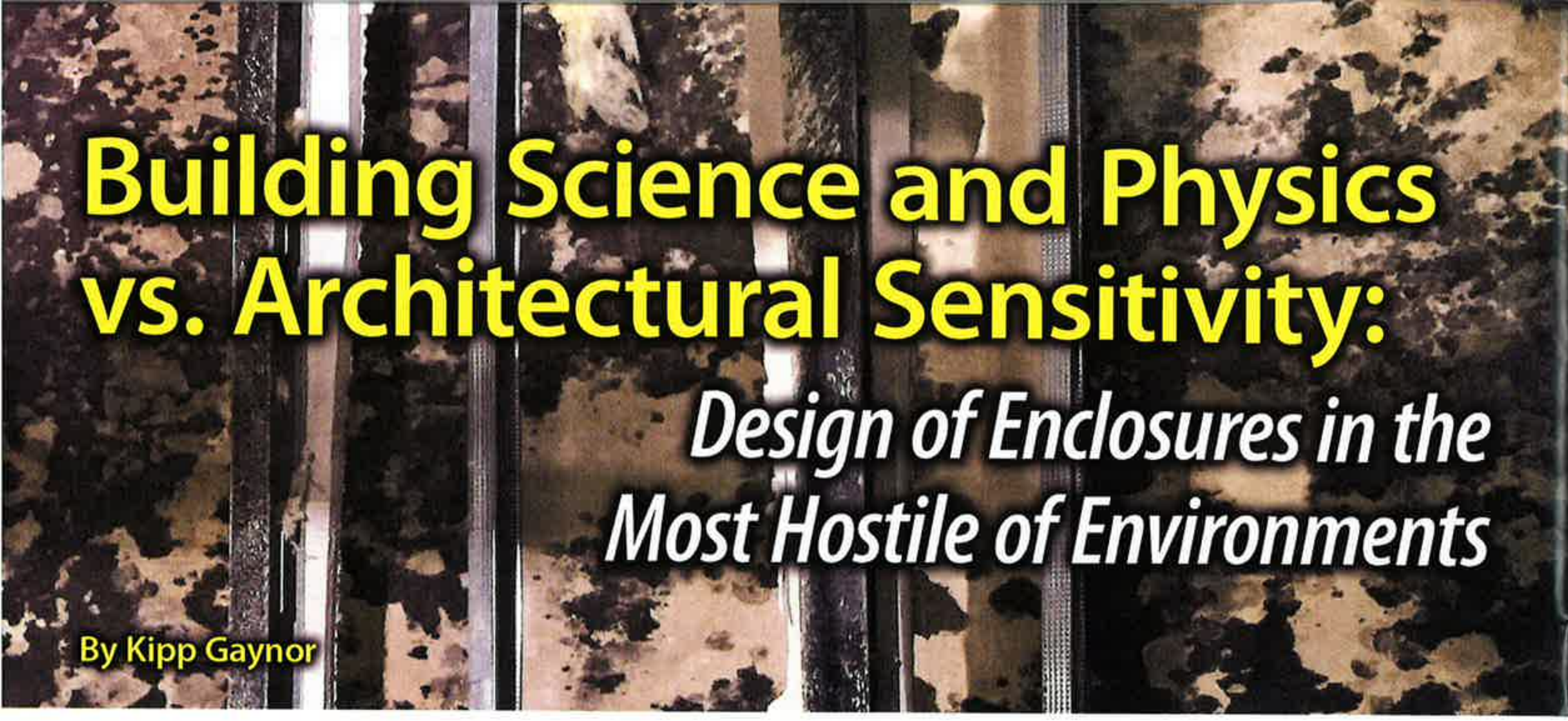

Building Science and Physics vs. Architectural Sensitivity:

Design of Enclosures in the Most Hostile of Environments

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ABSTRACT

Background

Architectural design and sensitivity to skyline views and noise concerns for penthouse unit occupants impacted the original design of the cooling system on a high-rise, leading to placement of the cooling towers in the basements of the east and west wings. Eleven-story air shafts facilitated the cooling tower exhaust, as well as the parking garage ventilation. Organic growth and saturated drywall were observed, giving rise to an investigation.

Evaluation

A fire-rated shaft assembly was determined to be woefully inadequate in reconciling the vapor drive and water management issues associated with the extremely high humidity and the temperature differentials across the enclosure. Physical configuration and a lack of thought led to systemic water and air leakage through the enclosure wall. Full shaft wall replacement was required.

Design

WUFI' analysis was used to validate the design concept using an exterior insulation approach, coupled with a redundant vapor barrier system. Further complicating the design were extreme vapor pressure differentials and flow reversals, as well as structural issues related to concrete deterioration and post-tensioned concrete pocket protection. Design provisions also included data logging, and a tattletale system to monitor for bulk water infiltration was designed into the enclosure system.

INTRODUCTION

Architectural design and sensitivity to skyline views and noise concerns for the penthouse units impacted the original design of the mixed-use complex's cooling system, leading to placement of the cooling towers in the basements of the east and west wings. Two exhaust air shafts were created to transport the cooling tower exhaust up 11 stories, as well as to provide for parking garage exhaust ventilation. The west shaft measured approximately 14 by 18 ft, and the east shaft measured 11 by 13 ft (see schematic plan view in **Fig. 1**). The original construction documents specified a UL fire-rated shaft wall to perform as an exterior enclosure wall as well as a fire barrier. Little detailing or consideration was given on the available building plans to manage the hostile environmental conditions the wall was to be exposed to.

So, take a Zone 4 climate, add rainforest humidity (approaching 100%), coupled with South Florida-type exhaust heat from the cooling tower exhaust, and add in the emergency generator radiator exhaust and cooling demands. Now cycle those conditions on and off multiple times an hour to cause frequent moisture drive reversals, mix in garage exhaust air flow to manage our Mid-Atlantic summer (100°F) and winter (10°F) environmental conditions, and season all of that with significant positive shaft pressurization and negative building pressurization. Let's also punch a bunch of holes through the walls for supply

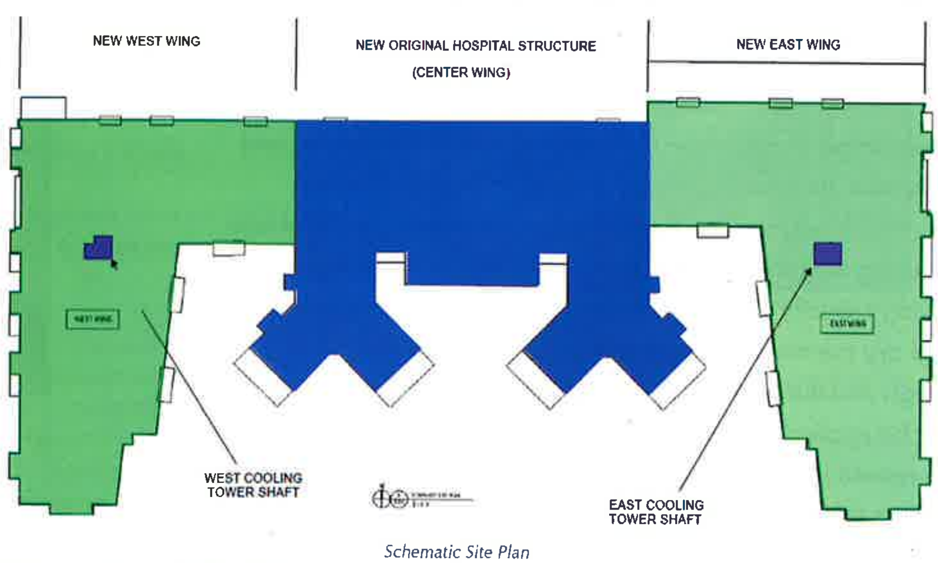


Figure 1. Schematic Site Plan.

Figure 2. Columbia Hospital for Women.

and return ducts and then seal them poorly or not at all. Fold all of that into the mix, and what do you get? Organic growth, saturated drywall, distressed finishes, and displeased residents. This perfect storm of conditions gave rise to our investigation of the exhaust shaft wall system in coordination with other prime consultants focused on the mechanical, environmental, and architectural aspects of this project.

PROJECT DESCRIPTION/BACKGROUND

The subject project is a mixed-use complex that features nine stories of high-end residential condominium units, plus commercial spaces (located at the street level) and two stories of below-grade parking for the complex.

The property features three prominent wings. The center wing was formerly the Columbia Hospital for Women, an ornate and historic Italian Renaissance-style structure with terra cotta tile, limestone, and tapestry brick that was built circa 1916 (see **Fig. 2**).. It was repurposed into a very attractive luxury residential condominium located in the center of Washington, DC's high-end residential real estate district.

The east and west towers were added during the conversion, and the property received its certificate of occupancy in 2006 to begin the structure's post-hospital career. The new wings were constructed of post-tensioned cast-in-place concrete with a masonry cavity wall enclosure that utilizes aluminum and glass punched windows, as well as window wall systems at various locations. The condominium includes 225 residential units, along with four commercial spaces (refer to **Table 1**). The conversion project also features a pool, community room, billiard room and several guest suites.

The east and west towers were configured with basement-level mechanical rooms that house garage ventilation fans, and several cooling towers to furnish chilled water to the water source heat pump loops in each tower. These towers serve the residential units as well as the commercial spaces. The cooling tower located in the west mechanical room is dedicated to the grocery store. It serves the refrigeration systems that operate the coolers. This cooling tower operates almost continuously throughout the year.

A computer-controlled active energy management system controls building heating and cooling as well as the garage exhaust/fresh air ventilation systems. The west and east shafts were coupled with the garage areas to manage all the exhaust through the shafts up to the roof, where fixed louvered panels line a rooftop cupola. The cooling towers were exhausted into a metal plenum space at the ceiling of the mechanical rooms (near the B-2 floor level), and this structure created the "floor" of the shafts. Automated variable-speed fans and mechanical louvers managed by the energy management system were supposed to flush the hot, humid air to the main-level roof exhaust point. The fan-driven exhaust ventilation of the cooling tower exhaust was intended to dilute the heavy-humidity air (fog) emanating from the cooling tower exhaust and move the air up the shaft. Static fan pressure was required to move the garage, generator, and cooling tower air through the shaft to the rooftop cupola, where it was exhausted to the environment.

The vertical shaft utilized concrete masonry unit (CMU) walls at the B-1 and first-floor levels to achieve a two-hour fire separation. The walls were treated with a black coating to impede moisture migration through the walls. From the second floor to the main roof level, the shaft utilized a shaft wall assembly to provide the required fire rating. The wall surfaces and concrete floor slabs and columns were also treated with the same black coating.

During the cooling seasons, the client observed moisture- and mold-related issues in the hallway and telephone/communication

West	East
• Residential units	• Residential units
• Commercial space (grocery store)	• Commercial space — Bike shop — Hardware store — Gym

Table 1. Shaft cooling tower layout by building wing.

Figure 3. Telephone closet at floor line. Note moisture reading during summer proposal visit.

West	East
Grocery store Cooling tower for coolers to be operational (7/24/365)	No cooling towers were operational (winter heating season for interior spaces).

Table 2. Operational status of air shafts at the time our investigative work.

closets (**Fig. 3**) at several residential floors adjacent to the west shaft, and in the hallway and trash rooms adjacent to the east shaft. An environmental hygienist and mechanical consultant had been retained (prior to our involvement) and had issued documents related to their findings to date.

Historical information indicated isolated reports of drywall repairs within a small number of residential units to address organic growth, as well as recurring maintenance issues and visible distress related to moisture damage along portions of the common-area corridors.

At the time of our proposal visit, the exterior conditions were hot and humid (DC is in the mixed-humid climate Zone 4). Moisture meter readings identified saturated drywall in the common-area telephone/communication closets, as well as visible organic growth on drywall at several floors in the west wing. Access to the west cooling tower plenum revealed a dense fog (like a steam room); visibility was approximately five feet. At the time of our proposal visit, we observed that the cooling tower fans were not operational, and the moisture was dwelling at the base of the exhaust shaft. Our firm rendered a proposal to investigate both shafts.

In late fall, the client authorized us to perform an investigation. The ideal timing to investigate the building would have been at the peak of the summer cooling season; however, access during the peak of the cooling season would have been difficult due to the visibility and wet, sauna-like conditions in the lower portion of the shaft present during the summer season cooling tower operations. Accordingly, we performed our investigation in December (after the east shaft cooling towers were shut down for the winter and only one cooling tower was operational in the west shaft (refer to **Table 2**). This made our evaluation work somewhat more challenging since the conditions that manifested during the peak of the cooling season (wet drywall, high static fan pressures, etc.) were not occurring during our investigation, so the winter sampling and testing results needed to be considered in light of the fact that the conditions and system operations had changed significantly between our first and follow-up visits to the project.

Our investigative work sought out explanations to the observations noted months earlier

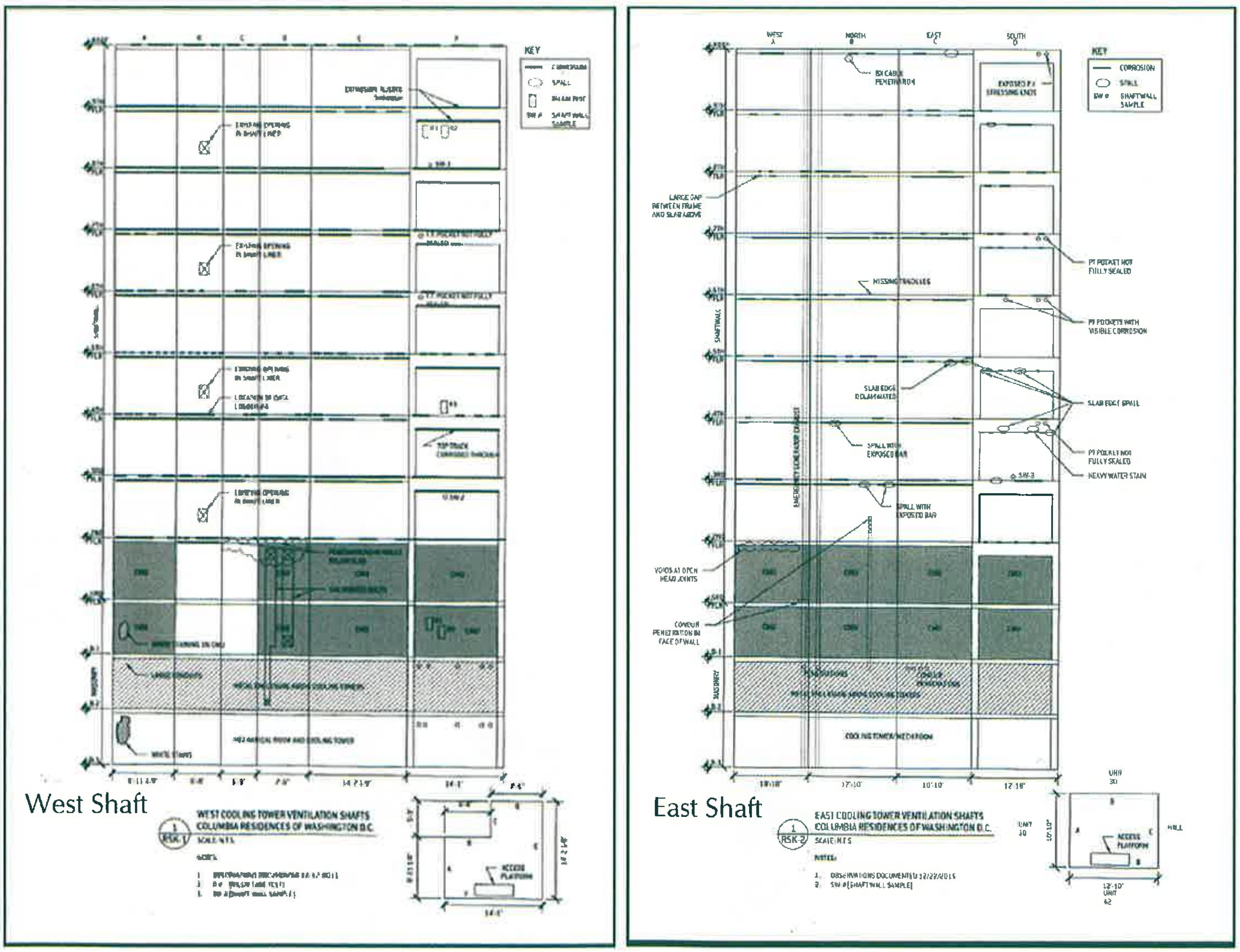


Figure 4. Significant visual observations of shaft conditions from swing stage access (through vertical shaft).

(during the summer proposal visit)—conditions that were no longer manifesting at the time of our investigation. Our evaluation was conducted over the course of several weeks and was completed prior to Christmas when ambient temperatures were in the mid-30s to high 40s Fahrenheit. At that time, no saturated drywall was present in locations that previously exhibited moisture during our August proposal visit.

The construction of the shaft includes a fire-rated shaft wall from the main roof (above the ninth floor) down to the second-floor level. A floor-to-ceiling CMU wall was constructed at the B-1 and first-floor levels to provide a fire separation wall from the commercial and first-floor units.

Separate from our involvement, the owner retained a mechanical engineering consultant to evaluate the mechanical systems and their operational issues to help address a number of mechanical problems. The owner also retained an environmental hygienist who was involved with the organic growth issues that had been manifesting for some time prior to our involvement.

SCOPE OF INVESTIGATIVE WORK

Our investigative work included the following:

1. Swing stages were erected to facilitate access to the exterior surfaces of both the west and east shafts to better determine the as-built construction and condition of the enclosure assembly that separates the cooling tower exhaust from the building's interior spaces. Rooftop rigging, including beams and counterweights, were erected at the main roof level. A cable-suspended platform allowed vertical access from the roof to the ground level (a large array of conduits precluded swing-stage passage to the B-1 and B-2 levels) within the shaft.
2. Moisture meter testing of spaces accessible from the building interior (telephone/communication closets, units, corridors, etc.). Testing was also performed at the face of the fire-rated shaft wall panels.
3. Visual inspection from corridors, private residences, mechanical rooms, roof areas, and telephone/communication closets.
4. Intrusive sampling of the fire-rated shaft wall assemblies.
5. Intrusive sampling of the interior drywall.
6. Infrared scan of the shaft walls.
7. Infrared thermometer spot checking of surface temperatures within the shafts.
8. RILEM tube test of the shaft wall coating and panel framing transitions.

SURVEY OBSERVATIONS

A number of significant conditions were encountered during the shaft survey performed from the swing stage. Refer to **Fig. 4**, which provides a schematic fold-out view of the wall planes observed in the two shafts.

The following is a summary of the significant items we encountered during our survey work:

1. Severe corrosion of the fire-rated shaft wall assembly was encountered throughout the shaft. The metal framing of the shaft wall assembly "bucks" water that gravity causes to flow down the face of the wall, thus directing water to the inside of the wall assembly (**Fig. 5**).
2. A thin, black, roller-applied coating was installed over the gypsum panels and concrete surfaces. The coating was discontinuous at metal framing/gypsum panel interfaces. RILEM tube testing indicated the coating was able to resist a static head pressure; however, our

observations revealed that it was not detailed to shed water at the metal transitions or metal-to-slab interfaces.

3. No transitional sealants or water management details at the exterior wall plane existed.
4. Concrete deterioration was visible along the slab edges (i.e., spalling, corrosion, exposed reinforcement, and failed post-tensioning pockets (**Fig. 6A** and **6B**).
5. The light-gauge metal framing components of the fire-rated shaft assembly were experiencing significant cross section loss. The metal was so severely corroded in areas that portions of the galvanized steel sill and head tracks could be removed by hand (**Fig. 7A** and **7B**).
6. Smoke bottle testing confirmed that the shaft wall transitions at the vertical concrete columns that are located at several corners of the exhaust shafts created a breach in the air control layer. The shaft wall construction terminated at and abutted the columns in some locations, so the assembly was not continuous around the perimeter of the shaft. A lack of fire caulking and detailed provisions for robust air sealing of the shaft wall system created the pathways for moisture-laden air to compromise the corridor wall finishes (**Fig. 8** and **9**).

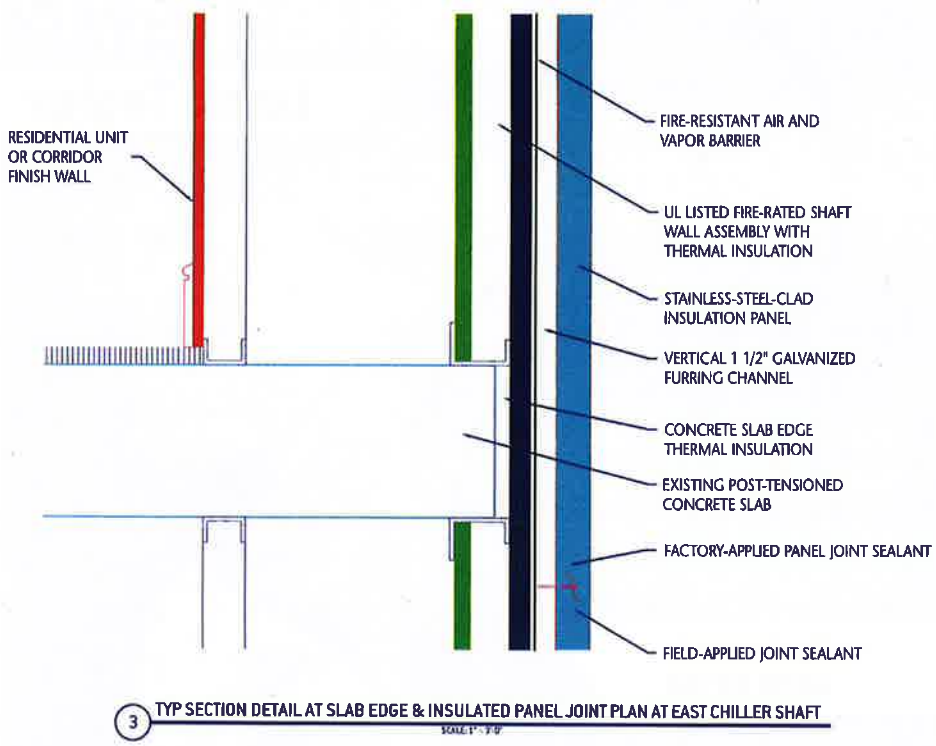


Figure 5. As-built shaft wall section.

WEST SHAFT

During our swing stage access, we noted that the cooling tower and fans would cycle off and on periodically. Humidity and temperature increases were noticeable with the ambient humidity and temperatures oscillating from approximately 40%/38°F to 60%/50°F when the exhaust fans were operating. The air speed during operations at that time of the year would be best described as a slight breeze. Subsequent to the investigative work, we had the opportunity to experience the shaft conditions during summer operations. Those conditions were measured with a humidity of approximately 99% and temperatures in the mid-80s. The air flow rate was significantly more dynamic in the summer cooling season than in the winter.

INTERIOR DESTRUCTIVE SAMPLING AND TESTING

Unit layouts were not typical floor to floor, and interior finishes varied with conditions/construction, ranging from tiled kitchens and baths to built-in cabinetry and closet/storage space. The wall cavity space between the demising wall and fire-rated shaft assemblies ranged from about 4 inches to as much as about 18 inches. Drywall sampling of interior demising walls was performed at limited random locations and revealed organic growth on the cavity side of the unit walls. The environmental hygienist subsequently performed air sampling of the cavity spaces at each floor as an initial step in establishing whether environmental

Figures 6A and 6B. Post-tensioning pockets exposed and vulnerable to shaft environment.

Figures 7A and 7B. Severe corrosion of sill and head tracks encountered at various floor lines.

conditions warranted further destructive sampling and testing.

The telephone/communication closet area was heavily stained from previous water contact. The facer of the wall was delaminated along the base of the wall as well as the ceiling (refer to **Fig. 3**). In addition, a ½-in. plywood panel had been installed to the wall to receive the telecommunications equipment. This plywood concealed organic growth at the closet wall across the surface of the closet adjacent to the shaft area.

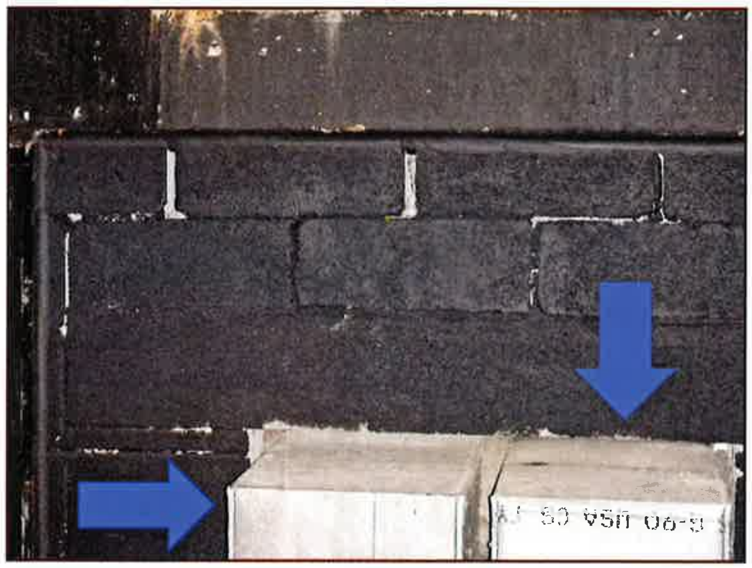


Figure 8. Fire-rated masonry wall separating shaft area and commercial/first-floor level. Note supply and return ductwork inside shaft with unsealed wall penetrations (see blue arrows).

Air leakage was detected along the closet-to-corridor wall transition. The hollow metal door frame openings were determined to be coupled with the shaft, based on smoke bottle testing and psychrometer readings. A micro manometer was used at various floor levels to establish what the pressure fields surrounding the shaft liner and unit/public space area were that immediately surround the shaft. Testing revealed significant variations in pressure fields and positive/negative pressurization. Much of the variation related to the timing of the fan operations at the base of the shaft.

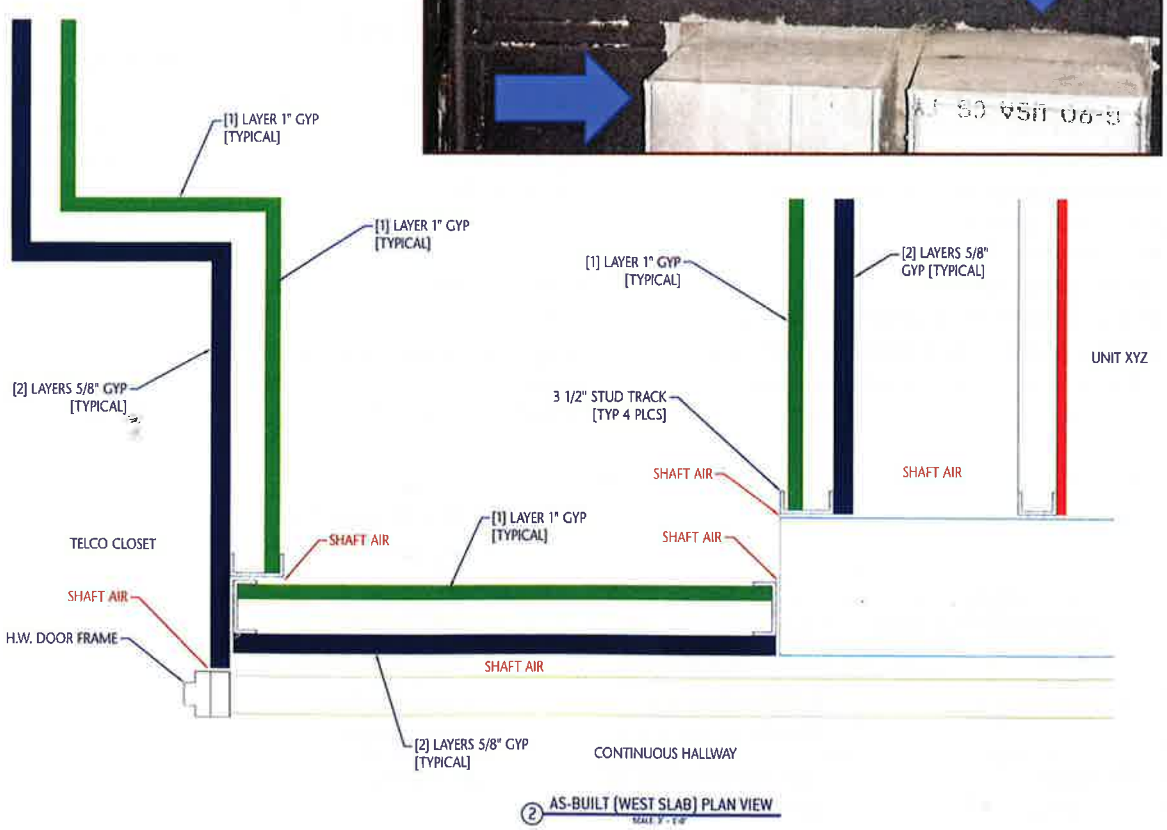


Figure 9. As-built (west slab) plan view.

The hallway walls were visibly distressed in the form of wrinkled drywall, cracked painter's caulk lines, and discolored wood crown molding (refer to **Fig. 6A**). Demolition of the hallway wall finishes revealed significant organic growth along the backside of the hallway wallboard.

FINDINGS

Our firm performed the structural engineering and enclosure evaluation, survey, and sampling, which revealed that the fire-rated shaft assembly was woefully inadequate to reconcile the vapor drive and water management issues associated with the extremely high humidity and the temperature differentials across the enclosure. Structural distress along the slab edges and vulnerable post-tensioning pockets were also identified as structural issues to be addressed. Our opinions of the enclosure issues included that the positive pressurization of the shaft, coupled with negative building pressurization, encouraged air leakage through the shaft walls/enclosure assemblies. The physical configuration of the shaft wall and a lack of detailing led to systemic water and air leakage through the enclosure wall, which in turn led to the need for complete rehabilitation of the shaft wall system.

DESIGN TEAM

Multiple prime consultants retained by the owner to manage the various issues may be seen in **Table 3**.

CONCEPTUAL DESIGN

Several design concepts were considered, including leaving the fire-rated shaft liner in place and developing structural repairs of the corroded elements to restore the existing fire-rated assembly. Those repairs would then be followed by an application of a waterproofing treatment to the existing shaft walls. Other considerations included overcladding of the shaft liner with an exterior insulation system, fabrication of a custom metal duct liner installed over spray-applied water and vapor control layers, liquid-applied membranes, metal cladding configured as a rain screen, and other combinations of cladding and vapor-impermeable treatments. One approach considered performing the remedial work from the interior of the units.

Removal and replacement of the existing fire-rated shaft wall system was also considered. Such removal would accommodate inspection for organic growth and abatement, as well as air sealing of the demising wall surfaces from the shaft side. In the conceptual design phase, several significant advantages to this approach were identified as follows:

1. Removal and replacement of the shaft liner alleviated the costs associated with performing the work from the unit side (where extensive finishes would impact costs).
2. Complete removal allowed for full inspection and access to perform abatement of organic contamination.
3. Air sealing of the shaft required a continuous plane on the shaft side of the wall from which to construct a robust air barrier. Reconfiguration of the fire-rated assembly would afford continuity of the surface from the roof to the plenum transition.
4. Resident safety was maintained, and inconvenience minimized.
5. Noise and dust controls were much more manageable with a shaft-side repair strategy.
6. Replacement of the shaft liner avoided the cost and time delays related to retaining a fire engineer and embarking on the process of submitting a design concept for the fire marshal's consideration.
7. Creation of a "positive-side" plane from which to construct the air and vapor control layer made the implementation efficient and simplified detailing.

Consultants	Design Responsibilities
Structural engineer	Structural design of fire-rated shaft supplemental framing, structural concrete repairs, and enclosure waterproofing design.
Environmental hygienist	Environmental consulting, testing, preparation of an abatement protocol, and air testing and monitoring.
Mechanical engineer	Reclamation system bypass, fan/louver system repairs, plenum drain design, and generator exhaust.
Architect	Fire-related shaft assembly design and insulated metal panel design.

Table 3.

The one drawback to this approach was that once the shaft wall demolition began, a fire watch would be required to protect the residents from a fire event until the fidelity of the shaft liner was restored. The cost of this watch was nominal in comparison to the other advantages, and the concept was presented for the owners' consideration and approval.

Working with the architect, it was established that in addition to the advantages listed above, the fire-rated shaft could be overlain without any detriment to the fire rating of the shaft wall. Addition of external components such as an air and vapor barrier, exterior insulation system, cladding, etc., would not decrease the fire rating. This opened the door to configuring an exterior insulation layer.

DESIGN

WUFI® analysis validated thermal control issues created by a lack of insulation across the original enclosure wall (shaft and demising wall construction). Various alternative wall configurations were considered to address the air, vapor, moisture, and water control aspects of the exhaust shaft enclosure wall design. South Florida (Miami) and New Orleans (Zones 1 and 2) warm-humid climates were considered to emulate the heat and humidity environments of the shaft. The environmental conditions in the shaft were, however, in our opinion, more hostile than either of the databases used in those analyses. Moisture durations were recurring on a heightened frequency with significantly shorter drying times.

We also performed a quantitative static dew point wall section analysis based on the estimated environmental conditions documented during our survey, as well as data logger information collected. Based on this information, we determined that condensation is likely to occur frequently during the cooling season that spans from spring to fall when the cooling towers emit high-humidity-laden discharge, and that humidified air makes contact with materials in the shaft such as metal framing, shaft wall panels, and the exposed concrete floor slabs. Structural Rehabilitation Group (SRG) also determined (by smoke bottle testing) that air leakage is occurring and surmised that such leakage is contributing to the propagation of condensation on demising wall surfaces and metal framing tempered by the air-conditioned spaces inboard of the shaft liner.

Vapor diffusion of a "vapor-open" assembly was considered. Such a retarder would need to manage frequent directional reversals multiple times per hour. An exterior installation (EI) concept with a vapor-closed air and vapor barrier was also considered and validated by qualitative and quantitative analysis. EI restored thermal control between oscillating high and low ambient temperatures across the wall assembly, which cycle back and forth every 5 to 20 minutes or so at the west shaft (wintertime ambient conditions) and addressed the deficient enclosure thermal and vapor control issues experienced in both the east and west shafts. The EI also accommodated the insulating of the slab edges and enhancement of the enclosure wall *R*-value. Our findings also indicated that the shaft wall alone was not sufficient to manage the thermal control demands of the enclosure. The installation of the EI as part of the primary shaft liner decoupled the slab and fire-rated shaft liner from the frequent temperature and humidity fluctuations occurring in the shaft.

The EI concept allowed for incorporation of a metal lined panel system, which provided for a primary vapor and air control layer at the outermost plane of the wall assembly. The use of an insulated metal panel system provided a robust and low-maintenance liner and lent itself to the restricted work area of the shaft by allowing modulization of the wall components for mobilization and erection.

The wall system design also needed to manage the significant mechanical pressurization/depressurization challenges born from a negatively pressured building and positively pressurized shaft. The building utilizes exhaust fans for kitchens and bathrooms, coupled with the occasional operation of the residential dryers. That net negative pressurization increased the potential for air leakage through the enclosure. The static fan pressures associated with the cooling tower exhaust and the garage ventilation systems positively pressurize the shaft walls. The original building design documents indicated that each shaft was intended to manage 99,000 CFM of air flow. Air flow was comparable to a constant 13-mph wind speed. Additionally, wind pressures and barometric changes external to the building added to the potential pressurization differentials between interior and exterior conditions, so a panel system with structural capacity was selected for this application.

DETAILS, DETAILS, DETAILS

Demising Wall

The condition of the demising wall framing and the paper-faced gypsum wallboard separating the shaft wall and the residential units was not well defined prior to the construction, and allowances for remediation were budgeted into the project. The incidence of organic growth on the cavity face of the demising walls was to be identified and abated as required once the shaft wall was removed. The environmental hygienist developed a remedial strategy to limit the drywall removal to the extent possible and provided guidance for the contractor and their subcontractor to treat and remediate organic growth where encountered (**Fig. 10A** and **10B**).

Fire-Rated Shaft Wall

The fire code required that the UL-rated assembly be installed in accordance with the system design requirements. Since the rated assembly resists fire from breaching the system from either side to achieve a two-hour rating, the orientation was reversed to leverage several benefits from the configuration utilized in the original construction. The face of the fire-rated shaft liner was flipped 180 degrees from its original design orientation to allow for a continuous double ⅝-in. gypsum layer to pass along the face of the slab edges (see **Fig. 11**). This change provided a continuous wall plane from which to configure the air and vapor barrier

Figures 10A and 10B. Organic growth was encountered at various locations on the cavity side of the demising partitions that required abatement.

and mount the insulated metal panel system. No longer were the floor slabs interrupting continuity of the wall assembly. This greatly simplified the installation for the contractor and limited the number of details required of them. Movement joints were detailed in the shaft wall at three locations (i.e., every three to four floors) to accommodate vertical and lateral shaft movement.

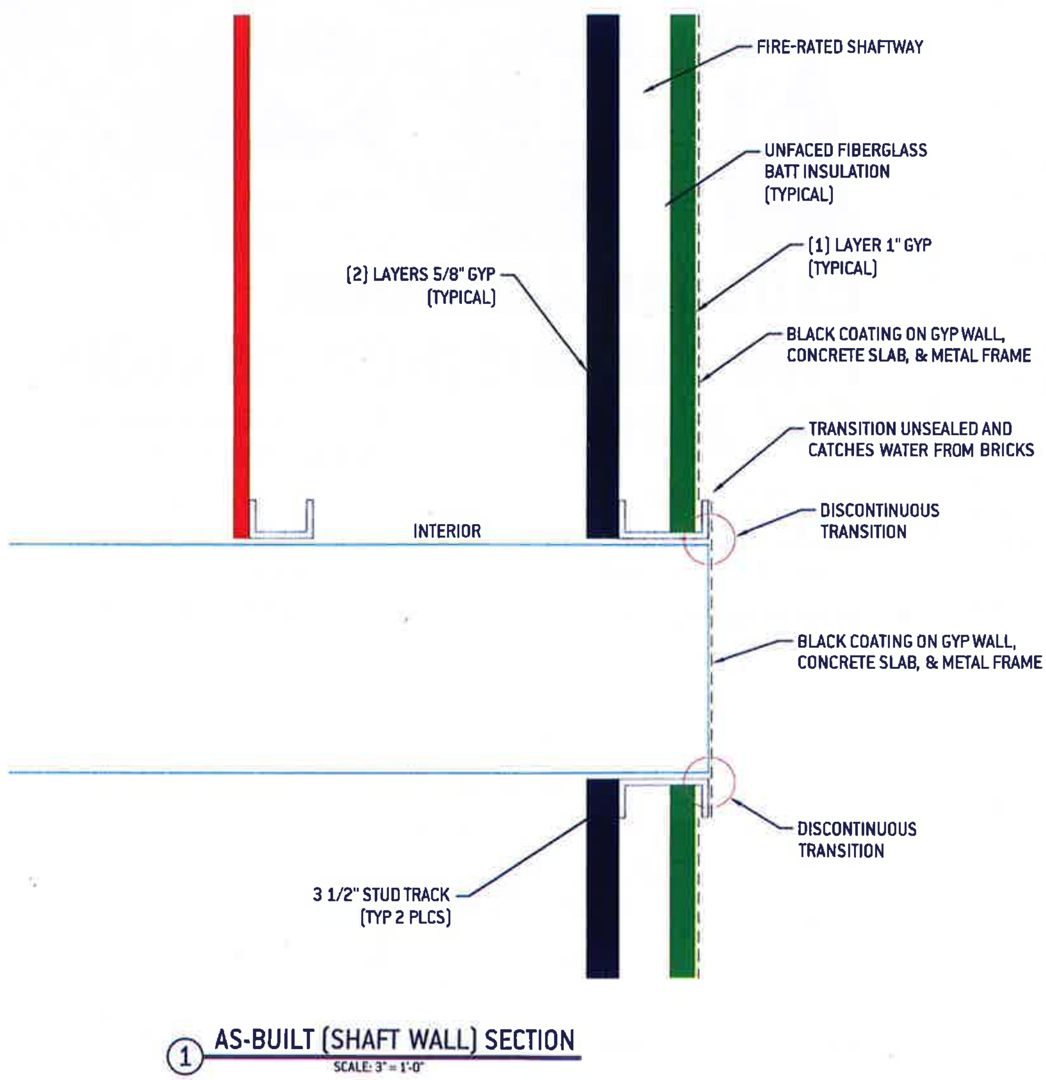


Figure 11. Typical section detail at slab edge and insulated panel joint plan at east chiller shaft.

The assembly was also specified and engineered to accommodate some eccentricity with respect to the floor construction. Erection tolerances in the original post-tensioned concrete slab edges at the perimeter of the shaft opening would need to have some adjustability to establish a vertical plane to receive the metal panel system. The bottom track of the framing was allowed a 0 to +¾-in. overhang. The contractor was charged in the project specifications with conducting a string line survey to field-verify where the framing plane would need to be located to achieve a uniform vertical plane at all six sides of the west shaft and all four sides of the east shaft.

SHAFT DESIGN DETAILS

Air and Vapor Control

A liquid spray-applied air and vapor control layer was selected to line the shaft. The outer face of the fire-rated assembly was designed to accommodate an efficient and simplified means of installation. The spray-applied system incorporated reinforcing scrim at corners, transitions, and penetrations to control cracking at joints and plane changes. Flexible horizontal joints were installed every three to four floors to accommodate structural concrete frame movement and axial shortening over time. The spray-applied barrier was applied in a continuous manner in two layers, in accordance with the manufacturer's requirements, to the outermost face of the fire-rated shaft wall. The air and vapor barrier extended from the metal plenum located immediately above the cooling towers up to the structural concrete roof slab above the ninth-floor (penthouse) level (**Fig. 12**).

At the commercial space level and upper garage level, CMU walls replaced the fire-rated shaft wall assemblies. At those levels, the fire-rated wall was masonry, so furring and framing were used to extend the plane of the wall vertically across these areas. Continuation of the two outer layers of gypsum emulated the outer layers of the fire-rated wall construction above. Transition details using flexible flashings, termination bars, and metal flashings were detailed to terminate the system at the top (roof cupola transition) and bottom (transition to the metal plenum located immediately above the cooling towers) of the shaft to maintain continuity of the air, vapor, and water control layers.

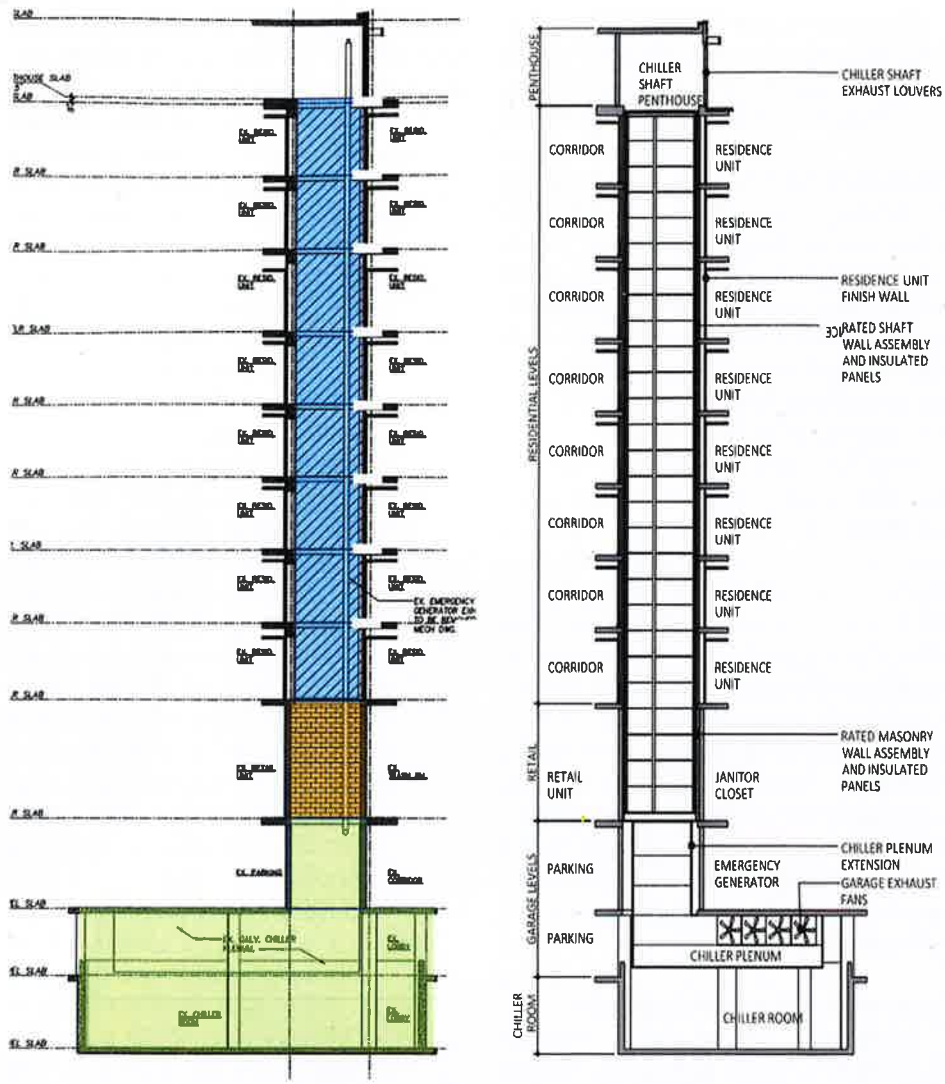


Figure 12. Section view of east shaft.

Thermal Control

The insulated metal panels were designed to be attached to hat channels attached to and aligned over the fire-rated shaft wall framing. The stainless-steel metal panel skin provided a low-maintenance shaft liner, as well as a robust surface for swing stages equipped with rollers to navigate the shaft walls without causing damage. The metal skin also served as a water and vapor control layer. The panels themselves were filled with a foam insulation.

The insulated panels provided a layer of protection over the air and vapor barrier located at the outer plane of the shaft wall system. The panels protected the air and vapor control layer from physical damage, UV exposure at the top of the shaft, and bulk water contact throughout the 12-story shaft—not to mention provided a thermally buffered environment for the air and vapor barrier to reduce movement from expansion and contraction. The EI, coupled with a metal skin, essentially eliminated the potential for condensation to occur in the cavity (i.e., between the back of the insulated metal panels and the face of the continuous air and vapor barrier).

On the downside, the metal panel system required the hat channels to be mechanically fastened. This required a lot of fasteners at a lot of locations, penetrating the otherwise continuous air and vapor barrier. To mitigate the effects of this, sealants and butyl tape were specified to create a gasket at the interface between the furring and the anchor penetrations.

System Performance Monitoring and Leak Detection System

Designed into the shaft renovation was a system to communicate if moisture-laden air or bulk water was breaching the outer face of the insulated shaft liner. The system included an access opening that was detailed into the roof level termination to provide space for insertion of a data logger. The wall was also detailed with a series of compartmentalized gutters at the base of the shaft at the transition of the metal plenum and insulated panel system (**Fig. 13**).

Figure 13. Gutters with saddle flashing transition to maintain compartmentalization and air control continuity.

Stainless-steel gutters were fabricated to collect any water that drained by gravity to the base of the shaft. The gutters featured soldered fittings that received clear plastic hoses. Shutoff valves were installed at the bottom of the hoses and marked to identify the specific wall (gutter) that the tube was connected to (i.e., north, south, east, or west elevation/wall). The lines continued vertically down to the mechanical room for periodic monitoring by the building's engineering staff and were essentially configured as sight glasses to provide a visual "tell" if liquid water was accumulating between the installed panel system and the air and vapor barrier.

After substantial completion of the west shaft, data loggers were also installed at the roof cupola, at the base of the plenum area (just above the cooling tower exhaust), as well as at a telephone/communication closet located at the fifth-floor level and in the shaft wall cavity. Data collected during the first summer (cooling) season of operation were retrieved and reviewed to see how the air cavity behind the insulated panels performed in relationship to the exterior and interior environments. Humidity in the cavity was significantly less than the shaft environment, and the cavity temperatures mitigated the potential for condensation in the shaft wall and demising wall construction during the cooling season.

Construction Phase Field Conditions

During the west shaft project, a number of conditions were encountered that required modifications to the infrastructure and/or adjustments to the work scope to address various challenges as outlined below.

1. To accommodate continued operation of the grocery store cooling system, a bypass valve and piping needed to be installed in the east mechanical room to redirect water to the east cooling towers and exhaust shaft (usually dormant in the winter) so the shaft could serve the store's cooling needs while the west cooling towers could remain shut down/dormant during the west shaft rehabilitation work.
2. Several bathroom and exhaust ducts at the eighth- and ninth-floor levels were installed through the original fire-rated shaft assembly that were not depicted on the original design drawings. Numerous large steel conduits were also installed through the fire-rated wall assemblies, which gave rise to significant detailing efforts to comply with the UL-rated assembly, as well as to maintain the air, water, and vapor control layer sealing requirements at the various wall planes at those wall penetrations.
3. Near the base of the shaft, several ducts related to supplying conditioned air to the elevator lobby areas protruded into the original shaft. The plane of the fire-rated assembly—as well as the insulated metal panel systems—were relocated inward (toward the center of the shaft) so the air and vapor barrier (as well as the insulated metal panels) could be constructed around the ductwork. This allowed the ductwork to remain inside of the enclosure system, thus placing it inside the conditioned environment and out of the severe shaft conditions. By locating the ducts inside the enclosure, it decoupled the pressure field of the shaft environment surrounding the ductwork from the ducts themselves and isolated the ducts from the heat, positive pressurization, and high-humidity conditions of the shaft. This greatly simplified the detailing and helped to maintain the fidelity of the control layers near the top of the cooling tower exhaust where the most hostile environmental conditions exist.
4. Negative pressurization of the work zone to control dust and organic contamination of the residential units was a challenge, as the contractor had to monitor the pressure fields as work progressed. As wall areas were demolished and the volume of the shaft workspace increased, the negative pressurization would drop. Plastic sheeting installed to help control dust would visually communicate where pressurizations would vacillate from negative to positive. As work reached the top floor, a large mechanical plenum space extended over the entire residential floor, which further complicated the fan sizing requirements to maintain the air volume necessary to keep the shaft negatively pressurized **(Fig. 14)**.

Figure 14. Fire-rated shaft wall has been removed, but framing remains. Note the ceiling chase area that extends across the ceiling of the ninth-floor units creating challenges to maintain negative pressurization.

DESIGN ENHANCEMENTS – LESSONS LEARNED APPLIED TO THE EAST SHAFT

The east shaft design was modified from the west shaft design to address conditions not present in the west shaft. A unique aspect of the east shaft was that this area facilitated radiator exhaust from the emergency generator located at the B-1 level. The shaft also provided a chase for the exhaust pipe to direct diesel exhaust to the roof level. The emergency generator exhaust was specified for replacement, and that in turn required that a temporary generator be rented to facilitate operations, should an emergency take place while the building's emergency generator was offline. The contractor proposed an alternate design of the diesel generator exhaust system that required further review, design, detailing mock-ups, testing/validation, and implementation coordination.

Enhancements to the design were also incorporated into the east shaft to simplify certain details and enhance the effectiveness of visual inspection during construction.

Figure 15. Note the limited physical access between the scaffolding and shaft wall plane. Note the continuous blue air and vapor barrier.

Lessons Learned

The investigation, design, and implementation of the west shaft revealed a number of challenges and constraints. These lessons learned were taken from the west shaft project and implemented on the east project during both the design and construction phases for the east shaft. These modifications helped to improve the constructability of the east shaft and invited collaboration of the owner, design team, and consultants, as well as the general contractor.

Some of these lessons included:

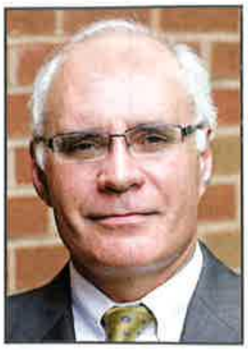
1. Due to the scaffolding configuration and restricted space during construction, the workspace was severely limited and did not accommodate inspector access alongside the installers when many of the critical details were being implemented (**Fig. 15**). Limited line-of-sight access further hampered visual observation of the critical butyl sealants and their continuity.
2. The sealant work performed at the insulated metal panel systems' mending plates and cover plates was produced at a very fast pace, which made it difficult to field-verify the work in progress on a consistent basis. Post-installation observation was also very difficult, given a lack of line-of-sight to the concealed sealants.
3. Challenges were revealed during the cover plate work. Any nonplanar wall construction resulted in buckling of the cover plates. This allowed discontinuities in how the cover plates engaged the butyl sealants.
4. Oil canning of the metal cover plates resulted in a lack of compression along the butyl sealant lines. Butyl sealant continuity between the cover plates (and mending plates) and the insulated panels was crucial to the system's performance and critical in order to meet the design intent. Modified details to produce a slight bleed-out of the butyl sealant and a tighter fastener spacing were specified in the second (east) shaft project, which greatly enhanced the inspector's ability to observe that the sealants were installed in a continuous manner.
5. Lighting in the shaft was poor, at best, and supplemental lighting was crucial to observe the detailing work. In addition, the scaffolding was not continuous around the perimeter of the shaft walls in order to facilitate a hoist area, which made for a lot of reaching to install certain cover plates, sealants, and fasteners.
6. The starter track at the base of the east and west shafts incorporated a compartmentalized gutter that featured saddle flashings to transition the air and vapor barrier into the leak detection gutter at the intersection of the

different gutters and the shaft liner. Omitted detailing at the gutter line was revealed, which required removal of two courses of the installed panels to access and make repairs. Removal of the panels revealed that a skinning-type butyl sealant had been applied instead of a nonskinning type, as required. The sealant was not in conformance with the shop drawings and manufacturer's requirements, so removal and cleaning of the panels and reinstallation with the proper materials were required.

7. As with most roofing and waterproofing projects, materials tend to get on everything. On this project we learned that the butyl sealants get on everything, including the panels, scaffolding, ladders, guard railings, clothes, skin, notebooks, measuring tapes, etc. Do you know what removes butyl sealant really well? WD-40 does the trick!

SUMMARY

The confined workspace, along with a high-end residential client and a hard stop for substantial completion, was a daunting challenge. Devising a system to manage the psychometric challenges of high static pressures, a negatively pressurized building, extremely high exhaust humidity for extended run times, and frequent on-off cycling required us to consider a number of issues, from psychometrics to constructability, when configuring the new enclosure assembly. Then, creating a design document set that would meet the owner's project requirements for a system that included minimal and infrequent preventative maintenance made this project interesting, challenging, and very unique. The excellent collaboration and teamwork of all the prime consultants resulted in what we expect will be a reliable, long-lasting, and low-maintenance shaft assembly that will serve the property for a long time to come. For the record, cooling towers in the basement of a tower: not the most practical idea. IIBEC



Kipp Gaynor

Kipp Gaynor has over 33 years of experience in the design and evaluation of new and existing buildings, with concentration in the evaluation and remediation of existing building problems such as deterioration of structural components and exterior wall system failures. His past projects have included commercial, large-scale residential, institutional, and governmental structures with a wide array of structural problems, including structural deterioration, foundation settlement problems, and moisture intrusion issues. Gaynor has extensive experience with a variety of repair projects. He received his BS in civil engineering technology from Pennsylvania State University in 1984, and he is a member of ASCE, ICRI, CSI, CAI, NRCA, ACI, IIBEC, DCMA, and AAMA.

Photo by Emmanuel Ikwuegbu on Unsplash

SPECIAL INTEREST

Use Technology to Tap a New Generation of Trade Workers

Where will the next generation of construction workers come from, and how can recruiters find them?

Recruitment is a concern across all industries, but the construction industry may have more ground to make up than others.

Calling construction's efforts to recruit younger workers "completely outdated," Brittany Bainum in *Construction Executive* noted the evolution of industry recruitment efforts. It wasn't long ago, she wrote, that prospective workers literally walked in the door looking to get hired. That recruitment method gave way to referral bonuses, which lost their effectiveness once Craigslist and Monster.com came along.

Today's industry needs to look to social media to recruit a younger generation—and by "younger," the industry needs to think of high schoolers. Construction-industry recruiters should acknowledge that Generation Z lives online, so they need to go where their audience is. They can do so by:

- Building an online presence—any online presence
- Making sure your website's "Careers" page is up to date
- Improving the ability of people to find you by thinking carefully about key words and search engine optimization
- Choosing to have a public presence on one or two regularly refreshed social-media sites
- Considering a job recruitment app specific to the construction industry.

Source: *Construction Executive*