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**URBAN DESIGN AND PUBLIC EXPOSURE
TO CARBON MONOXIDE**

ENVIRONMENTAL POLLUTANTS and the URBAN ECONOMY

Argonne National Laboratory
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URBAN DESIGN AND PUBLIC EXPOSURE TO CARBON MONOXIDE

Introduction

The air pollutant carbon monoxide (CO) is produced by incomplete combustion in motor vehicles, space heating, industrial processes, and incineration. Current research indicates that higher density residential developments, because they lead to reduced demand for fuels for home heating and transportation, tend to lower total carbon monoxide *emissions*. However, it is in these same areas that concentrations of CO are the highest because of the density of emitters. Since carbon monoxide standards specify maximum allowable concentrations rather than emissions, they tend to deter further development in locations where concentrations are already high — i.e., high density downtown areas. This deterrent effect contributes to greater total emissions of carbon monoxide; hence, it may be desirable to devise a means of controlling the public's risk of exposure to high CO levels in downtown areas without deterring new center city residential development.

In protecting the public from the risk of exposure to damaging levels of carbon monoxide, two approaches are possible: the pollutant's concentration may be lowered by traffic management measures or the public's rate of exposure may be reduced through urban design features. The present emphasis on traffic management stresses improving the flow and reducing the level of traffic — goals that are extremely costly to achieve in downtown areas. This paper examines ways to reduce risk of exposure by the physical design of new downtown residential developments. The concept is not a novel one, having been successfully implemented in industry to provide occupational health and safety.

In order to use physical design to protect the public from exposure to excessive carbon monoxide levels, an architect or planner needs to be able to answer the following questions:

- Where on a specific site will CO concentrations be the highest?
- At what types of locations should the public be protected?
- What design alternatives are available to provide this protection?

These questions are addressed in the following sections.

Locations with the Highest CO Concentrations

Current research into carbon monoxide emissions and concentrations indicates that violations of carbon monoxide standards are most often caused by queuing of vehicles at intersections or other impediments to traffic flow. This occurs because each vehicle emits carbon monoxide faster when idling or traveling at low speed, and for a given emission rate (mg/min) per vehicle, concentrations build up at locations such as stoplights where vehicles are stationary.

Higher CO levels also occur when the pollutant is trapped in troughs or tunnels where normal wind currents cannot disperse it. In a New York City study, examples were found where deep cut highways, urban canyons, tunnels, and air rights construction were associated with violations of the carbon monoxide standard even

when traffic was freely flowing. However, in situations where air circulation is good, carbon monoxide concentrations drop rapidly with distance from the emission source(s). Consequently, on a typical city block the properties of traffic flow and carbon monoxide dispersal characteristics guarantee that mid-block and interior locations will consistently have lower carbon monoxide levels than those near intersections.

Locations Requiring Protection of the Public

Any location which is subject to *and* in violation of a CO standard legally requires some form of exposure risk control. Since the duration of exposure is as important as the concentration level to which a person is exposed, a design objective should be to insure that people spend the majority of their time where concentrations are below the maximum acceptable level.

The U. S. Environmental Protection Agency (EPA) implicitly recognizes this objective in its definition of reasonable receptor sites:

Reasonable receptor or exposure sites shall mean such locations where people might reasonably be exposed for time periods consistent with the national ambient air quality standards for the pollutant specified . . .

Occupations requiring some exposure to CO as a performance criterion (traffic direction, cab driving, etc.) are subject to different standards, which are established by the Occupational Safety and Health Act (OSHA).

Most receptor sites which are deemed unreasonable are places where people might be on a roadway but not in an automobile. Portions of parking lots where the general public is not likely to have access continuously are also unreasonable receptor sites. The EPA applies an average risk criterion to persons walking on sidewalks, resulting in an intersection to intersection averaging procedure. This permits sidewalks to be built in areas where the standard is violated -- i.e., intersections -- as long as most of the likely sidewalk trip is in areas where CO concentrations are acceptably low.

Methods of Reducing Exposure Risk

For a given rate of emissions, distance from the source is the most effective way of reducing exposure rates. Furthermore, vertical distance from the source seems to be a more effective means of avoiding high concentrations than downwind horizontal distance, as illustrated in Table 1.

Some idea of the distances necessary to reduce current exposure rates to acceptable levels may be obtained by examining actual urban carbon monoxide concentrations. During the 1974-75 monitoring year for the City of Chicago, the worst "second highest" CO value (the regulation allows for exposure to one violation of the standard per year) was 19.7 mg m^{-3} averaged over an eight hour period. If this value is divided into the eight hour legal limit of 10 mg m^{-3} , the concentration reduction factor necessary to meet the standard is found to be 0.507. Assuming that the area in question represents a typical city block -- i.e., no urban canyons or similar impediments to CO dispersion -- then a vertical distance from this location of 35 ft or a downwind horizontal distance of 56 ft would provide the

TABLE 1 Equivalent Distances from Road Edge to Achieve Desired Concentration Reduction*

Desired Concentration Reduction Factor	0.97	0.74	0.57	0.44	0.34	0.27
Vertical Distance Necessary (ft)	10	20	30	40	50	60
Horizontal Downwind Distance Necessary (ft)	4	20	42	70	110	170

*Based on reference concentration curves published in the *Environmental Impact Handbook for Highway Systems* by T. D. Wolsko, K. T. Nelson, and L. J. Habegger, Argonne National Laboratory, ANL-ES-30, June 1974.

general public with an environmentally acceptable location in terms of carbon monoxide standards. By performing a similar calculation for the *average* Chicago carbon monoxide monitor, one finds that a vertical or horizontal distance of 20 ft would suffice. It should be emphasized here that while these monitors are not placed *at* the edges of roads, they often are near some of Chicago's more heavily travelled streets. Consequently, the distances implied by the above calculations are presented for illustrative purposes only.

Population exposure to carbon monoxide is also substantially reduced when people are indoors. Using data provided by the Chicago Department of Environmental Control, a regression model was developed which estimates CO concentration inside the ground floor entrance of a building as a function of the outdoor CO concentration. Selected estimates of these relationships are presented in Table 2.

Table 2 indicates that concentrations inside the typical building at ground level will be less than the maximum acceptable value when outdoor concentrations are up to twice the eight hour standard. In fact, Table 2 shows that CO concentrations would be environmentally acceptable inside the entrance of a building adjacent to an outdoor area with CO concentration patterns equivalent to the worst monitored in Chicago in 1974-75. The regression model that generated the estimates in Table 2 includes data for many older buildings, which surely are likely to have higher CO levels than new buildings in which central heating/cooling systems are used in conjunction with upper floor air intakes and exterior surfaces designed for low ambient air infiltration. If building entrances are placed away from CO sources, there should be little problem with excessive exposure in the structure, in view of the concentrations presently monitored in the Chicago area.

TABLE 2 Indoor CO Concentrations as a Function of Outdoor CO Concentrations

Outdoor CO Concentration (mg m ⁻³)	2.0	6.0	10.0	14.0	18.0	22.0
Estimated Indoor CO Concentration (mg m ⁻³)	2.1*	4.3	6.0	7.5	8.8	10.0

*At low concentrations, the indoor CO levels can exceed those outdoors because of smoking and/or fuel combustion for heating.

Use of Physical Design to Reduce Exposure Risk

It is apparent from the EPA definition of reasonable receptors described earlier that planning to meet EPA requirements can solve some exposure problems by manipulating the relationships between outdoor public space and spatial variation in CO concentrations.

For example, although sidewalks are traditionally constructed next to roadways, this certainly is not necessary. If they were to be moved away from roads in general and intersections in particular, the exposure rates of pedestrians would be reduced. It is possible to design sidewalks that will reduce the time of exposure at an intersection by the use of geometrical properties. At a uniformly congested intersection with random wind patterns, sidewalks oriented at 45° from the roadways minimize pedestrian CO exposure near the intersection. Away from the streets, sidewalks might resume a direction parallel to that of the roads. Given different relative congestion and wind directions, the optimum angle for the sidewalks would vary. Two sidewalk design options are illustrated in Fig. 1.

Another use of the sidewalks is for public transit stops at intersections, which are desirable from an operational standpoint since buses have to stop at intersections anyway. However, environmentally, a mid-block transit stop, out of the moving lanes of traffic, is more desirable when intersections are particularly bad.

A possibly unattractive way to prevent the public from using open spaces that are likely to have high levels of CO is to place fences around those areas. More aesthetically pleasing solutions, especially for a boundary between roads and residential developments, may be to (1) plant the area with appropriate shrubbery or (2) build earthen mounds covered with planting. The earthen mound design alternative can also reduce ground level noise within the area and provide a more pleasing ground level view for persons looking toward the street.

Fig. 1. CO Exposure Reducing Sidewalk Design

Fences can prevent short-cut pedestrian routes across ground level parking lots. Vehicle access points into parking lots or garages may be separated from pedestrian traffic by eliminating sidewalks at the vehicular entrance and placing sidewalks and pedestrian entrances at edges of the parking facility which are removed from the street. Within the parking facility itself pedestrian flow should be separate from vehicular flow, and the pedestrian and vehicular entrances and exits should be distinct, with vehicular passages designed to discourage pedestrian use.

The parking lot entrance or exit, since it is a location where a queue of automobiles may build up, is equivalent to an intersection. A parking facility serving a particular building will have peak parking volume at the same time as peak pedestrian volume, since many pedestrian entrants to a building are merely people who recently left their parked cars. Therefore, when parking facilities serve a particular building, it is environmentally desirable to separate the vehicular parking entrance from the pedestrian building entrance.

When all other things are equal, the property lines of hospitals, rest homes, and playgrounds should be further removed from areas of high CO concentration than those of other facilities. The populations of hospitals and rest homes are inherently more susceptible to the deleterious effects of carbon monoxide and playground exercise increases children's uptake of CO.

Other suggestions can be made with respect to street and building configuration and parking facility location. First, when internal roads are placed at the outside boundary of a site adjacent to high volume roadways, then these rather low volume streets act as buffers from high CO concentrations at the border of the site. Second, construction of parking facilities in the lower floors of a high rise residential structure increases vertical distance between high CO concentrations and living units. Finally, parking garages placed at intersections prevent ground level public use of such locations; public recreational facilities on the roof of this type of parking garage would be one way of maintaining desired environmentally acceptable public space.

Typical Buildings in Areas of High CO Concentrations

Carbon monoxide is likely to be a problem in areas close to high volume, stop and go traffic. Further, the extra traffic created by commercial and business activity generally leads to higher carbon monoxide levels. Usually sites with such characteristics will be located near the business core of a city or town, where net residential densities most often are considerably higher than in a city's purely residential areas. The type of residential building commonly found in such environments — i.e., the multi-floor mid- and high-rise building — is desirable from the point of view of reducing CO exposure.

Multi-story living in the vicinity of heavy traffic volume has several virtues. First, upper story dwelling units themselves have the advantage of vertical distance from the source of pollution which, as mentioned, is even more effective than horizontal distance. Second, in upper floor dwelling units, residents do not use the air space immediately adjacent to the unit for recreational purposes. Third, in multi-story buildings, it is possible (and common) to install air intakes for the building at upper levels for central heating and/or air conditioning. Finally, the entrance of a multi-story building may be designed to be a reasonable distance from sources of carbon monoxide. These desirable properties of multi-story buildings exist only when land coverage by buildings is not complete. If multi-story buildings are used at

Examples of the suggestions have been found. Public recreational facilities on the roof of this type of parking garage would be one way of maintaining desired environmentally acceptable public space.

all locations along a roadway, these virtues are eliminated because an urban canyon effect is created in which carbon monoxide emissions are trapped. Reasonably spaced buildings are necessary for good air circulation and carbon monoxide dispersal.

Factors Affecting Costs and Benefits

This paper has suggested that physical design can be employed to protect the public from carbon monoxide concentrations in the case of residential developments close to high volume, stop and go traffic. An important question is whether the suggestions made here are inexpensive and otherwise desirable methods of designing such residential developments. This question is best answered on an individual development-by-development basis. However, the suggestions made here do not require extraordinary innovations in designs. In fact, examples of each of the suggestions have been found to exist in Chicago and its suburbs, and these design alternatives did not arise from considerations of carbon monoxide concentrations. Consequently, it is reasonable to assert that some of the suggested design alternatives are likely to occur in a downtown (city or suburban) development even if exposure to carbon monoxide is not considered. Where high-rise or mid-rise buildings and parking garages are to be used for a particular development, then the suggestions made here amount only to careful selection of the locations of sidewalks, parking facilities, access roads, and buildings.

When the alternative to physical design is traffic manipulation, there will be many cases in which physical design will be the more economical means of lowering public exposure to CO. Another advantage of physical design over traffic control is that the method of meeting the objective is completely internal to the developer. It is not necessary to convince the public bodies responsible for road design to adopt traffic control measures that will affect more persons outside the site than within. Even when traffic control is a cost-beneficial solution on theoretical grounds, it may be difficult to operationally effect the transfer of benefits from the residents of the site to the drivers and passengers who pass by the site or who are forced to take an alternative route.

Policy Implications

This discussion has concerned a neglected and potentially cost-effective approach for complying with carbon monoxide air quality regulations. The discussion here has been necessarily brief, and falls short of providing all the knowledge needed for the site planner or architect to decide when the techniques suggested are useful and to what extent they could be applied. If the approach suggested here were to be accepted as a complement to CO emissions reduction through local traffic control, then design handbooks could readily be developed for use by the professional design community.

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