High-Volume Air Exchange for More Efficient Remediation

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Following Hurricane Katrina my company, Indoor Environmental Technologies, was retained to assist in the remediation of a large government building on the Gulf Coast. The project proved to be more complex than anticipated, with IET on-site for over three months. Procedures we developed with the remediation contractor resulted in a more than 50% reduction in both the estimated time and estimated cost of remediation.

Due to concerns created by the Oklahoma City bombing, the recently-built 10-story structure was designed to withstand a similar attack. This design also resisted damage from Katrina, despite a location only two blocks from the Gulf subjected to sustained winds above 140 mph. Two feet of water entered the ground floor due to storm surge, but physical damage to most of the building was remarkably light.

No windows broke, but they leaked. They leaked a lot. Windows and other building assemblies are seldom able to prevent leakage caused by very high winds. At sea level, wind pressure per square foot is calculated at about 13 pounds at 50 mph, 51 pounds at 100 mph and 100 pounds at 140 mph.

Materials in the building were not dried rapidly enough to prevent extensive mold growth on wet materials, especially in wall cavities and where up to five layers of drywall were present. Growth was generally found near the perimeter of the structure, especially on exterior walls.

Building management decided to use visual criteria to determine whether remediation was needed in an area and when remediation had been successfully completed. Air, surface and bulk sampling were not used. Intrusive inspection determined which areas and materials needed remediation.

IET's client was the remediation contractor. We cooperated with consultants working for the government and for the general contractor. Top priorities were to complete remediation rapidly and in a systematic manner so that reconstruction could begin as quickly as possible.

The Katrina project will be used in this article as a case study to illustrate some of the procedures IET developed to meet these objectives. Our primary discovery was that high air exchange rates combined with relatively small volume containments allows the remediation process to proceed more quickly. IET also de-

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veloped methods that allowed more than 200 small volume containments to be assembled and relocated rapidly and efficiently. We will discuss the second of these methods first.

Reusable Local Containment Barriers

Traditional remediation often involves isolating entire rooms, treating them as units. On the Katrina project, most affected materials were located on exterior walls, with growth often extending up the walls less than two feet, mostly inside cavities. We speculated that remediating effected walls rather than rooms would speed the process. On this particular project, the time required to remediate entire rooms would have been even greater than usual, as most areas had 20' ceilings and many of the rooms or areas were large.

For each affected area a floor sheet was installed, then lightweight reusable panels were used to form a barrier about 4' out from the wall. A containment ceiling was created by attaching poly to the wall with a 1x2 about 7' up, stretching the poly over to the panels, then attaching the poly to the outside of the panels with spray adhesive.

Panel frames were made of 1¼" Schedule 80 PVC pipe. A variety of connectors were used, including Ls, Ts, snap clamps, 3-way and 4-way fittings. Most panels were 7' wide by 5½' high, as this size could easily be moved from floor to floor on the elevators. Panels were also constructed in 3', 4', and 5' widths.

Panels were wrapped in 6 mil poly and secured with spray adhesive, snap clamps and tape. The poly was good for about 10 setups.

Panels were connected with PVC pipe fittings. 2" to 3" gaps between panels were left partly open for makeup air entry. To prevent the assembly from collapsing forward under negative pressure, 1x2 cross-members ran from the 1x2 ceiling support on the wall to each point where panels joined. See below for a more detailed description and diagrams of the process. See Figure 1 for a photo of a completed containment.

Massive Air Exchange

IICRC *S520 Standard and Reference Guide for Professional Mold Remediation* and other published standards generally recommend 4 to 12 air changes per hour (ACH) in contained areas as an engineering control for a safer working environment. Since this recommendation is a minimum, higher ACH creates no conflict with the standard. We wondered if significantly higher air exchange rates might contribute to more rapid and effective remediation.

It is commonly assumed the volume of air exchanged should be in rough proportion to the volume of the work zone, or that using a large negative air machine for a small containment causes problems. In fact, negative pressure is created when air is exhausted from a space while the total <u>area</u> of openings in that space available for infiltrating air is restricted. Negative pressure has no direct relationship to the <u>volume</u> of the space being exhausted. Small volume containments can easily be maintained at high air exchange rates but "normal" negative pressure by increasing the area of makeup air openings. As long as appropriate negative pressure is maintained, these openings can be any size or location.

Assume a local containment 25' long, 4' wide. Height averages 6', so volume is 600 CF. Attaching a 2000 CFM negative air machine generates 200 ACH.

The containment is sealed tightly so makeup air enters only at the far end from the exhaust point. Average air speed across the containment is 83.3 feet per minute. In other words, air will, on average, cross this work zone and be exhausted in about 18 seconds. This leaves little time for fine particles to settle onto surfaces or accumulate in the air!

In the real world, due to turbulence and other factors, these results are not consistently achieved. However, high air flow across the work zone has many benefits even when true laminar air flow is not maintained.

Benefits of high volume air flow include:

- Employee safety: High air exchange from a clean(er) source means that the air in the containment is significantly less contaminated. IET has no specific data, but it is reasonable to assume air exchanged at 200+ ACH will be at least 95% lower in contaminants than air being exchanged at 4 ACH. Effective engineering controls may justify reducing the level of PPE. However, due to high momentary exposures during initial phase remediation, respiratory protection is always needed. It is best to err on the side of safety.
- Employee comfort: Airflow helps keep workers cool, reducing heat stress. Decreasing the level of respiratory protection may also help worker comfort.
- Entry/exit controls: IET generally found it possible to complete controlled demolition and detailed cleaning in a single work period, eliminating entry/exit while work was in progress and minimizing cross-contamination.
- Processing time: The most labor-intensive and time-consuming aspect of mold remediation is detailed cleaning; often done by cleaning all surfaces, allowing aerosolized dust to settle, repeating as needed. Three or more rounds of detailed cleaning are sometimes required to reach a true "dust-free environment" level of cleanliness, which means that a minimum of four or five days may be needed for the entire process. Fine dust particles aerosolize easily and settle slowly. They are the most difficult to remove using traditional methods. Using the system discussed in this article, the area of surface to be cleaned is greatly reduced since only a small portion of the room is con-

tained; the volume of air that dust particles can disperse into is reduced to an even greater extent; and fine particles remain aerosolized for only brief periods. Most importantly, there is no need to wait for dust particles to settle between rounds of cleaning. When reusable containment panels were combined with high air flow, most work zones were contained, remediated and successfully "cleared" in one day. (See Figure 2.)

Concerns

The cleanliness of makeup air is critical. Under negative pressure, air infiltrates at multiple, usually unknown points. If contaminants are present in the path of infiltrating air, they may be pulled into the contained space, negatively impacting the remediation process and worker exposure.

High volume air exchange may pull in outside humid or hot air when exhausted to the exterior of the building. On this project, this was not an issue, as air exhausted back into the conditioned space.

For a given containment setup, increasing ACH does not change the pathways infiltrating air travels. When the same negative air pressure is maintained, the volume and velocity of airflow through any given infiltration pathway is about the same whether the exchange rate is 4 ACH or 400 ACH, so the chance of contamination from infiltrating air is also about the same.

Containments can be built to withstand high levels of negative pressure. Unlike high airflow, the volume and speed of air infiltrating at

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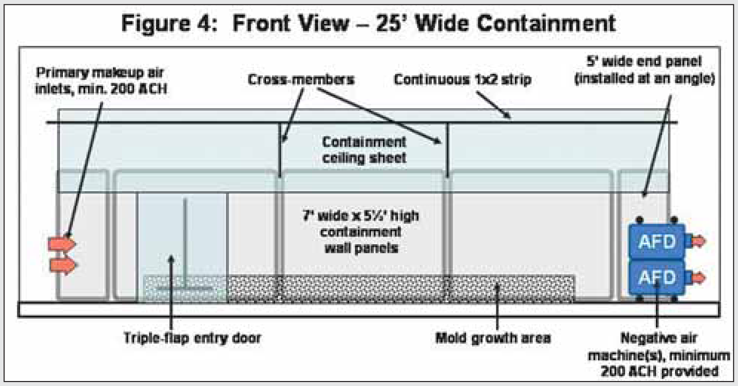
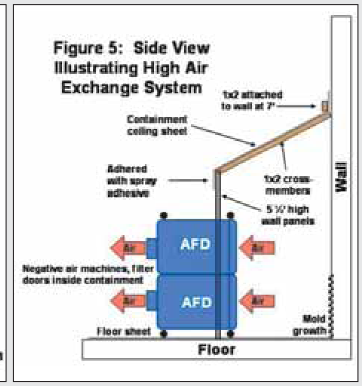
Figure 1. Reusable containment panels and high air exchange system operating at about 300 ACH. Note two 2000 cfm negative air machines and data-logging manometer.
Figure 2. Interior of containment after remediation, entire process completed in one day.
Figure 3. High air exchange system in use for a small volume containment. Approximately 1500 air changes per hour.





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uncontrolled points increases with high negative pressure. As air volume/speed increases, so does the chance that contaminants will be pulled in. Negative pressure higher than 10 Pa (0.04" wg) provides no real benefits and significantly increases both the potential for cross-contamination and the strain on the containment structure.

On larger containments, multiple negative air machines were used when needed to keep nominal ACH above 200. To maintain adequate negative pressure, multiple machines were also used in some situations where wall cavity design allowed massive infiltration. On some smaller containment setups, ACH was well over 1000. Workers likened this to working in a wind tunnel. (See Figure 3.)

Step-by-Step Process

Example: A typical containment area about 38' in length with an affected area about 30' wide. See Figures 4 and 5:

1. Install a floor sheet. Set up and connect panels. Five 7' wall panels and two 5' end panels (installed at a slight angle) are used, with one of the wall panels incorporating an entry door. Attach a 10' wide ceiling sheet to the wall at about 7' height with a continuous 1x2 furring strip. Install 1x2 cross-members under the ceiling sheet from the wall 1x2 to the wall panels to prevent air pressure from pushing the panels in and reducing working space. Stretch the ceiling sheet over the cross-members, securing to panels with spray adhesive.
2. Install two 2000 CFM negative air machines, providing 270 nominal ACH for this 888 CF containment. Test the system to ensure that containment is structurally solid. Adjust makeup air to maintain 5 to 10 Pa (0.02 to 0.04" wg) by covering openings between panels or cutting additional openings in panels. Ideally, most makeup air enters at the far end of the containment from the exhaust. Depending on conditions in the surrounding area, an exhaust diffuser may be used or the exhaust may be ducted into another area.
3. Four people don PPE and enter containment. Starting at the far end from the negative air machines, two workers remove drywall to 2' or 4' above the floor. A small-diameter circular saw/HEPA vac system minimizes dust. Drywall is cut into 2' squares. Removed materials are immediately bagged. The other two workers follow behind, removing screws and starting the cleaning process. On large containments, the number of workers may be increased.
4. When drywall removal is complete, all workers continue cleaning, primarily with HEPA vacs.
5. A second round of detailed cleaning starts at the far end of the containment and involves HEPA vacuuming followed by damp-wiping of all surfaces.
6. After the second round of cleaning, monitoring with a particle counter begins. The particle level of the makeup air at 0.5 μm/CF is compared to the level inside the containment. Soft bristle counter brushes are used on surfaces to aerosolize remaining dust particles. If measured particle levels climb when this is done, additional cleaning is performed. Remediation is complete when disturbing surfaces does not increase particle count. Workers vacuum off PPE and doff it, bagging gloves and protective clothing. Debris bags are double-bagged. Workers exit containment. Steps 3-6 can usually be completed in a single work period (2 to 3 hours).
7. IET performs post-remediation evaluation using visual inspection and particle counter methods.
8. If IET approves the work, the consultants working for the government and the general contractor inspect the work. If approved, the containment is disassembled and ceiling and floor sheets discarded. Panels are moved to the next scheduled work area.

The entire process from setup of containment to post-remediation verification and disassembly was usually completed in a single day.

As stated, on this project the client decided to use visual criteria to determine whether remediation had been successful, focusing on achieving a truly dust-free environment. However, on other projects, IET has set up an on-site laboratory with a microscope, using non-viable air and surface samples to document successful remediation. When work flow is properly structured, it is still possible to complete the whole process in a single day. IET has never had a work zone that passed the dust-free surface and particle count criteria fail our microbial sampling criteria.

For localized contamination, IET has found a strategy of minimizing the volume of the containment while maximizing airflow across the containment to be highly effective. It speeds the remediation process while increasing its effectiveness.

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