Empowering Graduate Students to Advance Laboratory Sustainability at the University of Pennsylvania

Highlights

- Master’s students conducted a fume hood behavior audit in two engineering buildings
- Sashimi was used to monitor sash height and hood use over a period of 3 months
- Students found $22,000 in untapped annual savings due to poor fume hood habits

Abstract

Chemical fume hoods are among the most energy-intensive components of laboratory infrastructure, yet the efficiency of modern VAV systems relies heavily on user compliance. This case study details a student-led initiative at the University of Pennsylvania designed to quantify and bridge the "behavior-technology gap" through the deployment of Internet of Things sensors. Utilizing the "Campus as Lab" framework, Master’s students in the Engineering Sustainability at Penn course deployed "Sashimi" monitoring systems across 12 fume hoods in four engineering laboratories. Over a three-month period, the team audited sash behavior and implemented a dual-intervention strategy consisting of visual prompts and weekly feedback reports. The study revealed that sash mismanagement was largely habitual rather than operational, with less than an 11% difference in sash openness between working and non-working hours. The identification of behavioral "plateaus"—periods where sashes remained open for days or weeks—uncovered nearly $22,000 in untapped annual savings across the pilot group. While the behavioral interventions yielded mixed immediate results, the project provided significant experiential learning outcomes, helping students develop critical skills in technical troubleshooting, stakeholder management, and the application of sustainability theory in active research environments.

Introduction

A single chemical fume hood can consume up to four times as much energy as a single-family home. While variable air volume (VAV) systems can mitigate this waste by reducing airflow when sashes are closed, their efficiency relies entirely on scientists’ behavior. With over 1,000 fume hoods at the University of Pennsylvania (UPenn), there is a significant opportunity to lower campus energy consumption simply by ensuring sashes are shut when not in use.

However, compliance with proper sash behavior is often low without structured interventions. Universities such as MIT and UC Berkeley, have employed competitions, real-time alerts, and personalized feedback to promote better habits. These initiatives have demonstrated that closing the feedback loop—rewarding scientists for positive behavioral changes—is the most effective strategy. Unfortunately, establishing such a program at UPenn has historically been difficult due to data fragmentation; sash height data is either not recorded, or it is siloed across incompatible building automation systems, preventing centralized analysis.

To address this, UPenn launched a new master's level course, Engineering Sustainability at Penn (ENGR 5020), in the Spring 2025 semester. Utilizing "Campus as Lab" principles, graduate students worked as engineering consultants to tackle authentic sustainability challenges. One team aimed to bridge the behavior-technology gap by implementing a pilot shut the sash program across four research laboratories. They utilized Sashimi, an IoT system that continuously measures sash height and transmits real-time data to the Sashboard, an online dashboard designed for fume hood analytics and driving behavioral change.

As part of this student-led project, and through their behavior audit, they discovered nearly $22,000 in untapped annual savings. This project could be replicated in other academic institutions for both student enrichment and energy savings.

Methods

Deployment of Sensors

Students were first given an introductory course on HVAC, the unique safety and airflow needs of laboratory facilities, and the significant energy burden imposed by VAV fume hoods. Following this theoretical grounding, the practical deployment phase began with the recruitment of participating laboratories. The study targeted research laboratories within the School of Engineering and Applied Sciences (SEAS) to capture potential variations in fume hood usage across different research disciplines.

A total of twelve (12) fume hood sensors were deployed across four distinct laboratories: the Osuji Lab (Chemical and Biomolecular Engineering), Tsourkas Lab (Bioengineering), Madl Lab (Materials Science and Engineering), and Winey Lab (Chemical and Biomolecular Engineering). The installation process utilized specialized Internet of Things sensors developed by Sustainabli, specifically the "Sashimi" system. These units utilize an infrared sensor paired with a gray-scale gradient strip installed along the sash track to measure height continuously.

Each sensor required a rigorous physical installation and calibration process to ensure accurate real-time data collection. The calibration was performed via a command-line interface, where users manually moved the sash to associate specific IR readings with physical sash positions. During this phase, critical safety and operational parameters were defined for each hood, including the minimum height, maximum height, and the "safe operating height" (typically 16 inches). Data from the sensors was transmitted to the "Sashboard," an online dashboard designed for visualizing sensor streams. Technical challenges during calibration, such as irregular readings or failure to complete the setup sequence, resulted in the exclusion of data from one fume hood in the Winey Lab.

Figure 1. Installed Sashimi Sensors that Monitor Fume Hood Sash Height. Examples of the physical placement of the sensor unit on the fume hood exterior and the corresponding gradient strip.

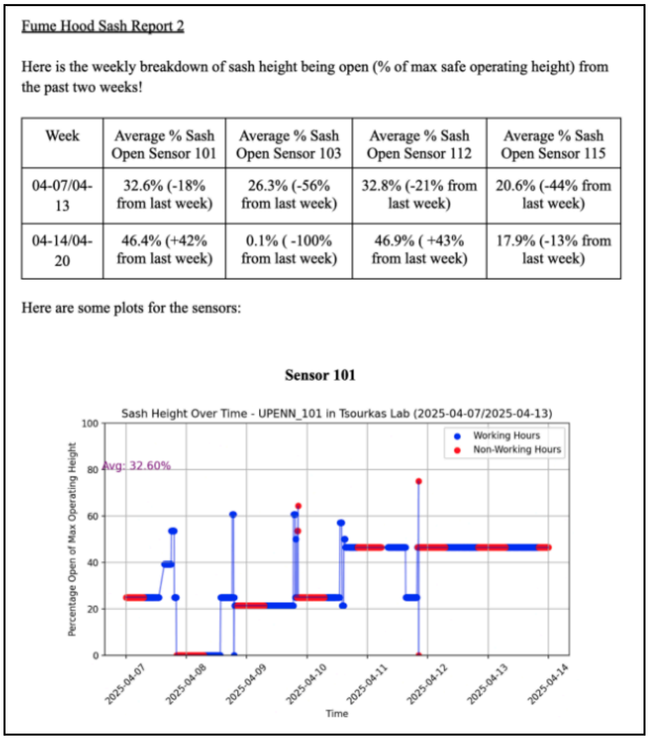
Behavior Intervention

To address the "behavior-technology gap" inherent in VAV systems, the study implemented a dual-intervention strategy consisting of static visual prompts and dynamic feedback loops. This intervention phase was launched on April 5th and continued through early May.

Visual Prompts: The first component involved the design and installation of "Shut the Sash" stickers. Unlike previous studies at institutions such as UC Santa Barbara or Cornell, which utilized complex arrow-shaped or two-part alignment stickers, this study opted for a simplified, low-text design to accommodate varying fume hood geometries and sash constructions. The final design featured a high-contrast graphic with the slogan "Shut the Sash / Save Energy, Stay Safe" and a visual indicator of a sash being lowered. These stickers were placed on the sash glass to serve as an immediate, point-of-action reminder for lab members.

Feedback Reports: The second component was the distribution of weekly "mini-reports" sent via email to laboratory representatives every Wednesday. These reports provided a data-driven reflection of the lab's performance, summarizing the average weekly "sash open percentage" and visualizing sash height trends over time. The sash open percentage was calculated by dividing the recorded sash height by the defined maximum safe operating height. The reports highlighted week-over-week changes (e.g., "-18% from last week"), aiming to foster accountability and encourage a culture of energy consciousness.

Figure 2. Example of the intervention's "Shut the Sash" sticker



Fume Hood Sash Report 2

Here is the weekly breakdown of sash height being open (% of max safe operating height) from the past two weeks!

Week	Average % Sash Open Sensor 101	Average % Sash Open Sensor 103	Average % Sash Open Sensor 112	Average % Sash Open Sensor 115
04-07/04-13	32.6% (-18% from last week)	26.3% (-56% from last week)	32.8% (-21% from last week)	20.6% (-44% from last week)
04-14/04-20	46.4% (+42% from last week)	0.1% (-100% from last week)	46.9% (+43% from last week)	17.9% (-13% from last week)

Here are some plots for the sensors:

Sensor 101

Figure 3. Example report shared with pilot labs on a weekly basis

Data Collection and Analysis

Data collection was segmented into two distinct stages: a pre-intervention baseline period (early March to April 4th) and an intervention period (April 5th to early May). The Sustainabli sensors measured sash height at a frequency of every [5] minutes, storing the values in a centralized online database.

The primary metric for analysis was the "Weekly Average Sash Height Open Percentage," which normalized usage across hoods of different sizes. To isolate the impact of active research versus neglect, the analysis stratified data into "Working Hours" (defined as 7:00 AM to 8:00 PM) and "Non-Working Hours" (8:00 PM to 7:00 AM).

Furthermore, a granular analysis of real-time sash movement was conducted to identify specific behavioral patterns. Usage profiles were categorized as "ideal" (characterized by peaks indicating use followed by immediate closure) or "non-ideal" (characterized by prolonged plateaus indicating the sash was left open during inactivity). This distinction allowed the researchers to identify specific instances of energy waste, such as sash hoods remaining open for multiple days or weeks.

Results

Baseline Sash Use Revealed Savings Opportunity

Analysis of the weekly average sash openness revealed significant disparities in fume hood management across the four participating laboratories. The Winey Lab consistently demonstrated the lowest weekly average sash height openness, serving as a benchmark for "good" user habits. In contrast, the Osuji Lab displayed highly variable usage across its three monitored hoods, while the Tsourkas and Madl Labs showed more uniform, yet less efficient, behavior among their respective units. By calculating the energy demands of these stagnant periods, the students identified the opportunity to save approximately $22,000 annually if this existing baseline behavior was corrected "perfectly" across the studied fume hoods.

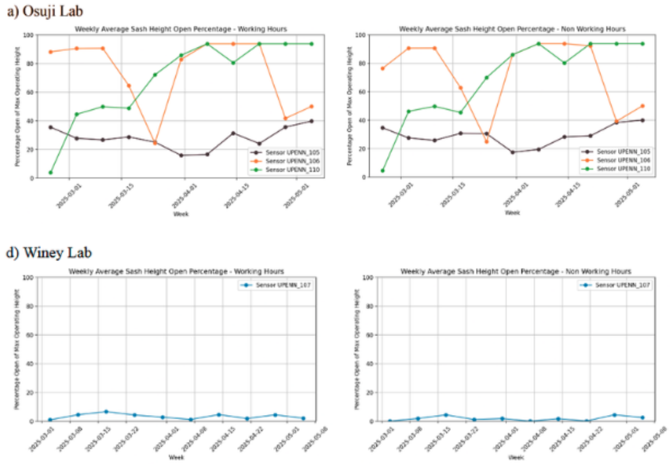


Figure 4. Weekly Average Sash Height Open Percentage within the Osuji and Winey Labs - Working vs. Non-Working Hours

To determine if sash mismanagement was primarily an issue of operational necessity during active experimentation, the study stratified data into "working hours" (7:00 AM – 8:00 PM) and "non-working hours" (8:00 PM – 7:00 AM). Contrary to the hypothesis that sashes are left open primarily during active use, the analysis found remarkably little difference between the two time blocks. Across all monitored fume hoods, the average sash openness during working hours did not exceed openness during non-working hours by more than 11%. This persistence of open sashes overnight suggests that the issue is not merely one of immediate operational need, but rather a habitual neglect to close sashes during idle periods.

Behavioral Interventions Demonstrated Mixed Impact

The introduction of the "Shut the Sash" stickers and weekly feedback reports yielded mixed quantitative results during the pilot period. While the Tsourkas Lab demonstrated a slight reduction in weekly average sash heights post-intervention, other areas did not show immediate improvement; one fume hood in the Osuji Lab actually exhibited increased average sash heights. These mixed averages necessitated a granular analysis of real-time sash movement, which distinguished between "ideal" usage (peaks indicating active use followed by closure) and "non-ideal" usage (long plateaus).

"Non-ideal" behavior was identified by sash heights remaining at a fixed open position for extended periods, a pattern most notably observed in the Osuji Lab, where one fume hood remained open for nearly the entire month of April. Granular analysis highlighted that while low-barrier interventions effectively raised awareness, the most significant opportunity for energy savings lies in targeting these specific instances of long-term static plateaus.

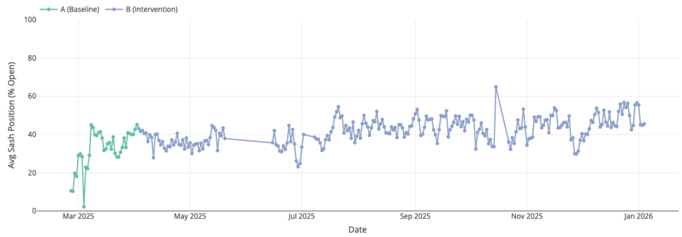


Figure 5. Average sash height during and after study period. Green line represents daily average sash height during baseline period. Blue line represents daily average sash height 9 months after baseline period, where the first month was intervention.

Student and Experiential Learning Outcomes

Beyond learning key theory, data analysis, and interpretation skills for HVAC mechanical engineering in complex facilities, the students stated they were able to form specific skills in the following areas (Table 1):

- Technical Adaptability and Troubleshooting
- Collaboration and Professional Feedback
- Stakeholder Management and Communication
- Bridging the Behavior-Technology Gap

> “The collaboration with Sustainabli was a **key strength**... Their platform enabled real-time monitoring and supported our behavioral outreach.”
>
> -Seito Sanford, Louis Tu & Nicole Zhao
> UPenn Graduate Students

Discussion

This case study highlights the critical intersection between infrastructure efficiency and occupant behavior within energy-intensive research environments. By deploying a student-led audit, this project successfully quantified the "behavior-technology gap" that often undermines the theoretical savings of VAV fume hood systems.

Here, a team of Master’s level engineering students conducted a comprehensive fume hood behavior audit across two engineering buildings within the SEAS at UPenn. The team utilized the "Sashimi" system—an IoT-enabled sash monitoring platform developed by Sustainabli. Over a period of three months, spanning from early March to early May, sensors tracked real-time sash height data across 12 distinct fume hoods in the Osuji, Tsourkas, Madl, and Winey laboratories. This longitudinal monitoring provided a level of granularity previously unavailable to the UPenn Sustainability office.

The most significant finding of the audit was the identification of specific periods where sashes remained open at fixed heights for days or even weeks at a time. While the VAV infrastructure is designed to reduce airflow when sashes are closed, its potential is nullified during these periods of neglect. By analyzing the airflow requirements of these specific "non-ideal" behaviors, the students discovered nearly $22,000 in untapped annual savings.

The results suggest that while low-barrier interventions like the "Shut the Sash" stickers and weekly feedback reports can increase awareness, they may not be sufficient to eliminate deep-seated habits of neglect in all laboratory cultures. Consequently, the study recommends that future sustainability initiatives move beyond general awareness campaigns to target these specific "plateau" events

Beyond its operational utility, the Sashimi system could serve as a pedagogical tool, transforming campus infrastructure into a "living laboratory" for experiential learning. The deployment process moved students beyond theoretical HVAC coursework, forcing them to navigate the complexities of real-world data collection, including troubleshooting inconsistent sensor calibration and managing data visualization limitations. The system also provides a robust platform for future educational cohorts to design hypothesis-driven behavioral experiments, such as testing whether gamified incentives like raffles or competitions are more effective than static reminders. By interacting directly with the technology and providing feedback to industry developers, students acquire essential professional skills that bridge the gap between academic study and professional engineering practice.

Skill	**Achievement through Experiential Learning**
Technical Adaptability and Troubleshooting	Navigated technical challenges during installation—particularly command line-based sensor calibration—and developed adaptability by troubleshooting irregular readings through repeated lab recalibration in collaboration with Sustainabli.
Collaboration and Professional Feedback	After identifying limitations in longitudinal data visualization, the team worked with Sustainabli to develop a custom data export for independent analysis and provided constructive technical feedback to support future scaling.
Stakeholder Management and Communication	The project required navigating distinct operational cultures across the laboratories. Students learned to coordinate with diverse lab representatives for installation and feedback, recognizing that “soft” barriers such as unpredictable research schedules were as critical to success as the hardware itself.
Bridging the Behavior-Technology Gap	Students learned that advanced hardware (e.g., VAV systems) is ineffective without user compliance, a lesson reinforced by non-linear behavior change, uneven intervention success across labs, and persistent open sashes after hours.

Table 1. Skill development and their achievement through experiential learning during the pilot