VALIDATING COST AND ENERGY SAVINGS FROM HARVARD'S SHUT THE SASH PROGRAM

Tackling energy use in labs

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HARVARD UNIVERSITY | Sustainability

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Fume hood behavior change programs provide opportunity to reduce costs and increase energy efficiency

Chemical fume hoods are one of the most energy intensive aspects of laboratory operation. Laboratories at Harvard University account for 22% of space, but are responsible for 44% of energy consumption. According to a report from Louis Stokes Laboratories, 44% of the energy used in their labs is directly related to ventilation. Harvard's Shut the Sash Program was created to reduce energy and save utility costs in line with its aggressive climate goals, while also facilitating a safe and sustainable culture in the laboratories.

Background

In order to safely handle materials such as volatile organic compounds, acids, and solvents, fume hoods are a necessity. Fume hoods provide a contained work space, known as the "cabinet", which is ducted outside of the building. Supply fans bring air in through the cabinets, and exhaust fans pull air through the lab, and out of the building. The user can adjust the hood's movable window, known as the "sash," to access the cabinet. Air is then driven away from the user at a proper rate, known as the "face velocity," to reduce exposure risk. Air that is pulled through the cabinet comes from inside the lab space, which is delivered by the building's heating, ventilation and air conditioning (HVAC) system. An example of a fume hood in operation can be seen in Figure 1. Fume hoods can place tremendous pressure on a HVAC system because they are constantly exhausting newly conditioned air out of a building. Due to the energy needed to maintain safe air flow rates, operational costs, per fume hood, can be equivalent to the average energy used by three U.S. homes.

Typically, laboratory ventilation is measured in air changes per hour (ACH). At Harvard, our labs operate at six-eight ACH when occupied, and four ACH when unoccupied. This is much higher than a typical residential or office space. Fume hoods are typically factored into these air changes. Even when closed, fume hoods are always responsible for some ventilation. If many fume hoods are consolidated in a small area, they can be the primary HVAC driver. At Harvard, reports have shown that certain labs can achieve 12-15 ACH, simply due to the ventilation required to operate the hoods.

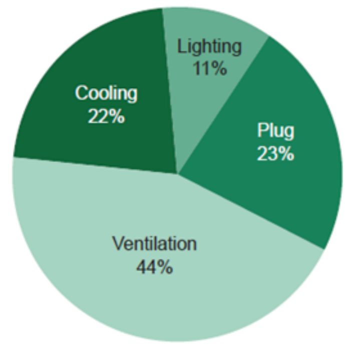


Figure 1. Annual electricity use in Louis Stokes Laboratory, National Institutes of Health, Bethesda, MD.

Verifying the results of behavior change programs in laboratories

Harvard's Shut the Sash Program was launched in 2005 when the Department of Chemistry & Chemical Biology (CCB) began exploring new ways to encourage people to shut fume hood sashes, and reduce the amount of air exhausted from labs. CCB is a fume hood intensive department, housing 278 fume hoods in a small four-building complex. Currently, 187 of these fume hoods are variable air volume (VAV) while the rest are constant air volume (CAV). CAV fume hoods operate with a constant flow, regardless of the position of the sash. VAV fume hoods change the air flow based on sash position. When a VAV fume hood is closed, the air flow is reduced to a lower cubic feet per minute (CFM). As the sash is raised, the CFM will increase. Fume hood CFM can range tremendously depending on size and intended use.

According to Jerome Connors, former Associate Director of CCB, the energy saved by the Shut the Sash Program through efficiencies to the HVAC system was approximately 70%. Utility savings are estimated at $200,000-$250,000 per year, with a greenhouse gas emissions savings at 300-350 metric tonnes of carbon dioxide equivalent (MTCDE).

Over the past ten years, some labs have left and new labs have joined the competition. Through all of the

HARVARD'S SHUT THE SASH PROGRAM

The Shut the Sash Program is an ongoing monthly competition between 19 labs with VAV fume hoods to encourage lab behavior change. Each lab has a customized CFM goal based on number of fume hoods, number of researchers, and type of research being conducted. Labs that achieve their goal are entered into a lottery for a party, which typically includes pizza and prizes.

Labs that consistently meet their goal are invited to a wine and cheese party, which takes place biannually. Staff, student, and faculty participation supports the program, and Harvard's Environmental Health & Safety department encourages shutting fume hood sashes to avoid accidental exposure. The program is managed by the Faculty of Arts and Sciences Green Program, a division of Harvard's Office for Sustainability, with significant help from CCB building operations staff and Siemens engineers.

changes, the competition has essentially operated the same way. Little change is needed to maintain the competition. Notably, some lab managers have applauded the competition, saying it helps foster team building and provides a common goal for researchers working on individual projects.

Beginning in late 2014, reports highlighted a number of locations where closing fume hoods would yield energy savings. Before jumping at the opportunity to expand the Shut the Sash Program, it was decided that an assessment should be done to verify the estimated cost and energy savings resulting from the Shut the Sash Program.

Data indicated that Shut the Sash participants practiced thoughtful management of their fume hoods. In addition, evidence indicated that automatic sash closers could be a useful alternative. Instead of having researchers close fume hood sashes, this technology shuts sashes automatically by sensing when a researcher is no longer present.

The design of the experiment was simple; fume hood sash management through behavior change in Shut the Sash labs was compared to labs that have automatic sash closers. As a control, we compared these to fume hoods that had neither automation nor competition. Fume hoods in three buildings were compared to hoods used in Shut the Sash: Engineering Science Laboratories, (ESL), Sherman Fairchild, (Fairchild), and Biological Laboratories, (Biolabs). These buildings are less fume-hood-dense than CCB, but savings could be found by closing hood sashes.

Data was collected over a two-month period on these buildings using the Siemens building automation system (BAS).

Delivering real energy and cost savings

The Sherman Fairchild laboratory building was chosen for the study because their labs have automatic sash closers installed on all of their fume hoods. ESL and Biolabs were chosen because VAV fume hoods, not already participating in Shut the Sash Program, were identified for their potential energy savings. Data availability by date can be seen in Figure II.

Distribution of fume hoods by count can be seen in Figure III. Note that ESL and Biolabs reported fume hood trends in 30-minute intervals as "Open" or "Closed" while CCB and Sherman Fairchild reported in 30-minute trends as current CFM. This inconsistency, as well as variability in fume hood size and face velocity, meant that we had to make some generalizations about fume hood operational cost.

Finding the average fume hood size and CFM was an important component of this study. With the help of Siemens specialists, as well as building managers and engineers, a consensus was established as an average fume hood. Those values were input in the Lawrence Berkeley Fume Hood Calculator. An example of the calculator can be seen in Figure IV. Cost per CFM per year as estimated at $7.43, which was in the range of expected cost, given Harvard's 2015 electricity price of 12.5 cents per kilowatt hour (kWh). Average annual cost of operation was estimated at $4,459 per hood.

Using the free statistics software RStudio, exhaust trends from all fume hoods in the study were graphed and analyzed. To determine if users of individual fume hoods had "good" or "bad" behavior, openings were identified in four categories. Less than five hours = good behavior, more than five hours = need for improvement, more than 12 hours = poor behavior, and more than 24 hours = worst behavior. An example of these graphs can be seen in Figure V, where they were graphed over one-week periods.

Analysis of the three fume hood treatment criteria yielded some notable results (see Table 1). First, there was very similar cost associated with operating fume hoods in Shut the Sash, and those with automatic sash closers. The cost of operating fume hoods in no treatment fume hoods was over $1,000 more per year, per fume hood.

In addition to total cost, it was necessary to verify if the sash operational cost was affected by researcher activity, since some fume hoods could be used more than others. The metric median-open-hours represents the median length of time that a fume hood is open across all open periods of a given sampled week. Median number of hours is used to summarize the length of open periods due to the skewed nature of open period lengths.

The distribution of this metric displayed below, shows that CCB and Sherman Fairchild have the shortest median hood openings, with most hoods in these groups opening for less than five hours, the timeframe identified in this study as "good behavior." This figure also highlights the high number of fume hoods in Biolabs and ESL that exhibited poor occupant behavior, with an average median open period of 69 consecutive hours and 33 hours respectively.

Results of the study confirmed that the Shut the Sash competition continues to save Harvard in excess of $200,000 per year and 300+ MTCDE. In addition, it made the case for expanding the competition to additional areas on campus where regular closing of VAV fume hood sashes could find savings.

Expanded paybacks

Based on the results of this study, Harvard's Shut the Sash was expanded to an additional 18 labs in September 2015, including labs in the Department of Molecular & Cellular Biology, Department of Organismal & Evolutionary Biology, and the Harvard John A. Paulson School of Engineering and Applied Sciences. These labs were chosen due to the

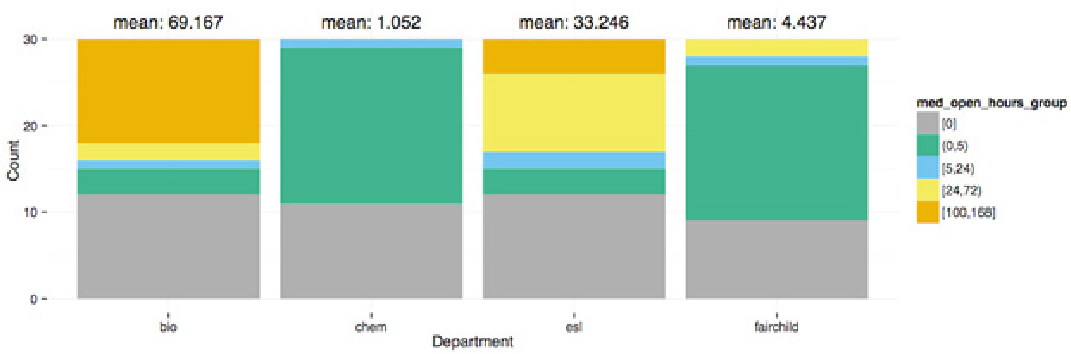


Table 1: Fume Hood Operation

TREATMENT	AVERAGE CFM	COST
Automation	231	$1,716
Shut the Sash	250	$1,858
None (Control)	409	$3,039

Note: The Shut the Sash Program is in Chemistry, and researchers use these hoods more frequently.

HOW TO START A SHUT THE SASH PROGRAM ON YOUR CAMPUS

To start a Shut the Sash competition on a research campus, work with building operations and engineers to locate VAV fume hoods where savings can be captured.

Once those locations are found, request exhaust trend reports from your BAS staff.

Download the package provided by the link at: http://www.green.harvard.edu/shut-the-sash, and follow the instructions in the appendix of this paper. This will provide you with summary statistics and graphs.

Finally, work with your building operations staff and engineers to determine the average fume hood size on your campus. Then use the Lawrence Berkeley Fume Hood Calculator to determine the cost per CFM at on your campus.

Report your findings to senior leaders if the data indicates that a Shut the Sash competition would yield savings.

way their fume hoods interact with the HVAC system, and are expected to yield additional savings of $50,000-$73,000 per year.

The new Shut the Sash competition is kept separate from the existing competition. An important consideration for ongoing environmental competitions in labs is to keep the size of the competition appropriate so that each lab has a chance of winning every one to two years.

In conclusion, an effective way to reduce lab operational cost, while pleasing lab occupants, is through a Shut the Sash competition. Once the BAS is setup to trend VAV hoods, the competition can be run on a modest budget. The competition is run by the labs coordinator for the FAS Green Program with a commitment of 10 hours per month, and an annual budget of $4,500.

LESSONS LEARNED

While exploring the buildings and labs during this study, one reoccurring theme became clear. Several scientists working in labs equipped automatic fume hood sash closers did not speak highly of the technology. They remarked that the technology tends to beep often, and closes at inopportune times.

Sherman Fairchild Building Manager, Paul Tighe, mentioned, "People have actually disabled the sensors and jammed pencils into the buzzers."

About Harvard's commitment to sustainability

Harvard is confronting the challenges of climate change and sustainability through research across disciplines, giving our students the tools to tackle complex global challenges, and acting on campus to model an institutional pathway to a more sustainable, low-carbon future. The Harvard Sustainability Plan, launched in 2014, aligns the University under a set of goals and priorities in five key topic areas – energy and emissions, campus operations, nature and ecosystems, health and wellbeing, and culture and learning. In 2008, President Drew Gilpin Faust and the Deans approved Harvard University's most ambitious sustainability goal: a long-term commitment to reduce the University's greenhouse gas emissions by the maximum practicable rate aligned with the best available science, and a short-term goal to reduce greenhouse gas emissions 30% by 2016, including growth, from a 2006 baseline.

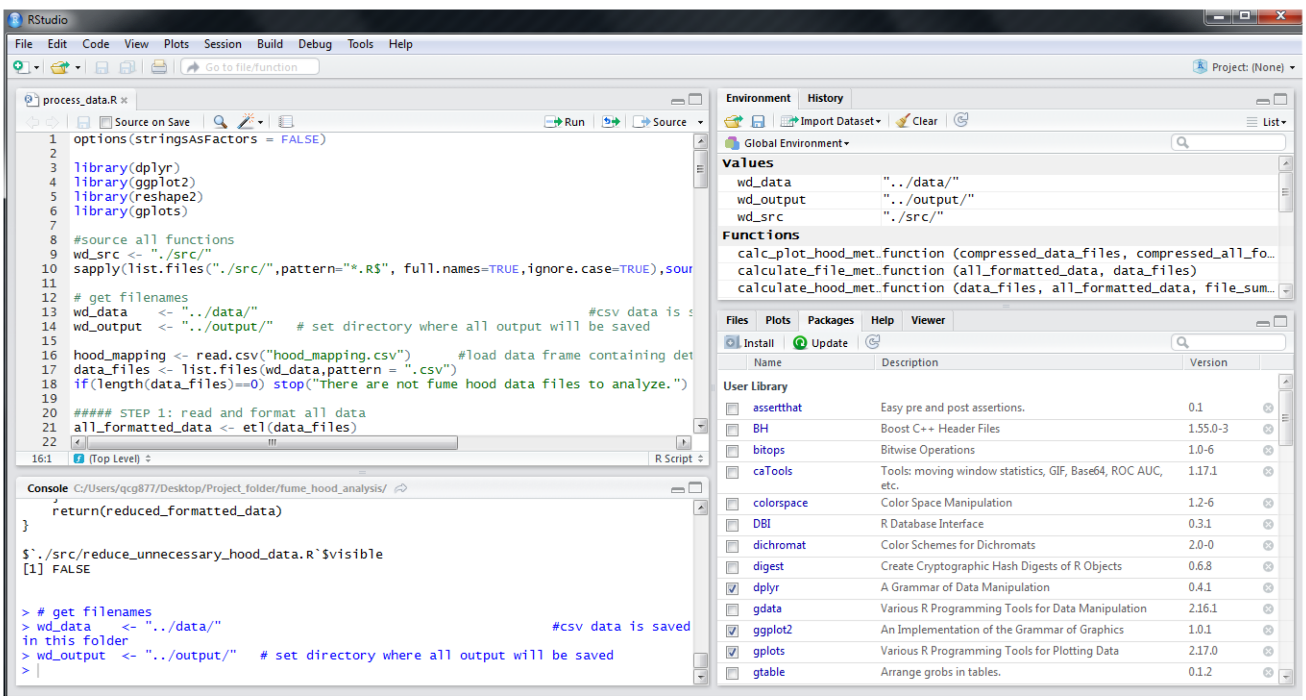
The Harvard Office for Sustainability brings faculty, students, and staff together to set and achieve goals for a healthier, more efficient and sustainable future. By connecting research and teaching with on-campus action, OFS works to model scalable and cost-effective solutions that enhance the well-being of the campus community and ultimately strengthen the University's academic mission.

Appendix I: Getting started with RStudio

This section will discuss the steps necessary to handle fume hood data files using RStudio. The scripts can handle either .csv or .txt files, and have been designed to handle a different formatting from the Siemens system. *Requires experience with R and may only work with Microsoft Windows.

- Step 1: Download RStudio.
- Step 2: Run RStudio and install the following R packages:
  - plyr
  - dplyr
  - ggplot2
  - reshape2
- Step 3: Download files from appendix II and setup directory structure shown in appendix III. It will need to contain:
  - Fume_hood analysis repository containing .csv and .R files
  - A data folder which you will put .csv data files with your fume hood data
  - An output folder into which all PDF figures and .csv output will be saved
- Step 4: Open up and run the R script 'process_data.R' in RStudio. This is the master script to perform the main fume hood data analysis.

R Studio Screenshot



Appendix II: Download scripts and process files

Click here to download the files and arrange them as shown in Appendix III. Zip will contain:

src folder	bug fix
.Rhistory	update code and visuals
README.md	update readme
hood_mapping.csv	bug fix
process_data.R	bug fix - error handling
report_visual.R	bug fix - error handling
visualize_data_summary_by_dept.R	bug fix - error handling
Example_fumehood_file.csv	example for formatting
Example_fumehood_file.txt	example for formatting

Appendix III: Directory structure for RStudio

```
+--Project folder
|   +-- fume_hood_analysis       (directory with cloned github repository)
|     +-- README.md
|     +-- hood_mapping.csv       (csv file with names of all fume hoods and their buildings)
|     +-- process_data.R         (script to process data)
|     +-- src                    (directory contains data processing, analysis functions)
+-- data                         (directory contains csv files with raw fume hood data)
+-- output                       (directory to save any graphs, output from calculations)
```

Appendix IV: Run the RStudio script

- Step 1: In RStudio go to Session ==> Set Working Directory ==> process_data.R
- Step 2: Place fume hood reports in 'data folder' of your directory.
- Step 3: Run each command one-by-one in the process_data.R file. This can be achieved by clicking on the first line of the process_data.R file, and pressing Ctrl+Enter one line at a time.
  *Note: Only run Step 2 if you have more than on fume hood file to process.
- Step 4: Proceed through steps 1 - 4 of the Process_data.R file. This should output most of the graphs and summary statistics you want. Continue through step 7 for additional statistics.
- Step 5: Collect your data from the output folder.

Debug: If you receive an error warning at any time, then the .csv or .txt file is formatted in a way that cannot be handled

by this program. Make sure the source files are formatted like the examples provided in the download.
*Note that the program is designed to handle additional variations beyond the example formats provided.

Appendix V: Average fume hood at Harvard Faculty of Arts & Sciences

Electricity - $0.125/kWh

Electricity Demand - $1/kW-year

Fuel - $24/million BTU

Operation - 24 hours/day

Hood Opening (Horizontal) - 48 inches

Hood Opening (Vertical) - 18 inches

Face Velocity - 100 feet/min

Fan Power (supply/exhaust) - 1.8 W/CFM

Cooling Plant Efficiency - .75 kW/ton

Heating System Efficiency - 90%

Heating - 65° F

Cooling - 55° F

Delivery Air Temperature - 68° F

Energy Type - Fuel

Flow Rate - 600 CFM

Chiller Energy - 2,840 kWh/year

Fan Energy - 9,461 kWh/year

Total - 12,300 kWh/year

Total Power - 3.2 kW/hood

of which fan - 1.1 kW/hood

of which chiller - 2.2 kW/hood

Heating supply load - 92 million BTU

Reheat load - 17 million BTU

Total Load - 109 million BTU

Energy (fuel) - 121 million BTU

Energy (electric) - 0 kWh

Average Reheat Power - 0 kW

Total Per-Hood Costs - $4,459/year

Cost per CFM - $7.43

Appendix VI: Metrics used to evaluate hood-weeks

Metric	Equation
Proportion of open intervals	$prop.open = \frac{\sum_{p=1}^{n} open.intervals_p}{total.intervals}$
Median open hours	$med.open.hrs = \frac{(n+1)}{2}\ th\ open.intervals\ term$
Proportion of open intervals exceeding 5 hours	$prop.open.exceeding.5 = \frac{\sum_{p=1}^{n} (intervals.5)_p}{total.intervals}$ $where\ intervals.5 = \begin{cases} 0, & open.intervals_p \le 10 \\ open.intervals_p - 10, & open.intervals_p > 10 \end{cases}$ *and 10 is the number of 30-minute intervals in 5 hours*
For above metrics,	*n is the total number of open sash periods for a given hood-week* *$open.intervals_p$ is the number of intervals in open-period p* *total.intervals is the total number of intervals on a given hood-week*

Figure I: Fume hood in use

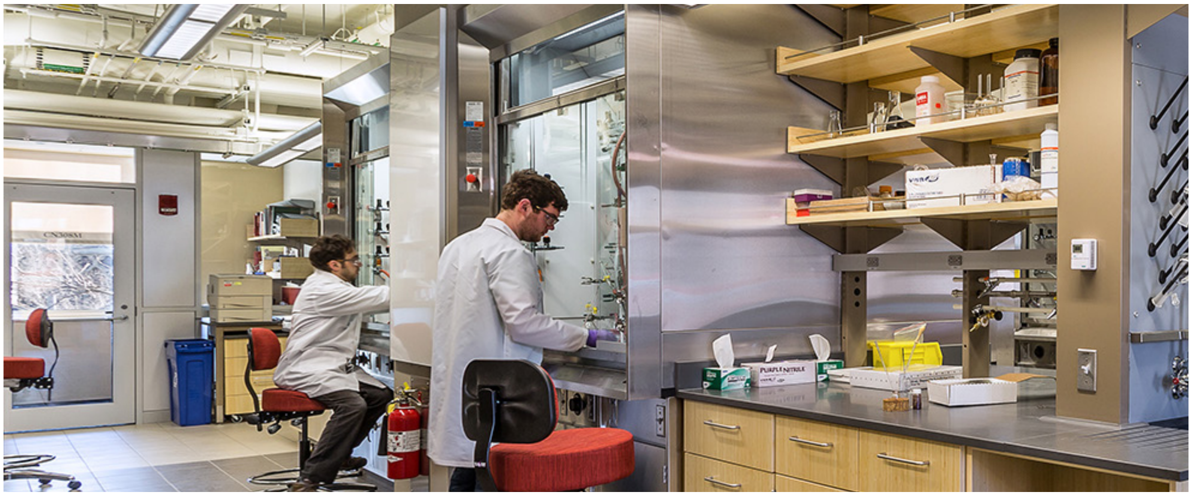
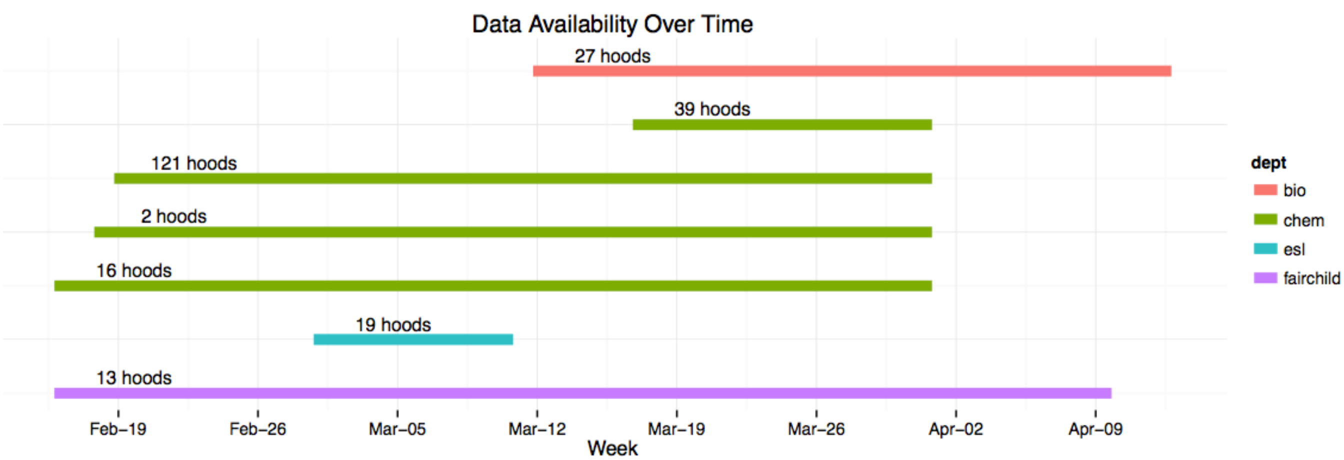


Figure II: Data availability by space



Key for figure II:

bio = Biological Laboratories (control)

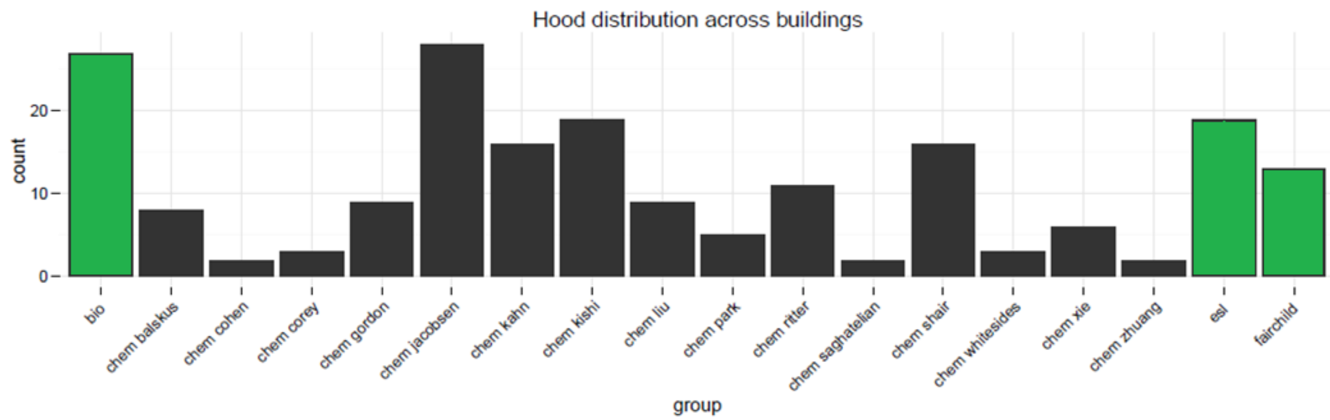
chem = CCB (shut the sash)

esl = Engineering Science Laboratories (control)

fairchild = Sherman Fairchild (automatic sash closers)

Whole-building fume-hood-count distribution is shown in green. For CCB, fume hoods for individual labs are shown in black. The purpose is to emphasize how many fume hoods individual labs in CCB have compared to entire lab buildings.

Figure III: Count of fume hoods by space



Key for figure III:

bio = Biological Laboratories (control)

chem = CCB (shut the sash)

esl = Engineering Science Laboratories (control)

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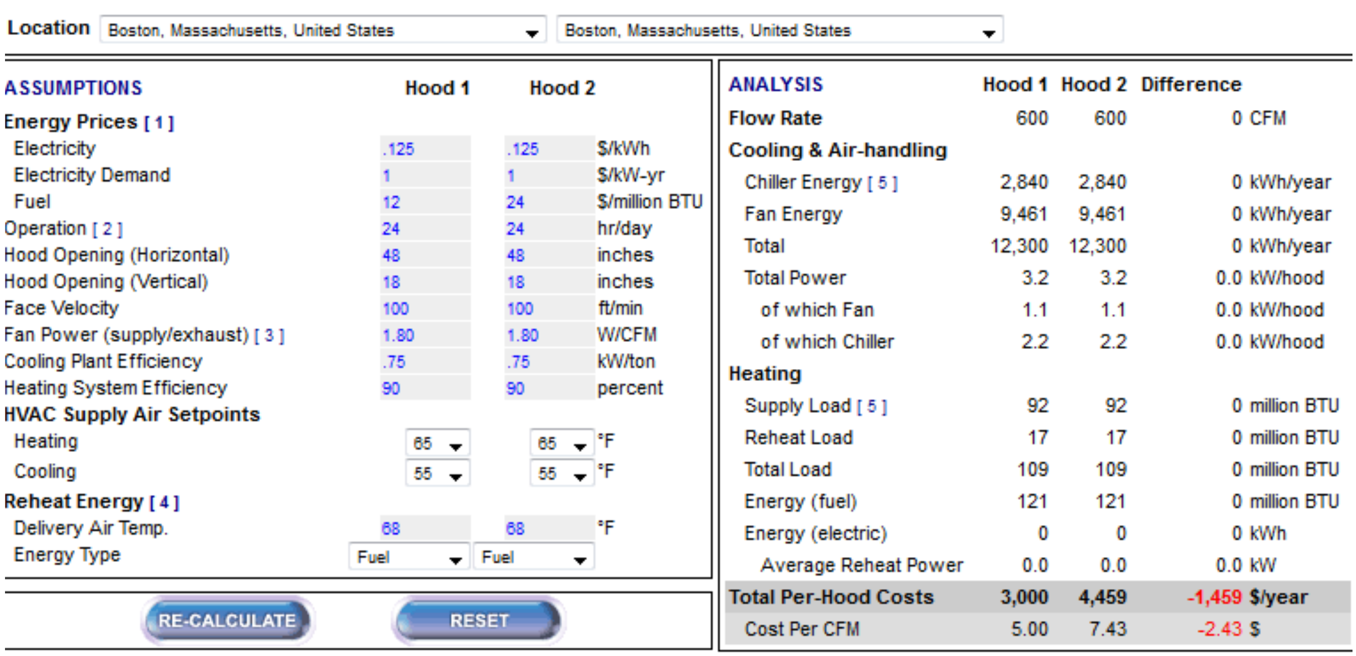
Whole-building fume-hood-count distribution is shown in green. For CCB, fume hoods for individual labs are shown in black. The purpose is to emphasize how many fume hoods individual labs in CCB have compared to entire lab buildings.

Figure IV: Lawrence Berkeley Fume Hood Calculator



Location: Boston, Massachusetts, United States | Boston, Massachusetts, United States

ASSUMPTIONS	Hood 1	Hood 2	
Energy Prices [1]			
Electricity	.125	.125	$/kWh
Electricity Demand	1	1	$/kW-yr
Fuel	12	24	$/million BTU
Operation [2]	24	24	hr/day
Hood Opening (Horizontal)	48	48	inches
Hood Opening (Vertical)	18	18	inches
Face Velocity	100	100	ft/min
Fan Power (supply/exhaust) [3]	1.80	1.80	W/CFM
Cooling Plant Efficiency	.75	.75	kW/ton
Heating System Efficiency	90	90	percent
HVAC Supply Air Setpoints			
Heating	65	65	°F
Cooling	55	55	°F
Reheat Energy [4]			
Delivery Air Temp.	68	68	°F
Energy Type	Fuel	Fuel	

RE-CALCULATE | RESET

ANALYSIS	Hood 1	Hood 2	Difference
Flow Rate	600	600	0 CFM
Cooling & Air-handling			
Chiller Energy [5]	2,840	2,840	0 kWh/year
Fan Energy	9,461	9,461	0 kWh/year
Total	12,300	12,300	0 kWh/year
Total Power	3.2	3.2	0.0 kW/hood
of which Fan	1.1	1.1	0.0 kW/hood
of which Chiller	2.2	2.2	0.0 kW/hood
Heating			
Supply Load [5]	92	92	0 million BTU
Reheat Load	17	17	0 million BTU
Total Load	109	109	0 million BTU
Energy (fuel)	121	121	0 million BTU
Energy (electric)	0	0	0 kWh
Average Reheat Power	0.0	0.0	0.0 kW
Total Per-Hood Costs	3,000	4,459	-1,459 $/year
Cost Per CFM	5.00	7.43	-2.43 $

Figure V: Fume hood week behavior graphs

< 5 hours – Good behavior

> 5 and < 12 hours – Sash accidentally left open

>12 hours <24 hours – Poor behavior, sash likely left open overnight

> 24 hours – Worst behavior, sash left open all weekend, or no consideration