DEVELOPMENT OF A TECHNICAL BASIS FOR CARBON MONOXIDE DETECTOR SITING

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The goal of this work was to develop a technical basis for carbon monoxide detector siting for use in general occupancies in support of the continued development and potential expansion of the scope of NFPA 720, Standard for the Installation of Carbon Monoxide (CO) Warning Equipment in Dwelling Units [1]. The project included a review of the scientific literature with regard to non-fire CO poisoning statistics, CO source characterization, CO dispersion in buildings, and CO detector siting findings in the research literature. Simple analytical expressions for CO dispersion were sought for potential application in detector siting. The modeling and experimental results from the scientific literature were synthesized to develop simple prescriptive type siting rules.

Several types of non-fire CO poisoning statistical studies were identified in the literature: national level statistical analysis of general incident data, state level statistical analysis of general incident data, and national level statistical analysis of special CO sources/problems.

National level studies and analysis have been developed by the Center for Disease Control (CDC), the Consumer Product Safety Commission (CPSC), the Bureau of Labor Statistics (BLS) the UK Health and Safety Executive, and the National Fire Protection Association (NFPA). Among these studies the scope of coverage of the CO poisoning differed depending upon the scope of responsibility of the sponsoring organization. For instance the CPSC studies did not include motor vehicle exhaust, boats, or any work related exposures. The overall finding from the collective body of work is that in the US there are approximately 500 CO poisoning deaths per year and about 15,000 individuals who receive treatment for CO poisoning.

The CO poisoning deaths and injuries have been steadily decreasing over recent decades. The steady decline has been attributed to improved motor vehicle emissions controls and general improvements in combustion devices. All the studies indicate that CO poisonings result from CO produced by combustion sources. Identified sources include furnaces, motor vehicles, ranges/ovens, stoves, water heaters, generators, engine-driven tools space heaters, and charcoal grills. Automobile incidents comprise about half the non-fire CO incidents and overwhelmingly involve idling vehicles. About ⅔ of all

CO exposures occur in the home, with the remainder most often found in public areas and facilities, temporary shelters, and the workplace.

The statistical data does not indicate that the CO poisoning problem in dwellings is fundamentally different from in other occupancies. CO sources are combustion devices in all occupancies. CO exposures are not statistically linked to sleeping. CO exposures are highly seasonal with the highest rates in the winter months in cold climates. Fatalities in adults over 65 years of age are about twice the rate as the general population. While CO exposures are not gender-biased, there are two to three times more deaths for males than females.

State level studies have been reported from California, Colorado, West Virginia, Washington State, and New Mexico. These studies generally follow national trends but highlight climatic differences and automobile emissions regulation effects. A Washington State study focused on racial and ethnic differences in CO poisonings. This study identified Blacks and Hispanics as experiencing higher risks than the general population. A special study of non-dwelling CO incidents identified higher ratios of injuries to deaths than in the general statistics and also found portable combustion devices as the CO source in 1/4th of the incidents. Special studies of CO poisonings associated with natural disasters and power outages indicated that engine powered devices, especially electrical generators, were a significant hazards.

The World Health Organization (WHO), US Environmental Protection Administration (EPA), and the National Institute for Occupational Safety and Health (NIOSH) identify chronic CO exposures to have important health effects in all settings (work and home). The WHO identified workers involved with automobiles (driving, parking servicing, traffic police), warehouse operations, firefighting, cooking, construction work, as well as working in the steel nickel, coke, carbon black and petroleum industries as having higher levels of CO exposure at work. Overall, CO levels are lowest in homes, churches, and health care facilities. WHO, NIOSH, and EPA CO exposure guidelines are well below the alarm levels of current CO alarms for dwellings.

Carbon monoxide is a normal product of combustion from all combustion sources. However, CO production rates can be significantly increased by abnormal operating conditions including problems with the combustion device or the exhaust ventilation system. The production rate of CO varies widely with the combustion device and the operating conditions. The indoor release levels are further widened by large variations in the fraction of CO released within the building. Typical CO generation rates for gaseous and liquid fuels are 0.04 mg/kW of nominal input. Abnormal operations of these devices can be about ten times larger. Internal combustion engines and solid fuel appliances are generally larger CO sources than gaseous or liquid fueled appliances. Normally operating diesel engines produce about 2 mg/kW, wood burning appliances produce 1-8 mg/kW, industrial and marine gas engines produce 14 mg/kW, and small gasoline powered tools produce 100-220 mg/kW. A reasonable range of CO emissions rates is 1–1000 mg/s.

Carbon monoxide dispersion in buildings has been studied experimentally and computationally in single rooms and home size buildings. Indoor air quality (IAQ) studies using tracer gases have been performed in larger buildings as well. Studies can be divided into two classifications; studies of CO movement in and from the room containing the CO source, and studies examining distribution of CO from a source room. CO transport and dispersion occurs via two major mechanisms; forced convection via mechanical ventilation systems and free (or passive) dispersion by natural forces. Natural forces of importance include the buoyancy of the CO source itself, buoyancy due to other appliances, buoyancy due to solar heating, buoyancy due to wall heat transfer to or from out of doors, buoyancy due to stack effect, infiltration due to wind, and occupant movement. These forces are largely involved in the thermal performance of buildings. Where present mechanical or forced convection dominate CO dispersion and result in a well-stirred environment within the ventilation zone.

Dispersion by natural forces is generally dominated by buoyancy. Mixing within a home size floor occurs on the time scales of one to two hours. Flows to lower floors are generally very small and cannot be relied upon for timely detection. Flows to upper floors are generally effective when sufficient openings between floors exist. Closed doors generally are very effective in mitigating CO dispersion. As such, where natural forces dominate the dispersion, a closed door can prevent a CO detector from effectively protecting occupants closer to the source than the detector behind a closed door.

The dynamics of buoyant CO releases is well described by the same modeling principles developed for fire plumes in a room. The dynamics involve a buoyant plume and the development of a heated upper layer that progressively fills the room from the top down. Filling times are typically minutes to tens of minutes. Flows out of a room warmed by the buoyant CO source are well described by classical buoyant door flow equation. Natural forces tend to stir house size areas on the time scales of an hour or two.

Modeling of CO and other contaminants has been pursued using network models that treat a building as a network of well-stirred rooms with transfer between rooms via mechanical and natural forces. As such, they cannot provide guidance regarding the height of detector placement and are not suitable for large space compartments and corridors. The most effective models are those designed to deal with the thermal performance of buildings, as these models better capture the natural mechanisms for mixing and dispersion. Simple contaminant transport models that lack the thermal performance modeling aspects are most useful for assessing mechanical ventilation and stack effect only.

Modeling of CO and other contaminants has also been pursued using computational fluid dynamics (CFD) models. These models provide a higher level of detail in that they model the detailed flows within a room as well as room to room flows. However, these models tend to not include all the relevant natural forces that are important to dispersion where mechanical systems are not in use. Given that mechanical ventilation gives rise to well stirred building areas, there is little value in detailed modeling under these circumstances. Lacking adequate modeling of natural forces seriously limits the utility of existing CFD models in studying natural dispersion in buildings.

The literature review and analysis suggests a two prong approach to CO detection: 1) CO detectors in all rooms containing a combustion source to serve in the role of combustion safety devices (CSD); and 2) CO detectors located in occupied areas to provide monitoring of the indoor air quality (IAQ) with respect to CO, to provide protection from mobile sources, and to provide backup protection with respect to fixed sources.

Siting of CSD CO detectors should be in every room containing a combustion device. The detector should be placed high in the space due to the important role of buoyancy within the source room. If pre-stratification potential exists due to heat sources high in the space
(e.g. heated pipes, solar heated roofing, etc), the detector should be lowered below the pre-stratification zone but no lower than nose level. If openings exist between the source room and the remainder of the building, the detector should be placed at the height of the opening or above to prevent CO dispersion to other spaces without detection in the source room.

For buildings with continuously operating HVAC ventilation systems, one IAQ detector should be provided per HVAC zone. The detector should generally be provided centrally within the zone and should not be located in a peripheral space behind a closed door.

For buildings where the HVAC system is not continuously operating, additional siting considerations apply. One IAQ CO detector should be installed per floor of the building. Where normally closed doors divide a floor area, one detector for each area defined by a closed door is needed. These same siting requirements apply to buildings without HVAC systems. IAQ detectors should generally be placed at nose level or above.

While ongoing progress in the reduction of CO emissions has had a significant safety benefit, there is an ongoing need for CO detection in buildings in general. Even as CO emissions are reduced, there are ongoing hazards associated with improperly installed or improperly operating combustion sources. Appropriate siting of CO detectors has benefits both for safety with respect to acute CO exposures and potentially in reducing health impacts of more chronic CO exposures.

If further work is to be conducted, the existing body of data is most lacking in large floor area spaces with a minimum of closed doors. These spaces would be typical of office areas where there are long corridors or other types of open areas. To date, most of the data is in smaller footprint buildings. It is recommended that experimental research in actual buildings be conducted. This would involve sources motivated by the findings of the current study. Gas sensors and temperature sensors should be distributed throughout the test area. CO or tracer gas sources could be utilized. Variables that should be included in the study include wind speed, solar heating conditions, HVAC operation, and door closures. Building leakage areas should be measured and documented via door fan methods and by tracer gas methods. These tests would provide additional data to evaluate the recommendations of the study and would provide a database of well-documented tests that could be used to develop and validate modeling methods in the future.

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References:

1. Beyler, C.L. and Gottuk, D.T., “Development of a Technical Basis for Carbon Monoxide Detector Siting,” The Fire Protection Research Foundation, Quincy, MA, October 2007.