations was typical of the baseline of the other hoods. Table 42 on the following page summarizes this estimate:

Table 42: Site #2 non-modified hood CFM Summary

FUME HOOD AVG. BASELINE CFM	
5/7 to 5/21 & 6/11 to 6/13	
#1	669.6
#2	528.0
#3	539.0
#4	457.5
#5	457.2
#6	563.0
AVERAGE	**535.7**

FUME HOOD AVG. BASELINE CFM	
5/7 to 5/21 & 6/11 to 6/13	
#1	669.6
#2	528.0
#3	539.0
#4	457.5
#6	563.0
AVERAGE	**551.4**

As we see in Table 42, there is some variation regarding airflow through each hood. The hoods have varied usage which accounts for the variations in airflow. The trended CFM data through each hood shows that Hood #1 through #5 vary frequently, with sash levels that are raised and lowered often; while hood #6 has slightly more consistent (but high) airflow indicating that the sash is adjusted slightly less frequently and left in a mostly open position much of the time. The CFM data trended for hoods 1 through 6 is shown on the following pages in Figure 13 through

Figure 18. There is data for 5/7/2011 through 5/21/2011 and 6/11/2011 through 11/15/2011, unfortunately the time period between 5/22 and 6/10 was not available. Please note ASPS technology was installed on hood #5 only, which took place on 6/14/2011. The average baseline airflow from hood #5 (test hood) was measured as 457 CFM, while the average from all other hoods measured was 551 CFM, indicating that the baseline airflow at the test hood is similar to, but significantly lower than the average airflow of the other hoods in the room over that same time period.

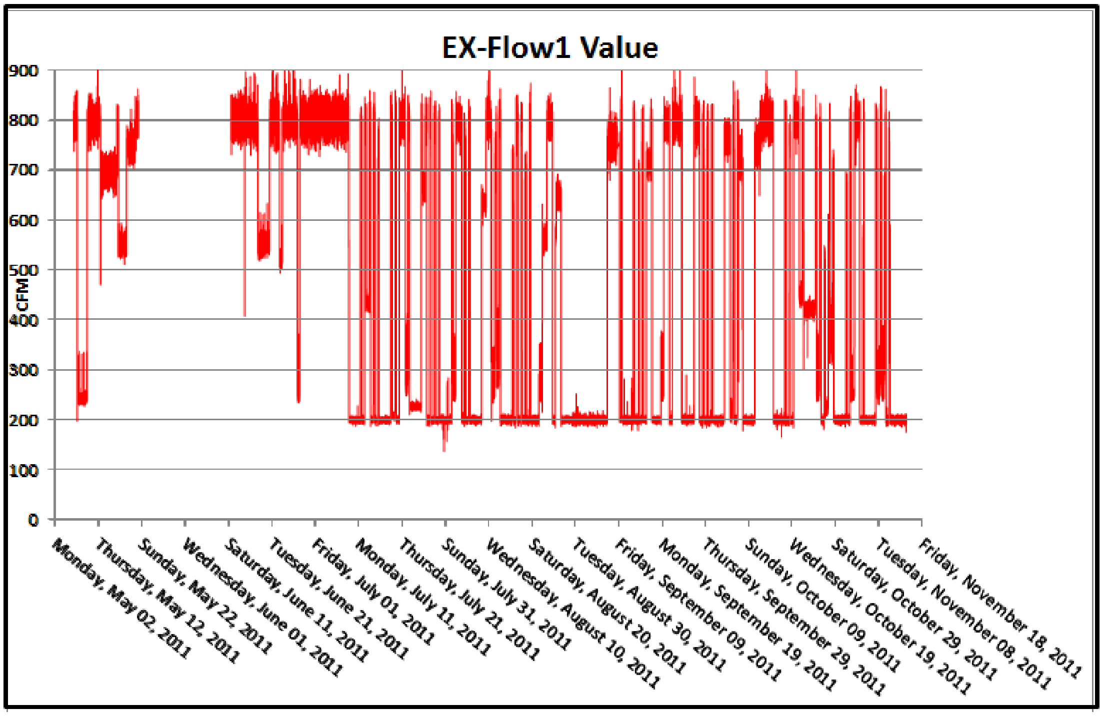

Figure 13: Site #2 Non-Modified Hood 1 CFM Profile

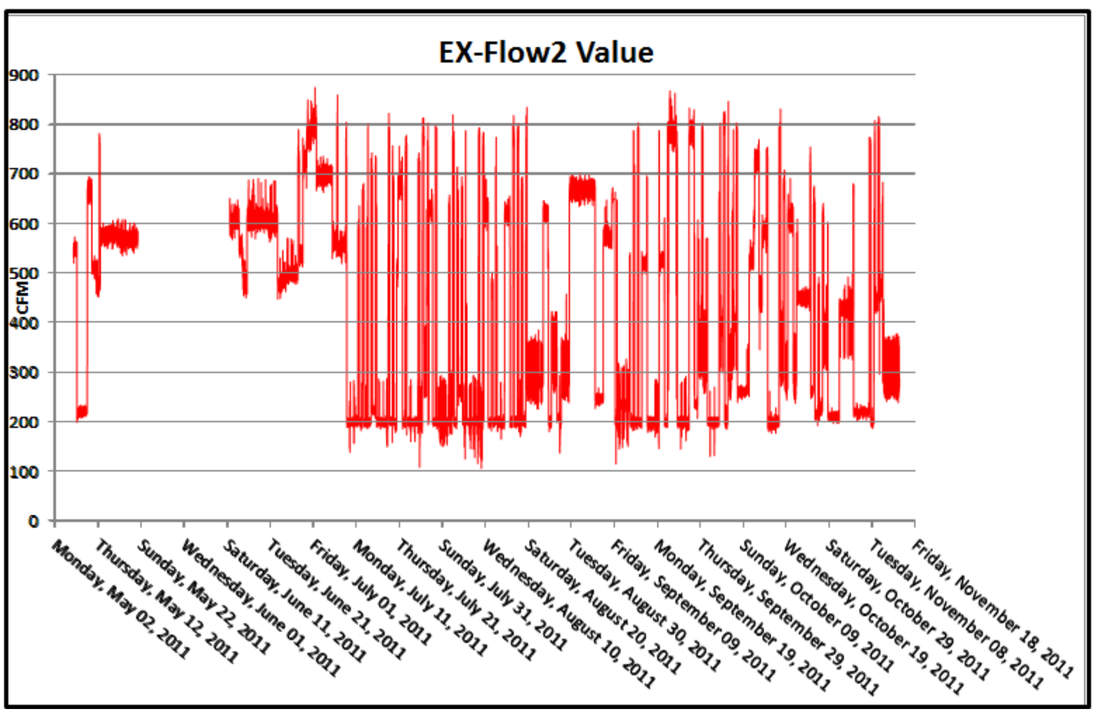

Figure 14: Site #2 Non-Modified Hood 2 CFM Profile

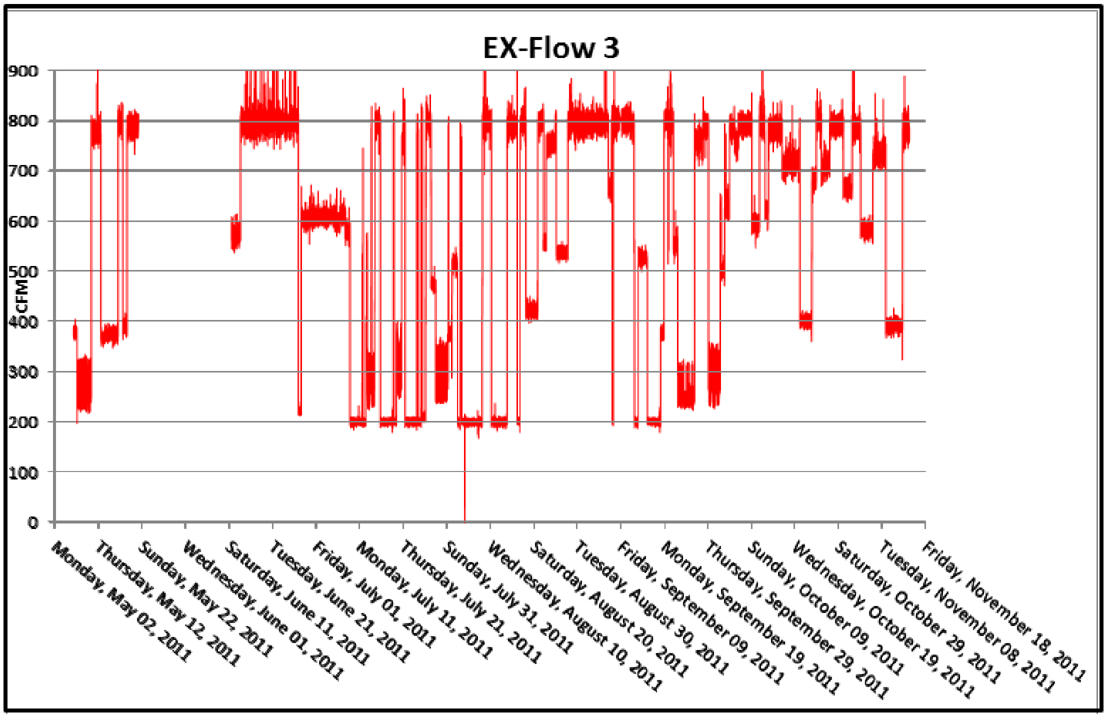

Figure 15: Site #2 Non-Modified Hood 3 CFM Profile

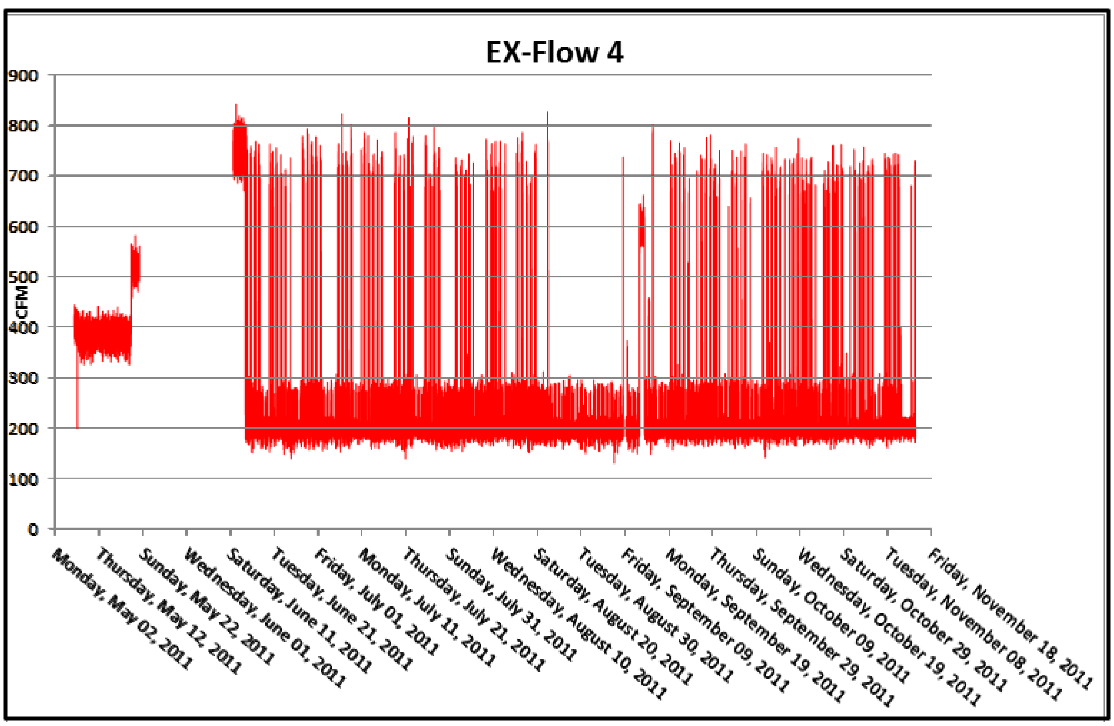

Figure 16: Site #2 Non-Modified Hood 4 CFM Profile

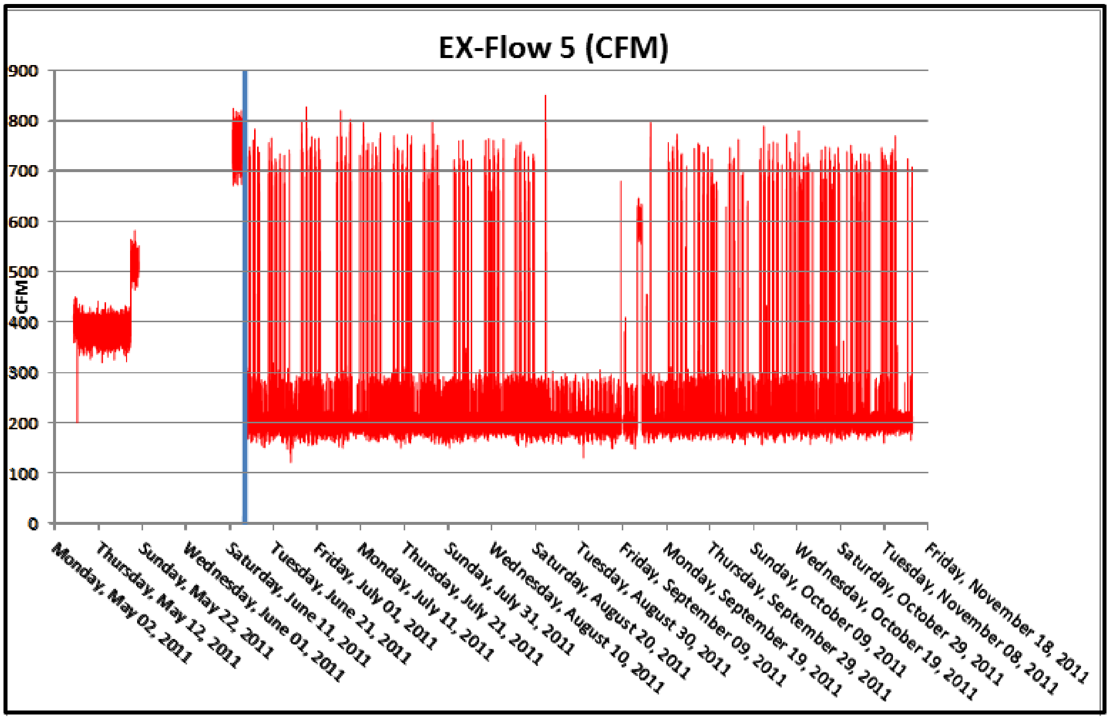

Figure 17: Site #2 Test Hood 5 CFM Profile

(Installation date at blue vertical line)

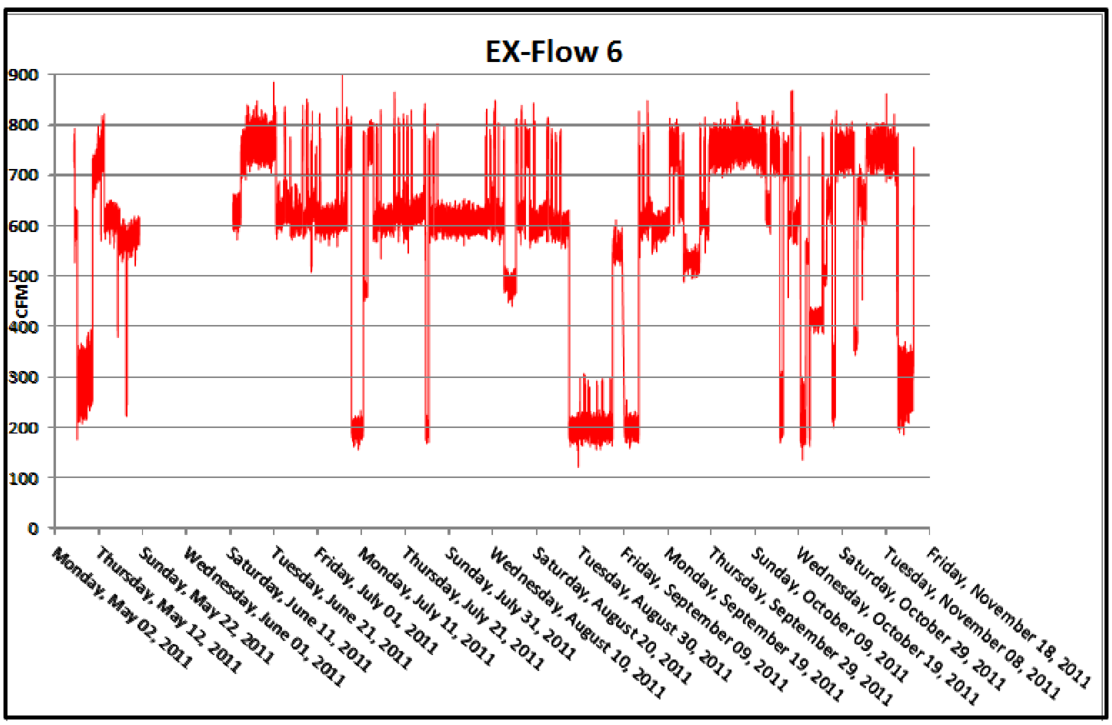

Figure 18: Site #2 Non-Modified Hood 6 CFM Profile

Using the airflow savings and the calculation methods presented in the previous section, the energy savings are estimated. Energy savings come in three parts: Direct (fan load) electricity savings, central plant cooling electricity savings, and central plant heating natural gas reductions. Please refer to Table 38 through Table 40 for summarized energy savings results.

The direct load electric savings are attributable to the supply and exhaust fans running at a reduced speed. It was found that in the baseline data the 3 hp exhaust fan ran at an average speed of 40.7 Hz. The 11 hp supply fan was estimated to run at the same average speed because baseline data on the supply fan was not available for the majority of the baseline time period due to building control system issues. Baseline CFM data was also available for the exhaust fan only for the majority of the time period. For post-retrofit calculations the supply and exhaust airflows were reduced by 241 CFM and the electric load was re-estimated at the reduced airflow, using an affinity law exponent of 2.4. Please see Figure 19 below for the results of the study on the test hood at site #2.

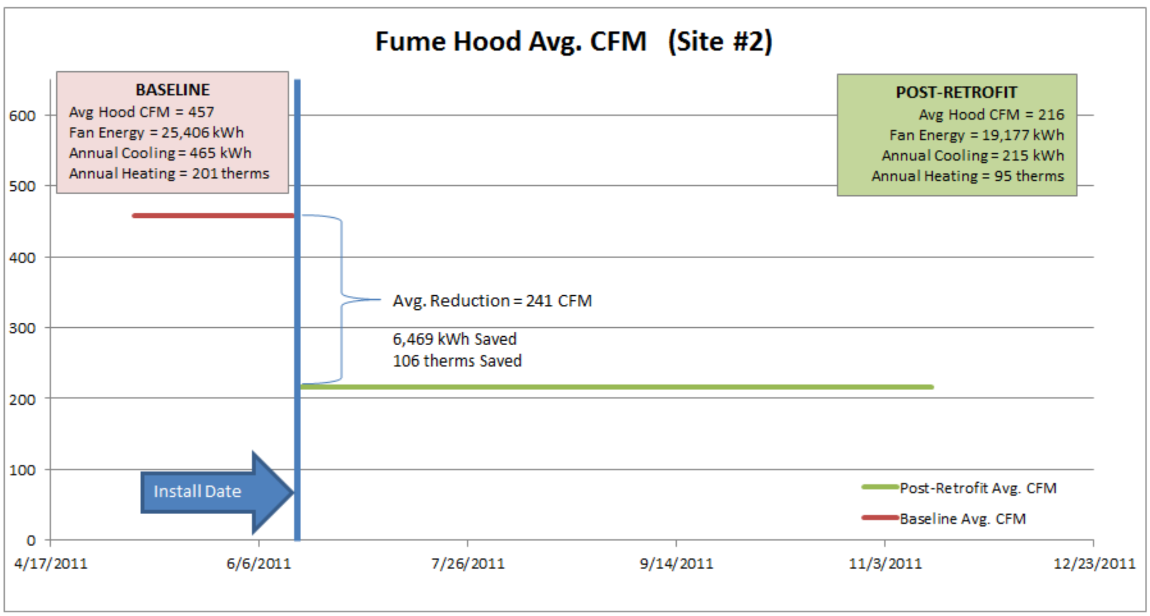

Figure 19: Site #2 Findings

The central plant energy reductions are calculated according to the equations and methodology presented in the previous section. The supply air temperature is estimated at a constant 59ºF based on the average supply air temperature in the provided data. Since this space is a laboratory 100% outside air is used. Cooling energy is estimated as the energy needed to bring the ambient outside air down to 59ºF. When outside air is colder than discharge air the energy to pre-heat the air to 59ºF is estimated. Humidity control is not a priority in this space. Natural gas is used for heating. A heating efficiency of 82% is estimated. Based on the facility provided information, a central plant efficiency of 0.60 kW/ton is used in all energy calculations. Financial calculations use an electric rate of $0.144/kWh and natural gas rate of $0.751/therm from the facility's previous 12 months of billing statements.

In general, savings can be expected to be much higher or much lower than they were at this test site, depending entirely on the pre-existing manual sash management practices. At this site, airflow through the test hood was reduced by 53% compared to the baseline conditions. Based on engineering calculations, this translates to an estimated annual savings of 6,469 kWh and 106 therms of natural gas for the single-hood retrofit that was undertaken. The avoided cost per CFM was calculated to be $4.19, with a simple payback of 5.7 years.

DETAILED RESULTS – Site #3

The summarized results from Test Site #3 are shown in the Tables below. Table 43 shows the airflow reductions, Table 44 and Table 45 show the direct load fan kWh savings on the supply and exhaust fans respectively, and Table 46 shows the financial savings and estimated simple payback period for the three hood retrofit.

Table 43: Site #3 Savings Summary

	Averaged Findings			
	BASELINE	*OPTIMIZED*	*SAVINGS*	*% SAVINGS*
Avg. CFM per Inch Width	19.5	8.6	10.9	56%
Cooling kWh	3,513	1,547	1,966	56%
Pre-Heat therms	1,572	692	880	56%

Table 44: Site #3 Supply Fan Savings Summary

Direct Load Supply Fan kWh Savings												
Equipment	Base Load Factor %	HP	Annual Hours	Est. Baseline SF CFM	Est. SF Avg. Baseline Hz	Three Hood Avg CFM Redution	SF % CFM Reduction	Measured SF Hz Post	SF Post Avg. CFM	SF kWh Pre	SF kWh Post	**SF kWh Saved**
Supply Fan 09	85%	50	8,760	34,219	40.5	2304	7%	37.8	31,915	114,473	100,562	**13,911**
TOTALS		**50**								**114,473**	**100,562**	**13,911**

The exhaust fans serving the same area as AHU 09 (shown below in Table 45) all ran at constant speed in the data collection; therefore, the direct fan savings from those motors will resemble the results of an inlet guide vane system if the ASPS were installed. The motors will not save as much as if they were VFD controlled, but by virtue of moving less air a reduced power load is required. The load experienced by the exhaust fans is calculated using design CFM and static pressure set-points provided by the building maintenance staff.

Table 45: Site #3 Exhaust Fan Savings Summary

Direct Load Exhaust Fan kWh Savings						
Equipment	SP (" H2O)	Eff %	Annual Hours	Change in Load (Δ HP)	Three Hood Avg CFM Redution	**EF kWh Saved**
Exhaust Fan 34	1.5	70%	8760	0	0	0
Exhaust Fan 36	1.5	70%	8760	0	0	0
Exhaust Fan 37	1.5	70%	8760	0.2	605	1,333
Exhaust Fan 38	1.5	70%	8760	0.6	1,699	3,744
Exhaust Fan 39	1.5	70%	8760	0	0	0
TOTALS				**0.8**	**2,304**	**5,077**

It was found that the supply fan can modulate up and down as required, and ran at an average speed of 38 Hz in the post-retrofit data. The static pressure set-point and CFM for AHU 09 were provided by the building maintenance staff.

As shown in Table 45, no energy savings were calculated for Exhaust Fans 34, 36, or 39 even though they serve the same area as AHU 09. Only Exhaust Fans 37 and 38 serve the area with the retrofit hoods; the airflow reduction was pro-rated between them. The exhaust fans serving the same area as AHU 09 are all constant speed; however there will be a load reduction experienced by the exhaust fans since less air being moved will require a reduced power load. The load is calculated using design CFM and static pressure set-points provided by the building maintenance staff.

Table 46 on the following page shows the financial summary information, including the unit cost provided by the distributor. The price shown is inclusive of installation. Energy costs were estimated from 12 months of consumption and billing data ending in December 2011. At the building in question, there is one meter that serves the central plant exclusively; over the 12 months the blended rate for this meter was $0.145/kWh which is used to compute the cooling kWh contribution to the total savings. To compute the contribution to the total savings by the Supply and Exhaust Fans, the 12 month average of all other electric meters serving the building was used. The fan kWh was assessed at $0.124/kWh. An estimated natural gas cost of $0.778/therm was used based on the blended rate from the single gas meter.

Table 46: Site #3 Financial Summary

FINANCIAL SUMMARY		
kWh Saved		25,356
Electric $ Saved	$	3,194
Gas Saved		880
Gas $ Saved	$	684
Total $ Saved	$	3,878
Cost/CFM	$	1.68
Measure Price	$	17,400
Simple Payback (yrs)		4.5

Using the airflow calculations shown Appendix C to compare the test hoods at Site #3 to the non-modified hoods, we show the difference of 2,304 CFM in Table 20.

Table 47: Site #3 Test Hood Summary

	Totalized Findings		
	BASELINE	*OPTIMIZED*	*SAVINGS*
Hood #3, #5, #8 Total CFM	4,118	1,813	2,304
Fan kWh	237,906	214,515	23,390
Cooling kWh	3,513	1,547	1,966
Pre-Heat therms	1,572	692	880

The baseline data from hoods #16, #17, and #18 was used to put together an estimate of the average airflow through hoods #3, #5, and #8. This was done to determine the baseline airflow estimate for the post-retrofit hoods because the data recording capabilities necessary were only implemented after the ASPS were installed. Table 48 summarizes this estimate in two parts:

Table 48: Site #3 Baseline CFM Summary

FUME HOOD AVG. BASELINE CFM			
Hoods 16, 17, 18			
Hood	Avg. CFM	inches width	CFM/in
#16	1231	62.5	19.7
#17	1313	62.5	21.0
#18	1115	62.5	17.8
AVERAGE	**1220**	**62.5**	**19.5**

FUME HOOD EST. BASELINE CFM			
Hoods 3, 5, 8			
Hood	CFM/in	inches width	Avg CFM
#3	19.5	62.5	1220
#5	19.5	62.5	1220
#8	19.5	86.0	1678
TOTAL	**19.5**	**211.0**	**4118**

As we see in the left part of Table 48, there is some variation regarding airflow through each hood. The hoods have varied usage which accounts for the variations in airflow. Table 49 below shows the average optimized CFM from hoods #3, #5, and #8.

Table 49: Site #3 Optimized CFM Summary

FUME HOOD AVG. OPTIMIZED CFM			
Hoods 3, 5, 8			
Hood	Avg. CFM	inches width	CFM/in
#3	479.3	62.5	7.7
#5	494.6	62.5	7.9
#8	839.6	86.0	9.8
TOTAL	**1813.4**	**211.0**	**8.6**

The average baseline airflow from the test hoods is shown to be on average much less than the non-modified hoods. The CFM data trended for non-modified hoods #16, #17, and #18 is shown on the following pages in Figure 20 through Figure 22. The CFM data trended for hoods #3, #5, and #8 is shown on the following pages in Figure 23 through Figure 25. Please note ASPS technology was installed on hoods #3, #5, and #8 only. The average baseline airflow from the 62.5” optimized test hoods was measured as 487 CFM, while the average from all other baseline 62.5” test hoods measured was 1,220 CFM, indicating that the ASPS has had a significant effect on the lab airflow.

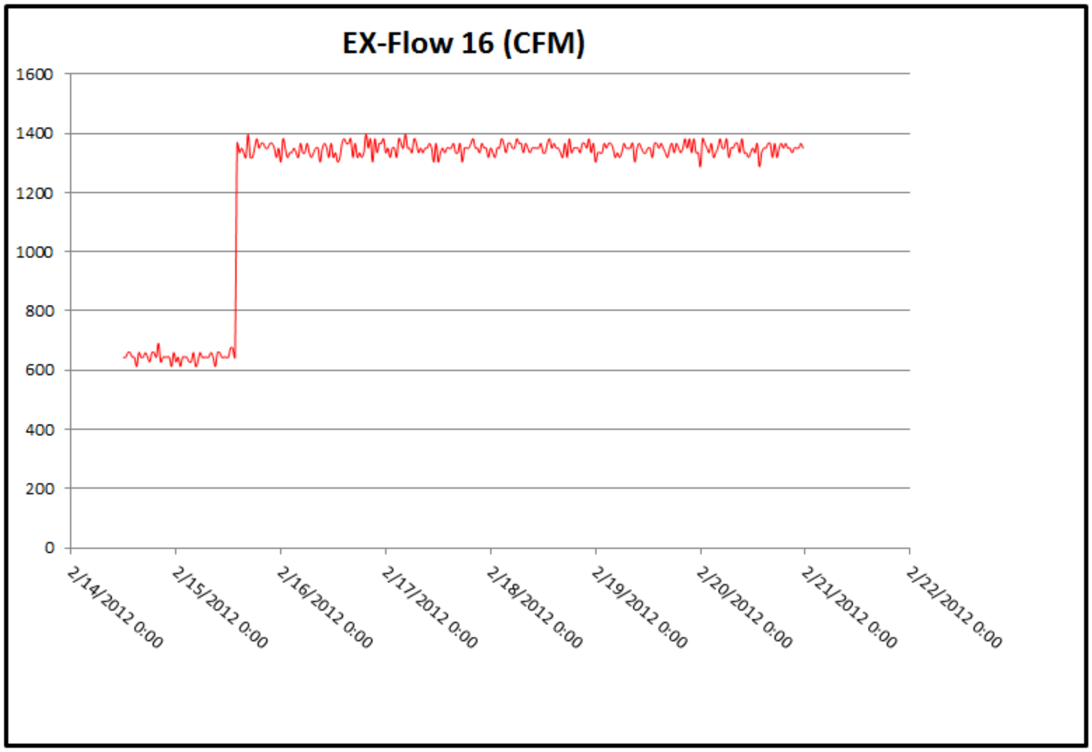

Figure 20: Site #3 Non-Modified Hood 16 CFM Profile

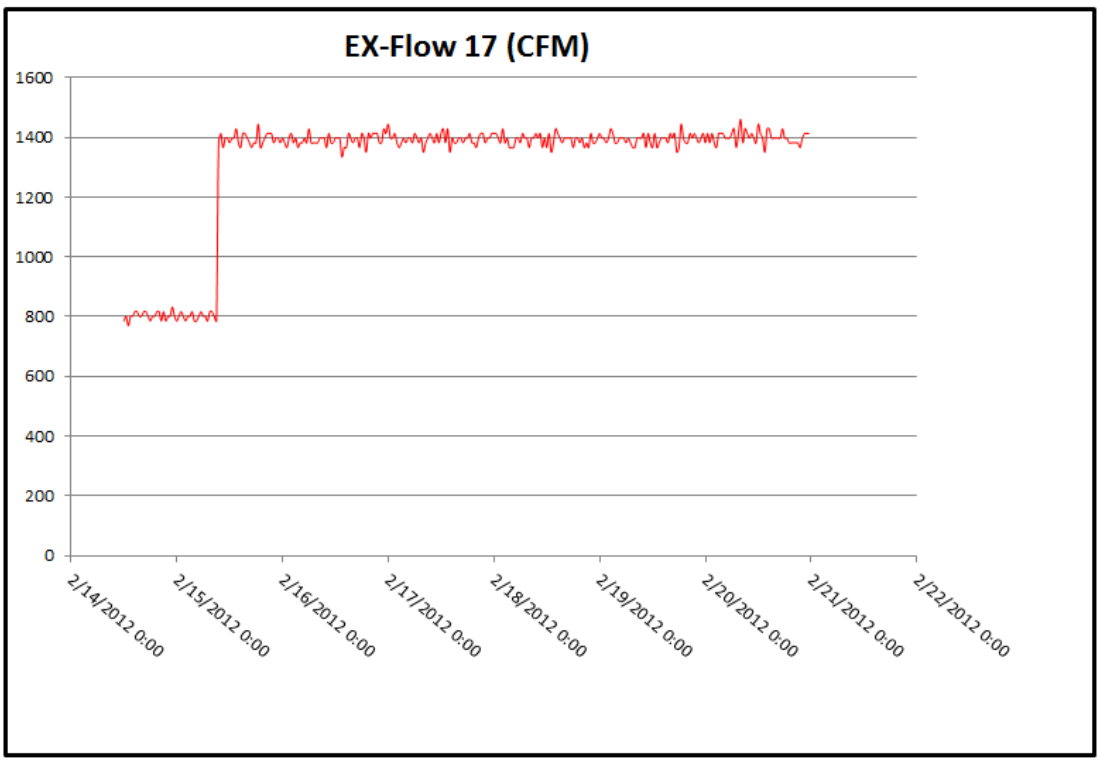

Figure 21: Site #3 Non-Modified Hood 17 CFM Profile

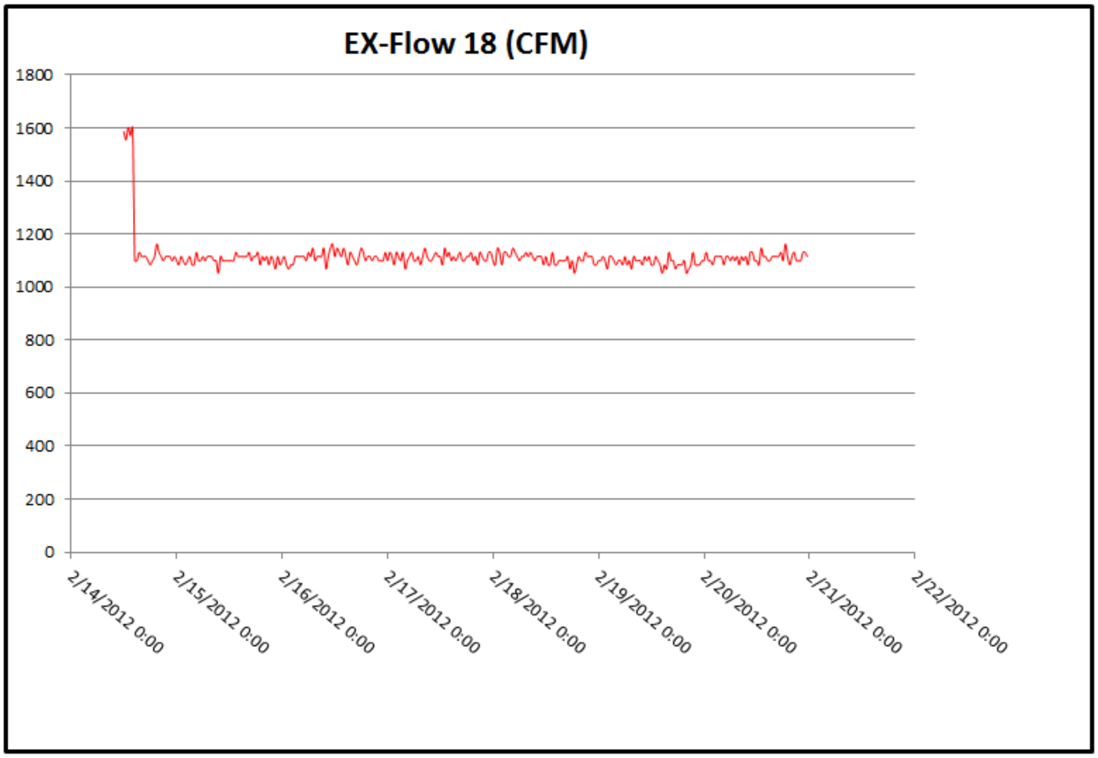

Figure 22: Site #3 Non-Modified Hood 18 CFM Profile

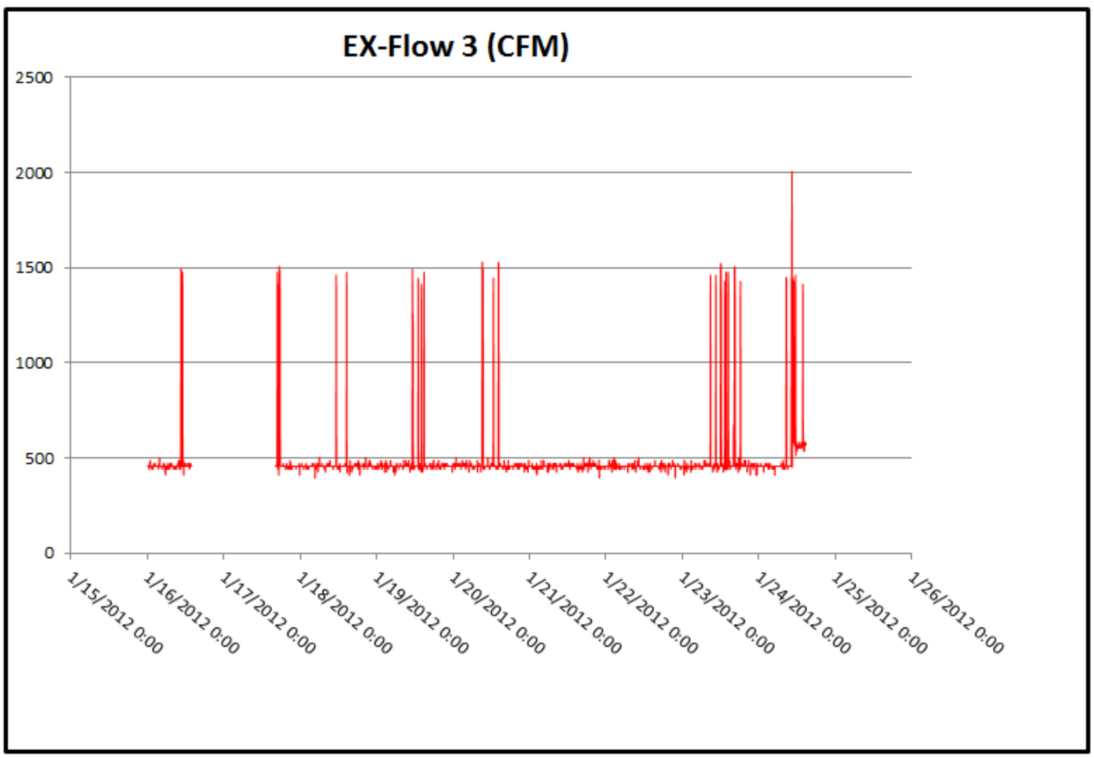

Figure 23: Site #3 Test Hood 3 CFM Profile

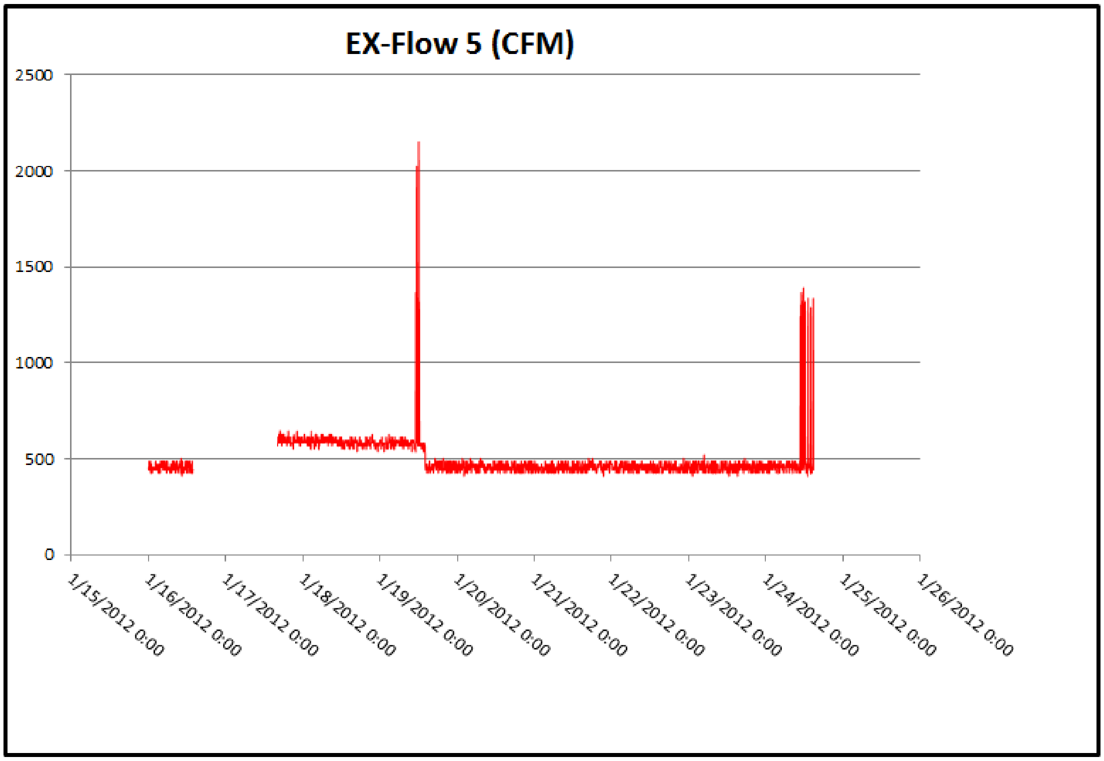

Figure 24: Site #3 Test Hood 5 CFM Profile

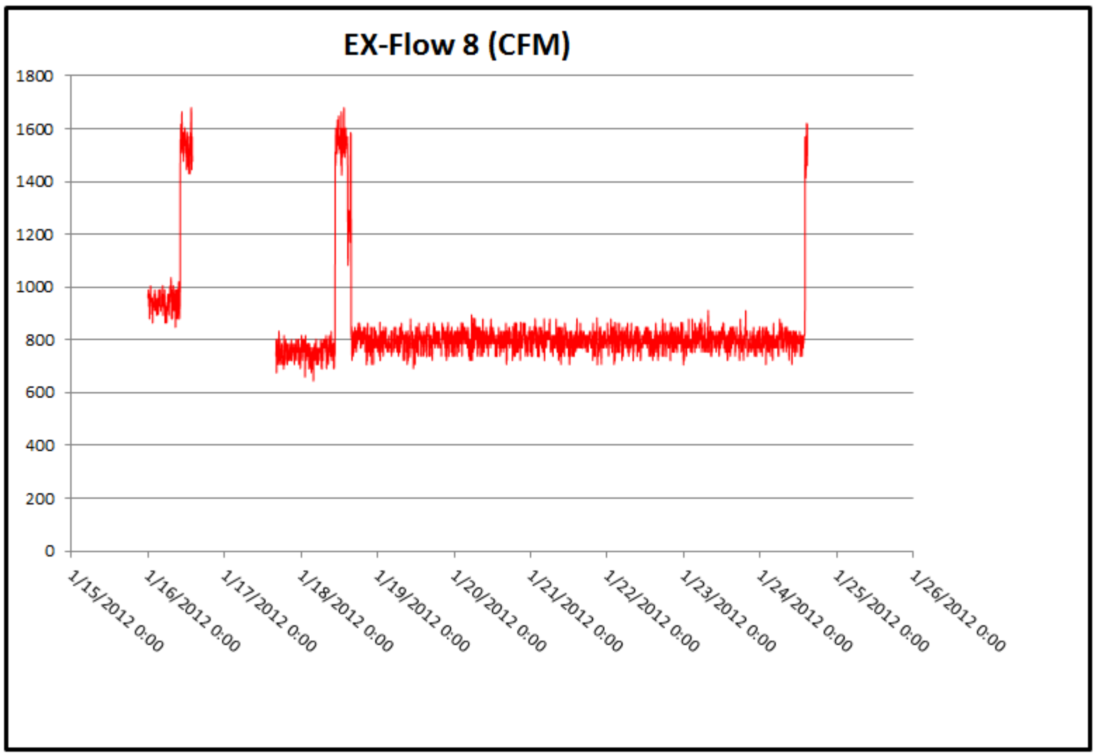

Figure 25: Site #3 Test Hood 8 CFM Profile

Using the airflow savings and the calculation methods presented in the previous section, the energy savings are estimated. Energy savings come in three parts: Direct (fan load) electricity savings, central plant cooling electricity savings, and central plant heating natural gas reductions. Please refer to Table 43 through Table 46 for summarized energy savings results.

The direct load electric savings are attributable to the 50 hp supply fan running at a reduced speed. In addition, the constant speed exhaust fans serving the area with the test hoods will experience a reduced airflow and therefore less power load.

The central plant energy reductions are calculated according to the equations and methodology presented in the previous section. The supply air temperature is estimated at a constant 62ºF based on the average supply air temperature in the data; this is higher than the other two sites which will impact energy savings. Since this space is a laboratory, 100% outside air is used. Cooling energy is estimated as the energy needed to bring the ambient outside air down to 62ºF. When outside air is colder than discharge air the energy to pre-heat the air to 62ºF is estimated. According to facility staff, humidity control is not a priority in this space. Natural gas is used for heating. A heating efficiency of 82% is estimated. Based on the information to IES, a central plant efficiency of 0.70 kW/ton is used in all energy calculations. Financial calculations at the central plant use an electric rate of $0.145/kWh and natural gas rate of $0.778/therm from the facility's previous 12 months of billing statements ending in December, 2011. Non-Central Plant blended electric rate is calculated as $0.124/kWh based on 12 months of data. A distributor provided pricing of $5,800 each was used for the ASPS, and includes professional installation in a retrofit application. This price was intended by the distributor to be representative of a typical installation.