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Design Considerations of a Large Central Laboratory Exhaust

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ABSTRACT

The primary purpose of a laboratory exhaust system is to remove and convey fumes from the fume hoods and laboratory spaces to an area for safe discharge. This requires discharge conditions that allow good dispersion and prevent re-entrainment. Since laboratories are usually designed for once-through air (100% makeup air with no recirculation), a secondary purpose is energy recovery from the exhaust stream.

Laboratory exhaust systems have typically one of two arrangements. They are either individual, with each hood having its own exhaust fan and stack, or they are central, with multiple hoods served by common fans and stacks.

This paper summarizes the rationale used during the design of a large central laboratory exhaust system. Considerations such as wake analysis, diversity, energy recovery, special exhausts, and fan sequencing to maintain stack velocity are presented.

INTRODUCTION

Laboratory exhaust systems have typically one of two arrangements: individual or central. Each arrangement has specific advantages and disadvantages. Sometimes unique situations clearly dictate one arrangement over the other. When either arrangement will work safely, the decision may come down to what the owner is familiar and comfortable with, or the cost.

With the possible exception of a single-story facility having roof-mounted equipment, the arrangement must be agreed upon early because of its impact on building layout. A multistory facility with individual exhausts typically requires greater floor area for the numerous vertical duct chases. The same facility with central exhaust may require a greater floor-to-floor height for the exhaust manifolds serving each level. Issues such as type and quantity of chemicals used and potential interaction should be reviewed with the researchers who will occupy the facility.

For many years, individual systems were the preferred arrangement for laboratory exhaust. Each hood had a single up-blast discharge fan, preferably located on the roof or in a fan room away from the laboratory space. Older installations were often constant volume or had on-off switches and an indicator light at each hood. Newer installations have variable-speed or two-speed fans, sometimes automatically controlled based on sash position or occupancy.

Advantages of an individual system include no possible interaction with other exhaust streams; exhaust fan shutdown affects only one hood; and simple, low-cost installation for a small number of hoods. Disadvantages include lower efficiency, difficult energy recovery, higher installed costs, higher maintenance costs, higher cost to provide redundancy, more roof penetrations, and a higher concentration of contaminants in individual streams. The minimum flow may be limited to maintain a minimum stack exit velocity.

The central system consists of multiple hoods connected to common fans and stacks. This arrangement is more prevalent in larger facilities where economies of scale take effect.

Advantages of a central system include dilution of contaminants, lower installed costs, lower energy use, improved energy recovery potential, less equipment to maintain, and easier to provide redundancy. Disadvantages include potential contamination of entire system from upset in one hood, potential hazards from intermixing chemicals, and the failure of one fan may affect several hoods.

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FACILITY DESCRIPTION

The facility described in this paper is a medicinal chemistry building that contains 50 wet chemistry laboratories with 150 fume hoods. The fume hoods are 12 ft wide and have four vertical sashes. The wet chemistry laboratories account for about 75% of the laboratory space. There are also several support and specialized laboratories.

The building has a gross floor area of approximately 138,000 ft^2 with four levels of laboratory space, a mechanical equipment penthouse on the fifth level, and a partial basement also for mechanical equipment.

The floors are arranged with a personnel corridor around the perimeter of the building and a service corridor longitudinally through the center. Offices are adjacent to the personnel corridor and have passage to the laboratories. The laboratories are between the offices and service corridor, with passage to either. There is a four-story atrium at the center with areas for informal interaction and breaks. Figure 1 shows a typical floor plan.

The facility was initially occupied in late 1995.

DESIGN CONSIDERATIONS

Central vs. Individual Exhaust Arrangement

This decision was easy. Considering the size of the facility, the number of hoods, and similarity of the research from lab to lab, we decided to use a central exhaust system. The initial cost, space requirements, energy use, and maintenance of over 150 individual fans would have been significantly more than the six large exhaust fans we currently have.

Although individual systems were discussed, they were never given serious consideration, except for a limited number of special exhausts that are discussed later.

Wake Analysis

The site is a research campus with a sloping terrain. There are multiple buildings and multiple laboratories of various heights. It was essential to determine the effect this building might have on others, as well as the effect the surrounding buildings might have on this building.

The analysis required establishing building configurations, stack locations flows, and emission rates for the existing and new facilities. The difficult part was estimating emission rates. Fortunately, the site environmental group had recently completed a study of a similar laboratory and estimated emissions with a material balance of chemical use over time. A probable emission rate was developed by creating a ratio of the linear feet of hood in the new facility to that of the similar facility. The analysis was based on a 3000 fpm exit velocity and assumed the total daily emissions occurred over an eight-hour period. The worst case results showed that the concentrations predicted to be entrained into the intakes were 0.04% to 5.62% of the eight-hour time-weighted average (TWA). The analysis

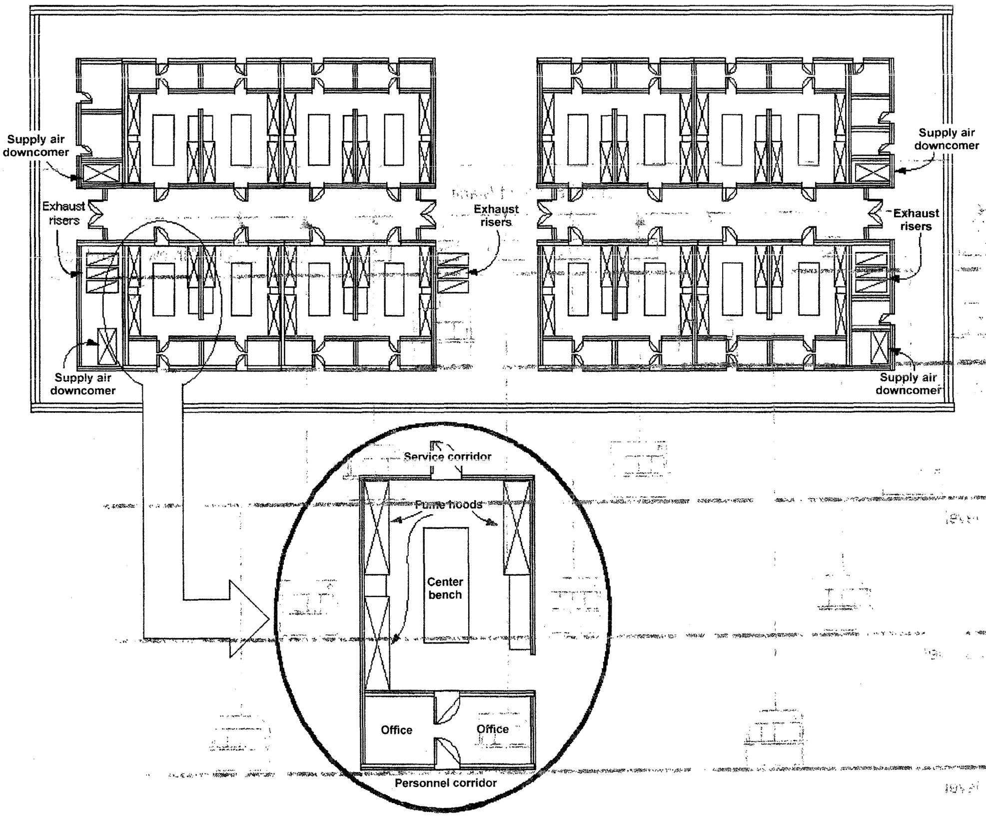

Figure 1 *Typical floor plan.*

also investigated a "master plan" configuration with proposed buildings considered.

The wake analysis was performed after the determination of basic building size and location. The decision to use a central exhaust arrangement had been made, but stack location was flexible, pending the results of the analysis. The final stack location was that assumed for the analysis.

Exhaust System Duct Configurations

We considered two possible configurations. The first had one common exhaust manifold located in the penthouse (Figure 2a). The individual hoods would be vertically ducted to the manifold. The individual airflow control valves would be in the penthouse just before each duct connected to the manifold. One advantage was a potential reduction in floor-to-floor height since a manifold was not required at each level. This arrangement was not chosen because the large number of duct risers would have an unacceptable space requirement at the upper levels. Some of the existing buildings use this arrangement. Renovation has been difficult when additional hoods or larger hoods are required. Ducts from the lower levels are difficult to run. We did not like the remote location of the control valves in relation to the hoods. The concern was a lag in the response, especially for the hoods on the lower levels.

The second configuration has an exhaust manifold on each level serving all the hoods on that level (Figure 2b). Each manifold then runs vertically to the penthouse where it connects to a manifold common for the facility. The control valves are located in each duct run near the hoods they serve. The ducts from the hoods to the manifold were arranged so the control valves were accessible and not over a hood or bench. This arrangement provides greater flexibility for future changes since the duct run from the hood to the manifold is relatively short and accessible. We chose to use the second configuration.

Energy Recovery

The facility uses once-through air with no recirculation. The high volume of conditioned air represents a significant energy cost. We installed run-around propylene glycol loops for energy recovery.

The system consists of six heat recovery coils in the exhaust stream (one for each exhaust fan, four heat recovery coils in the supply air handlers, and dual circulating pumps). The system circulates glycol when the exhaust air is cooler than the outdoor air during the cooling mode and warmer than the outdoor air during the heating mode. There is a dead band during mild weather when the circulating pumps do not operate.

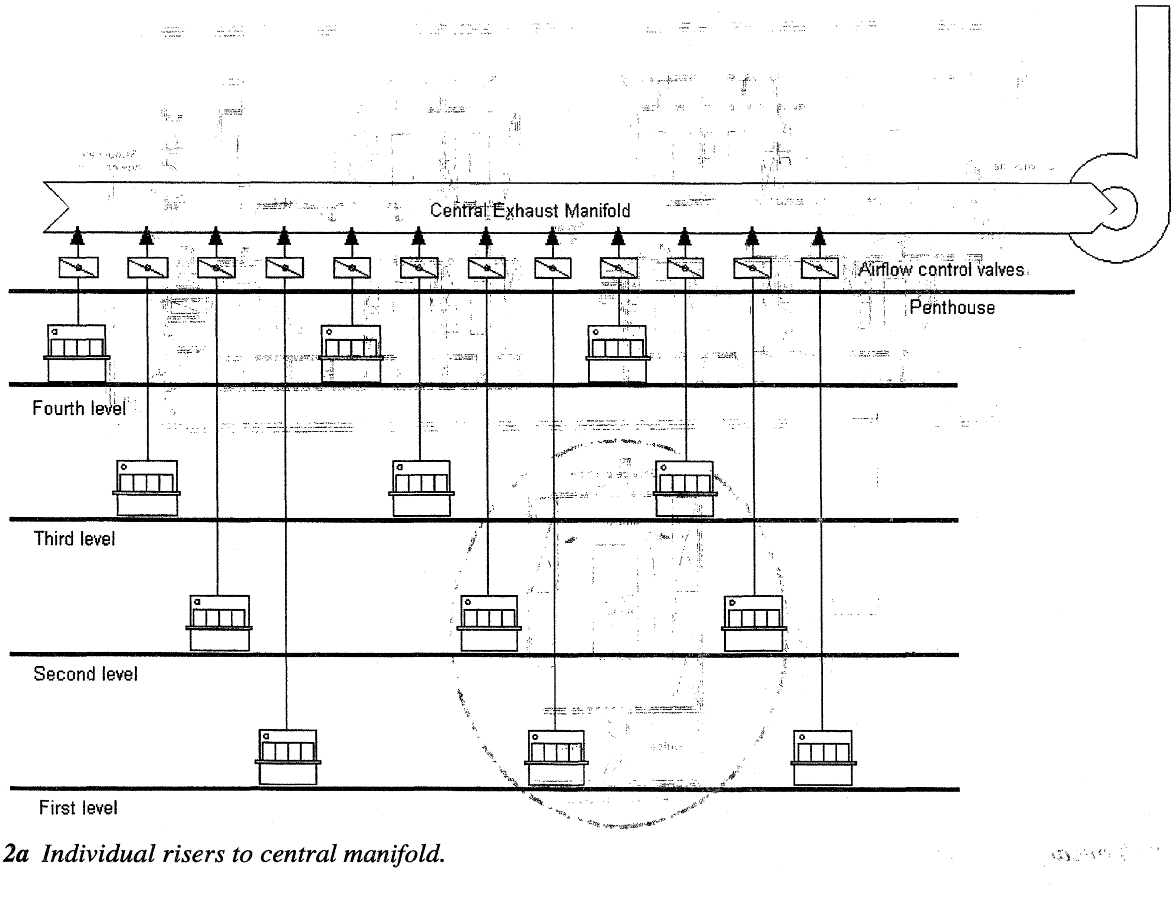

Figure 2a Individual risers to central manifold.

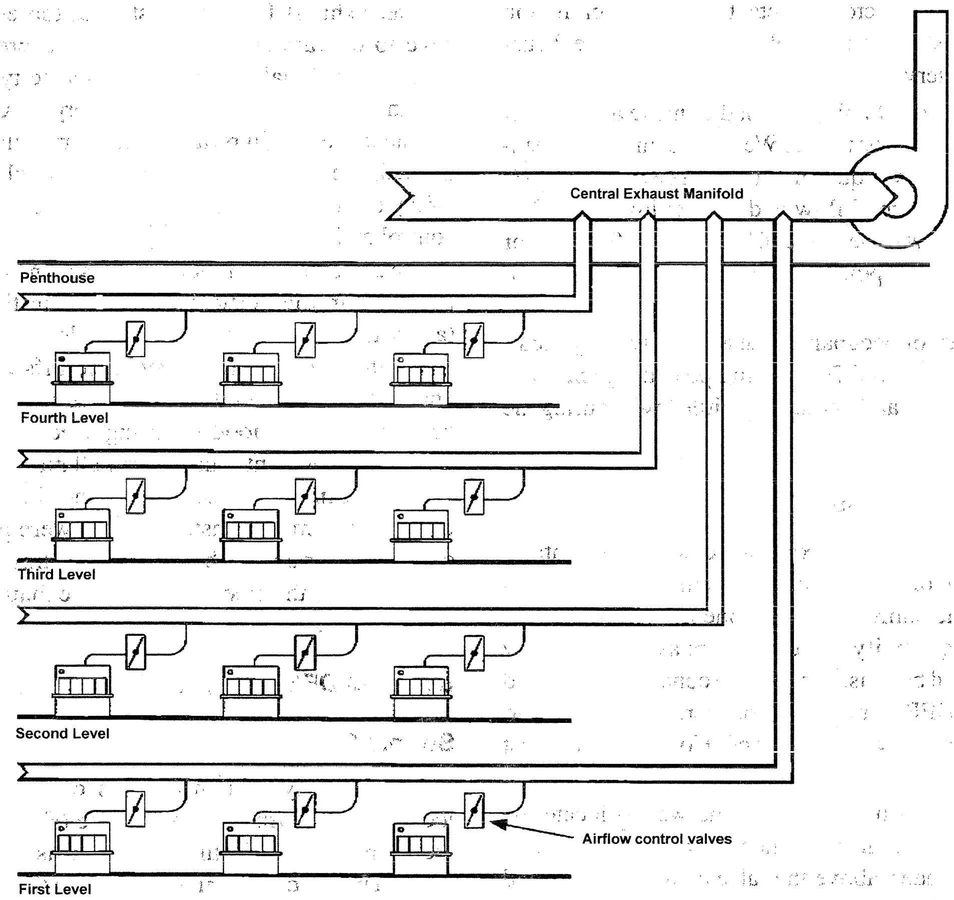

***Figure 2b** Manifolds from each level to central manifold.*

The run-around loop was chosen over other heat recovery systems primarily because of flexibility in locating the equipment. Although the exhaust fans and air handlers are all in the penthouse, they are not conveniently adjacent to each other. Using exchangers requiring adjacent exhaust and supply streams would have required additional runs of large ductwork. Since the exhaust stream was potentially hazardous, cross-contamination of the supply with the exhaust had to be eliminated. Another complicating factor was the unequal number of exhaust fans vs. supply units. A high degree of flexibility was desired since any combination of exhaust and supply equipment could be running at a given time.

The system is designed to raise the incoming air temperature about 27°F on a peak winter day (10°F outside air) and cool it about 7°F on a peak summer day (95° outside air). We have not run a formal capacity test on the system, but observations of temperature differentials using the control system instrumentation indicate it is performing close to design.

We had concerns regarding the safety of personnel during system cleaning and filter change, the cleaning frequency, and the long-term integrity of the heat recovery units. After approximately three years of operation, the interior of the units are exceptionally clean. The filter elements are changed about once per year. The units have not required cleaning other than vacuuming, which is performed as part of the filter change procedure. We do require maintenance personnel to wear protective equipment during maintenance procedures.

Diversity

The determination of diversity for a laboratory is different than for an office building. Variation in office cooling requirements is primarily due to variation in solar load. Since peak cooling loads on opposite sides of a building do not occur simultaneously, it is prudent engineering practice to size equipment to handle peak building load rather than to size for the sum of all the individual peaks. This is a value that can be predicted and calculated with reasonable accuracy.

In a laboratory with a high hood density, the ventilation load and load variation are dictated by hood use. At any point in time in a large facility, a percentage of personnel will be away on business travel, meetings, breaks, vacation, and so on. In a laboratory, some researchers may be at work at their desks and away from the fume hoods. If they are energy and safety conscious, the sashes will be in the minimum position.

The diversity factor for an individual exhaust arrangement does not affect exhaust duct or fan sizing since each individual system should be designed for 100% capacity. It may affect common elements such as the supply air system or building electrical service. For a central exhaust arrangement, the use of a diversity factor affects the entire ventilation system and allows smaller manifolds, supply fans, exhaust fans, and electrical service.

When designing our facility, we had to make a judgment call on what diversity factor to use. We agreed on 75%, meaning the maximum airflow requirement would be based on 75% of the fume hoods at normal flow and 25% at low flow. This allowed the design flow to be reduced by about 25,000 cfm, or about 10%, with a corresponding reduction of fan, coil, and duct size.

After three years of occupancy, the actual diversity factor is running between 65% and 70% during peak usage periods, usually between 10 a.m. and noon, and a little lower during the rest of the day.

Special Exhaust Systems

Disadvantages of a central exhaust include cross-contamination, interaction of the exhaust streams, and potential contamination of the entire system by one user. During laboratory programming activity, the users were asked to identify operations that would be sensitive to these concerns and would possibly require HEPA filtration or scrubbing prior to discharge. Less than five were identified. How could this best be accommodated?

We considered two possibilities. One was to locate the additional equipment when it was needed between the hood and main exhaust header, above the false ceiling. The second was to provide for a limited number of special exhausts in the original design.

The advantage of the first scenario was lower initial cost, as there would theoretically be no additional expenditure until a special exhaust was required. There were several disadvantages. Space limitations above the dropped ceiling may prevent installation of the required equipment. Filters and scrubbers impose an additional pressure drop. Unless a booster exhaust fan were installed, the entire system would have to operate at a greater negative pressure. This would require additional fan and motor capacity and a heftier duct design and would also waste energy. Access for frequent maintenance would be a problem, particularly since the material being collected was likely to be highly hazardous. Any spill would be in a normally occupied area and be difficult to control and remediate.

We decided to implement the second option and installed ten ducts in the vertical chases and in the stack enclosures (areas that would not be accessible after construction was complete). These would have take-offs at each level where horizontal duct could be run to a specific laboratory and connected to the hood requiring special exhaust. Space was reserved in the penthouse for installation of filters, scrubbers, and fans. Since the stacks would not be used until a special exhaust system was installed, caps were provided to prevent collection of rain and birds from building nests.

To date, the need for special exhaust systems has not materialized.

SYSTEM DESCRIPTIONS

Supply System

The supply system consists of four air-handling units located in the fifth-level penthouse (Figure 3). All four units are required to handle the peak loads, assuming 75% diversity. When a unit is down, three can handle the facility with administrative controls to remind researchers to maintain hood sashes at minimum positions. The supply fans are controlled with variable-frequency drives. The air is drawn through louvers into a plenum that is 8 ft deep and extends the length of the building. The air handlers draw from this plenum and discharge into a common supply manifold running the length of the penthouse. There is a damper at the outlet of each air handler that serves as both a smoke and isolation damper.

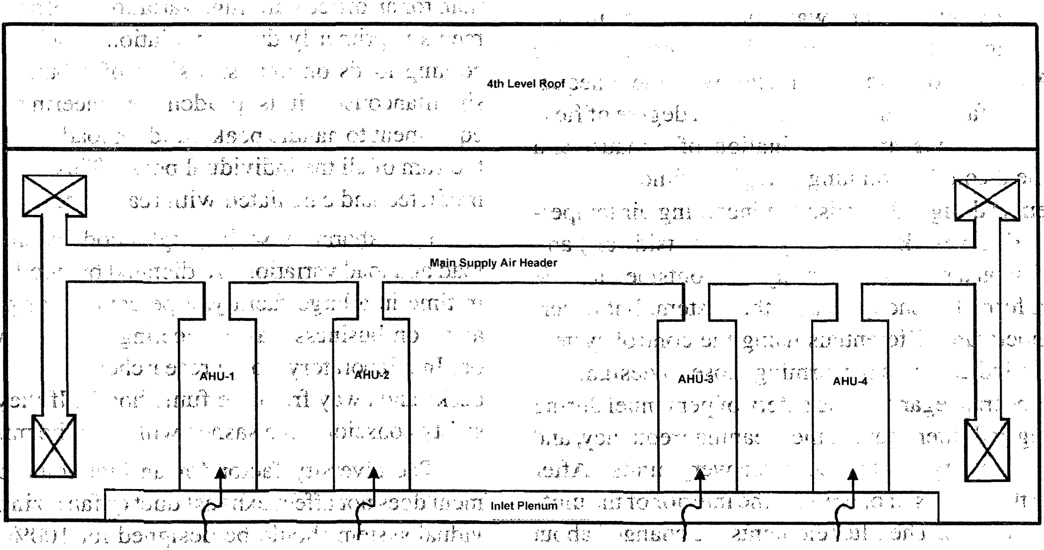

Figure 3 Penthouse plan, supply air system.

The supply manifold splits at either end of the penthouse into downcomers located at each corner of the building. The downcomers branch at each floor level. The main branches run above the personnel corridors on the north and south sides of the building and connect in the middle. The secondary branches of the office and laboratory supply come off the main branches.

One design issue was whether to locate the air handlers and air intakes high or low. Some other buildings on site have their air handlers at basement or ground level. We reviewed the pros and cons of each location and decided to locate them in the penthouse, pending the results of the wake analysis. As noted earlier, the predicted levels of entrainment were so low that this was not an issue.

The advantages of a ground floor or basement location include less potential for vibration and noise problems, shorter steam and chilled water pipe runs, and potentially easier removal and replacement of large bulky items such as motors, coils, and fan assemblies. It is also perceived that locating intakes further from the exhaust stack discharge reduces the possibility of entrainment of fumes. The disadvantages of a low intake include higher filter load due to traffic and lawn mowing. Several buildings with low intakes require more frequent filter changes when salt and sand are applied to the roads and parking lots. There is a higher concentration of exhaust fumes at ground level, and they are more noticeable in the buildings with low intakes. Perhaps the greatest disadvantage was cost, since significantly more basement area would be required to house the air handlers and associated duct. The site has many rock formations, and excavation carries a high contingency allowance.

Exhaust System

The exhaust system consists of six centrifugal exhaust fans, each with its own heat recovery coil and discharge stack (Figure 4). The fans are controlled with variable-frequency drives. Vertical exhaust ducts are run from each level at either end and from the center of the building to the penthouse. Here they connect to a large duct running the length of the penthouse and split to each exhaust fan. There is an isolation damper in each heat recovery unit to isolate each fan when it is not running.

The exhaust fans were sized so any five can handle the full building load. The rationale was that exhaust is more critical than supply, thus the spare fan. Why are there six exhaust fans and four supply air handlers? We tried to achieve some level of balance. Theoretically, we could have put three fans on one side and two on the other, but we were not confident of how well the system would balance out if a fan failed on the side that had only two fans.

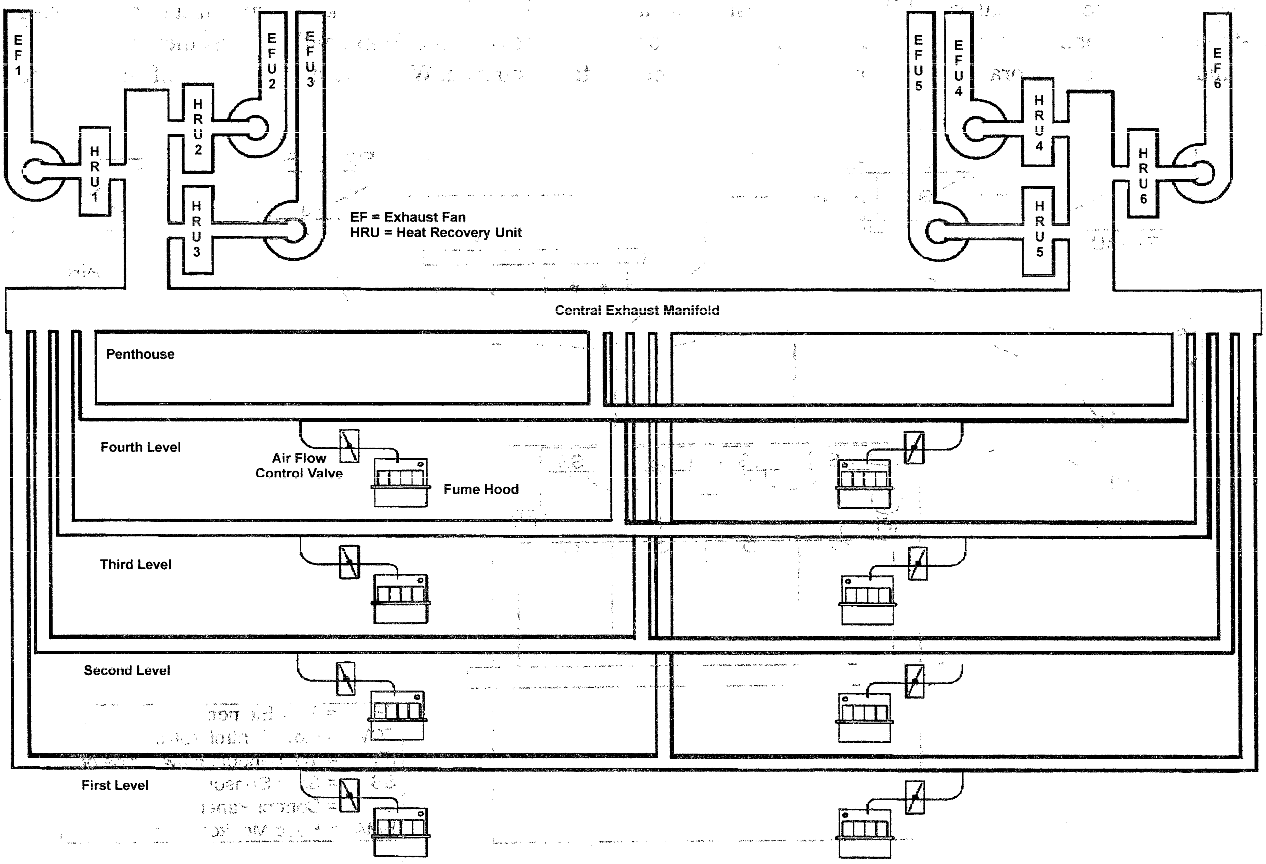

Figure 4 *Exhaust system diagram.*

Each fan has its own stack. The stacks are necked down at the discharge to increase exit velocity. For protection during extended outages, the ductwork to each stack has an internal dam and a drain to control rainwater and prevent it from running back to the fan. During normal operation, the exit velocity is sufficient to prevent rainwater entry.

Two exhaust fans are connected to the standby electrical supply to keep the hoods negative and provide a minimum exhaust flow during electrical outages. This should not be done on an individual exhaust arrangement unless done on all fans to prevent backflow through idle hoods.

Designing flexibility into a central arrangement in conjunction with administrative control can minimize the need for spare capacity. As noted earlier, five of the six exhaust fans will maintain adequate flow assuming 75% diversity. Four fans will maintain adequate flow at about 30% diversity. Although this would undoubtedly be an inconvenience to the occupants, they could continue their research safely as long as they kept two of the three hoods in the low-flow position until the fan was repaired. Compare this to an individual arrangement or a facility that had several smaller central arrangements that were not cross-connected. Unless there was a one-to-one redundancy, when a fan went down, the researchers would not be able to safely use the hood or hoods connected to it.

Controls

Because of the potential variability of exhaust flow, a well-thought-out control system and sequence is necessary for a safe and comfortable laboratory environment (Figure 5). The air volume is controlled at the laboratory level, while pressure control and fan sequencing are controlled at the system level.

Hood exhaust is controlled at two flow levels. When the sash aggregate opening is between 0% and 20%, the hood is at low flow. When the sash aggregate opening is 20% to 50%, the hood is at normal flow. The system alarms when the aggregate opening is greater than 50%. The determining factor for low flow is minimum comfort ventilation. Normal airflow is based on the minimum desired face velocity. The hoods are 12 ft wide and have four vertical sashes. During programming, the researchers agreed that they would not need aggregate openings greater than 50% except for an occasional setup. The supply air tracks the exhaust air. Each laboratory is balanced to draw approximately 800 cfm from the adjacent offices. There are five airflow sensors and control valves per laboratory: one for the supply air, one for each of the three fume hoods, and one for the weigh station. The flow control valves respond to the signal from the flow sensor and are pressure independent.

The system airflow is the sum of the individual hood and weigh station airflows. There is no overall system control for flow. The negative pressure in the exhaust manifolds from each level is monitored, and the exhaust fan speeds are changed in unison to maintain the desired set point of the lowest reading. Each exhaust fan has an airflow monitoring station in its inlet. This reading is used to determine stack exit velocity. When the stack velocity of any of the on-line fans falls below 3100 ft/min and remains there for five minutes, a fan is stopped. When the stack velocity of any of the fans goes

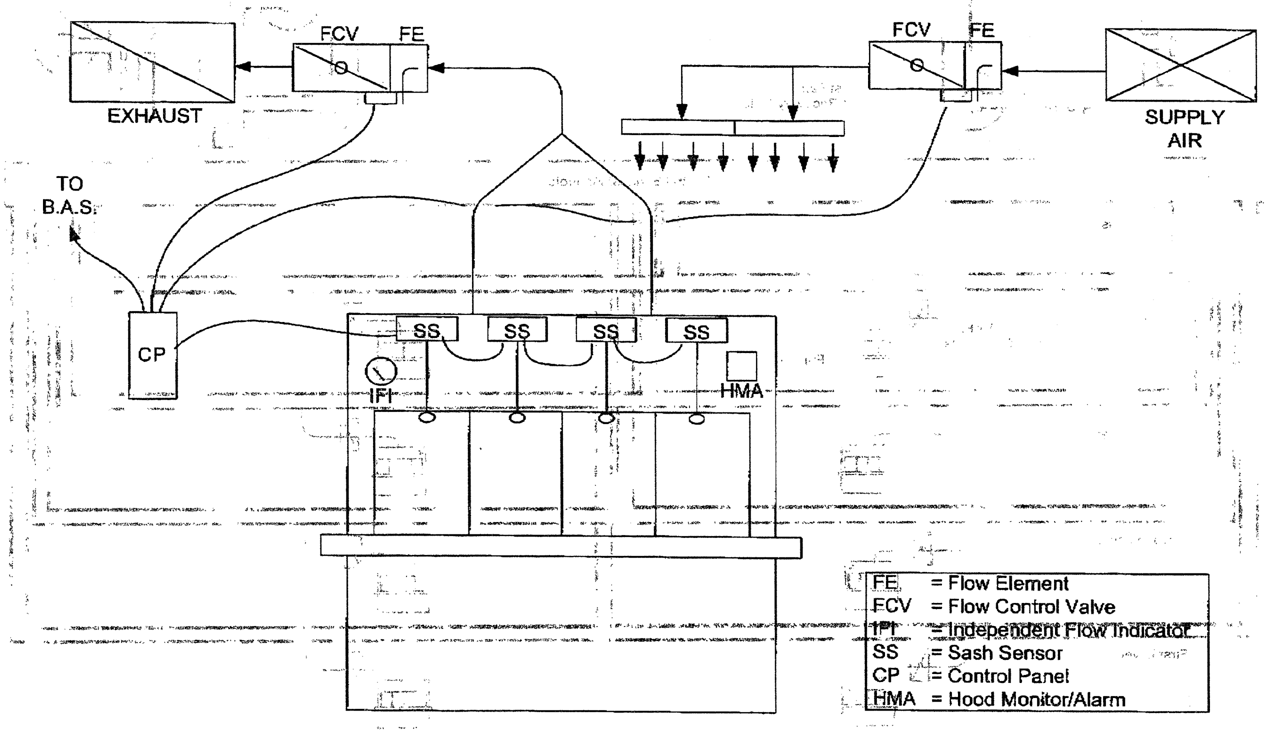

Figure 5 *Typical fume hood control.*

above 3600 ft/min and remains there for five minutes, another fan is started. When either happens, the on-line fans will change speed to maintain desired negative static pressure.

One of the drawbacks of an individual exhaust arrangement is maintaining a minimum exit velocity at minimum flow. A minimum exit velocity of 3000 ft/min is recommended

COMMISSIONING

Commissioning is important to verify that the facility operates in accordance with the intended design. It is more than the normal test-adjust-balance of the air systems or the verification of hood containment and face velocity. It is particularly critical for a central arrangement since improper operation affects all hoods. A deficiency may be difficult to correct without significant disruption once the facility is occupied. Unfortunately, commissioning takes place toward the end of a project when it is behind schedule and over budget. The temptation is to take shortcuts or eliminate it entirely.

We recognized the importance of proper commissioning for this facility because of the complexity of the control sequences. Although the airflows within each lab cycled correctly as the sashes were raised and lowered and the areas were kept comfortable, we felt that did not prove all controls sequences were functioning correctly.

Commissioning the exhaust system consisted of feeding false signals to the controls to simulate different temperatures, flows, and pressures, then observing how the equipment reacted vs. the design control sequence. The benefits were well worth the additional effort. As an example, we discovered errors in the algorithm that converted exhaust fan flow rate to stack velocity. They were simple algebraic errors. One was the wrong conversion factor and the other was a flipped fraction, which resulted in a decreased indicated stack velocity as the flow increased. These probably would never have been discovered over years of normal operation. It gave us the opportunity to experience design parameters such as programmed time delays and decide if they were reasonable. We also found the more typical deficiencies, such as sticking dampers and sensors requiring calibration.

CONCLUSION

There are several factors that influence the choice between individual and central exhaust arrangements. For many years, individual arrangements were preferred, but with the advent of larger facilities and better controls, it is becoming easier to maximize the benefits of central systems. The arrangement should be decided on early in the planning of a facility since each type is sufficiently unique to have a major impact on building layout.

Even after the basic arrangement is determined, there are variations that may be more suitable for specific applications. It is important to have a good understanding of how the researchers will use the facility and include them in the planning. This may dictate the arrangement of specific systems and will be helpful in predicting a reasonable diversity factor.

Use common sense when sizing duct and equipment. Flexibility may be more important than excess capacity in a central arrangement since capacity shortfall may be managed administratively to minimize impact.

Look for energy recovery opportunity. Because laboratories use once-through air, they are high energy consumers. Central arrangements simplify energy recovery.

Commissioning is an essential part of a successful project and is especially critical for central systems. A poorly commissioned facility will cost more in the long run from high energy use, safety incidents, and work disruption of an occupied facility.

Regardless of the arrangement, the safety of the occupants is the prime concern.

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REFERENCE

ASHRAE. 1997. *1997 ASHRAE Handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.