Indoor air pollution

Indoor air pollution is a continuing concern; simple, stable, and moisture-free HVAC systems can eliminate the "stuffy building syndrome"

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People always become ill in buildings;[1,2] however, due to the rising cost of energy, the problem has become almost epidemic.[1,3,4,5,6,7,8,9,10] News services across the country have actually given this problem a name: "stuffy building syndrome." Recent studies have shown that indoor air is frequently more contaminated than outdoor air, and with the advent of energy conservation, it seems that indoor air quality has become worse. Since people spend 80 to 90 percent of their time indoors, this contamination is bound to create health problems.[1,2,11,12]

Indoor air quality and energy conservation are not conflicting goals. Recent field studies of over 55 buildings, coupled with system laboratory work, determined that in each case the cause of either organic or inorganic contamination could be traced back to a poorly maintained, poorly designed, or poorly supplied mechanical system.

Table 1—Three basic building types.

Speculative	
Office buildings	Hospitals
Schools	Health care
University classrooms	Food processing
Institutional	
Hospitals	Laboratories
Health care	
Industrial	
Production facilities	Pharmaceutical
Research and development	Food processing

To study the problem, one first must define the building type. The three basic building types are described in Table 1. From Table 1, some types of buildings appear under the speculative (very commercial) type as well as the institutional (commercial) category or the industrial classification. The reason is purely financial depending on how it was built. There is no direct clear-cut method in defining a building as commercial, institutional, or industrial. One method is to ask the building operator or the consulting engineer what type of air handling unit was supplied. There are basically two types:

- Built-up air handling systems have units normally located inside buildings in a mechanical room. These take up floor space that could bring in revenue.
- Rooftop air handling systems have units normally located outdoors on top of buildings. These occupy no interior space so maximum floor space is utilized for revenue.

Any structure that utilizes rooftop units most probably was designed and built with economics as the governing factor.[21] Unfortunately, buildings that utilize either design can become unhealthy. However, built-up air handling units most likely can be corrected after the health problem source has been defined.

Built-up air handling systems

[1]*Superscripts refer to references at end of article.*

normally cost considerably more because they utilize backward inclined or vane axial rotary air moving equipment. These mechanical systems seem to have a greater dynamic stability and air volume turndown capability. Again, this does not guarantee that the building will operate safely.

In a study done by the Energy Systems Division of the Construction Engineering Research Laboratory (CERL), entitled "Theory Meets Practice in a Full-Scale Heating, Ventilating, and Air-Conditioning Laboratory," the following observations and conclusions were reported:

> Apparently, these relatively complex (HVAC) control systems of the type tested are difficult to maintain. While these systems can theoretically improve system efficiency, poor performance and failure of control system components suggest that the theoretical improvements may be difficult to achieve in the field.
>
> The measured performance of many of the HVAC system components tested did not meet the manufacturer's specifications as delivered. For much of the equipment, efficient performance was achieved only after field adjustment.
>
> Many, if not all, of the problems detected by the heavily instrumented HVAC system experiments would be undetected in a field application where there is little or no instrumentation.[17]

The inability to detect nonfunctioning instruments and equipment becomes a primary reason why the investigator, even with the consulting engineer's assistance, often cannot determine the problem. The usual answer is "the building was built according to the engineer's design and specifications." Consequently, it is now up to the investigator to determine why the facility does not work even though it meets guidelines.[16]

Distribution systems

The investigation begins by determining how the building was built and then asking what type of system control strategy for air distribution was used. There are two basic types of air distribution systems:

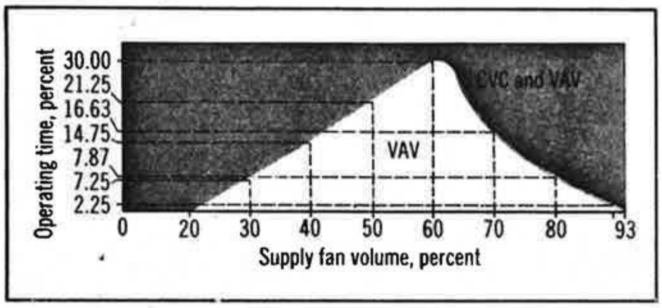
- Constant air volume (CVC).
- Variable air volume (VAV).

Constant air volume systems were probably the most widely used of the two until the energy "crunch" of the mid-70s. These systems supplied a constant volume of air and varied the temperature according to space conditions. After using this method for decades, engineers discovered that total building space never really had to be heated because the construction methods, number of lights, and number of people occupying the building space could have heated the structure on its own. In fact, engineers should have cooled the air even in the winter. This fact, and the energy "crunch," led to the acceptance of the variable air volume system. In this system, temperature is normally held constant (55 to 60 F), and volume is varied into the space to maintain temperate conditions.

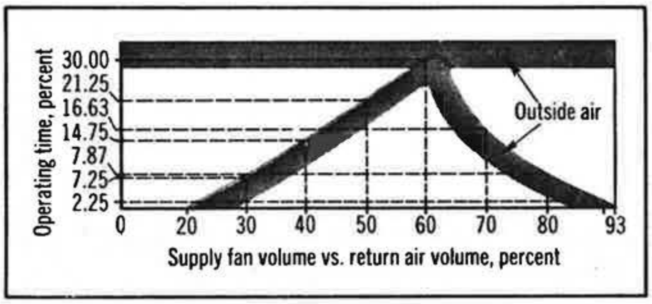
Fig. 1 illustrates the difference in the amount of air volume handled by the supply fans between CVC and VAV systems. Fig. 2 indicates the amount of outside air either system introduces into the building. Generally, the amount of outside air introduced is equal in either system.[22,23] The amount of outside air a building requires depends on the minimum required for occupancy; the loss due to exhaust fans such as lab hoods, toilet exhaust, and kitchen exhaust; and the elimination of infiltration of untreated air. Table 2 illustrates how expensive it is to maintain adequate outside air levels.

In most cases because of the energy cost, the outside damper is set at a minimum position to provide outside air. Many operators and engineers suggest strategies such as free cooling where they exhaust all the building air and replace it with outside air.[1,13,16,20] This strategy is great in theory except that frequent HVAC system equipment failure as indicated in the CERL report makes it an unreliable strategy. If the outside air damper and the exhaust damper change positions when 100 percent outside air comes in, and this occurs on either the coldest day of the year when the heating coils are frozen and then burst or the hottest and most humid day of the year when the air conditioning system is on overload, then the strategy of free cooling (enthalpy control) is disabled forever.

When asking questions of the operating engineer, the investigator should ask about the enthalpy control strategy and if it is actually utilized. The subject of possible coil damage should be discussed. The building operator may be quite candid and admit that this portion of the system is basically disconnected. This means that the outside air is always set at minimum conditions.[24]



1 Difference in the amount of air volume handled by the supply fans between a CVC and VAV system.



2 Amount of outside air introduced by a VAV or CVC system.

Common indoor pollutants

Asbestos—a known carcinogen (acoustical tiles, air duct or pipe insulation).
Carbon dioxide—from people.
Carbon monoxide—from parking garages, hot water heaters, boilers, etc.
Consumer products—plastics, paints, solvents, artificial fibers, cleaners, bleaches, disinfectants, deodorizers, and other substances all emit air contaminants either through evaporation or "out gassing."
Formaldehyde—used as a sealant in furniture, fire retardants, foam insulation, coatings on paper, and numerous other building materials.
Methanol—from duplicating machines.
Nitropyrenes—found in one type of photocopier toner (in March 1980, the formula was changed to reduce the nitropyrene content significantly).
Ozone—emitted from photocopy machines.
Polychlorinated biphenyls (PCBs)—from waterproof adhesives, carbonless paper, and various plastics.
Radon—found in building materials derived from soil and rock (a particular problem in the Denver, Colorado area).
Trichloroethylene (TCE)—found in correction fluids and attributed to at least four deaths.
Trinitrofluorenone (TNF)—found in copy machines.
Vinyl chloride—a known carcinogen and found in most plastics; it is also known to cause ulcers and chronic bronchitis.

The discussion so far has only looked at supplied mechanical systems. Once it has been determined how the building was supposed to operate and the quality of the equipment installed, the next step is to determine the type of irritant that is causing discomfort to the occupants.[24] Irritants can be classified as organic and inorganic in nature. Some of the more common indoor pollutants are described in the accompanying sidebar.

Table 2—Representative costs to process 1 cfm of air in various areas for a fan operating for 6240 hr per yr. Fan discharge of 5 in. WG and system (duct) static of 1 in. WG at terminal devices were used as average values in calculating cfm costs.*

Area	Cost per cfm, $
New York, NY	2.97
Washington, DC	2.12
Chicago, IL	2.81
Atlanta, GA	2.01
Boston, MA	3.91
Los Angeles, CA	1.75
Houston, TX	1.87
Denver, CO	3.16
Seattle, WA	3.04

*Costs are based on last quarter, 1981 power rates for indicated area.

Building pressures

The air quality in many of the buildings studied was worse than in some of the world's smoggiest cities.[1,26] One report described the quality of air in some buildings as "like everybody in the building taking a bath in the same water without ever changing it."[1,26] If the building ventilation system operates properly, *i.e.*, as designed, enough outside air should be introduced so that a negative vacuum pressure condition does not exist. One of the most important steps in investigating a problem in the building is to measure the general space pressure vs. the outdoor pressure.

Except for the very few strategically designed containment facilities, a building that runs negative to the outside is "an accident waiting to happen."[27,28,29,30,31] Most buildings that have ever been designed in this country should have been designed to be positive pressure.[2] This means that the buildings should have an internal pressure of 0.02 to 0.03 in. WG greater than the outdoors. This is equivalent to a 6 to 8 mph wind.[2] Unfortunately, few buildings operate this way. This is the most important sign to investigators that there is a potential health hazard in the building, and it is directly pinpointed to the air handling system.[7,15,31,32,33] Table 3 is a partial list of the hazards involved in a building that is running negative.

Any building that is running negative pressure is obviously deficient in the proper amount of outside air.[2,15] Buildings that run this way and are involved with a laboratory situation with hoods can never be balanced correctly, nor can they operate effectively. The first trap that the investigator will find is that engineers will say that the negative pressure of the building is caused by "stack effect." The ASHRAE *Handbook of Fundamentals, 1981*, on the subject of stack effect states:

> This chapter focuses on envelope and shell dominated buildings such as residence or small commercial buildings in which the energy load is determined by the construction performance of the building envelope. The physical principles discussed herein also apply to large buildings. With large buildings, however, ventilation energy load and indoor air quality conditions depend more on the ventilation system's design than on the performance of the building envelope.[66]

Many buildings, or portions of buildings, operate at a negative pressure to the outdoors even though air supply systems were designed to maintain a positive pressure. This may be due to the often mentioned "stack effect." However, it often is due to (or aggravated by) the fact that the return air fan sends back more air than the supply fan delivers.

Fig. 3 shows how an air handling unit should operate. Outdoor air and return air are mixed according to a desired ratio and delivered to the conditioned space by the supply air system. Return air, minus toilet and other local exhaust, is returned to the air handling unit. A desired amount is exhausted to the outdoors, and the balance is drawn to the supply air fan. If proper pressure control can be maintained in the building, infiltration of outdoor air through the building skin and building openings is minimized.

The same air handling equipment is used for constant air volume systems or variable air volume systems. Fig. 3 shows an optional return fan. For smaller buildings, relief openings are sometimes used instead of a return air fan. Also, sometimes the return air fan is eliminated and a relief air fan is used to handle the building exhaust air.

The following discussion describes an air handling unit applied to a constant volume system.

Constant volume systems

A constant volume system is set up by a balancing contractor who adjusts the supply fan and the return fan so that a minimum amount of outside air comes into the building plus whatever extra is required to make it slightly positive. There is nothing constant about a mechanical fan. The following list includes some of the things that can change air volume from time to time:

- Bearing wear,
- Belt wear,
- Voltage fluctuations (brownouts),
- Filter loading,
- Heating and cooling coil, silencers, and dirt and moisture contaminant buildup that causes frictional changes,
- Duct leakage changes,
- Duct friction changes (moisture, velocity wear on lined ducts, corrosion, and oxidation),
- Outside air damper positions or actuator failures,
- Chimney effect in return duct riser network.

Even though HVAC engineers have always considered CVC systems as constant, simple logic tells us that they are not. The return fan or the return volume balancing damper, in all actuality, should be used as a *brake* in the system.

Fig. 4 shows what happens when the return air volume is greater than the supply fan volume. The outside air opening becomes a building exhaust port. Even though the minimum outside air opening is wide open, no outside air is introduced.[2,33] If any outside air is introduced into the building, it will be done through mechanically induced infiltration.

The return riser is nothing more than an exhauster called a return fan. If left unmonitored or uncontrolled, as with every CVC designed system, then during the winter a tremendous stack effect develops in the return air chase. The return fan output overtakes the supply fan, and the building becomes negative to the outdoors. Cold air is introduced through the perimeter envelope where it produces drafts and overheating. This happens because the terminal perimeter heating systems generally are proportional control only devices. The overheated air expands and rises to floors above. This action is very similar to inducing a draft in a fireplace.

One of the studies mentioned earlier found that buildings as low as four stories could actually have static pressure differentials as high as 1.5 in. WG with respect to the outdoors on the top floor. Keep in mind that the supply fan is normally balanced to provide air volumes to the rooms with less than 1.0 in. WG system static pressure at the terminal device.

With this arrangement, the occupants on the upper floors receive insufficient volumes of supply air. Since the pressure of the space is greater than what the supply fan can deliver, these people suffer from dizziness, nausea, and artificial fatigue.[24,28] These conditions also play havoc in buildings where there are exhaust hoods and where very precarious balancing situations have to be attained. These conditions normally reach a point where complaints force the balancing contractor back into the building to balance it for that season. Of course, as the seasons change, so does the problem.

Perhaps the worst tragedy of all is the effect that occurs when the outdoor air system becomes an exhaust system. The system then cross contaminates other air handling systems that share the same outside air louver or the same side of the building.[2] This unfortunately was discovered in many hospitals and biologically sensitive facilities.[34]

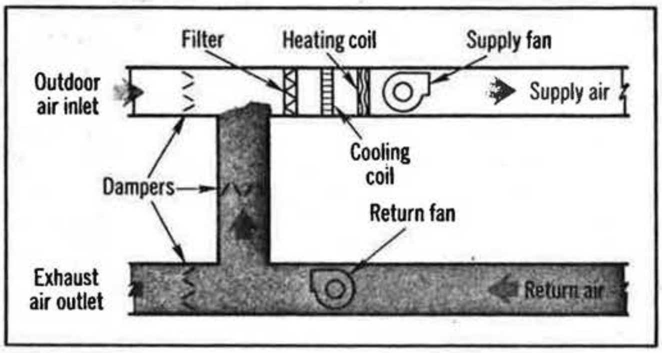
Table 3—Infiltration hazards from a building that is running negative vacuum.

Worker complaints about draft.
Ventilation through roof exhaust ventilators, chemical and biological hoods, and flow-through smoke stacks with natural or induced drafts greatly reduced.
Carbon monoxide hazards from backdrafting that takes place in hot water heaters, boilers, and furnaces.
Reduced general mechanical ventilation.
Doors that are difficult to open.
Reduced exhaust flows.
Infiltration of either unfiltered or treated air (will require greater housekeeping).
During winter, below recommended RH; during summer, above recommended RH (organic hazard).
Terminal reheat boxes that use proportional band control may overheat perimeter air that could then expand and rise to floors above.
Carbon monoxide from parking garages and exhaust vents on lower parking levels may infiltrate building.
Reduced velocity of exhaust rates affects plume development.
Energy waste and fan performance reduction.
Staircase pressurization failure that will cause fire and smoke problems.
Polluted outside air makeup due to cross ventilation.
Sewer gases induced into building from perculator effect through traps and drains.

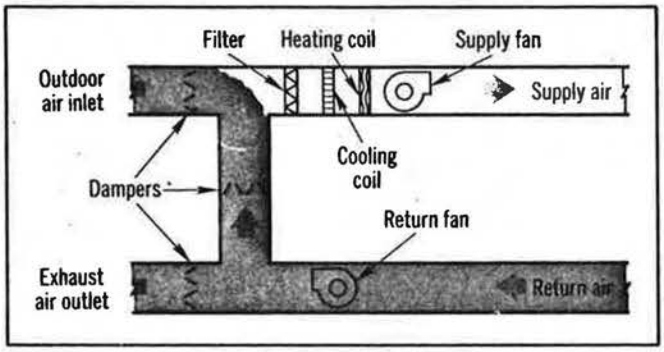
Loop control

Variable air volume systems are plagued by the same problem of the return fan being "insensitive" to what the supply fan is doing.[13,33] If the system studied is a VAV system, one of the first questions that the investigator must answer is if the control system is an "open loop" or a "closed loop" control system.

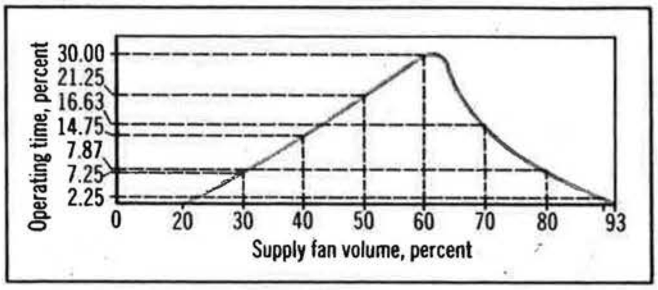
If the system uses open loop control, it can be guaranteed immediately that the negative building pressure is caused by this control strategy. Open loop control is where the static pressure of the supply system is measured; this signal is then sent to a device that manipulates the supply fan to maintain a constant static pressure discharge. This signal is also randomly sent to the return fan, which will theoretically track up and down the supply air volume. The 1980 *ASHRAE Handbook, Systems,* tells engineers not to use this type of system since it is insensitive to load changes and will cause the building to change pressurization. Engineers are learning that when a building goes negative pressure with respect to the outdoors, it may become unfit



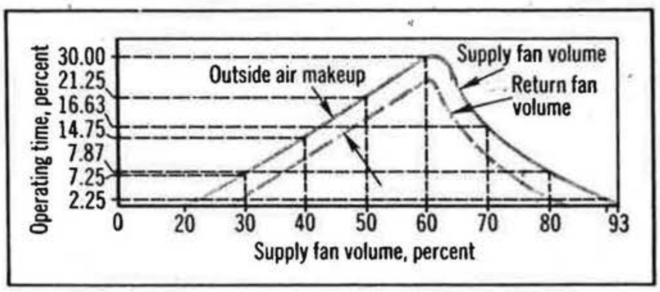
3 Proper operation of a VAV (or CVC) system.



4 Improper operation of a VAV air system. Return air fan overpowers the supply air fan, which forces return air out of the outdoor air inlet and creates a negative pressure within the building.



5 Duty cycle chart of TRNSYS modeling program for VAV system operation.



6 Industrial process control of supply and return fans with up to 35 percent overcapacity. Building remains positive over full range of system operation.

for occupancy.

The only reason open loop control systems are selected is because they are less costly than closed loop systems. Be particularly wary of some of the variable speed fan drive concepts being advocated. Marketing people have suggested that open loop control can work if both the supply and return fans are controlled by the same motor speed control device. However, each fan is subject to the previously listed mechanical factors that affect fan operation.

Fig. 4 shows what happens when the return air riser is affected by the chimney or stack effect. Therefore, with a VAV system, it may be necessary to vary the speed of the return air fan differently from that of the supply fan to have the return air volume properly track the supply air volume. If both fan motors are tied to the same speed controller, it is not possible to vary simultaneously the two fan speeds by a different amount.

Closed loop control is similar to open loop control only because they have identical static pressure systems. The air volume of the supply fan is measured and sent to a computing device. Likewise, the return air volume is measured and sent to the same computing device, which compares the two volumes and resets the return fan to maintain a fixed differential that is made up by the outdoor air component.[23] This control method is very similar to the strategy used for fuel air rationing in a combustion system. Combustion control suppliers use good, sound engineering practices; unfortunately, the analogy too often ends there.

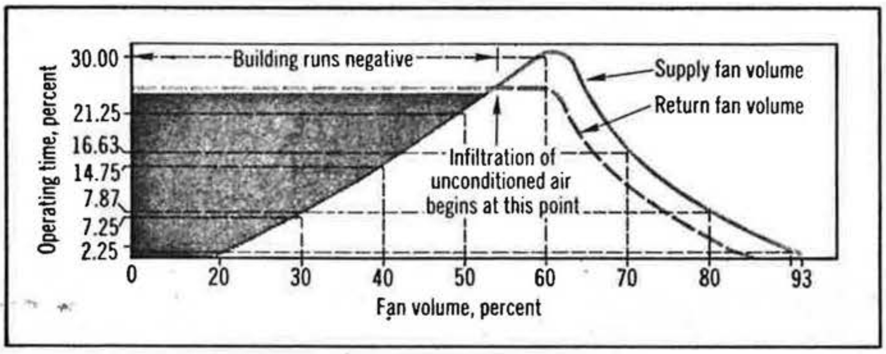
Usually, the instrumentation provided to measure the system supply volume and the return volume is so inadequate that it cannot trace the full building demand duty cycle curve. Fig. 5 has been developed by TRNSYS Modeling Program to indicate this curve.[22,35,36,37]

Fig. 6 shows the typical duty cycle required for a building. As noted, the air volume supply fan must turn down to a volume that is approximately 20 percent of its maximum volume output.[22,35,36,37] The return fan has to track or silhouette the supply fan demand curve. Fig. 7 indicates what happens when the return fan fails to track.[22] Like the constant volume system, the return fan acts like an exhaust fan, and the building becomes negative pressure. There are several reasons for this situation besides inadequate instrumentation. Many of the rooftop air handling systems that were discussed earlier cannot reduce volumes below 50 percent.

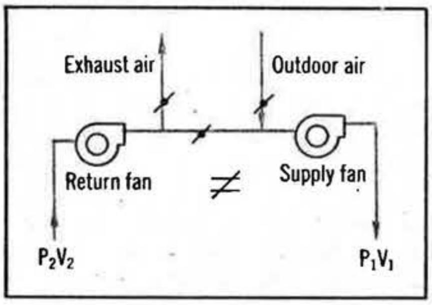
When the return fan is backed off to its minimum, it is still sending back 50 percent of volume. In fact, even some of the more expensive fan systems cannot back off far enough to prevent a catastrophe.[33] The majority of the fan systems designed are grossly oversized, which will ultimately require greater turndown. I have asked consulting engineers why, and the general answer is that a consulting engineer is never sued for making a system too large.[38] The oversizing will require greater turndown capability in the equipment as well as the instrumentation.

Energy conservation

Energy conservation will be a continuing design element for buildings. A building that is healthy today may be unhealthy in the future because the system became oversized due to energy conservation programs that placed greater demand on the existing equipment and its turndown capabilities. As one engineer stated, an HVAC engineer's only goal is to bring a little bit of outside air to each and every one in the building. Obviously, that goal is not met as often as it should be.



7 Commercial grade control of supply and return fans that are both precisely sized for system with no overcapacity. Building turns negative due to inability of controls to reduce return fan capacity.



8 To control a VAV system, closed loop control systems with sensors capable of responding to the full ranges of P_1V_1 and P_2V_2 are required.

The problem in controlling a VAV system can be best understood as the solution to the relationship in Fig. 8. An equation cannot be solved with more than one unknown. Operating constant volume systems with no supervision of any of the variables is like trying to solve the problem with four unknowns. A VAV system using open loop control is attempting to solve the control problem with three unknowns. The VAV system using closed loop control, but with sensors that cannot resolve the total duty cycle, is attempting to solve the problem only a portion of the time.

We do know that if the proper amount of ventilation is introduced into the building, the inorganic contamination can be diluted to the point where it is not harmful to the inhabitants.[14,15,29,32] Buildings that run negative pressure have the potential to be health time bombs. Some have already "exploded."

These control strategies were brought about to save energy, but they do not save as much energy as we are led to believe. If the systems were designed properly and if they actually functioned properly all the time, then health and energy savings could be achieved jointly.

Stack effect

One very fascinating sidelight to a negative pressure building is that all of the staircases become more negative than the spaces. In other words, not only is there a potential toxic problem, but there is a genuine smoke problem in case of fire.[39,40] It is totally impossible to provide stairwell pressurization to a building that runs negative.

An example of a building in which mechanically induced stack effect presents problems is illustrated in Fig. 9. This is a "pressure print" of an 80 story building that used a CVC system for system strategy. Fig. 9 shows the pressure relationship inside the building vs. the outdoors on a November day. On this day, the lobby was minus 0.25 in. WG with respect to the outdoors. The 80th floor was a positive 2.3 in. WG with respect to the outdoors. It was also noted that all the stairwells, as well as the elevator shafts, were also more negative than the general corridor space.

This building was divided into three zones for control: upper, middle, and lower. Each zone had its own mechanical room and associated air handling equipment. Because of the obvious problems in operating a building this way, the upper level was retrofitted to a VAV system. The system was unique in that the instrumentation and control system were designed to track the full duty cycle curve that the building experienced.

Fig. 10 illustrates the change in the building pressure print after the return fan system tracked the supply system. This curve indicates that the upper floor region is now being overpressurized by the "out of control mechanical systems" on the lower floors (lobby to 53rd floor). A very obvious correction has taken place on the upper level where the stack effect problem has been reversed in the proper direction.

It was noted that all the stairwells, as well as the elevators, became more positive with respect to the general space corridor. These changes were implemented to save energy, and the results indicated a three year payback. Improved health of the building was a bonus.

Generally, multistory buildings should be treated by engineers more like "chemical distillation columns" with each individual floor acting as a tray within the distillation column. Unfortunately, HVAC engineers generally treat a building as a "smoke stack." The use of open window control for ventilation has not been used for several decades; however, the tendency is to treat the buildings as if the technology has never changed.[38]

Microbial infestations

It is possible to have two tragedies in a building occurring at the same

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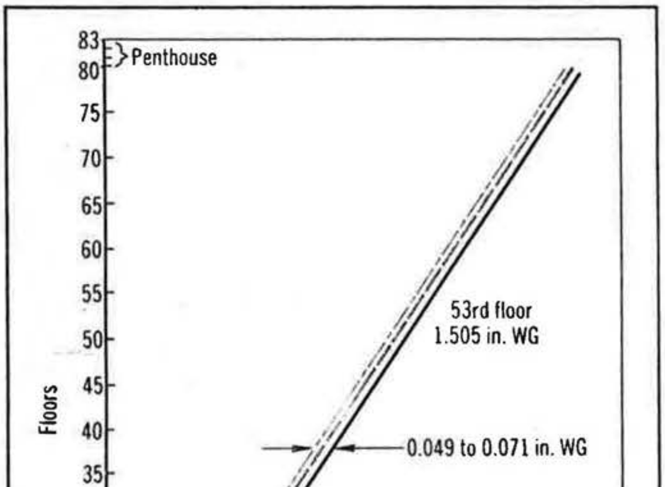
time. Not only does an improperly designed and a poorly maintained air conditioning system cause the building to be negative, but the same system can also pump millions of allergens and antigens into the workspace. This could cause flu-like symptoms, rheumatoid/arthritic symptoms, hay fever symptoms, and neurological complaints from many of the workers.[4,41,42,43] There are actual buildings in this country that have been abandoned because of microbial infestations that have made some work areas uninhabitable. The presence of moisture is necessary to have a building become a breeding ground for bacteria, fungi, and protozoa.[42,44]

Table 4 presents a partial listing of airborne transmission of diseases, microorganisms, and toxic substances that have been found recently in buildings with contaminated air.[45,46] The following is a checklist of some of the items that should be looked into if there is suspicion of microbial infestation:

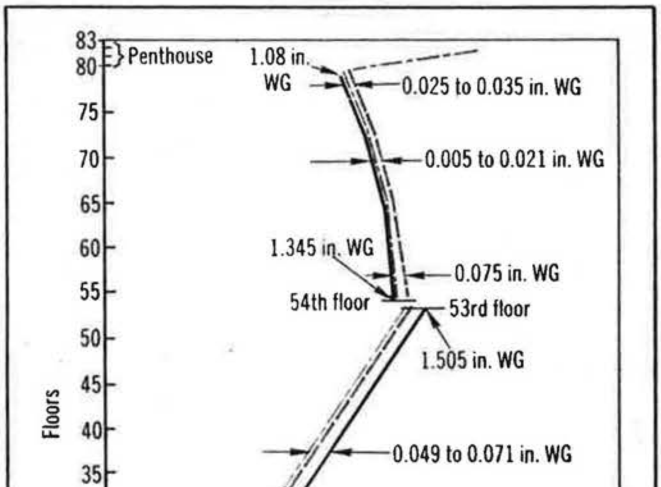
- The hot water supply temperature to the heating coils in an air handling unit used to be approximately 140 F. Because of the energy crunch, this temperature has often been reset to 120 F. This is an ideal temperature for microbial incubation.[47]

- Air handling packages, either "built-up" or "rooftop," are supported on concrete curbs. These curbs have no means of draining and allow stagnant water to accumulate.[41] Because these air handling systems are sometimes poorly manufactured and maintained, they leak like a "sieve"[48] and constantly introduce bacteria into the heating, ventilating, and air conditioning systems.

- The relative humidity should never be above 70 percent at any time.[41,47,49] Unfortunately, as discovered in the CERL testing, none of the commercially available humidity sensors operated more than a few days before failure. The few sensors that did operate registered humidities 30 to 40 percent in error.[17] Very few humidity sensors are calibrated to the U.S. National Bureau of Standards *NBS Two-Pressure Humidity Generator Standard.*

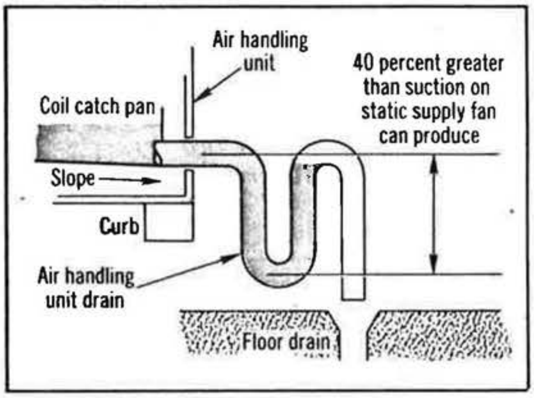


9 Pressure relationship inside an 80 story building vs. the outdoors on a November day.



10 Change in pressure relationship of an 80 story building after the return fan system tracked the supply system.

• Cooling coil assemblies at the air handling unit can either be "blow-through" (on the discharge side of the supply fan), or "draw-through" (on the suction side of the supply fan). According to ASHRAE standards, the air velocity through the cooling coil unit should not be above 500 fpm. This eliminates the possibility of moisture being entrained in the air and carried downstream into dirty glass fiber lined ducts and establishing a microbial breeding ground. Unfortunately, the investigators should check the velocity through these coil units. In too many cases, the coil units were actually much smaller than the casing sizes of the air handling units. During the construction phase of a project, air handling equipment suppliers routinely offer cost reductions for providing cooling coils at a higher velocity than requested. Some manufacturers attempt to provide a moisture capture device downstream of these high velocity cooling coil units, which nevertheless proves ineffective.[50]



11 Proper condensate drain trap design is essential for safe operation of air handling units.

• The investigator should check that the filter medium on the upstream side of the heating and cooling coil units at the air handling system is not velocity disintegrated or misaligned so that gaping holes appear in the filter section. The increased velocity through these openings can cause the same effects that too high a velocity through a cooling coil section causes.[21]

• Air filters should have properly rated "dust spot efficiencies," and pleated glass fiber filters should be checked for disintegration and possible glass fiber pollution.[41,47,51]

• Humidifiers should utilize steam (but not boiler steam!) as a water source and not recirculated water.[41,47,52,53,54,55,56,57,58]

• Spray coil systems should be abandoned. These are found primarily, but not exclusively, in the southern states in older buildings.[41,58]

• The investigator should measure the suction static on a supply fan. He should also check the fan specification to see the maximum negative pressure that the fan could possibly produce. As Fig. 11 illustrates, maximum suction pressure should be multiplied by 1.4. This dimension should then be compared to the height of the trap that is provided on the air handling unit. If the depth of the trap is equal to or less than the static pressure, it is basically ineffective for removing water from the cooling coil section. It should actually be generous enough to ensure that no problems exist. Many drain systems in buildings are basically ineffective, and they are actually drawing sewer gas into the air handling systems. The sewer gas combines with the inability of the water to be discharged. A "microbial soup" is thus produced.[47,59]

• The building should be checked to see if fan-coil and heat pump units are utilized for primary or secondary refrigeration and heating. Air from the supply fan is distributed to these fan-coil units, which have their own small fans. These take air from the space and recirculate it through a secondary cooling coil system. Unfortunately, many of these systems have "foolproof" methods of draining off moisture. This moisture collects on the coils, as well as on the catch pan, and it becomes a biological hazard. This type of mechanical system should be totally abandoned if proper installation and maintenance cannot be guaranteed.[5,41,44,56,57,58]

• What becomes a biological mass in one season becomes a spore release in another season. When individuals complain of sneezing and general allergy symptoms, the investigator should check the static pressure control loop on the supply fan. These systems are often so poorly designed that they do not have the proper algorithms to provide stable control. The supply fan's surging blows the dust, dirt, and spores trapped in the ducts throughout the building.[22,49]

• Air washers that utilize recirculating water systems should be abandoned.[41,55,56,57,58]

• Because of the energy crunch, some manufacturers have resurrected a method of spraying water on the roof to produce some evaporative cooling. This method should be carefully watched since with poor drainage, the casual water can backfill curbs on rooftop units and result in stagnant water accumulation.[41,56,58]

• The location of cooling towers and their relationship to the out-

Table 4—Partial listing of airborne diseases, microorganisms, and toxic substances that have been found in buildings.

Actinomyces thermophilia	Diseases of unknown etiology	Meningococcal meningitis
Airborne lead poisoning	Histoplasmosis	Micropolyspora faeni
Airborne phenol poisoning	Hypersensitivity pneumonia	Pseudomonas aeruginosa
Aspergillosis fungus	Influenza	Psittacosis
Bizarre case of airborne rabies	Inhalation anthrax	Pulmonary tuberculosis
Brucellosis	Klebsiella	Smallpox
Coccidioidomycosis	Legionella pheumophila	Staphylococcal and streptococcal pneumonia
Coxsackie	Lymphocytic choriomeningitis	

side air intake should be checked.[41,60,61,62]

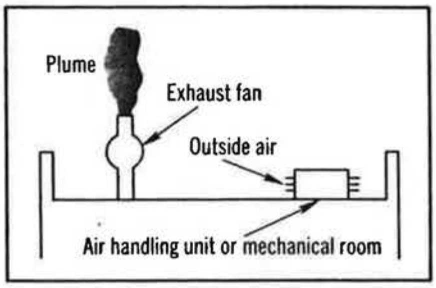
• As Fig. 12 illustrates, the exhaust fans used for lab hoods (chemical or biological) and toilet exhaust count on plume development and high discharge to send the pollutants into the atmosphere for dilution. When the energy crunch arrived, it became vogue to shut off hoods and reduce the discharge to save energy. As indicated in Table 2, 1 cfm of outside air costs anywhere from $2 to $3 per year.[22]

Fig. 13 shows what happens when the volume discharge of the exhaust fans is constantly reduced as each hood is shut off. The discharge plume disappears, and the pollutants hang around the roof of the building and almost become a toxic swimming pool that short cycles back into the outside air supply. If the building is running negative, this occurs through infiltration.

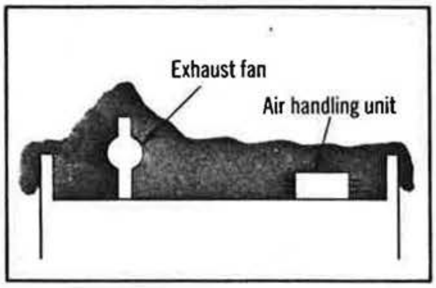
Fig. 14 strikes a compromise between individuals who are overzealous about energy savings and individuals who want a healthy, operating building. The static pressure on the exhaust fan is controlled by manipulating a raw outside air bypass for carrier air. The exhaust fan operates on constant volume; in this case, rather than using expensive indoor air, raw untreated outside air is mixed with the air from the hoods so the correct plume and terminal velocity are guaranteed. This method does use more brake hp; however, some energy must be spent to make a building safe.

• The collection pan for cooling coil condensate, located within the air handling unit, normally stands stagnant and undrained during shutdown periods when the building is unoccupied. In one recent test, water samples after 8 hr shutdown showed bacterial levels higher than those normally experienced in chemically treated cooling towers.

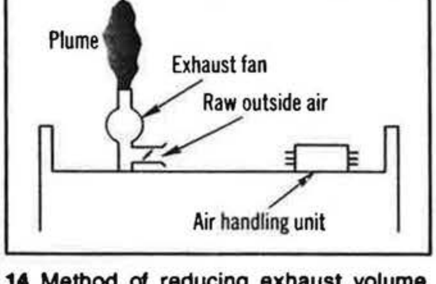
This contaminated moisture is then distributed in the air system downstream where the effects raise the bacteria level in the occupied areas as high as what is found in a "chicken coop."[41,42,55,56,57,58]



12 Adequate exhaust plume is necessary to disperse building exhaust to prevent concentrated exhaust from being drawn into the building.



13 Inadequate exhaust plume can cause pollutants to collect at roof level where they can be drawn back into the building.



14 Method of reducing exhaust volume while maintaining an adequate plume to disperse the exhaust.

I have only highlighted the more obvious items that should be included in an investigation of a "stuffy building." The maintenance of a mechanical system plays an equal role in this problem. Another problem is that HVAC engineers must not grade working systems in buildings by the mere fact that the owner does not complain. Many times the owner is an absent landlord and could not care less.

Mutual goals

Conservation of energy and indoor air quality need not be conflicting goals. Both the causes and the cures of indoor pollution are diverse and surprisingly simple. Systems should be less complex, have dynamic stability, and have uncontrolled excessive moisture corrected. Basically, all that is required is communication with the building through drift-free sensors (pressure, temperature, humidity, and flow). If these instruments report back information that is factual, then there is no problem in having a safely operating building. If they send back misinformation or lies, then catastrophe is around the corner.

My biggest fear is that there is a "new wave" in the HVAC industry that computers (the ultimate black box) will be the salvation of all the engineer's problems. Unfortunately, a computer is only as good as the software provided and the information sent. If garbage is sent to the computer, then garbage will come out. Nothing will replace good, sound engineering practices. Ω

This article was written while Mr. Morris was Systems Engineering Manager at Air Monitor Corporation's Research and Development Facility in Parsippany, New Jersey.

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A listing of recommended reading is available from the authors.