A jet fan installed in an enclosed car park

Enclosed Car Park Ventilation – Design, Pitfalls and Hybrid Systems

Troy Goldschmidt International Product Manager, Greenheck Fan Corporation, Schofield, Wisconsin, USA

Abstract

As cars are parked within an underground parking structure, Carbon Monoxide (CO) and other exhaust fumes are emitted into the atmosphere. There is a need for an efficient ventilation system that can remove these toxins, circulate fresh air, and assist fire fighters in case of an emergency. There are two traditional options for this task: ducted or ductless ventilation.

Ducted ventilation is heavily used in the US and other global markets. While this has been the standard for many years, innovations in the field of ventilation have shifted the conventional ventilation system towards ductless designs. Ductless designs use jet fans to dilute and remove contaminants and control the smoke. These systems provide greater control at a fraction of the cost of traditional ducted systems. In regions where ductless ventilation is not acceptable, a hybrid system combining ducted and ductless may be used.

About the Author

Troy Goldschmidt has 15 years' experience in the HVAC industry, most recently working with Greenheck Fan Corporation and previously with Johnson Controls. He creates system offerings for smoke and fire applications including car park ventilation and building pressurization. Troy has designed and sold systems globally in regions such as South America, Mexico, Latin America, India, and the Middle East. He has several patents and publications related to the HVAC industry. Troy received his BS and MS in electrical engineering from University of Wisconsin-Madison, and later received his MBA from University of Wisconsin-Milwaukee.

Introduction

Designing parking garages provides a unique set of challenges because there is a continuous influx of contaminants that may harm occupants on a regular basis. In addition, smoke from a fire must be controlled properly to ensure the safety of occupants. The initial system cost can be minimized by designing a dual-purpose system that accomplishes the following:

- Remove toxic gases during normal operation (CO and NOx)
- Control smoke in case of fire

Ductless ventilation system is a cost-effective and safe solution that continues to grow in popularity even though the corresponding requirements vary substantially across the globe.

Contaminant Levels and Control

Carbon monoxide (CO) is the primary concern in normal operation because the majority of vehicles operate on petrol. Diesel vehicles emit nitrous oxide which, when combined with oxygen, turns to nitrous dioxide that can be harmful to health. Gas sensors typically only sense carbon monoxide, which is acceptable as long as less than 20% of the vehicles are diesel. If there are greater than 20% diesel vehicles, nitrous dioxide must also be monitored.

continued on page 30

continued from page 28

The required CO levels differ depending on the location and authority having jurisdiction (AHJ). The U.S. National Institute for Occupational Safety and Health requires 35ppm CO in air for a one-hour period. The U.S. Environmental Protection Agency recommends 9ppm, while OSHA recommends 50ppm for an eight-hour period. Since most people are only in a particular parking garage for a few minutes to walk to or from their car, most international standards use 35ppm as a low alarm level to balance cost and safety.

To control gases to the desired levels, historical design techniques implemented a fixed number of air changes per hour (ACPH). This constant volume design results in significantly higher operational costs. A study sponsored by ASHRAE and conducted by Krarti and Ayari in 1998 analyzed the various global ACPH requirements and found that the majority of them were more conservative than necessary. They created a calculation to determine the required ACPH based on the desired contaminant levels, number of cars, length of time of operation, and emission rates. That resulted in an ACPH that was significantly more cost-effective than some of the standards.

Most locations require the ventilation design to be based on a fixed ACPH requirement but they also allow the airflow to vary based on the demand. For example, International Mechanical Code 2012 (IMC 2012) allows a demand-based system but still requires a minimum ventilation of 0.05 CFM per square foot of area. The system must be capable of operating at 0.75 CFM/square foot, and with a ceiling height of nine feet it results in five air changes per hour. The UK requires 3-10 ACPH, depending on whether the system is in normal or smoke control mode. The highest ACPH requirement is in India, which requires ACPH of 10-30 depending on normal or fire mode (NBC2005). However, this is in the process of being revised and lowered. Even though the overall ACPH still varies substantially across the globe, the overall design methodologies remain similar.

Ventilation Options

Natural Ventilation

The first design consideration is to determine what type of ventilation is required. Areas that have available land can use above-ground parking garages, which offer a lower-cost alternative from the ventilation perspective when the sides are open to free air. Typically if 5% of the surface area is open to the sides of the garage and evenly distributed on opposite sides, no additional ventilation is required. Often, however, due to area or building design constraints, an open-air design is not possible. Therefore, additional mechanical ventilation is required.

Mechanical Ventilation – Ducted Systems

Mechanical ventilation is required in parking garages that do not satisfy the free-area requirements. Enclosed vehicular facilities will require mechanical ventilation. The traditional way to do this is with ducts across the parking structure. *Figure 1* shows a typical design. The duct intakes at a high and low level and is distributed across the parking structure.

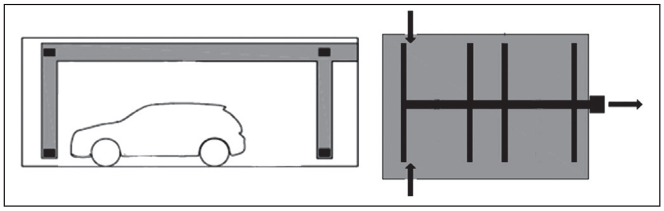

Figure 1: Vertical and top view of a typical ducted system

Even though ducted design systems are globally accepted, they have the following disadvantages:

- Costly and more complicated design time due to duct design requirements
- Increased installation and maintenance costs
- Higher operating costs because the entire area is being ventilated instead of a focused area
- Less ability to control smoke
- Larger space requirements
- Aesthetically less pleasing

These disadvantages led to improved design methodologies that result in a safer and less costly solution.

Mechanical Ventilation - Ductless Systems

Tunnel ventilation projects have been using jet fans for many years to create laminar flow and move pollutants and smoke throughout the tunnel. Research Projects like the Memorial Tunnel fire ventilation test program conducted in 1995 proved that jet fans can sufficiently move the air through entrainment to create an acceptable environment for the occupants to egress. In the late 1990s, jet fan systems for enclosed parking garages began to spread across Europe and continue to grow through the Middle East and Asia.

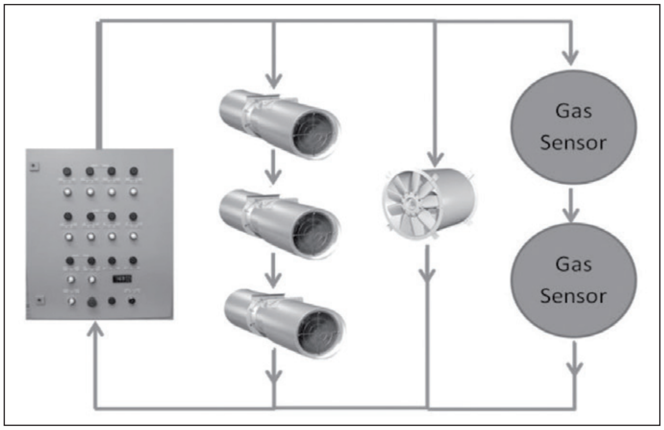

Figure 2: Block diagram of typical ductless car park components.

Figure 2 shows the basic components that are required in a ductless system. The supply and exhaust fans are required to provide the main air changes for the space. Jet fans are used to mix the air and eliminate any dead spots in the system. The number of jet fans can be greatly reduced with a proper supply and exhaust design. Ductless car park systems are typically demand-based to save energy by controlling the contaminant levels with sensors

continued on page 32

continued from page 30

and controls. One other often-overlooked component is the high-temperature cabling. The cabling can be a significant cost of the project, making the control panel and jet fan placement essential to eliminate initial cost.

In addition to the above components a computational fluid dynamic analysis (CFD) is required to validate the placement of the fans. The project is then completed with installation, commissioning, and in some regions a cold or hot smoke test to validate the control sequence programming and design.

This combination of products and services has several improvements over the traditional ducted system and when designed and installed properly has the following advantages:

Simplified Design

Eliminates the need to perform costly duct design.

Lower Construction Cost

Jet fans have less height than ducted systems, resulting in less excavation and lower overall construction cost.

Lower Installation Cost

A typical jet fan system results in less installation time overall.

Operational Costs

Eliminating the ducts reduces the static pressure required and allows the jet fans to run with less power. Additionally, the sensors allow running the system only when the demand requires.

Reduced Maintenance

In addition to eliminating duct cleaning, jet fans are more accessible for maintenance than traditional systems.

Installation Costs

The elimination of the ductwork eliminates the associated installation cost.

Enhanced Safety

Jet fans are more efficient at removing noxious fumes and clearing smoke, resulting in a safer environment with the added benefit of minimizing potential damage to the building.

Design Methodology

Purpose of Smoke Control

There are three primary goals for controlling smoke. The simplest goal is to clear the smoke after a fire has occurred. This method does not control the smoke in any particular manner and operates the same regardless of where the fire occurs. A ducted system acts in this manner because in the case of a fire the system turns on and air is pulled from all the duct inlets. It is conceivable to create a ducted system with control dampers that turn off areas that do not have smoke. However, the cost of the controls and dampers that this would require makes this method not cost-effective.

The next potential goal is to create a smoke free access point for firefighters. Once a fire begins the fire department needs to enter the building, set up their equipment and extinguish the fire. Therefore, it is beneficial to create a high-visibility, safe area five to ten meters downwind of the fire and smoke allowing easy access. The final potential goal is to similarly control the smoke, but with the goal of protecting the means of escape for building occupants in order to ensure that there is at least one exit available independent of where the fire occurs.

Of course it is best if the designed smoke control system can accomplish all three of the above goals. The ductless design along with a grid-based fire detection system allows the designer to create smoke control zones and turn on only the necessary jet fans moving the smoke in a much more controlled manner. Thus, the system not only works more effectively, but it does so at a lower cost.

Smoke Control Zones

The purpose of a smoke control zone is to limit the spread of smoke from one area to another. The requirement for the sizing of these areas varies greatly depending on the AHJ and is dependent on what other fire suppression systems are installed. For example, India requires a smoke zone to be 800 m^2 (8,611 ft^2) without a sprinkler, and 1,250 m^2 (13,455 ft^2) with a sprinkler system. United Kingdom requires 2,000 m^2 (21,530 ft^2) per zone.

In order for the smoke control system to work properly, it must have separate supply and exhaust locations in each zone, and the jet fans must be placed in such a way that smoke does not cross between zones in the event of a fire. In addition, the control panels are separated so if one panel is damaged from the fire, the other areas in the system still operate. Requirements for smoke zone control add redundancy and safety to the system, but can significantly drive up initial cost.

Supply and Exhaust Placement

Once the contaminant levels and purpose of smoke control is designed, the next step is to determine how many supply and exhaust shafts are required, and where they are to be placed. This is a critical design step, which can significantly impact the number of jet fans required and the overall air performance.

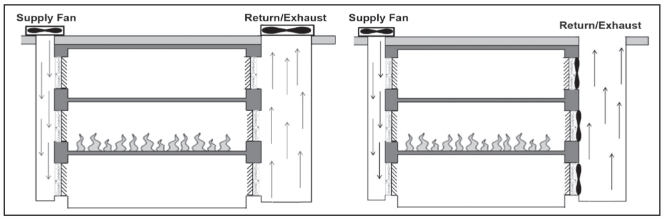

Figure 3: Typical three level underground parking garage with a shared supply and exhaust

Figure 3 illustrates two common design examples. The difference is that in the image on the left, the fan is placed at ground level and is pulling air from the basements. On the right, the fans are smaller and they will push the air up the shaft. As shown in the images, there are dampers and louvers shown on the inlet and the outlet of each level. The method on the left is a preferred design, because in the case of a fire on the second floor as indicated, the dampers on the non-fire floors should close and those corresponding fans should be off. However, in the case of a damper failure on basement one, for example, the smoke will go up and potentially enter the first basement. The design on the left does not have this problem because the exhaust fan is pulling the smoke out.

continued on page 34

continued from page 32

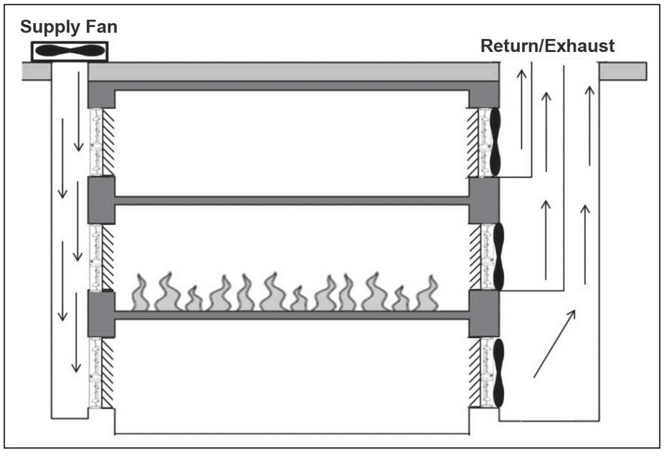

Figure 4: Typical three level underground parking garage with separated exhaust

Additionally, some regions require that the exhaust shafts be dedicated to each floor (as shown in *Figure 4*) to eliminate the possibility of smoke entering non-fire floors. This is the safest approach but adds initial cost to the building and requires more ventilation equipment located at ground level, which is detrimental to the aesthetics of the building.

One final note regarding supply fans is that often designers attempt to save cost by using the ramps for fresh air. This can sometimes work when there is only one or a maximum of two levels of underground parking, but it usually requires significantly more jet fans due to the contaminated air from the cars. It means typically less initial cost and operating cost to have forced supply on all levels of the car park because there will be less total fans, and less jet fans will need to run during normal operation.

Jet Fan Placement

Initial jet fan quantity is typically determined by rule-of-thumb. A common size axial jet fan is 315mm (12.4in) and generates about 25 Newton (N) of thrust. Typically, one Newton of thrust can cover an area of 10-15 m^2 (107- 161 ft^2). Therefore, a 25N fan could cover 250 - 375 m^2 (2,690-4,036 ft^2). The range depends on the layout of the space and the locations of the supply and exhaust. If the supply and exhaust are opposite each other, creating a laminar flow across the floor, the fans could cover an even greater area. However, if the placement creates a lot of dead spots and short-circuiting of air, more jet fans could be required.

The initial jet fan placement is done in a logical way where it makes sense to move fresh air into areas it would not otherwise get. To minimize the number of jet fans, this placement is typically not uniform across the parking structure. The goal is to mix the air and guide the fresh air from the supply to the exhaust. The distance to place one jet fan to another when the air is flowing in a laminar direction can be assisted using throw diagrams.

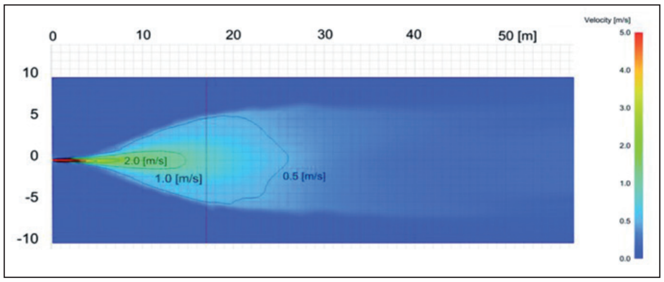

Figure 5: Typical throw diagram for a 315mm (12.4in) jet fan

Figure 5 shows a throw diagram of a jet fan. Generally it is desirable to keep the air moving at 0.2-0.5m/s (0.66- 1.64 ft/s). In the above example, the next jet fan could be placed about 25 m (82ft) from the previous to continue the flow.

CFD Analysis

Once the initial placement is complete, a computational fluid dynamics (CFD) analysis is required. The purpose of the CFD is to ensure that the building is designed in the safest, most cost-effective way possible.

The CFD can assist with the following:

- Optimize the number and placement of fans
- Simulate the space in normal mode and fire mode operation
- Determine the visibility, smoke and temperature throughout the garage
- Demonstrate the proper control to authorities and customers

It is critical to be careful when conducting the CFD or choosing a company to work with. Like most computer simulations, it is relatively easy to manipulate the results. The preferred CFD methodology is beyond the scope of this article, but many simulation parameters can be modified, such as the design fires size, method of CO injection, boundary conditions, meshing strategy and physics model selected. Make sure that all these parameters are the same when comparing multiple CFD simulations that may give conflicting results.

Control Sequencing

Once the design is finalized the control sequencing is relatively straightforward. The sequence below is an example of a normal ventilation demand-based sequence.

1. 0 PPM: Only supply and exhaust fans on (if required to maintain minimal ACPH)
2. CO>15 PPM: Supply and exhaust fans on
3. 15<CO<35 PPM: Select jet fans on
4. CO>35 PPM: All jet fans on
5. CO>100 PPM: All fans on high speed (fire mode)

In the case of a fire, an example sequence is the following:

1. Heat or smoke sensor triggers.
2. Waiting period to confirm fire or time out (in case of sensor failure).
3. Fire alarm goes off.
4. Turn on supply/exhaust fans on fire floor to maintain negative pressure. Close exhaust dampers on non-fire floors.
5. Wait a period to allow occupants to exit.
6. Turn on all jet fans at full speed.
7. Run system until the fire department turns it off.

The delays in the above example will vary based on the building type, size, and the number and type of occupants. The evacuation delay period, for example, can be calculated

continued on page 36

continued from page 34

assuming 0.5m/s (1.64 ft/s) travel speed. If it is a retirement community, however, it may be desirable to extend this period so the occupants have additional time to exit.

Product Requirements

Ductless car park ventilation designs are intended to be both a normal mode and smoke control system. Therefore, the equipment must be selected to operate within that environment. High temperature fans and cabling are required. As with other requirements, the temperature varies across the globe. The United States can use 250°C (482°F) for four hours. India varies regionally from 250°C (482°F) to 300°C (572°F) for two hours. United Arab Emirates and other Middle Eastern countries are transitioning to even higher temperatures requiring 400°C (752°F) for two hours. High temperature cabling must similarly be selected to ensure the equipment will run in the case of fire.

Market Pushback

Despite the many advantages of ductless car park systems, there are several regions that do not allow them to be used over ducted systems. The civil defense authorities in the United Arab Emirates (UAE) used to allow ducted systems but have since banned them. Authorities in some regions in India, such as Delhi, similarly do not allow ducted systems even though they were allowed previously. Other regions of the world allow the use of these systems, but lack the appropriate regulations and standards to optimize and verify the systems are designed, installed, commissioned and subsequently maintained properly.

As mentioned above, a primary item that is inconsistently done in the design phase is the CFD analysis. It is acceptable to conduct the simulations in different ways, but important when comparing the results to make sure that contaminants and smoke are injected consistently between different CFD vendors, and that other simulation parameters such as mesh size, time steps and convergence criteria are similarly equivalent. Given the high complexity of CFD analysis, this can be difficult, but if the regional AHJ or consultant specifies the simulation criteria it forces the designs to be more consistent.

Another concern for many regions is that the control sequencing is typically programmed and commissioned by a different group than the company performing the CFD analysis. Some regions in India and the Middle East address this problem by requiring a single system provider to design, install, and commission the car park system. Unfortunately, that requirement adds cost to the system because economies of scale cannot be leveraged. Other areas simply require the designing company and CFD supplier to provide the control sequencing that is consistent with what was simulated during the CFD analysis. That method also can work as long as the electrical and controls contractors are communicated to properly.

Hybrid Systems

The requirement for smoke control zones and other more redundant design criteria sometimes drive the cost of ductless systems higher than ducted systems. That is because supply and exhaust locations may be required at several locations in a particular building between floors and even on the same floor. Supply and exhaust shafts are not visually appealing and add excavation cost and area to the building. A simple potential solution to this is to use a hybrid system so that ducting can extend on opposite sides of the car park for the supply and exhaust. The ducting is sized so that the intakes and out-takes satisfy the smoke control zoning requirements, with the advantage of having a single supply and exhaust shaft per floor. Authorities and consultants are encouraged to consider this option when a fully ductless system is not viable due to ordinances or design constraints.

Conclusion

A ductless car park ventilation system is a low-cost alternative to the more traditional ducted design. Utilizing sensors and operating on demand according to the carbon monoxide or nitrous dioxide levels makes the system significantly more efficient during normal operation than a traditional system. During a fire, with proper smoke zoning and fire detection equipment, the jet fans can be used to control the smoke in a much more specific way, making it easier for the occupants to exit the building, and easier for the fire-fighters to fight the fire. Ductless car park systems create a more comfortable safe environment at a low cost. As long as proper design and installation practices are followed, ductless or hybrid systems allow for a superior design.

References

1. ASHRAE. (2015). In *ASHRAE Handbook - HVAC Publications* (pp. 15.18-15.21). Atlanta, Georgia, USA.
2. BSI Standards Publication. (2013). Components for Smoke and Heat Control Systems. In *BS 7346-7:2013*. BSI Standards Institution 2013.
3. International Code Council, Inc. (2015). *International Fire Code*. Illinois, USA.
4. International Code Council, Inc. (2012). *International Mechanical Code* (IMC). Illinois, USA.
5. Krarti, Ph. D., P.E., M., & Ayari, Ph.D., A. (2001). Ventilation for Enclosed Parking Garages. *ASHRAE Journal,* February 2001, pp52-57.
6. MDH/FHWA. (1995). *Memorial Tunnel fire ventilation test program, comprehensive test report*. Massachusetts Highway Dept., Boston, USA, and Federal Highway Administration, Washington, D.C., USA.
7. National Building Code of India NBC. (2005). *Bureau of Indian Standards.* Delhi, India.
8. NFPA 88A – Standard for Parking Structures. (2015). *National Fire Protection Agency.* Quincy, Massachusetts, USA.
9. NFPA 92 – Standard for Smoke Control Systems. (2015). *National Fire Protection Agency.* Quincy, MA.
10. Smoke Control Association. (2007). *CFD Modelling for Car Park Ventilation Systems.* Federation of Environmental Trade Associations