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

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

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.

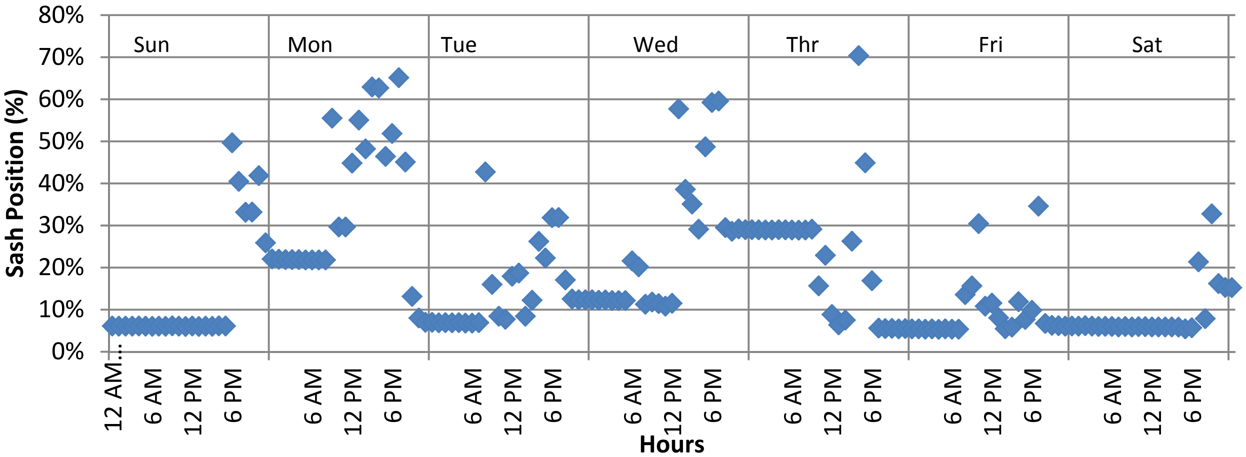


Figure 1: Sash Positions for Fume Hood #1 in a Sample Week.

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%

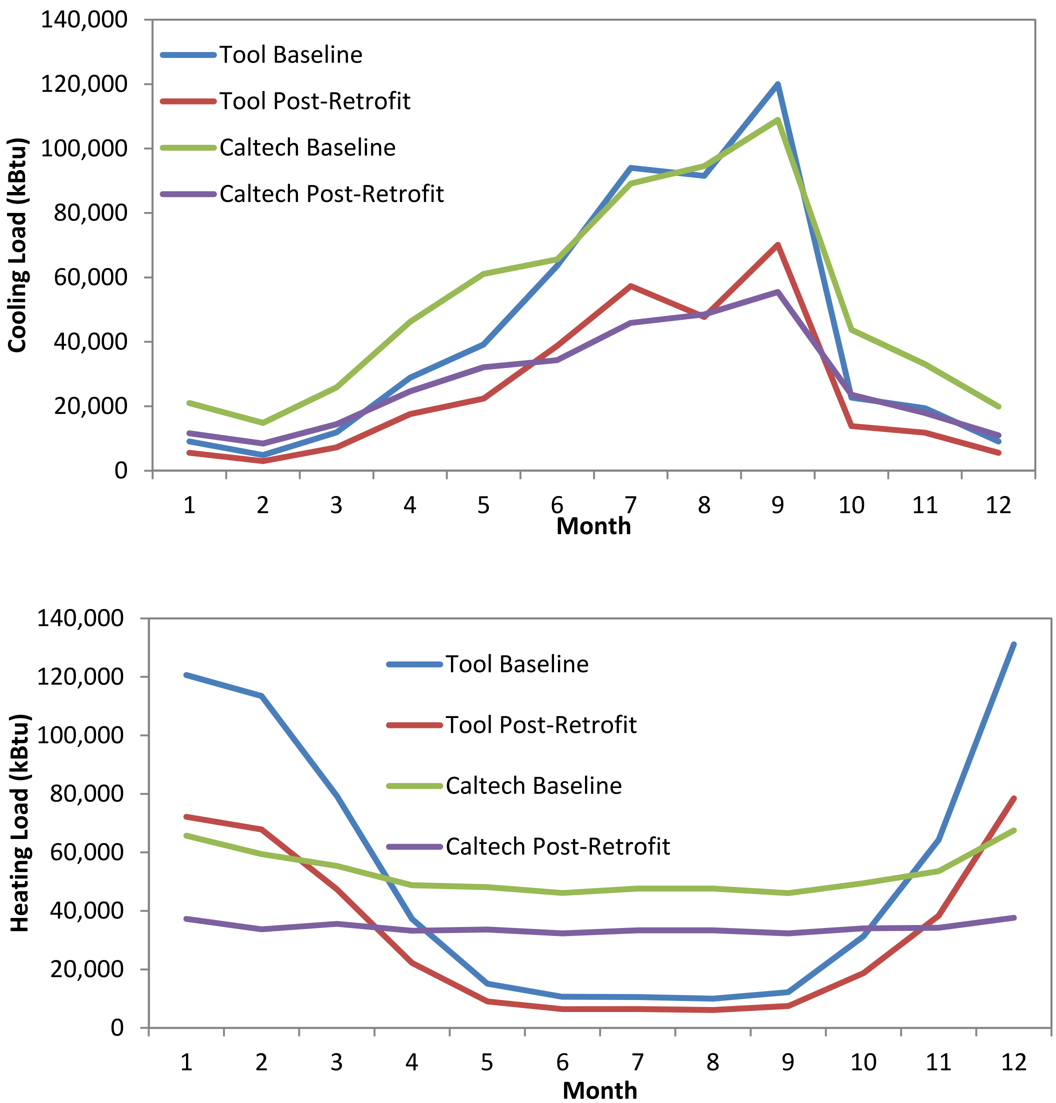


Figure 2: Cooling (above) and Heating (below) Load Comparison

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

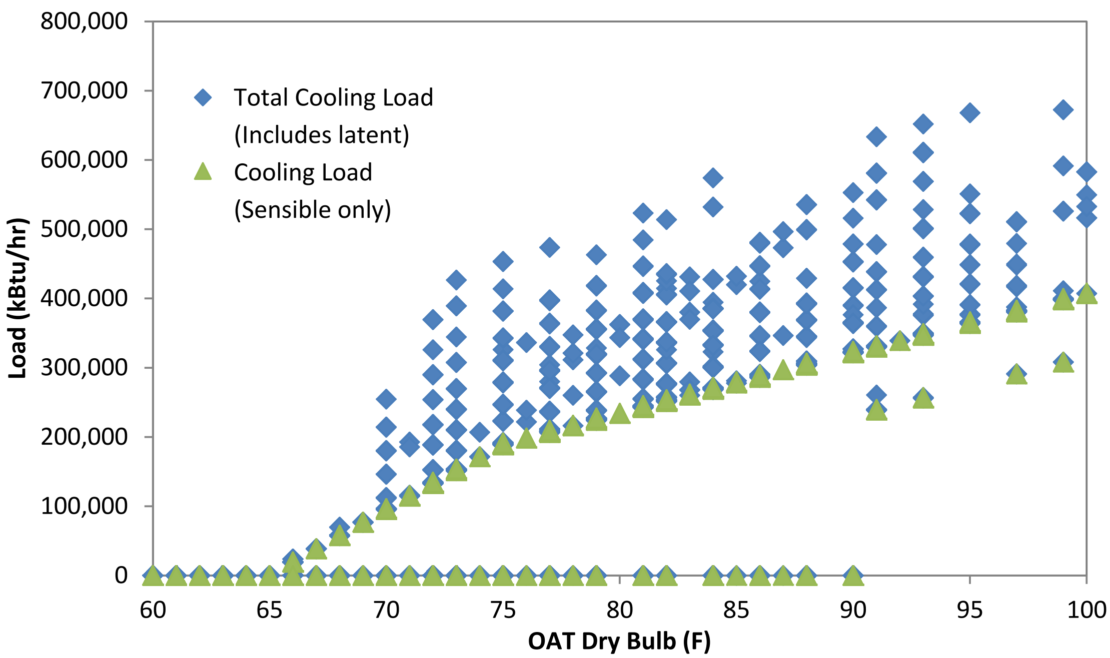
Latent Cooling Load Consideration

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*



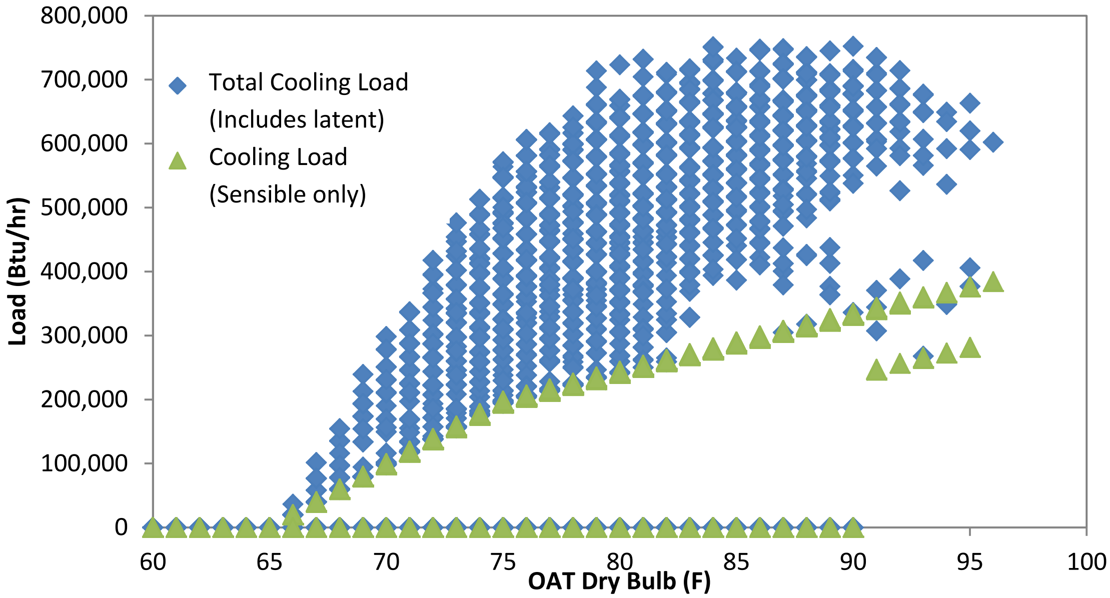


Figure 3: Calculated Total and Sensible Cooling Load for Pasadena, CA (above) and Miami, FL (below). ***(The deviation from the sensible cooling load line in green signifies the magnitude of added latent cooling load and the number of data points indicates the frequency of which dehumidification occurred)***

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).

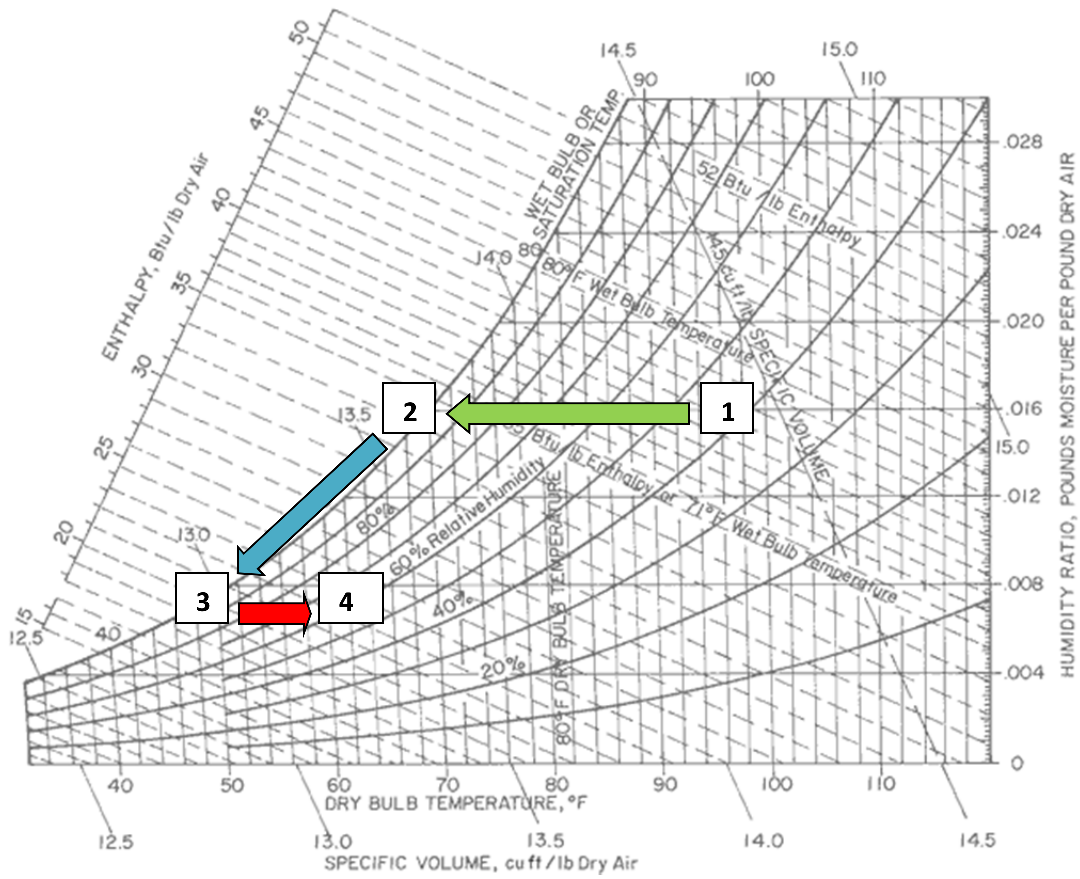


Figure 4: The dehumidification and reheat process calculated by the tool. Outside air (1) is first cooled sensibly up to dew point (2) then dehumidified up to the supply air temperature (3) that corresponds to the outside air temperature (see Appendix A1: Supply air reset schedule). If the reheat option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

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

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.

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

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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.

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

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:

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

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.

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

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.

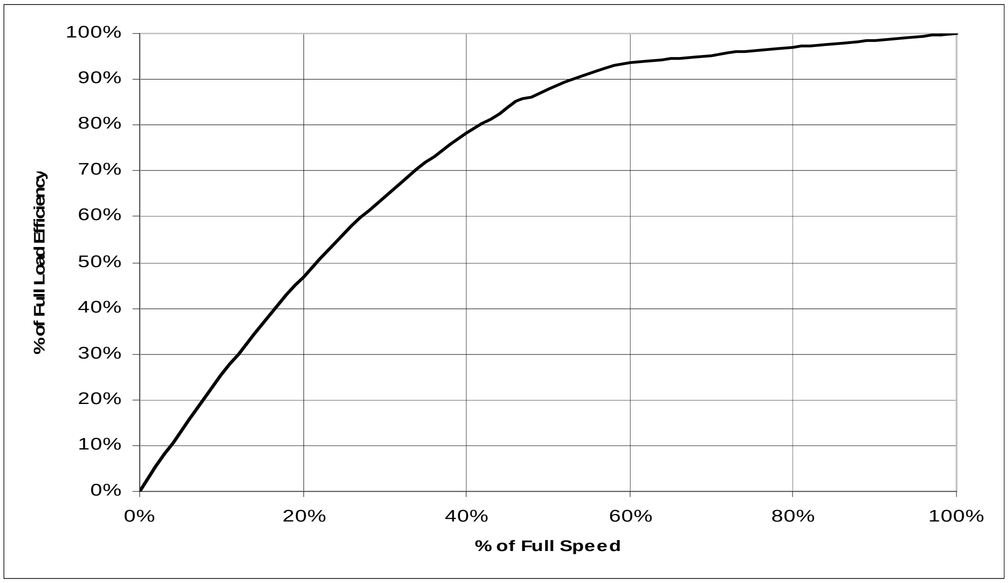

Figure A1: Generic Variable Frequency Drive Performance[4]

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	