Building Ventilation And Pressurization As a Security Tool

By Andy Persily, Ph.D., Fellow ASHRAE

In recent years many individuals and organizations have advocated the use of several ventilation-based strategies to protect building occupants from accidental and intentional releases of airborne chemical, biological and radiological (CBR) agents. For example, the protection offered by outdoor air filtration and air cleaning in combination with building pressurization has been highlighted. However, many of these recommendations have not considered the key role played by envelope airtightness in determining the effectiveness of these strategies.

This article discusses how ventilation impacts the vulnerability of buildings to airborne CBR releases, as well as some of the strategies where ventilation might be used to increase the level of building protection against such incidents. In particular, strategies involving pressurization of the building interior to protect against outdoor releases are discussed, with specific attention to the impact of envelope airtightness.

Ventilation and CBR Exposure

Ventilation systems are used in buildings for a variety of reasons, primarily to provide heating, cooling and humidity control for occupant comfort. But, they also are designed and hopefully operated to bring in sufficient outdoor air for contaminant control, to remove indoor air containing contaminants (e.g., toilet exhaust), and to create pressure differences to limit undesirable contaminant movement. For example, to limit the movement of motor vehicle exhaust from attached garages into the occupied portions of a building, garage exhaust fans are used to keep the garage at a lower pressure than the rest of the building. However, the actual performance of these systems depends on their design, installation, commissioning, operation and maintenance.

When all these factors are not adequately considered, the design intent may not necessarily be realized in practice. System commissioning is critical to achieving the design intent when the building is first constructed and the systems installed; recommissioning is critical to maintain performance throughout the life of a building.

Ventilation and air distribution are critical with respect to the issues of CBR agents entering buildings, their movement within buildings and their subsequent removal. However, ventilation can have either positive or negative impacts.

For a more complete discussion of ASHRAE's views, see its position paper on homeland security, "Risk Management Guidance for Health, Safety and Environmental Security Under Extraordinary Incidents," at www.ashrae.org/homelandsecurity. Also, the information presented here may not constitute the opinion of the Alfred P. Sloan Foundation.

About the Author

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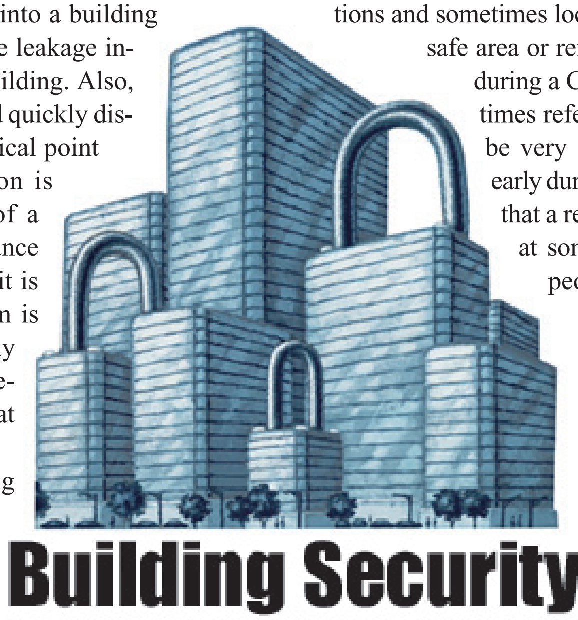
On the positive side, ventilation can reduce the levels of these agents through dilution with outdoor air (assuming the outdoor air is free of the agent of concern). Also, ventilation systems can carry air to filters and air-cleaning equipment, which can remove the contaminants. Ventilation systems also can be used to create pressure differences between zones, thereby isolating potentially contaminated areas from other spaces. For example, ventilation systems can keep mail rooms, loadings docks and public lobbies at lower pressures than general occupied spaces in an office building. If a release does occur in one of these locations, such pressure differences will greatly limit contaminant movement into other areas.

On the other hand, ventilation also can have negative impacts on CBR agent transport. For example, CBR agents that are released outdoors can be brought into a building via outdoor air intakes or via envelope leakage induced by negative pressures in the building. Also, ventilation systems can effectively and quickly distribute agents within buildings. A critical point here is that the impact of ventilation is strongly dependent on the layout of a building and the design and performance of its ventilation systems. Therefore, it is critical to understand what the system is intended to do, and what it is actually doing. This is especially important before developing CBR response plans that involve the ventilation system.



A number of strategies exist using ventilation to limit the impact of CBR events in buildings. While none will provide complete protection against all challenges, increasing the degree of protection is still worthwhile.

One can isolate vulnerable spaces where it might be easier for an agent to be released into a building, for example mail rooms, loading docks, and lobbies. This can be done by keeping these spaces at a lower pressure than adjacent spaces, which is easier to achieve if they are served by their own air-handling system. However, achieving such isolation requires consideration of the airtightness of the space and its boundary to the rest of the building, as well as the pressure differences that exist due to weather and the operation of other ventilation systems.

Another option is to increase the level of filtration as has been discussed elsewhere[1] and will be the subject of a future ASHRAE Journal article by Barney Burroughs, Presidential/Fellow/Life Member ASHRAE.

Many people have been advocating building pressurization as a means of protecting against exterior releases of CBR agents. This strategy involves supplying enough outdoor air to a building such that the indoor pressure increases above the outdoor pressure at all air leakage sites. In combination with good filtration and cleaning of the outdoor air intake, this approach can be effective against outdoor releases. However, successful application requires knowledge that a release has occurred and a level of building envelope airtightness that does not always exist in typical buildings. Furthermore, protection only will be provided against those agents that the filtration system can remove. For example, particle filters do not protect against chemical agents. This strategy, and the impacts of building airtightness, is discussed in some detail later.

Another approach is to use ventilation, tight interior partitions and sometimes local air cleaning systems to create a safe area or refuge where people can congregate during a CBR release. This strategy is sometimes referred to as shelter in place and can be very effective when it is implemented early during an event. Again, one must know that a release is imminent, or has occurred at some distance from the building, so people can be moved to the shelter. Also, if the implementation of shelter in place does not involve localized air cleaning, one must know when the outdoor agent has cleared and it is safe to leave the refuge.

Finally, one can implement changes in HVAC system operation based on CBR agent detection to achieve isolation of contaminated spaces and provision of safe egress paths or safe refuges for building occupants. This is similar to what is done with smoke control systems where smoke detectors are used to trigger damper and fan operation to isolate the fire zone and provide a safe exit route for the building occupants. However, using such systems for CBR agents requires agent detection capabilities that are beyond what is available at a reasonable level of cost and performance. This limitation in detection is particularly true for biological agents. Also, the appropriate response depends on the particular building, its ventilation system configuration and the location and type of release, and the appropriate HVAC changes are not always obvious in any given case. Therefore, it is very important not to implement changes in HVAC operation without understanding the system performance as it exists and how the change will impact the airflow patterns in the building. Making changes without a good understanding of the outcome could actually worsen the situation.

Building Pressurization and Envelope Airtightness

Some individuals and organizations are recommending that buildings be protected against outdoor CBR releases by pressurizing the building interior relative to the outdoors, and filtering and cleaning the incoming air to remove the CBR agents. This approach has the potential to provide very good protection against such outdoor releases if the filtration is adequate and the pressurization is effective. However, these recommendations often neglect the issue of contaminant entry into the building through leaks in the building envelope. Envelope airtightness is relevant because air that enters a building through leakage sites is uncontrolled in quantity and distribution and is not filtered.

Measurements of envelope airtightness in a large number of commercial and institutional buildings have shown that these buildings generally are quite leaky, except in those rare cases where they have been carefully designed and built to control air leakage.[2] *Figure 1* is based on those data and shows commercial building airtightness expressed in effective leakage area (ELA) at a reference pressure of 4 Pa (0.016 in w.g.) in units of cm^2 of ELA per m^2 of envelope area.[3] This plot also contains horizontal lines corresponding to the airtightness of leaky and tight U.S. homes and tight Swedish homes as reference points. These data show that commercial buildings are not particularly airtight, and that the available data do not correlate with year of construction. Therefore, no evidence supports the common expectation that newer buildings are much tighter than older buildings.

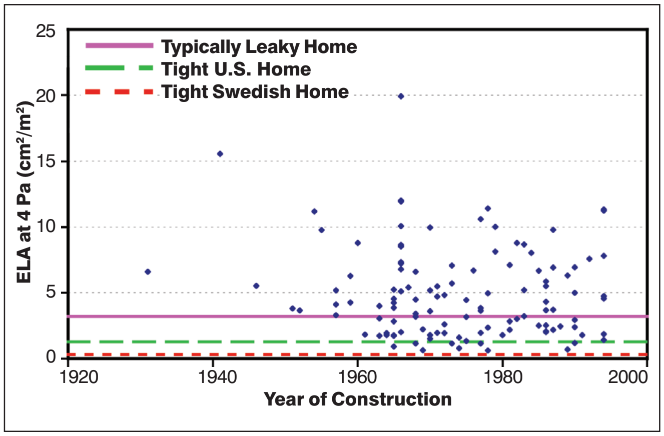


Figure 1: Commercial building envelope airtightness.

Combined with pressures caused by weather and ventilation system operation, envelope leakage can result in significant contaminant entry into a building. In addition, the existence of such envelope leakage can make it more difficult to maintain the desired level of pressurization. Therefore, for these pressurization strategies to work, one must pay attention to envelope airtightness and determine the airflow rate required for pressurization based on envelope leakage and the pressures induced by weather.

Figure 2 shows a building (represented by the rectangle) and its mechanical ventilation system (represented by the blue arrows above), with an agent outside the building that must be kept outside. In pressurization/filtration strategies, the intent is to bring the outdoor air into the building through an effective filter that removes the agent and at a quantity that maintains the indoor air pressure above the outdoor air pressure. If successful, air flows from indoors to outdoors at all leakage sites on the building envelope and the filter removes all the CBR agents, keeping the indoor air clean and safe. However, if this approach is not properly implemented, air infiltration can occur (as shown by the red arrow in the lower left-hand corner) allowing unfiltered air and agents to enter the building.

Success requires that the envelope is sufficiently tight and that the net airflow into the building is large enough to overcome the pressures created by outdoor weather conditions. The amount of airflow required is directly related to the building envelope leakage—the leakier the envelope, the more airflow is needed.

Fortunately, there is sufficient understanding of building airflows and pressures, as well as the calculation tools to design successful pressurization systems, to consider the impact of envelope leakage in designing these systems. NIST is working on more specific design guidance for building pressuriza-

Q&A on Building Security

The ASHRAE satellite broadcast on homeland security for buildings was seen by more than 20,000 viewers at 1,000 sites earlier this year. The broadcast discussed key issues related to building protection from chemical, biological and radiological attacks. The following is a Q&A with Andy Persily that was part of the satellite broadcast.

Q: What sources of data regarding commercial building envelope leakage rates exist, and what levels of leakage are typical for these buildings? How tight can a new building realistically be built? And, don't tight buildings have indoor air quality problems?

A: The envelopes of several hundred commercial and institutional buildings have been tested for leakage using the fan pressurization method. Some of these tests are described in a paper in the March 1999 issue of the *ASHRAE Journal* ("Myths About Building Envelopes"). These, and other tests, reveal that U.S. commercial buildings have envelope leakage rates similar to U.S. homes when normalized by envelope area, which are not particularly tight. However, there is significant variability among buildings that cannot be explained by

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tion strategies that should make it easier to determine the airflow required for successful pressurization as a function of weather conditions, envelope airtightness and building geometry, primarily building height.

Impact of Infiltration on Filter Effectiveness

Note that the entry of unfiltered air through envelope leakage can be thought of as a form of filter bypass. *Equation 1* is the mass of contaminant entering from outdoors M_C at constant outdoor concentration C_{out}, outdoor air intake rate Q_{intake} and envelope infiltration rate Q_{inf}.

$$M_C = C_{out}\, Q_{intake}\left(1-\varepsilon\right) + P\, C_{out}\, Q_{inf} \qquad (1)$$

A filter, with efficiency ε, is located at the outdoor air intake, and P is the penetration factor that accounts for any contaminant losses associated with infiltration (i.e., the building envelope itself acting as a filter). This equation can be rearranged as shown in *Equation 2* (assuming $P = 1$) and expressed in terms of Q_{total}, which is the total amount of outdoor air entering the building, i.e., Q_{intake} plus Q_{inf}.

$$M_C = C_{out}\, Q_{total}\left[1-\varepsilon\left(1-Q_{inf}/Q_{total}\right)\right] = C_{out}\, Q_{total}\left(1-\varepsilon'\right) \qquad (2)$$

where ε' is the effective filter efficiency based on the value of Q_{total}. *Figure 3* depicts the impact of agent entry via infiltration on the value of this overall filtration effectiveness ε'. The plot shows this effective efficiency of the system vs. the filter efficiency itself. Again, the effective efficiency on the vertical axis describes the actual efficiency of contaminant removal accounting for bypass around the filtration system due to envelope infiltration.

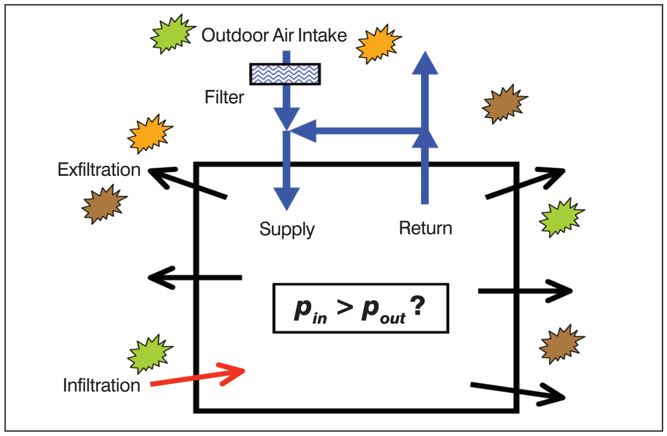

Figure 2: Pressurization/filtration protection.

The top black line represents the situation when there is no infiltration, and the effective efficiency is the same as the filter efficiency. The various colored lines are the effective efficiency for different values of the ratio of infiltration to intake (Q_{inf}/Q_{intake}). For example, if the infiltration rate through the envelope is the same as the intake rate through the system, as depicted by the yellow line, the effective efficiency is reduced by 50%.

Given current airtightness levels in commercial buildings, infiltration rates equal to outdoor air intake rates are not atypical, particularly for a system with airflow rates out of balance

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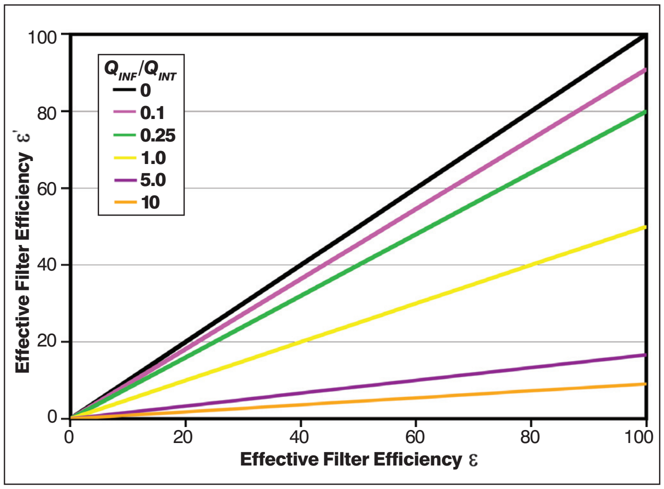
age, building type or construction. Tight commercial buildings can and are built in the U.S., Canada and elsewhere, through careful attention to detail in design and construction.

With respect to concerns about tight buildings and indoor air quality problems, that is why we have mechanical ventilation systems with outdoor air intakes. A properly designed, installed and operated mechanical system will bring in adequate amounts of outdoor air, filter it and deliver it to the occupied space, thereby reducing the likelihood of indoor air quality problems. In fact, envelope infiltration can lead to indoor air quality problems as the outdoor air entry via this mechanism is uncontrolled as to rate and distribution, unfiltered and can contribute to moisture problems.

Q: What level of building pressurization is recommended to keep CBR agents out of buildings, and is it realistic to overcome pressures caused by wind? Is it adequate to simply provide more supply than exhaust? What are the pressures needed to isolate specific rooms, such as mail rooms? What systems are available to accurately monitor pressurization of buildings relative to the outdoors?

A: While there have been some suggestions of recommended pressurization levels on the order of 5 Pa to perhaps 10 Pa (0.02 to 0.04 in. of water), no standard requirements have been established. In theory, as long as the pressure is higher indoors than outdoors, pressurization will be successful. However, in practice the level of pressurization should be based on the pressures that need to be overcome, primarily those due to wind and stack effects, but also those induced by system operation. Therefore, each building's pressurization strategy should be designed based on the climate, the building height and the envelope leakage. Note that while providing more supply than exhaust airflow is necessary to pressurize a building, it may not be sufficient. One must determine the amount of oversupply based on the design pressure differences, and consider the pressures over the entire building envelope as a function of height, as well as local effects such as those associated with return air plenums that are negatively pressurized relative to the occupied space.

The pressures and airflows required to isolate specific rooms, such as mail rooms, again must be based on considerations of the pressures that must be overcome as a function of weather and system operation. The use



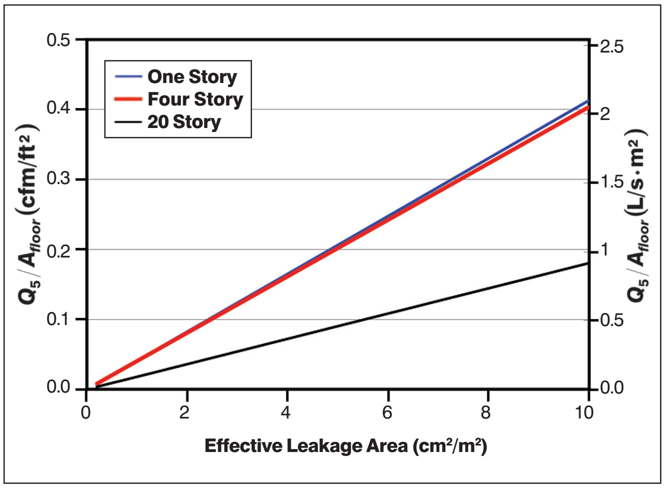


Figure 3 (left): Impact of infiltration on filtration effectiveness. Figure 4 (right): Airflow needed to achieve 5 Pa pressurization.

with their design values. This makes the need for good system operation and maintenance, including recommissioning, that much more important.

Sample Calculations of Infiltration Rates

To develop a better sense of the potential degradation in filtration effectiveness, calculations were performed for three generic office buildings used in a previous study of energy impacts of infiltration.[4] These three buildings included a one-story, four-story and 20-story building. For each building, Q_5, the airflow required to pressurize each building to 5 Pa (0.02 in. w.g.) was calculated, as well as the infiltration rate and envelope pressure difference under selected conditions of system operation and weather. An indoor-outdoor pressure difference of 5 Pa (0.02 in. w.g.) was used in this example, but is not a definitive criterion for successful building pressurization.

Figure 4 is a plot of Q_5 the net airflow rate per unit floor area required to achieve a +5 Pa (+0.02 in. w.g.) pressure inside the building as a function of the ELA value with no wind and no indoor-outdoor temperature difference (therefore no stack effect). This net airflow would be the outdoor air intake rate minus any exhaust or spill airflows. Alternatively, it can be thought of as the net supply airflow into the building minus any return or exhaust airflows. As expected, a leakier envelope means more

of a dedicated air handler or exhaust system in such spaces, along with real-time pressure monitoring and control, can help ensure the success of such strategies. There are many commercially available devices for monitoring pressure differences in buildings, including several commonly used in laboratory and health-care ventilation systems.

Q: How should a building's HVAC system be operated in the event of a CBR release? Should it be turned off, run at 100% outdoor air, or all exhaust? Does the recommendation depend on whether the release is internal or external? Would the answer be any different if the building is leaky or does not have effective filtration?

A: There are two critical issues that must be considered in responding to these questions. First, one is assuming that they know a release has occurred and where it has occurred. This is a big assumption given the current state of detection technology and the characteristics of many of the CBR agents of concern. Second, as stressed in the satellite broadcast, it is extremely difficult to generalize on the best response to a release, as it depends strongly on the building configuration, the HVAC system design, and the nature and location of the agent release.

In general, if the agent is released outdoors, the objective is to limit its entry into the building. This can be done through pressurization strategies if the system has that capability or by reducing the outdoor air intake by closing dampers or shutting down the system. However, any of these strategies needs to be developed for the specific building in question and evaluated as to its feasibility before being relied upon. If the release occurs indoors, the objective is to limit its transport beyond the release location and, if possible, to remove it from the occupied space by filtration or exhaust. In these situations, the principles of smoke control systems can be useful, where exhaust from the release area can achieve the desired end. Again, the details of how to implement such an approach are inherently building and system specific.

The ability of any HVAC-based strategy in limiting occupant exposure to a CBR agent will depend on the level of filtration, the envelope airtightness and the system capabilities. These factors should all be investigated as part of the planning process, as they will determine the effectiveness of any such strategy.

A DVD of the satellite broadcast is available at www.ashrae.org/bookstore.

	ELA = 1 cm²/m²				ELA = 10 cm²/m²		
	Δp Min., Pa	Q_{INF}/Q_{INT}	Q for 5 Pa L/s·m², (cfm/ft²)		Δp Min., Pa	Q_{INF}/Q_{INT}	Q for 5 Pa L/s·m², (cfm/ft²)
One-Story				**One-Story**			
ΔT = 0 °C, 0 m/s	+19.2	0	0.21 (0.04)	ΔT = 0 °C, 0 m/s	+0.6	0	2.12 (0.42)
ΔT = 20 °C, 5 m/s	+10.4	0	0.41 (0.08)	ΔT = 20 °C, 5 m/s	–8.2	1.29	3.83 (0.75)
Four-Story				**Four-Story**			
ΔT = 0 °C, 0 m/s	+19.9	0	0.21 (0.04)	ΔT = 0 °C, 0 m/s	+0.6	0	2.07 (0.41)
ΔT = 20 °C, 5 m/s	+4.8	0	0.51 (0.10)	ΔT = 20 °C, 5 m/s	–14.2	1.57	4.79 (0.94)
20-Story				**20-Story**			
ΔT = 0 °C, 0 m/s	+68.1	0	0.10 (0.02)	ΔT = 0 °C, 0 m/s	+2.0	0	0.93 (0.18)
ΔT = 20 °C, 5 m/s	+11.3	0	0.48 (0.09)	ΔT = 20 °C, 5 m/s	–39.2	1.32	4.02 (0.79)

Table 1: Results of infiltration calculations.

airflow is required to pressurize the building. The difference between the three buildings is based primarily on the ratio of their envelope surface area to their interior volume. Note that for the highest value of ELA shown in the figure, the net airflow required to pressurize the building is on the order of 1.5 L/s · m² (0.25 cfm/ft²), which is somewhat higher than typical minimum outdoor air intake rates for commercial buildings.

Infiltration rates, envelope pressures and infiltration-intake ratios were also calculated for the three buildings under the following conditions:

- Net outdoor air intake equal to 0.5 L/s·m² (0.1 cfm/ft²), based on 10 % of a supply airflow rate of 5 L/s·m² (1 cfm/ft²);
- ELA of 1 cm²/m² and 10 cm²/m² (0.01 and 0.14 in.²/ft²);
- Indoor-outdoor temperature difference of 0°C and 20°C (0°F and 36°F); and
- Wind speed of 0 m/s and 5 m/s (0 mph and 11 mph).

Table 1 shows the results of these calculations for the three buildings. For the two values of ELA, corresponding to relatively tight and leaky envelopes, the first column contains Δp min. in Pa, which is the minimum indoor-outdoor pressure difference calculated on the building envelope. A positive value indicates that the indoor pressure is higher than the outdoors at all locations, while a negative value indicates a lower indoor pressure somewhere on the envelope. The second column for each value of ELA is the ratio of the infiltration rate Q_{INF} to the outdoor air intake rate Q_{INT}, and the third column is the net airflow rate (per floor area) required to achieve a +5 Pa (+0.02 in. w.g.) indoor pressure difference relative to outside. These values are given for each building for zero wind speed and temperature difference and for elevated values of both.

Note that for the tight envelope case, the indoor-outdoor pressure difference is greater than 5 Pa (0.02 in. w.g.) for all cases, and therefore the ratio of infiltration to intake is zero. The net airflow required to maintain a 5 Pa (0.02 in. w.g.) of pressurization is less than or equal to the value assumed in the simulation. However, for the leakier envelope, negative pressures and, therefore, nonzero infiltration exist for the nonzero weather conditions in all three buildings.

As expected, the taller buildings have more negative pressures due to the stack effect. The infiltration-intake ratios are around 1.5 for these cases, resulting in significant degradation of filtration effectiveness as discussed with reference to *Figure 3*. Finally, the net airflow required to achieve at least 5 Pa (0.02 in. w.g.) of positive pressure everywhere on the envelope is significant for the leaky envelope case.

The results in *Table 1* show that the protection offered by building pressurization and outdoor air filtration/air cleaning can be degraded significantly by envelope leakage. Therefore, building pressurization strategies should be developed and implemented based on weather-induced pressures and envelope leakage.Building tightening should be considered as a protective measure itself, as it makes pressurization easier to achieve and increases "effective" filter efficiency. Nevertheless, more information is needed on building tightness and the penetration of outdoor contaminants through leakage, as well as additional analysis that considers other building and system configurations and other weather conditions.

Recommendations

While challenges remain in increasing the level of building protection to CBR agents, the ASHRAE Presidential Ad Hoc Committee on Homeland Security has made a number of recommendations that can be implemented almost immediately:[5]

- First, know your ventilation systems. Find the documentation, the fan specifications, the sequence of operations and other relevant material. If they are missing, you may need to create them. The objective here is to understand what your system was designed to do.

The next step is to evaluate its operation relative to the design intent. If it is not performing as intended, you need to address the deficiencies that exist. This will enable you to use the system more reliably in the event of a CBR incident. It is also very likely to improve indoor air quality conditions and energy efficiency during normal operation. As part of this effort, you should make sure you know how to shut off your ventilation systems quickly, including exhaust systems. While it won't always be clear when this needs to be done, the capability should be there. Some are even recommending quick shutoff switches that are easily accessible to emergency responders. As part of this system evaluation, verify that your system is operating in accordance with ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality,* and other relevant requirements, particularly the outdoor air intake quantities.

• Second, secure your mechanical rooms and outdoor intakes to prevent tampering. Air intakes should be located as high as practical aboveground. If relocating the intakes is not an option, access can still be limited or they can be monitored with surveillance cameras or alarms.

• Finally, it is critical to understand the consequences of any HVAC changes that are considered in response to CBR incidents. Without such understanding, some changes can make the situation worse. Therefore, do not take any actions regarding system operation unless the effects on airflow are thoroughly understood. Finally, do not make changes to normal building operation to "reduce building vulnerability" that degrade indoor air quality or comfort under normal operation.

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