User Manual NBSAVIS CONTAM88

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NIST

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USER MANUAL

NBSAVIS

CONTAM88

A User Interface for Air Movement and Contaminant Dispersal Analysis in Multizone Buildings

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Abstract

This manual describes the usage of two computer programs for analyzing the air movement and indoor air quality in multizone buildings. The first program **NBSAVIS** creates and edits a building description and generates the leakage, fan and contaminant source data necessary to predict the air infiltration and internal air movement in a building and perform an indoor air quality analysis. These data along with weather data are used by the program **CONTAM88** to calculate the air flows and both dynamic and steady state levels of indoor contaminants. **CONTAM88** also produces an output file which can serve as the input for the programs **CONTAM86** and **CONTAM87**.

Table of Contents

1 General Description

The National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards (NBS)) has over the past several years developed a series of public-domain computer models for calculating air flow and contaminant dispersal in multizone buildings.[1-5] However, these programs require a rather laborious preparation of input data and sophisticated building idealization in order to model realistic building configurations. To simplify the use of these models, a preprocessor program **NBSAVIS** (The National Bureau of Standards Air Infiltration, Ventilation and Indoor Air Quality Analysis Program in Multizone Buildings) was developed to prepare input files for air flow and indoor air quality analysis. The main features of the programs **AIRMOV**[1-2] and the programs **CONTAM86** and **CONTAM87**[4-5] have been combined into a program called **CONTAM88** which integrates multizone air flow analysis and contaminant dispersal analysis into one program. **NBSAVIS** is menu driven and has the capability of editing and creating a building description and calculating the required zone and opening data for multizone airflow and contaminant dispersal analysis.

Steps in Performing
Air Flow and Contaminant Dispersal Analysis
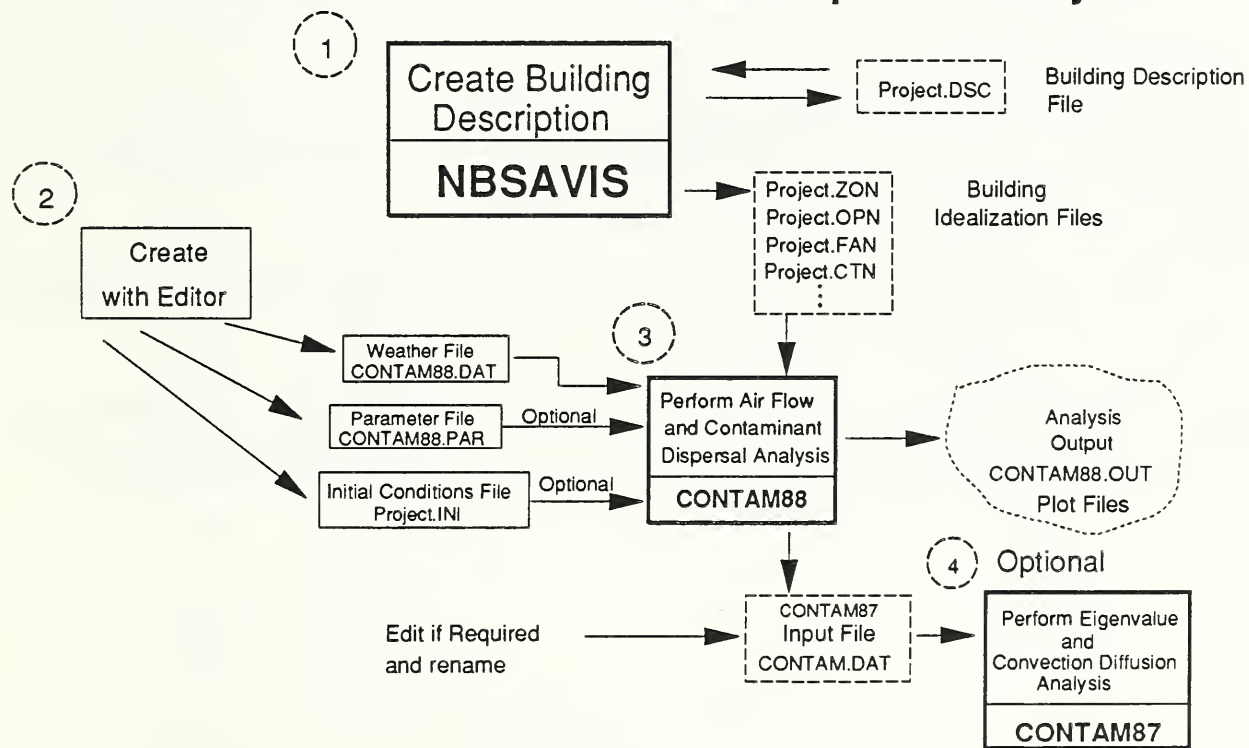
Figure 1. Steps in Performing Air Flow and Contaminant Analysis

The steps in analyzing the air movement and indoor air quality of a building are as follows:

1

Create and edit a building description using **NBSAVIS**.
Analyze air movement and contaminant dispersal using **CONTAM88**.
If a more detailed indoor air quality analysis is desired, use **CONTAM86** or **CONTAM87**.

This manual gives the general instructions for carrying out these steps. Section 2 contains a general description of the program **NBSAVIS**. Section 3 contains a tutorial on the use of **NBSAVIS**.

2 Description of the Program NBSAVIS

The program **NBSAVIS** is designed to run as a preprocessor for the interzonal air movement and contaminant dispersal analysis program **CONTAM88**, and the indoor air quality analysis program **CONTAM87**. It takes data on the building envelope construction, internal configuration, HVAC system and contaminant generation sources and prepares input files for **CONTAM88**. **NBSAVIS** is designed to create a building description which is modular in nature. The description of the building can be refined as more data are acquired or as a more detailed analysis of the air flows and contaminant dispersal into and within the building is desired. **NBSAVIS** supports the following basic functions:

1. Creation of a new building description.
2. Editing of an existing building description.
3. Saving a created or edited building description to disk.
4. Calculation of the opening, zone and fan data from the building description and preparation of the input files for **CONTAM88**.

In addition **NBSAVIS** has two program utility functions which allow:

5. Changing certain program parameters such as the physical units used and how building leakages are described (either as leakage areas or flow coefficients).
6. Returning to DOS in an orderly manner.

The input of data for the program **NBSAVIS** is controlled by a series of screen originated subroutines for the description of the building, exterior walls, exterior doors, windows, interior walls, interior doors, open passageways, miscellaneous openings, filters, fans, contaminant sources, contaminant physical properties, rooms, and HVAC systems.

NBSAVIS Interface Structure

Main Menu

| Edit | Create | Save | Calculate | Change Parameters | Quit |

- File Name ?
- As File ?
- As File ?
- Save ?
- Calculate ?
- Dos ?

Main Input Menu

| Building Description | Type Library Decription | Contaminant Data | Type Library Data | HVAC System Data | Building Physical Data | Return to Main Menu |

Building Description:
- Name
- Tightness Test Results
- Roof Height
- Number of Contaminants
- Number of Rooms
- Number of HVAC Systems

Type Library Decription:
- Number of
- Type of
- Ext Walls
- Ext Doors
- Windows
- Mis Openings
- Int Walls
- Int Doors
- Passage
- Fans
- Filter
- Sources
- Reactions
- Surfaces

Contaminant Data:
- Name
- Molecular Weight
- Activity
- Units

Type Library Data:
- Exterior Walls
- Exterior Doors
- Windows
- Interior Walls
- Interior Doors
- Passages
- Miscellaneous
- Fans
- Filters
- Sources
- Reactions
- Surfaces

HVAC System Data / Building Physical Data:
- Room Data
- Area
- Height above ref.
- Height
- Temperature
- Reaction #
- Ext Walls
- Int Walls
- Returns
- Supplies
- Sources

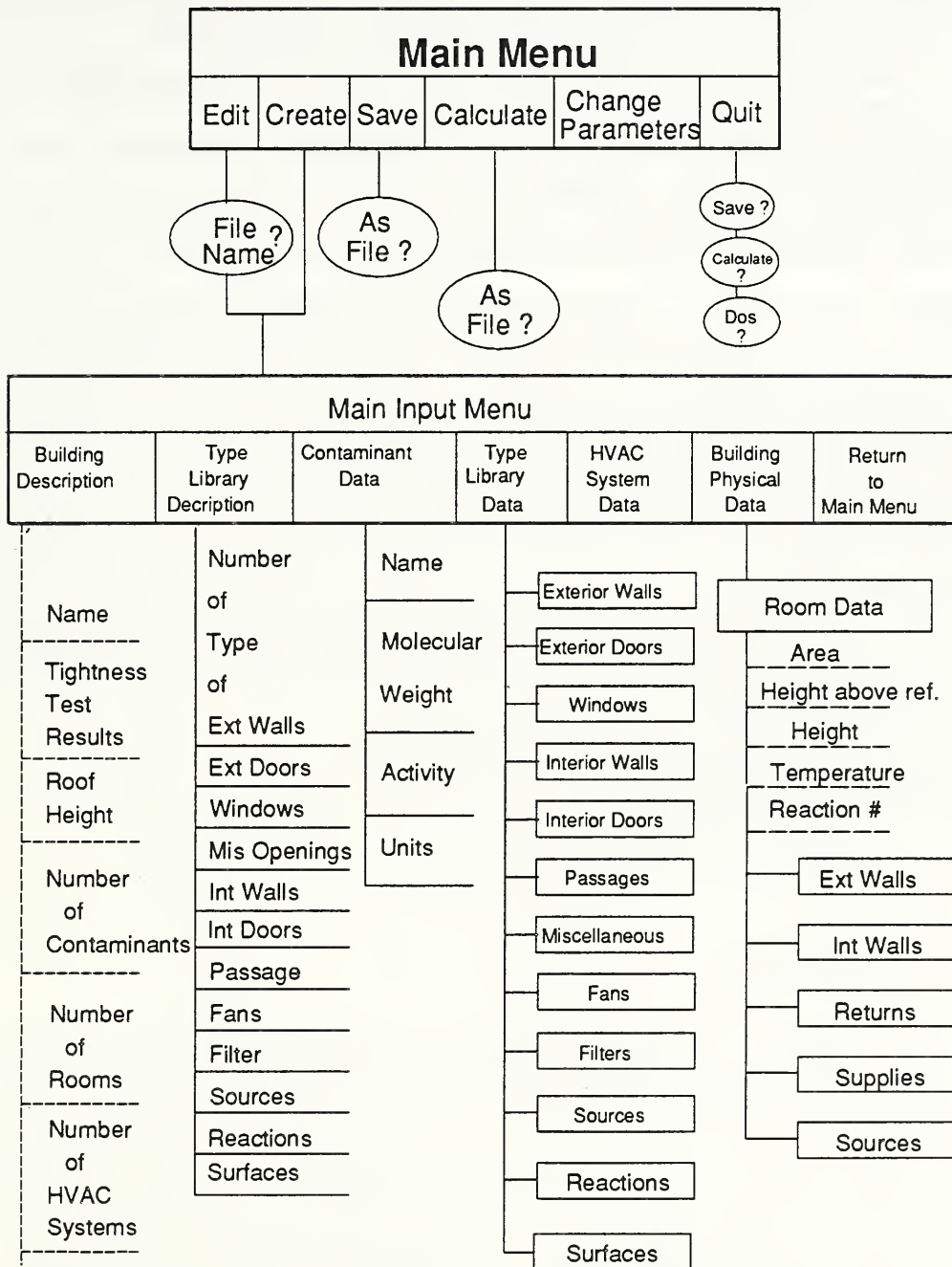Figure 2. **NBSAVIS** Interface Structure

For **NBSAVIS**, a building consists of rooms and HVAC systems. Rooms can be actual building rooms, hallways, basements, garages, porches and in general any physical volume. Rooms have physical properties, contaminant sources, HVAC system connections, exterior walls and interior walls. Exterior walls, interior walls and HVAC connections contain the flow paths for air and contaminants. Exterior walls consist of an opaque wall area, exterior doors, vents, windows, intake fans and exhaust fans. Interior walls consist of an opaque wall area, interior doors, open passages, vents, exhaust fans and intake fans. An exterior wall points to the outside, an interior wall points to a previously defined adjacent room. Ceilings, floors and roofs are input as walls.

Although **NBSAVIS** was designed as a preprocessor for small buildings, there is no restriction as to building size. Stairwells, elevator shafts, exhaust shafts, return air shafts, and supply shafts can be modeled using **NBSAVIS** and **CONTAM88** by considering such features to be rooms.

The specific leakage data, contaminant source data and fan flow rates are specified in a library of building component types, including exterior walls and doors, windows, interior walls and doors, open passages, miscellaneous types, vents, fans, filters, and contaminant sources. An actual building part is described by specifying its component types. Given such information on the construction of the building and the location of contaminant sources, **NBSAVIS** can construct an idealization of the building in terms of flow paths, zones and contaminant generation rates required to perform airflow and contaminant dispersal analysis consistent with the physical description of the building.

2.1 Building Description

It is recommended that the following information be included when running **NBSAVIS**:

1. The name of the building.
2. Results of a building pressurization test if available:
   a. total building leakage;
   b. total building flow exponent.

The following information is required:

3. Roof height.
4. Number of rooms.
5. Number of contaminants.
6. Number of HVAC systems.

The name of the building is used as a label for the project; it improves the readability of the results. If a value of the total building leakage is given, **NBSAVIS** (see Section 2.4.1.1) can use it to calculate the flow resistance through paths in the building envelope. This is accomplished by defining an exterior wall type (see Section 2.2.1) with a negative leakage area, or using a negative exterior wall type number in specifying the type of the exterior wall (see Section 2.3.1.1). The roof height is the height at which the wind speed is calculated by **CONTAM88**. **CONTAM88** assumes that the wind speed is specified at a height of 10 m, typical of data from a meteorological station. The number of rooms of the building is the number of physical volumes which can be considered separate well mixed zones. Attics, garages, halls, stairwells, porches are considered rooms by **NBSAVIS**. At least one room must be specified. The number of contaminants must be specified. If it is specified as zero,

only air movement will be analyzed by **CONTAM88**. The number of HVAC systems is the number of independent warm air HVAC systems the building has. None need be specified if the building does not have one, or if air flow through, and contaminant dispersal by the air handling system are negligible (usually an inaccurate assumption).

2.2 Contaminant Data

If a contaminant dispersal or indoor air quality analysis of the building is desired, the physical properties of the contaminants must be specified. The data required by **NBSAVIS** for each contaminant are:

1. Contaminant name.
2. Molecular weight or specific density.
3. Radioactive decay constant.
4. Concentration units.

The name of the contaminant is used as a descriptor for the input of contaminant source and sink data. The internal concentration units used by **NBSAVIS** and **CONTAM88** are kilograms of contaminant per kilogram of air (or for **NBSAVIS**, in English units, lbs of contaminant per lb of air). However the program allows the input of data using more conventional units if the molecular weight (or density) of the contaminant is specified. If the contaminant is radioactive, such as radon and its daughters, the specification of the activity (the substance's decay constant in s^{-1}) allows the use of normal radioactive units such as Bq/m^3 or pCi/l. Table 1 contains the radioactive decay constants for radon and its daughters. Table 2 gives the contaminant concentration units which **NBSAVIS** supports.

Table 1. Radioactive Decay Constants for Radon and its Daughters

^{222}Rn	$2.1 \cdot 10^{-6} \, s^{-1}$
^{218}Po	$3.6 \cdot 10^{-3} \, s^{-1}$
^{214}Pb	$4.31 \cdot 10^{-4} \, s^{-1}$
^{214}Bi	$5.86 \cdot 10^{-5} \, s^{-1}$
^{214}Po	$4.23 \cdot 10^{3} \, s^{-1}$

Table 2. Concentration Units Supported.

SI		non-SI	
per unit mass of air	per unit volume of air	per unit mass of air	per unit volume of air
kg/kg	kg/m^3	lb/lb	lb/ft^3
g/kg	g/m^3	g/lb	g/ft^3
mg/kg (ppm))	mg/m^3	mg/lb	mg/ft^3
μg/kg (ppb))	μg/m^3	μg/lb	μg/ft^3
ng/kg	ng/m^3	ng/lb	ng/ft^3
m^3/kg	m^3/m^3	ft^3/lb	ft^3/ft^3
L/kg	L/m^3	L/lb	L/ft^3
mL/kg	ppm (mL/m^3)	mL/lb	ppm
μL/kg	ppb (μL/m^3)	μL/lb	ppb
Bq/kg	Bq/m^3	pCi/lb	pCi/L

2.3 Type Component Library Data

The program **NBSAVIS** uses a building specific library of leakage types, filters, and fans.
The purpose of the library is to allow the same building component to be used in various
parts of the building without repeatedly inputting data which describes the component. The
type library contains the physical and leakage data for exterior walls, exterior doors,
windows, interior walls, interior doors, open passages (large openings), miscellaneous
leakages (vents), fans, contaminant filters, contaminant sources, kinetic reactions, and
exterior surfaces. One only needs to specify the type and number of components for which
one is preparing a description. For example, the north exterior wall of the master bedroom of
a building is of exterior wall construction type 1, has one exterior door of exterior door type
3, two exterior windows of window type 1, no vents, no exhaust fans and no intake fans. The
master bedroom has two contaminant sources, one of type 2, which is a kerosene heater and
another of type 3, which is an air freshener.

To create the type library, one must give the number of each type to be included in the
library. The data required for the specification of the type libraries are:

1. Number of exterior wall types in the building.
2. Number of exterior door types in the building.
3. Number of window types in the building.
4. Number of interior wall types in the building.
5. Number of interior door types in the building.

6. Number of open passage way types.
7. Number of miscellaneous leakage types.
8. Number of filter types.
9. Number of fan types.
10. Number of contaminant source/sink types.
11. Number of exterior surfaces.
12. Number of kinetic reactions.

It is not important to enter the exact number of each type. **NBSAVIS** has the capability to insert or delete type records. However if the number of a type is zero, one cannot enter the menu for inputting data for that type. The following contains a description of the data required for each library type.

2.3.1 Exterior Wall Types

The leakage through the exterior walls of the building is specified by the data in the exterior wall type library. The data required for an exterior wall type are:

1. Specific leakage per unit area.
2. Flow exponent.

The leakage specified for an exterior wall type is the leakage of the opaque wall area not including exterior doors, windows, vents or fans in the wall. If no doors, windows, vents or fans are specified, this is the total leakage through the wall per unit area.

Negative values of the specific leakage have a special meaning. They signify a wall with an unknown leakage which is determined from the specified total building leakage by weighting the wall area in proportion to the absolute value of the specific wall leakage. For example if one specifies a wall type with a specific leakage of -1.0, then another wall type with a specific leakage of -2.0 will be considered twice as leaky and one with a specific leakage of -0.5 half as leaky.

If the leakage through the opaque wall area is negligible, but there are other specified leakage paths in the wall, then an exterior wall type with zero specific leakage should be defined.

2.3.2 Exterior Door Types

The physical and leakage properties of exterior doors are contained in the exterior door type library. The data required for an exterior door type are:

1. Height of door.
2. Area of door.
3. Door leakage.
4. Door flow exponent.

The door leakage is the total leakage through the door (not the leakage per unit area). Doors are considered positioned in an exterior wall from the base of the exterior wall to the height of the door.

2.3.3 Window Types

The properties for the windows in the building are stored in the window type library. The data required for a window type are:

1. Height of top of window above the wall base.
2. Height of bottom of window above the wall base.
3. Area of window.
4. Window leakage.
5. Window flow exponent.

The window leakage is the total leakage through the window (not the leakage per unit area). The window is considered positioned in an exterior wall from a height of the bottom above the wall base to the height of the top above the wall base. If the same window is positioned at two different heights relative to the wall base, then two window types must be defined.

2.3.4 Interior Wall Types

The properties of an interior wall which determine its air leakage are contained in the interior wall type library. The data required for an interior wall type are:

1. Specific wall leakage per unit area.
2. Wall leakage exponent.

The specific wall leakage is the leakage through the opaque wall area excluding interior doors, open passages and any miscellaneous leakage types in the wall. If none of these types are specified for the interior wall, this leakage represents the total leakage of the wall. If the leakage is specified as zero, then the air flow through the wall occurs only through the interior doors, open passages and miscellaneous openings in the wall.

2.3.5 Interior Door Types

The leakage characteristics of closed interior doors are specified in the interior door type library. The data required for a interior door type are:

1. Interior door leakage.
2. Door leakage exponent.
3. Door height.
4. Door area.

The interior door is considered located in the interior wall from the wall base to a height equal to the height of the door above the wall base.

2.3.6 Open Passage Types

Large openings are treated as open passages by **NBSAVIS**. The library of open passage types contains the physical data defining open passages. The data required for an open passageway are:

1. Open passage height.
2. Open passage width.

An open passageway is a large opening in an interior wall, for example an open doorway. **NBSAVIS** treats an open passageway as two openings in order to model the airflow through large openings due to temperature differences across the opening.

2.3.7 Miscellaneous Leakage Types

Miscellaneous leakage paths are contained in the miscellaneous leakage type library. They are mainly used in **NBSAVIS** to model the air leakage though vents, though they can be used to model other types of leakage paths which do not fit any of the other categories, for example vents in interior or exterior walls. The data for a miscellaneous leakage type are:

1. Leakage.
2. Leakage exponent.
3. Total area.
4. Height above wall base.

2.3.8 Fan Type

The flow characteristics of fans are included in the fan type library. The data required by a fan type are:

1. Fan flow rate.
2. Fan cross-sectional area.

A fan type represents a constant specified flow from or to the exterior such as the flow generated by a supply intake fan or an exterior exhaust fan; from or to an interior space; or from or to the building HVAC system, such as the flow into a return air register or from a supply register.

2.3.9 Filter Type

The properties of air filters are defined in the filter type library. The data required for a filter type are:

1. Filter efficiency for each contaminant.

The filter efficiency is the single pass efficiency of the filter, that is, it is the fraction of contaminant (between 0.0 and 1.0) removed in a single pass through the filter. Though **CONTAM86** and **CONTAM87** allow filter efficiency to be specified with any flow, **NBSAVIS** allows filters to be specified with only fan flows. Individual room filtering devices can be modeled as a contaminant source type (see below).

2.3.10 Contaminant Source Type

The source emissions and sink removal rates of contaminant species by materials, appliances or activities in a building are specified in the contaminant source type library.

NBSAVIS can treat point or area sources, contaminant removal by deposition or plateout, materials emissions such as formaldehyde from pressed wood products which are governed by diffusion across a surface layer, and pressure driven sources. The data required for each contaminant source type are:

1. Generation rate.
2. Deposition flow rate (removal rate, cutoff concentration).
3. Whether the source is a point source or area source.
4. Units of source strengths.
5. Whether the source is pressure driven.

A contaminant sink can be modeled as a source with a negative generation rate. The generation rate is the amount of contaminant generated per unit time in units selected by Item 4. The deposition flow rate is intended to model several phenomena: diffusion-limited sources for volatile and semi-volatile contaminants such as formaldehyde emissions from pressed wood products, and plateout of a contaminant on surfaces or removal of a contaminant by a room air filtering device. In general, the source generation rate is given by an equation of the form:

$$S = G - D \cdot C$$

where S is the contaminant source strength, G is the generation rate, D is the deposition velocity and C is the concentration.

There are several common forms for the source equation depending on the contaminant being modelled. These can be specified by the user by selecting the units of G, D and C. For volatile organic compounds, the source equation is sometimes expressed in the form:

$$S = G\left(1 - \frac{C}{C_{cutoff}}\right)$$

where C_{cutoff} is the cutoff concentration at which point emission ceases. This form of the equation is specified by selecting the cutoff option in the unit selection for the deposition velocity. The units of the cutoff concentration are the same as the currently specified units of the contaminant concentration. Note that units of mass per unit time are used internally. Therefore, it is possible to input the cutoff concentration in one set of units and have **CONTAM88** report the results of the simulation in another set of units.

A room filtering or air cleaning device can be modeled by defining a source type with $G = 0.0$ and $D = f \cdot e$ where f is the flow rate of the room air filter and e is the single pass removal efficiency of the device.

Pressure driven flows are intended to model contaminant sources which are governed by the inside-outside pressure difference, such as radon or soil gas entry into a basement. In this case the source equation is

$$S = G \cdot (\Delta p)^n$$

NBSAVIS supports a variety of units for contaminant source strengths, as shown in Table 3.

Table 3. Source Strength Units

SI	non-SI
kg	lb
g	g
mg	mg
μg	μg
ng	ng
m^3	ft^3
L	L
mL	mL
μL	μL
Bq	pCi

The time units of the emission rate of the source are shown in Table 4.

Table 4. Time Units for Emission Rates

second (s)	minute (min)	hour (h)

For an area source, the emission rate is per unit area. For a pressure induced source the emission rate is per Pa^n in SI units or per $in.^n$ of water in English units.

2.3.11 Exterior Surfaces

The data required to describe an exterior surface are:

1. Number of surface coefficients.
2. The values of the surface pressure coefficients.

These data are used by **CONTAM88** to calculate the wind pressures on an exterior wall. If no exterior surface is specified for the exterior wall, a default algorithm is used.[6] The pressure coefficients must be referenced to a wind speed at the height of the building. Examples of representative wind pressure coefficients are given in Appendix A.

2.3.12 Kinetic Reactions

CONTAM87 and **CONTAM88** allow for chemical reactions among the contaminants. The coefficients specified must be consistent with the units specified for the contaminants. Internally, **NBSAVIS** and **CONTAM88** use units of kg contaminant/kg air. The production or destruction of a contaminant are given by:

$$R_\alpha = \sum_{\beta=1}^{N} \kappa_{\alpha\beta} C_\beta$$

where $\kappa_{\alpha\beta}$ are the reaction rate coefficients. **NBSAVIS** and **CONTAM88** use the convention that positive reaction coefficients produce an increase in contaminant concentration (**CONTAM87** uses the opposite definition: positive coefficients produce a decrease in contaminant specie concentration).

An example of a kinetic reaction element is the Jacobi model for radon and its attached and unattached daughters:

$$\begin{bmatrix} R_0 \\ R_1^u \\ R_2^u \\ R_3^u \\ R_1^a \\ R_2^a \\ R_3^a \end{bmatrix} = \begin{bmatrix} -\lambda_0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \lambda_1 & -(\lambda_1+\lambda_a) & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda_2 & -(\lambda_2+\lambda_a) & 0 & p_1\lambda_2 & 0 & 0 \\ 0 & 0 & \lambda_3 & -(\lambda_3+\lambda_a) & 0 & 0 & 0 \\ 0 & \lambda_a & 0 & 0 & -\lambda_1 & 0 & 0 \\ 0 & 0 & \lambda_a & 0 & (1-p_1)\lambda_2 & -\lambda_2 & 0 \\ 0 & 0 & 0 & \lambda_a & 0 & \lambda_3 & -\lambda_3 \end{bmatrix} \begin{bmatrix} A_0 \\ A_1^u \\ A_2^u \\ A_3^u \\ A_1^a \\ A_2^a \\ A_3^a \end{bmatrix}$$

where A_0 is the activity of radon, A_i^u and A_i^a (i=1 to 3) are the activities of the unattached and attached daughters of radon (Polonium-218, Lead-214 and Bismuth-214). In the above matrix, λ_i (i=0,3) are the decay constants for the daughters given in Table 1, λ_a is the attachment rate for radon to an aerosol (approximately 5 to 500 h^{-1}), and p is the recoil probability of an attached daughter to escape an aerosol (approximately 0.55).

2.4 Physical Building Data

The physical building data are the data required to describe a building in terms of its physical components. A small building is considered to be composed of rooms and HVAC systems. The rooms and HVAC systems are the well-mixed zones of the flow and contaminant dispersal analysis idealization which **NBSAVIS** creates. Attics, basements, halls, stairways, garages, porches etc are considered to be rooms. Rooms are connected to the HVAC systems through room supplies and returns, to other rooms through interior walls and to the exterior through exterior walls. These connections are the flow paths through which contaminants and air move throughout, into and out of the building. Rooms also have contaminant sources and sinks which generate or remove contaminants.

2.4.1 Room Data

The data required to describe a room are:

1. Room floor area.
2. Room height.
3. Height of room floor above reference.
4. Room temperature.
5. Number of exterior walls.
6. Number of interior walls.
7. Number of contaminant sources.
8. Number of returns.
9. Number of supplies.
10. Kinetic reaction number.
11. Interior zone.

The room floor area is the area which is multiplied by the room height to give the room volume. The room volume important for contaminant dispersal analysis. In case of a non-rectangular room, one should choose the room height as the maximum floor to ceiling height of the room and choose the room area such that the product of the room area and the room height give the correct room volume.

The height of the room floor above reference is the vertical distance of the floor of the room above an arbitrary ground reference plane. This height is used to calculate the room reference height for the stack effect. It is best to select the reference plane as the lowest point of the intersection of the ground and the building, though this is not necessary. For rooms below the reference plane (below grade), the height of the room above reference is negative. In the case in which the room has a pressure-induced contaminant source, the height of the room above reference is the height at which the pressure difference between the room and the exterior is calculated.

The number of exterior walls, number of interior walls, number of contaminant sources, number of returns and the number of supplies should be a number greater than zero if the room has one of these features. Though it is better to input the exact number, once one enters a number greater than 0, one can enter the input menu for the feature and add or delete items. Note: if a list of these features exists for the room, then these numbers cannot be changed except by entering the input menu for the feature and adding or deleting the specific feature.

The kinetic reaction number is the number of the kinetic reaction appropriate for the room. If no kinetic reactions occur in the room, a zero should be entered. A list of the name of possible kinetic reactions is displayed in a window in the lower right hand corner of the screen. This list can be scrolled to display the name of the appropriate kinetic reaction.

The interior zone parameter is a boolean value (yes/no) which indicates whether a zone is to be considered as an interior conditioned zone in the calculation of the total building air infiltration and exfiltration rates by CONTAM88. For example attics and garages are not usually considered interior zones.

2.4.1.1 Exterior Wall Data

An exterior wall is described by specifying the following data:

1. Exterior wall type number.
2. Width of wall.
3. Exterior surface number.
4. Orientation of wall.
5. Tilt angle.
6. Height of the wall.
7. Lowest height above room floor.
8. Number of windows.
9. Number of exterior doors.
10. Number of vents.
11. Number of outside supply fans.
12. Number of exhaust fans.
13. Surface number.

The exterior wall type number is the number specifying the construction class of the opaque part of the exterior wall from the types of exteriors walls for the building. A window in the lower part of the screen displays the possible type names. This window can be scrolled to display the desired type number. It is possible to enter the input routine for exterior wall types directly from the exterior wall data input routine. This allows one to examine the data for each exterior wall type or add a new exterior wall type. It is not possible to delete an exterior wall type without exiting the exterior wall data menu and the room input menu and entering the type library menu. A zero exterior wall type number signifies an exterior wall which has no leakage through its opaque wall area (it may have leakage through windows, doors, etc). A negative type number signifies an exterior wall whose opaque wall leakage is determined from whole building tightness test data using a weighting factor of 1.0.

The orientation of the exterior wall is the angle from north of the wall's exterior normal (north: 0°, east: 90°, south: 180°, west: 270°). The tilt angle is the angle of the exterior normal of the wall above horizontal (0° for a vertical wall, 90° for a horizontal wall). The number of the exterior surface is the number of the surface type containing the appropriate pressure coefficients. If the number of the exterior surface is zero, then a default algorithm is used to calculate surface coefficients. The tilt angle is not used when the exterior surface number is not zero.

The height of the wall is the distance of the plane of the wall from its lowest point to its highest point. The width of the wall is the distance by which the height is multiplied to give the area of the wall. It is the area that is used to calculate flows and leakages. Therefore, for non-rectangular surfaces, the width should be adjusted so that the correct area is produced. For a horizontal surface, there is no distinction between the width and the height. It is only necessary that their product give the wall area. The lowest height above the room floor is the minimum vertical distance from the surface to the height of the room floor above the building reference plane.

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An exterior wall can have additional components which permit air flow. There are exterior doors, windows, vents (or miscellaneous openings), outside supply fans and outside exhaust fans. The existence of such flow paths in the wall is indicated by entering an integer greater than zero in the appropriate menu location. This number indicates the number of different types of each component flow path for the wall. Again, the initial number is not important, as it can be adjusted by adding or deleting components in the list. Once the list of components has been created, then it can be changed only by entering the component input routine and using the insert and delete mode for the component.

A roof, ceiling or floor is considered an exterior wall if it is part of the building envelope.

The surface number is the number of the exterior surface type (see Section 2.3.11) which contains the wind pressure coefficients for the exterior wall. If the surface number is specified as zero, a default algorithm is used by **CONTAM88** to calculate the surface pressure coefficients.

2.4.1.1.1 Window Data

The data required for a window are:

1. Window type number.
2. Number of windows.

The window type names are displayed in a window on the screen. This list can be scrolled till the appropriate window type name is displayed. The number of windows refers to the specified type in the exterior wall. It is possible to enter the window type menu directly to examine and modify window type data. However it is not possible to delete a window type without exiting the building physical description menu and entering the type library menu.

2.4.1.1.2 Exterior Door Data

The data required for an exterior door are:

1. Exterior door type number.
2. Number of exterior doors.

The exterior door type names are displayed in a window on the screen. This list can be scrolled till the appropriate exterior door type name is displayed. The number of exterior doors refers to the specified type. It is possible to enter the exterior door type menu directly to examine and modify exterior door type data. However it is not possible to delete an exterior door type without exiting the building physical description menu and entering the type library menu.

2.4.1.1.3 Vent Data

The data required for a vent or miscellaneous opening are:

1. Miscellaneous opening type number.
2. Number of vents.

The miscellaneous opening type names are displayed in a window on the screen. This list can be scrolled till the appropriate miscellaneous opening type name is displayed. The number of vents is the number of miscellaneous openings of the specified type. It is possible to enter the miscellaneous opening type menu directly to examine and modify data. However it is not possible to delete a type without exiting the building physical description menu and entering the type library menu.

2.4.1.1.4 Outside Supply Fan Data

The data required for an outside supply fan are:

1. Fan type number.
2. Number of fans.

The fan type number is the type number of the fan in the list of fan types. A window on the screen displays a list of fan type names. This window can be scrolled until the appropriate fan type name is shown. It is possible to directly enter the type fan input routine to modify or add fan type data.

Outside supply fans are intended to model fixed flows of air from the outside.

2.4.1.1.5 Exhaust Fan Data

The data required for an exhaust fan are:

1. Fan type number.
2. Number of fans.

See Section 2.4.1.1.4 for an explanation.

Exhaust fans are intended to model fixed flows of air from the room to the exterior.

2.4.1.2 Interior Wall Data

The data which specify an interior wall are

1. Interior wall type number.
2. Width.
3. Adjacent room number.
4. Lowest height above room floor.
5. Height of wall.
6. Number of interior doors.
7. Number of open passages.

8. Number of vents.
9. Number of exhaust fans to adjacent room.
10. Number of intake fans from adjacent room.

The interior wall type number is the number of the interior wall type determining the properties of the opaque part of the wall. An interior wall type number of zero signifies that there is no leakage through the opaque wall area and that all leakage occurs through the components of the interior wall. This has the same effect as assigning the wall to a type whose specific leakage is 0.0. A list of interior wall type names is displayed in a window on the screen. This list can be scrolled to display the name of the appropriate interior wall type.

The width of the wall should be chosen so that the product of the width and the height gives the wall area.

The adjacent room number is the number of the room on the other side of the interior wall. A list of admissible room numbers and the corresponding room name are displayed in a window on the screen. This list can be scrolled and contains the numbers and names of all rooms whose number is less than the room to which the interior wall belongs. This convention prohibits double entry of the interior wall's flow paths.

The components of an interior wall which can allow air flow and leakage are interior doors, open passageways, vents (or miscellaneous openings), exhaust fans to other rooms and intake fans from other rooms. If the interior wall possesses one of these classes of flow paths, a number greater than zero should be entered, though as before it is better to enter the exact number. If the list of these flow components is non-empty, the number of the components can be modified only by entering the list input menu and inserting a new component or deleting an existing component.

A ceiling or floor not part of the building envelope is considered an interior wall.

2.4.1.2.1 Interior Door Data

The data required for an interior door are:

1. Interior door type number.
2. Number of interior doors.

The interior door type names are displayed in a window on the screen. This list can be scrolled till the appropriate interior door type name is displayed. The number of interior doors is the number of interior doors of the specified type. It is possible to enter the interior door type menu directly to examine and modify interior door type data. However it is not possible to delete an interior door type without exiting the building physical description menu and entering the type library menu.

2.4.1.2.2 Open Passage Data

The data required for an open passageway are:

> 1. Open passage type number.
> 2. Number of passages.

The names and number of the miscellaneous opening types are displayed in a window which can be scrolled. As with other types, it is possible to enter the miscellaneous type input menu directly to examine or modify (but not delete a type) the type data.

An open passage is located in the plane of the wall from the base of the wall to a height equal to the height of the open passage. If it is desired to have an opening whose lowest point is above the floor, the wall should be divided into two vertical parts and the open passage placed in the top part.

2.4.1.2.3 Vent Data

The data required for a vent or miscellaneous opening are:

> 1. Miscellaneous opening type number.
> 2. Number of vents.

See Section 2.4.1.1.3 for an explanation.

2.4.1.2.4 Intake Fan Data

The data required for an intake fan are

> 1. Fan type number.
> 2. Number of fans.

See Section 2.4.1.1.4 for an explanation.

2.4.1.2.5 Exhaust Fan Data

The data required for an exhaust fan are

> 1. Fan type number.
> 2. Number of fans.

See Section 2.4.1.1.4 for an explanation.

2.4.1.3 Contaminant Source Data

The data required for a room contaminant source are:

> 1. Contaminant source type number.
> 2. Number of sources in room.
> 3. Area of each source.

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The contaminant type number is the type number of the appropriate contaminant source. A list of defined contaminant sources is displayed in a window that can be scrolled to display the name and number of the desired source.

The source strength for an individual room is the product of the source strength of the contaminant source type, the area of the source and the number of sources in the room. If either the number of sources or the area of the source is non zero and the other quantity is zero, the other quantity is set to unity when calculating the room source strength. For pressure-induced sources, the exponent is not scaled.

2.4.1.4 Room HVAC Return Data

The data required for a HVAC return connection are:

1. HVAC system number.
2. Fan type number.
3. Filter type number.
4. Number of returns in room.
5. Height above floor.

The HVAC system number is the number of the HVAC system to which the return is connected. An appropriate list of defined HVAC systems is displayed.

The fan type number is the fan type which gives the flow into the HVAC system through the return. A list of defined fan types is displayed on the screen.

The flow of the fan type is multiplied by the number of returns in the room to produce the total return flow to the specified HVAC system.

The filter type number is the type number of any filter installed in the return air flow from the room. A filter type number of zero indicates that no filter is present. A list of defined filters is shown on the screen.

The height above the floor of the return register is not used.

2.4.1.5 Room HVAC Supply Data

The data required for the supply registers in the room are:

1. HVAC system number.
2. Fan type number.
3. Filter type number.
4. Number of supplies in room.
5. Height above floor.

The comments given in Section 2.4.1.4 hold equally for HVAC supply registers.

2.5 HVAC System Data

The HVAC systems of a building are defined by the following data:

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1. Volume of HVAC system.
2. Number of contaminant sources in HVAC system.
3. Kinetic reaction number.

The volume of the HVAC system is the physical volume of all the return and supply ducts of the system. If a zero volume is assumed, the contaminant dispersion equations for the duct system are treated in a steady state manner. It should be noted that giving the duct system a very small nonzero value can lead to stiff systems of equations which require very small time steps. A zero volume will alleviate this problem.

As for a room, a HVAC system can have contaminant sources/sinks and kinetic reactions. See Section 2.4.1.

2.6 Program Parameters

The program parameters which can be selected by the user are: SI or English units, leakage specified as a leakage area or a flow coefficient, and flow specified as a mass flow rate or a volumetric flow rate. There are also four basic parameters which the user can change: the height above sea level, the leakage area reference pressure, the reference temperature for flow measurements and the discharge coefficient used to define leakage area. The height above sea level is used to calculate the barometric pressure at which air density calculations are made. The reference temperature is the standard temperature at which volumetric flow rates are referenced.

2.7 General Keyboard Key Description

The program **NBSAVIS** uses screen originated input, that is, what is entered by the keyboard is displayed on the screen, but is not read by the program till certain keys are pressed.

The following keys do not end input:

Del: deletes character under the cursor

Ins: Toggles between insert mode and overtype mode. If in insert mode, the message "insert" is displayed on line 1 in reverse video. In the insert mode, the typed characters are inserted before the character under the cursor and all characters after the cursor are shifted to the right.

←: Moves cursor one position to the right

→: Moves cursor one position to the left

The following keys end a field input

←:
Accept data in field and move to next screen entry point.

→ or Shift-Right:
Accept data in field and move to field to right. If there is no field to the right, move down.

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⬅ or ⌈Shift-Left⌉:
Accept data in field and move to field to left. If there is no field, move up.

⬇:
Accept data in field and move to field below current field. If there is no field below current field, go to top field.

⬆:
Accept data in field and move to field above current field. If there is no field above current field, go to bottom field.

⌈Esc⌉:
Accept input and terminate input to list of records or terminate current menu.

⌈PgUp⌉:
Accept data field, end input to current record and start input to previous record in current list of records.

⌈PgDn⌉:
Accept data, end input to current record and start input to next record in current list of records.

⌈F1⌉-⌈F10⌉,⌈Shift-F1⌉:
Accept data field and perform action per menu instructions such as delete current record, insert a new blank record after the current record, enter a specific submenu, scroll an information display. ⌈F1⌉ Usually deletes the current record and all records which depend on the current record. For example delete an exterior wall type record deletes all exterior walls which have that type number. ⌈F2⌉ Usually inserts a new record and renumbers all references to records above the current record.

2.8 Files Produced by NBSAVIS

For a given project name (PROJECT), **NBSAVIS** produces the following files in the current directory:

PROJECT.DSC:
The building description file for the project (produced by the save command).

PROJECT.ZON:
The building zone data file.

PROJECT.OPN:
The leakage path data file.

PROJECT.FAN:
The fan data file.

PROJECT.ZLB:
Labels describing each zone.

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PROJECT.LOP:
Labels describing each leakage path.

PROJECT.FLB:
Labels describing the fan flows.

PROJECT.KIN:
Kinetic reaction data file.

PROJECT.SUR:
Surface pressure coefficients data file.

PROJECT.CTN
Contaminant Data File.

The file PROJECT.DSC is the data file created by NBSAVIS to provide a description of the building. The files PROJECT.ZON, PROJECT.OPN, PROJECT.FAN and PROJECT.CTN are required by **CONTAM88** to perform the air flow and contaminant dispersal analyses. The files PROJECT.ZLB, PROJECT.LOP and PROJECT.FLB are description files describing each zone, opening or fan. They are not currently used by **CONTAM88**; however it is worthwhile to study these files to assure that the idealization of the building in terms of zones, leakage paths and flow paths is what one intended.

Detailed descriptions of the data structure for these files are given in Appendix B.

2.9 Checking Input Data

NBSAVIS does not check input data for consistency or for errors. No warnings are issued, for example, to alert the user that two south-facing walls and no north-facing wall are entered for a room, that only three walls are used to specify a room, or that the width of opposite walls is unequal. (Of course, these inputs may have been intended by the user, but more likely are inadvertent errors.) The user may unintentionally omit specific openings, or enter incorrect numerical values (for example, molecular weights and radioactive decay constants).

The user must enter data cautiously because there is no general way to avoid and find input errors. It is strongly recommended that rooms be duplicated wherever possible using the special room-copying feature of **NBSAVIS**, in order to localize the source of errors to rooms that were entered manually. It is essential that all entered data be checked carefully by closely examining all output files.

2.10 General Data Structure

In general, data for **NBSAVIS** are organized as either global variables or as a field of records in a linked list. Global variables are usually properties of the whole building (such as building height, building leakage area) or govern the way one wishes to input data (SI or English units, leakage area or flow coefficient for leakage properties, mass or volumetric flow rates). Global variables always exist and a value must always be specified or the default value is assumed. Linked lists (**NBSAVIS** uses double linked lists) contain a series of related records. Records in general contain physical properties of items described by the record (for example, an exterior wall type, a room, etc), pointers to the next and previous record in the

list and pointers to the beginning of a list or records describing parts of the physical item described (for example, the exterior walls of a room, the doors and windows of an exterior wall). This data structure has been found to be efficient in describing a building in terms of its parts and the relationship between various components and the parts of the building. It allows for easy insertion or deletion of parts and components and permits a description of the interdependencies among the parts and components. This data structure also corresponds much to the way one physically views a building.
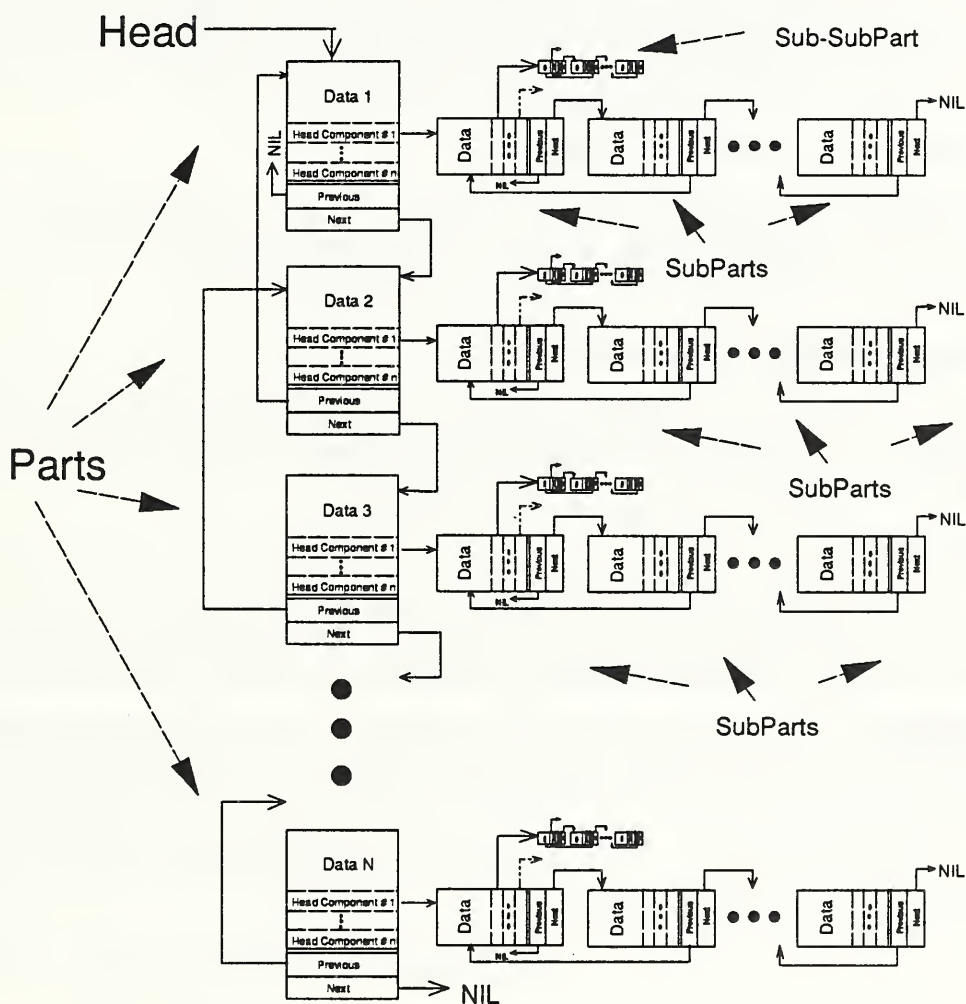
Figure 3. Schematic of Data Structure of NBSAVIS.

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3 Tutorial on the Use of NBSAVIS

This section contains a tutorial on the use of **NBSAVIS** to create a building description. The purpose of this tutorial is to demonstrate the features of NBSAVIS. Though the building descriptions used in this tutorial resemble real buildings, they are not intended to model any particular building or experimental setup.

3.1 Installing NBSAVIS

NBSAVIS requires approximately 380 KB of disk space and 300 KB of main memory to load. It consists of the executable file NBSAVIS.EXE and the overlay file NBSAVIS.OVR. It dynamically allocates memory as required by the building description. For most efficient operation, it should be run from a hard disk.

3.1.1 Dual Floppy Disk System

Place a working disk containing NBSAVIS.EXE in drive A. Copy the file NBSAVIS.OVR on the data disk. Change the current drive to the "B" drive (typing b: ⏎). Place the data disk in drive B. Type "a:NBSAVIS ⏎."

3.1.2 Single Floppy Disk System

A 720-KB, 1.2-MB or 1.44-MB floppy drive is required. Place a working disk with the program NBSAVIS.EXE, NSBAVIS.OVR and the data files in the floppy drive (assumed to be drive A). Type "A: ⏎ NBSAVIS ⏎."

3.1.3 Hard Disk

Copy NBSAVIS.EXE and NBSAVIS.OVR to any directory on the hard disk. Put the directory in the path variable. Create building description directories as desired. Make the desired building description directory the current directory. Type NBSAVIS ⏎.

Note: **NBSAVIS** always looks for building description files in the current directory. Thus placing NBSAVIS.EXE and NBSAVIS.OVR anywhere in the search path and making the current directory (or drive) the data drive will allow the operation of **NBSAVIS** from any directory or drive. If your system has expanded memory, the overlay file NBSAVIS.OVR will be loaded into expanded memory, greatly speeding up the operation of the overlay manager.

3.2 An Exercise Illustrating the Main Features of NBSAVIS

The purpose of this exercise is to develop a feel for the main features of the program **NBSAVIS**. To load the program, type:

NBSAVIS ⏎

or type:

NBSAVIS MONO ⏎

on a LCD screen or if you dislike colors. The NBSAVIS logo screen shown in Figure 4 should appear.
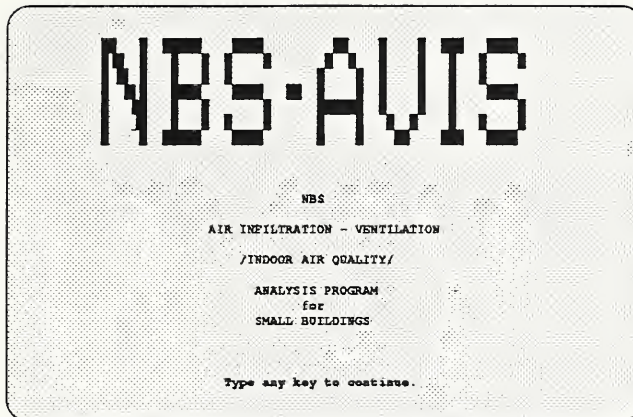
Figure 4. Logo Screen of NBSAVIS

Typing any key produces the main menu screen shown in Figure 5.
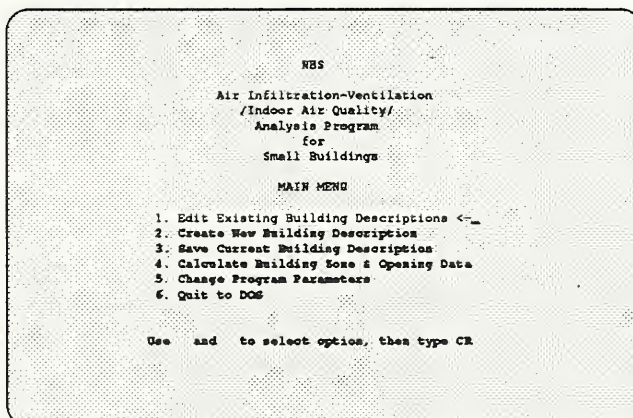
Figure 5. Main Menu Screen of NBSAVIS

Hit the ⊕ several times; the menu selections will be highlighted. A highlighted menu selection is activated by typing ⊖. Press ⊕ until the last main item is highlighted, press ⊕ once more. Notice that the first menu item is highlighted. NBSAVIS's menus and data input operate in this manner: selecting an item after the last item produces the first item in the list. Now press the ⊕ several times. The previous menu item is selected.

Press either ⊕ or ⊕ until the *Edit Existing Building Descriptions* item is highlighted. Press ⊖. The screen shown in Figure 6 will appear.

```
          Input building descripton file name (no extention) : _


                          Building Description Files

     RAD287F.DSC   6/30/90   NBSEXAM2.DSC   6/30/90   AVEC287F.DSC   6/11/90
     AVECF20.DSC   6/09/90   AVEC287.DSC    6/04/90   AVEC287B.DSC   6/01/90
     AVECENGL.DSC  6/01/90   NBSTEST.DSC    4/13/90   NBSEXAM5.DSC   6/30/90
     NBSEXAM4.DSC  6/30/90   NBSEXAM3.DSC   6/30/90   NBSEXAM1.DSC   6/30/90
     NBSEXAM6.DSC  11/17/89
```
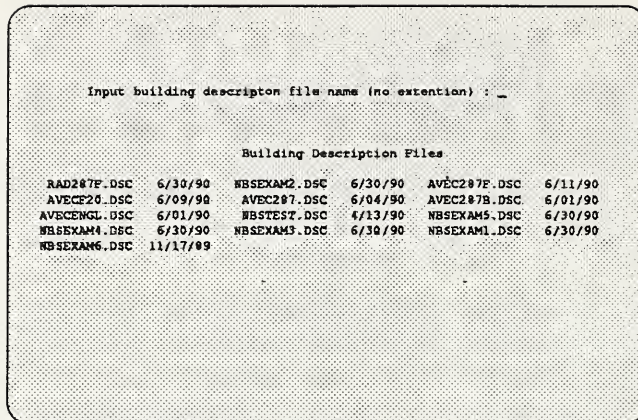
Figure 6. Edit Existing Building Description Menu

The *Edit Existing Building Descriptions* item allows one to edit an existing building description. The results of the editing can be saved either under the name of the original building description or under a new name using the Save Building Description item of the main menu. If one wishes to edit an existing building description, one types the name of one of the building descriptions listed on the screen. To exit the menu without editing an existing building press ⏎ and answer Ⓝ. Do this now to return to the Main menu.

Press either ⬆ or ⬇ until the Create New Building Description is highlighted. Press ⏎. The screen shown in Figure 7 will appear.


```
                            NBS

                 Air Infiltration-Ventilation
                     /Indoor Air Quality/
                       Analysis Program
                             for
                       Small Buildings

                    Main Data Input Menu

                 1. Building Description  <-_
                 2. Type Library Description
                 3. Contaminant Data
                 4. Type Library Data
                 5. HVAC System Data
                 6. Building Physical Data
                 7. Return to Main Menu


        Use     and   to select option, then type CR
```
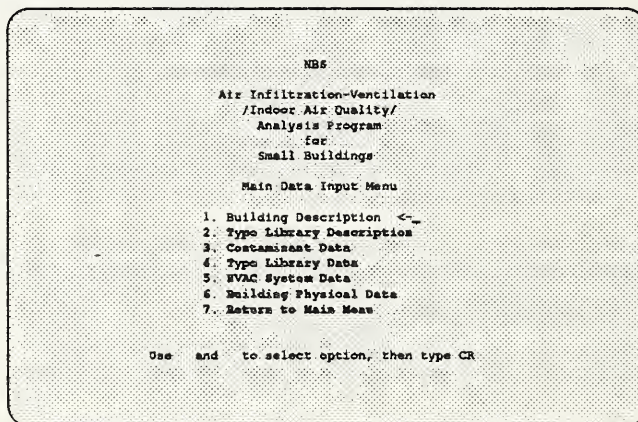
Figure 7. Main Data Input Menu

This is the main input menu. For the creation of a new building description, it is desirable, but not necessary, to create the building description in the order that the items appear in the menu.

Press either ⬆ or ⬇ until Item 1, *Building Description*, is highlighted. Press ⏎. The Building Description input menu will appear, as shown in Figure 8.

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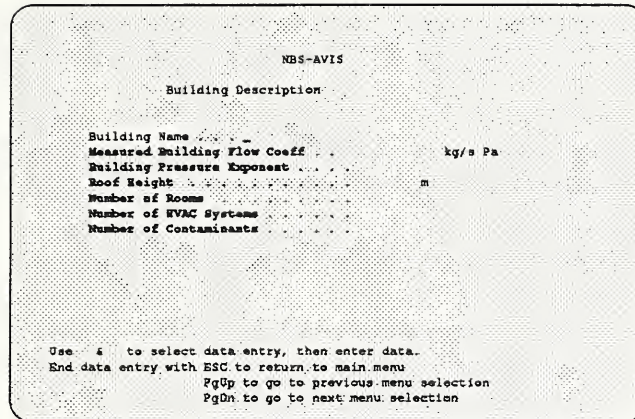
Figure 8. Building Description Menu

This menu accepts the input of the building name, roof height, number of rooms, and building tightness, HVAC system and contaminant data. Three types of input are permitted by NBSAVIS: string (building name), real or floating point (measured building flow coefficient and exponent), and integer (number of rooms, HVAC systems, and contaminants).

In the building name field type:

This is a Practice Session

Press ◄ several times. Note that the cursor moves within the data field. Any character in the data field can be changed by using ► and ◄ to position the cursor in the data field and overtyping the character. To insert data in the field, press (Ins) and type the data to be inserted. Note that the message "INSERT" appears on the screen. Pressing (Ins) again causes the "INSERT" message to disappear and places the input in the overtype mode. In the insert mode, typed characters will be inserted before the cursor. To delete or erase a character, position the cursor over the character and press (Del). Note that the ◄ does not delete characters. To end input, press ◄, ▼ or ▲ to accept the data and stay in the building description menu, or (PgDn), (PgUp) or (Esc) to leave the menu. (Esc) Causes a return to the main menu. (PgDn) Selects the next item of the main input menu (in this case Type Library Description) and (PgUp) selects the previous item of the main input menu (in this case Return to Main Menu since one is at the top of the menu list). When pressing ► and ◄, the bell will sound when one reaches the extremes of the field input region. The bell will also sound when an illegal character or value is entered for integer or real data. For real data, exponents of the form ddd.dde+nn or ddd.de-nn are allowed, where d and n are digits (Note: the decimal point is not required; however if it is used, it must be followed by a digit - a convention of Turbo Pascal; also either an upper or lower case "e" can be used with or without a plus or minus sign following it). If a field is entered which cannot be interpreted as an integer or a real, an error message will appear and the code number of the error displayed. This code number is the position in the field where interpretation of the field caused the error. If this occurs, edit the field. Note that no spaces are allowed in the input between numeric data; however leading or trailing spaces are allowed. Now enter for the roof height "3.0" and "1" for the number of rooms, HVAC systems and contaminants. As explained earlier, a nonzero

number is required to enter the input menus of room data, contaminant data and HVAC system data. This number can be changed by using the insert and delete record feature of the corresponding input menu.

Now press (PgDn) to return to the main input menu. Select the *Type Library Description* item and press ↵. The Leakage Type Descriptions Menu, shown in Figure 9, will appear.
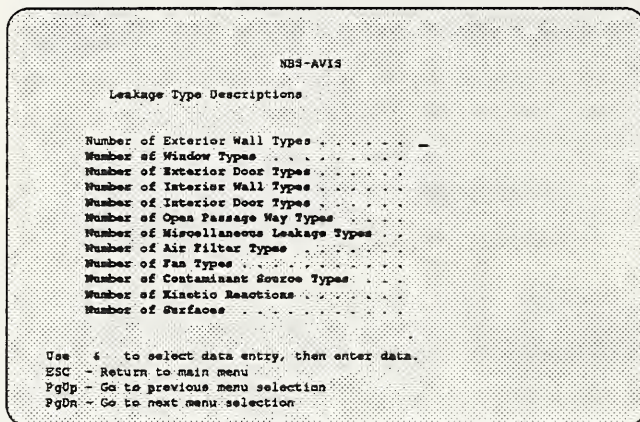
Figure 9. Leakage Type Description Menu

For the purpose of this exercise, enter 1 for each type to permit entry into each input menu. The number of types can be adjusted later by using the insert and delete record feature. Note that as long as one does not enter the input menu of a type, it is possible to re-enter the Type Description Menu and change the number of the corresponding type. Technical note: The type data are stored as a series of double linked lists. If the pointer to one of the series of linked lists is null, the number specifying the number of types can be changed. If the pointer is not null, then the number of items in the list can only be changed by using the insert and delete record feature.

Type (PgDn)↵ to leave the Type Library Description Input Menu.

Use the cursor keys to select the *Contaminant Data* item and press ↵.
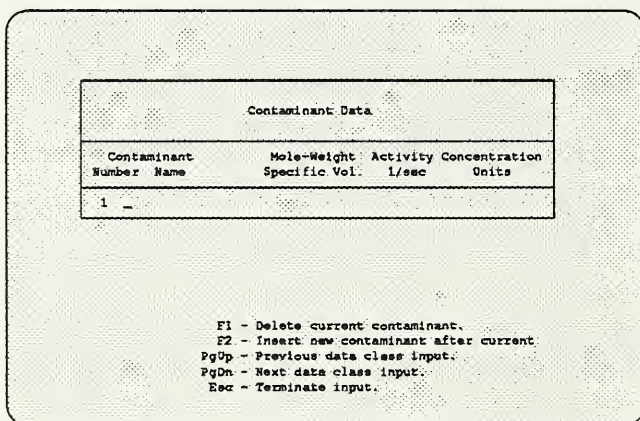
Figure 10. Contaminant Data Menu

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The Contaminant Input Data Menu will appear on the screen. This menu is typical of a list input menu. Each record of data is contained on a line in the data window of the menu. The various items in the data record are shown in the columns of the data window. Enter a name for the contaminant by typing (Formaldehyde)⏎. One is now in the second column of the data window. The second column represents a discrete choice: whether the next column represents the molecular weight or specific volume of the contaminant. Press ⊕ to display and change this value. When MW is displayed type ⏎. Enter the molecular weight of formaldehyde (30.03)⏎. Formaldehyde is not radioactive, so its activity is 0. Press ⏎. Now press ⊖ or ⊕ until the units ppb are displayed. Press ⏎. Press F2 three times. Notice that the data window been expanded and three new contaminant data records are added to the list. Press F1. Note that a data record has been removed from the list. Expand the list of contaminant data records till there are 10 contaminants by repeatedly pressing F2 (seven times if you have been following the exercise exactly). The number of contaminant records is now too big to fit all records in the data window. One can scroll the data in the window by using the ⊕ and ⊕ keys when the cursor is in the last or first line of the data windows respectively. Press these keys several times to observe this effect. Fill in the data for the contaminants in any manner that suites you. Typing names "Contaminant 2," "Contaminant 3," etc., and leaving the other data items at their default value will suffice for this exercise. Delete a few contaminants if you like to simplify the process.

When finished press (PgDn) and ⏎.
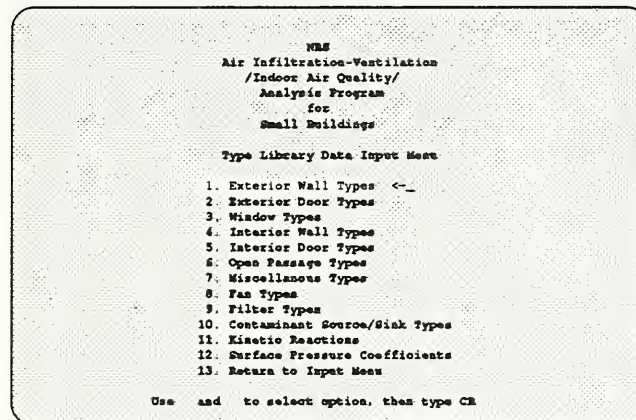
Figure 11. Type Library Data Input Menu.

The Type Library Data Input Menu shown in Figure 11 will appear. This menu functions as the main menu: use the ⊕, ⊕ keys to highlight an item and then press ⏎.

Highlight the *Exterior Wall Types* item and press ⏎.

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Figure 12. Exterior Wall Type Menu

The Input Exterior Wall Types data menu will appear. Expand the number of exterior wall types to 3 by using F2 key. Enter the data in Table 3 of Example 1 in the next section. Press (PgDn) when all data have been entered.

Repeat this exercise for Items 2 (Exterior Door Types) through 8 (Fan Types), using the data in Tables 3 to 10 of Example 1.

The remaining type input menus have a slightly different format. The input menu for Filter Types, Contaminant Source/Sink Types and the Kinetic Reactions depend on the number of contaminants.

Select the *Contaminant Source/Sink Type* item of the Type Library Data Input menu and press ◄┘. The input screen shown in Figure 13 will appear.

Figure 13. Contaminant Source Type Menu

First, input the name of the source, then specify whether the source is an area or point source, next whether it is pressure driven (the next two items in the input columns). Skip the numerical input of the generation rate (or pressure coefficient) by pressing ◄┘ or ─► and select the quantity and the time units of the generation rate. If the source is not pressure driven, skip the numerical data entry for the removal rate and specify whether the removal rate is a real removal rate or a cutoff concentration. Now enter the correct coefficients by

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returning to the numerical data fields using the cursor or tab keys. If a source emits more then one contaminant use ⒡3 and ⒡4 to page through the properties for each contaminant. Press ⒫PgDn⒭ to leave this menu.

Select the *Kinetic Reactions* item and press ⏎. The screen shown in Figure 14 will appear.
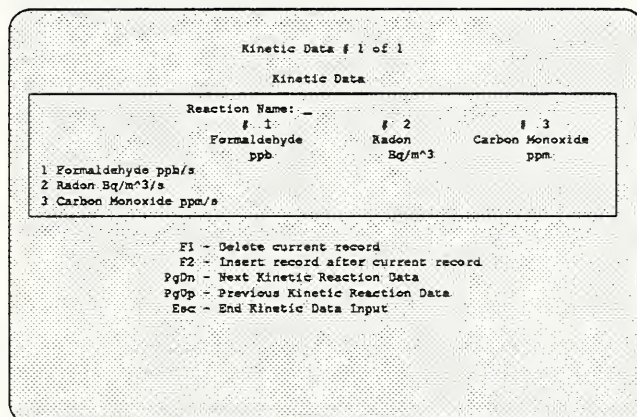
Figure 14. Kinetic Reaction Data Menu

Input the name of the kinetic reaction and a reaction coefficient for each non-zero term in the reaction rate matrix. The reaction rates must be consistent with the units of each contaminant, which are not displayed in the menu. Use the cursor or tab keys to move through the matrix. If the number of contaminants is greater than three, additional columns of the reaction rate matrix will be displayed when one reaches the third column. Similarly, if there are more than nine contaminants, additional rows will be displayed as one reaches the bottom row. Press ⒫PgDn⒭ to leave this input menu.

Select the *Surface Data* item and press ⏎. The menu shown in Figure 15 will appear on the screen.
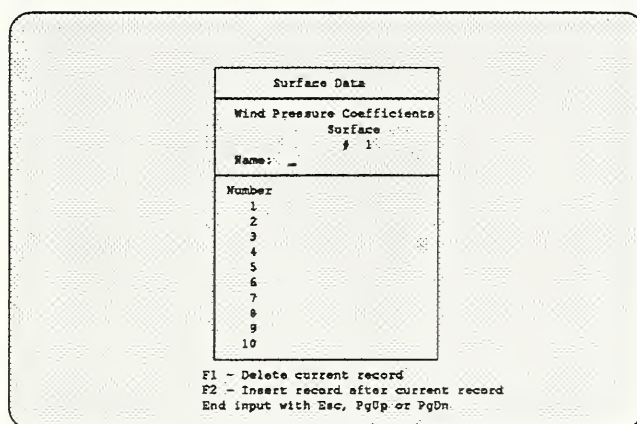
Figure 15. Surface Data Menu

Return to the Main Menu by pressing ⒠Esc⒭ twice. Select *Change Building Parameters* and press ⏎. The screen shown in Figure 16 will appear.

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```
                        NBS-AVIS

              Program Parameters

Physical Units: Metric              <-_
Leakage Data : Flow Coefficient
Flow Units : Mass Rate

Use    and    to select option, then type "C" to change parameter.
F1 - Change Basic Parameters
Type ESC to return to main menu.

                              ┌─────────────────────────────┐
                              │      Basic Parameters         │
                              ├─────────────────────────────┤
                              │  Reference Pressure      4 Pa  │
                              │  Reference Temperature  20.0 °C │
                              │  Height Above Sea Level    0 m  │
                              │  Discharge Coefficient   1.00   │
                              └─────────────────────────────┘
```
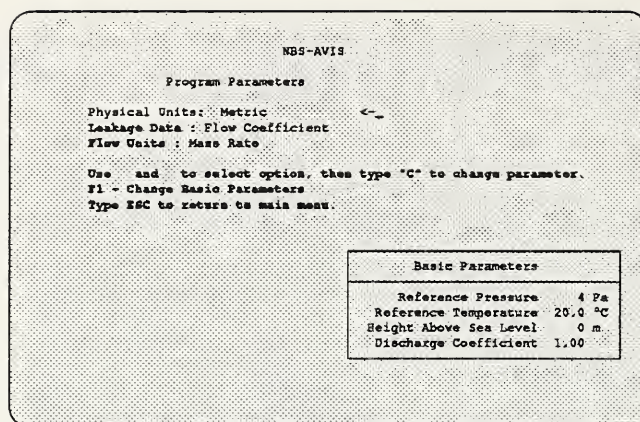
Figure 16. Basic Parameter Menu

This menu allows one to change the program parameters: the physical units (SI or English), leakage data (flow coefficient or leakage area) and flow units (mass or volume). The program parameters can be changed at any time during the creation or editing of a building description. NBSAVIS will make the appropriate conversion from one set of parameters to the other. In addition, NBSAVIS uses four basic parameters: the reference pressure for calculating leakage area, the temperature at which the standard flow conditions are calculated, the height of the building above sea level (used to calculate the barometric pressure), and the discharge coefficient used in the calculation of the leakage area. These basic parameters can be changed by pressing F1 and using the cursor keys to select and modify a parameter value. Press Esc to return to the Main Menu.

Return to the practice exercise by selecting *Edit Existing Building Description* and press ⏎. If a building description exists in the computer memory, selecting *Edit Existing Building Description* will produce the Main Data Input Menu. Later in this section, we will explain how to delete the existing building description and edit a new building description, either creating a new description without return to DOS or selecting a different building description from those stored in the current directory.

Select the *HVAC System Data* item of the Main Input Menu and press ⏎. The menu shown in Figure 17 will appear.

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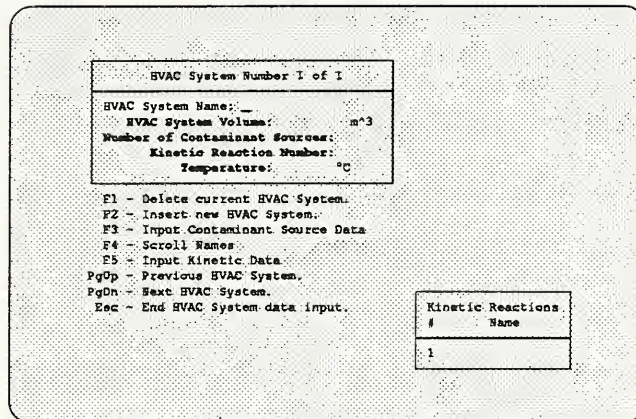
Figure 17. HVAC System Data Menu

Input a name for the HVAC system, and the physical volume. There are advantages to specifying a zero volume in transient analysis since larger time steps can usually be used. The HVAC system can have contaminant sources and a kinetic reaction associated with it. To enter a contaminant source, input the number of different source types in the HVAC system in the Number of Contaminant Sources data field, and press F3. We will demonstrate this process later when explaining how room data are prepared. The HVAC system can also have a kinetic reaction. If this is the case, select a number from the list of possible kinetic reactions displayed in the window in the lower left corner. If there are more kinetic reactions than can be displayed in this window, the list can be scrolled by pressing F4. It is also possible to examine, change or modify the kinetic reaction data if the list of kinetic reactions is not null by pressing F5. One can define a new kinetic reaction by this process but cannot delete any kinetic reaction from the list of reactions. If the building has more than one HVAC system, one pages through the list using PgDn or PgUp. End the input of HVAC system data by pressing Esc.

One should now be in the Main Data Input Menu. Select the *Building Physical Data* item and press ←. The Building Data Input Menu shown in Figure 18 will appear.
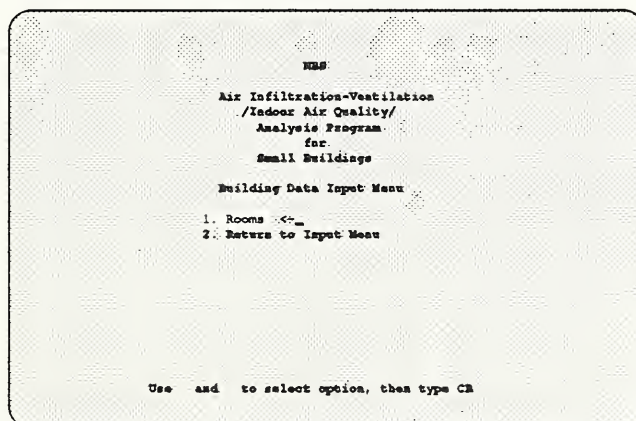
Figure 18. Building Physical Description Menu

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This is a dummy menu to allow for the addition of other building features in later versions (in NBSAVIL, the large building description processor, this menu allows selection of features such as elevators, stairways, return air shafts, supply air shafts, exhaust shafts and building interactions). Select the Rooms item and press ⏎. The data input menu for the first room will appear, as shown in Figure 19.

Figure 19. Room Data Menu

Enter the data required for the specific room in the appropriate data field in the menu. Entering a non-zero in any of the Number of ... data fields in this menu allows one to enter a menu for the component. Note the window displaying the possible kinetic reactions. For this exercise, enter the data in the first row of Table 1. Press (PgDn) and enter the second row of Table 1 in the next room menu. Note that as non-zero data are entered in the Number of ... fields, additional menus appear for entering data for these components. For example, to enter data for the exterior walls of the living room of Example 1 press (F3). The Exterior Wall input menu will appear, as shown in Figure 20.

Figure 20. Exterior Wall Data Menu

Enter the data in the third row of Table 14 in this menu. Then press (PgDn) and enter the data in the fourth row of Table 14. Press (PgDn) and enter the fifth row. To enter the exterior door data for this wall, press (F3) and enter the data from Table 15.

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```
              Room # 1 :  Living Room: Exterior Wall # 1

    ┌─────────────────────────┐        ┌─────────────────────────┐
    │     Exterior Doors       │        │   Exterior Door Types   │
    │                          │        │   #        Name         │
    │ Exterior       Number    │        │                         │
    │  Door    Type    of      │        └─────────────────────────┘
    │ Number  Number  Doors    │        F7 - Scroll Types
    │ ┌──────────────────────┐ │        F# - Input Exterior Door Types
    │ │    1        _        │ │
    │ └──────────────────────┘ │



              F1 - Delete current data record.
              F2 - Insert record after current data.
              PgUp - Previous data input.     PgDn - Next data input.
         Use Shift       and ← to select data entry  Type Esc to end input
```

Figure 21. Exterior Door Data Menu

When finished, press Esc. Press PgDn and you should be in the Exterior Wall Menu of the first wall of the living room, as shown in Figure 21. To enter the window data for this exterior wall, press F4. The menu shown in Figure 22 should appear.


```
              Room # 1 :  Living Room: Exterior Wall # 1

    ┌─────────────────────────┐        ┌─────────────────────────┐
    │        Windows           │        │      Window Types       │
    │                          │        │   #        Name         │
    │                Number    │        │                         │
    │ Window   Type    of      │        └─────────────────────────┘
    │ Number  Number  Windows  │        F7 - Scroll Types
    │ ┌──────────────────────┐ │        F# - Input Window Types
    │ │    1        _        │ │
    │ └──────────────────────┘ │



              F1 - Delete current data record.
              F2 - Insert record after current data.
              PgUp - Previous data input.     PgDn - Next data input.
         Use Shift       and ← to select data entry  Type Esc to end input
```

Figure 22. Window Data Menu

Enter the data in the second row of Table 16 into this menu. If this wall had several different window types, one would use PgDn to page through the list, entering the data for each window. Press Esc to return to the Exterior Wall menu. Enter 1 in the Number of Vents data field, then press F6 to obtain the Vent Data menu shown in Figure 23.

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Figure 23. Vent Data Menu

One should now have a feel for establishing a building description. Press [Esc] to return to the Room menu for the living room. To complete data entry for the living room, press [F9] to enter the contaminant source sink data, using the menu shown in Figure 24.

Figure 24. Contaminant Source/Sink Data Menu

Enter the data from the first row of Table 25. Press [Esc] when done.

Press [F8] to enter the data for the HVAC supply for this room using the menu shown in Figure 25.

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Figure 25. HVAC System Return Data Menu

Enter the data from the second row of Table 24. Press Esc when done.

To enter data for the interior wall between the living room and the kitchen, press F5 to obtain the menu shown in Figure 26.

Figure 26. Interior Wall Data Menu

Note that this menu has two display windows. One lists the names and numbers of previously defined rooms. These are permissible values for the Adjacent Building Part Number data field. This list can be scrolled using F10. The other window displays the defined interior wall types. This list can also be scrolled if it is too long to fit in the display window.

To terminate this practice session, press Esc twice. Select *Return to Input Menu* and press ←. Select *Return to Main Menu* and press ←. If one were doing an actual building description, one would select *Save Current Building Description*, press ←, select *Calculate Building Zone & Opening Data* and press ← to produce the files needed to perform the airflow and contaminant dispersal analysis using CONTAM88.

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If one wishes to create or edit another building description, one should select *Create New Building Description* from the Main menu. If a building description exists in memory, NBSAVIS will ask whether to delete the description; answer ⓨ. The Main Data Input menu will appear. At this point a new building description can be started. To edit a different building description in the current directory, select *Return to Main Menu*, press ⏎, select *Edit Existing Building Description* and press ⏎.

To exit from NBSAVIS, return to the Main Menu and select *Quit to DOS*, press ⏎. If you have modified an existing building description, you will be asked if you wish to save it. In this exercise answer Ⓝ. If you have not calculated the data for an airflow and contaminant dispersal analysis using CONTAM88, you will be asked if you wish to do so. Answer Ⓝ for this exercise. Finally, you will be prompted to confirm that you really wish to return to DOS. Answer Ⓨ. You should now be ready to use NBSAVIS to analyze buildings. The examples in the following sections give some data for prototypical residential single family detached buildings.

3.3 Example 1 - A Single Story Slab on Grade House

The first example contained in the tutorial is a one-story-slab on grade house with the floor plan shown in Figure 27.
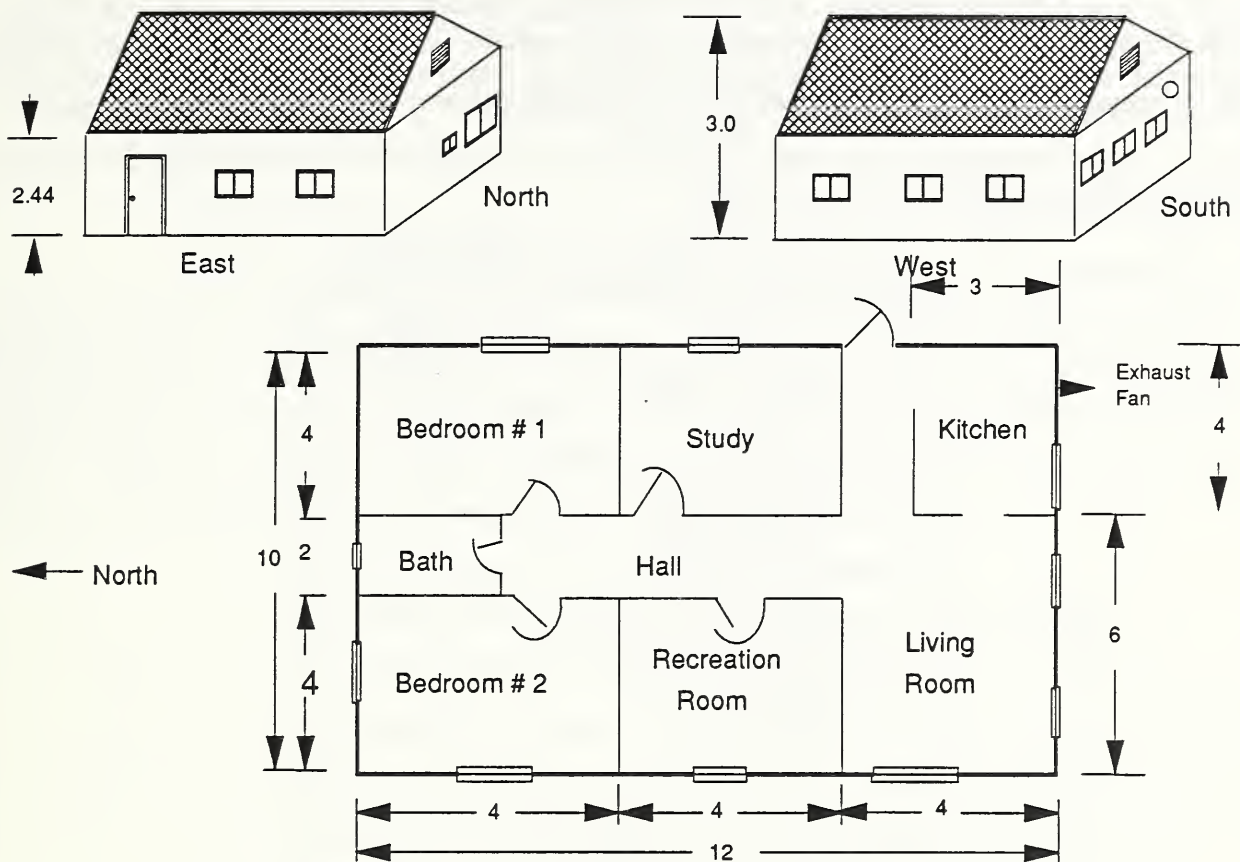
Figure 27. Schematic of Single Story House of Example 1.

We will consider this house to have 9 rooms: the 7 interior rooms shown in Figure 27, the hall and the attic. We shall consider only one contaminant, formaldehyde, in this example. In later examples, other contaminants and contaminant sources will be added. The only source of formaldehyde is underlayment, a pressed wood product made of urea-formaldehyde resins, used as subflooring on the first floor. However, the kitchen and bathroom are covered with linoleum, effectively eliminating any emission of formaldehyde from the underlayment in these rooms.

To enter the data for this example, start **NBSAVIS** as described above. Before creating the new building description, select the "Change Basic Parameters" item of the Main menu. Change the leakage coefficient option to leakage area, then return to the Main menu. Select "Create New Building Description" by highlighting this item and pressing ⏎. (Note: This example is included on the distribution disks as "NBSEXAM1." If one is lazy or bored after entering some of the data, enter the Create New Building Description menu and delete the current description, then enter Edit Existing Building Description menu and select NBSEXAM1. One can then browse through the data menus and compare the building description data with the data included in the tables of this subsection.)

From the Main Data Input Menu, select the Building Description item and press ⏎. Enter the Building name: "Example 1 - One-story slab on grade." Leave the results of the building tightness test blank. Enter 3.0 meters for the building roof height, 9 for the number of rooms, 1 for the number of HVAC systems and 1 for the number of contaminants. Press (PgDn).

Select the Type Library Description item and press ⏎. Enter the data from Table 5. Return to the Main Input menu by pressing (PgDn).

Table 5. Type Library Data for Example 1

Type	Number
Exterior wall	3
Window	3
Exterior door	2
Interior wall	2
Interior door	2
Opening passage	1
Miscellaneous	4
Air filters	2
Fan	4
Contaminant source	1
Kinetic reactions	2
Surface	-

Select the Contaminant Data item and press ⏎. Enter the data from Table 6. When finished, return to the Main Input Menu by pressing (PgDn).

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Table 6. Contaminant Data for Example 1

Contaminant Data				
Number	Name	Molecular weight/ Specific volume	Activity	Units
1	Formaldehyde	30.03 kg/mole	0.0	ppb

Select the Type Library Data item and press ⏎. From the Type Library input menu select the Exterior Wall Types item and press ⏎. Enter the data from Table 7 into the Exterior Wall Data menu and press ⎘ {Page Down} . Not all exterior wall types in Table 7 will be used in this example. However, the leakage areas of Table 7 are useful if one wishes to perform a parametric study of the effect of wall leakage on building air infiltration and contaminant levels. Comment: At present, there are not many sources of component leakage areas. Current sources are the ASHRAE Handbook of Fundamentals, Chapter 23.

Table 7. Exterior Wall Type Data for Example 1

Exterior Wall Types			
Number	Name	Leakage area cm^2/m^2	Exponent
1	Leaky wall	6.00	0.6
2	Average wall	2.00	0.6
3	Tight wall	1.00	0.6

Select the Exterior Door Type Data item by pressing ⏎. Enter the data from Table 8. For simplicity, Example 1 has only one exterior door type; however, we will enter two exterior door types to permit a parametric study of the effect of the tightness of the front door on the building air infiltration rate. Press PgDn.

Table 8. Exterior Door Type Data for Example 1

Exterior Door Types					
Number	Name	Leakage area cm^2	Exponent	Height m	Area m^2
1	Leaky ext door	2.0	0.6	2.2	2.2
2	Tight ext door	0.5	0.6	2.2	2.2

Select the Window Type Data item by pressing ↵. Example 1 has three types of windows: a bay window in the living room, a bath window in the bathroom, and a regular size window installed in the remaining rooms as shown in Figure 27. Enter the data from Table 9, and press PgDn.

Table 9. Window Type Data for Example 1

Window Types						
Number	Name	Leakage area cm^2	Exponent	Top m	Bottom m	Area m^2
1	Bay window	3.0	0.6	2.3	1.0	2.6
2	Regular window	1.5	0.6	2.3	1.0	1.3
3	Bath window	0.5	0.6	2.3	1.0	0.7

Select the Interior Wall Type Data item and press ↵. We will consider two types of interior wall leakages. The first type of interior wall will be a tight interior wall in which all interior leakage paths are prescribed by components such as interior doors and open passages. In this case the leakage area is 0.0. The second type is a leaky interior wall in which there is a background leakage of 1.0 cm^2/m^2 wall area, in addition to the leakage through the wall components. In Example 1, the interior walls will be considered to be of type 1, a tight interior wall. After entering the data from Table 10, press PgDn.

Table 10. Interior Wall Type Data for Example 1

Interior Wall Types			
Number	Name	Leakage area cm^2/m^2	Exponent
1	Tight int wall	0.0	0.6
2	Leaky int wall	1.0	0.6

Select the Interior Door Type Data item and press ↵. Example 1 has two types of interior doors: the bathroom door and the door used in the bedrooms and study. Enter the data from Table 11 in the Interior Door Type menu, and press PgDn.

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Table 11. Interior Door Type Data for Example 1

Interior Door Types					
Number	Name	Leakage area cm^2	Exponent	Height m	Area m^2
1	Bathroom	200.0	0.6	2.3	2.0
2	Bedroom	300.0	0.6	2.3	2.0

Now select the Open Passage Type Data item and press ↵. Example 1 will have only one open passage, an open interior door. Enter the data from Table 12. When finished, press [PgDn].

Table 12. Open Passage Type Data for Example 1

Open Passage Types			
Number	Name	Height m	Width m
1	Open door	2.3	0.8

Select the Miscellaneous Type Data item and press ↵. The miscellaneous leakage types in this example are a bath room vent, a kitchen vent, the attic hatch and the attic gable vents. The leakage data for these components are given in Table 13. Enter the data from Table 13 in the Miscellaneous Leakage type menu. Press [PgDn].

Table 13. Miscellaneous Type Data for Example 1

Miscellaneous Types					
Number	Name	Leakage area cm^2	Exponent	Height m	Area m^2
1	Bath vent	5.0	0.6	2.4	0.1
2	Kitchen vent	8.0	0.6	2.4	0.1
3	Attic hatch	50.0	0.6	0.0	1.0
4	Attic vent	4000.0	0.6	0.5	1.0

Now select the Fan Type Data item and press ↵. The fan types considered in this example are the HVAC system room supply flows, the HVAC system return air flow and exhaust fans for the bath room and the kitchen. The data for these flows are given in Table 14. Note that the flows are given in units of mass per unit time (kg/s). The flows can be entered in units of volume per unit time by pressing [Esc] [Esc] and selecting Change Basic Parameters. Choose

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the Basic Parameters menu, select the flow units items and change the units to volumetric. Return to the main menu by pressing (Esc). Return to the Fan Type Menu by selecting Edit Existing Building Description, selecting Type Library Data and then selecting the Fan Type Data item. Note that it is the user's responsibility to balance the HVAC system flows if that is his intention. An unbalanced HVAC system will be balanced by NBSAVIS by adding a flow to or from the exterior directly into the HVAC system. After entering the data from Table 14 into the Fan Type Menu, press (PgDn).

Table 14. Fan Type Data for Example 1

Fan Types			
Number	Name	Flow kg/s	Area m^2
1	Room supply	0.0400	0.1
2	House return	0.240	0.4
3	Bath exhaust	0.010	0.05
4	Kitchen exhaust	0.010	0.05

The Filter Type Data item should now be highlighted. Attempt to select this data entry by pressing (←). Note that the Contaminant Source Type Data item is highlighted. This is due to the fact that there were no filter types defined. Attempting to enter an undefined data type causes the next type to be selected. In this example there are three undefined data types: filter types, kinetic reactions and surface data since the number of each of these types was set to zero in the Library Type Definition menu.

Select the Contaminant Source/Sink Type data item and press (←). The only contaminant source in Example 1 is urea-formaldehyde underlayment. The data describing this source is given in Table 15. Enter the data from Table 15 into the Contaminant Source/Sink Type menu. This menu is different from the previous type menus. It contains several discrete selections: whether the source is a point source or an area source, whether the source is a pressure source and whether the second numerical entry represents a removal rate, a cutoff concentration or a pressure exponent. It is advisable to set these quantities for each source type before entering any numerical data. It is also advisable to set the quantity and time units of the source before any numerical data are entered. Press (←) until the choice is highlighted and making the selection using (+) or (-) keys. Then enter the data from Table 15.

Table 15. Contaminant Source/Sink Type Data for Example 1

Contaminant Source/Sink Types				
Number	Name	Area	Emission rate	Removal rate
1	Underlayment	A	0.216 mg/m^2·h	344 ppb

When finished with the entry of the Contaminant Source/Sink Type data, press Esc, select *Return to Input Menu* and press ← to terminate entry of Type Library data.

Select *HVAC System Data* and press ←.

Table 16. HVAC System Data for Example 1

HVAC System Data				
Number	Name	Volume m^2	Number of sources	Kinetic number
1	Warm air	2.0	0	0

Enter the HVAC data for Example 1 from Table 16. Press Esc when finished.

Select *Building Physical Data* item and press ←. Select *Rooms* and press ←. The room data for Example 1 is given in Table 17 (the kinetic number is zero for all rooms; all rooms except the attic are interior zones). Enter the data from the first row of Table 17 into the data fields for the first room. When finished press F3 to enter the exterior wall data. Enter the first row from Table 18 into the data fields for exterior wall 1 for the kitchen. Press PgDn and enter the second row of Table 17 into the data fields for the second wall, which has a window and an exhaust fan. Press F3 for the data menu for the windows, enter the data from the first row of Table 20, and press Esc. Now press F8 for the data menu for the exhaust fans. Enter the data from Table 22. Press Esc. Now enter the data for the supply register in the kitchen by pressing F8 and entering the data from the first row of Table 28. When finished, press Esc. The data entry for the kitchen is now complete. Press PgDn for the data menu for the living room. Enter the data from the second row of Table 17. Then enter the data for the exterior wall, interior walls, contaminant sources and HVAC supplies from Tables 17-29. Continue this process for the remaining rooms. When finished, it is good practice to check one's work by paging through the room data menus examining the data entries. When certain of the accuracy of the data press Esc. Select *Return to Input Menu* and press ←. Select *Return to Main Menu* and press ←.

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Table 17. Room Data for Example 1.

Room	Name	Area m²	Height above reference m	Height m	Temperature °C	Number of exterior walls	Number of interior walls	Number of Sources	Number of Returns	Number of Supplies
7	Kitchen	12	0.0	2.44	20.0	2	0	1	0	1
2	Living room	28	0.0	2.44	20.0	●	1	1	1	1
1	Recreation room	16	0.0	2.44	20.0	●	0	1	0	1
4	Bedroom 1	16	0.0	2.44	20.0	2	0	1	¿	1
5	Bedroom 2	16	0.0	2.44	20.0	2	0	1	0	1
6	Study	16	0.0	2.44	20.0	1	0	1	0	1
7	Bath	6	0.0	2.44	20.0	1	0	0	7	0
7	Hall	10	0.0	2.44	20.0	0	6	1	7	0
9	Attic	60*	2.44	1.0	10.0	2	1	0	0	0

* One half area of attic

Table 18. Exterior Wall Data for Example 1.

Room name	Wall number	Type number	Surface number	Width	Orient.	Height of wall	Height above floor	Number of Doors	Number of Windows	Number of Vents	Number Supply Fans	Number Exhaust Fans
Kitchen	1	2	0	3.0	90	2.44	0.0	0	0	0	0	0
Kitchen	2	2	0	4.0	180	2.44	0.0	0	1	0	0	1
Living room	1	2	0	6.0	180	2.44	0.0	0	1	0	0	0
Living room	2	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Living room	3	2	0	1.0	90	2.44	0.0	1	0	0	0	0
Recreation	1	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Bedroom 1	1	2	0	4.0	0	2.44	0.0	0	0	0	0	0
Bedroom 1	2	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 2	1	2	0	4.0	0	2.44	0.0	0	1	0	0	0
Bedroom 2	2	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Study	1	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bath	1	2	0	2.0	0	2.44	0.0	0	1	0	0	0
Attic	1	3	0	5.0*	0	1.00	0.0	0	0	1	0	0
Attic	2	3	0	5.0*	180	1.00	0.0	0	0	1	0	0

* One half actual width since wall is triangular. Note that all tilt angles are 0.

Table 19. Exterior Door Data for Example 1

Room	Wall number	Door number	Door type	Number of doors
Living room	3	1	1	1

Table 20. Window Data for Example 1

Room	Wall number	Window number	Window type	Number of windows
Kitchen	2	1	2	1
Living room	1	1	2	2
Living room	2	1	1	1
Recreation	1	1	2	1
Bedroom 1	2	1	2	1
Bedroom 2	1	1	2	1
Bedroom 2	2	1	2	1
Study	1	1	2	1
Bath	1	1	3	1

Table 21. Vent Data for Exterior Walls for Example 1

Room	Wall number	Vent number	Vent type	Number of vents
Attic	1	1	4	1
Attic	2	1	4	1

Table 22. Exhaust Fan Data for Exterior Walls for Example 1

Room	Wall number	Exhaust fan number	Fan type	Number of fans	Height above floor
Kitchen	2	1	4	1	2.0

Table 23. Interior Wall Data for Example 1.

Room name	Wall number	Type number	Adjacent room number	width	Height of wall	Height above floor	Number of doors	Number of Open Passages	Number of Vents	Number Supply Fans	Number Exhaust Fans
Living room	1	1	1	7.0	2.44	0.0	0	1	0	0	0
Hall	1	1	2	2.0	2.44	0.0	0	1	0	0	01
Hall	2	1	3	4.0	2.44	0.0	1	0	0	0	0
Hall	3	1	4	1.0	2.44	0.0	1	0	0	0	0
Hall	4	1	5	1.0	2.44	0.0	1	0	0	0	0
Hall	5	1	6	4.0	2.44	0.0	1	0	0	0	0
Hall	6	1	7	2.0	2.44	0.0	1	0	0	0	0
Attic	1	1	8	2.0	5.00	0.0	0	0	1	0	0

Table 24. Interior Door Data for Example 1

Room	Wall number	Door number	Door type	Number of doors
Hall	2	1	2	1
Hall	3	1	2	1
Hall	4	1	2	1
Hall	5	1	2	1
Hall	6	1	1	1

Table 25. Open Passage Data for Example 1

Room	Interior wall number	Open passage number	Type number	Number of open passages
Living room	1	1	1	2
Hall	1	1	1	1

Table 26. Vent Data for Interior Walls for Example 1.

Room	Interior wall number	Vent number	Type number	Number of vents
Attic	1	1	4	1

Table 27. HVAC Returns in Each Room for Example 1

Room	Return number	HVAC system number	Fan type	Filter type	Number of returns	Height above floor
Living Room	1	1	2	0	1	2.0

Table 28. HVAC Supplies in Each Room for Example 1

Room	Supply number	HVAC system number	Fan type	Filter type	Number of supplies	Height above floor
Kitchen	1	1	1	0	1	0.3
Living room	1	1	1	0	1	0.3
Recreation	1	1	1	0	1	0.3
Bedroom 1	1	1	1	0	1	0.3
Bedroom 2	1	1	1	0	1	0.3
Study	1	1	1	0	1	0.3

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Table 29. Room Contaminant Source/Sink Data for Example 1

Room	Source number	Source name	Number of sources	Area of source	Source type
Kitchen	1	Underlayment	1	12	1
Living room	1	Underlayment	1	28	1
Recreation	1	Underlayment	1	16	1
Bedroom 1	1	Underlayment	1	16	1
Bedroom 2	1	Underlayment	1	16	1
Study	1	Underlayment	1	16	1
Hall	1	Underlayment	1	10	1

The two final steps in producing a building description are to save the building description to disk and to calculate the zone and leakage path data for the program **CONTAM88**. Save the description first by selecting *Save Building Description* from the Main menu, and pressing ⏎. You will be asked for a file name to use for saving the building description. If the file exists, you will be asked to confirm whether you wish to overwrite it. If you answer Ⓝ, you will be asked for a new name. This example should be saved as NBSEXAM1. After you finish saving the building description, select *Calculate Zone and Opening Data* and press ⏎. This will produce the necessary zone, opening, fan and contaminant files for performing an air flow and contaminant dispersal analysis using **CONTAM88**. If the zone and opening files exist on the disk, you will be asked to confirm whether you wish to overwrite them. To terminate the program, select *Quit to DOS* from the Main Menu. Press ⏎. Confirm that you wish to return to DOS.

3.4 Example 2 - Adding a Basement

We shall now add a basement to house of Example 1. The new house is shown in Figure 28. We shall also consider the addition of radon to the list of contaminants.
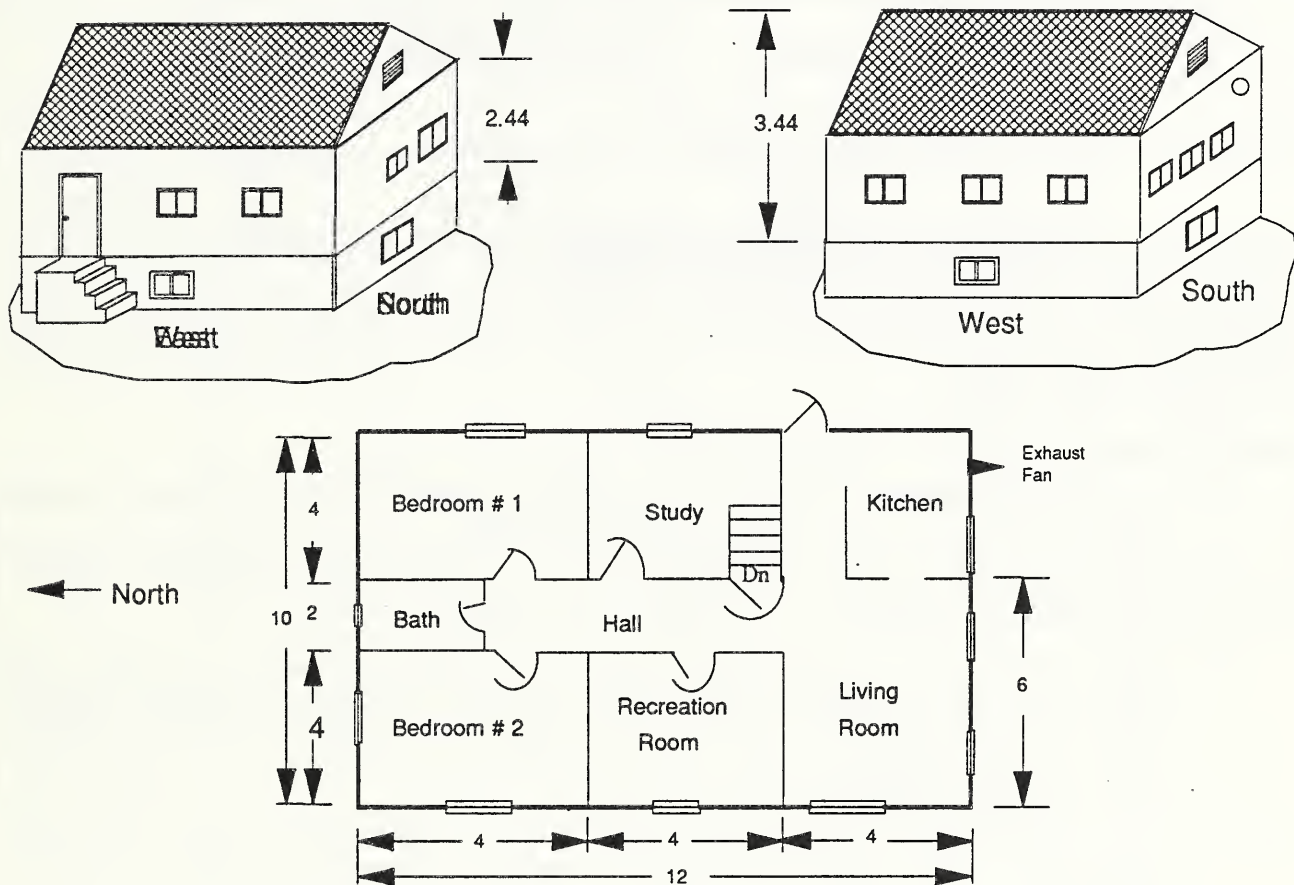
Figure 28. Schematic of Single Story House with Basement - Example 2

We will produce the building description by editing the building description of the first example and saving the results under a different name. Start NBSAVIS, select *Edit Existing Building Description* from the main menu, and press ↵. To bring into memory the building description of the first example, type (NBSEXAM1↵) (assuming that you are in the same data directory in which you saved NBSEXAM1).

From the Main Menu select *Building Description* and press ↵. Change the name of the building description to Example 2 - 1-Story house with basement, and change the building height to 3.44 (see Figure 3). The number of rooms and the number of contaminants will also be changed. However, this must be done by entering the appropriate data menu and using the insert record feature. Now press (PgDn) to exist the Building Description menu.

Select *Contaminant Data* and press ⏎. Press F2 to insert a new contaminant data record into the building description. Enter the data in the second row of Table 27 for radon. When finished, press (PgDn).

Table 30. Contaminant Data for Example 2

Contaminant Data				
Number	Name	Molecular weight/ Specific volume	Activity	Units
1	Formaldehyde	30.04 kg/mole	0.0	ppb
2	Radon	222.0 kg/mole	$2.1 \cdot 10^{-6}$	Bq/m^3

The addition of the basement also requires the addition of a new window type and of radon sources. Select *Library Type Data* from the Main menu and press ⏎. Select *Window Types* and press ⏎. Use ⏷ key to position the cursor in the last row of the data menu. Press F2 to insert a new window type record after the bath window type. Enter the data from the last row of Table 28. Press (PgDn).

Table 31. Window Type Data for Example 2

Window Types						
Number	Name	Leakage area cm^2	Exponent	Top m	Bottom m	Area m^2
1	Bay window	3.0	0.6	2.3	1.0	2.6
2	Regular window	1.5	0.6	2.3	1.0	1.3
3	Bath window	0.5	0.6	2.3	1.0	0.7
4	Basement	2.0	0.6	2.3	1.8	1.5

We shall consider two types of radon sources: a constant emission and pressure driven. Select *Contaminant Source/Sink Types* and press ⏎. Insert two new source types by pressing F2 twice. Enter the names, whether the source is a point source or an area source, and whether the source is pressure driven. Since there are now two contaminants, we must enter the emission properties of each source for each contaminant. Press F3 to enter the data for radon. Enter the data for radon from the second part of Table 30 for the new sources. Press (Esc) when finished.

Table 32. Contaminant Source/Sink Type Data for Example 2

Contaminant Source/Sink Types-Formaldehyde					
Number	Name	Area or point	Pressure	Emission rate	Removal Rate
1	Underlayment	A		0.216 mg/m$^2 \cdot$h	344 ppb
2	Sump	Pt	P	0.0	0.6
3	Floor	A		0.0	0.0

Contaminant Source/Sink Types-Radon					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or Removal Rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 Bq/(s$\cdot$Pa^n)	0.6
3	Floor	A		0.018 Bq/(m$^2 \cdot$s)	0.0

The addition of the basement changes the room data as shown in Table 33. To enter data, select *Building Physical Data* from the Main Data Menu, and press ↵ twice. For the existing rooms change the height above reference for each room according to Table 33. After the attic, insert a new room record by pressing [F2] and enter the data in the last row of Table 33. There are two ways to connect rooms at different levels in **NBSAVIS**. One is to define the height of the lower level room to be equal to the sum of the heights of both rooms and adjust the area of the lower room to give the correct volume. This is done in this example. The other method is to add a separate room for the stairway, as in the following example for connection of the first floor to the second floor (see Section 3.5).

Table 33. Room Data for Example 2.

Room	Name	Area m²	Height above reference m	Height m	Temperature °C	Number of exterior walls	Number of interior walls	Number of Sources	Number of Returns	Number of Supplies
1	Kitchen	12	1.0	2.44	20.0	2	0	0	0	1
2	Living room	28	1.0	2.44	20.0	3	1	1	0	2
3	Recreation room	16	1.0	2.44	20.0	1	0	1	0	1
4	Bedroom 1	16	1.0	2.44	20.0	2	0	1	0	1
●	Bedroom 2	16	1.0	2.44	20.0	2	0	1	0	1
6	Study	12	1.0	2.44	20.0	1	0	1	0	1
7	Bath	6	1.0	2.44	20.0	1	0	0	0	1
θ	Hall	5	1.0	2.44	20.0	0	6	1	1	0
9	Basement	61#	-1.44	4.88	20.0	4	1	2	0	1
10	Attic	60*	3.44	1.0	10.0	2	1	0	0	0

* One half area of attic since wall is triangular
# One half basement area plus 1 meter since height includes staircase

After entering the data from Table 33 in the room data menu for the basement, enter the appropriate exterior wall, interior wall and contaminant source/sink data menu and enter the new data from Tables 34-45.

Table 34. Exterior Wall Data for Example 2.

Room name	Wall number	Type number	Surface number	Width	Orient.	Height of Wall	Height above Floor	Number of Doors	Number of Windows	Number of Vents	Number Supply Fans	Number Exhaust Fans
Kitchen	1	2	0	3.0	90	2.44	0.0	0	0	0	0	0
Kitchen	2	2	0	4.0	180	2.44	0.0	0	1	0	0	1
Living room	1	2	0	6.0	180	2.44	0.0	0	1	0	0	0
Living room	2	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Living room	3	2	0	1.0	90	2.44	0.0	1	0	0	0	0
Recreation	3	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Bedroom 1	1	2	0	4.0	0	2.44	0.0	0	0	0	0	0
Bedroom 1	2	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 2	1	2	0	4.0	0	2.44	0.0	0	1	0	0	0
Bedroom 2	2	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Study	1	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bath	1	2	0	2.0	0	2.44	0.0	0	1	0	0	0
Basement	1	1	0	10.0	0	1.0	1.44	0	1	0	0	0
Basement	2	1	0	12.0	90	1.0	1.44	0	1	0	0	0
Basement	3	1	0	10.0	180	1.0	1.44	0	1	0	0	0
Basement	4	1	0	12.0	270	1.0	1.44	0	1	0	0	0
Attic	1	3	0	5.0*	0	1.00	0.0	0	0	1	0	0
Attic	2	3	0	5.0*	180	1.00	0.0	0	0	1	0	0

* One half actual width since wall is triangular. Note: all tilt angles are 0.

Table 35. Exterior Door Data for Example 2

Room	Wall number	Door number	Door type	Number of doors
Living room	3	1	1	1

Table 36. Window Data for Example 2

Room	Wall number	Window number	Window type	Number of windows
Kitchen	2	1	2	1
Living room	1	1	2	2
Living room	2	1	1	1
Recreation	1	1	2	1
Bedroom 1	1	1	2	1
Bedroom 2	1	1	2	1
Bedroom 2	2	1	2	3
Study	1	1	2	1
Bath	1	1	3	1
Basement	1	1	4	1
Basement	2	1	4	1
Basement	3	1	4	1
Basement	4	1	4	1

Table 37. Vent Data for Exterior Walls for Example 2

Room	Wall number	Vent number	Vent type	Number of Vents
Attic	1	1	4	1
Attic	2	1	4	1

Table 38. Exhaust Fan Data for Exterior Walls for Example 2

Room	Wall number	Exhaust fan number	Fan type	Number of fans	Height above floor
Kitchen	2	1	4	1	2.0

Table 39. Interior Wall Data for Example 2.

Room name	Wall number	Type number	Adjacent room number	Width	Height of wall	Height above floor	Number of doors	Number of Open Passages	Number of Vents	Number Supply Fans	Number Exhaust Fans
Living room	1	1	1	7.0	2.44	0.0	0	1	0	0	0
Hall	1	1	2	2.0	2.44	0.0	0	1	0	0	01
Hall	2	1	3	4.0	2.44	0.0	1	0	0	0	0
Hall	3	1	4	1.0	2.44	0.0	1	0	0	0	0
Hall	4	1	5	1.0	2.44	0.0	1	0	0	0	0
Hall	5	1	6	4.0	2.44	0.0	1	0	0	0	0
Hall	6	1	7	2.0	2.44	0.0	1	0	0	0	0
Basement	1	1	8	1.0	2.44	2.44	1	0	0	0	0
Attic	1	1	8	2.0	5.00	0.0	0	0	1	0	0

Table 40. Interior Door Data for Example 2

Room	Wall number	Door number	Door type	Number of doors
Hall	2	1	2	1
Hall	3	1	2	1
Hall	4	1	2	1
Hall	5	1	2	1
Hall	6	1	1	1
Basement	1	1	2	1

Table 41. Open Passage Data for Example 2

Room	Interior wall number	Open passage number	Type number	Number of open passages
Living room	1	1	1.	2
Hall	1	1	1	1

Table 42. Vent Data for Interior Walls for Example 2.

Room	Interior wall number	Vent number	Type number	Number of vents
Attic	1	1	4	1

Table 43. HVAC Returns in Each Room for Example 2

Room	Return number	HVAC system number	Fan type	Filter type	Number of returns	Height above floor
Living room	1	1	2	0	1	2.0

The room sources and sinks for the contaminant generation rates become:

Table 44. HVAC Supplies in Each Room for Example 2

Room	Supply number	HVAC system number	Fan type	Filter type	Number of supplies	Height above floor
Kitchen	1	1	1	0	1	0.3
Living room	1	1	1	0	1	0.3
Recreation	1	1	1	0	1	0.3
Bedroom 1	1	1	1	0	1	0.3
Bedroom 2	1	1	1	0	1	0.3
Study	1	1	1	0	1	0.3

Table 45. Room Contaminant Source/Sink Data for Example 2

Room	Source number	Source name	Number of sources	Area of source	Source type
Kitchen	1	Underlayment	1	12	1
Living room	1	Underlayment	1	28	1
Recreation	1	Underlayment	1	10	1
Bedroom 1	1	Underlayment	1	16	1
Bedroom 2	1	Underlayment	1	16	1
Study	1	Underlayment	1	14	1
Hall	1	Underlayment	1	10	1
Basement	1	Sump	1	1.0	2
Basement	2	Floor	1	120	3

When you are finished, press (Esc) until you are in the main menu. Save the results of this modified building description as NBSEXAM2. Calculate the zone and leakage data for the air flow and contaminant dispersal analysis using **CONTAM88**, using NBSEXAM2 as the name for these files. This building description will be used for the next example. When finished, select *Quit to DOS* and press (Ins).

3.5 Example 3 - Adding a Second Floor

We shall now add a second story to the house of Example 2. The new house is shown in Figure 29.

East   North   West   South

1st Floor   2nd Floor
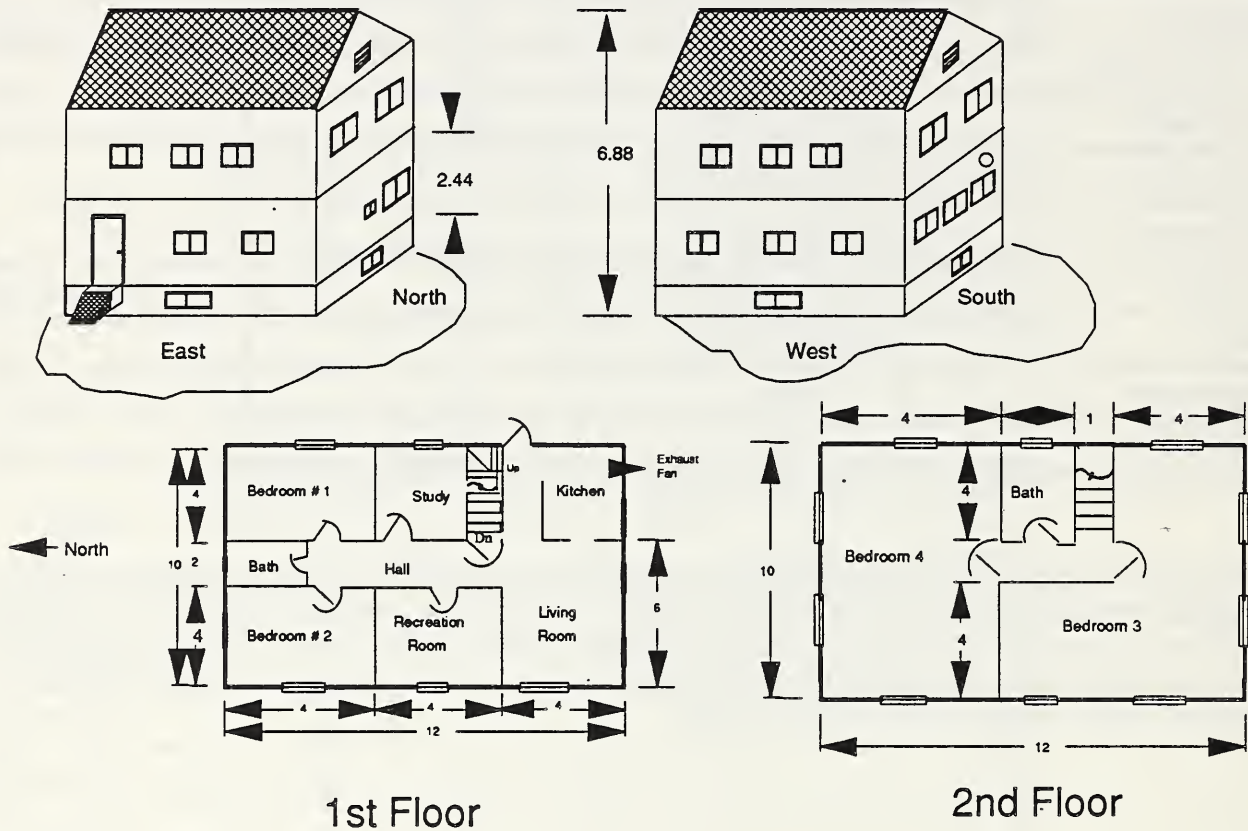
Example of a Two Storey House

Figure 29. Schematic of Two Story House Used in Example 3.

To produce a building description for this house, start **NBSAVIS**, select *Edit Existing Building Description* and load the description of NBSEXAM2. From the Main Menu, select *Building Description* and change the building name to "Example 3 - Two-story house." Change the building height to 5.88 m. Return to the Main Menu by pressing (PgDn). There is no need to modify the Type Library data or the Contaminant Data for this example. The new room data required for the addition of the second floor are given in Table 30.

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Table 46. Room Data for Example 3.

Room	Name	Area m²	Height above reference m	Height m	Temperature °C	Number of exterior walls	Number of interior walls	Number of Sources	Number of Returns	Number of Supplies
1	Kitchen	12	1.0	2.44	20.0	2	0	0	0	1
2	Living room	28	1.0	2.44	20.0	●	●	1	0	2
3	Recreation room	16	1.0	2.44	20.0	1	0	1	0	1
3	Bedroom 1	16	1.0	2.44	20.0	●	0	1	0	1
●	Bedroom 2	16	1.0	2.44	20.0	●	0	1	0	1
6	Study	12	1.0	2.44	20.0	1	0	1	0	1
7	Bath	6	1.0	2.44	20.0	1	0	0	0	1
8	Hall	10	1.0	2.44	20.0	0	6	1	1	0
2	Stairs	4	1.0	4.88	20.0	1	1	0	0	0
10	Basement	61#	-1.44	4.88	20.0	0	1	2	0	1
11	2nd floor hall	8	3.44	2.44	20.0	0	6	1	1	0
12	Bedroom 3	56	3.44	2.44	20.0	0	6	1	1	0
13	Bedroom 4	40	3.44	2.44	20.0	0	6	1	1	0
14	2nd floor bath	12	3.44	2.44	20.0	0	6	1	1	0
15	Attic	60*	5.88	1.0	10.0	2	1	0	0	0

* One half actual area of attic   # One half actual basement area + 1 square meter for basement stairs.

Note that the stairway between the first and second floors is considered as a room with two interior walls (one of which is assigned to the second floor hall due to the number scheme used).

To enter the room data select *Building Physical Data* from the main data menu, and press ⏎ twice. Page through the room data menu to the hall room data menu. Insert a new room after this record by pressing F2. Enter the data from row 9 of Table 46 into this record. Enter the corresponding data form the exterior walls, interior walls, windows, doors, open passages, HVAC returns and supplies, and contaminant sources/sinks from Tables 47-54.

Table 47. Exterior Wall Data for Example 3

Room Name	Wall number	Type number	Surface number	Width	Orient.	Height of wall	Height above floor	Number of doors	Number of Windows	Number of Vents	Number Supply Fans	Number Exhaust Fans
Kitchen	1	2	0	3.0	90	2.44	0.0	0	0	0	0	0
Kitchen	2	2	0	4.0	180	2.44	0.0	0	2	0	0	1
Living room	1	2	0	8.0	180	2.44	0.0	0	2	0	0	0
Living room	2	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Living room	3	2	0	1.0	90	2.44	0.0	1	0	0	0	0
Recreation	1	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Bedroom 1	1	2	0	4.0	0	2.44	0.0	0	0	0	0	0
Bedroom 1	2	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 2	1	2	0	4.0	0	2.44	0.0	0	1	0	0	0
Bedroom 2	2	2	0	4.0	270	2.44	0.0	0	1	0	0	0
Study	1	2	0	3.0	90	2.44	0.0	0	1	0	0	0
Bath	1	2	0	2.0	0	2.44	0.0	0	1	0	0	0
Basement	1	1	0	10.0	0	1.0	1.44	0	1	0	0	0
Basement	2	1	0	12.0	90	1.0	1.44	0	1	0	0	0
Basement	3	1	0	10.0	180	1.0	1.44	0	1	0	0	0
Basement	4	1	0	12.0	270	1.0	1.44	0	1	0	0	0
Stairs	1	2	0	1.0	90	4.88	0.0	0	0	0	0	0
Bedroom 4	1	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 3	2	2	0	10.0	180	2.44	0.0	0	1	0	0	0
Bedroom 3	3	2	0	8.0	270	2.44	0.0	0	1	0	0	0
Bedroom 4	1	2	0	10.0	0	2.44	0.0	0	1	0	0	0
Bedroom 4	2	2	0	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 4	3	2	0	4.0	270	2.44	0.0	0	1	0	0	0
2nd fl. bath	1	2	0	3.0	90	2.44	0.0	0	1	0	0	0
Attic	1	1	0	5.0*	0	0.56	0.0	0	0	1	0	0
Attic	2	1	0	5.0*	180	0.56	0.0	0	0	1	0	0

* One half actual width since wall is triangular. Note: all tilt angles are 0°.

Table 48. Window Data for Example 3

Room	Wall number	Window number	Window type	Number of windows
Kitchen	2	1	2	1
Living room	1	1	2	2
Living room	2	1	1	1
Recreation	1	1	2	1
Bedroom 1	1	1	2	1
Bedroom 2	1	1	2	1
Bedroom 2	2	1	2	1
Study	1	1	2	1
Bath	1	1	3	1
Bedroom 3	1	1	2	1
Bedroom 3	2	1	2	2
Bedroom 3	3	1	2	2
Bedroom 4	1	1	2	2
Bedroom 4	2	1	2	1
Bedroom 4	3	1	2	1
2nd fl. bath	1	1	1	1
Basement	1	1	4	1
Basement	2	1	4	1
Basement	3	1	4	1
Basement	4	1	4	1

Table 49. Interior Wall Data for Example 3.

Room name	Wall number	Type number	Adjacent room number	width	Height of wall	Height above floor	Number of doors	Number of Open Passages	Number of Vents	Number Supply Fans	Number Exhaust Fans
Living room	1	1	1	7.0	2.44	0.0	0	1	0	0	0
Hall	1	1	2	2.0	2.44	0.0	0	1	0	6	01
Hall	2	1	3	4.0	2.44	0.0	1	0	0	0	0
Hall	3	1	4	1.0	2.44	0.0	1	0	0	0	0
Hall	4	1	5	1.0	2.44	0.0	1	0	0	0	0
Hall	5	1	6	3.0	2.44	0.0	1	0	0	0	0
Hall	6	1	7	2.0	2.44	0.0	1	0	0	0	0
Basement	1	1	7	2.0	2.44	2.44	1	0	0	0	0
Stairs	1	1	2	1.0	2.44	0.0	0	1	0	0	0
2nd floor hall	1	1	9	1.0	2.44	0.0	0	1	0	0	0
2nd floor hall	2	1	11	1.0	2.44	0.0	1	0	0	0	0
Bedroom 4	1	1	12	1.0	2.44	0.0	1	0	0	0	0
2nd floor bath	1	1	12	3.0	2.44	0.0	1	0	0	0	0
Attic	1	1	12	2.0	5.00	0.0	0	0	1	0	0

Table 50. Interior Door Data for Example 3

Room	Wall number	Door number	Door type	Number of doors
Hall	2	1	2	1
Hall	3	1	2	1
Hall	4	1	2	1
Hall	5	1	2	1
Hall	6	1	1	1
2nd floor hall	1	1	1	1
Bedroom 4	1	1	1	1
2nd floor bath	1	1	1	1
Basement	1	1	2	1

Table 51. Open Passage Data for Example 3

Room	Interior wall number	Open passage number	Type number	Number of open passages
Living room	1	1	1	2
Hall	1	1	1	1
Stairs	1	1	1	1
2nd floor hall	1	1	1	1

The HVAC data for the second floor are given in Tables 52-53.

Table 52. HVAC Returns in Each Room for Example 3

Room	Return number	HVAC system number	Fan type	Filter type	Number of returns	Height above floor
Living room	1	1	2	0	1	2.0
2nd floor hall	1	1	2	0	1	2.0

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Table 53. HVAC Supplies in Each Room for Example 3

Room	Supply number	HVAC system number	Fan type	Filter type	Number of supplies	Height above floor
Kitchen	1	1	1	0	1	0.3
Living room	1	1	1	0	1	0.3
Recreation	1	1	1	0	1	0.3
Bedroom 1	1	1	1	0	1	0.3
Bedroom 2	1	1	1	0	1	0.3
Study	1	1	1	0	1	0.3
Bedroom 3	1	1	1	0	3	0.3
Bedroom 4	1	1	1	0	2	0.3
2nd floor bath	1	1	1	0	1	0.3

We will consider the second floor to have only particleboard underlayment as a contaminant source. The source/sink data are given in Table 54.

Table 54. Room Contaminant Source/Sink Data for Example 3

Room	Source number	Source name	Number of sources	Area of source	Source type
Kitchen	1	Underlayment	1	12	1
Living room	1	Underlayment	1	28	1
Recreation	1	Underlayment	1	10	1
Bedroom 1	1	Underlayment	1	16	1
Bedroom 2	1	Underlayment	1	16	1
Study	1	Underlayment	1	12	1
Hall	1	Underlayment	1	10	1
2nd floor hall	1	Underlayment	1	10	1
Bedroom 3	1	Underlayment	1	56	1
Bedroom 4	1	Underlayment	1	40	1
Basement	1	Sump	1	1.0	2
Basement	2	Floor	1	120	3

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When finished, return to the Main Menu by pressing (Esc) until the main menu appears. Save the results as NBSEXAM3 and calculate the zone and opening data under the same name. Terminate this section by selecting *Quit to DOS* and press (↵).

3.6 Example 4 - The Use of Pressure Coefficients

Building surface pressure coefficients, if available, can be used by CONTAM88 instead of those specified by a default algorithm. Some wind pressure data are included in Appendix A. We shall demonstrate the use of these data for the house of Example 3. We shall consider this house to be in a moderately sheltered urban location. From the dimensions of the house, it is appropriate to consider two types of surfaces: a long vertical surface and a short vertical surface. The corresponding pressure coefficients are given in Table 55.

Table 55. Surface Data for Example 4.

	Type 1	Type 2
Number	Long vertical wall	Short vertical wall
1	0.50	0.60
2	0.25	0.20
3	-0.50	-0.90
4	-0.80	-0.60
5	-0.70	-0.35
6	-0.80	-0.60
7	-0.50	-0.90
8	0.25	0.20

Surface data for the exterior walls in Example 4 are given in Table 56.

Table 56. Exterior Wall Data for Example 4

Room name	Wall number	Type number	Surface number	Width	Orient.	Height of wall	Height above floor	Number of Doors	Number of Windows	Number of Vents	Number Supply Fans	Number Exhaust Fans
Kitchen	1	2	1	3.0	90	2.44	0.0	0	0	0	0	0
Kitchen	2	2	2	4.0	180	2.44	0.0	0	1	0	0	1
Living room	1	2	2	6.0	180	2.44	0.0	0	2	0	0	0
Living room	2	2	1	4.0	270	2.44	0.0	0	1	0	0	0
Living room	3	2	1	1.0	90	2.44	0.0	1	0	0	0	0
Recreation	1	2	1	4.0	270	2.44	0.0	0	1	0	0	0
Bedroom 1	1	2	2	4.0	0	2.44	0.0	0	0	0	0	0
Bedroom 1	2	2	1	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 2	1	2	2	4.0	0	2.44	0.0	0	1	0	0	0
Bedroom 2	2	2	1	4.0	270	2.44	0.0	0	1	0	0	0
Study	1	2	1	3.0	90	2.44	0.0	0	1	0	0	0
Bath	1	2	2	2.0	0	2.44	0.0	0	1	0	0	0
Basement	1	1	2	10.0	0	1.0	1.44	0	1	0	0	0
Basement	2	1	1	12.0	90	1.0	1.44	0	1	0	0	0
Basement	3	1	1	10.0	180	1.0	1.44	0	1	0	0	0
Basement	4	1	2	12.0	270	1.0	1.44	0	1	0	0	0
Stairs	1	2	1	1.0	90	4.88	0.0	0	0	0	0	0
Bedroom 4	1	2	1	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 4	2	2	2	10.0	180	2.44	0.0	0	1	0	0	0
Bedroom 3	3	2	1	6.0	270	2.44	0.0	0	1	0	0	0
Bedroom 4	1	2	2	10.0	0	2.44	0.0	0	1	0	0	0
Bedroom 4	2	2	1	4.0	90	2.44	0.0	0	1	0	0	0
Bedroom 4	3	2	1	4.0	270	2.44	0.0	0	1	0	0	0
2nd fl. bath	1	2	1	3.0	90	2.44	0.0	0	1	0	0	0
Attic	1	3	2	5.0*	0	0.56	0.0	0	0	1	0	0
Attic	2	3	2	5.0*	180	0.56	0.0	0	0	1	0	0

* One half actual width since wall is triangular.

To create the building description for this example, load **NBSAVIS**, select *Edit Existing Building Description*, and load the description for Example 3 (NBSEXAM3). Edit the description as follows: Change the building name in the Building Description Menu to "Example 4 - Pressure Coefficients." In the Type Library Description Menu, enter 2 for the

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number of surfaces. Now enter the Library Data Menu, select the *Surface Data* item and enter the data from Table 56. Enter the *Building Physical Data* item of the main input menu, and for each exterior wall of each room, change the surface number from 0 to the corresponding number obtained from Table 56. Save the results in NBSEXAM4. Calculate the opening and zone data and exit to DOS.

3.7 Example 5 - An Example of Kinetic Reactions (Radon)

We shall now consider the inclusion of kinetic reactions in which radon disintegrates into progeny Po^{218}, Pb^{214} and Bi^{214}. The progeny may exist attached to particulate matter, or in an unattached state. Load NBSAVIS and edit the building description of Example 4 (NBSEXAM4). Change the building name in the Building Description menu to "Example 4 - Jacobi Model." Enter the Contaminant Data menu and add six more contaminants using the [F2] key. Enter the contaminant data from Table 57.

Table 57. Contaminant Data for Example 5

Number	Name	Molecular Weight/ Specific Volume	Activity	Units
1	Formaldehyde	30.04 kg/mole	0.0	ppb
2	Radon	222.0 kg/mole	$2.1 \cdot 10^{-6}$	Bq/m^3
3	Po218-u	218.0 kg/mole	$3.6 \cdot 10^{-3}$	Bq/m^3
4	Pb214-u	214.0 kg/mole	$4.31 \cdot 10^{-4}$	Bq/m^3
5	Bi214-u	214.0 kg/mole	$5.86 \cdot 10^{-5}$	Bq/m^3
6	Po218-a	218.0 kg/mole	$3.6 \cdot 10^{-3}$	Bq/m^3
7	Pb214-a	214.0 kg/mole	$4.31 \cdot 10^{-4}$	Bq/m^3
8	Bi214-a	214.0 kg/mole	$5.86 \cdot 10^{-5}$	Bq/m^3

To use the Jacobi model for radon and its daughters,[6] call up the Library Description menu, and enter 1 for the number of kinetic reactions and 1 for the number of filters; we shall also model the effect of a filter on the fraction of attached and unattached daughters. Now enter the Type Library Data menu and select Kinetic Reactions. Enter the data from Table 58.

Table 58. Kinetic Reaction Data for Jacobi Model - Example 5

	HCHO	Radon	Po218-u	Pb214-u	Bi214-u	Po218-a	Pb214-a	Bi214-a
HCHO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radon	0.0	$-2.1 \cdot 10^{-6}$	0.0	0.0	0.0	0.0	0.0	0.0
Po218-u	0.0	$3.6 \cdot 10^{-3}$	$-1.75 \cdot 10^{-2}$	0.0	0.0	0.0	0.0	0.0
Pb214-u	0.0	0.0	$4.31 \cdot 10^{-4}$	$-1.43 \cdot 10^{-2}$	0.0	$2.37 \cdot 10^{-4}$	0.0	0.0
Bi214-u	0.0	0.0	0.0	$5.86 \cdot 10^{-5}$	$-1.39 \cdot 10^{-2}$	0.0	0.0	0.0
Po218-a	0.0	0.0	$1.39 \cdot 10^{-2}$	0.0	0.0	$-3.60 \cdot 10^{-3}$	0.0	0.0
Pb214-a	0.0	0.0	0.0	$1.39 \cdot 10^{-2}$	0.0	$1.94 \cdot 10^{-4}$	$-4.31 \cdot 10^{-4}$	0.0
Bi214-a	0.0	0.0	0.0	0.0	$1.39 \cdot 10^{-2}$	0.0	$5.86 \cdot 10^{-5}$	$-5.86 \cdot 10^{-5}$

Now enter the Filter Type menu and enter the data from Table 59 (use the F3 key to page through the efficiencies for each contaminant).

Table 59. Filter Data for Example 5

	HCHO	Radon	Po218-u	Pb214-u	Bi214-u	Po218-a	Pb214-a	Bi214-a
Efficiency	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8

Now add a source/sink type for modeling the deposition of the attached and unattached radon daughters to surfaces in the room. For this example, we shall assume a deposition velocity of 8.0 m/h for the unattached daughters and 0.8 m/h for the attached daughters. Enter the Source/Sink Type data menu and add a source/sink type using F2. Enter the data from the following tables, paging through the contaminants using F3.

Table 60. Contaminant Source/Sink Type Data for Example 5

Contaminant Source/Sink Types-Formaldehyde					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.216 mg/m^2·h	344 ppb
2	Sump	Pt	P	0.0	0.6
3	Floor	A		0.0	0.0
4	Surface depos	A		0.0	0.0 h^{-1}

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Contaminant Source/Sink Types-Radon					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.6
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.0
4	Surface depos	A		0.0	0.0 m/h

Contaminant Source/Sink Types- Po_{218}-u					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.6
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.0
4	Surface depos	A		0.0	8.0 m/h

Contaminant Source/Sink Types- Po_{214}-u					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.6
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.0
4	Surface depos	A		0.0	8.0 m/h

Contaminant Source/Sink Types- Bi_{218}-u					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.0
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.0
4	Surface depos	A		0.0	8.0 m/h

Contaminant Source/Sink Types- Po_{218}-a					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.6
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.0
4	Surface depos	A		0.0	0.8 m/h

Contaminant Source/Sink Types- Po_{214}-a					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.0
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.0
4	Surface depos	A		0.0	0.8 m/h

Contaminant Source/Sink Types- Bi_{218}-a					
Number	Name	Area or point	Pressure	Emission Rate	Exponent or removal rate
1	Underlayment	A		0.0	0.0
2	Sump	Pt	P	2.77 $Bq/(s \cdot Pa^n)$	0.6
2	Floor	A		0.018 $Bq/(m^2 \cdot s)$	0.6
4	Surface depos	A		0.0	0.8 m/h

Now enter the *Building Physical Data* item of the Main Input menu, change the kinetic number from 0 to 1 for each room, and add the source/sink data from the deposition of the radon daughters on room surfaces given in Table 61.

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Table 61. Room Contaminant Source/Sink Data for Example 5

Room	Source number	Source name	Number of Sources	Area of Source	Source type
Kitchen	1	Underlayment	1	12	1
Kitchen	2	Deposition	1	12	4
Living Room	1	Underlayment	1	28	1
Living Room	2	Deposition	1	28	4
Recreation	1	Underlayment	1	16	1
Recreation	2	Deposition	1	16	4
Bedroom 1	1	Underlayment	1	16	1
Bedroom 1	2	Deposition	1	10	4
Bath	1	Deposition	1	1	4
Bedroom 2	1	Underlayment	1	16	1
Bedroom 2	2	Deposition	1	16	4
Study	1	Underlayment	1	12	1
Study	2	Deposition	1	12	4
Hall	1	Underlayment	1	10	1
Hall	2	Deposition	1	10	4
Stairs	1	Deposition	1	10	4
2nd floor hall	1	Underlayment	1	16	1
2nd floor hall	2	Deposition	1	40	4
Bedroom 3	1	Underlayment	1	52	1
Bedroom 4	2	Deposition	1	52	4
Bedroom 4	1	Underlayment	1	40	1
Bedroom 4	2	Deposition	1	40	4
2nd floor bath	1	Deposition	1	40	1
Basement	1	Sump	1	1.0	2
Basement	2	Floor	1	120	3
Basement	3	Deposition	1	120	4
Attic	1	Deposition	1	120	4

Return to the main menu and save the results of this session under the name NBSEXAM5. Calculate the zone and opening data and return to DOS.

3.8 Example 6 - Use of Building Tightness Test Data - The Lawrence Berkeley Laboratory (LBL) Model.

It is possible to construct a simple model of a building using NBSAVIS which is comparable to the LBL model for air infiltration for single-zone buildings.[8] This can be accomplished by giving the results of a building pressurization test in the Building Description menu. In the Physical Description menu, treat the building as one room with four walls of the appropriate dimensions. Specify for each wall a wall type of -1. NBSAVIS will calculate a specified leakage distribution consistent with the pressurization test results and the building dimensions. The building description file LBL.DSC contains the data for a simple description of the house of Example 1.

It should be noted that CONTAM88 solves for the induced internal pressure in the building rigorously and does not use the simplifying assumptions of the LBL model with respect to the addition of the wind and stack pressures and the addition of forced flows. CONTAM88 does not use terrain classes and the weather file must be prepared in terms of local wind speeds at a height of 10 meters.

It is possible to be more general then the LBL model in the use of building pressurization data in the calculation of the air flow in buildings. For example, if one defines three wall types according to Table 62, then one can distribute the undefined leakage according to whether one considers certain parts of the building (such as the basement) as leakier than other parts (see Section 2.3.1 and Section 2.4.1.1).

Table 62. Exterior Wall Type Data for Example 6

Number	Name	Leakage area cm^2/m^2	Exponent
1	Leaky wall	-2.00	0.6
2	Average wall	-1.00	0.6
3	Tight wall	-0.500	0.6

4 Use of CONTAM88

The program CONTAM88 performs interzone air movement and contaminant dispersal analysis for building descriptions created by NBSAVIS (see Appendix C for a detailed description). The current version of CONTAM88 is written in "C." It has been (with minor modifications) successfully compiled using "Turbo C," "Microsoft C," and "Metaware High C." The program itself requires approximately 170 KB of memory and dynamically allocates memory needed for the data of a particular problem (typically less then 50 KB for the examples above).

CONTAM88 can be run from either a floppy or hard disk. The file CONTAM88.EXE can be in any directory in the path variable, or it can be invoked by specifying the path on the command line. All other files: CONTAM88.PAR, CONTAM88.DTA, PROJECT.* etc. must be in the current directory.

To run the program **CONTAM88** after **NBSAVIS** creates the zone, fan and opening files, one must create a weather file called CONTAM88.DTA with an editor, as shown below. The file consists of a series of free input records. Each record contains a date, time, building description file name without extension, the exterior temperature, wind speed, wind direction and exterior contaminant concentration for each time period. Acceptable date formats are month/day/year, month/day or day. Acceptable time formats are hour/minute/second, hour/minute or hour. The building description name can be changed as long as no change is made in the number of zones or number of contaminants. This is a useful feature for describing different states of the building, for example when the HVAC system is on, when interior doors are open, and when windows are open. One uses **NBSAVIS** to produce a building description file for each state of the building. The units of the exterior temperature, wind speed and wind direction are °C, m/s, and degrees from north for SI units; and °F, mph, and degrees from north, in English units. The units for exterior concentration are those in which the results of the contaminant dispersal analysis are be to output (specified in **NBSAVIS**).

4.1 Sample Weather File CONTAM88.DTA

```
8/31/88  10:0:0  nbsexam4   10.0   1.0   0.0    0.0   0.0   0.0
8/31/88  11:0:0  nbsexam4    5.0   1.0   0.0    0.0   0.0   0.0
8/31/88  12:0:0  nbsexam4    0.0   1.0   0.0    0.0   0.0   0.0
8/31/88  13:0:0  nbsexam4   -5.0   1.0   0.0    0.0   0.0   0.0
8/31/88  14:0:0  nbsexam4  -10.0   1.0   0.0    0.0   0.0   0.0
8/31/88  15:0:0  nbsexam4   10.0   5.0   0.0    0.0   0.0   0.0
8/31/88  16:0:0  nbsexam4    5.0   5.0   0.0    0.0   0.0   0.0
8/31/88  17:0:0  nbsexam4    0.0   5.0   0.0    0.0   0.0   0.0
8/31/88  18:0:0  nbsexam4   -5.0   5.0   0.0    0.0   0.0   0.0
8/31/88  19:0:0  nbsexam4  -10.0   5.0   0.0    0.0   0.0   0.0
8/31/88  20:0:0  nbsexam4    5.0   1.0   0.0    0.0   0.0   0.0
```

4.2 Structure of Parameter File for CONTAM88.PAR

CONTAM88 looks for an optional program parameter file, CONTAM88.PAR, in the current directory. Table 63 explains the meaning of the program parameters contained in the following sample file:

MaxIt=20 List=1 Alpha=0.75 Pressure=0 Transient=1 Steady=0
metric Print=3600 MaxStep=60

Note that the last specification of a parameter is used, that any combination of upper and lower case letters can be used, and that there should be no space before and after the equal sign ("=").

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Table 63. Explanation of Control Parameters for CONTAM88

Parameter	Keyword	Default	Description
Maximum Iterations	MAXIT=	20	Controls maximum number of iterations for air flow analysis.
Printout Control	LIST=	0	Controls for quantity of information to the file CONTAM88.OUT and the plot files. LIST=0: prints only the total building air infiltration and exfiltration rates and the results of the contaminant dispersal analysis. LIST=1: prints also the zone air infiltration, exfiltration, total zone intake and exhaust rates and the interzonal air flows LIST=2: prints also the zone, opening and fan input data and the zone pressures and individual opening flows. LIST>2: used for diagnostics. Prints all matrices and intermediate results of calculations. Produces voluminous amounts of output.
Transient Solution Print Interval	Print=	600	
Transient Solution	transient=	1	transient=0: no transient solution transient=1: do a transient analysis
Steady Solution	steady=	1	steady=0: no steady state analysis steady=1: do steady state analysis
Units	metric English	metric	Selects the use of SI or English units
Flow Units	mass volume ACH	mass	Selects flow output as mass flow rate, volume flow rate, or air change rate. If SI units are specific, mass flow rates are in kg/s and volume flow rates are in L/min. In English units, mass flow rates are in lb/min and volume flow rates are in cfm.

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Pressure Solution Initialization	Pressure=	1	Control initialization of pressures: Pressure=0: initialization each step. Pressure=1: use last interval pressures.
Predictor Corrector Parameter	alpha=	0.75	Parameter in predictor corrector scheme. For stability alpha should be great then 0.5 and less than or equal to 1.0. Alpha = 0.0 is Euler's method which is potentially unstable.
Absolute Convergence Criteria	E1=	0.000001	Controls absolute convergence criteria. See Appendix D.
Relative Convergence Criteria	E2=	0.0001	Controls relative convergence criteria. See Appendix D.
Maximum Allowable Time Step	MaxStep=	600	Controls maximum allowable time step in transient solution under automatic time step estimating. Note, no time step greater the print interval "print" is allowed.
Matrix Storage Scheme	ASYM_FULL SYM_FULL SYM_COMPACT ASYM_COMPACT ASYM_COMPACT2 SYM_SKYLINE ASYM_SKYLINE	SYM_SKYLINE	Selects the matrix storage technique. See Appendix D. If a symmetric type is selected, the Jacobian is symmetric and the contaminant dispersal matrix is asymmetric of the same type. If an asymmetric type is selected, both matrices are asymmetric.

4.3 Initial Condition File PROJECT.INI

For transient contaminant dispersal analysis, initial conditions can be specified in a file PROJECT.INI. Enter on one line the initial concentration for each contaminant in each for building zone, using the same units specified by NBSAVIS for printing concentration results (see Appendix B). Separate the values on each line by a space.

4.4 Sample Output File

The following is a sample output file for Example 5, the two-story house with a basement, containing sources of formaldehyde, radon and radon daughters. (Attached radon daughters are denoted "-a;" unattached daughters by "-u." The output has been truncated for brevity.

```
Date of Analysis: Fri Feb 16 15:18:57 1990
```

```
              CONTAM88
Interzonal Air Movement & Contaminant Dispersal Program
       National Institute of Standards & Technology
          Indoor Air Quality & Ventilation Group
             version date: Nov 8, 1989
***** Solution Parameters *****
 Maximum Number of Iterations:  20
         Print Output Control:   1
                        ALPHA:  0.75
               Print Interval: 3600 seconds
Absolute Convergence Criteria: 1.000e-06
Relative Convergence Criteria: 1.000e-04
Pressure Solution Type: 1
Steady State Solution
No Transient Solution
Physical Units: Metric
Air Flow Units: kg/s
Pressure matrix type:   Symmetric skyline matrix
Flow matrix type:   Asymmetric skyline matrix

Starting Date & Time

 8/31/88  10:00:00

Initial Building File: nbsexam5.

Building Title: Ex 5 2 Story House w Attic & Basement
Number of Pressure Zones = 15

Number of Contaminants = 8

Barometric Pressure 101332

    Zone Labels
Zone  1 Kitchen
Zone  2 Living Room
Zone  3 Recreation Room
Zone  4 Bedroom 1
Zone  5 Bedroom 2
Zone  6 Study
Zone  7 Bath
Zone  8 Hall
Zone  9 Stairs
Zone 10 Basement
Zone 11 2nd Floor Bdr 3
Zone 12 2nd Floor Hall
Zone 13 2nd Floor Bdr 4
Zone 14 2nd Floor Bath
Zone 15 Attic
Zone 16 Warm Air

    Contaminant Data
Contaminant 1 Formaldehyde
Density = 1.243 kg/m^3  Activity =   0.00e+00/s  Units: ppb
Contaminant 2 Radon
Density = 9.196 kg/m^3  Activity =   2.10e-06/s  Units: Bq/m^3
Contaminant 3 PO218-u
```

Density = 9.031 kg/m^3   Activity =   3.60e-03/s   Units: Bq/m^3
Contaminant 4 PB214-u
Density = 8.865 kg/m^3   Activity =   4.31e-04/s   Units: Bq/m^3
Contaminant 5 Bi214-u
Density = 8.865 kg/m^3   Activity =   5.86e-05/s   Units: Bq/m^3
Contaminant 6 PO218-a
Density = 9.031 kg/m^3   Activity =   3.60e-03/s   Units: Bq/m^3
Contaminant 7 PB214-a
Density = 8.865 kg/m^3   Activity =   4.31e-04/s   Units: Bq/m^3
Contaminant 8 Bi214-a
Density = 8.865 kg/m^3   Activity =   5.86e-05/s   Units: Bq/m^3

*** No initial conditions.
    Initial concentrations assumed to be zero.

  Number of Openings = 115.

  8/31/88   11:00:00

Begin next time step
  HBTSTP   TA   PB   WS   WD   Ambient Concentrations
    3600   10.00   101332   1.00   0   0.000   0.000   0.000
0.000   0.000   0.000   0.000   0.000

Number of iterations: 5
Time to solve airflow system: 0.33 seconds

Infiltration Rate: 0.14 /hr   Exfiltration Rate: 0.13 /hr

	Zone Infiltration	Zone Exfiltration
Kitchen	1.03e-02 kg/s	0.00e+00 kg/s
Living Room	9.58e-03 kg/s	0.00e+00 kg/s
Recreation Room	0.00e+00 kg/s	3.94e-03 kg/s
Bedroom 1	1.41e-03 kg/s	4.46e-03 kg/s
Bedroom 2	1.26e-03 kg/s	4.25e-03 kg/s
Study	5.24e-04 kg/s	2.77e-03 kg/s
Bath	2.79e-03 kg/s	0.00e+00 kg/s
Hall	0.00e+00 kg/s	0.00e+00 kg/s
Stairs	0.00e+00 kg/s	0.00e+00 kg/s
Basement	8.26e-03 kg/s	0.00e+00 kg/s
2nd Floor Bdr 3	0.00e+00 kg/s	8.50e-03 kg/s
2nd Floor Hall	0.00e+00 kg/s	0.00e+00 kg/s
2nd Floor Bdr 4	2.43e-03 kg/s	2.83e-03 kg/s
2nd Floor Bath	0.00e+00 kg/s	4.61e-04 kg/s
Attic	5.91e-02 kg/s	6.84e-02 kg/s

Total Intake Flow: 0.14 /hr   Total Exhaust Flow: 0.13 /hr

	Zone Total Intake	Zone Total Exhaust
Kitchen	1.03e-02 kg/s	0.00e+00 kg/s
Living Room	9.58e-03 kg/s	0.00e+00 kg/s
Recreation Room	0.00e+00 kg/s	3.94e-03 kg/s
Bedroom 1	1.41e-03 kg/s	4.46e-03 kg/s
Bedroom 2	1.26e-03 kg/s	4.25e-03 kg/s
Study	5.24e-04 kg/s	2.77e-03 kg/s
Bath	2.79e-03 kg/s	0.00e+00 kg/s
Hall	0.00e+00 kg/s	0.00e+00 kg/s

```
                    Stairs   0.00e+00 kg/s        0.00e+00 kg/s
                 Basement    8.26e-03 kg/s        0.00e+00 kg/s
        2nd Floor Bdr 3      0.00e+00 kg/s        8.50e-03 kg/s
         2nd Floor Hall      0.00e+00 kg/s        0.00e+00 kg/s
        2nd Floor Bdr 4      2.43e-03 kg/s        2.83e-03 kg/s
         2nd Floor Bath      0.00e+00 kg/s        4.61e-04 kg/s
                   Attic     5.91e-02 kg/s        6.84e-02 kg/s
                Warm Air     0.00e+00 kg/s        0.00e+00 kg/s
```

        InterZonal Flows

```
To Kitchen
    From Exterior               1.03e-02 kg/s
    From Warm Air               4.00e-02 kg/s
To Living Room
    From Exterior               9.58e-03 kg/s
    From Kitchen                5.03e-02 kg/s
    From Hall                   1.40e-01 kg/s
    From Warm Air               4.00e-02 kg/s
To Recreation Room
    From Warm Air               4.00e-02 kg/s
To Bedroom 1
    From Exterior               1.41e-03 kg/s
    From Warm Air               4.00e-02 kg/s
To Bedroom 2
    From Exterior               1.26e-03 kg/s
    From Warm Air               4.00e-02 kg/s
To Study
    From Exterior               5.24e-04 kg/s
    From Warm Air               4.00e-02 kg/s
To Bath
    From Exterior               2.79e-03 kg/s
To Hall
    From Recreation Room        3.61e-02 kg/s
    From Bedroom 1              3.70e-02 kg/s
    From Bedroom 2             3.70e-02 kg/s
    From Study                 3.78e-02 kg/s
    From Bath                  2.79e-03 kg/s
    From Basement              8.26e-03 kg/s
To Stairs
    From Hall                   1.87e-02 kg/s
To Basement
    From Exterior               8.26e-03 kg/s
To 2nd Floor Bdr 3
    From Warm Air               1.20e-01 kg/s
To 2nd Floor Hall
    From Stairs                 1.87e-02 kg/s
    From 2nd Floor Bdr 3        1.11e-01 kg/s
    From 2nd Floor Bdr 4        1.20e-01 kg/s
To 2nd Floor Bdr 4
    From Exterior               2.43e-03 kg/s
    From Warm Air               1.20e-01 kg/s
To 2nd Floor Bath
    From 2nd Floor Hall         4.61e-04 kg/s
To Attic
    From Exterior               5.91e-02 kg/s
```

```
      From 2nd Floor Hall        9.32e-03 kg/s
To Warm Air
      From Living Room           2.40e-01 kg/s
      From 2nd Floor Hall        2.40e-01 kg/s
         Steady State Concentrations
                      Formaldehyde              Radon                    PO218-u
          Kitchen     1.40e+02 ppb       1.57e+02 Bq/m^3       3.07e+01 Bq/m^3
      Living Room     1.51e+02 ppb       1.97e+02 Bq/m^3       3.87e+01 Bq/m^3
   Recreation Room    1.79e+02 ppb       1.96e+02 Bq/m^3       3.84e+01 Bq/m^3
        Bedroom 1     1.62e+02 ppb       1.90e+02 Bq/m^3       3.72e+01 Bq/m^3
        Bedroom 2     1.63e+02 ppb       1.91e+02 Bq/m^3       3.74e+01 Bq/m^3
            Study     1.66e+02 ppb       1.94e+02 Bq/m^3       3.81e+01 Bq/m^3
             Bath     0.00e+00 ppb       0.00e+00 Bq/m^3       0.00e+00 Bq/m^3
             Hall     1.57e+02 ppb       2.26e+02 Bq/m^3       4.42e+01 Bq/m^3
           Stairs     1.57e+02 ppb       2.25e+02 Bq/m^3       4.51e+01 Bq/m^3
         Basement     0.00e+00 ppb       8.94e+02 Bq/m^3       1.74e+02 Bq/m^3
   2nd Floor Bdr 3    1.71e+02 ppb       1.97e+02 Bq/m^3       3.86e+01 Bq/m^3
    2nd Floor Hall    1.68e+02 ppb       1.97e+02 Bq/m^3       3.83e+01 Bq/m^3
   2nd Floor Bdr 4    1.66e+02 ppb       1.93e+02 Bq/m^3       3.77e+01 Bq/m^3
   2nd Floor Bath     1.68e+02 ppb       1.70e+02 Bq/m^3       3.33e+01 Bq/m^3
            Attic     2.37e+01 ppb       2.77e+01 Bq/m^3       4.65e+00 Bq/m^3
         Warm Air     1.60e+02 ppb       1.97e+02 Bq/m^3       3.86e+01 Bq/m^3
         Steady State Concentrations
                      PB214-u                   Bi214-u                  PO218-a
          Kitchen     2.40e+00 Bq/m^3    9.54e-03 Bq/m^3       9.77e+01 Bq/m^3
      Living Room     3.13e+00 Bq/m^3    1.24e-02 Bq/m^3       1.31e+02 Bq/m^3
   Recreation Room    3.15e+00 Bq/m^3    1.25e-02 Bq/m^3       1.32e+02 Bq/m^3
        Bedroom 1     2.83e+00 Bq/m^3    1.13e-02 Bq/m^3       1.13e+02 Bq/m^3
        Bedroom 2     2.84e+00 Bq/m^3    1.13e-02 Bq/m^3       1.13e+02 Bq/m^3
            Study     2.90e+00 Bq/m^3    1.15e-02 Bq/m^3       1.15e+02 Bq/m^3
             Bath     0.00e+00 Bq/m^3    0.00e+00 Bq/m^3       0.00e+00 Bq/m^3
             Hall     3.59e+00 Bq/m^3    1.41e-02 Bq/m^3       1.52e+02 Bq/m^3
           Stairs     4.00e+00 Bq/m^3    1.63e-02 Bq/m^3       1.69e+02 Bq/m^3
         Basement     1.50e+01 Bq/m^3    5.94e-02 Bq/m^3       6.52e+02 Bq/m^3
   2nd Floor Bdr 3    3.04e+00 Bq/m^3    1.21e-02 Bq/m^3       1.24e+02 Bq/m^3
    2nd Floor Hall    3.05e+00 Bq/m^3    1.20e-02 Bq/m^3       1.29e+02 Bq/m^3
   2nd Floor Bdr 4    2.89e+00 Bq/m^3    1.15e-02 Bq/m^3       1.16e+02 Bq/m^3
   2nd Floor Bath     2.90e+00 Bq/m^3    1.15e-02 Bq/m^3       1.25e+02 Bq/m^3
            Attic     3.27e-01 Bq/m^3    1.10e-03 Bq/m^3       1.65e+01 Bq/m^3
         Warm Air     3.10e+00 Bq/m^3    1.23e-02 Bq/m^3       1.30e+02 Bq/m^3
         Steady State Concentrations
                      PB214-a                   Bi214-a
          Kitchen     4.48e+01 Bq/m^3    3.95e+00 Bq/m^3
      Living Room     7.20e+01 Bq/m^3    1.13e+01 Bq/m^3
   Recreation Room    7.77e+01 Bq/m^3    9.23e+00 Bq/m^3
        Bedroom 1     4.51e+01 Bq/m^3    3.64e+00 Bq/m^3
        Bedroom 2     4.54e+01 Bq/m^3    3.66e+00 Bq/m^3
            Study     4.67e+01 Bq/m^3    3.78e+00 Bq/m^3
             Bath     0.00e+00 Bq/m^3    0.00e+00 Bq/m^3
             Hall     8.68e+01 Bq/m^3    1.61e+01 Bq/m^3
           Stairs     1.24e+02 Bq/m^3    2.26e+01 Bq/m^3
         Basement     6.13e+02 Bq/m^3    2.10e+02 Bq/m^3
   2nd Floor Bdr 3    5.87e+01 Bq/m^3    5.32e+00 Bq/m^3
```

2nd Floor Hall	6.19e+01 Bq/m^3	6.24e+00 Bq/m^3
2nd Floor Bdr 4	4.86e+01 Bq/m^3	4.01e+00 Bq/m^3
2nd Floor Bath	1.23e+02 Bq/m^3	4.67e+01 Bq/m^3
Attic	8.98e+00 Bq/m^3	9.76e-01 Bq/m^3
Warm Air	6.71e+01 Bq/m^3	8.81e+00 Bq/m^3

Time to solve steady state contaminant dispersal equations: 1.16 seconds

Next Building File: nbsexam5.

8/31/88 12:00:00

Begin next time step

HBTSTP	TA	PB	WS	WD	Ambient Concentrations		
3600	5.00	101332	1.00	0	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000			

Number of iterations: 5
Time to solve airflow system: 0.28 seconds

Infiltration Rate: 0.16 /hr   Exfiltration Rate: 0.15 /hr

	Zone Infiltration	Zone Exfiltration
Kitchen	1.17e-02 kg/s	0.00e+00 kg/s
Living Room	1.06e-02 kg/s	0.00e+00 kg/s
Recreation Room	8.85e-04 kg/s	3.31e-03 kg/s
Bedroom 1	2.65e-03 kg/s	4.00e-03 kg/s
Bedroom 2	2.42e-03 kg/s	3.81e-03 kg/s
Study	1.32e-03 kg/s	2.50e-03 kg/s
Bath	3.15e-03 kg/s	0.00e+00 kg/s
Hall	0.00e+00 kg/s	0.00e+00 kg/s
Stairs	0.00e+00 kg/s	0.00e+00 kg/s
Basement	1.00e-02 kg/s	0.00e+00 kg/s
2nd Floor Bdr 3	0.00e+00 kg/s	1.21e-02 kg/s
2nd Floor Hall	0.00e+00 kg/s	0.00e+00 kg/s
2nd Floor Bdr 4	1.21e-03 kg/s	5.95e-03 kg/s
2nd Floor Bath	0.00e+00 kg/s	7.51e-04 kg/s
Attic	5.89e-02 kg/s	7.03e-02 kg/s

Total Intake Flow: 0.16 /hr   Total Exhaust Flow: 0.15 /hr

	Zone Total Intake	Zone Total Exhaust
Kitchen	1.17e-02 kg/s	0.00e+00 kg/s
Living Room	1.06e-02 kg/s	0.00e+00 kg/s
Recreation Room	8.85e-04 kg/s	3.31e-03 kg/s
Bedroom 1	2.65e-03 kg/s	4.00e-03 kg/s
Bedroom 2	2.42e-03 kg/s	3.81e-03 kg/s
Study	1.32e-03 kg/s	2.50e-03 kg/s
Bath	3.15e-03 kg/s	0.00e+00 kg/s
Hall	0.00e+00 kg/s	0.00e+00 kg/s
Stairs	0.00e+00 kg/s	0.00e+00 kg/s
Basement	1.00e-02 kg/s	0.00e+00 kg/s
2nd Floor Bdr 3	0.00e+00 kg/s	1.21e-02 kg/s
2nd Floor Hall	0.00e+00 kg/s	0.00e+00 kg/s
2nd Floor Bdr 4	1.21e-03 kg/s	5.95e-03 kg/s

```
    2nd Floor Bath      0.00e+00 kg/s      7.51e-04 kg/s
           Attic        5.89e-02 kg/s      7.03e-02 kg/s
        Warm Air        0.00e+00 kg/s      0.00e+00 kg/s
          InterZonal Flows
To  Kitchen
    From Exterior              1.17e-02 kg/s
    From Warm Air              4.00e-02 kg/s
To  Living Room
    From Exterior              1.06e-02 kg/s
    From Kitchen               5.17e-02 kg/s
    From Hall                  1.38e-01 kg/s
    From Warm Air              4.00e-02 kg/s
To  Recreation Room
    From Exterior              8.85e-04 kg/s
    From Warm Air              4.00e-02 kg/s
To  Bedroom 1
    From Exterior              2.65e-03 kg/s
    From Warm Air              4.00e-02 kg/s
To  Bedroom 2
    From Exterior              2.42e-03 kg/s
    From Warm Air              4.00e-02 kg/s
To  Study
    From Exterior              1.32e-03 kg/s
    From Warm Air              4.00e-02 kg/s
To  Bath
    From Exterior              3.15e-03 kg/s
To  Hall
    From Recreation Room       3.76e-02 kg/s
    From Bedroom 1             3.86e-02 kg/s
    From Bedroom 2             3.86e-02 kg/s
    From Study                 3.88e-02 kg/s
    From Bath                  3.15e-03 kg/s
    From Basement              1.00e-02 kg/s
To  Stairs
    From Hall                  2.91e-02 kg/s
To  Basement
    From Exterior              1.00e-02 kg/s
To  2nd Floor Bdr 3
    From Warm Air              1.20e-01 kg/s
To  2nd Floor Hall
    From Stairs                2.91e-02 kg/s
    From 2nd Floor Bdr 3       1.08e-01 kg/s
    From 2nd Floor Bdr 4       1.15e-01 kg/s
To  2nd Floor Bdr 4
    From Exterior              1.21e-03 kg/s
    From Warm Air              1.20e-01 kg/s
To  2nd Floor Bath
    From 2nd Floor Hall        7.51e-04 kg/s
To  Attic
    From Exterior              5.89e-02 kg/s
    From 2nd Floor Hall        1.15e-02 kg/s
To  Warm Air
    From Living Room           2.40e-01 kg/s
    From 2nd Floor Hall        2.40e-01 kg/s
```

```
Steady State Concentrations
                Formaldehyde          Radon                  PO218-u
      Kitchen   1.26e+02 ppb    1.47e+02 Bq/m^3      2.87e+01 Bq/m^3
  Living Room   1.35e+02 ppb    1.88e+02 Bq/m^3      3.68e+01 Bq/m^3
Recreation Room 1.62e+02 ppb    1.85e+02 Bq/m^3      3.62e+01 Bq/m^3
    Bedroom 1   1.45e+02 ppb    1.78e+02 Bq/m^3      3.48e+01 Bq/m^3
    Bedroom 2   1.45e+02 ppb    1.79e+02 Bq/m^3      3.50e+01 Bq/m^3
        Study   1.49e+02 ppb    1.83e+02 Bq/m^3      3.59e+01 Bq/m^3
         Bath   0.00e+00 ppb    0.00e+00 Bq/m^3      0.00e+00 Bq/m^3
         Hall   1.40e+02 ppb    2.18e+02 Bq/m^3      4.26e+01 Bq/m^3
       Stairs   1.40e+02 ppb    2.17e+02 Bq/m^3      4.35e+01 Bq/m^3
     Basement   0.00e+00 ppb    8.47e+02 Bq/m^3      1.65e+02 Bq/m^3
2nd Floor Bdr 3 1.57e+02 ppb    1.89e+02 Bq/m^3      3.71e+01 Bq/m^3
2nd Floor Hall  1.54e+02 ppb    1.92e+02 Bq/m^3      3.73e+01 Bq/m^3
2nd Floor Bdr 4 1.53e+02 ppb    1.88e+02 Bq/m^3      3.67e+01 Bq/m^3
2nd Floor Bath  1.54e+02 ppb    1.75e+02 Bq/m^3      3.42e+01 Bq/m^3
        Attic   2.61e+01 ppb    3.23e+01 Bq/m^3      5.43e+00 Bq/m^3
     Warm Air   1.45e+02 ppb    1.90e+02 Bq/m^3      3.72e+01 Bq/m^3

Steady State Concentrations
                PB214-u               Bi214-u                PO218-a
      Kitchen   2.24e+00 Bq/m^3 8.91e-03 Bq/m^3      9.11e+01 Bq/m^3
  Living Room   2.98e+00 Bq/m^3 1.18e-02 Bq/m^3      1.24e+02 Bq/m^3
Recreation Room 2.96e+00 Bq/m^3 1.18e-02 Bq/m^3      1.24e+02 Bq/m^3
    Bedroom 1   2.64e+00 Bq/m^3 1.05e-02 Bq/m^3      1.05e+02 Bq/m^3
    Bedroom 2   2.65e+00 Bq/m^3 1.06e-02 Bq/m^3      1.05e+02 Bq/m^3
        Study   2.73e+00 Bq/m^3 1.09e-02 Bq/m^3      1.09e+02 Bq/m^3
         Bath   0.00e+00 Bq/m^3 0.00e+00 Bq/m^3      0.00e+00 Bq/m^3
         Hall   3.46e+00 Bq/m^3 1.36e-02 Bq/m^3      1.46e+02 Bq/m^3
       Stairs   3.83e+00 Bq/m^3 1.55e-02 Bq/m^3      1.61e+02 Bq/m^3
     Basement   1.42e+01 Bq/m^3 5.62e-02 Bq/m^3      6.17e+02 Bq/m^3
2nd Floor Bdr 3 2.93e+00 Bq/m^3 1.16e-02 Bq/m^3      1.20e+02 Bq/m^3
2nd Floor Hall  2.98e+00 Bq/m^3 1.17e-02 Bq/m^3      1.26e+02 Bq/m^3
2nd Floor Bdr 4 2.82e+00 Bq/m^3 1.12e-02 Bq/m^3      1.13e+02 Bq/m^3
2nd Floor Bath  2.98e+00 Bq/m^3 1.18e-02 Bq/m^3      1.29e+02 Bq/m^3
        Attic   3.82e-01 Bq/m^3 1.28e-03 Bq/m^3      1.93e+01 Bq/m^3
     Warm Air   2.99e+00 Bq/m^3 1.18e-02 Bq/m^3      1.25e+02 Bq/m^3

Steady State Concentrations
                PB214-a               Bi214-a
      Kitchen   4.14e+01 Bq/m^3 3.67e+00 Bq/m^3
  Living Room   6.89e+01 Bq/m^3 1.12e+01 Bq/m^3
Recreation Room 7.25e+01 Bq/m^3 8.58e+00 Bq/m^3
    Bedroom 1   4.16e+01 Bq/m^3 3.40e+00 Bq/m^3
    Bedroom 2   4.19e+01 Bq/m^3 3.43e+00 Bq/m^3
        Study   4.37e+01 Bq/m^3 3.60e+00 Bq/m^3
         Bath   0.00e+00 Bq/m^3 0.00e+00 Bq/m^3
         Hall   8.49e+01 Bq/m^3 1.62e+01 Bq/m^3
       Stairs   1.11e+02 Bq/m^3 2.00e+01 Bq/m^3
     Basement   5.74e+02 Bq/m^3 1.91e+02 Bq/m^3
2nd Floor Bdr 3 5.66e+01 Bq/m^3 5.21e+00 Bq/m^3
2nd Floor Hall  6.17e+01 Bq/m^3 6.61e+00 Bq/m^3
2nd Floor Bdr 4 4.77e+01 Bq/m^3 4.02e+00 Bq/m^3
2nd Floor Bath  1.25e+02 Bq/m^3 4.56e+01 Bq/m^3
        Attic   1.06e+01 Bq/m^3 1.20e+00 Bq/m^3
     Warm Air   6.55e+01 Bq/m^3 8.91e+00 Bq/m^3
```

Time to solve steady state contaminant dispersal equations: 1.16 seconds
Next Building File: nbsexam5.
    9/01/88   1:00:00
Begin next time step
   HBTSTP   TA   PB   WS   WD   Ambient Concentrations
     3600   -10.00   101332   0.00   0   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
Number of iterations: 6
Time to solve airflow system: 0.33 seconds

Infiltration Rate: 0.24 /hr   Exfiltration Rate: 0.22 /hr

	Zone Infiltration	Zone Exfiltration
Kitchen	1.53e-02 kg/s	0.00e+00 kg/s
Living Room	1.15e-02 kg/s	0.00e+00 kg/s
Recreation Room	4.04e-03 kg/s	2.08e-03 kg/s
Bedroom 1	7.15e-03 kg/s	3.95e-03 kg/s
Bedroom 2	6.64e-03 kg/s	3.70e-03 kg/s
Study	4.04e-03 kg/s	2.08e-03 kg/s
Bath	3.95e-03 kg/s	0.00e+00 kg/s
Hall	0.00e+00 kg/s	0.00e+00 kg/s
Stairs	0.00e+00 kg/s	0.00e+00 kg/s
Basement	1.44e-02 kg/s	0.00e+00 kg/s
2nd Floor Bdr 3	0.00e+00 kg/s	1.97e-02 kg/s
2nd Floor Hall	0.00e+00 kg/s	0.00e+00 kg/s
2nd Floor Bdr 4	0.00e+00 kg/s	1.60e-02 kg/s
2nd Floor Bath	0.00e+00 kg/s	1.36e-03 kg/s
Attic	5.91e-05 kg/s	1.82e-02 kg/s

Total Intake Flow: 0.24 /hr   Total Exhaust Flow: 0.22 /hr

	Zone Total Intake	Zone Total Exhaust
Kitchen	1.53e-02 kg/s	0.00e+00 kg/s
Living Room	1.15e-02 kg/s	0.00e+00 kg/s
Recreation Room	4.04e-03 kg/s	2.08e-03 kg/s
Bedroom 1	7.15e-03 kg/s	3.95e-03 kg/s
Bedroom 2	6.64e-03 kg/s	3.70e-03 kg/s
Study	4.04e-03 kg/s	2.08e-03 kg/s
Bath	3.95e-03 kg/s	0.00e+00 kg/s
Hall	0.00e+00 kg/s	0.00e+00 kg/s
Stairs	0.00e+00 kg/s	0.00e+00 kg/s
Basement	1.44e-02 kg/s	0.00e+00 kg/s
2nd Floor Bdr 3	0.00e+00 kg/s	1.97e-02 kg/s
2nd Floor Hall	0.00e+00 kg/s	0.00e+00 kg/s
2nd Floor Bdr 4	0.00e+00 kg/s	1.60e-02 kg/s
2nd Floor Bath	0.00e+00 kg/s	1.36e-03 kg/s
Attic	5.91e-05 kg/s	1.82e-02 kg/s
Warm Air	0.00e+00 kg/s	0.00e+00 kg/s

    InterZonal Flows

```
To Kitchen
     From Exterior               1.53e-02 kg/s
     From Warm Air               4.00e-02 kg/s
To Living Room
     From Exterior               1.15e-02 kg/s
     From Kitchen                5.53e-02 kg/s
     From Hall                   1.33e-01 kg/s
     From Warm Air               4.00e-02 kg/s
To Recreation Room
  \  From Exterior               4.04e-03 kg/s
     From Warm Air               4.00e-02 kg/s
To Bedroom 1
     From Exterior               7.15e-03 kg/s
     From Warm Air               4.00e-02 kg/s
To Bedroom 2
     From Exterior               6.64e-03 kg/s
     From Warm Air               4.00e-02 kg/s
To Study
     From Exterior               4.04e-03 kg/s
     From Warm Air               4.00e-02 kg/s
To Bath
     From Exterior               3.95e-03 kg/s
To Hall
     From Recreation Room        4.20e-02 kg/s
     From Bedroom 1              4.32e-02 kg/s
     From Bedroom 2              4.29e-02 kg/s
     From Study                  4.20e-02 kg/s
     From Bath                   3.95e-03 kg/s
     From Basement               1.44e-02 kg/s
To Stairs
     From Hall                   5.52e-02 kg/s
To Basement
     From Exterior               1.44e-02 kg/s
To 2nd Floor Bdr 3
     From Warm Air               1.20e-01 kg/s
To 2nd Floor Hall
     From Stairs                 5.52e-02 kg/s
     From 2nd Floor Bdr 3        1.00e-01 kg/s
     From 2nd Floor Bdr 4        1.04e-01 kg/s
To 2nd Floor Bdr 4
     From Warm Air               1.20e-01 kg/s
To 2nd Floor Bath
     From 2nd Floor Hall         1.36e-03 kg/s
To Attic
     From Exterior               5.91e-05 kg/s
     From 2nd Floor Hall         1.81e-02 kg/s
To Warm Air
     From Living Room            2.40e-01 kg/s
     From 2nd Floor Hall         2.40e-01 kg/s
```

Steady State Concentrations

	Formaldehyde	Radon	PO218-u
Kitchen	9.51e+01 ppb	1.18e+02 Bq/m^3	2.30e+01 Bq/m^3
Living Room	1.01e+02 ppb	1.58e+02 Bq/m^3	3.10e+01 Bq/m^3
Recreation Room	1.25e+02 ppb	1.47e+02 Bq/m^3	2.89e+01 Bq/m^3

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	PB214-u	Bi214-u	PO218-a

Bedroom 1	1.04e+02 ppb	1.38e+02 Bq/m^3	2.70e+01 Bq/m^3
Bedroom 2	1.05e+02 ppb	1.39e+02 Bq/m^3	2.73e+01 Bq/m^3
Study	1.11e+02 ppb	1.48e+02 Bq/m^3	2.89e+01 Bq/m^3
Bath	0.00e+00 ppb	0.00e+00 Bq/m^3	0.00e+00 Bq/m^3
Hall	1.02e+02 ppb	1.87e+02 Bq/m^3	3.67e+01 Bq/m^3
Stairs	1.02e+02 ppb	1.87e+02 Bq/m^3	3.74e+01 Bq/m^3
Basement	0.00e+00 ppb	7.61e+02 Bq/m^3	1.48e+02 Bq/m^3
2nd Floor Bdr 3	1.26e+02 ppb	1.62e+02 Bq/m^3	3.19e+01 Bq/m^3
2nd Floor Hall	1.21e+02 ppb	1.68e+02 Bq/m^3	3.27e+01 Bq/m^3
2nd Floor Bdr 4	1.23e+02 ppb	1.63e+02 Bq/m^3	3.18e+01 Bq/m^3
2nd Floor Bath	1.21e+02 ppb	1.59e+02 Bq/m^3	3.12e+01 Bq/m^3
Attic	1.25e+02 ppb	1.72e+02 Bq/m^3	2.87e+01 Bq/m^3
Warm Air	1.11e+02 ppb	1.63e+02 Bq/m^3	3.19e+01 Bq/m^3

Steady State Concentrations

	PB214-u	Bi214-u	PO218-a
Kitchen	1.79e+00 Bq/m^3	7.11e-03 Bq/m^3	7.23e+01 Bq/m^3
Living Room	2.50e+00 Bq/m^3	9.92e-03 Bq/m^3	1.04e+02 Bq/m^3
Recreation Room	2.35e+00 Bq/m^3	9.33e-03 Bq/m^3	9.82e+01 Bq/m^3
Bedroom 1	2.02e+00 Bq/m^3	8.09e-03 Bq/m^3	7.97e+01 Bq/m^3
Bedroom 2	2.05e+00 Bq/m^3	8.19e-03 Bq/m^3	8.07e+01 Bq/m^3
Study	2.18e+00 Bq/m^3	8.72e-03 Bq/m^3	8.65e+01 Bq/m^3
Bath	0.00e+00 Bq/m^3	0.00e+00 Bq/m^3	0.00e+00 Bq/m^3
Hall	2.97e+00 Bq/m^3	1.17e-02 Bq/m^3	1.26e+02 Bq/m^3
Stairs	3.24e+00 Bq/m^3	1.30e-02 Bq/m^3	1.36e+02 Bq/m^3
Basement	1.27e+01 Bq/m^3	5.03e-02 Bq/m^3	5.52e+02 Bq/m^3
2nd Floor Bdr 3	2.51e+00 Bq/m^3	1.00e-02 Bq/m^3	1.03e+02 Bq/m^3
2nd Floor Hall	2.63e+00 Bq/m^3	1.04e-02 Bq/m^3	1.12e+02 Bq/m^3
2nd Floor Bdr 4	2.45e+00 Bq/m^3	9.73e-03 Bq/m^3	9.84e+01 Bq/m^3
2nd Floor Bath	2.71e+00 Bq/m^3	1.08e-02 Bq/m^3	1.17e+02 Bq/m^3
Attic	1.97e+00 Bq/m^3	6.50e-03 Bq/m^3	1.00e+02 Bq/m^3
Warm Air	2.58e+00 Bq/m^3	1.02e-02 Bq/m^3	1.08e+02 Bq/m^3

Steady State Concentrations

	PB214-a	Bi214-a
Kitchen	3.21e+01 Bq/m^3	2.91e+00 Bq/m^3
Living Room	5.90e+01 Bq/m^3	1.02e+01 Bq/m^3
Recreation Room	5.61e+01 Bq/m^3	6.52e+00 Bq/m^3
Bedroom 1	3.06e+01 Bq/m^3	2.62e+00 Bq/m^3
Bedroom 2	3.12e+01 Bq/m^3	2.66e+00 Bq/m^3
Study	3.41e+01 Bq/m^3	2.94e+00 Bq/m^3
Bath	0.00e+00 Bq/m^3	0.00e+00 Bq/m^3
Hall	7.59e+01 Bq/m^3	1.55e+01 Bq/m^3
Stairs	8.84e+01 Bq/m^3	1.71e+01 Bq/m^3
Basement	5.02e+02 Bq/m^3	1.56e+02 Bq/m^3
2nd Floor Bdr 3	4.88e+01 Bq/m^3	4.66e+00 Bq/m^3
2nd Floor Hall	5.69e+01 Bq/m^3	7.12e+00 Bq/m^3
2nd Floor Bdr 4	4.18e+01 Bq/m^3	3.71e+00 Bq/m^3
2nd Floor Bath	1.12e+02 Bq/m^3	3.78e+01 Bq/m^3
Attic	5.66e+01 Bq/m^3	7.33e+00 Bq/m^3
Warm Air	5.81e+01 Bq/m^3	8.68e+00 Bq/m^3

Time to solve steady state contaminant dispersal equations: 1.15 seconds

Next Building File: nbsexam5.
    *** appending EXCITDAT.DTA to CONTAM.DTA ***
    **** appending DYNAM.DTA to CONTAM.DTA ***

```
Minimum Time Step: 3600
Initial memory available 393624 bytes.
Memory not used 321832 bytes.
Memory used 71792 bytes.
End of Analysis: Fri Feb 16 15:20:09 1990
```

4.5 Plot Files

CONTAM88 also produces plot files EXFIL.PLT, INFIL.PLT, INTAKE.PLT, EXHAUST.PLT, STEADY.PLT, TRANSIENT.PLT, and FLOW.PLT, which can be imported into a spreadsheet such as Lotus 123 and Quatro-Pro. The file INFIL.PLT contains the weather conditions and infiltration rates, the file EXFIL.PLT contains the weather conditions and the exfiltration rates, INTAKE.PLT the total air intake rates, and EXHAUST.PLT the total exhaust rates. If the parameter LIST = 0, these files contain only the value for the whole building. If LIST > 0, they contain also the zone flows. The file FLOW.PLT contains the interzonal air flows if LIST > 0. The output at each time step is in the form of a matrix. The diagonal elements are the total flow out of the zone, the off-diagonal elements are the flow into the row zone from the column zone. The last column and row are the exterior of the building. The files STEADY.PLT and TRANSIENT.PLT contain the results of the steady-state and transient contaminant dispersal analysis. The last column contains the infiltration into the row zone, the last row contains the exfiltration from the column zone. For each time interval, each plot file contains labels and headers which make them readable if a column width of 16 is used in the spreadsheet.

5 Use of the Programs CONTAM86 and CONTAM87

The program **CONTAM88** produces an output file CONTAM.DTA which can be made to serve as an input file to the programs **CONTAM86** and **CONTAM87**. To do this rename CONTAM.DTA without an extension (for example, the name of the description file used for **NBSAVIS** without the extension). One should consult the user manuals for **CONTAM86** and **CONTAM87** for details on using these programs.[4-5] CONTAM.DTA does not contain any removal rates or particulate plateout terms since **CONTAM87** can only handle these effects by the creation of pseudo-kinetic elements. If one wishes to do steady-state analysis with **CONTAM87**, the input must be edited.

6 Summary

The programs **NBSAVIS** and **CONTAM88** form a package for preparing a description of a building for performing airflow and contaminant dispersal analysis. The program **NBSAVIS** allows the preparation of a building description in terms of the physical components of the building and calculates the necessary opening, zone and contaminant generation rates for analysis of the buildings interzonal airflows and contaminant dispersal. This manual presents a description of these programs, various examples on how to use the programs, and, in appendices, the theory underlying the programs and their structure.

Acknowledgments

References

1. Walton, G. N., "A Computer Algorithm for Estimating Infiltration and Inter-Room Air Flows," 1983, NBSIR 83-2635, National Institute of Standards and Technology, Gaithersburg, MD.

2. Walton, G. N., "A computer algorithm for predicting infiltration and interroom airflows," 1984, ASHRAE Transactions, Vol. 90, Part 1B, Pp. 601-610.

3. Persily, A. K., & Grot, R. A., "The Airtightness of Office Building Envelopes," in "Thermal Performance of Exterior Envelopes of Buildings III," 1986, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. publication no. SP49, Atlanta.

4. Axley, J., "Indoor Air Quality Modeling Phase II Report," 1987, NBSIR 87-3661, National Institute of Standards and Technology, Gaithersburg, MD.

5. Axley, J., "Progress Toward A General Analytical Method for Predicting Indoor Air Pollution in Buildings - Indoor Air Quality Modeling Phase III Report," 1988, NBSIR 88-3814, National Institute of Standards and Technology, Gaithersburg, MD.

6. Liddament, M. W., "Air Infiltration Calculation Techniques - An Applications Guide," 1986, Air Infiltration and Ventilation Centre, Coventry, UK.

7. Nazaroff, W. W, & Nero, A.V. (Editors), Radon and Its Decay Products in Indoor Air, 1988, John Wiley & Sons, New York.

8. ASHRAE Handbook of Fundamentals, 1988, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

9. Walton, G. N., "AIRNET - A Computer Program for Building Airflow Network Modelling," 1989, NISTIR 89-4072, National Institute of Standards and Technology, Gaithersburg, MD.

Appendix A. Building Pressure Coefficient Data

There are few existing sources of wind pressure coefficients for use in building air infiltration analysis. The following data are taken from Reference 6.

Table A1. Wind Pressure Coefficients for an Exposed Building - Aspect Ratio 1:1

Building height	less then 3 stories
Length to width ratio	1:1
Shielding condition	exposed
Wind speed reference height	building height

	Wind Angle Relative to Surface Normal							
Surface	0	45	90	135	180	225	270	315
Vertical wall	0.7	0.35	-0.5	-0.4	-0.2	-0.4	-0.5	0.35
Roof flat	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Roof (<10° pitch)	-0.8	-0.7	-0.8	-0.5	-0.4	-.0.5	-0.6	-0.7
Roof (11-30°pitch)	-0.4	-0.5	-0.6	-0.5	-0.4	-0.5	-0.6	-0.5
Roof (>30° pitch)	-0.3	-0.4	-0.6	-0.4	-0.5	-0.4	-0.6	-0.4

Table A2. Wind Pressure Coefficients Building Surrounded by Half Height Obstacles - Aspect Ratio 1:1

Building height   less then 3 stories

Length to width ratio   1:1

Shielding condition   surrounded by obstacles equal to 1/2 building height

Wind speed reference height   building height

Wind Angle Relative to Surface Normal								
Surface	0	45	90	135	180	225	270	315
Vertical wall	0.4	0.1	-0.3	-0.35	-0.2	-0.35	-0.3	0.1
Roof flat	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Roof (<10° pitch)	-0.6	-0.5	-0.4	-0.5	-0.6	-.0.5	-0.4	-0.5
Roof (11-30° pitch	-0.35	-0.45	-0.55	-0.45	-0.35	-0.45	-0.55	-0.45
Roof (>30° pitch)	0.3	-0.5	-0.6	-0.5	-0.5	-0.5	-0.6	-0.5

Table A3. Wind Pressure Coefficients for a Building Surrounding Full Height Obstacles - Aspect Ratio 1:1

Building height   less then 3 stories

Length to width ratio   1:1

Shielding condition   surrounded by obstacles equal to building height

Wind speed reference height   building height

Wind Angle Relative to Surface Normal								
Surface	0	45	90	135	180	225	270	315
Vertical wall	0.2	0.05	-0.25	-0.3	-0.25	-0.3	-0.25	0.05
Roof flat	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Roof (<10° pitch)	-0.5	-0.5	-0.4	-0.5	-0.5	-.0.5	-0.4	-0.5
Roof (11-30° pitch	-0.3	-0.4	-0.5	-0.4	-0.3	-0.4	-0.5	-0.4
Roof (>30° pitch)	0.25	-0.3	-0.5	-0.3	-0.4	-0.3	-0.5	-0.3

Table A4. Wind Pressure Coefficients for Exposed Building - Aspect Ratio 2:1

Building height	less then 3 stories
Length to width ratio	2:1
Shielding condition	exposed
Wind speed reference height	building height

	Wind Angle Relative to Surface Normal							
Surface	0	45	90	135	180	225	270	315
Long vertical wall	0.5	0.25	-0.5	-0.9	-0.7	-0.9	-0.5	0.25
Short vertical wall	0.6	0.2	-0.9	-0.6	-0.35	-0.6	-0.9	0.2
Roof flat	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Roof (<10° pitch)	-0.7	-0.7	-0.6	-0.7	-0.7	-0.7	-0.8	-0.7
Roof (11-30° pitch	-0.7	-0.7	-0.7	-0.6	-0.5	-0.6	-0.7	-0.7
Roof (>30° pitch)	0.25	-0.0	-0.6	-0.9	-0.8	-0.9	-0.6	-0.0

Table A5. Wind Pressure Coefficients for Semi-sheltered Building - Aspect Ratio 2:1

Building height	less then 3 stories
Length to width ratio	2:1
Shielding condition	semi-sheltered
Wind speed reference height	building height

	Wind Angle Relative to Surface Normal							
Surface	0	45	90	135	180	225	270	315
Long vertical wall	0.5	0.25	-0.5	-0.8	-0.7	-0.9	-0.5	0.25
Short vertical wall	0.6	0.2	-0.9	-0.8	-0.35	-0.6	-0.9	0.2
Roof flat	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Roof (<10° pitch)	-0.7	-0.7	-0.8	-0.7	-0.7	-0.7	-0.8	-0.7
Roof (11-30° pitch	-0.7	-0.7	-0.7	-0.6	-0.5	-0.6	-0.7	-0.7
Roof (>30° pitch)	0.25	-0.0	-0.6	-0.9	-0.8	-0.9	-0.6	-0.0

Table A6. Wind Pressure Coefficients for Sheltered Building - Aspect Ratio 2:1

Building height	less then 3 stories
Length to width ratio	2:1
Shielding condition	sheltered
Wind speed reference height	building height

	Wind Angle Relative to Surface Normal							
Surface	0	45	90	135	180	225	270	315
Long vertical wall	0.06	-0.12	-0.2	-0.38	-0.3	-0.38	-0.2	0.12
Short vertical wall	0.18	0.15	-0.3	-0.32	-0.2	-0.32	-0.3	0.15
Roof flat	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47	-0.47
Roof (<10° pitch)	-0.49	-0.46	-0.41	-0.46	-0.49	-0.46	-0.41	-0.46
Roof (11-30° pitch)	-0.49	-0.46	-0.41	-0.46	-0.4	-0.46	-0.41	-0.46
Roof (>30° pitch)	0.06	-0.15	-0.23	-0.6	-0.42	-0.6	-0.23	-0.15

Appendix B. Data File Structure

The program **NBSAVIS** produces a series of files: PROJECT.DSC, PROJECT.ZON, PROJECT.OPN, PROJECT.FAN, PROJECT.KIN, PROJECT.SUR, and PROJECT.CTN, which are used by **CONTAM88**. The data structure of these files is described below.

Kinetic Data   File: PROJECT.KIN

The file PROJECT.KIN stores data for the kinetic reactions. The first line of the file contains the integer M, the number of kinetic reactions. If there are no kinetic reactions in the analysis, this file is not created. The reaction data is stored on the remaining lines of the file in matrix row, column format. Thus this file has $N \cdot M + 1$ lines, where N is the number of contaminants. The data on each line are separated by a space and are in floating point format.

Line	Data
1	M
2	$R_1[1,1] \ R_1[1,2] \ ... \ R_1[1,N]$
	$R_1[2,1] \ R_1[2,2] \ ... \ R_1[2,N]$
	...
	$R_1[N,1] \ R_1[N,2] \ ... \ R_1[N,N]$
N+1	$R_2[1,1] \ R_2[1,2] \ ... \ R_2[1,N]$
N+2	...
2N	$R_2[N,1] \ R_2[N,2] \ ... \ R_2[N,N]$
2N+1	$R_3[1,1] \ R_3[1,2] \ ... \ R_3[1,N]$
	...
(M-1)N	$R_M[1,1] \ R_M[1,2] \ ... \ R_M[1,N]$
	.
$M \cdot N+1$	$R_M[N,1], R_M[N,2], ... \ R_M[N,N]$

where $R_I[k,l]$ for I = 1 to M and k,l = 1 to N are the kinetic rate coefficients of the Ith chemical reaction.

Surface Data   File: PROJECT.SUR

The file PROJECT.SUR contains the surface pressure coefficients for the exterior surfaces used in the air flow analysis. The first line of the file contains the integer N, the number of surfaces in the analysis. If this file does not exist CONTAM88 uses a default algorithm for the surface pressure coefficients. The remaining N lines of the file each contain the data for each surface. Each line starts with an integer M_J, the number of pressure coefficients for the surface. The remaining data on the line are the M_J pressure coefficients for the surface.

Line	Data
1	N
2	M_1 $C_1[1]$ $C_1[2]$ ... $C_1[M_1]$
3	M_2 $C_2[1]$ $C_2[2]$ ... $C_2[M_2]$
...	
N+1	M_N $C_N[1]$ $C_N[2]$ ... $C_N[M_N]$

where $C_J[k]$, J = 1 to N, k = 1 to M_J is the kth pressure coefficient of the Jth surface.

Initial Data   File: PROJECT.INI

The file PROJECT.INI contains the initial contaminant concentrations for each zone for starting the transient contaminant dispersal analysis. This file must be created with an ASCII editor. It contains N lines of data, where N is the number of building zones. Each line contains an integer J, the zone number, followed by the M initial concentrations of the contaminants in the zone.

Line	Data
1	1 $C_1[1]$ $C_1[2]$ ... $C_1[M]$
2	2 $C_2[1]$ $C_2[2]$ ... $C_2[M]$
...	
N	N $C_N[1]$ $C_N[2]$ ... $C_N[M]$

where $C_J[k]$, J = 1 to N, k = 1 to M is the initial concentration of the kth contaminant of Jth zone. If this file does not exist, the initial concentration is assumed to be zero.

Zone Data   File: PROJECT.ZON

The file PROJECT.ZON contains the data for the zones of the buildings. The file contains 2 + N·(1+M) lines where N is the number of zones and M is the number of contaminants. The first line contains the title of the project. The second line contains two integers N and M, and the floating point number PB where N is the number of zones, M is the number of contaminants and PB is the initial barometric pressure. The remaining lines of the file are organized in N blocks of M+1 lines of data, a block for each zone. The first line of each block contains an integer n, followed by the floating point numbers V, T and Z, followed by two integers k and m, where n is the zone number, V is the zone volume in m^2, V is the zone volume in m^3, T is the zone temperature in degrees Celsius, Z is the height of the zone above the reference height (usually ground level) in meters, k is the number of the kinetic reaction number occurring in the zone (k=0 indicates that no kinetic reaction occurs in the zone), and m is an integer indicating if the zone is to be considered as an interior zone for the purpose of reporting total building infiltration and exfiltration (m=1 indicates an interior zone, m=0 indicates that the zone is not to be considered an interior zone). The remaining M lines of the block contain the source strength data for each contaminant for the contaminant sources in the zone. Each of these lines contains four floating point numbers $SO_J[l]$, $SLOPE_J[l]$, $CP_J[l]$, and $EP_J[l]$, where $SO_J[l]$ is the source strength of the non-pressured induced contaminant emissions for the Jth zone, l^{th} contaminant; $SLOPE_J[l]$ is the removal rate in J^{th} zone of lth contaminant due to disposition, plateout or diffusion with materials in the zone, $CP_J[l]$ is the coefficient of the source strength of the pressure induced component of the Jth zone emissions of the lth contaminant, and $EP_J[l]$ is the exponent of the pressure induced component. The source strength $S_J[l]$ of the lth contaminant in the Jth zone is given by:

$$SJ[l] = SOJ[l] - SLOPE[l] \cdot cJ[l] + CP[l] \cdot dPJ^{\{EP[l]\}}$$

where $c_J[l]$ is the concentration of the lth contaminant in the Jth zone and dP_J is the exterior-interior pressure difference of the J^{Th} zone (if $dP_J < 0$, then dP_J is set to zero in the above expression.

Line	Data
1	TITLE
2	N M PB
3	n_1 V_1 T_1 Z_1 k_1 m_1
4	$SO_1[1]$ $SLOPE_1[1]$ $CP_1[1]$ $EP_1[1]$
...	
3+M	$SO_1[M]$ $SLOPE_1[M]$ $CP_1[M]$ $EP_1[M\}$
4+M	n_2 V_2 T_2 Z_2 k_2 m_2
5+M	$SO_2[1]$ $SLOPE_2[1]$ $CP_2[1]$ $EP_2[1]$
...	
4+2M	$SO_2[M]$ $SLOPE_2[M]$ $CP_2[M]$ $EP_2[M]$

...

...

$2+(N-1)M$ n_N V_N T_N Z_N k_N m_N

$3+(N-1)M$ $SO_N[1]$ $SLOPE_N[1]$ $CP_N[1]$ $EP_N[1]$

...

$2+N(M+1)$ $SO_N[M]$ $SLOPE_N[M]$ $CP_N[M]$ $EP_N[M]$

Leakage Data   File: PROJECT.OPN

The file PROJECT.OPN contains the opening leakage data. It has L lines, where L is the number of openings. Each line contains three integers j, n_j, and m_j, followed by six floating point numbers A_j, X_j, AZ_j, AT_j, ZS_j, and ZT_j, followed by the integer ns_j. In the above, j is the opening number, n_j refers to the originating zone, m_j refers to the destination zone (if the flow is positive) ($m_j = 0$ indicates the exterior), A_j is the opening flow coefficient in kg/s·Pa$^{(Xj-1/2)}$ Pa, X_j is the opening flow exponent, AZ_j is the azimuth angle of the surface containing the opening in degrees from north, AT_j is the tilt angle of the surface containing the opening in degrees from the horizontal, ZS_j is the height of the opening above the reference height in meters, ZT_j is the top height of the surface containing the opening at which the local wind speed is calculated in meters (**NBSAVIS** sets all ZT_j's equal to the building height) and ns_j is the number of the surface type which contains the opening (ns_j, is used to indicate which set of pressure coefficients should be used to calculate the wind pressures on the opening; if $ns_j = 0$, the default algorithm is used).

Line	Data
1	1 n_1 m_1 A_1 X_1 AZ_1 AT_1 ZS_1 ZT_1 ns_1
2	2 n_2 m_2 A_2 X_2 AZ_2 AT_2 ZS_2 ZT_2 ns_2
...	
L	L n_L m_L A_L X_L AZ_L AT_L ZS_L ZT_L ns_L

Fan Data   File: PROJECT.FAN

The file PROJECT.FAN contains the fan data. It has L lines of data, where L is the number of fans in the building. Each line contains three integers j, n_j, and m_j, followed by M+1 floating point numbers F_j, and $E_j[1]$,...,$E_j[M]$, where L is the number of fan flows and M is the number of contaminants. In the above, j is the fan flow number, n_j refers to the originating zone ($n_j = 0$ indicates the exterior), m_j refers to the destination zone (if F_j is positive) ($m_j=0$ indicates the exterior), F_j is the fan flow rate in kg/s, $E_j[l]$ for $l= 1$ to M is the efficiency of the jth fan filter for the lth contaminant.

Line	Data
1	1 n_1 m_1 F_1 $E_1[1]$ $E_1[2]$ ... $E_1[M]$
2	2 n_2 m_2 F_2 $E_2[1]$ $E_2[2]$ ... $E_2[M]$
...	
L	L n_L m_L FL $E_L[1]$ $E_L[2]$ ... $E_L[m]$

File: PROJECT.CTN

The file PROJECT.CTN contains the contaminant data for the indoor pollutants studied in the analysis. This file has M lines of data, where M is the number of contaminants. Each line contains an integer n, followed by a space, a field 16 characters wide containing the name of the contaminant, a space, two floating numbers D_n and A_n, where D_n is the density of the contaminant in kg/m^3 and A_n is the radioactive decay constant of contaminant in s^{-1} ($A_n = 0.0$ for a non-radioactive contaminant), and an integer m_n indicating the units of the contaminant.

Line	Data
1	1 [name$_1$] D_1 A_1 m_1
2	2 [name$_2$] D2 A_2 m_2
...	
M	M [name$_M$] D_M A_M m_M

Appendix C. Description of CONTAM88

The program **CONTAM88** implements the airflow and contaminant dispersal theory described by Walton and Axley.[1-2,4-5] The structure of the program **CONTAM88** is shown in Figure C1. **CONTAM88** starts by initializing the global variables and pointers to arrays and linked lists. It then reads the parameter file, CONTAM.PAR, if it is found in the current directory, or uses default parameters if the file is not found. **CONTAM88** then opens the weather data file, CONTAM88.DTA, and reads the starting date, time, and the name of the initial building description. It then proceeds to open the corresponding data files for the zone data, contaminant

Flow Diagram
CONTAM88
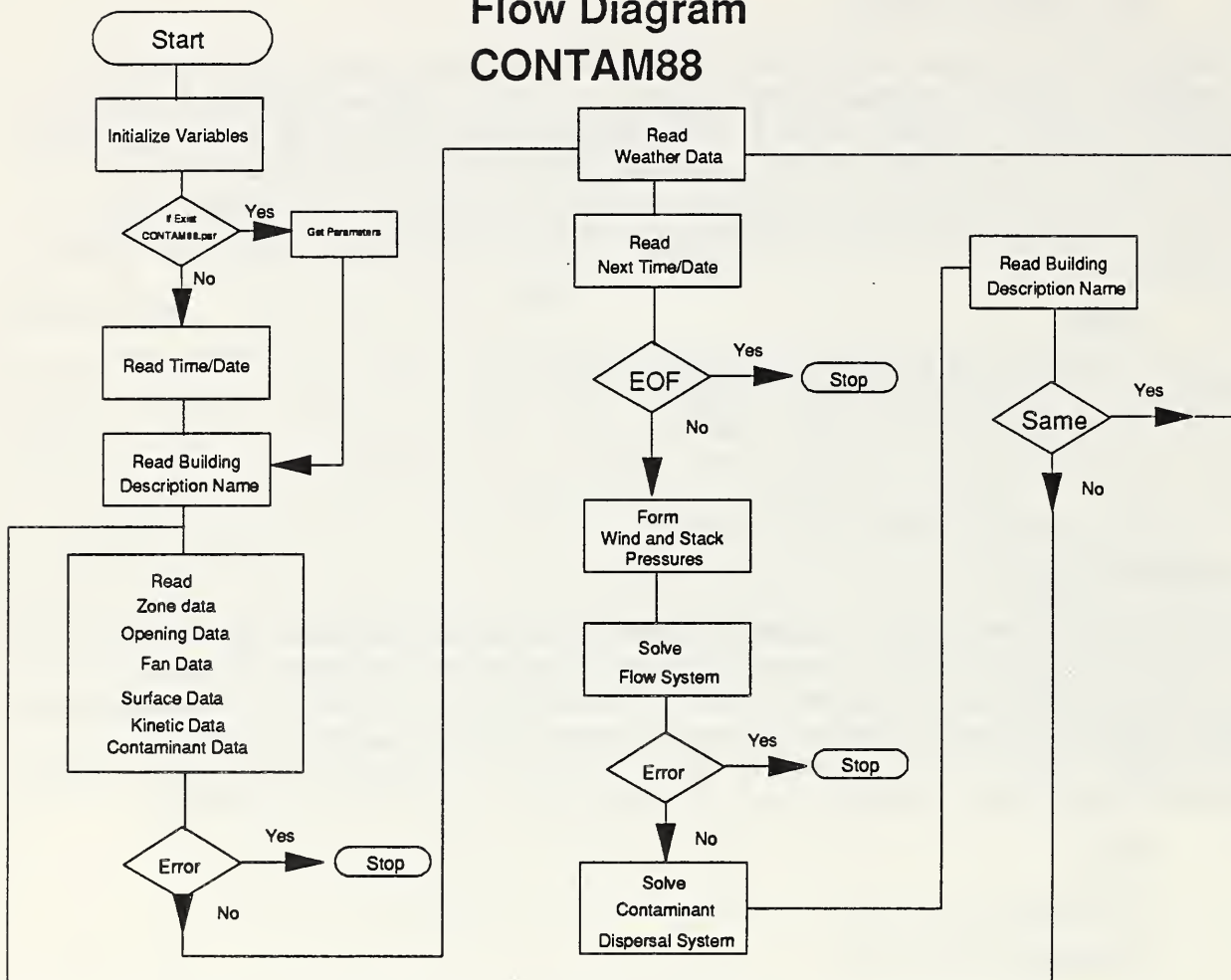
Figure 1 Schematic of Airflow and Contaminant Dispersal Program **CONTAM88**.

data, opening data, fan data, surface data and kinetic reaction data. In reading these files, the corresponding linked lists and arrays are created and the data are stored in these data structures. If an error occurs in reading these files or in allocating the required data storage, an error flag is set, and upon exit from the corresponding input routine, the program is terminated with an error message. **CONTAM88** then reads the weather data, advances to the next data record and reads the next date and time. If an end of file is encountered in advancing the data record, the program terminates. The flow system of equations is then formed and solved. If an error occurs in the solution of the flow system, the program terminates with an error message. The logic for solving the flow system of equations is presented in the next subsection. **CONTAM88** then forms and solves the contaminant dispersal system of equations if the number of contaminants is greater than zero. If an error occurs in the solution of the contaminant dispersal system, an error message is given, but the program does not terminate. **CONTAM88** then reads the next building description name. If it is different from the previous building description name, the zone data, contaminant data, opening data, fan data, surface data and kinetic data are read for the new

description. Some basic checks of the new building description are made to determine if it is consistent with the previous description, that is that the number of zones has not changed and that the number of contaminants is the same. The next weather data are then read and **CONTAM88** proceeds to solve the new flow and contaminant dispersal systems. This process continues till an end of file is encountered on the weather data file. Note that the weather data on the last record are not processed; therefore if one wishes to analyze the flows and contaminant dispersal for these weather conditions, a dummy record must be added. Note also that if the next date and time is earlier than the previous date and time, the program will also terminate.

The solution of the dynamic response of the transient contaminant dispersal system of equations uses the predictor-corrector model explained in the reports of Axley.[4,5] Three vector work arrays, dE, dC, and ddC, are allocated along with the storage for the modified dispersal matrix K_M. The initial rate of change of the contaminant concentrations is estimated from the dispersal equations and used to estimate the time step dt to guarantee at least an accuracy of 5 percent in the solution. The time is incremented and the modified dispersal matrix is calculated. For each time step dt, an initial estimate of the increment dC is determined, a correction is calculated, and the concentration is updated. If the print interval is reached, the concentrations of the massless nodes are calculated and the concentrations for each zone are printed both to the screen and the output file. This process continues till the end of the time interval is reached.

Flow Diagram - Solution of Flow Equations
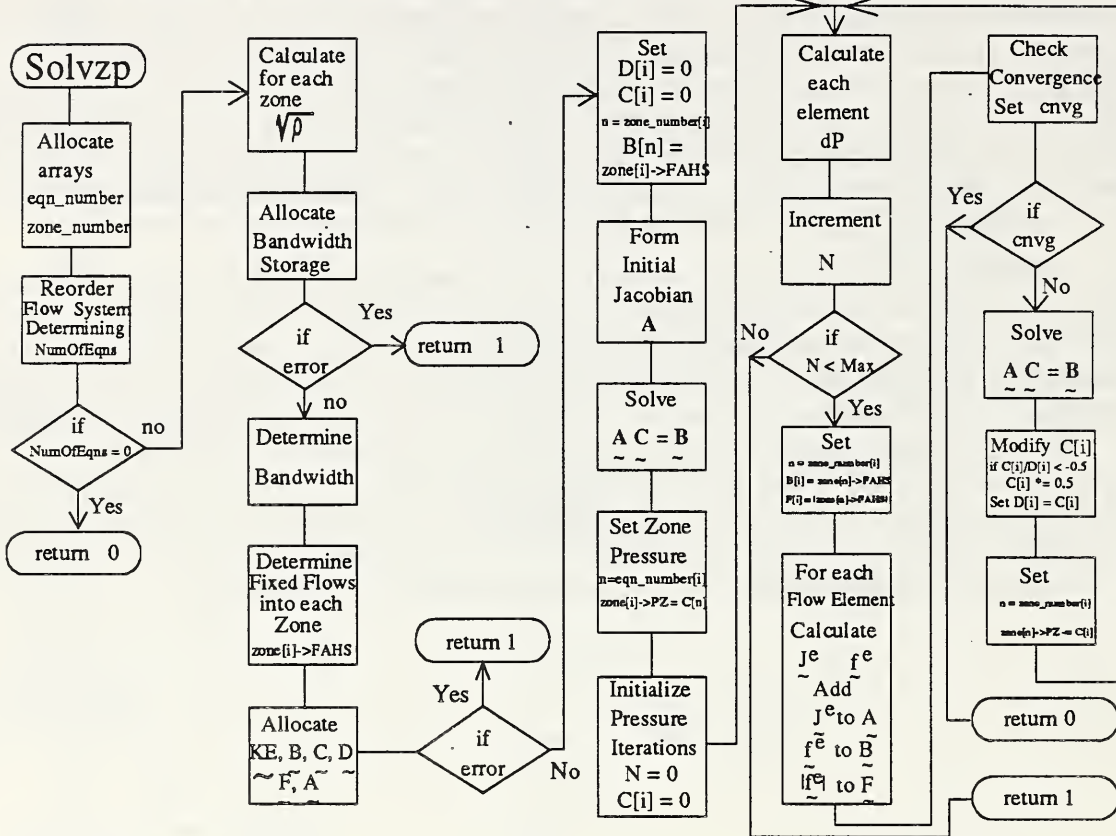
Figure C2. Schematic of Solution Method for Airflow Analysis Used by **CONTAM88**.

The solutions scheme for the air flows in the building is depicted in Figure C2. The subroutine SOLVZP allocates arrays eqn_number and zone_number. If i is an index of a zone, then eqn_number[i] is the number of the flow equation for the zone; if n is an equation number, then zone_number[n] is the zone number corresponding to the equation. The system of flow equations is then reordered in such a way that zones which are not coupled by openings to other zones are excluded from the system. (Such zones would have a zero diagonal in the Jacobian matrix.) The logic used to reorder the flow system equations is shown in Figure C3. The diagonal of the Jacobian of the unordered flow system is formed. The equations are renumbered so that all zones with non zero diagonal elements occur first, the zone with zero diagonals in the Jacobians appear last. Examples of zones which would have zero diagonal elements in the Jacobian are HVAC systems or zones coupled by only specified flows. The reorder subroutine returns the number of equations which are to be solved. If this number is zero (as would happen if all flows were specified), the solution algorithm is terminated. The square of the air densities in each zone are then calculated and stored. Storage is allocated for the bandwidth vector used to determine the storage requirements of the Jacobian matrix. The flow elements are then traversed, determining their connectivity and their influence on the bandwidth vector. The sums of all fixed flows into each zone are determined and stored these in each zone memory structure. Storage is then allocated for the element Jacobian matrix, the four vectors needed for the solution technique (**B**, the sum of the flows into a zone; **C**, the corrections to the zone pressures, **D**, the previous pressure correction vector; and **F**, the sum of the absolute values of the flows into or out of the zone), and **A**, the Jacobian matrix for the flow system. The flow system is then solved using a Newton-Raphson technique which is described in more detail below.

Re-ordering of Flow System
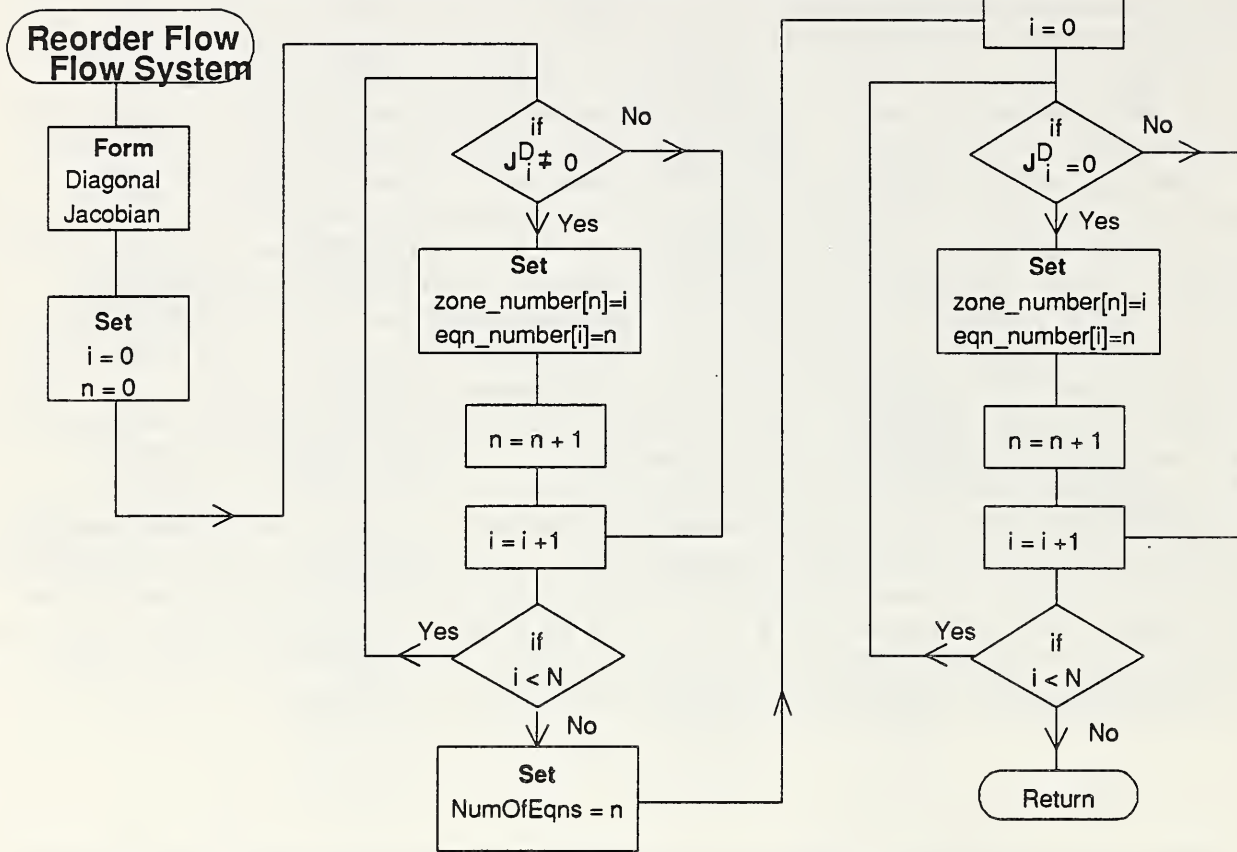
Figure C3. Schematic of Method for Re-ordering Flow System of Equations

After solving for the airflows between zones, CONTAM88 formulates and solves both the steady state and transient contaminant dispersal problem. The general method for solving the contaminant dispersal problem is shown in Figure C4.
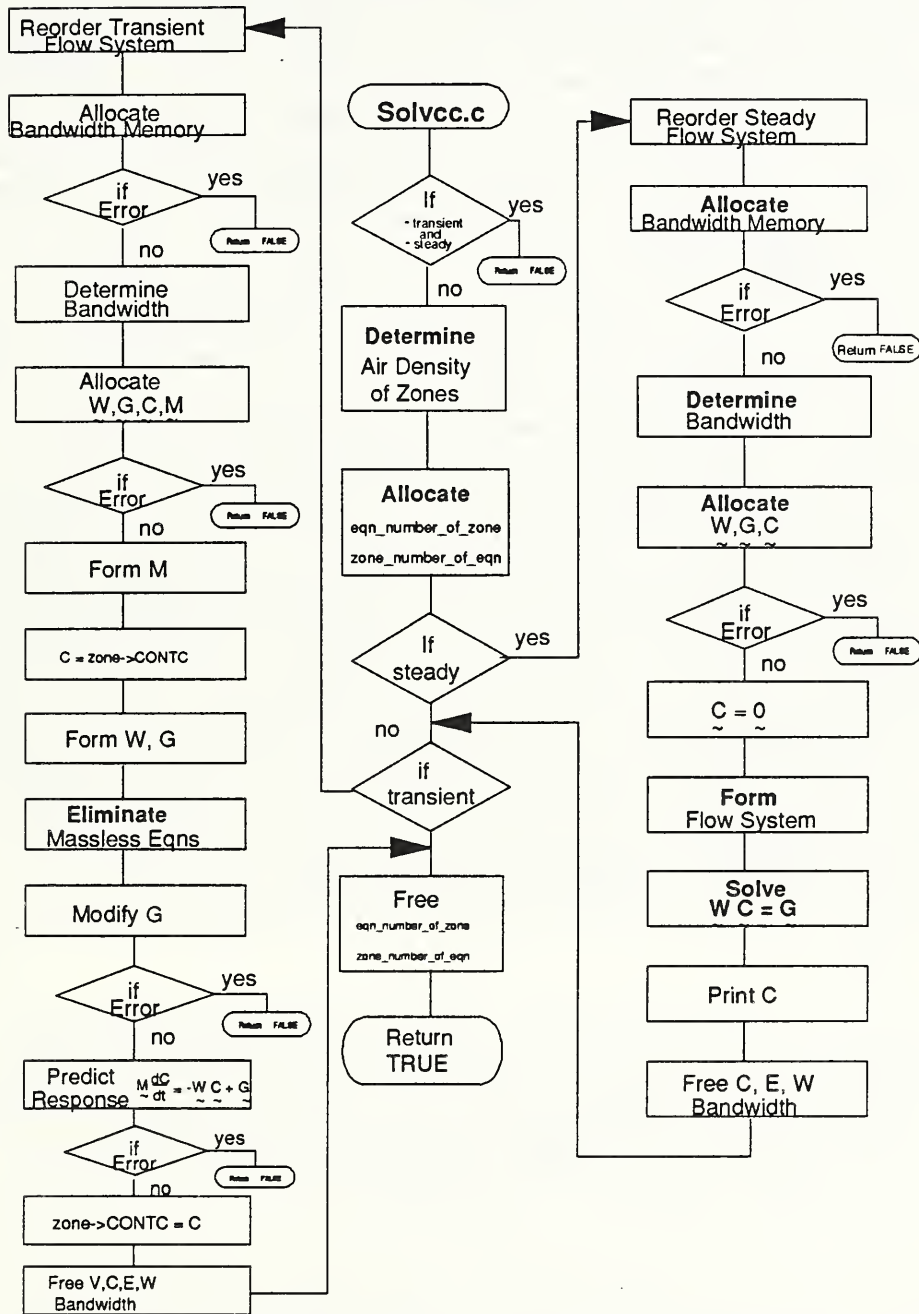
FLOW DIAGRAM
Solve Contaminant Dispersal

Figure C4. Schematic of Solution Method for Contaminant Dispersal Analysis Used by **CONTAM88**.

If the number of contaminants is greater then zero, **CONTAM88** checks to see if either a transient or steady state analysis of the contaminant dispersal problem was specified by the user. **CONTAM88** can do either one or both for each set of weather conditions. If no contaminants were specified, it returns to the main program; otherwise, it determines the air density of each zone and allocates memory for two integer arrays: eqn_number_of_zone which will later give the contaminant equation number of the zone, and zone_number_of_eqn, which will give the zone corresponding to the contaminant equation. **CONTAM88** will reorder the contaminant dispersal equations to eliminate isolated zones and for the transient analysis eliminate zones with zero volume. If a steady-state analysis was specified, **CONTAM88** formulates and solves this problem. It first reorders the flow system such that zones with non-zero airflows on the diagonal of the dispersal matrix appear as the first N_f·M unknown contaminant concentrations and the remaining $(N-N_f)$·M are contaminant concentrations for isolated zones where N is the number of zones in the building and M is the number of contaminants. The number N_f is the number of non-isolated zones and is determined by the reordering algorithm. The bandwidth of the dispersal matrix is then determined, and the memory storage required for the dispersal matrix W, the contaminant generation vector E, and the unknown contaminant concentrations C are allocated. If an error occurs in the allocation of memory, the solution is aborted. The contaminant dispersal system is then formulated and solved, and the results are written to both a file and the screen. The memory required to solve the steady state dispersal problem is then freed. **CONTAM88** checks whether a transient contaminant dispersal solution was specified. If so, it eliminates dispersal system zones which both are isolated and have zero volume. It then partitions the remaining equations so the non-zero volume zones are first. The bandwidth of the renumbered dispersal system is then determined, memory allocated for the dispersal matrix **W**, the contaminant generation vector **E**, the reordered zone mass vector **V** and the transient concentrations **C** of the reordered system. If an error occurs in the allocation of memory, the solution is aborted. The dispersal mass vector **V** is then formed, the initial concentrations are retrieved from the zone data structures and the dispersal matrix **W** and the generation vector **E** are formed. If there are equations with zero volumes (massless equations), they are eliminated from the transient system of dispersal equations.[1] The equation:

$$\overleftrightarrow{M}\frac{d\vec{C}}{dt} = \overleftrightarrow{W}\vec{C} + \vec{E}$$

is solved. Figure C5 gives the schematic of the logic for solving the transient system of equations. After the transient solution is finished for the time interval for which the weather conditions are valid, the results are stored in the zone data structures, and the memory required for the transient solution is freed. **CONTAM88** then frees the memory for the arrays eqn_number_of_eqn and zone_number_of_eqn, and returns to the main routine.

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1 The massless equations are in essence a steady state subsystem. The notes need only be solved when the results of the transient solution are written to either the screen or a file.
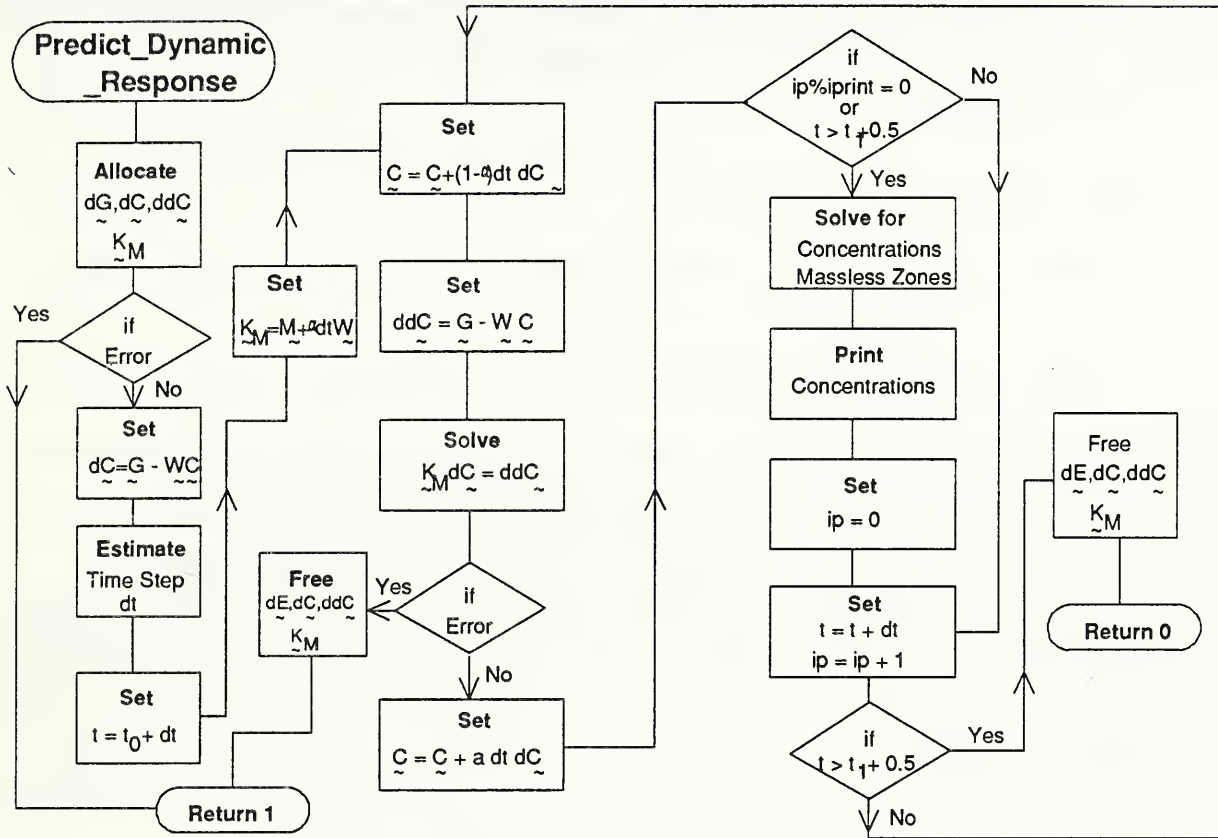
Flow Schematic

Predict Dynamic Response

Figure C5. Schematic of Solution of Transient Contaminant Dispersal Equations

Appendix D. Theory of Airflow and Contaminant Dispersal Analysis Used by CONTAM88

The basic theory of airflow analysis used by **CONTAM88** is based on the idealization that a building can be treated as a series of pressure nodes connected by a group of flow paths and that the flow through each flow path is a function of the pressures at the nodes connected by the flow paths. In buildings, the pressure nodes are usually called zones and the flow paths are called flow elements. A zone requires three parameters to specify its state for flow analysis: its pressure, its temperature and its volume. The pressure is considered an unknown to be solved by the system of equations formulated by **CONTAM88**, and the zone's temperature and volume are considered specified, though not necessarily constant. (For example, the volume of an elevator shaft below and above the elevator may change.) A flow element is specified by giving the numbers of the pressure nodes it connects and the functional form of the relation between the flow through the element and the element node pressures.

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CONTAM88 uses two types of flow elements: openings and fans. Both of these are two-node elements. If we consider the index i, i = 1,2 then the element can be defined by determining the quantities $({}^ef_i, {}^ep_i, {}^eT_i,)$ where ${}^ef_i$ is the flow into i^{th} node from the element and ${}^ep_i$ and ${}^eT_i$ are the node's pressure and temperature, respectively. These quantities are not independent. Conservation of mass on the element requirements requires that:

$$ {}^ef_1 = -{}^ef_2 \equiv {}^ef(\delta p^e) \tag{1} $$

$$ where \quad \delta p^e = {}^ep_2 - {}^ep_1 + {}^ep_w + {}^ep_s \tag{2a} $$

$$ and \quad {}^ep_s = g(\rho_2 h_2 - \rho_1 h_1) = \text{stack pressure} \tag{2b} $$

$$ and \quad {}^ep_s = \frac{1}{2} pc[m_s] \rho_0 V(H_s)^2 (\delta_{0n_2} - \delta_{0n_1}) = \text{wind pressure} \tag{2c} $$

In the above, ${}^ep_w$ is the wind pressure on the element, ${}^ep_s$ is the stack pressure across the element. h_1 and h_2 are the heights of the element above the reference height of zones n_1 and n_2, respectively, where n_1 is the zone number of the originating zone and n_2 is the zone number of the destination zone (if ${}^ef$ is positive). ρ_1 and ρ_2 are the density of air in zones n_1 and n_2, respectively. A convention that **CONTAM88** uses is that the number of the exterior zone is 0. In the expression for the wind pressure, p_w, $V(H_s)$ is the wind speed at the height of the surface containing the opening.

$$ V(H_s) = V_m \left(\frac{H_s}{10}\right)^{0.143} \tag{3} $$

where V_m is the measured meteorological wind speed at a height of 10 meters.

$pc[m_s]$ is the m_s^{th} pressure coefficient of the surface. The integer m_s is determined from the wind direction, a_w, and the azimuth angle, a_z, of the surface which contains the opening:

$$ m_s = n_s \cdot \frac{\phi}{360} + \frac{1}{2} \quad if \quad m_s \leq n_s \tag{4} $$

$$ where \quad \phi = a_w - a_z \quad if \quad a_w \geq a_z $$

$$ = 360 - (a_z - a_w) \quad if \quad a_w < a_d $$

$$ m_s = 1 \quad if \quad m_s > n_s $$

In Equation 4, n_s is the number of surface coefficients of the surface containing the opening.

Flow-Pressure Equation for an Opening.

In **CONTAM88**, the mass airflow through the opening is related to the pressure drop across the opening by a power-law equation in the turbulent flow regime and by a quadratic equation in the laminar flow regime.

$$^{e}f = \sqrt{\rho_i}\, C \delta p |\delta p|^{x-1} \quad \text{if} \quad |\delta p| \geq \Delta p_t \tag{5}$$

$$= \sqrt{\rho_i}\, \delta p (\alpha + \beta |\delta p|) \quad \text{if} \quad |\delta p| < \Delta p_t$$

where

$$\alpha = (2 - x) C \Delta p_t^{x-1}$$

$$\beta = (n - 1) C \Delta p_t^{x-2}$$

$$\Delta p_t = \frac{0.0034}{C} \tag{6}$$

and ρ_i is the inlet air density: $i = 2$ if $\delta p \geq 0$, $i = 1$ if $\delta p < 0$

In the above equation Δp_t is the transient pressure at which the flow through the element changes from laminar to turbulent. The relationship between the flow and pressure difference assures convergence of the mathematical method used to solve the flow system of equations. Note that if a linear region is not assumed about 0, the derivative of the flow equation with respect to pressure is infinite. In contrast to AIRNET,[9] CONTAM88 requires that both f and its derivative are continuous at the transient pressure. The expressions for α and β are derived from these conditions.

One can justify the expression for the transition pressure by the following reasoning: Let U be the velocity of air passing through the opening.

$$U = \frac{f}{\rho A_l} \tag{7}$$

$$A_l = \frac{C}{k} \tag{8}$$

$$k \equiv \frac{\delta P_{ref}^{0.5-x}}{\sqrt{2}} \tag{9}$$

where A_l is the leakage area of the opening and k is the discharge coefficient. The reference pressure δP_{ref} is usually chosen to be 4 Pa in the United States. Then the Reynolds number, Re, of the flow through the opening can be expressed as:

$$Re \equiv U \frac{L}{\nu} \tag{10}$$

ν is the viscosity of air $= 1.5 \cdot 10^{-5}$

L is a representative length $\cong \sqrt{A_l}$

In the turbulent flow region, the Reynolds number can be related to the pressure drop across the flow path by:

$$Re = \sqrt{\frac{2A_l k}{\rho} \frac{k}{\nu}} \delta p^x \tag{11}$$

The transition pressure, Δp_t, can thus be estimated by the expression:

$$\Delta p_t = \left(\sqrt{\frac{\rho}{2A_l} \frac{Re_t}{k}} \nu \right)^{\frac{1}{x}} \tag{12}$$

$$= \left(\sqrt{\frac{\rho}{2Ck}} Re_t \nu \right)^{\frac{1}{x}}$$

$$\cong \frac{\rho}{2Ck} (Re_t \nu)^2$$

where Re_t is the Reynolds number at which the flow becomes turbulent.

If one assumes that the transition to turbulence occurs for a Reynolds number of about 5,000, one obtains the previous given expression for Δp_t.

Fan Flow Element

The fan flow element used by **CONTAM88** is a simple fixed flow element whose flow pressure relation is given by:

$$f(\delta p^e) = F_0 \tag{13}$$

If F_0 is positive, flow is from node 2 to node 1 of the element; if F_0 is negative, the flow is from node 1 to node 2. There is no mathematical difficulty in introducing fan curves into the theory; however the present version of **CONTAM88** treats fans as constant flow elements.

Formation of the Flow System

The system of flow equations which are to be solved for the pressure in each zone can be formulated by defining the flow and pressure vectors for each element as:

$$\vec{\mathbf{p}}_e \equiv \begin{bmatrix} {}^e p_1 \\ {}^e p_2 \end{bmatrix} \tag{14}$$

$$\vec{\mathbf{f}}_e \equiv \begin{bmatrix} {}^e f_1 \\ {}^e f_2 \end{bmatrix} \tag{15}$$

If one defines the system pressure vector $\vec{\mathbf{p}}$ and zone flow vector, $\vec{\mathbf{f}}$, such that:

$$\vec{\mathbf{p}} \equiv \begin{bmatrix} p_1 \\ p_2 \\ \dots \\ p_N \end{bmatrix} \qquad \vec{\mathbf{f}} \equiv \begin{bmatrix} f_1 \\ f_2 \\ \dots \\ f_N \end{bmatrix} \tag{16}$$

where p_i is the pressure of the ith zone, f_i is the system of the mass flows into the ith zone minus the sum of the flows out of the ith zone from all elements, and N is the number of independent pressures nodes for the system.

One can then consider the mapping of the element node pressures into the zone pressures given by the equation:

$$\vec{\mathbf{p}}_e = \vec{\mathbf{B}}_e \vec{\mathbf{p}} \tag{17}$$

where

$$\vec{\mathbf{B}}_e \equiv [B_{ij}^e] = \begin{bmatrix} B_{11} & B_{12} & \dots & B_{1N} \\ B_{21} & B_{22} & \dots & B_{2N} \end{bmatrix} \tag{18}$$

where $\quad B_{ij}^e = \delta_i 1 \delta_{jn_1} + \delta_i 2 \delta_{jn_2}$

In Equation 18, n_1 is the zone number of element node 1, and n_2 is the zone number of element node 2. Zone numbers n_1 and n_2 are determined by the building description processor **NBSAVIS**, and stored by **CONTAM88** in the data structure for each element.

The system flow vector, $\vec{\mathbf{f}}$, can then be formed from the element flow vectors by the operation:

$$\vec{\mathbf{f}}(\vec{\mathbf{p}}) = \sum_{\forall e} \vec{\mathbf{B}}_e^T \vec{\mathbf{f}}_e (\vec{\mathbf{B}}_e \vec{\mathbf{p}}) \tag{18}$$

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where the summation is over all flow elements.

The conservation of mass at each zone requires that:

$$\vec{f}(\vec{p}) = \frac{d\vec{m}}{dt} \tag{19}$$

where $\vec{m}$ is the vector of zone masses.

$$\vec{m} \equiv \begin{bmatrix} \rho_1 V_1 \\ \rho_2 V_2 \\ \dots \\ \rho_N V_N \end{bmatrix} \tag{20}$$

where ρ_i is the air density of the ith zone and V_i is the zone volume.

The above set of equations constitutes a nonlinear system of N equations for the N zone pressures.

In most cases, the right hand side of the flow equations is zero (that is, there is no rate of change of mass inside the zone). However, there are instances in which these terms cannot be neglected. For example, in the case of changing zone temperature or varying barometric pressure, the zone air densities will change with time. If one is modelling two sections of an elevator shaft with a moving elevator, the volumes of the two zones will change with time. CONTAM88 does, however, consider the right hand side of the flow equations to be negligible.

Solution of the Flow System

The system of flow equations is solved using a Newton-Raphson technique. If one defines the Jacobian matrix:

$$\vec{\vec{J}}(\vec{p}) \equiv -\frac{\partial \vec{f}}{\partial \vec{p}} \tag{21}$$

then the flow system can be solved iteratively by the procedure:

$$\vec{J}(\vec{0})\Delta\vec{p}^0 = \vec{f}(\vec{0}) - \frac{d\overrightarrow{m}}{dt} \tag{22}$$

$$^1\vec{p} = \Delta\vec{p}^0$$

then for $\alpha = 1 \ldots$

$$\vec{J}(^\alpha\vec{p})\Delta\vec{p}^\alpha = \vec{f}(^\alpha\vec{p}) - \frac{d\overrightarrow{m}}{dt} \tag{23}$$

$$^{\alpha+1}\vec{p} = {}^\alpha\vec{p} + \overrightarrow{\omega}\Delta\vec{p}^\alpha$$

where
$$\overrightarrow{\omega} \equiv \begin{bmatrix} \omega_1 & 0 & \ldots & 0 \\ 0 & \omega_2 & \ldots & 0 \\ & \ldots & \ldots & \\ 0 & 0 & \ldots & \omega_N \end{bmatrix}$$

and $\omega_i = 1$

unless $\dfrac{\Delta p_i^\alpha}{\Delta p_i^{\alpha-1}} < -0.5$

in which case

$\omega_i = 0.5$

until the convergence criteria are satisfied or $\alpha > MAXIT$

In the above scheme, ω_i are relaxation factors used to prevent oscillations in the convergence of the solution.

It can be shown that the Jacobian matrix of the flow system can be formed from the Jacobian matrices of the flow elements:

$$\vec{J}(\vec{p}) = \sum_{\forall e} \vec{B}_e^T \vec{J}_e \vec{B}_e \tag{24}$$

where $\vec{J}_e \equiv -\dfrac{\partial \vec{f}_e}{\partial \vec{p}_e}$

For two-node flow elements in which the flow depends on the difference of the nodal pressures, it can be shown that the element Jacobian has the form:

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$$\vec{\mathbf{J}}_e = d^e f \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \quad \text{if } n_1 \neq 0 \text{ and } n_2 \neq 0 \tag{25}$$

$$= d^e f \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \quad \text{if } n_2 = 0$$

$$= d^e f \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \quad \text{if } n_1 = 0$$

$$\text{where} \quad d^e f \equiv \frac{d^e f}{d\delta p}$$

Note that since the element Jacobian matrices are symmetric, the flow system Jacobian is symmetric. Also, since $d^e f > 0$, the diagonal elements are positive and the off-diagonal elements are negative or zero, and the sum of the absolute value of off-diagonal elements is less than or equal to the diagonal elements for each element matrix. The same holds true for the system Jacobian. Therefore, the system Jacobian is a symmetric M-matrix, and if a diagonal element of the system flow matrix is zero, then all elements in the row and column which contain the diagonal element are zero. That the Jacobian is an M-matrix has two important consequences for the theory. First, the system of Equations 23 for $\Delta \mathbf{p}$ can be solved by LU decomposition without pivoting. That pivoting is not required allows the use of compact and skyline matrix storage techniques which could be destroyed by pivoting. Second, that a zone is isolated can be determined by checking whether the diagonal element of the Jacobian is zero. Note also from the form of the element pressure-flow relation, a zero diagonal element at any pressure implies that the flow coefficients of all elements connected to the zone are zero; therefore, the diagonal element is identically zero at all pressures.

Convergence Criteria

CONTAM88 uses a combination of an absolute and relative convergence criteria on the components of the zone flow vector.

if $|f_i| > \varepsilon_1$ and $|f_i| / \sum_{\forall e} |{}^e f_i| > \varepsilon_2$ for any i, then cnvg = false; otherwise convg = true

The default values for ε_1 and ε_2 are 0.000001 and 0.0001, respectively.

Reordering of the Flow System

The above properties of the Jacobian matrix are used to check if the flow system contains non-pressure coupled zones. In general such zones are coupled only by fixed fan flows. For the flow system to be consistent in this case, the sum of the fixed flows for such a zone must be zero. **NBSAVIS** guarantees that this is the case for HVAC systems (which are examples of such zones). However, it is possible to consider buildings which have rooms coupled only by fixed flows. For a consistent contaminant dispersal system, the analyst must guarantee that such flows sum to zero. Such rooms are eliminated from the flow system of equations by the reordering scheme shown in Figure C3. The diagonal of the Jacobian matrix is formed for the case of an element dp = 1 for each element, and the system is renumbered such that the first N_p equations have non-zero diagonal elements, where N_p is the number of pressure equations.

Contaminant Dispersal

The contaminant dispersal theory implemented by **CONTAM88** is a slightly modified version of the well-mixed zone theory presented by Axley[4-5]. The theory of **CONTAM87** has been expanded to include the phenomenon of plateout, without resorting to the use of dummy kinetic reaction elements. The convection diffusion element of **CONTAM87** has not been included in **CONTAM88**. The contaminant dispersal theory of **CONTAM88** is a multi-contaminant theory which includes the physical effects of the transport of contaminants by air movement, the removal of contaminants by plateout and the kinetic reaction of contaminants within a zone. The theory also includes contaminant sources which can depend on the exterior-interior pressure differences across the building (for example, pressure driven radon sources). The basic equations for the contaminant dispersal in a building can be derived from the conservation of mass for each contaminant specie in each zone of the building:

$$\frac{d}{dt}(m_i C^\alpha_i) = -(f^{(out)}_i + R^\alpha_i)C^\alpha_i + \sum_{\forall e}\sum_{j=0}^{N}(1 - {}^e\eta^\alpha)^e f^{(in)}_{ij}C^\alpha_j + m_i\sum_{\beta=1}^{M}\kappa^i_{\alpha\beta}C^\beta_i + g^\alpha_i \quad , i=1...N \tag{26}$$

where $m_i \equiv \rho_i V_i$

In Equation 26, C^α_i is the concentration of the αth contaminant specie in the ith zone, m_i is the mass of air in the ith zone, $f^{(out)}_i$ is the sum of all air flows out of the ith zone, $f^{(in)}_{ij}$ is the sum of all air flows into the ith zone for the jth zone, R^α_i is the removal rate by plateout or deposition of the αth specie in the ith zone, ${}^e\eta^\alpha$ is the filter efficiency for the eth flow element and the αth specie, $\kappa^i_{\alpha\beta}$ is the kinetic reaction coefficient in the ith zone between α^{th} and β^{th} species and g^α_i is the generation rate of the αth specie in the ith zone. In Equation 26, j = 0 denotes the exterior zone; that is $f^{(in)}_{i0}$ is the flow into the ith zone form the exterior and ${}^\alpha C_0$ is the concentration of the αth specie in the exterior zone. **CONTAM88** uses mass flow rates for airflows, and units of mass of contaminant per unit mass of air for the concentration of pollutant species in contaminant dispersal calculations. Note also the definition of the kinetic rate matrix is such that a positive coefficient produces an increase in contaminant mass (**CONTAM87** uses the opposite sign convention).

If for each flow element we define ${}^e f^{(out)}_i$ as the flow out of the zone through the flow element and ${}^e f^{(in)}_{ij}$ as the flow into the ith zone from the jth zone, then:

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$$^e f_i^{(out)} = \delta_{i n_2} {}^e f \quad \text{if} \quad {}^e f \geq 0 \qquad (27)$$

$$= -\delta_{i n_1} {}^e f \quad \text{if} \quad {}^e f < 0$$

$$^e f_{ij}^{(in)} = \delta_{i n_1} \delta_{j n_2} {}^e f \quad \text{if} \quad {}^e f \geq 0 \qquad (28)$$

$$= -\delta_{i n_2} \delta_{j n_1} {}^e f \quad \text{if} \quad {}^e f < 0$$

$f^{(out)}_i$ and $f^{(in)}_i$, the total flows out of and into the ith zone respectively, are given by:

$$f_i^{(out)} = \sum_{\forall e} {}^e f_i^{(out)} \qquad (29)$$

$$f_i^{(in)} = \sum_{j=0}^{N} \sum_{\forall e} {}^e f_{ij}^{(in)} \qquad (30)$$

From the conservation of mass for the air in the ith zone (Equation 19), it can be shown that $f^{(out)}_i$ and $f^{(in)}_i$ are related by:

$$\frac{dm_i}{dt} = -f_i^{(out)} + f_i^{(in)} \qquad (31)$$

Therefore, Equation 26 can be written as:

$$m_i \frac{d^\alpha C_i}{dt} = -{}^\alpha R_i {}^\alpha C_i - \sum_{j=0}^{N} \sum_{\forall e} \{ {}^e f_{ij}^{(in)\alpha} C_i - (1 - {}^e \eta^\alpha) {}^e f_{ij}^{(in)\alpha} C_j \} + m_i \sum_{\beta=1}^{M} \kappa_{\alpha\beta}^{\ j} {}^\beta C_i + g_i^\alpha \qquad (32)$$

Note that Equation 32 is the correct form of the conservation of species equation for the case where the m_i are not constant but time varying functions (the coefficient of $^\alpha C_i$ in the equation for $^\alpha C_i$ is the sum of the flows into the ith zone, not necessarily the flow out of the zone).

Defines for each zone and species, the vector $\vec{C_i}$:

$$\vec{C_i} = \begin{bmatrix} {}^1 C_i \\ {}^2 C_i \\ \dots \\ {}^M C_i \end{bmatrix} \qquad (33)$$

For each element, define the element vector $^e \vec{C}^\alpha$:

$$^e \vec{C}^\alpha \equiv \begin{bmatrix} {}^\alpha C_1^e \\ {}^\alpha C_2^e \end{bmatrix} \qquad (34)$$

The element vectors form the system contaminant vector $\vec{C}$:

$$\vec{C} \equiv \vec{C}_1 \oplus \vec{C}_2 \oplus \ldots \oplus \vec{C}_N = \begin{bmatrix} \vec{C}_1 \\ \vec{C}_2 \\ \ldots \\ \vec{C}_N \end{bmatrix} \qquad (35)$$

The contaminant dispersal equations can be written in the form:

$$\overleftrightarrow{m}\frac{d\vec{C}}{dt} = -\overleftrightarrow{W} \cdot \vec{C} + \vec{g}' \qquad (36)$$

where $\overleftrightarrow{m}$ is the system mass matrix, $\overleftrightarrow{W}$ is the total system dispersal matrix and $\vec{g}'$ is the total system contaminant generation vector.

The system mass matrix is:

$$\overleftrightarrow{m} \equiv \overleftrightarrow{m}_1 \oplus \overleftrightarrow{m}_2 \ldots \oplus \overleftrightarrow{m}_N = \begin{bmatrix} \overleftrightarrow{m}_1 & \vec{0} & \vec{0} & \cdots & \vec{0} \\ \vec{0} & \overleftrightarrow{m}_2 & \vec{0} & \cdots & \vec{0} \\ \vec{0} & \vec{0} & \cdots & \cdots & \vec{0} \\ \vec{0} & \vec{0} & \cdots & \vec{0} & \overleftrightarrow{m}_N \end{bmatrix} \qquad (37)$$

where $\overleftrightarrow{m}_i$ is the mass matrix of the ith zone:

$$\overleftrightarrow{m}_i \equiv m_i \overleftrightarrow{I}_M \qquad (38)$$

where $\overleftrightarrow{I}_M$ is the $M \times M$ unit matrix

The system dispersal matrix $\overleftrightarrow{W}$ is given by:

$$\overleftrightarrow{W} \equiv \overleftrightarrow{R} + \overleftrightarrow{F} - \overleftrightarrow{K} \qquad (39)$$

where $\overleftrightarrow{R}$ is the removal rate matrix given by:

$$\overleftrightarrow{R} \equiv \overleftrightarrow{R}_1 \oplus \overleftrightarrow{R}_2 \oplus \ldots \oplus \overleftrightarrow{R}_N = \begin{bmatrix} \overleftrightarrow{R}_1 & \vec{0} & \vec{0} & \cdots & \vec{0} \\ \vec{0} & \overleftrightarrow{R}_2 & \vec{0} & \cdots & \vec{0} \\ \vec{0} & \vec{0} & \cdots & \cdots & \vec{0} \\ \vec{0} & \vec{0} & \cdots & \vec{0} & \overleftrightarrow{R}_N \end{bmatrix} \qquad (40)$$

with:

$$\overleftrightarrow{\mathbf{R}}_i \equiv \begin{bmatrix} {}^1R_i & 0 & 0 & \cdots & 0 \\ 0 & {}^2R_i & 0 & \cdots & 0 \\ 0 & 0 & \cdots & \cdots & \\ 0 & 0 & \cdots & \cdots & {}^MR_i \end{bmatrix} \tag{41}$$

$\overleftrightarrow{\mathbf{F}}$ is the flow matrix:

$$\overleftrightarrow{\mathbf{F}} \equiv \sum_{\forall e} \sum_{\alpha=1}^{M} {}^{\alpha}\overrightarrow{\mathbf{B}}^{eT} \cdot {}^e\overleftrightarrow{\mathbf{f}}^{\alpha} \cdot {}^{\alpha}\overrightarrow{\mathbf{B}}^e \tag{42}$$

where ${}^e\overrightarrow{\mathbf{B}}^{\alpha}$ is the mapping of the element species onto the system contaminant species:

$$ {}^e\overrightarrow{\mathbf{B}}^{\alpha} \equiv [{}^eB^{\alpha}{}_{ij}] = \begin{bmatrix} {}^eB^{\alpha}{}_{11} & {}^eB^{\alpha}{}_{12} & \cdots & {}^eB^{\alpha}{}_{1N_c} \\ {}^eB^{\alpha}{}_{21} & {}^eB^{\alpha}{}_{22} & \cdots & {}^eB^{\alpha}{}_{2N_c} \end{bmatrix} \tag{43}$$

where $\quad {}^eB^{\alpha}{}_{ij} = \delta_{in_{1\alpha}} + \delta_{jn_{2\alpha}} \quad i,j = 1 \ldots N_c$

and $\quad n_{\alpha l} = M(n_l - 1) + \alpha \quad$ if $\quad n_l \neq 0$

$$= 0 \quad \text{if} \quad n_l = 0 \quad \text{for } l=1,2$$

${}^e\overleftrightarrow{\mathbf{f}}^{\alpha}$ is the element flow matrix for the αth species:

$$ {}^e\overleftrightarrow{\mathbf{f}}^{\alpha} = {}^ef \begin{bmatrix} 1 & 0 \\ -(1 - {}^e\eta^{\alpha}) & 0 \end{bmatrix} \quad \text{if} \quad {}^ef \geq 0 \tag{44}$$

$$= -{}^ef \begin{bmatrix} 0 & -(1 - {}^e\eta^{\alpha}) \\ 0 & 1 \end{bmatrix} \quad \text{if} \quad {}^ef < 0$$

$\overrightarrow{\mathbf{g}}'$ is the system generation vector:

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$$\vec{\mathbf{g}}' \equiv \vec{\mathbf{g}}'_1 \oplus \vec{\mathbf{g}}'_2 \oplus \ldots \oplus \vec{\mathbf{g}}'_N = \begin{bmatrix} \vec{\mathbf{g}}'_1 \\ \vec{\mathbf{g}}'_2 \\ \ldots \\ \vec{\mathbf{g}}'_N \end{bmatrix} \tag{45}$$

where $\quad \vec{\mathbf{g}}'_i \equiv \begin{bmatrix} {}^1g'_i \\ {}^2g'_i \\ \ldots \\ {}^Mg'_i \end{bmatrix}$

with $\quad {}^{\alpha}g'_i = g{^{\alpha}}_i + \sum_{\forall e} {}^e f_i^{(in)} 0 (1 - {}^e\eta^{\alpha})^{\alpha} C_0 \quad$ for $\alpha = 1 \ldots M$

$\vec{\mathbf{K}}$ is the system reaction matrix:

$$\vec{\mathbf{K}} \equiv \vec{\mathbf{K}}_1 \oplus \vec{\mathbf{K}}_2 \oplus \ldots \oplus \vec{\mathbf{K}}_N = \begin{bmatrix} \vec{\mathbf{K}}_1 & \vec{\mathbf{0}} & \vec{\mathbf{0}} & \cdots & \vec{\mathbf{0}} \\ \vec{\mathbf{0}} & \vec{\mathbf{K}}_2 & \vec{\mathbf{0}} & \cdots & \vec{\mathbf{0}} \\ \vec{\mathbf{0}} & \vec{\mathbf{0}} & \cdots & \cdots & \vec{\mathbf{0}} \\ \vec{\mathbf{0}} & \vec{\mathbf{0}} & \cdots & \vec{\mathbf{0}} & \vec{\mathbf{K}}_N \end{bmatrix} \tag{46}$$

where $\quad \vec{\mathbf{K}}_i = [\kappa^i_{\alpha\beta}]$

$$= \begin{bmatrix} \kappa^i_{11} & \kappa^i_{12} & \cdots & \kappa^i_{1M} \\ \kappa^i_{21} & \kappa^i_{22} & \cdots & \kappa^i_{2M} \\ \ldots & \ldots & \ldots & \ldots \\ \kappa^i_{M1} & \kappa^i_{M2} & \cdots & \kappa^i_{MM} \end{bmatrix}$$

The method used in **CONTAM88** for forming and solving the system of equations for the building contaminant dispersal are discussed below.

Reordering the Contaminant Dispersal Equations

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There are two situations in which the contaminant dispersal equations could become singular or for which a more efficient method of solution could be used. These are the case in which there exist isolated nodes which in the steady-state contaminant dispersal analysis would produce a singular system and the case of massless nodes which can be eliminated from the transient solution by modifying the dispersal matrix and the generation rate vector. **CONTAM88** reorders the dispersal system of equations in order to eliminate these nodes from the solution technique. A separate reordering is done for the steady-state contaminant dispersal analysis and for the transient dispersal analysis.

Steady-State Reordering of Dispersal Equations

In the steady-state contaminant dispersal analysis, an isolated zone into or out of which there is no airflow, will result in a singular dispersal matrix if there are no chemical reactions or plateout occurring in the zone. This can occur when, for example, the HVAC system is turned off or a door is closed. If there is a source in such a zone, the building description is inconsistent. However, without a source, such a zone has no contaminant buildup. To solve such a system, **CONTAM88** renumbers the contaminant equations such that the dispersal matrix can be partitioned so that the upper left submatrix is non-singular. The method used for this reordering is based on the fact that the dispersal matrix is an M-matrix and therefore possesses the property that if the diagonal element of the matrix is zero, all elements in the corresponding row and column are zero.

$$W_{ii} = 0 \quad \Rightarrow \quad W_{ij} = W_{ji} = 0 \quad \forall j \tag{47}$$

CONTAM88 forms the diagonal of the dispersal matrix and checks for zero components. The reordering is accomplished by forming three arrays: the first gives the zone number of the equation (zone_number_of_eqn), the second gives the contaminant number of the equations (contaminant_number_of_eqn) and the third, a two dimensional matrix, gives the equation number of the jth contaminant of the nth zone (eqn_number[j][n]):

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```
int n,j,l, NumOfEqns;
matrix F;

n = 0;
for(l=0;l++;l<N)
   for(j=0;j++;j<M)
   {
      if (F[j][l] != 0.0 )
      {
         eqn_number[j][l] = n;
         zone_number_of_eqn[n] = l;
         contaminant_number_of_eqn[n] = j;
         n++;
      }
   }
NumOfEqns = n;
for(l=0;l++;l<N)
   for(j=0;j++;j<M)
   {
      if (F[j][l] = 0.0 )
      {
         eqn_number[j][l] = n;
         zone_number_of_eqn[n] = l;
         contaminant_number_of_eqn[n] = j;
      }
   }
```

where F[j][n] is the diagonal flow element corresponding to the equation of the j^{th} contaminant of the n^{th} zone.

With this reordering of the flow equations, the dispersal matrix $\overleftrightarrow{W}$ has the form:

$$\overleftrightarrow{W} = \begin{bmatrix} \overleftrightarrow{W}_{FF} & \vec{0} \\ \vec{0} & \vec{0} \end{bmatrix} \tag{48}$$

$$\vec{g} = \begin{bmatrix} \vec{g}_F \\ \vec{0} \end{bmatrix} \tag{49}$$

The steady-state dispersal equations reduce to:

$$\overleftrightarrow{W}_{FF}\vec{C}_F = \vec{g}_F \tag{50}$$

$$\text{where} \quad \vec{C} = \begin{bmatrix} \vec{C}_F \\ \vec{C}_{isol} \end{bmatrix}$$

where $\vec{C}_F$ is the contaminant vector of the subset of zones which are not isolated, and $\vec{C}_{isol}$ is the vector of concentrations for the isolated zones.

Transient Solution Reordering

For transient solutions of the contaminant dispersal equations, stiff systems of equations can be avoided if zones with small mass (or volume) are treated as zones with zero mass (or volume). The subsystem with non-zero mass is solved dynamically while the subsystem with zero mass is solved algebraically. There is the added complication of a zone with zero mass and isolated from the building by having no flow into or out of it (such as a HVAC system which is turned off). To solve such a system, **CONTAM88** reorders the system of dispersal equations in order that the system is partitioned:

$$\overleftrightarrow{M} = \begin{bmatrix} \overleftrightarrow{M}_{FF} & 0 \\ 0 & \overleftrightarrow{M}_{isol} \end{bmatrix} \tag{51}$$

$$\overleftrightarrow{W} = \begin{bmatrix} \overleftrightarrow{W}_{FF} & 0 \\ 0 & 0 \end{bmatrix} \tag{52}$$

$$\vec{g} = \begin{bmatrix} \vec{g}_F \\ 0 \end{bmatrix} \tag{53}$$

$$\vec{C} = \begin{bmatrix} \vec{C}_F \\ \vec{C}_{isol} \end{bmatrix} \tag{54}$$

The non-isolated subsystem F is further partitioned into zones with mass and massless zones:

$$\vec{C}_F = \begin{bmatrix} \vec{C}_M \\ \vec{C}_0 \end{bmatrix} \quad \overleftrightarrow{M}_{FF} = \begin{bmatrix} \overleftrightarrow{M}_{MM} & 0 \\ 0 & 0 \end{bmatrix} \quad \overleftrightarrow{W}_{FF} = \begin{bmatrix} \overleftrightarrow{W}_{MM} & \overleftrightarrow{W}_{M0} \\ \overleftrightarrow{W}_{0M} & \overleftrightarrow{W}_{00} \end{bmatrix} \quad \vec{g} = \begin{bmatrix} \vec{g}_M \\ \vec{g}_0 \end{bmatrix} \tag{55}$$

The transient equations can thus be written in the form:

$$\overleftrightarrow{M}_{MM} \frac{d\vec{C}_M}{dt} = \overleftrightarrow{W}_{MM}\vec{C}_M + \overleftrightarrow{W}_M 0\vec{C}_0 + \vec{g}_M \tag{56}$$

$$0 = \overleftrightarrow{W}_0 M + \overleftrightarrow{W}_{00}\vec{C}_0 + \vec{g}_0 \tag{57}$$

The subvector $\vec{C}_0$ can be eliminated from the differential equations, obtaining the system:

$$\overrightarrow{\mathbf{M}}_{MM}\frac{d\vec{C}_M}{dt} = \overleftrightarrow{\mathbf{W}}_{MM}^{(m)}\vec{C}_M + \vec{g}_M^{(m)} \tag{58}$$

where

$$\overleftrightarrow{\mathbf{W}}_{MM}^{(m)} = \overrightarrow{\mathbf{W}}_{MM} - \overrightarrow{\mathbf{W}}_M 0 \overrightarrow{\mathbf{W}}_{00}^{-1}\overrightarrow{\mathbf{W}}_{0M} \tag{59}$$

$$\vec{g}_M^{(m)} = \vec{g}_M - \overleftrightarrow{\mathbf{W}}_{00}^{-1}\vec{g}_0 \tag{60}$$

$$\vec{C}_0 = -\mathbf{W}_{00}^{-1}(\vec{g}_0 + \overrightarrow{\mathbf{W}}_{0M}\vec{C}_M) \tag{61}$$

The actual method for producing the modified dispersal matrix is to use Gaussian elimination on the matrix $\overleftrightarrow{\mathbf{W}}_{MM}^{(m)}$.

The algorithm for Gaussian elimination is:

set $\quad \overleftrightarrow{\mathbf{W}}_{FF}^{(m)} = \overleftrightarrow{\mathbf{W}}_{FF} \quad \mathbf{g}_F^{(m)}$

then

for $\quad s = N_F,\ldots,N_M + 1$

$$W_{sk}^{(m)} = W_{sk}^{(m)} - \frac{1}{W_{ss}^{(m)}}\sum_{l=1}^{s-1} W_{sl}^{(m)}W_{lk}^{(m)}$$

$$g_k^{(m)} = g_k^{(m)} - \frac{W_{ks}^{(m)}}{W_{ss}^{(m)}}g_s \qquad \text{for} \quad k = 1,\ldots,s-1$$

where N_F is the number of non-isolated equations and N_M is the number of non-isolated massless equations $(N_M \le N_F)$. The zero-mass contaminant vector $\vec{C}_0$ can be solved at any time using the algebraic equations:

for $\quad s = N_M + 1,\ldots,N_F$

$$C_s = \frac{1}{W_{ss}^{(m)}}\left(g_s^{(m)} + \sum_{k=N_M+1}^{s-1} W_{sk}^{(m)}C_k\right)$$

Note that after modification for the elimination of massless equations, the matrix $\overleftrightarrow{\mathbf{W}}_{FF}^{(m)}$ has the form:

$$\overleftrightarrow{\mathbf{W}}_{FF}^{(m)} = \begin{bmatrix} \overleftrightarrow{\mathbf{W}}_{MM}^{(m)} & \overrightarrow{0} \\ \overleftrightarrow{\mathbf{W}}_{0M} & \overleftrightarrow{\mathbf{W}}_{00}^{(m)} \end{bmatrix}$$

where

$$\overleftrightarrow{\mathbf{W}}_{00}^{(m)} = \begin{bmatrix} W_{(N_M+1)(N_M+1)}^{(m)} & 0 & 0 & \cdots & 0 \\ W_{(N_M+2)(N_M+1)}^{(m)} & W_{(N_M+2)(N_M+2)}^{(m)} & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ W_{N_F N_{(M+1)}}^{(m)} & W_{(N_F)(N_M+2)}^{(m)} & \cdots & \cdots & W_{N_F N_F}^{(m)} \end{bmatrix} \quad \text{is lower diagonal}$$

Transient Solution Technique

The transient equation:

$$\overleftrightarrow{\mathbf{M}}_{MM} \frac{d\overrightarrow{\mathbf{C}}_M}{dt} = -\overleftrightarrow{\mathbf{W}}_{MM}^{(m)} \overrightarrow{\mathbf{C}}_M + \overrightarrow{\mathbf{g}}_M^{(m)} \tag{62}$$

is solved using the predictor-corrector described by Axley. This procedure is first started by estimating a time step dt such that the error in the procedure is kept to less than 5 percent. The procedure then estimates a value for the concentration at the next time steps, solves for a correction to the rate of change in the concentrations, and corrects the estimate.

$$d\overrightarrow{\mathbf{C}}_M^{(0)} = \overleftrightarrow{\mathbf{M}}_{MM}^{-1}\left(-\overleftrightarrow{\mathbf{W}}_{MM}^{(m)} \overrightarrow{\mathbf{C}}_M^{(0)} + \overrightarrow{\mathbf{g}}_M^{(m)}\right) \tag{63}$$

$$t^{(0)} = t_i$$

for n = 1 to $t^n = t_f$

$$t^{(n)} = t^{(n-1)} + dt$$

predict:

$$^*\overrightarrow{\mathbf{C}}_M^{(n)} = \overrightarrow{\mathbf{C}}_M^{(n-1)} + (1-\alpha)dt\,d\overrightarrow{\mathbf{C}}_M^{(n-1)} \tag{64}$$

solve:

$$\left(\alpha dt\,\overleftrightarrow{\mathbf{W}}_{MM}^{(m)} + \overleftrightarrow{\mathbf{M}}_{MM}\right)d\overrightarrow{\mathbf{C}}_M^{(n)} = \overrightarrow{\mathbf{g}}_M^{(m)} - \overleftrightarrow{\mathbf{W}}_{MM}^{(m)}\,{}^*\overrightarrow{\mathbf{C}}_M^{(n)} \tag{65}$$

correct:

$$\overrightarrow{\mathbf{C}}_M^{(n)} = {}^*\overrightarrow{\mathbf{C}}^{(n)} + \alpha dt\,d\overrightarrow{\mathbf{C}}_M^{(n)} \tag{66}$$

$$n = n + 1$$

For each solution interval, the time step is estimated from the equation:

$$dt_{est} = \frac{\left(p \mid d\overrightarrow{\mathbf{C}}_M^{(0)} \mid + \sqrt{p^2 \mid d\overrightarrow{\mathbf{C}}_M^{(0)} \mid^2 + 2.0 p \mid \overrightarrow{\mathbf{C}}_0^{(m)} \mid \cdot \mid dd\overrightarrow{\mathbf{C}}_0^{(m)} \mid} \right)}{\mid dd\overrightarrow{\mathbf{C}}_0^{(m)} \mid} \tag{68}$$

where $dd\overrightarrow{\mathbf{C}}_0^{(m)} = -\overleftrightarrow{\mathbf{W}}_{MM}^{(m)} d\overrightarrow{\mathbf{C}}_M^{(0)}$

and p is the accuracy of the solution. **CONTAM88** uses p = 0.05.

Data Structure

CONTAM88 uses a linked list data structure for storing the data for the zones, openings, fans, kinetic reaction data and surface data. These linked lists are allocated dynamically when the corresponding data are read. The contaminant physical data are stored in a series of dynamically allocated arrays.

The zone data structure is shown in Figure D1. The zone data structure contains physical data which describes the zone (its volume, temperature, height above the reference), variables which are the results of the calculations (zone air density, total mass of air in the zone, the zone pressure and a pointer to the results of the last transient contaminant dispersal analysis) and pointers to arrays which describe the contaminant sources (generations rates, removal rates, coefficients and exponents of pressure driven sources) in the zone and the kinetic reaction occurring in the zone. Each zone data structure contains a pointer to the data structure of the next zone. The pointer to the head of the list, FirstZone, is a global variable. The last data structure in the list contains a NULL pointer. In **CONTAM88**, the first zone data structure (pointed to by FirstZone) contains the outside ambient conditions. The first building zone is the second zone data structure (pointed to by FirstZone->NextZonePtr). The data contained in the file PROJECT.ZON are stored in the linked list of zone data structures.

The opening and fan data structures are shown in Figure D2. The data structure of an opening contains the physical description of the opening contained in the data file PROJECT.OPN, the zones connected by the opening, LM[2] - where LM[0] = n_1, LM[1] = n_2, the zone numbers of the first and second node of the element), the flow coefficient, the flow exponent, the opening stack height, the height of the surface containing the opening, the azimuth angle and tilt of the wall containing the opening and the number of the surface containing the opening. The opening data structure also contains results derived from these quantities: the transient pressure and the laminar region coefficients. During the airflow calculations, the wind pressure, stack pressure, the flow through the opening and the pressure drop across the opening are stored in the zone data structure. Thus, these quantities do not have to be recalculated every time they are needed. The fan data structure consists of the number of the zones connected by the fan (LM[2] has the same meaning as for an opening), the fan flow rate and a pointer to the efficiencies of any contaminant removal filters the fan may have. The head of each of these linked lists is determined by the global variables FirstOpening and FirstFan, respectively. Each list is NULL terminated.
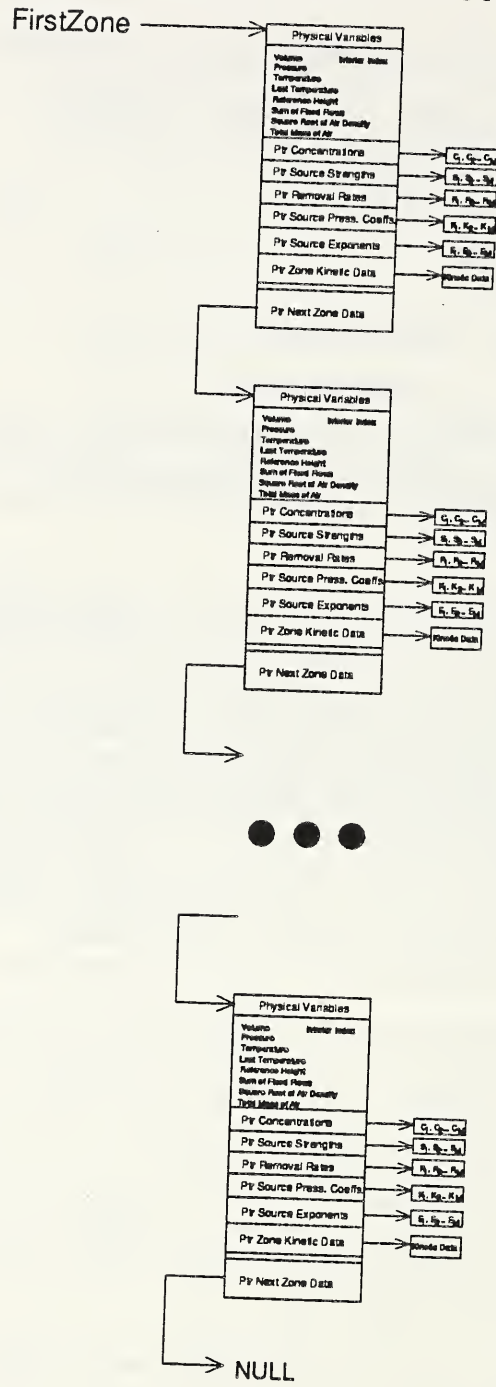
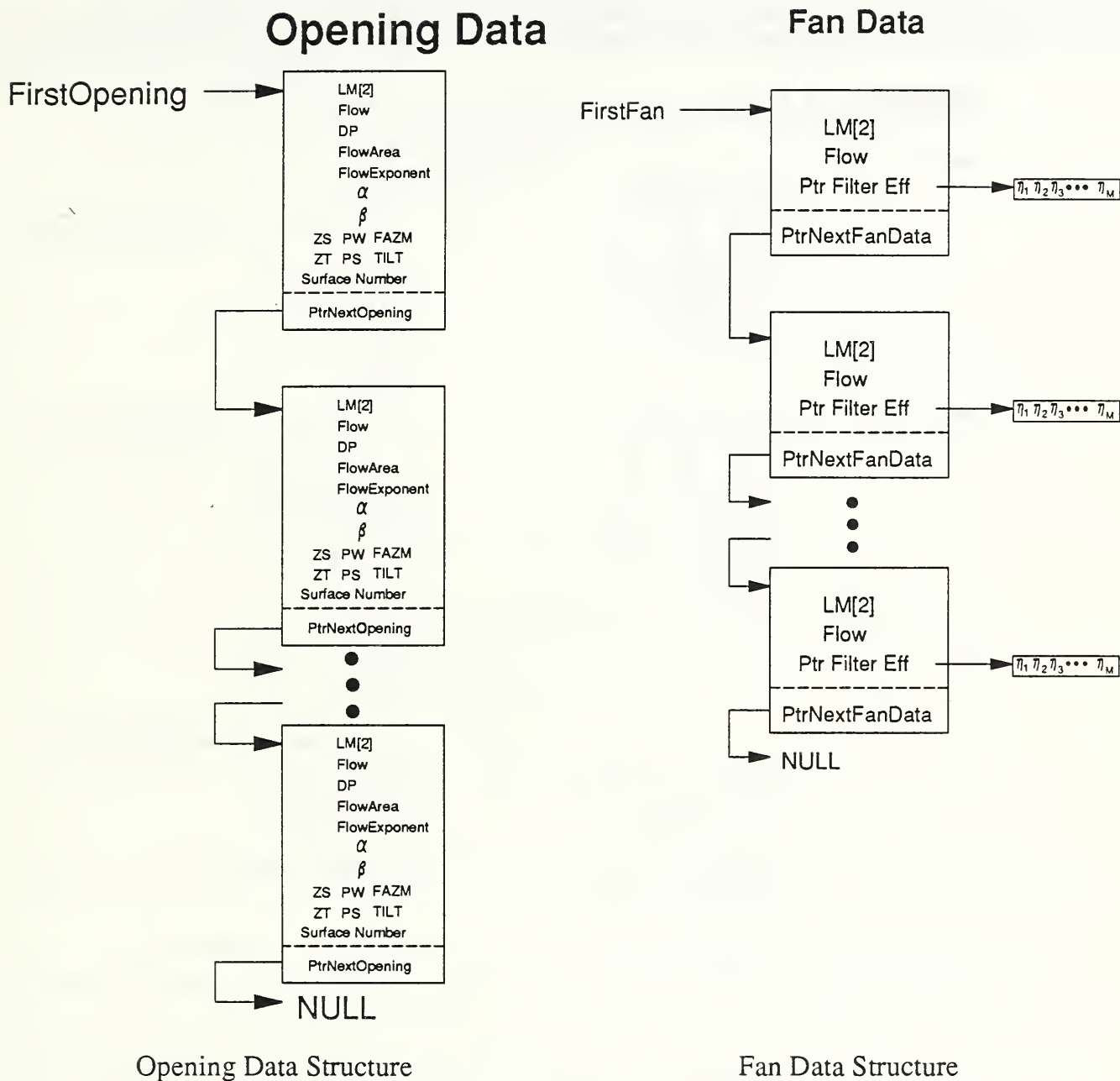125

Zone Data Structure

Figure D1. Zone Data Structure

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Opening Data

FirstOpening →

```
        LM[2]
        Flow
        DP
        FlowArea
        FlowExponent
           α
           β
        ZS  PW  FAZM
        ZT  PS  TILT
        Surface Number
- - - - - - - - - - - - -
        PtrNextOpening
```

```
        LM[2]
        Flow
        DP
        FlowArea
        FlowExponent
           α
           β
        ZS  PW  FAZM
        ZT  PS  TILT
        Surface Number
- - - - - - - - - - - - -
        PtrNextOpening
```

•
•
•

```
        LM[2]
        Flow
        DP
        FlowArea
        FlowExponent
           α
           β
        ZS  PW  FAZM
        ZT  PS  TILT
        Surface Number
- - - - - - - - - - - - -
        PtrNextOpening
```

→ NULL

Opening Data Structure

Fan Data

FirstFan →

```
        LM[2]
        Flow
        Ptr Filter Eff   →  η_1 η_2 η_3 ••• η_M
- - - - - - - - - - - - -
        PtrNextFanData
```

```
        LM[2]
        Flow
        Ptr Filter Eff   →  η_1 η_2 η_3 ••• η_M
- - - - - - - - - - - - -
        PtrNextFanData
```

•
•
•

```
        LM[2]
        Flow
        Ptr Filter Eff   →  η_1 η_2 η_3 ••• η_M
- - - - - - - - - - - - -
        PtrNextFanData
```

→ NULL

Fan Data Structure

Figure D2. Data Structure of Flow Elements

The data structure for the kinetic reaction data and the surface data are shown in Figure D3. The data are stored in simple linked lists which contain only the physical data which describe the kinetic reactions, and the surface pressure coefficients. The kinetic data structure contains a pointer to a dynamically allocated matrix of the reaction coefficients (see the following section on matrix storage techniques). The surface data structure contains an integer indicating the

number of pressure coefficients of the surface (this can vary from surface to surface), and a pointer to a dynamically allocated array containing the pressure coefficients. The global variables which point to the headers of these linked lists are FirstKineticData and FirstSurface.
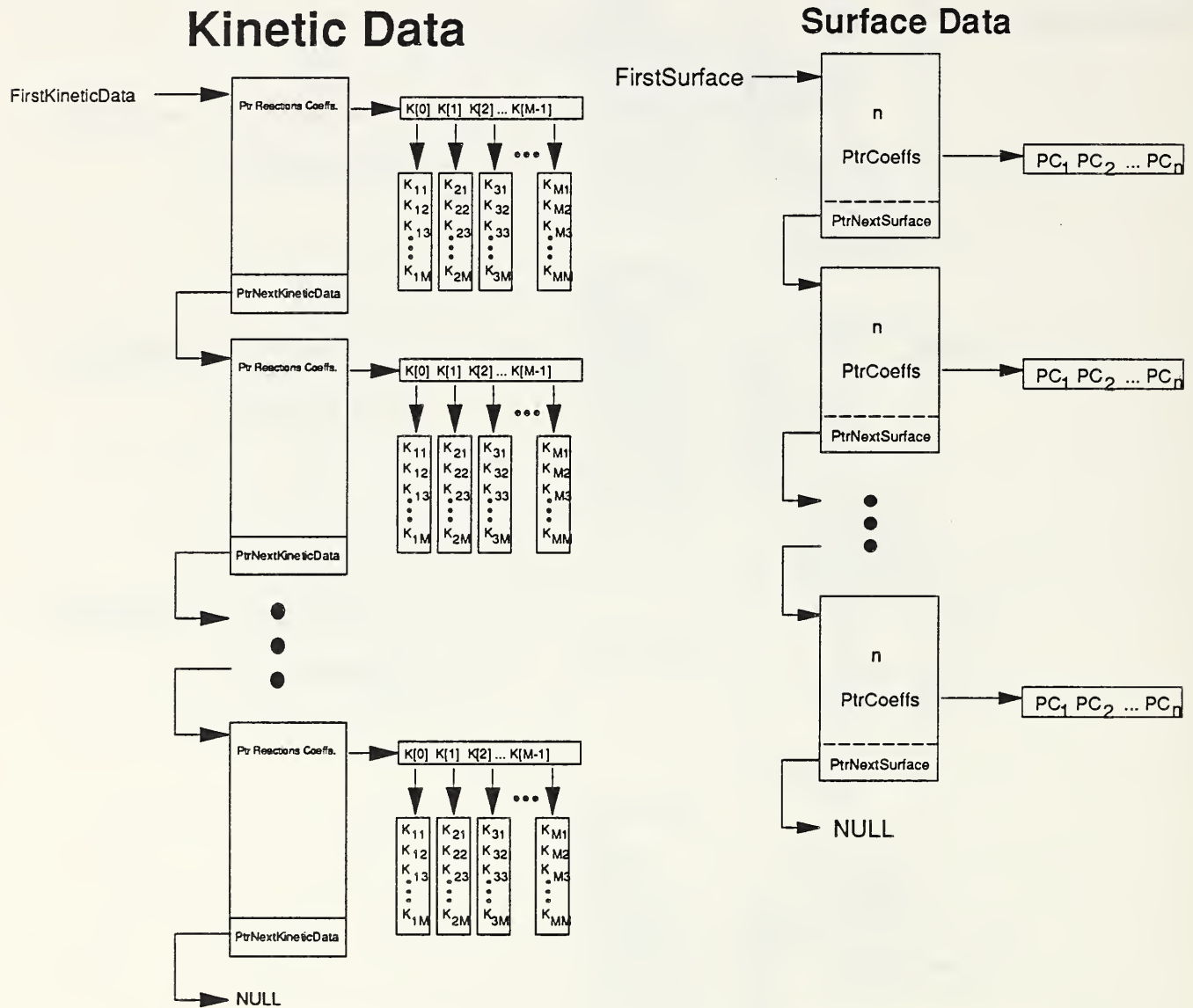

Figure D3. Kinetic Data Structure   Surface Data Structure

The data describing the properties of the contaminants are stored in dynamically allocated arrays: an array of string variables containing the contaminant name, an array of doubles containing the radioactivity of the contaminant, an array of doubles containing specific density of the contaminant, a boolean array indicating whether the results are to be expressed in mass of air or

volume of air, and an array of integers indicating the units to be used in outputting the concentration results for the contaminant. There is also an array of string variables which contain the name of the zones.

Contaminant Data

ContaminantName   Activity

$name_1$		$activity\ _1$
$name_2$		$activity\ _2$
$\vdots$		$\vdots$
$name_M$		$activity\ _M$

Density   per_mass   units

$Density\ _1$	per_mass_1	$units\ _1$
$Density\ _2$	per_mass_2	$units\ _2$
$\vdots$	$\vdots$	$\vdots$
$Density\ _M$	per_mass_M	$units\ _M$
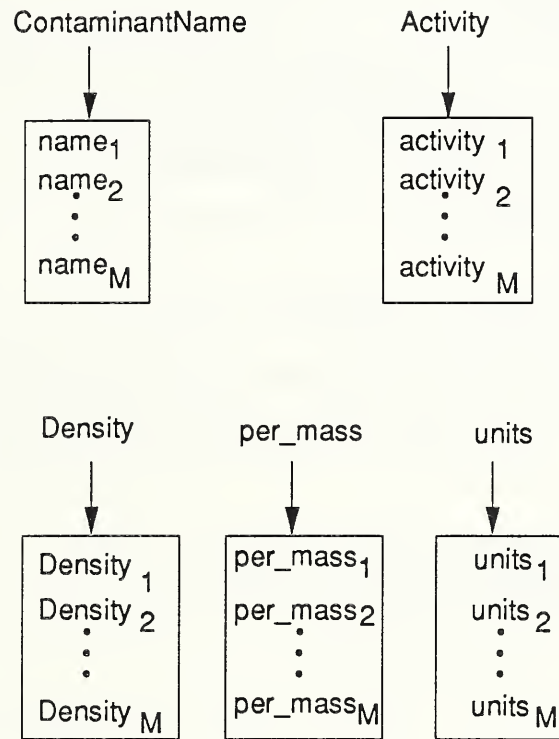
Figure D4. Contaminant Data Structure

The Use of CONTAM88 Data Structure to Form the Airflow and Contaminant Dispersal Equations

The above data structure permits a simple and compact method for forming the air flow and contaminant dispersal systems of equations. The equations of the system Jacobian $\overleftrightarrow{J}$ (Equation 24) and the system contaminant dispersal matrix $\overleftrightarrow{W}$ contain theoretical matrices $\overleftrightarrow{B}_e$, $^e\overleftrightarrow{B}^\alpha$, etc. The lists of elements (for airflow analysis: opening and fan linked lists; for the contaminant dispersal matrix: opening, fan, and zone linked lists) are traversed, the element matrices are constructed and added to the system matrix using the integer array which contains the equation number of nodes of the element. The following program listing indicates this process for the air flow Jacobian.

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"C" Code Forming Air Flow Equations

```c
/* Form Flow Jacobian and Zone Flows */
  LastOpening = FirstOpening;
  i = 0;
  while(LastOpening != NULL)
  {
    i++;
    n = LastOpening->AFSPTR[0];
    m = LastOpening->AFSPTR[1];
    LastZone = ZonePointer(n);
    NearZone = ZonePointer(m);

/* Calculate pressure drop across opening */

    LastOpening->DP = ZonePointer(m)->PZ - ZonePointer(n)->PZ
                      +LastOpening->PS + LastOpening->PW;

/* Calculate flow through opening */

    LastOpening->Flow = 0.0;
    DPL = LastOpening->pl;
    if(fabs(LastOpening->DP) > DPL) /*Turbulence flow */
    {
      if(LastOpening->DP < 0.0)
        LastOpening->Flow = - LastOpening->FlowArea * LastZone->SQRTDZ
                    *pow(-LastOpening->DP,LastOpening->FlowExponent);
      else
        LastOpening->Flow = LastOpening->FlowArea * NearZone->SQRTDZ
                    *pow(LastOpening->DP,LastOpening->FlowExponent);
    }
    else  /* Laminar Flow */
    {
      LastOpening->Flow = LastOpening->DP * (LastOpening->ALaminar +
      fabs(LastOpening->DP) * LastOpening->BLaminar);
      if (LastOpening->DP < 0.0)
        LastOpening->Flow *= LastZone->SQRTDZ;
      else
        LastOpening->Flow *= NearZone->SQRTDZ;
    }

/* Calculate Derivative of Flow with respect to DP */

    if(fabs(LastOpening->DP) > DPL)
    {
      DF = LastOpening->Flow * LastOpening->FlowExponent/LastOpening->DP;
    }
    else
    {
      DF = LastOpening->ALaminar
           + 2.0 * LastOpening->BLaminar * fabs(LastOpening->DP);
      if(LastOpening->DP < 0.0)
          DF *= LastZone->SQRTDZ;
      else
          DF *= NearZone->SQRTDZ;
    }
/* Add Element Flow into first node to Zone Flows */

    BB[eqn_number[n-1]] += LastOpening->Flow;
    SUMAF[eqn_number[n-1]] += fabs(LastOpening->Flow);

/* Form Element Jacobian */

    nelem = 1;
    LM[0] = eqn_number[n-1];
    LM[1] = 0;
    KE[0][0] = -DF;
    KE[1][1] = 0.0;
```

```
    KE[0][1] = 0.0;
    KE[1][0] = 0.0;
    if(m > 0) /* m = 0 indicates exterior */
    {
/* Node 2 of element is building zone */
    nelem = 2;
    LM[1] = eqn_number[m-1];
    KE[1][1] = -DF;
    KE[0][1] = DF;
    KE[1][0] = DF;
/* Add element node 2 to Zone Flows */
    BB[eqn_number[m-1]] -= LastOpening->Flow;
    SUMAF[eqn_number[m-1]] += fabs(LastOpening->Flow);
    }
/* Add Element Jacobian to System Jacobian A */
    add_element_matrix(AA,PressureMatrixType,NZON,BandWidth,KE,LM,nelem);
    LastOpening = LastOpening->NextOpeningPtr;
    }
    if(LIST > 4) dump_matrix(AA,PressureMatrixType,NZON,BandWidth);
    if(LIST > 4) dump_vector(BB,NZON);
    factored = FALSE;
/* Solve for Pressure Correction */
    solve_linear_system(AA,BB,CC,&factored,PressureMatrixType,
                                        NumOfEqns,BandWidth);
/* Update Zone Pressures */  n = 0;
    if(LIST > 3) printf("\n     Initial ZonePressures \n");
    if(LIST > 3) fprintf(dataoutfile,"\n     Initial ZonePressures \n");
    LastZone = FirstZone->NextZonePtr;
    while((LastZone != NULL) && (n < NZON))
    {
      LastZone->PZ -= CC[eqn_number[n]];
      if(LIST > 3 )
      {
        printf(" PZ: %4d %15.3e\n",n+1,LastZone->PZ);
        fprintf(dataoutfile," PZ: %4d %15.3e\n",n+1,LastZone->PZ);
      }
      LastZone = LastZone->NextZonePtr;
      n++;
    }
/* Calculate Pressure Across Openings */
    LastOpening = FirstOpening;
    while(LastOpening != NULL)
    {
      n = LastOpening->AFSPTR[0];
      m = LastOpening->AFSPTR[1];
      LastOpening->DP = ZonePointer(m)->PZ - ZonePointer(n)->PZ
                        +LastOpening->PS + LastOpening->PW;
      LastOpening = LastOpening->NextOpeningPtr;
    }
/* Check Convergence */
```

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Matrix Storage

CONTAM88 uses seven types of matrix storage techniques: three of symmetric matrices and four of asymmetric matrices. The asymmetric matrix storage types are: storage for the full N by N matrix (asymmetric_full), storage for a diagonally banded matrix by rows (asymmetric_compact) and storage for a diagonally banded matrix by arrays parallel to the diagonal (asymmetric_compact2) and a skyline storage technique. The symmetric matrix storage techniques are: storage for the $N \cdot (N-1)/2$ diagonal and upper diagonal elements (symmetric_full), storage by arrays parallel to the diagonal by a diagonally banded symmetric matrix (symmetric_compact) and a skyline technique for symmetric matrices (skyline_symmetric). The above matrix storage techniques are used dynamically in **CONTAM88** [2].

---

[2] The current version of **CONTAM88** is written in "C" and the following explanation assumes a "C" type language; however the same techniques have been used by the author in other languages which have pointers and dynamic memory allocation, for example Pascal and Modula-2. The contaminant dispersal program **CONTAM86** and **CONTAM87** used a large blank common area in FORTRAN to simulate dynamic memory allocation - the CALSAP routines developed at the University of California's Civil Engineering Department. These routines implicitly assume a contiguous memory structure to blank common which may be violated in computer systems with segmented memory structures such as IBM-PC with Intel 8086 family of micro-processors. For example, the old IBM-Professional FORTRAN compiler or the Ryan-McFarland FORTRAN compiler seem to allocate blank common contiguously; the Microsoft FORTRAN compiler does not. In any case, this technique uses non-standard FORTRAN assumptions, which may be violate by fully ANSI-FORTRAN compilers and therefore is not good programing practice.
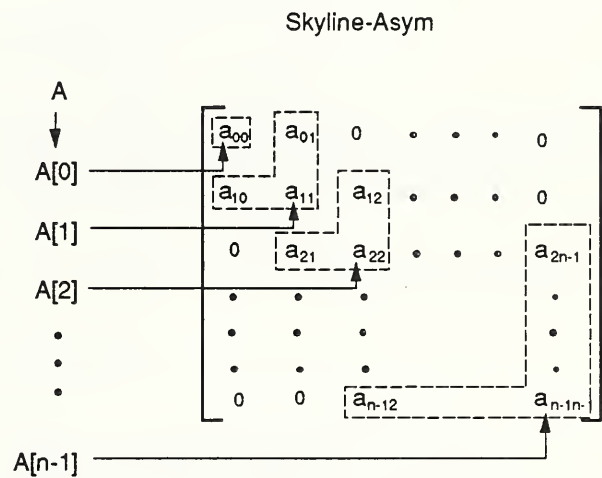
Asym-Full
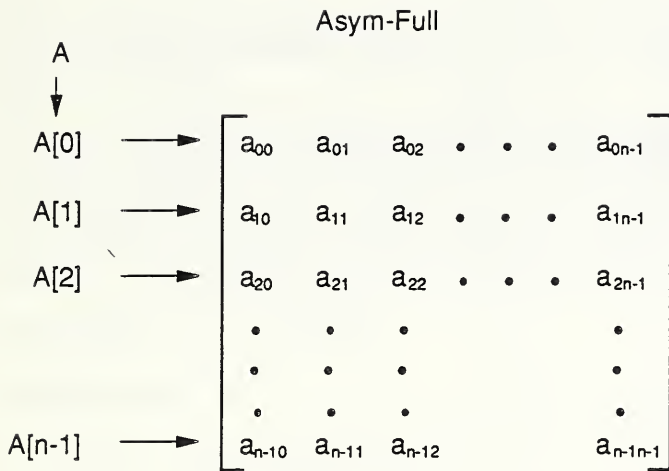
Asymmetric Full Matrix Storage Technique
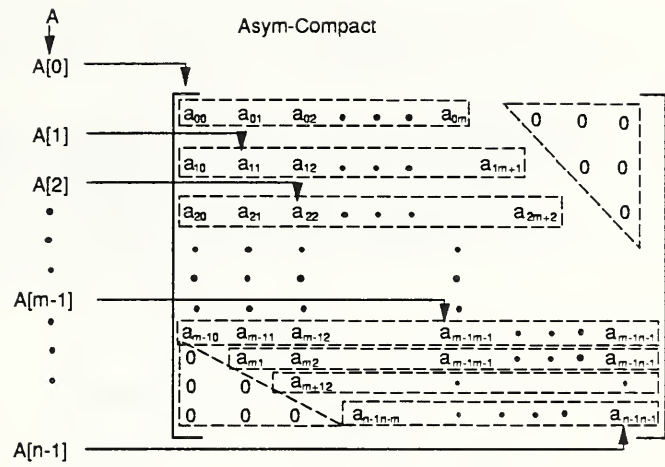
Asym-Compact

Storage Technique Asymmetric Compact
Matrix - Row

Asym-Compact2   **Bandwidth m**
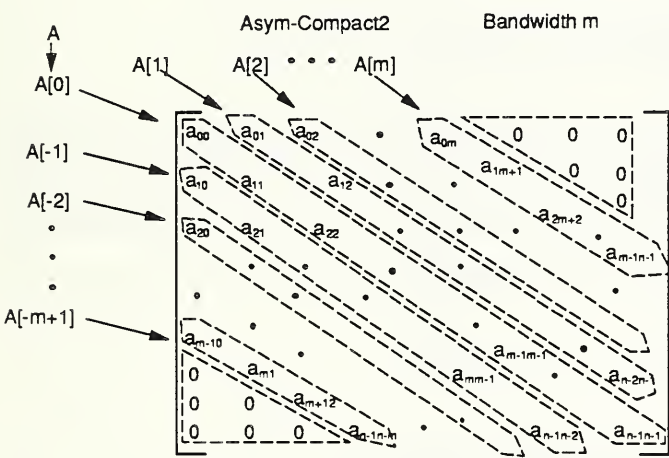
Asymmetric Compact Matrix - Diagonal
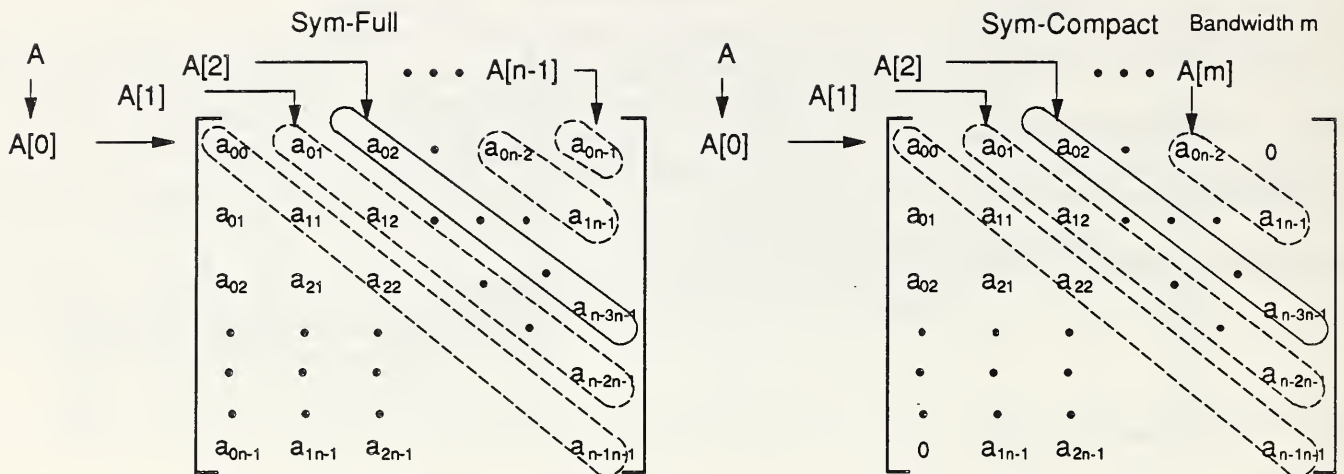Storage Technique

Skyline-Asym

Asymmetric Skyline Matrix Storage Technique

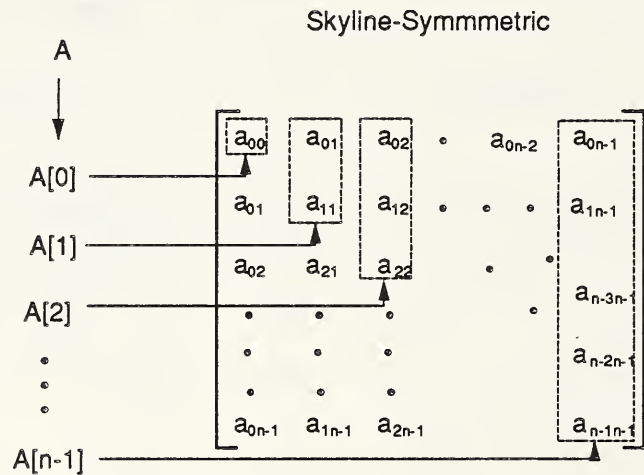**Figure D5.** Schematics of Asymmetric Matrix Storage Techniques

The basic method of dynamically allocating a matrix in a structured language, such as "C," containing pointers as a data type, is to allocate storage for an array of pointers which point to the storage for the one-dimensional arrays which make up the matrix and then allocate the storage for each of these one-dimensional arrays. To illustrate this technique consider defining the two data types vector and matrix for the storage of "double" variables.

```
typedef  double *vector
typedef  vector *matrix
```

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Sym-Full

A
↓
A[0] → A[1] A[2] ••• A[n-1]

a_{00} a_{01} a_{02} • a_{0n-2} a_{0n-1}
a_{01} a_{11} a_{12} • • a_{1n-1}
a_{02} a_{21} a_{22} • • a_{n-3n-1}
• • • a_{n-2n-1}
a_{0n-1} a_{1n-1} a_{2n-1} a_{n-1n-1}

Symmetric Full Matrix Storage Techniques

Sym-Compact   Bandwidth m

A
↓
A[0] → A[1] A[2] ••• A[m]

a_{00} a_{01} a_{02} • a_{0n-2} 0
a_{01} a_{11} a_{12} • • a_{1n-1}
a_{02} a_{21} a_{22} • • a_{n-3n-1}
• • • a_{n-2n-1}
0 a_{1n-1} a_{2n-1} a_{n-1n-1}

Symmetric Compact Matrix Storage Technique

Skyline-Symmmetric

A
↓

A[0] — a_{00} a_{01} a_{02} • a_{0n-2} a_{0n-1}
       a_{01} a_{11} a_{12} • • • a_{1n-1}
A[1] — a_{02} a_{21} a_{22} • • a_{n-3n-1}
A[2] — • • • • a_{n-2n-1}
       a_{0n-1} a_{1n-1} a_{2n-1} a_{n-1n-1}
A[n-1] —

Skyline Symmetric Matrix Storage Techniques

Figure D6. Schematics of Symmetric Matrix Storage Technique

```
typedef  double  *vector
typedef  vector  *matrix
```

To allocate memory for an N⊗N matrix, first allocate storage for an array A of N "vectors"
{A[0], ..., A[N-1]}. Then for each A[l], l=0, ..., N-1, allocate storage for a linear array of N
doubles. This can be accomplished with the "C" code (where error checking has been omitted):

```
int l;
matrix A;

A = (matrix) calloc(N,sizeof(vector));
for(l=0;l<N;l++) A[l] = (vector) calloc(N,sizeof(double));
```

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Then either the notation *A[k][l]* or *(*(A+k)+l)* can be used to store or retrieve the double variable stored in the kth row and lth column of the matrix. Figure D5 illustrates the meaning of these variables.

In many physical problems, the matrix describing the system contains many zeros and the non-zero elements exist near the diagonal. Such matrices are called banded (see Figure D5). **CONTAM88** allows two types of storage schemes for compact asymmetric matrices as illustrated in Figure D6. The first stores data by rows, the second by one-dimensional arrays parallel to the diagonal. If m is the half bandwidth of the matrix:

$$m = \max |i - j| \quad \ni A_{ij} \neq 0$$

then the code:

```
int l,n1,n2,N,m; /* N = dimension, m = half bandwidth */
matrix A;

A = (matrix) calloc(N,sizeof(vector);
for(l=0;l<N;l++)
{
  n1 = (l-m > 0) ? l-m : 0;   /* max(l-m,0) */
  n2 = (l+m > N-1) ? N-1 : l+m ; /* min(l+m,N-1) */
  A[l] = (vector) calloc(n2-n1+1,sizeof(double));
  A[l] += n1; /* shift pointer to diagonal */
}
```

allocates the storage for the banded matrix and leaves the pointer A[l] pointing to the diagonal element. Leaving the pointer A[l] pointing to the diagonal element, in the author's opinion, produces cleaner code. Beware that in freeing the allocated memory, the pointer must be restored to its value when memory was allocated.

The value stored in A[i][i-j] is the non-zero value of the element in the ith row and jth column:

$$A_{ij} = A[i][i-j] \quad \text{if} \quad |i - j| \leq m$$

$$= 0 \quad \text{if} \quad |i - j| > m$$

The storage of a band asymmetric matrix by one-dimension arrays parallel to th diagonal can be accomplished by the code:

```
int l,N,m; /* N = dimension, m = half bandwidth */
matrix A;

A = (matrix) calloc(2m+1,sizeof(vector));
A *= m; /* shift A to point to diagonal *
for(l=-m;l<m+1;l++)
{
  A[l] = (vector) calloc(N-abs(l),sizeof(double));
}
```

The value stored in A[j-i][min(i,j)] is the non-zero value of the element in the ith row and jth column:

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$$A_{ij} = A[j - i][\min(i,j)] \quad \text{if} \quad |i - j| \leq m$$

$$= 0 \quad \text{if} \quad |i - j| > m$$

Probably the most efficient storage scheme is the last one illustrated in Figure D5, the skyline scheme. In this scheme one stores the non-zero elements in arrays A[l] which include the diagonal, the column of values to the last non-zero element above the diagonal, and the row of values to the last non-zero element to the right of the diagonal. If m[l] is the half bandwidth of this row/column:

$$m[l] = \max_{\forall i < l} (l - i) \ni A_{kl} = 0 \quad \text{and} \quad A_{lk} = 0 \quad \forall k > i$$

The code for allocating memory for a skyline matrix is:

```
int l,N,*m; /* N = dimension, m -> half bandwidth */
matrix A;

A = (matrix) calloc(N,sizeof(vector);
for(l=0;l<N;l++)
{
   A[l] = (vector) calloc(2*m[l]+1,sizeof(double));
   A[l] += m[l]; /* shift pointer to diagonal */
}
```

The value stored in A[max(i,j)][j-i] is the non-zero value of the element in the ith row and j^{th} column.

$$A_{ij} = A[\max(i,j)][j - i] \quad \text{if} \quad |i - j| \leq m[\max(i,j)]$$

$$= 0 \quad \text{if} \quad |i - j| > m[\max(i,j)]$$

Figure D6 illustrates the three storage schemes for symmetric matrices.

The full symmetric matrix and the banded compact symmetric matrix both store the upper triangular part of the matrix by one-dimensional arrays parallel to the diagonal. Both these methods can be allocated by the code:

```
int l,m,N; /* for a full symmetric matrix m = N-1 */
matrix A;

A = (matrix) calloc(m+1,sizeof(vector);
for(l=0;l<m+1;l++)
{
   A[l] = (vector) calloc(N-l,sizeof(double));
}
```

In these cases A[|i-j|][min(i,j)] is the value of the non-zero element in the ith row and j^{th} column.

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$A_{ij} = A[|j - i|][\min(i,j)]$ for a full symmetric matrix

and

$A_{ij} = A[|j - i|][\min(i,j)]$ if $|i - j| \leq m$

    $= 0$ if $|i - j| > m$ for a banded symmetric matrix

The code for allocating memory for a symmetric skyline matrix is

```
int l,N,*m; /* N = dimension, m -> half bandwidth */
matrix A;

A = (matrix) calloc(N,sizeof(vector);
for(l=0;l<N;l++)
{
    A[l] = (vector) calloc(m[l]+1,sizeof(double));
}
```

The value stored in A[max(i,j)][|j-i|] is the non-zero value of the element in the ith row and jth column.

$A_{ij} = A[\max(i,j)][|j - i|]$ if $|i - j| \leq m[\max(i,j)]$

    $= 0$ if $|i - j| > m[\max(i,j)]$

As shown in the following sections, the bandwidths can be determined without forming the matrices by using the indices of the element nodes and the matrix solution. CONTAM88 preserves the structure of the matrices (that is, it does not destroy the bandwidth).

Solution of Linear System of Equations

The linear systems of equations formed by **CONTAM88** are solved using LU decomposition followed by forward and backward substitution of the factored matrix. This method preserves the matrix structures treated above: that is the solution technique requires only the values stored in the banded and skyline storage schemes. If one considers the linear set of equations:

$$\overrightarrow{A X} = \overrightarrow{F}$$

Then it is possible to factor the matrix $\overrightarrow{A}$ into the product of a lower triangular matrix $\overleftrightarrow{L}$ and an upper triangular matrix $\overleftrightarrow{U}$:

$$\overrightarrow{A} = \overleftrightarrow{L} \cdot \overleftrightarrow{U}$$

where
$$\overleftrightarrow{L} = \begin{bmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ L_{21} & 1 & 0 & 0 & \cdots & 0 \\ L_{31} & L_{32} & 1 & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ L_{N-11} & L_{N-12} & \cdots & \cdots & 1 & 0 \\ L_{N1} & L_{N2} & \cdots & \cdots & L_{NN-1} & 1 \end{bmatrix}$$

and
$$\overleftrightarrow{U} = \begin{bmatrix} U_{11} & U_{12} & U_{13} & U_{14} & \cdots & U_{1N} \\ 0 & U_{22} & U_{23} & U_{34} & \cdots & U_{2N} \\ 0 & 0 & U_{33} & U_{34} & \cdots & U_{3N} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & \cdots & U_{NN} \end{bmatrix}$$

The decomposition can be accomplished by the algorithm:

$$U_{11} = A_{11}$$

for $s = 2, \ldots, N$

$$L_{si} = \left(A_{si} - \sum_{m=1}^{i-1} L_{sm} U_{mi} \right) \frac{1}{U_{ii}} \quad i = 1, \ldots, s-1 \tag{69}$$

$$U_{is} = A_{is} - \sum_{m=1}^{i-1} L_{im} U_{ms} \quad i = 1, \ldots, s \tag{70}$$

Note that in performing the LU decomposition of matrix A, the results can be stored in the same storage locations as the original matrix $\overrightarrow{A}$ if the 1's on the diagonal of lower triangular matrix $\overleftrightarrow{L}$ are not stored.

$$\vec{A} = \begin{bmatrix} U_{11} & U_{12} & U_{13} & U_{14} & \cdots & U_{1N} \\ L_{12} & U_{22} & U_{23} & U_{24} & \cdots & U_{2N} \\ L_{31} & L_{32} & U_{33} & U_{34} & \cdots & U_{2N} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ L_N 1 & L_N 2 & L_N 3 & \cdots & L_{NN-1} & U_{NN} \end{bmatrix}$$

using the algorithm

for $s = 2, \dots, N$

$$A_{si} = \left(A_{si} - \sum_{m=1}^{i-1} A_{sm} A_{mi} \right) \frac{1}{U_{ii}} \quad i = 1, \dots, s-1 \tag{71}$$

$$A_{is} = A_{is} - \sum_{m=1}^{i-1} A_{im} A_{ms} \quad i = 1, \dots, s \tag{72}$$

For a symmetric matrix, the upper and lower triangular matrices are related by:

$$L_{jm} = \frac{1}{U_{mm}} U_{mj} \quad \text{for} \quad j > m \tag{73}$$

and the LU decomposition becomes:

$$U_{11} = A_{11}$$

for $s = 2, \dots, N$

$$U_{is} = A_{is} - \sum_{m=1}^{i-1} \frac{U_{mi} U_{ms}}{U_{mm}} \quad i = 1, \dots, s \tag{74}$$

Once the matrix $\vec{A}$ has been decomposed, the linear system of equations can be solved by forward and backward substitution:

Forward substitution

$$X_1 = F_1$$

for $i = 2, \ldots, N$

$$X_i = F_i - \sum_{j=1}^{i-1} L_{ij} X_j \tag{75}$$

Backward substitution

$$X_N = \frac{1}{U_{NN}} X_N \tag{76}$$

for $i = N - 1, \ldots, 1$

$$X_i = \frac{1}{U_{ii}} \left(X_i - \sum_{j=i+1}^{N} U_{ij} X_j \right) \tag{77}$$

If the decomposition is stored in the original matrix:

For a decomposition stored in A

Forward substitution

$$X_1 = F_1$$

for $i = 2, \ldots, N$

$$X_i = F_i - \sum_{j=1}^{i-1} A_{ij} X_j \tag{78}$$

Back substitution

$$X_N = \frac{1}{A_{NN}} X_N$$

for $i = N - 1, \ldots, 1$

$$X_i = \frac{1}{A_{ii}} \left(X_i - \sum_{j=i+1}^{N} A_{ij} X_j \right) \tag{79}$$

Note that it is not necessary to decompose $\overrightarrow{A}$ more then once if one wishes to solve the linear system for several $\overrightarrow{F}$'s. This fact is used in the procedure for predicting the transient response in contaminant dispersal analysis.

For symmetric matrices, the solution algorithm reduces to:

Forward substitution

$$X_1 = F_1$$

for $i = 2, ..., N$

$$X_i = F_i - \sum_{j=1}^{i-1} \frac{U_{ji}}{U_{jj}} X_j \tag{80}$$

Back substitution

$$X_N = \frac{1}{U_{NN}} X_N$$

for $i = N - 1, ..., 1$

$$X_i = \frac{1}{U_{ii}} \left(X_i - \sum_{j=i+1}^{N} U_{ij} X_j \right) \tag{81}$$

or if the decomposition is stored in the original matrix:

For the decomposition stored in A

Forward substitution

$$X_1 = F_1$$

for $i = 2, \ldots, N$

$$X_i = F_i - \sum_{j=1}^{i-1} \frac{A_{ji}}{A_{jj}} X_j \qquad (80)$$

Back substitution

$$X_N = \frac{1}{A_{NN}} X_N$$

for $i = N - 1, \ldots, 1$

$$X_i = \frac{1}{A_{ii}} \left(X_i - \sum_{j=i+1}^{N} A_{ij} X_j \right) \qquad (81)$$

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This manual describes the usage of three computer programs for analyzing the air movement and indoor air quality in multizone buildings. The first program NBSAVIS creates and edits a building description and generates the leakage, fan and contaminant data necessary to predict the air infiltration and internal air movement in a building and perform an indoor air quality nanlysis. These data are used by the program CONTAM88 which calculates the air flows and both dynamic and steady state levels of indoor contaminants. CONTAMEZ also produces an output file which can serve as the input for the NIST programs CONTAM86 and CONTAM87 developed by Dr. James Axley.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

Indoor air quality, air flow analysis, contaminant dispersal, user interface, multizone analysis.

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