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Case study of a 10-story office building with four 200,000 CFM fan-wall arrays

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Fan-walls are increasingly used as an alternative to air-handing units with one or two large fans because of greater reliability through fan redundancy, lower maintenance costs, energy savings, reduced footprint, and purported quieter operation. This paper will present a case study of a new 10-story office building which used four 200,000 CFM fan-wall arrays housed in penthouse rooms to provide the supply and return for the entire building. The installation of the fan-walls in penthouse rooms, rather than in enclosed rooftop units, resulted in significant vertically radiated noise concerns to executive offices on the 10th floor. While fan-walls are purported to have lower overall sound levels, the blade-pass frequency of the plug fans can result in high noise levels in the 250 Hz or 500 Hz octave bands. Fan-walls typically offer options for coplanar silencers to reduce the overall sound levels, however the silencers do not typically eliminate the blade-pass frequency tone on both the intake and discharge sides of the fan. This study will identify the key noise issues that such an unconventional design presented and illustrate the mitigation measures that were implemented, which include duct-borne fan noise, aerodynamically generated turbulent noise, vertically radiated noise through the floor/ceiling assembly, duct break-out noise, and environmental radiated noise.

1 INTRODUCTION

This paper presents a case study of an air handling system comprised primarily of four 200,000 CFM fan-wall arrays housed in rooftop penthouse mechanical rooms that support a new design-build 10-story office building. The critical acoustical issues posed by such a design are identified and discussed and the proposed measures for resolving those issues are presented.

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The following figure provides a schematic diagram of the airflow and mechanical layout for the two fan-wall systems in the rooftop penthouse mechanical rooms.

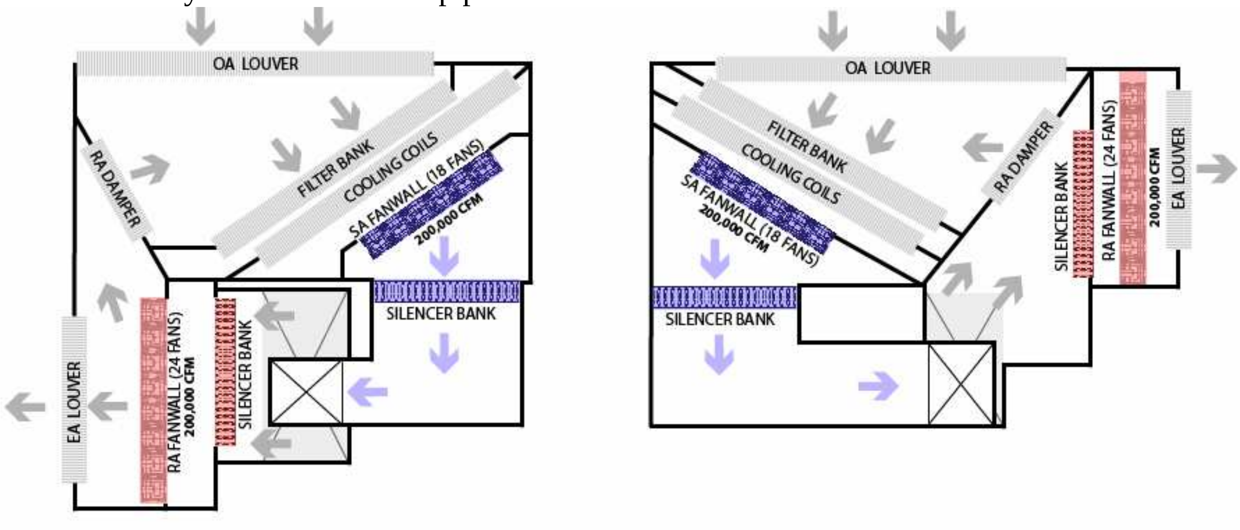

Fig. 1 – Schematic Diagram of the Preliminary sMechanical Plan of Rooftop Penthouse Fan-Wall Arrays. Arrows indicate direction of airflow. SA = Supply Air; RA = Return Air; OA = Outside Air; EA = Exhaust Air.

Each supply-air fan-wall is comprised of an array of 18 fans (6 wide x 3 high) for a maximum of 200,000 CFM; each return-air fan-wall is comprised of an array of 24 plug fans (8 wide by 3 high) for a maximum of 200,000 CFM. The fan-walls are installed in a metal frame which sits on top of a concrete curb.

Supply air is ducted into the shaft, while return air uses the negative space of the shaft as an open plenum return. Supply air is designed to use a mixture of fresh outside air and return-air, which is controlled through a bank of dampers.

2 DESIGN CRITERIA

Mei Wu Acoustics established design criteria for maximum interior sound levels due to the mechanical system, which were based upon ASHRAE[1] design guidelines: NC-35 for private offices; NC-40 for Open Offices and Circulation Spaces.

3 NOISE IMPACTS

The fundamental acoustical issue posed by the project's mechanical design is the consolidation of the supply and return air into two massive systems, which not only concentrates mechanical noise sources together but also results in extremely high airflow with potentially high velocities at centralized locations.

A more conventional mechanical design would likely use multiple rooftop air-handling units to service various zones throughout the building. This would distribute mechanical noise sources and airflow requirements to different parts of the building, which would typically result in lower overall mechanical sound levels, smaller duct sizing requirements, and potentially lower airflow velocities. For example, if five 40,000 CFM air-handling units were used in place of a single 200,000 CFM fan-wall, the mechanical noise would be distributed such that each AHU would be 7 dB quieter by comparison to the single fan-wall.

Fan-walls are increasingly used as an alternative to air-handling units with one or two large fans because of greater reliability through fan redundancy, lower maintenance costs, energy savings, reduced footprint, and purported quieter operation. Fan-walls can be provided in enclosures like a traditional air-handling unit, or in the case of this project, they may be installed in mechanical rooms.

The following sections identify specific acoustical issues associated with this project's mechanical design, which have been organized into the following categories: 1) Vertically Radiated Noise through the Roof/Ceiling Assembly 2) Duct-borne Fan Noise 3) Aerodynamic Turbulent Noise.

3.1 Vertically Radiated Noise through the Roof/Ceiling Assembly

As is common for multi-story office buildings, the top floor is reserved for executive offices and meeting spaces, which have lower background noise criteria than open-plan offices. The fan-wall arrays were designed to sit on top of a concrete curb and be housed in an open mechanical room on the roof above the executive floor. Because the fan-walls were not enclosed in a unit, the floor/ceiling assembly was the only sound isolation barrier between the top floor offices and the fans. The floor/ceiling assembly was designed as lightweight concrete over metal deck with a T-Bar acoustical ceiling throughout. This assembly design was determined to provide insufficient vertically radiated sound isolation and would not achieve the design criteria for interior sound levels.

The following table provides sound power levels of a preliminary selection for a single fan in the fan-wall array. Given that the supply arrays were comprised of 18 fans and return arrays of 24 fans, the total sound pressure levels in the rooftop mechanical rooms were extremely high.

Table 1 – Sound Power for a single fan [dB re: 10^$^{-12}$ watt]

	Frequency [Hz]								
	63	***125***	***250***	***500***	***1k***	***2k***	***4k***	***8k***	***LwA***
Supply Fan Inlet w/ coplanar silencer	88	83	81	89	84	83	83	79	94
Supply Fan Outlet w/ coplanar silencer	77	74	79	73	73	71	69	64	83
Return Fan Inlet w/ coplanar silencer	88	85	82	83	78	77	75	66	85
Return Fan Outlet w/ coplanar silencer	74	73	84	70	69	68	63	54	78

While fan-walls are marketed for their reduced overall sound power levels, there is often a significant peak in the 250 Hz or 500 Hz octave bands due to the blade-pass frequency of the fan. Fan-walls offer options for coplanar silencers to reduce the overall sound levels, however these silencers do not typically eliminate the blade-pass frequency tone on both the intake and discharge sides of the fan. As shown in Table 1, the supply fan inlet has a distinct peak at the 500 Hz octave band, whereas the supply fan outlet has a modest peak at the 250 Hz octave band. The blade-pass frequency tone posed a concern for this project because while the coplanar silencer could reduce the noise on one side of the fan-wall array, the opposite side still contained an elevated tone that resulted in vertically radiated noise issues.

The blade-pass frequency peak can also present challenges if the demising partition has reduced transmission loss performance in that frequency range. As well, if a floated floor is used to increase the overall transmission loss performance of the demising assembly, there may be a resonance dip that aligns with the blade-pass frequency tone, which should be evaluated.

3.2 Duct-borne Fan Noise

The top floor of the building is the first to be served by the fan-wall system. This presents significant noise issues because the path is short and lined ductwork cannot be relied upon as the only means for attenuating noise. Fans were selected for the quietest operation, which included the use of coplanar silencers on each fan. Architectural requirements placed limitations upon the dimensions of the array and the quantity of fans, which factored into the equipment selection sound power levels.

Silencers were necessary to achieve the design criteria and a bank of silencers was placed between each fan-wall array and the mechanical shaft as shown in Fig. 1. The insertion loss performance of the silencer bank was limited by both mechanical performance requirements and space constraints. Additional measures, such as duct lining and lagging, were required downstream of the silencers at each floor of the building.

The mechanical engineers designed the return air as a plenum return above the T-bar ceiling at each floor, with short stubs directly into the mechanical shaft. The Return Air was not ducted inside the shaft but rather used the negative space of the shaft as an open plenum. This design was particularly challenging at the upper floor of the building where the vertical distance between the top of the shaft and the return air stub was only a few feet. Because the return was not ducted, the stub was essentially an opening into the shaft that could allow noise to radiate freely in to the office ceiling plenum.

3.3 Aerodynamic Turbulent Noise

Aerodynamically generated turbulent noise can be avoided by maintaining low airflow velocities in large ducts, avoiding multiple duct transition elements in series, and designing duct elements with low loss-coefficients. The consolidation of all building air service to two large fan-wall systems resulted in extremely high airflow volumes (200,000 CFM) concentrated at two central shafts in the building. Maintaining low velocities at such volumes requires extremely large ductwork, which is often undesirable or not feasible because of space constraints either horizontally above the ceiling or vertically with the sizing of shafts through each floor. For example, if 200,000 CFM velocities are maintained at 2000 fpm, the duct cross-section would be 100 square feet. A duct sizing ratio of 2:1 would require dimensions of 170”x85” at 2000fpm, which would not be practical in some contexts, particularly a horizontal run above a ceiling.

Mei Wu Acoustics worked closely with the Mechanical Engineering team in the layout and sizing of major ductwork and duct elements and provided recommendations for low loss-coefficient transitions. Service to the top floors presented the most significant challenge in part because of the short distance and close proximity of several duct transition elements in series. When duct elements are in close proximity to one another they have additive effects in terms of the aerodynamic turbulence generated. Shaft take-offs in particular are difficult to design with low loss-coefficients and given the close proximity of the top floor take-off to the major transitions at the penthouse level, very high levels of turbulence would have resulted. A novel solution to reduce turbulence at this location was to eliminate the take-off from the shaft and add a separate penetration in the penthouse floor to directly serve the top floor supply ductwork. This reduced the number of large duct elements in close proximity to one another for the top floor and also reduced the velocity and airflow volume in the supply shaft.

At the upper floors, mechanical shafts were increased to provide lower velocities for both the supply ductwork and the plenum return air. Shaft sizes were reduced slightly at lower floors as the airflow volumes decreased, which allowed floors to regain some lost floor space.

4 SUMMARY OF MAJOR MITIGATION MEASURES

The following is a summary of the significant mitigation measures implemented to achieve the design criteria:

- Fans were selected for the quietest operation feasible, including the use of coplanar silencers. The coplanar silencers can reduce overall sound levels but may not eliminate the blade-pass frequency tone.
- Silencer banks were installed between the fan-walls and the shafts
- To address vertically radiated noise, the penthouse mechanical room used a floated concrete floor to increase the transmission loss of the floor/ceiling assembly.
- Silencers were installed at the stubs into the return air shaft at the top two floors; lined elbows were used for stubs at all other floors
- Duct lining was provided for all ductwork between the supply fan-wall silencer banks and the first take-off at the top floor
- Duct lining was provided for the first 25-feet of supply ductwork following the shaft take-off at each floor.
- Low air velocities were maintained by adequately sizing ductwork.
- Major duct elements were designed for low loss-coefficient transitions.
- Duct layouts avoided major transitions in series
- The top floor avoided a supply shaft take-off by adding a penetration in the penthouse floor to directly serve the top floor.

5 CONCLUSION

The consolidation of a building's air-handling requirements into two major systems, such as the fan-walls presented here, can pose significant challenges for controlling noise. A large singular air-handling system, by comparison with smaller distributed systems, can result in higher overall equipment noise levels and extremely large duct sizing requirements in order to maintain appropriate airflow velocities.

While fan-walls are purported to have lower overall sound levels compared to traditional air-handling units, the blade-pass frequency of the fans can still result in high noise levels in the 250 Hz or 500 Hz octave bands. Although fan-walls offer options for coplanar silencers to reduce the overall sound levels, these silencers do not typically eliminate the blade-pass frequency tone on both the intake and discharge sides of the fan.

6 REFERENCES

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, *2011 ASHRAE Handbook: HVAC Applications*, ASHRAE, (2011).