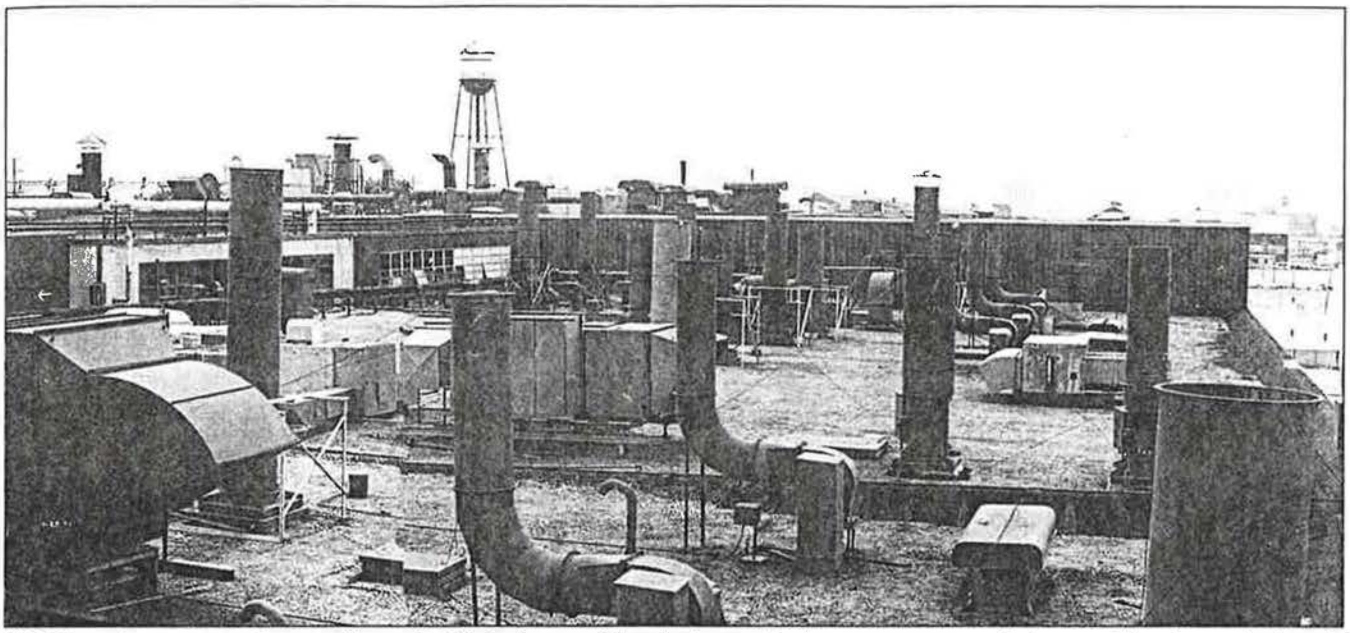

HVAC engineers are often confronted with 'a forest of fans' when asked to correct a ventilation problem for an industrial client.

The Basics of Industrial Ventilation Design

Proper ventilation design for the industrial client requires the correct application of ventilation principles, and overcoming the misconception of 'air changes'

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HVAC in the industrial environment assumes many roles from general ventilation to process related applications. Because of the variety of applications and the documentation available for the design of each, it is not the intent of this article to review each one. However, industrial clients often have misconceptions that lead to misapplications of ventilation design and equipment.

One of the more common misconceptions is that ventilation equipment should be sized based on volumetric air changes, regardless of the application. This article will review a generalized approach to ventilation calculations, the fallacy of air changes, and our role as HVAC engineers to provide the industrial client a properly applied ventilation design and thorough knowledge of its operational parameters.

Client Understanding

The industrial process and its related performance are priorities for the industrial client. Often, plant engineers are not as well versed in HVAC principles as HVAC design engineers, and their knowledge of HVAC equipment can be limited. The majority of their efforts are concentrated on production and its myriad of equipment and controls that provide the end product and profits for the facility.

As such, HVAC often receives minor consideration, after initial design, in a facility's operational plan. Even when an HVAC malfunction occurs, it is sometimes ignored and forgotten until it creates uncontrollable environments or catastrophic equipment destruction.

It is usually at the point of severe HVAC degradation that the HVAC design engineer is called to "fix" a problem, often involving some type of ventilation. Typical of such problems are persistent hot spots, uncontrollable humidity, or excessive negative pressure in a space. Regardless of the problem, however, one of the most asked questions to the HVAC design engineer is, "How many air changes will it take?"

To the astute HVAC design engineer, the problem may and usually will transcend this rather simplistic notion of air changes. The HVAC design engineer realizes that air changes are usually a result of the ventilation design. Plant engineers, however, commonly maintain the notion that air changes dictate the ventilation design. With two different views to the same problem, each view must be tempered by knowing when designing by air changes is appropriate and why in most cases it is not.

About the Author

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The concept of designing by air changes can probably be traced to the early days of mechanical ventilation. Fan energy was relatively inexpensive, few industrial plants were air conditioned, dilution ventilation was common, and workers were tolerant of less comfortable environments.

Furthermore, processes did not require the specialized exhaust and climate controls utilized in today's industrial environments. Current processes and energy costs require modern ventilation systems to be acutely tuned to the environment they are trying to maintain. Air changes cannot dictate air flow quantities for process exhaust, makeup, heat relief, humidity control, and other operations that modern ventilation systems are called upon to perform. Rather, air changes, in most cases, are simply a byproduct of a ventilation system's design.

Why the air change concept has managed to persist can probably be explained by the fact that it is an easy concept to understand. Basically, an air change is the volume of the space in question. The air change rate is the number of air changes per a given time period. The result is Cubic Feet per Minute (CFM) and one can easily size a fan or air handling unit for submittal to purchasing. Unfortunately, it's not quite that simple.

Load Calculations

Regardless of the HVAC system, it must begin from a load calculation. Sizing of most industrial HVAC systems will be dominated by the ventilation required for process exhaust/makeup, heat relief, and general ventilation. It is, therefore, the responsibility of the HVAC engineer to take an accounting of all process equipment within their associated spaces to determine specific required volumetric air flow rates.

This represents the first step for plant engineer interaction and his understanding of how air volumes are determined. The succeeding steps outline the calculations themselves and for ventilation purposes can be broken into four realms: 1) Process exhaust; 2) Heat relief; 3) General ventilation; and 4) Special Cases.

Process Exhaust

Process exhaust and its associated makeup air can range from the large quantities required by a paper machine to small quantities required of a grinding wheel. Regardless, total makeup air for exhaust in a given space will equal the sum of the parts. Modern industrial machinery requiring exhaust often comes equipped with integral pickups and stated design volumetric air flow rates.

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A complete liaison between the HVAC and plant engineer is essential to determine exhaust air based on the manufacturer's process requirements. Here, exhaust quantities are clearly directed by the process and air changes play no role. For machinery not providing pickups or desired volumetric air flow rates, it is incumbent upon the HVAC engineer to design pickups or hoods for fume or particle removal.

It is now generally accepted that close-capture exhaust systems offer the most efficient means of process exhaust. Apart from inhibiting contaminants to escape into the space, close-capture exhaust utilizes less air than dilution ventilation by depending on capture velocity rather than volumetric air flow rates. It is, therefore, velocity in a close-capture system that in turn determines the volumetric air flow rates required.

However, for close-capture exhaust to work effectively, it does depend on proper hood and pickup design. Two accepted design guides for determining process exhaust and its capture methods are the *1995 ASHRAE Handbook: HVAC Applications* and the American Conference of Governmental Industrial Hygienists' *Industrial Ventilation.* By following these guidelines for close capture exhaust, it is evident that the air change concept has no bearing on ventilation rates.

Heat Relief

Apart from general ventilation, heat relief is often required in a variety of separated spaces dedicated to specific equipment; i.e. electrical rooms, control rooms, and machine rooms. These spaces are often unoccupied and the primary criteria is to limit temperatures to protect the equipment. Environmental parameters vary with equipment and will determine the requirements for additional heating, cooling, pressurization, purge, and humidity control. Taken as a separate entity though, heat relief ventilation requires the removal of sensible heat via a temperature increase of volumetric air flow through a space. The standard-air sensible heat gain equation is:

$$CFM = BTUH/(1.08)(T_o - T_i)$$

where

BTUH = Internal Heat Gain

CFM = Volumetric Air Flow Rate, Cubic Feet per Minute

T_i = Entering Air Temperature to Space, Degrees Fahrenheit

T_o = Leaving Air Temperature from Space, Degrees Fahrenheit

Internal heat gain from equipment is best obtained from the plant engineer's or manufacturer's data. Here, an opportunity exists to include the plant engineer in an understanding of the ventilation rates and how they relate to his facility. Lacking definitive data, as often occurs, the HVAC engineer must then rely on catalogue data of similar equipment or a reliable estimate from the plant engineer most knowledgeable about the equipment in question. A reliable estimate of heat gain for motor driven machinery and miscellaneous equipment can be determined from the *1993 ASHRAE Handbook: Fundamentals.*

In determining internal heat gain from equipment, it is important to inventory all sources of heat. Along with motors, one must include lights, people, and radiant heat sources such as electrical

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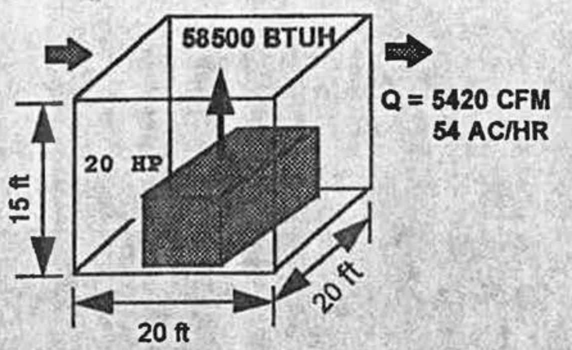

Fig 1. Ventilation and air change rate determined by internal sensible heat gain.

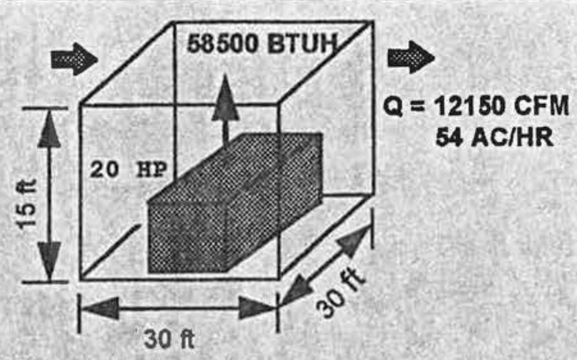

Fig 2. Excessive ventilation rate created by allowing air changes to dictate flow.

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gear, steam piping, kilns, and drying ovens. The placement of such equipment in the space should be noted as to its effect on the ventilation load.

In large ventilation systems, heat gain from system fans and motors themselves can be significant and must be included in the sensible heat gain equation. This is particularly true for makeup air units where the entering airstream temperature (T_i) will experience an immediate rise from fan heat.

One of the most challenging and subjective decisions will be the application of diversity factors toward the heat gain equation. While much of the equipment operates 100% of the time, there can be a significant amount that operates on intermittent or part-load duty. Lights, for example, will probably have no diversity whereas conveyor motors may operate only 50% of the time.

Because of the different operating characteristics, it is recommended that individual diversity factors be applied to component heat gains rather than applying a universal diversity factor to the overall heat gain equation. It bodes well for the HVAC design engineer to closely determine and document realistic diversity factors with the plant engineer before calculating the ultimate simultaneous heat gain to a space.

When utilizing the sensible heat equation, the most difficult part becomes the determination of the correct temperature differential. The upper limit (T_o) is determined by the temperature limitations of the protected equipment. For motors and electrical equipment, the upper temperature usually required by manufacturers is 104°F (40°C).

The difficulty lies in choosing the lower temperature since it is set by outdoor design ambient conditions. In many locales, ambient design temperatures approach or exceed the upper temperature limit requiring inordinately high volumetric air flow rates or providing no heat transfer at all. In such cases, an evaluation should determine if refrigerated cooling of the air is required or if the equipment itself can be water cooled. However, as a rule of thumb, a 10°F (-12°C) temperature rise is an adequate minimum for most cases allowing for an entering ambient temperature of 94°F (34°C). If larger temperature differentials are feasible, they should be used to decrease CFM and consequently decrease the size of the ventilation equipment.

When utilizing the sensible heat equation, the most difficult part becomes the determination of the correct temperature differential. The difficulty lies in choosing the lower temperature since it is set by outdoor design ambient conditions.

In the case of heat relief, air changes once again have no bearing on determining required volumetric air flow rates for a given space. Consider a 20ft by 20ft by 15ft (6.1m by 6.1m by 4.6m) space housing a 20 HP (196 kW) motor with machinery as illustrated in *Figure 1*.

Using the ASHRAE estimate for motor heat gain and the sensible heat equation, an air flow of 5420 CFM (2 547 L/s) is required using a 10°F (12°C) temperature differential. The result is an air change rate of 54 AC/HR.

In *Figure 2*, the space increases to 30ft by 30ft by 15ft (9.1m by 9.1m by 4.6m) while maintaining an air change rate of 54 AC/HR.

By allowing the air change rate to dictate air flow, based on *Figure 1*, the ventilation rate increases to 12150 CFM (5 711 L/s) for the same 20 HP (196kW) motor.

The space in *Figure 2* now receives 225% of the required heat relief ventilation rate. The result is oversized ventilation equipment mismatched to the actual heat relief requirements of the space.

Therefore, air change rates must be dependent on the heat load and not conversely as the air change concept would have us believe. The converse would be true for reducing a space's volume.

It is true that skin loads are affected by modifying a space's dimensions, but they are often minimal compared to the sensible load of the enclosed equipment.

Nonetheless, skin loads must be determined and included in the sensible heat equation. An air temperature rise through the space implies an internal temperature greater than the external temperature whereby a slight cooling effect may be realized through skin conduction.

However, skin cooling will largely be offset by solar gain in cases of areas exposed to the sun. Regardless, air changes play no part in the sensible heat calculation.

Special Cases

There are always exceptions. Special cases do exist where air change rates are utilized to determine volumetric air flow rates.

One common case requires room purge cycles where gases may be present and evacuation is required over a period of time. Another case requires continuous pressurization of a room to prevent contaminants from entering. Such are control rooms found in highly corrosive atmospheres common to paper mills.

Usually, these areas are isolated and treated as individual entities. In these special cases, experimentation and practice have established workable air change rates.

General Ventilation

General ventilation requirements are the final leg of the load calculations. General ventilation can be regarded as ventilation required to maintain a minimum health level of fresh air in a facility.

The word "fresh" must be used with some caution as it is a relative term. There is little "fresh air" to be found in the vicinity of a paper mill, for example.

Nonetheless, general ventilation must be provided and its determination involves a two-step approach. The first step is to determine minimum required ventilation as set by governing codes and standards, or standard industry practice. The second step is to determine if the required minimum ventilation rates will be provided by volumetric air flow rates for exhaust makeup and heat relief.

To determine the minimum ventilation rates, the design engineer must first seek out the governing codes. Codes may range from city codes to state codes to OSHA, but as these are ordinances, they must be adhered to.

The problem is that codes can be quite ambiguous. In many cases they tend to lean more toward office environments than factory enclosures. However, the plant engineer is usually in the best position to assist the HVAC design engineer, as he is more knowledgeable about the officials who oversee his facility and administrate the governing codes. In industry, the insurance carrier will often dictate minimum safety requirements as well.

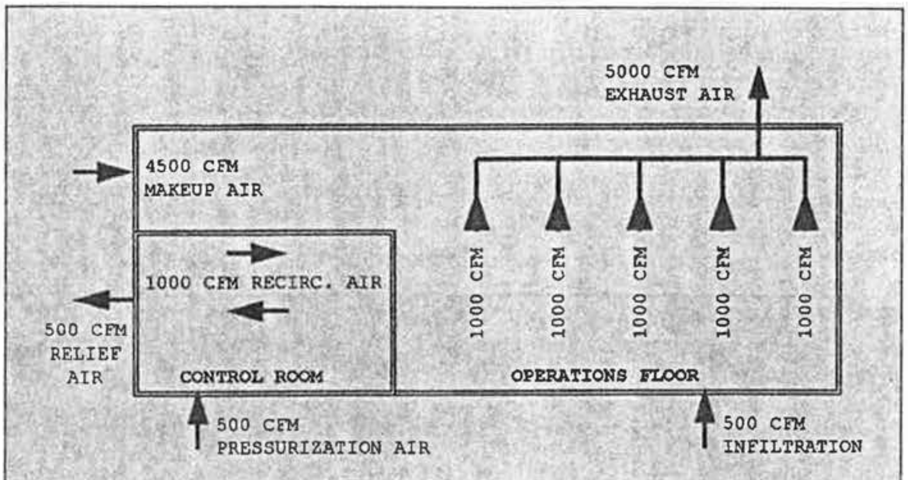

Fig 3. Typical Air Balance Diagram

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>
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In the event that a code search should fail to throw any light on ventilation rates, *1995 ASHRAE Handbook: HVAC Applications, ASHRAE Standard 62-89 Ventilation for Indoor Air Quality,* and *ASHRAE Standards 55-92-Thermal Environmental Conditions for Human Occupancy* offer ventilation guidelines for a variety of industrial applications. Moving one step further, specific industries typically publish periodicals and guidelines that can provide an excellent source of accepted ventilation rates.

Regardless of the source, however, the HVAC and plant engineer should understand that minimum industrial ventilation rates are determined largely by empirical data and experience. It is here that we come close to an air change concept, but even so, air changes are a result of experimentation rather than a determinant to it.

Having determined the minimum ventilation rate required, it is then a matter of comparing these rates with the rates required for exhaust makeup and heat relief.

If minimum general ventilation rates are met or exceeded, then general ventilation is simply a by-product of the process. If not, additional measures must be designed to achieve minimum ventilation rates.

However, pitfalls exist. Process exhaust makeup may not operate full time at 100%. The HVAC and plant engineers must determine minimum process exhaust operating at any given time.

Additionally, fans for heat relief may not operate in winter, diminishing their utility towards general ventilation. Further, zoning of smaller individual systems may or may not have an effect on an area's general ventilation.

Maintaining positive or negative pressure in a space can also have a huge effect on ventilation rates. All scenarios must be accounted for by the HVAC engineer and conveyed to the plant engineer. It is said, "a picture is worth a thousand words," and here, an air balance diagram is of considerable importance.

An air balance diagram not only assists in tracking ventilation across zones and related equipment, but provides the plant engineer with an overall understanding of his ventilation system. A simplified air balance diagram is illustrated in *Figure 3*.

Conclusion

With increased understanding of the principles behind a properly designed ventilation system, the plant engineer will increase his understanding of what his ventilation systems are trying to accomplish.

Increased understanding is dependent upon the HVAC engineer to impress that ventilation design expands far beyond the simplified concept of air changes.

To do so, the HVAC engineer must demonstrate that ventilation is an integral part of a facility's operations and not an adjunct system.

Finally, the plant engineer must accept that ventilation and HVAC systems do perform a vital service in providing improved production, and above all, improved safety and comfort for the employees.

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