JULY 1974

EPA-450/3-74-046-b

AIR POLLUTION CONSIDERATIONS IN RESIDENTIAL PLANNING VOLUME II: BACKUP REPORT

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

EPA-450/3-74-046-b

AIR POLLUTION CONSIDERATIONS IN RESIDENTIAL PLANNING VOLUME II: BACKUP REPORT

by

T. M. Briggs, M. Overstreet,
A. Kothari, and T. W. Devitt

PEDCo-Environmental Specialists, Inc.
Suite 13, Atkinson Square
Cincinnati, Ohio 45246

Contract No. 68-02-1089

EPA Project Officer: John Robson

Prepared for

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
Washington, D. C. 20410

and

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

July 1974

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This report was furnished to the Environmental Protection Agency by PEDCo-Environmental Specialists, Inc., Cincinnati, Ohio 45246, in fulfillment of Contract No. 68-02-1089. The contents of this report are reproduced herein as received from PEDCo-Environmental Specialists, Inc. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Publication No. EPA-450/3-74-046-b

ACKNOWLEDGEMENT

This report was prepared for the U.S. Environmental Protection Agency and the Department of Housing and Urban Development by PEDCo-Environmental Specialists, Inc., Cincinnati, Ohio and Vogt, Sage and Pflum, Cincinnati, Ohio. Timothy W. Devitt was the PEDCo Project Manager. Principal investigators were Mr. Terry Briggs, Mr. Mace Overstreet and Mr. Atul Kothari.

Mr. John Robson was Project Officer for the U.S. Environmental Protection Agency and Mr. Charles Z. Szczpanski served as Project Officer for the Department of Housing and Urban Development. The authors appreciate the assistance and cooperation extended to them by members of the U.S. Environmental Protection Agency and the Department of Housing and Urban Development.

The procedures presented in the manual should not be considered accurate estimating methods. They represent a first attempt to present simplified procedures for determinging the impact of air pollutants at residential developments. The procedures presented in the manual have not been tested empirically to determine their validity.

The manual has been written for use, primarily by residential planners and assumes the user has little or no formal training in air pollution and related scientific disciplines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

SCOPE OF THE PROJECT

The contract for this project calls for production of two documents: (1) a manual for use by land-use planners, engineers, or designers in evaluating air pollution aspects of residential development, and (2) a backup technical report for use by professional air pollution specialists and urban planners, citing the research materials used in preparing the manual, outlining development of procedures and models, and presenting recommendations.

The principal objective for the project is to identify site design practices that will reduce exposures to air pollutants in residential environments, with resulting benefits to human health. Environmental impacts other than human health effects are not considered.

OBJECTIVES OF THE MANUAL

The manual was developed as a practical calculation procedure for the residential planner, who is assumed to have limited background in the scientific/technological aspects of air pollution control. We therefore omit theoretical explanations of the procedures. To the extent possible, procedures are presented in an orderly, step-wise fashion to reduce confusion and the possibility of error.

Following are some of the objectives that guided preparation of the manual.

1. The methodology should enable the planner to assess impacts of air pollution sources on any proposed residential configuration likely to be found in this country. The procedures must therefore be valid for a wide range of cases, encompassing variations in locale and type of housing.

2. The manual should be concise and easy for the planner to use.

3. The manual should outline recommended practices for design of building sites and for planning of structural and mechanical features of the buildings. Sub-objectives are that the practices recommended should be practical, economical, and compatible with other characteristics ordinarily desired by the land-use planner or developer.

CONTENT OF THIS REPORT

This final report presents the rationale that underlies the procedures given in the manual. Section 2 considers the technical basis for selection of particulates, sulfur dioxide, and carbon monoxide as the air pollutants to be evaluated and for the exclusion of other significant air contaminants.

Section 3 describes development of the pollutant standards presented in the manual by adapting various elements of the National Ambient Air Quality Standards.

Section 4 presents the basis for selection in evaluating and outdoor pollutant sources to be considered in evaluating pollution impact at a residential site.

Section 5 describes the basic dispersion model as it is applied to the different pollutants and meteorlogical conditions.

Section 6 considers development of emission data for the various classes of outdoor pollution sources presented in the manual.

Section 7 describes in detail the development of a model for conversion of outdoor to indoor pollutant levels, citing pertinent empirical data.

Section 8 describes briefly the background information on which the recommended design practices are based. This information is recognized to be both limited and essentially qualitative.

Section 9 evaluates the over-all project, indicating the perceived strengths and weaknesses, and giving recommendations for further research efforts toward evaluation and reduction of air pollution impact at residential sites.

2 SELECTION OF POLLUTANTS

For this study, consideration of the impact of air pollutants is restricted to their effects on human health. Effects on plants and materials are not evaluated, primarily because including these elements would further complicate the procedures of overriding concern: those for evaluating effects on human health.

Pollutants selected for evaluation in the manual are particulates, sulfur dioxide, and carbon monoxide. Their effects on human health are fairly well established, and they are widely dispersed in the atmosphere. Additionally, they are the only pollutants whose atmospheric dispersion can be calculated for local impacts and short time durations. They are among the few pollutants for which reliable emission data are available. They are the only pollutants for which we can fairly reliably determine atmospheric concentrations that can be correlated with human health effects.

Several significant pollutants and pollutant groups, known to be hazardous to human health, are excluded. In the following, we consider these pollutants and the reasons for their exclusion.

1) Hydrocarbons - We evaluated in detail the procedures for calculating hydrocarbon levels, but determined that in the context of residences the sources for which hydrocarbon

emissions could be calculated are too close to the receptor to create significant deleterious health effects. The national air quality standards for hydrocarbons are based on their ability to interact in the atmosphere to form photochemical oxidants. The normal time required to form significant oxidant levels is in the order of a few hours. Procedures in the manual, however, can adequately determine the impact only of pollutants within a few kilometers; at this close range a hydrocarbon discharge does not have sufficient time to participate in formation of oxidants to an appreciable extent.[1,2]

2) Nitrogen oxides - Nitrogen oxides are strongly implicated in acute and chronic respiratory disease and in systemic effects. Additionally, they are precursors of photochemical oxidant formation in the atmosphere. Unfortunately, since retraction of the EPA method for sampling and analysis of nitrogen oxides in June 1973, no reliable and accepted analytical method is available. For that reason, nitrogen oxides are not included in the calculation procedures. It is recommended that procedures for determining impact of nitrogen oxides be added to the manual when reliable data and methods become available.[2]

3) Oxidants - Although oxidants constitute a major class of air pollutants, they are secondary pollutants and are thus beyond the scope of the manual.

4) Particulate sulfates - It appears that the degradation products of sulfur dioxide, namely particulate sulfates and sulfuric acid aerosols, are more potent irritants than SO_2 itself. Again, however, particulate sulfates are secondary pollutants

and their concentrations cannot be determined adequately by procedures of the manual. The calculated levels of SO_2 therefore must be used to estimate particulate sulfate levels. Because of the paucity of available data, the validity of this assumption is not known.[2]

5) Carcinogenic air pollutants - A number of known carcinogens have been shown to occur in polluted air. These include polynuclear aromatics; azaheterocyclic compounds; various metals such as nickel, chromium, and arsenic; asbestos fibers; and radionuclides. At present no method is available for determining the levels of individual carcinogens, or of total carcinogens.[2]

6) Lead - Airborne lead represents a serious hazard mainly in urban areas. Since airborne lead compounds result mainly from auto emissions, the highest concentrations occur in areas adjacent to heavily trafficked roadways. No adequate predictive model of atmospheric lead levels is presently available. It appears, furthermore, that lead in ambient air is not the major source of the current health problems related to lead.[3,4]

CO levels should be a fairly good guide to prediction of relative lead levels, since emissions of both are predominently from auto exhaust.[5]

7) Asbestos - Inhalation of high levels of asbestos fibers has been associated with asbestosis and cancer. A long latent period of 20 years or more usually occurs between the initial exposure and the recognition of cancer; the latent period for asbestosis is often much shorter. At present, the only epidemiological data showing a definite health hazard from exposure

to asbestos fiber relate to industrial workers with exposure levels far higher than those to which the general public is exposed.

A residential development adjacent to an asbestos fiber processing plant may receive high exposure levels, but we have no data to verify this. Additionally, there is no adequate and reproducible analytical method for determining asbestos fiber concentrations in air. Section 6.0 of the manual, Recommended Design Practices, includes no caution against the use of asbestos insulation as a construction material. There are no data to indicate that the resulting potential levels of exposure present any health hazard; or in fact, whether any exposure does result. Further, since asbestos insulation affords some degree of fire protection and conserves thermal energy, any condemnation of its use in construction must be well justified.

The manual presents a list of hazardous air contaminants and of industries with which they are commonly associated (Appendix B). This material is included primarily as a warning of the potential local health hazards presented by a large number of pollutants. The distance at which these pollutants should be considered by the planner is designated as 2 kilometers, with the proviso that realistic hazard evaluation can be obtained through the local air pollution control agency. The data in Appendix B were obtained from Sittig.[8]

REFERENCES

1. Air Pollution, Vol. I, Ed. Stern, A.C., 2nd Edition, Academic Press, 1968.

2. Summary of Proceedings, Conference of Health Effects of Air Pollution, National Academy of Sciences, prepared for the Committee on Public Works United States Senate, U.S. Government Printing Office, November 1973.

3. Kehoe, R. A. Toxicological Appraisal of Lead in Relation to the Tolerable Concentration in the Ambient Air, J. Air Pollution Control Association. 19,690 (1969).

4. An American Chemical Society Symposium, Air Quality and Lead. Environmental Science Technology. 4,217 (1970); 4,305 (1970).

5. Stern, A. C. et al., Fundamentals of Air Pollution, Acedemic Press, 1973.

6. Cralley, L. J. Epicemiologic Studies of Occupational Diseases, in: Industrial Environmental Health, The Worker and the Community (L. V. Cralley ed.), Academic Press, 1972.

7. Bloomfield, B. D. and Barrett, J. C. Hazard Evaluation and Control, ibid 6.

8. Sittig, M. Pollutant Removal Handbook, Noyes Data Corp., 1973.

3 AIR QUALITY STANDARDS

The initial approach to defining air quality standards for residential developments was to present acceptable, marginally acceptable, and unacceptable levels for each pollutant. The hope was that within these ranges we could specify permitted types of human exposure. The air quality standards, however, were set to protect the most susceptible segment of the population; thus a safety factor is already built into the existing standards. Because the available experimental exposure data are sparse and difficult to interpret, one standard concentration for each pollutant was all that could realistically be defined.

The national air quality standards for short-term exposures are expressed as the level not to be exceeded more than once per year for that time interval. Since the methods presented in the manual are intended for general, nationwide application, we avoided dealing with extreme local meteorological conditions. Accounting for such extreme conditions would have complicated presentation of the emission data and the dispersion models. We therefore considered only moderate meteorological conditions, defined as the worst case not to be exceeded more than 3 percent of the time periods, per year. We applied the Larsen mathematical model[1] to adjust the national standard to the 3 percent level.

The following equation from Larsen was used to make the transformation:

$$Sg = \exp \frac{\ln (Cn/Cs)}{Zq-Zs}$$

where: Cn = pollutant concentration of adjusted standard at 3 percent level

Cs = national air quality pollutant concentration

Zq = Number of standard deviations between the 3 percent level and the median

Zs = number of standard deviation between the national standard and the median

Sq = standard geometric deviation

Use of this equation requires knowledge of the standard geometric deviation, which is a function of location. The standard geometric deviation data presented by Larsen for different U.S. cities were used to arrive at average standard geometric deviation levels for determining the adjusted pollutant concentration (C) standard.

Following are listed the relevent national air quality standards not to be exceeded more than once in the given time period per year and the adjusted standards not to be exceeded more than 3 percent of the time period per year:

	National air quality std.	Adjusted standard
CO duration	1 hr	1 hr
level mg/m^3	40	15
duration	8 hr	-
level, mg/m^3	10	-
SO_2 duration	24 hr	-
level $\mu g/m^3$	365 (primary)	-
duration	3 hr	3 hr
level, $\mu g/m^3$	1300 (secondary)	450
Particulates duration	24 hr	24 hr
level $\mu g/m^3$	260	210

The Preliminary Evaluation presented in Section 2 of the manual employs annual average air quality standards for particulates and SO_2. Continuous Air Monitoring Program (CAMP) data is used for this analysis. Annual average CAMP data is used since this is more readily available data interpreted to generate worst case not exceeded more than once per year or 3 percent of the time period.

A few words are appropriate here concerning the known health effects of the three pollutants and their relation to the standards.

The present national carbon monoxide standard is based on the atmospheric concentration necessary to result in a 3 percent blood carboxyhemoglobin (COHb) level. This is the level at which predictible angina has been found. At the 3 percent CoHb level, patients suffering from angina pectoris develop pains sooner after exertion. The following data show the relationships between atmospheric carbon monoxide levels and the percentage of COHb for 1-hour and 8-hour exposures[2]:

1-hour exposure

% COHb	Rest	Light activity	Exercise
		mg/m^3 CO	
2.0	90	57	46
3.0	143	90	73
4.0	196	123	99

8-hour exposure

2.0	18	18	15
3.0	29	24	23
4.0	39	33	31

These data show that the national CO standard provides a substantial margin of safety.

It is known that altitude significantly affects the COHb level and can cause serious problems when persons having coronary artery disease go to high altitudes. Such people can, however, become acclimatized, and the effect is moderated with time. The manual does not account for this effect, since the EPA has not modified the CO standard in this regard. The manual does emphasize that the procedures presented cannot be applied to unusual terrains, extremes of climate, and the like.

Health effects of paticulate and SO_2 are more complex and not well understood.[3] No well-defined physiological responses to these pollutants have been observed. It does appear, however, that the products of their interaction, particulate sulfates, are significantly more hazardous.

The SO_2 standard presented in the manual is a 3-hour value derived by combining the Federal 24-hour primary standard and the 3-hour secondary standard. Again, we applied Larsen's statistical techniques. Although the secondary standard is not intended to protect human health directly, it is less difficult to meet than the 24-hour primary standard.[3]

The manual's pariticulate standard was not adjusted to the 3 percent level by Larsen's technique, since that procedure would yield unrealistically low levels. The standard selected (210 $\mu g/m^3$) lies between the Federal primary standard (260 $\mu g/m^3$) and the secondary standard (150 $\mu g/m^3$). To improve the accuracy of the pollutant dispersion models, we tried to establish short-term standards whenever possible. For particulates, however, a time period of less than 24 hours was not feasible, since no adverse health effects could realistically be considered for a shorter time period.[2]

REFERENCES

1. Larsen, R. I., A Mathematical Model for Relating Air Quality Measurements to Air Quality Standard, EPA, AP-89, 1973.

2. Personal communication with Dr. Love, National Environmental Research Center, Human Studies Lab., Research Triangle Park, N.C.

3. Vaughn, D. J. and Stanek, E. J. Sulfur Dioxide Standards-Primary More Restrictive than Secondary? Journal of the Air Pollution Control Association, Vol. 23, No. 12, December 1973.

4. Air Pollution, Vol. I, Ed. Stern, A.C., 2nd Edition, Academic Press, 1968.

4 SELECTION OF POLLUTANT SOURCES

OUTDOOR POLLUTION SOURCES

The manual presents procedures for estimating levels of pollutants from several sources: roadways, parking lots, point sources, space heating, and airports. These are the source categories known to emit particulates, SO_2, and CO in such a way as to exert significant localized, short-term impact on nearby receptors. Thus their proximity to a residential development could entail hazards to health.

Motor vehicles represent by far the largest sources of carbon monoxide. Under the meteorological conditions producing high concentrations of CO from roadways, the only other significant local sources of CO are parking lots. The major local sources of particulates and SO_2 are activities involving the burning of fossil fuels. The major emitters, such as individual industrial plants, are listed in the NEDS point source inventory. The smaller but more widespread area sources are mainly space heating units.

Although airports constitute significant local sources of carbon monoxide, particulates, and hydrocarbons, no simple and accurate dispersion model allowing manual computation is available. Thus the procedure for estimating potential significance of airports was included as a safeguard against use of the manual to evaluate a residential site close to a major airport.

Following are types of emission sources not included in the manual and the reasons for their exclusion.

1. Construction and demolition. These tend to be short-term projects that should not affect the pollutant levels at a site on a continuous basis. Also, these emissions can be estimated only very crudely.

2. Shipyards. Emissions from major shipyards can have a significant impact on local receptors. Shipyard activities, however, would affect only a few areas in the country. Further, the emission rates are poorly defined, and meteorological conditions at shipyard sites tend to deviate significantly from the average conditions considered in the manual. Thus, the manual specifies that professional help should be sought in evaluating sites located close to a large body of water.

3. Railroads. Emissions from trains averaged over the time periods specified in the standards are not significant. Generally, the only significant emissions are from the railyards. The emission rates from railyards are poorly defined as a rule; large railyards are considered, however, among the point sources recorded in the NEDS forms.

4. Emissions from natural phenomena such as forest fires. There is no acceptable way of measuring these emissions. For short-term standards, their contribution should be negligible.

INDOOR POLLUTION SOURCES

Research

Gas Cooking

The evidence is clear that gas-fueled cooking stoves add measurable increments of carbon monoxide and oxides of nitrogen to indoor air. Yocom et al. (1969)[1] found that gas space heaters did not affect indoor concentrations of CO in test homes, but gas cook stoves did. W. C. Eaton et al. (1973)[2] measured concentrations of NO_2 in the vicinity of the kitchen gas ranges with the cooktop or the oven in use. High concentrations occurred near the stove even with a hood-type exhaust vent in operation. This study also noted a positive correlation between usage of gas stoves and the incidence of lower respiratory infections among 146 Long Island families. The sample was small, and the time period covered only one season. Without further evidence from more definitive studies one cannot state categorically that gas-fueled cooking is a causative factor in lower respiratory illness.

Particulate Generation

Significant particulate emissions indoors are due to cooking and smoking. Particulates that settle are regenerated and kept in suspension by activities of the people inside the house. These relationships are adequately documented by Benson et al.,[3] and are not discussed further here.

SO_2 Generation

No study indicates significant indoor generation of SO_2 that is not directly traceable to faulty heating equipment.

Recommended Measures

Calculations presented in the manual account for only gas-fired cooking units and attached garages. These calculations entail tack-on factors for attached garages or gas cookstoves. In formulating the recommended design procedures, we strongly considered a flat recommendation against gas cooking appliances, but decided that present data are not yet strong enough to warrant such a recommendation. If further significant data are gathered in support of the Eaton study, banning of gas cooking appliances appears in order. For the moment the manual recommends inclusion of outdoor-vented hood fans.

A number of other indoor pollutant generators, some of which we believe warrant consideration, were not included in our analysis:

1. Housecleaning, smoking of tobacco, and turbulence of movement are shown to generate particulates indoors,[4] but these activities are not controllable by the builder and at present are not well quantified.

2. Emissions from furnaces, fireplaces, hot water heaters, or other generators attached to a flue are considered insignificant, provided the flue connections are in proper order.[1,5] No data were found for evaluating the impact of fireplaces.

3. Gas clothes dryers also are excluded because of the

lack of dependable data. With adequate venting to outdoors, the dryer is theoretically an insignificant source.

4. Various aerosol sprays are reported to be potential health hazards. Again, use of these sprays is not controllable by the builder.

Garages

Attached - The manual recommends a positive sealing door between an attached garage and living space. "Vapor barrier" materials in the walls between garage and living space are also beneficial.

Underground - The manual does not consider the impact of underground garages since we found no adequate model for or data on the infiltration of emissions. Only qualitative measures to reduce infiltration through the garage ceiling and elevator shafts are discussed. The primary impact should be from the vent exhaust as an outside generator. A number of design variables makes this a complex relationship that warrants further work.

Future Research

Validation and quanitification of the findings on CO generation in kitchens and garages deserve highest priority because relationships have been demonstrated and the expected results should be maximum for the dollars spent. Such research could determine the effectiveness of various hood vent configurations, and of connecting the oven to a flue. The research effort should include a thoroughgoing analysis of routes of pollutant travel from garage to dwelling structure and of economical means for reducing such movements.

REFERENCES

1. Yocom, J. E., W. A. Cote, and W. L. Clink. Summary Report of a Study of Indoor-Outdoor Air Pollution Relationships to the National Air Pollution Control Administration. Contract No. CPA-22-69-14. The Travelers Research Corp., Hartford, Conn. 1969.

2. W. C. Eaton, Carl M. Shy, John F. Finklea, James N. Howard, Robert M. Burton, George H. Ward, and Ferris B. Benson. "Exposure to Indoor Nitrogen Dioxide from Gas Stoves". Human Studies Laboratory, National Environmental Research Center, Environmental Protection Agency, Research Triangle Park, North Carolina. Revised January 1973.

3. Ferris B. Benson, John J. Henderson, J. E. Caldwell. "Indoor-Outdoor Air Pollution Relationships: A Literature Review". Environmental Protection Agency, National Environmental Research Center, Research Triangle Park, North Carolina. August 1972.

4. Lefcoe, N. M. and I. I. Inculet. Particulates in Domestic Premises; I. Ambient Levels and Central Air Filtration. Arch. Environ. Health. 22:230-238, February 1971.

5. Biersteker, K., et al. Indoor Air Pollution in Ratterdam Homes, Int. J. Air Water Pollution, 1965.

5 TRANSPORT AND DISPERSION OF AIR POLLUTANTS

The pollutants emitted at a source disperse in the surrounding atmosphere in a manner that depends on the meteorological state of the local atmosphere. The dispersion process and the dispersion equation used in this manual are reviewed briefly here. References 1 and 2 provide a detailed presentation.

DISPERSION

Major Factors Affecting Dispersion[1,2]

Four parameters characterize the atmospheric dispersion process:

1. Wind Speed - determines "ventilation" rate.
2. Wind Direction - determines path of direct transport of pollutants.
3. Mixing Height - determines the depth of the atmosphere available for vertical spread of pollutants.
4. Atmospheric Stability - a measure of turbulence in the atmosphere. A stability classification method, based on wind speed and solar radiation or cloud cover, proposed by Pasquill, is presented in Table 5.1.

Table 5.1 KEY TO STABILITY CATEGORIES (AFTER TURNER)[2]

Surface Wind Speed (at 10m) m sec^{-1}	Day Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly Overcast or 4/8 Low Cloud	3/8 Cloud
2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

Class A is the most unstable class, and Class F the most stable one.

High wind speed, unstable atmosphere, and "unlimited" mixing height enhance the dispersion process and therefore are favorable conditions for dispersal of pollutants. Low wind speed, stable atmosphere, and limited mixing height lead to "buildup" of pollutants in the atmosphere. An air pollution episode could occur if these conditions prevail over several days in which significant amounts of pollutants are emitted.

The topography of a region affects the air movement over the surface, and hence affects the dispersion process.

Dispersion Equation

There are two basic approaches to mathematical description of dispersion processes: 1) statistical modeling; and 2) modeling by conservation equations. Several variations of these two approaches are available.[3,4] The steady-state Pasquill-Gifford dispersion equation (Gaussian distribution) is amenable to hand calculations when only a few sources must be considered and its precision is comparable to that of more sophisticated equations. Calculations presented in the manual are based on this equation.

The effluent from a stack normally continues upward movement for a while before it begins downward motion. Stack parameters, such as gas flow rate and temperature, and meteorological conditions determine extent of plume rise. This amount of plume rise determines the effective height of emission of pollutants, and consequently affects the dispersion process. A method for estimating plume rise is described later. When a source emits pollutants near ground level, e.g. an automobile, the emission height is usually taken as zero.

The ground-level concentration, C, at a point (X, Y, O) due to a continuous source with an effective emission height, H, is given by the equation below.

$$C\ (X,Y,O;H) = \frac{2Q}{u} \cdot \frac{\exp\left(-\frac{H^2}{2\sigma_z^2}\right)}{\sqrt{2\pi}\ \sigma_z} \cdot \frac{\exp\left(-\frac{Y^2}{2\sigma_y^2}\right)}{\sqrt{2\pi}\ \sigma_y}$$

C = concentration of a pollutant, usually expressed as ($\mu g/m^3$) or (mg/m^3)

X, Y, Z = are coordinates of the point (receptor) at which concentration is estimated, meter

H = effective emission height, meter

Q = source strength (pollutant emission rate), gm/second

π = a constant, 3.14

σ_y and σ_z = lateral and vertical dispersion coefficients, meter. These depend on stability, surface roughness, wind speed, and distance between source and receptor. σ_y and σ_z increase with distance between source and receptor. These also depend on concentration averaging time; and their values are available for averaging times of a few minutes.

u = mean wind speed, m/sec

This equation applies over a relatively smooth terrain. Figure 5.1 illustrates a source-receptor system. The X-axis is usually oriented along the direction of wind; and it is convenient to consider the source as the origin for the coordinate system.

When the concentration is to be calculated along X-axis (i.e., along the direction of wind, Y=O), the equation simplifies to:

$$C\ (X,Q,O;H) = \frac{Q}{\sigma_y\ \sigma_z\ u} \exp\left(-\frac{H^2}{2\ \sigma_z^{\ 2}}\right)$$

If the source discharges essentially at ground-level, then:

$$C\ (X,O,O:O) = \frac{Q}{\sigma_y\ \sigma_z\ u}$$

Estimation of Plume Rise[5,6,7]

A number of equations are available for estimating plume rise.[5] It is difficult to choose among these formulas. Reference 8 provides detailed discussion of plume rise formulas. The Briggs equations for neutral conditions (D stability) is used in the manual for estimation of plume rise, ΔH:

$$\Delta H = \frac{1.6\ F^{1/3}\ (3.5\ x*)^{2/3}}{u}$$

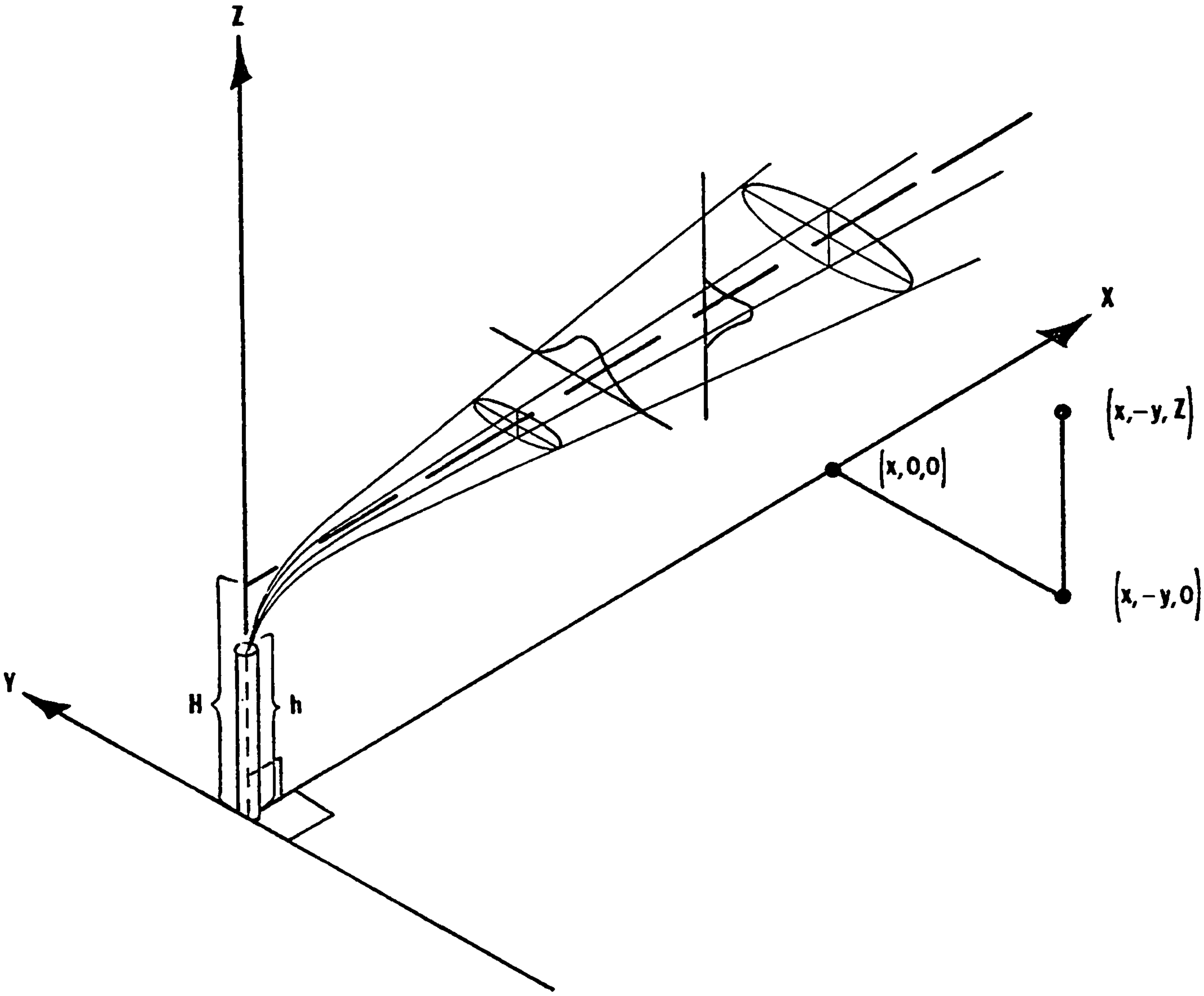

Figure 5.1 Coordinate system showing Gaussian distributions in the horizontal and vertical.

where:

$$F = 3.14 \; V_f \; (\frac{Ts - T}{Ts})$$

T = ambient air temperature, °K

Ts = stack gas exit temperature, °K

u = average wind speed at stack level, m/sec

V_f = stack gas flow rate, m^3/sec

F = buoyancy flux parameter, m^4/sec^3

x^* = distance at which atmospheric turbulence begins to dominate entrainment, m

$x^* = 14 \; F^{5/8}$ For F less than 55

$x^* = 34 \; F^{2/5}$ For F greater than or equal to 55

Figure 4-7 in the manual was prepared with this equation. For a group of stacks, the average stack parameters are used in calculating the plume rise. The effective height of emissions is obtained by adding plume rise to physical stack height.

$H = h + \Delta H$, meter

IDENTIFICATION OF WORST CASE CONDITIONS[2,7,9]

Temporal and spatial emission patterns, emission rates, and the state of the atmosphere determine the level of pollution at a site. As mentioned previously, an air pollution episode could occur if conditions of low wind, stable atmosphere, and limited mixing height prevail over several days. The manual is not intended, however, for use in estimating concentrations that could occur about 3 percent of the time.

The concentration averaging time for a pollutant, specified in air quality standards, is based on health effects. In estimating worst-case concentrations for a pollutant, one must consider temporal and spatial emission patterns, averaging time for the pollutant, and meteorological conditions simultaneously. Because particulate and SO_2 have similar emission characteristics, they are treated together in this analysis; CO is considered separately.

Carbon Monoxide (CO)

The major portion of CO is emitted essentially at ground level by roadway vehicles and aircraft. For ground-level sources (consider equation 5.3), higher concentrations occur with low wind speed and stable atmosphere. The CO emission rate on a road is usually highest during morning peak of traffic volume. The concentration averaging time for CO is 1 hour, and during the morning hours stable atmosphere could prevail. Consequently, stability Class F, 1 m/sec wind speed, and morning peak hour are designated as worst-case conditions for CO.

Particulate and SO_2

The major portion of these pollutants is emitted by elevated stationary sources (e.g. power plants, space heaters). For elevated sources (consider equation 5.2), higher concentrations over a time period of a few minutes occur with unstable atmospheric conditions. However, as wind directions fluctuate widely during unstable conditions, these concentrations also fluctuate considerably. These high concentrations occur near the source (from 1 to 5 stack heights downwind), and the concentrations decrease rapidly downwind with increasing distance.

Under stable conditions, the maximum concentrations occurring for a time period of a few minutes are lower than those occurring under unstable conditions. Concentrations averaged over a time period of a few hours, however, could be higher during stable conditions because of narrow flucuations in wind direction. Further, these maximum concentrations occur at greater distances, and consequently, significant concentrations could occur over large areas.

Stable atmospheric conditions (classes E and F) occur during evening and early morning, and during day time neutral stability (class D) could prevail. Industrial activities, and hence particulate and SO_2 emission rates, are at their peak during the day. The concentration averaging times for particulate and SO_2 are 24 hours and 3 hours, respectively. Thus, in estimating concentrations, the temporal variations of emission rates and stability should be weighted over the averaging time period. Variations in emission rates are difficult to estimate. The combined consideration of stability, emission rates, and concentration averaging times led to selection of D stability as the worst-case condition for particulate and SO_2.

For ground-level sources, the ground-level concentration increases as the wind speed decreases. This is not so for elevated sources over relatively short time periods. The plume rise is inversely proportional to the wind speed, and the ground-level concentration decreases exponentially as emission height increases. Thus, maximum concentration occurs at some intermediate wind speed. The combined consideration of average emission characteristics and D stability led to selection of 4.5 m/sec wind speed as the worst-case wind speed for particulate and SO_2.

For each given receptor and set of sources there is a unique set of meteorological conditions that yield maximum concentrations. Generally, however, it is very difficult to determine the atmossheric conditions of wind direction, wind speed, and stability that will result in the maximum combined concentration from multiple sources. Thus, D stability and a wind speed of 4.5 m/sec are general conditions likely to result in high concentrations.

SIGNIFICANT SOURCES

The pollutant concentration at a site due to a source depends on: 1) rate of pollutant emissions; 2) location of the source in relation to the site (source-receptor geometry); and 3) meteorological conditions.

The pollutant concentrations due to a ground-level source decrease as the distance between the source and the site increases. Pollutant concentrations from an elevated source pass through a maximum before they start decreasing with distance. Thus, a source located far from the site may have only marginal impact on the site. Further, since pollutant travel time increases with increasing distance from source to site, if emission rates vary markedly and the concentration averaging time is short, the source may become insignificant. The ambient air quality standard (AAQS) is, of course, an important factor in determining significance of a source. When the concentration at a site due to a source is less than certain percentage (say, 5%) of the standard, the source may be considered insignificant and need not be accounted for in calculating total pollutant concentration at the site. To minimize the number of required calculations, the manual gives criteria for identifying significant sources in each source category. The methodologies for estimating emission rates and concentrations are discussed separately under each source category in the following section.

REFERENCES

1. Air Pollution, Vol. I, Ed. Stern, A.C., 2nd Edition, Academic Press, 1968.

2. Turner, D. B. Workbook of Atomspheric Dispersion Estimates. U. S. Dept. HEW, PHS Pub. No. 999-AP-26, 1969.

3. Darling, E. M., Jr. Computer Modeling of Transportation Generated Air Pollution. Report No. DOT-TSC-OST-72-20, U. S. Dept. of Transportation, June 1972.

4. Rote, D. M. et al. Studies of the Argonne Integrated - Puff Model. ANL/ES - 9, Argonne National Laboratory, October 1971.

5. Carson, J. E. and H. Moses. "The Validity of Several Plume Rise Formulas", J.Air Poll. Control Assoc., 19:862, 1969.

6. Briggs, G. A. Plume Rise. TID-25075, U. S., AEC, 1969.

7. Personal communication with Paul Morganstern, Walden Research, Cambridge, Mass.

8. Stern, A.C. et al. Fundamentals of Air Pollution, Academic Press, 1973.

9. Rote, D. M. and J. W. Gudenas. "A Steady State Dispersion Model Suitable for Air Pollution Episodes", Paper presented at 64th APCA meeting, June-July 1971.

6 POLLUTANT EMISSIONS AND CONCENTRATIONS

This section describes development of techniques for estimating pollutant emissions and concentrations at the site resulting from each major category of sources considered in the manual..

ROADWAYS

Emission Factors[1,2,3,4,5]

The emission rate of CO on a road depends on three major factors*: 1) number of vehicles on a unit segment of the road; 2) types of vehicles; and 3) mode of operation of these vehicles - starting, accelerating, decelerating, idling, or cruising at steady speed. Vehicles of different size, type, and age+ emit CO at different rates. Populations of these vehicles vary on different types of roads in different areas. For simplification, we used data on national vehicle population in developing weighted average emission rates for different modes of operation. These average emission rates are known as emission factors.

Because driving patterns (based on mode of operation) are distinctly different on local roads (collector streets, arteries) and on freeways, the manual provides emission factors for both types of roadway.

---

* Data for estimating effects of ambient temperature are not available.

\+ The emission control device (if any) deteriorates with age, leading to higher emissions.

Local Roads

The driving cycle used by EPA in emission rate test procedures (1975 Federal Test Procedure, FTP) is based on normal driving patterns on local roads. Emission factors given in the manual for local roads are based on this cycle. Although the driving patterns on different local roads are similar, the average running speeds and consequently emission factors, are different. Therefore, speed correction factors are used for estimating emission rates at different speeds. The average running speed for 1975 FTP is 19.6 mph, and the emission rate of this test is used as a reference.

Measurements of average traffic speed on a local road during rush hour are usually not available. The posted limits on these roads give some indication of average running speed. Following are the speeds used in preparing Table 4.1 for application to local roads:

Posted speed limit, mph	45	40	35	30,	25	15
Average peak-hour running speed in Table 4.1, mph	30	25	25	20	20	10

Emission factors for different years and different speeds are calculated as follows:

Emission factor for a particular speed = 1975 FTP emission factor for that year x speed correction factor

The data are taken from Reference 1, which gives a detailed presentation. The 1975 FTP emission factors and speed correction graph are in the Appendix.

Freeways

On freeways, the car travels essentially at constant speed. The speed, however, varies with traffic volume. The emission ratio, presented in Reference 1 and defined below, was used in calculating emission factors for different steady speeds.

$$\text{Emission Ratio} = \frac{\text{Emission rate at the steady speed}}{\text{1975 FTP emission rate}}$$

Because this ratio is essentially constant for different years, only one emission ratio is given for each steady speed. The emission ratios are tabulated in the Appendix.

Estimating Emission Density

The volume of peak-hour traffic on a road is usually available from the local traffic authority. If this is not available, the Annual Average of Daily Traffic (AADT) can be used to estimate peak-hour traffic, which is about 8 to 15 percent of the AADT. Chapter 3, Reference 6, gives details on estimation procedures. Peak-hour traffic speed on a highway, if not available, can be estimated by the procedure in the manual. Reference 6 describes the method in detail.

When traffic volume and speed on a road are known, emissions on the road, usually expressed as emission density, can be calculated as follows:

$$Q_{CO} = K \times V \times E_{CO}$$

where:

Q_{CO} - CO emission density, $\frac{gm}{sec\text{-}m}$

V - peak hour traffic volume, vehicles per hour

E_{CO} - emission factor, mile

K - conversion factor, calculated as below.

$$K = \left(\frac{hour}{second}\right) \left(\frac{mile}{meter}\right) = \frac{1}{3600} \times \frac{1}{1610} = 1.73 \times 10^{-7}$$

Estimating Concentrations[7,8,9,10]

The dispersion equation 5.1 can be used to estimate CO concentration due to a road when the road is at grade-level and the surrounding terrain is smooth. The elevation (or depression) of a road affects the air movement pattern and, consequently, the dispersion process.

Some experimental dispersion data for at-grade, elevated, and depressed roads are given in Reference 8. Because it is difficult to account for all factors affecting dispersion in an equation, we applied these data in preparing the manual. Figure 4.3 in the manual is taken from Reference 8; and the values are valid when the angle between the wind direction and the road, θ, is greater than 22.5°. When θ is less than 22.5°, it should be considered to be equal to 22.5°. Further, values in this figure apply only if the road is "infinitely" long. No correction factors are introduced, however, to simplify calculation procedures.

Calculating Total CO Concentration from Roads

The CO concentration at a site usually varies with wind direction. Since identification of the wind direction that results in maximum CO concentrations is often difficult, CO concentrations at the site are calculated for eight wind directions to determine maximum CO concentration. As it is difficult to estimate CO concentration when the angle between the road and the wind direction is less than 22.5°, only eight wind directions are considered.

Significant Roads

The standard used in the manual for CO is 15 mg/m^3. If the worst-case CO concentration at the site due to emissions on a road is less than 20 percent of that standard (i.e., $0.2 \times 15 = 3\ mg/m^3$), the road may be considered insignificant. The significance criteria for local roads and freeways are discussed below.

Local Roads

Because traffic volume on the feeder (residential) streets is very low, these streets are not considered in calculating total CO concentration at the site. For "collector streets", the maximum traffic volume is estimated at 3000 vph. At 25 mph traffic speed, the CO emission density is $2.5 \times 10^{-2}\ \frac{gm}{sec\text{-}m}$ for the year 1974. The distance at which the worst-case CO concentration due to this road falls below 3 mg/m^3 is estimated to be 400 meters. The angle between the road and the wind direction is taken to be 22.5°. Thus, collector streets within 400 m radius of the site should be considered in calculating total CO concentration.

Freeways

Most freeways outside of a city are four-lane roads, and near or within the city they become six-lane roads. The rush-hour traffic volume on a six-lane freeway could be 12,000 vph. At 45 mph traffic speed, the emission density on this freeway is 4.5×10^{-2} (gm/sec-meter) for the year 1974. The distance at which the CO concentration falls below 3 mg/m^3 is estimated to be 2000 meters. Thus, freeways within 2000 meters radius of the site should be considered in calculating total CO concentration at the site. At 1 m/sec wind speed, the pollutant travel time for this distance is more than half an hour. The concentration averaging time for CO is 1 hour, and the CO emissions on a road drop considerably after rush hour. Consequently, the maximum distance for significant freeways is limited to 1000 meters.

POINT SOURCES

Emission Rates[11]

Emission rates for particulate and SO_2 from point sources are obtained from the National Emission Data System (NEDS) prepared by the EPA.[11]

A single plant may have more than one stack emitting pollutants. Each NEDS form is considered here to represent a stack at the source. Ideally, each stack at the source should be evaluated separately. To minimize calculations, however, stacks that discharge pollutants at approximately equal effective heights are grouped together. Stack parameters, such as stack height and exit gas flow rate, and meteorological conditions determine effective emission height. Selection of the parameters and their ranges for grouping stacks is somewhat arbitrary; it is a compromise between amount of computation and precision of results. The emission rates are converted from tons per year to grams per second by use of operating schedule data.

Estimating Concentrations[7]

The procedure for calculating effective emission heights for elevated sources is described in Section 5.0, Estimation of Plume Rise.

The ground-level concentration along the wind direction (i.e, downwind concentration) due to a point source can then be calculated by the equation:

$$C\ (X,O,O:H) = \frac{Q}{\sigma_y \sigma_z u} \exp\left[-\frac{H^2}{2\sigma_z}\right]$$

As values of dispersion coefficients are available for a time period of a few minutes only, this concentration value is valid for that time period. Because of meandering of wind, the downwind concentrations become lower over longer averaging times. The concentration averaging times for particulate and SO_2 are 24 hours and 3 hours, respectively. Hence, it is necessary to adjust the concentration that is calculated with the equation.

The relationship between longer and shorter averaging times depends on a number of factors.[12,13] A power law relation[7] is often used, but is not well established. For 24-hour periods, the downwind concentrations were multiplied by 0.6; and for 3-hour periods, the calculated value was used.

The ground level concentration at a point not along the wind direction can be calculated from the equation:

$$C\ (X,Y,O:H) = \frac{Q}{\sigma_y \sigma_z u} \exp\left[-\frac{Y^2}{2\sigma_y^2}\right] \exp\left[-\frac{H^2}{2\sigma_z^2}\right]$$

The expression $\exp\left[-\frac{Y^2}{2\sigma_y^2}\right]$ is termed the Correction Factor.

As before, this concentration is valid for a time period of a few minutes. But, unlike the downwind concentration, this concentration is greater for longer averaging times because of meandering of wind. No definite relationship is established for calculating concentrations over longer averaging times. So, concentrations for longer averaging times were calculated by adjusting the correction factor to a higher value. The lateral coefficient σ_y increases as the atmosphere becomes less stable. A 3-hour concentration for SO_2 is taken to be the same as the concentration for a period of a few minutes; the correction factors were calculated by using σ_y for D stability. For particulate, correction facotrs were calculated by using σ_y for C stability.

The dispersion coefficients used in the manual are taken from Reference 7, and are valid for rural or suburban areas when the terrain is smooth.

Total Pollutant Concentration Due to Point Sources

When the proposed site is affected by a number of point sources, identification of wind direction that will result in maximum particulate and SO_2 concentration is often difficult. The ground-level concentration due to point source decreases rapidly as lateral distance from the wind direction increases. The procedure used for calculating maximum CO concentration therefore is not suitable here. In the manual, then, concentrations are calculated for four source-to-receptor wind directions associated with the four major point sources. One of these wind directions could be expected to give the maximum likely concentration. The procedure is the same for calculating particulate and SO_2

concentrations.

Significant Point Sources

The air quality standard given in the manual for particulate is 210 $\mu g/m^3$ for 24-hour averaging time; for SO_2 it is 450 $\mu g/m^3$ for 3-hour averaging time. If the pollutant concentration due to a point source is less than 10 percent of the standard, the source may be considered insignificant. A downwind concentration of 40 $\mu g/m^3$ for a period of a few minutes was selected as the criterion for determining significance of a source of particulate or SO_2. Since 24-hour particulate concentration is obtained by multiplying short-term concentration by 0.6, 40 $\mu g/m^3$ is about 11 percent of the air quality standard for particulate. The 3-hour SO_2 concentration is taken to be the same as the concentration for a period of a few minutes; thus, 40 mg/m^3 is about 9 percent of the standard for SO_2.

In preparing the plot of distance versus source strength (Figure 4.5 in the manual), we designated the effective emission height as 10 meters, then obtained the normalized concentration (C/Q) for different distances and calculated source strength Q for concentration C = 40 $\mu g/m^3$.

SPACE HEATING

Introduction

A precise analysis of pollution loads due to space heating would involve an inventory of the spaces heated in every enclosed structure in a prescribed area surrounding the potential site, together with knowledge of the fuel used to heat each structure, the unit heat load required for each space (which would vary with structure and insulation), and the efficiency and condition of each space-heating unit. These data, coupled with a valid dispersion model for the worst-case condition, would yield the optimum result we can presently conceive.

The major pollutants from space-heating emissions are particulate and SO_2. Point sources, however, usually, contribute more than 75 percent of these pollutant concentrations at a site. Of the remaining 25 percent, emissions from area sources in the immediate vicinity of the site contribute most of the pollutant (due to area sources) at the site. Since proximity is significant, we designated a square with a 1-kilometer side, centered on the wind direction vector associated with maximum pollutant concentration from point sources, to represent the area sources. Reference 15 gives a detailed presentation.

The procedure presented in the manual falls far short of the ideal, chiefly because of the overwhelming cost of collecting the data needed to provide precise, quantitative values. The only method now available for collecting the needed data would be a door-to-door survey of a 2 kilometer-diameter area around the site. Recognizing that the manual-user must do an analysis with currently available data, we devised a patchwork procedure based on a number of information sources and involving a number of generalizing assumptions. The following section outlines the procedure for analyzing the impact of space-heating sources.

Estimating Emissions

Values for the amount of residential heated space are based on data from aerial photographs and "Census Tracts", augmented with data from field interviews or building permits, or both. A pro-rata apportionment is made for tracts partially included in the area influencing the site. A representative floor area was selected for each size dwelling in the census tract data.

Data on commercial, industrial and institutional space heating are much harder to acquire. We suggest a combination of references to city directories and state "directories of manufacturers", and interviews in the field as the basic data sources.

The percentages of residences heating with each fuel type are tabulated for cities over 10,000, counties, and SMSA's in the Census Bureau's "Detailed Housing Characteristics". These percentages were applied to all building types and uses, multiplying the percentage value by total floor area.

Data on average coal and oil usage were taken from Reference 11, and emission data were taken from Reference 2. These data are tabulated below.

Fuel	[Amount / (dwelling) (Degree-day)]	Pollutant Emissions	
		Particulate	SO_2
Coal	0.0012 ton	20 lb/ton	57 lb/ton
Fuel	0.18 gallon	10 lb/10^3gal	43.2 lb/10^3 gal

We selected an area of 10^6 square meters for estimating emission density. Using 1250 square feet as the average floor area per dwelling unit, we expressed the emission data as follows:

Pollutant $\frac{\text{gms} \times 10^{-11}}{(\text{sec-m}^2)\ (\text{degree})\ 10^3\ \text{sq. ft.}}$	Coal	Oil
Particulate	10.1	0.8
Sulfur dioxide (SO_2)	28.7	3.3

Estimating Concentrations[14,15,16]

Space heating emission sources are too numerous to be treated individually. Particulate and SO_2 concentrations due to space heating emissions could be calculated by (1) representing the source with a single virtual point source, or by (2) considering the emissions to be uniformly distributed over the area. The second approach gives better results and is commonly used. Several methods based on this approach are available for estimating pollutant concentrations.

The method proposed by Hanna-Gifford is simple and gives results comparable to those obtained with more complex methods. References 15 and 16 provide detailed information.

The pollutant concentration C is given by:

$$C = K \frac{Q}{U}$$

where:

C - pollutant concentration, $\mu g/m^3$

Q - emission density $\frac{gm}{second\text{-}m^2}$

U - wind speed, m/sec

K - function of stability, source distribution, and pollutant

Although this model is generally used to calculate annual mean concentrations of a pollutant, it is also suitable for calculating short-term averages. The values of K, suggested by Hanna-Gifford, are 225 for particulate and 50 for SO_2. Figure 4.11 in the manual is based on these values of K.

Findings and Conclusions

If it were not that emissions from space heating are usually minor in relation to emissions from industries and motor vehicles, the procedure just outlined would probably be judged to entail too great a potential margin of error. We include it in the manual because it is the only method by which one can deal with space-heating emission sources, short of the grossly expensive door-to-door canvass method.

Recommendations

The procedure outlined could be made less cumbersome and more accurate if the Bureau of the Census could gather and print data by urban block giving number of rooms per dwelling and heating fuel used, and also publish values for heated floor areas and fuel types used in industrial and business establishments at the tract level in the "Census of Business". The analysis could be strengthened also if local building inspection departments could provide data tabulated by street address or by coordinates. Instituting these measures would increase both the ease and the accuracy of the space-heating analysis. As it stands, the procedure is one of the weakest in the manual.

PARKING LOTS

Estimating Emissions[18,19]

The magnitude of CO emissions on a parking lot depends on the number of cars operating on the lot at the given time and the average time (termed "residence time") a car operates on the parking lot. Residence time is a function of size of the parking lot, the number of gates, and traffic on the adjacent streets. For the manual, the average residence time is taken to be 1.2 minutes.

Mode of operation of vehicles on a parking lot varies from idle to about 15 mph. Since emissions from a car at low speed do not differ significantly from those at idle, we calculated emission density on the parking lot on the basis of a car at idle. Individual parking areas range from 150 to 300 square feet; an average is 200 square feet. For calculating maximum emission density on a parking lot, we assumed that 70 percent of the cars are started in the morning rush-hour period. Emission density, Q, can be calculated as follows:

$$Q = \frac{N}{3600} \times T \times E \times \frac{1}{N \times A} \times 0.70$$

where:

N - number of parking spaces

T - average residence time, minute

E - emission factor, $\frac{gms}{min}$

A - average area per parking space, square meter

As the parking lot is assumed to become 70 percent empty in a fixed time period (1 hour), the maximum emission density Q is independent of parking lot size. The emission factor E varies with years; a reference value of 15 $\frac{gms}{min}$ is used in the calculation of Q below.

$$Q = \frac{1.2\ (min)}{3600\ (sec)} \times 15\ \frac{gms}{min} \times \frac{10.8\ (sq.\ ft/m^2)}{200\ \ (sq.\ ft\ \ )}$$

$$= 2.7 \times 10^{-4}\ \frac{gm}{sec\text{-}m^2}$$

Estimating Concentrations[7,20,21]

CO concentrations at the site due to parking lots depend on the distance from the lot to the site, geometry of the lot, and meteorological conditions. The worst-case meteorological conditions for CO are F stability and 1 m/sec wind speed.

Emissions on the parking lot may be considered to be occuring at some point on the parking lot, and the CO concentration can then be calculated by use of the dispersion equation. Alternatively, the parking lot may be divided into a number of small elements, and each element treated as a point source. If the parking lot is assumed to be of "infinite" length in directions perpendicular to the wind direction, the lateral component of dispersion equation can be taken as unity (1.0). The parking lot can then be divided into infinitesimally narrow strips, oriented perpendicularly to the wind direction, and the concentration can then be calculated by integrating the dispersion equation over the depth of parking lot. To simplify calculation procedures, we used this approach in the manual. The integrated form of the dispersion equation is presented below.

$$C(X,0,0;H) = \frac{2Q}{U} \frac{1}{\sqrt{2\pi}} \int_{x_1}^{x_2} \frac{1}{\sigma z} \exp\left(-\frac{H^2}{2\sigma_z{}^2}\right) dx$$

Q - the emission density is assumed to be constant over the parking lot.

Figure 4.4 in the manual is based on this equation. Dispersion coefficients σz were taken from Reference 7, and H is assumed to be 2 m to account for initial dispersion in the parking lot.

AIRPORTS

CO emissions associated with a commercial airport may be grouped into two categories: (1) emissions from aircraft and ground-service vehicles at the airport; and (2) emissions from access vehicles in the area surrounding the airport.

The major portion of CO comes from aircraft operations, and the relative strengths of the sources depend on the nature of the airport; for example, an airport with a large number of transfer passengers may have relatively small access-traffic volume. CO emissions from access vehicles could be as much as 50 percent of aircraft emissions; CO emissions from ground-service vehicles could be as much as 25 percent of aircraft emissions. In evaluating the CO impact of an airport, the spatial and temporal CO emission patterns should be considered.

CO emissions due to access and ground-service vehicles occur over a large area at and around the airport, and it is difficult to estimate the impact without details of airport operation and without use of a computer. As a conservative approach one could assume that all CO emissions from aircraft occur over the runway. The runway could then be treated as a road, and the distance from the runway at which CO concentrations fall below a certain level could be calculated. Beyond this distance the airport does not have significant impact.

Emissions from an aircraft depend on the number of engines and the type of aircraft. Emissions at the airport are a function of the number of landing and take-off operations (LTO) of these aircraft. Listed below are some average distributions of aircraft types and LTO's.

Distribution of operations at major commercial airports[18]

	Percent of LTO at airport
Long-range jet	38
Medium-range jet	49
Turboprop	13

The weighted average CO emission for this distribution was calculated to be 41.52 kilogram/LTO[2]. Note that these are average data; actual values vary widely among airports.

Peak-hour aircraft traffic usually occurs in the morning and constitutes about 10 percent of daily LTO. A runway could handle a maximum of 60 landing or take-off operations an hour. The average active runway length is about 1600 meters, and the emissions from aircraft occur at about 6 meters above ground. The worst-case meteorological conditions for CO in morning hours are F stability and 1 m/sec wind speed. CO concentration of 4 mg/m^3 may be considered a low concentration for assessing impact of airports. Assuming this value, we then calculated the distance at which the CO concentration due to a runway, with wind direction perpendicular to the runway, falls below 4 mg/m^3.

Yearly LTO	Minimum distance between the outer boundary of the airport and the site at which airport has insignificant impact, kilometer
Less than 36500	1.0
Less than 54750	1.5
73000 or more	3.0

Beyond 3 kilometer distance, the travel time for a pollutant at 1 m/sec wind speed is more than 1 hour. Thus, beyond 3 kilometer distance the airport does not have significant CO impact for 1 hour averaging time.

RECOMMENDED IMPROVEMENTS TO POINT SOURCE CALCULATION PROCEDURE

The calculation of point source emissions by the present Manual procedure is by far the most involved and time-consuming procedure presented. Simplier procedures were considered, such as developing industrial pollution indices for each Standard Industrial Classification (SIC) codes, as presented by Epstein, et al.[22] However, in metropolitan areas most of the particulate and SO_2 pollution can be attributed to stationary sources. To develop any confidence in the emission rates from the point source emitters, the best available data should be employed. The effects of different pollution control equipment can result in orders-of-magnitude differences in emission rates. At precent the only up-to-date point source emission data readily available on a national basis are from the EPA National Emission Data System (NEDS).

Although they present all the necessary information on point sources, the NEDS forms were not developed for general use. Acquiring the needed data to follow the procedure presented in the Manual may present difficulties in certain cases. Zimmer and Armentrout[23] found that state agencies had little experience with NEDS reports and were not familiar with the other available NEDS output formats. Of particular interest to this project is the available report titled "Plant Emission Summary". This summary lists the total pollutant emissions from all sources within a facility and could be used for the Point Source Significance Test. Use of the totalled emission data would eliminate the summing of all emission points within a facility. For larger facilities with more than 100 emission points, the calculation procedure can be a very tedious task. Thus, as a minimum step it is recommended that local air pollution agencies or HUD A-95 offices maintain complete files of NEDS forms and emission summaries for their region, updated semi-annually.

The procedure in the Manual for grouping stacks and determining effective stack height, resulting downwind concentration, and pollutant impact from different wind directions is a lengthy one. If many point sources are involved, each containing multiple emission points, this procedure becomes very lengthy. The problem is compounded in calculations for medium and large low-density developments, since multiple cases must be run to evaluate the impacts at different sight locations.

It is recommended that a computer program be developed to handle NEDS data to allow the user to feed in site location(s) and receive a printout of total pollutant concentrations. This would eliminate the entire point source calculation procedure in the Manual and allow the user to obtain values for cases by simply submitting the locational coordinates of each site position of interest.

Because the NEDS was developed primarily as an enforcement tool for surveillance of stationary sources, such a computer program is not planned. It could, however, be applied in assessing the feasibility not only of residential developments but of proposed industrial developments. Wider use of NEDS forms and data would then justify the maintenance of an updated data file.

A computer model would be similar to the procedure used in the Manual. The overall logic flow is shown in Figure 6-1. Advantages of the computer system over the Manual procedure other than ease of use are:

1. The significance test can be developed with lower cut-off limits to consider more sources.

2. The emission point data need not be grouped, and estimation of plume rise is thus more accurate.

3. Actual meteorological data can be used to allow calculation of the worst case, not to be exceeded more than once per year. The Manual simplifies by considering the worst 3% level and a wind speed of 4.5 m/sec.

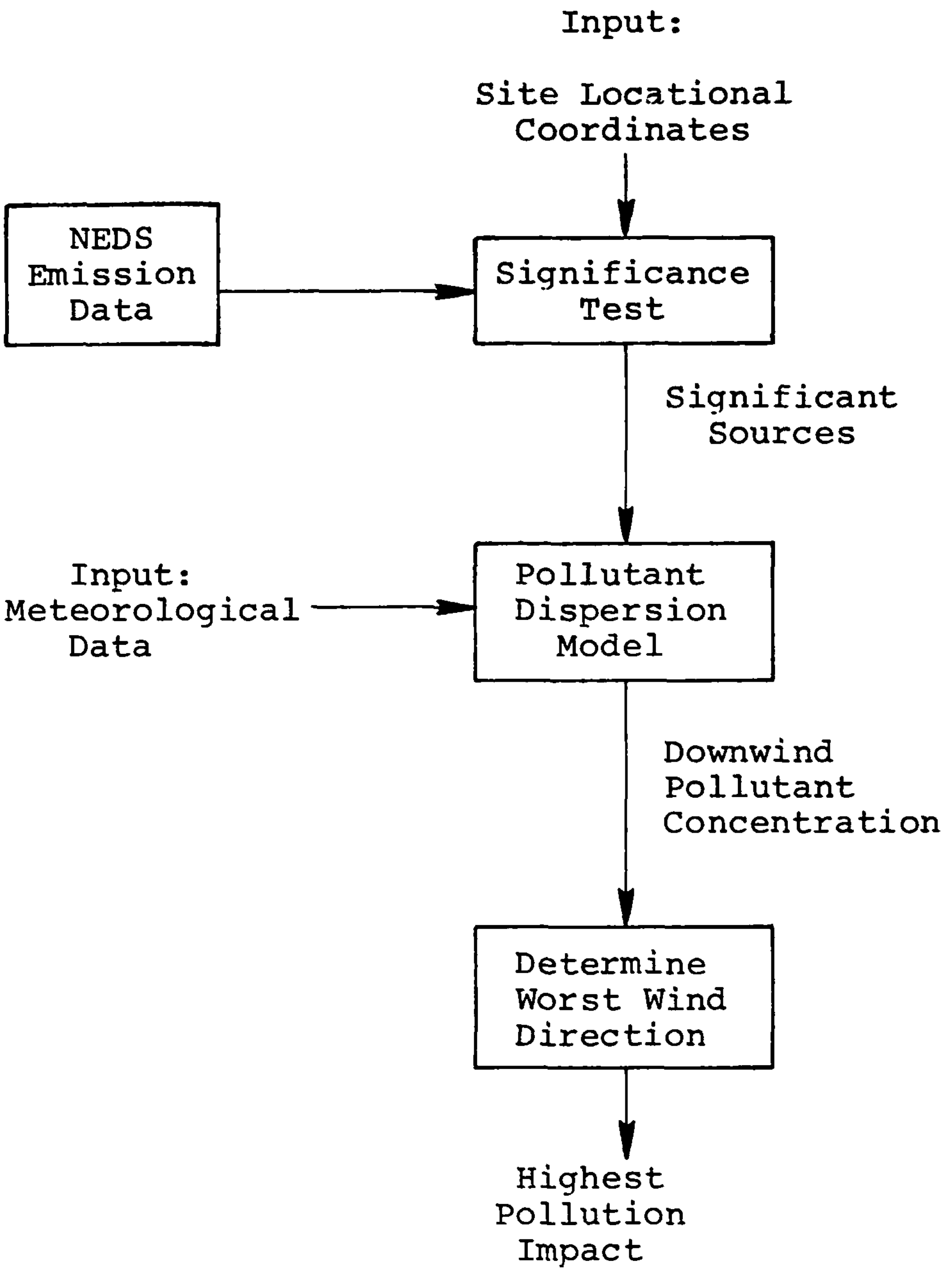

Figure 6-1 Computerized point source model.

4. The wind direction resulting in the highest pollution level can be determined with greater accuracy. The method used in the Manual considered only wind directions corresponding to vectors drawn between the major point sources and the site. A simple iterative technique can be used to determine the worst-case wind direction.

For such a computer program to be functional it should be available on a local basis, perferably at HUD A-95 offices. The turn-around time required for use of a central federal facility computer would likely be prohibitive for local planning applications.

REFERENCES

1. Cirillo, R.R. and T.D. Wolsko. Handbook of Air Pollutant Emissions From Transportation Systems, Argonne National Laboratory, ANL/ES-28, December 1973.

2. Compliation of Air Pollutant Emission Factors, Second Edition U.S. EPA, AP-42, April 1973.

3. A Study of Emissions from Light Duty Vehicles in Six Cities, U.S. EPA, APTD-1497, March 1973.

4. Kircher, D. S. and D. P. Armstrong. An Interim Report on Motor Vehicle Emission Estimation, U.S. EPA, Pub. No. EPA-450/2-73-003, October 1973.

5. Unpublished data provided by G. W. Taylor, Mobile Sources Division, Environmental Protection Service, Ottawa, Ont. K1AOH3, Canada.

6. Highway Procedures Workbook, Report 133, Dept. of Transportation, 1971.

7. Turner, D. B. Workbook of Atmospheric Dispersion Estimates. U.S. Dep. HEW, PHS Pub. No. 999-AP-26, 1969.

8. Air Quality Manual, Vol. 5, Appendix to Vol. 5, Federal Highway Administration, Office of Research, Washington, D.C. 20590, April 1972. Available from NTIS, Report No. FHWA-RD-72-37.

9. Sklarew, R. C., Modeling Transportation Impact on Air Quality, EPA, National Environmental Research Center, Div. of Meteorology, Research Triangle Park, N.C. 27711.

10. Johnson, W. B. "An Urban Diffusion Simulation Model for Carbon Monoxide", J.A.P.C.A., 23:490, June 1973.

11. Guide for Compiling a Comprehensive Emission Inventory, U.S. EPA, APTD-1135, June 1972.

12. Singer, I. A. "The Relationship Between Peak and Mean Concentrations", J.A.P.C.A., 11:336, July 1961.

13. Montgomery, T. L. et al., The Relationship Between Peak and Mean SO_2 Concentrations. Tennessee Valley Authority, Muscle Shoals, Alabama.

14. Clark, J. F. "A Simple Diffusion Model for Calculating Point Concentrations from Multiple Sources", J.A.P.C.A., 14:347, September 1964.

15. Hanna, S.R. "A Simple Method of Calculating Dispersion from Urban Area Sources", J.A.P.C.A., 21:774, December, 1971.

16. User's Guide for the Climatological Dispersion Model. EPA, National Environmental Research Center, Office of Research and Monitoring, Research Triangle Park, N.C. 27711, EPA-R4-73-024, June 1973.

17. Norco, J. E. et al., An Air Pollution Impact Methodology for Airports - Phase I, U.S. EPA, APTD-1470, January 1973.

18. Geomet, Inc. Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics-Sub-Task-2-Airports, EPA, Research Triangle Park, N.C. 27711.

19. Ibid-Sub-Task-4-Parking Facilities.

20. U.S. EPA, Federal Register, 121:0329, Appendix 0, 1973.

21. Personal communication with Edwind L. Meyer, Jr., Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, N.C. 27711.

22. Epstein, A.H., Leary, C.A., McCandless, S.T. A Guide for Considering Air Quality in Urban Planning, EPA-450/3-74-020

23. Zimmer, C.E., Armentrout, D., Establishment of a Non-EPA User System for State Implementation Plans, EPA Contract No. 68-02-1001, Task 4.

7 ANALYSIS FOR SITE DESIGN

Analysis for site design entails a set of calculations and procedures required to optimize the choice of alternative site layouts for the various elements of design, such as buildings, landscaping, parking areas, and outdoor recreation. At the beginning of the study our goal was to quantify and formulate the variables involved with transporting, mixing, concentrating, or stagnating polluted air on or across a site and to use the resulting formulae to develop rational design procedures. We were greatly disappointed with the results achievable at this time; quantitative data are scarce and the problem is complex.

RESEARCH

The data search was particularly frustrating because much research has been done in this area, and many opinions stated, however subjectively, as to the air pollution control benefits of various configurations; yet almost none of this work is quantifiably reducible to general rules.

We discovered little in the way of conclusive new data in this area since the excellent review by Rydell and Schwarz in 1968[1], with a few exceptions that will be noted. We document here those design practices for which there is a preponderance of reinforcing opinion, regardless of the degree of precision provided by presently available data.

Effects of Building Shape and Arrangement

Almost all the deductions concerning these effects are "rules of thumb." Having investigated in depth, we believe that these relationships are much too complex to be condensed into a simple series of graphs to be readily manipulated by the mathematically unskilled.

a. Urban "canyons" created by long, smooth-faced building walls set in parallel rows have the capacity to greatly increase the velocity of windflows along the faces.[2,3]

> "Streets, like buildings, alter microvlimate by changing topography and creating new land shapes. Canyon-like rows of tall buildings along narrow streets create a funnel effect, frequently doubling the wind speed, or, if the wind enters at a 45-degree angle, accelerating the velocity on the windward side and creating slower currents on the leeward."[2]

b. Wind eddies should be considered in site design, since they can concentrate pollutants in the eddy areas.

> "The orientation of a building with respect to winds also has an important influence on the impact of air pollution. Various building configurations with respect to winds create different sized eddies around the structure. An eddy, which is a slowly revolving stationary mass of air, can trap pollution, increasing its concentration many times. The larger the eddies around a building, the smaller the volume of the wind that passes by the building to sweep the pollutants away."[4] "As the pitch of the roof, the thinness, and the height and width of a building or a building block increases, the size of the eddies around the building increases. A row of uneven roofs creating rough surfaces can slow the wind, holding pollution in the area longer.

c. Arrangement of Structures. Arrangement of structures in such a manner as to block through movements of prevailing winds tends to trap, pool, and eddy air. Therefore, long linear blocks of structures without breaks should be avoided if at all possible.

> "Not only is the impact of air pollution on a building affected by how the building changes winds and eddies, but by the kind of climate the edifice itself creates. Placed on a slope, a building or mining debris can act like an artifical hill, creating a new slope climate."[6]

> "The building can block cold air from spreading downhill, holding the air stagnant to gather increasing concentrations of pollution. In some southern climates, houses on stilts allow hot ground air to "roll" under rather than through the buildings, avoiding the heat and any pollution carried in the wind."[1]

Effects of Site Grading

a. Sumps. Site grading that creates low sump areas should be avoided. During cold weather, these sumps collect a stratified body of air in which pollutants are trapped. As stated before, a building "courtyard" can also act as an artifical sump.

> "In the natural environment hills or uneven slopes can block up pools of cool air. When streets or railroad beds are constructed that cut through these cold air dams, they may create cold air floods. If pollution is involved, air drainage may have serious consequences for the health of people in the valley. A new highway can also create a new alley for cold air and pollution to settle in. Anyone who drives knows of the efficiency of open-cut highways for trapping automobile exhausts. This principle also works in reverse: where there was once free drainage a railroad embankment or an artifically level highway can dam up pools of cold air and highly concentrated pollution."[1]

b. Road Grading. The General Electric studies in New York[7] pointed up the fact that a road at the grade of the surrounding topography, or somewhat higher, allows better dissipation of traffic pollutants than does a road in a cut.

Setbacks

As a general rule, pollutant concentrations decrease with distance from a high-traffic street or intersection. There are enough disturbing anomalies in data, however, (probably due to turbulence and eddying) that dependable general relationships are not yet possible.

> "Traditionally, planners have used open spaces as a major tool to improve the quality of life in the city. Today, we have even more reason to use this technique because open space, especially planted open space is not only aesthetically desirable, but acts to diminish the impact of air pollution in several ways.
>
> Greenery absorbs moisture and cools by evaporation, creating a cooler, more humid climate than stone and exposed soil. Temperatures over grassy surfaces on sunny summer days are 10 to 14 degrees cooler than over exposed soil, and there can be as much as 1500 BTU per square foot less heat per season over grassy surfaces."[8]

The buffer areas, which can be related to prevailing winds, provide an opportunity for pollutants to be diluted or dispersed. Hilberseimer[9] considers this subject in detail. Others have studied wind and temperature changes over green areas compared with built-up urban areas, the implication being that planted strips may aid in generating air currents that will carry away pollutants.

Landscaping

Small-scale landscaping has shown no significant effect in reduction of pollutants in the air; it does tend to increase air turbulence increases mixing, which results in a lower net pollutant concentration at a given downwind point.

Kalyuzhnyi et. al.[10] found that concentrations of pollutants decreased by about half with 500 meters of open space, and by two-thirds to five-sixths with 500 meters of planted land. He suggestes strips of green space to aid in wind formation to carry pollution away. He measured a 75 percent reduction in dust particle count over a 600-foot-wide strip in Leipzig.[1] Wainwright and Wilson[11], however, found over a London park that the decrease in concentration of sulfur dioxide with distance in the direction of the wind was not related to wind speed but instead correlated closely with variation of temperatures with height above the ground.

<u>Parking</u>

Large masses of parking space should, if possible, be avoided in favor of a more dispersed parking scheme. Such a scheme tends to reduce the peak pollution load on any given structure by simple disperson, although it also tends to increase the average exposure throughout the development. Setbacks of buildings from parking should prove beneficial.

CONCLUSION

The only contribution this study and the resultant manual can make to present residential design practice is to make the planner aware, in very general terms, of those variables he can manipulate that are likely to decrease pollution levels at a given site. The only present-day alternative to this approach is for the planner to schedule a series of scale-model wind tunnel tests for his project. The implications for future research are clear, since we now have no reliable quantitative relationships on which to base onsite or near-site analysis for residential planning.

REFERENCES

1. Rydell, C. Peter, and Gretchen Schwartz. "Air Pollution and Urban Forms: A Review of Current Literature," Journal of the American Institute of Planners, Vol. 34, No. 2 (March 1968).

2. Graham, W.E. "The Influence of Microclimate on Planning," Planning Outlook, Spring 1949

3. Landsberg, H.E. "Microclimatology, "Architectural Forum," Vol. LXXXVI, March 1947.

4. Kuhn, Eric, "Air Flow Around Buildings," Architectural Forum, Vol. 107, September 1967.

5. Kuhn, Eric. "Planning the City's Climate," Landscape, Vol. 8, Spring 1961.

6. Lawrence, E.N. "Microclimatology and Town Planning," Weather, Vol. 9, August 1954.

7. Final Report on Study of Air Pollution Aspects of Various Roadway Configurations. Submitted to New York City Department of Air Resources. By The General Electric Company, Philadelphia, Pennsylvania. September 1, 1971.

8. Olgyay, Victor. Design with Climate - Bioclimatic Approach to Architectural Regionalism, Princeton, N.J.: Princeton University Press, 1963.

9. Hilberseimer, L. The New City. Chicago: Paul Theobold, 1944.

10. Kalyuzhnyi, D.N., Kostovetskii, T.J., Devydov, S.A., Akselrod, M.B. Effectiveness of Sanitary Clearance Zones Between Industrial Enterprizes and Residential Quarters, Gigiena i Sanitariya, 1962, p. 9-12, Tranky B. Levine.

11. Wainwright, C.W.K., Wilson, M.J.G. Atmospheric Pollution in a London Park, Air and Water Pollution International Journal, Vol. 6, 1962, pp. 337-347.

8 INDOOR-OUTDOOR POLLUTANT RELATIONSHIPS

RESEARCH

Of great value in our search of available reference material were the literature review by Benson, Henderson, and Caldwell of EPA[1] and certain materials provided by Mr. Henderson. A comprehensive list of references is included with this section.

One of the first attempts to model the inflow-outflow parameters of buildings was presented by Holcombe and Kalika[2], in a report sponsored by ASHRAE. This report summarizes the effects of air-conditioning devices on intake air pollutant concentrations, and more importantly develops formulae expressing theoretical indoor-outdoor relationships for a number of typical air conditioning systems under steady-state conditions.

Also important to the methodology and theory developed in our study were papers by Frederick H. Shair et al.,[3,4] not yet published at the time of our data search. Also useful were several issues of the "Proceedings"[5] of ASHRAE, together with their publication "Handbook of Fundamentals."[6]

FINDINGS

The findings of most of the earlier studies were disappointingly inconclusive. Although measurements of indoor-outdoor concentrations of many pollutants have been taken at a great number of locations, the usual result is a series of concurrent readings, from which the reader must sort out relationships or inferences. Sulfur dioxide is the only commonly monitored pollutant for which reasonably consistent data can be plotted on graphs of indoor-outdoor versus outside concentration ratios.[7,8,9,10,11]

Many tests indicate the effectiveness of filters in removing pollen and other particulates from the indoors.[14,32] A number of less general findings are listed below:

1. Gas cookstoves and attached garages contribute noticable CO to the inside atmosphere.[12]
2. Tobacco smoking is an important source of indoor particulates.[13]
3. Indoor fluctuations of pollutant concentration follow outdoor fluctuations closely, with a time lag and generally lower peaks.[12]
4. No relationship has been established between building types and indoor-outdoor pollutant ratios.

The Holcombe-Kalika report,[2] though a great step forward theoretically, does not show strong numerical correlations in results of measurements at two Connecticut office buildings, chiefly because of uncontrolled variables and because the steady-state equations do not adequately represent rapidly varying outdoor concentrations.

Shair et al.[3,4] show good correlations between test data and model equations in studies of buildings on the Cal

Tech campus. Their equations were set up to respond rapidly to fluctuations in outdoor pollutant levels.

THEORY AND MODELING

In the beginning stages of the study we made a number of false starts in attempts to model indoor-outdoor pollutant relationships on the basis of data then available. First we tried to set up the indoor-outdoor ratio as the dependent variable, with building-type categories as the independent variable. We reasoned that the potential user of the manual would be more familiar with building types than with some of the more theoretical and mathematical variables required for the more rigorous approach.

We soon found that the system of building type classification was inadequate to our needs, even with adaptation. The significant variables seemed to be building volume and surface area, which vary widely within each building category, and air circulation and filtration characteristics, which do not directly relate to building types. When this set of deficiencies became apparent, we decided to set up a theoretical model based on the concept of the building shell forming a system boundary for a closed container with good internal mixing of constituent gases or suspended matter.

The Holcombe-Kalika study provides good basic mathematics for use in steady-state conditions, but did not respond to actual fluctuations in outdoor concentrations and did not provide good enough correlations with actual test conditions. We therefore decided to proceed with a general model that would respond to rapidly changing outdoor conditions and indoor generation of pollutants.

METHODOLOGY FOR CALCULATING INDOOR POLLUTION CONCENTRATIONS

The model we constructed for predicting indoor air pollutant concentrations makes use of data on permeability factors for exterior walls of the structure, structural dimensions and volume, characteristics of the air circulation and filtration system, and internal generation. The model is simply an accounting system for tracing the movements of various air massed into, out of, and within a dwelling unit over short increments of time.

Although the movement of air massed into and inside a dwelling is continuous, we thought it well within the limits of accuracy of available data to express the mathematics in terms of net concentration changes occurrring within short time segments. The mathematics thus could be simplified into a format more easily manipulated and computer-programmed. As data from continuously monitored indoor-outdoor environments are accumulated and a more precise method is developed to account for infiltration factors and rates, this model could be revised to incorporate continuous-change-state mathematics, if this is deemed desirable.

The general equation for the change in pollutant concentration in a dwelling space over a short period of time can be expressed as follows:

$$C_2 = \frac{C_gQ_g + C_eQ_e + C_vQ_v + (C_1Q_r)(1-e)_r + C_mQ_m(1-e_m) + C_1(V-Q_m-Q_e-Q_g-Q_r)+g-R}{V}$$

Definitions

C_1 = Concentration in interior space in the beginning of the incremental period.

C_2 = Concentration in the interior space at end of incremental period.

C_e = Concentration in the exterior space adjacent to exterior walls.

C_g = Concentration in garage adjacent to exterior wall (also in carport area adjacent to wall)

C_v = Concentrations within the units above and/or below the unit under evaluation. During the heating season, vertical infiltration from thelower level could have a significant effect; during cooling season, the opposite could occur. This factor requires a good deal more information.

C_m = Concentration at exterior air intake of a forced air system.

Q = Generally, incremental quantity of influent or effluent air in a given period.

Q_e, Q_g, Q_v, Q_m are quantities corresponding to the above C_e, C_g, C_v, C_m.

Q_r = Quantity of air from dwelling space recirculated.

V = Volume of dwelling unit or interior space in question.

g = Amount of interior generation during the incremental period (grams)

R = An expression of the attenuation rate of reactive pollutants on interior surfaces

e = Filtration efficiency, percent removal for single pass

e_m = efficiency of make-up air filter

e_r = efficiency of recirculation air filter

Figure 8-1 illustrates the relationships involved.

Mixing Factors:

The formula assumes complete mixing between applications of the formula, an assumption most nearly assured of being correct in applications that involve a typical forced-air system. If the quantity of recirculated air approaches or exceeds the volume of the dwelling unit, mixing seems virtually assured. The most obvious way to deal with the unknown "mixing effect" is to "calibrate" the formula by comparison with monitored data from buildings having known infiltration, circulation, and volume parameters.

Testing the Indoor-Outdoor Pollution Model

New data from Cal Tech (Shair, et al.) are based on a modified form of the formula we have set up. In tests of their formula against monitored readings in various buildings on the Cal Tech campus, correlations were good.

We decided that the best available test of our form of the formula would be to apply it to the same building configurations reported in the Cal Tech study and to determine correlations with the Cal Tech formula and with the monitored readings. We therefore programmed the data and applied the model to two configurations of the Dabney Hall location at Cal Tech. The results correlate very well with data from the Cal Tech formula and somewhat less well with the data obtained in monitoring pollutant levels. In each case the correlation is much stronger than the input data.

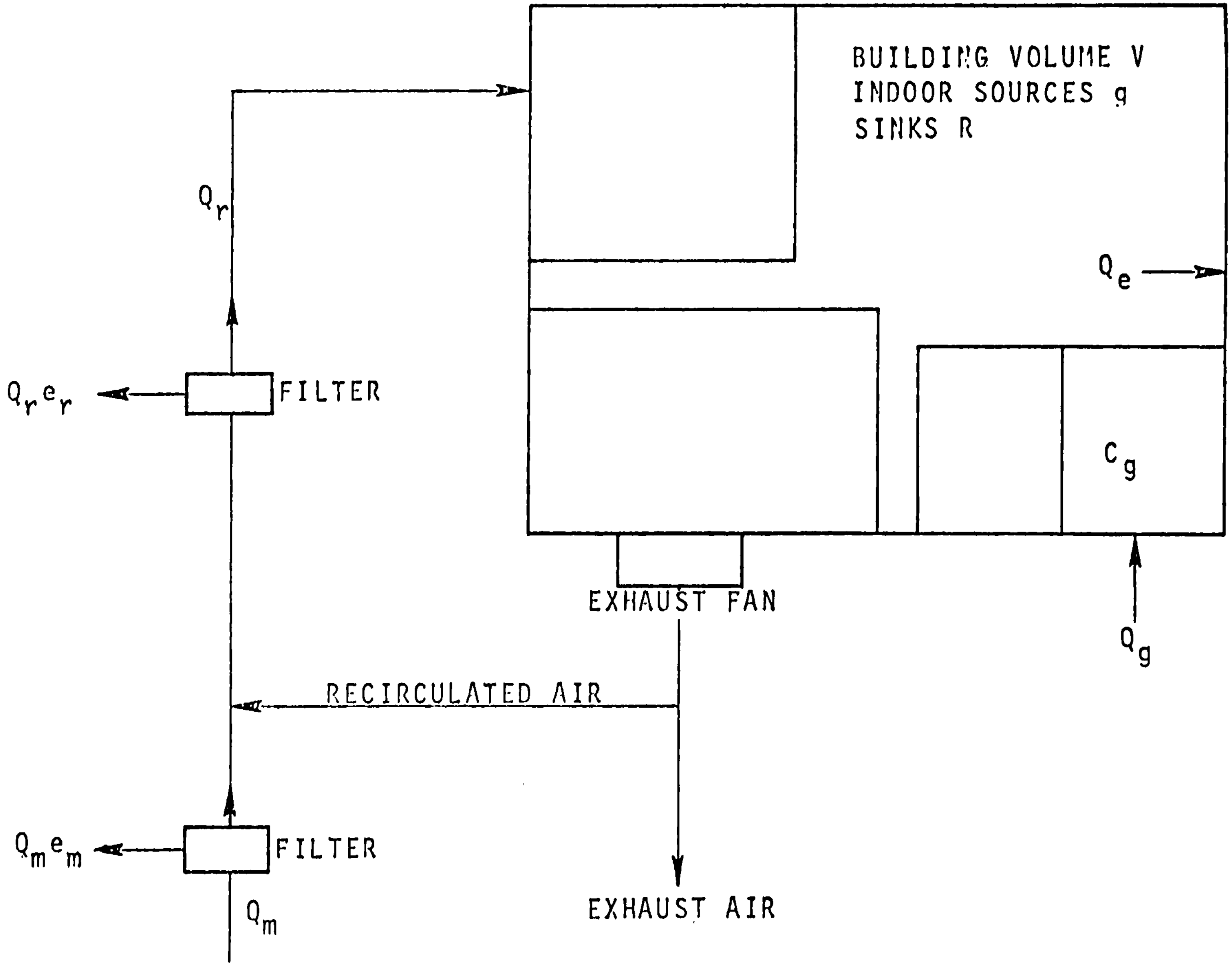

Figure 8-1 Schematic representation of outdoor-indoor model.

Our first run-through of the Dabney Hall data assumed 5-minute time increments between iterations of the formula. We theorized that an even closer correlation with data from the Cal Tech formula would be achieved by use of a shorter time increment. Therefore we ran the data through again using a 2-minute increment; the resulting values, however, were virtually identical with those obtained with the 5-minute increments. From this we can guess that (1) possibly the Cal Tech formula is slightly flawed by deletion of certain small factors for mathematical convenience, or (2) perhaps a very small time increment would be required to match the integral formula. Since the correlation was adequate for our purposes, we did not test the model further.

Computer Investigation of Cases

Having been validated with Shair's test results, the model seemed sufficiently accurate for use in exploring the impact of variables in building and mechanical design and construction on interior air pollution. A variety of prototype cases were analyzed by means of the computer. Following is a short summary of the building types and variables tested:

Building Types and Floor Areas

1. Single-Family Dwellings
   - A. 1000 ft^2 single-story
   - B. 1600 ft^2 single-story
   - C. 2000 ft^2 two-story

2. Low-Rise Apartments

   A. Two-story single-load (or townhouse)

   B. Three-story double-load (8DU/floor)

3. High-Rise Apartments

   A. Single Long-corridor 10-story, 20 DU/floor

   B. Double short-corridor, 12 DU/floor

   C. Three-wing composite 30-story, 36 DU/floor

<u>Heating/Cooling Systems</u>

1. Hot-water or steam radiator

   A. Closed-window

   B. Open-window

2. Forced-air Systems

   A. Unfiltered

   B. Filtered

      (1) Efficiency = 0.2

      (2) Efficiency = 0.9

      (3) Filter on return air only

      (4) Filter make-up air only

      (5) Filter on make-up and return air

<u>Structural Permeability Variables</u>

1. Modern "tight" building

2. Old "leaky" building

<u>Source Variables</u>

1. Interior generation

2. Infiltration from subterranean garage

3. Make-up air intake at a low-pollution location

4. Pollution reaction with walls, floors, ceilings

5. Exterior levels were assumed to follow a prototypical two-humped curve, with morning and afternoon peak levels, as indicated in Figure 8-1. Also a constant exterior level representing industrial TSP and SO_2 emissions was included as in input.

OPERATIONAL ASSUMPTIONS

Where data were sufficient to allow formulation of a statistically correct (i.e., 97th percentile, etc.) parameter, we attempted to insert into the model a conservative condition. The following section attempts to explain and justify some of the assumptions made.

Outdoor Concentration Time Gradient

The simplified outdoor concentration profile shown in Figure 8-2 was used to represent a typical time-concentration relationship. The type of pollution sources and prevailing meteorological conditions determine the shape of this curve. This two-humped curve is, however typical for locations with significant impact from roadways.

Wind Driving Pressure

Wind driving pressure equivalent to that generated by a 10 mph wind (0.05 in. of H_2O) was selected as the maximum that might be expected in conjunction with high-pollution conditions. Statistically, this seems quite conservative, but this factor was possibly overdone in order to compensate for factors not considered in the model because of lack of data, such as chimney effect. An equal vacuum was assumed on the leeward side of the structure.

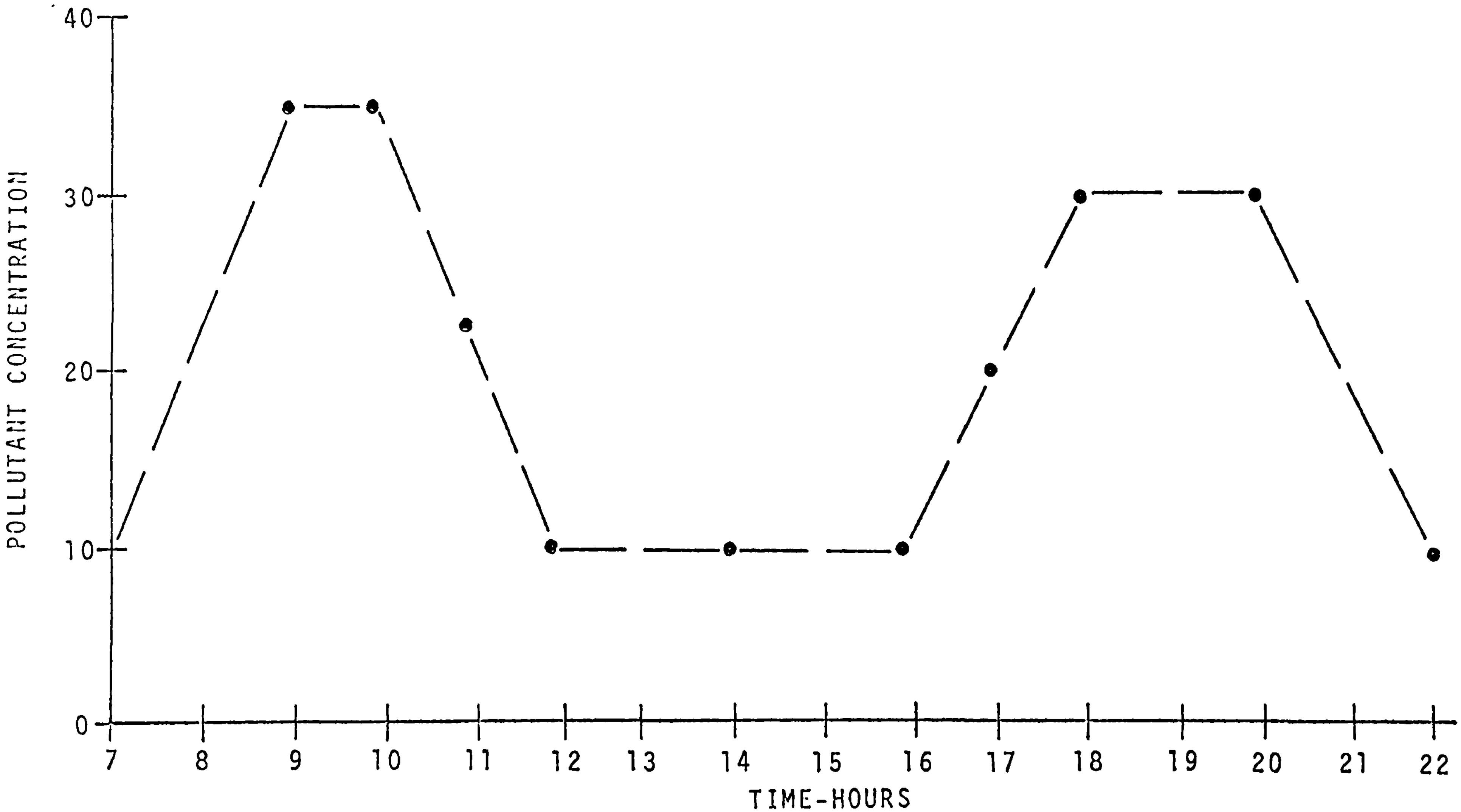

Figure 8-2 Typical outdoor pollution profile.

Effective Infiltration Area

We assumed that wind driving pressure acts equally on all upwind walls. In other words, wall area available for infiltration was taken as half of the total wall surface, deducting door and window areas, which were assumed to be in the same proportion on the upwind and downwind sides.

We assumed that full wind pressure acted on the cooling of the top story, with infiltration occurring over the upwind half of the ceiling and exfiltration on the downwind half.

We assumed that floors have no significant infiltration driving force exerted and assigned them a zero value. This assumption is obviously valid for slab floors, and probably not entirely valid for a structure with crawl space below the floor. A basement structure has some small potential for infiltration through small basement windows, but such a value is not established by available data, and subjectively it appears small.

Infiltration Rates

For walls we assumed that an infiltration rate of 0.5 $ft^3/hr/ft^2$ is representative of modern construction with vapor barriers. Much lower values are observed in test sections, but occasional poor workmanship can reduce sealing effectiveness; therefore we considered 0.5 a reasonable value that is obtainable with ordinary workmanship and inspection. For older structures we assumed an infiltration rate of 5.0

$ft^3/hr/ft^2$, very much a "ballpark" estimate. An old structure with exterior stucco and interior plaster in good condition could duplicate the rates of modern structures. In many older masonry structures, however, the infiltration rates range much higher than 5.0. The choice was based solely on a judgment of what values would be both conservative and representative.

For windows and doors, we assumed values of 14 ft^3/hr/ft of sash or edge crack with weatherstripping and 140 ft^3/hr/ft without weatherstripping.

Single-Family Structures

The first structure selected for analysis was a 1600 square foot single-story building. We calculated surface area from an assumed floor plan, computed length of windows and door cracks, using the infiltration rates mentioned earlier, computed total infiltration in ft^3/hr for both "modern" and "old" structures. For other single-family prototypes, the infiltration rate was assumed to vary directly with surface area of the structure.

Multi-Family Structures

Multi-family prototpyes were selected from actual floor plans. We measured interior volumes and exterior surfaces directly and again took infiltration as proportional to the outside surfaces. Because of the many complicating factors and the absence of supporting data, we abandoned the attempt to calculate infiltration for a single living unit in a structure. The calculations for multi-family structures assume a uniform distribution of air pollutants throughout.

Interior Generation

All that we know definitely about indoor pollutant generation are the general categories of sources and the fact that in some structures with given circulation characteristics these sources could increase localized pollutant concentrations. Because present data are not adequate to deal with localized variations, the factors for internal generation assume good mixing throughout the dwelling. The model is capable of handling any pattern of internal generation and any attenuation when valid values become available.

Data Format

The data resulting from each computer run for each building prototype took the form of interior concentrations at 5-minute intervals over the period of the run. For our purposes, results were as good and much more convenient when the computer continued the 5-minute iterations but printed out readings only on the hour.

The indoor-outdoor ratio was computed by averaging the peak readings for the applicable period of time for both indoor and outdoor locations. For example, if an 8-hour standard were under consideration, the averages of readings for the highest 8-hour period in the day were computed for both indoor and outdoor concentrations. These periods did not usually coincide because of the time lag required for infiltration of pollutants to exert an effect on indoor levels. We then divided the high indoor level by the high outdoor level and plotted the result.

The indoor-outdoor ratios and periods selected for inclusion in the manual were determined by the time periods finally selected for the air quality standards. The total range of ratios calculated and graphed, for the two-humped curve characteristic of auto emissions, included ratios for interval of 1, 3, 8, and 24 hours. For the uniform emission rate characteristic of industrially generated SO_2 and particulates, the 3-hour and 24-hour ratios were calculated. Modeling of SO_2 was abandoned because of insufficient data on internal attenuation by paint, fabrics, and other materials. We therefore deal with SO_2 very simplistically as a fixed ratio.

RELATIONSHIPS

The key variables in indoor-outdoor pollutant levels appear to be interior volume of the structure as related to surface area. For any given set of conditions of air circulation, permeability, filtration, and other parameters, the plot of volume-to-surface-area ratio (V/SA) versus pollutant reduction shows a consistent and significant trend. It is possible therefore to deal with the design problem in a graphical format. With this goal in mind, we plotted the results of our studies with V/SA on the Y-axis and the proportion of indoor to outdoor concentrations on the Y-axis.

Some cases modeled did not conform well to graphing on this set of axes, at least not without interpretation. The case in which concentration of a pollutant at a forced-air system intake is significantly lower than at the exterior walls generally, is dominated by the concentration of the intake air. In most cases, the plot of V/SA versus inlet pollution level exhibits the same ratio as the plot of V/SA versus general outdoor pollution level, so the significant and consistent indoor-outdoor comparison in this case is indoor to inlet ratio.

Also, a large garage infiltration will throw an inconsistency into the ratio, depending on a great number of ill-defined variables. This situation was handled with "tack-on" factors.

Generally, the effect of tighter building construction and larger V/SA ratio is to slow infiltration of pollutants from the outside. This evens out the peaks and valleys and, therefore, is most successful with highly fluctuating exterior concentration values. The reduction of infiltration is most apparent in calculations that entail a pollutant standard covering a shorter time period. For example, the 1-hour standard for carbon monoxide is highly responsive to building sealing; the 24-hour standard for particulates responds hardly at all.

The effect of filtration devices or chemical removal agents is less linked with time. An effective filtration device has as much effect on particulates with the 24-hour standard as on CO with the 1-hour standard.

An open-window case was run to demonstrate that indoor pollutant levels closely follow those outdoors when windows are open. The model verified this supposition fully.

RECOMMENDATIONS

Because of time limitations on this project, we did not process a number of somewhat less-typical cases that might have exhibited some significant variation from our model. A more significant weakness is that only two real test cases (those with Dabney Hall data) were run to confirm the accuracy of the model. A program of further testing should be specifically aimed at verifying the model for a wider range of structures, materials, and operating conditions.

A great body of knowledge still requires research to fully validate the indoor-outdoor model for dependable everyday use by a residential planner with limited technical training. Investigation of the following factors could significantly strengthen the work.

1. Permeability of modern building materials, including:

   Taped plaster board

   "Sandwich" construction panels

   Plywood sheathing

   Modern masonry and hollow-core block

   Masonry veneer over stud walls

   New vapor barrier materials, such as plastic and aluminum or composites.

2. Internal generation of pollutants:

   Co from stoves and fireplaces

   HC from tobacco smoking

   Dust from vacuuming and other household cleaning.

3. Room-to-room variations in pollution levels.

4. Unit-to-unit air movements in multi-family configurations.

5. Vertical permeability of high-rise structures, including more cause-and-effect modeling. Studies of the "chimney effect."

6. Relative permeabilities of various gases. Is a "vapor" barrier the best barrier against CO or SO_2?

7. The graphical displays show clearly that any form of reasonably effective filtration in a forced-air system with typical recirculation rates is highly effective. Even a 10 percent effective filter, for instance, can significantly reduce levels of some pollutants. This finding suggests research into low-efficiency filters for the gaseous pollutants.

8. Dependable exterior air-current analysis. How much pollutant recirculates into the structure from its own flue? What are the effects of eddying?

9. Effects of kitchen or bathroom fan vents.

10. Concentrations of pollutants in various garage structures.

11. Reaction rates of pollutants with building materials and furnishings. This study would produce an alternative factor, which is required to develop a more quantitative relationship for SO_2 infiltration.

Infiltration Rates - Single-Family Modern

Case I - 1-Story, 1600 S.F. floor area
12,800 ft^3 interior volume

```
Wall Area  =  1,312 ft²
              - 197 Windows @15%
              1,115 ft² net walls
              x 0.5
                558 ft² infiltration surface walls
                800 ft² roof
              1,358 ft² Total
              x 0.5 ft³/hr/ft² =
                679 ft³ infiltration through walls

Windows - 4 -  3 x 5 double-hung
               3 x 3 =  9
               2 x 5 = 10
               5 x     19 - 95 L.F. window crack

               1 - 3 x 7 Doors
                   20 x = 20 LF door crack

               Total Leakage     115 LF crack length
                               x  14 CF/hr/LF
                               1,610 ft³/hr windows, doors
                                 679 ft³/hr walls
                               2,289
                    Round off to 2300
```

Infiltration Rates - Single-Family "Leaky"

Case 2 - Single-story 1,600 SF floor area
12,800 ft^3 interior volume

Wall Infiltration:	1,115	ft^2 net walls
	x 0.5	
	558	ft^2 infiltration surface, walls
	800	ft^2 infiltration surface, ceilings
	1,358	ft^2 infiltration surface, Total
	x 5	$ft^3/hr/ft^2$
	6,790	ft^3/hr infilt. walls & ceilings
Windows & Doors	115	LF Crack Length (from Sht. 1)
	x 140	$ft^3/hr/ft$ crack
	16,100	ft^3 through doors & windows
Total Infiltration	6,790	ft^3 walls
	16,100	windows & doors
	22,890	

BUILDING PROTOTYPES SELECTED FOR MODELING

1. One Story, 1000 ft^2 $V = 8{,}000\ Ft^3$

   Area Walls 1040

   Roof 1000

   2040

   $R = 3.92$

2. One Story, 1600 S.F. $V = 12{,}800$

   Area Walls 1300 ft^2

   Area Roof 1600 ft^2

   2900 ft^2

   $R = 4.41$

3. Two-Story, 2000 S.F.

   24' x 42' exterior dims.

   $V = 2000 \times 8' = 16000\ ft^3$

   A = 2112 Walls + 1000 Roof = 3112 Total

   $R = 5.14$

4. Two Story Apartment, Single-load or Townhouse Rows of 8

   $A = 8800 \times 2 = 17{,}600\ ft^2$

   $V = 140{,}800\ ft^3$

   Area Walls = 6,880 ft^2

   Area Roof = 8,800 ft^2

   15,680 ft^2

   $R = 8.98$

5. Three-Story Apartment, Double Load

$V = 265{,}200\ ft^3$

Area Walls	=	$11{,}280\ ft^2$
Area Roof	=	$\underline{11{,}050}\ ft^2$
		$22{,}230\ ft^2$

$R = 11.99$

6. Ten-Story Long-Corridor

Area/floor = $20{,}000\ ft^2$

Volume = $20{,}000 \times 10 \times 10 = 2{,}000{,}000\ ft^3$

Wall Area = $12{,}000\ ft^2 \times 10$ =	120,000
Roof	$\underline{20{,}000}$
S.A.	140,000

$R = 14.28$

7. Twenty-Story High Rise (12 D.U./floor)

$V = 64 \times 145 \times 20 \times 10$	=	1,856,000
Area Walls	=	83,600
Area Roof	=	$\underline{9{,}280}$
		92,880

$R = 19.98$

8. Thirty-Story Three-Wing Apartment

Area of one floor = $29{,}840\ ft^2$

$V = 29{,}840 \times 30 = 8{,}952{,}000\ ft^3$

Area Walls = $1{,}152 \times 10 \times 30$ =	$345{,}617\ ft^2$
Area Roof =	$\underline{29{,}840}\ ft^2$
S.A.	$= 375{,}487\ ft^2$

$R = 23.84$

REFERENCES

1. Benson, F.B., Henderson, J.J. and Caldwell, D.E. Indoor-Outdoor Air Pollution Relationships: A Literature Review, Environmental Protection Agency, August 1972.

2. Holcombe, J.K. and Kalika, P.W. The Effects of Air Conditioning Components on Pollution in Intake Air, ASHRAE Transactions 1971.

3. Shair, F.H., and Heitner, K.L. A Theoretical Model for Relating Indoor Pollutant Concentrations to Those Outside, October 1973.

4. Hales, C.H., Rollinson, A.M., and Shair, F.H. Experimental Verification of the Linear Combination Model for Relating Indoor-Outdoor Pollutant Concentrations, November 1973.

5. American Society of Heating, Ventilating and Air Conditioning Engineers (ASHRAE). Proceedings.

6. American Society of Heating, Ventilating and Air Conditioning Engineers (ASHRAE). Handbook of Fundamentals, 1971 Edition.

7. Phair, J.J. Shephard, R.J. Carey, C.G.R., and Thomson, M.L. The Estimation of Gaseous Acid in Domestic Premises, Brit, J. Ind. Med. (London). 15:283-292, October 1958.

8. Biersteker, K., de Graaf, H., and Nass, Ch. A.G. Indoor Air Pollution in Rotterdam Houses, Int. J. Air Water Poll. 9:343-350, 1965.

9. Wilson, M.J.G. Indoor Air Pollution, Proc. Roy. Soc., Ser. A. (London). 300:215-222, 1968.

10. Weatherly, M.L. Air Pollution Inside the Home, Warren Spring Laboratory INvestigation of Atmospheric Pollution, Standing Conference of Cooperating Bodies, May 16, 1966.

11. Weatherly, M.L. In: Symposium on Plume Behavior, Int. J. Air Water Poll. 10:404-409, 1966.

12. Yocom, J.E. and Cote, W.A. Indoor/Outdoor Air Pollutant Relationships for Air-Conditioned Buildings, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York. Preprint of paper for inclusion in ASHRAE Transactions, 1971.

13. Yocom, J.E., W.A. Cote, and W.L. Clink. Summary Report of a Study of Indoor-Outdoor Air Pollution Relationships to the National Air Pollution Control Administration. Contract No. CPA-22-69-14. The Travelers Research Corp. Hardford, Conn. 1969.

14. Cohen, Milton B., M.D. Further Observations on the Use of Filtered Air in the Diagnosis and Treatment of Allergic Conditions.

15. Cohen, Milton B., M.D. Preliminary Report of the Treatment of Hay Fever in Rooms Made Pollen Free by a New Filter.

16. Gay, L.N., M.D. The Treatment of Hay Fever and Pollen Asthma by Air-Conditioned Atmosphere.

17. Studies Concerning the Effects of Atmospheric Pollution on the Indoor Environment and Measures to Prevent Pollution by Air Filtering System Designing Committee.

18. Shozaburo Mshido. Air Conditions in Dwellings with Special Reference to Numbers of Dust Particles and Bacteria.

19. Ishido. Air Pollution in Osaka City and Inside of Buildings.

20. Richardson, N.A. Evaluation of Filters from Removing Irrtants from Polluted Air.

21. The Reduction of Smog Effects in California Institute of Technology Campus Buildings.

22. Weatherly, M.L. Air Pollution Inside the Home.

23. Whitby, K.T. Size Distribution and Concentration of Air-Borne Dust.

24. Whitby, K.T. The ASHRAE Air-Borne Dust Survey.

25. Kranz, Peter. Indoor Air Cleaning for Allergy Purposes.

26. Whitby, K.T. Field and Laboratory - Performance of Air Cleaners.

27. Criep, L., M.D. Air Cleaning as an Aid in the Treatment of Hay Fever and Bronchial Asthma.

28. Rappaport, B.Z., M.D. Effect of Air Filtration in Hay Fever and Pollen Asthma.

29. Nelson, Tell, M.D. The Effect of Air Filtration in in Hay Fever and Pollen Asthma.

30. Spiegelman, Jay, M.D. Annals of Allergy. Effects of an Air Purifying Apparatus on Ragweed.

31. Spiegelman, Jay, M.D. The Effect of Central Air Filtration and Air Conditioning on Pollen and Microbial Contamination.

32. Vaughan, W.T., M.D. Air Conditioning as a Means of Removing Pollen and Other Particulate Matter and of Relieving Pollinosis.

33. Bahnfleth, D.R., Moseley, T.D., and Harris, W.S., ASHRAE Research Report No. 1614 - Measurement of Infiltration in Two Residences, Part I - Technique and Measured Infiltration. ASHRAE Transactions, Vol. 36, 1957, p. 439.

34. Sasaki, J.R. and Wilson, A.G. Air Leakage Values for Residential Windows. ASHRAE Transactions, Vol. 71, Part II, 1965, p. 81.

35. Larson, G.L., Nelson, D.W., and Braatz, C. ASHVE Research Report No. 851. Air Infiltration Through Various Types of Brick Wall Construction. ASHVE Transactions, Vol. 36, 1930, p. 90.

36. Larson, G.L., Nelson, D.W. and Braatz, C. ASHVE Research Report No. 868. Air Infiltration Through Various Types of Wood Frame Construction. ASHVE Transactions, Vol. 36, 1930, p. 397.

9 CONCLUSIONS

SUMMARY OF RESULTS

The chief aim of this research effort was to produce an evaluation method for general, nationwide use to help minimize the effects of air pollutants on residential environments. Results of this effort are now published in the form of a manual and this more detailed technical report, which together have some important auxiliary uses:

1. The manual/report presents a summary documentation of the current state of the art in workable small-scale diffusion modeling.
2. The manual/report sets up a number of relationships and hypotheses that may be judged to warrant further research.

Models are provided for the assessment of large point sources and of area sources consisting of large parking areas and the heating of residential, business, institutional, and manufacturing spaces. A model is also given for assessment of impacts on residential sites from nearby traffic sources. Recommended design practices are outlined, more generally than we originally intended. Although some of these practices entail possible economic impacts, they are mostly compatible with other practices recognized as good design procedures.

LIMITATIONS

The chief weakness of the manual is that many of the relationships must be further validated experimentally to ensure a reasonable degree of accuracy. Another shortcoming, caused by time and budget constraints, is that the various models do not handle a wider range of input conditions.

The manual is not as concise or as easy to use as was originally envisioned. Nor is the precision of results attainable as great as we had hoped. Accuracy was not fully validated for all cases, especially the complicated high-density case. In addition, the methodology cannot be applied to all of the important pollutants because base data of sufficient quality were not available.

A weakness related more to the entire context of residential planning than to the manual is that the cost/benefit ratios for the procedures developed in the manual have not been weighed against those of alternative procedures. Subjectively, we feel that the best results could be obtained by reducing the generation of pollutants rather than by treatment of site design and building construction to reduce their impact. Many of the procedures outlined are stopgap methods, useful only until better regional models are set up for larger metropolitan areas. This is especially true with the assessment of impacts from point sources.

We made no effort to develop a procedure for estimating lifetime pollutant exposures because we think that a short-term model is a more accurate indicator of human health effects than a long-term model, which would be required to determine lifetime exposures at a residential site.

We do not believe that use of the manual procedures would cause any significant change in other facets of environmental concern such as noise abatement, water pollution control, or solid waste disposal, and therefore did not pursue that line of investigation.

PRESENT USEFULNESS OF THE MANUAL

In spite of the weaknesses just mentioned, we believe that the manual is usable and valid with residential construction in this country. We cite the weaknesses of the manual only to point out that a more concise, more usable, and more accurate manual could be produced with, we feel, a small amount of additional research and testing.

RECOMMENDATIONS FOR FURTHER STUDY

Following are some of the projects recommended as further efforts to improve the techniques of residential site evaluation.

1) A network for point source analysis that would enable a local air pollution control agency to provide a maximum pollutant level at any coordinate point resulting from all point sources plotted with NEDS data.

2) Validation of the Shair et al. indoor-outdoor model by testing of construction materials and mechanical equipment and by documentation of the range of outdoor pollutant levels

encountered in the U.S.

3) Research of indoor pollutant generators, particularly fireplaces and gas appliances such as dryers and cookstoves.

4) Consultation with the Bureau of the Census concerning possible publication of fuel source data by census tracts or city blocks rather than in county-wide tabulations.

5) Longer-term and intensive analysis of air movements near and on residential sites, such studies to encompass many significant variables and provide dependable numerical data. We believe that this research has had low priority because production of usable data would require a great deal of work.

6) Experimental application of the evaluation models to different housing site configurations and meteorological conditions.

APPENDIX

Table A-1 gives automobile emission data referred in the Report and used in the calculation procedures in the Manual. Table A-2 lists model emission ratios for light-duty, gasoline-powered vehicles. Figure A-1 shows relationships of average route speed and speed correction factors for three pollutants.

Table A-1 1975 FTP (HOT OPERATING) CO EMISSION FACTOR BASED ON NATIONAL POPULATION VEHICLE MIX[18] (LOW ALTITUDE AREAS)

Mid-Year	CO Emission Factor
1970	71.89
1971	67.28
1972	61.82
1973	55.98
1974	50.68
1975	45.55
1976	39.46
1977	33.79
1978	28.85
1979	24.82
1980	21.00
1985	12.10
1990	10.76

TABLE A-2. Light Duty Gasoline-powered Vehicle Modal Emission Ratios[18]

Mode	Modal Ratio[a] Low Altitude and California CO	HC	NO_x	High Altitude CO	HC	NO_x
Idle[b]	0.225	0.197	0.027	0.153	0.172	0.054
Steady State Speed (mph)						
15	0.936	0.750	0.182	0.771	0.706	0.373
30	0.417	0.439	0.486	0.465	0.436	0.686
45	0.386	0.426	1.022	0.503	0.459	1.377
60	0.396	0.419	1.542	0.634	0.451	2.027
Acceleration Deceleration Sequences						
1	1.686	1.733	2.743	2.424	1.479	2.063
2	0.650	0.823	0.559	0.616	0.699	0.673
3	2.647	2.379	1.554	2.431	1.933	1.121
4	1.009	0.970	1.821	1.319	0.850	1.525
5	0.628	0.691	2.015	1.178	0.652	1.884
6	0.309	0.412	0.583	0.335	0.350	0.808
7	1.258	0.881	2.161	2.053	0.874	1.704
8	0.330	0.426	0.753	0.405	0.408	1.256
9	0.630	0.661	2.185	1.308	0.652	2.198
10	0.382	0.617	0.607	0.424	0.548	1.032
11	1.130	0.896	2.379	2.255	0.967	1.570
12	0.446	0.720	0.704	0.505	0.652	1.211
13	1.151	1.014	2.719	2.220	1.106	1.794
14	0.352	0.529	0.559	0.434	0.513	0.987
15	0.513	0.632	0.389	0.508	0.582	0.583
16	1.926	1.718	0.583	1.602	1.514	0.583
17	1.295	1.146	2.403	2.361	1.176	1.570
18	0.447	0.573	0.486	0.471	0.513	0.718
19	1.136	0.984	2.209	2.035	0.978	1.391
20	0.573	0.735	0.534	0.591	0.676	0.763
21	1.642	1.160	2.452	2.791	1.211	1.391
22	0.466	0.749	0.583	0.563	0.664	0.987
23	1.671	1.630	2.379	2.474	1.572	1.749
24	0.801	0.720	2.209	1.628	0.734	1.525
25	0.341	0.500	0.583	0.450	0.419	1.032
26	0.807	0.940	0.534	0.735	0.827	0.808
27	0.978	0.896	2.500	1.925	0.943	1.704
28	0.482	0.735	0.534	0.558	0.664	0.987
29	1.581	1.469	2.015	2.100	1.339	1.749
30	1.056	0.779	2.136	1.913	0.885	1.435
31	0.340	0.470	0.631	0.446	0.431	1.077
32	0.846	0.970	0.510	0.729	0.885	0.673

[a]Emissions in mode/Emissions in 1975 FTP (grams/vehicle-mile/ grams/vehicle-mile).

[b]Grams/minute/ grams/vehicle-mile.

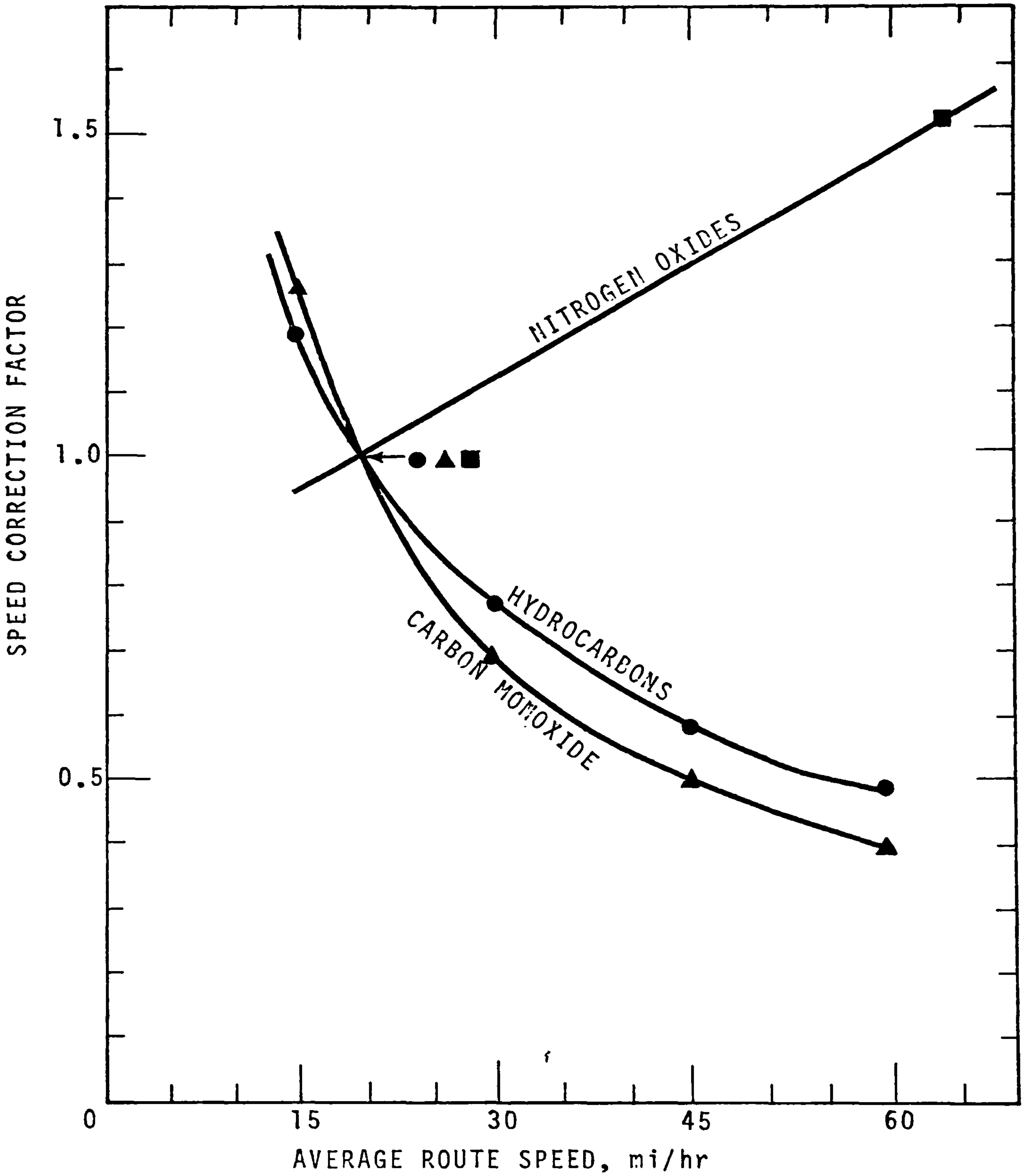

Figure A-1 Average speed correction factors.[18]

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-74-046-b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Air Pollution Considerations in Residential Planning Volume II: Backup Report		5. REPORT DATE July 1974 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) T. M. Briggs, M. Overstreet, A. Kothari, T. W. Devitt		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square Cincinnati, Ohio 45246 Vogt, Sage and Pflum, Cincinnati, Ohio		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-1089
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency Office of Air Quality Planning & Standards Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared in cooperation with the U. S. Dept. of Housing & Urban Development, Office of Community & Environmental Standards

16. ABSTRACT

The backup report presents the technical basis for the air quality estimation procedures presented in the manual. Included are the justification for selecting only particulates, SO_2 and CO for study, and the basis of the air quality criteria levels. A detailed description of the method for converting outdoor pollutant levels to indoor concentrations is also presented. Limitations of the manual's procedures are presented together with recommendations for future research.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Land Use, Planning and Zoning, Design Standards, Permits, Urban Areas, Residential Areas, Diffusion		

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 103
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)