Energy Saving Potentials In Laboratory Facilities In The Context Of Safe Environment

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SUMMARY

Laboratory facilities are known as significant energy consumers. High ventilation rates are required for providing safe and comfortable environment as well as optimum operation of the equipment. Air from laboratories involving chemical activity is exhausted to the outdoors and should be replaced by outside air. Recirculation is not considered a good practice with regard to safety. Protection of the outside surroundings is an additional environmental challenge. The purpose of the study is to reveal various ways of saving energy through minimizing the ventilation rates in laboratory facilities in the contest with providing safety conditions in laboratory space. Two key contributors are analyzed: the air flow requirements from laboratory exhaust equipment and the minimum air change recommended by laboratory design guides or engineering and safety practice.

INTRODUCTION

Providing safe environment, the health and comfort of the occupants is the primary goal of the design of laboratory air conditioning system [1]. Among air exhaust equipment in laboratories the fume hoods (fume cupboards) represent the most important energy consumer. Used to prevent the exposure to hazardous materials, the fume hoods could exhaust to the exterior a considerable amount of conditioned air. Reducing the air flow, while maintaining safe conditions, has been an enduring objective of HVAC industry. Most of the latest innovations in fume hood design aim to reduce the face velocity or to restrict the hood opening area. Their implementation in laboratory practice has been received with mixed reactions revealing psychological and habitual resistance from some the users. The face velocity accepted in practice as satisfying safety conditions may vary from 0.3 to 0.6 m/s. The most common design value is 0.5 m/s. Adopting low velocities of this range is not always received with confidence by the safety managers and the users comfortable with traditional values employed over the years. However, 20% to 40% reduction is generally acknowledged in practice at least for periods when the operators are not present in front of the hood. On the other hand, the measure of minimizing the hood opening area challenges the users on accepting restricted access to the work area. Some tend not to be appreciative, viewing it as work restraint. Limitations of the vertical sash opening or various combinations of vertical and horizontal sashes have been developed. Reducing the energy cost of operating the fume hoods is a multidisciplinary mission involving the designers, the managers and the users.

On the safety side, it is common in the design practice to impose a minimum air change rate (air changes per hour -ACH) as an operating limit of the ventilation system. The recommended values for various types of laboratories fit into a range of 4 to 15 ACH, sometimes higher. No method or procedure, other than practical considerations and observation, is known to be the source of these values. Adjusting this range on more justified basis has been objective of energy saving in laboratory ventilation. The concentration of hazardous substances in a laboratory
environment is the major criterion in discussing the minimum ACH. The release of chemicals inside the laboratory environment could only happen by accident. A spill of a chemical could result from defective material, equipment malfunction or negligence. Laboratory protocols do not allow the use of hazardous materials in open laboratory space. Chemicals must always be handled in containment equipment such as fume hoods, biological safety cabinets or glove boxes. Regardless of the limits of the design of laboratory ventilation system, the air dilution or replacement could not protect personnel from exposure to concentrated bursts [2]. If this point of view is acknowledged, the current minimum air change rates in laboratories could be reconsidered based on calculations and measurements of the concentration levels.

METHODS AND RESULTS

Methods of reducing the laboratory fume hood exhaust flow rates are analyzed considering a variety of design solutions and operational measures. The possibility of minimizing the air flow is discussed from the safety viewpoint, by evaluating the concentration of hazardous substances and comparison with the permissible safety limits.

Reducing the air flow of at fume hoods (cupboards)

A comparison of various fume hood design solutions for reducing the access area is presented in Table 1. A 1,800 mm wide fume hood is used for reference. A laboratory of 90 m³ and 3 m ceiling height is considered for evaluating the corresponding number of air changes per hour (ACH). In the concept of modular laboratory design the space is equivalent to a laboratory module.

Table 1. Comparison of design solutions

<table>
<thead>
<tr>
<th>Design solution</th>
<th>Face velocity</th>
<th>Face opening</th>
<th>Air flow</th>
<th>Air flow reduction</th>
<th>ACH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m/s</td>
<td>m²</td>
<td>l/s</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Full open sash - 70 cm open</td>
<td>0.5</td>
<td>1.20</td>
<td>600</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>Vertical sash - 45 cm open</td>
<td>0.5</td>
<td>0.76</td>
<td>380</td>
<td>36</td>
<td>15</td>
</tr>
<tr>
<td>4 horizontal sashes on 2 tracks</td>
<td>0.5</td>
<td>0.57</td>
<td>285</td>
<td>52</td>
<td>12</td>
</tr>
<tr>
<td>Vertical sash at 45 cm open low velocity</td>
<td>0.4</td>
<td>0.57</td>
<td>285</td>
<td>52</td>
<td>12</td>
</tr>
<tr>
<td>Vertical sash at 45 cm open minimum velocity</td>
<td>0.3</td>
<td>0.57</td>
<td>215</td>
<td>64</td>
<td>9</td>
</tr>
<tr>
<td>Combination of vertical and reduced height horizontal sashes on 2 tracks</td>
<td>0.5</td>
<td>0.33</td>
<td>165</td>
<td>72</td>
<td>7</td>
</tr>
</tbody>
</table>

It results that this measure has a potential of reducing the flow rates more than three times of full open sash reference case. It should be noted that the rates of air change remain high. The room yet changes 7 volumes of air even in the most extreme saving solution. Further reductions are possible with the user’s input in employing the features offered by design along with a relentless sash position management.

The variable air flow control solution based on sash position (VAV) is a traditional measure of reducing the energy consumption of exhaust equipment. Employing the benefits of this solution involves a dependable attitude of the user of maintaining low or closed sash position. The technology of automatic sash position control has been developed; the sash moves safely as
sensing the presence at the hood. The ideal scenario is that the sash should be actually open only during the loading, unloading or interacting with the process inside.

The current concept of low-velocity hoods is based on constant flow. Optimizing the pattern of the flow inside the hood enclosure is used to enhance the containment at lower face velocities. Such hoods have passed the required safety tests at velocities as low as 0.3 m/s. In the case of constant air flow (CV) hoods, the only means of reducing the energy consumption is using two position control settings for occupied/non-occupied periods. During the non occupied time, the hood face velocity is usually reduced to 60%.

A comparison of various methods under different operating conditions using as reference a conventional hood operating at constant flow (CV), with full open sash is illustrated in Fig. 1. A good management of keeping the sash closed 20 hours a day can potentially reduce the flow to 20%. For the 90 m³ reference laboratory this represents a drop from 25 to 5 ACH.

Figure 1. 24 hour potential savings using various fume hood design and operating conditions.

Figure 2 shows the average airflow and air changes per hour in a 3-module laboratory (270 m³) with the same hood in the similar operating configurations.

Fig. 2. Average air change rates from one 1,800 mm fume hood in a 3-module laboratory.
With the chemical activity safely contained inside the fume hood the volume of air in the laboratory environment could be changed to as low as 2 to 4 times every hour. Reducing the exhaust flow from fume hoods should not be a concern with regard to safety of the outside environment. Along with the substantial dilution in the fume hood, combining the effluents from fume hoods into a single exhaust system provides further dilution and reduces the energy consumption [3] [4].

It could be concluded that various design solutions, along with proper fume hood usage and management, offer great opportunities of reducing the room air changes and consequently the energy consumption in laboratory environment. The remaining question is whether the low level of air change possible to be employed through these measures assures a safe environment in the laboratory, outside the fume hood. The next section intends to offer a response by focusing on the concentration in laboratory environment.

Minimum air change in laboratories

The discussion of minimum air changes per hour (ACH) is primarily related to the level of concentration of hazardous materials in the laboratory environment. An extreme condition of an accidental spill is analyzed.

The concentration of chemicals is neither steady, nor homogeneous because of continuous change of air patterns affected by the air diffusing system, people’s movement or doors opening. The development of a generalized model that quantifies the influence of all interfering factors inside the space is not possible. In case of a spill, the maximum concentration at the source is diminished but the distribution in space is not known. Permissible exposure limits imposed by the safety codes must be satisfied regardless the location.

In safety practice, Permissible Exposure Limits (PEL) criterion was introduced, along with other similar criteria, for defining the concentration of chemicals in air under which it is believed that workers could be exposed without adverse effects.

This section evaluates the concentration produced by evaporation of a chemical liquid spill. The results are compared with permissible exposure limits (PEL) and correlated with air changes (ACH) in the laboratory space. The procedure of the analysis is described in Sandru and Xing [5]. The rate of evaporation of 1 m² of liquid area is calculated and used for calculating the average volumetric concentration in the 90 m³ volume of the reference laboratory. 20 chemicals frequently used in laboratory practice, in the range from low to extreme health hazard are examined. Heat-mass transfer analogy was applied considering steady state conditions of a parallel flow over smooth liquid surface, at uniform liquid and air temperature. The mass flow rate from convective evaporation was determined by equation

\[ m_v = h_m A_v \left( \rho_{v,s} - \rho_{v,\infty} \right), \]  

where \( h_m \) is the average mass transfer coefficient, \( A_v \) is the area of mass transfer, \( \rho_{v,s} \) is the vapor density at liquid-air interface and \( \rho_{v,\infty} \) the vapor density in the free air stream.

The mass transfer coefficient was evaluated from heat and mass transfer analogy [6].
Sherwood number \((Sh)\) was calculated considering parallel flow over a flat plate and \(D_v\), the diffusion coefficient of vapor into air selected from CRC Handbook [7].

Volumetric concentration \(C_v\) \((ppm)\) was calculated as

\[
C_v = \frac{\dot{m}_v}{\rho_{v,s}} \times 10^6, \tag{3}
\]

where \(\dot{Q}\) is the air flow rate in the space \((m^3/h)\).

The results are illustrated in Figure 3. Remarkably low air changes are shown to be sufficient for diluting the moderate and low hazardous substances. However the highly hazardous chemicals could not be safely diluted within the air change rates currently accepted in laboratory design. It is obvious that increasing the ventilation air flow could not eliminate the hazard generated by an accidental spill.

![Figure 3. Air changes per hour required to attain permissible exposure limits. Evaporation of 1 m² of spill in 90 m³ laboratory space.](image)

Evaporation from an open tray of 0.04 m² in the 90 m³ reference laboratory space is also evaluated for comparison. As in the case of the large spill the air velocity was selected at 0.2 m/s, simulating possible air drafts from laboratory ventilation. The results displayed in Figure 4 lead to the similar conclusions. With one exception, the low evaporation rate brings the concentration below the PEL at air changes within the current range of 4-15 ACH.
DISCUSSION

Two ways of reducing the energy consumption related to laboratory ventilation have been analyzed. Various methods of reducing the average air flow exhausted from laboratory fume hoods have been compared. Current design solutions available in industry along with user’s discipline in operation the fume hoods offer great potentials for energy saving. The analysis reveals the fact that a fume hood could operate at average flow rates as low as 20% of maximum flow in ideal conditions of operation.

Safety aspects of saving energy by adopting low flow rates in laboratories handling hazardous substances are discussed. The air changes per hour necessary to maintain the laboratory environment below permissible exposure limits are calculated in the case of an accidental chemical spill. The evaluation is theoretical considering the homogeneous distribution of concentration in space. The odor criterion has not been considered. The analysis proves that, regardless the level of the air flow, most hazardous chemicals could not be diluted to safe limits. Maintaining high flow rates could not avoid the hazard. Purging the space with high emergency flow rates could only provide a faster dilution before the space could be reoccupied. The results also show that extremely low air changes are sufficient to dilute the moderate and low hazardous substances. In this context could be observed that:

High flow rates are not justified to ventilate the space where chemicals are not present. Lower than traditional minimum flow rates could be considered in designing the laboratory ventilation system. The observations are based on the fact that the laboratory written code of behaviors does not allow the use of hazardous materials in open laboratory space and always requires immediate evacuation of the space in case of an accidental spill.
REFERENCES