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Applicable Input Data for a Proposed Ventilation Modeling Data Guide

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ABSTRACT

One task in the current work program of the Air Infiltration and Ventilation Centre is to identify and collate applicable default input data for ventilation and air infiltration modeling. (These data are also essential for coupled thermal and ventilation modeling.) Previous work has covered building airtightness data. The present task extends this to include data and algorithms concerning wind pressure coefficients, ventilation systems, occupancy, meteorological conditions, indoor pollutant modeling, and model evaluation data. The intention is to publish these electronically in the form of a "Ventilation Modeling Data Guide."

It is intended that the ventilation modeling data guide should be largely based on results collected from various expert groups. This paper describes some potential data sources and gives an overview of the form of each data type. Additionally, it gives an illustrative application of the data. It is anticipated that the data guide may enable improved ventilation designs to be adopted.

INTRODUCTION

The Proposed Ventilation Modeling Data Guide

One task in the current work program of the Air Infiltration and Ventilation Centre (AIVC) is to identify and collate applicable default input data suitable for ventilation and air infiltration modeling. (These data are also essential for coupled ventilation and thermal modeling.) Previous work has covered the compilation of building airtightness data (Orme et al. 1998). This database was mainly based on both published and previously unpublished data from leading research groups in many countries. The database has itself been used extensively by other collaborative International Energy Agency (IEA) projects ("Annexes"), and reference is made to it in the draft European CEN Standard, *Calculation Methods for the Determination of Air Flow Rates in Dwellings*. The present task extends this to include wind pressure coefficient data, ventilation system data, meteorological data, occupancy data, pollutant modeling data, and model evaluation data. The intention is to published these electronically in the form of a "Ventilation Modeling Data Guide."

The target audience for the ventilation modeling data guide includes designers and other building services professionals who are interested in using air infiltration and ventilation models. They may, therefore, require default data as well as algorithms to adjust data for their requirements. It is anticipated that the guide will facilitate improved acceptance and use of ventilation modeling by practitioners. This may enable better ventilation designs to be adopted. The collected data may also have wider applicability to other, complementary modeling techniques. This may include input data for coupling of ventilation with thermal models. A further application would be to set mass flow rate boundary conditions for use in computational fluid dynamics.

Ventilation and Air Infiltration Models

Numerical ventilation and air infiltration models may be used to calculate airflow rates into and out of buildings and sometimes between individual rooms or "zones" within a building. This paper discusses their required input data and a project that has been initiated to collect such data. Orme (1999) describes a number of ventilation and air infiltration models that are available either commercially or in the public domain.

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Applicability of Ventilation Models

There are a number of general reasons why ventilation modeling is desirable. Principally these are (according to Liddament 1996):

- pre-construction or retrofit evaluation of design,
- prediction of indoor climate,
- energy efficient air-conditioning and ventilation design, or
- validation of design.

These, in turn, may depend on supplementary calculations, requiring airflow and ventilation predictions that include

- determining the energy impact of ventilation,
- predicting pollutant concentration (indoor air quality analysis and pollutant removal effectiveness),
- estimating the transfer of pollutants between zones or between the outside and inside of a building,
- calculating room and building pressures for back-drafting or cross-contamination assessment,
- sizing of ventilation openings (to optimize ventilation performance),
- cost and energy performance analysis (e.g., to compare alternative ventilation strategies), and
- thermal comfort analysis (temperature and draft risk).

Input Data Requirements

In so-called "network models," a building is represented by a collection of "zones," interconnected by airflow paths. This representation is known as an airflow path network. Typically, each zone represents an individual room, while flow paths represent air infiltration routes, purpose-provided openings, or ducts. Flow equations are applied that relate the pressure difference across each flow path to the resultant flow through it. Additional equations represent pressure differences generated by ventilation fans. The essential steps for configuring network models are

- identifying the relevant flow equations for air leakage paths, ventilation openings, or ducts,
- developing an airflow path network,
- specifying the wind pressure coefficient distribution on the building, and
- specifying the natural (wind and temperature difference) or mechanical (ventilation fans) driving forces.

Further steps may specify pollutant generation schedules, occupancy patterns, and window opening, if required.

The principle underlying network models is that for given boundary conditions, they predict the steady-state mass flow rate of air through a building's envelope (i.e., its exterior surface) and sometimes between different zones inside a building. It is a basic assumption in these models that the incoming and outgoing flow rates must balance each other due to conservation of mass.

STRUCTURE OF THE VENTILATION MODELING DATA GUIDE

It is planned that the ventilation modeling data guide should be largely based on results collected from various expert groups with periodic updates as new data become available. The main focus is likely to be for dwellings, due to availability of information, although data and associated data manipulation algorithms will be included for nonresidential buildings whenever available. An indication of the possible contents of the ventilation modeling data guide is given within the sections below with examples for some of the data.

Specification

In recent years, certain data manipulation packages and programming languages have become commonly used worldwide. Therefore, there are a number of possibilities for the data and algorithm formats. The key idea is that data would be published in an open and accessible format. It is planned that the final version will not impose restrictions on the accessibility of either data or the manipulation algorithms (i.e., the source code for any algorithms would be available).

A number of general plans have emerged, including the provision of

- tools to use data as well as data themselves (i.e., data manipulation algorithms),
- the ranges of applicability and limitations of algorithms provided in the guide,
- tools to summarize model results, and
- interpretation of results from simulations, including target values and standards.

BUILDING AND TERRAIN-RELATED INPUT DATA

Airtightness and wind surface pressures are aspects of a building's construction fundamentally influencing how it interacts with driving forces. These are outlined below.

Airtightness Data

Air leakage data are essential for the formulation of airflow networks and, therefore, for ventilation modeling. Orme et al. (1998) have summarized available data concerning air leakage paths for construction elements and their characteristics. Available airtightness data for different construction elements are as follows, and measured data exist to a varying extent for each.

- Windows
- Doors
- Interface of window or door frames with walls
- Wall constructions, ceilings, and floors
- Ceiling or floor to wall interfaces
- Wall to wall interfaces
- Service penetrations
- Roofing
- Fireplaces and flues
- Trickle ventilators and vents

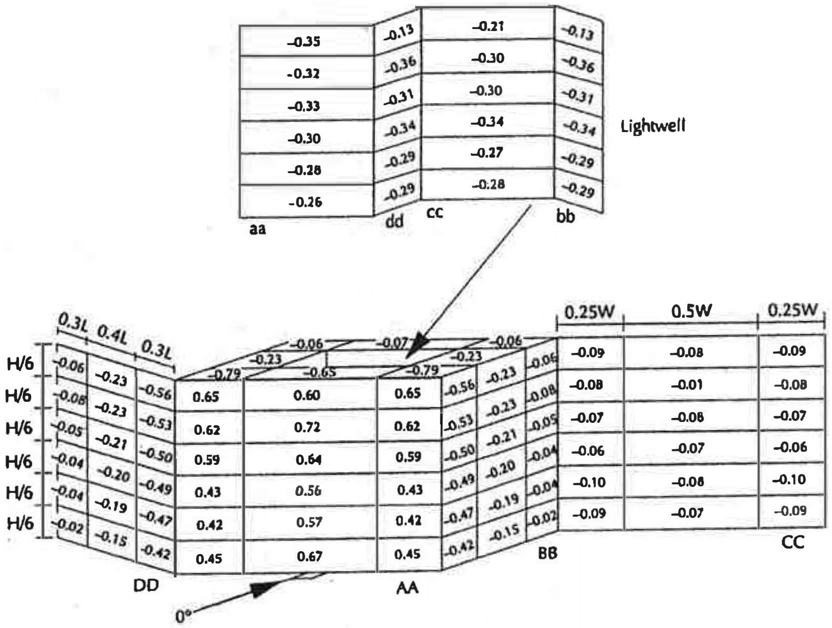


Figure 1 *Wind pressure coefficients for a three-level office with lightwell.*

The data guide may cover

- airtightness data for whole buildings and building components,
- prediction techniques for building airtightness, and
- simplified data sheets (e.g., Orme et al. 1998).

Wind Surface Pressure Coefficient Data

The shape of a building and the degree of wind shielding by other structures (or vegetation) together determine the surface pressures due to wind forces for any given wind direction. These surface pressures will vary with the wind direction. Wind pressure coefficients are dimensionless coefficients that allow the pressure distribution due to the wind pressure acting on a building to be reconstructed for all wind speeds. They are specific to a particular building, with given wind shielding, and for a specified wind direction. Furthermore, it is important to realize that they are always relative to wind velocity at a stated reference height in the undisturbed airstream.

There are a number of techniques available to determine wind pressure coefficients:

- basic "default" data from tables (e.g., Orme et al. 1998),
- wind tunnel measurements,
- modeling using computational fluid dynamics (CFD), or
- wind pressure coefficient generation tools.

As an example, Figure 1 (Orme et al. 1998, based on BRE data) shows wind pressure coefficients derived from wind tunnel tests performed on a 1:1200 scale model of a tall building with a flat roof and a central lightwell, located in an array of flat-roof low-rise buildings. The low-rise buildings are randomly orientated and one-third of the height of the taller building. The high-rise building has dimensions of 60 m × 50 m × 33 m (200 ft × 160 ft × 110 ft) (width × length × height) to scale. The lightwell measures 30 m × 20 m × 33 m (98 ft × 67 ft × 110 ft) to scale and is centrally placed and completely open to the wind. The wind pressure coefficients are referenced to the undisturbed wind velocity at the height of the roof. The pressure coefficients of the external building surface, including the lightwell, are indicated in Figure 1, in which aa is the lightwell wall adjacent to outer wall AA of the building, etc. The wind direction for these coefficients is normal to and toward wall AA.

VENTILATION PROVISIONS

Flow characteristics of components of conventional HVAC systems are reasonably well documented, mainly because they can be laboratory tested (e.g., ASHRAE 1997). However, these systems strongly interact with other building characteristics, such as air leakage paths and purpose-provided openings in the building envelope. Ideally, therefore, modeling must take into account all of the above. Pressure loss coefficients of ducts, fittings, filters, passive stack terminals, and fan pressure rise characteristics will be incorporated whenever possible.

METEOROLOGICAL DATA

Required Data

There are two main driving forces that affect air infiltration and natural ventilation rates through purpose-provided openings. These are wind pressure on buildings and temperature differences between the indoor and outdoor environments. Many models are able to take into account not only steady-state conditions but also varying meteorological conditions (for instance, using "hourly" weather data files as inputs). Moreover, meteorological data should be obtained from a measurement site as close as possible to the building location. Orme (1999) comments on the applicability of meteorological data to locations distant from the measurement site. In fact, "test reference years" of meteorological data suited to ventilation-related applications may differ from those selected for other purposes, such as heating or cooling load calculations.

Table 1 shows the coincidence of hourly wind speed with temperature data for London (Heathrow) for all data within the 20-year period 1975 to 1995. Clearly in this example, there are certain combinations of these parameters that are observed to occur together more often than others. These combinations then produce certain driving forces. Figures 2a and 2b indicate the observed occurrence of these natural ventilation driving forces for locations across Europe during spring and autumn, respectively. (They are based on assumptions about the wind pressure distribution and ventilation stack height.) During these seasons, in general, occasions with high natural ventilation driving forces are more common in Stockholm and Copenhagen than in the other three locations.

TABLE 1
Coincidence of Hourly Wind Speed with Temperature Data for London (Heathrow) Between 1975 and 1995 (Data Source: Sanders 1998)

Speed, m/s (mph) / Temp. (°C)	0 - 2 (0-4)	2 - 4 (4-9)	4 - 6 (9-13)	6 - 8 (13-18)	8 - 10 (18-22)	10 - 12 (22-27)	12 - 14 (27-31)	14 - 16 (31-36)	16 - 18 (36-40)	18 - 20 (40-45)	All speeds
-10.0 to -8.1	0.00										0.00
-8.0 to -6.1	0.01	0.01	0.00								0.02
-6.0 to -4.1	0.03	0.02	0.01	0.00							0.06
-4.0 to -2.1	0.16	0.06	0.03	0.01	0.01	0.00					0.27
-2.0 to -0.1	0.45	0.19	0.09	0.06	0.04	0.01	0.00				0.85
0.0 to 1.9	2.64	1.97	0.91	0.40	0.13	0.04	0.01				6.10
2.0 to 3.9	2.36	2.25	1.32	0.58	0.14	0.03	0.01	0.00			6.69
4.0 to 5.9	2.60	3.09	1.86	0.80	0.23	0.04	0.01	0.00	0.00		8.63
6.0 to 7.9	2.91	3.76	2.28	1.03	0.32	0.08	0.01	0.00	0.00		10.40
8.0 to 9.9	2.94	4.21	2.92	1.40	0.43	0.09	0.02	0.00	0.00	0.00	12.03
10.0 to 11.9	2.91	4.36	2.99	1.54	0.47	0.12	0.03	0.00	0.00		12.42
12.0 to 13.9	2.99	4.25	2.58	1.21	0.37	0.08	0.02	0.00		0.00	11.50
14.0 to 15.9	2.55	4.05	2.43	0.91	0.19	0.03	0.01	0.00			10.17
16.0 to 17.9	1.76	3.16	2.12	0.76	0.13	0.02					7.96
18.0 to 19.9	1.06	2.12	1.60	0.57	0.08	0.01					5.44
20.0 to 21.9	0.60	1.28	1.02	0.33	0.04	0.00	0.00				3.28
22.0 to 23.9	0.31	0.83	0.63	0.19	0.02						1.98
24.0 to 25.9	0.18	0.53	0.36	0.13	0.01	0.00					1.21
26.0 to 27.9	0.07	0.25	0.18	0.08	0.01						0.59
28.0 to 29.9	0.01	0.10	0.08	0.04	0.01						0.24
30.0 to 31.9	0.00	0.04	0.04	0.02	0.00						0.11
32.0 to 33.9	0.00	0.02	0.02	0.00							0.04
34.0 to 35.9		0.01	0.00								0.01
All temp.	26.58	36.54	23.47	10.07	2.62	0.57	0.13	0.01	0.00	0.00	100.00

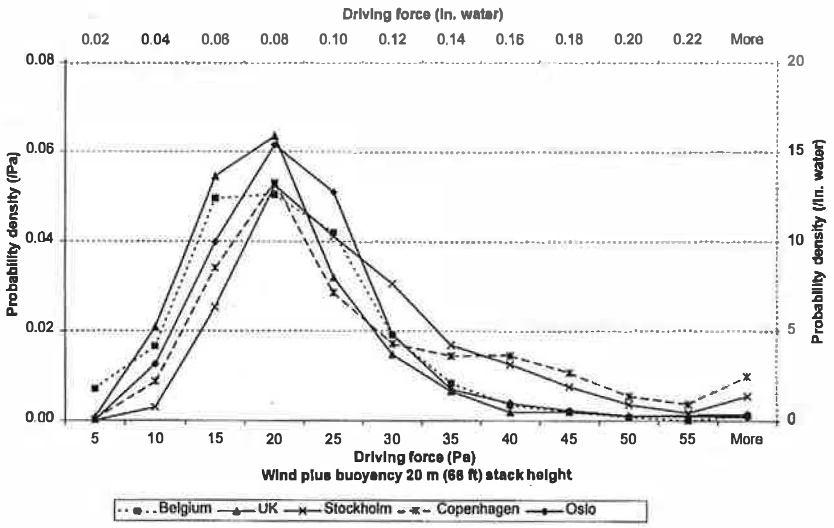


Figure 2a *Natural ventilation driving forces for locations across Europe during spring (Schild 1999).*

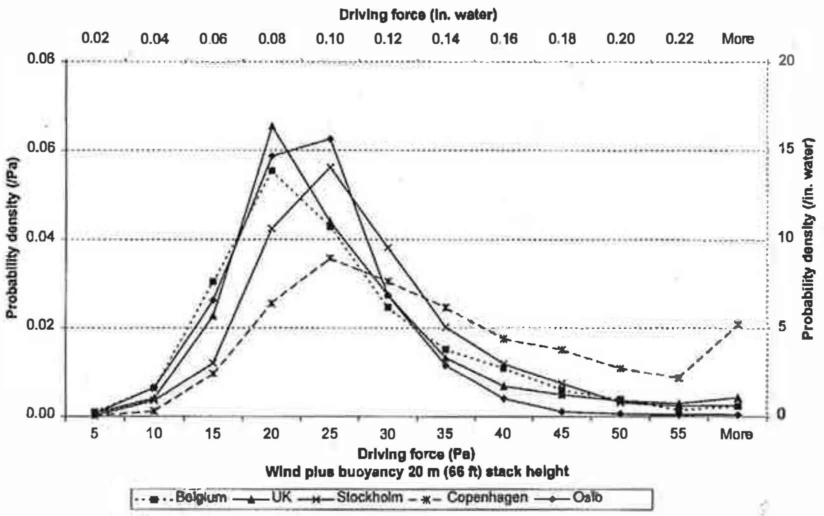


Figure 2b *Natural ventilation driving forces for locations across Europe during autumn (Schild 1999).*

Influence of Meteorological Conditions on Ventilation Rates

Meteorological conditions have a very strong influence on ventilation rates. Figure 3 illustrates air changes rates in a dwelling calculated using a multi-zone network model for an entire "heating season." (A heating season means the period of the year in which it is necessary to provide heating to the incoming outdoor air to provide adequate thermal comfort.) The dependence of air change rate on external temperature and wind speed are shown. Although they are not the only significant factors, they provide the main driving forces. Additionally, the dependence of air change rate on wind direction may be important, particularly locally within multi-zone buildings. The particular climatic information used here was for London and consisted of real weather data for a heating season. (Notice that the wind speeds only occur in multiples of 0.5 m/s [approximately 1 mph] on account of the precision with which they were reported.) The simulated building is a two-story single-family dwelling, ventilated by passive stacks connected to the "wet rooms" (i.e., kitchen, bathroom, and toilet) and fixed area ventilation openings. The airtightness of the building is 5 ach (air changes per hour) at 50 Pa (0.20 in. water) pressure difference. The input data are based on assumptions derived from statistical information about dwellings in eight industrialized countries (IEA 1996). Window airing by occupants is not included in the calculation. In fact, the average air change rate was determined to be 0.54 ach over the heating season.

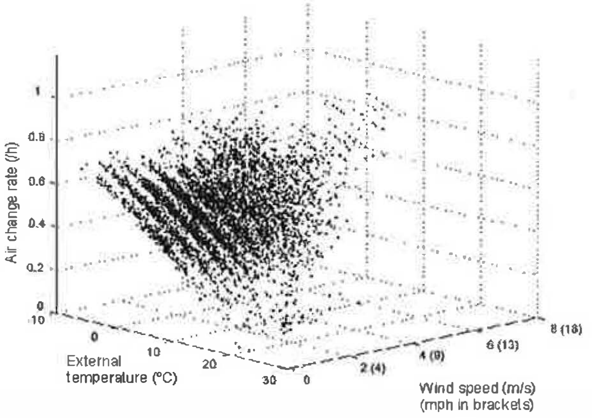


Figure 3 *Calculated hourly air change rate for a single-family dwelling over a whole heating season—dependence on wind speed and external temperature.*

OCCUPANT-RELATED DATA

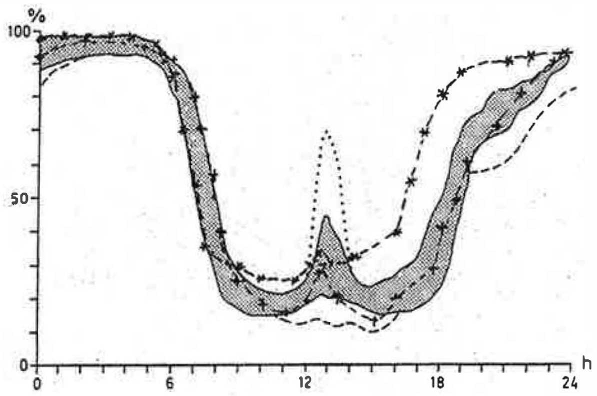
Occupancy refers both to the number of people present (occupant density) and to the times during which they are present. Typical occupancy schedules will be dependent on building type. In particular, Annex 27 (IEA 1996) includes representative schedules for occupants (including occupant densities) and associated pollutant generation schedules for a variety of dwelling types. These were statistically based on a survey of occupancy patterns in dwellings covering a number of countries (Månsson 1995). Figures 4a and 4b indicate occupancy by time of day for employed men and women, respectively, in residential buildings from this survey.

Additionally, Dubrul (1988) highlights work undertaken concerning occupant behavior with respect to ventilation in dwellings. For example, the percentage of windows that are open may have a significant impact on the ventilation rate. This must be taken into account for accurate predictions of ventilation rates.

POLLUTANT MODELING DATA

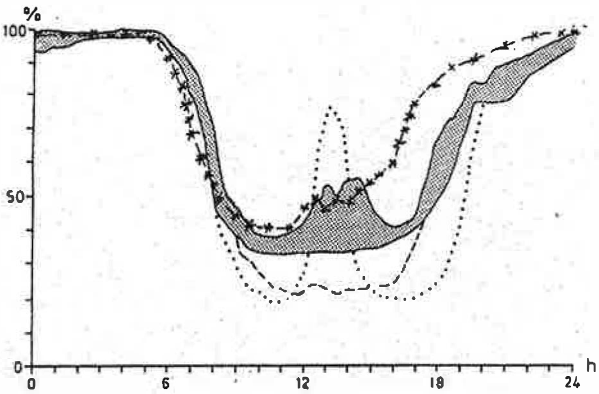
Pollutants may enter the air within a zone by being emitted internally or by being transported in air from external sources outside the zone. Similarly, pollutants may leave the zone air by being deposited, adsorbed, or absorbed internally or by being transported elsewhere. Pollutant models make use of the air flow rates calculated as solutions to an air flow network when it is subjected to certain driving forces, often with the assumption of uniform mixing. They then predict pollutant concentrations as functions of time. Occupant exposures can then be evaluated.

The hourly exposure of a typical dwelling occupant to a pollutant (CO_2) over a heating season is depicted in Figure 5. This is based on the same input data and calcu-



Belgium, Germany (west) and Sweden (shaded area);
France (dotted line); Japan (--+--); USA (hatched line);
Sweden 1990-91 (*---*---*)

Figure 4a *Percentage of employed men at home on weekdays (Månsson 1995).*



Belgium, Germany (west) and Sweden (shaded area);
France (dotted line); USA (hatched line); Sweden 1990-91 (*-*-*)

Figure 4b *Percentage of employed women at home on weekdays (Månsson 1995).*

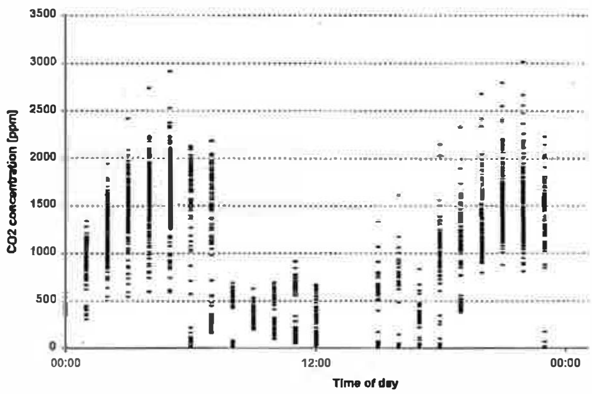


Figure 5 *Hourly CO_2 exposure of a dwelling occupant over a whole heating season.*

lated results as Figure 3. The exact values encountered will be strongly dependent on the total occupants present, in which rooms they are located, as well as the interzonal air flows within the building. Methods to summarize this type of information would include the total number of hours over the heating season that the occupant was exposed to, e.g., CO_2 above 800 ppm or CO_2 above 1600 ppm.

MODEL EVALUATION DATA

Model evaluation data may be used by researchers and practitioners wishing to confirm that they are able to successfully predict the ventilation-related behavior of buildings by modeling a building for which experimental results are available. It is intended to provide model evaluation data in "coincident" form whenever possible, i.e., input and output data will be reported in "simultaneous" form. Useful model evaluation data require detailed descriptions of both the building and measurement circumstances. Harrje and Piggins (1991) have attempted to assist this process by producing guidelines that may be followed. Potential evaluation data sources include measurements made within the context of IEA annexes (e.g., Fürbringer et al. 1996a, 1996b). Also, "benchmark cases" may be provided.

CONCLUSIONS

It is anticipated that the ventilation modeling data guide will facilitate wider acceptance and use of ventilation modeling by practitioners. This may enable improved ventilation designs to be adopted. The intention is that this task will extend earlier work covering airtightness data for whole buildings and building components to include data and algorithms concerning wind pressure coefficients, ventilation systems, meteorological conditions, occupancy, pollutant modeling, and model evaluation. These will then be published in electronic form.

Specific data types that may be incorporated are, for example, pressure loss coefficients of air distribution system components and fan pressure rise characteristics. An additional example is that, for certain building types, typical occupancy schedules and densities will be supplied. Methods to summarize results produced from pollutant modeling would include the number of hours of occupant exposure to a pollutant above a certain concentration. It is also planned to supply model evaluation data in coincident form whenever possible and benchmark cases may be provided. Future developments may include linking the data guide to external third party applications, but, this would not be done at the initial stage.

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