PARKING FACILITIES AND VAPOR INTRUSION MITIGATION:
Design and Operation Considerations for Parking Facilities as Vapor Intrusion Mitigation Options




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Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	ASTM International
CFM	Cubic Foot per Minute
CO	Carbon Monoxide
DCV	Demand Controlled Ventilation
DOE	Department of Energy
EPA	Environmental Protection Agency
HVAC	Heating, Ventilation, and Air Conditioning
IBC	International Building Code
IECC	International Energy Conservation Code
IMC	International Mechanical Code
LEED	Leadership in Energy & Environmental Design
MPCA	Minnesota Pollution Control Agency
NIOSH	National Institute for Occupational Safety and Health
NO_2	Nitrogen Dioxide
OSHA	Occupational Safety and Health Administration
O&M	Operation and Maintenance
Pa	Pascal
perm	Permanence = 1 grain of water per hour per square foot per inch of mercury pressure
ppm	Parts per Million
SF	Square Foot
VOCs	Volatile Organic Compounds

1.0 Executive Summary

This Document was prepared to facilitate a detailed and comprehensive understanding of parking facility design, construction, and operation as it relates to sub-slab vapor intrusion and vapor intrusion mitigation. This Document presents a review of readily available literature, codes, parking facility products, experiences with parking facility forensic investigations, and discussions with design professionals to understand current design, construction, operation, and use. This Document is intended to be used by design professionals when a parking facility is being considered as a mitigation option for vapor intrusion. Design professionals include engineers, architects, and consultants who may design or may influence the design of a parking facility.

Current codes outline the requirements for flow of air between parking facilities and occupied space within, adjacent to, and above a parking facility. The requirements fall primarily into two main categories: physical barriers to reduce migration of air and ventilation (natural and/or mechanical) of harmful vehicle exhausts.

Building materials selected for parking facility construction play a major role in the potential for vapor intrusion into occupied space. Even with the best construction materials and methods, seals and air barriers can leak. These leaks may increase with time if the physical barriers are not properly maintained. Because no building is perfectly sealed and building materials degrade over time, if a parking structure does not vent effectively, there is potential for vapors to migrate into adjacent occupied space. Thus, combining physical barriers with ventilation will provide additional protection from vapor intrusion.

All parking facilities are required to have some form of ventilation. Ventilation can be in the form of a mechanical system that forces fresh air into the structure while venting the “stale” air out. In the case of open structures, ventilation occurs naturally through wind across and through the structure.

While the codes are designed to significantly reduce air (and associated vehicle exhausts) from a parking structure entering into occupied space, many factors can influence how a parking facility and the associated occupied space interact. This includes the pressure differential between an occupied space and a parking facility, preferential pathways such as elevators and stairwells, and the type and operation of the ventilation system. Ventilation is utilized to pull fresh air into parking structures to minimize harmful vehicle exhaust accumulation. However, ventilation can alter the pressurization of a parking facility.

In recent years, energy efficiency has become a major consideration for parking facility design and operation. Codes focus on reducing overall energy use while still preventing unsafe levels of CO and other harmful constituents of vehicle exhaust from migrating into adjacent occupied space. The amount of ventilation that actually occurs in a parking facility can vary greatly depending upon the conditions, occupancy, and traffic frequency.

If a parking facility is utilized for a vapor intrusion mitigation option, it is important to be able to rely on the ventilation system and building components as originally installed. Ongoing regular maintenance coupled with monitoring of the ventilation system may be required to confirm future effectiveness. Additional measures should be considered to increase the long term effectiveness, including post-construction confirmation sampling, diagnostic testing, and implementation of an O&M plan to verify a parking facility provides the required vapor intrusion protections. Because parking facility designs are unique, system verification approaches and O&M plans will need to be facility-specific depending on each design consideration used to address vapor intrusion.

Parking facilities can be designed to mitigate vapor intrusion. However, the potential for vapor intrusion into a parking facility needs to be evaluated during the design process. Each parking facility is designed for a specific development and building use; therefore, there is not an all-inclusive design matrix that can be developed for mitigation. If vapor intrusion is a concern, then building components should be evaluated and designed specifically for vapor intrusion mitigation needs.

For existing structures, when building components have already been constructed, a design professional should review the various aspects of the site conceptual model and the parking facility design to evaluate the need for vapor intrusion protections. Additionally, a building-specific O&M plan should be created for ongoing maintenance and inspections of a parking facility following its construction to ensure long-term protection from vapor intrusion.

2.0 Introduction

The MPCA retained Braun Intertec Corporation to prepare this Document to facilitate a more comprehensive understanding of the design, construction, and operation of parking facilities as these topics relate to vapor intrusion and vapor intrusion mitigation. Of primary concern is subsurface soil vapor contaminated with non-petroleum and petroleum related VOCs that may enter a parking facility and subsequently into adjacent occupied space.

This Document provides a summary of readily available literature, codes, parking facility products, experiences with parking facility forensic investigations, and discussions with design engineers to understand current design, construction, operation, and use of parking facilities. The objective of this effort was to understand the various design approaches and requirements for typical parking facilities, including those required under existing codes, and how different design approaches may affect the potential for vapor intrusion. This Document is intended to be used by design professionals when a parking facility is being considered as a mitigation option. Design professionals include engineers, architects, and consultants who may design or may influence the design of a parking facility.

In general, this Document focuses on the following:

- Rules, regulations, codes, industry standards, and common practices related to parking facilities for the State of Minnesota and also industry-wide standards or relevant federal requirements.
- Requirements for air barriers in between parking facilities and adjacent occupied space, and how these air barriers influence the potential for vapor intrusion.
- Parking facility ventilation and pressurization.
- Construction practices for parking facilities as they relate to the potential for vapor intrusion.
- Facility use and unintended consequences as they relate to potential for vapor intrusion into the structure.
- Design considerations for when a parking facility itself is intended as the vapor intrusion mitigation system.

It should be noted, that this Document is not intended to be a comprehensive review of all available research, codes, or requirements, but rather to present information on common parking facility design elements, code requirements, and operational features as they relate to the potential for vapor intrusion into occupied space adjacent to a building equipped with a parking facility.

In order for a parking facility to be considered a vapor intrusion mitigation system, the facility needs to be evaluated for the potential for vapor intrusion during the design process. There are no standard recommendations that can be made to fit all situations because parking facilities are customized to their site. This Document provides various considerations and recommendations that are primarily for situations where a parking facility itself is the vapor intrusion mitigation system in lieu of a more typical/traditional mitigation systems (sub-slab depressurization or sub-slab ventilation systems).

Design professionals should utilize this Document to support evaluations, which include assessment of the overall protection to human health and the environment; compliance with relevant and appropriate building requirements (i.e. building codes, energy codes, etc.); short and long-term effectiveness and performance of designed vapor intrusion mitigation systems; the anticipated reduction in potential vapor intrusion risks to occupied space; and implementability and cost of the recommended vapor intrusion mitigation approach.

3.0 Definition of Parking Facility

The term "parking facility" can refer to several different designs of facilities used for vehicle parking. Some designs have a parking facility located beneath the occupied portions of a building, while other facilities may be adjacent to occupied space. The term "adjacent to occupied space" is used because there are many variations of parking facilities, such as multi-level parking surrounded by or abutting occupied space. For example, a multi-level parking ramp wrapped in commercially leased space, or condominiums surrounding a parking facility with the rear of the units having direct access to a parking garage.

Additionally, parking facilities can be fully open to the atmosphere, partially enclosed, or fully enclosed and may be above ground, partially below-ground, or completely below-ground. There are several definitions that have been created or defined by codes and other organizations to differentiate the range of designs/styles of parking facilities, including:

- Eight or less stalls: this can be from a single stall tuck-under garage for a single or twin home to a fully enclosed parking surface that is below grade or partially exposed.

- Parking deck: this term is used for parking that occurs on an elevated structural slab that allows the parking of vehicles above and below the elevated deck. Often, this type of structure is open on the sides and is ventilated by ambient air passing through the openings and removing vehicle exhaust fumes (natural ventilation).

- Parking structure or parking ramp: this is the general term for a parking facility. It can be a fully enclosed facility, an open sided facility, or a combination of both. Structures or ramps are often multiple levels. Larger facilities of this type may have open sides for natural ventilation as this reduces the enclosure construction costs as well as the on-going costs for ventilation equipment.

- Parking garages: this type of facility is often used under residential apartments, private condominiums, and office buildings. There may be several levels, or tiers, that are connected to each other by sloped access ramps. They are typically fully enclosed on the perimeter and require ventilation to extract the exhaust generated by vehicles within a facility. There may also be a combination of fully enclosed and open sided parking on multiple levels that could be used for parking.

- Automated parking structure: this is a system of shuttles and conveyors that are often constructed out of steel. The automated system takes a vehicle and shuttles it to a given destination, similar to placing a book on a shelf. When the vehicle owner returns, the vehicle is pulled off the "shelf" and returned to the ground floor. This style of facility has a much higher construction cost, which is sometimes offset by the efficiency of floor space. These designs typically do not require as much ventilation because the vehicles are not running as they move through the facility.

The type of parking facility is a consideration when evaluating vapor intrusion risk. For example, above ground open air parking decks, open parking ramps, and similar structures ventilated with ambient air should provide sufficient protections from potential vapor intrusion. However, even with an open parking structure, elevator shafts, enclosed accessory areas, or enclosed conditioned stairwells may require a vapor intrusion evaluation. Similarly, fully enclosed structures will require a vapor intrusion evaluation of both the parking areas and other potential pathways (i.e. stairwells, elevators, etc.).

4.0 Summary of Relevant Codes

Technology and regulations change over time. They evolve and adapt as new studies, new research, and new theories arise. In Minnesota, the Uniform Mechanical Code and Uniform Building Code were generally followed to comply with construction of parking facilities until approximately the year 2000. Currently, Minnesota parking facility design and operation typically complies with the IMC and IBC for design and construction. Other codes that apply to parking facilities include ASHRAE, State of Minnesota Rules, Minnesota State Energy Code, and Model Energy Code.

The rules, regulations, codes, industry standards, and common practices related to parking facilities typically fall into two main categories: building design/construction and/or operation of facilities. Based on our review, a summary of relevant codes is provided in the following tables. This summary is not an "all inclusive" review of the rules, regulations, standards, and codes used for design of parking facilities, but rather is a list of codes, rules, and regulations that could affect the potential for vapor intrusion into occupied space. For the purpose of this paper, the term "code(s)" refer to the sum total of the rules, regulations, codes, industry standards, and common practices related to parking facilities referenced in this document.

The relevant codes summarized below are organized by State of Minnesota codes (Table 4.1) and federal/national codes (Table 4.2). As rules, regulations and codes change, considerations will need to be made as to the potential effect on the ability for a parking facility to provide adequate protection as a vapor intrusion mitigation system. For example, the current code-required general ventilation within parking facilities has been reduced by approximately one-half from earlier codes. These updated ventilation requirements have evolved through further understanding of energy use within parking facilities and the objective to maintain healthy spaces while minimizing the energy expended for O&M.

Table 4.1 Summary of Minnesota Regulatory Codes Related to Potential for Vapor Intrusion

MINNESOTA MECHANICAL AND FUEL GAS CODE (CHAPTER 4)	
Code Reference	**Description/Notes**
401.6	Contaminant Source - "Stationary local sources producing airborne particulates, heat, odors, fumes, spray, vapors, smoke or gases in such quantities as to be irritating or injurious to health shall be provided with an exhaust system in accordance with Chapter 5 or a means of collection and removal of the contaminants. Such exhaust shall discharge directly to an approved location at the exterior of the building." The code does not provide the means or methods for this removal.
403.3	Lists occupancy classification for multiple use and single use dwellings.
	Common exhaust airflow rate for multiple units is 0.75 CFM per SF of garage space.
	Common exhaust airflow rate for single dwellings is 100 CFM per vehicle.
Table 403.3	Lists minimum ventilation rate for repair garages, enclosed parking garages of 0.75 CFM per SF.
	There is a footnote that indicates ventilation systems in enclosed parking garages shall comply with Section 404 (Piping System Installation) which is specific to enclosed parking garages.

MINNESOTA RULES CHAPTER 1346.0404	
Code Reference	**Description/Notes**
Section 404.1	Parking garages that house vehicles that emit CO or NO_2 shall have monitors that will trigger the HVAC system to operate automatically. The monitors shall have a low level threshold of 25 ppm for CO and 3 ppm for NO_2.
Section 404.2	Mechanical ventilation shall be sized for a minimum exhaust rate of 0.75 CFM per SF of garage floor area.
Section 404.3	Accessory spaces to parking facilities (i.e. offices, waiting rooms, ticket booths, elevator lobbies, etc.) must maintain a positive pressure to the garage, per IMC Section 403.3.
Section 404.4	Prohibits heated commercial parking per Minnesota Commercial Energy Code Chapter 1323.

HISTORICAL REFERENCE - MINNESOTA CHAPTER 7670 (FORMER MINNESOTA ENERGY CODE, REPEALED IN 2009 AND REPLACED WITH IECC)	
Code Reference	**Description/Notes**
7670.04	The code defines a moisture vapor retarder as a material that performs to the level ability of one perm (perm = 1 grain of water/hour/SF/inch of mercury pressure), or a minimum of 4-mil poly, if the moisture vapor retarder is not cross laminated.
7670.45	ASHRAE 1993 Handbook of Fundamentals Chapters 25-27.
	ASHRAE Standard 62-1989 on ventilation.
	Defines the ASHRAE 62 ventilation requirements, Enclosed parking ramps must follow Chapter 1350.
7670.047	Defines how components in a building are to operate and how "tight" a building must be assembled as it related to heat loss and air leakage from a building.
	- Category 1 is typically used for Residential and require mechanical ventilation.
	- Category 2 is a structure where infiltration and positive ventilation are relied upon for year-round ventilation and may have a mechanical ventilation system.
	Firestop around openings is required to block air movement.
	Envelope penetrations at electrical, communication, fan housings, etc. must be sealed to prevent air leakage.
	Moisture vapor retarders in heated buildings are intended to be installed on the inside (“warm-in-winter” side of the wall). This may also be intended as an air barrier, which MUST be continuous. These differences in the integrity of the moisture vapor retarder also occur between Category 1 and Category 2 buildings. The Category 1 and 2 are intended to describe the “tightness” of a building as it relates to heat loss and air leakage from a building.

HISTORICAL REFERENCE - MINNESOTA CHAPTER 7670 (FORMER MINNESOTA ENERGY CODE, REPEALED IN 2009 AND REPLACED WITH IECC) - continued	
Code Reference	**Description/Notes**
7670.047 (continued)	The air leakage rates of less than 0.24 CFM per SF of conditioned space at 50 Pa needs to be maintained. This is tested in accordance with ASTM 779-87. This leakage refers to the total aggregate leakage for all 6 sides of the conditioned space. The leakage can vary (i.e. around windows) as long as the aggregate for the conditioned (occupied) portion of a building leakage meets the code requirements.
7670.061	Requires insulation for the slab edge must extend to the top surface of the slab. This will conflict with the desire to have a soil vapor mitigation if the air is allowed to bypass the slab edge. The air gap is required in order to create a thermal bridge between the floor slab and the structural footings.
	Note, after 1978 commercial parking for greater than 3 vehicles may not be heated, but may use exhaust air from adjacent spaces if the openings in the exterior envelope is protected by fire dampers and fire doors.

2015 MINNESOTA STATE ENERGY CODE	
Code Reference	**Description/Notes**
2012 International Energy Conservation Code (Adopted by Minnesota)	Outlines how a building envelope will need to be sealed from the environment. C402.4.1.
	The air barrier needs to be applied to concrete block or 1/2 inch of stucco, and yields an average leakage of less than or equal to 0.04 CFM per SF of area according to tests per ASTM E 2357, E1677 or E283. Or the space should not exceed air leakage in excess of 0.40 CFM per SF of area at 0.3-inches of water column pressure per ASTM E779.
	Window air leakage should be less than 0.20 CFM per SF of window. Storefront and curtain wall shall be less than 0.06 CFM per SF of area as 6.24 PSF.
	Stairway smoke venting dampers maximum leakage rate is 4 CFM per SF of damper at 1-inch of water column pressure.
	Lighting cans in the ceiling must be Type 1C with either a gasket or caulking of the penetration and be less than or equal to 2 CFM.

MINNESOTA STATE BUILDING CODE (2015)	
Code Reference	**Description/Notes**
402.4.2.3	If parking is adjacent to a shopping mall, storage of not more than 9 vehicles must be separated from the mall by a 2-hour fire rated structure.
403.1	High Rise Buildings - Open parking garages constructed in accordance with 406.5 do not need to follow 403.2 to 403.6. This incorporates items such as types of fire rated construction, sprinklers, etc. that would normally be inside a building, rather than a parking structure.
405	The requirements for underground parking and sprinklers.
406	Motor Vehicle Occupancies
406.3.4	Deals with the separation of habitable R occupancy space and U occupancy space. They are to be separated by a minimum of 1/2 inch to 5/8 inch gypsum board and have solid wood doors or steel doors separating the spaces. Any ducts must be steel construction and no openings are permitted in the garage. It should be noted that most ductwork contains some level of leakage at the joints in the duct sections.
406.4	Public Parking Garage - Enclosed garages follow 406.6, open garages follow 406.5, and there is a reference to Section 510 for special requirements.
406.4.5	Bituminous may be used as a floor for slab-on-grade parking garages.
406.5	Open garages need to follow 406.5.1 to 406.5.11 referencing parking garages and conditions for ventilation.
406.5.2.1	Openings below garages for natural ventilation must have a clear outside horizontal space 1.5 times the depth. The width must be maintained.
406.6.2	Enclosed Parking - Must have a mechanical ventilation system per IMC. Something that is not addressed by this code is a backup power system for the ventilation. At this time there is nothing that would require any emergency power to keep ventilation operating during electrical downtimes. Note, currently the MPCA does not require backup power systems for active mitigation systems in the event of a power failure.

Table 4.2 Summary of Other Relevant Regulatory Codes or Industry Standards Related to Potential for Vapor Intrusion

AMERICAN SOCIETY OF HEATING, REFRIGERATING, AND AIR-CONDITIONING ENGINEERS (ASHRAE)	
Code Reference	**Description/Notes**
62.1-2013 Table 6.5	Air flow rates should be designed for 0.75 CFM per SF of area. This has lowered by almost half from past requirements.
90.1-2010 Section 6.4.3.4.5.	Establishes a mandatory DCV system as a means of power savings. This is also used for LEED points in order to reduce the amount of electrical consumption. A DCV is a control method that regulates the exchange of fresh air into an enclosed space in order to meet the codified air standards while reducing the energy consumption.
Fundamentals Chapter 25 and 26	Outlines the desirable air-flow dynamics that occur in a building. This indicates an air barrier should not leak more than 0.40 CFM per SF of area at 0.3-inches of water column pressure. These codes also outline that the moisture vapor retarder and the air barrier may be served by the same material. Humidity often affects the permeability rating of the air barrier or moisture vapor retarder.

INTERNATIONAL BUILDING CODE	
Code Reference	**Description/Notes**
2003 and 2006 (Natural Ventilation)	Allows for natural ventilation on the exterior of the structure. The open spaces need to be on at least two sides of a building, and each tier of parking must have at least 20% of the wall area open. The aggregate length of the openings should be a minimum of 40% of the perimeter. Interior walls must also be at least 20% uniformly open.
	Open structures are affected by how close a building can be set to the property line. This is due to building setback requirements in the community or distance from other structures per fire code. Air intake or exhaust could create some issues depending on the proximity of intakes, discharges, and the height of the exhaust that serve the ventilation.
	A truly open structure does not require any mechanical ventilation.

5.0 Summary of Separation Requirements

Several current codes regulate the flow of air between parking facilities and occupied space within, adjacent to, and above a parking facility. These codes are written with three primary goals: fire protection, energy efficiency, and preventing migration of harmful vapors generated within a parking facility into an occupied space. The requirements to meet these three goals fall into two main categories: physical barriers to prevent or reduce migration of air, and ventilation (natural and/or mechanical) of harmful vapors or “stale” air.

In recent years, energy efficiency has become a major consideration for parking facility design and operation. Recent code changes focus on reducing overall energy usage while still preventing unsafe levels of CO and other harmful constituents of vehicle exhaust from migrating into occupied space.

Codes require separation (air barrier) between a parking facility and occupied space that is adjacent and/or above a parking facility. For purposes of this Document, an air barrier is defined as a mechanical system, design feature, and/or set of materials designed and constructed to control airflow between an occupied space (office space, residential apartments, etc.) and an unoccupied space (parking facility).

Note, there are additional code requirements for “accessory areas” within a parking facility (i.e. guard shacks, maintenance/storage rooms, parking attendance offices, etc.). For example, codes require that accessory areas must maintain a positive pressure relative to the adjacent parking facility. However, the term “occupied space” refers to offices, retail shops, residential units, and similar areas that are located adjacent to or above a parking facility, not within a parking facility itself, and where the primary purposed is for human occupancy.

A summary of each of these two categories of building code requirements (i.e. physical barriers and mechanical systems) are provided below, and the discussion centers on how they each influence the migration of air between a parking facility and an adjacent occupied space.

5.1 Physical Air Barriers

Normally, a parking facility is located below (subgrade) or comprises the ground level to either business occupancy (retail stores, restaurants, and services) or residential occupancy (apartments and condos).

Codes require that the “floor/ceiling/wall assembly” that separates these two spaces (parking facility and occupied space) be fire rated. The penetrations through the separating assembly also need to be sealed for air entry/leakage and as a firestop. Firestop refers to a passive system of various materials or components used to seal joints and openings in a fire resistant wall, floor, or ceiling assembly. Most of the time, this separation is made by the floor structure that typically is concrete. This can be poured-in-place concrete, precast concrete, post-tensioned concrete, or some structure that requires fireproofing of metal members. These structures are also penetrated by utilities that service the floors above and drain lines that connect to utilities beneath the structure, which require sealing with appropriate materials (firestop, gaskets, sealant, etc.).

In addition to the firestop requirements for separation, there are codes that define the physical properties of air barrier separation that is required related to energy efficiency and the migration of harmful vapors. This is where having an air tight separation, in regards to the connections with the adjacent or overlying occupied space, is important. Utility penetrations, doors, windows, and lighting all need to have an air barrier (i.e. firestop, gaskets, sealant, etc.) to prevent air leaks from a parking facility into an occupied space.

The air barriers that are utilized can be of a variety of materials. Plywood, sheetrock, plastic polyethylene sheeting, mechanically attached membranes, liquid applied barriers, or “peel and stick” barriers are all allowed under current codes. The performance characteristics of each material is variable. Some of the barriers may serve a multi-functional role by also acting as a moisture vapor retarder, weather barrier, and/or water resistant barrier. The joining of the materials can vary from overlapping of sheets with or without tape, self-adhesive sheets, or monolithic liquid membranes. These materials are used both on the floor/ceiling assembly and the wall assemblies. Codes require a continuous air barrier on the interior (all 6 surfaces) of a building to prevent air leakage and entry. The quality of the materials selected during design, the quality of the installation, and specifically the joining of these various physical barriers across a parking facility will influence how “tight” and effective the physical air barrier will perform. Current commercial codes do not require the tightness or effectiveness of the air barrier to be tested prior to occupancy. However, residential codes require tightness testing on single-family or multi-family residential with less than three stories.

Based on our project experience, vehicle exhaust (specifically CO) can migrate through penetrations that are not properly sealed or seals that degrade over time. This may allow vehicle exhaust to build up in wall cavities or elevator shafts and can then potentially create adverse health effects for building occupants. It is typically not possible to seal all penetrations, such as elevator shafts, stairwells, etc., with physical barriers alone, which is why the codes also include provisions for ventilation requirements.

5.2 Parking Facility Ventilation Systems

All parking facilities are required to have some form of ventilation. The Minnesota Mechanical and Fuel Gas Code requires structures where airborne particulates, heat, odors, fumes, spray, vapors, smoke, or gases may accumulate to levels that can be irritating or injurious to human health, emitted or produced from within the facility, be provided with an exhaust system. Even if a parking facility is built with materials to prevent exhaust from entering an occupied space, systems are required to evacuate the buildup of exhaust and contaminants from within a parking facility.

There are various ventilation systems allowed under current codes. Ventilation can be in the form of a mechanical system that pulls fresh air into the structure while venting the "stale" air out. In the case of open structures, ventilation occurs naturally by both ambient wind and temperature differentials. It should be noted the quality of the fresh air being pulled into a parking facility affects the quality of air inside.

The codes regarding parking facility ventilation were written primarily to address potential buildup of harmful emissions from vehicle exhaust and heating systems, and therefore, the codes are written primarily for mitigation of CO and NO_2. Various codes address maximum allowable concentrations for CO or NO_2 that can be present in a parking facility. The codes typically set threshold concentrations for CO or NO_2 concentrations that will trigger the ventilation system to operate. Several organizations have published codes or recommended levels to trigger ventilation.

Table 5.1 summarizes the recommended concentrations of CO that should not be exceeded within a parking facility. This would be the maximum threshold at which ventilation should activate.

Table 5.1 Carbon Monoxide Monitor Activation Thresholds

Agency	Recommendations for Low Level Alarm Setting for CO
ACGIH	25 ppm
IMC	25 ppm
Minnesota Rules	25 ppm (or 3 ppm of NO_2)
NIOSH	35 ppm
EPA	35 ppm
OSHA	35 ppm (over 8 hours)

CO and VOC vapor contamination act similarly when looking at the physical movement and migration of gases. However, it should be noted that the threshold mass concentration to activate ventilation between CO and a particular vapor contaminant (the subject contaminant of a vapor intrusion investigation), may be significantly different. Additionally, current codes only require monitoring for CO and in some cases NO_2. Other vapors that may accumulate in parking facilities are not addressed under current code requirements for ventilation or air separation.

Ventilation system designs that meet the above requirements vary based upon parking facility construction and cost considerations. Sections 5.2.1 and 5.2.2 summarize common ventilation approaches in parking facilities. Ventilation systems can be, and many times are, customized to the building project. However, all of the ventilation systems fall into two basic categories: mechanical or natural ventilation.

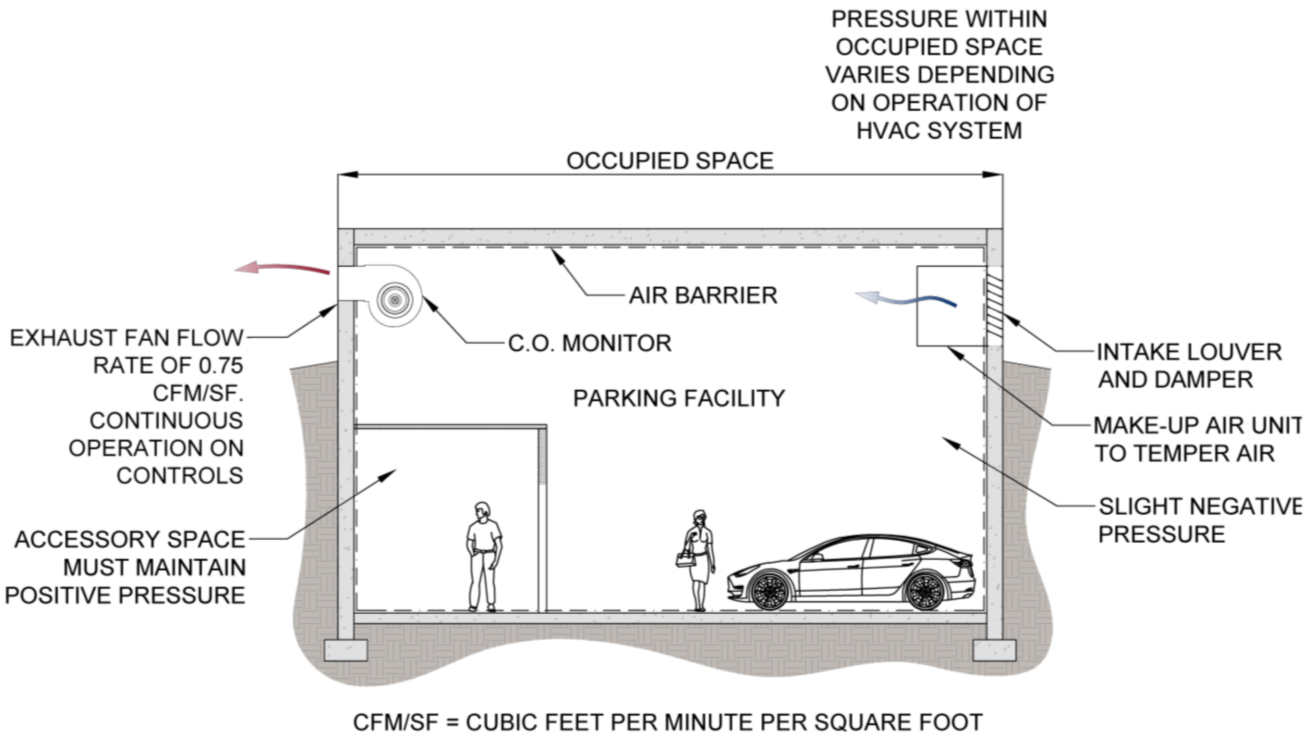
5.2.1 Mechanical Ventilation

Mechanical ventilation systems for parking facilities have two main types of operation: full-time or demand-based. These mechanical ventilation systems operate by creating a vacuum within a parking facility to pull fresh air into the structure and scrub the “stale” air out. Full-time operation describes a parking facility where the ventilation system is continuously operating. This is a requirement in some states (i.e. California). Continuous operation is not required by current Minnesota codes. Currently Minnesota codes require parking facilities to be equipped with sensors that operate the HVAC system sufficiently to prevent harmful buildup of CO and NO_2. Figure 5.1 depicts a typical full-time operating system. The benefit of a full-time operating ventilation system is there are typically more air exchanges per day within a parking facility than for a demand-based system. If designed and operated properly, this type of system does not allow vehicle exhaust or vapor contamination concentrations to build up significantly within the structure. Additionally, continuous air movement can prevent moisture buildup and moisture issues (i.e. mold, odors, etc.).

The primary disadvantage of full-time operating ventilation systems is the cost for O&M and electrical consumption. For this reason, systems that operate continuously at full power are not common anymore. Instead, some designs incorporate variable fan drives to reduce electrical consumption, where fans will continuously operate at low speeds, but increase air circulation during high traffic periods through a parking facility. The monitors or sensors, to trigger the increased air circulation, may be based on CO, NO_2, and/or vehicle traffic (motion). More recent codes have moved away from motion trigger systems that were allowed under the IMC in the mid 2000’s, and have moved to the CO/NO_2 concentration sensor requirements to determine the need for ventilation. However, if CO/NO_2 or motion sensors are not used to control air ventilation, then continuous operation is mandated by the IMC and ASHRAE.

Additionally, to reduce energy costs, and heat the parking facility, some ventilation systems are designed to reuse an occupied space’s conditioned air as makeup air for the parking facility. This is accomplished by discharging the conditioned air from an occupied space into the parking facility, which is then discharged to the exterior of the structure through the parking facility.

Figure 5.1 Typical Parking Facility with Full-Time (Continuous) Ventilation

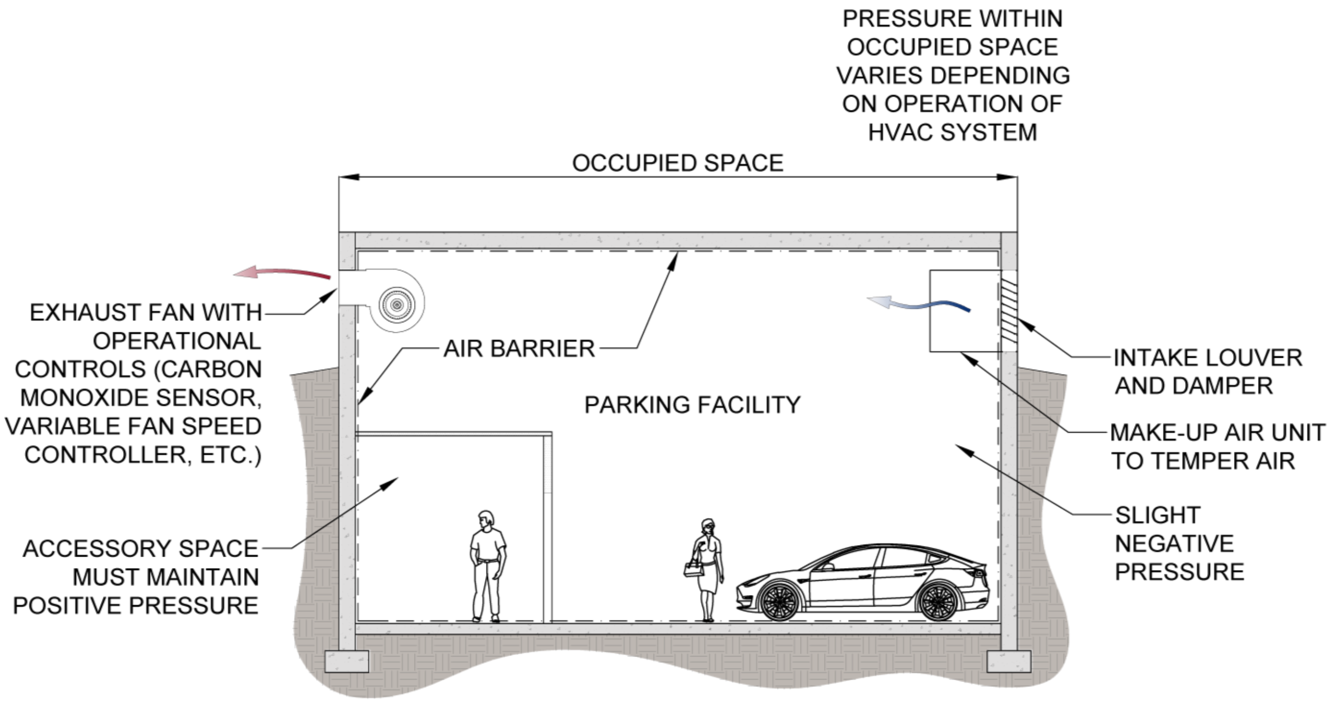


Most parking facilities in Minnesota that operate using mechanical ventilation utilize demand-based systems. Demand-based systems operate utilizing a monitor or sensor to trigger operation of the ventilation system. Figure 5.2 depicts a demand-based operating system. As discussed previously, the system will typically monitor for CO and NO_2. Table 5.1 summarizes regulatory recommendations on threshold concentrations of CO and NO_2 when ventilation should activate. According to the International Parking & Mobility Institute (2014 Nagle), 80 to 90 percent of parking facility ventilation systems that are demand-based utilize a CO sensor to trigger the exhaust and make-up air systems.

The primary benefit of a demand-based ventilation system is energy efficiency. Typically, operation times would only be during high-traffic periods. However, some electric companies apply peak usage fees, so the cost differential between demand-based operation and full-time operation on low fan speeds may not be as significant. Additionally, in Minnesota it is common to have additional temperature-based sensors (thermostats) or time-based monitors operating the ventilation system during the heating season to prevent freezing pipes or to define a minimum air exchange per day.

The primary disadvantage to a demand-based ventilation system with respect to vapor intrusion is the potential for vapor contaminants to build up in a parking facility during non-traffic periods (i.e. overnight, weekends, holidays, etc.). Additionally, sensors require periodic inspections, calibration, and maintenance to maintain their effectiveness.

Figure 5.2 Typical Demand-Based Ventilation System



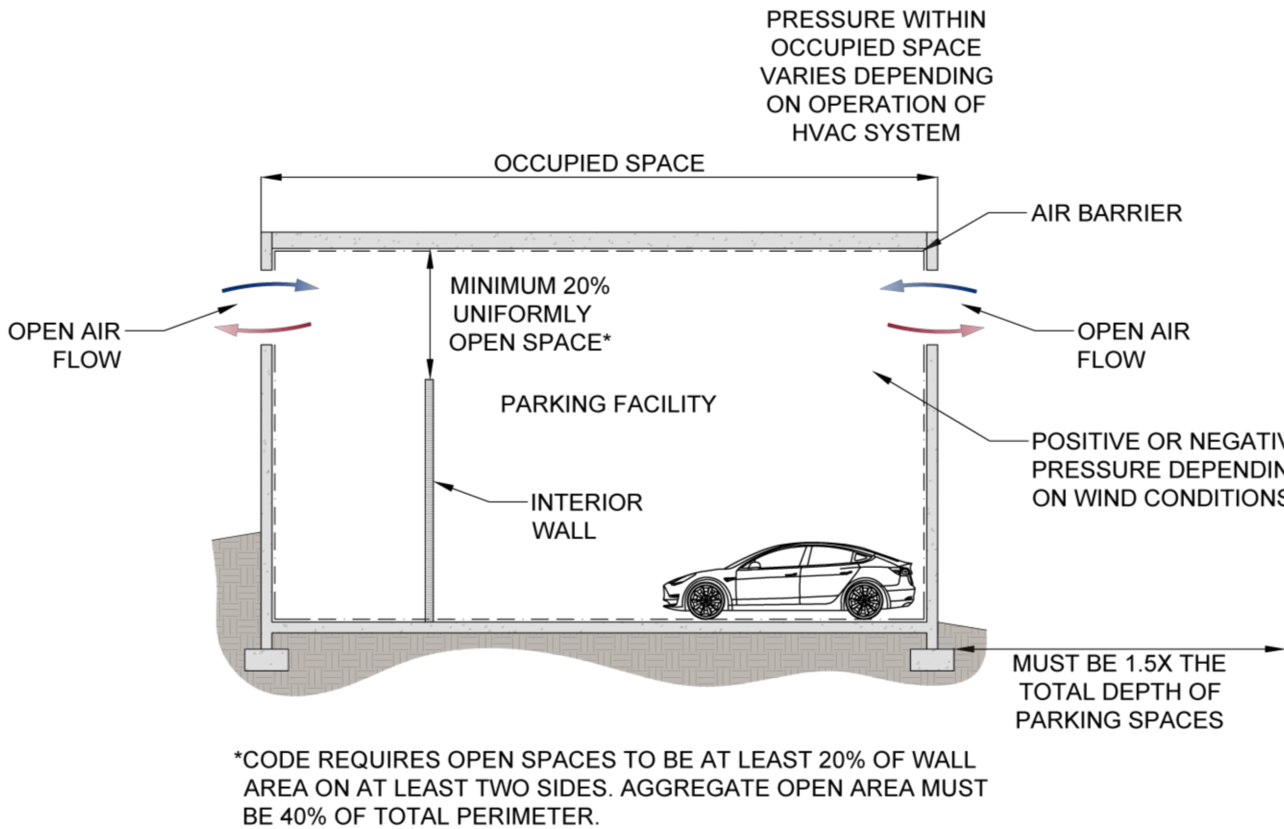
The intended use of the facility can influence the type of ventilation system used and also the number of air exchanges that may be completed within a parking facility. Residential and office use typically have low turnover of vehicles during the day, where most users enter and exit twice a day. Retail use typically has a high turnover of vehicles throughout the day. The intended use is an important design consideration because when less exhaust is generated, demand-based ventilation systems operate less, which results in fewer air exchange events during the day. It should be noted that because demand-based systems are primarily based upon CO and NO_2 concentrations, as electric or low-emission vehicles become more prevalent, these systems may run at greatly reduce frequencies as compared to present day conditions.

While there are various codes that require ventilation, the codes for demand-based ventilation systems do not currently require a specific number of air exchanges per day, but rather the codes define the air exchange rates and sizing of fans required to meet air flow rates when triggered. This may increase the potential for vapor intrusion into occupied space for facilities with low vehicle traffic.

5.2.2 Natural Ventilation

Codes allow for natural ventilation to the exterior of the structure and regulate the number and size of interior wall openings and the open area distance between adjacent structures for the facility to be considered naturally venting. Figure 5.3 displays a typical naturally venting facility.

Figure 5.3 Typical Natural Ventilation Facility



Naturally ventilated parking facilities have some special considerations. Typically these parking facilities operate without any mechanical ventilation, so there is no consistent pressure differential to create a negative (vacuum) or neutral pressure in a parking facility to prevent exhaust from entering an adjacent occupied space. In fact, it is possible there could be a slight positive pressure in a parking facility under certain weather conditions. Wind across a structure will have an effect on the pressurization of occupied spaces of a building. Wind will create a positive pressure on the windward side of a building and a negative pressure on the leeward side of a building and with temperature differentials can lead to significant negative air pressures/vacuums within a building.

6.0 Construction Practices

Common construction practices can influence the potential for vapor intrusion into occupied space near a parking facility. Two main designs for structural walls are concrete block and poured concrete. Concrete block is a very porous material and can allow air and vapor movement through the block. The cores of the concrete blocks, which are open and are not typically filled with mortar or insulation, can allow for free movement of air vertically within walls. Poured concrete walls tend to be less porous, so there would be less movement of air and vapor through or up walls. Painting or coating either type of wall surface with material such as a waterproofing product or membrane can significantly reduce the amount of air and vapor that passes through a wall.

Floors within parking facilities are typically constructed of concrete and in some cases bituminous pavement. The type of floor materials utilized may be different based on whether a parking facility is underground or slab-on-grade. Concrete floors are more common; however, bituminous floors are occasionally used when there could be significant movement due to poor sub-soil geotechnical conditions. Bituminous floors are more common in open air designs; however, current codes do allow bituminous floors in any slab-on-grade parking facility. It should be noted that the vapor intrusion attenuation factors used in the current MPCA risk based guidance assumes a concrete floor slab. If a parking structure includes a bituminous floor, the presence of a bituminous floor will alter (typically lower) the sub-slab to indoor air attenuation factor for vapor intrusion.

Within a parking facility, a moisture vapor retarder or vapor barrier membrane are not typically required to be placed beneath the floor slab for moisture control like it would be for an occupied slab-on-grade floor. For conditions when mitigation of water vapor transfer is needed, a moisture vapor retarder is placed just below the concrete slab. Moisture vapor retarders can also be used along the walls and ceiling to create the air barrier around a parking facility. Per the past Minnesota Energy Code 7670.0400, a moisture vapor retarder is defined based on certain performance criteria or a minimum of 4-mil polyethylene sheeting. However, 4-mil polyethylene sheeting is generally not considered adequate for chemical vapor intrusion protection. Virgin polyethylene vapor barrier membranes (10-mil or greater) are significantly more effective than 4-mil polyethylene sheeting. Though it is not a requirement in Minnesota, it is common practice to design a vapor intrusion mitigation system for new construction or major renovations (i.e. total floor replacement) with an upgraded vapor barrier membrane. The additional cost of the upgraded moisture barrier material is a consideration when designing a parking facility and unless vapor intrusion mitigation is a known objective, parking facility designers typically will not have a reason to specify more than the 4-mil polyethylene sheeting other than only when there is a concern regarding high moisture content soils.

6.1 Radon-Resistant Construction

Radon-resistant construction includes design elements similar to both passive and active vapor intrusion mitigation systems and is a code requirement for new residential construction. Typical radon-resistant construction features include a coarse aggregate layer and vapor barrier membrane (upgraded moisture vapor retarder) beneath the floor slab, and exhaust pipes which extend from below the floor slab beneath a building to the exterior typically through the roof. However, because the current code requirements are not specific concerning buildings where an occupied space is underlain by a parking facility, design professionals do not always include radon-resistant construction beneath residential parking facilities. If a parking facility is designed with radon-resistant construction, the radon system could be modified or upgraded to mitigate for vapor intrusion.

6.2 Post-Construction Operation

Typically upon construction completion, a parking facility's ventilation system is commissioned to verify that it is operating as designed. The ventilation system is then maintained by the property management/maintenance staff for a building. However, it is not standard practice or required by current codes to test the ventilation system beyond the initial commissioning or for building owners to implement a formal O&M plan for a parking facility's ventilation system. Therefore, with standard parking facility operation, there is currently no long-term verification requirements that the ventilation system is operating effectively to prevent vapor intrusion.

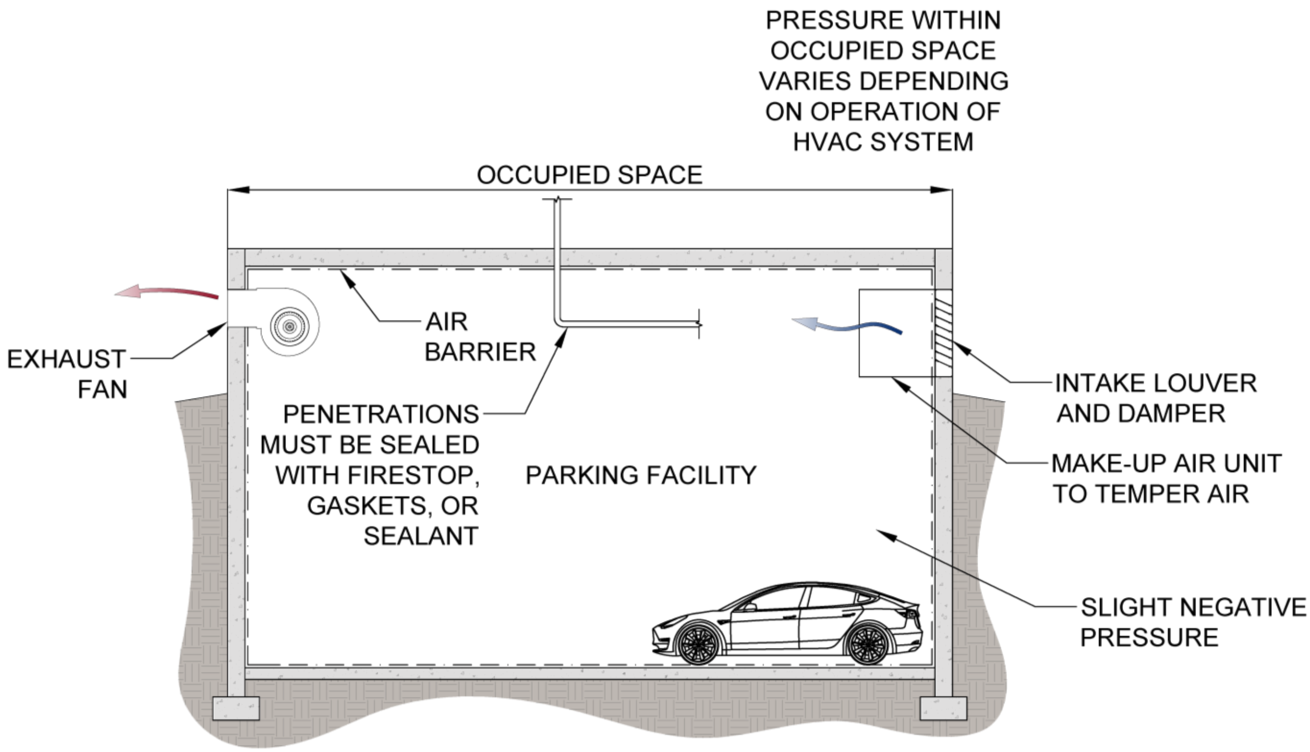
7.0 Building Parking Pressurization and Stack Effect

7.1 Building Parking Pressurization

All enclosed parking facilities are required to have ventilation systems, which usually include a series of exhaust fans on each floor of the structure. Section 5.2.1 discusses operation of two types of ventilation systems. Based on typical HVAC design and operation, occupied space typically operate at a slight positive pressure. The air is generally "blown" into occupied portions of a building, distributed through a pre-designed series of ducts and vents, and then exhausted through louvers that regulate the resultant positive pressure within an occupied space. Our research, however, did not identify current code requirements that an occupied space within a building are required to be kept under positive pressure, with the exception of accessory spaces within a parking facility. As discussed in Section 5.0 - Summary of Separation Requirements, accessory spaces within a parking facility (i.e. ticket booths, offices, maintenance rooms, etc.) must maintain a positive pressure measured against the parking area of the facility.

Pressures can be used to provide additional protection from vapor intrusion from a parking facility. If a parking facility operates with a slight negative pressure (vacuum) compared to an occupied space, as illustrated in Figure 7.1, this creates the potential between the two spaces for vapor to be drawn into a parking facility instead of into occupied space. The vacuum within a parking facility will then, however, create a potential for vapor intrusion from sub-surface soils or adjacent to below ground walls.

Figure 7.1 Common Ventilation System Construction and Operation



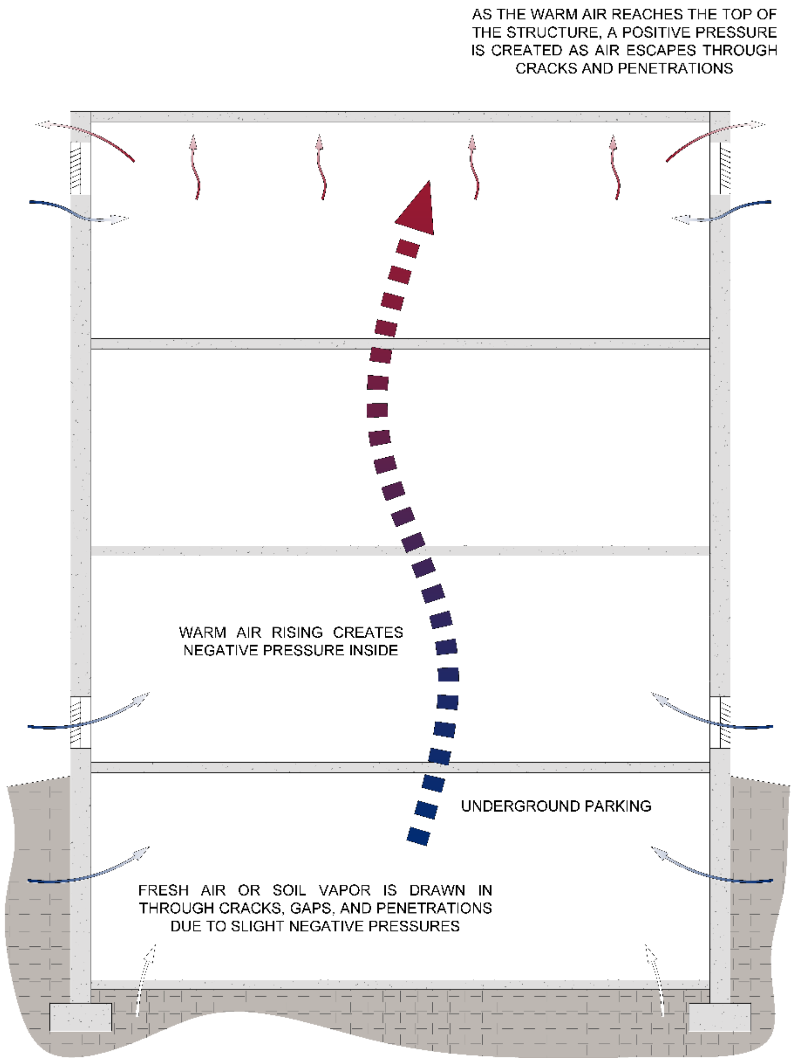
There are many different types of heating and cooling systems for occupied space, typically operated by a thermostat. Changes throughout the year will affect whether a building's occupied space is truly under a positive pressure. This is especially true in residential buildings during the "shoulder" seasons (transitional seasons between the high/low temperature seasons) when HVAC systems may run only intermittently. Most HVAC systems are designed to correct for climate differences in an occupied space. However, at times, if one area of a building requires cooling and another does not require any conditioning, the ventilation system might not operate. In order to prevent a situation where up to half the ventilation fans are not operating, a central make up air unit is used to add fresh air to the central corridors. The supply air is discharged to one end of the corridor, drawn through the corridor, and then exhausted from the opposite end.

While the codes are designed to limit air from entering into occupied space from a parking facility, many factors can influence how a parking facility and the associated occupied space interact. Ideally, occupied space is under a slight positive pressure to provide an additional air barrier to harmful vapors that accumulate in a parking facility. Depending on a parking facility design, this may be affected by wind (if the facility is open to ambient air) and/or by seasonal temperature variations causing areas of an occupied space to not be under positive pressure. A lack of proper maintenance or intentionally altering the HVAC system, can greatly change the pressure relationship between an occupied space and a parking facility.

7.2 Stack Effect

In addition to the pressures created by the HVAC systems and building air flow, pressures will additionally be influenced by a condition called stack effect. Stack effect is the non-mechanical ventilation condition that occurs naturally within buildings. Warmer air will tend to rise in the structure through pipe chases, stairwells, atriums, and elevator shafts. The rising air is replaced by cooler air, and the cycle continues. This effect can occur to varying degrees, but in high rise structures, it is more noticeable and can lead to significant vacuums within occupied space. For example, as you enter a building, it seems like there is a vacuum pulling on the other side of the door; this is the stack effect making a building operate in a negative pressure (vacuum) condition. Figure 7.2 depicts pressure influences from stack effect without mechanical system influence. Mechanical systems can be designed to counteract some of the differential by balancing the incoming air and the exhaust air that is being discharged or leaked out through a building envelope. However, this may be difficult depending on building construction, weather conditions, and building use.

Figure 7.2 Pressurization from Stack Effect without Mechanical Ventilation Influence



As discussed further in Section 8.0 - Facility Use and Unintended Consequences, central heating and exhaust units use energy to operate. It is often found that management companies or facility managers will turn off the central corridor conditioning to save energy costs. This changes the pressure balance of a building, which can cause negative pressures through stack effect, winds, and other conditions that change the pressure regimen throughout a building, and potentially allow vapors to migrate into occupied space.

Openings in a building for stairwells and elevators that connect into a parking facility may provide a conduit for air to enter occupied space. These openings can then circulate contaminants (vehicle exhaust or vapor contaminants) via stack effect or by a building's ventilation system throughout occupied space. For example, CO has been measured on the third floor of an apartment building which has been attributed to a parking facility below. This was likely the result of a breakdown of air barriers (gaskets, firestop, sealant, etc.), modifications to the mechanical ventilation system, and CO entering into stairwells and elevator shafts. Potential modifications to ventilation systems that can allow migration of CO into occupied space include activities such as turning off the ventilation system in the common areas (i.e. hallways, lobbies, etc.) or deactivating the CO sensors in a parking garage to save on energy costs. By altering the ventilation regime in a building, a mechanical ventilation system may no longer counteract stack affect, therefore allowing CO to be drawn up through elevators shafts, stairwells, and wall cavities into occupied space. If a parking facility is also under a vacuum to begin with, and no barrier for vapor intrusion mitigation was designed and constructed, vapors could be present within a parking facility and could be drawn into occupied space along with the CO.

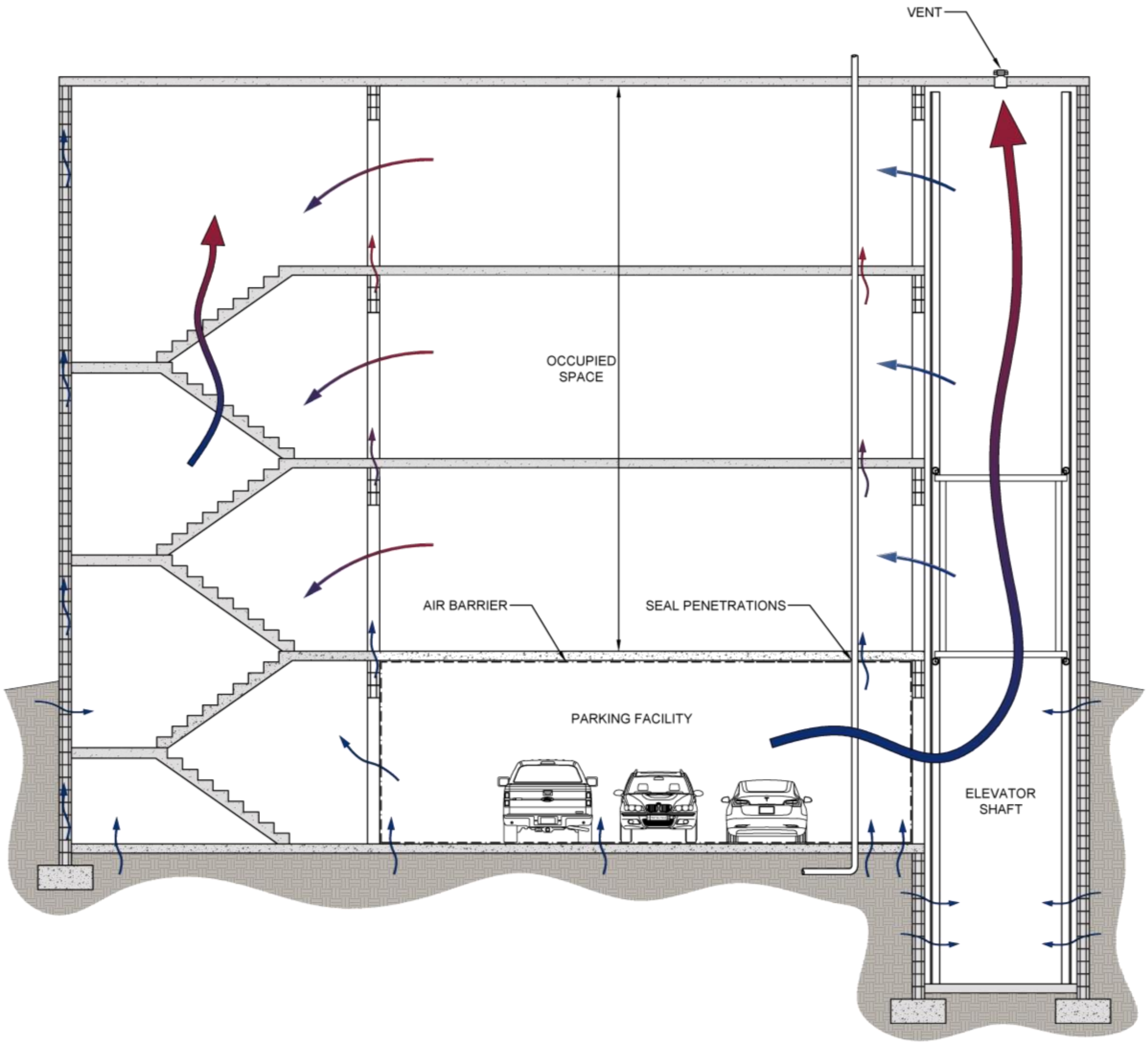
7.3 Elevator Shafts

In addition to stack effect, elevator shafts act like a piston, driving air up into the higher levels as the elevator rises to the upper floors and vice versa when the elevator drops to the lower floors. Sumps, drains, and unsealed pits in an elevator shaft can be a potential source for vapor intrusion. Based upon the pressure regimen inside of a building, air may flow in or out of the elevator shaft, moving air throughout the building. The flow of air into or out of an elevator shaft may vary based upon the HVAC operating conditions throughout a building and whether the elevator is static, rising up or lowering down. Because no building is perfectly sealed (especially in stairwells and elevator shafts), and building materials can degrade over time, if a parking structure does not vent effectively, there is a risk of vapors present in parking structures migrating into occupied space.

8.0 Facility Use and Unintended Consequences

The success for a construction project is often measured by how the design minimizes both short term construction costs and future O&M costs. It is a balancing act to keep building construction costs low while minimizing future maintenance costs. Certain building materials may be more cost-effective during construction, but may require maintenance sooner or more frequently than other building materials. Generally, as a facility ages, periodic maintenance tends to be more reactionary than proactive. If a parking facility is constructed and maintained properly, vehicle exhaust and vapor contaminants should be exhausted prior to intruding into occupied space. However, there are many factors that may influence whether a parking facility's design, construction, and operation provides complete protection from vehicle exhaust or other vapor contaminants. Potential entry-points for exhaust or vapor contaminants need to be evaluated based on the building design and construction materials selected. Figure 8.1 depicts some potential vapor intrusion entry-points to consider.

Figure 8.1 Potential Entry-Points for Vapor Intrusion Migration



Driving surfaces and flooring materials are a parking facility's components that most frequently require maintenance. For example, additional membranes of urethane or epoxy are sometimes applied as traffic coatings to reduce the penetration of chlorides (salts) reaching the metal reinforcement in the concrete. These coatings may significantly reduce corrosion, and by extension, provides additional resistance to vapor intrusion due to the low permeability of these coatings. While these membrane/coatings can decrease the vapor intrusion potential, these membrane materials may break down over time, requiring patching or replacement in order to maintain the assumed effectiveness. Additionally, these membrane materials only decrease the permeability of the floors on which they are applied. They do not influence potential vapor intrusion through unsealed portions of a parking facility (i.e. foundation floor, elevator shafts, block walls, etc.).

Overall, inadequate management of aging facilities can lead to unintended consequences. Building materials are manufactured with a life expectancy. Firestop, gaskets, and spray-applied barriers will dry out and disintegrate.

Most of these building materials are behind walls or in maintenance closets that are not frequently used and where maintenance may be infrequent.

As building management changes hands, O&M plans may be forgotten or passed over, and scheduled services for each equipment can be skipped. Studies published in the 2013 California Building Energy Efficiency Standards (California Utilities Statewide Codes and Standards Team, 2011) showed that the CO detectors are often not maintained, calibrated, or changed with time. Failure to maintain, test, and calibrate CO/NO_2 sensors over time will decrease the effectiveness of the ventilation system. If a parking facility is utilized for vapor intrusion mitigation option, it is important to be able to rely on the ventilation system and other building components as originally installed.

While existing codes require periodic maintenance for mechanical ventilation systems, the desire to keep operating costs low may cause unintended consequences. For example, altering operation times of mechanical ventilation systems, to lower electrical usage, may still be within design recommendations for vehicle exhaust management, but may potentially allow soil vapor concentrations at unacceptable levels to build up in a parking facility.

9.0 Conclusions

Current codes require both physical barriers and ventilation to provide continuous air barriers between parking facilities and occupied spaces. Building materials selected for parking facility construction play a major role in potential for vapor intrusion to be minimized. Common building materials used to construct parking facilities may not prevent vapor intrusion, which is why vapor intrusion should be considered during the design process. Even with the best construction materials and techniques, seals and air barriers can leak. The leaks may increase with time if these barriers are not properly maintained. Because no building is perfectly sealed and building materials degrade over time, if parking structures do not vent effectively or periodically, there is a risk of vapors migrating into occupied space. Thus, combining physical barriers with ventilation will provide additional protection from vapor intrusion.

All parking facilities are required to have some form of ventilation. Ventilation can be in the form of a mechanical system that forces fresh air into the structure while venting the “stale” air out. In the case of open structures, ventilation occurs naturally by wind and should be, then, sufficient for vapor intrusion protection. Ventilation systems can be designed to prevent buildup of soil vapor contamination; however, most parking facility ventilation systems are not designed with vapor intrusion considerations in mind. The codes regarding parking facility ventilation are focused primarily preventing the buildup of harmful emissions from vehicle exhaust and heating systems (CO and NO_2 specifically). Additionally, accessory spaces (i.e. offices, ticket booths, etc.) should be evaluated separately for vapor intrusion potential during the design process.

Most parking facilities in Minnesota that utilize mechanical ventilation typically operate using a demand-based system. The ventilation system is not operational until a sensor (typically CO and NO_2) reaches certain threshold levels to activate the ventilation. Parking facility usage and traffic frequency affects operation of demand-based ventilation systems. Especially as electric or low-emission vehicles become more prevalent, these systems may run at greatly reduced frequencies compared to present day conditions. This method of ventilation operation can be cost-effective; however, the lack of air circulation can cause soil vapor to concentrate in a parking facility as well as increase the potential for moisture issues.

If a parking facility is utilized for a vapor intrusion mitigation option, it is important to be able to rely on the ventilation system and building components as originally installed. Ongoing regular maintenance coupled with monitoring of the ventilation system may be required to confirm future effectiveness.

Additional measures should be considered to increase the long term effectiveness, including post-construction confirmation diagnostic testing, and implementation of an O&M plan to verify a parking facility provides the required vapor intrusion protections. Because parking facility designs are unique, sampling approaches and O&M plans will need to be facility-specific depending on each design consideration used to address vapor intrusion.

9.1 Design Considerations

Based on the current codes and practices, parking facilities can be designed to mitigate vapor intrusion into occupied space. However, the potential for vapor intrusion into a parking facility needs to be evaluated during the design process. Each parking facility is designed for a specific development and building use; therefore, there is not an all-inclusive design matrix that can be developed for mitigation. However, if vapor intrusion is a concern, building components can be evaluated and designed specifically for vapor intrusion mitigation needs. Design professionals should evaluate, at a minimum, the following building components for vapor intrusion mitigation in Table 9.1.

Table 9.1 Building Component Design Considerations for Vapor Intrusion Mitigation

Building Component	Design Considerations
Floor Slab	Epoxy/urethane coating, seal all cracks and saw cuts
Concrete Block Wall	Fill voids with concrete/insulation, paint block wall
Ceiling/Walls	Waterproofing membranes, coat, or paint walls
Stairwells and Elevator Shafts	Additional ventilation
HVAC/Ventilation Units	Adjust operation frequency, minimum air exchanges per hour, digital control system
Utility Penetrations	Upgrade firestop/sealing to extend replacement period
Vapor Retarder/Barrier	Upgrade thickness of barrier or vapor intrusion specific barrier
Radon System (if required for building type)	Upgrade system for vapor intrusion mitigation
Operations and Maintenance	Minimize “human error/control,” building-specific O&M plan to evaluate condition of building materials and ventilation systems, periodic effectiveness testing

For existing structures, when building components have already been constructed, a design professional should review the various aspects of the site conceptual model and the parking facility design to evaluate the need for vapor intrusion protections. Additionally, a building-specific O&M plan should be created for ongoing maintenance and inspections of a parking facility following its construction to ensure long-term protection from vapor intrusion.

9.2 Other Considerations

This Document is not intended to be a comprehensive review of all available research, codes, or requirements, but rather designed to present information regarding common parking facility design elements, code requirements, and operational features as they relate to the potential for vapor intrusion into occupied space adjacent to a building equipped with a parking facility. Therefore, we have noted other considerations that have not been addressed or discussed in this Document, including:

- The DOE published papers on energy savings and ventilation quality in January 2014. They have recognized that there needs to be more research on managing indoor air pollutants by means other than outdoor air exchanges. They see that and other issues with outdoor air sources as a key gap in the evaluation.

- Changing building use over time and/or mixing building uses such as residential and retail can lead to temporary or permanent changes in the HVAC systems that affect the indoor building pressures. This may lead to changes in the potential for vapor intrusion.

- Future use of existing parking facilities and the potential for adaptive reuse of these facilities may alter the needs for ventilation. As vehicle demand changes, parking facilities may be turned into residential or commercial space. Former parking garages/on grade parking facilities with open side ventilation have been closed off to capture underutilized square footage and converted into retail space or housing. If a parking facility is converted into occupied space, the Site would need to be re-evaluated in regards to vapor intrusion risk.

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The Braun Intertec Team has incorporated project-related experiences related to parking facilities, forensic services, and vapor intrusion assessment and mitigation throughout this Document. Collectively, our engineers, architects, and scientists have experience with complex aspects of parking facility projects and related vapor intrusion mitigation decisions discussed herein.

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