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**Ventilation and Building Characterization for
Indoor Air Quality Investigations**

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ABSTRACT

A series of parameters have been developed to describe building and HVAC characteristics of commercial buildings for use in conjunction with indoor air quality investigations. The parameters include features deemed essential to an investigation intended to obtain baseline information on a space within a building as opposed to a detailed research study or an effort to diagnose a specific problem. The building characterization includes general information on the whole building and more specific information on the space within the building that is being investigated. This so-called test space will in general be only a portion of the building, but it could be the entire building.

This paper presents the building and HVAC parameters and discusses checklists developed for obtaining these parameters in the field. The checklists or forms, along with the instructions for completing the checklists, are divided into four areas, Whole Building Description, Test Space Description, HVAC System Description, and HVAC System Performance. The Whole Building Description checklists provide a description of the basic features of the building being studied. The Test Space Description checklists are used to obtain more detailed information on the test space within the building. The HVAC System Description checklists describe the HVAC system serving the test space, and the HVAC System Performance checklists cover selected performance measurements on the HVAC system.

1. INTRODUCTION

Despite the obvious impact of building and ventilation system characteristics on indoor air quality, many air quality investigations have given inadequate attention to the assessment of important building features including ventilation. In some investigations the assessments of building and ventilation characteristics have been very limited, while others have involved no consideration of these factors at all. Ventilation system design values are sometimes evaluated, but no actual performance measurements are made. In other cases, performance measurements are conducted, but unreliable and inappropriate measurement procedures are employed. Indoor air quality investigations that do characterize the building and its HVAC systems generally employ different approaches, making the comparison of their results difficult. These circumstances exist due in part to an inadequate understanding of building characteristics and ventilation systems on the part of some indoor air quality investigators, along with a lack of standardized approaches to the assessment of building and HVAC characteristics. In order to address the need for improvements in the characterization of building and HVAC systems, parameters were identified for assessing building and HVAC characteristics for indoor air quality investigations in commercial buildings. These procedures provide for the assessment of those features deemed essential to an investigation intended to obtain

baseline or core information on a building, as opposed to a detailed research study or an effort to diagnose a specific indoor air quality problem. This paper describes checklists or forms that were developed to record these building and HVAC parameters in the field, along with the instructions for completing these checklists. The checklists are divided into four groups: A) Whole Building Description, B) Test Space Description, C) Test Space HVAC System Description and D) Test Space HVAC System Performance. The checklists and the associated instructions for completing them are contained in reference [1].

The Whole Building Description checklists cover basic information on the building including age, size, space use, occupancy, climate and site, building equipment and information on potential sources within and outside of the building. The Test Space Description checklists provide more detailed information on the space being studied, in general only a portion of the building. These checklists include information on space use, occupancy, interior furnishings and potential contaminant sources. The Test Space HVAC Description checklists are used to record design information on the HVAC equipment serving the test space. The last set of checklists, Test Space HVAC Performance, are used to obtain selected information on the performance of the HVAC equipment serving the test space. The ventilation performance measurements contained in this evaluation are intended to require only 2 to 4 person-days and are appropriate to personnel familiar with standard airflow measurement techniques.

The checklists were developed for use in conjunction with the EPA Building Assessment and Evaluation Program (BASE). The BASE Program is a multi-year research effort intended to collect baseline information on the indoor environmental performance of commercial buildings throughout the U.S. Building investigations conducted under the BASE Program are to include a characterization of the building and HVAC system using the checklists described in this paper, selected environmental measurements including pollutant levels and thermal comfort parameters, and the application of an occupant questionnaire to record occupant perceptions of the indoor environment and other relevant information. Each building investigation under the BASE Program is intended to be completed in less than one week by three to four people. Although the building and HVAC checklists described in this paper were developed as part of the BASE Program, they are expected to be useful for other indoor air quality investigations as well.

The fact that the building and HVAC checklists were developed for the BASE Program affects their content and approach. The BASE studies are not intended for the diagnosis of air quality problems in specific buildings, and therefore the checklists are focused on gathering general information about the building and HVAC system as opposed to the detailed and specific information required in diagnostic efforts. In addition, while it is hoped that the information obtained in the BASE

program may generate hypotheses regarding the impact of building features on the indoor environment and occupant perceptions, no specific hypotheses drove the formulation of these checklists.

The BASE program studies will involve so-called test spaces within buildings, occupied by fifty to one-hundred people, as opposed to entire buildings. In some cases the test space will be a whole building, but generally not. Therefore, only general information is obtained on the whole building, while specific information on the test space and its systems. In the section on HVAC performance, only established measurement procedures are employed that are accessible to personnel with a reasonable level of engineering expertise. Although recent research efforts have developed and demonstrated measurement techniques that may be more widely used in the future, no research level procedures are employed in the HVAC performance assessment. In addition, the measurement procedures selected are consistent with the level of effort associated with the BASE studies, i.e., two to four person-days for the HVAC performance measurements. These restrictions to well-established procedures that can be completed in a relatively short period of time limits the nature of the information that can be obtained, but they were necessary given the nature of the BASE Program. Other research efforts and other building investigations are expected to use more advanced and complete evaluation procedures than the BASE studies in a smaller number of buildings.

2. WHOLE BUILDING DESCRIPTION

There are two forms used to obtain information on the whole building, Form A-1 Building Description and A-2 Source Information. The first contains general information on space use, occupancy, climate and site, building equipment and the building envelope. This information is acquired through a combination of an examination of the building plans, a building walk-through, and discussions with the building owner, manager and operator. The second form is used to obtain information on contaminant sources potentially impacting the building.

Form A-1, Building Description, contains the following parameters to describe the whole building.

Building age

Floor area: The total floor area of the building, including the space on all floors enclosed by the exterior walls and uncorrected for the building core, interior walls or columns.

Number of floors below grade

Number of floors above grade

Space use: Information on space use within the building including location and approximate floor area associated with the following activities: office, retail, public assembly, laboratory, food services, and parking.

Occupancy: Information on the approximate number of building occupants, the days per week that the building is occupied and the occupied hours per day.

Climate: Heating degree days, Cooling degree days, Winter design drybulb temperature, Summer design drybulb temperature, and Summer design wetbulb temperature.

Site: Characterization of the building site as urban, suburban or rural, along with subcategories under each.

Ventilation: An indication of whether the building is ventilated naturally or mechanically.

Air conditioned: An indication of whether the building is air conditioned or not.

Cooling equipment: The type(s) of systems that are employed in cooling the building.

Heating equipment: The type(s) of systems that are employed in heating the building.

HVAC equipment operating schedule: Information on space-conditioning and ventilation equipment operation, including days per week and hours per day.

Wall construction

Roof construction

Glazing: Information on the number of panes of glass in the glazing system, whether the windows are operable and when they incorporate shading elements.

Form A-2, Source Information, contains the following parameters related to contaminant sources impacting the building.

Outdoor Sources: An indication of the existence of garbage dumpsters, heavy motor vehicle traffic, emergency generators, power plants, construction activities or industrial stacks in the vicinity of the building.

Smoking policy: An indication of whether smoking is allowed in the building, and whether it is restricted to smoking lounges or private offices.

Water damage: Information on past occurrences of water damage in the building and on current water leaks.

Fire damage: Information on past occurrences of fire damage in the building.

Renovation: Information on recent and current renovation, including painting, new carpets, reroofing, new furniture and partition replacement.

Cleaning: Information on cleaning activities in the building.

Pest control: Information on pest control activities in the building.

Special-Use Spaces: Information on special-use spaces in building including their existence, location and connection to the rest of the building.

3. TEST SPACE DESCRIPTION

There are two forms used to obtain information on the test space, B-1 Building Description and B-2 Source Information. The first is concerned with general information on space use, occupancy, and interior finishes and furnishings. The second form is used to obtain information on contaminant sources potentially impacting the test space.

Form B-1, Building Description, contains the following parameters to describe the test space.

Floor Area

Ceiling Height

Space Use Change: Information on whether the space use of the test space has changed since the original design of the building, and whether the ventilation system was redesigned based on the space use change.

Number of Work Stations: With a distinction between private offices, partitioned space and open office space.

Number of Occupants: Based on actual body counts two times a day for one week.

Design Floor Area per Occupant: The design value for the floor area per work station if available.

Interior Finishes: Wall, partitions, ceiling and floor.

Furniture: Surface finish, and whether it is systems furniture or movable.

Lighting: Lamp type, and the existence of task lighting, and desk lamps.

Supply Vents: Type and number.

Return Vents: Type and number.

Auxiliary Environmental Equipment: Existence of air cleaners, space heaters, humidifiers, dehumidifiers and fan.

Form B-2, Source Information, contains the following parameters related to contaminant sources within the test space.

Smoking Policy: An indication of whether smoking is allowed in the test space, and whether it is restricted to smoking lounges or private offices.

Water Damage: Information on past occurrences of water damage in the test space and on current water leaks.

Fire Damage: Information on past occurrences of fire damage in the test space.

Renovation: Information on recent renovations in the test space.

Cleaning: Information on cleaning activities in the test space.

Pest Control: Information on pest control activities in the test space.

Special-Use Spaces: Information on special-use spaces in the test space, such as smoking lounges, copy rooms, photo labs and graphic arts facilities, including their existence and location.

4. TEST SPACE HVAC SYSTEM DESCRIPTION

The description of the HVAC system serving the test space employs a series of forms, with the specific forms used and their number depending on the system. The forms involved in the HVAC system description are as follows:

- C-1 CENTRAL AIR HANDLING AND DISTRIBUTION SYSTEM
- C-2 PERIMETER ZONE UNITS
- C-3 UNITARY SYSTEMS
- C-4 EVAPORATIVE COOLING SYSTEMS
- C-5 OUTDOOR AIR INTAKE CONTROL
- C-6 NATURAL VENTILATION SYSTEMS
- C-7A AIR HANDLER SPECIFICATIONS
- C-7B EXHAUST FAN SPECIFICATIONS
- C-8 FILTRATION AND AIR CLEANING SYSTEMS
- C-9 AIR WASHERS
- C-10 HUMIDIFICATION SYSTEMS
- C-11 MAINTENANCE
- C-12 INSPECTION

The particular subsystems that comprise the HVAC system determine which of Forms C-1 through C-10, and how many, are used. Forms C-11 and C-12 are used in all buildings.

Form C-1 is used to describe the central air handling and distribution systems serving the test space, if such a central system serves the test space. One form is required for each central system serving the test space. Central systems, sometimes also referred to as "all-air," provide space conditioning to the space by supplying conditioned air. The system description includes information on the system type based on a classification scheme developed specifically for air handlers employed in North America, based in part on the ASHRAE HVAC Systems and Equipment Handbook [2] as well as other references [3,4].

Form C-2 is used to describe systems that provide space conditioning to perimeter or exterior zones, assuming these zones are not conditioned by the central system. If no perimeter system exists, then this form does not need to be completed. The system type is recorded on the form, along with additional information specific to each system type. Forms C-3 and C-4 are used to describe unitary and evaporative cooling systems, if such systems are employed to condition the test space. Form C-5 provides information on the means of outdoor air intake employed in the mechanical ventilation system serving the test space, and C-6 is used to describe the ventilation strategy employed in naturally ventilated buildings. Forms C-7A and C-7B are used to record the design specifications of all air handlers and exhaust fans. One copy of each form is required for each such system serving the test space.

The information on these forms include design airflow rates and the space served by the system.

Forms C-8, C-9 and C-10 are used to record information on filtration and air cleaning systems, air washers and humidifications systems respectively. Form C-8 contains information on the filters employed in the air handlers, including their type and their rated efficiency. In addition, the form is used to record information on gaseous air cleaners. Forms C-9 and C-10 are used to record the type of air washer and humidification system respectively, if such a system exists in the air handler.

Form C-11 is used to record information regarding HVAC system maintenance procedures and schedules concerning the air handler, air filters, ductwork and other system components. Form C-12 is used to conduct an on-site inspection of the components of the ventilation system. Both of these checklists are used, regardless of the type of HVAC system serving the test space.

5. TEST SPACE HVAC SYSTEM PERFORMANCE

The evaluation of the performance of the test space HVAC system was developed based on a level of effort of 2 to 4 person-days and on the use of standard measurement techniques that are accessible to personnel with a reasonable level of engineering expertise. Therefore, the measurements are fairly simple and somewhat limited, and do not employ the tracer gas techniques and other procedures associated with more complete ventilation system evaluations. The specific forms employed in the performance assessment, and their number, depend on the building being evaluated. The checklist forms for HVAC performance are as follows:

- D-1A SUPPLY AIRFLOW RATE
- D-1B PERCENT OUTDOOR AIR INTAKE
- D-1C OUTDOOR AIR INTAKE RATE
- D-1D SUPPLY AIR TEMPERATURE AND RELATIVE HUMIDITY
- D-2A EXHAUST FAN OPERATION
- D-2B EXHAUST FAN AIRFLOW RATE
- D-3A LOCAL VENTILATION PERFORMANCE - AIRFLOW RATE
- D-3B LOCAL VENTILATION PERFORMANCE - SUPPLY AIR TEMPERATURE
- D-4A NATURAL VENTILATION - CONTINUOUS CARBON DIOXIDE
- D-4B NATURAL VENTILATION - CARBON DIOXIDE DECAY
- D-5A MECHANICAL VENTILATION - AIR INFILTRATION RATE: TEST DESCRIPTION

- D-5B MECHANICAL VENTILATION - AIR INFILTRATION RATE: SUPPLY AIRFLOW RATE
- D-5C MECHANICAL VENTILATION - AIR INFILTRATION RATE: PERCENT OUTDOOR AIR INTAKE
- D-5D MECHANICAL VENTILATION - AIR INFILTRATION RATE: OUTDOOR AIR INTAKE RATE
- D-5E MECHANICAL VENTILATION - AIR INFILTRATION RATE: CARBON DIOXIDE DECAY
- D-5F MECHANICAL VENTILATION - AIR INFILTRATION RATE: DATA ANALYSIS

Evaluations of mechanically ventilated buildings require forms D-1, D-3 and D-5, with the number of forms based on the number of air handlers serving the test space. Naturally ventilated buildings require the D-4 forms. Either type of ventilation system will require the D-2 forms if the test space has any mechanical exhaust systems.

Forms D-1A through D-1D are used to evaluate the air handlers serving the test space. Form D-1A is used to measure the supply airflow rate of the air handler using a pitot tube or hot-wire anemometer traverse. Form D-1B describes the measurement of the percent outdoor air intake by the air handler as determined with a mass balance of occupant generated carbon dioxide at the air handler. The outdoor air intake rate is recorded on Form D-1C, based either on a direct measurement at the air handler or by multiplying the supply airflow rate from Form D-1A by the percent outdoor air intake from Form D-1B. Form D-1D is used to record the supply air temperature and relative humidity. These four forms are to be used together to evaluate the performance of each air handler serving the test space in the morning and afternoon on two consecutive days of monitoring, at approximately 10 am and 3 pm on each day. Therefore, four sets of these forms are required for each air handler.

Forms D-2A and D-2B are used in the evaluations of the exhaust fans serving the test space, with one of each form required for each exhaust fan. Form D-2A records the operation of each exhaust fan serving the test space based on an inspection conducted twice a day, once in the morning and once in the afternoon, on five consecutive working days. Form D-2B is used to measure the airflow rate in each exhaust fan serving the test space, with only one airflow rate measurement required in each exhaust fan.

Forms D-3A and D-3B are used in the ventilation system evaluation within the test space, with one copy of each form required. Form D-3A is used to record the airflow rate out of each supply air diffuser within the test space using a flow measuring hood. This evaluation is only conducted once in the test space. Form D-3B is used to record the supply air temperature at each supply air diffuser within the test space,

again with this evaluation being conducted only once in the test space.

Forms D-4A and D-4B are used in the evaluations of naturally ventilated buildings. Form D-4A is used to record the results of continuous carbon dioxide monitoring at three locations within the occupied portions of the test space. This monitoring is to take place for two full days, and therefore two of these forms are required. Form D-4B is used to record the results of a post-occupancy carbon dioxide decay test in the building conducted to estimate the whole building air change rate. This test is to be conducted in accordance with ASTM E741, and therefore a tracer gas other than carbon dioxide can be employed in this measurement.

Forms D-5A through D-5F are used to estimate the envelope infiltration rate in mechanically ventilated buildings. This is done by conducting a post-occupancy carbon dioxide (or other tracer) decay test with the air handlers operating to determine the whole building air change rate. The outdoor air intake rate is then measured at the air handlers and subtracted from the whole building air change rate to determine the envelope infiltration rate for the building. Only one such test is required.

6. SUMMARY

Parameters have been developed to describe building and HVAC system characteristics in commercial building for use in indoor air quality investigations. The values of these parameters are recorded in the field on a series of checklists. These checklists and the associated instructions for their completion are published in a separate report [1]. The use of these checklists will lead to improved standardization in describing building and system characteristics, and the ability to correlate these building attributes with indoor environmental performance.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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