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Standard Practice for Specifying Data for Evaluation of Energy Used in Residential Buildings[1]

This standard is issued under the fixed designation E 1410; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Section 8 was added editorially in September 1997.

1. Scope

1.1 This practice is applicable to the measurement of energy used for space conditioning and domestic water heating in both single and multifamily buildings. It is intended to assist those who design test methods for field monitoring projects. It establishes a uniform set of guidelines for specifying the data needed to evaluate energy used for space conditioning and domestic water heating in residential buildings, and is intended to promote the exchange of data and to improve measurement practices.

1.2 This practice neither specifies the complete experimental design nor defines the data analysis technique to be used.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 1060 Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings[2]

E 631 Terminology of Building Constructions[3]

E 741 Test Method for Determining Air Change in a Single Zone by Means of Tracer Gas Dilution[3]

E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization[3]

2.2 *ANSI/ASHRAE Standards:*[4]

ANSI/ASHRAE Standard 101: Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics

ANSI/ASHRAE Standard 103: Methods of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers

ANSI/ASHRAE Standard 116: Methods of Testing for Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps

US/DOE Appliance Efficiency Standards 10CFR 430[5]

3. Terminology

3.1 Terms in this standard are defined in Terminology E 631.

4. Significance and Use

4.1 Variations in the building envelope, indoor temperature, weather, occupant behavior, and equipment performance can cause large variations in energy performance. In order to determine whether a new building performs as designed, or whether a retrofit of an existing building saves energy as predicted, the measured energy performance must be adjusted to standard conditions. This practice describes the kinds of data that must be collected to perform such an adjustment, but does not describe the necessary adjustment.

4.2 At present, insufficient data are available to assess the in-situ effectiveness of most energy-saving techniques. Gathering and storing energy-use data in a standard format would allow the development of a database and facilitate such an assessment. This practice contains a recommended format for the storage of data.

4.3 This practice is to be used in the development of an experimental design to measure the energy used for space conditioning and domestic water heating of a residential building. The set of parameters to be collected depends on the analysis technique that will be used. Details of experimental

[1] This practice is under the jurisdiction of ASTM Committee E-6 on Performance of Buildings and is the direct responsibility of Subcommittee E06.25 on Whole Buildings and Facilities.

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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 04.07.

[4] Available from American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329.

[5] Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. U.S. Department of Energy, Report No. DOE/CE-0220. Title 10—*Energy*, Chapter 11—*Department of Energy*, Subchapter D—*Energy Conservation*. Part 430—*Energy Conservation Program for Consumer Products*.

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TABLE 1 Core Data Set

Measurements	System Evaluated		
	Heating	Cooling	DHW
Continuous Measurements:			
Space Conditioning			
Heating energy consumption	•		
Cooling energy consumption		•	
Non space-conditioning energy use	•	•	
Indoor temperature	•	•	
Utility Bills	•	•	
Domestic Water Heating (DHW)			
DHW energy consumption			•
Hot water consumption			•
Cold water temperature			•
Hot water temperature			•
Weather Conditions			
Outdoor air temperature	•	•	
Wind speed	•	•	
Outdoor humidity		•	
One-time Measurements:			
Building description			
Areas	•	•	
Envelope characteristics	•	•	
Exterior energy use	•	•	
HVAC system description			
Equipment	•	•	
Nameplate information	•	•	
Thermostat and controls	•	•	
Auxiliary equipment	•	•	
Power consumption	•		
DHW system description			
Equipment			•
Nameplate information			•
Thermostat and controls			•
Power consumption			•
Occupant survey			
Number of occupants	•	•	•

design may be found in: Guiding Principles Concerning Design of Experiments, and Measuring Techniques;[6] Monitoring Methodology Handbook for Residential HVAC Systems;[7] and Monitoring the Performance of Solar Heated and Cooled Buildings, Vols 1 and 2.[8]

4.4 The user of this practice needs to be familiar with the fundamental techniques of energy monitoring.

5. Data Acquisition

5.1 The parameters that must be collected to evaluate the energy consumption of heating, cooling, and domestic hot water (DHW) systems are shown in the following two tables. Table 1 (Core Data) gives the minimum required data that must be collected, and Table 2 (Specific Data) gives additional data that is needed for more detailed energy analysis, or for the evaluation of specific energy systems, for example, an active or passive solar system.

5.1.1 Core data is required in all cases. Specific data must be taken whenever this data has significant impact. (See text for guidance.)

5.2 *Continuous Measurements*:

5.2.1 Because they vary throughout the test period, building operating characteristics, energy consumption, indoor conditions, and weather conditions must be monitored continuously. The length of the test period depends upon the experimental design that has been chosen and determines the level of accuracy that can be expected. For a retrofit, the *before* and *after* test periods should be of similar lengths and contain similar weather conditions.

5.2.2 The data collected is known as time-series data. Store data weekly or hourly; hourly values are preferred. Building conditions, such as occupancy or temperature or DHW use, often change every hour, and it may not be possible to extract representative values from weekly data.

5.2.3 Store time-integrated (average or sum) hourly values using real-time data acquisition systems that scan sensors at least once per hour; more frequent reading will be necessary in some cases. Store weekly readings from individual time integrating sensors.

5.2.4 *Space Conditioning*:

TABLE 2 Specific Data Set

Measurements	System Evaluated		
	Heating	Cooling	DHW
Continuous Measurements:			
Space Conditioning and DHW			
Auxiliary conditioning	•	•	
Indoor humidity		•	
Multiple indoor temperatures	•	•	
Fenestration management	•	•	
Exterior energy use	•	•	
Air temperature near boiler	•		•
Weather Conditions			
Solar insolation	•	•	
On-site wind speed and direction	•	•	
One-time Measurements:			
Building description			
Additional building data	•	•	
Pressurization test (Test Method E 779)	•	•	
Infiltration test (Test Method E 741)	•	•	
Solar shading	•	•	
Wind shielding	•	•	
Thermography	•	•	
HVAC system description			
Heating system efficiency	•		
Cooling system effiency		•	
DHW system description			
DHW system efficiency			•
DHW appliances			•
Occupant survey			
Extended questionnaire	•	•	•

[6] *Guiding Principles Concerning Design of Experiments, Instrumentation, and Measuring Techniques* ISBN 91-540-3955-X. Swedish Council for Building Research, edited by Gian Fracastoro and Mats Lyberg, Stockholm, Sweden (1983). (In English)

[7] *Monitoring Methodology Handbook for Residential HVAC Systems*, EPRI/EM-3003, Electric Power Research Institute, Palo Alto, California, May 1983.

[8] *Monitoring and Performance of Solar Heated and Cooled Buildings, Volumes 1 and 2*, EPRI/ER-1239/1 and EPRI/ER-1239/2. Electric Power Research Institute, Palo Alto, California, November 1979.

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5.2.4.1 The core time-series data set for space conditioning consists of four parameters: the energy consumed for heating by the primary heating source, the energy consumed for cooling by the primary cooling source, the energy consumed for non-space-conditioning purposes (for example, lighting, appliances, DHW), and the indoor temperature. Auxiliary space conditioning energy use must also be measured (see 5.2.4.2). Indicate whether the air temperature sensor is shielded or unshielded, that is, the sensor is measuring the radiant (globe) temperature or the air temperature. When a single indoor temperature is difficult to define, record air temperatures at a number of points to ensure temperature is representative of the space as a whole. Monthly utility billing data for electricity, gas, and oil consumption are required as a back-up. This information will provide a cross-check of the time-series sensor values, and may be useful in filling in information if there are short-term failures of the sensors.

5.2.4.2 The specific time-series data set for space conditioning includes monitoring any auxiliary heating and cooling equipment (for example, wood stoves, space heaters, space air conditioners, fans, evaporative coolers), as well as indoor humidity, air temperature at the furnace, thermostat and other locations, and window openings; it also includes previous years' billing records.

5.2.5 *Domestic Hot Water System*:

5.2.5.1 The core time-series data set consists of four parameters for the DHW system: energy consumption, hot water consumption, cold water temperature, and hot water temperature.

5.2.5.2 The specific time series data for DHW includes ambient air temperature at the boiler in order to normalize for standby losses.

5.2.6 *Weather Data*:

5.2.6.1 The core data set for weather conditions consists of outdoor dry-bulb temperature, outdoor humidity and wind speed. Set up an on-site weather station if hourly data are collected, or there is known to be a substantial variation between the nearest weather station and the test site. If weekly data are sufficient, obtain data from the local weather station.

5.2.6.2 The specific data set for weather parameters includes outdoor humidity and on-site wind direction. If solar systems, either active or passive, are to be evaluated, collect solar insolation data as well. Set up an on-site weather station if hourly solar data are collected, or there is known to be a substantial variation between the nearest weather station and the test site.

5.3 *One-time Measurements*—One-time measurements are used to aid in the evaluation of the time series data. The core data set includes important physical parameters concerning four areas: the building envelope, the heating, ventilation and air conditioning (HVAC) system, the domestic hot water (DHW) system, and the building occupants. Collect data by visual inspection, by surveys of building owners and occupants, or by direct measurement.

5.3.1 *Building Envelope Description*:

5.3.1.1 The building envelope description consists of the areas and materials of the building shell components. Record construction material, thickness, presence of insulation, condition, and openings for walls, foundations, and roofs. Draw a plan of the building, indicating the general layout, compass directions, overall dimensions, and floor areas of conditioned zones. Take ground-level photographs of all sides of the building. Take photographs of the surrounding areas from the roof of the building. Record the wind shielding class.[9] Record the age and geographic location of the building using street, city, state and ZIP code. List exterior energy uses, for example, exterior or parking lighting, block heaters.

5.3.1.2 The specific data set includes additional description of the building including any special features relevant to energy consumption. Note attic type, access, and ventilation, as well as any indications of moisture damage. Characterize foundation and basements, noting the number and location of windows, as well as any shafts, chases or flues connecting to upper levels. For multifamily buildings, record the number and layout of apartments and the number and type of windows.

5.3.1.3 The specific data set includes pressurization data performed according to Test Method E 779, and infiltration tests following Test Method E 741, as well as additional information on the shading and shielding of the building. Thermographic pictures of the building shell are made following Practice C 1060 and ASHRAE Standard 101-1981.

5.3.2 *HVAC System Description*:

5.3.2.1 Describe the HVAC system in the building, giving the fuel type, number and type of equipment, its location, distribution system (that is description of ductwork insulation) thermostat controls, and the overall condition of the system. Photograph the main components of the HVAC system.

5.3.2.2 Nameplate information includes the manufacturer, model number, and rated input capacity, output capacity, and operating efficiency. Note the type, location, and operation (including set-back cycle) of the heating and cooling controls; also note any modifications or previous retrofits to the system. Obtain the gas heating value from previous fuel bills for the site or from the gas utility company. Calculate a yearly average if possible. Record the source of the air to all combustion devices.

5.3.2.3 Record the presence of auxiliary sources of heating and cooling, including fireplaces (noting condition and presence of any controls), wood stoves, space heaters, room air conditioners, and so forth. Determine the use of auxiliary heating and cooling in the occupant surveys.

5.3.2.4 The specific data set for HVAC description includes a measurement of the heating and cooling system efficiency. As no standards exist for *field* measurements of seasonal efficiency, perform these measurements following ASHRAE Standards 103 and 116, respectively, as guidelines. Make one-time measurements of the steady-state efficiency of gas- and oil-fired furnaces by flue gas analysis. For air distribution systems, measure the supply and return air temperatures, supply air flow rate, fuel input rate, and fan power once the system has reached a steady-state operating condition. For a heat pump or air conditioning system, measure the compressor and fan power draws, the supply and return air temperatures, supply air-flow

[9] See ASHRAE Handbook of Fundamentals, Chapter 23, Table 6, 1989.

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rate, high and low refrigerant pressures, refrigerant temperature, and outdoor temperatures at steady-state operating conditions.

5.3.3 *Domestic Hot Water (DHW) System Description*:

5.3.3.1 Describe the DHW system in the building, including the energy source, distribution system and the controls. The information required includes the location of the tank, the nameplate (rated) information, the distribution system (for example, pumped loop, thermosiphon loop), the source of the combustion air, and the type of insulation on the tank and pipes. Make a one-time measurement of the burner fuel flow rate for gas-fired domestic hot water heaters using the building gas meter. Record the presence of energy and water conserving devices, such as solar systems and low-flow showerheads. Photograph the principal components of the DHW system.

5.3.3.2 The specific data set for DHW description includes a measurement of the DHW system efficiency, following US/DOE 10CFR 430.22(e) as a guideline. Make one-time measurements of the steady-state efficiencies of gas- and oil-fired boilers by flue gas analysis. Count major hot-water appliances, such as dishwashers and washing machines, and note their locations.

5.3.4 *Occupant Surveys*:

5.3.4.1 Use occupant surveys to seek information on who uses energy in the building, and where and when it is used. The core information includes the number of occupants and average number of occupants at home during different periods of the day.

5.3.4.2 When the occupant data is likely to have a significant impact on energy use the specific data must be included. The specific data set on occupant behavior includes information on thermostat-setting practices, window opening patterns and management of shades and drapes, use of auxiliary heating or cooling and schedules of hot water use. It includes standard sociodemographic data on the occupants: age, sex, education, income, employment, and health. It also asks about whether they are owners or renters; if they are renters whether they pay for utilities, how long they have lived in the building and whether they have problems with over- or under-heating. Additional questions on occupant comfort will reveal other activities undertaken by the occupants to modify their environment. Include questions about draftiness, stuffiness, and moisture problems such as condensation, excessive dryness or use of humidifiers. Record when and where occupants close off rooms.

6. Report

6.1 Report the following information:

6.2 *Continuous Measurements*—specify time interval, for example, hourly, daily.

6.2.1 *Space Conditioning*:

6.2.1.1 Heating energy consumption,

6.2.1.2 Cooling energy consumption,

6.2.1.3 Non space-conditioning energy consumption,

6.2.1.4 Indoor temperature—indicate type (shielded or unshielded), number, and location of sensor(s),

6.2.1.5 Utility energy bills for previous 12 months,

6.2.1.6 Auxiliary conditioning energy consumption,

6.2.1.7 Indoor humidity—indicate type, number and location of sensor(s),

6.2.1.8 Fenestration management—number of open windows, area open, duration, and time of day,

6.2.1.9 Exterior energy use, and

6.2.1.10 Air temperature near boiler.

6.2.2 *Domestic Water Heating*:

6.2.2.1 DHW energy consumption,

6.2.2.2 Hot water consumption,

6.2.2.3 Cold water temperature,

6.2.2.4 Hot water temperature, and

6.2.2.5 Air temperature near tank.

6.2.3 *Weather Conditions*—location and height of meteorological measurement.

6.2.3.1 Outdoor air temperature,

6.2.3.2 Wind speed,

6.2.3.3 Wind direction,

6.2.3.4 Solar insolation, and

6.2.3.5 Outdoor humidity.

6.3 *One-time Measurements*

6.3.1 *Building Description*:

6.3.1.1 Areas of building shell components,

6.3.1.2 Characteristics of building shell components,

6.3.1.3 Exterior energy use—indicate major uses,

6.3.1.4 Pressurization test (Test Method E 779),

6.3.1.5 Infiltration test (Test Method E 741),

6.3.1.6 Thermography (Practice C 1060),

6.3.1.7 Solar shading, and

6.3.1.8 Wind shielding.

6.3.2 *HVAC System Description*:

6.3.2.1 *Equipment*—type, number, location, distribution, condition, previous retrofit, and source of combustion air.

6.3.2.2 *Nameplate information*—manufacturer, model number, rated input capacity, output capacity, operation efficiency, fuel type, and heating value.

6.3.2.3 *Thermostat and controls*—type, number, location of thermostat or other controls. Note operation strategy, set-back, and so forth.

6.3.2.4 *Auxiliary heating and cooling equipment*—number, type, location, condition, and controls.

6.3.2.5 Heating system efficiency.

6.3.2.6 Cooling system efficiency.

6.3.3 *DHW System Description*:

6.3.3.1 *Equipment*—type, number, location, distribution, condition, previous retrofit, and source of combustion air

6.3.3.2 *Nameplate information*—manufacturer, model number, rated input capacity, output capacity, operation efficiency, fuel type, and fuel heating value

6.3.3.3 *Thermostat and controls*—type, number, location of thermostat or other controls. Note operation strategy, set-back, and so forth.

6.3.3.4 Burner-fuel flowrate for gas-fired DHW using the building gas meter.

6.3.3.5 DHW system efficiency.

6.3.3.6 *DHW appliances, washing machines, dishwashers*—number and location.

6.3.4 *Occupant Survey*:

6.3.4.1 Number of occupants, and

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6.3.4.2 Occupant questionnaire.

6.4 For space heating system monitoring the report must include at least the following: 6.2.1.1, 6.2.1.3-6.2.1.6, 6.2.3.1, 6.2.3.2, 6.3.1.1-6.3.1.3, 6.3.2.1-6.3.2.4, 6.3.4.1.

6.5 For space cooling system monitoring the report must include at least the following: 6.2.1.2-6.2.1.6, 6.2.3.1, 6.2.3.2, 6.3.1.1-6.3.1.3, 6.3.2.1-6.3.2.4, 6.3.4.1.

6.6 For domestic hot water system monitoring the report must include at least the following: 6.2.2.1-6.2.2.5, 6.3.3.1-6.3.3.4, 6.3.4.1.

7. Data Storage

7.1 An archive copy of the data must be made, preferably on magnetic disk or magnetic tape. The format in Appendix X1 is recommended.

8. Keywords

8.1 energy; residential buildings; space conditioning

APPENDIX

(Nonmandatory Information)

X1. FORMAT FOR STORAGE OF DATA

X1.1 It is recommended that an archive copy of the data be produced and stored on magnetic disk or magnetic tape. The archive copy must clearly identify missing data points. The format used for storage is to be either standard Data Interchange Format (DIF),[10] or alphanumeric characters recorded in American Standard Code for Information Interchange (ASCII) with each place of data separated by a comma and each line of data terminated with a carriage return. Data stored in these formats can be read by a wide range of computer systems and computer programs.

X1.2 Non-standard formats, such as compressed data formats, or binary or random access formats, are not recommended for this archive copy. Such formats, while they may be essential to reduce the volume of data for intermediate storage, are often difficult to read with widely-available software.

X1.3 The data stored on magnetic medium is to include a short description of the building and the measurement equipment.

[10] Details of the format may be obtained in *File Formats for Popular PC Software* by Jeff Walden, published by John Wiley & Sons, Inc., 1986. ISBN 0-471-83671-0, pages 53–58.

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