DOCKETED

Docket Number:	17-BSTD-01
Project Title:	2019 Building Energy Efficiency Standards PreRulemaking
TN #:	221711
Document Title:	Jason Sparbel Comments Submitted in support of Auto-Sash language in Part 6
Description:	N/A
Filer:	System
Organization:	Jason Sparbel
Submitter Role:	Public
Submission Date:	11/10/2017 9:20:00 AM
Docketed Date:	11/13/2017

Comment Received From: Jason Sparbel
Submitted On: 11/10/2017
Docket Number: 17-BSTD-01

Submitted in support of Auto-Sash language in Part 6

To Whom It May Concern:
â€¢ Who we are? TEL Americas â€“ a manufacturer and distributor of automatic sash systems
â€¢ What we do? Install and commission automatic sash
â€¢ How we do it? OEM and retrofit

The opinions below are "real life" and from a global group that actually manufacturers and installs automatic sash. TEL has installed automatic sash on every brand of fume hood in the industry. Whether the fume hood counterweight systems are cable and pulley, chain and sprocket, or belt and sprocket, the installation principles remain the same. The following statements are not meant to discredit the opinions of others, they are simple facts.
1. Price point for equipment: $2,500.00
2. Installation: $500.00
3. Payback (using Stanford's math) = under 2 years
4. Maintenance cost - $0 (see attached 5 and 20 year stress test)
5. Training cost - $0 on the web
6. If TEL's auto sash is over-ridden (powered off), the BMS will be notified.
7. TEL's auto sash complies with section 140.9(c)2-1. UL listing and cut sheet attached.
8. Auto Sash safely allows diversity for new and retrofit projects. When considering "true" hood usage, 50% diversity is often applied. Auto sash guarantees up front mechanical cost avoidance and minimum 50% saving moving forward (new projects). Sample 50% diversity drawings attached.
9. Generally speaking, you can't rely on people to "shut the sash". Unless you're paying the utility bills, you don't have a vested interest. To guarantee health, safety and savings, remove the human element. These statements may not apply at Stanford and UC Davis but they do apply to a very high percentage of lab spaces. TEL has been testing and certifying fume hoods for over 26 years. We've tested and certified well over 50,000 fume hoods in this period and sash management is always an issue!
10. ZPS (zone presence sensing): With auto sash, ZPS is not recommended. When considering fume hoods are being used (occupant standing in front of hood with arms inside hood) on average 2 hours per day (see attached SCE report), TEL does not see a point to risk chemical exposure when the hood is not being used by setting back face velocity from 100 FPM to 60 FPM. When considering cross velocities should not exceed 30% of the inflow velocity, it's difficult to manage hood containment in most lab spaces that don't have laminar flow supply diffusers. In addition, cross velocities created by lab occupants walking behind the user often exceed the inflow velocity of a fume hood. Knowing this, maintaining 100 FPM when the fume hood is being used is a good practice. This concern is defeated slightly with high performance fume hoods that have extra deep countertops. However, when considering the majority of lab spaces don't have this type of fume hood and supporting supply diffuser system, ZPS should only be applied on a case by case basis. In summary, keep your fume hoods at 100 FPM and use auto sash to close your sash 22 hours per day (up to an 85 % energy savings). For people that are inconvenienced by having to open a closed sash door, TEL offers a "sash open" feature that is activated by a foot switch. This way, occupants can observe activity within the hood and keep the sash shut. In other words, we can't "auto open" the sash via an occupancy sensor.

Additional submitted attachment is included below.

Auto-sash Documentation – Table of Contents

Submitted by Jason Sparbel, TEL Americas, Nov 10, 2017

jasons@tel-americas.com, 941-374-2753

The following six documents were compiled for docket number "17-BSTD-01" and "Draft 2019 Building Energy Efficiency Standards" in response to issues in the October 4th version of Title 24, Part 6 - High Efficiency Fume Hoods in Laboratory Spaces.

We are in favor of the language in the October version of this document.

1. **ASPS Final Report v10_peer reviewed.pdf** – 93 pages 2-94
   Engineering Measurement & Verification Study: Laboratory Fume Control Hood & Automatic Sash Positioning System. Prepared For: SDG&E Emerging Technology Program.

2. **Auto Sash Longevity Test Report.pdf** – 10 pages 95-104
   Methodology and conclusions for Life Span, Overloading, Mains Quality, Back Voltage, and Temperature tests.

3. **GSK Sash Closer.pdf** – 2 pages 105-106
   Automatic Sash Positioning System test conducted for Glaxo Smith Kline.

4. **PGE Report.pdf** – 110 pages 107-216
   Pacific Gas and Electric Company Emerging Technologies Program - Application Assessment Report 2007: Automatic Fume Hood Sash Closure Demonstration and Test at The University of California, Davis.

5. **PWP_DEED_Savings_Comparison_Final.pdf** – 25 pages 217-240
   AESC Results Review for American Public Power Association's (APPA) Demonstration of Energy and Efficiency Developments (DEED) Grant Project, "Evaluation of Tek-Air Accuvalve in Retrofit Applications -- Demonstration of Energy Efficiency, Operations Benefits and Relevance Across Multiple Target Markets"

6. **SCE Final Report by HGI (7-25-07).pdf** – 32 pages 241-272
   Automatic Sash Positioning System (ASPS): An Energy Assessment Study on Fume Hoods for Amgen Inc. - Final Report

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

NegaWatt Consulting, Inc.

www.negawattconsult.com
(619) 309-4191

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.

____

Marc Esser
President of NegaWatt Consulting, Inc.

Table of Contents

EXECUTIVE SUMMARY 9

PROJECT OBJECTIVE 10

PROJECT SETTING AND METHODOLOGY 10

TECHNOLOGY OVERVIEW 10

STATEWIDE MARKET POTENTIAL 12

Market Overview *13*

HOST SITE 1 OVERVIEW 14

HOST SITE 2 OVERVIEW 14

HOST SITE 3 OVERVIEW 15

MEASUREMENT & VERIFICATION PLAN OVERVIEW 16

APPLICABLE CODES & STANDARDS 16

PROJECT RESULTS & DISCUSSION 18

SYSTEM COST AND COST INFLUENCING FACTORS 18

VERIFICATION OF SYSTEM OPERATION & DESIGN 19

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #1 & Site #2 .... *19*

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #3 .... *19*

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #1 & Site #2 .... *19*

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #3 .... *20*

RESULTS 21

RESULTS – Site #1 .... *22*

RESULTS – Site #2 .... *26*

RESULTS – Site #3 .... *30*

CUSTOMER FEEDBACK 34

SAVINGS INFLUENCING FACTORS 34

APPLICIBILITY OF FUTURE REBATE/INCENTIVE PROGRAMS 35

PROJECT ERROR ANALYSIS 35

PROJECT PLAN DEVIATION 35

ANOMALOUS DATA AND TREATMENT 36

CONCLUSIONS 36

BENEFITS OF EVALUATED TECHNOLOGY 37

POSSIBLE DRAWBACKS & RISKS OF EVALUATED TECHNOLOGY 37

TECHNOLOGY IMPROVEMENT OPPORTUNITIES 37

APPLICABILITY OF FINDINGS TO OTHER LOAD TYPES AND SECTORS 38

CONSIDERATIONS FOR LARGE SCALE PERSISTANT MARKET IMPLIMENTATION 38

POSSIBLE FUTURE STUDY 38

GLOSSARY AND ACRONYMS 39

APPENDIX A: PROJECT PLAN 40

APENDIX B: M&V PLAN 41

APPENDIX C: Methodology 47

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #1 & Site #2 47

METHODOLOGY for EVALUATION of AIR FLOW REDUCTION – Site #3 48

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #1 & Site #2 49

METHODOLOGY for EVALUATION of ENERGY SAVINGS – Site #3 51

APPENDIX D: UTILITY DATA 53

TEST SITE #1 53

TEST SITE #2 56

TEST-SITE #3 58

APPENDIX E: Detailed Results by Site 61

DETAILED RESULTS – Site #1 61

DETAILED RESULTS – Site #2 66

DETAILED RESULTS – Site #3 73

LIST OF FIGURES

FIGURE 1: ASPS COMPONENT DETAILS 11

FIGURE 2: SITE #1 FINDINGS 25

FIGURE 3: SITE #2 FINDINGS 29

FIGURE 4: SITE #1 ELECTRIC CONSUMPTION HISTORY 54

FIGURE 5: SITE #1 NATURAL GAS CONSUMPTION HISTORY 55

FIGURE 6: SITE #2 ELECTRIC CONSUMPTION HISTORY 56

FIGURE 7: SITE #2 NATURAL GAS CONSUMPTION HISTORY 57

FIGURE 8: SITE #3 CENTRAL PLANT ELECTRIC CONSUMPTION HISTORY 58

FIGURE 9: SITE #3 NON-CENTRAL PLANT METERS ELECTRIC CONSUMPTION HISTORY 59

FIGURE 10: SITE #3 NATURAL GAS CONSUMPTION HISTORY 60

FIGURE 11: SITE #1 TEST HOOD CFM PROFILE 64

FIGURE 12: SITE #1 FINDINGS 65
FIGURE 13: SITE #2 NON-MODIFIED HOOD 1 CFM PROFILE 69
FIGURE 14: SITE #2 NON-MODIFIED HOOD 2 CFM PROFILE 69
FIGURE 15: SITE #2 NON-MODIFIED HOOD 3 CFM PROFILE 70
FIGURE 16: SITE #2 NON-MODIFIED HOOD 4 CFM PROFILE 70
FIGURE 17: SITE #2 TEST HOOD 5 CFM PROFILE 71
FIGURE 18: SITE #2 NON-MODIFIED HOOD 6 CFM PROFILE 71
FIGURE 19: SITE #2 FINDINGS 72
FIGURE 20: SITE #3 NON-MODIFIED HOOD 16 CFM PROFILE 77
FIGURE 21: SITE #3 NON-MODIFIED HOOD 17 CFM PROFILE 77
FIGURE 22: SITE #3 NON-MODIFIED HOOD 18 CFM PROFILE 78
FIGURE 23: SITE #3 TEST HOOD 3 CFM PROFILE 78
FIGURE 24: SITE #3 TEST HOOD 5 CFM PROFILE 79
FIGURE 25: SITE #3 TEST HOOD 8 CFM PROFILE 79

LIST OF TABLES

TABLE 1: ENERGY SAVINGS SUMMARY 10
TABLE 2: STATEWIDE MARKET POTENTIAL EXAMPLE 12
TABLE 3: AVERAGE ANNUAL ENERGY SAVINGS PER HOOD 21
TABLE 4: COMBINED CFM STUDY SUMMARY 21
TABLE 5: 62" SASH WIDTH FINDINGS SUMMARY 22
TABLE 6: ALL HOODS SUMMARY 22
TABLE 7: SITE #1 SAVINGS SUMMARY 23

TABLE 8: SITE #1 FAN SAVINGS SUMMARY 23
TABLE 9: SITE #1 FINANCIAL SUMMARY 24
TABLE 10: SITE #1 HOOD 2-80 CFM SUMMARY 24
TABLE 11: SITE #2 SAVINGS SUMMARY 26
TABLE 12: SITE #2 FAN SAVINGS SUMMARY 26
TABLE 13: SITE #2 FINANCIAL SUMMARY 27
TABLE 14: SITE #2 HOOD #5 CFM SUMMARY 27
TABLE 15: SITE #2 NON-MODIFIED HOOD CFM SUMMARY 28
TABLE 16: SITE #3 SAVINGS SUMMARY 30
TABLE 17: SITE #3 SUPPLY FAN SAVINGS SUMMARY 30
TABLE 18: SITE #3 EXHAUST FAN SAVINGS SUMMARY 31
TABLE 19: SITE #3 FINANCIAL SUMMARY 32
TABLE 20: SITE #3 TEST HOOD SUMMARY 32
TABLE 21: SITE #3 BASELINE CFM SUMMARY 33
TABLE 22: SITE #3 OPTIMIZED CFM SUMMARY 33
TABLE 23: SCE CUSTOMIZED INCENTIVE 35
TABLE 24: MEASUREMENT AND VERIFICATION OPTIONS 41
TABLE 25: M&V OPTION SELECTED 42
TABLE 26: SITE #1 ELECTRIC UTILITY SUMMARY 53
TABLE 27: SITE #1: NATURAL GAS UTILITY SUMMARY 55
TABLE 28: SITE #2 ELECTRIC UTILITY SUMMARY 56
TABLE 29: SITE #2 NATURAL GAS UTILITY SUMMARY 57
TABLE 30: SITE #3 CENTRAL PLANT ELECTRIC UTILITY SUMMARY 58
TABLE 31: SITE #3 NON-CENTRAL PLANT METERS ELECTRIC UTILITY SUMMARY 59

TABLE 32: SITE #3 NATURAL GAS UTILITY SUMMARY 60
TABLE 33: SITE #1 SAVINGS SUMMARY 61
TABLE 34: SITE #1 FAN SAVINGS SUMMARY 61
TABLE 35: SITE #1 FINANCIAL SUMMARY 62
TABLE 36: SITE #1 HOOD 2-80 CFM SUMMARY 62
TABLE 37: SITE #1 NON-MODIFIED HOOD CFM SUMMARY 63
TABLE 38: SITE #2 SAVINGS SUMMARY 66
TABLE 39: SITE #2 FAN SAVINGS SUMMARY 66
TABLE 40: SITE #2 FINANCIAL SUMMARY 67
TABLE 41: SITE #2 HOOD #5 CFM SUMMARY 67
TABLE 42: SITE #2 NON-MODIFIED HOOD CFM SUMMARY 68
TABLE 43: SITE #3 SAVINGS SUMMARY 73
TABLE 44: SITE #3 SUPPLY FAN SAVINGS SUMMARY 73
TABLE 45: SITE #3 EXHAUST FAN SAVINGS SUMMARY 74
TABLE 46: SITE #3 FINANCIAL SUMMARY 75
TABLE 47: SITE #3 TEST HOOD SUMMARY 75
TABLE 48: SITE #3 BASELINE CFM SUMMARY 76
TABLE 49: SITE #3 OPTIMIZED CFM SUMMARY 76

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.

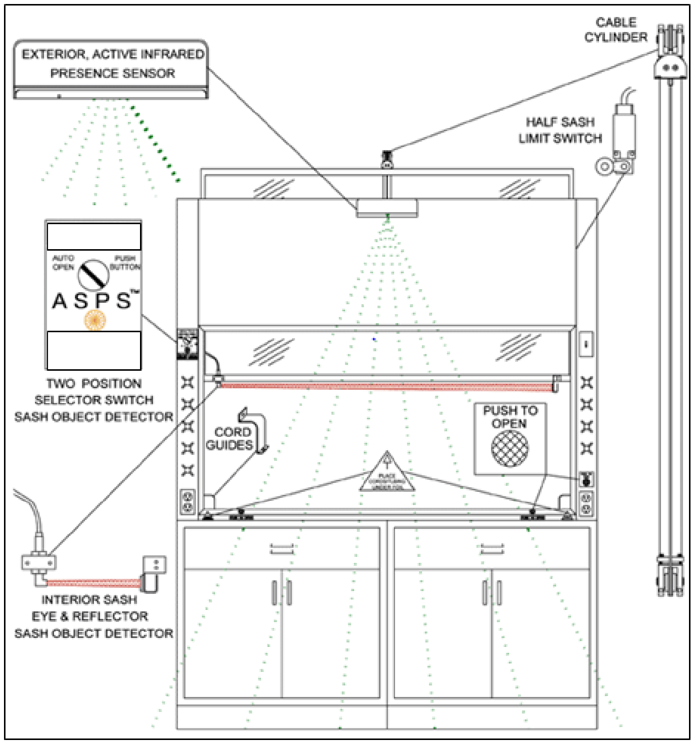


Figure 1: ASPS Component Details

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.

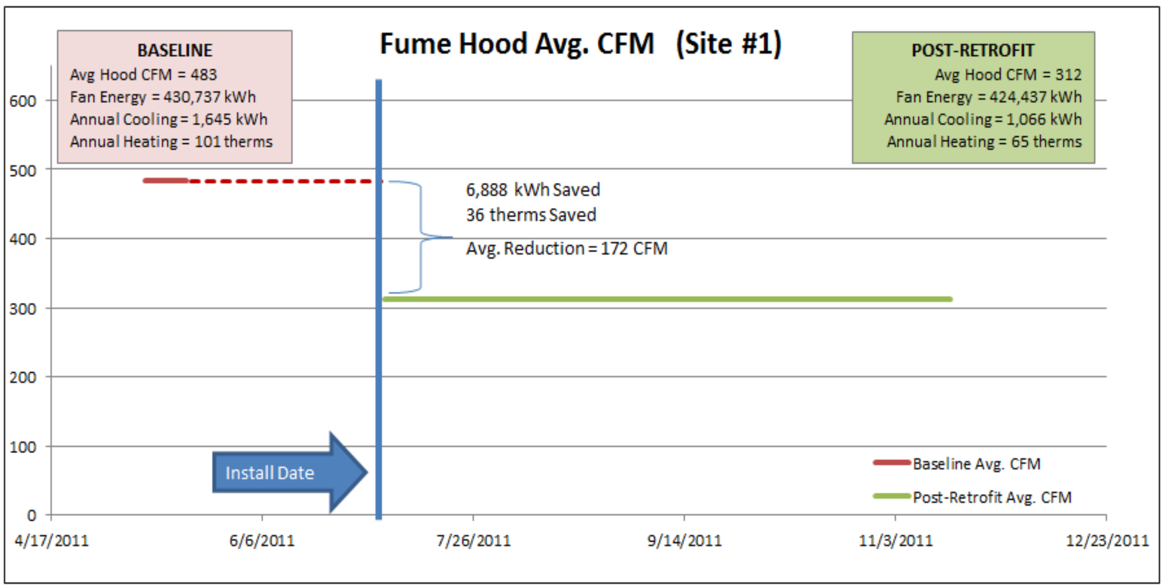


Figure 2: Site #1 Findings

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.

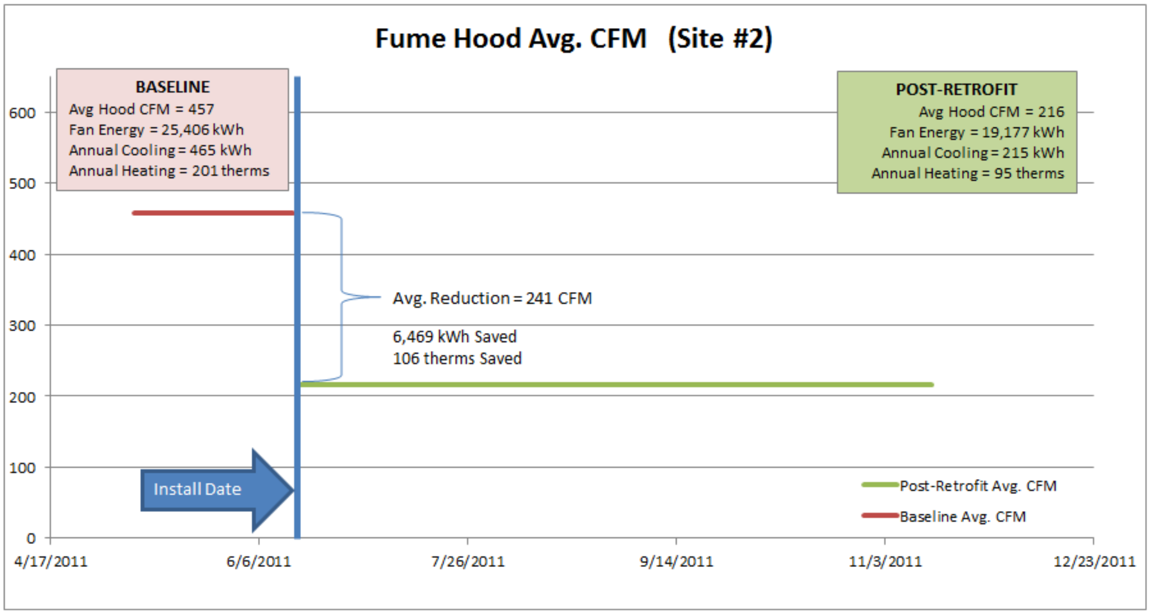


Figure 3: Site #2 Findings

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

FAN kWh SAVINGS EXAMPLE CALCULATION

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

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

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

Where:

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

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

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

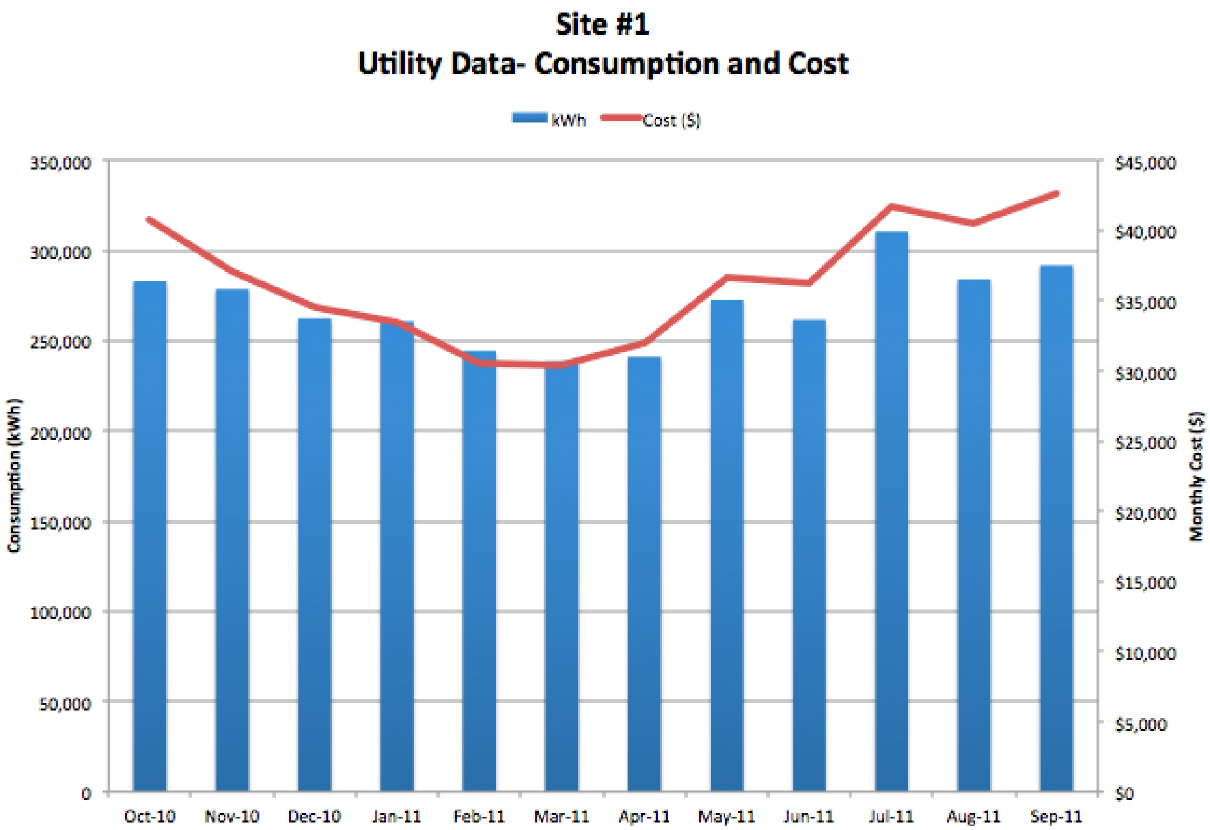


Figure 4: Site #1 Electric Consumption History

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

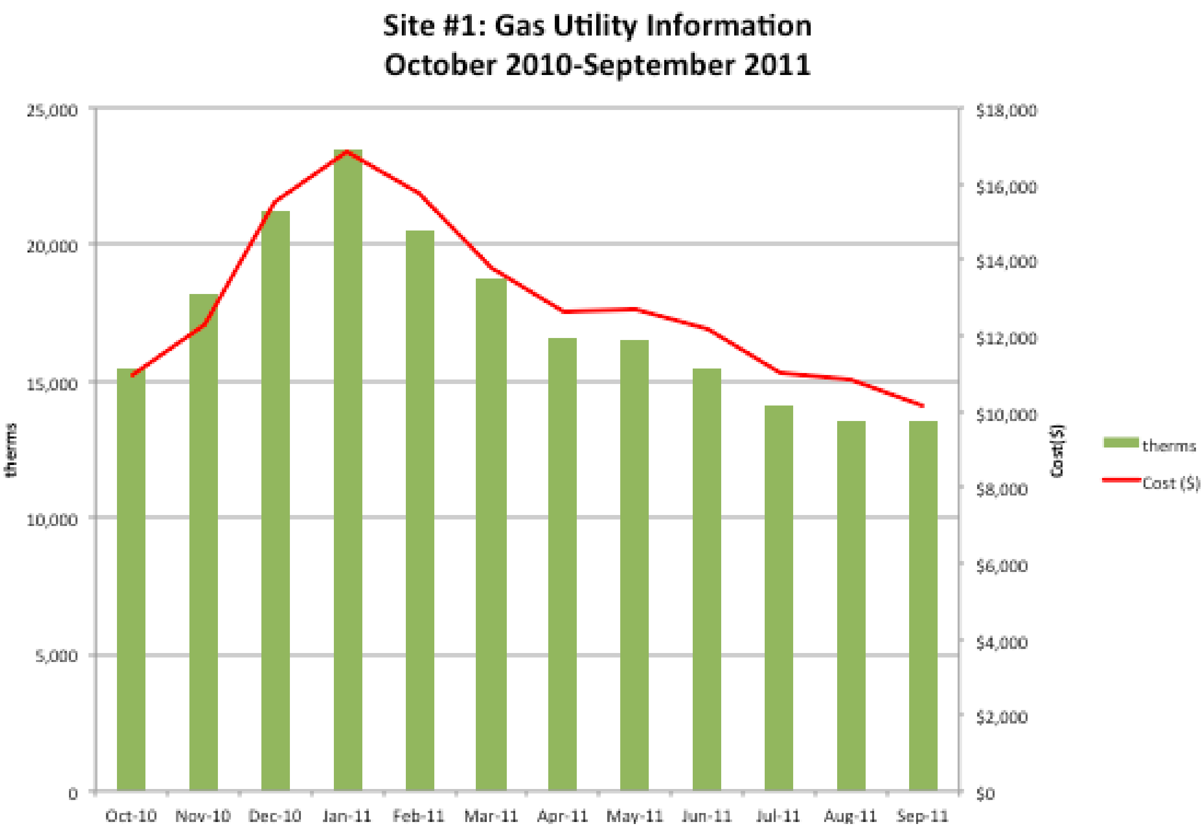


Figure 5: Site #1 Natural Gas Consumption History

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

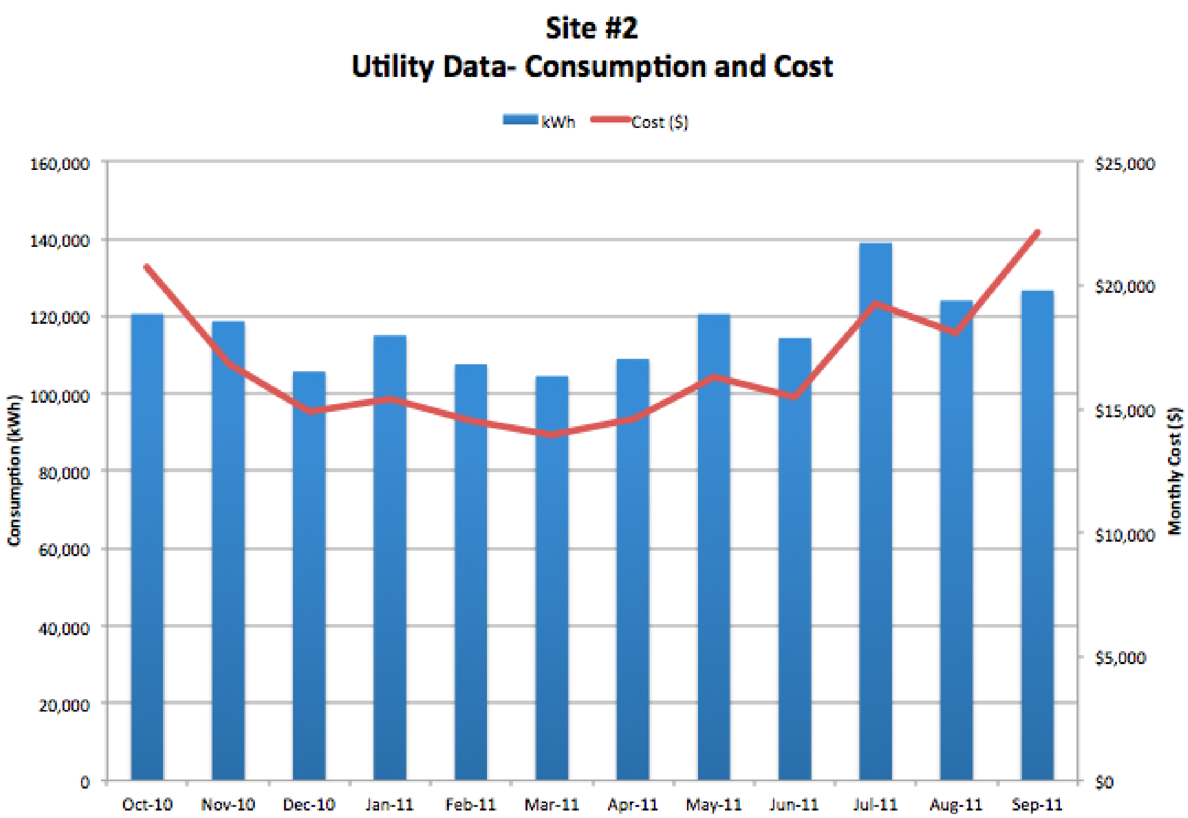


Figure 6: Site #2 Electric Consumption History

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

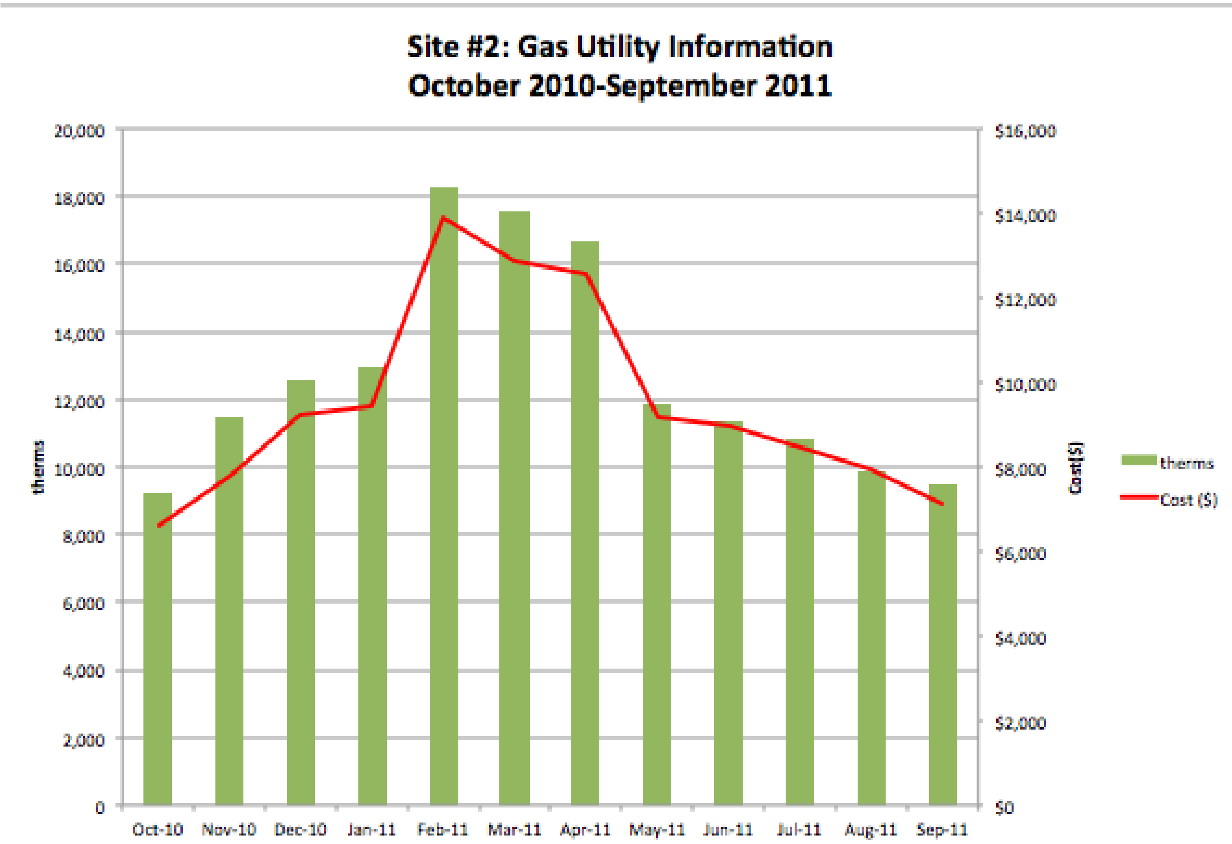


Figure 7: Site #2 Natural Gas Consumption History

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

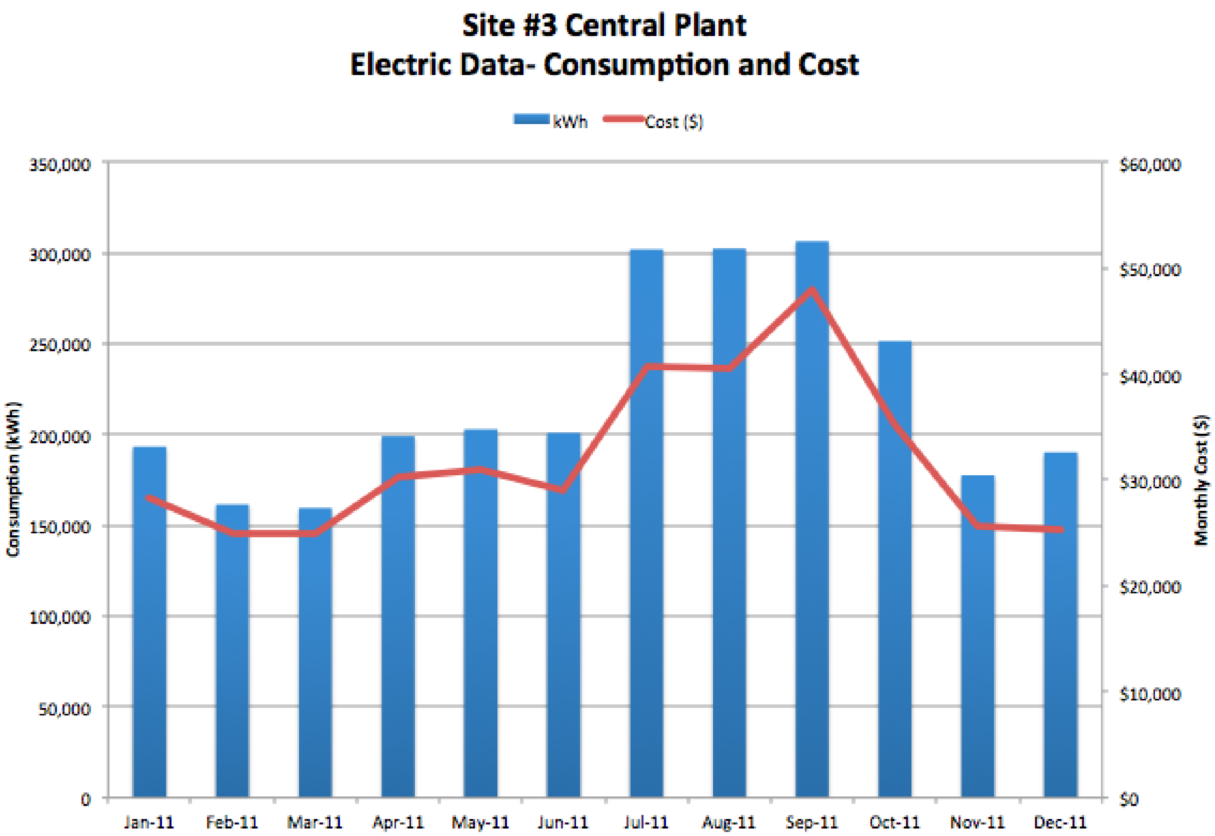


Figure 8: Site #3 Central Plant Electric Consumption History

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

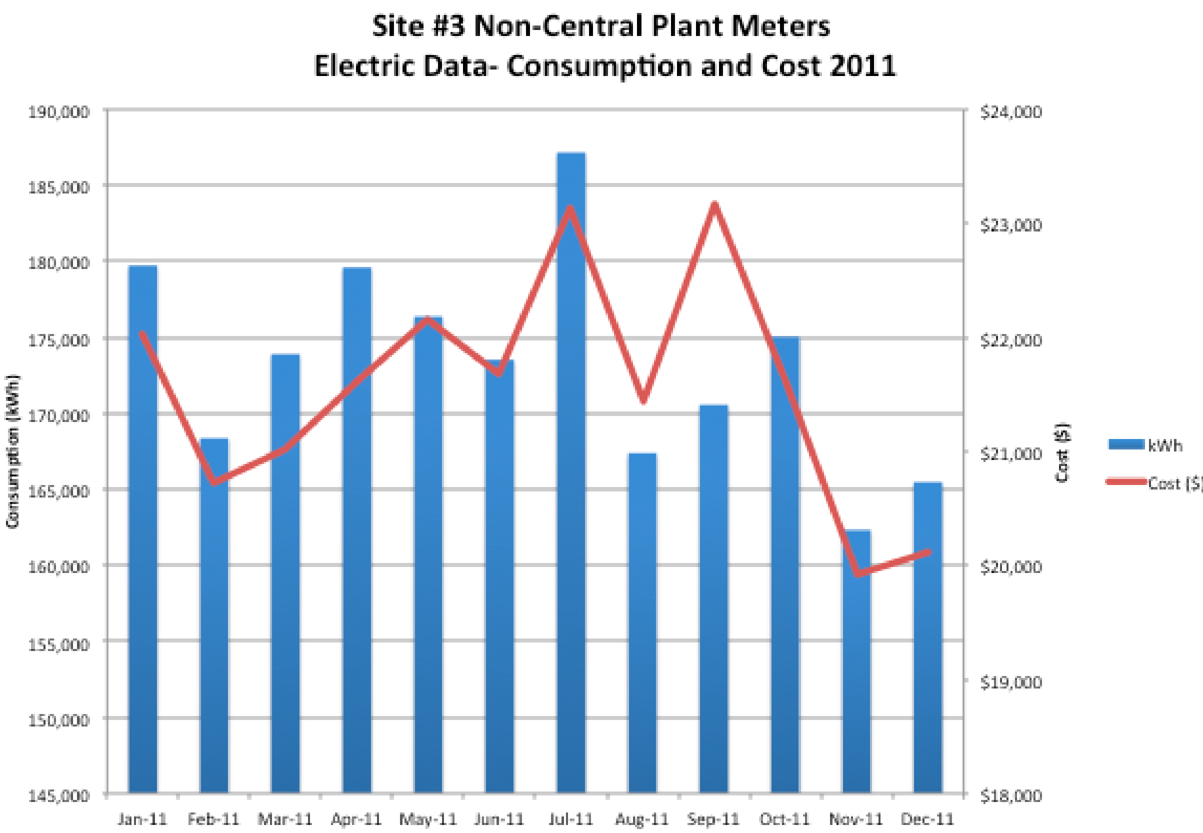


Figure 9: Site #3 Non-Central Plant Meters Electric Consumption History

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

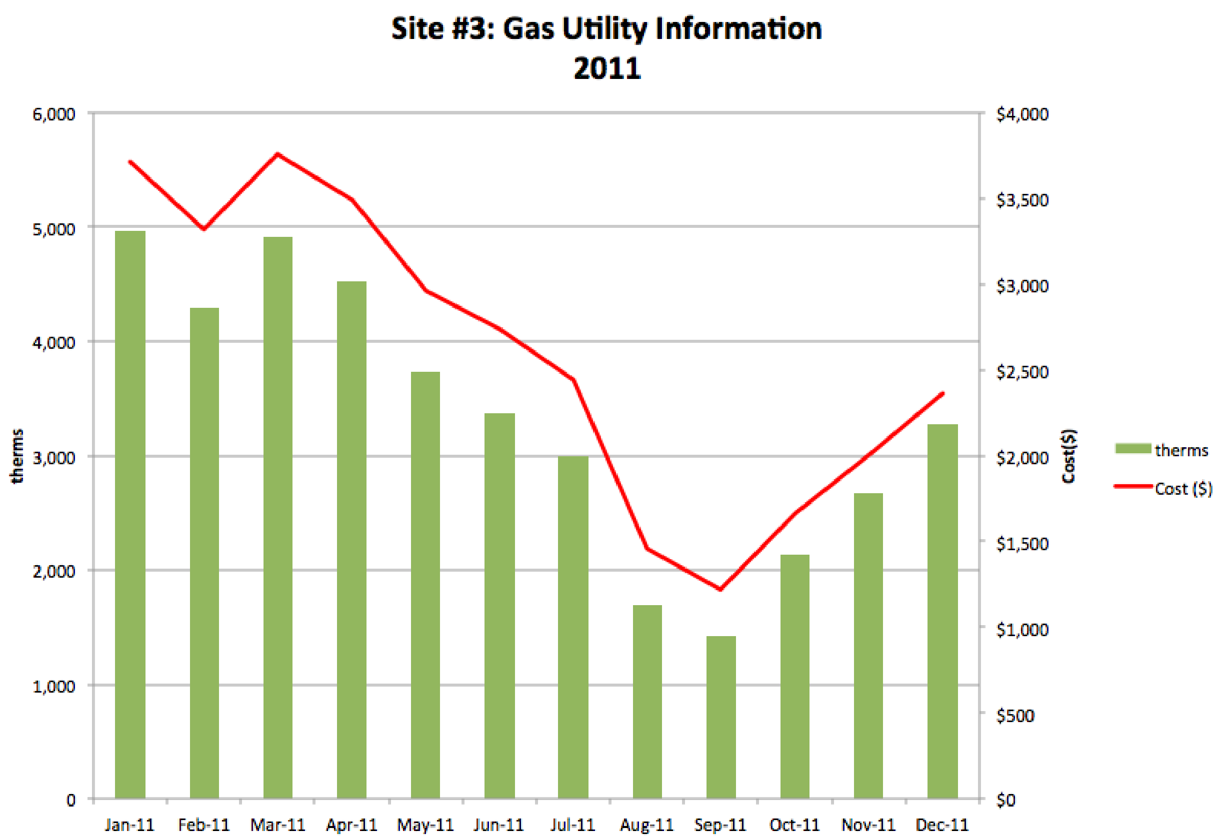


Figure 10: Site #3 Natural Gas Consumption History

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.

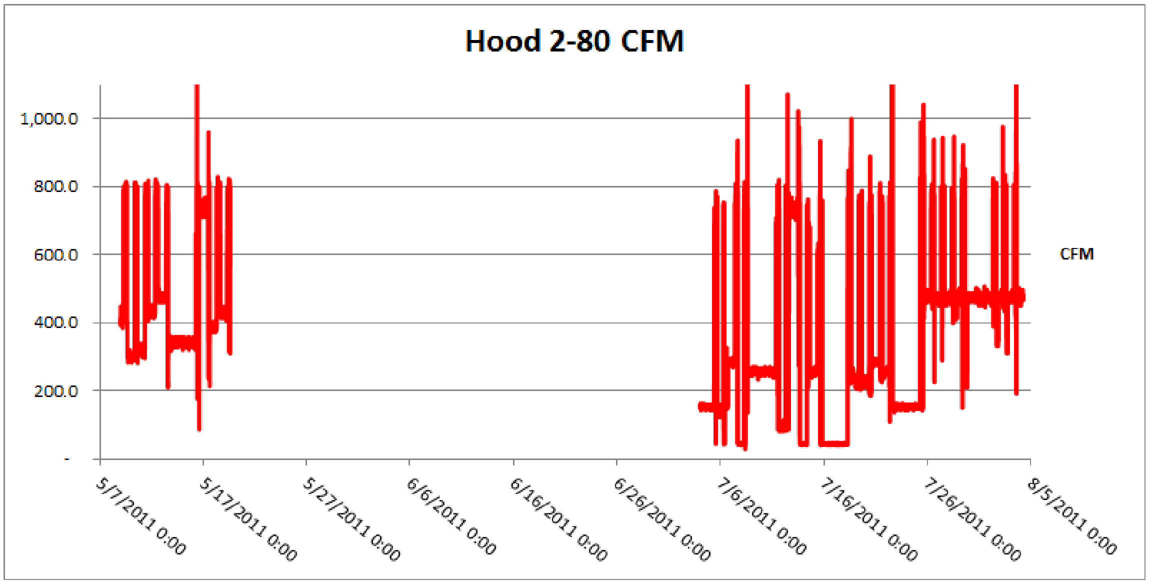


Figure 11: Site #1 Test Hood CFM Profile

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.

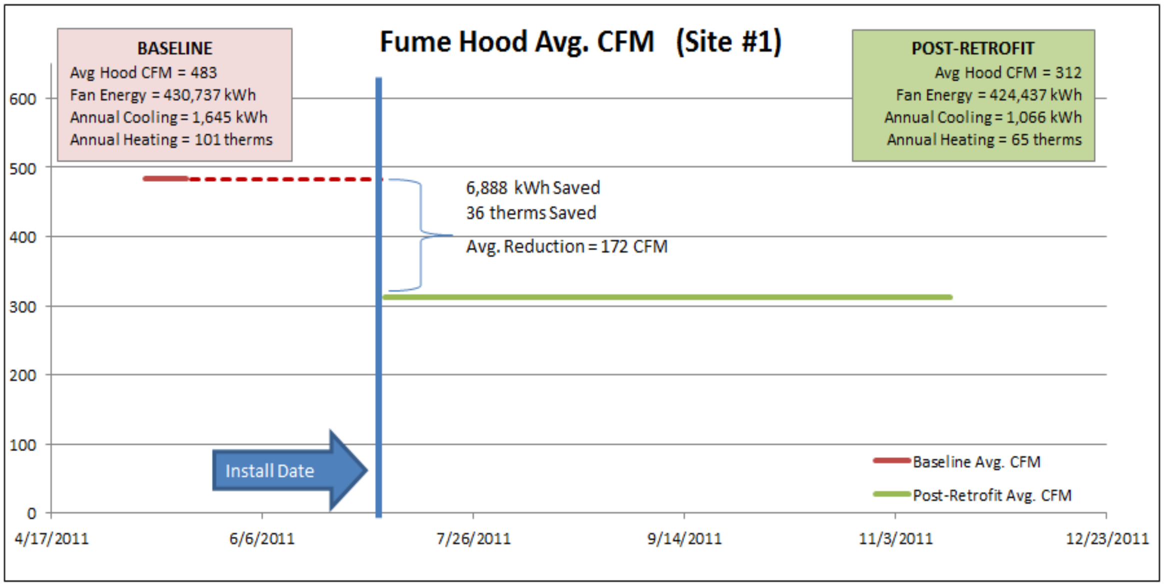


Figure 12: Site #1 Findings

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.

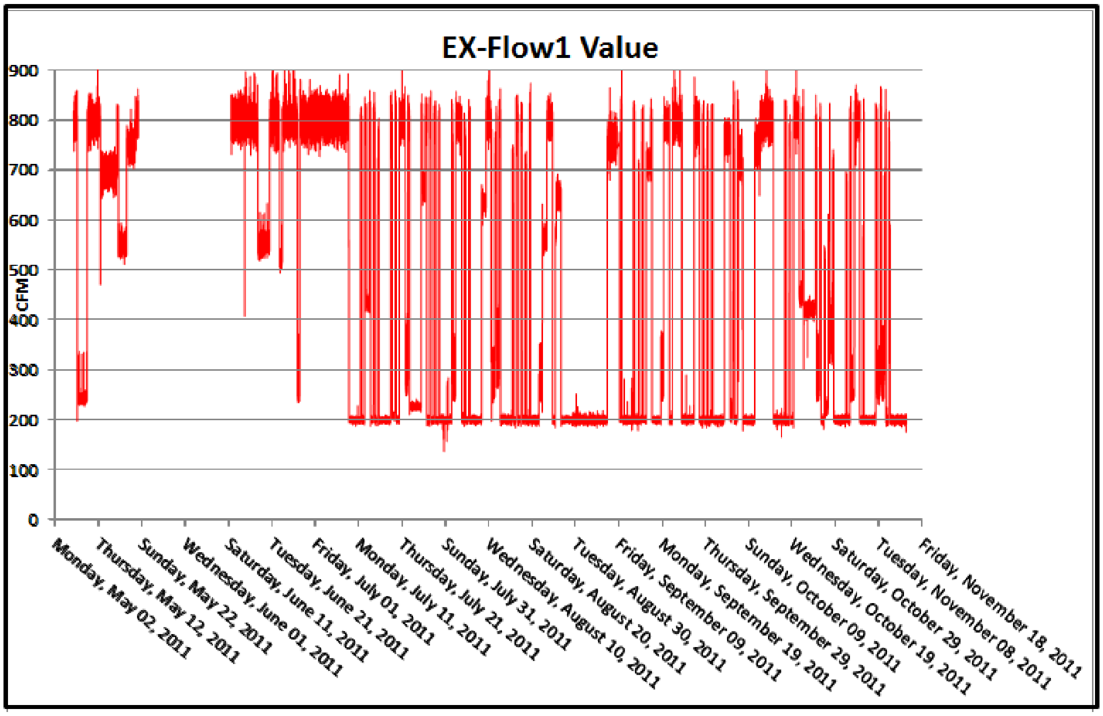


Figure 13: Site #2 Non-Modified Hood 1 CFM Profile

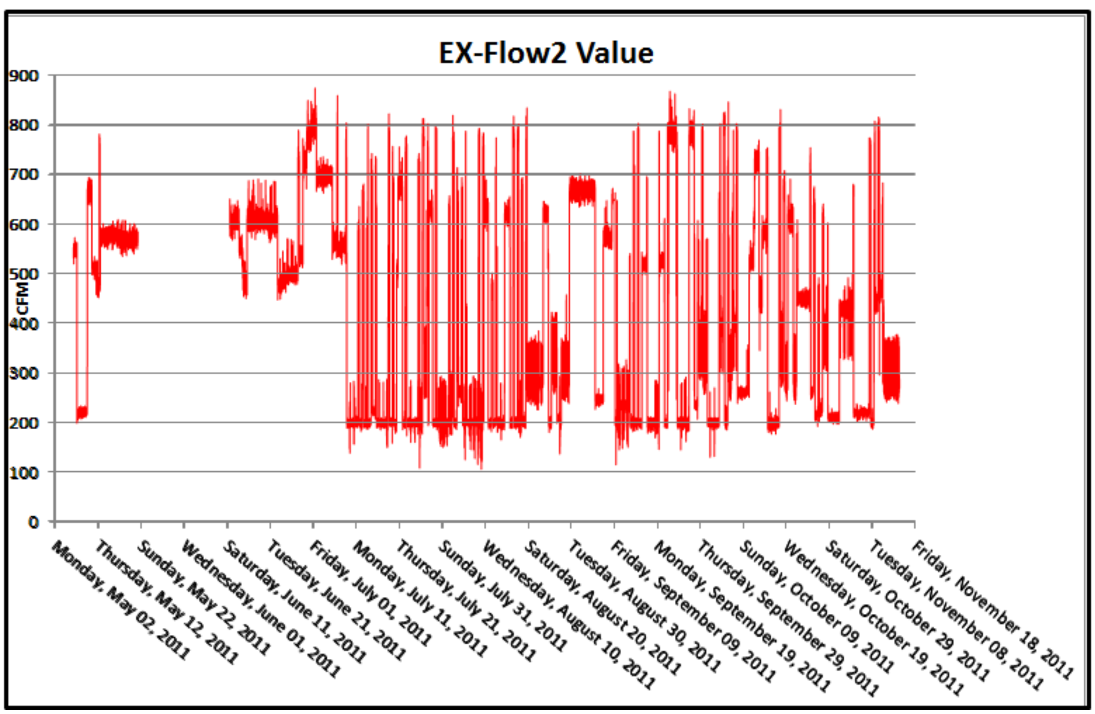


Figure 14: Site #2 Non-Modified Hood 2 CFM Profile

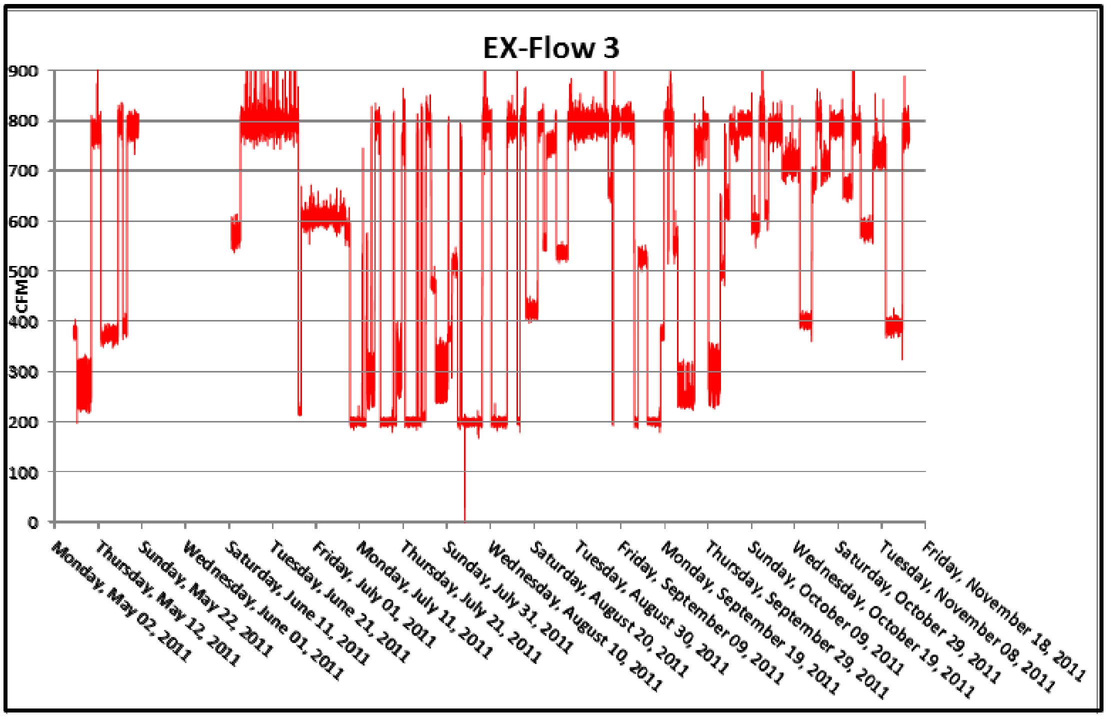


Figure 15: Site #2 Non-Modified Hood 3 CFM Profile

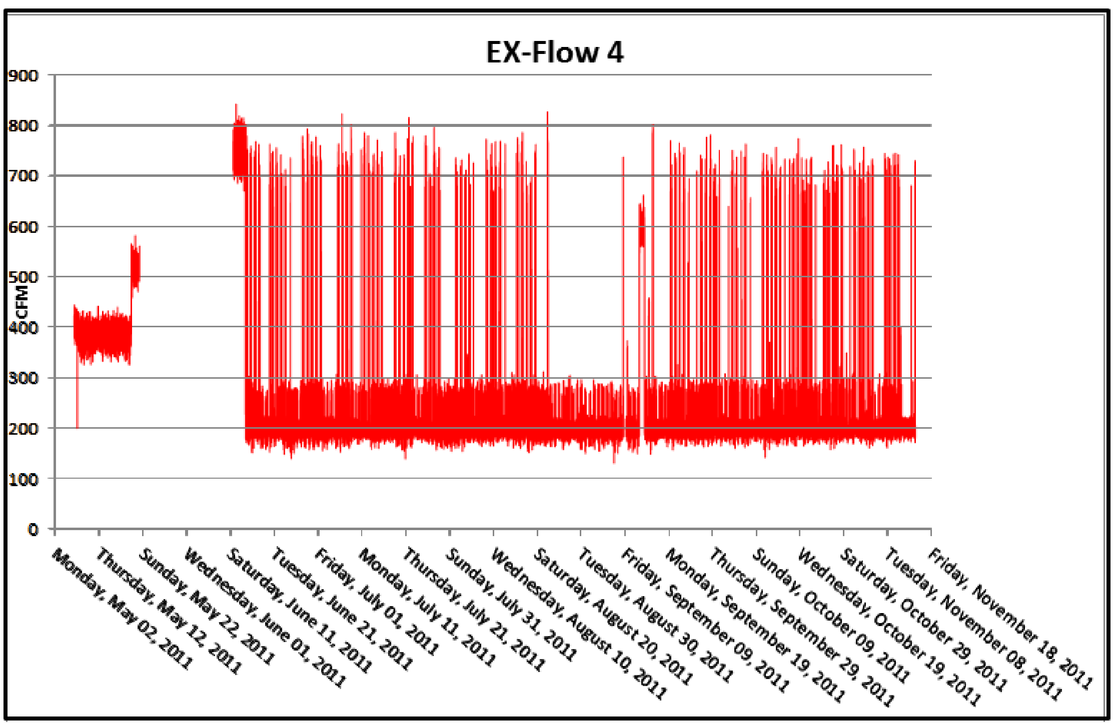


Figure 16: Site #2 Non-Modified Hood 4 CFM Profile

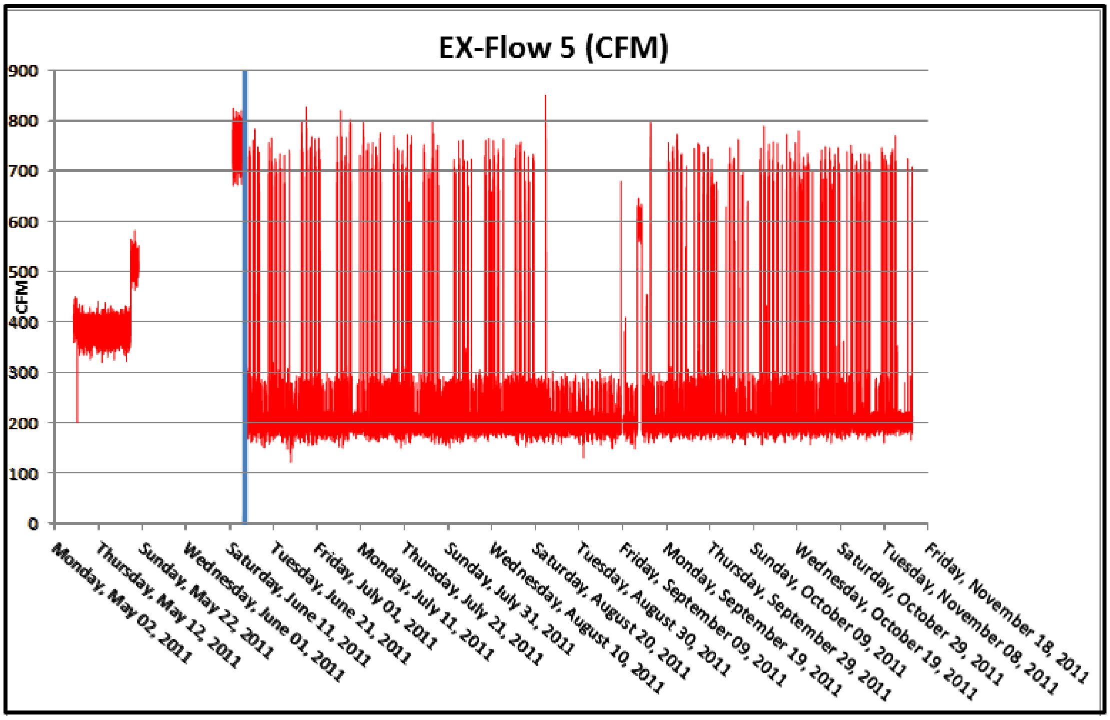


Figure 17: Site #2 Test Hood 5 CFM Profile

(Installation date at blue vertical line)

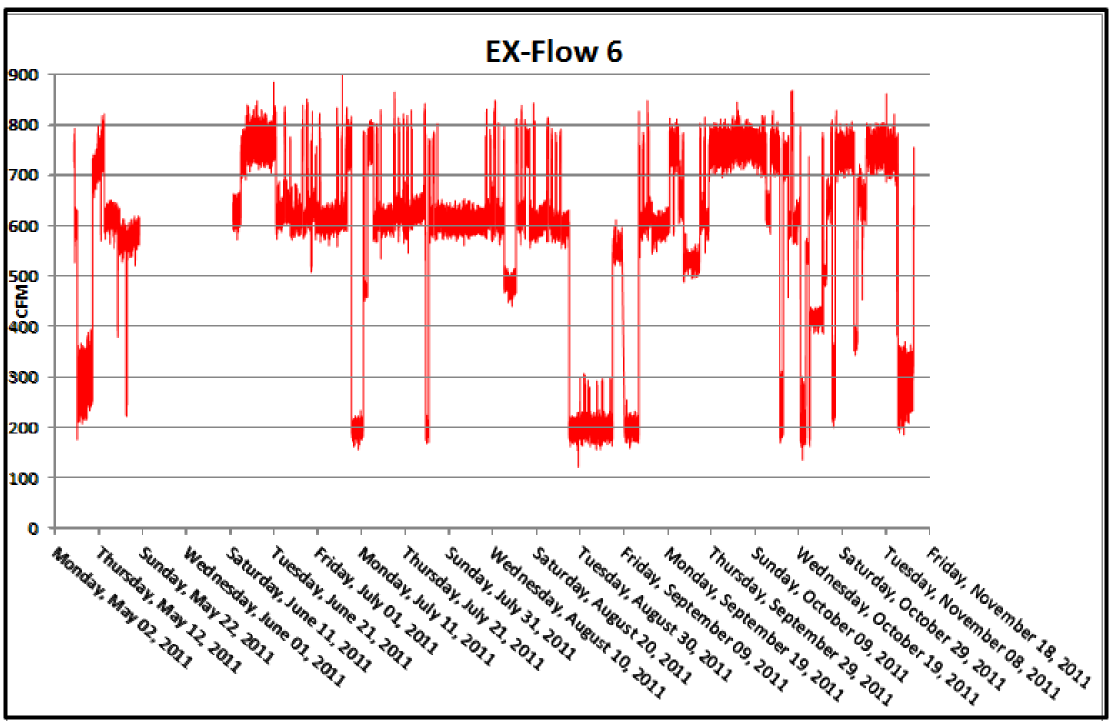


Figure 18: Site #2 Non-Modified Hood 6 CFM Profile

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.

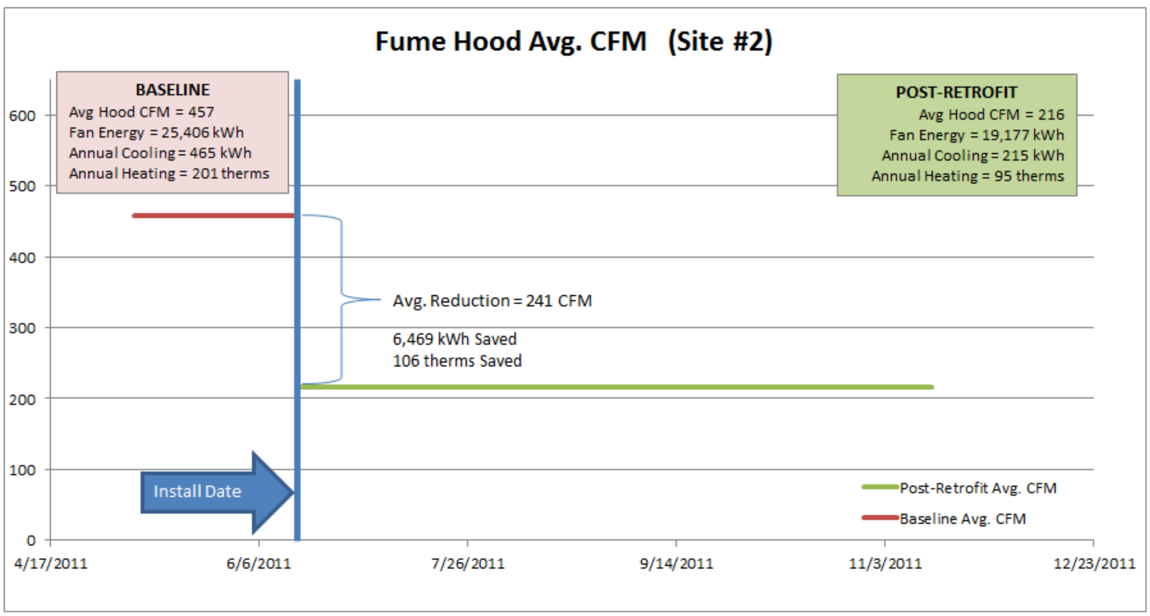


Figure 19: Site #2 Findings

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.

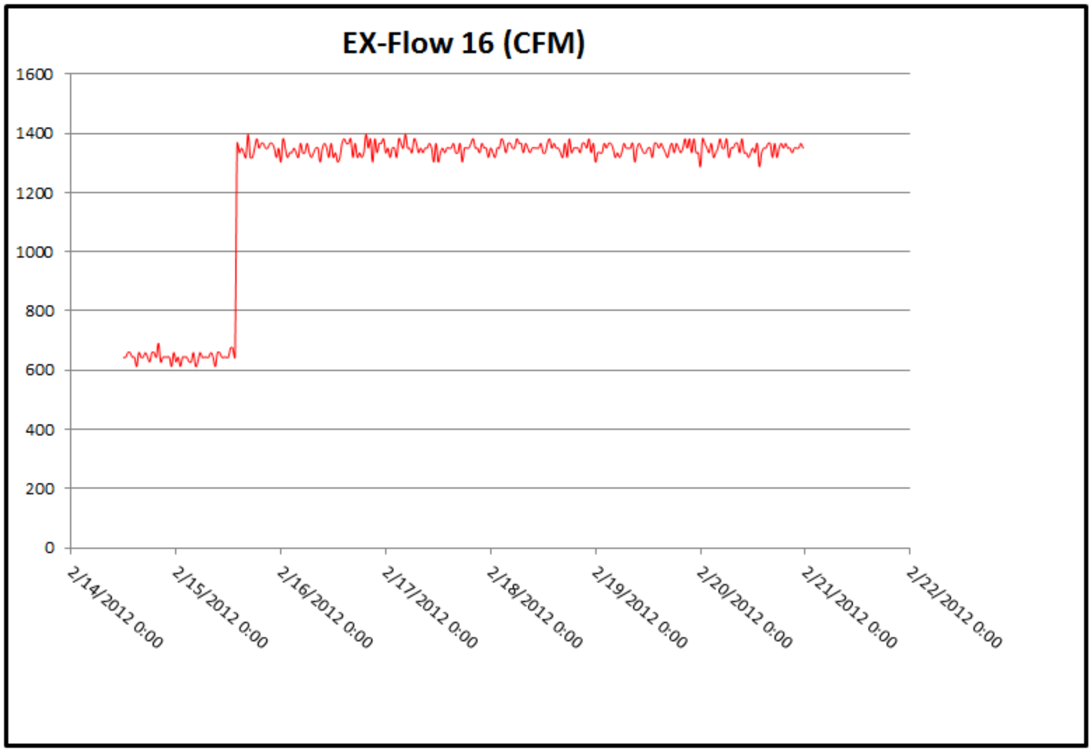


Figure 20: Site #3 Non-Modified Hood 16 CFM Profile

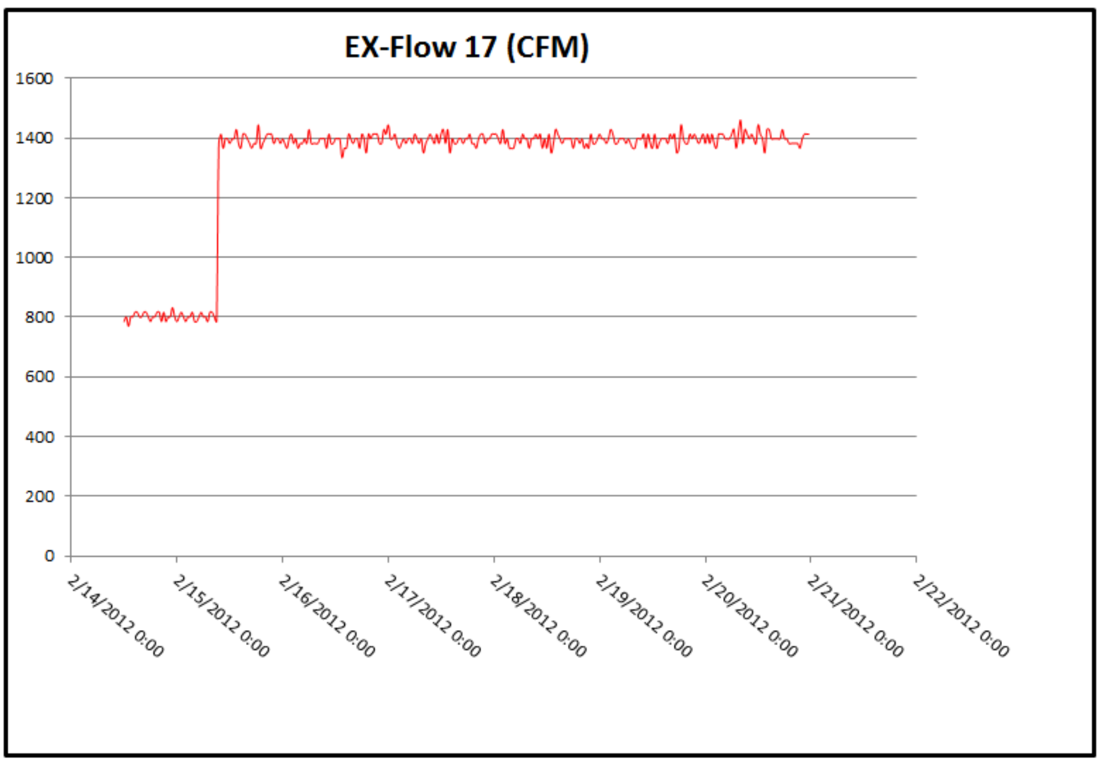


Figure 21: Site #3 Non-Modified Hood 17 CFM Profile

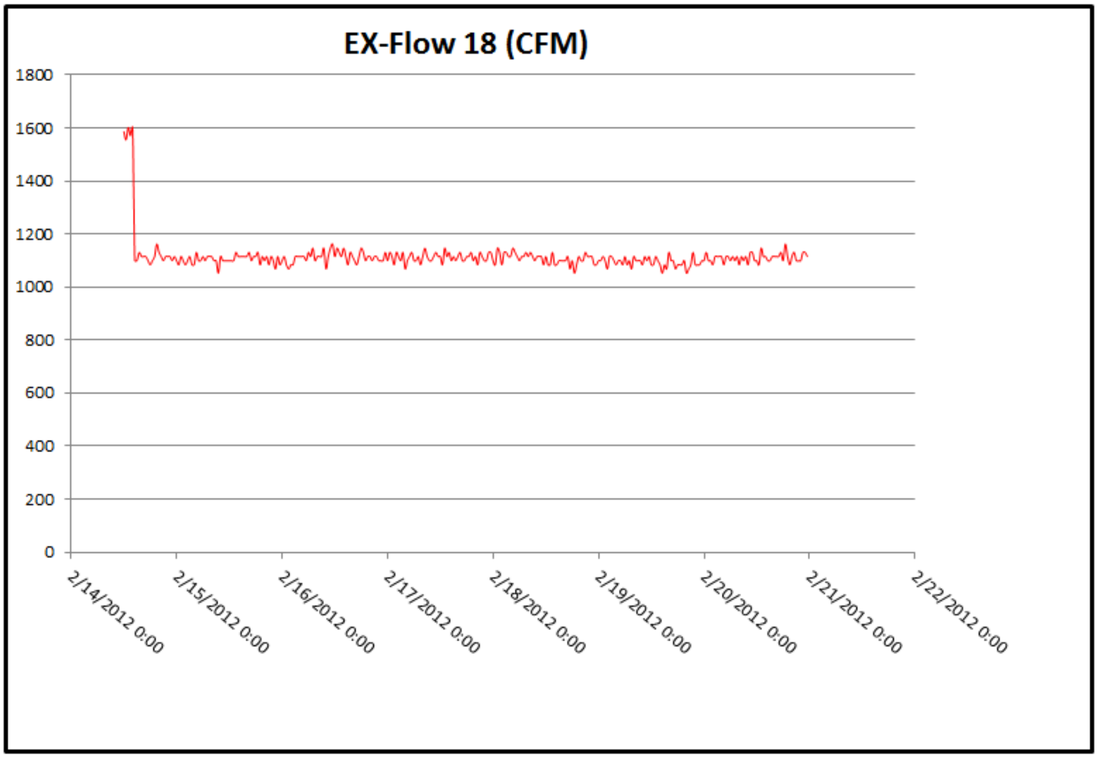


Figure 22: Site #3 Non-Modified Hood 18 CFM Profile

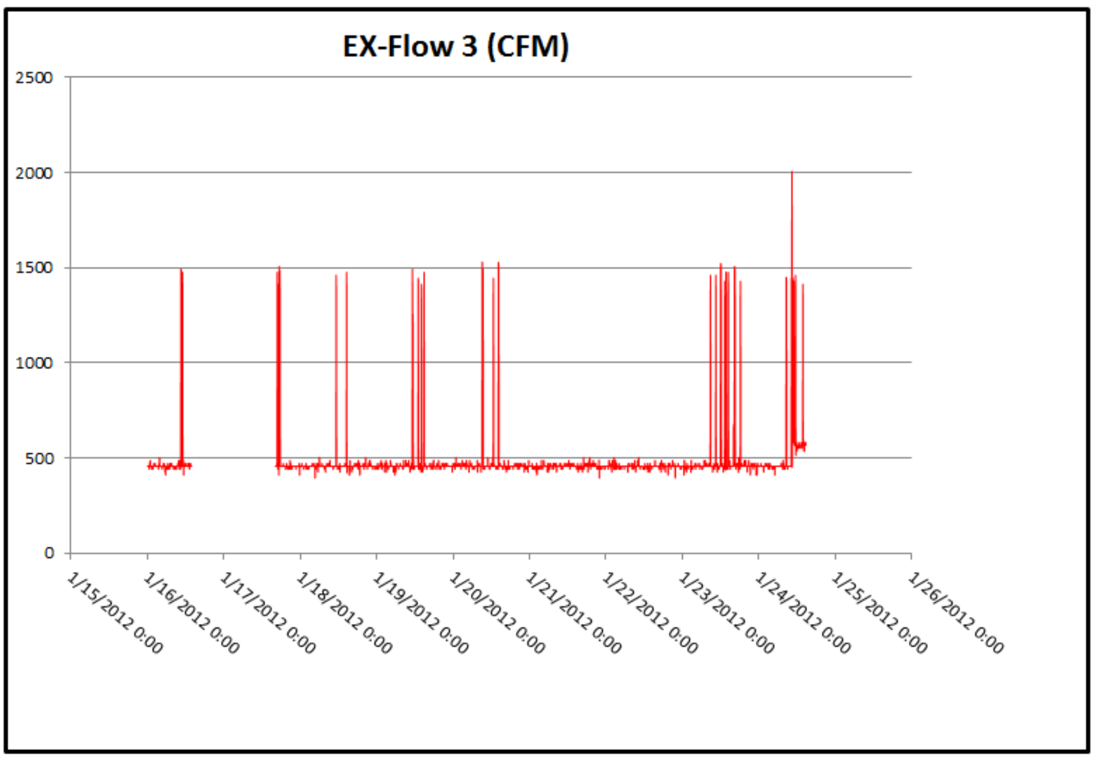


Figure 23: Site #3 Test Hood 3 CFM Profile

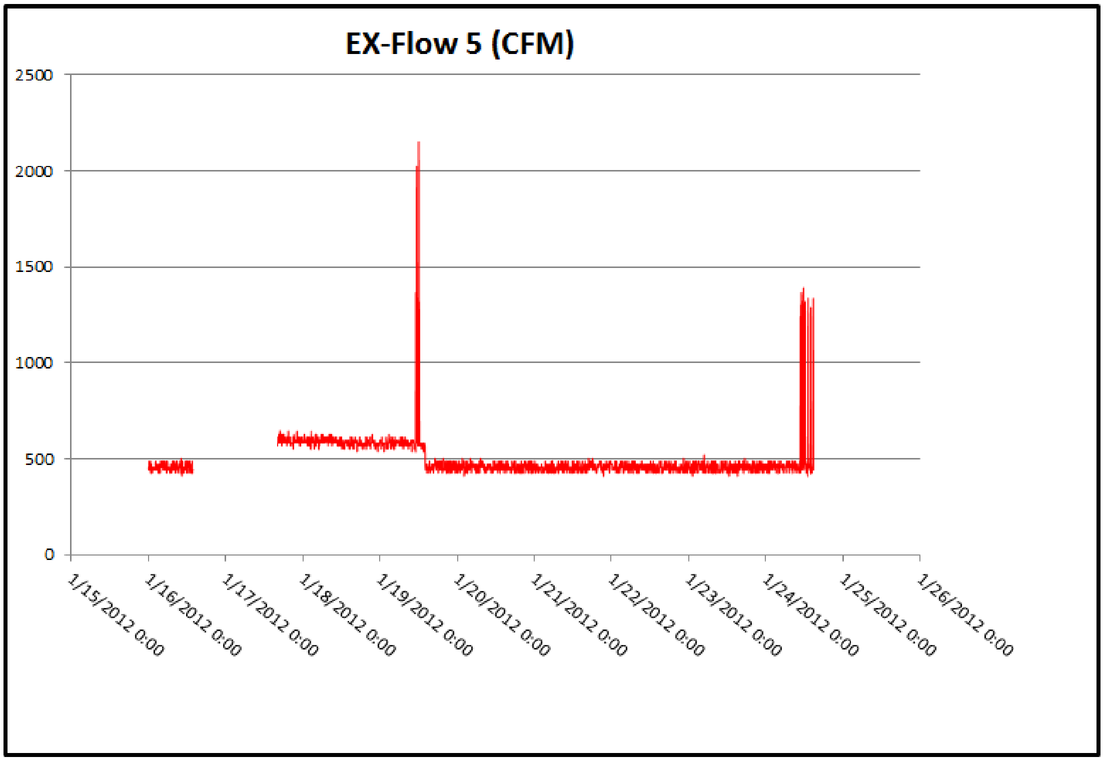


Figure 24: Site #3 Test Hood 5 CFM Profile

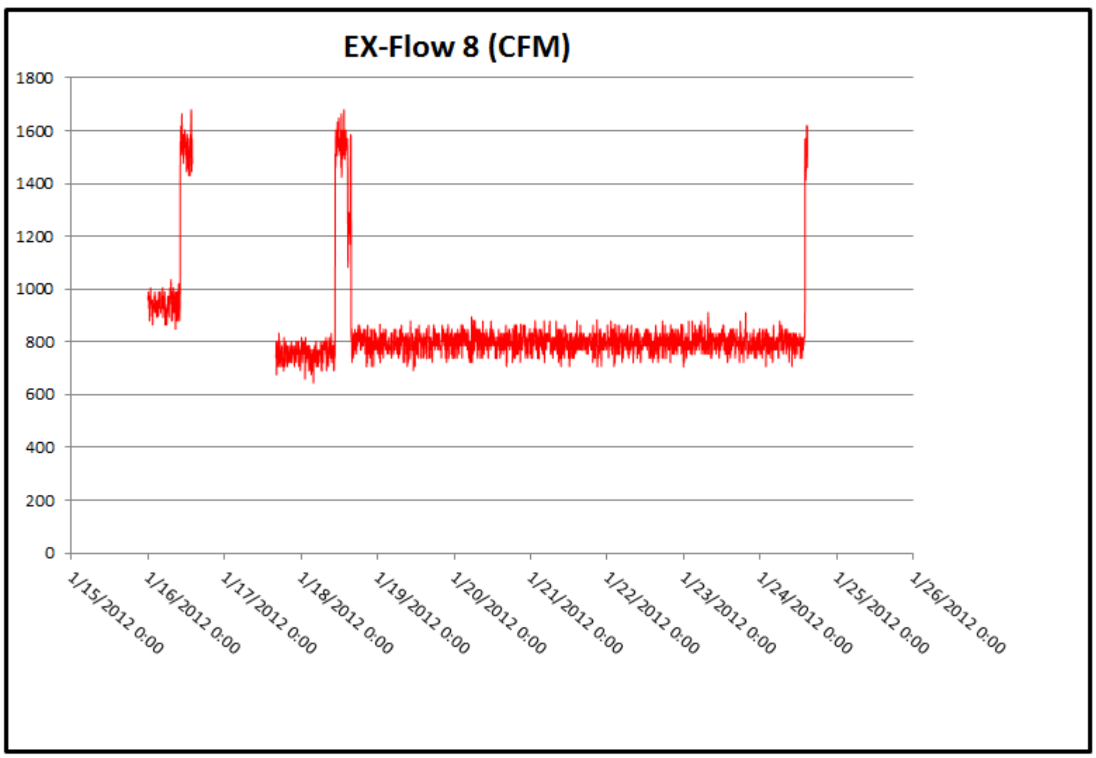


Figure 25: Site #3 Test Hood 8 CFM Profile

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.

Auto Sash Controls

Test Report

Contents

Chapters	2.0	Overview of Test Methods	3
	3.0	Test 1 - Bench Test - Temperature	4
	4.0	Test 2 - Bench Test - Back Voltage	6
	5.0	Test 3 - Bench Test - Main Quality	7
	6.0	Test 4 - Bench Test - Overloading	8
	7.0	Test 5 - Bench Test - Lifespan test	9
	8.0	Conclusion	10

The Auto Sash controls use a switch mode power supply to enable a working mains power voltage range of 100 to 230V. The tests were carried out at the maximum voltage (230V) as this is the maximum rated voltage.

A further test was done with an input voltage of 280V to test the effect of overvoltage.

The Auto Sash control PCB is mounted in an enclosure which relies on free air cooling for the internal power supplies. As the enclosure could be mounted in any orientation and could also be mounted closely to other equipment an internal Temperature test was done on the PCB with the enclosure mounted vertically and horizontally.

A further test was done with the air vents on the enclosure and power supplies blocked to test the effect of zero cooling.

The controller drives a motor and clutch assembly so oscilloscope tests were done to test for any back voltage into the power supplies.

The controller was tested for mains quality issues by creating noise on the mains supply.

The controller was also tested for overloading.

The controller was then tested for longevity with continuous running on a Fume Cupboard.

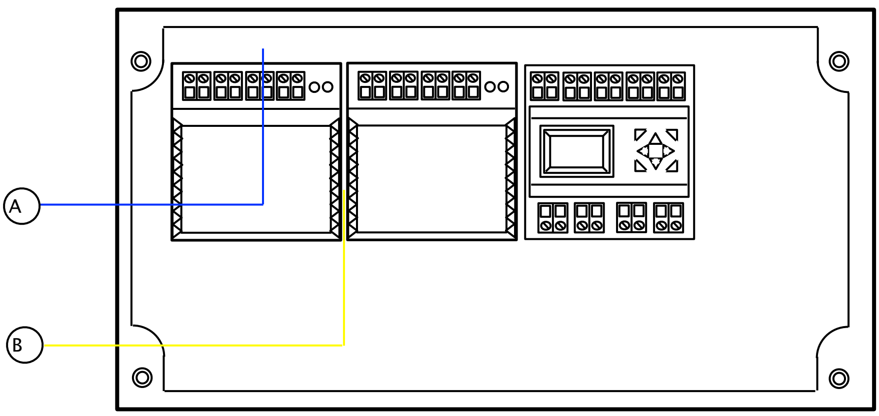
1. Temperature (Over heating)

a. Bench test to measure operating temperature of the enclosure and power supply.
b. Bench test to try to overheat the power supply
c. Bench test with enclosure mounted vertically and horizontally
d. Compare results with manufacturer's specifications

Test 1	Run Auto Sash at full load and measure internal enclosure temperature (1 hour)
Test 2	Repeat test 1 measuring the power supply enclosure temperature (1 hour)
Test 3	Run Auto Sash at full load for 24 Hours and measure internal enclosure temperature.
Test 4	Repeat test 3 measuring the power supply enclosure temperature.
Test 5	Block Power supply vents and run at full load measuring internal power supply temperature (1 Hour)
Test 6	Repeat test 3 for 24 Hour period.
Test 7	Fix Enclosure vertically and repeat tests 3 & 4.

Temperature probe positions for the tests were

A - Enclosure internal temperature - measured where most heat left the power supply
B- Power supply enclosure temperature - measured where the 2 power supplies touched.



	Enclosure internal Temperature Deg C (A)	Power Supply Case Temperature Deg C (B)	Power supply Internal Temperature Deg C (Blocked Vents)	Manufacturers Specifications	Output V	Pass / Fail
Test 1	30			45	24.2	Pass
Test 2		40		n/a	24.2	n/a
Test 3	35			45	24.2	Pass
Test 4		45		n/a	24.2	n/a
Test 5			50	n/a	24.2	Pass
Test 6			60	n/a	24.2	Pass
Test 7	27	47		n/a	24.2	n/a

Considerations

The power supply specification states that the power supply has Over Temperature protection (Tj 135 deg C on heat sink of power transistor) and has a Max operating temperature of 45 Deg C that we assume is ambient air temperature (separate test show the power supply case temperature varies drastically over its full area and has hot spots and cool spots).

The purpose of the tests was to see if the power supply is within specification during normal working conditions and also to see if it is possible to get the power supply to shut down on over heat protection.

Conclusions

The results of the test show that the power supply is within specification during normal working conditions and also show that it is not possible to get the power supply to shut down on Over Heat even when the power supply vents are blocked.

We assume that the power supply Over Heat protection is designed to switch off the power supply at the temperature level that would damage any of the components and also assume that the max operating temperature of 45 Deg C is to protect the power supply from long term low level heat issues on components (e.g. capacitors drying out).

2. Back EMF

a. Test 24V supply at the Clutch using an oscilloscope.
b. Test 24V supply at the power supply terminals.
c. Test 24V supply with clutch disconnected.
d. Compare with manufacturer's specifications.

Test 1 Using an Oscilloscope measure the 24V supply at the clutch at full load when clutch engages.
Test 2 Using an Oscilloscope measure the 24V supply at the clutch at full load when clutch disengages.
Test 3 Using an Oscilloscope measure the 24V supply at the power supply at full load when the clutch engages.
Test 4 Using an Oscilloscope measure the 24V supply at the power supply at full load when the clutch disengages.
Test 5 Using an Oscilloscope measure the 24V supply at the power supply with Clutch disconnected when the PLC relay energizes.
Test 6 Using an Oscilloscope measure the 24V supply at the power supply with Clutch disconnected when the PLC relay de-energizes.

	Voltage change at Clutch when Engaged	Voltage change at Clutch when Disengaged	Voltage change at Power Supply when Clutch Engaged	Voltage change at Power Supply when Clutch Disengaged	Duration of change
Test 1	50V				1 Micro second
Test 2		100V			1 Micro second
Test 3			200mV		50 Milliseconds
Test 4				300mV	100 Milliseconds
Test 5			200mV		50 Milliseconds
Test 6				300mV	100 Milliseconds

Considerations

The voltage measured at the clutch shows the voltage change at the clutch caused by the PLC relay contact (spikes when the relay energizes and de-energizes).

The voltage measures at the Power supply shows any spikes / back voltage at the power supply.

The power supply has Over Voltage protection rated at 32.4V (Shut down o/p voltage), The voltage deviations at the power supply are -200mV to + 300mV (23.8 to 24,3V) so are well within the manufacturers specification.

Mains Quality 5.0

1. Test power supply at maximum possible voltage.

The Auto Sash controls were connected up to a variac delivering 280VAC for a 24 hour period of time and the voltages and temperatures were tested with no issues found.

2. Test Auto Sash Controls with mains noise.

The Auto sash controls were connected and a standard typical Fume Cupboard fluorescent light and high power contactor were connected to the same mains power supply and set as follows:-

a. Auto sash clutch and motor engages - Fluorescent Light and Contactor power off

b. Auto sash clutch and motor disengages - Fluorescent Light and Contactor power on

The above created a 10A mains spike when the Auto Sash output de-energized.

The Auto sash controls were set to cycle on for 3 seconds the off for 3 seconds, this was run for 8 hours per day for 5 days.

The Auto Sash controller operated without any issues and the power supplies were checked visually checked for any browning / damage and the output voltage was checked for variations and spikes and no problems were found.

The following tests were carried out using a Mach Aire fully operational re-locatable Fume Cupboard fitted with the Auto Sash Controls in Mach Aires factory shop floor.

Test 1 Measure the clutch current when energized.
Test 2 Measure the motor current when energized.
Test 3 Measure the full load current at the power supply when the sash is driving.
Test 4 Measure the full load current at the power supply when the controller has timed out (fault mode).
Test 5 Measure the full load current when the sash is obstructed (fault mode).
Test 6 Measure the enclosure temperature after 1 hour continual operation

	Clutch current	Motor Current	Power supply Full Load Current when sash is driving	Power supply Full Load Current on time out fault	Power supply Full Load Current on Sash Obstruction	Power supply enclosure Temperature
Test 1	0.464 A	1.3 A	0.565 A	0.138 A	0.141 A	32 Deg C

Conclusions

The power supply specification is 2Amps with Over Load protection of 150% load.,

The tests consider all of the Sash Controller operating modes (idle, run, alarm etc)

The Maximum current taken by the Sash Controls is approx 28% of the power supply rated current so in conclusion the power supply is not over loaded in any condition.

Life span Test | 7.0

An initial test was done in 2006 at Mach Aires test room with an Auto sash controller fitted to a Fume Cupboard as follows:

a. Delay - 20 seconds
b. Drive closed (10 seconds to close)
c. Delay 20 seconds
d. Drive sash open (10 seconds to open) (500mm sash height)

This then gave an open/close cycle of 1 minute.

The controller was left to run for 1 week without interruption and gave 10,000 operations without issues.

This test was done to simulate 6 years operation for a project at GSK.

A further recent test was done with the Sash Control system connected up on the bench with all of the ancillary components. An addition PLC was added to act as a low switch to enable the controller to drive the motor for 3 seconds every 3 seconds.

Test 1 - 6 year test

Test 2 - 20 Year test at double motor and clutch load.

Test 1 = considering 2 closures per day, 5 days per week, 48 weeks per year the controller was required to run for 2,880 cycles. (2*5*48*6).

At 6 second cycles this equated to 4.8 Hours continuous operation.

Test 2 = considering 2 closures per day, 5 days per week, 48 weeks per year the controller was required to run for 9,600 cycles. (2*5*48*20)

At 6 second cycles this equated to 16 Hours continuous operation.

The Auto sash controller ran without any issues with all components checked for visual wear and tear and also voltage tests were done and no issues were found.

Conclusions 8.0

All of our own testing has indicated that all aspects of the control system function within component specification and no issues have been found during the tests,

We have not been able to produce a fault or failure during the tests,

In conclusion we cannot find any potential problems with the control system that would cause any failures or faults in the field.

4.0 Other Issues

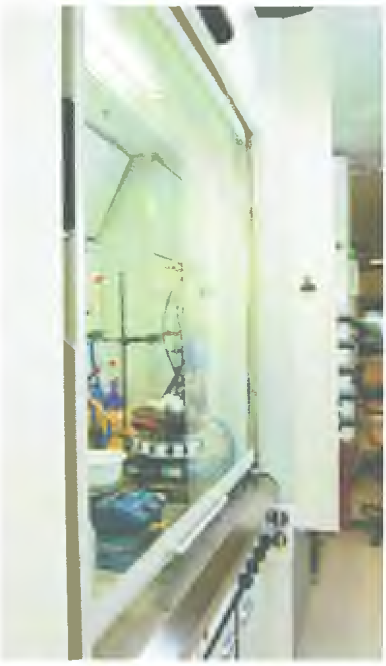
4.1 Automatic sash closing mechanisms

With the increase in numbers of fume cupboards required and the attendant air volumes for extract and supply air make up, fume cupboards that previously operated at a Constant Air Volume (CAV), were superseded by Fume Cupboards that were controlled as Variable Air Volume (VAV). Excessively high air demand at all times was avoided and high air change rates only occurred during times of maximum allowable fume cupboard use. We now know the out-of-use times can be as high as 70% of the life of a fume cupboard and we also now have the ability to reduce the sash rate of ventilation to its lowest possible level. It was a requirement now to improve the laboratory behaviour of manually closing the sash when not working at the face in order to benefit from the lower ventilation rates.

As outlined above, laboratories with the lowest environmental impact have low flushing volumes when fume cupboad sashes are closed. This also supports the safest condition for laboratory users. GSK have worked with fume cupboard manufacturers and as a result, have developed an acceptable and safe system that closes the sash following periods of use by scientists.

To confirm the philosophy, two identical laboratories that were being refurbished were fitted out with fume cupboards, one lab with the automatic sash closing system and the other without. The use of sashes was monitored to detect trends, and the data acquired

Sash closing in operation



generated the following comparison (see Figure 4.01). It was clear from the monitoring of all of the sashes in each laboratory that in aggregate, manually closed sashes were left open or partially open for longer periods than the automatic sash closing fume cupboards.

Fig 4.01 shows the air handling used per week, with differences of 70,000 m^3 per week. This difference in air handling requirements will be both for additional extraction from the fume extract system as well as the required fresh air make up. The reduction in quantity of air extracted and consequent make up air was significant to a point where payback for the additional investment in automatic sash closing was less than 24 months. This validated the investment for including automatic sash closing devices on all future Fume Cupboard purchases.

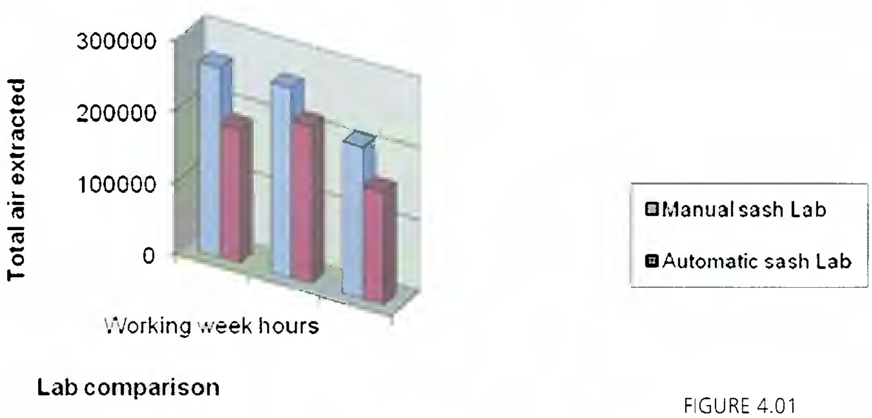


FIGURE 4.01

The automatic sash closing system monitors the area immediately in front of cupboard and starts the closure procedure once the area immediately in front of the cupboard has been unattended for a selectable duration. Light beam sensors positioned to the left and right hand sides of the fume cupboard opening, detect that the void is clear of any obstructions. When satisfied, the sash drive starts to close the sash and this movement is monitored until the closed position is reached, verified by a proximity sensor. In the event of any device preventing or stopping the closing procedure, the system is turned off and a red light is illuminated, requiring a manual reset before the automated process can be reinstated.

4.2 Face velocity and Containment – Model Specification

Fume cupboard testing in the UK can be carried out in accordance with the BS EN 14175. The standard includes specified tests and procedures for Type Testing of fume cupboard in a specially designed test room to BS EN 14175 – 3:2003 and also when delivered, with On Site Tests to BS EN 14175-4:2004.

Pacific Gas and Electric Company

Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report 0607

Automatic Fume Hood Sash Closure

Demonstration and Test at:
The University of California, Davis

Issued: **November 5, 2007**

Project Manager: **Alicia Breen, Francois Rongere**
Pacific Gas and Electric Company

Prepared By: **Lawrence Berkeley National Laboratory and**
Cogent Energy, Inc.

Contents

I. ACKNOWLEDGEMENTS 3
II. EXECUTIVE SUMMARY 4
III. BACKGROUND 7
A. Introduction 7
B. End State Goal 7
C. Fume Hood Energy Consumption and Potential Savings 8
D. Fume Hood Energy Efficiency 9
E. Automatic Sash Closure 18
IV. OBJECTIVES 19
V. DEMONSTRATION DESIGN AND PROCEDURES 19
VI. HOST SITE 20
A. Plant and Environmental Sciences (PES) Lab 1247 20
B. Genome Building Lab 1010 23
VII. RESULTS 24
A. Energy and Demand Savings 24
B. Limitations 43
C. Sensitivity Analysis 44
D. Economic Analysis 47
E. Issues Encountered 49
F. Feasibility for wide-spread implementation 50
G. Market size and potential 50
VIII. CONCLUSIONS 52
IX. RECOMMENDATIONS FOR FUTURE WORK 55
X. APPENDICES 56
A. Monitoring and Evaluation Plans 57
B. PG&E Brochure 60
C. Test Site Solicitation and Requirements 62
D. Power Point Presentation 65
E. Report to Campus 77

I. Acknowledgements

The primary authors if this report were:

Dale Sartor, Lawrence Berkeley National Laboratory
Rishabh Kasliwal, Cogent Energy, Inc.

The authors would like to thank:

From Cogent Energy, Inc.:
Michael Daukoru
Doug Chamberlin

From UC Davis:
Mark Anthony Nicholas
Mark D Nicholas
Dave Henderson
Debbie Decker, Campus Chemical Safety Officer, EH&S
Elaine Bose, Safety Coordinator, Department of Plant Sciences

From PG&E:
Alicia Breen
Francois Rongere

From Lab Specialists:
David Sweitzer

II. Executive Summary

Fume hoods contribute to approximately 2,495 GWh/year, 574 MW, and 18 Trillion BTUs/year in California. Assuming one third the hoods are in the PG&E territory (28,000 hoods), their estimated energy requirement is 800 GWh/year, 190 MW, and 60 million therms. The end-state goal is to reduce airflow through fume hoods by 75%. This goal will be accomplished through multiple technology options including:

- Reduce the number and size of fume hoods
- Restrict the sash opening
- Two "speed" occupied and un-occupied
- Variable Air Volume (VAV)
- High Performance Hoods

This study focuses on a variation of two "speed" occupied and un-occupied, and variable air volume (VAV) by installing an automatic sash closure system on a VAV hood that is controlled by an occupancy sensor. This technology has the potential to meet the end state goal of saving 75%

Demonstration automatic fume hood sash closure systems were installed in two laboratories at UC Davis. A summary of the results are presented in Table 1 – Annual Savings per CFM, Table 2 – Savings per Hood, and Table 3 – Demand Savings.

Table 1
Automatic Fume Hood Sash Closure Annual Savings per CFM
(Energy and Dollars)

Configuration	**PES**			**Genome**		
	Therms	**KWh**	**$**	**Therms**	**KWh**	**$**
1. Gas cooled	2.5	4.0	$2.39	3.0	9.2	$3.16
2. Electric cooled	2.1	5.8	$2.17	2.0	13	2.56
3. Electric w/ normal 55 deg. F supply (PES only)	1.9	9.2	$2.25			
4. Same as #3 w/ commercial PG&E rates	1.9	9.2	$3.44	2.0	13	3.90

Table 2
Savings Per Hood Assuming Typical Configuration and Utility Rates (CFM and Dollar)

Configuration	PES (6 ft. Hood)		Genome (5 ft. Hood)	
	CFM	**$**	**CFM**	**$**
1. Base ("Typical")	533	$1834	293	$1143
2. Hood driven load (all savings captured)	533	$1834	433	$1689
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$4586	866	$3377

Base (typical conditions) is configuration #4 in Table 1

Table 3
Demand Savings

	Per CFM	**Per Hood** (533 cfm PES and 433 cfm Genome)
PES gas cooled	1.6 W	.9 kW
PES electric chiller	3.5 W	1.9 kW
Genome gas cooled	2.3 W	1 kW
Genome electric cooled	4.8 W	2.1 kW

<u>Cost Effectiveness</u>

At a cost of $4,500 per hood, the simple payback is 1 to 4 years based on the two test conditions and PG&E commercial rates. 2.3 to 2.5 year payback would be typical for a hood driven load. Low utility rates and other unique conditions at UC Davis yielded a lower unit savings and a longer payback.

While the energy savings and cost effectiveness is attractive in retrofit, there could be even greater advantages in new construction. If the automatic fume hood sash closure system is deployed in new construction, and the design team assumes a small fraction of the hoods are simultaneously open, the reduced infrastructure size and cost (fans, ducts, boilers, chillers, etc.) can offset the increased hood control cost.

CO2 Savings

Assuming 1.1 lbs/kWh and 11.7 lbs/therm and the base case (typical conditions), the annual CO_2 savings, is estimated as:

	Per CFM	**Per Hood**
PES (533 cfm)	32 lbs	17K lbs
Genome (433 cfm)	37 lbs	16K lbs

III.Background

A. Introduction

Exhaust hoods protect operators from breathing harmful fumes by capturing, containing, and exhausting hazardous gases created in laboratory experiments or industrial processes. These box-like structures, often mounted at tabletop level, offer users protection with a movable, window-like front “face” called a sash. Fans draw fumes out the tops of the hoods.

Standard fume hood in use.

Fume hood exhaust induces airflow through the fume hood’s “face.” The generally accepted “face velocity” is 100 feet/minute; a high airflow rate causing large exhaust flows. Interestingly, increasing face velocity does not necessarily improve containment. Instead, errant eddy currents and vortexes can be induced around hood users as air flows into the hood, reducing containment effectiveness.

Fume hoods exhaust large volumes of air at great expense. The energy to filter, move, cool, heat or reheat, and in some cases scrub (clean) this air is one of the largest loads in most lab facilities. Fume hoods frequently operate 24 hours/day. Since many laboratories have multiple hoods, they often dictate a lab’s required airflow and thus the supply and exhaust systems’ capacity. The result is larger fans, chillers, boilers, and ducts compared to systems having less exhaust. Consequently, fume hoods are a major factor in making a typical laboratory four to five times more energy intensive than a typical commercial space.

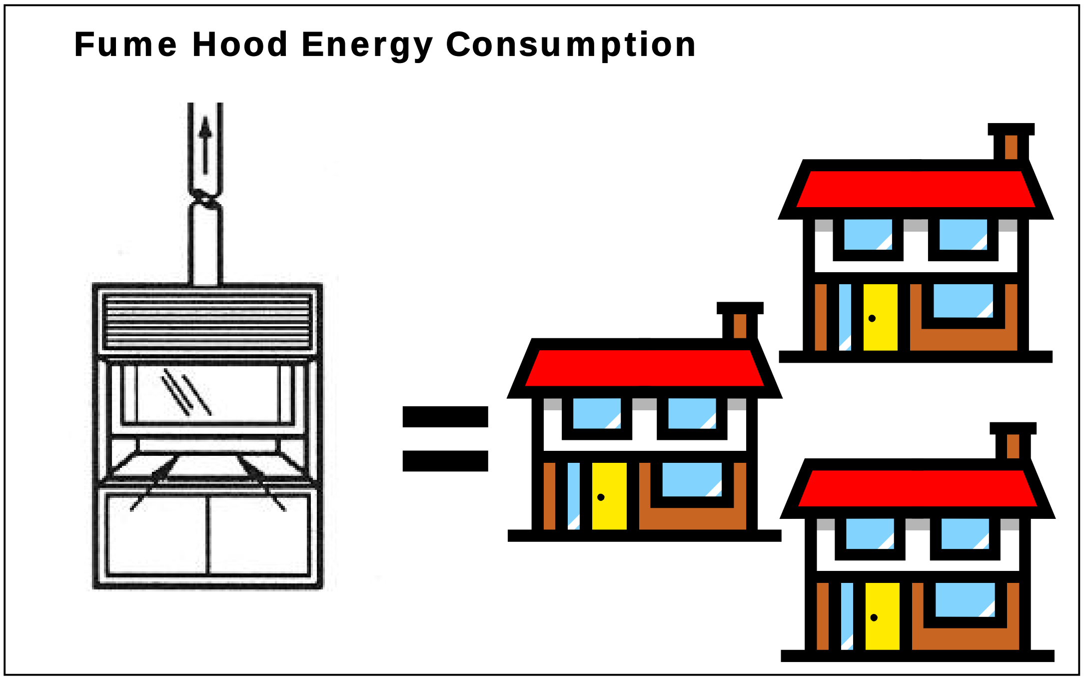
Most state-of-the-art, energy-efficient fume hood systems require several interactive features and diligent users. Sophisticated controls, for each hood and for supply and exhaust air streams combine to provide the recommended face velocity and pressure differential between the laboratory and adjacent space.

B. End State Goal

The end state goal in reducing the energy impact of California fume hoods is a 75% reduction in airflow (NFPA minimum flow requirements for dilution) while maintaining or improving safety.

C. Fume Hood Energy Consumption and Potential Savings

A six-foot-wide hood typically exhausts 1250 cubic feet per minute (cfm), 24 hours per day, consuming three-times more energy than an average house. Greenhouse-gas emission caused by operating the typical hood is equivalent to six automobiles.



Using the fume hood calculator developed by LBNL (available at http://hightech.lbl.gov/fh-calc.html) an estimate of California fume hood energy use (gas, electric, and peak) follows. This was based on the assumption of an equivalent of 85,000 1250 cfm fume hoods installed.

Electricity GWh/year:	2,495
Total Peak Power MW:	574
Total Natural Gas Trillions BTUs/year:	18

California ratepayers are spending over $400 million to operate their fume hoods. While the goal is to reduce fume hood airflow 75%, energy savings will be different:

1. Two thirds of the KWh and one third of the KW savings are from the fans. In a static system, fan energy reduces at approximately the cube of the flow. Therefore a 75% reduction in fume hood flow can result in more energy savings, especially in the main supply fans which provide air for other purposes than the hoods (the impact will be at the margin where flow reductions will have the greatest impact). However as will be seen in this case study, more sophisticated controls will be required to achieve this potential.
2. Fume hoods don't always "drive" the required air change rate. In labs with few hoods, other factors such as the minimum air change rate and thermal loads can

dictate the required airflow. In these situations, reductions of airflow through the fume hoods are "made-up" by increases in the general room exhaust.

We are assuming that 1 and 2 cancel each other out for electricity, and therefore assume that the end state goal will result in a 75% electrical savings. We assume that the savings for natural gas is discounted 20% (of 75%) to yield a 60% potential savings:

Saved Electricity GWh/year:	1,871
Saved Peak Power MW:	431
Saved Natural Gas Trillions BTUs/year:	11

D. Fume Hood Energy Efficiency

The end goal will be achieved through multiple technology options:

1. Reduce the number and size of fume hoods
2. Restrict the sash opening
3. Auxiliary air hoods
4. Two "speed" occupied and un-occupied
5. Variable Air Volume (VAV)
6. High Performance Hoods

1. **Reduce the number and size of fume hoods**

   New labs often standardize on a single hood size (increasingly larger) and install more than needed to allow for growth and flexibility (for example two per lab module). Existing labs often have rooms needing hoods (one of the reasons new labs get so many), while many other rooms have underutilized hoods. It is best to:

   - Size distribution for ample capacity but install only hoods needed immediately
   - Provide tees, valves, and pressure controls for easy additions and subtractions
   - Encourage removal of underutilized hoods (some labs are going to hoods as a shared resource)

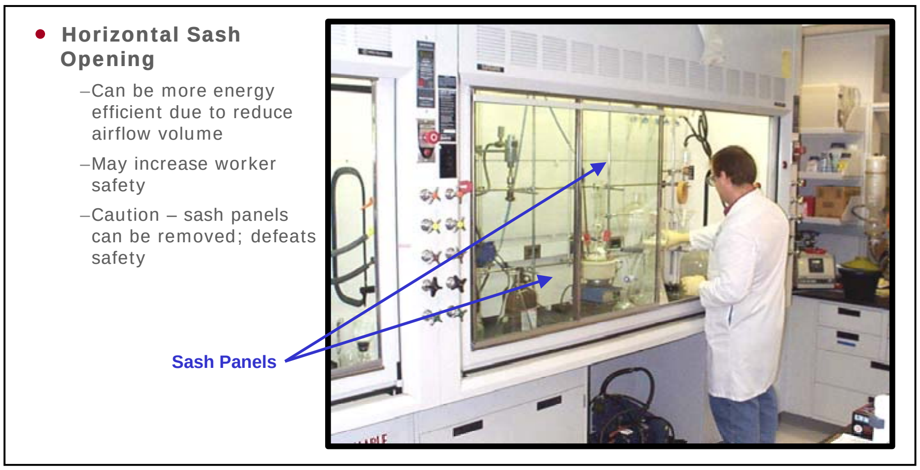
Is this hood intensity necessary?

2. Restrict the sash opening

In an effort to maintain 100 fpm face velocity, fume hood designs have been developed to simply reduce/restrict the sash opening and thus save air/energy. The two most popular techniques are horizontal sliding sashes and sash stops.

a. Horizontal sliding sashes

Horizontal sliding sashes are used to restrict the fume hood opening and protect the user. In theory these sliding sashes cannot be opened all the way but two (or more) can overlap, creating an opening. Some users feel the sashes get in the way and remove them (not a safe or efficient option). Further the sashes' sharp edges can cause turbulence, reducing the ability of the hood to contain. Some companies, with strong sash management cultures, have successfully used this technique.



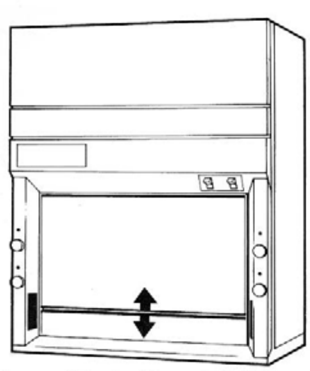


Figure 9. Hood with vertical-rising sash

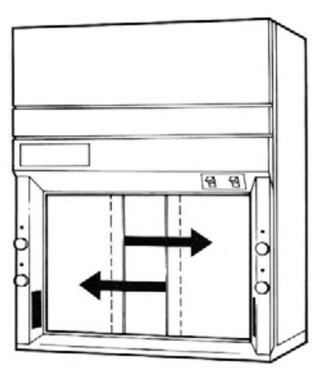


Figure 10. Hood with horizontal-sliding sashes

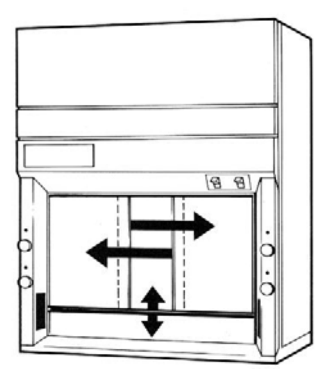


Figure 11. Hood with combination "A-style" sash

b. Sash stops

Sash stops prevent the sash from opening all the way. Usually the stops are placed at 18" thus blocking the top two fifths of the opening. In most cases the stops are designed for easy override to lift the sash out of the way during setup. Systems designed for the 18" opening violate Cal/OSHA standards when the sash stops are bypassed. A corporate culture that assures bypass only when hazards are not present is needed. Sash stops "encourage" diversity in VAV hoods (at least the hood is partially closed – 2/5ths or more – most of the time).

- **Vertical Sash Opening**
  - Most common sash
  - Good horizontal access
  - Energy use reduced with sash stop

3. Auxiliary air hoods

Auxiliary air hoods bring tempered make-up air directly to the hoods and introduce it above the sash (above the users head). These hoods were introduced in the 1970's for energy efficiency. They are still shown in manufacturers' catalogs, however their popularity has waned due to comfort and safety issues. Energy savings has been less than anticipated as the "tempered" air is conditioned to provide comfort. Auxiliary air hoods are not recommended.

- **Auxiliary Air Hood**
  - Wastes energy
  - Reduces containment performance
  - Decreases worker comfort
  - Disrupts lab temperature and humidity
  - **Not Recommended**

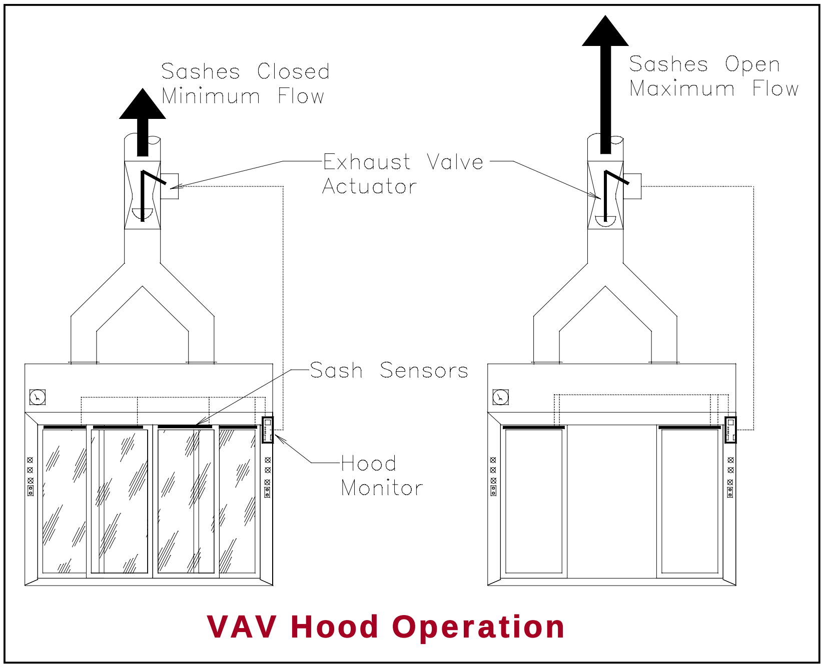
4. **Two "speed" occupied and un-occupied**

In theory, a hood that is unoccupied doesn't need the same airflow than one with a person at or near its face. Control companies offer an occupancy sensor based two-position control that reduces the face velocity from 100 fpm to around 60 fpm unoccupied. These systems are sometimes marketed as a "substitute" for VAV but they could be combined with VAV and other technologies. There benefit is assured savings even when the fume hood sash is left open. Therefore, in an environment of poor sash management, they can save more energy than VAV. Cal/OSHA has recently approved this technology (with conditions such as tracer gas testing) for use in California.

Two speed control with occupancy sensor range

5. Variable Air Volume (VAV)

VAV fume hood systems control the airflow to maintain a constant face velocity. As the sash is closed, the exhaust air volume is automatically decreased. In a VAV system, energy savings occur when a hood's sash is less than fully open, which reduces exhaust flow while maintaining a constant face velocity. Each hood user must operate the sash properly to ensure that the system achieves full energy savings potential.



The VAV exhaust must be coupled with a VAV supply system to maintain required air pressure relationships in labs. "Rightsizing" the HVAC system requires an assumption regarding the diversity of the sashes. The most conservative designers assume all the hoods are open when sizing their equipment. Other designers assume up to a 50% (closed) diversity depending on the number of hoods (greater diversity is assumed with larger numbers).

Since its introduction in the 1980's, VAV has grown to a large market share in new construction. Assuming 30% of the hoods installed in California have VAV and 50% of the potential end state savings is achieved, VAV has already captured 15% of the potential savings outlined above.

The biggest problem with VAV is no energy is saved if the fume hood sashes are left wide open. Therefore, the savings depends on the users. Energy and safety goals are synergistic with VAV hoods – a closed hood is much safer than an open hood.

a. Sash management

Any effort to encourage sashes being closed is called sash management. This can include: signs, pamphlets, training, incentives (e.g. monetary awards when spot checks find sashes closed), and penalties (e.g. monitoring systems that can provide information to back-charge users for individual fume hood use). A study at Duke University showed user training improved sash management by over 30% (from 5% of the time closed to 39% of the time closed).

b. Demand responsive sash management (unutilized technique)

Using a variety of notification systems (PA, e-mail, and telephone) this sash management technique would alert users to peak conditions and request closure of fume hood sashes. Users would be provided feedback via a graphical web site that shows reduction in energy, demand, and cost resulting from their action. A large potential savings in peak cooling will occur as reductions in outside air will occur at peak outside air temperature conditions. Also supply and exhaust fan savings can approach a cubed function (small reduction in flow yields large reduction in energy). This technique was demonstrated in another PG&E Emerging Technology project.

c. Occupied and unoccupied set points

The two "speed" technology described above can be applied to VAV such that the velocity set point can be reset when the hood is "unoccupied." Savings would accrue as a result of both the hood being unoccupied as well as the sash being closed or partially closed.

d. Auto sash closure systems

Auto sash closure systems are a form of sash management, and are the focus of this study. See the next section for more details.

6. High Performance Hoods

e. First generation (20 to 40% savings)

Several high performance hoods (safe and low flow) are on the market (outside of California). They offer advantage (over VAV) of simplicity (generally constant volume), lower peak requirements, safety, and the ability to downsize the mechanical/electrical systems (no diversity assumptions required). There is a major institutional barrier to high performance hoods in California where Cal/OSHA requires hoods to have 100 ft/min face velocity.

High performance fume hoods by Air Sentry and Labconco (representative)

b. Second generation (40 to 75% savings)

Second generation high performance fume hoods are similar to the first generation, but with lower flow requirements to provide the same level of safety. The “Berkeley Hood” is the only known second generation high performance hood under development. While it may be possible to reach the end state goal solely with a second generation high performance hood, it may be easier (technically and from a cost standpoint) to achieve the goal with a hybrid hood system (combining high performance with control options).

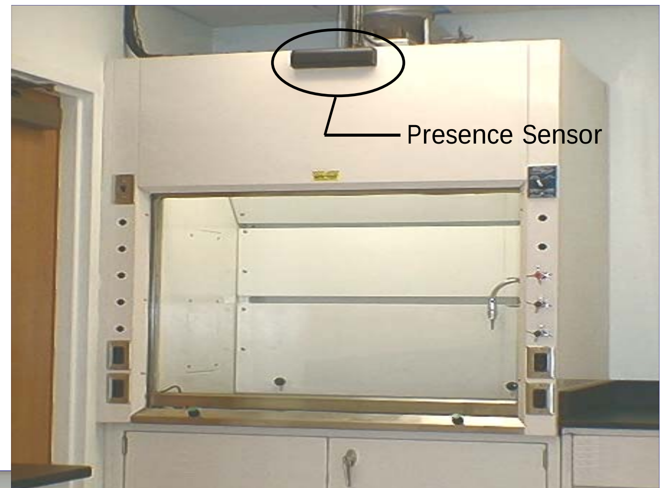
Berkeley Hood by LBNL

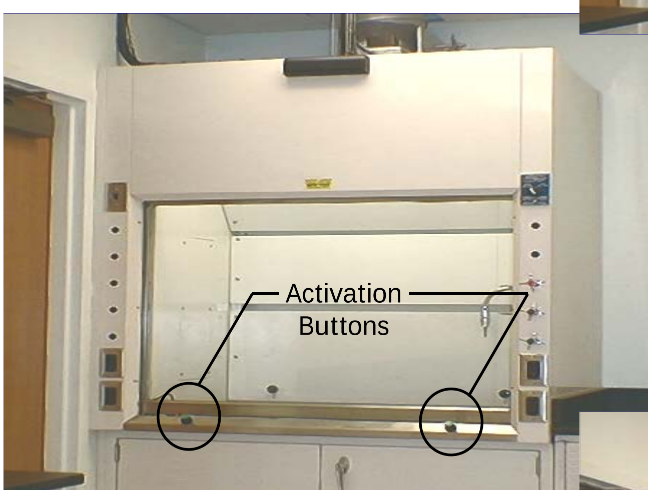
– Air Divider Technique
– Perimeter Air Supply
– Perforated Rear Baffle
– Slot Exhaust
– Optimized Upper Chamber
– Designed to minimize escape by reducing reverse flow

E. Automatic Sash Closure

1. Description of technology

In response to poor sash management, several companies have introduced automated sash closure systems. An auto sash closure system coupled with a VAV or two position fume hood control system will come very close to meeting the end state goals since most hoods are "occupied" only a few hours a week. Much higher diversity assumptions could be made with such a system, potentially reducing first cost.





The New-Tech Automatic Sash Positioning System

2. Market Status

Market penetration of fume hood automatic sash closure systems has been slow, especially in California. Reports of problems in early installations (i.e. 1980's) have reinforced general concerns about the technology (e.g. what if it closes or opens when you don't want it to). There were no known operating installations in California in 2005 (an abandoned installation exists at UC Berkeley). However the current state-of-the-art seems to have overcome these barriers and concerns, and the technology is being actively marketed in California. Enhancements to the technology include:

- Pneumatic sash positioning allows one finger override (up or down)
- Fails in any desired position
- Safety eye stops sash closure before it hits any protrusion
- Opens on presence or activation of buttons (user option)
- Option for multiple sash opening selector
- Advanced presence sensor technology
- Selectable time delay prior to sash closing
- Monitoring options

3. Related work (SCE and UCI)

In addition to this demonstration/test at UC Davis, the technology is being tested at UC Irvine and at Amgen in the Southern California Edison service area. In both cases the technology has been well received.

IV. Objectives

The objective of this project was to demonstrate and evaluate the opportunity for energy and demand savings in laboratories based on an automated fume hood closure system. The demonstration involved the retrofit of two existing VAV controlled fume hood in a laboratory where the fume hoods drive the outside air requirements most of the time. This project will:

- Demonstrate and evaluate emerging technology
- Document baseline and post retrofit conditions to assess savings
- Estimate actual energy and demand impact
- Demonstrate operator acceptance of the automatic sash closure system
- Promote the project and use of auto-closure fume hoods (subject to positive test results)

V. Demonstration Design and Procedures

A draft monitoring and evaluation plan was prepared by LBNL dated October 9, 2006 (see appendix). Site requirements and selection criteria were also developed (see appendix) that called for:

1. PG&E Customer

2. Customer willing to share performance information
3. Customer willing to cost share
4. Existing VAV fume hood and room pressure control system
5. Hood driven load
6. Poor existing sash management (based on visual inspection and interview(s))
7. Low hazard lab with no obvious safety hazards or operational concerns
8. Easily monitored system
9. Easily accessible

UC Davis was selected as the demonstration site and a kick off meeting was held on March 5, 2007.

A final monitoring and evaluation plan was prepared by Cogent Energy dated June 11, 2007 (see appendix). The plan generally followed the draft plan and provided details on the demonstration facilities, the M&E approach, sources of expected energy and demand reductions, monitoring equipment to be used, M&E procedures, and trending (monitoring) points.

VI. Host Site

A. Plant and Environmental Sciences (PES) Lab 1247

Laboratory 1247 is in an area served by one air handler (AHU-4), two exhaust fans (EF-7 and EF-8), and forty four (44) associated terminal units. It is 11 x 32 feet (350 sqft) and contains one six foot hood.

Exterior of the Plant and Environmental Sciences Lab

PES Demo hood prior to retrofit

PES hood prior to retrofit with hose that would not allow sash to close

Existing PES hood with VAV control (indicating 105 fpm)

PES Demo hood prior to retrofit (Note sash stop restricts sash opening more than 50%)

Demonstration Fume Hood in PES 1247 (after installation)

B. Genome Building Lab 1010

Laboratory 1010 is an area in the Genome Building served by one air handler (AHU-4), an exhaust fan (EF-2), and thirty eight (38) associated terminal units. It is 21 x 39 feet (820 sqft) and contains one five foot hood.

Exterior of Genome Building

Demonstration Fume Hood in Genome Building Lab 1010

VII. Results

A. Energy and Demand Savings

Field measurements were taken for:

- Supply air temperature and reheat temperature
- Sash position or fume hood exhaust
- Supply and exhaust air volume to/from the lab (and hood)
- Power and air volume (cfm) of the air handler units (AHUs)
- Power of associated exhaust fans

See measurement and evaluation (M&E) plan for details of field measurements.

Data from short term monitoring was used in an energy model to estimate annual energy use before and after retrofit and estimate energy savings. Assumptions relating to the energy use have been documented in the M&E Plan included in the Appendix.

1. Key assumptions used:

- Chilled water system (including distribution) efficiency: 1 kW/ton for electric driven chillers, and .15 Therms/ton for gas driven chillers plus .4 kW/ton for auxiliary electric needs.
- Heating system (including distribution) efficiency: 70%
- Minimum hood air flow is the equivalent of a 6” sash opening allowing for 25 cfm per square foot (NFPA minimum) for a 24” deep interior
- Sash stops were placed at 18” thus allowing for a potential savings over a 12” sash travel
- The six foot hood in PES has a 5’4” by 36” (max) sash opening, and the five foot hood in Genome has a 4’4” by 30” (max) sash opening
- Combining the above three assumptions:

	Airflow in cfm (at 100 ft/min velocity)	
	PES	Genome
Nominal (max.)	1600	1083
Design (18” sash stop)	800	650
Minimum (NFPA)	267	217
Savings with 12” sash movement	533	433

- Exhaust fan power savings was considered negligible as the fans are constant volume (with bypass at the roof) to maintain constant discharge velocities
- Heating degree hours (based on 63 deg. F supply): 72,000 (compared to 32,000 with a 55 deg. F supply)
- Cooling ton hours (based on 63 deg. F supply): 3 tons/cfm (compared to 6.4 tons/cfm at 55 deg. F supply)

- Utility costs:

	UC Davis	PG&E Commercial
Electricity blended per kWh	$.066	$.10
Gas per therm	$.85	$1.30

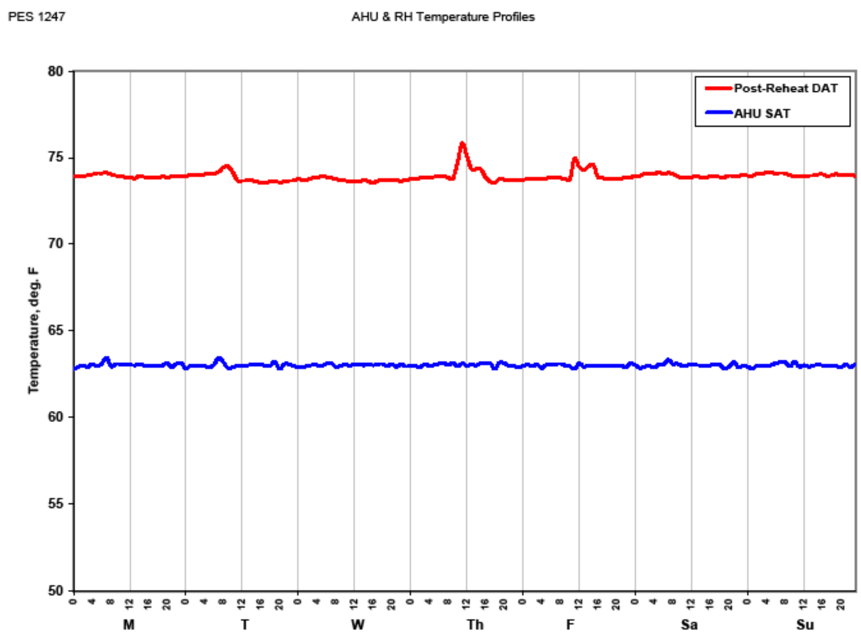
- Key assumptions based on field measurements:

	PES	Genome
Hood cfm savings	402 (inc. to 533)[1]	293 (inc. to 433)[2]
Supply air temperature deg. F	63	55
Re-heat temperature deg. F	74 (reduce to 70)[3]	66.2
Supply fan Watts/cfm	.32	.75

[1] PES measured savings of 402 cfm (average) was with reheat valve stuck contributing to increased flow to maintain room temperature. Assume savings will increase to 533 cfm with valve fixed and hood minimum flow adjusted per prior table.
[2] Genome measured savings of 293 cfm constrained by minimum room ventilation (large lab space with only one hood). Had the labs airflow been hood driven, the savings is assumed to be 433 cfm per prior table.
[3] PES reheat supply temperature is high because of a leaking valve. Assume reduced to 70 deg. F when valve fixed.

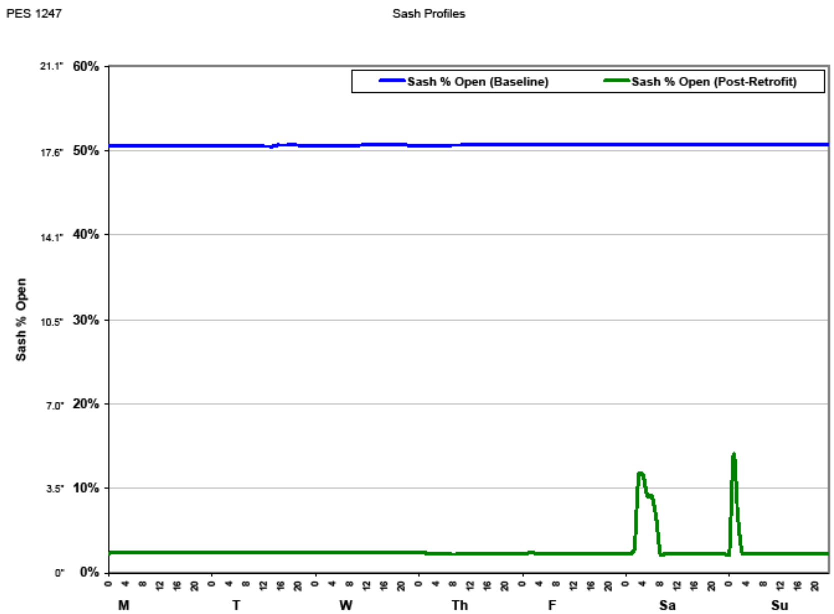
2. Plant and Environmental Sciences (PES) Lab #1247

Supply and reheat temperatures:



The average supply air temperature was approximately 63 deg. F and remained reasonably constant. Likewise the reheat temperature was approximately 74 deg. F and was also constant. Therefore, the level of reheat was approximately 11 degrees. Note, this is an excessive level of reheat, and it appears that the reheat valve is leaking (allowing bypass of undesirable heating water).

Sash Position:



The pre-retrofit sash position at PES was constant at 18.” The fume hood was rarely closed and the stop was never bypassed. This hood has a tall sash so that the stop was providing a significant efficiency benefit – reducing the nominal hood design air flow approximately 50%. Therefore the sash stop provided 60% of the potential savings (as the hood must have a minimum air flow even with the sash closed).

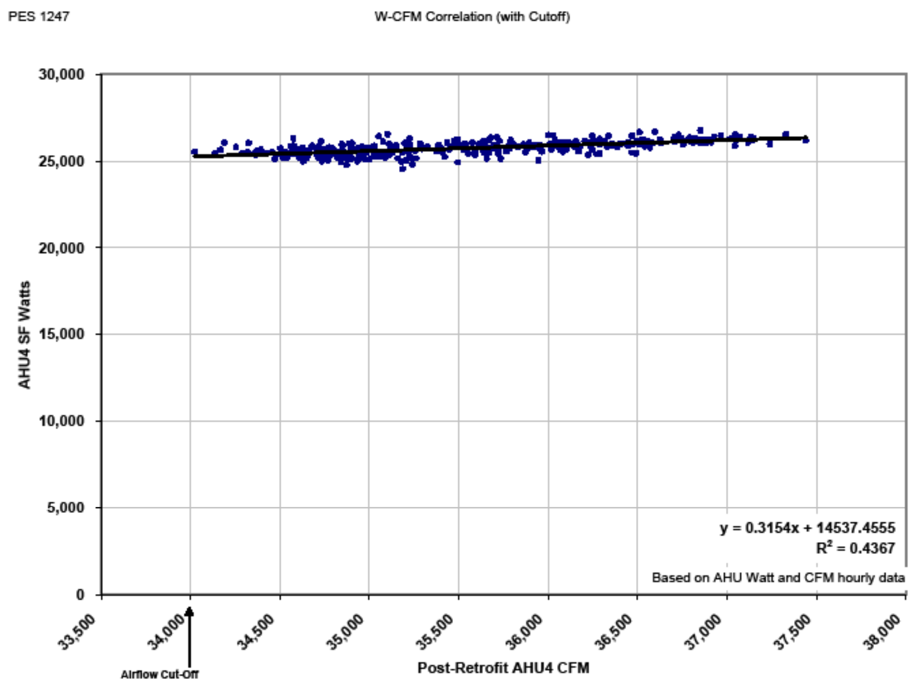
The post retrofit sash position is almost always closed. It is used two days in the average week. Note the above graph illustrates an average opening over an extended period of time. In reality the sash is opened much more for a short period of time and closes between uses. This graph better illustrates the consequences of hood use. The hood is at or near the minimum (NFPA) flow almost all the time. Therefore, the previously described end state goal is met.

Air flow saved by sash stop:	50%
Air flow saved by auto closure:	33.3%
Minimum air flow:	16.7%

Had sash stops not been deployed on this hood the savings attributed to the auto closure system would have been significantly more (83% if deployed on a constant volume hood).

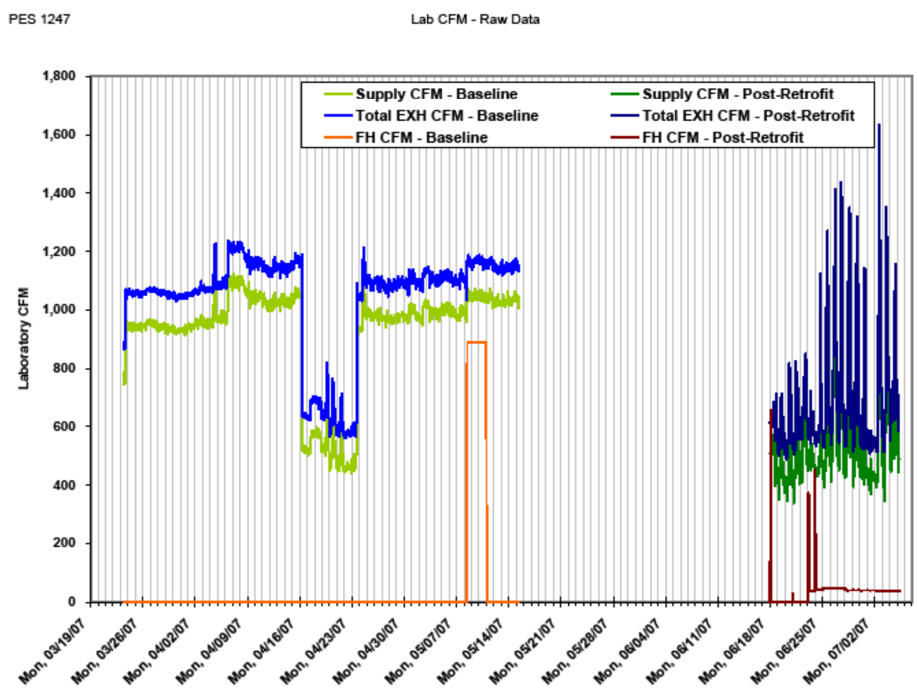
Had there been better sash management of the hood such that the existing VAV system was better utilized, the savings attributed to the auto closure system would have been less.

Supply Fan Power:



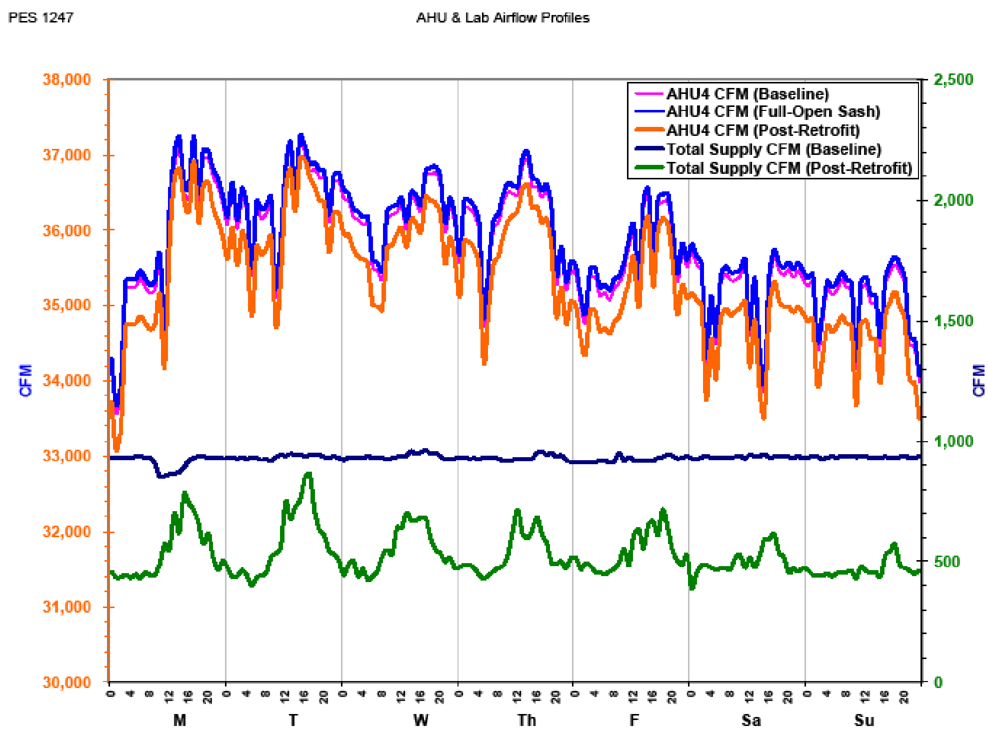
The supply fan power and air flow was monitored over its normal operational range. While the watts per cfm is actually a curve, the tangent of that curve (linear fit of operating points) in the operating range yields a slope of only .32 watts per cfm. The average (system) watts per cfm is .73, more than twice the savings in the operating range. At higher air flows the curve gets steeper and the watts per cfm would dramatically increase. One reason for the lack of savings at the margin is the supply system operates at a constant pressure. Instead of a cubed function, it is closer to linear. It may be possible to significantly improve the savings by implementing a pressure reset strategy – as the flow rate through the system decreases; the static pressure set point is also decreased, significantly reducing the load on the fan.

Lab Air Flow Rates Before and After Retrofit:



The air flow rates (supply and exhaust) were reasonably stable before the retrofit. The short duration of fume hood use is only because that was the period of time the hood was tested, not that it had zero flow most of the time (see sash position graph). The post retrofit data is spiky representing increases in general exhaust and supply air in an attempt to cool the space with 74 deg. F air. Once the reheat valve is fixed and the supply air temperature is reduced, the air flow should stabilize at the minimum air flow. Note the post retrofit fume hood spikes represent the few times that the hood is used.

Average Air Flow Rates Before and After Retrofit:



This graph of average airflow rates smoothes out the data making it easier to see the savings. Airflow at the AHU displays some time of day and time of week fluctuation, but note the axis starts at 30K cfm; the AHU operates in a relatively tight range of 34K to 37K cfm. Prior to the retrofit, the air flow into the lab of constant 74 deg. F air was reasonably constant. After the retrofit (reduction of airflow by approximately 50%) the system has a difficult time maintaining comfort with a supply temperature of 74 deg. F, so the air flow increases to accommodate modest cooling loads. This reduced the average savings to 402 cfm. Once the leaking reheat valve is fixed, the supply air flow to the lab should stabilize at less than 400 cfm (room size is 350 sqft and minimum hood flow is approximately 217 cfm – room size governs).

Energy and Demand Savings:

1. Airflow reduction:
   a. Before reheat fixed: PES is a six foot hood (approximate 64" opening). Measured savings was 402 cfm, however as noted the potential savings was not realized do to a leaking reheat valve causing a demand for excessive airflow.
   b. After reheat fixed: Savings based on 12" of closure and corresponding control (last 6" used to satisfy minimum flow) yields 533 cfm (Reduced flow = 100fpm x 5.33ft x 1ft = 533 cfm). Given that the reheat is/was always on, assume capture of the full cfm savings all the time (once the reheat control is fixed). Any reduction in total exhaust has a corresponding reduction is supply (assumes no infiltration from the exterior of the building into the lab).
2. Reheat:
   a. Prior to reheat repair: 11 deg F prior to reheat repair, then (11deg x .018btu/deg/cf x 60min x 8760 hrs/year) / (.7eff x 100,000btu/therm) = 1.49 therms/cfm.
   b. After reheat repair: Assume average reheat reduced to 7 deg F: (7deg x .018btu/deg/cf x 60min x 8760 hrs/year) / (.7eff x 100,000btu/therm) = 0.95 therms/cfm.
3. Heat outdoor air to 63 deg F. Assume 72,000 heating degree hours. This is conservative as 100% outside air requires heat at night even when the average temperature is "neutral." Saves: 72,000deghrs x .018btu/deg/cf x 60min) / (.7eff x 100,000btu/therm) = 1.11 therms/cfm
4. Gas cooling: Assume 3 tons/cfm and .15 therms/ton, then .45 therms/cfm
5. Total annual gas savings:
   a. Before reheat fixed = 1.49 + 1.11 + .45 = 3.1 therms/cfm (2.6 w/o gas cool)
   b. After reheat fixed = .95 + 1.11 + .45 = 2.5 therms/cfm (2.1 w/o gas cool)
6. Saving at $.85/therm:
   a. Before reheat fixed = $2.64/cfm ($2.21 w/o gas cool)
   b. After reheat fixed = $2.13/cfm ($1.79 w/o gas cool)
7. Fan power: .32 W/cfm, then .32 W/cfm x 8760hrs/1000W = 2.8 kWh/cfm
8. Electric power w/ gas cooling: Assume 3 ton-hours/cfm and .4 kW/ton then 1.2kWh/cfm
9. Total annual electric kWh/cfm with gas cooling: 2.8 + 1.2 = 4 kWh/cfm
10. Savings at $.066/kWh: $.26/cfm
11. Total savings per cfm with gas cooling
    a. Before reheat fixed: $2.64 + $.26 = $2.90
    b. After reheat fixed: $2.13 + $.26 = $2.39
12. Electric chiller option: Assume 3 ton-hours/cfm at 63 deg. supply temperature and 1 kW/ton then 3 kWh/cfm
13. Total annual electric savings w/ electric chiller: 2.8 + 3 = 5.8kWh/cfm
14. Savings at $.066/kWh: $.38/cfm
15. Total savings per cfm with electric cooling
    a. Before reheat fixed: $2.21 + $.38 = $2.59
    b. After reheat fixed: $1.79 + $.38 = $2.17

16. Annual UC Davis savings
    a. Gas cooling with broken reheat: 402cfm x $2.90/cfm = $1,166
    b. Gas cooling with reheat fixed: 533cfm x $2.39/cfm = $1,274
    c. Electric cooling with broken reheat: 402cfm x $2.59/cfm = $1,041
    d. Electric cooling with reheat fixed: 533cfm x $2.17/cfm = $1,157
17. Demand Savings:
    a. Gas cooling: Assume 99 deg. F design temp (peaks higher but not all summer), therefore the delta T = 99 – 63 = 36 deg F. 36deg x .018btu/cf/deg x 60min / 12,000 btu/ton = .00324 tons/cfm. With 400 W/ton, then 1.3 W/cfm for cooling. Add .32 w/cfm for fan power = 1.6 W/cfm demand savings. With 533 cfm, the hood's demand savings is .9 kW.
    b. Electric cooling: Same as above (.00324 tons/cfm) but 1 kW/ton, therefore, 3.2 W/cfm for cooling. Add .32 w/cfm for fan power = 3.5 W/cfm demand savings. With 533 cfm, the hood's demand savings is 1.9 kW.

Table 4
PES Automatic Fume Hood Sash Closure Savings per CFM (Energy and Dollars)

Configuration	PES		
	Therms	**KWh**	**$**
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)			
1. Base case: 63 deg. F supply, 74 deg. reheat, .32 W/cfm	3.1	4.0	$2.90
2. Fix reheat: reduce to 70 deg. F	2.5	4.0	$2.39
Electric Cooled (assumes 1 kW/ton)			
3. Base case (same as #1)	2.6	5.8	$2.59
4. Fix reheat: reduce to 70 deg. F	2.1	5.8	$2.17
5. Same as #4 w/ normal 55 deg. F supply, 70 deg reheat)	1.9	9.2	$2.25

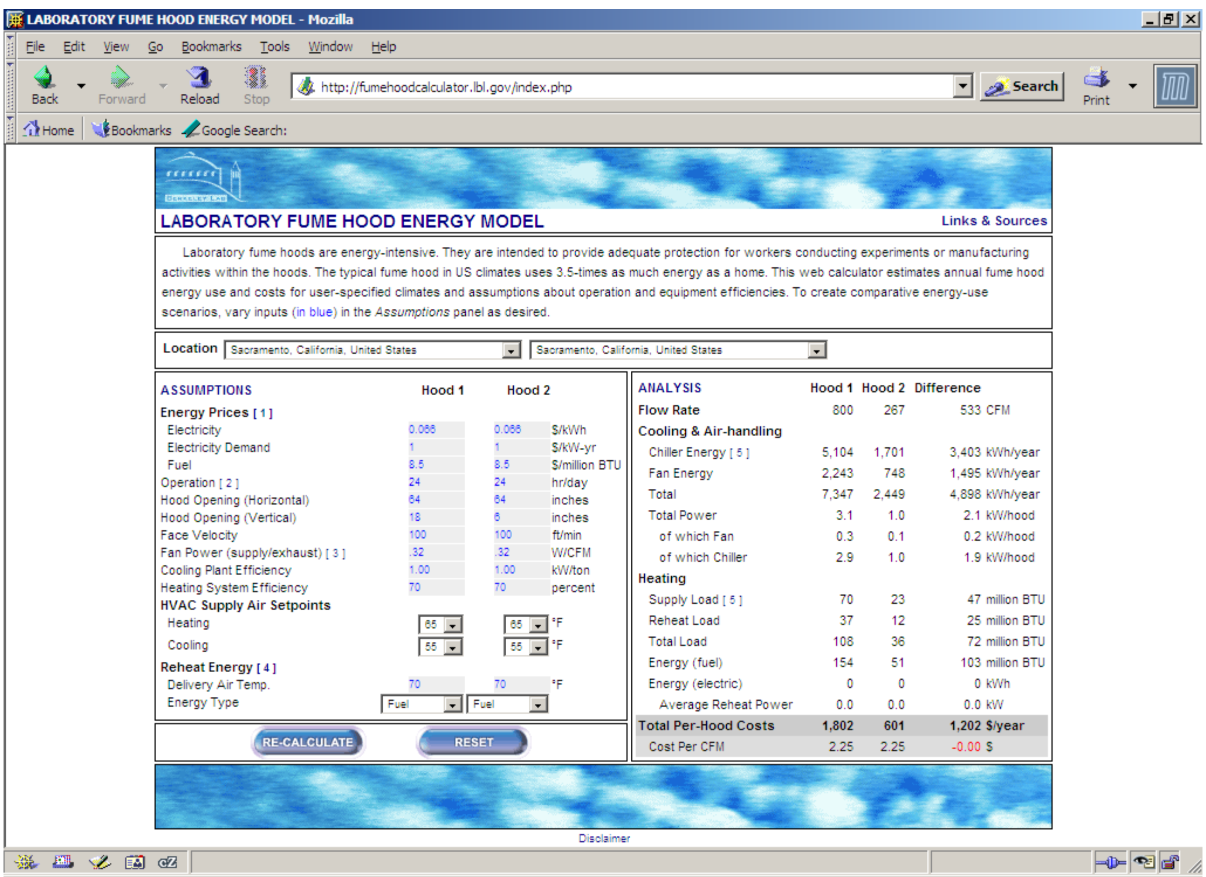
Configuration #5 from LBNL Fume Hood Calculator (http://fumehoodcalculator.lbl.gov/) – see below

Table 5
Savings Per Hood Assuming PES Configuration and Davis Utility Rates (CFM and Dollar)

Configuration	Gas cooled (6 ft. Hood)		Electric cooled (6 ft. Hood)	
	CFM	$	CFM	$
1. As Found (reheat valve leaking)	402	$1,166	402	$1,041
2. Base (reheat valve fixed)	533	$1,274	533	$1,157
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$3,186	1333	$2,893

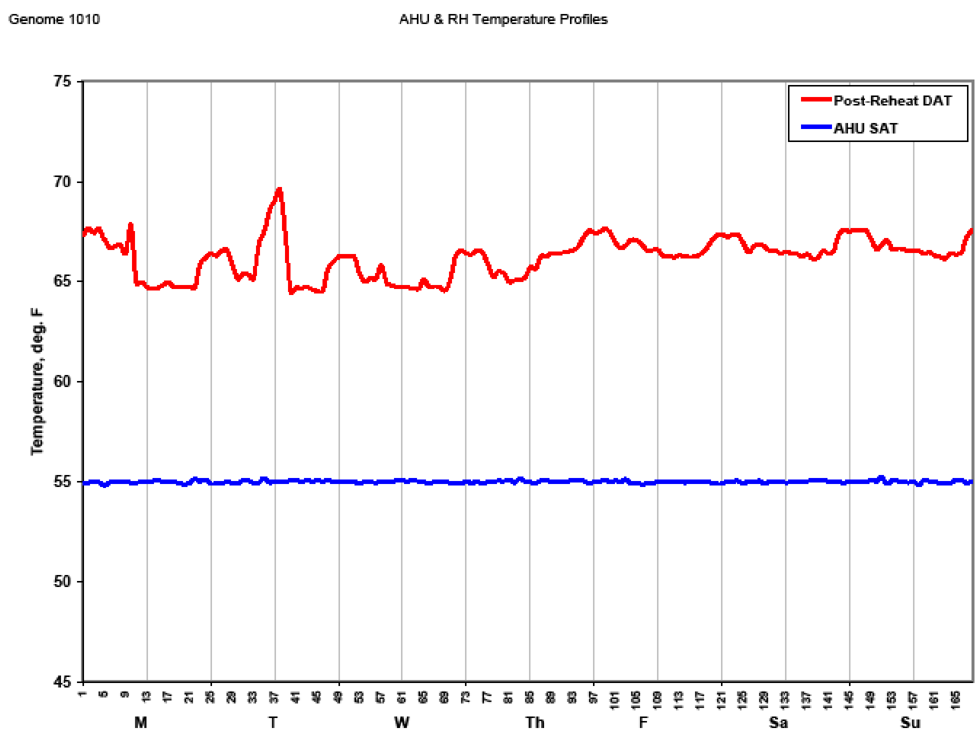
Base is configuration #2 and #4 in Table 4 (assuming reheat fixed – higher cfm savings, but lower savings per cfm)

LBNL Fume Hood Calculator (http://fumehoodcalculator.lbl.gov/) w/ 55 deg. F Supply and 70 deg. F Reheat (see Sensitivity Analysis for discussion of supply air temperature):



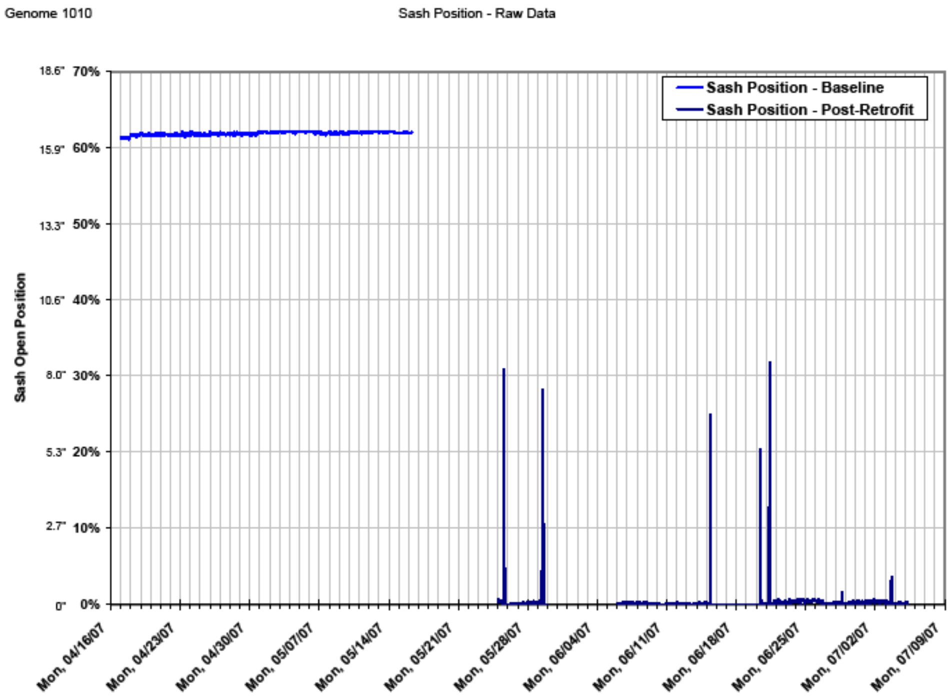
3. Genome Building Lab #1010

Supply and reheat temperatures:



The average supply air temperature was approximately 55 deg. F and remained reasonably constant. The reheat temperature varied depending on the cooling load, but averaged 66.2 deg. F. Therefore, the level of reheat was approximately 11.2 degrees F.

Sash Position:



The pre-retrofit sash position at Genome was constant at 18." The fume hood was rarely closed and the stop was never bypassed. The stop was providing a significant efficiency benefit – reducing the nominal hood design air flow approximately 40%. Therefore the sash stop provided 50% of the potential savings (as the hood must have a minimum air flow even with the sash closed).

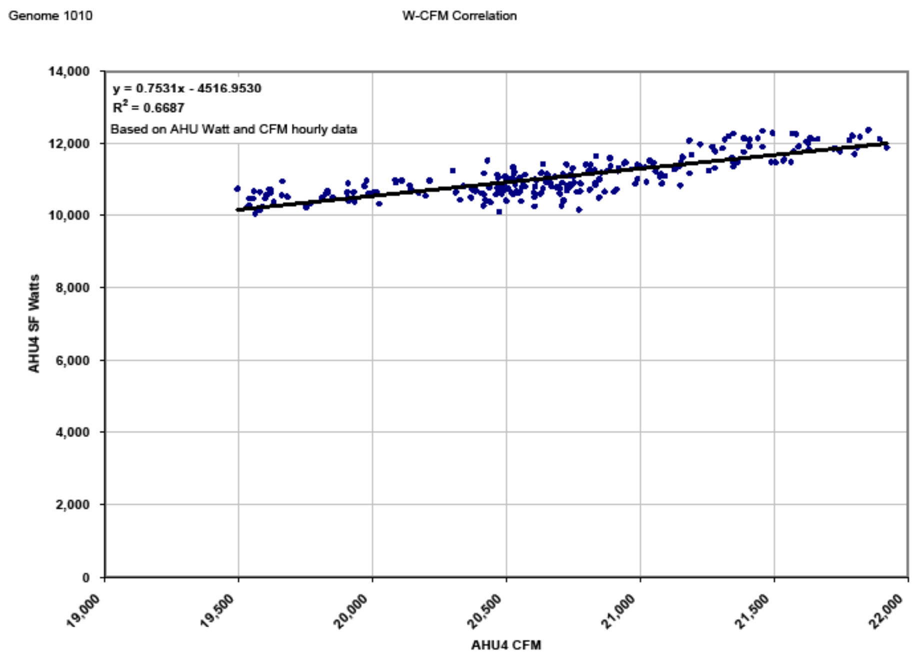
The post retrofit sash position is almost always closed. Note the spikes in the above graph illustrate an average opening over a period of time. In reality the sash is opened much more for a short period of time and closes between uses. The hood is at or near the minimum (NFPA) flow almost all the time. Therefore, the previously described end state goal is met.

Air flow saved by sash stop:	40%
Air flow saved by auto closure:	40%
Minimum air flow:	20%

Had sash stops not been deployed on this hood the savings attributed to the auto closure system would have been significantly more (doubled to 80% if deployed on a constant volume hood).

Had there been better sash management of the hood such that the existing VAV system was better utilized, the savings attributed to the auto closure system would have been less.

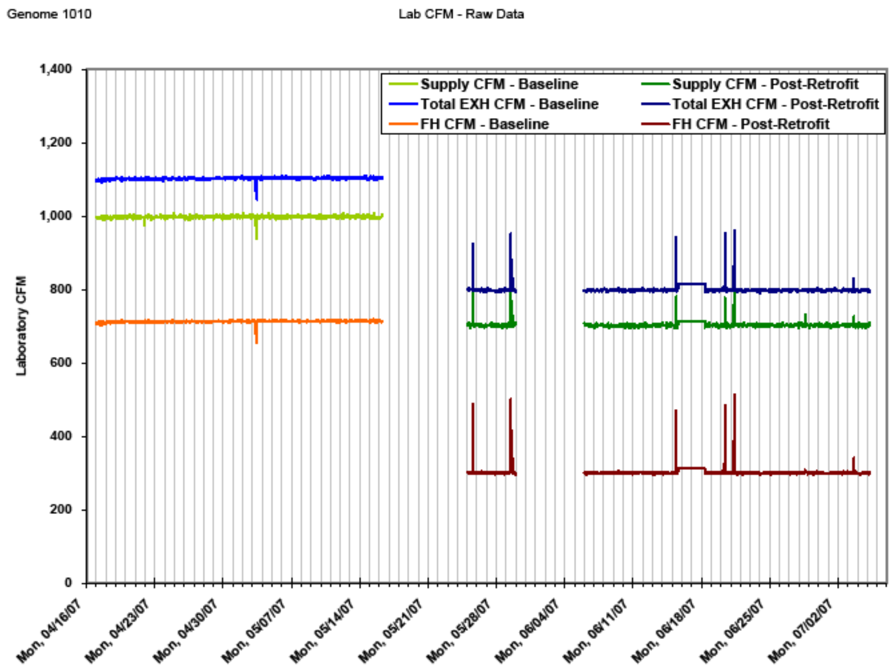
Supply Fan Power:



Watts/cfm savings at operating point approximately 50% greater than average w/cfm – further improvement possible with advanced controls (static reset).

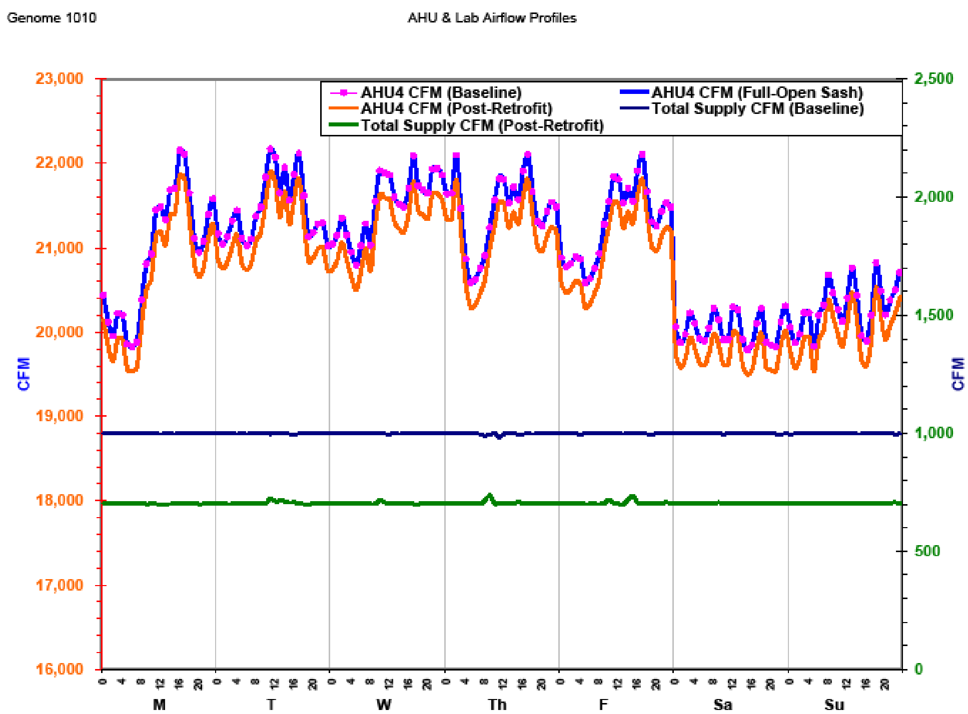
The supply fan power and air flow was monitored over its normal operational range. While the watts per cfm is actually a curve, the tangent of that curve (linear fit of operating points) in the operating range yields a slope of .75 watts per cfm. This will be the savings per cfm in the operating range. The average (system) watts per cfm is .53, indicating that the operating range in the steep portion of the system curve. At higher air flows the curve gets steeper and the watts per cfm increases. Even though the savings is higher than the average, it is lower than expected (e.g. the default in the Fume Hood Calculator). One reason for this low savings is the supply system operates at a constant pressure. Instead of a cubed function, it is closer to linear. It may be possible to significantly improve the savings by implementing a pressure reset strategy – as the flow rate through the system decreases; the static pressure set point is also decreased, significantly reducing the load on the fan.

Lab Air Flow Rates Before and After Retrofit:



Supply and total exhaust reduced approximately 300 (293 average) while fume hood exhaust reduced approximately 400 (expected value: 12x52x100/144=433 assuming a 12" effective closure). Therefore general exhaust increased approximately 100 to 140 cfm to maintain the minimum air change rate (approximately 820 cfm with 820 sqft). The air flow rates (supply and exhaust) were reasonably stable before the retrofit. The post retrofit data has a few spikes representing the few times that the hood is used.

Average Air Flow Rates Before and After Retrofit:



This graph of average airflow rates smoothes out the data. Airflow at the AHU displays some time of day and time of week fluctuation, but note the axis starts at 16K cfm; the AHU operates in a relatively tight range of 20K to 22K cfm.

Energy and Demand Savings:

1. Airflow reduction:
    a. Genome is a five foot hood (approximate 52" opening). Measured savings was 293 cfm average, however as noted the potential savings was not realized do to the minimum airflow requirements of the lab space. If the minimum flow was based on the hood only (hood driven) the savings would increase to 433 cfm assuming savings on 12" of closure and corresponding control (last 6" used to satisfy minimum flow). Reduced flow = 100 x 4.33 x 1 = 433 cfm. However, while hood exhaust may have gone down 400 cfm or more, the room is quite large (relative to one hood) and had to maintain the minimum air change rate, so the total exhaust (fume hood plus general) only went down 293 cfm.
2. Reheat: 11.2 deg F (55 to average 66.2 deg F), then savings 11.2 deg x .018btu/deg/cf x 60min x 8760 hrs/year) / (.7eff x 100,000btu/therm) = 1.51 therms/cfm.
3. Heat outdoor air to 55 deg F. Assume 32,000 heating degree hours. Saves: 32,000deghrs x .018btu/deg/cf x 60min) / (.7eff x 100,000btu/therm) = .49 therms/cfm
4. Gas cooling: Assume 6.4 tons/cfm and .15 therms/ton, then .96 therms/cfm
5. Total annual gas savings: 1.51 + .49 + .96 = 3.0 therms/cfm (2.0 w/o gas cool)
6. Saving at $.85/therm: $2.55/cfm ($1.70 w/o gas cool)
7. Fan power: .75 W/cfm, then .75 W/cfm x 8760hrs/1000W = 6.6 kWh/cfm
8. Electric power w/ gas cooling: Assume 6.4 ton-hours/cfm and .4 kW/ton then 2.6 kWh/cfm
9. Total annual electric kWh/cfm with gas cooling: 6.6 + 2.6 = 9.2 kWh/cfm
10. Savings at $.066/kWh: $.61/cfm
11. Total savings per cfm with gas cooling: $2.55 + $.61 = $3.16
12. Electric chiller option: Assume 6.4 ton-hours/cfm at 55 deg. supply temperature and 1 kW/ton then 6.4 kWh/cfm
13. Total annual electric savings w/ electric chiller: 6.6 + 6.4 = 13 kWh/cfm
14. Savings at $.066/kWh: $.86/cfm
15. Total savings per cfm with electric cooling: $1.70 + $.86 = $2.56
16. Annual UC Davis Genome savings
    a. Gas cooling: 293 cfm x $3.16/cfm = $926
    b. Gas cooling and hood driven minimum: 433 cfm x $3.16 = $1,368
    c. Electric cooling with: 293cfm x $2.56/cfm = $750
    d. Electric cooling and hood driven minimum: 433 cfm x $2.56 = $1,108
17. Demand Savings:
    a. Gas cooling: Assume 99 deg. F design temp (peaks higher but not all summer), therefore the delta T = 99 – 55 = 44 deg F. 44deg x .018btu/cf/deg x 60min / 12,000 btu/ton = .004 tons/cfm. With 400 W/ton, then 1.6 W/cfm for cooling. Add .75 w/cfm for fan power = 2.3 W/cfm demand savings. With 433 cfm, the hood's demand savings is 1 kW.

b. Electric cooling: Same as above (.004 tons/cfm) but 1 kW/ton, therefore, 4 W/cfm for cooling. Add .75 w/cfm for fan power = 4.75 W/cfm demand savings. With 433 cfm, the hood's demand savings is 2.1 kW.

Table 6
Genome Automatic Fume Hood Sash Closure Savings per CFM (Energy and Dollars)

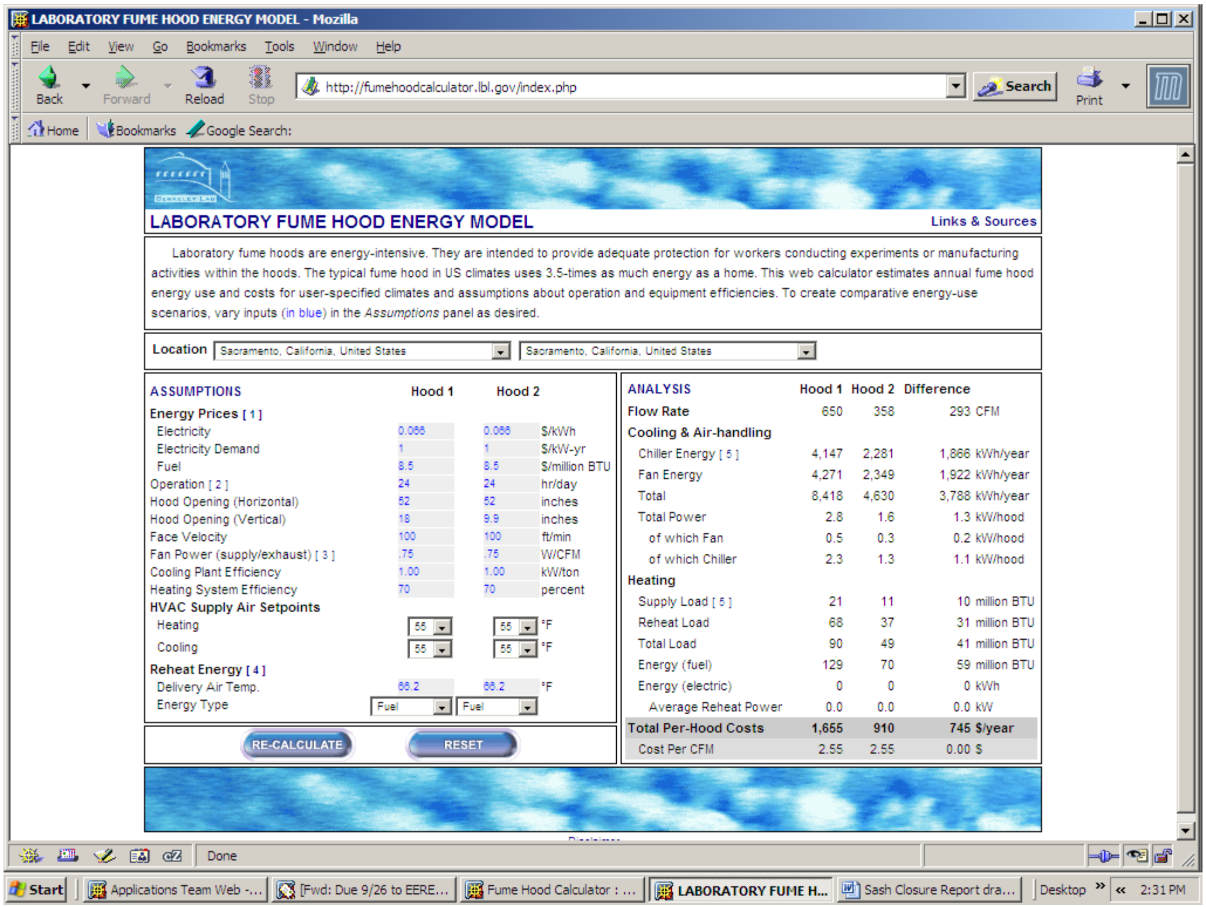
Configuration	Genome		
	Therms	**KWh**	**$**
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)			
1. Base case: 55 deg. F supply, 66.2 deg. Reheat, .75 W/cfm	3.0	9.2	$3.16
Electric Cooled (assumes 1 kW/ton)			
2. Base case (same as #1)	2.0	13	2.56

#2 was based on LBNL fume hood calculator (http://fumehoodcalculator.lbl.gov/) using Sacramento weather – see below.

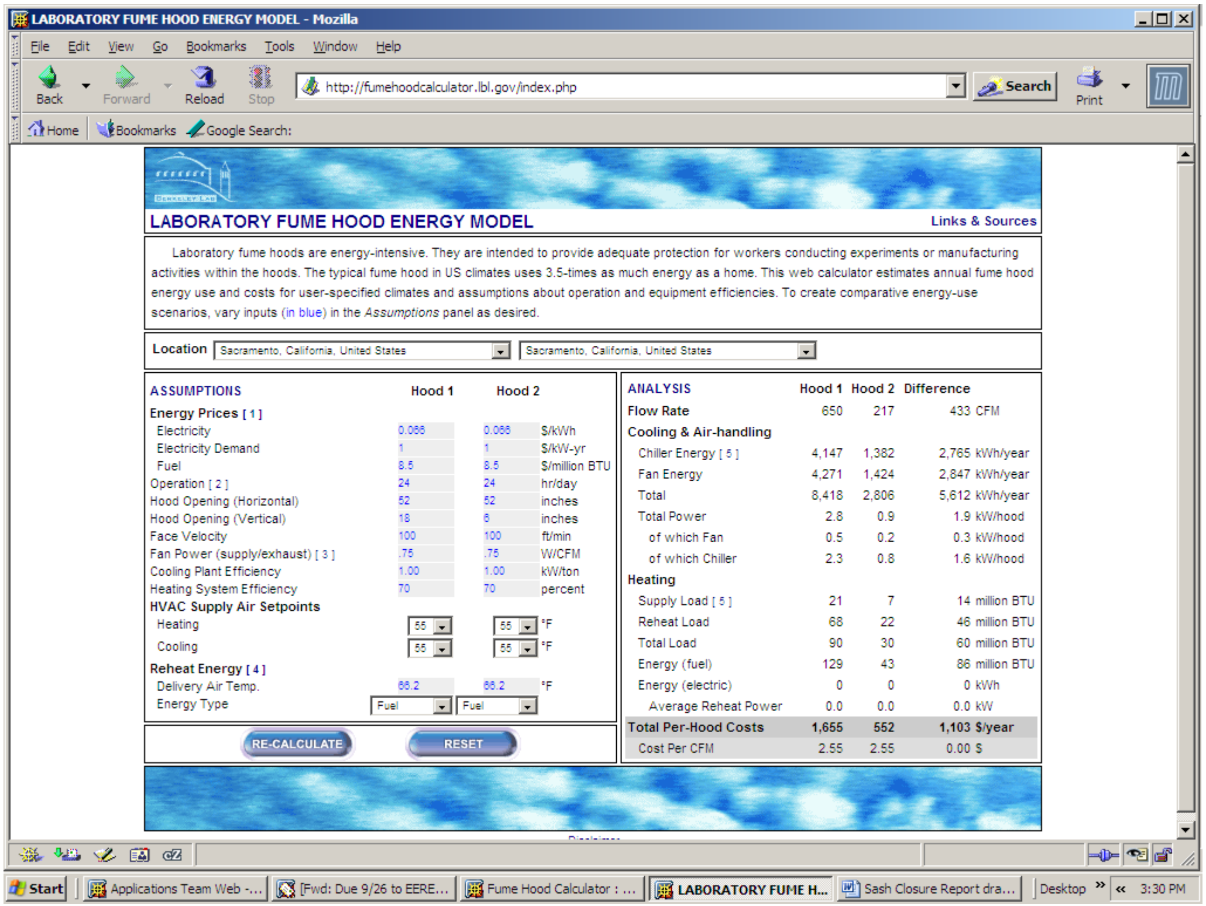
Table 7
Savings Per Hood Assuming Genome Configuration and Davis Utility Rates (CFM and Dollar)

Configuration	Gas Cooled (5 ft. Hood)		Electric Cooled (5 ft. Hood)	
	CFM	**$**	**CFM**	**$**
1. Base ("Typical")	293	$926	293	$750
2. Hood driven load (all savings captured)	433	$1,368	433	$1,108
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	866	$2,737	866	$2,217

Genome- LBNL Fume Hood Calculator (http://fumehoodcalculator.lbl.gov/) Base Case with electric chiller and 293 cfm savings (limited by minimum lab air change):



<u>Genome- LBNL Fume Hood Calculator (http://fumehoodcalculator.lbl.gov/) electric chiller and 433 cfm, savings (not limited by minimum lab air change):</u>


LABORATORY FUME HOOD ENERGY MODEL - Mozilla

http://fumehoodcalculator.lbl.gov/index.php

LABORATORY FUME HOOD ENERGY MODEL

Links & Sources

Laboratory fume hoods are energy-intensive. They are intended to provide adequate protection for workers conducting experiments or manufacturing activities within the hoods. The typical fume hood in US climates uses 3.5-times as much energy as a home. This web calculator estimates annual fume hood energy use and costs for user-specified climates and assumptions about operation and equipment efficiencies. To create comparative energy-use scenarios, vary inputs (in blue) in the *Assumptions* panel as desired.

Location: Sacramento, California, United States | Sacramento, California, United States

ASSUMPTIONS	Hood 1	Hood 2	
Energy Prices [1]			
Electricity	0.066	0.066	$/kWh
Electricity Demand	1	1	$/kW-yr
Fuel	8.5	8.5	$/million BTU
Operation [2]	24	24	hr/day
Hood Opening (Horizontal)	52	52	inches
Hood Opening (Vertical)	18	6	inches
Face Velocity	100	100	ft/min
Fan Power (supply/exhaust) [3]	.75	.75	W/CFM
Cooling Plant Efficiency	1.00	1.00	kW/ton
Heating System Efficiency	70	70	percent
HVAC Supply Air Setpoints			
Heating	55	55	°F
Cooling	55	55	°F
Reheat Energy [4]			
Delivery Air Temp.	66.2	66.2	°F
Energy Type	Fuel	Fuel	

RE-CALCULATE | RESET

ANALYSIS	Hood 1	Hood 2	Difference
Flow Rate	650	217	433 CFM
Cooling & Air-handling			
Chiller Energy [5]	4,147	1,382	2,765 kWh/year
Fan Energy	4,271	1,424	2,847 kWh/year
Total	8,418	2,806	5,612 kWh/year
Total Power	2.8	0.9	1.9 kW/hood
of which Fan	0.5	0.2	0.3 kW/hood
of which Chiller	2.3	0.8	1.6 kW/hood
Heating			
Supply Load [5]	21	7	14 million BTU
Reheat Load	68	22	46 million BTU
Total Load	90	30	60 million BTU
Energy (fuel)	129	43	86 million BTU
Energy (electric)	0	0	0 kWh
Average Reheat Power	0.0	0.0	0.0 kW
Total Per-Hood Costs	**1,655**	**552**	**1,103 $/year**
Cost Per CFM	2.55	2.55	0.00 $

B. Limitations

Many factors affect the energy use and potential savings relating to laboratory fume hoods. The UC Davis case studies represented neither the best or worst opportunity. Characteristics that made them good opportunities included:

- VAV was already installed (lowers retrofit cost)
- There was poor sash management (hoods left open)

Characteristics that reduced the potential savings included:

- Hood density was not high, such that general exhaust and cooling drive the required air flow (for example in the Genome building the 433 cfm potential hood savings was limited to approximately 293 cfm because of general exhaust needs
- Fume hood air flow was designed around a "restricted sash" - sash stops set at 18," thus reducing the potential savings approximately 60% at PES and 50% at Genome (assuming a 36" max. opening at PES, a 30" max. opening at Genome, and a 24" counter depth inside the hood at both)
- A relatively small five foot hood was retrofitted at the Genome Building at the same cost, but with much less savings than a larger hood
- UC Davis enjoys abnormally low utility rates
- Supply fan savings was linear and low (e.g. .32 and .75 watts per cfm vs. typical 1.8) vs. a theoretical cubed function (static pressure reset could yield significantly more supply fan savings)
- No savings from the constant volume exhaust fans (savings could be increased with a reconfigured VAV or staged exhaust fan system)

C. Sensitivity Analysis

1. Steam driven cooling vs. electric driven chillers

UC Davis uses steam absorption chillers as the prime driver for chilled water production. This has a major impact on the electric energy and demand savings associated with a more common electric chiller configuration. Therefore, savings was estimated for both scenarios:

Table 8
Automatic Fume Hood Sash Closure Savings per CFM
(Energy and Dollars)

Configuration	**PES**			**Genome**		
	Therms	**KWh**	**$**	**Therms**	**KWh**	**$**
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)						
1. Base case: PES: 63 deg. F supply, 74 deg. reheat, .32 W/cfm Genome: 55 deg. F supply, 66.2 deg. Reheat, .75 W/cfm	3.1	4.0	$2.90	3.0	9.2	$3.16
Electric Cooled (assumes 1 kW/ton)						
3. Base case (same as #1)	2.6	5.8	$2.59	2.0	13	2.56

2. Fix PES Reheat

The reheat system at the test lab in PES is stuck at a 74 deg. F supply temperature. If the reheat valve is fixed it is assumed that the supply temperature could be reduced to 70 deg. F. This will eliminate the need for additional general exhaust to cool the room and will reduce the amount of reheat (from 11 deg. to 7 deg. F).

Table 9
Automatic Fume Hood Sash Closure Savings per CFM
(Energy and Dollars)

Configuration	**PES**		
	Therms	**KWh**	**$**
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)			
2. Fix PES reheat	2.5	4.0	$2.39
Electric Cooled (assumes 1 kW/ton)			
4. Fix PES reheat: reduce to 70 deg F.	2.1	5.8	$2.17

3. Standard PES Supply Air Temperature (55 deg. F)

The supply temperature at PES (from the AHU) is set at 63 deg. F; 55 deg. F is a more standard set point.

Table 10
Automatic Fume Hood Sash Closure Savings per CFM
(Energy and Dollars)

Configuration	**PES**		
	Therms	**KWh**	**$**
Electric Cooled (assumes 1 kW/ton)			
5. Same as #4 w/ normal 55 deg. F supply, 70 deg reheat PES only)	1.9	9.2	$2.25

See PES results for a copy of the LBNL Fume Hood Calculator for this configuration.

4. UC Davis vs. PG&E utility rates

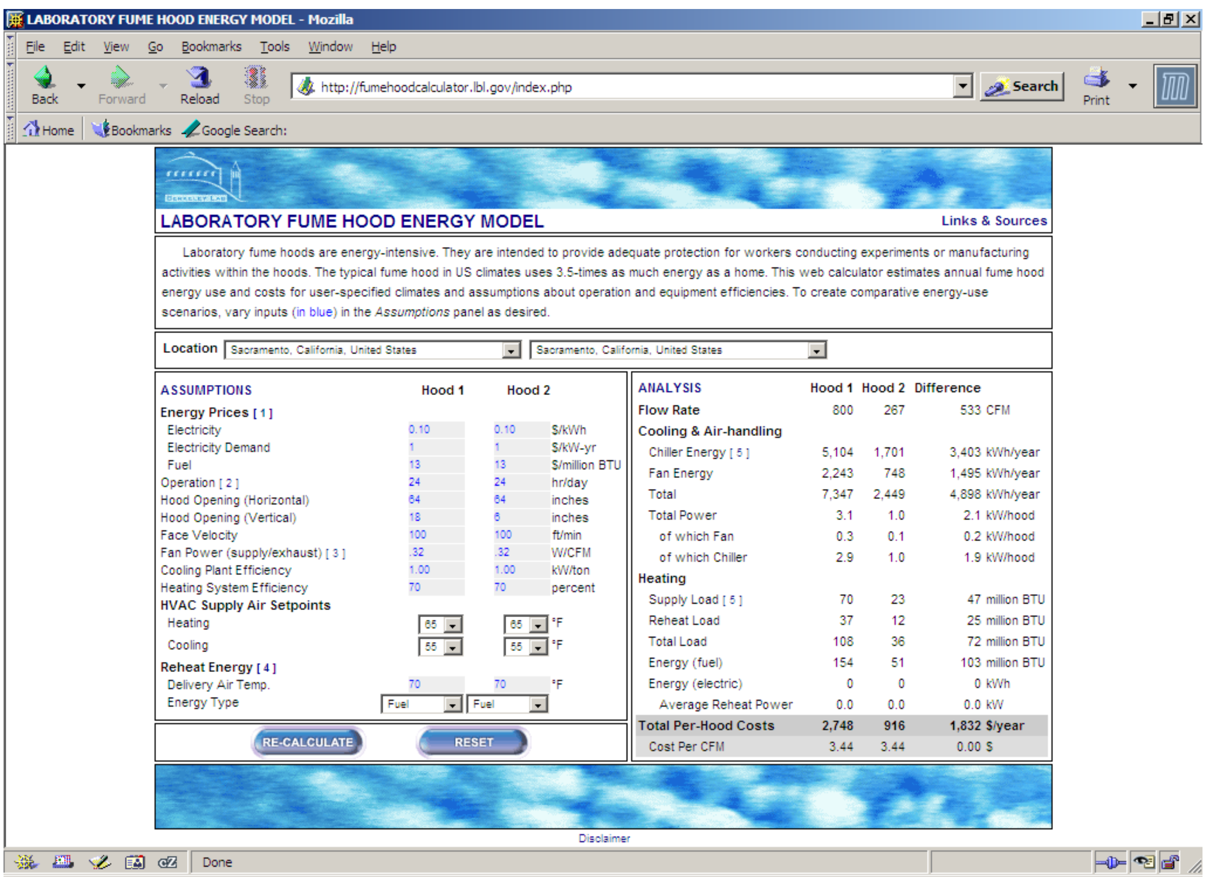
Utility rates for UC Davis are lower than typical PG&E customers. The following estimates the savings per CFM using standard PG&E commercial rates for gas ($1.30/therm) and electricity ($.10/kWh):

Table 11
Automatic Fume Hood Sash Closure Savings per CFM, PG&E Rates (Energy and Dollars)

Configuration	PES			Genome		
	Therms	KWh	$	Therms	KWh	$
Electric Cooled						
6. Same as #5 w/ commercial PG&E rates (.10/kWh, 1.30/therm)	1.9	9.2	$3.44	2.0	13	3.90

This condition is considered the typical for commercial PG&E lab customers.

<u>PES - LBNL Fume Hood Calculator (http://fumehoodcalculator.lbl.gov/) 55 deg. F Supply, 70 deg. F Reheat and Commercial PG&E Utility Rates:</u>



D. Economic Analysis

1. System Cost

The automatic fume hood sash closure system is currently being marketed for $5,500 per hood installed in small quantities. The cost in larger quantities (e.g. a lab building with 80 hoods) was quoted at $4,300 per hood installed. In both cases there may be additional costs associated with providing electrical power and compressed air at the top of the hood, decontaminating the hood to allow working in and around it, and repairing the sash operation (if stuck or sticky). We believe as the market (volume) increases, and potential competitors enter the market, the price will reduce.

2. Energy Cost Savings

a) UC Davis

A blended electric rate of $.066/KWh and an average gas rate of $.85/therm were used for analysis of the savings at UC Davis. As described under the sensitivity analysis, UC Davis has abnormally low rates. UC Davis also uses gas driven chillers which shift electric energy and demand charges from more commonly deployed electrically driven chillers. Both of these factors contribute to Davis being an unusual application. The annual savings for PES at UC Davis was $2.39 per cfm (assuming the reheat is fixed) and $3.16 per cfm at the Genome Building.

Table 12
Savings Per Hood Assuming Davis Configuration and Utility Rates
(CFM and Dollar)

Configuration	**PES (6 ft. Hood)**		**Genome (5 ft. Hood)**	
	CFM	**$**	**CFM**	**$**
1. Base	533	$1,274	293	$926
2. Hood driven load (all savings captured)	533	$1,274	433	$1,368
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$3,186	866	$2,737

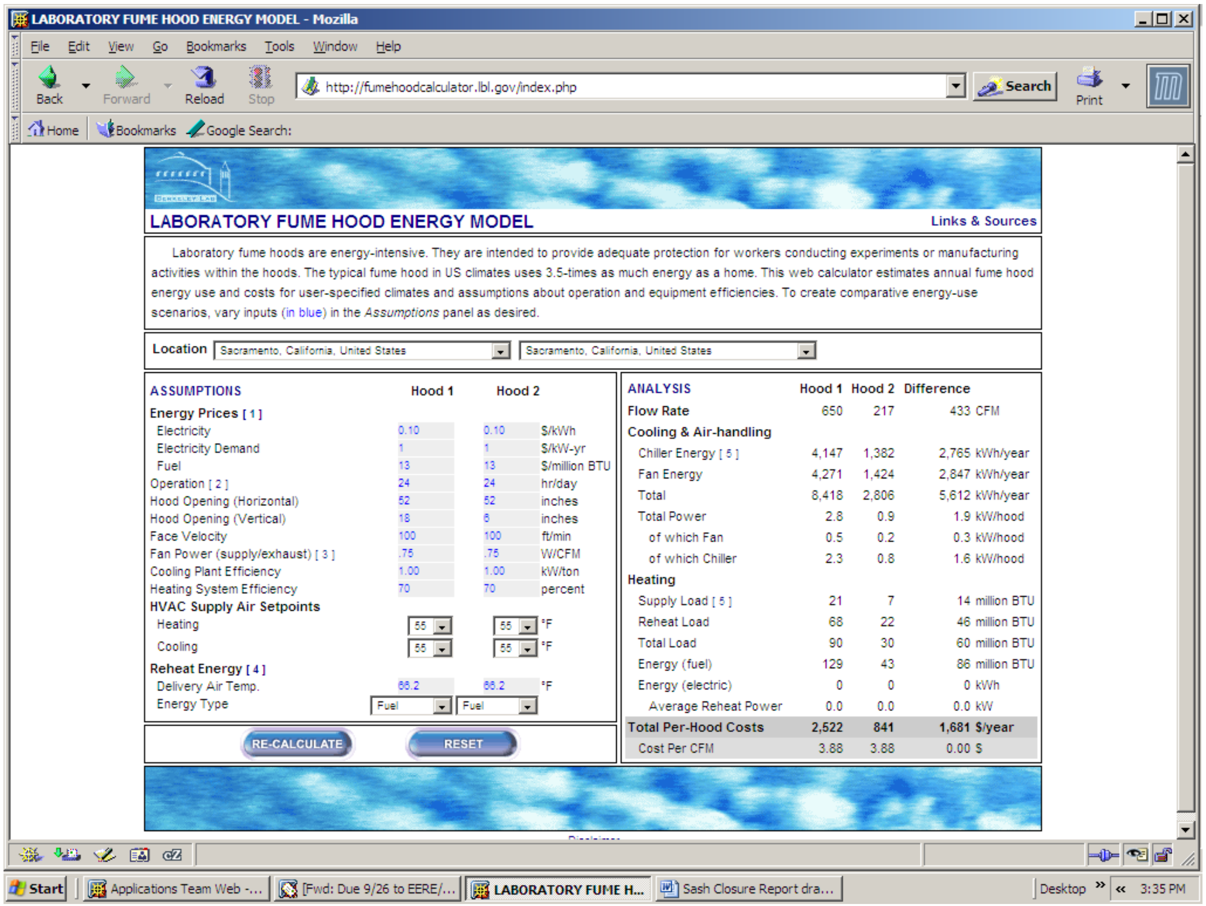
b) Typical PG&E Laboratory Customer

To address the issue of UC Davis's low utility rates and gas driven chillers, an analysis was done assuming standard PG&E commercial rates ($.10/kWh blended, and $1.30/Therm) and a typical electric driven chiller plant with an efficiency of 1 KW/ton (including distribution). In addition, PES had a leaking reheat valve wasting heat and increasing the cfm as the system tried to cool with 74 deg. F supply air. Further, the PES's AHU supplies air at 63 deg. F vs. the more standard 55 deg. F. Sensitivity analysis described above, evaluated the impacts of these factors. A base case for a typical PG&E customer was developed assuming standard commercial utility rates, standard 55 deg. F supply temperature, and a properly functioning reheat system. The annual savings for these typical conditions was $3.44 per cfm for an application similar to PES and $3.90 per cfm for conditions similar to Genome. Note these values are below "rules of thumb" that often assume $5/cfm. This is likely due to the mild climate, high fan efficiency (.32 and .75 W/cfm vs. 1.8 default in web calculator), and no savings from the exhaust fan (constant volume).

Table 13
Savings Per Hood Assuming Typical Configuration and PG&E Utility Rates (CFM and Dollar)

Configuration	PES (6 ft. Hood)		Genome (5 ft. Hood)	
	CFM	$	CFM	$
1. Base	533	$1834	293	$1,143
2. Hood driven load (all savings captured)	533	$1834	433	$1,689
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$4586	866	$3,377

<u>Genome - LBNL Fume Hood Calculator (http://fumehoodcalculator.lbl.gov/) 55 deg. F Supply, 66.2 deg. F Reheat, 433 cfm savings and Commercial PG&E Utility Rates:</u>



3. Other considerations – new construction

If the automatic fume hood sash closure system is deployed in new construction, and the design team assumes a small fraction of the hoods are simultaneously open, the reduced infrastructure (fans, ducts, boilers, chillers, etc.) size and cost will offset the increased hood control cost.

E. Issues Encountered

Most of the issues that were encountered related to specific site characteristics, for example, low utility costs, abnormal supply temperatures, and leaking valves. There were no systemic issues encountered relative to the emerging technology. However, a problem with misalignment of the sash safety sensor was noted.

<u>Fan savings lower than anticipated</u>: The lack of significant fan savings at the margin (in the operating range) was a surprise. Fan laws that would put the reduction of power as the cube of the reduction of flow are often quoted relative to the potential savings associated with airflow controls. However, what is more important is the system curve and how the system

is controlled. Both demonstration projects had variable speed drives on the supply fans. They did respond to changes in the system, however, only to reduce the flow, not the pressure. Controlling fans to a fixed static pressure is a common strategy but the energy savings is not nearly as great. As airflow to an individual lab is reduced, the air control valve closes, increasing the pressure drop to that zone. There is significant potential savings to reset the static pressure of the system as the airflow requirement is reduced. In PES the average fan watts per cfm was higher than (over twice) the savings at the margin (operational range). Thus PES is operating low on the curve where the slope is relatively flat. As the airflow increases, the system curve (watts per cfm) gets steeper. This is the case at Genome where the average watts per cfm is lower than the savings at the margin. However, the average fan power as well as the fan savings in both buildings was lower than the average watts per cfm found in many laboratory designs.

Sash safety sensor: An "electric eye" sensor along the leading edge of the sash stops the sash closure if anything is protruding from the fume hood. In this demonstration, the sensors in both hoods lost alignment and failed within several months of operation. In circumstances where a sash sensor misalignment occurs, the sash on the fume hood is fully functional manually, but the automatic closure does not operate. Such a condition could go undetected, rendering the system ineffective for extended periods of time. This problem was discussed with the manufacturer who recommended an adjustment to the sensor's sensitivity. Adjustments were made and the systems were returned to full operation. The problem seems less significant in other applications, but monitoring and maintenance is warranted to assure ongoing savings.

F. Feasibility for wide-spread implementation

The results of these two demonstration projects would suggest that the emerging technology of automatic fume hood sash closure systems is feasible for wide-spread implementation.

A challenge for wide-spread implementation is understanding the individual baseline and potential savings under specific applications – how much of the load is fume hood driven (vs. minimum lab airflow and cooling needs), what are the characteristics of the mechanical systems, what is the energy savings at the margin (specific operating range), and what is the existing sash management performance. It is difficult to generalize – every hood will have a different savings potential.

G. Market size and potential

Fume hoods contribute to approximately 2,495 GWh/year, 574 MW, and 18 Trillion BTUs/year in California. The end-state goal is to reduce airflow through fume hoods by 75%. Energy savings is not directly proportional to airflow savings:

1. Two thirds of the KWh and one third of the KW savings are from the fans. In a static system, fan energy reduces at approximately the cube of the flow. Therefore a 75% reduction in fume hood flow can result in more energy savings, especially in the main supply fans which provide air for other purposes than the hoods (the impact will be at

the margin where flow reductions may have the greatest impact). However, more sophisticated controls will be required to achieve this potential than were present in this demonstration project.

2. Fume hoods don't always "drive" the required air change rate. In labs with few hoods, other factors such as the minimum air change rate and thermal loads can dictate the required airflow. In these situations, reductions of airflow through the fume hoods are "made-up" by increases in the general room exhaust. This was the case in Genome.

If we assume that 1 and 2 cancel each other out for electricity, the end state goal will result in a 75% electrical savings, and if we further assume that the savings for natural gas is discounted 20% (of 75%) to yield a 60% potential savings, the overall potential is:

Saved Electricity GWh/year:	1,871
Saved Peak Power MW:	431
Saved Natural Gas Trillions BTUs/year:	11

This goal will be accomplished through multiple technology options. For example, since its introduction in the 1980's, VAV has grown to a large market share in new construction. Assuming 30% of the hoods installed in California have VAV and 50% of the potential end state savings is achieved, VAV has already captured 15% of the potential savings outlined above. Assuming approximately 1/3 of the State's estimated fume hoods are in the PG&E territory, and assuming a 35% market share for this emerging technology and a 10% market penetration per year, the added savings per year is estimated as:

Saved Electricity GWh/year:	22
Saved Peak Power MW:	5
Saved Natural Gas Billions BTUs/year:	200

VIII. Conclusions

Table 14
Automatic Fume Hood Sash Closure Annual Savings per CFM
(Energy and Dollars)

Configuration	PES			Genome		
	Therms	**KWh**	**$**	**Therms**	**KWh**	**$**
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)						
1. Base case: PES: 63 deg. F supply, 74 deg. F reheat, .32 W/cfm Genome: 55 deg. F supply, 66.2 deg. F Reheat, .75 W/cfm	3.1	4.0	$2.90	3.0	9.2	$3.16
2. Fix PES reheat: reduce to 70 deg. F	2.5	4.0	$2.39			
Electric Cooled (assumes 1 kW/ton)						
3. Base case (same as #1)	2.6	5.8	$2.59	2.0	13	2.56
4. Fix PES reheat: reduce to 70 deg. F	2.1	5.8	$2.17			
5. Same as #4 w/ normal 55 deg. F supply, 70 deg reheat PES only)	1.9	9.2	$2.25			
Typical Conditions						
6. Same as #5 w/ commercial PG&E rates (.10/kWh, 1.30/therm)	1.9	9.2	$3.44	2.0	13	3.90

Table 15
Savings Per Hood Assuming Typical Configuration and Utility Rates (CFM and Dollar)

Configuration	PES (6 ft. Hood)		Genome (5 ft. Hood)	
	CFM	$	CFM	$
1. Base ("Typical")	533	$1834	293	$1143
2. Hood driven load (all savings captured)	533	$1834	433	$1689
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$4586	866	$3377

Base (typical conditions) is configuration #6 in Table 14

Table 16
Demand Savings

	Per CFM	Per Hood (533 cfm PES and 433 cfm Genome)
PES gas cooled	1.6 W	.9 kW
PES electric chiller	3.5 W	1.9 kW
Genome gas cooled	2.3 W	1 kW
Genome electric cooled	4.8 W	2.1 kW

The above tables summarize the analysis of the demonstration project and the extrapolation to more typical practice (both in terms of system configuration as well as utility rates).

At a cost of $4,500 per hood, the simple payback is 1 to 4 years based on the two test conditions and PG&E commercial rates. 2.3 to 2.5 year payback would be typical for a hood driven load. Low utility rates and other unique conditions at UC Davis yielded a lower unit savings and a longer payback.

With the exception of PES's assumed ton hours of cooling, and heating degree hours (to 63 deg. F), the estimates are based on field test data collected by UC Davis and Cogent Energy, and LBNL's web based fume hood calculator, as well as the hand calculations shown.

The fan system at PES provides much less savings at the margin than Genome (.32 W/cfm vs. .75 W/cfm) and much less than assumed as default in the LBNL fume hood calculator (1.8 W/cfm). These values result (along with other factors) in a lower overall savings of $2.39/cfm at PES vs. $3.16 at Genome. Typical industry values are double that, partially due to the higher fan energy mentioned, as well as higher utility rates. While the savings per cfm is lower at PES, the tested hood in Genome is smaller (5' vs. 6') and the savings in Genome is further constrained by a minimum room exhaust (exhaust is not hood driven), so the cfm savings in PES is much higher than in Genome (533 cfm vs. 293 cfm).

The fan savings could be significantly increased with a static pressure reset strategy (a potential retro commissioning opportunity).

The reheat in the PES lab is out of control. It looks like the valve is stuck or leaking, adding approximately 11 deg. F whether it is desired or not. This is particularly a problem with the abnormally high supply air temperature (63 deg. F vs. 55 in Genome). When the room temperature rises, a lot more 74 deg. air at is required to maintain comfort, and this detracts from the savings due to sash control. The savings for reducing the reheat from 74 deg. to 70 deg. is shown in configuration #2 (first table). In calculating the savings per hood, the potential loss of savings with increased air flow was ignored and we assumed the reheat would be fixed and that the 63 deg. F supply air could maintain comfort at the minimum flow rate.

Monitoring and maintenance of the sash safety sensor is required: To assure ongoing savings, monitoring and alarms should be established to check that the sash is being closed by the system (continuous monitoring based commissioning). Shortly after the demonstration period, the sash safety sensor on both hoods lost alignment and rendered the systems ineffective (reverting to manual control). Such a condition could go undetected. To improve performance, the sash closure control system itself could be monitored (dry contact in the control box indicating "obstruction"), or the fume hood exhaust airflow could be monitored to confirm the exhaust does not exceed the minimum for more than a few hours at a time. Such a monitoring system would alarm maintenance if potential savings are not being achieved.

Generic conditions: While the demonstration analysis focused on specific applications at UC Davis, it is desirable to reach more "generic" conclusions. Therefore, the impact of using electric chillers for both buildings was evaluated. Electric cooling is less expensive than the existing gas cooling based on the assumptions made (see first table configuration #3+). Other "normalization" measures included:

- PES was analyzed for a more common 55 deg. supply air temperature (already used by Genome, see configuration #5).
- UC Davis has abnormally low utility rates ($.066/kWh and $.85/therm) so more standard commercial rates ($.10/kWh and $1.30/therm) were used to estimate savings of $3.44 to $3.90/cfm for "off campus" labs (configuration #6).

Even with these adjustments, the mild climate, low marginal cost/savings of supply air, and no savings on the exhaust air, yields an estimated savings lower than the often quoted "rule-of-thumb" of $5+/cfm.

The generic savings rates of $3.44 and $3.90/cfm were applied to the actual hood cfm savings in PES and Genome. As noted, the air change rate in the Genome lab was not hood driven and the savings was constrained to 293 cfm. Had a 5 ft hood been retrofitted in a hood driven lab (as in PES), the savings would have increased to approximately 433 cfm (second table, configuration #2). In both cases, we assumed air flow savings derived from a

12” reduction is sash height (while staying above the minimum flow assuming a 24” deep interior).

UC Davis already had installed two fume hood efficiency measures:

1. VAV fume hood controls
2. Restricted sashes (sash stops)

The sash stops restrict the sashes from fully opening. This was particularly effective at the “tall” hood in PES. If the sash stops were not used and the hoods were left fully open (or CAV hoods were used), the savings would have been much higher (i.e. approximately 1333 cfm for PES, and 866 for Genome). These are extreme conditions and represent the maximum potential savings from the technology (see second table, configuration #3).

As the table below shows, the increase in minimum airflow required for Genome significantly detracted from the savings due to the auto closure system:

Approximate breakdown of airflow	PES	Genome	Genome w/ min air driven by room
Airflow saved by sash stop:	50%	40%	40%
Airflow saved by auto closure system:	33.3%	40%	28%
Minimum airflow (not savable):	16.7%	20%	32%

Bottom line: At $3.44 to $3.90 per saved cfm (many hoods are higher), a typical 5 or 6 foot hood would save approximately $1689 to $1834 per year with this emerging technology. If a static pressure reset strategy is integrated with the retrofit, the savings could be greater. Gas use dominated the savings (even with electric chillers). Low utility rates at UC Davis reduce the savings approximately one third. To estimate the savings in a building or set of buildings, an analysis of the number and size of hoods, as well as the size of the rooms is required. Savings would need to be adjusted (down) for VAV hoods demonstrating better sash management, as well as labs with significant heat gain.

IX. Recommendations for Future Work

The following actions are recommended:

1. Develop baselines (e.g. average sash position). Need to develop baselines for various applications and confirm improvement (time intervals and degree of sash opening by time-of-day before and after installation). Degree of diversity and opportunity for savings is generally unknown, and may vary by type of hood application as well as “corporate culture.” Further the degree to which fume hoods drive the exhaust air volume (vs. the minimum general exhaust or thermal requirements) is not known.

Such an analysis would be required to establish market incentive programs. While two hoods were evaluated in this study, a much more robust sample size is required.
2. Run side-by-side tests. Independent evaluation of options is needed for the market to understand and compare competing hood efficiency technologies.
3. Perform Impact Analysis and Prepare Business Case. Although a potential for significant energy savings appears to exist, our statewide energy impact analysis is generalized and hinges on a number of key assumptions. Improved data are needed on the overall population of hoods, current sales rates, geographical distribution, and baseline energy use of standard hoods across a range of industry and climatic settings. Improved energy analysis, coupled with cost-benefit information, should be assembled into a coherent business case. The potential for retrofit-driven savings and new market segments (e.g. wet benches) should also be identified and analyzed.
4. Develop Industry Partnerships. Liaisons should be maintained with industry organizations (AIA, ASHRAE, Labs21), as well as major design influencers (key lab planners and specialized A&E firms) and major users of fume hoods (e.g. R&D labs, and universities).
5. Information Transfer. Information transfer should include technical guidelines (e.g. fume hood design/selection guide), education/training (e.g. advanced workshop on fume hoods), and direct technical assistance (providing customers with access to technical experts). Outreach activities should include development and maintenance of a Taming the Hood website, presentations, and publications in professional and popular literature. A slide presentation is included in the Appendix.
6. Develop incentive programs. The current retrofit cost is quite high and the savings is not well understood (see “need to develop baselines”). Utility rebates can be used to provide market incentives, offset costs, and add credibility, thus increasing market acceptance.
7. Product development. More analysis and perhaps some product development on the sash safety sensor may be warranted. This sensor determines if something is protruding from the hood to stop the sash from hitting it. The system fails in the manual mode, and in our demonstration, both hoods failed due to misalignment of the sensors within several months of operation. At least one competitor uses a pressure sensitive switch along the leading edge of the sash. While this system is less prone to misalignment, it could result in experimental apparatus being knocked and perhaps damaged prior to activating the switch.

X. Appendices

See attached for the following:

A. Monitoring and Evaluation Plans
B. PG&E Brochure
C. Test Site Solicitation and Requirements
D. Power Point Presentation
E. Report to Campus

A. Monitoring and Evaluation Plans

Preliminary LBNL Plan October 9, 2006
Cogent Plan June 11, 2007 – See Appendix E: Report to Campus

Automatic Fume Hood Closure System Pilot Test

DRAFT Monitoring and Evaluation Plan

October 9, 2006

Dale Sartor. (510) 486-5988

1. Assess existing sash management
    a. Minimum: Observe sash position and interview user(s) to estimate sash position over 24 hour/7 day period (typical week)
    b. Ideal: Sash monitoring or exhaust airflow monitoring to determine typical sash position over 24 hour/7 day period
    c. Develop sash position schedule for typical week
2. Estimate exhaust air flow at various sash positions (including closed)
    a. Minimum: Use design data
    b. Ideal: Use existing monitoring system
    c. Confirm with one-time face velocity measurements
3. Based on 1 & 2, develop schedule of:
    a. Typical exhaust airflow for test hood
4. Confirm supply airflow responds to changes in exhaust airflow
    a. Minimum: Note air velocity at register changes as fume hood sash is opened and closed
    b. Ideal: Use existing supply airflow monitoring system
5. Develop schedule of supply airflow
    a. Minimum: Use observations, design data, and engineering assumptions
    b. Ideal: Use existing monitoring of airflow or fan motor speed
    c. Develop schedule of estimated supply fan airflow
6. Estimate supply fan energy at various air flows
    a. Minimum: Use design data and engineering assumptions
    b. Ideal: Use existing monitoring of KW or fan motor speed
    c. Check with one-time KW measurement
    d. Develop schedule of estimated supply fan energy at various flows
7. Based on 5 and 6 develop spread sheet model (schedule) of supply fan airflow and energy use
8. Monitor KW at supply fan for various sash positions of the test hood
    a. If the system is small (change in energy detectable for one hood) and stable (little variation), differences in fan energy based on test hood sash position should be captured and used
9. Based on 3, 7, and 8 develop spread sheet model of supply air flow and fan energy as a function of fume hood exhaust
    a. A function of the test hood exhaust (all other hoods constant)
        - This model will be used to calculate before and after supply fan energy use and savings for the test hood
    b. A function of the all hoods
        - This model is expected to be less robust than the first, but would be used to estimate savings if all existing fume hoods served by the supply fan were to be retrofitted with the automatic fume hood sash closure system

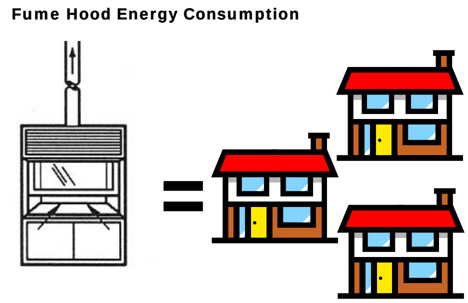
    - This model should account for a minimum general exhaust of 1 cfm per square foot (assuming a completed retrofit would remove the fume hoods from being the exhaust system "driver")

10. Assess energy impact of VAV on fume hood exhaust system
    a. Exhaust system impact will likely be less than supply and will depend on the configuration of the system (could be negligible)
    b. If potential savings from exhaust fan is not negligible develop similar spread sheet model as described in 9.
11. Assess cooling system cost as a function of airflow
    a. Using design data, engineering judgment, and readily available measured data, estimate average cooling system efficiency (KW/Ton)
    b. Using design data, engineering judgment, and readily available measured data, develop spread sheet model of estimated cooling energy as a function of airflow
    c. Unless better data is available:
       - Assume .6 KW/ton overall system efficiency
       - Assume 55 deg F supply air
       - Use bin temperature data and assume 24 hour operation
12. Assess re-heat system energy cost as a function of airflow
    a. Using design data, engineering judgment, and readily available measured data, estimate average heating system efficiency (%)
    b. Using design data, engineering judgment, and readily available measured data, develop spread sheet model of estimated heating energy as a function of airflow
    c. Unless better data is available:
       - Assume air handler supply air temperature reduced to 55 deg F at outdoor conditions above 55 deg F
       - Assume re-heat (zone supply) temperature is 65 deg F
       - Assume 70% overall heating system efficiency
       - Use bin temperature data and assume 24 hour operation
13. Assess post retrofit sash management
    a. Minimum: Monitor sash closure system to determine minutes per week that the sash is open. Observe sash position and interview user(s) to estimate open sash position
    b. Ideal: Sash monitoring, exhaust airflow monitoring, or monitor on auto sash closure system will determine sash position over 24 hour/7 day period (typical week)
    c. Develop sash position schedule for typical week
14. Using schedules and models developed for exhaust and supply airflow, and energy consumption for fans, cooling plant and heating plant, estimate energy consumption and savings
    a. Based on one hood retrofit (test condition)
    b. All hoods retrofitted
15. Visit the site to review system in operation. Interview available facility managers and users (operators) to determine acceptance, strengths and weaknesses of the automatic fume hood closure system.

B. PG&E Brochure

Auto-closure Fume Hoods

Description:
Fume hoods are a major energy drain in California. Poor management leads to high demand in electricity. Surveys have shown that most operators leave the hoods fully open all the time. Some new technologies are emerging to automatically optimized the sash position in function of the activity.



The consumption of a single fume hood equals three homes


Auto-closure fume hoods with occupancy detection

The numbers :

- About 28,000 fume hoods in PG&E territory
- 800 GWh/year, 190 MW, 60 Millions Therms
- 35% of the energy may be saved
- With 10% market penetration per year we expect **14 GWh/year of additional savings each year**

The project:
The project will assess and demonstrate the use of an auto-closure fume-hood in a typicall laboratory environment: acceptance, integration in the laboratory work process and actual energy performance would especially be evaluated.
The project will be **performed during the second part of 2006.**
Collaboration with an SCE project run at Amgen.

Looking for participants:
The requirements are:
- High Fume hood intensity laboratory (the hoods drive the outside air requirement)
- Fume hoods with VFD equiped fans to adjust the airflow to the sash position.
- Consistent work load to compare the tested fume-hood and the baseline

C. Test Site Solicitation and Requirements

PG&E and LBNL Looking for Fume Hood Auto Sash Closure Demo Site

PG&E and LBNL have initiated a project to demonstrate an emerging fume hood technology. The technology automatically raises and lowers the fume hood sash depending on the user's presence and preferences. A host site is being sought.

The technology works in conjunction with an existing VAV fume hood control system to maximize energy efficiency and laboratory safety. The outside make-up air in the demonstration lab must be driven by the fume hood exhaust requirements. The demonstration will document the reduction in outside air and resulting energy savings. It will be done at a PG&E customer facility, and will require some cost sharing by the host site.

If you are looking for ways to reduce the cost of operating fume hoods at your facility and would consider participating in this demonstration, please respond to this e-mail or contact Francois Rongere at PG&E (415-973 6856), or Dale Sartor at LBNL (510-486-5988).

Thank you for your consideration.

Opportunity to Work With PG&E and LBNL On Demo of Fume Hood Auto Sash Closure

There is still an opportunity for a laboratory owner to participate in the demonstration and evaluation of an emerging fume hood technology. PG&E and LBNL have initiated a project to demonstrate an off-the-shelf technology that automatically raises and lowers the fume hood sash depending on the user's presence and preferences. A host site is being sought.

The technology works in conjunction with an existing VAV fume hood control system to maximize energy efficiency and laboratory safety. The outside make-up air in the demonstration lab must be driven by the fume hood exhaust requirements. The demonstration will document the reduction in outside air and resulting energy savings. It will be done at a PG&E customer facility, and will require some cost sharing by the host site.

If you are looking for ways to reduce the cost of operating fume hoods at your facility and would consider participating in this demonstration, please respond to this e-mail or contact Alicia Breen at PG&E (415-973-0317), or Dale Sartor at LBNL (510-486-5988).

Thank you for your consideration.

Automatic Fume Hood Closure System Pilot Test

Site Requirements and Selection Criteria

October 9, 2006

Dale Sartor, (510)486-5988

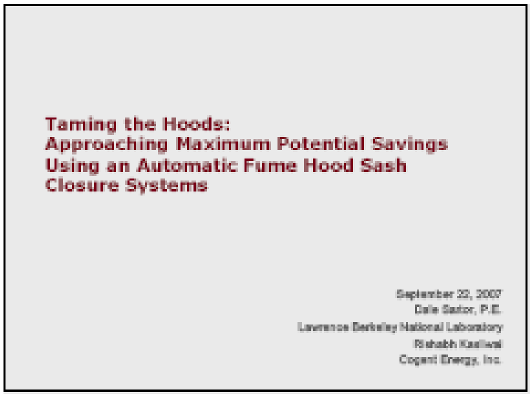
Requirements:

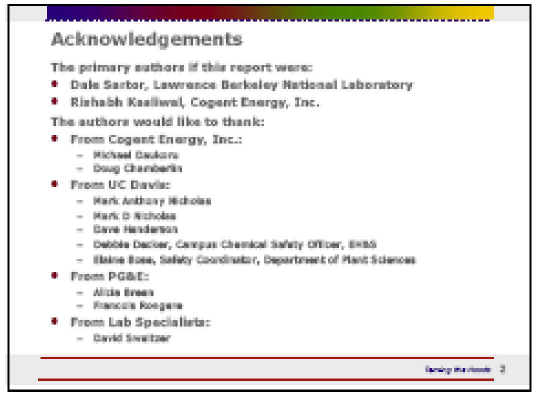
10. PG&E Customer
11. Customer willing to share performance information
    a. Anonymity acceptable but not preferred
12. Customer willing to cost share
    a. Purchase and install system (approximately $5K)
    b. In-house effort to support project
13. Existing VAV fume hood and room pressure control system
14. Hood driven load
    a. Closure of hood results in reduced supply airflow to lab and reduced supply fan horse power
15. Poor existing sash management (based on visual inspection and interview(s))
16. Low hazard lab with no obvious safety hazards or operational concerns (this does not imply any type of formal evaluation)

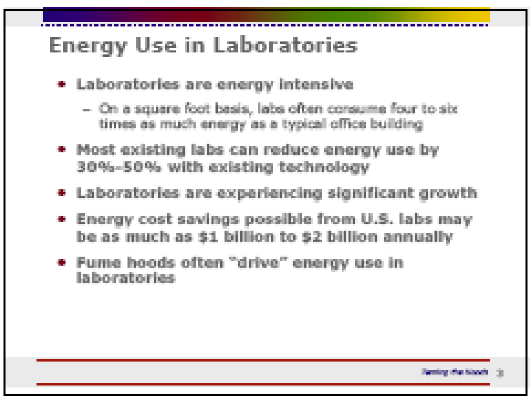
Desirable traits:

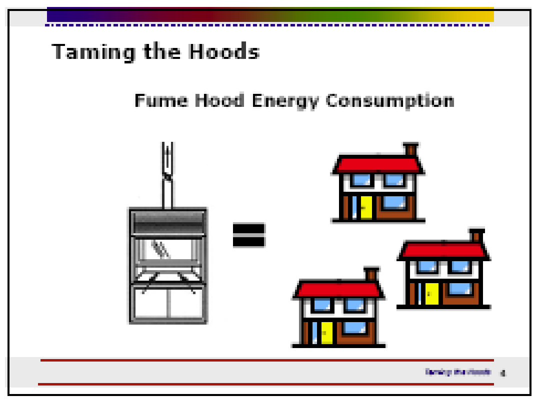
1. Easily monitored system, e.g. existing:
    a. Sash position or exhaust airflow monitor
    b. Supply airflow and temperature monitors
        - Outside air
        - Supply air
        - Reheat
    c. Supply fan energy (watts) or speed calibrated to watts
2. Easily accessible
    a. Bay area location
    b. Limited security requirements

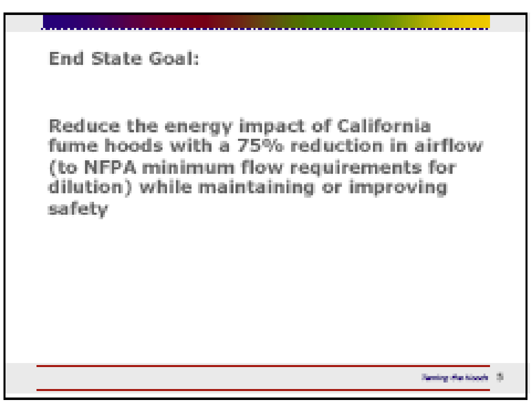
D. Power Point Presentation

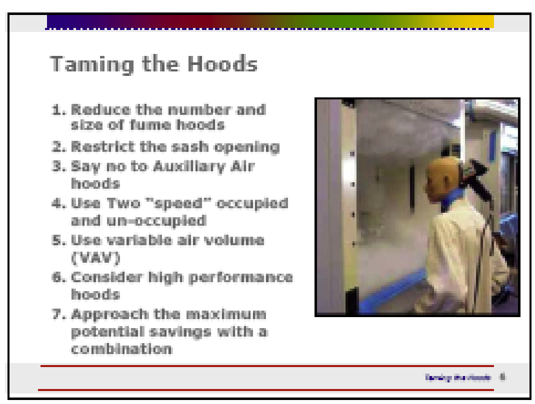












1. Reduce the number and size of hoods

- Size distribution for ample capacity
- Install only hoods needed immediately
- Provide tees, valves, and pressure controls for easy additions/subtractions
- Encourage removal of underutilized hoods
- Consider hoods as a shared resource

Is this hood intensity necessary?

2. Restrict sash openings

Sash stops | Horizontal sashes | Combination

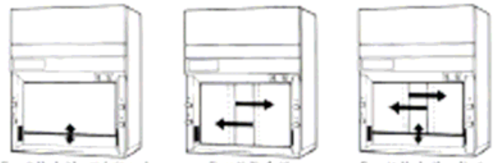


Figure 9: Hood with vertical-rising sash | *Figure 10: Hood with horizontal-sliding sashes* | *Figure 11: Hood with combination "A-style" sash*

2. Restrict sash openings

- Vertical Sash Opening
  - Most common sash
  - Good horizontal access
  - Energy use reduced with sash stop

Vertical Sash Stop

2. Restrict sash openings

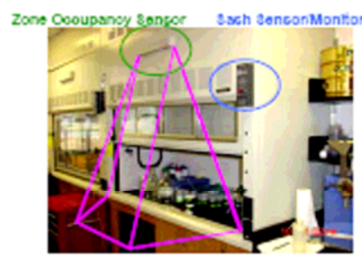
- Horizontal Sash
  - Can be more energy efficient due to reduce airflow volume
  - May increase worker safety
  - Caution – sash panels can be removed; defeats safety

Sash Panels

3. Auxiliary air hoods

- Auxiliary Air Hood
  - Wastes energy
  - Reduces containment performance
  - Decreases worker comfort
  - Disrupts lab temperature and humidity
  - Not Recommended

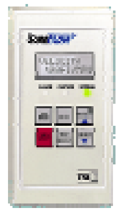
4. Two "speed" occupied/un-occupied



5. Variable air volume (VAV)

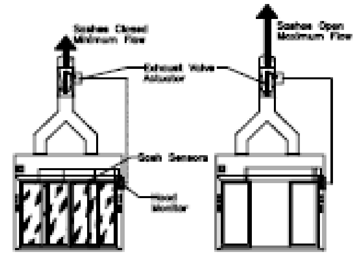
VAV:
...Combination of sophisticated monitoring sensors and controls

How Do They Operate?
...Communicate between hood and supply/exhaust systems
...Modulate supply/exhaust systems
...Maintain constant face velocity and room pressure relationships



TSI Controller

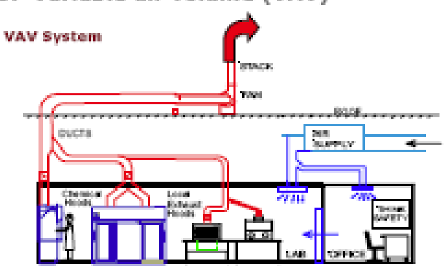
5. Variable air volume (VAV)



VAV Hood Operation

5. Variable air volume (VAV)

VAV System



5. VAV Drawbacks

Key Requirement
Diligent users must close sash to reduce air flow

Energy Savings
Reduced fan speed with closed sash

Typical Worst Case Sizing
Assume all sashes open 100%

Result
Oversized fans and central plants

5. VAV sash management

- Training and education
- The stick
- The carrot
- Demand responsive sash management
- Automated sash management
  - occupied and unoccupied set points (reset velocity set point)
  - Auto sash closure system

6. High Performance Hoods

Does the Low Flow / Low Velocity Hood provide:

- Energy-efficient operation?
- Equivalent or Better Containment at Reduced Face Velocities and Flow Volumes?
- Improved performance for all users, even under misuse conditions?
- More Robust and Less Susceptible to External Factors?
- Better Monitoring and Flow Control?

If so… = High Performance Hood

6. High Performance Hoods

- **Improved Performance Through Better Design…**
  - Aerodynamic Entry
  - Directed Air Supply
  - Perforated or Slotted Rear Baffle
  - Airfoil Sill and Sash Handle
  - Integrated Monitors
  - Interior Dimensions
- **First Generation: 20 to 40% savings**
- **Second Generation: 40 to 75% savings**

6. High Performance Hoods

- **Current fabricators…**
  - Lab Crafters
  - Labconco
  - Fisher Hamilton
  - Kewaunee Scientific
  - Laboratory Equipment Manufacturers
  - Esco Global
  - Others

6. High Performance Hoods

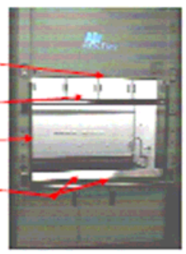
Lab Crafters Air Sentry HPFH

Upper chamber Turning Vane

Aerodynamic Sash Frame

Side Post Airfoils

Multi-Slot Front Airfoil



6. High Performance Hoods

Labconco XStream Hood

Modified Aerodynamic Sash Pull

Modified Baffle and Slots

Aerodynamic Airfoil

6. High Performance Hoods

Fisher Hamilton PIONEER

- Automatic sash closer
- Directed supply flow @ full open sash
- Flush Airfoil Sill

6. High Performance Hoods

Berkeley Hood by LBNL

- Push/Pull Air Divider Technique
- Perimeter Air Supply
- Perforated Rear Baffle
- Slot Exhaust & Optimized Upper Chamber
- Designed to minimize escape by reducing reverse flow
- Reduces air flow 50-75%

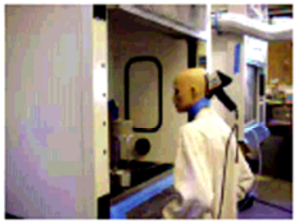
Laboratory Fume Hood Testing for Safety

Smoke in Supply Plenums…

Exhaust:
40% "normal" flow

Ejector:
8L/min.

Breathing Zone:
18 inches



25

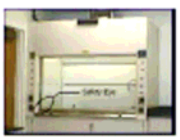
Laboratory Fume Hood Testing for Safety

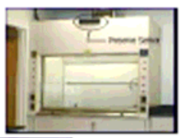
Smoke containment…

Smoke visualization test at 30% "normal" flow

26

7. Combination VAV and Sash Management Using an Automatic Sash Closure System





The New-Tech Automatic Sash Positioning System

27

UC Davis demonstration project Objectives:

- Demonstrate and evaluate an automated fume hood closure system. The project involved retrofit of two VAV controlled fume hoods. The project will:
  - Demonstrate and evaluate emerging technology
  - Document baseline and post retrofit conditions
  - Estimate actual energy and demand impact
  - Demonstrate operator acceptance of the automatic sash closure system
  - Promote the project and the use of auto-closure fume hoods (subject to positive test results)

28

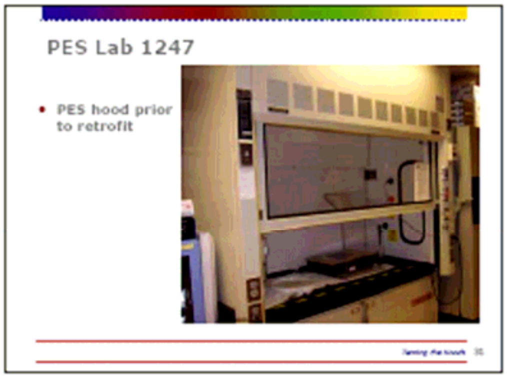
Host Site: Plant and Environmental Sciences (PES)

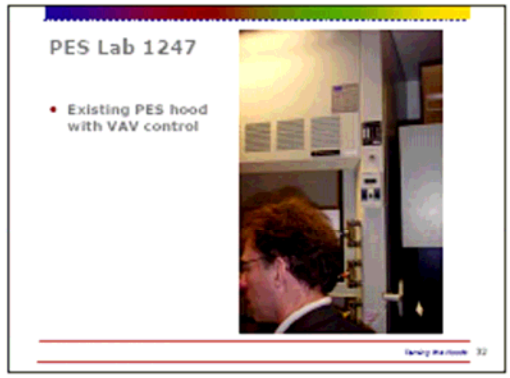
29

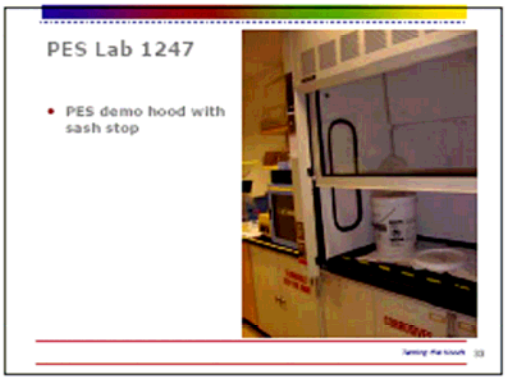
PES Lab 1247

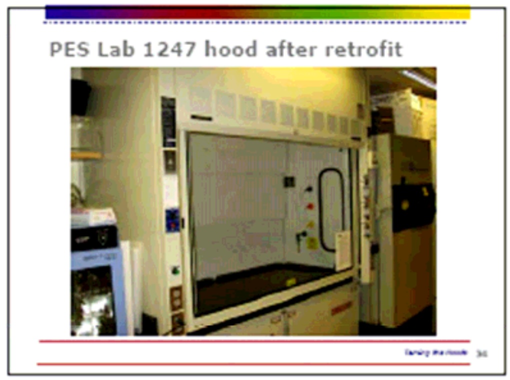
- 11 x 32 feet (350 sqft)
- One six foot hood

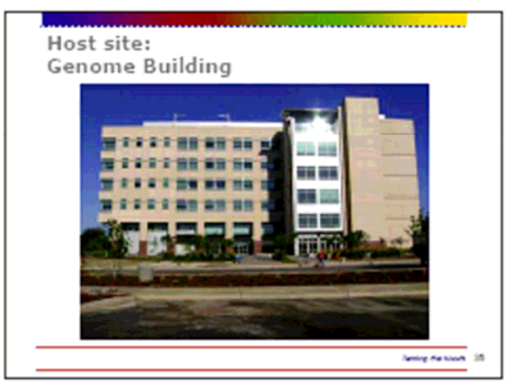
30

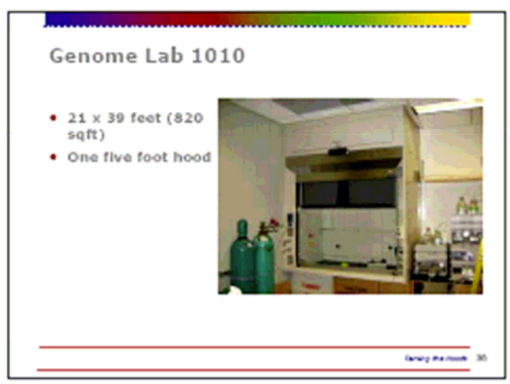

PES Lab 1247
• PES hood prior to retrofit


PES Lab 1247
• Existing PES hood with VAV control


PES Lab 1247
• PES demo hood with sash stop


PES Lab 1247 hood after retrofit

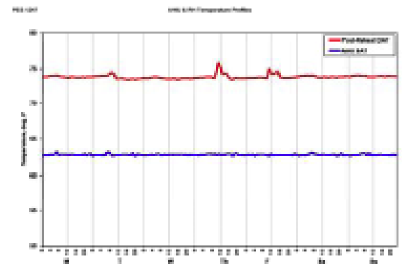

Host site:
Genome Building


Genome Lab 1010
• 21 x 39 feet (820 sqft)
• One five foot hood

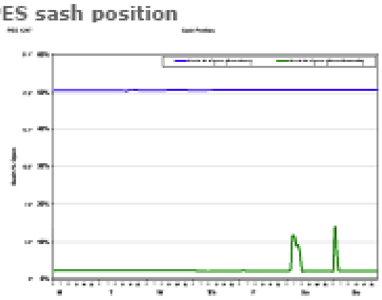
Field Measurements

- Supply air temperature and reheat temperature
- Sash position or fume hood exhaust
- Supply and exhaust air volume to/from the lab (and hood)
- Power and air volume (cfm) of the air handler units (AHUs)
- Power to exhaust fans

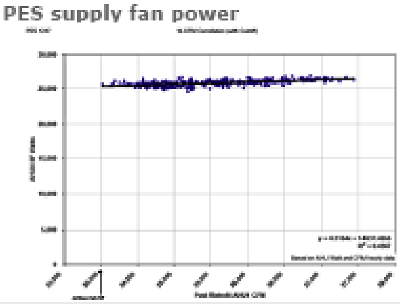
PES supply and reheat temperatures



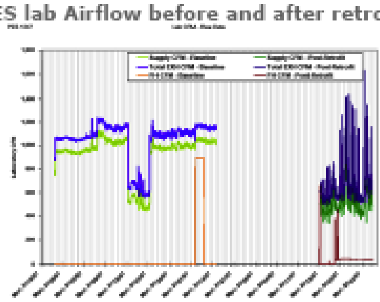
PES sash position



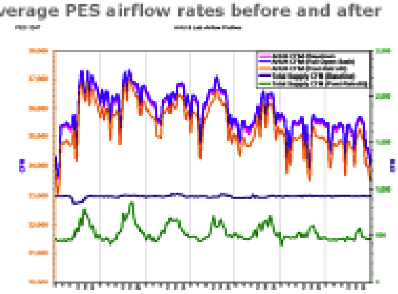
PES supply fan power



PES lab Airflow before and after retrofit

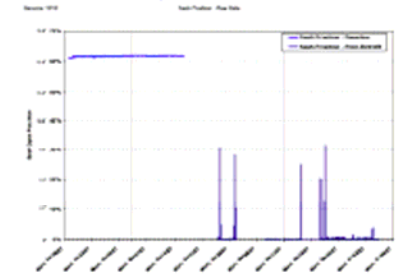


Average PES airflow rates before and after

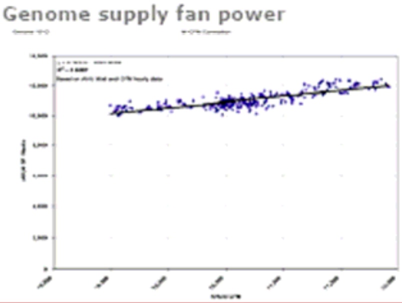


Genome supply and reheat temperatures

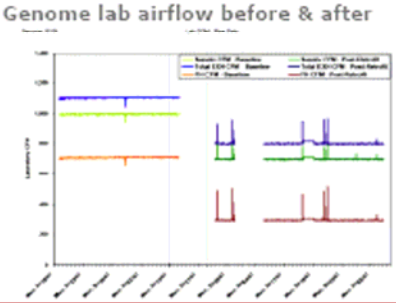
Genome sash position



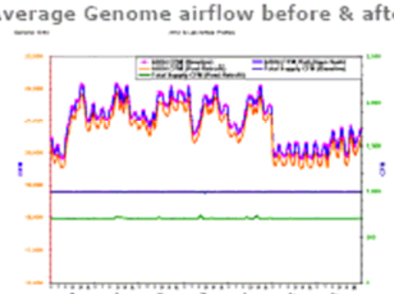
Genome supply fan power



Genome lab airflow before & after



Average Genome airflow before & after



Key measurements:

	PBS	Genome
Hood cfm savings	402 (inc. to 533)	293 (inc. to 433)
Supply air temperature deg. F	63	55
Re-heat temperature deg. F	74 (reduce to 70)	66.2
Supply fan Watts/cfm	.32	.75

- No exhaust fan savings

Key assumptions:

- 1 kW/ton for electric driven chillers
- .15 Therms/ton for gas driven chillers + .4 kW/ton for auxiliary electric needs
- 70% heating system efficiency
- Minimum hood air flow 25 cfm per square foot (NFPA minimum) for a 24" deep interior
- Sash stops at 18"
- Potential savings over a 12" sash travel
- 5'4" by 36" (max) sash opening in PES
- 4'4" by 30" (max) sash opening in Genome
- Combining the above three assumptions:

Taming the hoods 49

Airflow assumptions:

	Airflow in cfm	
	PES	Genome
Nominal (max.)	1600	1083
Design (18" sash stop)	800	650
Minimum (NFPA)	267	217
Savings with 12" sash movement	533	433

Taming the hoods 50

Utility rate assumptions:

	UC Davis	PG&E Commercial
Electricity blended per kWh	$.066	$.10
Gas per therm	$.85	$1.30

Taming the hoods 51

PES annual savings per cfm

Configuration	PES		
	Therms	KWh	$
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)			
1. Base case: 65 deg. F supply, 74 deg. reheat, .32 W/cfm	3.1	4.0	$2.90
2. Fix reheat: reduce to 70 deg. F	2.5	4.0	$2.39
Electric Cooled (assumes 1 kW/ton)			
3. Base case (same as #1)	2.6	5.8	$2.59
4. Fix reheat: reduce to 70 deg. F	2.1	5.8	$2.17
5. Same as #4 w/ normal 55 deg. F supply, 70 deg reheat)	1.9	9.2	$2.25

Taming the hoods 52

PES savings per hood

Configuration	Gas cooled (6 ft. Hood)		Electric cooled (6 ft. Hood)	
	CFM	$	CFM	$
1. As Found (reheat valve leaking)	402	$1,166	402	$1,041
2. Base (reheat valve fixed)	533	$1,274	533	$1,157
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$3,186	1333	$2,893

Taming the hoods 53

PES savings

Taming the hoods 54

Genome annual savings per cfm

Configuration	Genome		
	Therms	KWh	$
Gas Cooled (assumes .15 therms & .4 kW per ton, .7 heating eff., and $.066/kW & $.85/therm)			
1. Base case: 55 deg. F supply, 66.2 deg. F Reheat, .75 W/cfm	3.0	9.2	$3.16
Electric Cooled (assumes 1 kW/ton)			
2. Base case (same as #1)	2.0	13	2.56

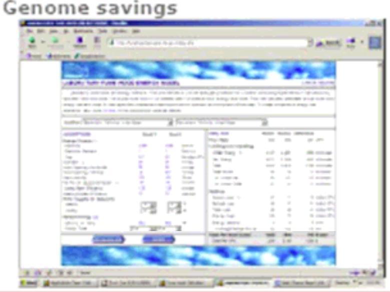
Taming the Hoods 55

Genome savings per hood

Configuration	Gas Cooled (5 ft. Hood)		Electric Cooled (5 ft. Hood)	
	CFM	$	CFM	$
1. Base ("Typical")	293	$926	293	$750
2. Hood driven load (all savings captured)	433	$1,368	433	$1,108
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	866	$2,737	866	$2,217

Taming the Hoods 56

Genome savings



Taming the Hoods 57

Positive characteristics

- VAV was already installed (lowers retrofit cost)
- There was poor sash management (hoods left open)

Taming the Hoods 58

Negative Characteristics

- Low hood density
  - general exhaust and cooling drive the required air flow
  - Genome's 433 cfm potential savings limited to approximately 293 cfm
- Sash stops reduce potential savings
  - 60% at PES
  - 50% at Genome
- Small hood saves less than a larger hood (same cost)
- Low UC Davis utility rates
- Supply fan savings was linear and low
  - .32 and .75 watts per cfm vs. typical 1.8
  - Theoretical cubed function not realized
  - Static pressure reset could yield more savings
- No savings from the constant volume exhaust fans
  - Savings could be increased with a reconfigured system

Taming the Hoods 59

Sensitivity Analysis

- Steam driven cooling vs. electric driven chillers
- Fix PES Reheat
- Standard PES Supply Air Temperature (55 deg. F)
- UC Davis vs. PG&E utility rates
  - Base case (typical) for commercial PG&E customers

Taming the Hoods 60

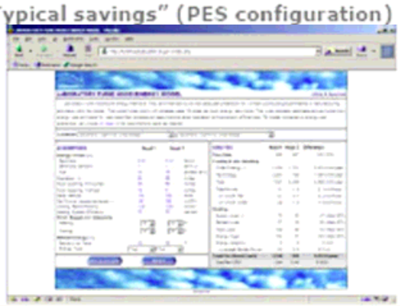
Airflow savings and minimum airflow

Approximate breakdown of airflow	PES	Genome	Genome w/ min air driven by room
Airflow saved by sash stop:	50%	40%	40%
Airflow saved by auto closure system:	33.3%	40%	28%
Minimum airflow (not savable):	16.7%	20%	32%

"Typical" savings per cfm

Configuration	PES			Genome		
	Therms	KWh	$	Therms	KWh	$
Electric Cooled						
6. Commercial PG&E rates (.10/kWh, 1.30/therm)	1.9	9.2	$3.44	2.0	13	3.90

"Typical savings" (PES configuration)



"Typical" savings per hood

Configuration	PES (6 ft. Hood)		Genome (5 ft. Hood)	
	CFM	$	CFM	$
1. Base ("Typical")	533	$1834	293	$1143
2. Hood driven load (all savings captured)	533	$1834	433	$1689
3. Remove sash stops and assume CAV (or open VAV) - most energy intensive scenario	1333	$4586	866	$3377

Demand Savings

	Per CFM	Per Hood (533 cfm PES and 433 cfm Genome)
PES gas cooled	1.6 W	.9 kW
PES electric chiller	3.5 W	1.9 kW
Genome gas cooled	2.3 W	1 kW
Genome electric cooled	4.8 W	2.1 kW

Typical cost per hood

- Small quantities (1-2 test):
  - $5,500
- Larger quantities (lab building):
  - $4,500
- Plus miscellaneous costs:
  - Electrical
  - Compressed air
  - Decontamination
  - Repair of sash operation

New Construction

- Reduced cost of infrastructure (ducts, fans, boilers, and chillers) will offset higher cost of fume hood controls

Issues Encountered

- Low utility cost
- Abnormal supply air temperature
- Leaking reheat valve
- Low fan energy savings
  - Savings closer to linear than cubed function
  - Savings at the margin lower than average (PES)
  - Static pressure reset could help
- Sash safety sensor alignment/sensitivity

The emerging technology of automatic fume hood sash closure systems appears feasible for wide-spread implementation

Recommendations for UC Davis

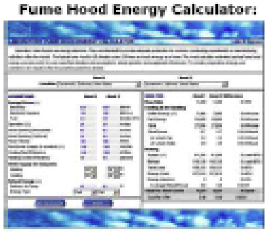
- Fix reheat valve in PES
- Implement static pressure reset control on supply fans
- Commission fume hood and lab controls to minimize excessive (minimum) airflow
- Evaluate optimum supply air temperature
  - 63 deg. F minimizes reheat, but may significantly increase air volume (fan) and cooling
- Monitor sash safety sensor

Recommendations to PG&E

- Develop baselines (e.g. average sash position)
- Run side-by-side tests
- Perform impact analysis and prepare business case
- Develop industry partnerships
- Information transfer
- Develop incentive programs

Resource...

Fume Hood Energy Calculator:



The calculator can be used to test the energy and cost impacts of improving component efficiencies (e.g. fans or space conditioning equipment), modifying face velocities, and varying energy prices. Supply air set points can be varied, as can the type of reheat energy. Several hundred weather locations around the world are available. The calculator allows for an instantaneous comparison of two scenarios.

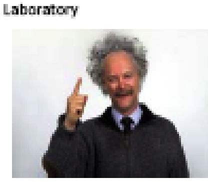
Calculator web site:

http://fumehoodcalculator.lbl.gov/

Contact Information:

Dale Sartor, P.E.
Lawrence Berkeley National Laboratory
Applications Team
MS 90-3111
University of California
Berkeley, CA 94720

DASartor@LBL.gov
(510) 486-5988
http://Ateam.LBL.gov



E. Report to Campus

AUTOMATIC FUME HOOD CLOSURE PILOT

RESULTS SUMMARY

PLANT AND ENVIRONMENTAL SCIENCES LAB 1247 AND GENOME BUILDING LAB 1010, UC DAVIS

Prepared for:
UC DAVIS

Submitted on:
10/20/2007

Prepared by:

Cogent Energy, Inc.
2300 Clayton Road, Suite 480
Concord CA, 94520
Ph: (925) 521-9600
www.cogentenergy.com

Background

Two automatic fume hood sash closure devices were installed on a trial basis in two UC Davis laboratories. One each were installed in Genome Laboratory #1010 and Plant and Environmental Sciences (PES) Laboratory #1247, as part of an automatic fume hood closure pilot project. The primary objectives of the pilot project were as follows:

- Evaluating the feasibility of installing sash closure devices on fume hoods.
- Estimating the energy and demand impact of such a device, per the measurement & evaluation (M&E) plan dated June 11, 2007.
- Evaluating savings from auto closure device applied to both variable air volume and constant volume fume hoods.

Pacific Gas and Electric Company in conjunction with Lawrence Berkeley National Laboratory (LBNL) is compiling the results of this pilot project as applicable to institutional and non-institutional clients. The project background, technology being evaluated, Measurement and Evaluation (M&E) methodology, energy analysis, economic analysis and sensitivity analysis will be described in their report.

This report summarizes the energy and cost savings as applicable for UC Davis for the two test sites.

Appendix A and B include the profiles developed for analysis purposes as part of this project. The data behind these profiles was utilized in the energy models to accurately simulate the air handling systems with and without automatic fume hood sash closure devices installed.

Savings Summary

Table 1 and Table 2 provide a summary of the estimated energy and cost savings associated with the installation of a sash closure device for one fume hood each in PES #1247 and Genome #1010. The savings estimates were performed for two scenarios. The first (Table 1) assumes the use of steam absorption chillers as the prime mover for providing chilled water for the associated air handling units (AHU). The second (Table 2) assumes the use of centrifugal chillers as the prime mover.

The savings listed in these tables have been estimated based on customized energy models developed to simulate the HVAC energy use of the systems serving the test site at each building. These systems include:

- Genome Building – AHU-4, Exhaust Fan EF-2 and forty four (44) associated terminal units
- PES Building - AHU-4, Exhaust Fans EF-7 and EF-8 and thirty eight (38) associated terminal units

Table 3 and Table 4 illustrate the estimated savings and costs associated by extrapolating the results from Table 1 and Table 2 to all the associated fume hoods on the AHU serving the pilot laboratories.

A blended electric rate of $0.066/kWh and an average gas rate of $0.85/therm have been used for this analysis. Other assumptions relating to the energy use have been documented in the M&E Plan developed for this project and is included in Appendix A.

Data and input profiles from the measurement and evaluation process are included in Appendix B and Appendix C.

Table 1. Estimated Energy and Cost Savings from one Auto Sash Closure Retrofit (using Steam Absorption Chillers at Chiller Plant)

Utility Rate Schedule	Location	Steam Absorption Chiller																	
		Baseline					Post-Retrofit					Savings					Cost Savings	Cost	Payback (yrs)
		Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms	Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms	Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms			
Davis	PES 1246	329,941	55,725	0	20,897	84,978	328,826	55,255	0	20,721	83,939	1,115	470	0	176	1,039	$ 1,137	$6,594	5.80
	Genome 1010	506,284	58,189	0	21,821	40,093	504,348	57,344	0	21,504	39,541	1,936	844	0	317	552	$ 922	$6,594	7.15

Table 2. Estimated Energy and Cost Savings from one Auto Sash Closure Retrofit (using Centrifugal Chillers at Chiller Plant)

Utility Rate Schedule	Location	Centrifugal Chiller																	
		Baseline					Post-Retrofit					Savings					Cost Savings	Cost	Payback (yrs)
		Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms	Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms	Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms			
Davis	PES 1246	329,941	55,725	83,587	0	84,978	328,826	55,255	82,883	0	83,939	1,115	470	704	0	1,039	$ 1,034	$6,594	6.38
	Genome 1010	506,284	58,189	87,283	0	40,093	504,348	57,344	86,016	0	39,541	1,936	844	1,267	0	552	$ 737	$6,594	8.95

Table 3. Estimated Economic Summary from retrofit of all associated fume hoods on the AHU serving the pilot laboratory (using Steam Absorption Chillers at Chiller Plant)

Utility Rate Schedule	Location	Steam Absorption Chiller													
		Baseline					Savings					Cost Savings	Cost	Payback (yrs)
		Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms	Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms			
Davis	PES 1246	329,941	55,725	0	20,897	84,978	42,362	17,846	0	6,692	39,478	$43,218	$174,800	4.04
	Genome 1010	506,284	58,189	0	21,821	40,093	85,188	37,152	0	13,932	24,304	$40,575	$202,400	4.99

Table 4. Estimated Economic Summary from retrofit of all associated fume hoods on the AHU serving the pilot laboratory (using Centrifugal Chillers at Chiller Plant)

Utility Rate Schedule	Location	Centrifugal Chiller													
		Baseline					Savings					Cost Savings	Cost	Payback (yrs)
		Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms	Fan kWh	Cooling Aux. kWh	Cooling kWh	Cooling therms	Heating therms			
Davis	PES 1246	329,941	55,725	83,587	0	84,978	42,362	17,846	26,769	0	39,478	$39,297	$174,800	4.45
	Genome 1010	506,284	58,189	87,283	0	40,093	85,188	37,152	55,728	0	24,304	$32,411	$202,400	6.24

APPENDIX A

MEASUREMENT AND EVALUATION (M&E) PLAN

AUTOMATIC FUME HOOD CLOSURE PILOT

MONITORING AND EVALUATION PLAN

PLANT AND ENVIRONMENTAL SCIENCES LAB 1247 AND GENOME BUILDING LAB 1010, UC DAVIS

PREPARED FOR:

PACIFIC GAS & ELECTRIC COMPANY

AND

LAWRENCE BERKELEY NATIONAL LABORATORY

Submitted on:
6/11/2007

Prepared by:

Cogent Energy, Inc.
2300 Clayton Road, Suite 480
Concord CA, 94520
Ph: (925) 521-9600
www.cogentenergy.com

Background

As part of a pilot project to demonstrate and assess the effectiveness of automatic fume hood sash closure devices, Cogent Energy has developed this Monitoring & Evaluation Plan. The purpose of the Plan is to outline the methods that will be used to estimate the energy and demand savings realized from the trial installation of two of these devices in campus laboratories. The application of this device is intended for two position and Variable Air Volume (VAV) type laboratory airflow control systems.

The automatic fume hood closure device operates by closing the sash after a set interval (typically one minute, adjustable) if it does not detect an occupant or any activity in front of the fume hood. The device is intended to reduce fume hood exhaust airflow which should lead to a reduction of supply airflow.

It is expected that lower supply airflow will result in lower cooling and heating (including reheat) energy use. Energy and demand savings would be realized at the fans and in the central plant cooling and heating systems. Note that energy savings at the hot water and chilled water distribution pumps are assumed to be negligible and are not included in the savings boundary of this project.

The primary requirements for choosing the test sites were that they contain VAV type laboratory airflow control systems including Direct Digital Controls (DDC) on the supply and exhaust for airflow monitoring. After investigating a number of possible options such as Life Sciences Addition, CCM and Equine AC Lab (Maddy Lab) the project team selected PES #1247 and Genome Lab #1010 as pilot test sites.

PES Lab #1247 is an 11 foot by 32 foot laboratory with one 6 foot fume hood. Supply air is delivered to the room by air handler AHU-4 and regulated by a make-up air valve. Fume hood and general room exhaust is provided by a general exhaust air duct served by two constant-volume exhaust fans EF-7 and EF-8. There are 43 other make-up air valves on AHU-4 (total 44).

Genome Lab #1010 is a 21 foot by 39 foot laboratory with one 4 foot fume hood. Supply air is delivered to the room by air handler AHU-4 and regulated by a variable air volume terminal. Fume hood and general room exhaust is provided by a general exhaust air duct served by one constant-volume exhaust fan EF-2. There are 37 other VAV terminals on AHU-4.

Facility Contact Information

Elaine Bose
Safety Coordinator
Department of Plant Sciences
UC Davis
Davis, CA 95616
(530) 752-6915
eabose@ucdavis.edu

Debbie Decker
Campus Chemical Safety Officer
EH&S
167 Hoagland Hall, UC Davis
Davis, CA 95616
(530) 754-7964
dmdecker@ucdavis.edu

Project Objectives

The primary objectives of the automatic fume hood closure pilot project are to:

- Evaluate the feasibility of installing sash closure devices on fume hoods.
- Estimate the energy and demand impact of using this device via this M&E process.
- Evaluate savings of VAV vs. constant volume hood control, and savings from auto closure vs. both existing VAV and constant volume operation.

The following sections present the methodologies that will be used to estimate the energy and demand impact of utilizing this device, specific to the two test sites.

Monitoring and Evaluation Approach

The approach described here uses monitored data along with other observations, assumptions, calculations, and documentation to define baseline performance, and to estimate energy savings that are attributable to the project.

Sources of Expected Energy and Demand Reductions

It is expected that through the application of this technology, energy and demand reductions will be realized in the following systems:

1. PES
    - i. Supply fan energy and demand due to reduced airflow
    - ii. Cooling energy (via chilled water, measured in ton-hours) due to reduced ventilation rates (as this is a 100% outside air system)
    - iii. Heating energy (including reheat) due to reduced ventilation rates
2. Genome Building
    - i. Supply fan energy and demand due to reduced airflow
    - ii. Cooling energy (via chilled water, measured in ton-hours) due to reduced ventilation rates (as this is a 100% outside air system)
    - iii. Heating energy (including reheat) due to reduced ventilation rates

Note:

1. Exhaust Fans at both building are single speed constant volume type and minimal energy savings are expected.
2. Chilled Water pumping and cooling tower heat rejection energy savings at the central chiller plant and building level are included in the overall chiller plant kW/ton usage.
3. Hot water pumping energy savings at the building heating plants are not included.

Monitoring Equipment

The majority of the operational data for both test sites will be gathered using the existing Siemens Apogee Energy Management System (EMS). Please refer to the control points list in Appendix A.

Additionally, portable data loggers will be used to estimate the amount of heating (or reheat) by measuring the temperature difference across the reheat coil (combined with air flow from the EMS).

The fume hood face velocity will be spot checked during a field visit for both test sites.

The total fan supply airflow will be measured using the EMS for both test sites. The supply CFM for all the terminal units (or make-up valves) supplied by the test AHU will be added to arrive at the total supply airflow. Supply fan kW will also be made available through the EMS.

It is expected that a reasonable variation in AHU supply airflow and kW will be visible in the collected trend data and that data will be used to determine the change in power for a corresponding change in CFM in the operating range of the AHU i.e., a marginal $\Delta W/\Delta CFM$ parameter will be arrived at for both test sites.

Spot measurements of the exhaust fan kW will be conducted for both sites over the natural operating range (morning vs. late afternoon) to confirm the assumption that the exhaust fan kW is relatively constant for the single speed exhaust fan motors.

Temporary monitoring equipment will be installed at the test site at PES to determine the fume hood sash position in order to estimate the fume hood exhaust airflow using an average face velocity of 100 feet per minute.

Monitoring and Evaluation Procedure

The intent of this M&E procedure is to estimate the energy and demand impact of using this device and will be divided into the four following steps:

STEP 1 - Establish baseline operational profiles for fume hood sash position
STEP 2 - Establish operational profiles with sash locked at full open
STEP 3 - Establish post retrofit operational profiles for fume hood sash position
STEP 4 – Establish supply/exhaust airflow profiles and estimate annual energy use for STEPS 1, 2 and 3 and calculate energy savings

The process is aimed at developing baseline operational profiles (STEP 1) for the sash position. Corresponding profiles will be developed during STEP 2 (sash locked at the full open position) and STEP 3 (post retrofit). These profiles will then be extrapolated to annual profiles based on the measured data with the assumption that the sash usage during the monitored period is representative of typical use.

The corresponding AHU supply and exhaust airflow profiles will be developed during STEP 4 in the following manner.

<u>AHU Supply Airflow profile</u>

The AHU supply airflow needs to be determined for developing the AHU supply airflow profile. This control point was programmed in the EMS on May 25, 2007 after the automatic sash positioner installation on May 24, 2007. Thus AHU supply airflow data for the AHU is not available for the baseline or sash full open conditions.

The AHU supply airflow profile for a typical week for STEP 3 (post retrofit) will be developed using the trend data from May 25, 2007 onwards.

Lab supply airflow data for the baseline period (STEP 1) prior to the installation of the automatic sash positioner will be utilized to develop an hourly lab supply airflow profile. The difference in CFM between this profile and the hourly lab supply airflow for STEP 3, will be added to the AHU supply airflow profile from STEP 3 to establish a supply airflow profile for STEP 1.

Sustained trending over a week or two week period is not critical for STEP 2 as the fume hood will be full open and it is expected that the lab airflow will remain relatively constant. The fume hood will be locked open for a few minutes and the difference in lab supply airflow at such condition to the lab supply airflow from STEP 1, will be added to the AHU supply airflow profile from STEP 1 to establish a supply airflow profile for STEP 2.

<u>Exhaust Fan Airflow profile</u>

At PES, the exhaust fans EF-7 and EF-8 are dedicated to AHU-4 (which serves lab #1247) and the exhaust fan airflow profile for STEP 3 will be developed using the total exhaust airflow control point made available in the EMS on May 25, 2007.

At Genome, the exhaust fan EF-2 is not dedicated to AHU-4 (which serves lab #1010) and the exhaust airflow will be estimated either by (1) adding up the supply vs. exhaust offsets for each of the labs served by AHU-4 or (2) mathematically using the spot measurements of exhaust fan kW and engineering calculations.

It is assumed that there will be little or no change in the exhaust fan airflow and the exhaust fan airflow profile developed for STEP 3 will be utilized for STEP 1 and STEP 2.

Also in STEP 4, a customized energy model (spreadsheet based bin simulation) will be developed to estimate the annual energy use of the post retrofit condition based on the operational profiles developed in STEP 3 and STEP 4. The monitored points such as AHU supply air temperature and heating (including reheat) temperature will be utilized in the model to simulate the observed conditions as accurately as possible. Total fan airflow will be determined and utilized as described in the Monitoring Equipment section.

Also, the same model will be utilized to estimate the annual energy use corresponding to STEP 1 and STEP 2 by simply inserting the operational profiles developed for those "STEPs" and using the marginal ΔW/ΔCFM parameter as applicable. The differences in annual energy use estimated by the models for the different "STEPs" will determine the energy and demand savings.

The following steps apply to both sites unless specifically noted.

STEP 1 - Establish baseline operational profiles

1. Assess baseline (restricted sash) sash management and develop sash position profile
    a. Sash monitoring or fume hood exhaust airflow monitoring to determine typical sash position over a one or two week period
    b. Develop sash position schedule for typical week

    Note: Control points for sash position and fume hood airflow as well as general exhaust airflow are available at Genome building EMS. Temporary monitoring equipment to determine sash position and an assumed face velocity (at 100 fpm) will be used to establish the sash position and fume hood exhaust at PES.

2. Develop operational profiles for supply/exhaust airflow
    a. These will be developed in STEP 4.

STEP 2 - Establish operational profiles with sash locked at full open

1. Assess sash management (Note: this is *not applicable* as the sash will be forced to remain full open during this period).
2. Develop operational profiles for supply/exhaust airflow
    a. These will be developed in STEP 4.

STEP 3 - Establish post retrofit operational profile

1. Assess post retrofit sash management and develop sash position profile
    a. Sash monitoring or fume hood exhaust airflow monitoring to determine typical sash position over a one to two week period
    b. Develop post-retrofit sash position schedule for typical week

Note: Control points for sash position and fume hood airflow as well as general exhaust airflow are available at Genome building EMS. Temporary monitoring equipment to determine sash position and an assumed face velocity (at 100 fpm) will be used to establish the sash position and fume hood exhaust at PES.

2. Develop post-retrofit operational profiles for supply/exhaust airflow
    a. These will be developed in STEP 4.

STEP 4 – Calculate energy savings

1. Develop operational profiles for supply/exhaust airflow as explained in the Monitoring and Evaluation Procedure section.
2. Develop customized energy model to simulate energy use for STEPS 1, 2 and 3. The model will account for supply fan energy, exhaust fan energy, cooling energy and heating (including reheat) energy in the following manner.
    a. Supply Fan Energy - Estimate supply fan energy using the supply airflow profile for the STEP 3 and the marginal ΔW/ΔCFM parameter for STEP 1 and STEP 2.

Note: Fan kW and AHU CFM will be monitored directly using the EMS at both buildings. The marginal ΔW/ΔCFM parameter developed during STEP 3 will be applied to the additional airflow in STEP 1 and STEP 2 to estimate additional fan KW.

    b. Exhaust Fan Energy – Estimate exhaust fan energy using spot measurements of motor kW. Both buildings have single speed constant volume type exhaust fans and exhaust fan energy will remain relatively constant. Also, exhaust fan energy is not expected to change much between STEPS 1, 2 and 3.

Note: Where more than one exhaust fan is connected to a common plenum, exhaust fan energy will be calculated using design data and engineering calculations.

    c. Cooling energy - Estimate cooling energy using the supply airflow profiles for the respective STEP, Outside Air Temperature (OAT) (for UC Davis Climate Zone) and Discharge Air Temperature (DAT) at the AHU. OAT and DAT will be monitored at the EMS. Although, it is intended to use the TMY 30 climatic data (OAT) for the UC Davis Climate Zone, the OAT is being monitored so that the operational profiles can be normalized based on weather if needed.

    The cooling energy will be estimated by modeling electric centrifugal and absorption chillers as the source of chilled water. A chiller plant efficiency of 1 kW/ton will be used for electric centrifugal chillers. A COP of 0.8 will be used to convert CHW ton-hrs to estimate the equivalent gas usage at the absorption chillers at UC Davis chiller plant and an additional 0.4 kW/ton will be used to account for the auxiliary electric usage when using absorption chillers.

    d. Heating energy (including reheat) - Estimate heating (and reheat) energy using the supply airflow profiles, Outside Air Temperature, Discharge Air Temperature (DAT) at the AHU and Reheat Air Temperature. Significantly less reheat energy is expected at PES as the building operates at a higher system DAT than Genome building. We will use a nominal heating plant efficiency of 70%.

2. Establish annual energy use for each STEP.

3. Determine energy savings between baseline energy use (STEP 1) and post-retrofit energy use (STEP 3) based on one hood retrofit.
4. Determine energy savings between baseline energy use (STEP 1) and post-retrofit energy use (STEP 3) based on retrofit of all hoods at the building.
5. Determine energy savings between sash locked at full open (STEP 2) and post-retrofit energy use (STEP 3) based on one hood retrofit. This step will help illustrate an example of savings for a site with poor sash management practices.
6. Determine energy savings between sash locked at full open (STEP 2) and post-retrofit energy use (STEP 3) based on retrofit of all hoods at the building. This step will help illustrate an example of savings for a site with poor sash management practices
7. Determine energy savings between constant volume operation and post-retrofit energy use (STEP 3) based on retrofit of all hoods at the building. (It is possible that operation under STEP 2 with sash locked open will be similar to a constant volume operation)
8. Determine the above energy savings for an alternate PES operating condition i.e., with a constant 55°F discharge air temperature.

Appendix A

The following is a list of points to be trended by the EMS, to be used for the energy calculations

Table 1: Trending Points List at PES

	Building	**PES**				
	Lab #	**1247**				
	Point Desciption	**Identifier**	**Trend Interval**	**Type**	**Status**	**Notes**
1	Hood Sash position	# 1247	5 mins	AI		Using temporary monitoring equipment
2	Fume Hood Exhaust Airflow CFM	# 1247 (HEV)				Calculated from Sash position and assumed face velocity
3	General Exhaust Airflow CFM	# 1247 (EXV)	5 mins	AI		Calculate from Overall Exhaust Airflow & Hood Airflow
4	Lab Supply Ariflow CFM	# 1247 (MAV)	5 mins	AI	Exists	
5	Overall Exhaust Airflow CFM	# 1247	5 mins	AI	Exists (EXV CFM + HEV CFM)	
6	Exhaust Fan Speed	EF 7/8	NA	NA	NA	* CAV Exhaust Fans
7	Supply Fan Speed (Hz)	AHU 4	5 mins	AI	Exists	
8	Supply Fan Static Pressure	AHU 4	5 mins	AI	Exists	
9	Exhaust Fan Static Pressure	EF 7/8	5 mins	AI	Exists	
10	OAT	--	5 mins	AI	Exists	
11	DAT (at AHU 4)	AHU 4	5 mins	AI	Exists	
12	Reheat Temp (at Diffuser)	# 1247	5 mins	AI	Install Logger	Using temporary monitoring equipment
13	Reheat Valve Posn	# 1247	5 mins	AI	Exists	
14	Room Temperature	# 1247	5 mins	AI	Exists	
15	MAV Valve Position	# 1247 (MAV)			Not Available	These will not be monitored
16	HEV Valve Position	# 1247 (HEV)			Not Available	These will not be monitored
17	EXV Valve Position	# 1247 (EXV)			Not Available	These will not be monitored
18	AHU 4 Supply CFM	AHU 4	5 mins	AI	Added	
19	EF7 & EF8 Exhaust CFM	EF 7/8	5 mins	AI	Added	

Table 2: Trending Points List at Genome

	Building	**Genome**				
	Lab #	**1010**				
	Point Desciption	**Identifier**	**Trend Interval**	**Type**	**Status**	**Notes**
1	Hood Sash position	# 1010	5 mins	AI	Exists	
2	Fume Hood Exhaust Airflow CFM	# 1010 (HEV)				
3	General Exhaust Airflow CFM	# 1010 (EXV)				
4	Lab Supply Ariflow CFM	# 1010 (VAV)	5 mins	AI	Exists	
5	Overall Exhaust Airflow CFM	# 1010	5 mins	AI	Exists (EXV CFM + HEV CFM)	
6	Exhaust Fan Speed	EF 7/8	NA	NA	NA	* CAV Exhaust Fans
7	Supply Fan Speed (Hz)	AHU 4	5 mins	AI	Exists	
8	Supply Fan Static Pressure	AHU 4	5 mins	AI	Exists	
9	Exhaust Fan Static Pressure	EF 7/8	5 mins	AI	Exists	
10	OAT	--	NA	NA	NA	Use from PES
11	DAT (at AHU 4)	AHU 4	5 mins	AI	Exists	
12	Reheat Temp (at Diffuser)	# 1010	5 mins	AI	Install Logger	Using temporary monitoring equipment
13	Reheat Valve Posn	# 1010	5 mins	AI	Exists	
14	Room Temperature	# 1010	5 mins	AI	Exists	
15	VAV Damper Position	# 1010 (VAV Dmpr%)	5 mins	AI	To be programmed	
16	HOOD Damper Position	# 1010 (Hood Dmpr%)	5 mins	AI	To be programmed	
17	EXH Damper Position	# 1010 (Exh Dmpr%)	5 mins	AI	To be programmed	
18	AHU 4 Supply CFM	AHU 4	5 mins	AI	Added	

APPENDIX B

PLANT AND ENVIRONMENTAL SCIENCES (PES) PROFILES

PES

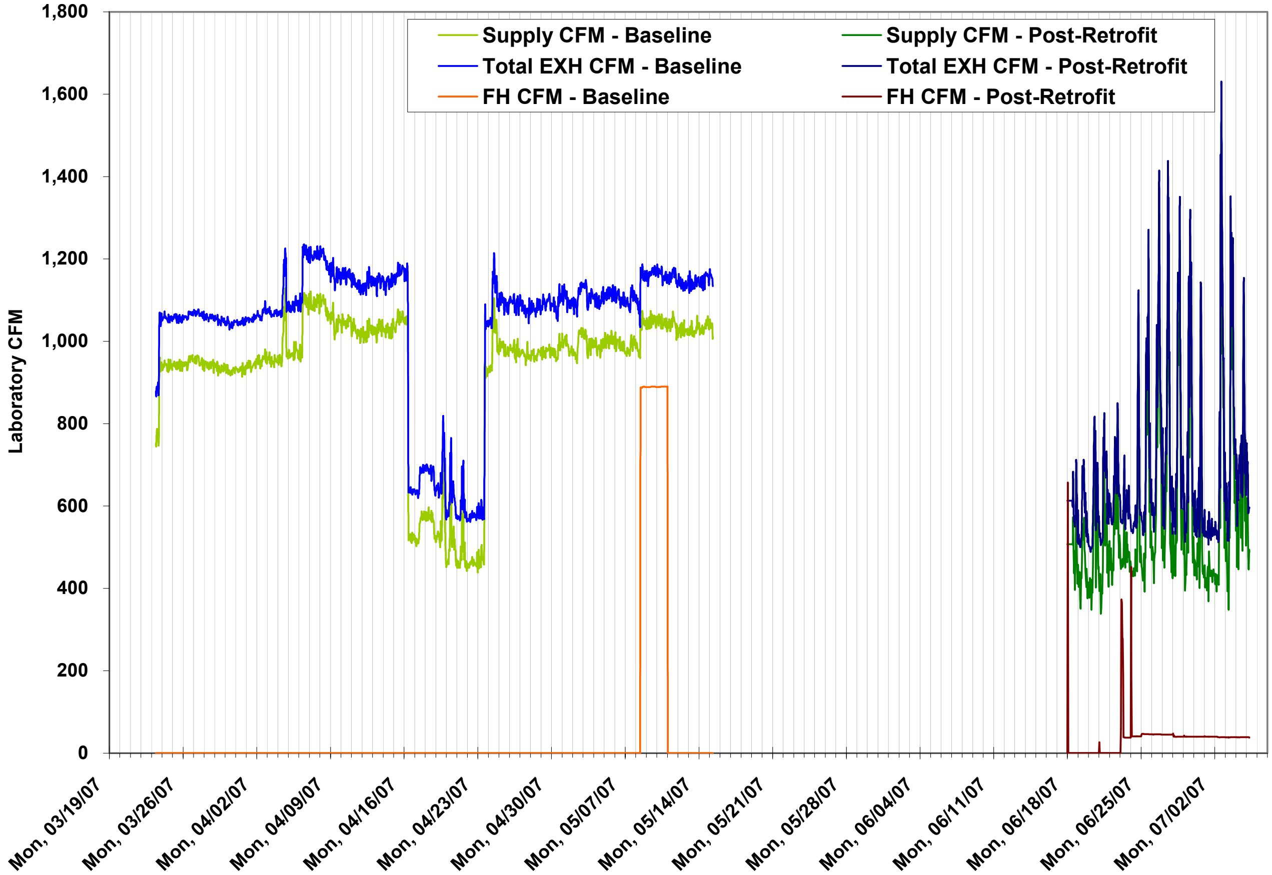


Figure 1.1: Laboratory Airflow - Raw Data - PES 1247

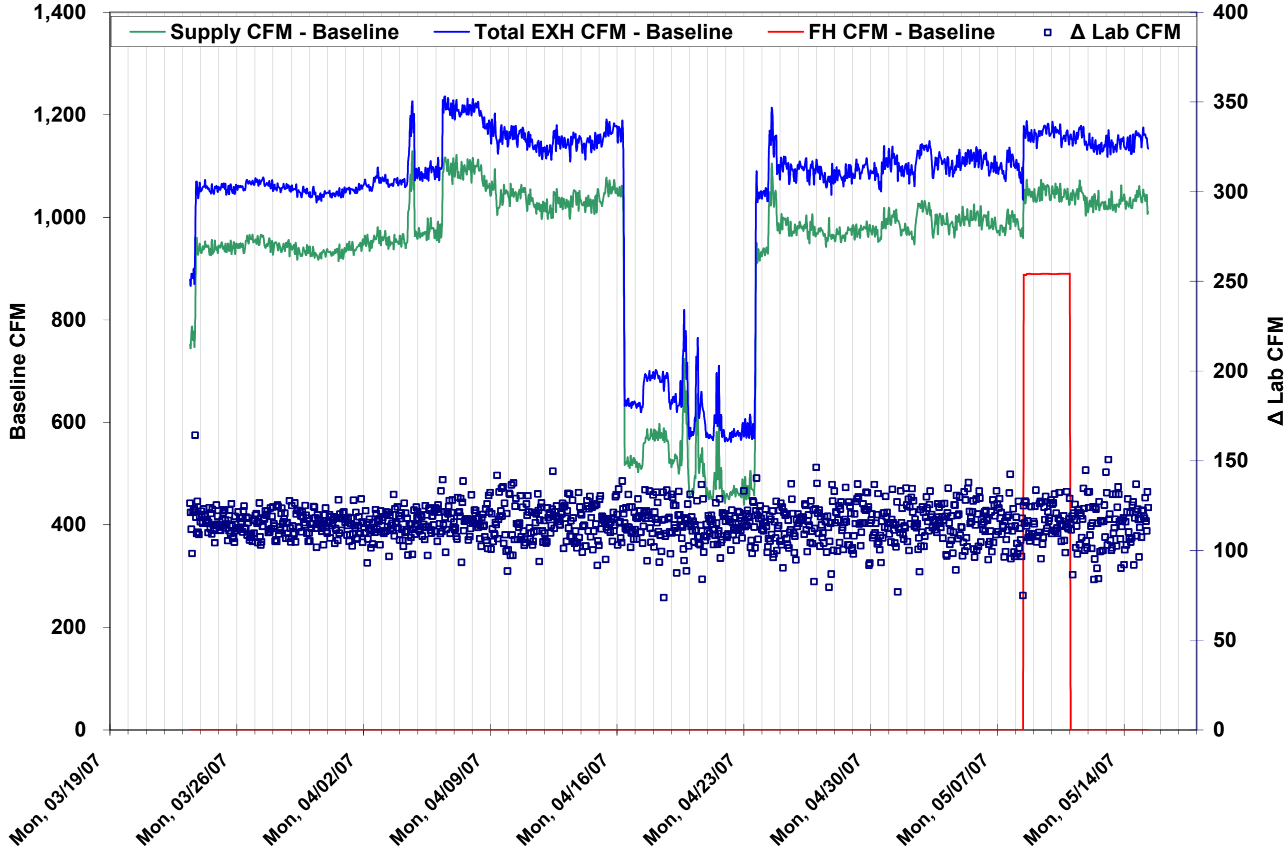


Figure 1.2: Laboratory Baseline Airflow - Raw Data - PES 1247

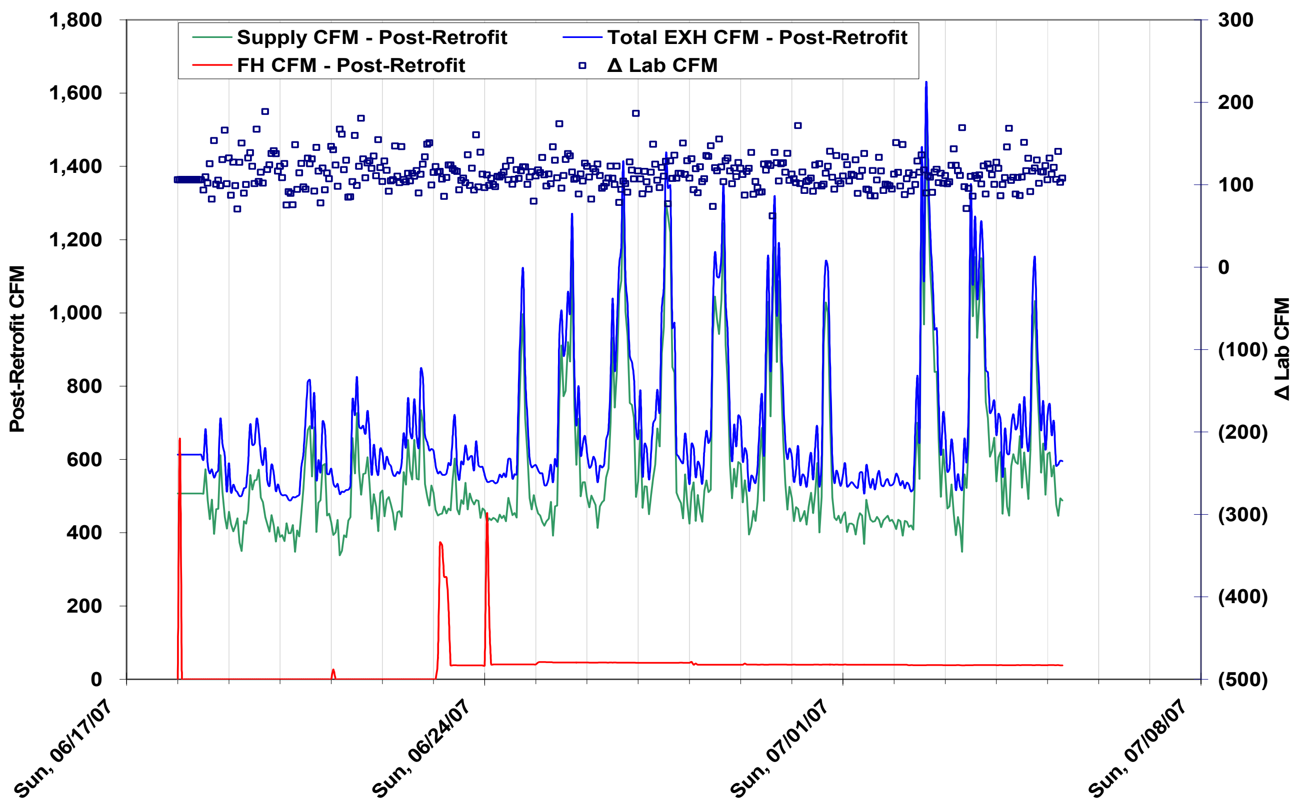


Figure 1.3: Laboratory Post-Retrofit Airflow - Raw Data - PES 1247

Cogent Energy

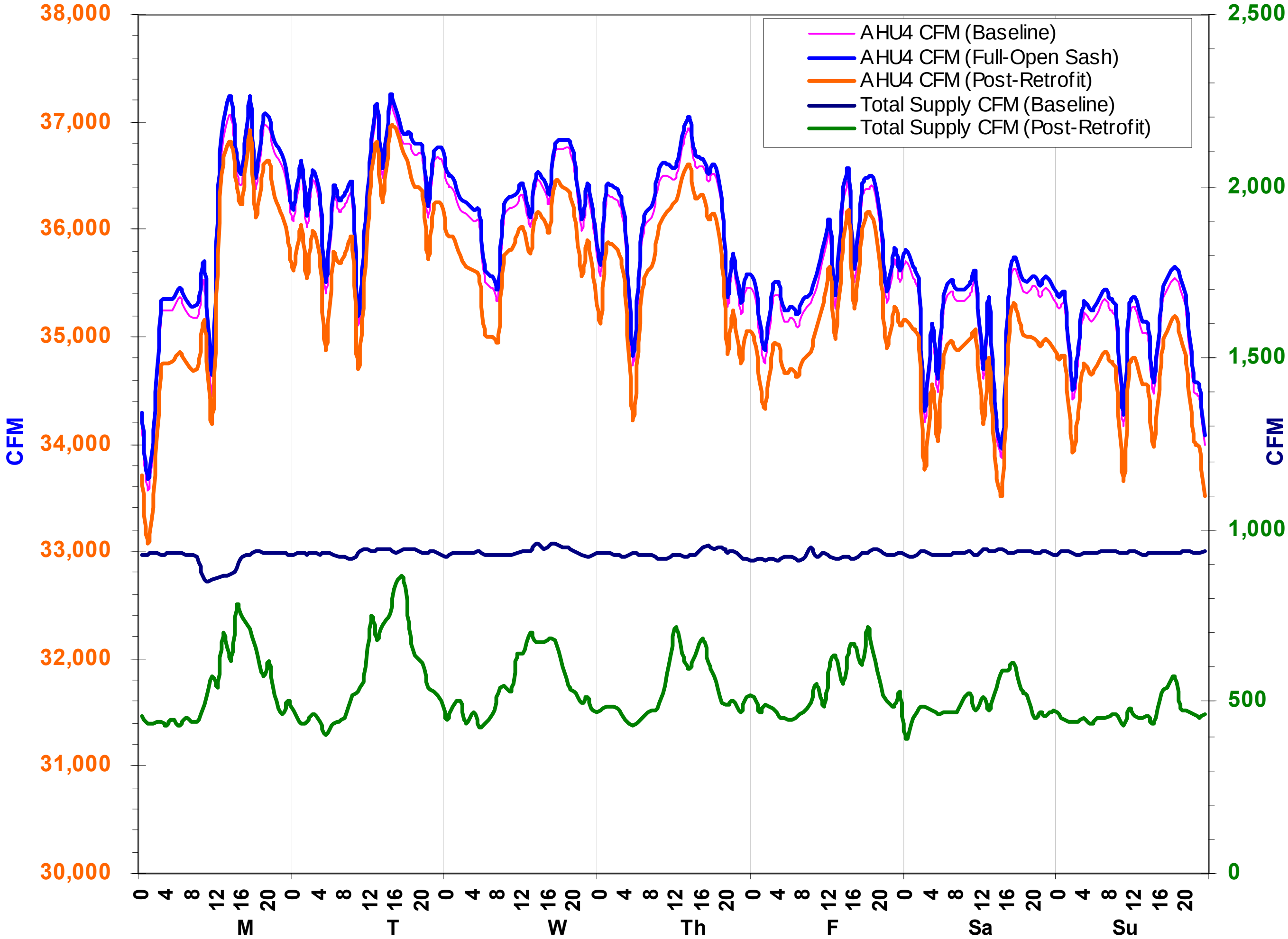


Figure 1.4: Laboratory Supply and AHU Airflow - Profiles - PES 1247

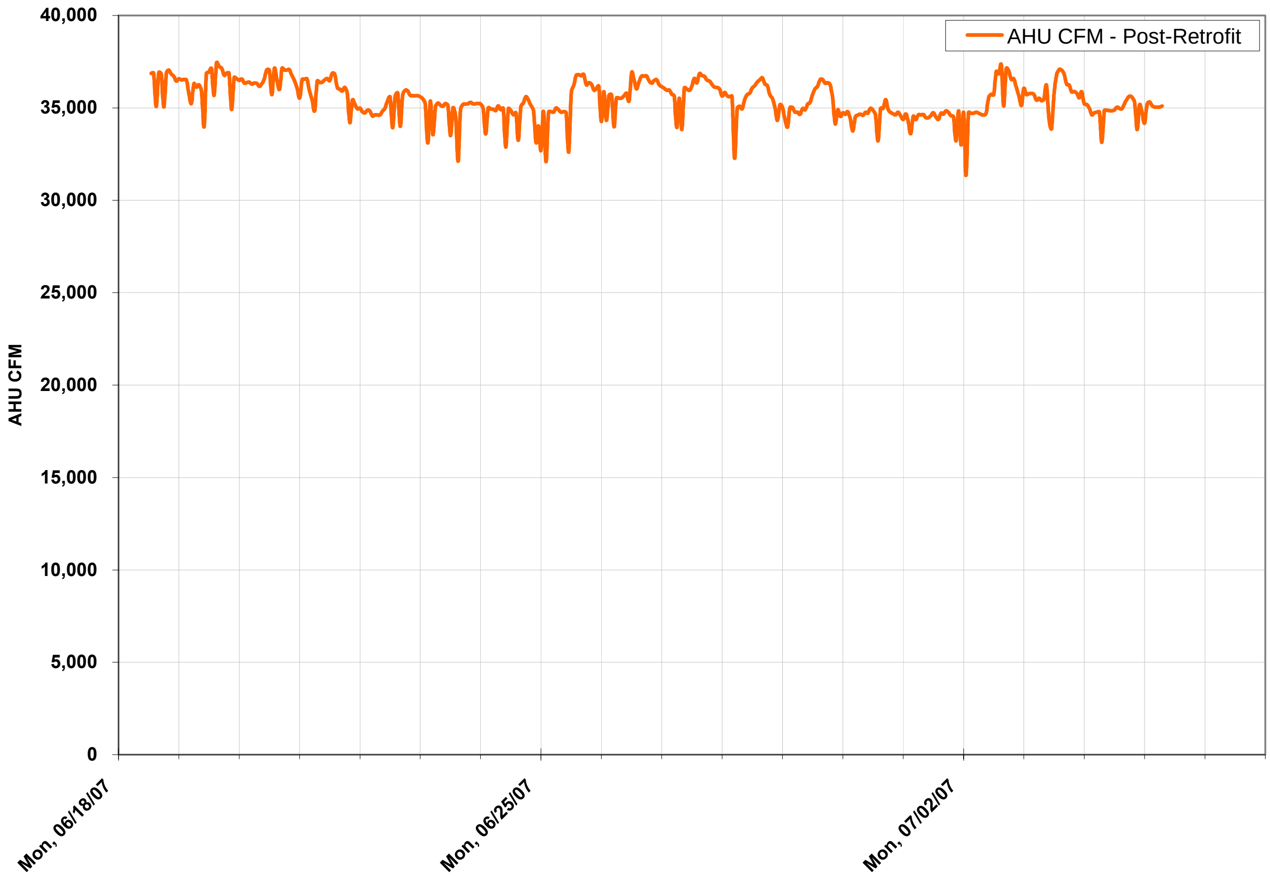


Figure 1.5: AHU Post-Retrofit Airflow – Raw Data - PES 1247

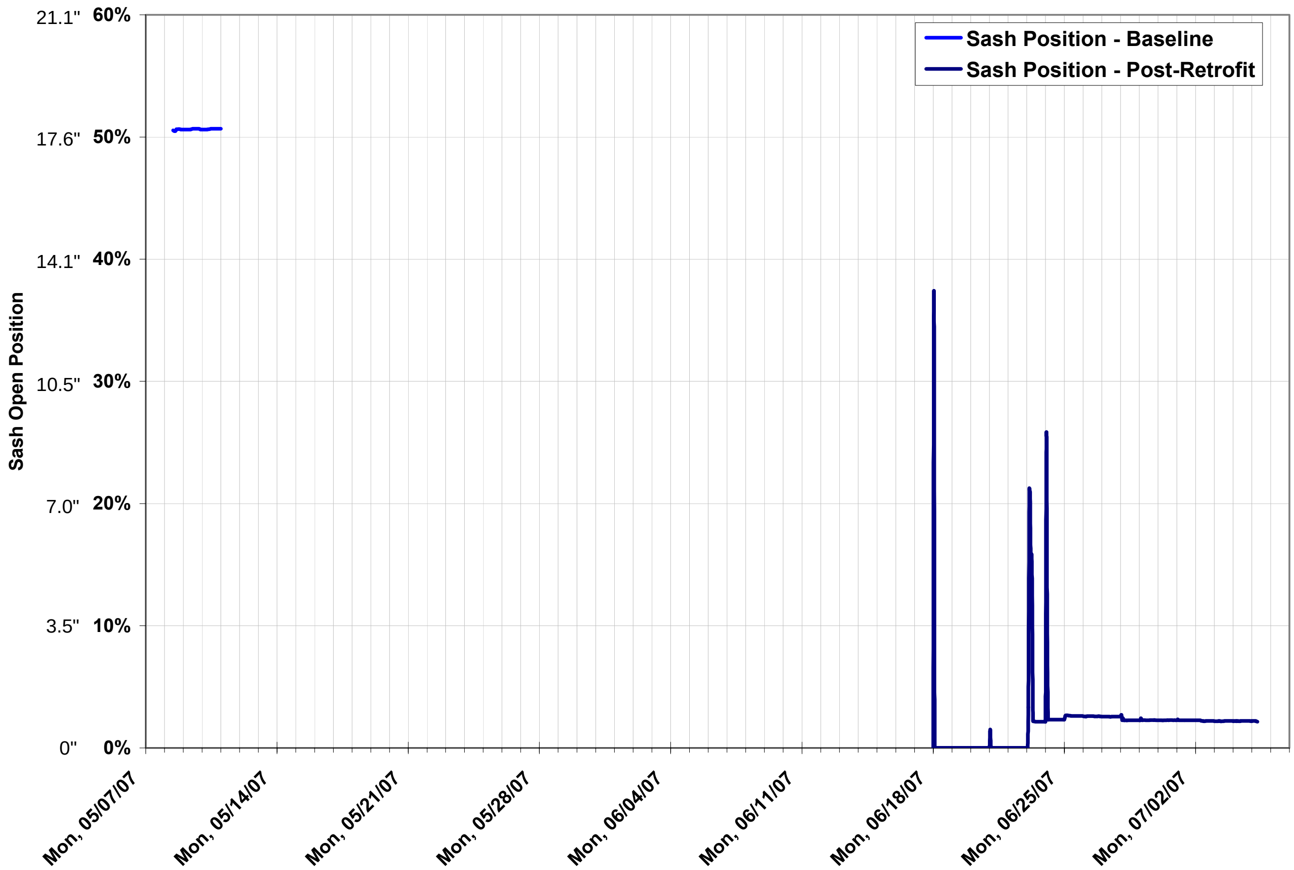


Figure 1.6: Sash Open Position - Raw Data - PES 1247

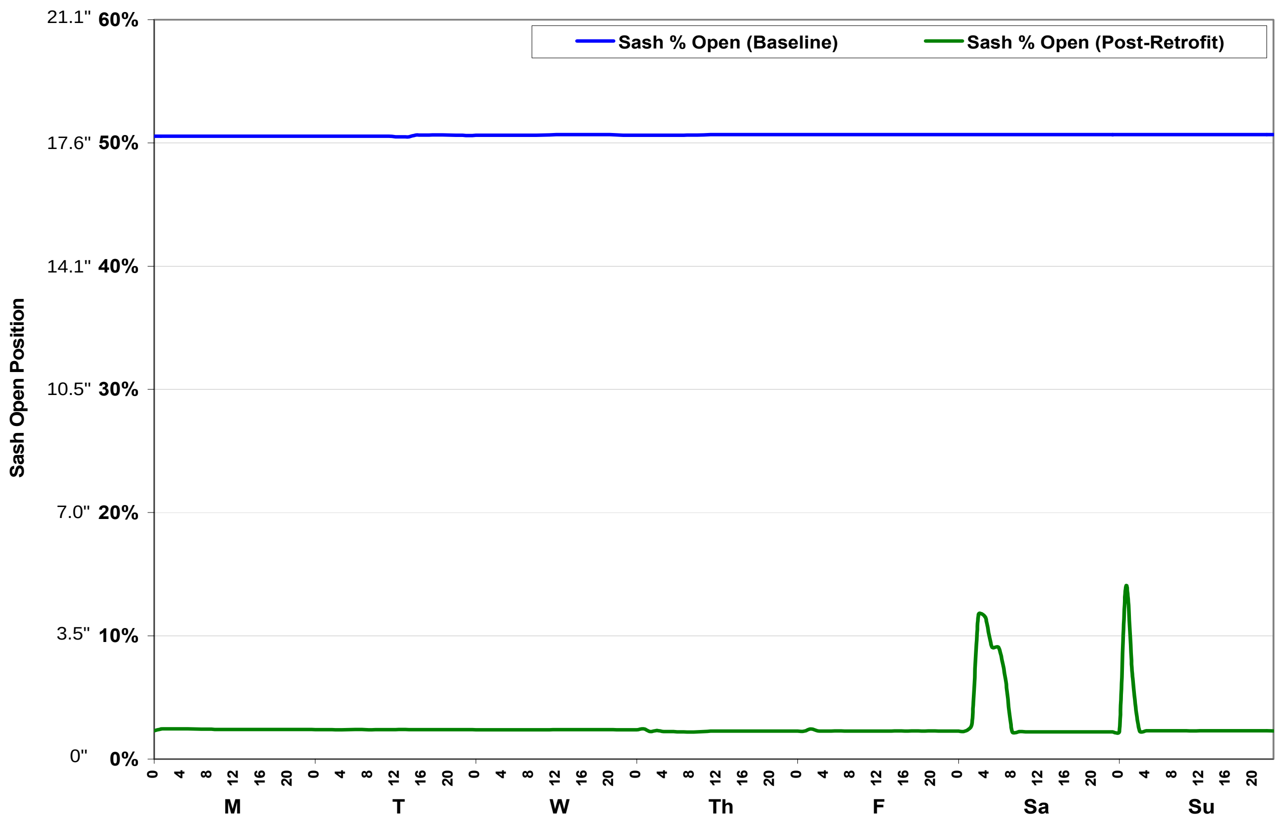


Figure 1.7: Sash Open Position - Profiles - PES 1247

Cogent Energy

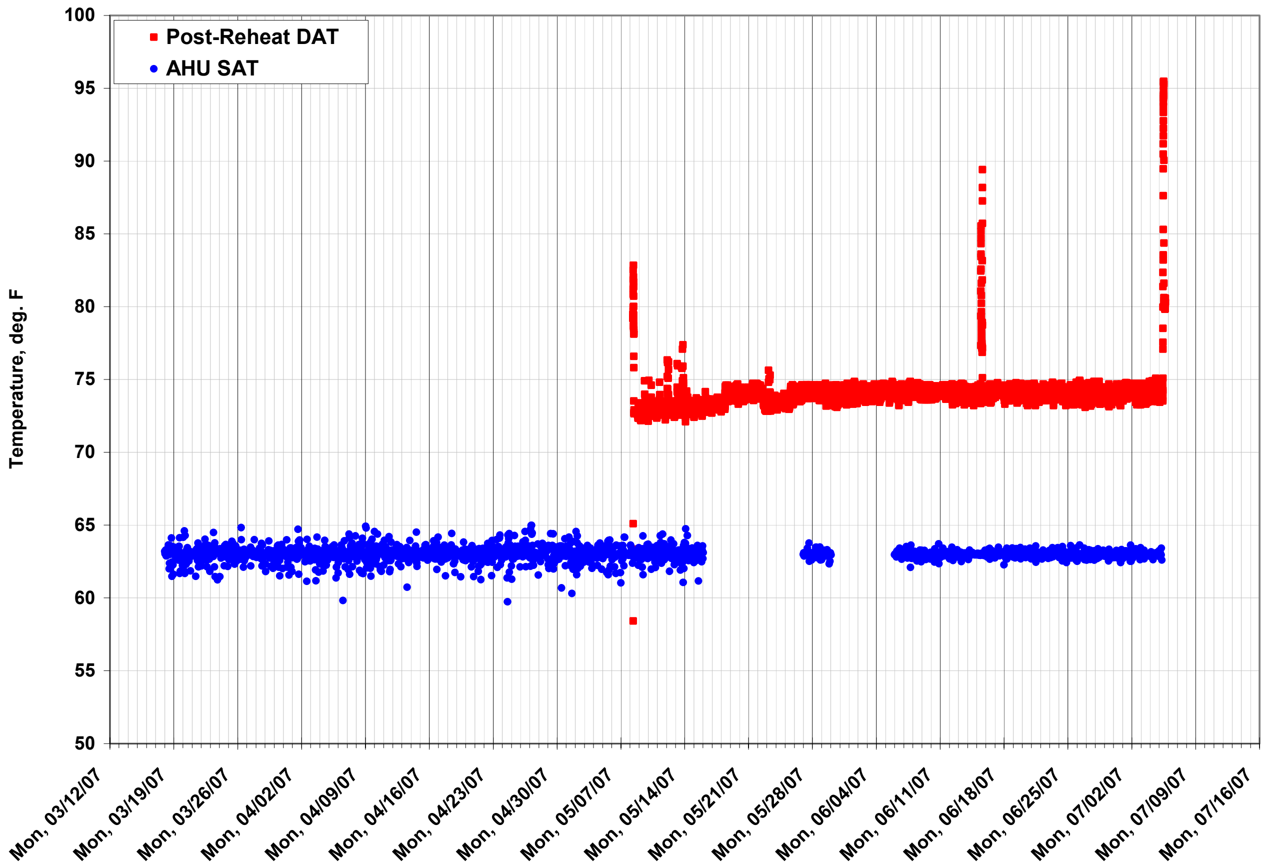


Figure 1.8: AHU Supply and Post-Reheat Discharge Temperatures – Raw Data - PES 1247

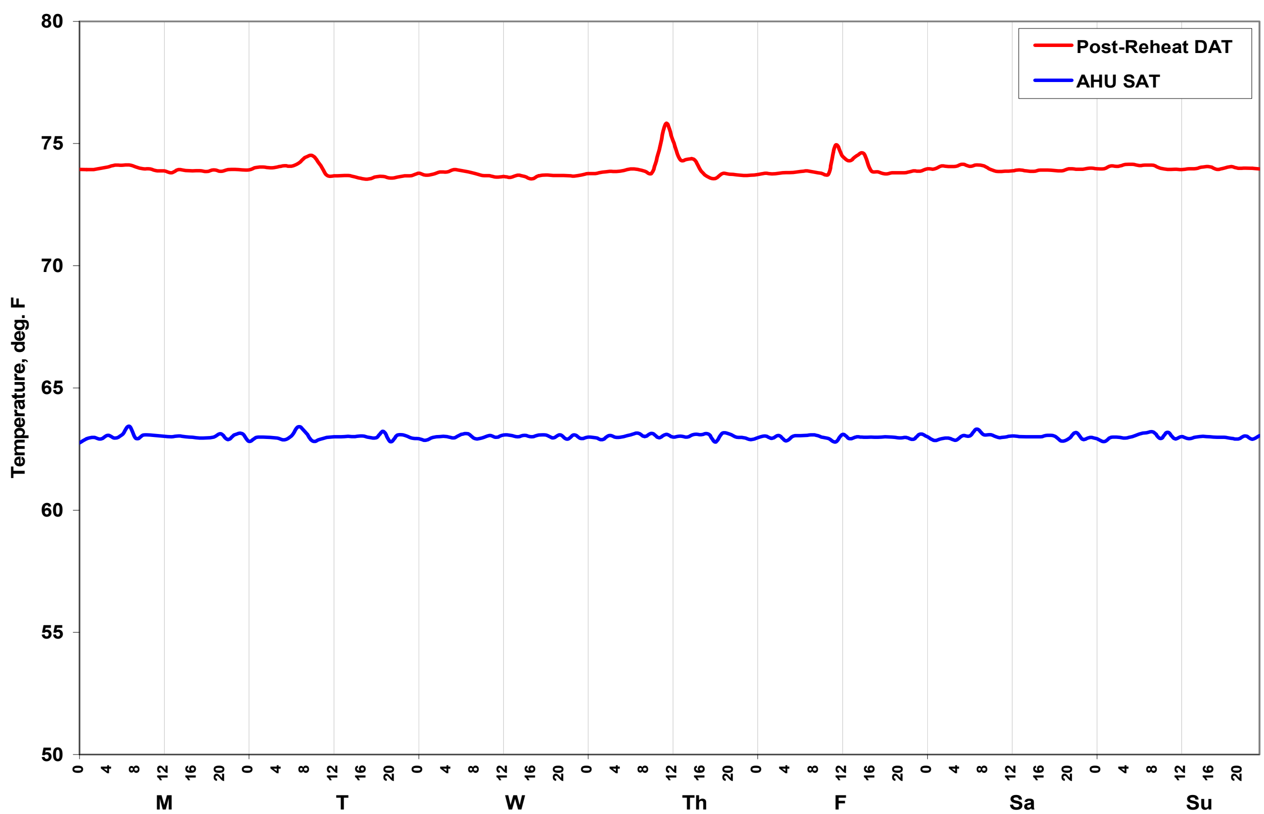


Figure 1.9: AHU Supply and Post-Reheat Discharge Temperatures – Profiles - PES 1247

Cogent Energy

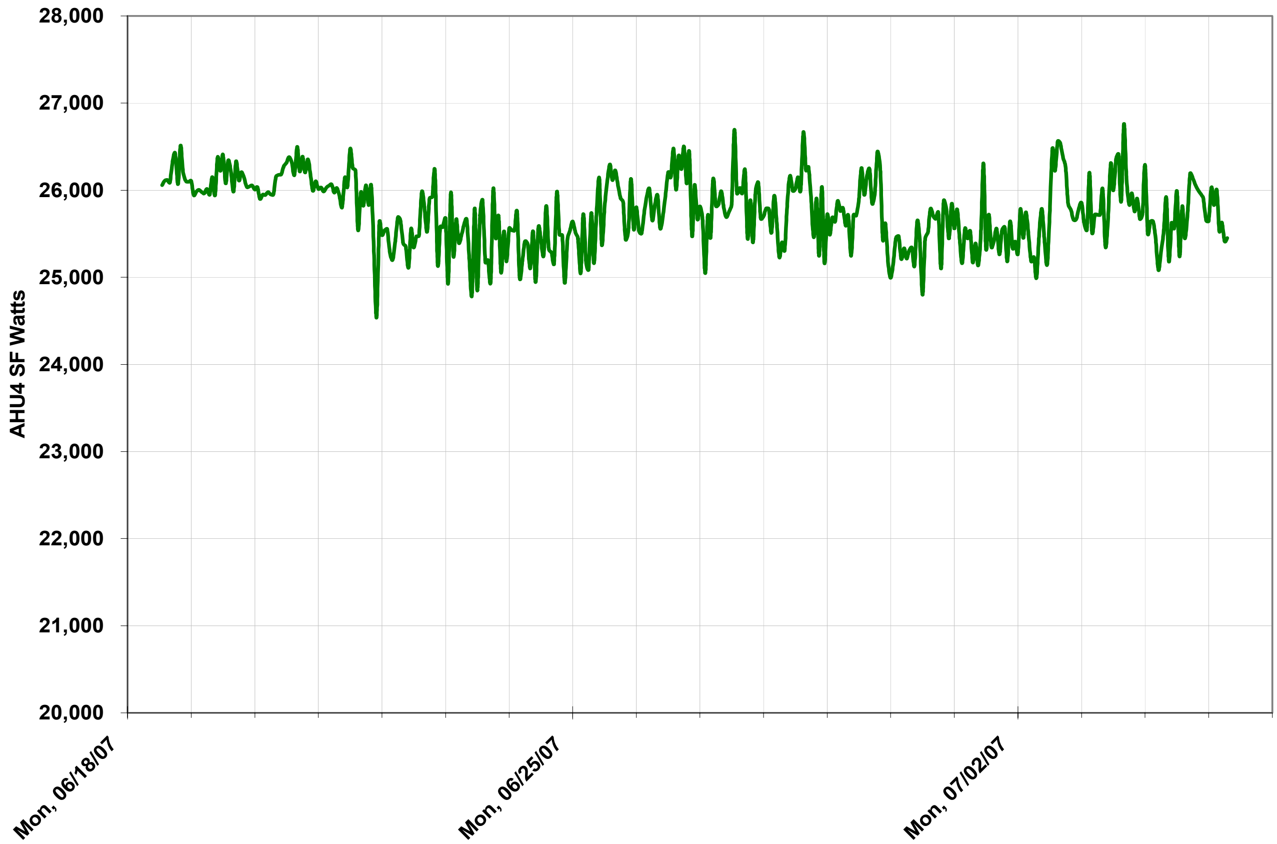


Figure 1.10: AHU Supply-Fan Power – Raw Data - PES 1247

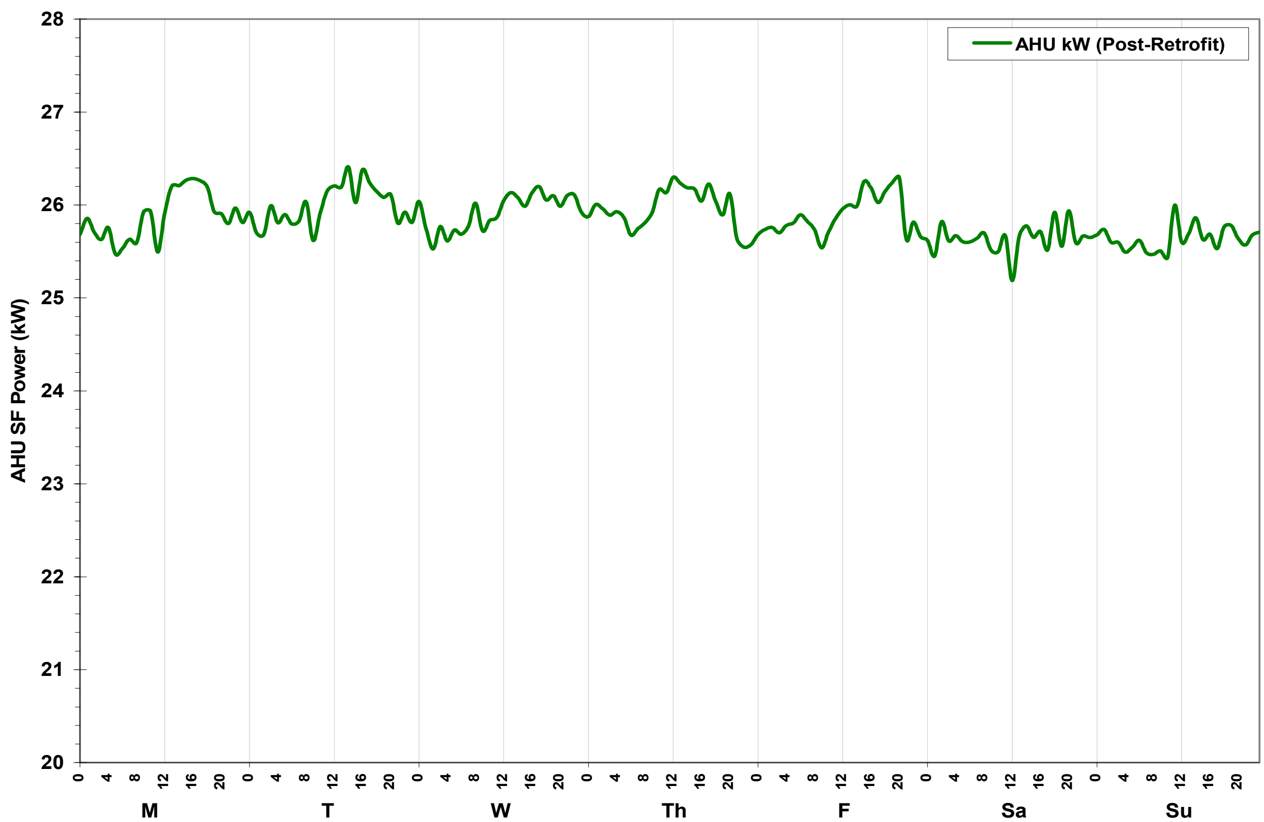


Figure 1.11: AHU Supply-Fan Power – Profile - PES 1247

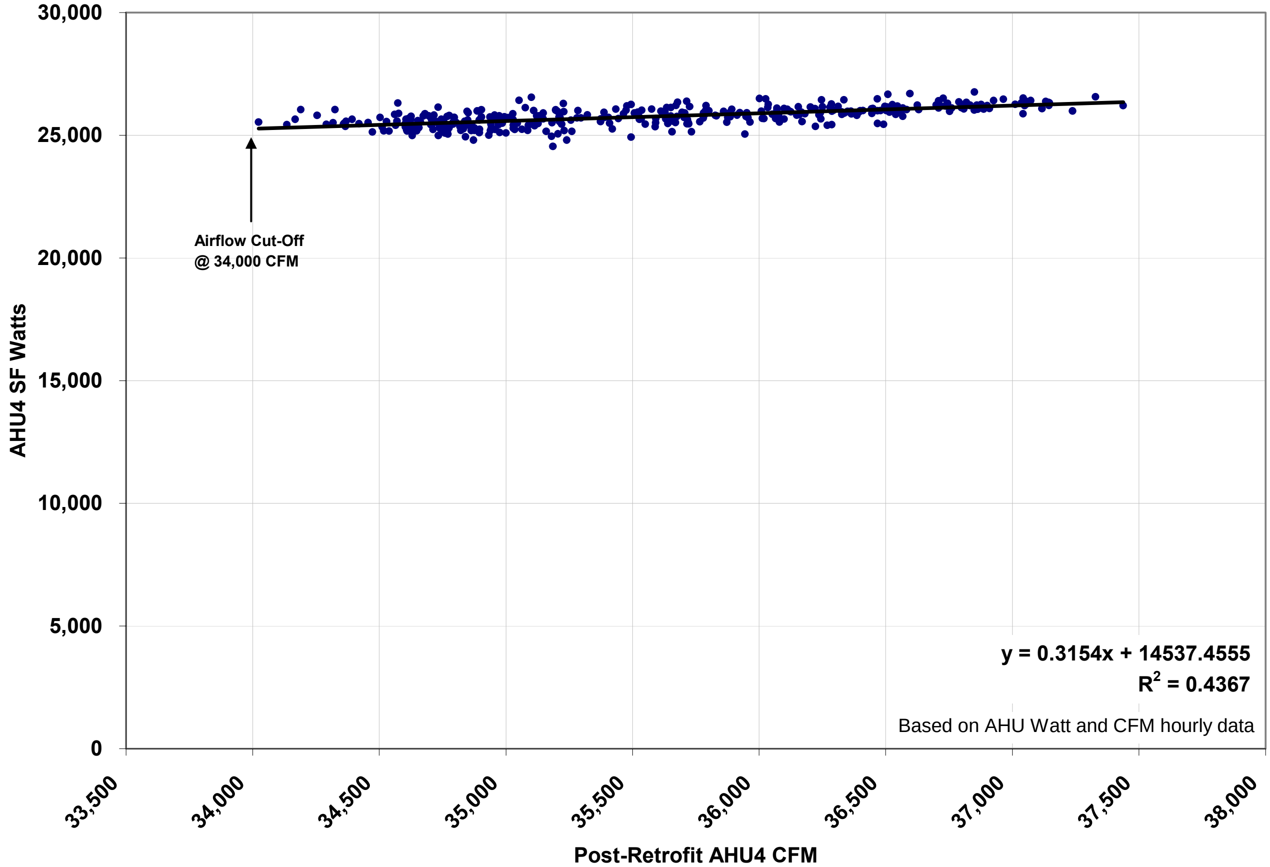


Figure 1.12: AHU Power-Airflow (Watts-CFM) Correlation – Raw Data - PES 1247

APPENDIX C

GENOME PROFILES

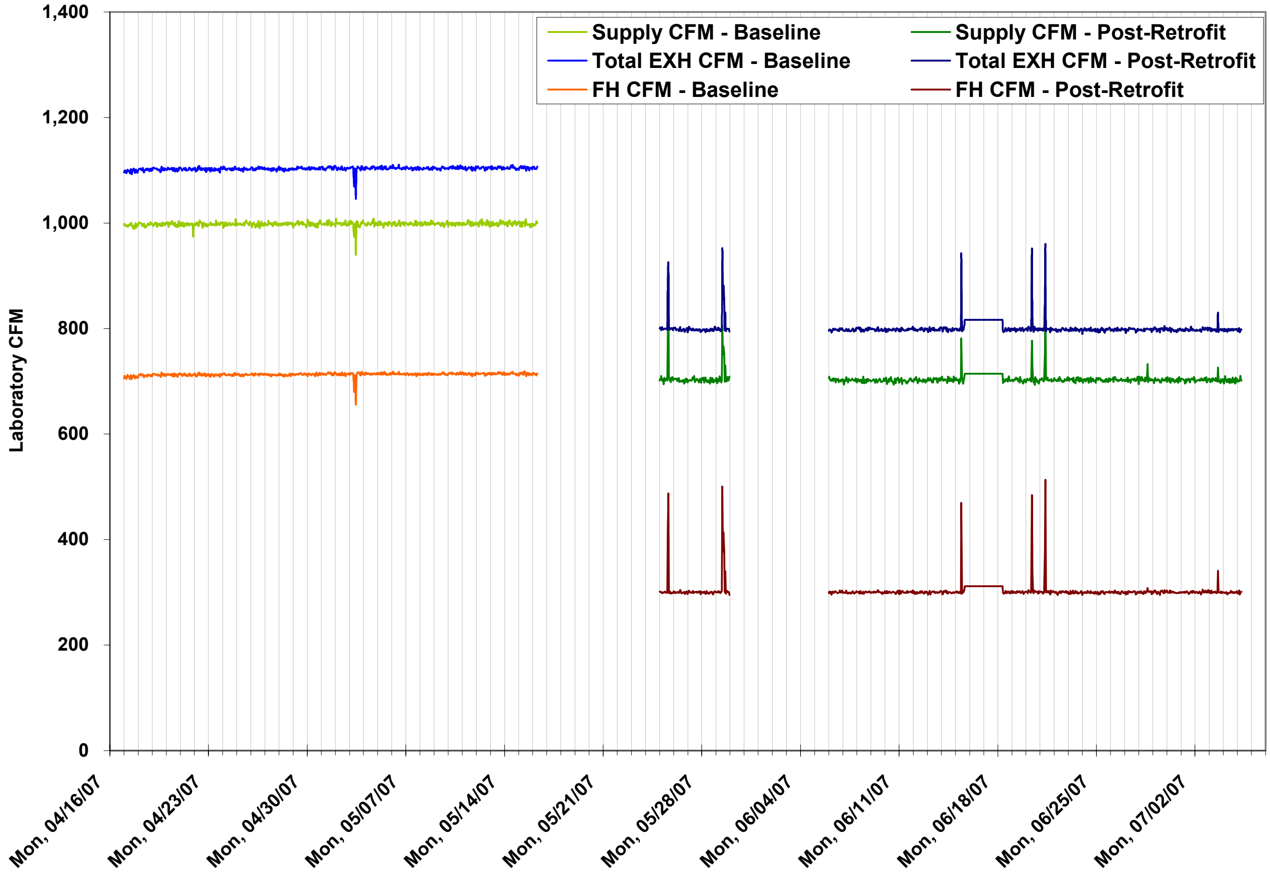


Figure 2.1: Laboratory Airflow - Raw Data – Genome 1010

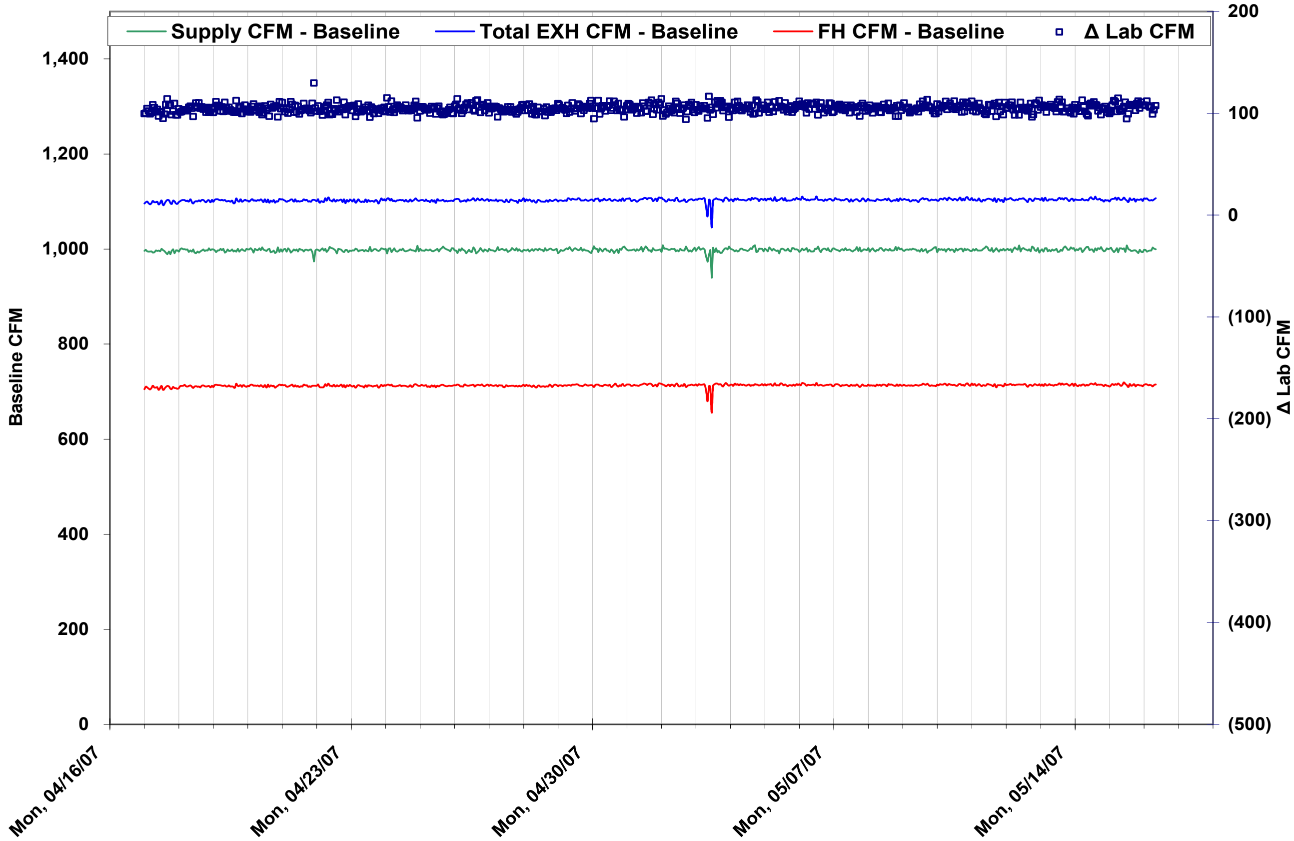


Figure 2.2: Laboratory Baseline Airflow - Raw Data - Genome 1010

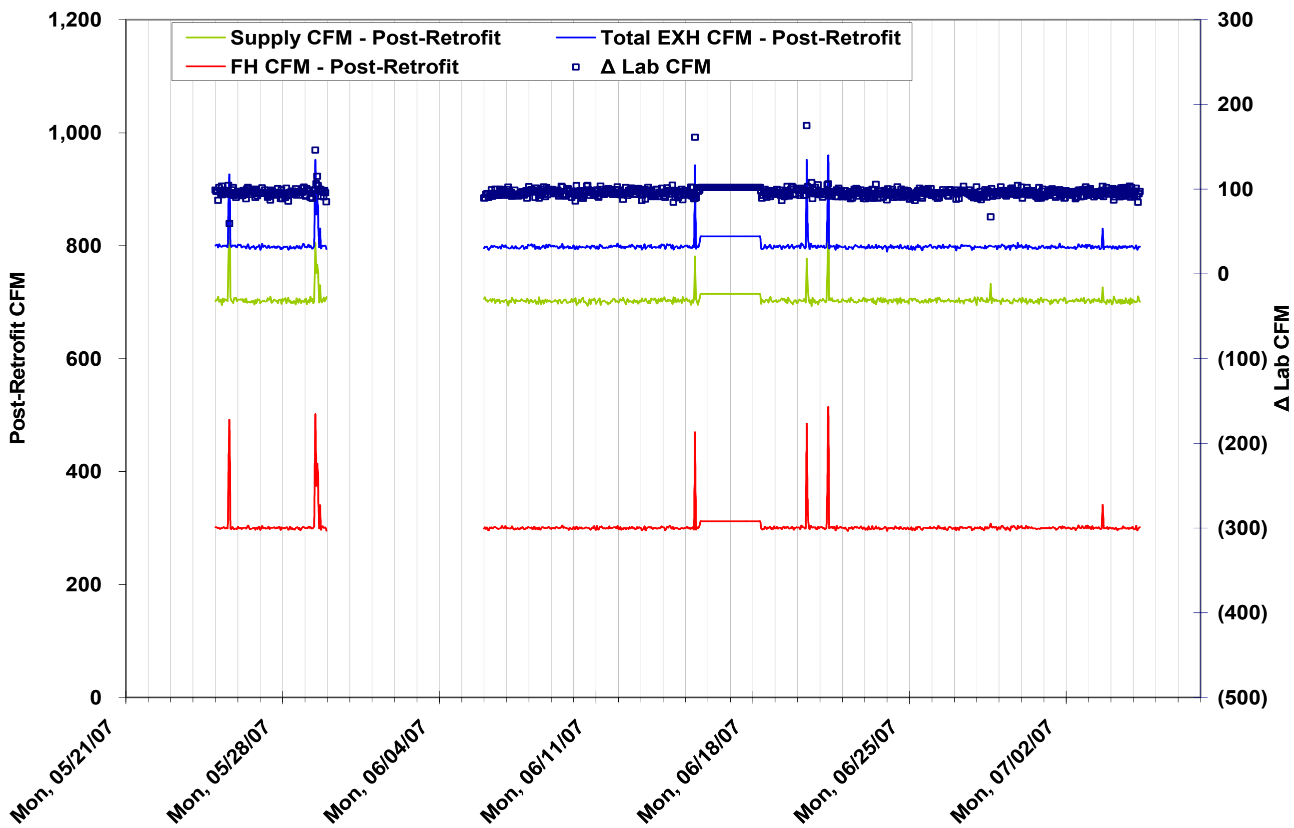


Figure 2.3: Laboratory Post-Retrofit Airflow - Raw Data - Genome 1010

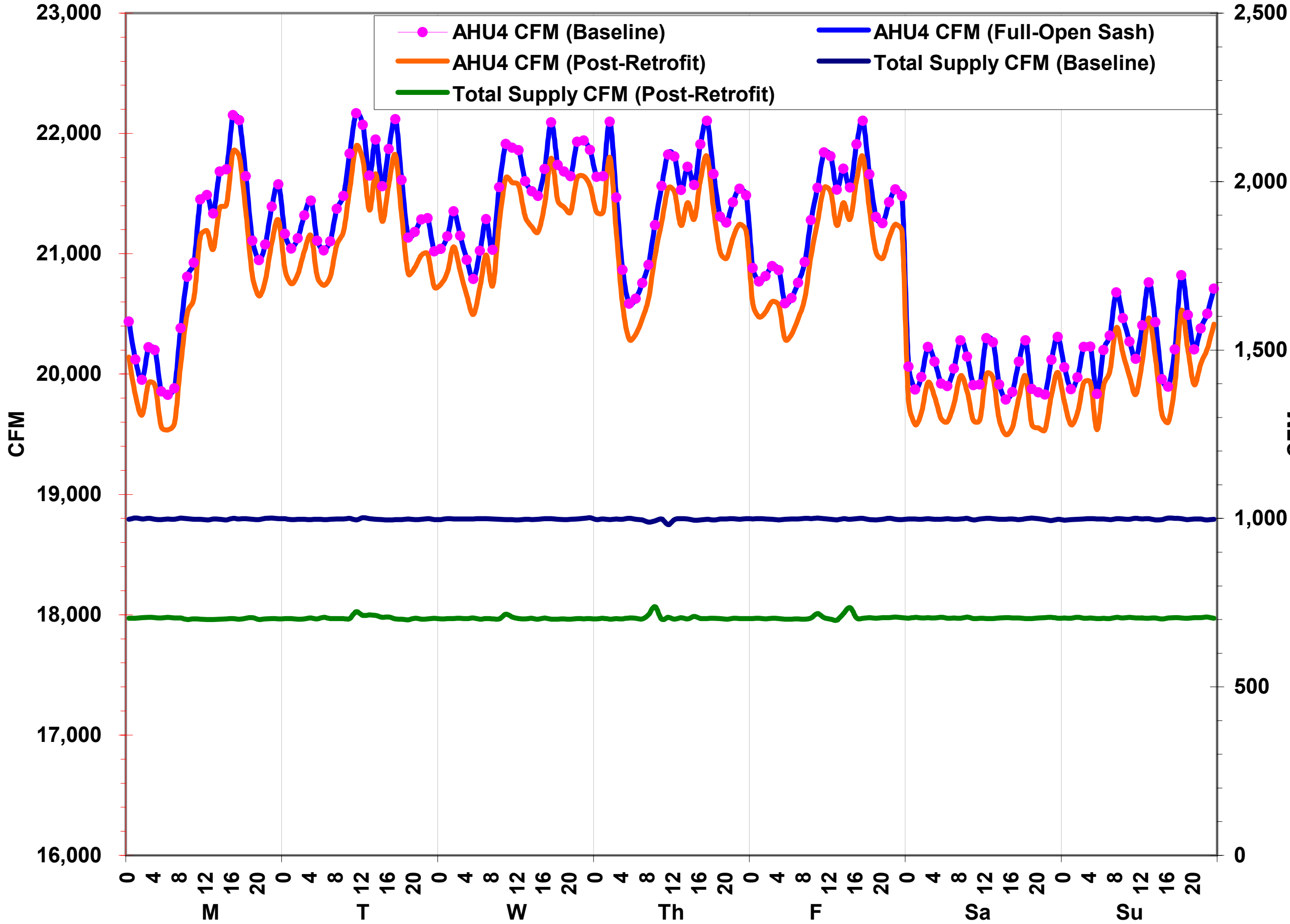


Figure 2.4: Laboratory Supply and AHU Airflow - Profiles - Genome 1010

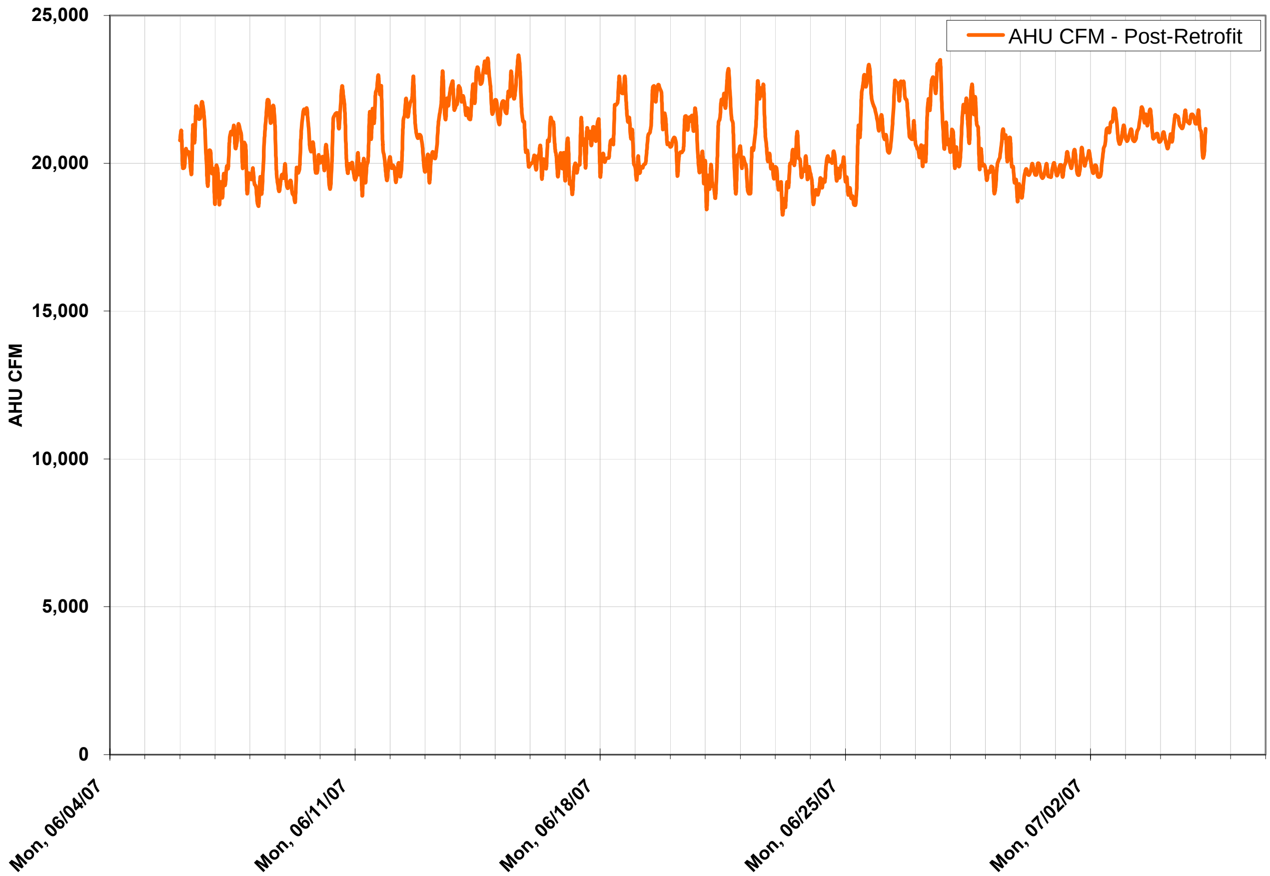


Figure 2.5: AHU Post-Retrofit Airflow – Raw Data - Genome 1010

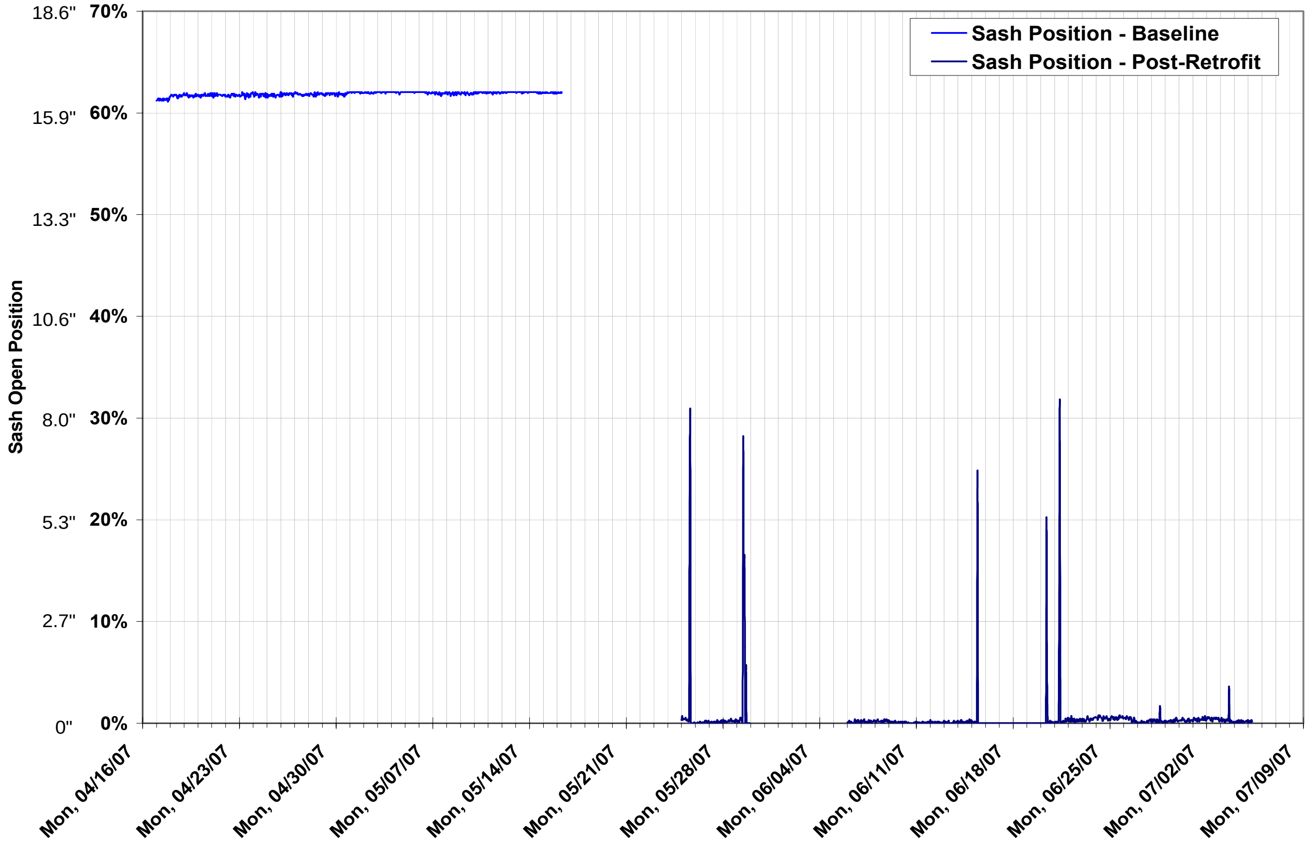


Figure 2.6: Sash Open Position - Raw Data - Genome 1010

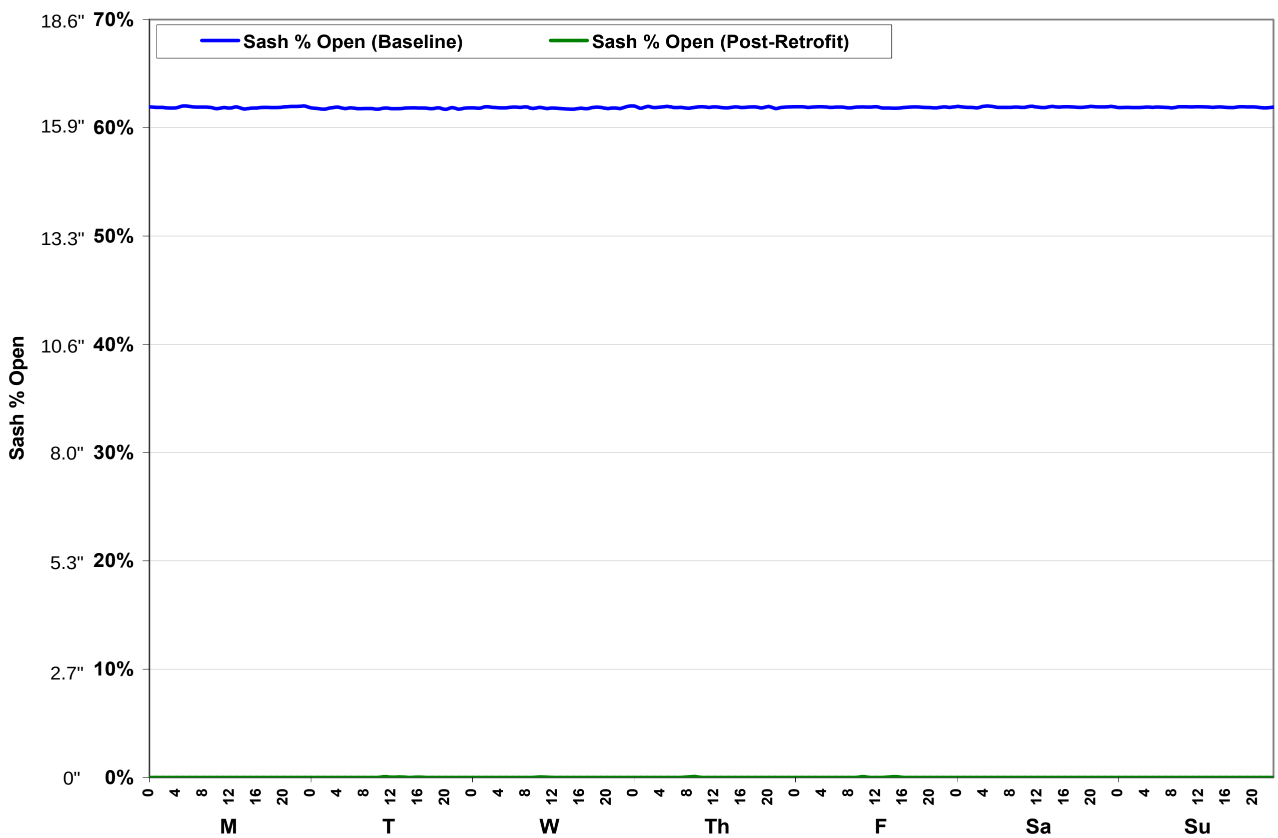


Figure 2.7: Sash Open Position - Profiles - Genome 1010

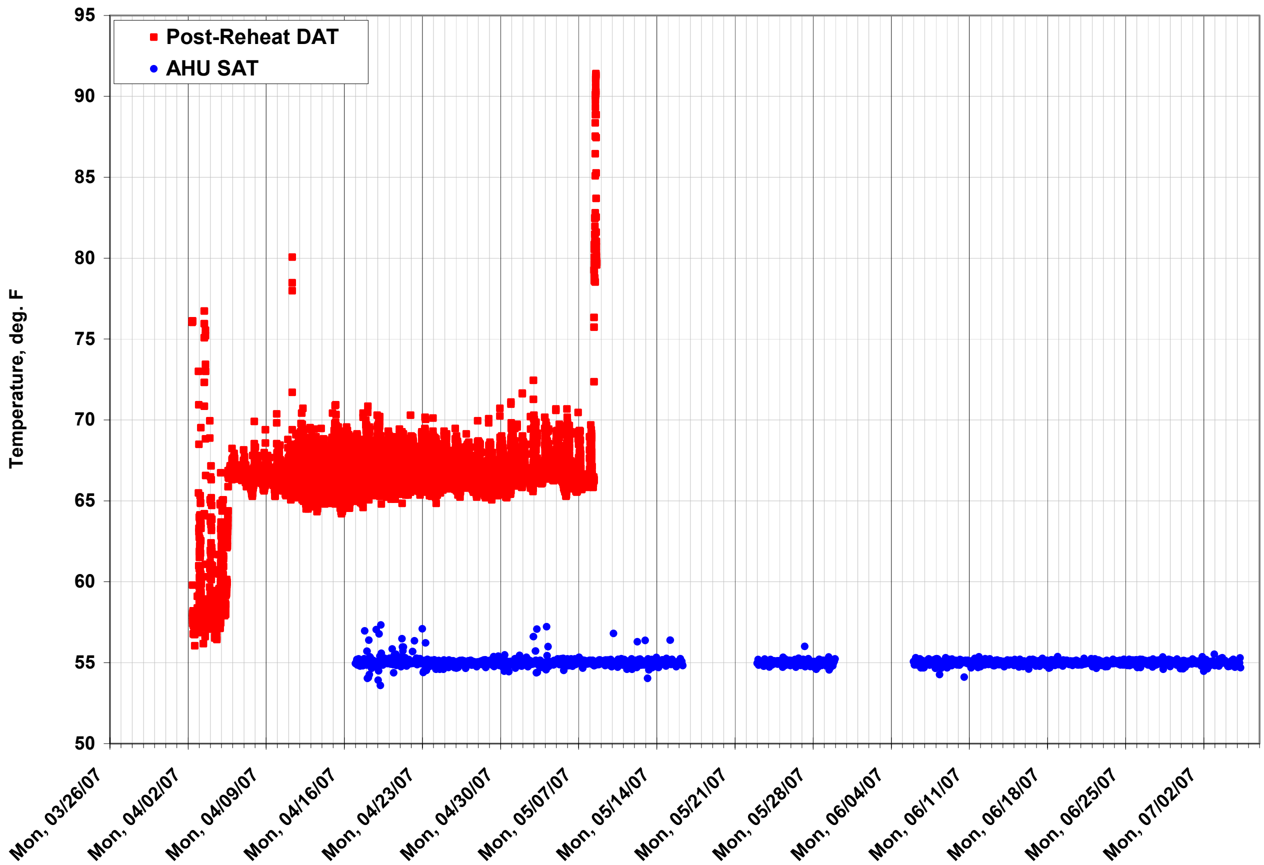


Figure 2.8: AHU Supply and Post-Reheat Discharge Temperatures – Raw Data - Genome 1010

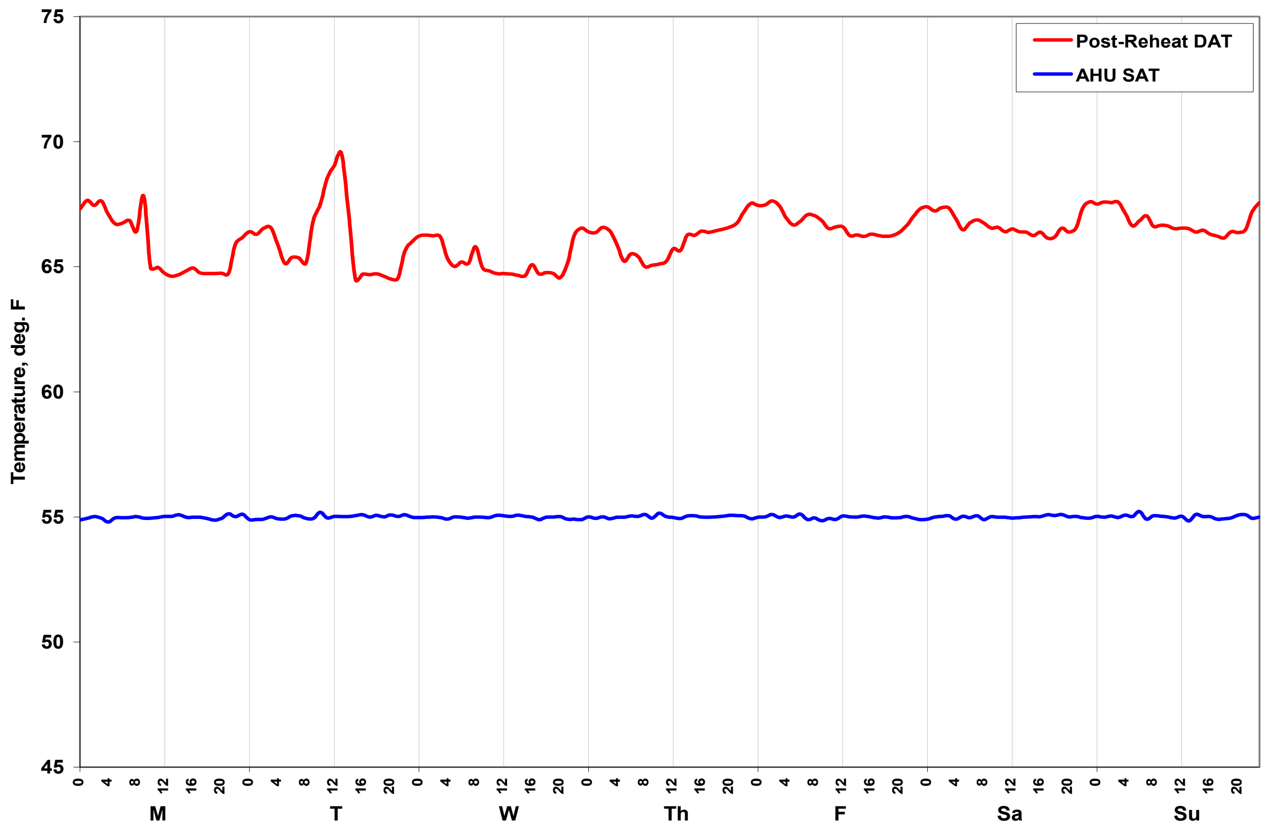


Figure 2.9: AHU Supply and Post-Reheat Discharge Temperatures – Profiles - Genome 1010

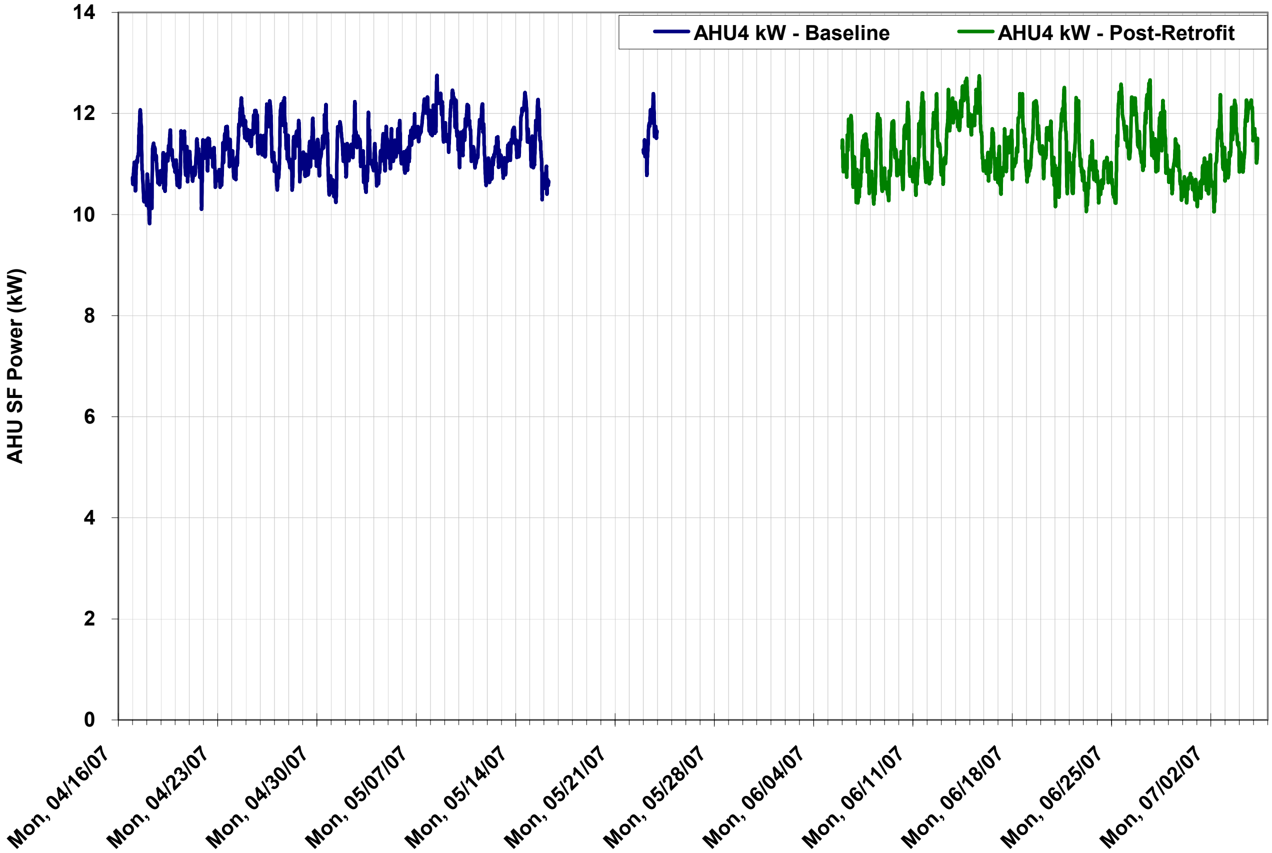


Figure 2.10: AHU Supply-Fan Power – Raw Data - Genome 1010

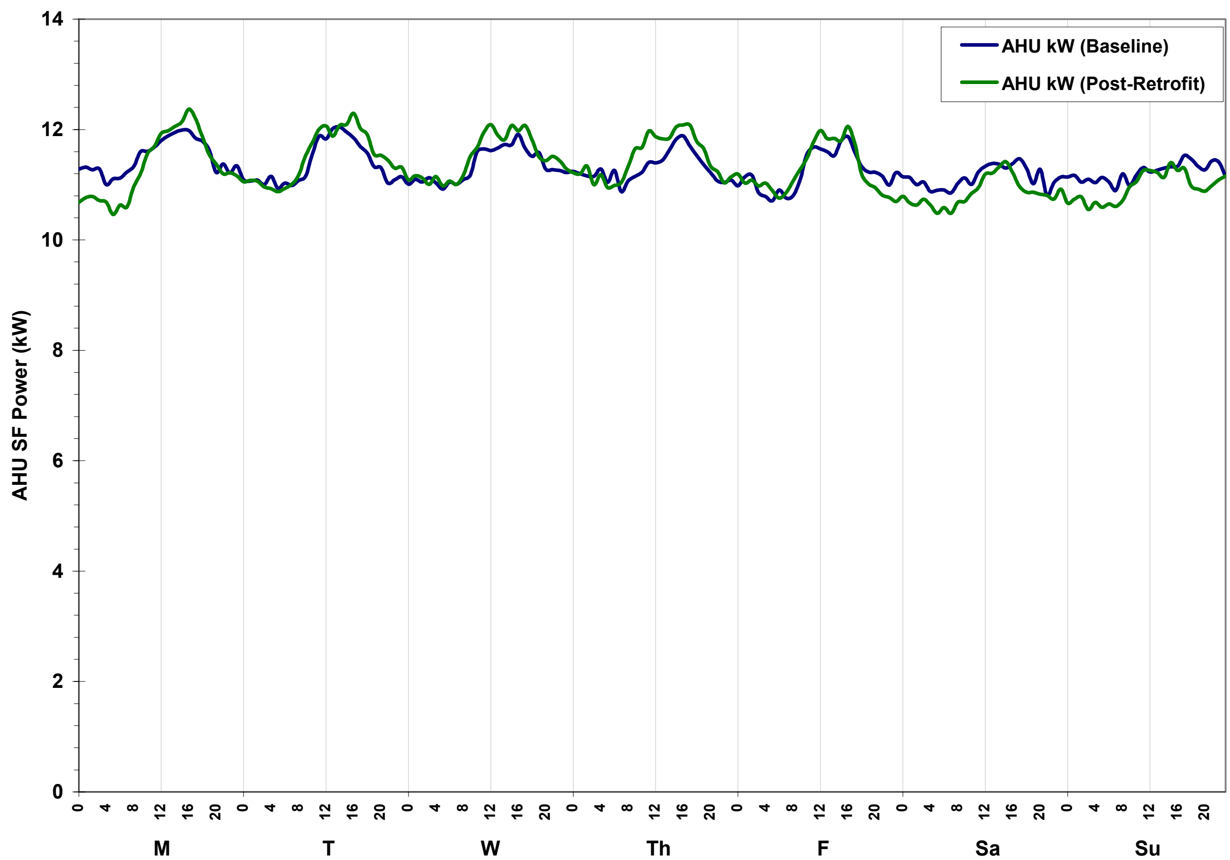


Figure 2.11: AHU Supply-Fan Power – Profiles - Genome 1010

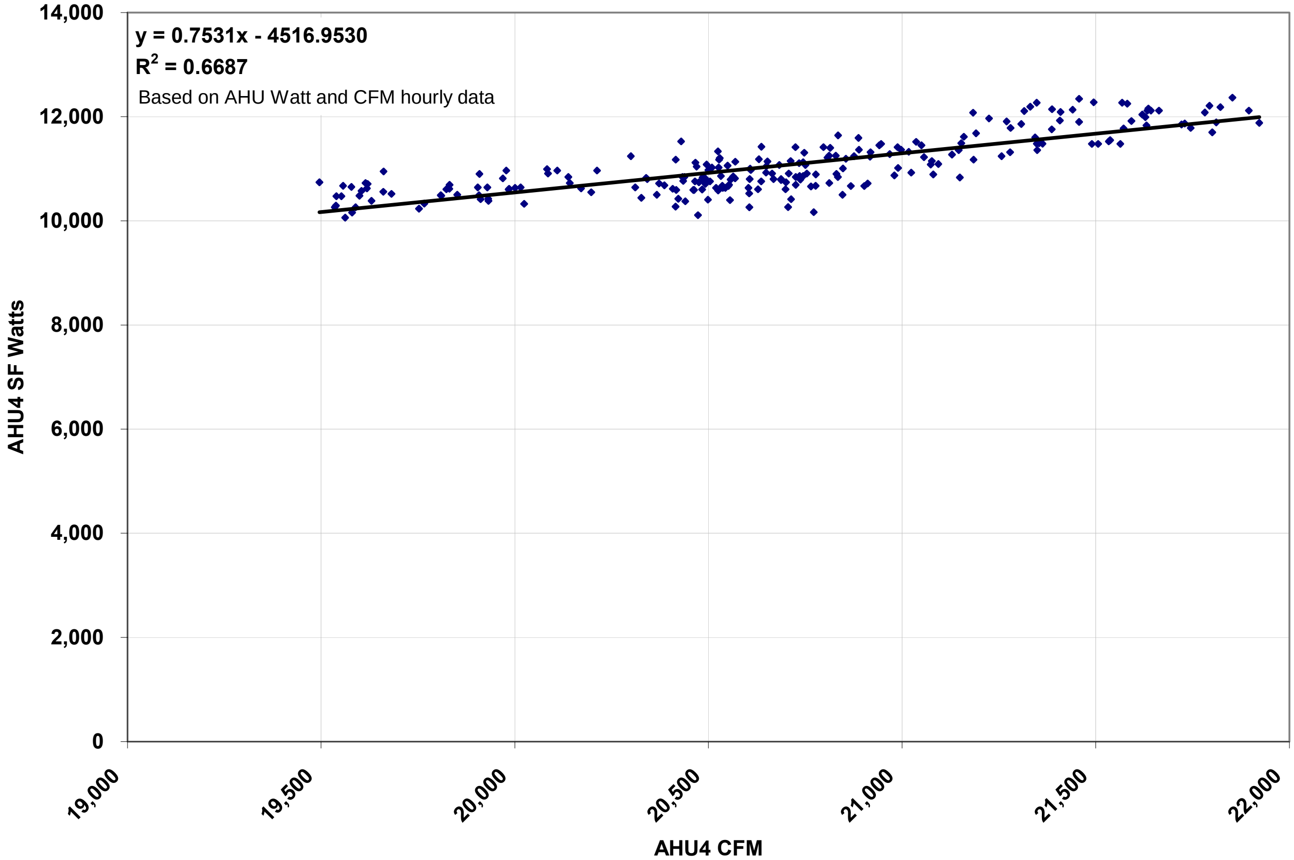


Figure 2.12: AHU Power-Airflow (Watts-CFM) Correlation – Raw Data - Genome 1010

AESC Results Review for APPA DEED Grant Project "Evaluation of Tek-Air Accuvalve in Retrofit Applications -- Demonstration of Energy Efficiency, Operations Benefits and Relevance Across Multiple Target Markets"

Background

The American Public Power Association's (APPA) Demonstration of Energy and Efficiency Developments (DEED) is a research and development program funded by and for public power utilities. Their goal is to encourage activities that promote energy innovation, improve efficiencies and lower costs of energy to customers. Pasadena Water and Power and the California Institute of Technology with the help of subcontractors, Emcor Service/Mesa Energy Systems and Taylor Engineering developed the subject project as a means of demonstrating the energy savings potential of retrofitting constant volume fume hoods to variable volume fume hoods. This study also prompted a subsequent study to evaluate retrofit of an automatic sash closure device on existing fume hoods.

Fume hoods are used to exhaust toxic fumes and particles in numerous applications in many laboratories. A fume hood that uses a constant speed fan and a bypass damper to make up reduced flow when the sash is closed is referred to as a constant air volume (CAV) fume hood. Traditionally, CAV fume hoods have been used due to their low initial cost. However, CAV fume hoods are inefficient, consuming large amounts of energy for both the high fan flow as well as HVAC energy to condition the large amount of makeup air that is being exhausted even when the sash is closed to a minimum position.

Variable air volume (VAV) fume hoods, equipped either with a variable speed fan or a throttling valve on the fume hood exhaust, in lieu of a bypass valve, can reduce the amount of exhaust while maintaining the required face velocity. This exhaust reduction can afford significant opportunities for HVAC energy savings and exhaust fan energy savings if a variable speed drive is installed on the exhaust fan. Even greater savings can be achieved with an added control feature called auto sash closing, which allows the sash to automatically close when a fume hood is unattended for a set period of time.

As the independent Measurement and Verification (M&V) consultant on the project, AESC was tasked with:

- Reviewing and validating the project results,
- Developing a spreadsheet based tool that could assist potential users in estimating the potential savings, and
- Examining the type of rebate or incentive that could be offered to encourage end user adoption of this energy saving measure.

Approach

AESC developed a tool to estimate savings associated with the installation of CAV fume hoods equipped either with a variable speed fan or throttling valve on the fume hood exhaust. The tool was developed based on first order principles. A detailed description of the tool and the principles involved is provided in Appendix A. As a part of tool verification, and as a means of validating the project results against theoretical savings, estimates based on the results calculated by the tool were compared against the measured data. For this analysis, pre- and post-installation measurement data were obtained as part of the APPA DEED project.

Below, tables summarize the calculated savings results obtained from the measured data and from the tool when the fume hood operating schedules were modified to match the post-retrofit supply fan power. Although the tool estimated smaller savings for chilled water and slightly greater savings for hot water usage, the results were deemed reasonable given the uncertainty involved in both the tool inputs and the measured data analysis.

Table 1: Savings Results Comparison

	Measured		Tool	
	Savings	**Savings**	**Savings**	**Savings**
Chilled water (kBtu/yr)	296,000	47%	213,000	41%
Hot water (kBtu/yr)	225,000	35%	256,000	40%
Electricity* (kWh/yr)	24,900	75%	22,900	75%

** -- Air-handler supply fan savings*

Tool inputs

Existing and proposed/installed fume hood specifications and HVAC system information were either collected from Caltech or from the M&V reports. The following table summarizes the tool input values used to calculate the savings.

Table 2 – Tool Input Values

<table>
<tr><th colspan="2">Input Name</th><th colspan="4">Value used</th></tr>
<tr><td colspan="6">Lab Schedule Information:</td></tr>
<tr><td colspan="2">24/7 Operation?</td><td colspan="4">No</td></tr>
<tr><td colspan="2">Operations vary by day?</td><td colspan="4">Yes</td></tr>
<tr><td colspan="6">Fume Hoods Information:</td></tr>
<tr><td colspan="2">Total Number of Fume Hoods</td><td colspan="4">4</td></tr>
<tr><td colspan="2">All Same Model?</td><td colspan="4">No</td></tr>
<tr><td colspan="6">Proposed Fume Hood Usage Schedule:</td></tr>
<tr><td colspan="2">Fume Hood #</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="2">Max Flow, CFM</td><td>1,660</td><td>1,180</td><td>1,180</td><td>730</td></tr>
<tr><td colspan="2">Min. Face Velocity, fpm</td><td>100</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td colspan="2">Hood Width, ft</td><td>86.25</td><td>62.25</td><td>62.25</td><td>38.25</td></tr>
<tr><td colspan="2">Min. Sash Opening Height, inch</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td colspan="2">Internal Hood Depth, inch</td><td>23.5</td><td>23.5</td><td>23.5</td><td>23.5</td></tr>
<tr><td colspan="2">Automatic Closing Feature Installed?</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td colspan="2">% Time Sash Fully Open during unoccupied hours, %</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td colspan="6">HVAC System:</td></tr>
<tr><td rowspan="2">Cooling System</td><td>Type</td><td colspan="4">Chilled Water Coils</td></tr>
<tr><td>Efficiency</td><td colspan="4">0.75 kW/ton</td></tr>
<tr><td rowspan="2">Heating System</td><td>Type</td><td colspan="4">Hot Water Coils</td></tr>
<tr><td>Efficiency</td><td colspan="4">80% (default)</td></tr>
<tr><td colspan="6">Air Distribution System:</td></tr>
<tr><td rowspan="5">Supply Fans</td><td>System Type</td><td colspan="4">Variable Air Volume (VAV)</td></tr>
<tr><td>VAV Reheat</td><td colspan="4">Yes</td></tr>
<tr><td>Heating Type</td><td colspan="4">Heating Coil</td></tr>
<tr><td>Total System CFM</td><td colspan="4">9,105</td></tr>
<tr><td>Fan Size</td><td colspan="4">3.81 total kW</td></tr>
<tr><td rowspan="3">Exhaust Fans</td><td>System Type</td><td colspan="4">Constant Air Volume (CAV)</td></tr>
<tr><td>Total System CFM</td><td colspan="4">4,750 (calculated)</td></tr>
<tr><td>Fan Size</td><td colspan="4">2.5 in. WG (default)</td></tr>
</table>

Due to laboratory usage varying day to day, lab occupancy hours as well as fume hood operating schedules were not available, the tool inputs were therefore estimated based on trend data. The trend data used to monitor the sash opening positions of all four fume hoods in the lab was first used to estimate the fume hood operation. Recorded sash position (% open) trend data were collected from October 1st to November 14th at one minute intervals. The trend data was compared and analyzed week by week to estimate the occupancy schedule of the lab. An example of fume hood activity is shown in Figure 1 below.

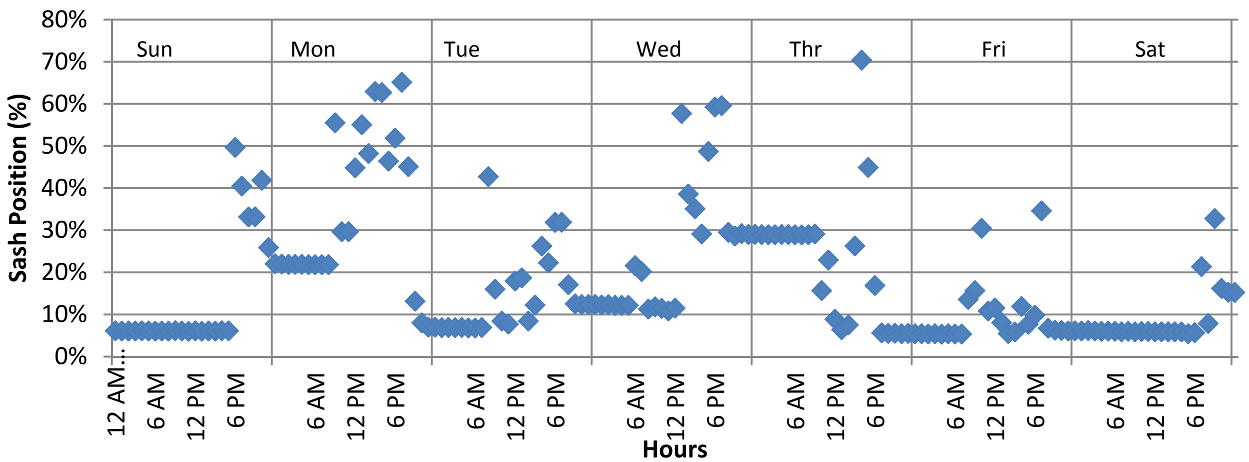


Figure 1: Sash Positions for Fume Hood #1 in a Sample Week.

The lab was assumed to be occupied when the sash position is not at minimum. Using the data for all four fume hoods, the occupancy schedule of the lab was estimated as tabulated below.

Table 3: Estimated Lab Daily Operating Schedule

Day	Start	End
Mon	8:00 AM	10:00 PM
Tue	8:00 AM	10:00 PM
Wed	6:00 AM	11:00 PM
Thu	6:00 AM	11:00 PM
Fri	8:00 AM	10:00 PM
Sat	12:00 PM	8:00 PM
Sun	Closed	Closed

The sash position data for each hood was then averaged to estimate the percentage of time when the sash was open or closed and tabulated below. Note that fume hood #1 and #4 never operated at a fully open position over the three month monitoring period and #2 and #3 only operated for a total duration of less than half an hour each (less than 0.01% of total operating hours).

Table 4: Estimated Fume Hood Operation When Lab was Occupied

Sash #	% Time Sash Fully Open	% Time Sash Closed to Min.
1	0%	17%
2	0%	91%
3	0%	44%
4	0%	39%

The tool was initially run using the estimated lab occupancy schedule and fume hood opening schedule, which resulted in reduced savings compared with the measured savings. The tool estimated higher post-retrofit electricity usage (supply fan) than the measured data. Fan electricity savings are the most straightforward to estimate and any difference is the likely result of inaccurate operating schedules. Additionally, it was discovered that the usage measurements and fume hood sash position trend data were collected over two different time frames. The observed difference in fan power usage may be due to this fact. It was determined that the fume hood operating schedule should be modified before reviewing cooling and heating savings further. The current tool does not account for seasonal changes in operating schedule and this modification may need to be considered for future upgrade.

Table 5: Savings Results Calculated by the Tool Using Sash Position Trend Data

	Baseline	Post-retrofit	Savings	Savings (%)
Chilled water (kBtu/yr)	514,000	348,000	166,000	32%
Hot water (kBtu/yr)	636,000	406,000	229,000	36%
Electricity* (kWh/yr)	33,400	11,000	22,400	67%

** -- Supply air-handler fan savings.*

The quarterly report indicated that the baseline fan power was constant at 3.81kW, which was used as a tool input, and the fan power demand after the retrofit was approximately 0.97 kW on average. To obtain the similar post-retrofit fan power demand, percentage of time when the sash is closed to minimum was increased as following.

Table 6: Modified Operating Conditions of the Fume Hoods During Lab Occupied Period.

Sash #	% Time Sash Fully Open	% Time Sash Closed to Min.
1	0%	90%
2	0%	91%
3	0%	91%
4	0%	90%

The following figures and tables compare the results calculated by the tool with the adjusted fume hood schedule and the estimate from the measured data.

Table 7: Measured and Calculated Savings Summary

Measured	Baseline	Post-retrofit	Savings	Savings
Chilled water (kBtu/yr)	624,000	328,000	296,000	47%
Hot water (kBtu/yr)	635,000	410,000	225,000	35%
Electricity (kWh/yr)	33,400	8,500	24,900	75%

Calculated	Baseline	Post-retrofit	Savings	Savings
Chilled water (kBtu/yr)	514,000	301,000	213,000	41%
Hot water (kBtu/yr)	636,000	380,000	256,000	40%
Electricity (kWh/yr)	33,400	8,500	24,900	75%

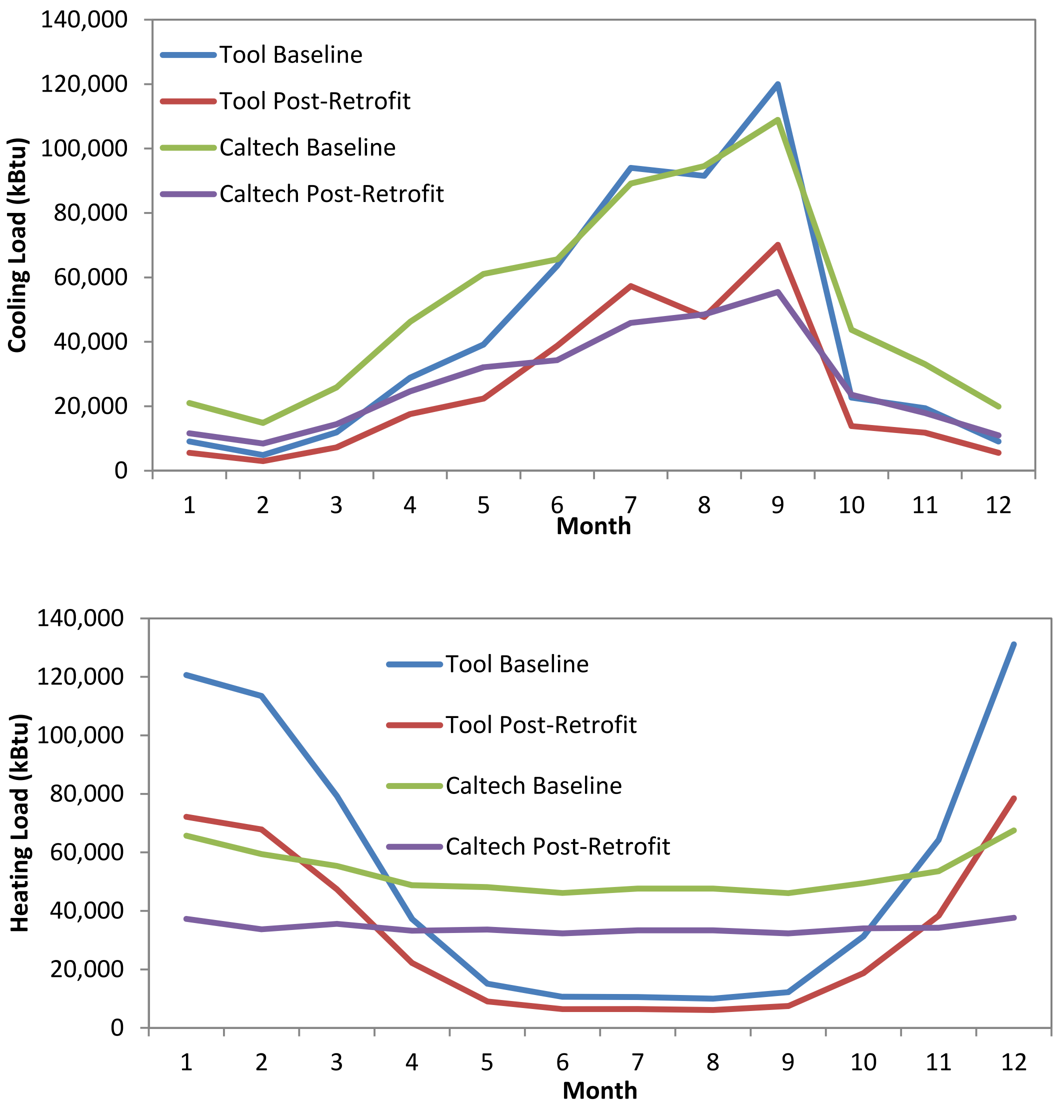


Figure 2: Cooling (above) and Heating (below) Load Comparison

The cooling load calculated by the tool is in good agreement with the measured data especially during the summer months. According to the measurement and verification report, supply fan electrical usage, chilled water usage, and hot water usage were measured and then extrapolated to estimate annual usage using the regression analysis. Since the pre-retrofit data is limited to only two months in the winter prior to the installation and three months in the summer after the installation, the disagreement may be due to the difference in fume hood usages: The fume hoods may have been more frequently used during pre-retrofit measurement than in the summer.

The calculated heating load shape was quite different from the one estimated by the tool. The main difference is likely due to a low level of reheat assumed in the tool, but this assumption is consistent with most HVAC systems in California climate zones. We believe that the calculated load shape is reasonable; however, the flat load shape of the measured data is unusual. We were unable to determine the cause for the measured heating load being relatively constant throughout the year, but further investigation may determine the cause.

Next, a correlation matrix was created to analyze the cooling and heating trends. The analysis showed strong positive correlations, validating the tool's capability to follow the trends of the measured cooling and heating load. The calculated correlation values are shown in Table 8.

Table 8: Correlation Matrix of the Monthly Savings Estimated by the Tool and the Measured Data

Correlation		Tool Baseline	Tool Post-Retrofit
Cooling	Measured Baseline	0.98	-
	Measured Post-Retrofit	-	0.97
Heating	Measured Baseline	0.97	-
	Measured Post-Retrofit	-	0.98

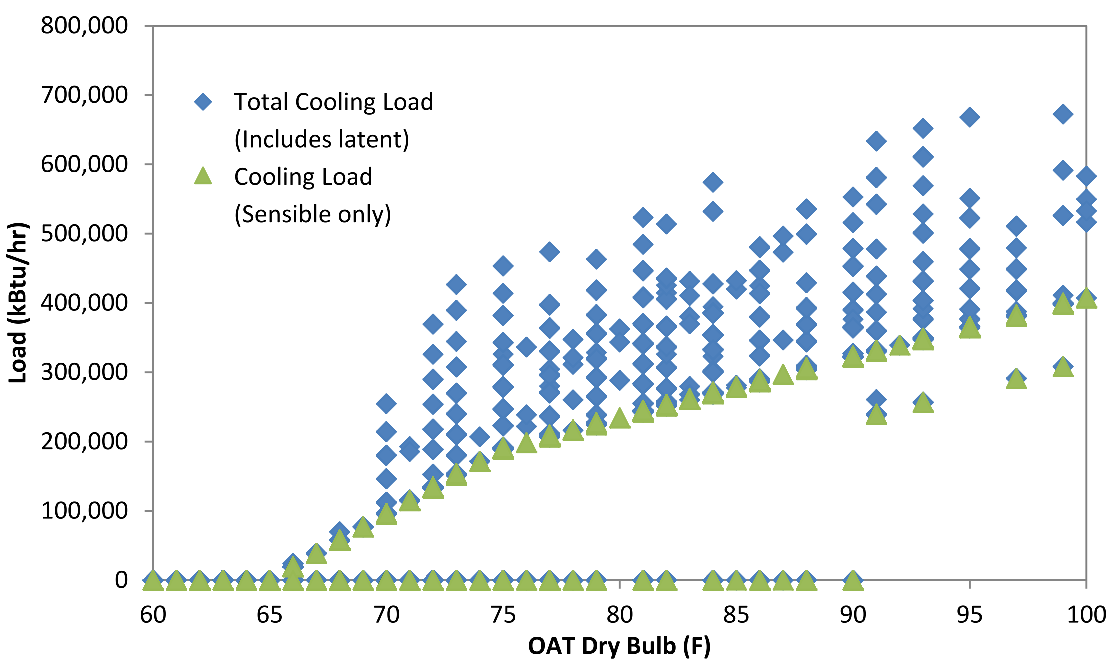
Latent Cooling Load Consideration

As this tool was developed with potential nationwide use in mind, the latent cooling load was incorporated into the calculations. When latent load becomes significant during cooling seasons (i.e. programmed supply air temperature falls below ambient dew point temperature), the tool estimates the latent load associated with dehumidification up to desired supply air temperature. The following table and figures summarize the impact of latent load for different parts of the United States. Table 9 shows latent load is significant in south eastern regions, whereas it is negligible in most California climate zones.

Table 9: The Impact of Latent Load at Various Locations

Location	% Latent Load	% Load Increase*
Pasadena, CA	15	17
Sacramento, CA	6	7
Santa Maria, CA	1	1
Miami, FL	50	100
Atlanta, GA	39	63

** -- Compared to all sensible cooling load*



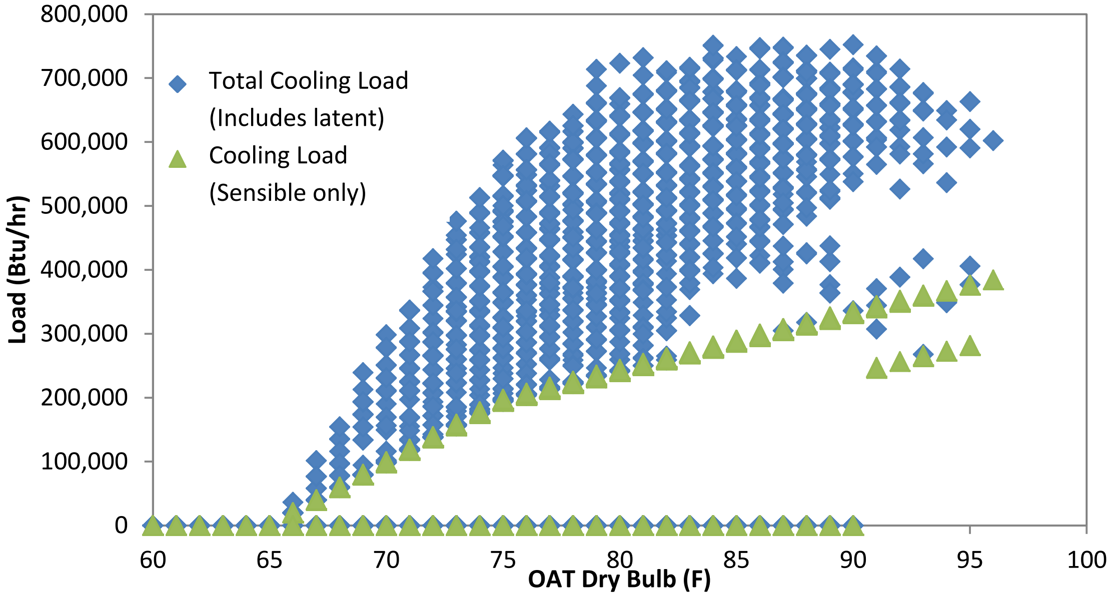


Figure 3: Calculated Total and Sensible Cooling Load for Pasadena, CA (above) and Miami, FL (below). ***(The deviation from the sensible cooling load line in green signifies the magnitude of added latent cooling load and the number of data points indicates the frequency of which dehumidification occurred)***

The tool allows the user to select VAV with reheat as an option. If this feature is selected, the tool calculates the added sensible heat assuming five degrees increase for reheat including the heat gain across the supply fans as well as added heat from the heat coil or electric heating element. It should be noted that since the tool assumes dehumidification up to supply air temperature, the supply air temperature reset schedule (listed in Appendix A1) may need to be modified in regions where severe dehumidification and reheat are required (so that the desired supply air temperature and humidity is achieved).

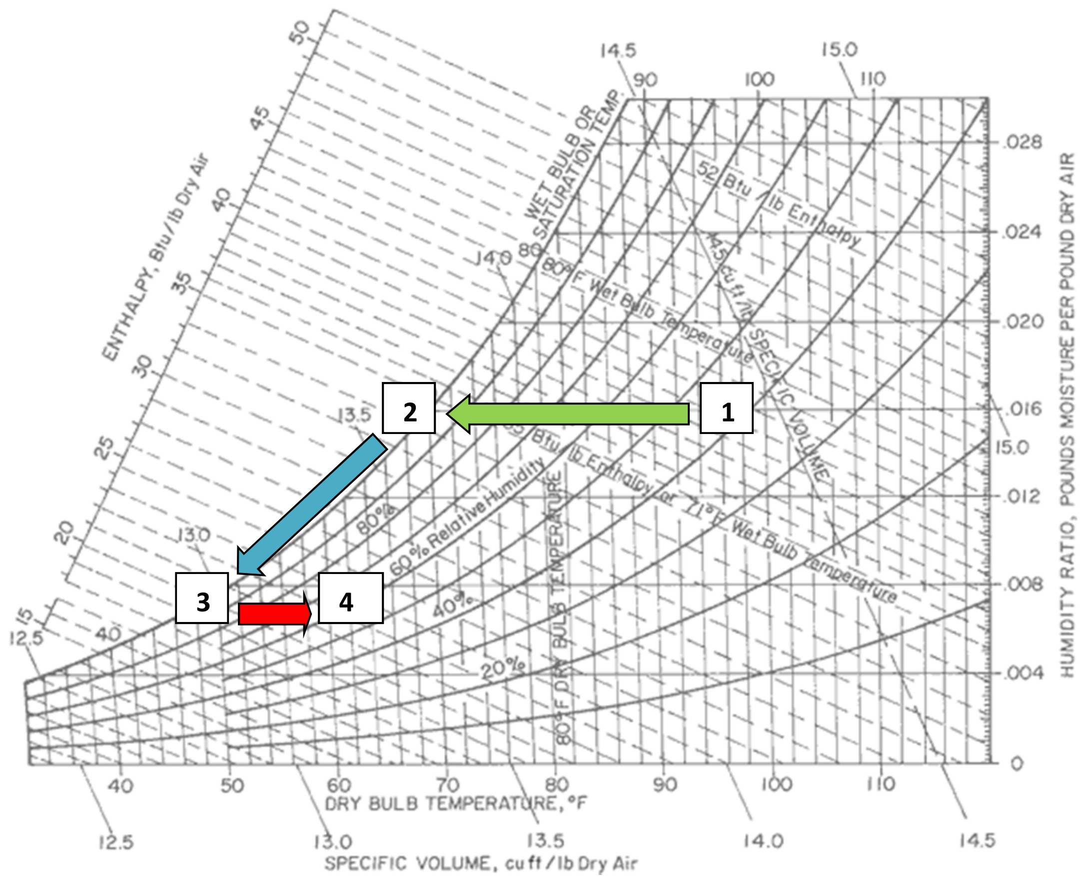


Figure 4: The dehumidification and reheat process calculated by the tool. Outside air (1) is first cooled sensibly up to dew point (2) then dehumidified up to the supply air temperature (3) that corresponds to the outside air temperature (see Appendix A1: Supply air reset schedule). If the reheat option is selected, the air is sensibly heated to the final state (4).

Automatic Sash Positioning System Discussion

An automatic sash positioning system (or auto-closer) achieves savings by maximizing the time that the sash is in the minimum position. The auto-closer reduces the sash to the minimum position whenever it senses that the hood is unattended. Savings can therefore be achieved during the normally occupied time as well as during afterhours, or the normally unoccupied time. Estimating the amount of “typical” savings associated with an auto-closer is impractical since it is dependent on the personnel associated with an individual site. Conscientious personnel that consistently set the sash to the minimum position when they leave the lab either during the day or prior to leaving at the end of the day will achieve comparable results. Unfortunately, not all personnel are that conscientious and even conscientious personnel can slipup in a busy lab environment.

The fume hood tool incorporates an auto-closer feature that allows the end user to estimate the potential savings during unoccupied hours. The fume hood tool does not attempt to account for potential savings associated with auto-closer operation during occupied hours as it would be impractical, without extensive monitoring across many sites/institutions, to draw any statistically significant conclusions about operation during occupied hours. Sash auto closer related savings are based solely on operation during unoccupied hours with the idea being that savings occur when the auto closer closes a sash that someone inadvertently left open when they departed at the end of the day. An input is provided that allows the user to set this default value (% of time that the fume hoods are left in full open position during unoccupied hours).

The user has the option of indicating that an auto closer is installed (yes/no), on each of the fume hoods. When “no” is selected the percentage of time that the fume hood operates with the sash fully open is set to the default value that the user has previously specified. The remainder of unoccupied operation is set to operation at the minimum position. When “Yes” is selected the percentage of time that the fume hood operates with the sash set to the minimum position is set to 100% (0% in fully open position).

Incentive Type Discussion

Utilities use a variety of methods to encourage their customers to implement energy saving measures. Monetary incentives in the form of rebates are commonly used. These rebates or incentives are classified into two basic types. A “deemed” savings rebate has a proscribed or fixed value that is awarded to the customer upon completion of the project. The amount of the rebate and the energy and demand savings associated with the energy saving measure is estimated, in advance, based on assumed operating conditions and system performance parameters. Historical information and demonstration/pilot projects, etc. are used to support the savings estimates and associated incentives. This type of rebate is the simplest to apply and requires the least amount of effort for both the utility to administer and for the customer to obtain. This type of rebate is most often applied to energy saving measures that have relatively few variables impacting performance or when these variables can be readily classified and accommodated via tables etc. For this reason, this type of rebate is typically applied to appliances and lighting etc. where size and operating hours are the primary factors affecting overall savings.

The second type of incentive or rebate is called a “calculated” incentive. As the name implies, this type of incentive is calculated based on the estimated savings for the specific energy saving measure project. To obtain this type of incentive the utility customer would typically provide the utility with an estimate of both the baseline and proposed equipment performance and the associated savings. Depending on the technology involved and the application this approach may require building/equipment modeling and/or monitoring of energy use both before and after installation of the energy saving measure. In some cases, the performance of the energy saving measure can be modeled and a dedicated “tool” developed that allows both the customer and utility to estimate the savings in a consistent fashion using inputs that are relatively easy to obtain.

Based on review of the technology and the principles involved, AESC recommends that fume hood saving measures be incented using a calculated incentive approach. The number of variables impacting the savings achieved (e.g., weather, chiller performance, boiler performance, fan/motor performance, HVAC system configuration, lab and fume hood sash operating hours, etc.) are too numerous and varied and do not lend themselves to a deemed approach. However, in order to facilitate estimation of measure savings and the associated incentives, AESC has developed the spreadsheet based tool described in Appendix A.

Conclusion

Given the general agreement in load shape, savings percentage, and positive correlations between the savings calculated by the tool and the savings estimated from the measured data, we believe the tool is able to calculate savings with a reasonable confidence level. Furthermore, since the tool is capable of calculating the latent load during cooling seasons, it can be used in regions outside of California, where latent load may be significant. Although the initial results seem reasonable, the fine-tuning of this feature and further validations may be needed.

APPENDIX A: VAV FUME HOOD ENERGY SAVINGS CALCULATION TOOL VERIFICATION

1. MEASURE TOOL DESCRIPTION

Fume hoods are used to exhaust toxic fumes and particles in numerous applications in many laboratories. A fume hood that uses a constant speed fan and a bypass damper to make up reduced flow when the sash is closed is referred to as a constant air volume (CAV) fume hood. Traditionally, CAV fume hoods have been used to ventilate hazardous gas due to their low initial cost. However, CAV fume hoods are inefficient, consuming large amounts of energy for both the high fan flow as well as HVAC energy to condition the large amount of makeup air that is being exhausted (even when its sash is closed to a minimum position).

Variable air volume (VAV) fume hoods, equipped either with a variable speed fan or a throttling valve on the fume hood exhaust (in lieu of a bypass valve) can reduce the amount of exhaust while maintaining the required face velocity. This exhaust reduction can afford significant opportunities for HVAC energy savings and exhaust fan energy savings if a variable speed drive is installed on the exhaust fan. Even greater savings can be achieved with an added control feature called auto sash closing, which allows the sash to automatically close when a fume hood is unattended for a set period of time.

Under the sponsorship of Pasadena Water and Power (PWP), a tool was developed to assist end users in identifying and estimating VAV fume hood energy saving opportunities. This tool allows the user to:

- Calculate HVAC energy savings along with the energy savings associated with the installation of exhaust throttling valves and variable speed drives (VSD) in exhaust and/or supply fans, and
- Calculate additional savings related to installation of the auto sash closing feature.

This tool currently estimates savings for the following measures:

- Installation of a variable speed drive on the supply in conjunction with installation of an exhaust throttling valve, without auto sash closing feature,
- Installation of a variable speed drive on the supply fan in conjunction with installation of a variable speed drive on the exhaust fans without auto sash closing feature, and
- Installation of an auto sash closing feature with either of the preceding two measures.

1.1. Appropriate Use of the Tool

The VAV Fume Hood Upgrade tool can be used for fume hoods and measures having the characteristics shown in Table A1.

Table A1: VAV Fume Hood Common Measure Features

Description	Measure Feature
# of Fume Hoods	1 – 20
Fume Hood Types and Sizes	Constant Volume and Constant Face Velocity
Supply Fan Drive	Conventional and Variable Speed Drive (VSD)
Exhaust Fan Drive	Conventional and Variable Speed Drive (VSD)
Auto Sash Closing	When fume hood is not attended, the Auto Sash Closing feature will lower the sash to the minimum opening position

1.2. Applicable Types of Equipment and size Covered by the Tool

The VAV fume hood tool covers the size and capacities of HVAC systems described in Table A2.

Table A2: VAV Fume Hood Upgrade Measure Equipment Coverage Matrix

Description	Type	Default Unit
HVAC Cooling System Types	DX Coils Chilled Water Coils Absorption Chiller	EER kW/ton COP
HVAC Heating System Types	Hot Water Coils Electric Resistance Heat Pump Furnace	% kW COP %
Supply and Exhaust Fans	CV or VAV	in WG BHP kW

2. Measure Tool Use

2.1. Tool Inputs

The Fume Food System Upgrades measure is only available for use with retrofit (same load applications). Fields with colored backgrounds require user inputs; ones with yellow backgrounds require user entries while green backgrounds require user selections.

Table A3 – Site/Utility Inputs

Input Name	Description / Purpose
Site Name	Site identifier/inspection purposes
Site Address	Site identifier/inspection purposes
State	Select state from pull down
Location	Select location closest to the project site. Weather file associated with the location is used when calculating the saving
Utility Name	Enter utility name for gas and electricity.
Utility Rate	For information purpose only
Incentive Rate	Used to estimate the incentive values for calculated savings
Lab Description	For information purpose only.

Table A4 – Existing Lab Operations Inputs

Input Name	Description/Purpose
Lab Schedule Information:	
24/7 Operation?	Select "Yes" if the lab is occupied/used all day, every day. Otherwise, select "No".
Operations vary by day?	Select "Yes" if the lab occupied hours are different from day to day (i.e. closed on weekends). Otherwise, select "No".
Lab Schedule by Day:	
Occupied	Select "Yes" if the lab is occupied/used. Otherwise, select "No".
Start	For days when the lab is occupied, select time when the lab opens.
End	For days when the lab is occupied, select time when the lab closes.

Table A5 – Proposed Fume Hoods Usage Schedule Inputs

Input Name	**Description / Purpose**
Fume Hoods Information:	
Total Number of Fume Hoods	Enter the total number of fume hoods. Note that this tool can only be used for the same load (i.e. The number of existing fume hoods = the number of proposed fume hoods).
All Same Model?	If all existing fume hoods are the same model and operate coincidently, select "Yes" and only one usage schedule is required to be entered. Otherwise, select "No" and usage schedules for all fume hoods will be prompted.
Proposed Fume Hood Usage Schedule:	
Max Flow, CFM	Fume hood nameplate data (max flow when sash is fully open)
Min. Face Velocity, fpm	Fume hood nameplate data
Hood Width, ft	Fume hood nameplate data
Min. Sash Opening Height, inch	Fume hood nameplate data
Internal Hood Depth, inch	Fume hood nameplate data – this information is required if Min. Sash Opening Height is not specified
% Time Sash Fully Open, % (Occupied Hours)	Percentage of time when the sash is left at the maximum opening position when the lab is occupied.
% Time Sash Closed to Min. (Occupied Hours)	Percentage of time when the sash is closed to the minimum opening position when the lab is occupied.
Automatic Closing Feature Installed?	Automatic closing feature will lower the sash to the minimum opening position whenever the fume is unattended. Select "Yes" if this feature will be installed.
% Time Sash Fully Open, % (Unoccupied Hours - Optional)	Percentage of time when the sash is left at the maximum opening position when the lab is unoccupied. The calculator assumes 0% if Automatic Closing Feature is installed and otherwise uses the user entered value.

Table A6 – HVAC and Distribution System Inputs

Input Name		Description / Purpose
HVAC System:		
Cooling System	Type	Select cooling system type from DX Coils, Chilled Water Coils, or Absorption Chiller
	Efficiency	Enter cooling system efficiency. Enter default value shown in column L if the system efficiency is not known
Heating System	Type	Select cooling system type from Hot Water Coils, Electric Resistance, Heat Pump, or Furnace
	Efficiency	Enter heating system efficiency. Enter default value shown in column L if the system efficiency is not known
Air Distribution System:		
Supply Fans	System Type	Select proposed supply air distribution system type from CV (constant air volume) or VAV (variable air volume) systems.
	VAV Reheat	Select yes if the terminal VAV box is equipped with reheat mechanisms
	Heating Type	Select reheat type from Heating Coil or Electric.
	Total System CFM	For multi-zone system, total max CFM is the sum of CFM of all fans associated with the air distribution system. For dedicated system,
	Fan Size	Fan size based on the sum of all fans in the above air distribution system. Enter numeric value for the fan size and select unit from in WG, kW, and BHP.
Exhaust Fans	System Type	Select proposed supply air distribution system type from CV (constant air volume) or VAV (variable air volume) systems.
	Total System CFM	Total Max CFM of exhaust fans is calculated from fume hood information entered
	Fan Size	Fan size based on the sum of all fans in the above air distribution system. Enter numeric value for the fan size and select unit from in WG, kW, and BHP.

2.2. Tool Outputs – Savings Summary

The following table describes the tool outputs.

Table A7- Measure Energy Savings and Incentive

Name	Description / Purpose
Baseline, therms	Estimated annual natural gas usage of the existing heating system (calculated if Hot Water Coils or Furnace is selected for HVAC Heating System)
Proposed, therms	Estimated annual natural gas usage of the existing heating system (calculated if Hot Water Coils or Furnace is selected for HVAC Heating System)
Baseline HVAC, kWh/yr	Estimated annual energy use of the existing HVAC system or fans
Proposed HVAC, kWh/yr	Estimated annual energy use of the proposed HVAC system or fans
Baseline, kW	Estimated maximum on-peak demand of the existing HVAC system or fans (based on average demand during May-Sept between 12pm and 6pm)
Proposed, kW	Estimated maximum on-peak demand of the proposed HVAC system or fans (based on average demand during May-Sept between 12pm and 6pm)
Savings, therms	Estimated on-peak demand savings for measure (difference between baseline and proposed)
Savings, kW	Estimated on-peak demand savings for measure (difference between baseline and proposed)
Savings, kWh/yr	Estimated annual energy savings for measure (difference between baseline and proposed)
Incentive ($)	Estimated incentive amount in $ based on incentive rate entered

3. Measure Tool Calculation Methodology

Annual energy savings is calculated by subtracting the proposed energy usage from the baseline usage. Incentive values are then calculated as the product of the incentive rate and the estimated energy savings value.

Annual Savings (kWh) = Baseline kWh – Proposed kWh

Incentive Amount = Annual Savings (kWh) * Incentive Rate ($/kWh)

In the case of VAV Fume Hoods measures, the savings can be derived from two parts; those dealing with reduced HVAC energy consumption and those dealing with reduced fan power.

3.1 Baseline Energy Use – HVAC

Baseline HVAC energy usage is estimated using a TMY3 weather file, corresponding to the state and location selected on the user input page, downloaded from the National Solar Radiation Data Base website[1]. The tool assumes that the existing system is constant air volume (total CFM provided by the user) and that the cooling initiates when outside dry bulb air is at 65°F. Two sets of supply air temperature reset schedules are used, which may be modified. The default supply air temperature reset schedules can be found in Appendix A1.

Heating as well as cooling is assumed to be carried out sensibly when latent load is not significant. The following formula[2] is used to calculate the sensible heat gain.

$$q_{tot} = q_s = 60 \cdot \frac{1}{v} \cdot Q \cdot (0.24 + 0.45W) \cdot |T_{OA} - T_{SA}|$$ **Equation 1**

where:

q_s = Sensible heat gain (Btu)

v = Specific volume (ft^3/lb_{da})

Q = Air flow (cfm)

W = Humidity ratio (lb_w/lb_{da})

T_{OA} = Outside air dry bulb temperature (°F)

T_{SA} = Supply air dry bulb temperature (°F)

When latent load becomes significant during cooling seasons (i.e. programmed supply air temperature falls below dew point temperature of the outside air), dehumidification load is accounted into the total cooling load. In such cases, the equation below[3] is used.

$$q_{tot} = q_s + q_l = 60 \cdot \frac{1}{v} \cdot Q \cdot \{(h_{OA} - h_{SA}) + h_w(W_{OA} - W_{SA})\}$$ **Equation 2**

---

[1] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

[2] 2009 ASHARE Handbook – Fundamentals, 18.14 (9)

[3] 2009 ASHARE Handbook – Fundamentals, 1.16 (45)

q_l = Latent heat gain (Btu)

h_w = Enthalpy at saturation (Btu/lb_w)

W_{OA} = Outside air humidity ratio (lb_w/lb_{da})

W_{OA} = Supply air humidity ratio (lb_w/lb_{da})

When VAV with reheat is selected, the additional sensible heat gain is calculated. The tool assumes five degrees increase for reheat including the heat gain across the supply fans as well as added heat from the heat coil or electric heating element. For regions where severe dehumidification is required, however, the supply air temperature reset schedule may need to be modified so that the desired supply air temperature is achieved after the reheat.

User entered cooling and heating device efficiencies are then applied to corresponding loads to calculate the baseline energy usage per equipment type as follows:

$$kW_{HVAC} = \frac{q_{tot,cool} \cdot \eta_{kW/ton}}{12,000} + \frac{q_{tot,heat} \cdot \eta_{COP}}{3,412} \quad \text{Equation 3}$$

$$therms = \frac{q_{tot,cool} \cdot \eta_{COP}}{100,000} + \frac{q_{tot,heat} \cdot \eta_{\%}}{100,000} \quad \text{Equation 4}$$

q_{tot} = Total cooling or heating load (Btu/hr)

η = User specified equipment efficiency

The annual energy usage is calculated as the sum of all demands. Additionally, summer peak demand is based on the average demand during 12pm to 6pm through May to September.

3.2 Proposed Energy Use – HVAC

The proposed HVAC energy usage is estimated to decrease proportionally to the reduction in supply air volume. Therefore, $q_{tot} = q_s = 60 \cdot \frac{1}{v} \cdot Q \cdot (0.24 + 0.45W) \cdot |T_{OA} - T_{SA}|$ Equation 1and $q_{tot} = q_s + q_l = 60 \cdot \frac{1}{v} \cdot Q \cdot \{(h_{OA} - h_{SA}) + h_w(W_{OA} - W_{SA})\}$ Equation 2 above are also used to calculate the proposed energy usage except Q in the equations in proposed case represents the reduced air flow, which is calculated as following:

$$Q_i = Q_{full} \times \%\,Time_{full} + Q_{int} \times \%\,Time_{int} + Q_{min} \times \%\,Time_{min}$$

where:

Q_{full} = Total air flow when fume hood sash is fully open (cfm)

$\%\,Time_{full}$ = % time when fume hood sash is fully open during occupied period (%)

Q_{int} = Total air flow when fume hood sash is partially open (cfm)

$\%\,Time_{int}$ = % time when fume hood sash is partially open during occupied period (%)

The proposed total HVAC energy usage is the product of the total load calculated and the equipment efficiency as described in Equation 3 and Equation 4 as the tool can only be used for fume hood and fan retrofit (i.e. no HVAC equipment upgrades). The proposed summer peak demand is also calculated using the hourly demand average during 12pm to 6pm through May to September.

3.3 Baseline Energy Use - Fan

The electric demand of a fan is calculated using the following expression.

$$kW_{FAN} = 0.7457 * K_p * \frac{Q_F * P_S * \rho_{in}}{6349.6 * \eta_F * \eta_d * \eta_e * \rho_{std}}$$ **Equation 5**

where:

- Q_F = Fan flow (CFM)
- Ps = Fan static discharge pressure (inches WG)
- K_p = Compressibility Factor (set to 1.0)
- ρ_{in} = Air density corrected for fan inlet conditions = ρ_{std} assumed
- ρ_{std} = Air density at standard conditions (0.075 lbs/ft^3)
- η_F = Fan efficiency @ operating conditions (0.7 assumed)
- η_e = Electric drive motor efficiency (0.9 assumed)
- η_d = Drive efficiency (if belt drive)

**Note that fan total static pressure has been substituted for total pressure in the above expression.*

Many of the variables shown in this expression are dependent on operating conditions, but general assumptions were made for parameters that remains the same for baseline and proposed cases as indicated above.

When BHP entered directly, fan kW is subsequently estimated using the following expression:

$$kW_{FAN} = 0.7457 * \frac{BHP_{Motor}}{\eta_e}$$ **Equation 6**

Baseline energy use is the product of the fan kW and the total annual operating hours.

3.4 Proposed Energy Use - Fan

The electric demand of a fan operating under VFD control is calculated using the same basic expressions described above. The fan affinity laws state that with a constant impeller diameter and varying fan speed the following ratios are maintained without any change to fan efficiency.

$$\frac{P_1}{P_2} = \left(\frac{Q_1}{Q_2}\right)^{2.7}$$ **Equation 7**

where:

- Q = Fan flow (CFM)
- P = Fan power (kW)

Variable frequency drive efficiency variation depicted in below figure was incorporated in by modifying the exponent to 2.7.

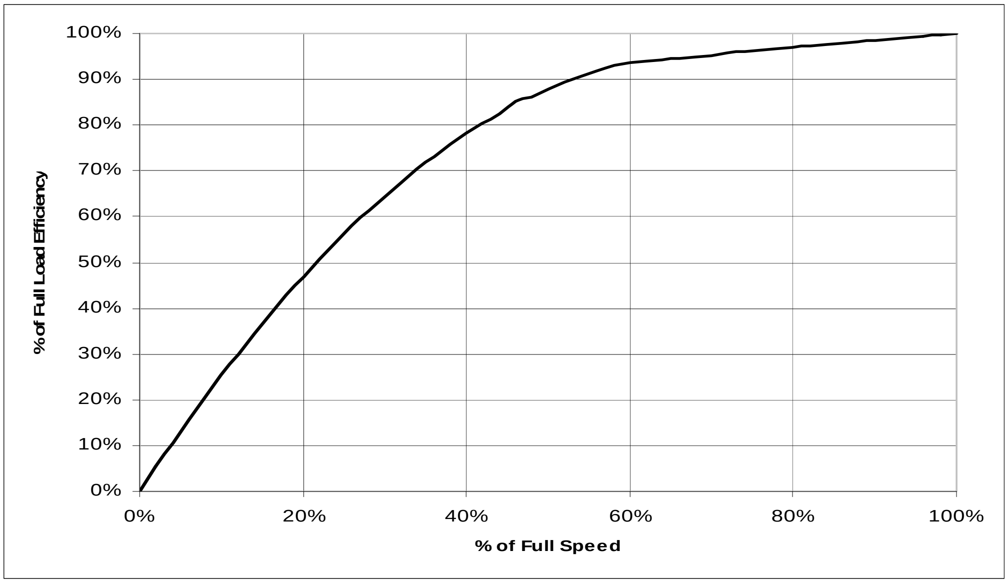


Figure A1: Generic Variable Frequency Drive Performance[4]

The proposed energy use for each sash position (closed to minimum, intermediate, and fully open) is the product of the fan kW and the total annual operating hours calculated for each operating mode based on the lab schedule and fume hood operating schedule entered. The sum of the energy use of all of the operating modes is equal to the annual energy use of the proposed fan.

Calculation of peak electric demand for the proposed equipment is accomplished by using the weighted average demand for all operating modes.

[4] Derived from EPRI TR-101140 Adjustable Speed Drives Application Guide

Appendix A1: Supply Air Temperature Reset Schedules

	Occupied		Unoccupied	
	CLG	HTG	CLG	HTG
OAT (°F)	SAT (°F)	SAT (°F)	SAT (°F)	SAT (°F)
27		90		90
28		90		90
29		90		90
30		90		90
31		90		89
32		90		88
33		90		87
34		90		86
35		90		85
36		90		84
37		90		83
38		90		82
39		90		81
40		90		80
41		89		79
42		88		78
43		87		77
44		86		76
45		85		75
46		84		74
47		83		73
48		82		72
49		81		71
50		80		70
51		79		69
52		78		68
53		77		67
54		76		66
55		75		65
56		74		64
57		73		63
58		72		62
59		71		61
60	60	70	60	60

Appendix A1: Supply Air Temperature Reset Schedules

	Occupied		Unoccupied	
	CLG	HTG	CLG	HTG
OAT (°F)	SAT (°F)	SAT (°F)	SAT (°F)	SAT (°F)
61	61	61	61	61
62	62	62	32	62
63	63	63	63	63
64	64	64	64	64
65	65	65	65	65
66	64	66	66	66
67	63	67	67	67
68	62	68	68	68
69	61	69	69	69
70	60	70	70	70
71	59		71	
72	58		72	
73	57		73	
74	56		74	
75	55		75	
76	55		76	
77	55		77	
78	55		78	
79	55		79	
80	55		80	
81	55		81	
82	55		82	
83	55		83	
84	55		84	
85	55		85	
86	55		86	
87	55		87	
88	55		88	
89	55		89	
90	55		90	
91	55		65	
92	55		65	
93	55		65	
94	55		65	
95	55		65	

Appendix A1: Supply Air Temperature Reset Schedules

	Occupied		Unoccupied	
	CLG	HTG	CLG	HTG
OAT (°F)	SAT (°F)	SAT (°F)	SAT (°F)	SAT (°F)
96	55		65	
97	55		65	
98	55		65	
99	55		65	
100	55		65	
101	55		65	
102	55		65	
103	55		65	
104	55		65	
105	55		65	
106	55		65	
107	55		65	
108	55		65	
109	55		65	

Design & Engineering Services

Automatic Sash Positioning System (ASPS)

An Energy Assessment Study on Fume Hoods for Amgen Inc.

Final Report

Prepared by:

Design and Engineering Services

Customer Service Business Unit

July, 2007

SOUTHERN CALIFORNIA EDISON

An EDISON INTERNATIONAL® Company

Acknowledgements

Southern California Edison's Design & Engineering Services (D&ES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technology program under internal project number DR 06.05. D&ES project manager Dr. Roger Sung conducted this technology evaluation with overall guidance and management from Dr. Henry Lau. For more information on this project, contact *roger.sung*@sce.com.

Disclaimer

This report was prepared by David Yamashiro of Harris Group Inc. (HGI) from Seattle, Washington and funded by California utility customers under the auspices of the California Public Utilities Commission. Reproduction or distribution of the whole or any part of the contents of this document without the express written permission of SCE is prohibited. This work was performed with reasonable care and in accordance with professional standards. However, neither SCE nor any entity performing the work pursuant to SCE's authority make any warranty or representation, expressed or implied, with regard to this report, the merchantability or fitness for a particular purpose of the results of the work, or any analyses, or conclusions contained in this report. The results reflected in the work are generally representative of operating conditions; however, the results in any other situation may vary depending upon particular operating conditions.

ABBREVIATIONS AND ACRONYMS

ASPS	Automatic Sash Positioning System
AVG	Average
BMS	Building Maintenance System
CFM	Cubic Feet per Minute
IR	Infra Red
PSI	Pounds per square inch
SCE	Southern California Edison
VAV	Variable Air Volume

TABLES

Table 1. Valves 4150.4 & 4250.4 test 8
Table 2. Valves 4120.6 & 4250.4 test 9
Table 3. Cost per CFM for 16 Regions 13
Table 4. ASPS Savings per 1000 cfm 14
Table 3A. Valves 4280.6 & 4120.4 18
Table 4A. Valves 4250.6 & 4150.6 18
Table 5. Valves 4220.4 & 4180.6 19
Table 6. Valves 4220.6 & 4210.6 tests 20
Table 7. Valves 4180.4 & 4280.4 tests 20
Table 8 Valves 4220.4 & 4180.6 Test 21
Table 9. Valves 4220.6 & 4210.6 tests 22
Table 10. Valves 4120.6 & 4250.4 tests 22
Table 11. Valves 4180.4 & 4280.4 tests 23
Table 12. Valves 4280.6 & 4120.4 tests 24

GRAPHS

Graph 1. Valves 4150.4 & 4250.4 test 8
Graph 2. Valves 4120.6 & 4250.4 test 9
Graph 3. Valves 4280.6 & 4120.4 18
Graph 4. Valves 4250.6 & 4150.6 19
Graph 5. Valves 4220.4 & 4180.6 tests 19
Graph 6. Valves 4220.6 & 4210.6 tests 20
Graph 7. Valves 4180.4 & 4280.4 tests 21
Graph 8. Valves 4220.4 & 4180.6 tests 21
Graph 9. Valves 4220.6 & 4210.6 tests 22
Graph 10. Valves 4120.6 & 4250.4 tests 23
Graph 11. Valves 4180.4 & 4280.4 tests 23
Graph 12. Valves 4280.6 & 4120.4 tests 24
Graph 13. Monday 24 hour Exhaust Profile 24
Graph 14. Tuesday 24 hour Exhaust Profile 25
Graph 15. Wednesday 24 hour Exhaust Profile 25
Graph 16. Thursday 24 hour Exhaust Profile 26
Graph 17. Friday 24 hour Exhaust Profile 26
Graph 18. Saturday 24 hour Exhaust Profile 27
Graph 19. Sunday 24 hour Exhaust Profile 27

CONTENTS

EXECUTIVE SUMMARY 1

INTRODUCTION 3

Background on Amgen 3

Importance of Energy Usage and Conservation 3

What is ASPS? 4

How Does ASPS hoods help to Conserve Energy? 4

Photos 4

COMPARISON OF ASPS WITH NON-ASPS HOODS 7

Data – Test #1 8
Data – Test #2 9

DISCUSSIONS 10

Results - Test 1 10

Results – Test 2 11

Conclusions: 15

Recommendations: 15

APPENDIX 18

EXECUTIVE SUMMARY

This laboratory study is based air flow monitoring using the BMS system at Building 29 of Amgen Inc., Thousand Oaks, California. Twelve fume hoods were used to compare difference in exhaust usage between six Automatic Sash Positioning System (ASPS) and six non ASPS for a period of fourteen days, twenty-four hours per day.

The performance of existing Central Plant System equipment and HVAC System, using Trace 700 computer simulations were used to evaluate load profiles. Southern California Edison Company and Southern California Gas Company rate structures were used for 16 climate zones in California. Central plant equipment includes chillers, pumps, and boilers.

Two sets of data were collected for two different time periods. The first set of data was collected from November 8, 2006 to November 22, 2006. Study results show very little difference in cfm usage due to obstructions in the direct path of the automatic sash hoods such as empty bottles and buckets. The average difference in cfm observed ranged from -301 to 350. The automatic sash hood was working correctly with the IR sensor, but the obstruction prevented normal closure. As a result, excessive exhaust was vented. Also in the first data results, users were closing the non sash hoods due to an energy conservation "Awareness campaign". Signs were posted on these hoods to "Please close sash when not in use". Consequently, results were skewed and not displaying normal hood operations. More than normal energy was conserved because of the environment changes from users along with the ASPS hoods within the same area.

As a result, the second set of data was collected between March 26, 2007 and April 9, 2007. Monitoring results show averages of 296-554 cfm difference between ASPS and non ASPS hoods. During the second set of data, daily walk through inspections of the test hoods was undertaken to verify proper operations of ASPS and non ASPS hoods.

The following Table is a summary finding showing the comparison of annual kWh usage and energy cost of ASPS hoods and the non ASPS hoods for 16 climatic zones.

These sixteen regions throughout Southern California were studied which resulted in an average cost of $6.41 CFM/yr. Amgen in Thousand Oaks, Region 9, the cost/CFM/yr. with ASPS was $6.20. The sum of CFM daily averages from the six test hoods with ASPS was 1960 cfm and 4622 cfm (six hoods) without ASPS. The annual utility cost using the Trace program has shown a total combination of electric and gas cost difference of $15,106 with and without ASPS. Installation costs for six ASPS units was approximately $27,000, divided by the difference of utility cost ($15,106) has resulted in a cost benefit ratio of 1.79 years.

The KWH savings has resulted in a total difference of 102,872KWH for the six hoods in Region 9. (185,017KWH non ASPS verses 82,145KWH with ASPS). Each sash hood with ASPS installed would save approximately 17,145KWH/year. If Amgen installed ASPS on every vertical sash hood (150 hoods), would result in potential savings of 2,571,750 KWH/year or approximately $377,650/year.

	Region 1		Region 2		Region 3		Region 4	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$13,324	$30,649	$12,102	$28,256	$11,360	$26,481	$12,411	$27,024
COST PER CFM	$6.79		$6.17		$5.79		$6.33	
Annual KWH usage	79,357	181,290	78,200	182,158	76,109	177,000	81,749	179,208
On-Peak Demand (kW)	9	21	12	29	11	25	11	26
Off-Peak Demand (kW)	9	21	12	28	10	24	10	24
Mid-Peak Demand (kW)	9	21	11	27	10	24	11	25
	Region 5		**Region 6**		**Region 7**		**Region 8**	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$11,590	$27,039	$11,513	$28,435	$12,138	$28,169	$12,689	$26,869
COST PER CFM	$5.91		$5.87		$6.19		$6.47	
Annual KWH usage	76,513	178,007	78,997	197,435	85,440	199,081	86,097	184,313
On-Peak Demand (kW)	11	25	13	29	12	27	13	30
Off-Peak Demand (kW)	10	24	12	27	11	26	13	30
Mid-Peak Demand (kW)	10	24	13	29	12	27	13	30
	Region 9		**Region 10**		**Region 11**		**Region 12**	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$12,152	$27,258	$12,835	$29,557	$12,562	$29,414	$12,228	$28,533
COST PER CFM	$6.20		$6.55		$6.41		$6.29	
Annual KWH usage	82,145	185,017	85,392	197,715	82,158	192,096	79,050	183,982
On-Peak Demand (kW)	12	29	13	28	17	39	13	30
Off-Peak Demand (kW)	12	28	11	27	14	33	12	29
Mid-Peak Demand (kW)	12	28	12	27	15	36	12	28
	Region 13		**Region 14**		**Region 15**		**Region 16**	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$13,647	$29,314	$13,037	$28,232	$13,748	$29,319	$13,936	$29,979
COST PER CFM	$6.96		$6.65		$7.01		$7.11	
Annual KWH usage	87,878	189,631	86,950	188,361	95,751	200,721	85,183	183,830
On-Peak Demand (kW)	13	31	12	29	14	36	14	33
Off-Peak Demand (kW)	13	30	12	29	14	35	12	28
Mid-Peak Demand (kW)	12	29	12	28	13	35	13	31

INTRODUCTION

BACKGROUND ON AMGEN

Amgen Inc. is an international biotechnology company headquartered in the Newbury Park section of Thousand Oaks, California. Located in the Conejo Valley, it is one of the top biomedical corporations in Southern California. Amgen is the largest *independent* biotech firm, with approx. 15,000 staff members in 2005. Its products include EPOGEN, ARANESP, ENBREL, Kineret, Neulasta, NEUPOGEN, and Sensipar / Mimpara. EPOGEN and NEUPOGEN (the company's first products on the market) were the two most successful biopharmaceutical products at the time of their respective releases.

BusinessWeek recently ranked Amgen fourth on the S&P 500, as the most "future-oriented" corporations. *BusinessWeek* ostensibly calculated the ratio of research and development spending, combined with capital spending, to total outlays; Amgen had the fourth highest ratio, at 506:1000. In addition, Amgen is the largest employer in Thousand Oaks and second only to the United States Navy in terms of number of people employed in Ventura County.

Currently, Amgen Inc., Thousand Oaks has a total of 651 hoods, 351 are on VAV, which 150 have vertical sash and can be retrofitted with ASPS.

IMPORTANCE OF ENERGY USAGE AND CONSERVATION

As a result of rapid growth over the past few years, Amgen Inc. is very concerned about the capacity of their central plant systems to meet the energy needs within its campus. Consequently it has instituted an energy conservation policy to reduce energy usage of HVAC, Gas, Steam, Chilled Water, and Electricity whenever possible. Amgen hopes to prevent the need for additional utility constructions.

Also by conserving energy, Amgen has proven to create a safer working environment as required by the National Fire Protection Agency.

The National Fire Protection Agency has the following Standard requirements for using & closing Fume/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, it's 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 sashes to be open only when needed and only as much as necessary.**

WHAT IS ASPS?

Automatic Sash Positioning System (ASPS) is a non-intrusive device that automatically opens and closes a fume hood sash, based on personnel presence. The system uses cable cylinder to move the sash open and closed. Active Infra Red (IR) sensor is installed (see picture below). Lower limit switch is required for walk-in hoods. The system also has IR eye for object detection with reflector. Each hood has Auto/manual selector switch and (2) manual push buttons. (See photos below)

As a worker approaches a sash hood, IR sensor opens the sash to a preset height. This allows the user to have hands free operation. When the user leaves the hood, the ASPS closes the sash with pre-selected time delay of 30 seconds. If an object is detected during the sash decent, the sash stops without touching the obstruction.

After 30 minutes the ASPS can be set to turn off lights inside the hood.

Additional feature of the ASPS is operation of the sash can be automatic or manual.

Utility requirements for ASPS are 120 V AC power and 20 psi. of clean air with regulator.

HOW DOES ASPS HOODS HELP TO CONSERVE ENERGY?

Only 9% of the time personnel are actually in front of a hood which means the majority of the time, hoods are left unattended and not in use. Unless personnel close the sash hood, the VAV exhaust valves have to remain 80-100% open to be in compliance with Cal OSHA's face velocity requirements. For an eight foot wide hood, the exhaust can reach 800-1400 cfm with the sash in the open position.

Using the ASPS, after personnel walks away from the sash hood, the hood automatically closes the sash reducing the exhaust to 200-300 cfm. The savings are the difference of 500-800 cfm per hood, with a corresponding reduction in kWh usage and energy demand from the central plant.

PHOTOS

The following photos are displaying major components of ASPS.

Photo #1 shows complete ASPS installed on Walk in type Fume hood.

Photo #2 is a close up of Auto/manual switch. A user can switch to manual mode and use the push buttons shown on Photo #3 to raise and lower sash.

Photo #4 shows the cable/pulley system on top of each fume hood to open and close sash to correct predetermined height.

Photo #5 shows typical tie in to existing air lines on top of each fume hood with pressure regulator to activate cable/pulley system shown in photo #4.

Photo #6 shows Infra red sensor to prevent sash from closing on any objects within the sliding track.

Photo #1

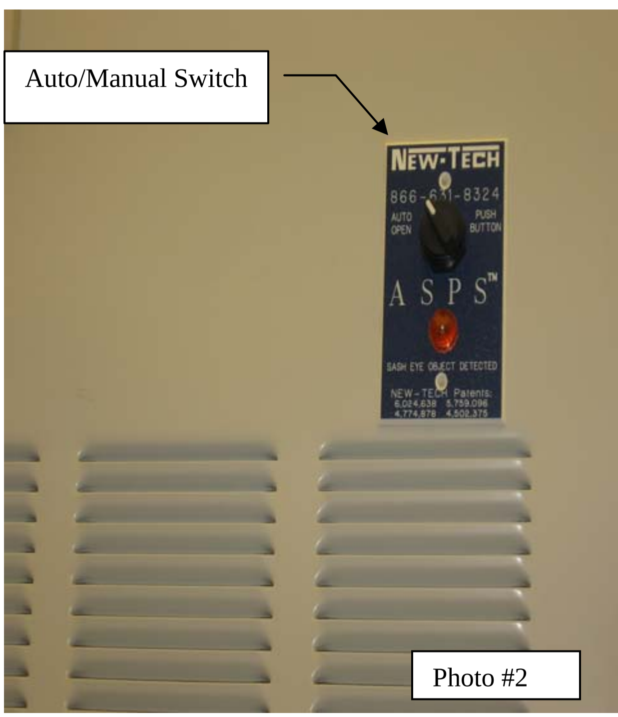


Photo #2

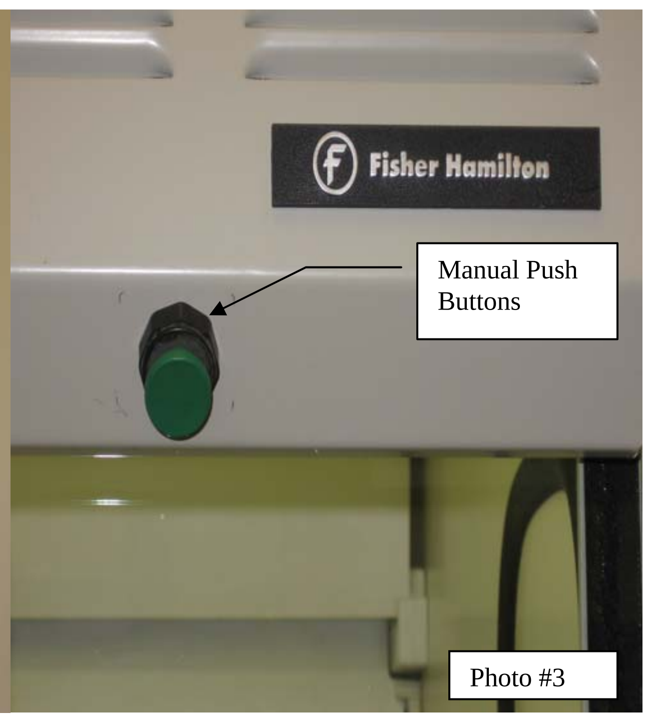
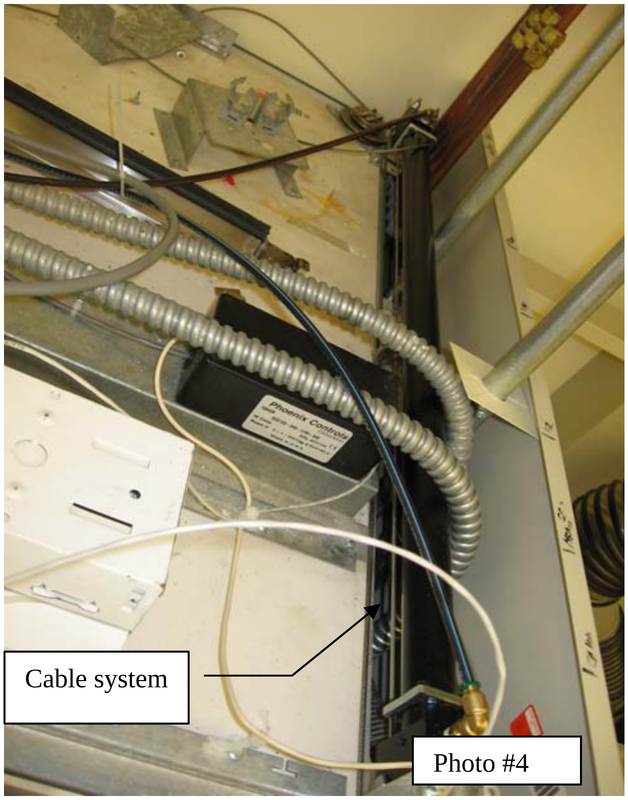
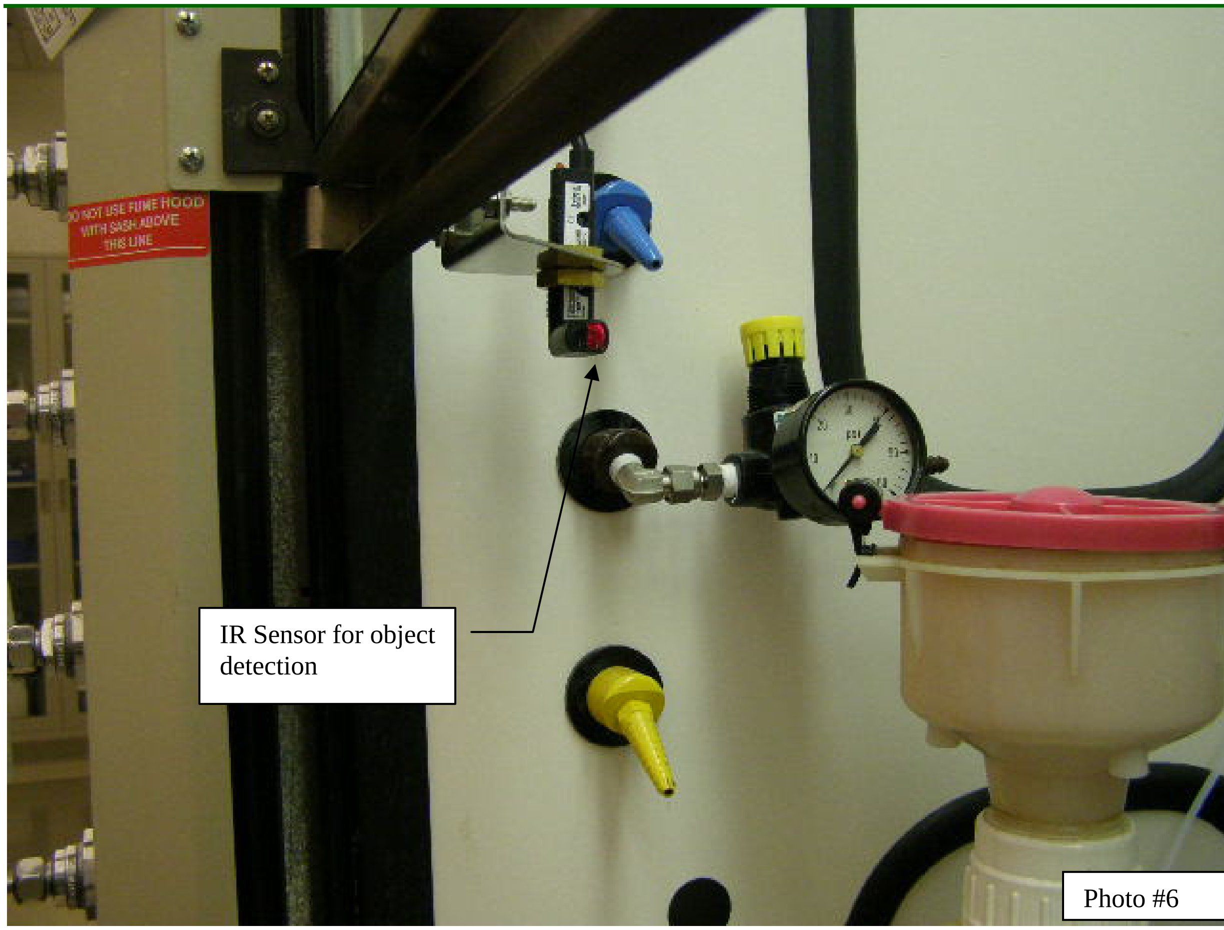


Photo #3


Cable system
Photo #4


Clean air supply with regulator
Photo #5



COMPARISON OF ASPS WITH NON-ASPS HOODS

Twelve sash hoods were monitored from November 8, 2006 through November 22, 2006. Of these six hoods with ASPS, three were walk-in hoods and three were modified bench top hoods. To be consistent during the data comparison, three walk-in hoods and three bench top hoods were also selected for the non ASPS hoods in close proximity within the same building. All walk-in and modified bench top hoods were 8 feet wide.

This set of data collected was over a fourteen day period, 24 hours a day, and in 30 minute increment snap shots from Amgen's Building Maintenance System (BMS). The data was converted from bitmap files to excel spreadsheets by an independent company to determine average flowrates in cfm of each hood and sash position.

During test data set #2, data collected was over a different fourteen day period, 24 hours a day, but the time intervals for collection were reduced to 15 minutes. Pi historian program was used to convert data from BMS to excel spreadsheets.

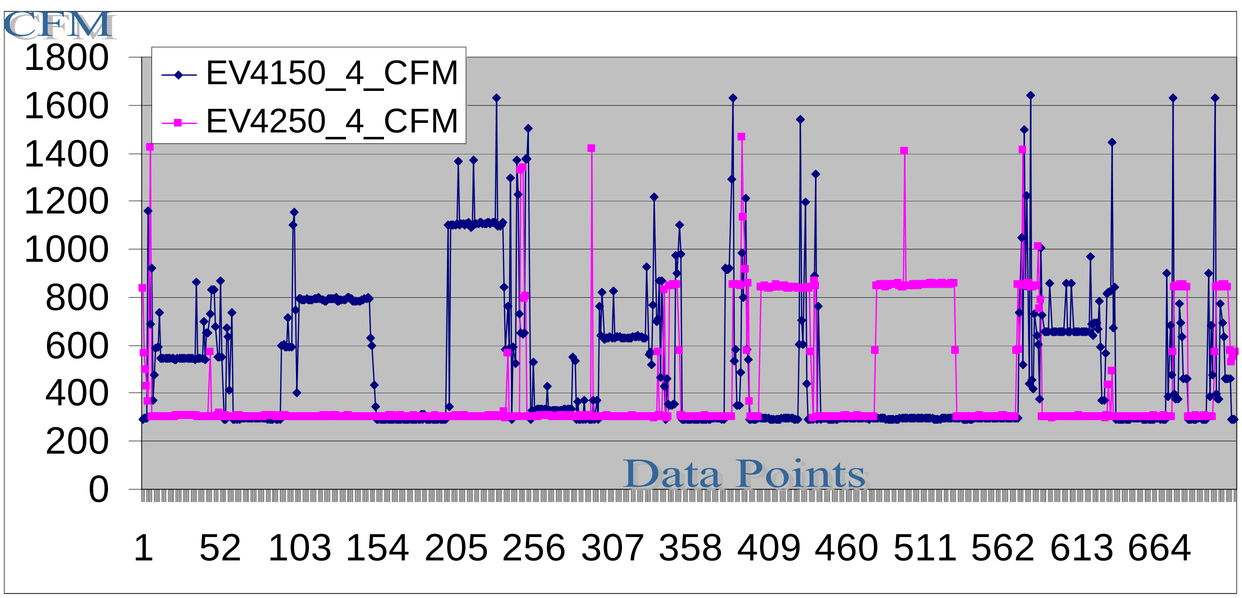
DATA – TEST #1

TABLE 1. VALVES 4150.4 & 4250.4 TEST

Valve #	4150.4	4250.4		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	456	378		78
On-Peak	577	551		26
Mid-Peak	520	406		113
Whole Day Avg	515	425		89

Table 1 shows a comparison of an ASPS Walk-in hood to a non ASPS Walk-in hood. Off-Peak period was from Midnight to 6 a.m., On-Peak period was from was from 12 p.m. to 6 p.m., Mid-Peak period was from 6 a.m. to 12 p.m. and 6 p.m. to midnight. An average exhaust rate was extracted daily for each time period from the 14 day test period. Whole day average is the total duration of 14 days, 24 hours per day in 30 min. increments from the tables in the appendix. The remaining tables and graphs of the 10 hoods comparing ASPS vs. without ASPS are found in the appendix.

GRAPH 1. VALVES 4150.4 & 4250.4 TEST



Graph 1 represents exhaust cfm along the Y-axis and all the data points in 30 minute increments over the 14 day test period in the X-axis. EV-4150_4 is without ASPS and EV-4250_4 is with ASPS. Minor problems with first test data has unexpected results and minimal cfm difference between both hoods. Between the two hoods, it is not obvious which hood has the ASPS installed. Please see Graph 2.

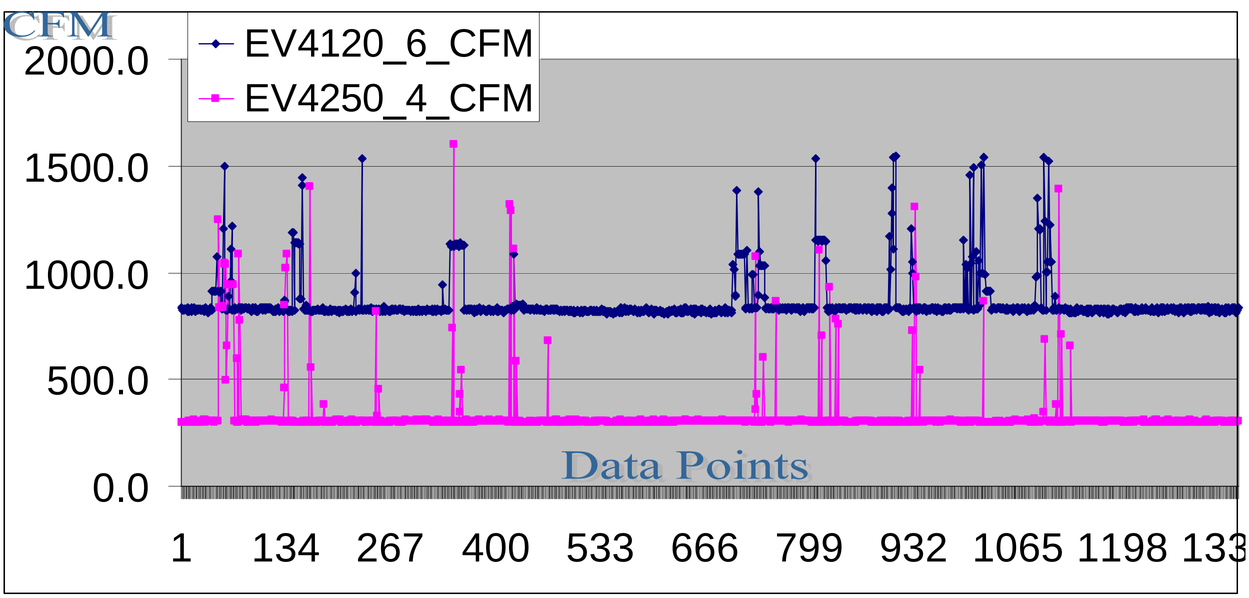
DATA – TEST #2

TABLE 2. VALVES 4120.6 & 4250.4 TEST

Valve #	**4120.6**	**4250.4**		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	827	303		513
On-Peak	888	367		522
Mid-Peak	868	323		539
Whole Day Avg	858	328		530

Table 2 depicts the same comparison over the same time periods between peak and off-peak as in Test 1. An average exhaust rate was extracted daily for each time period from the 14 day test period. Whole day average is the total duration of 14 days, 24 hours per day in 15 min. increments from the tables in the appendix. The remaining tables and graphs of the 10 hoods comparing ASPS vs. without ASPS are shown in the appendix. Note: Savings with ASPS has resulted in averages of over 500 cfm.

GRAPH 2. VALVES 4120.6 & 4250.4 TEST



Graph 2 represents exhaust rate (cfm) along the Y-axis and all data points in 15 minute increments over the 14 day test period in the X-axis. EV-4120_6 is without ASPS and EV-4250_4 is with ASPS. These sets of data points have resulted in cfm differences of over 500 cfm. It is clearly visible that the hood with ASPS uses less energy than non ASPS hood.

DISCUSSIONS

RESULTS - TEST 1

Test results from the first set of data, hoods with ASPA when compared to the non ASPS hoods, were unexpected and contradictory. The ASPS hoods showed averaged flowrates of 294 cfm to 685 cfm, while the non ASPS hoods averaged 384 cfm to 654 cfm.

- Table 1 and Graph 1 of EV 4150.4 (non ASPS) & 4250.4 (ASPS) Walk-in hoods.

For these walk-in hood comparisons, results with problems were observed with the lower limit switch not making contact for the ASPS hood. The limit switch was actually knocked off the sash. The glass was cracked and the hood was manually closed by the users (425 cfm avg). Because of these unexpected incidents, the difference observed was only 90 cfm between the ASPS and non ASPS (515 cfm avg) manually close by the users (425 cfm avg).

- Table 3 and Graph 3 of EV 4280.6 (non ASPS) and EV 4120.4 (ASPS) modified bench-top hood.

In comparing the two hoods, the results of 350 cfm difference were considered reasonable between the hoods. The ASPS installed hood was working properly (304 cfm avg.), but the users were partially closing the non ASPS hood (654 cfm avg.) as a result of the visible campaign sign to conserve energy.

- Table 4 and Graph 4 of EV 4250.6 (non ASPS) & 4150.6 (ASPS) modified benchtop hoods.

On these two hoods, the results of 283 cfm difference between the hoods are very similar to the results in Table 1. The ASPS installed hood was working properly (294 cfm avg.), but the users were again partially closing the non ASPS hoods (577 cfm avg.).

- Table 5 and Graph 5 of EV 4220.4 (non ASPS) & 4180.6 (ASPS) modified benchtop hoods.

Both hoods have comparable cfm usage with a 118 cfm difference in usage. The ASPS hood was working correctly, but there was an empty bottle obstruction restricting the sash to fully close (407 cfm avg). (see photo #7) The non-ASPS hood also has lower readings (524 cfm) due to users partially closing the sash.

- Table 6 and Graph 6 of EV 4220.6 (non ASPS) & 4210.6 (ASPS) Walk-in hoods.

Comparison of the two hoods gives a negative difference in cfm readings. An ASPS hood as a rule uses less exhaust than a non-ASPS hood. Because of the lower limit switch not making contact for the ASPS hood, the upper sash remained open during data testing, resulting in an error reading of -301 cfm avg. Chemical storage containers raised the lower sash in (photo #8) The ASPS hood used 685 cfm avg.exhaust while again the non-ASPS hood was partially close showing only 384 cfm avg exhaust.

- Table 7 and Graph 7 of EV 4180.4 (non ASPS) & 4280.4 (ASPS) Walk-in hoods.

Instead of fully opened, the non-ASPS hood was again partially opened with the light turned off (480 cfm avg). We believe that the hood was rarely in use. Because of this obvious error, it was determined to use data from a replacement walk-in hood as observed in Test data #2. The ASPS hood was working correctly in that case and was in use (352 cfm avg). The resulting difference between the two hoods was 136 cfm avg.

The results from the first set of data were reviewed by Amgen, SCE representatives, and Harris Group Engineers. The group recommended that a second set of data be collected to study the potential savings of the ASPS with increased accuracy.

During teleconferences involving SCE, Amgen, and Harris Group, the group agreed on shorter time intervals for readings on the hood positions. The appendix has print outs of the six ASPS hoods with 5 minute increments. There were no appreciable differences in average cfm usage when compared to 30 minute increments. Because of this, for the second set of data, the increments were reviewed at 15 minutes.

RESULTS – TEST 2

Before trending the data for Test 2, Amgen made minor repairs to existing ASPS hoods. Lower limit switch was reattached and buckets were move outside the lower sash for the limit switches to make contact. Daily walk through the laboratories were instituted on both ground and second floors to verify all ASPS hoods were operational and non ASPS hoods were not intentionally closed to conserve energy. Users in the selected laboratories in B29, were still partially closing the non ASPS hoods, EV-4180.4 and EV-4220.4, resulting in average flowrates of 625 and 560 cfm respectively. The non ASPS hoods with users not assisting in closing the sash, the average exhaust increased to 800-890 cfm. For ASPS hoods, based on data collected, the average exhaust is only 300 cfm.

As seen in the graph 2, and graphs 8-12, there is a definite difference between the ASPS and the non ASPS hoods. There is a solid base line at 300 cfm for all ASPS hoods compared to a base line at 850 cfm for non ASPS hoods. As users close the non ASPS hoods the required cfm drops below the base line of approximately 850 cfm and reduces down to 550-600 cfm.

Table 3 was generated from a summary of Trace 700 program which evaluates sixteen regions throughout California (see page next page). General time of use schedules were used for on-peak, mid-peak, and off-peak periods. Amgen's rate schedule was used to generate annual energy costs evaluating all six hoods with ASPS and six without ASPS hoods.

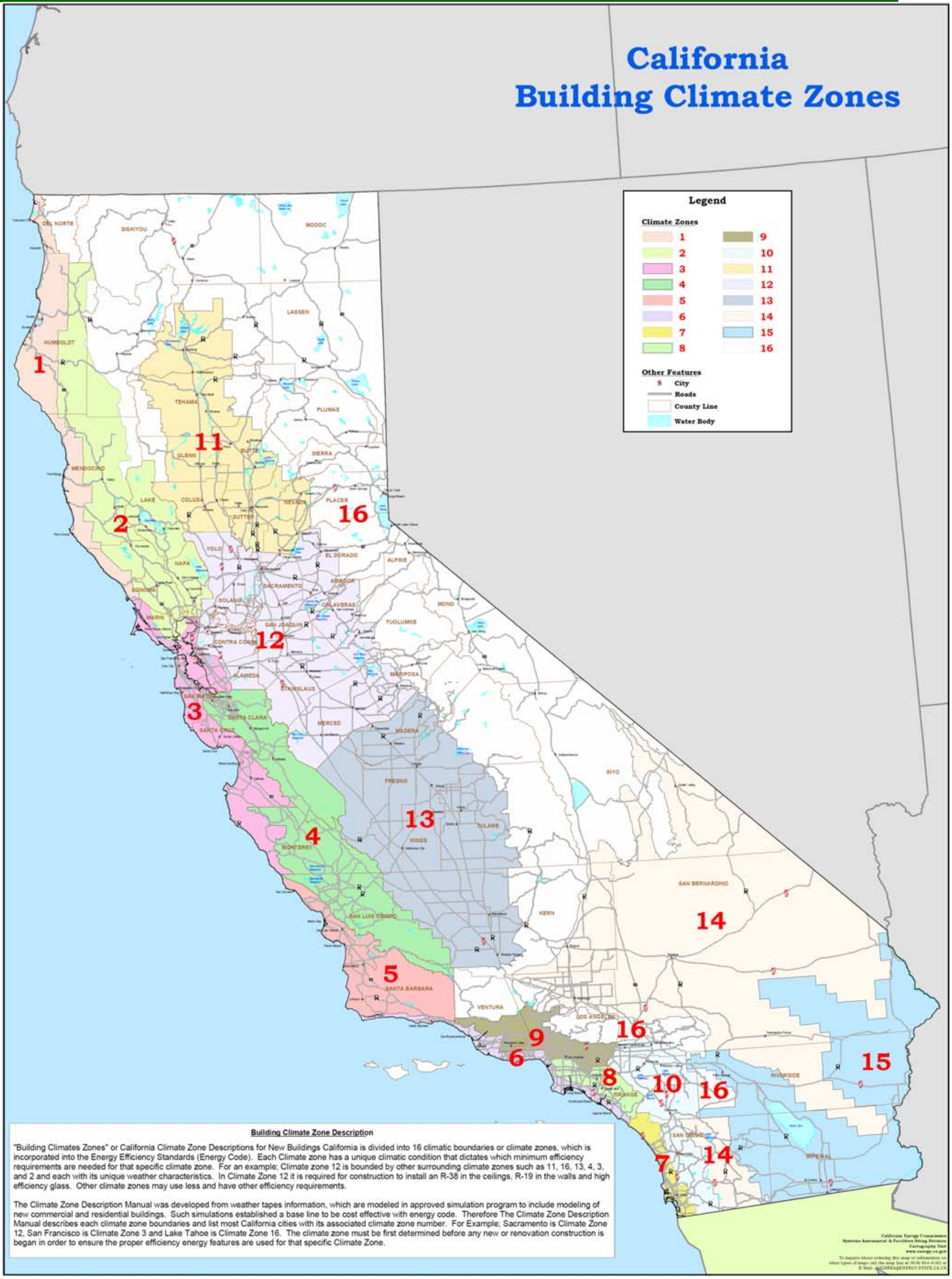

California
Building Climate Zones
Legend
Climate Zones
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Other Features
City
Roads
County Line
Water Body
Building Climate Zone Description
"Building Climates Zones" or California Climate Zone Descriptions for New Buildings California is divided into 16 climatic boundaries or climate zones, which is incorporated into the Energy Efficiency Standards (Energy Code). Each Climate zone has a unique climatic condition that dictates which minimum efficiency requirements are needed for that specific climate zone. For an example; Climate zone 12 is bounded by other surrounding climate zones such as 11, 16, 13, 4, 3, and 2 and each with its unique weather characteristics. In Climate Zone 12 it is required for construction to install an R-38 in the ceilings, R-19 in the walls and high efficiency glass. Other climate zones may use less and have other efficiency requirements.
The Climate Zone Description Manual was developed from weather tapes information, which are modeled in approved simulation program to include modeling of new commercial and residential buildings. Such simulations established a base line to be cost effective with energy code. Therefore The Climate Zone Description Manual describes each climate zone boundaries and list most California cities with its associated climate zone number. For Example; Sacramento is Climate Zone 12, San Francisco is Climate Zone 3 and Lake Tahoe is Climate Zone 16. The climate zone must be first determined before any new or renovation construction is began in order to ensure the proper efficiency energy features are used for that specific Climate Zone.

TABLE 3. COST PER CFM FOR 16 REGIONS

	Region 1		Region 2		Region 3		Region 4	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$13,324	$30,649	$12,102	$28,256	$11,360	$26,481	$12,411	$27,024
Air Flow (CFM)	1960	4622	1960	4622	1960	4622	1960	4622
COST PER CFM	$6.79		$6.17		$5.79		$6.33	
Annual KWH	79,357	181,290	78,200	182,158	76,109	177,000	81,749	179,208
Annual energy savings	**$17,325 (101,933 Kwh)**		**$16,154 (103,958Kwh)**		**$15,121 (100,891 Kwh)**		**$14,613 (97,459 Kwh)**	
	Region 5		**Region 6**		**Region 7**		**Region 8**	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$11,590	$27,039	$11,513	$28,435	$12,138	$28,169	$12,689	$26,869
Air Flow (CFM)	1960	4622	1960	4622	1960	4622	1960	4622
COST PER CFM	$5.91		$5.87		$6.19		$6.47	
Annual KWH	76,513	178,007	78,997	197,435	85,440	199,081	86,097	184,313
Annual energy savings	**$15,449 (101,494 Kwh)**		**$16,922 (118,438 Kwh)**		**$16,031 (113,641 Kwh)**		**$14,180 (98,216 Kwh)**	
	Region 9		**Region 10**		**Region 11**		**Region 12**	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$12,152	$27,258	$12,835	$29,557	$12,562	$29,414	$12,228	$28,533
Air Flow (CFM)	1960	4622	1960	4622	1960	4622	1960	4622
COST PER CFM	$6.20		$6.55		$6.41		$6.29	
Annual KWH	82,145	185,017	85,392	197,715	82,158	192,096	79,050	183,982
Annual energy savings	**$15,106 (102,872 Kwh)**		**$16,722 (112,323 Kwh)**		**$16,852 (109,938 Kwh)**		**$16,305 (104,932 Kwh)**	
	Region 13		**Region 14**		**Region 15**		**Region16**	
	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS	ASPS	NON ASPS
Annual Energy Cost	$13,647	$29,314	$13,037	$28,232	$13,748	$29,319	$13,936	$29,979
Air Flow (CFM)	1960	4622	1960	4622	1960	4622	1960	4622
COST PER CFM	$6.96		$6.65		$7.01		$7.11	
Annual KWH	87,878	189,631	86,950	188,361	95,751	200,721	85,183	183,830
Annual energy savings	**$15,667 (101,753 Kwh)**		**$15,195 (101,411 Kwh)**		**$15,571 (104,970 Kwh)**		**$16,043 (98,647 Kwh)**	

TABLE 4. ASPS SAVINGS PER 1000 CFM

	With ASPS		**Without ASPS**
Daily Averages (cfm)	322		876
	297		809
	254		560
	430		894
	328		858
	329		625
Sum Daily averages (cfm)	**1960**		**4622**
From TRACE program:			
Annual Electric Cost:	$11,425		$25,898
Annual Gas Cost:	$727		$1,360
Total Annual Utility Cost	**$12,152**		**$27,258**
Electric Cost per cfm/yr	$5.19		$4.96
Cost per 1000 cfm/yr	$5,190		$4,964
Gas Cost per cfm/yr	$0.37		$0.29
Cost per 1000 cfm/yr	$371		$294
Total Cost per cfm/yr	$5.56		$5.26
Total Cost per 1000 cfm/yr	$5,561		$5,259
Cost Benefit Ratio based total annual utility costs			
From the above annual utility costs		**$27,258-$12,152 =**	**$15,106**
The cost to install ASPS per fume hood is	**$4,500**		
For six fume hoods the installation costs is $4500 x 6 units = $27,000			
$27,000/$15,106 =	**1.79 yrs**		
Cost Benefit Ratio	**1.79 yrs**		

CONCLUSIONS:

Table 3 shows the annual energy costs, air flows for the ASPS and non-ASPS fume hoods, and the costs per cfm. With the ASPS, the annual utility savings result in a Cost Benefit Ratio of about two years. The annual cost savings with ASPS can be directly applied to the utility plant equipment. With the installation of the ASPS, energy usage for the water chiller, chilled water pump, cooling tower, cooling tower pump, boiler, and hot water pump will be significantly reduced.

Similarly, with the reduction in air usage, the amount of chilled water and pre-heated hot water utilized by the air handling systems is reduced as well. The air handling unit(s) will work at a reduced capacity. The savings for the air handling unit(s) will be a significant reduction in utility costs at the Central Plant. Future laboratory buildings will require fewer water chillers, smaller cooling towers, and less boiler capacity.

The unexpected data results in Test 1 were not used in the data evaluation, but were critical in determining the maximum potential in cfm differences between the ASPS and non ASPS hoods. For example, objects can obstruct the sash from closing. This will result in excessive exhaust as shown in test 1. To help prevent obstructions from occurring and to remind users of a sash warning zone, a strip of 6” caution tape inside the sash hood would eliminate the potential for future obstructions of the sash. An alternative building could have been used to study the non ASPS hoods. Normal fume hoods are left 100% open for a 24 hour day. The environment near the ASPS hoods with personnel was very difficult to change once non ASPS hoods were partially closing after use as shown on graphs 8, 9, 11, and 12.

RECOMMENDATIONS:

There is a define need for installing ASPS on all hoods at Amgen with VAV valves. Specifically for Amgen Inc., Region 9, the cost savings are $6.20/cfm/yr per hood. Each hood that is retrofitted with the ASPS, a minimum difference of 550-600 cfm would be realized. The cost per cfm/yr. on table 13 shows that the 16 different regions only ranged from $5.79/cfm/yr. to $7.11/cfm/yr.

SCE has three options on determining incentive rebates for reducing utility costs: Option #1, rebate 50% of the initial installation cost of the ASPS or base rebates on annual cost savings from feasibility studies. For this study, 50% of the installation cost would be $13,500 from Table 4.

Option #2, match the annual KWH savings of approximately $14,473 for the six ASPS installed also from Table 4. (up to maximum of 50% installed cost)

Option #3, base a rebate on KWH savings. For Amgen, in region 9, the KWH annual usage is 185,017 without ASPS and 82,145 with ASPS. The KWH saving difference between with ASPS and without is 102,872 KWH multiplied by a rebate factor of ($0.08/KWH) would result in $8,230 or $1,372 for each ASPS installed.

An incentive program from SCE would reduce Amgen’s cost ratio from 1.79 years to 0.94 years for options 1 and 2, 1.15 years for option 3.

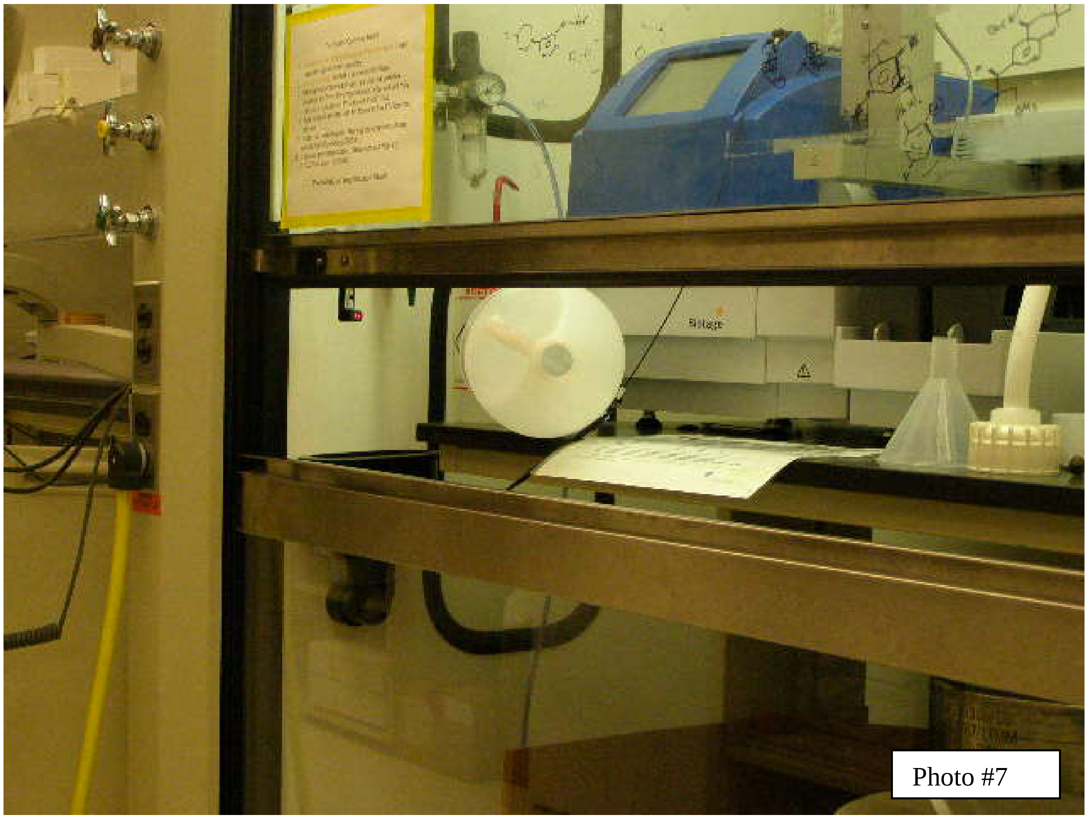


Photo #7

ASPS Hood 4180.6 with empty bottle obstruction causing excessive exhaust usage.

Photo #8

Amgen's awareness campaign to conserve energy. This signage was applied to all VAV hoods.

Photo #9

Chemical buckets and other obstructions are keeping the lower limit switch to make contact. This caused the upper sash to remain in the full open position or users were in manual mode leaving upper sash partially or full open.

Correcting obstructions from photo #8 by lengthening hoses and moving chemical buckets outside lower sash. ASPS can now work properly without user assistance.

APPENDIX

TABLE 3A. VALVES 4280.6 & 4120.4

Valve #	**4280.6**	**4120.4**		Benchtop
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	635	295		340
On-Peak	683	330		353
Mid-Peak	653	301		353
Whole Day Avg	654	304		350

GRAPH 3. VALVES 4280.6 & 4120.4

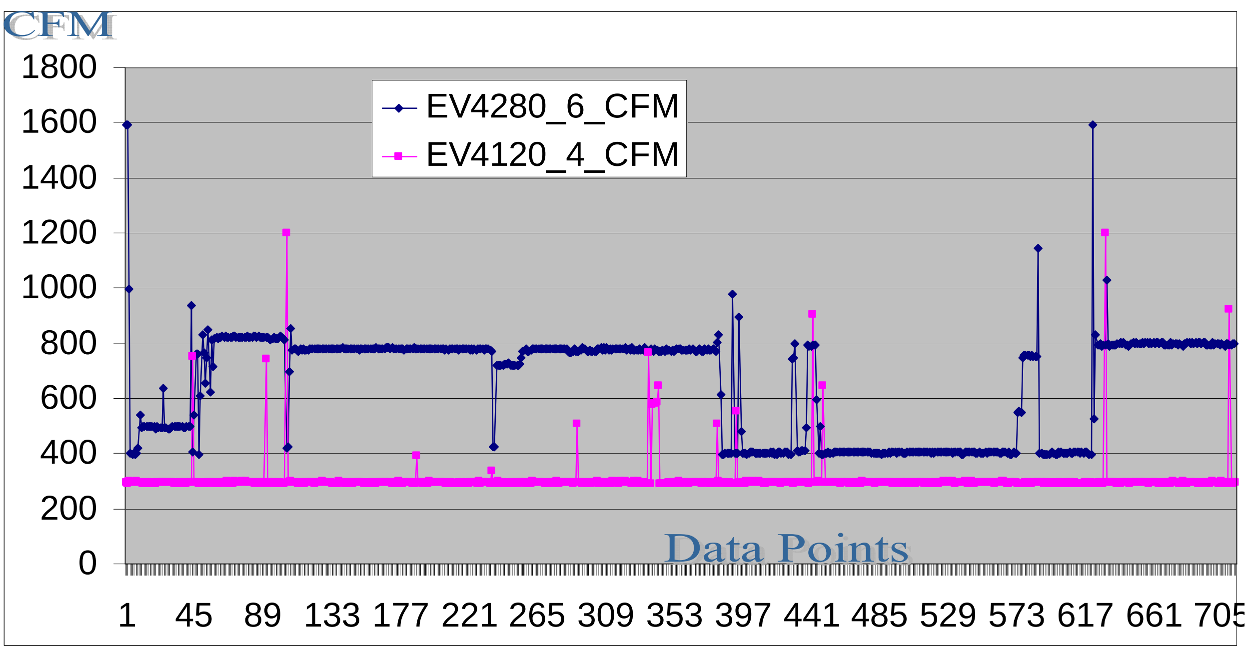


TABLE 4A. VALVES 4250.6 & 4150.6

Valve #	4250.6	4150.6		Benchtop
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	552	289		263
On-Peak	683	314		369
Mid-Peak	555	289		265
Whole Day Avg	577	294		283

GRAPH 4. VALVES 4250.6 & 4150.6

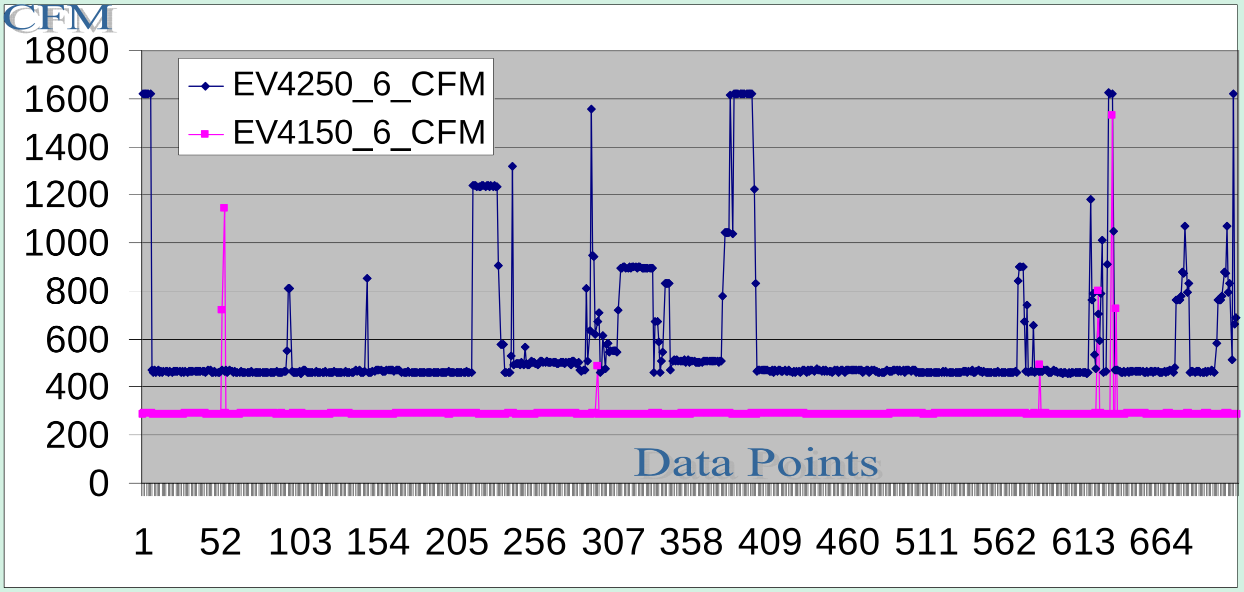


TABLE 5. VALVES 4220.4 & 4180.6

Valve #	**4220.4**	**4180.6**		Benchtop
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	529	412		117
On-Peak	523	422		100
Mid-Peak	522	400		123
Whole Day Avg	524	407		118

GRAPH 5. VALVES 4220.4 & 4180.6 TESTS

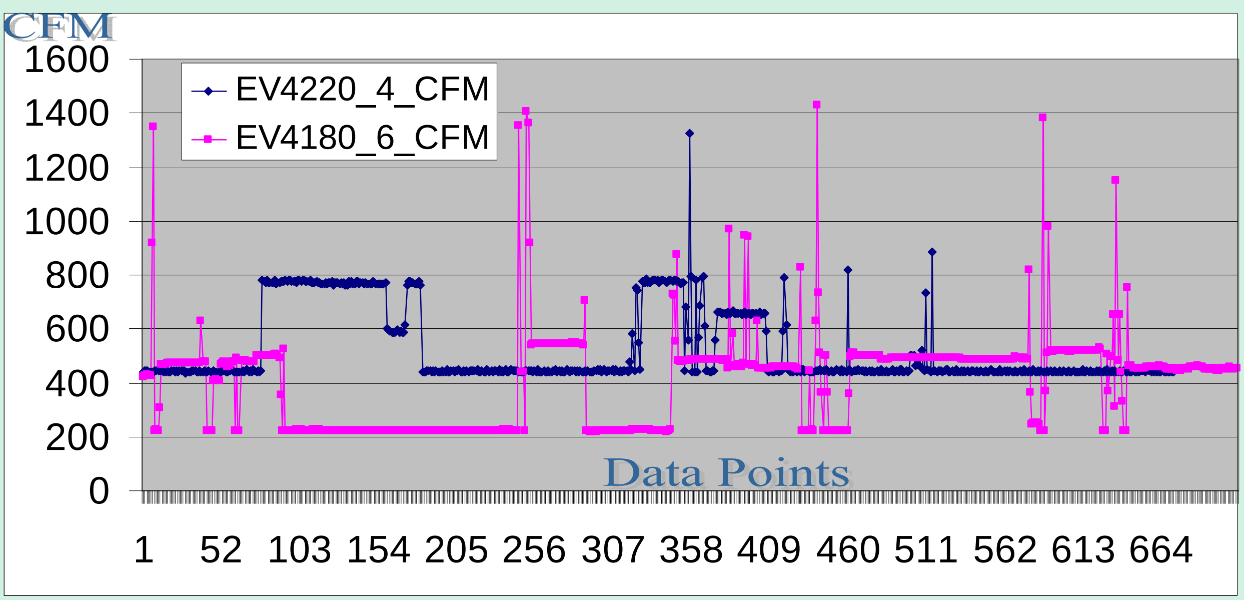


TABLE 6. VALVES 4220.6 & 4210.6 TESTS

Valve #	4220.6	4210.6		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	361	681		-321
On-Peak	410	693		-283
Mid-Peak	386	684		-298
Whole Day Avg	384	685		-301

GRAPH 6. VALVES 4220.6 & 4210.6 TESTS

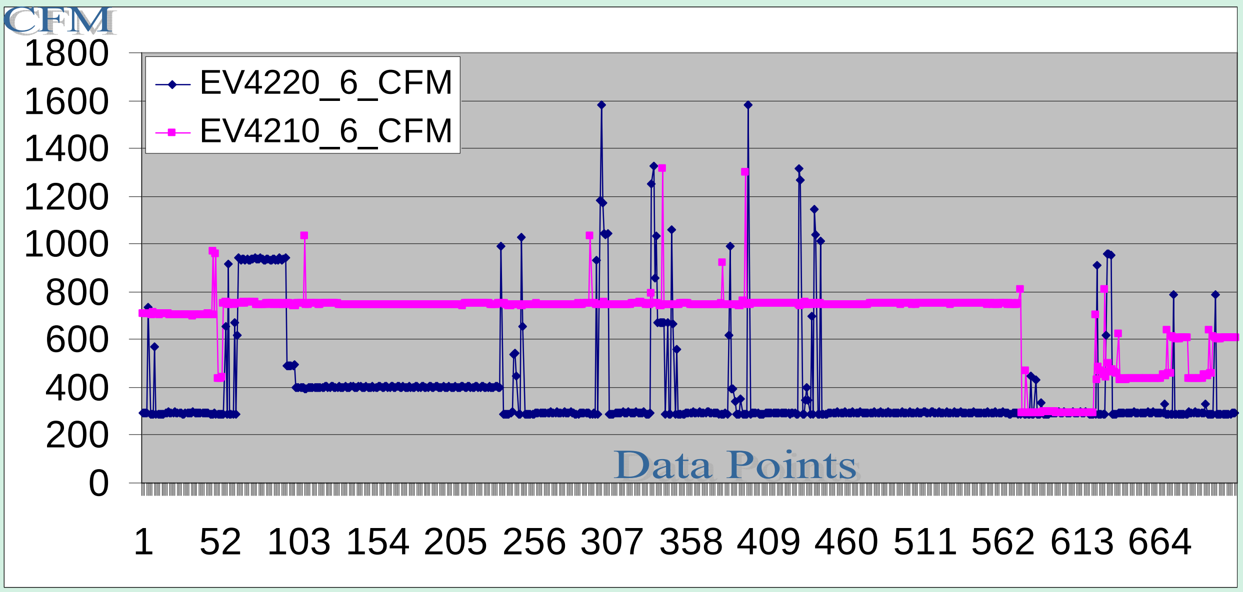
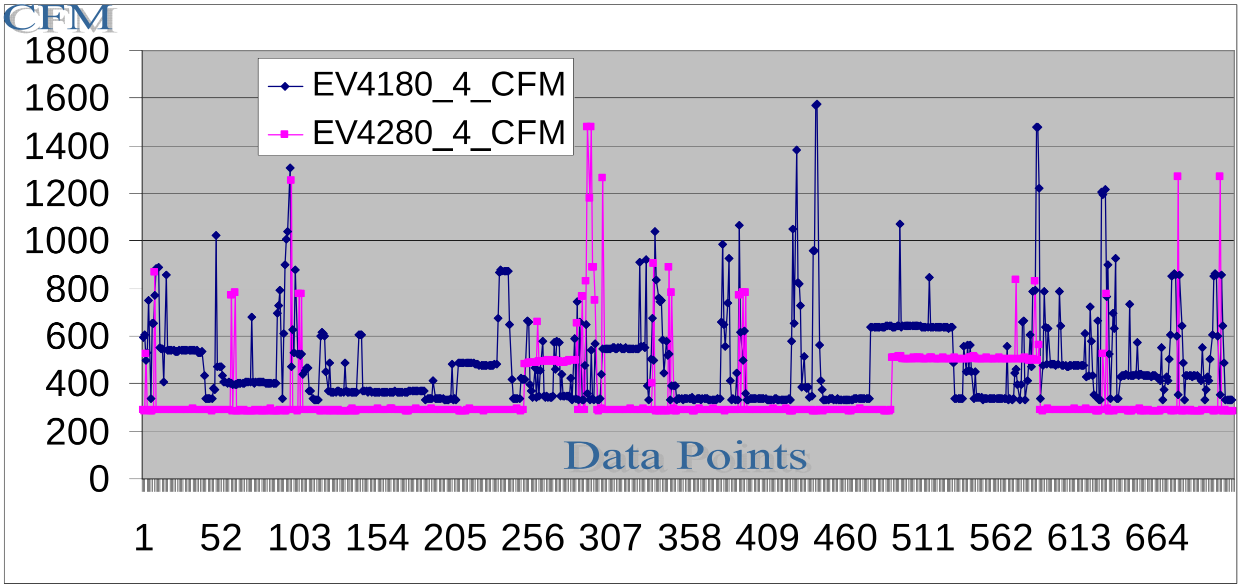


TABLE 7. VALVES 4180.4 & 4280.4 TESTS

Valve #	4180.4	4280.4		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	433	332		101
On-Peak	560	418		142
Mid-Peak	490	341		149
Whole Day Avg	489	352		136

GRAPH 7. VALVES 4180.4 & 4280.4 TESTS



TEST 2 Tables & Graphs

TABLE 8 VALVES 4220.4 & 4180.6 TEST

Valve #	4220.4	4180.6		Benchtop
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	566	227		339
On-Peak	551	293		258
Mid-Peak	561	254		307
Whole Day Avg	560	254		306

GRAPH 8. VALVES 4220.4 & 4180.6 TESTS

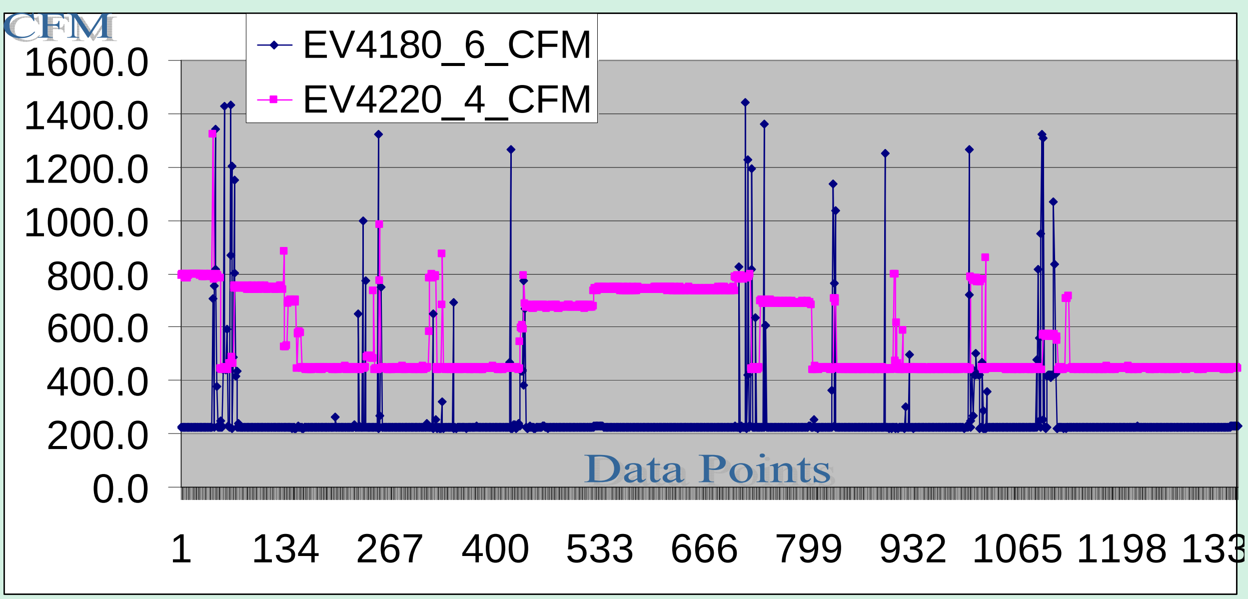


TABLE 9. VALVES 4220.6 & 4210.6 TESTS

Valve #	4220.6	4210.6		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	870	403		467
On-Peak	924	477		447
Mid-Peak	896	423		473
Whole Day Avg	894	430		464

GRAPH 9. VALVES 4220.6 & 4210.6 TESTS

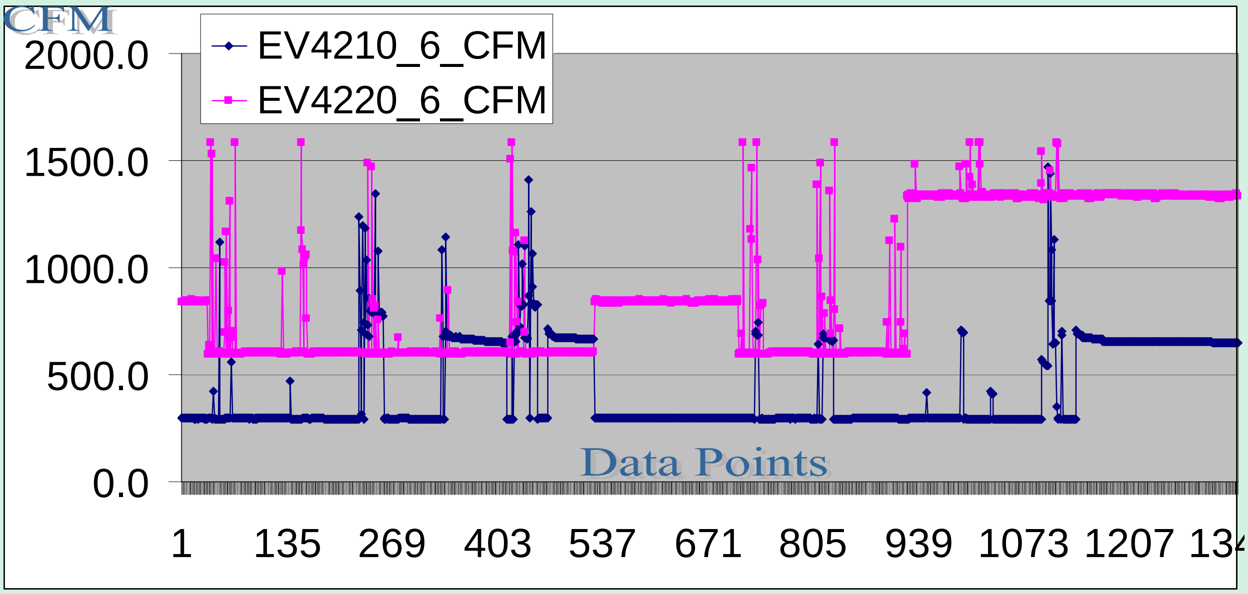


TABLE 10. VALVES 4120.6 & 4250.4 TESTS

Valve #	4120.6	4250.4		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	827	303		524
On-Peak	888	367		521
Mid-Peak	868	352		516
Whole Day Avg	858	328		530

GRAPH 10. VALVES 4120.6 & 4250.4 TESTS

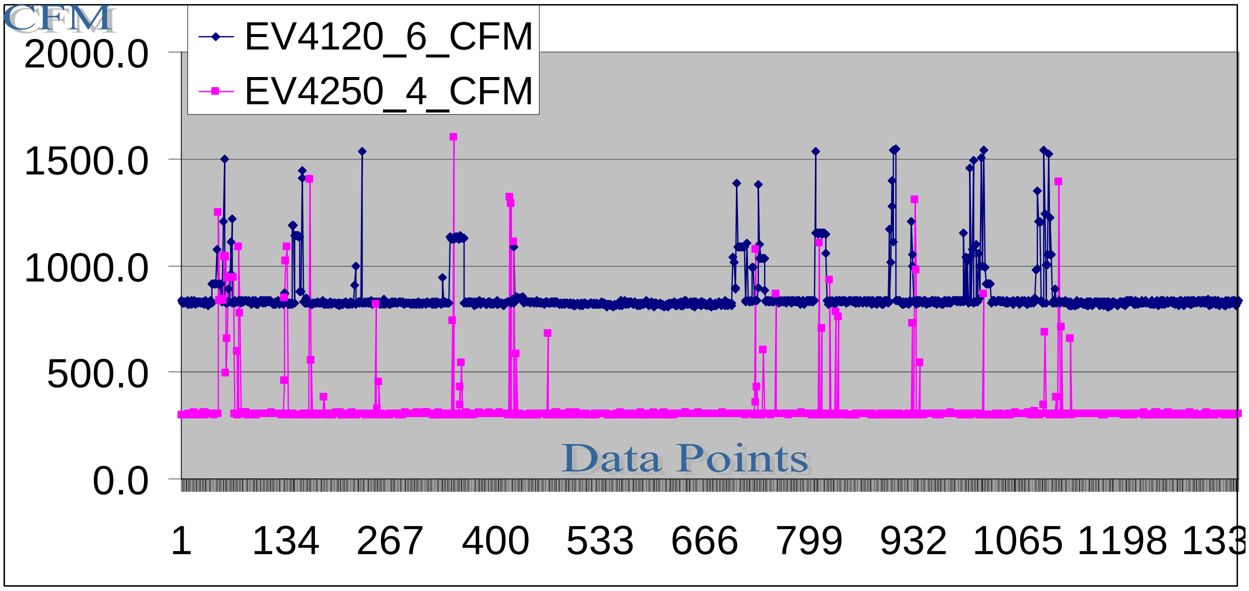


TABLE 11. VALVES 4180.4 & 4280.4 TESTS

Valve #	**4180.4**	**4280.4**		Walk-In
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	568	290		278
On-Peak	679	376		303
Mid-Peak	642	332		310
Whole Day Avg	625	329		296

GRAPH 11. VALVES 4180.4 & 4280.4 TESTS

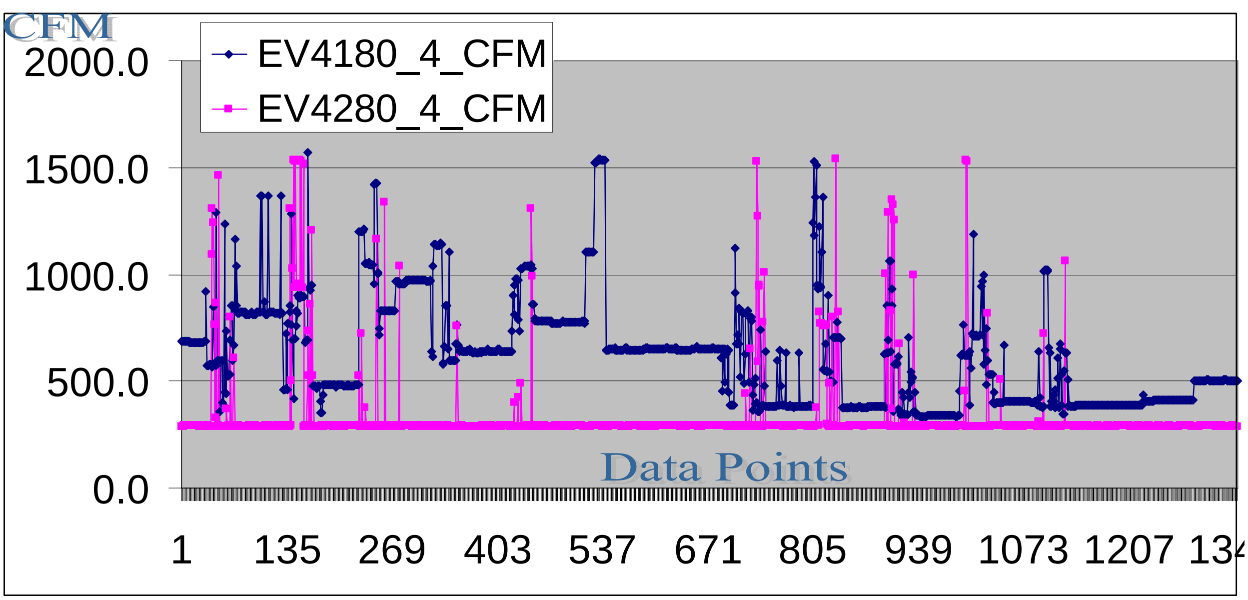
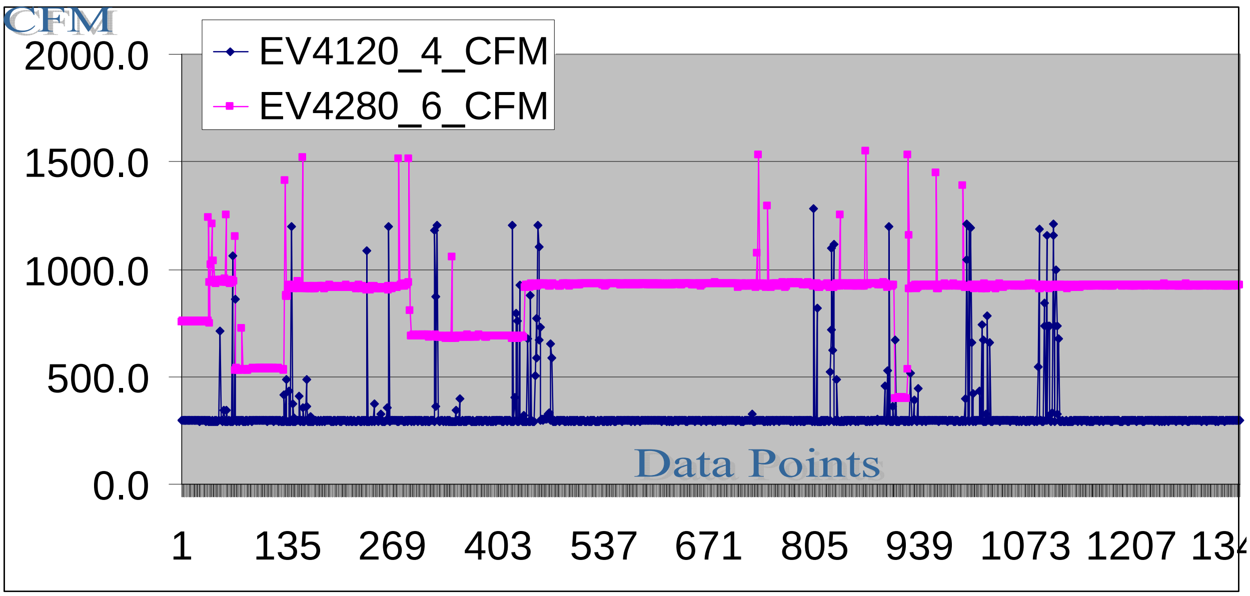


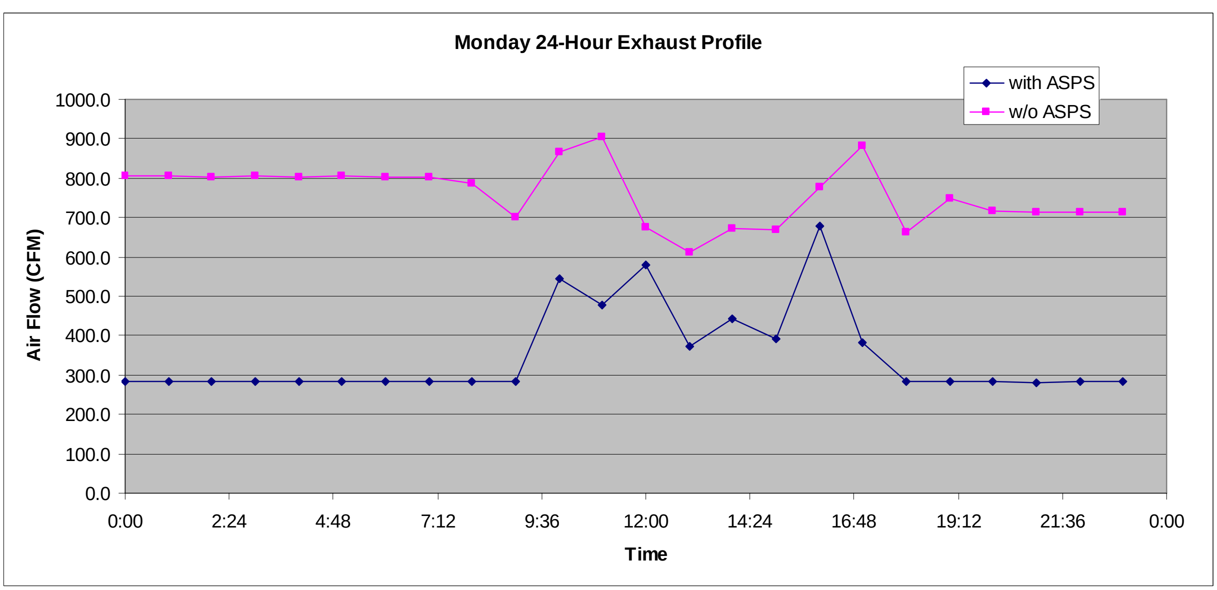
TABLE 12. VALVES 4280.6 & 4120.4 TESTS

Valve #	4280.6	4120.4		Benchtop
Time Period	CFM Without ASPS	CFM With ASPS		CFM Difference
Off-Peak	860	295		565
On-Peak	893	343		550
Mid-Peak	880	333		547
Whole Day Avg	876	322		554

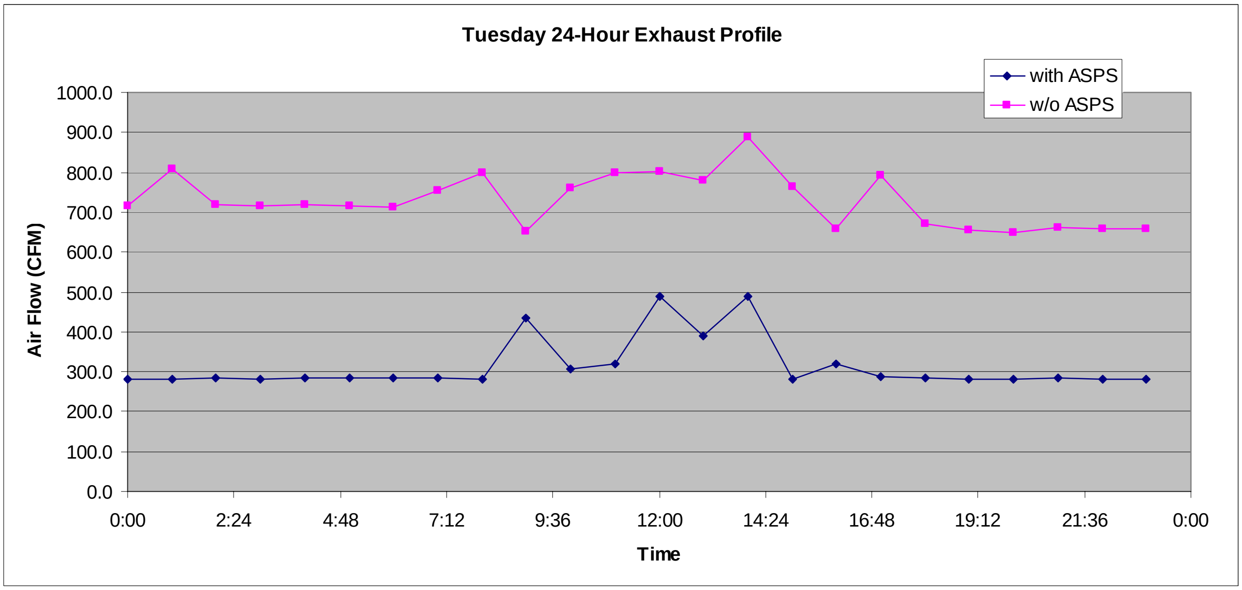
GRAPH 12. VALVES 4280.6 & 4120.4 TESTS



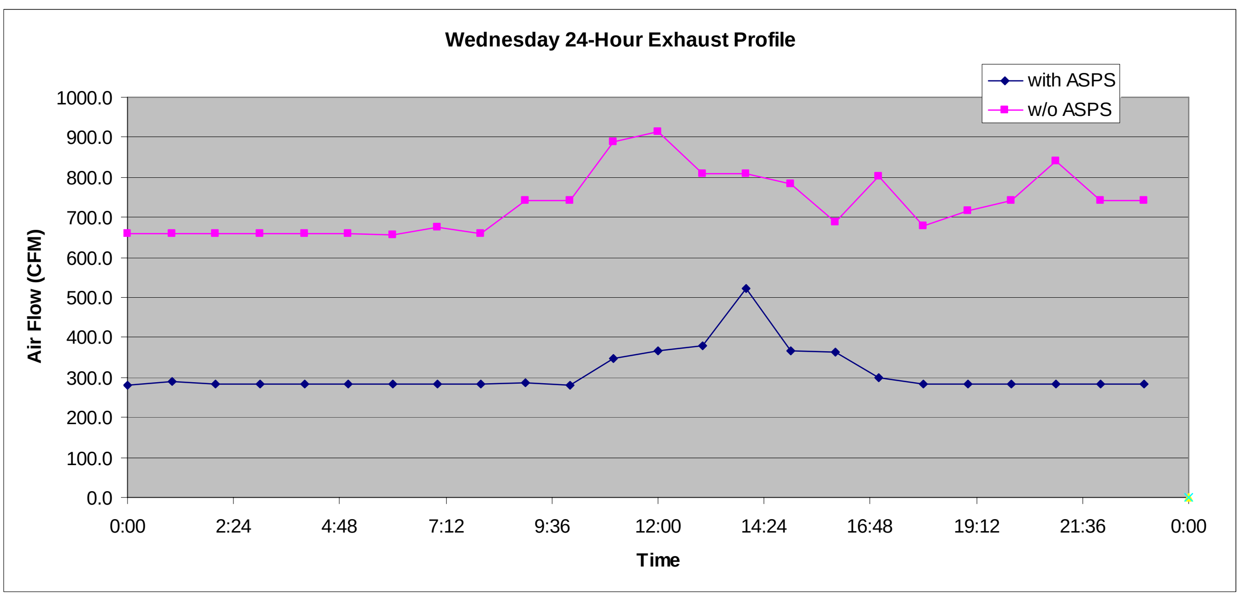
GRAPH 13. MONDAY 24 HOUR EXHAUST PROFILE



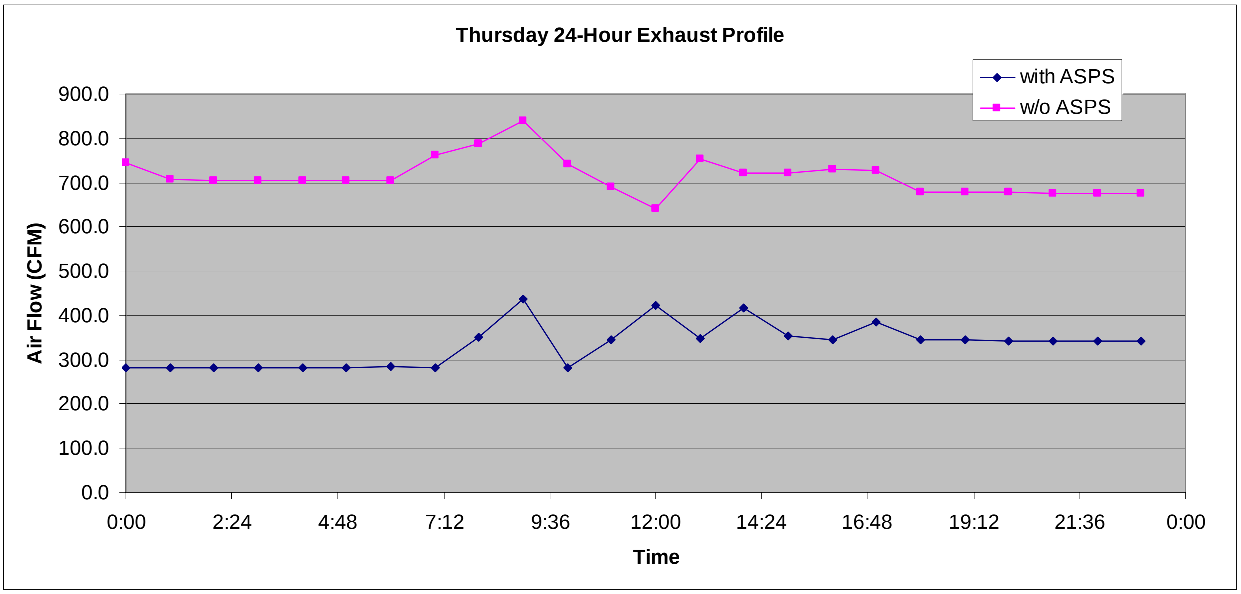
Graph 14. Tuesday 24 hour Exhaust Profile



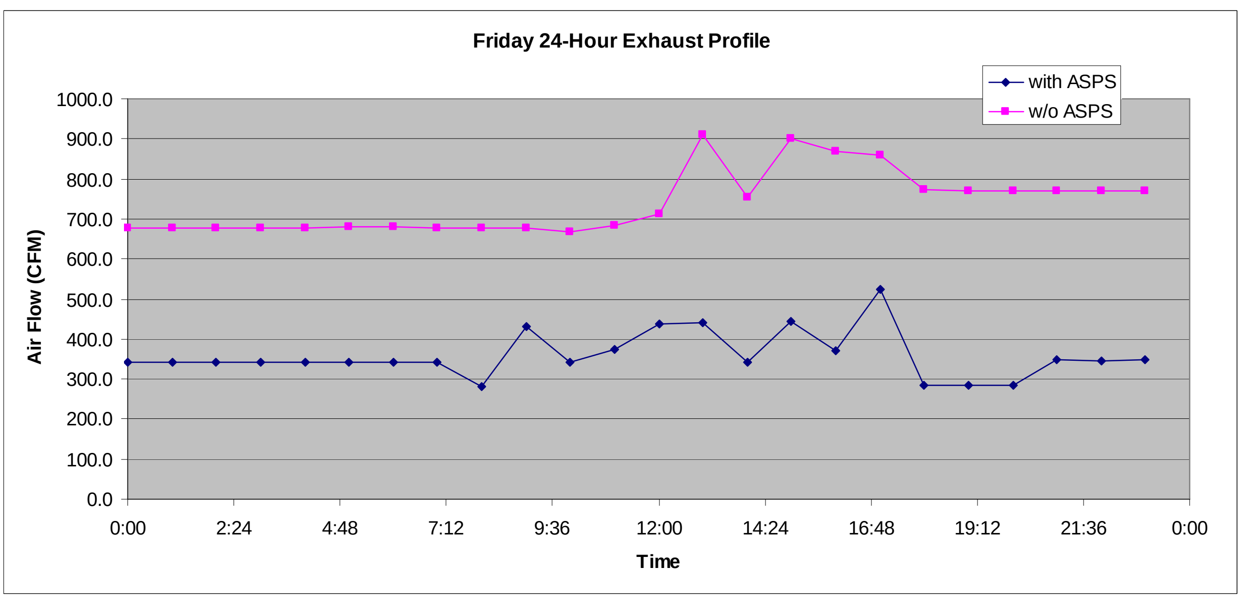
Graph 15. Wednesday 24 hour Exhaust Profile



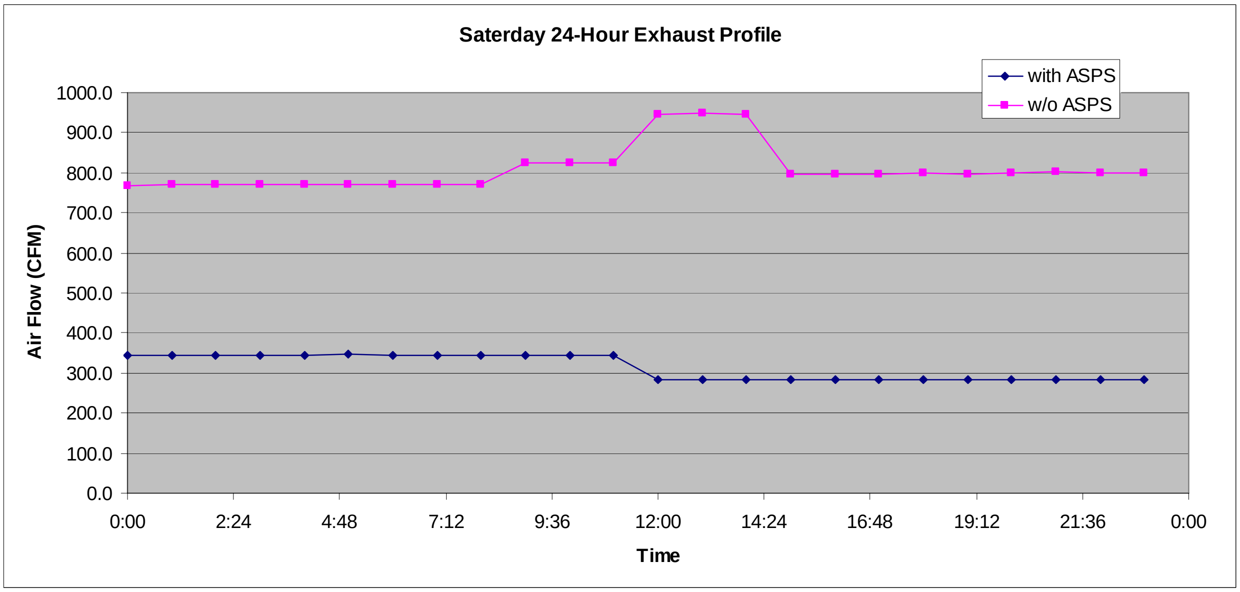
GRAPH 16. THURSDAY 24 HOUR EXHAUST PROFILE



GRAPH 17. FRIDAY 24 HOUR EXHAUST PROFILE



GRAPH 18. SATURDAY 24 HOUR EXHAUST PROFILE



GRAPH 19. SUNDAY 24 HOUR EXHAUST PROFILE