The Sick Building Syndrome:

What It Is, and How To Prevent It

By Virginia L. Bishop, David E. Custer, and Robert H. Vogel

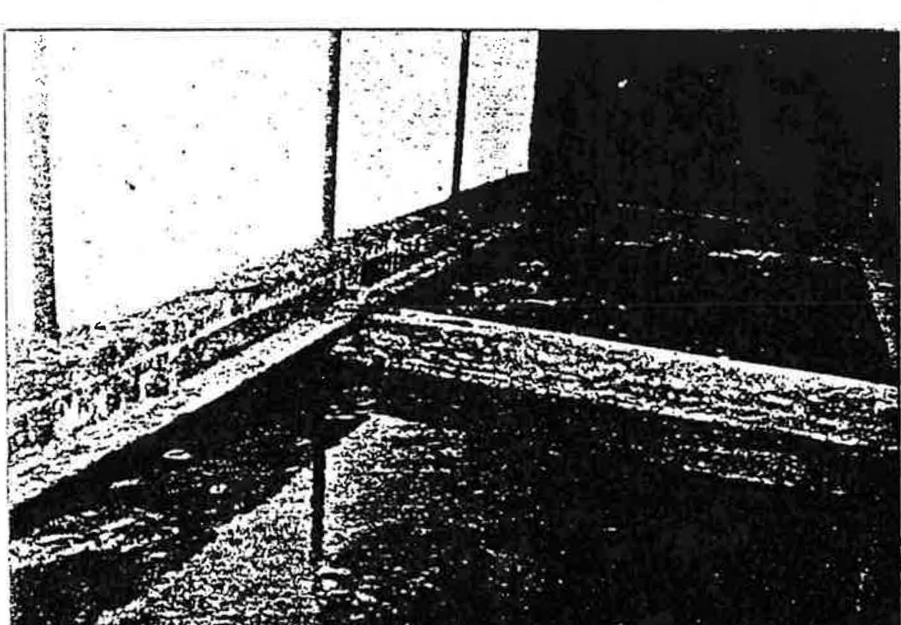
In 1976, 29 American Legionnaires died from a mysterious disease, eventually linked to microbacteria flourishing in the cooling towers of the victims' convention hotel in Philadelphia. A total of 221 people were taken ill by what was eventually named *Legionnaire's Disease*.

By October of 1978, more than 50 different strains of the pneumophila concerned had been identified; they were found to be the cause of at least two dozen major outbreaks of of illness characterized by pneumonia-like symptoms, such as high fever, diarrhea, and dizziness. The *Legionella* bacteria were nurtured by the warm, moist climate found in many cooling towers atop commercial buildings. Outbreaks have since been recorded in other U.S. cities and throughout the world. Last summer, more than two dozen employees of the *New York Times* were taken ill with *Legionnaire's Disease* at the newspapers headquarters in midtown Manhattan.

Legionnaires Disease is one of the most distinctive and potentially fatal of a host of infectious diseases that are specific to "tight" or "sick" buildings—supersealed facilities with air conditioning and heating systems that have become infested with harmful microbial contamination to such an extant that whole populations of those living or working inside are harmed. Although selected researchers have been aware of these potentially life-threatening conditions since World War II, they did not become a major concern to government officials, building and air system designers and engineers, or building operators until just about a decade ago.

When the price of petroleum skyrocketed during the energy crisis of the early 1970's owners and operators of all types of facilities—from private homes to huge skyscrapers and factories—had to find a way to reduce energy costs and conserve supplies. Most buildings in use at this time had windows that opened and closed, introducing comparatively large quantities of fresh air from the outside into rooms, corridors, and staircases. This fresh air, hot or cold, was considered one element of a building's heating and cooling system. Thermostats in most buildings were raised in the winter and lowered in the summer to provide maximum comfort for occupants without regard to energy costs

When cost did become a major concern, windows were permanently sealed and weather-stripped or replaced by new, super-insulated units. Insulation was increased in older buildings while new ones were designed and built with inoperable windows and high performance insulating materials that minimized the entry of any unintended outside air into the building. These features necessitated elaborate heating,



Shown here is microbial growth in a condensate tray of an inside air handling unit.

ventilating, and air conditioning (HVAC) systems that utilized energy recovery components, air washes, humidifiers, and complex air flow mechanisms to keep the environment within the sealed building livable without losing hot or cold air in the process.

William F. Heineman, an architect, compared the new, supersealed buildings to a space ship: "Once we enter, we are completely dependent upon its support systems for survival. The quantity and quality of the air we breath is totally contained within the system." The air in such a system is not only capable of picking up fungus and bacteria and recirculating it throughout a building, air-borne viruses and "germs" from a worker's coughing or sneezing, as well as cigaret smoke, is able to wander through the system for hours before it escapes through exhaust vents. Moreover, if air filters within a HVAC system are not changed regularly, microorganisms trapped by the filter can multiply in it, turning what should be a cleaning component into a source of harmful contaminants.

Microorganisms or pathogens and pollutants from building inhabitants are not the only sources of human health hazards in sealed buildings, Some of the more cost-efficient and effective insulation and building materials now in use are suspected of causing cancer. Asbestos and formaldehyde-containing foam insulation and particle board have become a major concern for governmental health inspectors and private building owners and operators. Also at loose in the office environment are other gaseous by-products related to human occupation: heating, cooking, power machinery, and automobiles (in underground garages) or in-plant vehicles using carbon fuels emit a variety of harmful gases, such as nitrogen dioxide, carbon monoxide, carbon dioxide, and traces of hydrogen cyanide (a byproduct of some gas cooking appliances). Each gas can cause symptoms ranging from dizziness and nausea to death.

Microbiological health hazards are the most prevalent and preventable of the categories of potential health hazards in supersealed buildings.

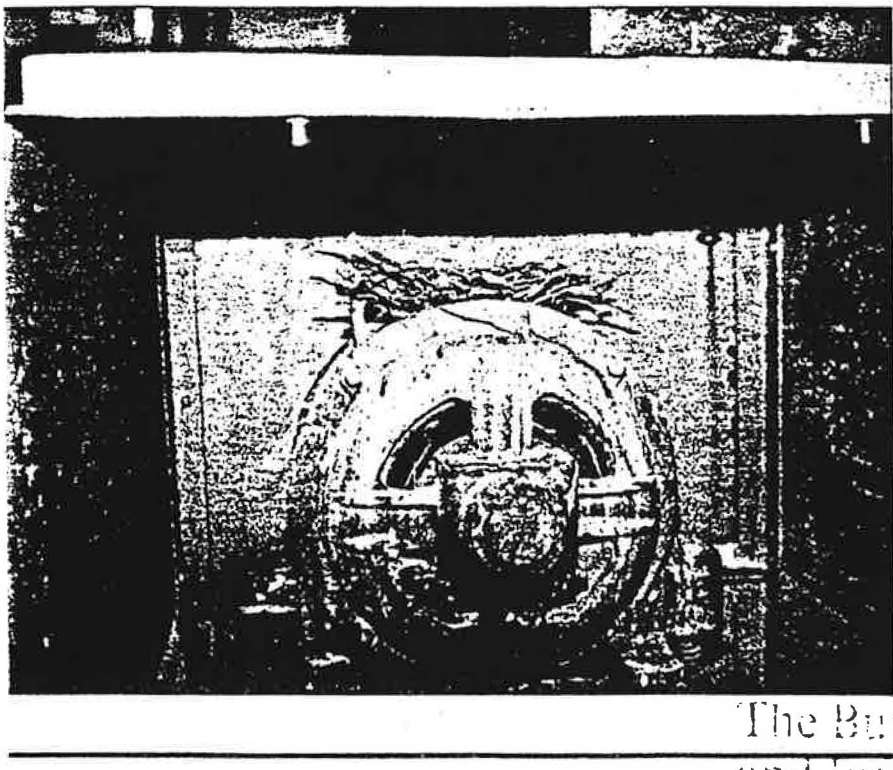
Government awareness One of the first published studies concerning indoor air contamination was published in England in 1948. A few scattered clinical and technical reports appeared in the 1960s and '70s, but the potential health problems associated with modern, supersealed buildings did not become prominent until the dramatic loss of life in Philadelphia in 1976.

Around this time, both government agencies and professionals in the air conditioning and heating industry were becoming aware of the many insidious pathogens able to grow and multiply in ducts, humidifiers, air filtering systems, and in air conditioners themselves, in almost any building. The sister agencies, OSHA and NIOSH, are equipped to monitor for bio-hazards.

Government activity was in part spawned by slowly accumulating medical evidence of the effects of indoor air pollutants on human populations. One of the first medical articles on the subject was published in the *New England Journal of Medicine*—world-renowned for its pre-science of emerging medical problems.

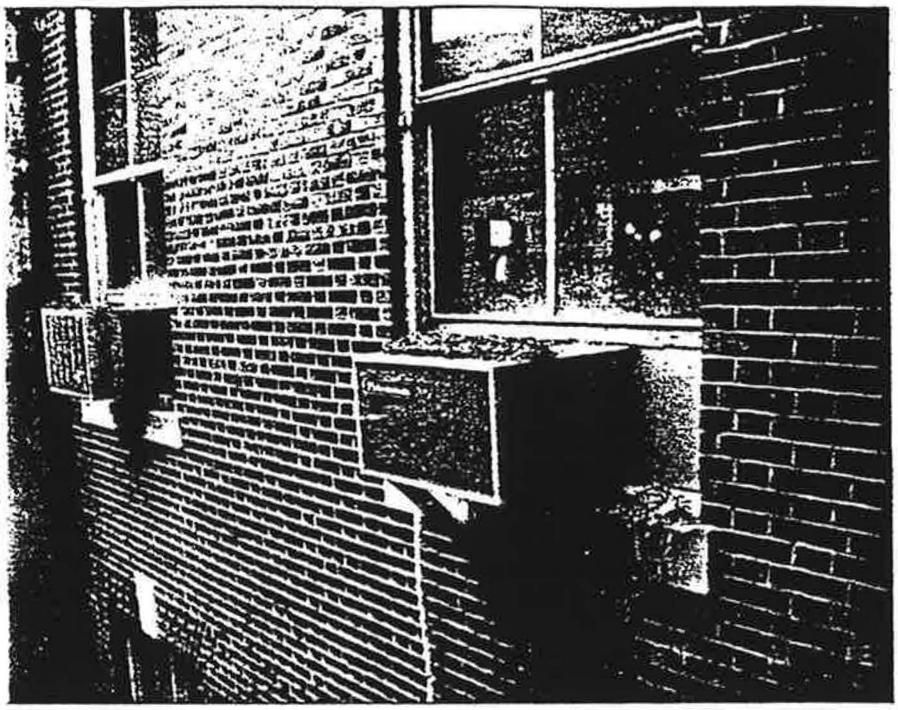
NIOSH, created as a research arm for OSHA, began publishing recommendations and guidelines for builders and building operators in the mid-1970's. In 1976, NIOSH published *Criteria for a Recommended Standard...Occupational Exposure to Carbon Monoxide*; that same year the agency published a study of occupational health in hospitals that focused on indoor environmental elements. In 1977, NIOSH published a second set of criteria dealing with exposure to fiber glass. Dr. Philip Morey, a NIOSH hygienist, has projected himself as an expert researcher and educator on the vast umbrella of topics that are included under the heading "indoor air pollution," including microbial building contamination,

The EPA has also been aware of, and involved in, educating itself and the public at large about the hazards of indoor air pollu-



Bird nests and feces near air-handling equipment can ensure that the inside air of an air-tight building will be contaminated.

Outside air intake component of these window air conditioning units are covered with pigeon feces.



tion. In 1981, the EPA co-sponsored with the Department of Energy and six other governmental and private organizations the International Symposium on Indoor Air Pollution, Health, and Energy Conservation; that same year the EPA also sponsored the development and publication of a 537-page compendium, *Indoor Pollutants.*

One of the sponsors of the EPA's international symposium was the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), which publishes ventilation system design and operational standards, as well as minimum fresh outside air (OA) requirements. In 1977, ASHRAE published *Indoor Ventilation Standards*, which provided a guideline for many buildings constructed during the past eight years. In 1981, ASHRAE updated those criteria with *Ventilation for Acceptable Indoor Air Quality*, which, for example, calls for higher OA ventilation where tobacco smoking is permitted. OSHA is currently moving full speed ahead to promulgate new indoor air quality standards at a faster rate than at any time in its history, based largely on NIOSH and ASHRAE research.

In 1983, NIOSH's Dr. Morey presented a sampling of sick building problems to a gathering of the American Industrial Hygiene Association in Philadelphia. The federal researcher is always careful to point out that NIOSH is more familiar with indoor pollution problems in federal buildings because they are usually called in to investigate, so whatever paper work is generated is still available. Similiar private buildings undoubtably have the same problems, but are not likely to make the problems known to the public because of fear of lawsuits and poor public image.

Some examples of sick buildings from NIOSH files are:

• In 1982, 41 employees in a seventh floor office suite in a federal building complained of headaches, muscle pains, chest tightness, and nausea that persisted during weekdays and dissipated over the weekend. Investigators found that repeated floods from an eighth-floor cafeteria had spawned microbial bloom in the building space between floors. The office suite had to be completely refurbished.

• The older section of a federal building complex that housed 1,500 workers was found to harbor microbial slimes in its air handling units; three workers on the buildings seventh floor fell ill due to air-borne contaminants.

• In the mid 1970's, the sandstone portion of an older building had to be gutted to its structural components due to an outbreak of hypersensitivity pheumonitis, and was then rebuilt. However, NIOSH was called back to investigate a recurrence of the problem in 1983.

• In a building where the air-handling units' fans were downstream from "chiller" decks, stagnant water had spawned thick layers of microbial slime. Improper drainage of air-handling units throughout the building forced its abandonment in the mid-1970's. This was because the filtration system in the building was unable to remove microbes after they aerolized into the building's air supply. Before the building could be reoccupied, in Morey's words, "every ceiling tile every piece of carpet, the entire heating, ventilation and air conditioning system was totally removed from the building and the structure was rebuilt." When the building was finally reoccupied in 1980, 31 new air handlers had been installed. Again, however, NIOSH officials were called back after reports of the same type of symptoms workers experienced when the building was first closed.

• In another government building, asbestos had combined with microbial contaminants in the building for a double whammy. At the same time, investigators discovered that fragments of asbestos had broken off of pipes and beams and entered the building's air supply, air directional vanes to the building's cooling tower were found to be coated with brownish microbial growth, and a layer of sludge was found at the bottom of the cooling tower reservoir. Air handling units serving the cafeteria likewise contained brownish green slime in and around the condensate tray.

NIOSH recommends that stagnant water in air handling equipment and cooling tower reservoirs not be allowed to exceed 100 to 1,000 bacteria per milliliter of water. Bacteria levels in this building were at approximately 1.2 million colonies with fungi at 500 colonies per milliliter of water.

Cause and effect The vast majority of microbial contamination is caused by stagnant water and dirt built up in systems that are not regularly cleaned. Dr. Morey's descriptions of the combinations of these two conditions are very telling:

- Wooden supports between two floors of a building covered with slime;
- Leaks from the roof producing "incipient stalactites" hanging from the structural surfaces;
- Plates from a fan pushing air through the ventilation that are covered with a dark green slime;
- A deep pool of slime covering a stagnating drainage pan underneath the air conditioning unit;
- A roof-top cooling bank that resembles a large microbial culture plate or petri dish.

As has been indicated previously, cleaning out contaminated elements in a building isn't always a permanent solution. Structural defects may be just as responsible as simple neglect in the occurence and reoccurence of dead building syndrome.

An elementary school in a community outside Washington, DC had recuring microbial contamination for several years. Water leaks through walls, windows, around doors, and around roof and foundation, combined with high humidity within the structure, gave rise to phenomenal microbial contamination in many area in the school.

Teachers working in the building complained of unusually frequent health problems, such as pneumonia, upper respiratory infections, allergic rhinitis, allergic asthma, as well as hyper-sensitivity pneumonitis. Although teachers conceded that such problems occur with varying frequency throughout the year, most agreed that they became worse when the teachers entered the building. In addition, teachers and pupils complained of watering eyes and moldy textbooks.

At the end of 1984, four teachers at the school filed claims with the state's Workers' Compensation Board with the hope of getting paid for some 350 sick days. . Parents concerned with the persistent microbial-related illnesses finally demanded that the school take drastic measures to correct the many problems rooted in the excess water present on the building site. Examples of the problems included: dust, spider webs, and insects in the fresh air return ducts; grayish-black particles in the insulation for the plenums between floors; slime growing at the base of coils and on the steel frame supporting the air system coils; a colony of flying insects found living in an air-conditioning unit; drains clogged with microbial growth throughout the building.

A consulting group recommended that the school clean all parts of the air system possible with blasts of hot water and an-anti-microbial solution. All air filters had to be replaced and were to be replaced regularly. Carpets saturated with mold and mildew were to be removed if they could not be completely dried and disinfected.

Most significant of all, however, school officials were told that these problems would not be eliminated until extensive run-off systems were built around the school. The facility was built on low-lying land that trapped ground water from the surrounding areas. Moreover, its air systems were all located underneath the school. Unless this stagnating water was routed away from the building's foundation, the problems mentioned could come back again and again.

Building contamination usually falls into two broad categories: microbial bloom allowed to take root and run amok due to poor or non-existing maintenance of the HVAC system; problems caused by ineffective design and equipment. The former category is preventable and the latter can be permanently corrected, although often at great expense. Of course, the clean up and preventive maintenance needed to deal with micobial bloom can be quite expensive, depending on the size of the building, its design, and the climate where it is located. Aside from ignorance, the expense associated with cleaning up the "sick building syndrome" is the greatest stumbling block facing industrial hygienists, government inspectors, and professionals in architecture and the HVAC industries.

In supersealed buildings, HVAC systems are the lifeline for the occupants—duplicating nature by taking out the bad air and pumping in the good. Unfortunately, as one professional, commentator put it: "It may be that we have overestimated our technological skill at reconstituting the complexity of the natural environment." Studies conducted by NIOSH have shown that the air inside many sealed buildings is as much as 30 times more polluted with gases, cigaret smoke, and microbial flora as the air outside on a typical week day in many cities.

Air filters for HVAC systems collect the multitude of particles and gases and supposedly prevent them from circulating throughout a building. But when those filters become clogged, or if they are not fine enough to catch all the substances coming through, these filter systems themselves can become a breeding ground for the contaminants they are designed to contain.

One thing that continually leaps off the pages of the research papers addressing microbial contamination, is moisture incursion into occupied spaces. Higher than normal levels of carbon dioxide, lower levels of oxygen, and temperatures within the human comfort zone create an ideal environment for microbial life to flourish. These ideal conditions occur most frequently in and around HVAC units — condensation trays are notorious breeding grounds, as are areas around humidifiers and air washes. Unfortunately, this is also where air is picked up and pushed through the duct system by fans that may be eventually be covered by slime themselves.

Another major contributor to systemic building contamination is the inefficiency of the HVAC system itself. Most HVAC depend upon a mechanism of blowers to ensure that air flows evenly in and out of a building. Yet conventional fan motors often are not capable of varying their speed more than 50 per cent in response to changing air conditions. Negative or positive air flow into and out of a building may vary as much as 30 per cent, depending on the temperature and wind conditions outside, amount of activity inside, and the placement of intake ducts. It is not uncommon to find a negative air pressure situation inside a building that causes air top flow out from *all* openings—with little or no fresh air able to flow in.

Moreover, it is often difficult and expensive to checkout components of an HVAC system regularly to make sure that everything is working. Building maintenance workers seldom have the mechanical background to examine or repair a faulty blower or humidifier. Many do not even change air conditioner filters regularly, or check drainage pans for clogging. Taking on the simplest HVAC maintenance tasks or calling in a repairman is seldom contemplated unless it is absolutely needed, a viewpont again due to costs.

One of the first companies to make its mark cleaning up contaminated buildings is Blackmun-Mooring of Texas. It focuses on private residence problems and natural disaster clean-ups more than industrial or office fumigation, although the company is aware of the need for this type of preventive maintenance. "When you have a member of someone's family who can't inhabit a new house because that person is asthmatic and the house is full of animal hair or some kind of mildew, it's a fairly clear-cut need," explains a company founder. "But when it comes to a large building with fans, humidifiers, ducts, etc., they just don't want to hear about maintenance charges." Natural disasters and contamination from asbestos or PCPs are more tangible and serious, making clean-up almost imperative, he said.

"It's sad to admit it," he said, "But it takes a drastic event to make people realize there are certain kinds of maintenance work that must be done."

In the case of the sick building syndrome, those drastic events have included outbreaks of *Legionnaire's Disease* and episodes, such as the one at the suburban school, that have resulted in lawsuits on the part of victims of the microbial flora. Now another drastic event has turned the nation's attention to the cleanliness of its buildings and living spaces—Acquired Immune Deficiency Syndrome (AIDS). While health officials and physicians continue to repeat that the viral agent responsible for AIDS cannot be transmitted by casual contact, paranoia of catching as yet this incurable (and nearly always fatal) disease has spread quickly throughout the U.S. Janitorial services are asked whether their product is effective against AIDS. Apartments, hotel rooms, surgery suites, and hospital beds that may have been used by AIDS victims are being scoured before they are used again.

Thus the question now starting to appear most often in conversations and in print on the subject of building maintenance is not "What's wrong with my building?" but "What do I do about microbial contamination?"

This borescope photograph shows a rag and microbial growth in stagnant water inside a condensate tray.

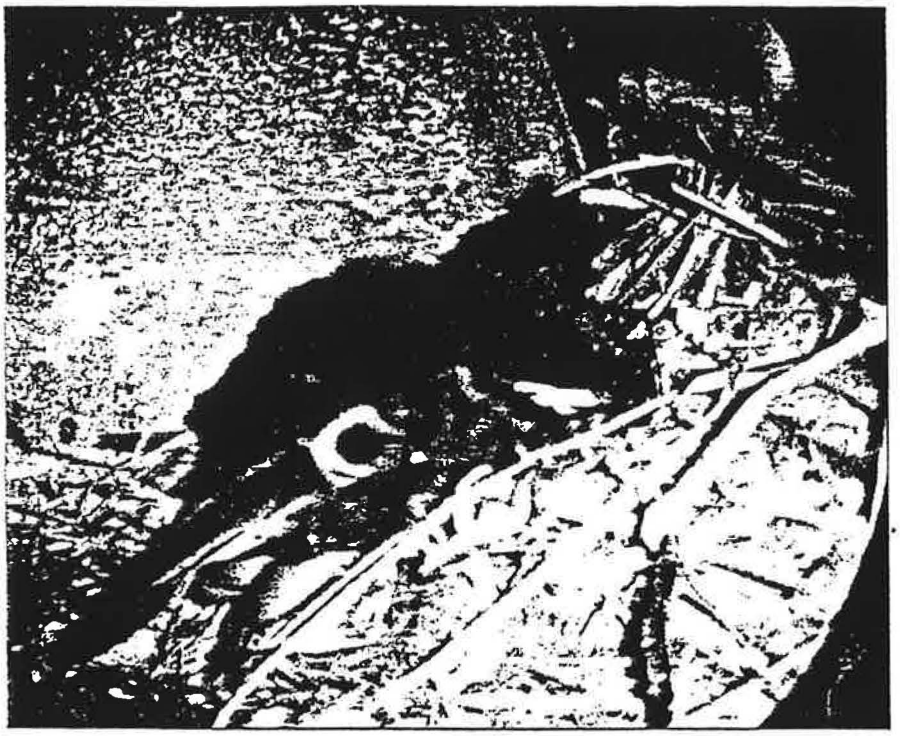
Clean-up and prevention There are three perspectives to dealing with sick building syndrome: *Contamination clean up, preventive maintenance,* and *preventive design.*

Asbestos, PCBs, and where possible, certain formaldehyde-containing insulation must be removed where they are found in amounts above OSHA limits. In many cases, (in all cases of PBC contamination) workers are evacuated until the job is done.

With microbial contamination, often times workers must stay away because the cure is worse than the disease. Following are basic steps to take where microbial contamination has been discovered in the HVAC system as well as other areas of the building.

• *Replace all dirty air filters.* Consult with a specialist in HVAC systems to determine which grade of filter is required to screen out adequately the majority of harmful particulate matter coming into and circulating in the building's air system.

• *Empty all condensate drainage trays.* Clean them thoroughly; then apply an effective anti-microbial to eliminate any possibilty of retrenchment by microorganisms. Thoroughly clean every accessible element of the affected building's HVAC system with hot water



A nest and a dead bird in the fresh air intake makes this air conditioner a carrier of microbials.

wherever possible; then treat with an effective antimicrobial. Any equipment from which microbial organisms cannot be removed should be replaced, because the problem can reoccur from a minimal presence of live bacteria or fungi.

Condensate trays that have been thoroughly cleaned and whose drainage systems have been completely unclogged and treated with an antimicrobial solution should be rinsed, then repositioned so that water will not stagnate in them. Stagnation is the most common instigator of microbial contamination problems. It is strongly recommended that these pans be checked frequently for stagnating water and clogs, and that care be taken to drain them if the HVAC system is to be shut down for any length of time, such as over a weekend. The angle of the pan should be such that water cannot collect, and stagnate and the drain should be clog free.

A recent study conducted by professionals in the industry indicated that water samples after an eight-hour shut down showed bacteria levels higher than those normally experienced in chemically treated cooling towers.

It must always be kept in mind when cleaning any of these segments of the central unit of an HVAC system that any microbial growth living there is automatically blown into a building's air supply by the fan mechanisms of the unit.

- *Use hot water* wherever possible to clean microbial growth off of condenser coils and other HVAC locations, including system casings, tubing, wires, etc. Treat all contaminated surfaces with an effective microbial solution.

- *Swab down* all suspected ductwork with an antimicrobial solution. Also treat any accessible interior spaces with an effective antimicrobial solution.

- *Remove materials* and treat involved open areas if a surface or interior area, such as above ceiling panels or behind a wall, are found to be infested and cannot be cleaned. There are many NIOSH case studies where ceiling tiles, walls, and even floors have had to be removed from buildings with severe microbial contamination. Removal is costly, however, and should be resorted to only after consultation with a competent professional.

- *Carpeting and furniture,* in general, can be treated with antimicrobial solutions and reused after a thorough airing. If, however, carpeting in particular has been overwhelmed by microbial growth or cannot be dried properly, it should be discarded.

- *Check out* all equipment in the HVAC system to make sure it is fully operational after the cleanup has taken place. All drains should be kept in working order.

This type of cleaning process is made difficult by two scarce resources: knowledgeable help and an effective antimicrobial solution. In earlier incidents of severe microbial contamination, work crews have resorted to the traditional hot water and bleach. However, bleach is a caustic substance that can burn eyes, skin, and nose, and thus is not considered safe for work crews or buildings where the evacuation of people must be minimized.

By the same token, many heating and air conditioning installation companies do not know how to cope with microbial infestations, which may only tangentially involve the HVAC system in a building. The most practical way of locating a competent microbiological decontamination specialist is to begin with HVAC system installers; then contact a local EPA or OSHA office for advice. As a last resort, the NIOSH office located at Washington, DC, will send investigators to do air samplings and quality studies whenever possible.

While traditional quaternary ammonia compounds and phenol-based germicides have been promoted for this type of decontamination jobs, their low-level efficacy and intermittent performance have thrown doubt upon their ability to eradicate stubborn mold, mildew, and bacteria effectively. Moreover, most quats and phenols perform very poorly against the tough viruses that many people fear, such as the causal agents of hepatitis, AIDS, severe colds, and flu.

For this reason, industrial hygienists have recently turned their attention to a new class of disinfecting solutions based upon glutaraldehyde — a synthetic chemical that is a distant, tamer, more efficacious relative of formaldehyde. It is so potent, yet gentle, that glutaraldehyde is used throughout hospitals, doctor's offices, commercial laboratories, and in large industrial facilities to sterilize or disinfect everything from delicate fiberoptic scopes to the walls of pharmaceutical facilities and industrial respirators.

Glutaraldehyde-based solutions are, however, smelly. None were recommended, until the past few years, as a surface decontaminant because the smell of the chemical could last for hours and burn the eyes and nose, even though it does a dependable job of broad spectrum decontamination. However, one company has recently begun promoting what it calls the "original tamed glutaraldehyde." The product, called Wavicide-05 (some trade names are Steamacide, BUF 625, and MC25), has virtually no odor at its recommended use, and is described as strong and potent against microorganisms that flourish in the dark, moist atmosphere of a building's or cooling tower's infrastructure.

Two more new chemical disinfectants being promoted as surface decontaminators are are sold under the brand names of LD and EXSPOR. Their formulation is based on a mixture of sodium chlorite and organic acid with water.

Preventive maintenance Any veteran building operator who has had to eradicate a stubborn case of sick building syndrome knows that an ounce of prevention, in such a case, may be worth tons of the cure. Preventive measures that have been recommended by experts in the field include:

- *Keep hot water supply* temperatures above 120 degrees F. At that temperature, and slightly below, bacteria incubate. Before energy conservation came into vogue, hot water supplies used to be kept at 140 degrees F., which, if nothing else, inhibited the growth of many of these microorganisms

- *Air handling packages,* either built up or rooftop, are supported on concrete curbs that usually have no means of draining. Stagnant water can often come through the surrounding materials and introduce bacteria into the HVAC systems and building materials. These areas must be sealed with water-proof treatents and provided with a draining system to keep water from standing.

- *Relative humidity* should never be above 70 per cent at any time. Unfortunately, most commercially available sensors that operate for more than a few days falter. Though very few humidity sensors are calibrated to the Bureau of Standards' figures, buildings that appear prone to microbial slimes, mold, and mildew, should have one that has been installed and checked frequently.

- *Air washers* that use recirculating water systems should be abandoned.

- *Humidifiers* should use steam, (not boiler steam!) as a water source, not recirculated water.

- *Spray coil systems* should be abandoned. These are most commonly found in the southern states

- *Find out* if the building uses fan-coil and heat pump units. This type of of unit uses systems of fans that recirculate conditioned air through a secondary system. This is the type of system that uses draining pans under the coils, and these may become a source of biological pollution. Coils, pans, drainage systems, and duct work must be kept clean and free flowing at all times.

- *Air filters* should have properly rated dust spot efficiencies; pleated glass fiber filters should be checked regularly for disintegration and possible glass fiber pollution.

- *After the energy crisis* of the 1970s, some building operators resorted to spraying water on the roofs of their buildings as an inexpensive way to cool that space. Where this is done, the remaining water must be disposed of whenever possible to prevent microbial bloom in the stagnant water.

- The previously mentioned checking should be done with cooling towers on the roof and elsewhere in the building where intake ducts are located. Microbial bloom located near these ducts is a sure and swift way to introduce mold, mildew, and bacteria into the building.

Preventive design Perhaps the most significant accomplishment of air system designers during the past 15 years is the realization that the systems now in use aren't doing what many thought they would be able to do. Design innovation on a practical level today starts with several basic elements:

- *Chose an HVAC system* that fits the building size and use anticipated;

- *Allow for a generous* number of intake and outtake vents.

- *Fit the HVAC system* with regulating generators that are flexible enough to adjust to the varying air pressures they will be subjected to by intake and outake vents.

- *Use only steam* humidifiers—not recirculated air humidifiers.

- *Prefilters* should be used to clean the air prior to passage over higher efficiency filters.

- *A preventive maintenance* program, must be instituted at the very installation of any system with provisions for regular inspection of drain pans, filters, and any area of the HVAC that is accessible, and might fall prey to microbial infestation.

- *Intake vents* should be located where they will receive the largest supply of fresh air. That means away from cars or factories, as close as possible to any natural flora.

Dr. Morey has pointed out that of the 100 or so buildings sampled each year by NIOSH, only a small percentage are determined to have serious health problems. What is of more concern, however, are privately owned buildings whose owners have had unreported outbreaks of "humidifier fever" and even Legionnaire's Disease.

The severity of the problem depends upon the age, location, HVAC system, and maintenance program of the building. Government and industry professionals alike have pushed for elimination of inadequate systems that breed and then cannot recapture airborne microorganisms, as well as programs to check filters, drainage trays, and condenser coils on a regular basis.

As one safety engineer, who wished to remain anonymous, put it, "When it comes to the possibility of population-wide health problems that you as an operator could be held responsible for, an ounce of prevention is worth more than your weight in gold." Ω

Bishop

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Custer

Vogel

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Sick Building Syndrome
Sources of Building Contamination

By David E. Custer

There are many sources and causes of indoor air pollution.

Improperly designed and maintained HVAC systems have been found to be a major cause of indoor air contamination.

Inhalation of microbial contaminants that have been able to enter and breed within a heating, ventilation, and air conditioning system (HVAC) can cause allergic reactions that result in inflammation of the nose (allergic rhinitis), the airways and alveolar spaces (allergic asthma), or alveoli and bronchioles (hypersensitive pneumonitis). The aerodynamic diameter of particles determines where they will be deposited within the human respiratory tract. Particles whose aerodynamic diameter is 20 microns or more, and half the particles down to five microns are deposited in the nose and upper respiratory tract. The respirable fraction involves particles such as bacteria, mold, and fungi that are four microns or less and deposited in the bronchi and alveoli.

Filters Fresh air intakes for HVAC systems filter incoming air to reduce levels of air-borne particulates entering the building. Many buildings use low efficiency filters that allow many particulates to enter the system. These particles themselves can cause respiratory irritation, and when deposited in ductwork can themselves multiply as well as serve as a breeding ground for other microbial growth and contamination.

Location of air intakes Many air intakes are located in or near underground garages, in alleys, or near loading docks, where high concentrations of carbon monoxide can be drawn into the ventila-