CARBON MONOXIDE: THE SILENT KILLER

An education in carbon monoxide poisoning, incomplete combustion and other dangerous things you do *not* want coming from your store's HVAC system.

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It is every facility manager's worst nightmare. Employees and customers are complaining of feeling ill after entering one of your stores. Some complain of headaches. Some are experiencing nausea. Others are feeling lightheaded and ambulances arrive to remove those who are feeling faint. The fire department arrives with the emergency medical personnel and one of the firefighters walks through the store with a small instrument that contains a flexible tube and a digital display. He tells the manager that he is getting positive readings of carbon monoxide within the store. The store is evacuated and the HVAC equipment is shut down. The utility company is summoned and they lock the gas service off at the meter.

The scenario described above is quite real. It can occur and has occurred in retail stores in the past. We all have read newspaper articles describing incidents where people have died in their homes of carbon monoxide poisoning due to a malfunctioning furnace or chimney. Carbon monoxide poisoning in residences often results in death due to two factors. The first is that drowsiness is one of the end stage symptoms of carbon monoxide poisoning, so people lie down in their beds and just never wake up. The second is the fact that homes are not nearly as well ventilated as commercial buildings and dangerous concentrations of this deadly gas can build up far more quickly in a home than in a retail store.

The Risk

So, while you probably don't have to worry about your heating systems killing anyone, the threat of making your customers and store personnel ill is reason enough to learn about avoiding the consequences of a carbon monoxide incident. Carbon monoxide (CO) is an odorless, colorless gas that occurs as a result of incomplete combustion of a fossil fuel. It is both a cumulative and a direct poison. CO combines with hemoglobin in the blood stream and replaces oxygen in the blood until it completely overcomes the body. The harmful effects of carbon monoxide differ from person to person based upon concentration in the air, exposure time, age, sex and general health. The maximum allowable concentration for short term exposure in a living area is 9 parts per million. At 35 parts per million, you're at the maximum allowable concentration for continuous exposure in any 8-hour period. At 200 parts per million, the symptoms include slight headache, dizziness, fatigue and nausea after 2 to 3 hours of exposure. At 1,600 parts per million, the above symptoms occur within 20 minutes and death occurs within 1 hour.

How It Occurs

In order for CO to become an issue, two situations must be present. A malfunction in the heating system must cause carbon monoxide to be produced, and there must be a way for CO to enter the occupied space. In order to understand how a heating system creates CO and how it can enter a store, one must first understand the proper operation of a heating system that burns fossil fuels.

Most retail stores located in the United States are heated with furnaces that burn natural gas. These furnaces may be built into a packaged, roof mounted, heating and cooling unit. They may take the form of a duct furnace attached to a split system air handler. Finally, they may stand alone with their own fan or blower, in which case they are considered unit heaters or hot air furnaces.

In each case, heat is generated by burning gas. Most often, this gas is natural gas that is piped to the store. In some rural areas, propane is stored in large underground tanks on site and is burned within the furnace to generate heat. Some stores are heated by burning a liquid fuel such as #2 fuel oil. Oil burners are also capable of producing carbon monoxide; however, the flue gases from an oil burner have an odor that is normally detected before CO poisoning can become an issue.

How a Heating System Operates

On a call for heat from the thermostat, an electrically operated valve opens slightly. This valve allows a small flow of natural gas to be ignited by a spark or by a hot ceramic surface. Once this pilot flame is sensed by a device which proves that ignition has been established, another valve opens, allowing gas to flow into the burner or burners. Burners allow the correct quantity of air to mix with the gas and provide a controlled clean burning flame.

A clean burning gas flame should be blue with little or no yellow in it. The flame should never appear orange or smoky. A blue flame is a sign of complete combustion. The flue gases will contain carbon dioxide and water vapor and excess air. An orange flame is a sign of incomplete combustion. The flue gases will contain carbon dioxide, carbon monoxide and soot in extreme cases. This orange flame is an indicator that combustion is not complete. Furnaces should never be allowed to operate in this condition.

The burner injects the flame into the interior of a group of steel pipes or a steel drum that is called a heat exchanger. The burning gases travel through the interior of the heat exchanger and air from the store is blown over the exterior of the heat exchanger. Heat from the burning gases in the interior of the heat exchanger is transferred to the air passing over the outside of the heat exchanger. The temperature of the air is normally raised between 20 degrees and 40 degrees as it passes over the heat exchanger.

The burning gases leave the heat exchanger and are vented to the outdoors. Draft is the difference in pressure measured between the burner inlet and the flue gas outlet, which causes the flue gases to flow. Most furnaces located in packaged rooftop units utilize a draft inducer or a forced draft burner to pull or push the gases through the furnace. Some older furnaces are called natural draft furnaces where the flue gases flow due to a combination of the temperature of the gases and the height of the flue stack or chimney.

The Combustion Process

For our purposes, the mixing of the gaseous fuel with air and the burning of this mixture is considered combustion. The combustion process involves the carbon within the fuel combining with oxygen in the air to form CO_2 (carbon dioxide) and hydrogen in the fuel combining with oxygen in the air to form H_2O (water vapor). Both of these substances represent no health hazard. However, if there is insufficient air, too much fuel or insufficient heat available for complete combustion to take place, CO (carbon monoxide) is formed and so is solid carbon. It makes sense when you think it through. If there are not enough oxygen molecules available for two oxygen atoms to combine with each carbon atom, the end result will be the combining of one oxygen atom with each carbon atom. The carbon atoms that cannot find an oxygen atom or two oxygen atoms to combine with are deposited as solid carbon or soot.

This process is termed incomplete combustion and it is the only way that your heating system can produce carbon monoxide.

Malfunctions That Cause Incomplete Combustion

Any malfunction that causes the fuel-to-air ratio to become too rich can cause incomplete combustion. "Too rich" is defined as too much fuel, or not enough air. One malfunction we see occasionally is failure or maladjustment of the gas pressure regulator. The regulator is designed to maintain a constant pre-set gas pressure at the burner inlet. If the pressure at the outlet of the regulator increases above its design pressure, the flow of gas to the burner is increased and there may not be enough air in the mixture to support complete combustion. Another malfunction that causes incomplete combustion is blockage of the combustion air entering the burner. This can be caused by improper adjustment of the air shutters on the burner, or by physical blockage of the air path. Something as simple as a piece of insulation blocking the burner air inlet can cause incomplete combustion. We've even seen cases where equipment that hadn't run in awhile was buried in a snowdrift and could not obtain enough combustion air for complete combustion. Blockage of heat exchanger tubes, flues and chimneys can also reduce the flow of combustion air to the point that combustion is incomplete. This same condition can occur if draft is reduced due to failure or partial failure of a draft inducer blower wheel.

Typical of residential carbon monoxide incidents is a scenario that begins with a blocked chimney or flue. With the outlet restricted, flue gases are spilled back into the room containing the furnace. As these gases build up, they displace the oxygen in the air into the furnace room and eventually there is insufficient oxygen in the air in the room to support complete combustion. At this point, the gases spilling back into the furnace room contain carbon monoxide and as these gases infiltrate into the occupied areas of the home, the potential for carbon monoxide poisoning exists.

The most common cause of incomplete combustion in gas furnaces is heat exchanger failure. As described earlier, combustion takes place within the steel tubes or drum. Air is drawn from the conditioned space, blown over the outside of these tubes and is sent back to the conditioned space after being warmed by the tubes. If the tubes or drum become perforated, depending on the difference in pressure between the gases burning within the tubes and the air circulated around the tubes, the air-to-fuel ratio and the flow of the gases can be affected to the degree that incomplete combustion occurs. Heat exchanger failure is extremely dangerous because, in addition to causing CO to be produced, it also provides a path for this deadly gas to enter the air that is being distributed to the conditioned space. Remember, the burning gases are inside the tubes and the room air is circulating around the tubes. Once the tubes are holed, the gases within the tubes can mix with circulated air.

How CO Enters the Conditioned Space

We cited two methods above for CO to enter the conditioned space. The first being flue gases that roll out of the furnace due to a blocked chimney or flue, and the second being a cracked or perforated heat exchanger. There are many other ways for the products of combustion to enter the conditioned space. Where multiple rooftop units are located close together, the flue gases from one unit may enter the outdoor air ventilation intake of another unit. If these flue gases contain carbon monoxide, there is now a path for the CO to enter the conditioned space. As a matter of fact, any ventilation opening on the roof is a possible inlet for CO if a unit nearby is operating with incomplete combustion. Considering this, one must always assume that if a piece of heating equipment is producing carbon monoxide, there will be some way for this deadly gas to find its way into the conditioned space.

Preventing CO Incidents

There is no substitute for proper installation practice and regular inspections by a trained technician as a means of preventing carbon monoxide incidents. A qualified technician knows the symptoms of incomplete combustion and heat exchanger failure. The color of the flame and the steadiness of the flame are good indicators. If there is visible rust in the combustion chamber, or visible carbon streaking on the flue gas outlet, the technician knows he has a problem. Technicians also use the age of the equipment to judge which components need careful inspection.

Heat exchangers should last at least 10 years under normal conditions. However, there are certain situations that will shorten the life of a heat exchanger. Most of these are installation issues. Today, most technicians carry carbon monoxide detectors that allow them to analyze the content of the flue gases. If there is any reading of CO in the flue gases, the cause must be found as it is obvious that combustion is incomplete. It should also be noted that heat exchangers, flue passages and draft inducers deteriorate year round, although they can only be thoroughly checked when test firing the unit in heating mode. In a retail application, this occurs at the beginning of the heating season.

Every unit should be checked thoroughly by a competent service technician at the beginning of each heating season. This inspection will predict and prevent future failures as well as allowing the diagnosis of current problems. This practice also gives you a leg to stand on if an issue should occur during the heating season and your liability is questioned. Usual and customary practice within the HVAC industry is to inspect heating equipment at the beginning of each heating season.

Installation Issues

As stated earlier, flue gases containing CO from one source on a roof can sometimes enter a building through ventilation intakes. The HVAC design of a building should take this into consideration. Most mechanical codes require that there must be at least 10 feet of horizontal separation between any outdoor air intake and the discharge of any flue gases. In addition, flue gases are required to be discharged a minimum height above any structure on the roof. In addition to code required separation, I recommend setting rooftop units so that outdoor air intakes face each other. Be extremely careful not to set equipment on low roofs surrounded by higher roofs without giving some consideration as to where the flue gases and outdoor air are going.

Heat exchangers fail prematurely due to cracking and corrosion. Both of these situations are often caused by insufficient air flow or uneven air flow over the heat exchanger. If the air distribution system is not designed and installed properly, the heat exchanger can run at too high a temperature or can develop hot spots. Either situation shortens heat exchanger life. Operating a unit with worn drive belts or sheaves can cause the same problem due to insufficient air flow.

Premature failure due to corrosion can occur from chemical contaminants in the combustion air or from condensation of the flue gases within the heat exchanger. Once again, good design and installation is the answer. Beauty salons, swimming pool supply stores, dry cleaning plants and many other specialized processes produce chemicals that can reduce the life of a standard aluminized steel heat exchanger to one-fifth its normal lifespan. In these applications, stainless steel heat exchangers must be specified to avoid nasty consequences.

As with most other facilities related issues, good design, quality installation, a working knowledge of the possible problems and their causes and a regular inspection program performed by capable technicians are the only ways to limit your exposure to a very dangerous situation. **PRSM**

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