

Improving Performance of HVAC Systems to Reduce Exposure to Aerosolized Infectious Agents in Buildings; Recommendations to Reduce Risks Posed by Biological Attacks

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The prospect of biological attacks is a growing strategic threat. Covert aerosol attacks inside a building are of particular concern. In the summer of 2005, the Center for Biosecurity of the University of Pittsburgh Medical Center convened a Working Group to determine what steps could be taken to reduce the risk of exposure of building occupants after an aerosol release of a biological weapon. The Working Group was composed of subject matter experts in air filtration, building ventilation and pressurization, air conditioning and air distribution, biosecurity, building design and operation, building decontamination and restoration, economics, medicine, public health, and public policy. The group focused on functions of the heating, ventilation, and air conditioning systems in commercial or public buildings that could reduce the risk of exposure to deleterious aerosols following biological attacks. The Working Group's recommendations for building owners are based on the use of currently available, off-the-shelf technologies. These recommendations are modest in expense and could be implemented immediately. It is also the Working Group's judgment that the commitment and stewardship of a lead government agency is essential to secure the necessary financial and human resources and to plan and build a comprehensive, effective program to reduce exposure to aerosolized infectious agents in buildings.

COMMERCIAL AND PUBLIC BUILDINGS have been the targets of terrorist attacks in the United States and abroad. Terrorists have used high explosives to destroy or damage the World Trade Center, the Pentagon, and the Alfred P. Murrah Building; U.S. embassies in Dar es Salaam, Tanzania, and Nairobi, Kenya; and the Khobar Towers in Saudi Arabia.¹ In October 2001, terrorists sent biological weapons, *Bacillus anthracis* spores, through the U.S. mail to news media companies and to U.S. Congressional offices. Workers in the former Brentwood Post Office (renamed the Curseen-Morris Processing and Distribution Center); the Trenton, New Jersey, regional

mail processing center in Hamilton Township; the Hart Senate Office Building; the American Media Inc. (AMI) Building; and Rockefeller Center were exposed to infectious spores when contaminated letters were processed or opened. Following these exposures, 22 people became ill, 5 of whom died.² More than 30,000 people are estimated to have received antibiotics as a result of possible exposure to anthrax spores.³ Hundreds of millions of dollars were spent in decontamination and restoration of the attacked buildings and on hardening security in U.S. postal facilities and mailrooms in high-profile buildings throughout the country.

The prospect of biological attacks is a growing strategic threat.^{4,5} Covert aerosol attacks inside a building are of particular concern.⁶ Given the fact that many Americans spend a great deal of their lives in commercial buildings, it is worth examining whether practical actions can be taken to reduce risk to commercial building inhabitants from an aerosolized biological attack.

To this end, the Center for Biosecurity of the University of Pittsburgh Medical Center (UPMC) convened a Working Group to determine what steps should be recommended to reduce the risk of exposure of building occupants after an aerosol release of a biological weapon. The Working Group was composed of subject matter experts in air filtration, building ventilation and pressurization, air conditioning and air distribution, biosecurity, building design and operation, building decontamination and restoration, economics, medicine, public health, and public policy. The Working Group focused on functions of the heating, ventilation, and air conditioning (HVAC) systems in commercial or public buildings that could reduce the risk of exposure to biological aerosols following biological attacks.

This Working Group report provides practical recommendations intended to reduce the risk of building inhabitants to biological hazards. These recommendations are focused primarily on the use of currently available technologies whose applications would be neither prohibitively expensive nor require major renovations or retrofit. The report also includes a brief overview of HVAC systems for those not trained in the science, design, construction, or operation of HVAC systems. This Working Group report draws extensively on the findings and judgments made in a number of important reviews and guidance documents.^{7–12}

WORKING GROUP METHOD

Working Group members from the Center for Biosecurity compiled and reviewed evidence and recommendations from (a) literature published from January 1966 to June 2005; (b) guidance documents written by professional engineering societies and/or government agencies on reduction of building vulnerability to terrorism and on improvement of indoor air quality; and (c) reports and interviews with experts on building security and indoor air quality. Based on this review, core concepts and principles were drafted.

The Working Group was convened on June 13–14, 2005, to discuss and critique the initial draft of the concepts and principles. Following this meeting, a report was drafted that incorporated the Working Group's oral and written suggestions. This draft was circulated to the Working Group for critique in October 2005. The Work-

ing Group's critiques of this draft were incorporated into a second draft, which was circulated in December 2005. The final report incorporates the critiques of the Working Group. All named authors of this report are in accord with the recommendations. Some Working Group members participated as *ex officio* members; those members have no position on the recommendations.

WORKING GROUP PRESUMPTIONS

For the purposes of the recommendations in this document, the Working Group agreed to presume the following:

- Improvements in the performance of HVAC systems that reduce occupant exposure to airborne particles in the range of 1–3 microns in diameter could potentially reduce exposure not only to weaponized infectious agents (the size range of *Bacillus anthracis* spores) but also to naturally occurring infectious agents and allergens of similar size.^{6,13}
- In the future promising new and evolving technologies, such as ultraviolet germicidal irradiation and electronic filtration, might be definitively shown to play an important role in reducing risk to building occupants from deleterious agents in indoor air. However, these technologies have yet to be independently evaluated using standardized methods. The absence of such data does not mean the technologies are ineffective; it means that there was no consensus in the Working Group on their performance characteristics, and, therefore, no recommendations about these technologies were made. New standards are being developed for many classes of devices. The Working Group could support their use in reducing the risk posed by bio-aerosols if their performance characteristics are documented by standardized methods.
- Aerosolized infectious particles fall out of suspension and settle on work surfaces, furniture, and floors; these particles also can stick to clothing and skin and present a risk from contact exposure. This type of risk would not necessarily be ameliorated by improved HVAC system functions.

HVAC SYSTEM OVERVIEW: CURRENT OPERATIONS, POSSIBLE CHANGES

HVAC systems are integral components of most commercial and public buildings.¹⁴ HVAC systems are intended to provide for the health, comfort, and safety of occupants by maintaining thermal and air quality conditions that are acceptable to the occupants^{15,16} through

energy-efficient and cost-effective methods during normal conditions¹⁷ and, to the extent possible, to be responsive to hazardous exposures during extraordinary conditions.¹¹ In principle, all HVAC systems have similar characteristics, but, in practice, they vary from a simple system serving a single thermostatic zone with a single air-handling unit to complex systems comprised of many air-handling units serving hundreds of thermostatic zones controlled by centralized energy management, life-safety, and security systems. Furthermore, in some commercial and public buildings (e.g., hospitals), the HVAC systems must have the capability to remain operational in critical areas during emergency conditions.

Buildings can be commissioned to ensure that building systems, including the HVAC system, are designed to function—and actually do function—according to specifications that address the preparedness and responsiveness requirements of the facility, including those of biological attacks. Building commissioning and re-commissioning are processes conducted by a team of experts and include design review, installation, performance testing, and balancing of systems according to intended design and applicable standards and codes.¹⁸ Well-commissioned buildings have efficient ventilation, pressurization, conditioning, and filtration functions. Air leakage into and out of buildings is low. These improved functions result in better-performing HVAC systems; the quality of indoor air improves, and operating costs are reduced (8–20%).¹⁸ Unfortunately, many buildings are neither commissioned nor re-commissioned.

The design of an HVAC system is influenced by many factors, including but not limited to: the function, size, and configuration of the building; the selection of building materials and furnishings; construction methods; the budgets for HVAC capital equipment, maintenance, and operation; the air-quality requirements based on occupancy and use of the building; and the outside environment. Together, these factors determine the rates at which heat, water, and air contaminants have to be removed from the occupied spaces. Building renovations may change the initially designed airflow patterns and air supply route(s).

The performance of an HVAC system is evaluated by two criteria: system capacity (i.e., size) and system control (i.e., regulation of rate changes). *System capacity* is determined by the HVAC system's ability to provide sufficient heating, cooling, humidification, dehumidification, air dilution, and air cleaning to maintain the desired indoor conditions at design-specified ambient (i.e., likely peak environmental) conditions. *System control* is determined by the HVAC system's ability to regulate the rates of these functions to maintain the desired indoor conditions during all ambient conditions.¹⁹

A typical HVAC system has three basic components, as shown in Figure 1.¹⁴ These components are: (a) out-

door air intake and air exhaust ducts and controls; (b) air-handling units (a system of fans, heating and cooling coils, air filters, controls, etc.); and (c) an air distribution system (air ducts, diffusers, and controls; return and exhaust air collectors; grilles and registers; return and exhaust air ducts and plenums).

HVAC systems perform multiple interdependent functions, including heating, humidification, cooling, dehumidification, ventilation, pressurization, and filtration/cleaning. In most systems, several of these functions are performed simultaneously. These functions affect the occupants' exposure to airborne contaminants, including aerosolized infectious agents. In the context of protection from biological attacks, HVAC systems can simultaneously perform three interdependent functions—ventilation, pressurization, and filtration—while providing the required temperature and humidity control. The Working Group considered each function to determine what changes to each might reduce the risks posed by biological attacks. The Working Group focused primarily on changes that might be made using currently available technologies.

Ventilation

Ventilation is the process of supplying air to or removing air from a space to reduce contaminant levels and to optimize humidity and temperature of the air within the space.¹⁶ For commercial and public office buildings, ventilation is usually achieved by exhausting some of the return air (recaptured indoor air) to the outside environment, replacing it with outdoor air, and mixing the outdoor air with the portion of return air that is being recirculated. After this mixture is filtered, it is conditioned (i.e., heated or cooled, humidified or dehumidified), and delivered to the occupied space as supply air (Figure 1). Improvements in three aspects of supply air might reduce the indoor concentrations of particles (including infectious particles that would be released during an attack): (a) the rate of air exchange (delivery of supply air and exhaust of return air); (b) the airtightness of the return air system; and (c) the effectiveness of the filtration and air cleaning processes (described later).

Rate of Air Exchange

There are two types of air exchange rates in HVAC systems: the supply air exchange rate, which is primarily determined by the thermal loads in the spaces, and the outdoor air exchange rate, which is primarily determined by the floor area and maximum number of occupants. Both of these air exchange rates are important for ventilation control. If the particulate concentration in the outdoor air is lower than in the indoor air, higher outdoor air exchange rates reduce the indoor particle concentrations

Basic HVAC System

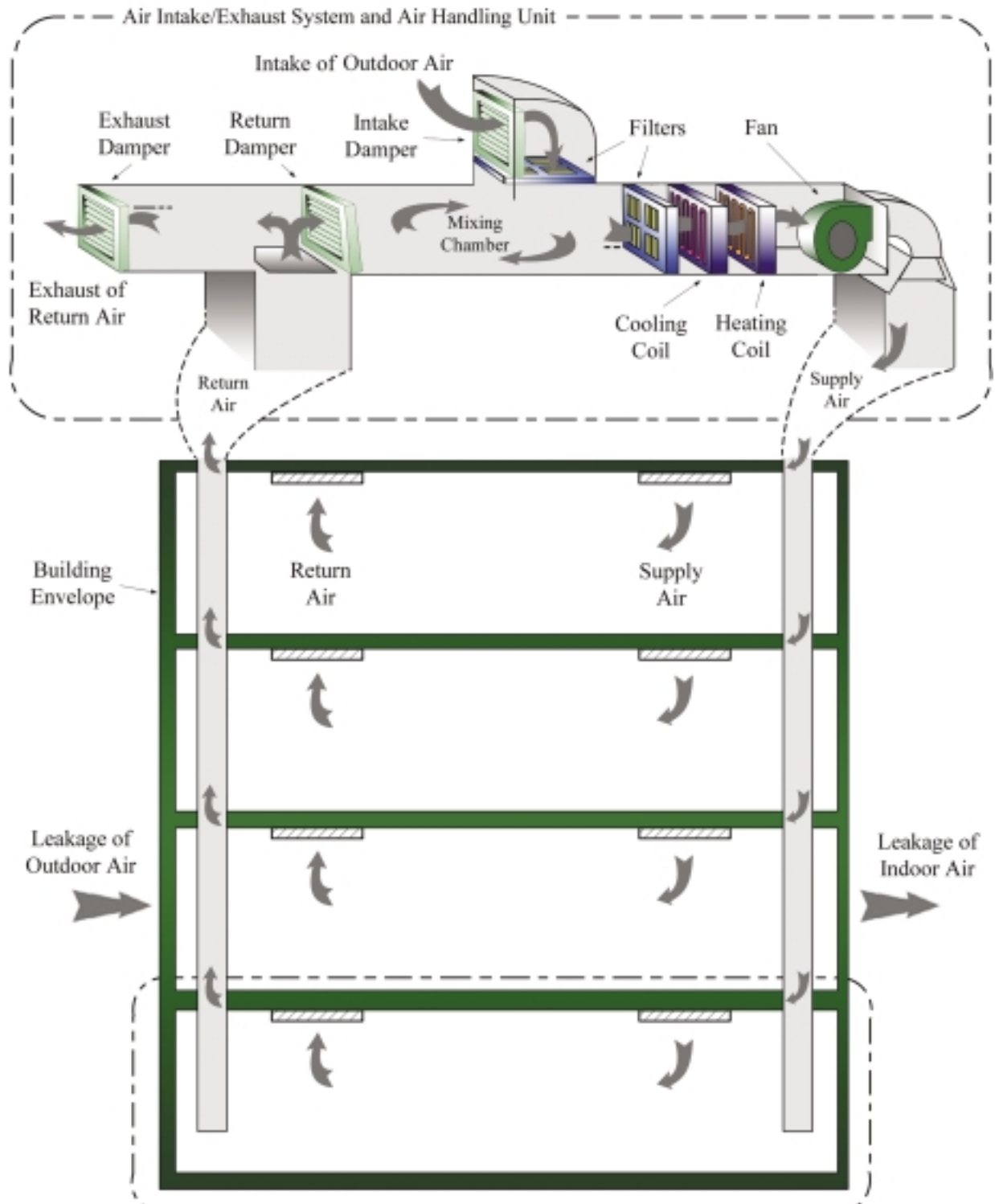


FIGURE 1. BASIC HVAC SYSTEM

by exhausting more of the particle-laden return air and diluting the recirculated return air with cleaner outdoor air. Thus, the indoor particle concentrations are decreased by exhausting and by diluting the return air; this process is referred to as *dilution ventilation*.⁶ Dilution ventilation requires that the system have the capacity for conditioning increased amounts of the outdoor air.

Use of higher exchange rates to maximize the effect of dilution ventilation has advantages and disadvantages. Control strategies for protecting against external and internal releases of biological agents are different. If the particle concentration in the outdoor air is less than the indoor air, a high rate of air exchange will reduce the concentrations of indoor particles. In this case, as the quantity of outdoor air intake is increased, more energy is needed to condition the outdoor air. These processes increase operating costs. If the outdoor concentration of particles (if the aerosol attack involved external releases of biological agents) is higher than indoor concentrations, an increase in outdoor air exchange rate will increase the particles in the supply air. Dilution ventilation will not offer protection against external releases unless special filtration and air cleaning at the outdoor air intake is employed (shown in Figure 1).²⁰

HVAC systems typically vary supply air exchange rates to control temperature and outdoor air exchange rates based on outdoor air temperature, or to reduce carbon dioxide concentration (see Figure 1). In principle, some HVAC systems may be able to control the rates of outdoor and supply air exchange and perform dilution ventilation specifically in response to increased concentrations of indoor air particles. Detection of increases in indoor and/or outdoor particle concentrations requires the use of devices that measure particle concentration in the air and a control system that could either adjust air exchange rates accordingly or generate a warning signal to indicate the need for manual adjustment.^{11,21}

Particle counters are commercially available and are used to measure particle counts in industrial clean rooms. Furthermore, particle counters can be gated so that when the concentration of indoor and/or outdoor air particles in a particular size range increases beyond a certain point, signals can be sent to control devices to modify air exchange rates in zones in which particulate concentrations have increased. Particle counters can measure the concentration of particles of a given size (1–3-micron range) but are not specific for biological material. However, application of particle counters in commercial and public buildings is not widespread, and published literature on performance characteristics in typical commercial settings is limited. Therefore, use of these devices in conjunction with dilution ventilation is not recommended at this time.

The Return Air System

The return air system removes a portion of the supply air from the occupied zones and returns this air to the air-handling units for exhaust or recirculation (Figure 1). One of two methods is used to return air to the HVAC system: the *ducted return* or the *plenum return* (the plenum is the space between the finished ceiling and the floor slab above). *Ducted returns* collect air from each room or zone using return air devices in the ceiling or walls of the occupied spaces that are directly connected by ductwork to the air-handling unit (Figure 2A). The *plenum return* collects air from several rooms or zones through return air devices that empty into the negatively pressurized plenum. The air collected in the plenum is then returned to the air-handling unit by ductwork or structural conduits (Figure 2B). The effectiveness of the return air system plays a key role in indoor air quality since the HVAC system can only exhaust, filter, or condition indoor air that is returned to the handling unit. Regardless of whether the HVAC system has a ducted return or a plenum return, increasing the seal integrity of the return air system and air-handling units (Figure 1) will help to ensure that more air is returned to and reconditioned by the air-handling unit. This can be accomplished by improving the seam seals, recaulking and replacing failed gaskets, and sealing unlined structural conduits. Because return plenums draw air from openings into building cavities, return plenums are more difficult to seal than ducted returns.

Pressurization

Building pressurization describes the maintenance of a pressure differential between the inside and the outside of the building or between different areas or zones within a building. Pressurization also can be used to limit the movement of particles into and/or within a building. If the building pressure is negative compared to the outside, or the zone pressure is negative compared to adjacent zones, particles can enter the building or lower-pressure zones through any opening. The capacity for positive pressurization is controlled by adjusting the difference between the intake of outdoor air and the exhaust of return air at the air-handling units. Creation of a pressure differential between spaces or zones within a building requires that sources of air leakage be eliminated and that the HVAC system be able to provide sufficient air to a zone to create a positive pressure relative to its surroundings (Figure 1). Plenum air returns make it more difficult to achieve pressurization control in a zone, whereas ducted return air systems make it easier to achieve pressurization control in a zone.

A protective effect is achieved by preventing contaminated air movement from an area of lower pressure into an area of higher pressure. Positively pressurized spaces

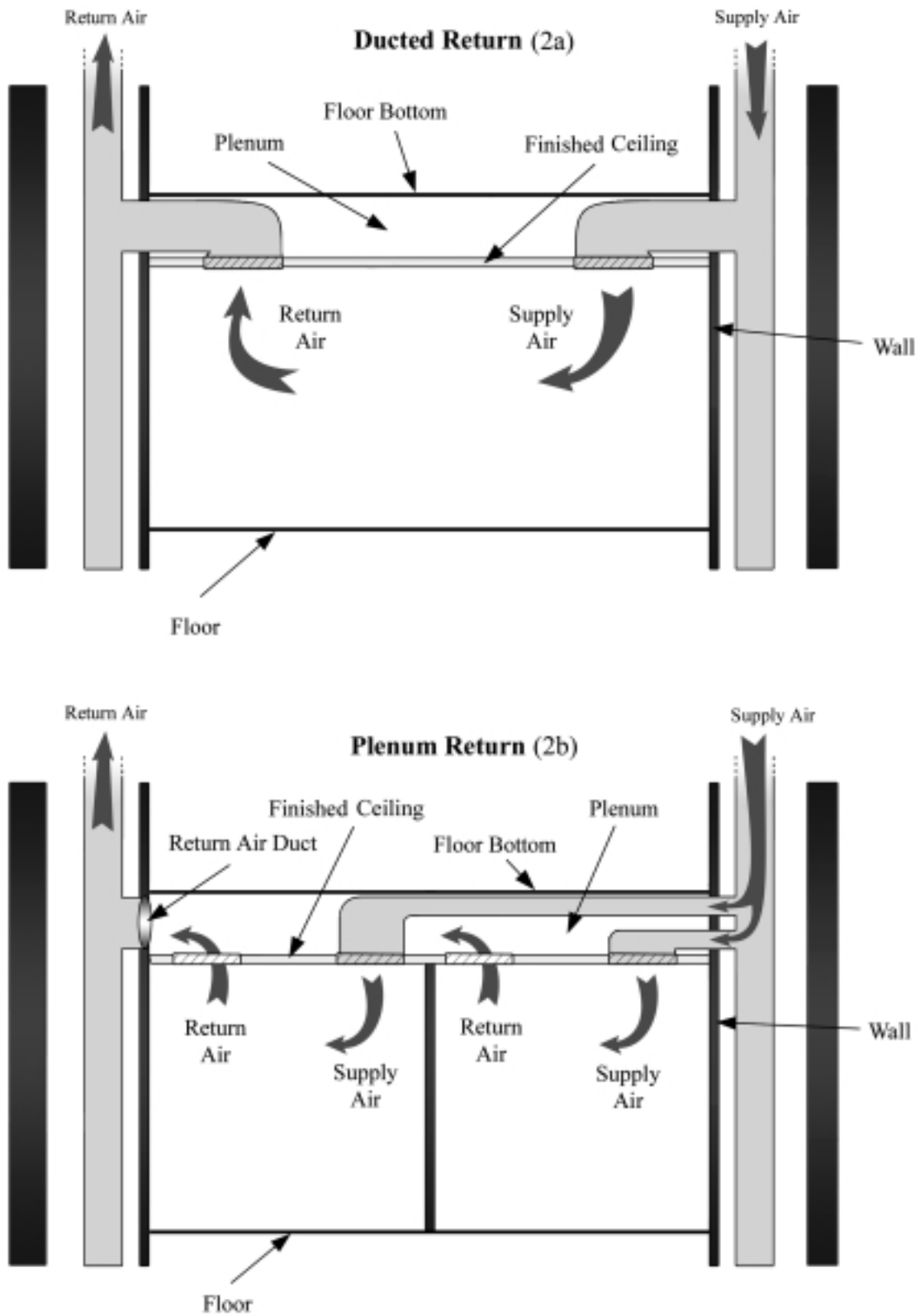


FIGURE 2. THE RETURN AIR SYSTEM

reduce entry of airborne particles; positive pressure is used in hospitals to protect immune-compromised patients; in industrial clean rooms to protect contamination-sensitive products and equipment; and in fire escapes and stairwells to prevent smoke from entering escape routes. If infectious agents were deliberately released outside a building that is positively pressurized, the entry of the particles through the building's outer shell (the envelope) would be retarded but not absolutely prevented. If infectious agents were deliberately released within a zone of a building, dispersion would be significantly affected by the relative pressures in the release zone compared to adjacent zones.¹¹ It is possible to use negative pressurization to reduce the escape of particles from a space. For example, clinical diagnostic laboratories or mailrooms use negative pressure to retain airborne infectious particles and prevent their spread to surrounding (positively pressurized) parts of a building.^{22,23}

Effective pressurization is difficult to achieve when exterior walls, interior partitions, return air systems, and toilet and local exhaust air systems are not designed and constructed to achieve adequate levels of air tightness. In such buildings, a variable amount of air enters buildings unintentionally by a variety of forces, including wind and stack effect (i.e., the chimney effect that occurs when there is a temperature difference between the outdoor and indoor air). Outdoor air also penetrates a building by infiltration through cracks, porous building materials, and damaged sites in the envelope. Air can move into or out of a building or zone through these defects, depending on the pressure differential. This phenomenon is called *envelope leakage*. Most buildings leak, some more than others.^{22,24} Exceptions are buildings that have been designed and appropriately constructed to perform at higher indoor air quality standards (e.g., commercial clean rooms or some laboratories) and those that have been designed and constructed for efficient use of energy.²⁵

Air leakage in ceiling plenums, return and exhaust ductwork, in toilet and local exhaust ducts, and in structural pathways also affects pressurization control. Leakage interferes with pressurization control as air enters through unintended routes and disrupts the balance of supply and return air. If return and exhaust air flow rates are not balanced with the supply air rates in a zone, the required positive or negative pressure in the zone cannot be maintained.

The supply air required for positive pressurization is normally provided by the air-handling unit. Building leaks therefore affect the sizes of the air-handling unit required to maintain positive pressure. Air leakage into buildings reduces the performance levels of the HVAC system (e.g., decreases filtration effectiveness) and increases energy consumption. Envelope leakage can be reduced; depending on the source of leakage, the reduction

is often costly and time-consuming to achieve. Newer techniques are being used to reduce leakage and to decrease moisture and mold accumulation. However, in buildings with severe envelope leakage, it may be impractical to use increased pressurization to reduce the risk during a biological attack.²⁴ Nevertheless, within a given building, pressure differences between zones (e.g., mailrooms) of the building can be effectively used to control particle movement.

Filtration

For the practical purpose of this report, *filtration* is simply defined as the removal of particles from air using a filter. The filtration effectiveness of HVAC systems depends on many factors, including the airflow rate through the filter, the particulate concentration of the air entering the filter, the type of filter, the efficiency of the filter, the location of filters, the filter housing, and the filter maintenance schedule. HVAC system design and building characteristics affect filtration effectiveness. Key factors in determining filtration effectiveness are the method of capture for return air (e.g., ducted or plenum returns), the efficacy of the ventilation system, and the building's envelope leakage. Some of these factors are more amenable to improvement than others.

An HVAC filter element is constructed of semiporous, fibrous material that impedes the passage of particles. Filtration will remove a percentage of particulate matter, depending on the filter material, its depth, and the related fiber or pore size. Filters are characterized by their Minimum Efficiency Reporting Value (MERV),^{11,26} which range from 1 to 20. Filters with higher MERV ratings capture more particles and smaller-sized particles.

High-Efficiency Particle Air (HEPA) filters are equivalent to filters rated between MERVs 17 and 20. At the specified flow rate, these filters effectively remove more than 99.9% of small particles 0.3 microns or larger. HEPA filters are used for specialized rooms in hospitals (e.g., intensive care units, dialysis clinics) and in industrial clean rooms. To function properly, HEPA systems must be designed to match specific pressure requirements (e.g., amount of air flow) and must include appropriate physical housing for the filter to prevent filter bypass. For most commercial applications, implementation of HEPA filtration would be technically and financially impractical.

Currently, most commercial buildings use filters ranging from MERV 5 to MERV 8.¹¹ These filters do not effectively filter particles of 1–3 micron or less. Lower efficiency filters, such as MERV 5, are used to prevent dust and lint from collecting on the heat exchange surfaces or the HVAC mechanical equipment, not to clean air. Depending on the quality of the building's ventilation sys-

tem, most HVAC systems can filter more effectively with higher MERV filters than those that are typically used.¹⁶ However, if a higher MERV filter is used with an air-handling unit that lacks sufficient fan capacity to move air through this filter, the pressure drop through the filter will substantially diminish the supply airflow rate. A large pressure differential can jeopardize the integrity of the filter, allowing air to pass through tears in the filter and to move around the edge of the filter, thereby defeating the filtration process.

Improper fit also can be a source of filter bypass. Filters are located in housings (or racks) within the air-handling unit or associated ductwork. Together, the filter and the housing form a filter system and operate as a functional unit. If the filter does not fit tightly in its housing or is not well sealed, air bypasses the filter, resulting in a net reduction in efficiency.

The amount of particles that are trapped in the filter also has an impact on filtration effectiveness. Trapped particles build up in the filter over time. As the filter becomes loaded with trapped particles, the amount of air that passes through the filter will decrease. A pressure drop from a clogged filter will substantially diminish the supply airflow rate through the air-handling unit if additional power is not provided to the fan.

Among the various factors that affect an HVAC system's filtration effectiveness, three are amenable to improvement: the grade of MERV filters used, the fit of filters in the filter housing, and the frequency of filter changes.

The potential impact of higher MERV filters on particle reduction was analyzed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).^{11,26} Based on these findings, the estimates of collection efficiency were modeled using published dimensions of the pathogens and analytical approximations

of filter performance data with similar sized, surrogate particles.⁶ These findings are summarized in Table 1. According to this study, the use of MERV filters 13–16 would capture >95% of 1–3-micron particles (to include the spores of *Bacillus anthracis*) entering the filter. MERV 15 and 16 filters would capture >95% of rod-shaped particles, such as the tuberculosis bacilli, and would capture a portion of smallpox or influenza virus particles. These data are illustrated in Figure 3.

The effectiveness of filtration also can be improved with prefilters. Prefiltration involves the use of lower MERV filters in series with MERV filters 13 or higher.²⁸ The use of a prefilter of lower MERV can increase the life cycle of the final filters; however, this strategy should be considered only under heavy contaminant load conditions and only after evaluating filter cost and operating life cycle costs. Prefilters also can be placed at the outdoor air intake in tandem with higher MERV filters (13 or higher) to filter out particles in the outdoor air and increase the useful life of higher MERV filters downstream.¹¹

Filtration effectiveness can be maintained if the filters are changed at recommended intervals. Unusual weather conditions can result in higher levels of dust and other particles in the outdoor air; these may cause the filter to clog prematurely. Filter replacement is indicated when the threshold (maximum allowable) pressure drop across the filter is reached or on a schedule dictated by the filter manufacturer.^{8,25}

Optimizing the fit between the filter and the filter housing (filter rack) reduces the amount of air that bypasses the filter. The specifications of the filter housing must be matched to the requirements of the selected filter to achieve this. Proper maintenance of all components of the filtration system is required in order to achieve high performance levels and ensure long-term reliability of

TABLE 1. FILTRATION EFFICIENCY OF PATHOGEN REMOVAL

Organism	Average size (microns)/shape ^b	Estimated filtration efficiency for MERV-rated filters (%) ^a					
		MERV 6	MERV 8	MERV 10	MERV 13	MERV 15	MERV 16
<i>Bacillus anthracis</i>	1.1/spherical spores	15.5	36.7	39.2	96.3	99.9+	99.9+
TB bacilli	0.64 × 1–5/rod	7.4	18.1	19.5	78.6	98.0	98.1
Smallpox virus	0.22/complex capsid	3.7	7.4	7.9	39.6	68.0	70.6
Influenza A Virus	0.098/helical	6.2	11.2	12.0	46.2	71	76

^aResults based on models of MERV test results from two filter manufacturers; reported in reference 6.

^bReported in reference 27.

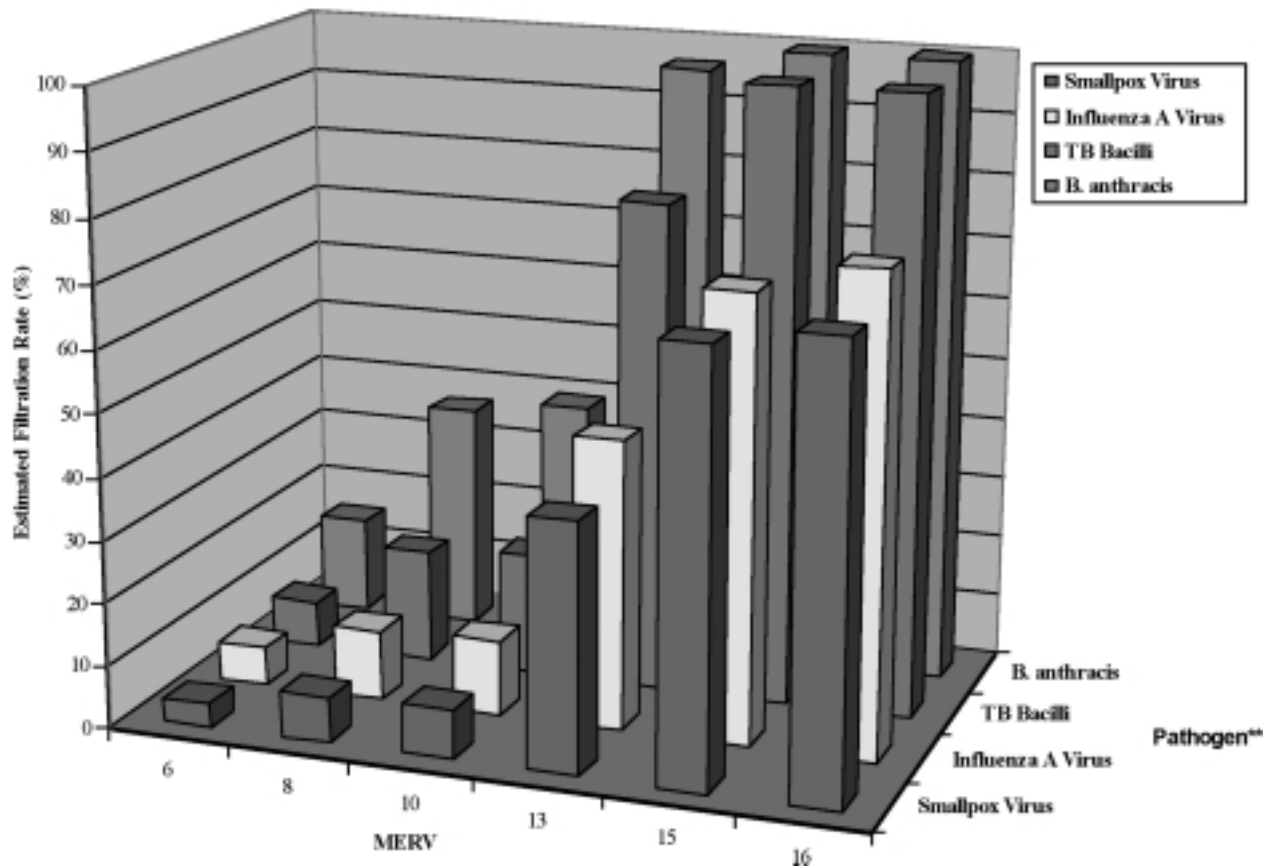


FIGURE 3. ESTIMATED FILTRATION EFFICIENCY OF PATHOGEN REMOVAL*

*Results based on models of MERV test results from two filter manufacturers.^{6,27}

**Average size (microns)/shape for reported pathogens are: Smallpox virus 0.22/complex capsid; Influenza A virus 0.098/helical; TB bacilli 0.64 × 1-5/rod; and B.anthraxis 1.1/spherical spores.²⁷

the filter system. The filter housing can be replaced if damaged, or it can be modified using sealants and gaskets to seal the leaks between the filter and its housing.

Potential Impact of Improved Air Quality on Health and Productivity

Available scientific data suggest that improved indoor air quality may improve the health and increase the productivity of building occupants, and improvements in HVAC systems would be a critical component of improving indoor air quality.²⁹⁻³² A review of existing literature provides evidence linking the indoor air environment to rates of communicable respiratory disease, allergy, and asthma, as well as linking the prevalence of symptoms associated with sick building syndrome (e.g., headache, fatigue, difficulty breathing) to worker perfor-

mance.³² One study estimated that improving indoor air quality could reduce respiratory illnesses, allergies, asthma, and sick building syndrome symptoms, resulting in \$23 billion to \$56 billion (1996 \$US) in annual savings in the United States (Table 2).³²

Some building engineers and operators are concerned that improving indoor air quality by using higher MERV filters is so energy intensive as to be prohibitively expensive.³³ However, cost-benefit analyses have suggested that the direct and indirect benefits of improved filtration efficiency significantly outweigh the costs. One study estimated that the total costs of air filtration (e.g., filter cost, labor costs, energy costs) range from \$0.70 to \$1.80 per person per month and concluded that these costs are “insignificant relative to salaries, rent, or health insurance costs.”³³ Another study found that the cost of upgrading air filtration efficiency to high-efficiency filtra-

TABLE 2. ESTIMATED POTENTIAL PRODUCTIVITY GAINS FROM IMPROVED INDOOR ENVIRONMENTS IN 1996 U.S. DOLLARS^a

<i>Source of productivity gain</i>	<i>Potential annual health benefits</i>	<i>Potential annual savings or gains</i>
Reduced respiratory illness	16–37 million avoided cases of common cold or influenza	\$6–14 billion
Reduced allergies and asthma	10–30% decrease in symptoms in 53 million allergy sufferers and 16 million asthmatics	\$2–4 billion
Reduced sick building syndrome (SBS) symptoms	20–50% reduction in SBS health symptoms experienced frequently at work by ~15 million workers	\$15–38 billion

^aReported in reference 32.

tion (i.e., $\geq 95\%$ efficiency at 0.3 micron) in an office building cost \$24 per person per year (cost includes filter purchase and increased energy costs).³² The author of that study estimated that if the improved filtration resulted in a 10% reduction in respiratory disease, a 1% increase in the productivity of workers who suffer from allergies, and 0.25% reduction in productivity losses associated with sick building syndrome, this could potentially result in an annual savings of roughly \$220 per worker per year.³²

RECOMMENDATIONS OF THE WORKING GROUP

The following Working Group recommendations are made with the intention of reducing the risks to building occupants during bioattacks as well as providing other health benefits to building inhabitants as is possible. Recommendations 1–7 are appropriate for immediate implementation by building owners and/or building operators, as appropriate.

1. Seal, caulk, and replace gaskets to minimize air leakage between the filter and the filter housing and in the return air distribution system. The efficiency rating of any filter is only applicable if the air actually passes through the filter media. Leakage of air from the HVAC system for any reason compromises function. Filter housings are often damaged or not constructed according to specification, so the filter does not fit tightly into the housing. The filter size should be based on the measurements of the filter housing. Duct tape, gaskets, or other sealants should be used to seal the spaces between the filter and the housing. These are simple, inexpensive modifications that will reduce air leakage around the filter.

Return air distribution systems typically consist of sheet metal ductwork and plenums and vertical path-

ways constructed of drywall or masonry materials. Use of odorless mastic and/or other appropriate sealants will reduce the air leakage. If replacement of the seals in the return ductwork or other structural pathways is part of the routine maintenance of the HVAC system, the pressurization control, air exchange rate, and effectiveness of the filtration will be enhanced.

2. Replace existing filters with the highest Minimum Efficiency Reporting Value (MERV) filters that do not cause excessive pressure drops (ones that would significantly diminish the supply airflow rate to the occupied spaces). The use of higher MERV-rated filters can significantly increase removal of the particulates that enter the filter (e.g., MERV 13 will remove $>95\%$ of particles that are 1–3 microns). The cost differences among MERV 3, MERV 8, and MERV 13 filters are minimal, while efficiency of particle removal increases dramatically over the 1–3 micron range (from $<5\%$ to $>96\%$). Use of a prefilter of lower MERV followed by a filter of higher MERV would increase the lifespan of the higher MERV filter and should be considered as an option.

3. Install filters in the outdoor air intake. Use of pre-filters and high MERV filters in the outdoor air intake will reduce the number of particles entering the building and decrease the exposure of building occupants if a bioattack occurs via an outdoor release or a release directly into the air intake of a building.

4. Building operators should change filters routinely based on manufacturers' recommendations or when pressure drop across the filters becomes excessive (indicated by filter gauge pressure). Clogged filters reduce air flow. Furthermore, in humid climates microbes that are entrapped in filters can actually grow in the filters and seed the air as it is filtered.³⁴ The manufacturer's recommendations on the life of the filter are based on average conditions. Actual ambient operating conditions can alter the con-

centration of dust and mold particles in the outside air, increasing the particles trapped in filters.

5. **Consider improvements in control of air exchange rates and pressurization.** Not all HVAC systems have adequate capacity to meet the higher design heating and cooling loads that would result with increased air exchange rates. However, increasing the rate of air exchange is possible in some HVAC systems, although it might increase operating costs. These costs may be justified in buildings that are thought to be at high risk of a bioattack.
6. **Require standardized training programs for people who maintain HVAC systems.** No matter how comprehensive the maintenance plan, if the HVAC system is not routinely and properly serviced, the plan is of limited value. Recommendations 1 through 5 require building operators and HVAC maintenance staff to have appropriate training. Such training should emphasize compliance with HVAC maintenance protocols, proper disposal of HVAC filters, and recognition and management of occupational risks. Many building operators and HVAC maintenance staff have not had formal training for this work, nor do they have opportunities for continuing education.
7. **Commission buildings.** Buildings should be commissioned during the initial phases of design and construction, and re-commissioned (i.e., reevaluated after a period of use) routinely during occupancy. Many commercial buildings have never been commissioned, and so there has been no formal evaluation of the effectiveness of the HVAC systems. Buildings that were not initially commissioned should now be commissioned and then re-commissioned on a regular basis.
8. **A lead government agency for indoor air quality, to include biological hazards, is needed. The lead agency would coordinate with all government and professional organizations that have responsibility for indoor air quality.** In addition to these duties, the lead agency would be responsible for identification and amelioration of the deficiencies in the science base, in technology development, in the technical evaluation capability, in the training requirements for building owners/operators, and in information sharing to improve HVAC technology, operations, and function.

The lead government agency should:

- **Make strategic investments in HVAC science, technology, and operations research, including the development of standardized training programs for HVAC technicians and building operators/managers.** An expanded and coordinated government re-

search effort is needed to address a series of scientific and operational knowledge gaps related to indoor air quality, risk of infectious disease, and optimization of HVAC systems to reduce risk of exposure to infectious agents. Thorough analysis of relevant research programs underway at government agencies (including EPA, DOD, DHS, DHHS, and DOE), at academic institutions, and in professional organizations would provide an assessment of scientific gaps and unmet research priorities.

- **Establish requirements and procedures for evaluating the performance characteristics of existing and new technology, including a robust technology acquisition and evaluation capability.** This resource would provide critical information about technology requirements and methods for evaluating technical performance to guide manufacturers in technology development efforts. The evaluation component should perform independent technical evaluation of devices according to standard protocols using agreed-on standards.
- **Establish a mechanism to share technical information and research findings with government agencies, academia, industry, and professional organizations.** A system to disseminate information about new HVAC technologies and operating systems will expedite the evaluation and adoption of technical advances.
- **Conduct pilot programs in selected buildings to further expand our knowledge base.** Such programs could be funded and coordinated by government and/or professional organizations. Additional information about the impact of HVAC improvements on particle concentration in occupied space would serve to improve approaches to HVAC system operations and provide empirical evidence of effectiveness, appropriateness, and cost.

CONCLUSION

The Working Group's recommendations for building owners are based on the use of currently available, off-the-shelf technologies. These recommendations are modest in expense and could be implemented immediately (i.e., they require no major renovations or retrofits). It is the Working Group's judgment that, despite gaps in scientific evidence and limitations in available technology, a number of practical improvements in HVAC systems can be made now that have the potential to reduce the consequences of an aerosol bioattack as well as the risk of naturally acquired infections. The commitment and leadership of a lead government agency is essential to secure the necessary financial and human resources and to plan and build a comprehensive, effective program.

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