Challenges in HVAC Design for R&D LABS

A view of several fume hoods connected to exhaust ducts. Photo courtesy of Opal HVAC Engineers.

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With the advent of foreign collaborations, the requirements of the collaborators and their consultants has changed the way HVAC systems are designed for labs and also the way the installation looks. The imported designs of HVAC systems need to be redesigned to suit Indian conditions applicable to comfort, initial cost and operating costs. These aspects are also brought out in this article.

Air conditioning of laboratories poses several challenges. It is related to the comfort, health and safety of the laboratory occupants. A typical laboratory currently uses five times as much energy and water per square foot as a typical office building. The following design considerations need to be addressed:

1. To provide the necessary outside air to ensure proper indoor air quality, comfortable temperature and humidity for the occupants.

2. The chemical fumes and other airborne contaminants have to be removed

3. To ensure that there is no mixing of the exhaust air with the supply air stream.

4. There should not be strong and localized air drafts as these can interfere with the functioning of the fume hoods leading to air spill-out from hoods and thus exposure of laboratory occupants to toxic contaminants.

5. To ensure that the area is under negative pressure with respect to the corridor.

In addition, there could be considerations like fire hazards, chemical spills, explosions etc. that may need to be addressed.

Laboratory fume hoods are a subject by themselves and it is not the purpose of this article to discuss them in detail. However, since the laboratory ventilation system has to be relevant to the type of hoods used, a mention is being made here about the various type of hoods.

Laboratory fume hoods are meant for keeping toxic or irritating vapors out of the general working area. The fume hoods also act as a shield between the worker and the equipment. Laboratory hoods are comprised of the hood itself and a sash, which can be opened and closed to maximize access and minimize airflow.

The efficiency of a laboratory hood is measured by its hood face velocity and required air flow. Hood face velocity is a measure of air flow speed across the imaginary plane running between the bottom of the sash to the work surface. Greater the hood face velocity, the more quickly toxins and other vapors can be flushed from the system. Required airflow is related to hood face velocity in that it is a measurement of the amount of air flow required to achieve a laminar flow velocity of around 100 feet per minute.

Though the Scientific Apparatus and Manufacturers' Association

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(SAMA) no longer publishes standards, its standard on fume hoods is often referred to. It classifies fume hoods according to chemical risk as follows:

Class A - Used for materials of extreme toxicity. Recommended average face velocity is 125 to 150 fpm.

Class B - Used for materials of moderate toxicity, which includes most materials and operations. Recommended average face velocity is 100 fpm.

Class C - Used for materials of low toxicity. Recommended average face velocity is 75 to 80 fpm.

Fume Hood Types

Standard Fume Hood

These hoods have a constant air volume (CAV) for exhaust air. Because of this, the face velocity of air in a a CAV hood is inversely proportional to the sash height. Lowering the sash results in higher face velocity. CAV hoods can be installed with or without a bypass provision which is an additional opening for air supply into the hood. When the sash is in a near-closing-condition, the face velocity is very high. For this reason, users leave it open.

Bypass Hood

This hood is similar to a standard CAV type of hood. There is this additional feature of a bypass arrangement shown in *Figure 1*. In these hoods the exhaust flow is constant. The open bypass area increases as the sash is closed. On account of this, the face velocity varies less with the sash opening. However, as in the standard hood, the face velocity is pretty high near closing and users tend to leave the sash open.

Auxiliary Bypass

The auxiliary fume hood is a bypass hood with the addition of directly ducted auxiliary air to provide unconditioned or partially conditioned outside makeup air. Auxiliary air hoods were designed to save cooling energy costs, but increase the mechanical and operational costs due to the additional ductwork, fans, and air tempering facilities. The air velocity of the auxiliary air needs to be carefully adjusted. The air curtain created will affect the hood operation and may pull vapors out of the hood interior. In humid places, there is the additional possibility of condensation of make-up air coming in contact with cold inside air. The disadvantages of this type of hood outweigh the benefits.

Variable Air Volume

The air flow is varied to maintain constant face velocity. Thus, minimum air quantity is when the sash

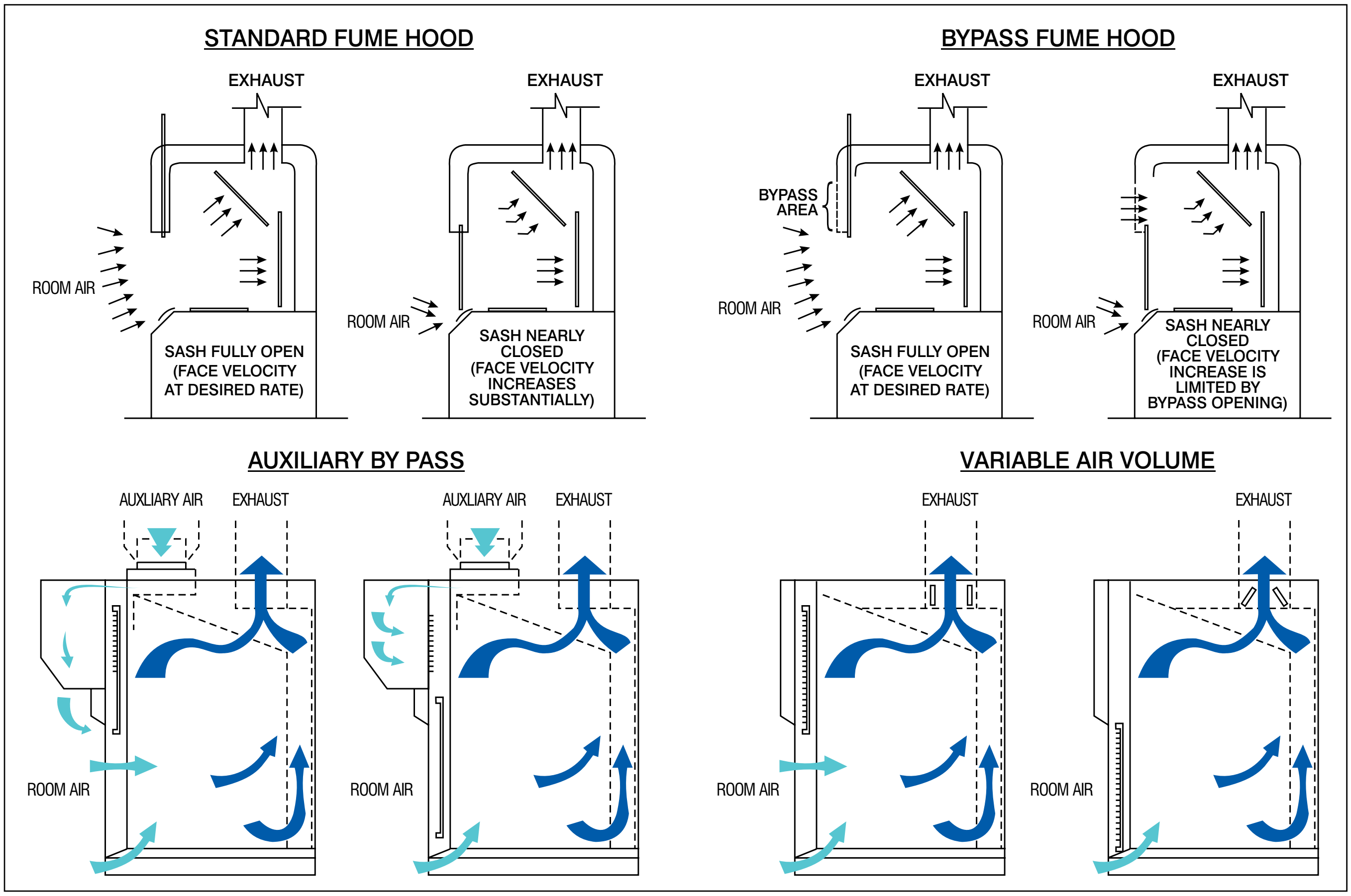

Figure 1 : Different types of fume hoods.

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is fully closed and maximum flow is when the sash is completely open. Users find no objection to close the sash, for safety, because the air velocities are not increased due to sash closing.

The total supply and exhaust flows are variable to meet the needs. This type of hood is thus energy efficient.

Air conditioning System for the Laboratory

Design Room Temperature

For a particular project in Thane, Maharashtra, with VAV type of fume exhaust hoods, around 25°C was considered the appropriate room temperature consideration. Because of the phenomenal amount of energy that goes into the HVAC systems, we designed for this higher temperature as we were confident that the occupants will not get agitated if the temperatures goes upto 27°C on occasions. This criterion had the ready acceptance of the customer.

Supply Air Quantity and Supply Air Temperature

The calculation of air quantity and supply air temperature is entirely based on room sensible heat. This is on account of the fact that relative humidity is not an overriding concern. This is a significant departure from the usual dehumidified air quantity calculations wherein room sensible heat factor and apparatus dew point play an important part.

Design conditions indicated that at peak summer (37.8°C DB, 27.8°C WB), for a room sensible load of 17kW (57000Btu/hr), for the minimum total supply air flow rate of 7075m^3/hr (4161cfm), the air needed to be cooled to 18°C. For the maximum total supply air flow rate of 10750 m^3/hr (6323cfm), the air needed to be cooled to 20.4°C. This indicated air conditioning load of 27.04 tons and 33.32 tons at 18°C and 20.4°C air outlet temperatures respectively from the air-handling unit.

For monsoon (30°C DB, 28.3°C WB), the room sensible load was calculated as 8.2kW (28000BTU/hr). At minimum flow rate, the air needed to be cooled to 21.5°C and 22.7°C respectively for minimum and maximum flow. This indicated air conditioning load of 26.7 tons at 22.7°C and 20.6 tons at 21.5°C air outlet temperatures respectively from the air-handling unit.

Relative humidity not being a primary concern, the total monsoon loads, based on sensible heat calculations was less than the summer loads.

Being a once thru' system with widely varying capacity requirement between summer, monsoon and winter, AHU with condensing units was considered inappropriate for the application as there would be a potential risk of failure due to and the possibility of compressor head getting overheated due to high suction pressures. Further, there would be great chance of liquid flood back in winter.

So, chilled-water based AHU working in conjunction with a 36 ton nominal capacity air-cooled water chilling package with 6×6 ton scroll compressors was selected to provide adequate cooling with one compressor giving the necessary redundancy.

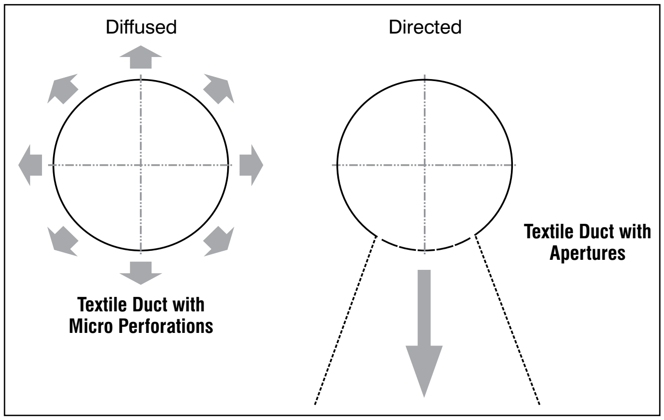

Figure 2 : Textile ducts with two types of air flow.

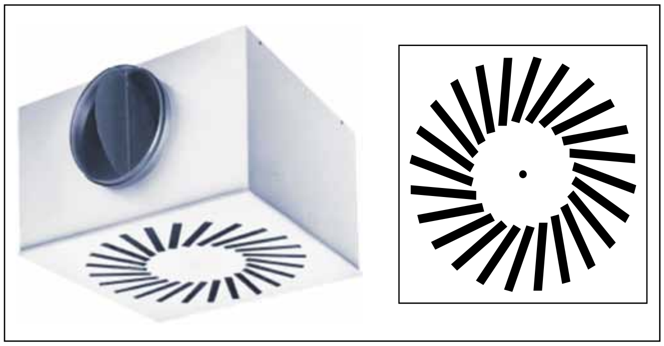

Figure 3 : Swirl Diffusers

Air-Distribution System for the Laboratory

As noted at the beginning of the article, supply air into the room should not be in the form of strong and localized drafts as these can interfere with the functioning of the fume hoods. The best air distribution was found to be with textile diffusers. Textile ducts give two types of air flows as shown in the *Figure 2*.

Textile diffusers with micro-perforations giving diffused air flow instead of textile diffusers with apertures giving directed flow was selected to avoid air drafts and still give comfort to the lab personnel. The textile diffusers were placed above all aisles between fume exhaust hoods. The manufacturer of the product did the selection of the diffusers based on the throw, air-quantity and temperature difference between air inside the duct and the room temperature.

The non-woven textile fabric can endure a minimum of 50 washings and the customer was advised to keep a spare set for change.

Textile diffusers need to be imported and need significant lead time. This is something which does not go down well with most customers. This is where the Indian genius comes into the picture. Swirl diffusers are good substitutes for textile diffusers. Further, these are readily available.

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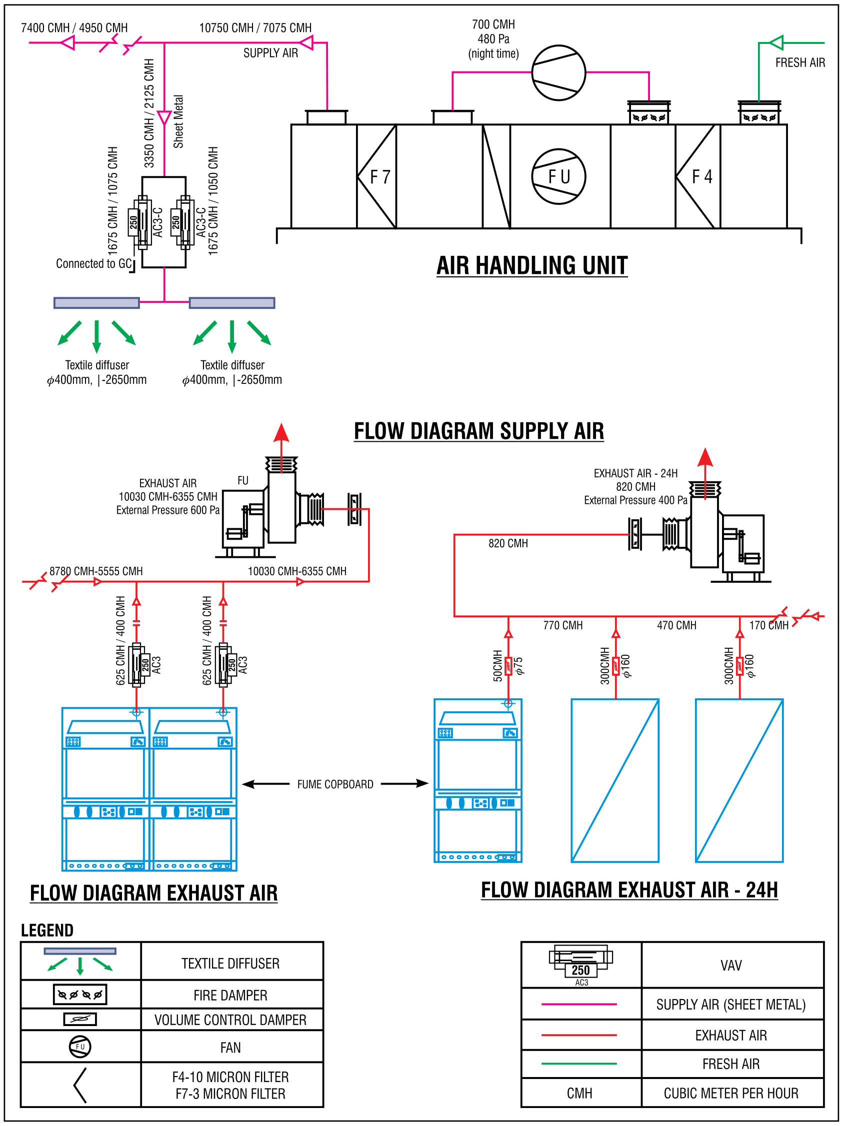

Figure 4 : Schematic layout of air flow.

Thus, a portion of the lab where short completion period did not allow import time for the textile diffusers, swirl diffusers were installed to give a very low draft. Swirl diffusers with radially angled slots with air deflectors along with plenum box and dampers were selected.

Air Handling Unit Design

The filtration requirement for the once thru' air-conditioning was EU5 (equivalent to 10micron) pre-filters followed by EU7 (equivalent to 3micron) fine filter bank. As the schematic drawing (*Figure 4)* for air flow shows, we have in succession EU5 filter bank, a damper section, a plenum, a plug fan, chilled water coil section, EU7 filter bank followed by an outlet plenum.

The plug fan was in blow thru' format, so that fan heat gets into the cooling coil and thus prevents it from becoming a component of room heat. The blow thru' format has the additional advantage of pressurizing the cooling coil plenum so that drain water is pressured out of the AHU. This ensures that condensate does not accumulate in the AHU drain pan.

Air Balance and Infiltration

Certain hoods and storage cupboards are provided with 24hour exhaust to prevent fume build-up. The total supply air from AHU is at all times a little short of the total exhaust from fume-hood exhaust blower and the 24hour operation blower. This ensures that the lab is always under a slight negative pressure. In the particular installation, at maximum flow, total supply air is 10750m^3/hr and the exhaust is 820m^3/hr (24hr exhaust) + 10030m^3/hr (fume hood exhaust) = 10850m^3/hr, a difference of 100m^3/hr. At minimum flow, the corresponding figures are 7075m^3/hr supply air and 820m^3/hr + 6355m^3/hr = 7175m^3/hr, a difference of 100m^3/hr.

A relatively low 100m^3/hr infiltration was considered adequate keeping in mind the elaborate controls in place to ensure only a slight negative pressure at all times. The trouble with high negative pressure is that there is a likelihood of infiltration of unconditioned air from unknown sources which will result in condensation inside the laboratory when the air conditioning system is functioning.

By-Pass Air for 24 hour Operation

During night-time operation, the air-conditioning system is "off" and 820m^3/hr is exhausted. This air needs to be compensated with filtered supply air. This is achieved by having a bypass blower of 700m^3/hr as shown in the schematic diagram *Figure 4*.

Control Strategy

With sash position control, the exhaust flow through individual hood is controlled by a direct measurement of air flow is used in a flow control loop, consisting of a flow sensor (such as a pitot tube), a controller, and a final control element (such as a butterfly damper). In this method, the set point of the loop is varied according to the sash position measurement.

A group controller integrates the total exhaust air quantity for all the hoods combined and signals VAV opening or closing in supply air ducts to deliver an air quantity equal to total exhaust air less 100m^3/hr to ensure a slightly negative pressure at all times.

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For the hoods in this particular project, the maximum flow was 625m^3/hr per hood and the minimum flow was 400m^3/hr as per the hood manufacturer and consequently the maximum total flow for the lab was 10030m^3/hr and minimum flow was 6355m^3/hr.

The control strategy mentioned above ensures that less total supply and exhaust occurs when some or all of the hoods have sash totally or partially closed, while at the same time it also ensures an overall negative pressure at all times. In the bargain we get considerable energy savings in air conditioning energy requirements.

Duct pressure sensors in the extreme end of supply and exhaust ducts give signals to VFD drives of AHU and exhaust fan drives respectively to vary the fan speed to maintain constant duct pressures. In the case of AHU, filter clean or clog condition also affects the pressure sensed by the duct pressure sensor and the VFD drive thus responds to the system needs and affords energy savings in fan input power.

Energy Recovery

Considering the great energy input in lab air-conditioning systems and the fact that cool room air gets exhausted into the atmosphere, energy recovery from exhaust is an attractive proposal. However there are constraints that need to be addressed.

1. Enthalpy wheels which can normally be expected to give the maximum heat recovery have this aspect of a certain quantity, albeit minute, of exhaust air mixing back into the supply air stream due to sweeping action of the wheel. As the fumes are toxic, the customer in question did not accept enthalpy wheel as an option.

2. The other option is to use heat pipes. Here there is no leakage of exhaust air into the supply air. For the application with 10750m^3/hr supply air, up to 9 tons of cooling was possible to be recovered from exhaust air. However, the customer being skeptical about corrosion issues related to exhaust fumes was not ready to experiment with the associated investment for the time being.

Conclusion

Air-conditioning of laboratories is very challenging indeed. The issues concerned are comfort and safety of operators. Air distribution in particular needs careful planning so that air drafts do not come in the way of hood performance. Control of supply and exhaust air quantities are of paramount importance for energy conservation. Energy recovery needs to be considered after carefully studying safety and corrosion issues. ❖

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