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Brief note

Energy use and savings potential for laboratory fume hoods

Evan Mills*, Dale Sartor

Lawrence Berkeley National Laboratory, Energy Analysis Department, University of California, 1 Cyclotron Road, Mailstop 90-4000, Berkeley, CA 94720, USA

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Abstract

Fume hoods—small but essential safety devices used in laboratory environments—are highly energy-intensive, each one consuming more energy than three homes in an average U.S. climate. Increasing airflow rates in an effort to enhance safety not only elevates energy use but can in fact compromise safety by causing dangerous turbulence that can foil containment. New design strategies have been demonstrated to reduce energy use by 75%, while maintaining or enhancing safety. The energy savings potential for these hoods across the United States is $1.5 billion annually. If incorporated in new laboratory construction, high-performance fume hoods can also yield substantial first-cost savings by allowing downsizing of heating, ventilating, and air-conditioning infrastructure. However, there are material hurdles to widespread adoption of new fume hood technologies. The problems reside in regulations and standards that stipulate absolute airflow rates, rather than direct metrics of containment and safety.

1. Introduction

Fume hoods have long been used to protect laboratory workers from breathing harmful gases and particles, and are ubiquitous in pharmaceutical and biotechnology facilities, industrial shops, medical testing labs, private research labs, and academic settings. Fume hoods are box-like structures, with a movable window-like front called a sash. Fume hoods capture, contain, and exhaust airborne hazardous materials, which are drawn out of the hood by fans through a port at the top of the hood. Their fundamental design has gone largely unchanged for the past 60 years [1].

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* Corresponding author. Tel.: +1 510 486 6784; fax: +1 510 486 6996.
E-mail address: emills@lbl.gov (E. Mills).

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An integral part of laboratory ventilation systems, fume hoods are a major contributor to making typical laboratories four- to five-times more energy intensive than typical commercial buildings [2]. A fume hood consumes 3.5-times more energy than an average house. Efforts to improve energy efficiency in fume hoods and elsewhere must attend to a host of 'non-energy' considerations. In many cases, including that of fume hoods, non-energy benefits can provide an additional impetus for technology innovation beyond the value of direct energy savings [3–5].

Amplifying the need to improve fume hood design, recent research shows that increasing the amount and rate of airflow (and, consequently, energy use) does not tend to improve containment [2]. Instead, errant eddy currents and vortexes can be induced as air flows around hood users and into the hood, reducing containment effectiveness and compromising safety. Certain standards, however, today work at cross purposes with the goals of safety and energy efficiency.

2. Baseline energy use

We have developed a model for fume hood energy use and applied it to a variety of weather locations around the world Fig. 1.[1] Depending on climate and system design, estimated annual energy costs range from approximately \$130 to \$260/m^3-min (\$3.70 to \$7.40/cfm) for the locations analyzed here (and more if electric reheat is used).

It is important to note that, for safety reasons, laboratory ventilation is based on 100% outside air; thus all the air exhausted by a fume hood has to be made up with unconditioned outside air. Due to safety considerations and standards, fume hoods are normally required to operate continuously.[2]

Many labs use 'reheat.' Typically, the outdoor air is initially cooled to 12.7 C (55 °F) or lower and then reheated at each zone to the required temperature to maintain a set-point temperature. Unfortunately, it is possible for only one laboratory zone to actually require maximum cooling. No cooling is required if the outside air temperature is below the supply air set-point. However, if outside air is a 'perfect' 18.3 C (65 °F), it is first cooled at the central air handlers and then re-heated at many zones. The perverse result of this reheat practice is that in many labs the dominant cooling load is imposed by the boiler and the dominant heating load is imposed by the chiller. As a result, labs in climates presenting zero or negligible heating loads still use appreciable heating energy. Labs can be designed much better than this, but many are worse than the assumptions used in our calculations.

Approximately 150,000 laboratories populate the United States, with 500,000 to 1,500,000 fume hoods installed. This range is based in part on interviews of industry experts conducted on behalf of the US Environmental Protection Agency's Labs21 program. The only formally published estimate indicates that there were more than one million units in 1989 [6]. Our calculations assume a perhaps

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[1] An on-line calculator based on our methodology may be found at http://fumehoodcalculator.lbl.gov

[2] Per ANSI standard for laboratory ventilation: '5.3.2.11 continuous operation. exhaust systems shall operate continuously to provide adequate ventilation for any hood at any time it is in use and to prevent backflow of air into the laboratory when the following conditions are present: (1) Chemicals are present in any hood (opened or unopened), (2) Exhaust system operation is required to maintain minimum ventilation rates and room pressure control, and (3) There are powered devices connected to the manifold. Powered devices include, but are not limited to: biological safety cabinets, in-line scrubbers, motorized dampers, and booster fans.'

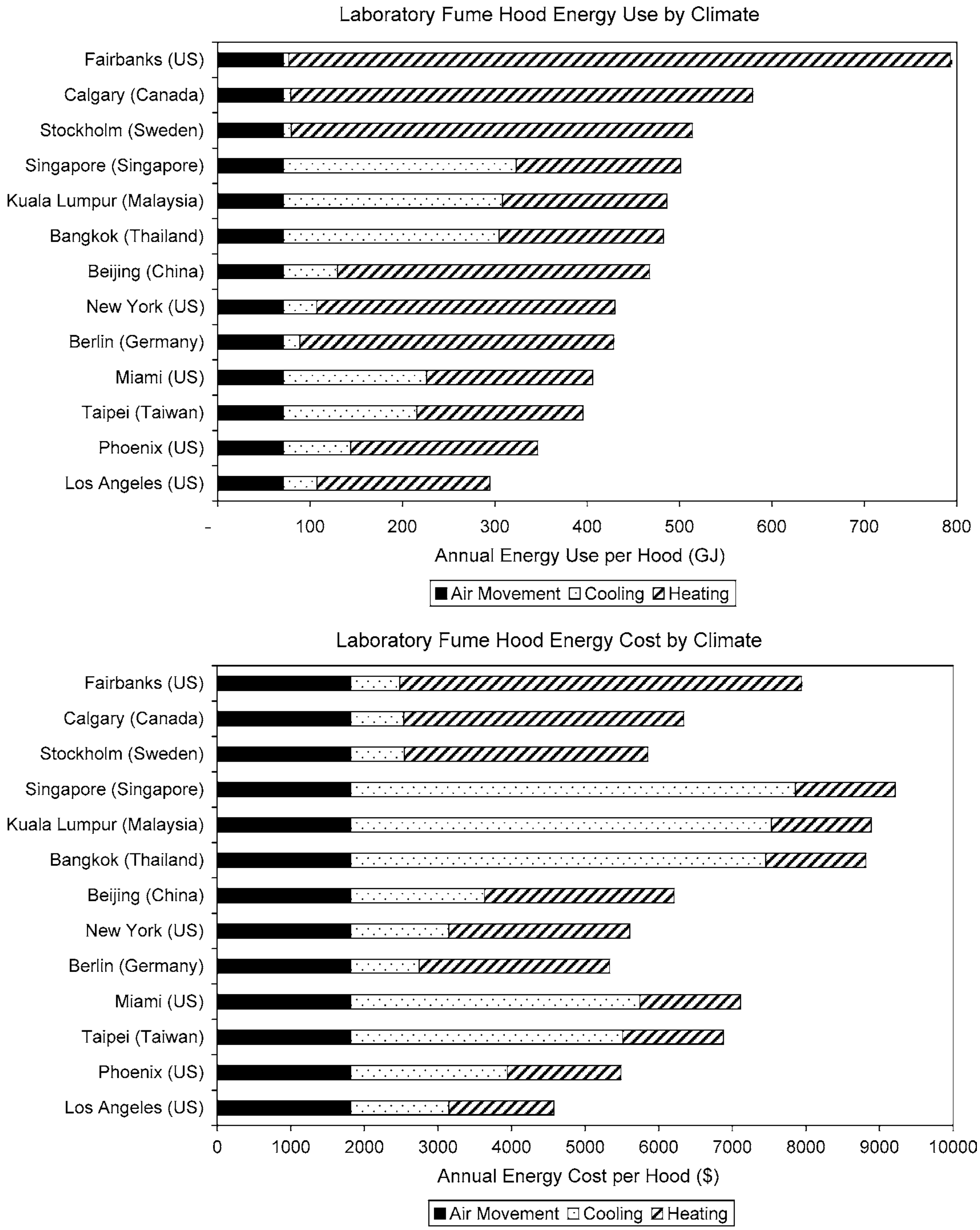

Fig. 1. Assumes a 2-meter nominal hood opening, 30.5 m/min face velocity, fuel reheat, 24-h operation per ANSI standards, weather data from [7], cooling plant efficiency 1.0 kW/ton, ventilation system efficiency of 1.8 W/CFM per [8], and reheat results in a load of 3,525 MJ/m^3-min-year (94,608 BTU/cfm-year). Electricity counted at 3.6 MJ/kWh.

Table 1
Fume hood energy use and savings potential[a]

	United States[a]	California
Per-hood values		
Electricity use (kWh/year)	34,871	29,326
Peak electricity demand (kW)	6.74	6.74
Fuel use (GJ/year)	272	223
Annual energy cost per hood ($)		
Total	5,624	6,031
$/CFM	4,50	4.83
Macro-scale baseline energy use		
Number of hoods	750,000	85,000
Total electricity (GWh/year)	26,153	2,493
Total peak power (MW)	5,057	573
Total natural gas (10^{15}J, PJ/year)	204	19
Total energy cost ($ million/year)	4,218	513
Macro-scale energy savings		
Per-hood energy savings[b]	50%	50%
Maximum potential market penetration	75%	75%
Electricity ($ million/year)	771	112
Peak electrical demand ($ million/year)	228	26
Natural gas ($ million/year)	583	54
Total energy savings ($ million/year)	1,582	192
Total electricity savings (GWh/year)	9,808	935
Total peak electrical demand savings (MW)	1,896	215
Total heating fuel savings (10^{15}J, PJ)	77	7

[a] Engineering assumptions shown in caption to Fig. 1. US average weather conditions modeled as average of Los Angeles, Chicago, Miami, and New York. Commercial-sector energy prices (2003): US average $0.0786/kWh; California $0.12kWh. Gas $7.62/GJ in both cases.

[b] Estimate is conservative given that R & D goal is to reduce air flow by 75% and theoretical fan savings is a cubed function (a 50% reduction in flow would result in over an 80% savings in fan HP). This conservatism balances existing use of VAV hoods, and the potential that fume hood exhaust may drop below general lab exhaust requirements.

conservative ‘central value’ of 750,000. Based on this estimate of the stock, the annual operating cost of US fume hoods is $4.2 billion, with corresponding electricity use of 26 TWh, peak electrical demand of 5,100 megawatts, and 204 Petajoules (193 TBTU) of heating fuel.

3. Approaches to containment, safety, and energy efficiency

Several design strategies have been employed to reduce fume hood energy use [2].

- Introducing tempered outdoor air near the face of the hood,
- Combining dampers, variable speed ventilation, and digital controls to vary air volume while maintaining constant face velocity, and
- Restricting a hood’s face opening while maintaining a constant airflow.

While these strategies can result in energy savings, they are complicated, may fall short of the full potential, and have varying degrees of efficacy in ensuring safe operating conditions.

One new approach to managing fume hood airflow, the Berkeley Hood technique, supplies air in front of the operator, while drawing only 20–40% of the air from around the operator [2]. This supplied air creates a protective layer of fresh air free of contaminants. Even temporary mixing between air in the face of the fume hood and room air, which could result from pressure fluctuations in the laboratory, will keep contaminants contained within the hood. As a result, far lower exhaust rates are required to contain pollutants and remain virtually unaffected by adjustments to the sash opening.

The Berkeley Hood uses a 'push-pull' displacement airflow approach. Displacement air 'push' is introduced with supply vents near the top and bottom of the hood's opening. Displacement air 'pull' is provided by simultaneously exhausting air from the back and top of the hood. The low-velocity supply airflows create an 'air divider' between an operator and a hood's contents that separates and distributes airflow at the sash opening (unlike an air curtain approach that uses high-velocity airflow). The need to exhaust large amounts of air from the hood is largely reduced.

Field trials of state-of-the-art designs have demonstrated containment down to 34% of full flow [2]. Based on per-hood energy savings of 50% and 75% overall market penetration, the aggregate US energy savings potential is significant, at approximately $1.5 billion annually (Table 1).

An added benefit of high-performance designs is that, in new construction, capital cost savings are realized as a result of downsized heating, ventilating, and air conditioning systems and less complicated controls. Alternatively, more laboratory workstations can be supported without increasing HVAC system size.

4. Barriers to improving performance and energy savings

There are material hurdles to widespread adoption of new fume hood approaches. The problems reside in regulations and standards that stipulate absolute airflow rates, rather than direct metrics of containment and safety.

A face-velocity value of 30.5 m/min. (100 feet/min, fpm) is widely applied. While this rule-of-thumb has limited technical merit, its simplicity and pervasiveness presents the most significant barrier to widespread adoption of methods that result in lower airflow rates (even if safety is not compromised).

ASHRAE Standard 110–1995 is the most used test method for evaluating a hood's containment performance in North America. This method recommends three types of tests but does not stipulate *performance* values to be attained by a fume hood. ASTM sets performance thresholds when using the ASHRAE test. High-performance hoods using the above-mentioned push–pull technique provide containment of tracer gas and smoke per the ASTM/ASHRAE test but have an 'equivalent' face velocity of approximately 9.1–15.2 m/min. (30–50 fpm) (with the internal supply fans off). The actual velocity is much less as most of the air is introduced at the face.

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