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A discussion of laboratory ventilation design methodology and equipment

A Guide to Efficient Laboratory Ventilation

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It is fair to say that most people actively involved in the design or execution of laboratory ventilation systems—especially, the non-recirculating or 100 percent "fresh air" type required in laboratories handling potentially hazardous chemicals—are aware that the systems require a higher level of technology and experience than common recirculating systems. A significant number of fresh air systems installed today are not designed or executed by seasoned veterans, and unfortunately, many of these installations have failure reports associated with them.

In light of this reality, this article presents a number of recent and not-so-recent advances in state-of-the-art laboratory HVAC design that we uncovered during research for a pre-design study for a non-U.S. firm that is one of the world's largest corporations. It is our hope that the material contained in this article will be used as a reference guide and will motivate the reader to seek out additional information from the sources provided. After all, we all know that good engineering starts with knowing where to find good information.

Alternate design methodology

Since our client was a process-oriented company, they were particularly interested in having our study incorporate a narrative describing specific details of the methodology that should be used by the successful engineering firm. This methodology had to cover all required laboratory building engineering systems (mechanical, electrical, plumbing), and how it would be translated into the final design.

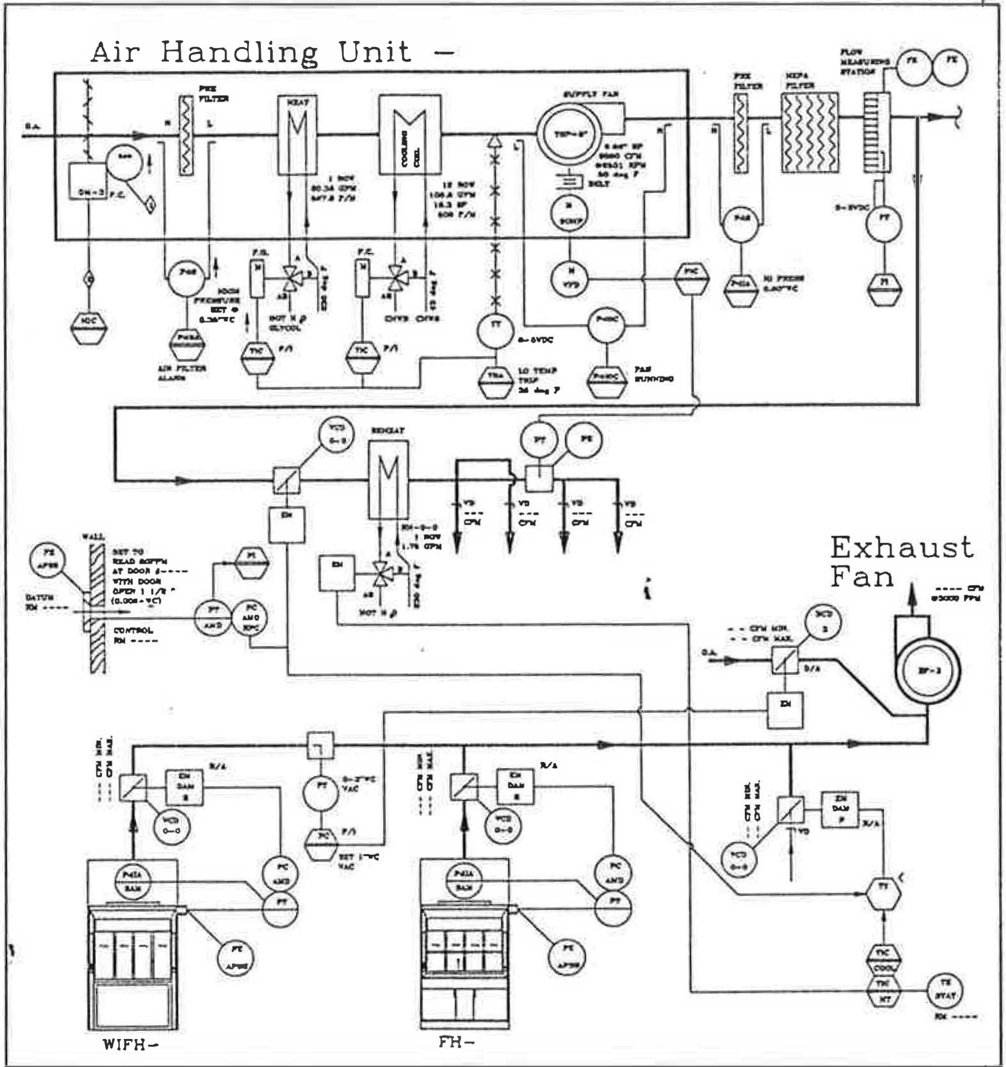
The client was surprised to learn that we were not planning to adopt the process approach (steps or functions required to produce a product) incorporating piping and instrumentation drawing (P&ID) documentation—the methodology commonly used in process industries to conceptualize systems design. However, they asked what alternatives we could recommend.

We pointed out that the majority of American engineering consultants with extensive chemical laboratory experience who would normally be deemed excellent candidates for consideration had little or no process experience, and therefore, did not routinely provide P&ID services. We explained that the traditional method used in this country be described as "reactive design." This approach could best be illustrated by the following comments directed to a client by a project engineer during a recent kick-off meeting on another project: "You must give us specific functional and technical criteria for all systems, such as energy conservation, redundancy, fuel type, and specific needs for each location in the building before we can even begin to think about starting our work." In essence, their conceptual design would respond only to the specific needs of the moment rather than be developed as a living process that could be refined throughout the design exercise.

Our client directed us to seek out only those engineering firms with process and P&ID experience, and if any of those otherwise qualified engineering firms lacked that experience, they should be advised to add that capability to their team if they wish to be considered.

At this point, you are probably wondering what was behind the client's insistence that the process design approach and execution of P&ID documentation be utilized. "In every process," as stated by the Instrument Society of America (ISA), "there are steps or functions that must be measured and controlled in order to produce a quality product. Instrumentation is used to monitor and assist in the control of each process function. To develop a thorough understanding of how a process functions, it is essential to know which devices are included in the process system, how these devices are arranged, and where they are located."

In essence, each laboratory building engineering system, especially HVAC, is a process and should be conceptualized as such at the outset and constantly refined as additional information becomes available. Unfortunately, this is not the way these systems are routinely designed in America, where control packages are typically applied after the system design is completed. In fact, it is not unusual for vendors to provide engineers with this documentation as a proprietary "black box" with little detail other than perhaps a verbal "sequence of operation." Could this, in part, explain the number of HVAC process failures or IAQ difficulties experienced in recent years? At any rate, the client directed us to incorporate process and P&ID documentation throughout the design exercise.



1 This sample P&ID document illustrates the major elements typical of both laboratory supply air and fume hood exhaust systems. Note that the process control components are tagged using ISA standard symbology, and all valves, sensors, fans, filters, and hoods are clearly defined.
(Courtesy, Configuration Management Consultants, Chatham, N.J.)

P&ID documentation

"P&ID," as defined by ISA, "is a map of a process that provides an overall view of the process and the instrumentation in a standard format. Instrumentation diagrams identify each of the instruments in a process, their functions, and their relationship to the other components in the system." Since the completed P&ID provides an overview of each system and its components using standard symbology, flowline diagrams, and alpha/numeric tagging systems allowing for rapid and simplified identification of system and instrument functions, it can be used both during commissioning and in maintenance operations to help troubleshoot the system. In addition, this documentation will be necessary if the facility you are planning will be ISO 9000-certified.

ISA has developed a standard format and symbology for the preparation of P&ID that it refers to as "the language of instrumentation," which is now the conformance standard for ANSI and ISO. Today, the P&ID approach is routinely used by system control industries to identify system sequence of operation for the design of all engineering processes, including laboratory building engineering systems, with one exception—American HVAC systems.

We strongly recommend that anyone who is not acquainted with this design methodology contact ISA (Fig. 1).

Compact air handler

As the design process began in earnest, the engineer estimated that 250,000 cfm would be required to support all anticipated operations. He proposed that four identical custom air handler units in his design were connected to a common fresh air inlet plenum and supply air header to provide the required redundancy if one of the units went off-line. The suggested schematic layout with the units placed in tandem and occupying over 7500 sq ft drove the client to demand an alternative approach.

We suggested that the design

team investigate an approach incorporating the compact type of air handler that we had used on a previous project. One vendor responded to our inquiry by submitting a proposal to use two 130,000 cfm compact air handlers, each equipped with a unique fan motor mounting mechanism capable of supporting two fans and allowing one to be removed for service by rolling it out of the way with a minimum down time. The compact air handler has another unique feature that minimizes its size. Unlike traditional air handlers that force outside air into and through a long straight tunnel-like structure while passing through a series of filters and cooling coils, the compact configuration arranges the cooling coils and filters in a multi-directional array, perpendicular to the fans, making the unit more square and significantly smaller than conventional units without any reduction in operating efficiency.

It was determined that adapting the compact approach would reduce the space required to house the air handling equipment package by as much as 60 percent—a very significant factor since the client had mandated that all mechanical equipment be housed inside the building envelop. In addition, using two units instead of four reduced energy consumption and maintenance costs (Fig. 2).

HOPEC fume hood

The fume hood is viewed by most engineers and facility managers as an "energy hog" that drives up the operating costs of the typical laboratory facility. However, with rare exception, this view is not supported by the facts. In light of the current regulatory environment, more often than not it is the air change rate established by the facility's industrial hygiene or safety professional to dilute pollutants in the air or to dissipate heat generated by laboratory equipment that drives energy consumption in a typical laboratory facility, not the fume hood.

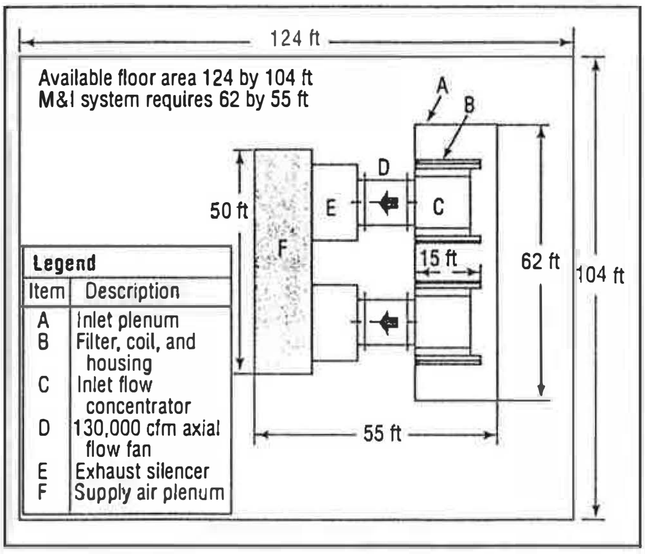
Three options were available to the design team to keep the hood's energy consumption below the other two factors:

- Minimize the hood population
- Minimize hood size
- Minimize hood exhaust capacity without adversely affecting its performance.

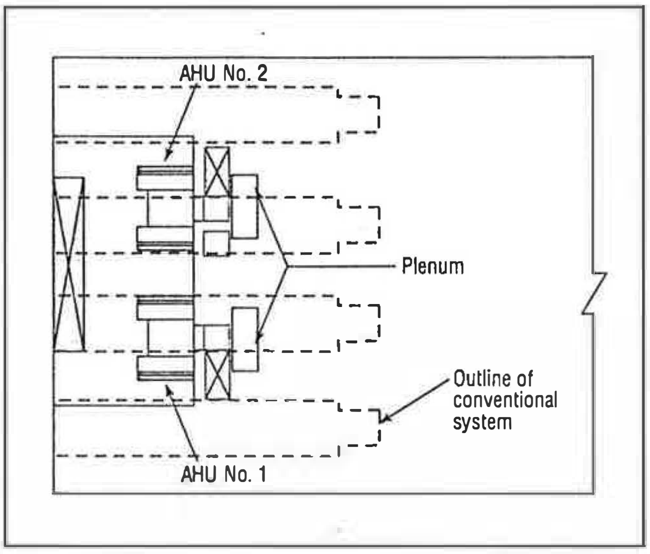
While all are technically viable, only the third option has gained wide acceptance because its adoption will not adversely affect laboratory operations.

Today, most fume hood manufacturers produce a unit that is capable of operating effectively with 50 percent less exhaust air than a traditional hood by simply incorporating a combination horizontal/vertical sash. The concept of using the sash to minimize hood exhaust demand is called "Hand-Operated Positive Energy Control" (HOPEC). In addition to its energy efficiency, recent testing utilizing the current ASHRAE 110-1995 test protocol indicates that its containment performance is the highest of all hood types tested.

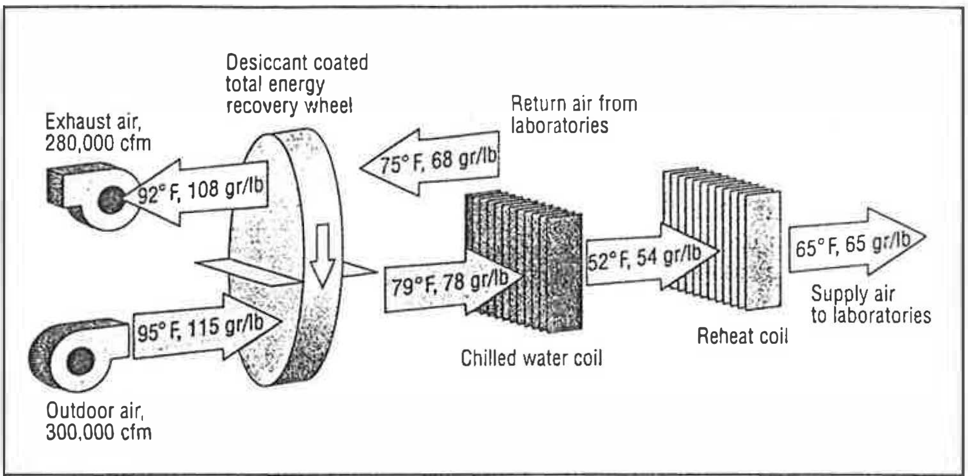
If the fume hood is connected to an integrated, building-wide exhaust system and its exhaust requirements are less than the other two factors, then it is clear that the hood demand is not the culprit. In fact, since it is part of the building exhaust system, one can rationalize that there is no direct energy cost related to the hood operation. In essence, the key to a successful design is to determine which criteria is greatest: hood exhaust requirement,



2A Dimensioned layout of the proposed 260,000 cfm compact air handling unit including component legend. (Courtesy, M&I Air Systems Engineering Ltd., Mississauga, Ontario, Canada)



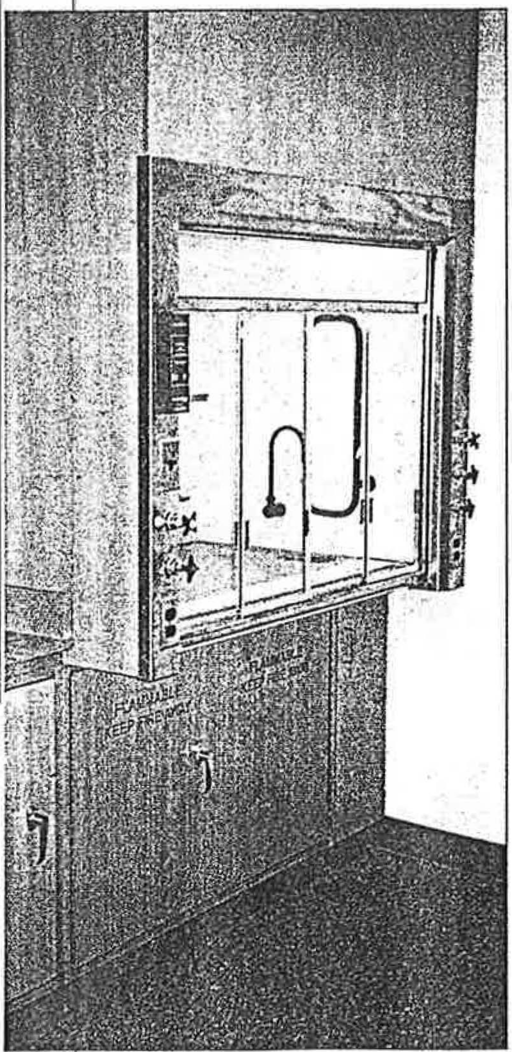
2B Overlay drawing illustrating the two design options being considered; (4) 125,000 cfm traditional air handlers vs. (2) 250,000 cfm compact air handlers. (Courtesy, M&I Air Systems Engineering Ltd., Mississauga, Ontario, Canada) air change rate, or heat dissipation volume. Once identified, this criterium becomes the ultimate driver for sizing the facility's HVAC system. The client directed the team to incorporate this hood type into the design (Fig. 3).



4A During the cooling season, 95 F outside air is tempered to 79 F and dehumidified when passing through the enthalpy wheel mechanism prior to its entry into the chilled water coils. (Courtesy, Semco Inc., Columbia, Mo.)

Enthalpy wheel

Heat wheel technology, an energy-saving device based on a rotating mechanism that captures heat from exhausted air and introduces it into the fresh air stream to temper the fresh air, has been around for many years. It has never enjoyed wide-spread acceptance among the mechanical engineering, safety, and industrial hygiene community for chemical and biological laboratory applications. Resistance to the approach has been focused on the concern that chemical and/or biological contaminants could be trapped in the "wheels" transfer medium, released into the fresh air stream, and eventually recycled back into occupied laboratory space—thereby exposing occupants without any warning. This process, called "cross contamination" is quantified in the *1996 ASHRAE Handbook: Systems and Equipment, 42.12*. Purging is also discussed in section 42, and by adding a purge sector in the recovery, wheel contamination can be reduced below 0.1 percent of the exhaust air stream concentration. Regardless, engineers should review specifications pertaining to codes and discuss the issue with company-safety personnel.



3 The HOPEC IV low-volume fume hood with wood exterior surface to match the adjacent casework.

In recent years, improvements to the transfer medium have made this type of device more acceptable to the design and health communities. One manufacturer has developed a fluted recovery wheel and coated it with a 3-Angstrom molecular sieve desiccant allowing only molecules smaller than 3 Angstroms in diameter to pass into the fresh air supply. This barrier effectively traps most pollutants and trace chemicals and minimizes the potential for their re-entrainment into the building.

By using a desiccant-based media, the unit has the added advantage of allowing moisture to be exchanged between the supply and exhaust air streams, thereby recovering latent energy during the cooling season. When it is in cooling mode, the desiccant unit pre-cools and dehumidifies the air; in the heating mode, it preheats and humidifies the air. Because the desiccant approach removes both sensible and latent load from the exhaust stream, the building's chiller capacity can be dramatically reduced. In a recent installation, the chiller size was reduced by more than 50 percent with an initial cost savings of over a million dollars. Overall operating costs were reduced to more than $500,000 less—compared to conventional solutions. The successful performance of the overall system drove the client's representative to observe that the air conditioning system does not know if it is summer or winter.

Another significant advantage in applying this approach is the

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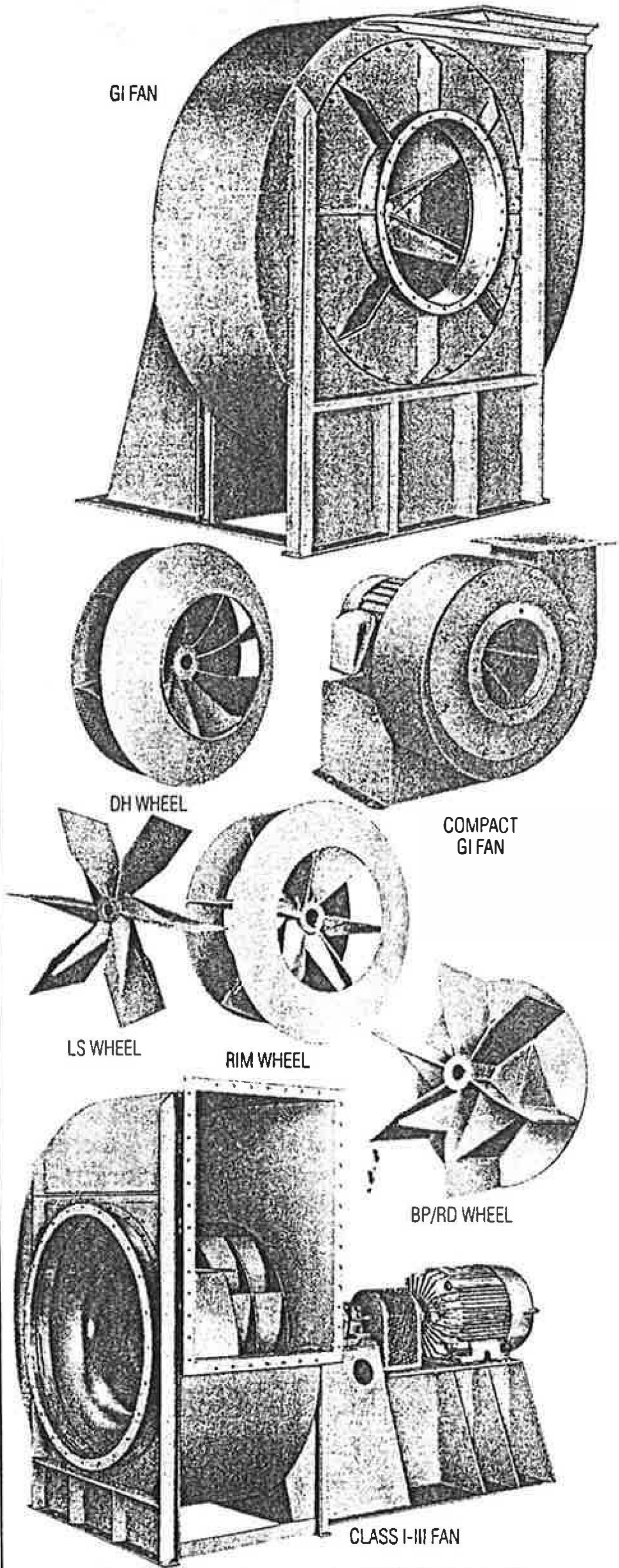

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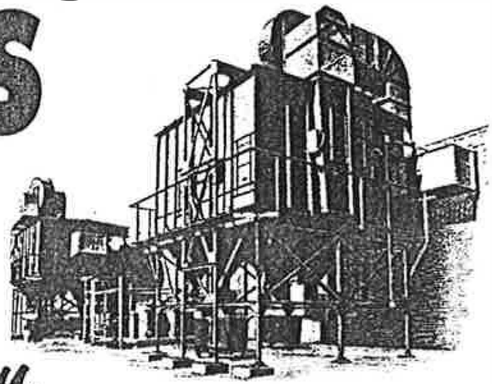
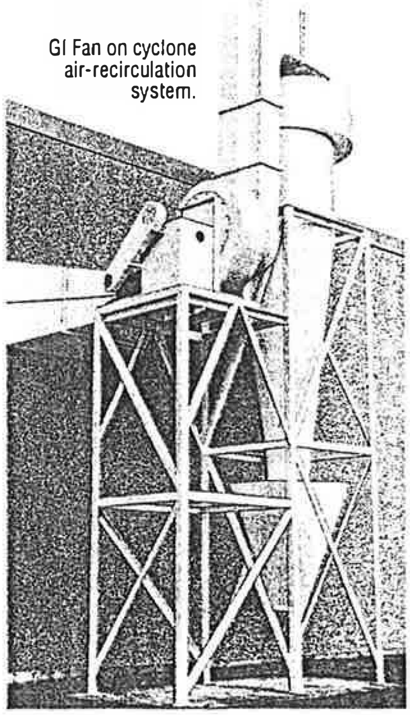
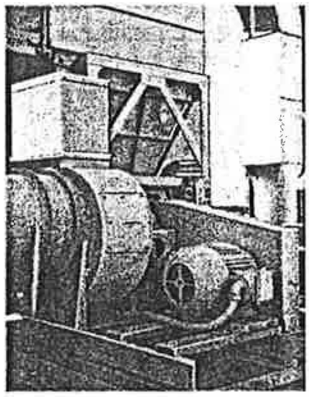
APPLICATIONS





GI Fan on cyclone air-recirculation system.



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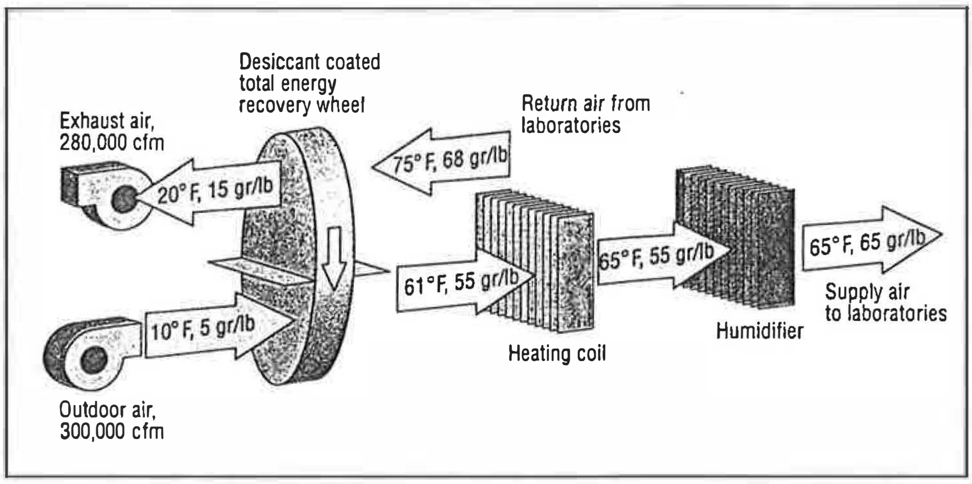

4B During the heating season 10 F outside air is heated to 61 F, and humidity is added when passing through the enthalpy wheel mechanism. (Courtesy, Semco Inc., Columbia, Mo.)

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elimination of expensive and cumbersome variable-air-volume (VAV) control packages. The desiccant approach allows the 100 percent fresh-air system to function as if it were a recirculated system (Fig. 4). For an energy and cost savings example using a generic recovery "wheel" diagram similar in Fig. 4, see accompanying sidebar.

Bi-furcated fan/exhaust stack assembly

Once it was decided that all laboratory air and fume hood exhaust systems, with the exception of those hood operations involving perchloric acid and radioisotopes, would be ganged together to a common exhaust system, attention turned to the selection of the exhaust fan. Of special concern to the client was that the design preclude the re-entrainment of contaminated exhaust air back into the laboratory and neighboring buildings. Compliance with NFPA 45 and ANSI Z9.5 were, of course, required. As part of that exercise, the following critical design issues were covered in depth: penthouse or open installation, stack height, exhaust-fume height and dispersion, exhaust tip velocity, belt vs. direct drive systems, and the use of a raw air bypass and roof-mounted plenum to allow the fan to operate at constant volume. In addition, both initial and operating costs, including energy and maintenance, were factored into the system-selection process.

Based on our analysis, we recommended a dual-modular, bi-furcated, or split-flow fan/exhaust stack assembly consisting of a direct-drive fan with a low-silhouetted, high-velocity exhaust nozzle and a self-contained mixing box or plenum. The direct-drive system was selected to avoid the regular inspection requirements of belt-driven systems for belt slippage, bearing noise, and lubrication leaks as well as the associated cost of maintenance. In addition, it was determined that the direct-drive system could reduce the overall system static pressure—thereby reducing energy cost.

In selecting the direct-drive system with its minimum inspection and maintenance requirement, we were able to rationalize the elimination of a conditioned penthouse to protect maintenance personnel. This decision permitted a reduction in the building's gross area and the costs associated with

"Molecular sieve" energy recovery wheels

An example of estimated savings using "molecular sieve" energy recovery wheels for a 100 percent fresh air makeup application for a laboratory located in northern Ohio, could be as follows:

Makeup of outside air (fresh) = 300,000 cfm

Exhaust air passing through recovery wheels = 280,000 cfm

Supply air to laboratory space:
cooling operation 55 F db and 54 F wb — Heating operation 65 F db & 53 F wb

Exhaust air to recovery wheels:
cooling operation 75 F db and 62.5 F wb — Heating operation 70 F db & 55.8 F wb

Laboratory operates on a 2 shifts per day, 7 days per week----Bin hours = 5847

Cost of energy: $0.10 per KWH and $0.40 per Therm

SUMMARY:

Estimated energy required without recovery:
Heating operation = 39.5 million Btus per annually
Cooling operation = 21.3 million Btus per annually
Total estimated operating cost annually for energy = $395,000

Estimated energy savings with recovery (includes purge sector in each wheel):
Heating operation = 34.2 million Btus per annually
Cooling operation = 3.3 million Btus per annually
Total estimated operating cost savings annually for energy = $160,000

its construction and operation.

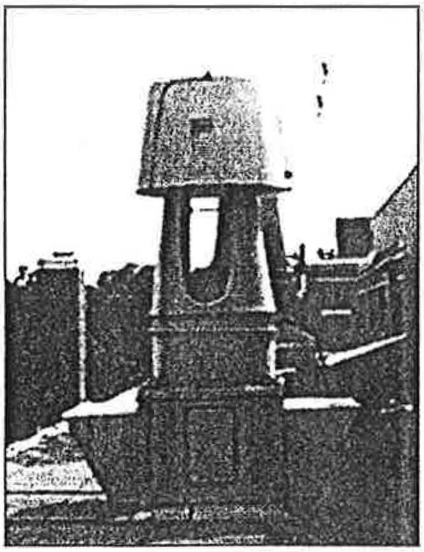
The split-flow, low-silhouette stack was selected when it was demonstrated that the configuration aspirated clean air into the exhaust stack through the motor chamber void area and diluted the contaminated air under the stack's shroud. This allowed the reduction of the stack height without compromising the primary design directive of avoiding re-entrainment of contaminated air. The low profile made the architect happy because he did not want the building looking like the Queen Mary crossing the meadow (Fig. 5).

Wind tunnel testing

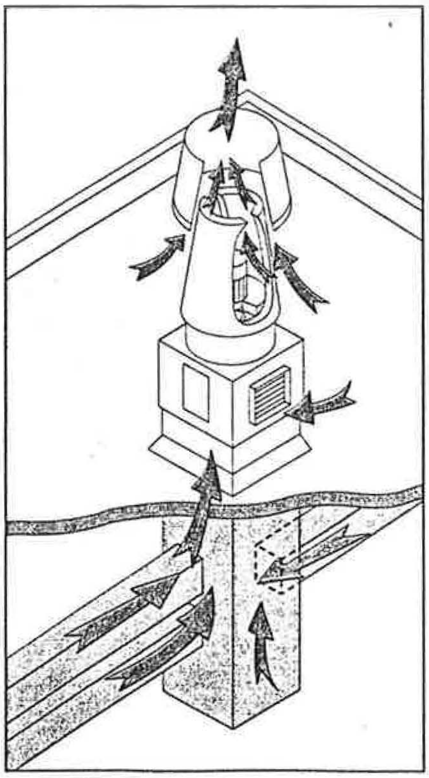
We recommended that once the building design was complete, the engineer should arrange for a wind tunnel test of the building to confirm that re-entrainment would not occur. The test incorporates both smoke visualization and site sensor technology to provide the necessary data. Our concern was based on two recent experiences in which the wind tunnel test revealed that the buildings would have failed in spite of the fact that all appropriate standards and guidelines were followed. In one case, the test demonstrated that the fresh air intake was too close to the idling diesel fuel-truck station, and the intake was too close to the diesel emergency generator exhaust stack.

Because of their unusual equipment requirements, there are only a few nationally recognized consultants who provide wind tunnel testing services. Preparing for a wind tunnel test requires that the design team compile a significant body of detailed information. The quality of this information will ultimately determine the reliability of the test results. The information requirements include:

- A detailed topographical plan of the site and surrounding area. The plan must show the location and size of neighboring buildings and provide information about their air supply and exhaust points.
- Emission source locations, flow parameters, and characteristics of diesel, process, and laboratory exhausts.
- Local meteorological data (annual, hourly averages).
- Architectural building drawings of sufficient detail to allow the testing consultant to construct a scale model.



5 The bi-furcated fan design allows fresh air to be aspirated into the contaminated air stream as well as through the stack shroud, thereby encapsulating the contaminated air in the exhaust plume and allowing the stack to be shortened.
(Courtesy, Strobic Air Corp., Bensalem, PA)



Conclusion

A client's demand that all aspects of the design be executed using an approach unusual to most members of the design team offered us the enviable opportunity to finally validate assumptions and criteria that we, as design professionals, routinely took for granted for years. The breaking of this design paradigm also created a climate that fostered the pursuance of innovative and efficient solutions to common problems. **HPAC**

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