Title

DATA SPECIFICATION PROTOCOL FOR MULTIFAMILY BUILDINGS

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Data Specification Protocol for Multifamily Buildings

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Data Specification Protocol for Multifamily Buildings

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Summary

Introduction: Monitoring Retrofit Performance

The 22 million housing units in multifamily buildings represent a largely untapped area for significant energy savings. Little conservation work has been carried out in this sector, however, due to a combination of technical and institutional barriers. One of the primary technical barriers is the lack of quantitative, that is, *measured,* energy performance of retrofits in multifamily buildings. To address this need, Lawrence Berkeley Laboratory has developed a data specification protocol for multifamily buildings, as part of the Department of Energy's Existing Building Efficiency Research.

Objectives

There are five main objectives in this work:

- Provide a uniform set of monitoring guidelines for evaluating retrofits in multifamily buildings
- Identify the critical data parameters needed to determine the energy performance of retrofits
- Identify additional data parameters for more detailed monitoring
- Promote the exchange of data between researchers conducting similar monitoring projects.
- Improve typical field monitoring practice.

Scope

As this data specification protocol is only one part of retrofit evaluation in multifamily buildings, it is important to differentiate what the protocol does and does not specify.

The Protocol specifies the:

- minimum data parameters required to perform a retrofit performance evaluation

The Protocol *does not* specify the:

- general experimental design
- monitoring equipment and installation
- data analysis technique to be used
- specific format for recording data and reporting results.

Organization

The heart of the data specification protocol is given in the following two tables. The first table specifies the core data set, broken down into the two data parameters, (continuous measurements and one-time measurements) and the three retrofit types (heating, cooling, and domestic hot water). The second table specifies the specific data set, which provides the additional data needed for certain analyses.

Table 1. CORE DATA SET

	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	•	•	
Burner-fuel flowrate or power consumption	•		
DHW system description			
Equipment			•
Nameplate information			•
Thermostat and controls			•
Burner-fuel flowrate			•
or power consumption			•
Occupant survey			
Number of occupants	•	•	•

Table 2. SPECIFIC DATA SET

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

*Note: "Fenestration management" includes all relevant aspects of the opening and closing of windows and doors.

1.0 MONITORING RETROFIT PERFORMANCE

1.1 Introduction

Energy conservation retrofits, if widely implemented, have the potential for significantly reducing national energy use in multifamily housing. While continuing laboratory research and development efforts are useful, there is also a need to understand how well the energy conservation retrofits operate in occupied multifamily buildings.

One barrier to wide-scale implementation of many energy-saving retrofits is the lack of quantitative performance information. Energy professionals need to know the quantitative and qualitative differences in projected performance of various retrofits for their particular location and building type in order to develop specifications and recommendations. Building owners want evidence that a proposed retrofit will achieve the projected savings to be convinced of the cost effectiveness of the retrofit. Policy makers also need more quantitative information on retrofits so that their impact and benefits can be compared when developing incentive or prescriptive programs.

The increased availability of measured performance data would advance our understanding of existing retrofit techniques, and would aid the development of new retrofit techniques. While researchers can pursue theoretical techniques for retrofit selection and optimal component sizing, such methods must eventually be based on, or validated with, measured performance data.

Despite these and other expressed needs for measured performance data, only a few multifamily buildings have been monitored adequately to yield the quality of data required. The performance of individual and combined energy conservation retrofits and their effect on the occupant behavior in multifamily buildings has not been extensively researched in a systematic manner. The results from the limited number of studies that have been conducted indicate that the actual energy savings from installed retrofit measures diverge widely from predicted values for individual buildings.

The retrofit performance studies conducted to date have typically used one of two different monitoring techniques to collect performance data: a collection of detailed information from a small number of buildings or a collection of utility billing data on a larger number of buildings. Although the data collected using these approaches have been useful, they are insufficient to perform generalized retrofit performance analysis.

Results obtained from the detailed monitoring of a small number of buildings are not necessarily representative of how a wide range of occupied multifamily buildings perform under normal operating conditions. Utility billing data have been able, to a limited extent, to evaluate the overall effect of a set of retrofits on energy consumption, but this information is insufficient to understand the performance of the individual retrofits. Variations in microclimatic conditions, occupancy, architectural detailing, and HVAC detailing can cause significant variation in the thermal performance of a retrofit. This sensitivity makes it very difficult to generalize about the performance of a retrofit without examining variations in performance under numerous environmental, behavioral, and structural conditions. Although relatively easy to obtain, billing data can not explain the cause of the energy consumption change, the occupant effects, and the deviations from predicted results.

All these considerations suggest that a large number of retrofit configurations need to be monitored. The data obtained from such programs must be collected in sufficient detail to understand the impacts of retrofit measures in actual occupied buildings. Because of the high cost associated with monitoring many building sites, there is no single program to collect such data. An alternative approach for increasing the data base is to standardize the monitoring that is being conducted so that a common set of data can be compiled from existing research programs.

A preliminary effort[1] was undertaken by the U.S. Department of Energy (DOE) to develop an assessment of several topic areas concerning a DOE-sponsored Retrofit Monitoring Program. This effort produced several recommendations and conclusions:

1: Federal participation in a retrofit monitoring program is justified and would include an active role in overall planning, coordination of various potential user groups, and funding.
2: A variety of users would utilize building retrofit monitoring data and results in there decision making process, including utilities, the building industry, building owners and managers, product manufacturers, universities and laboratories, financial institutes, and trade associations.
3: No study of a national significance has been performed which incorporates all of the needed data to analyze the retrofit performance as previously discussed.
4: A retrofit performance monitoring program should be initiated to provide uniform monitoring methodology and well-documented data. This program should focus on specific building types (such as single-family, multifamily, commercial) and be able to answer questions regarding occupant behavior, quality of retrofit materials and installation, and micro-climate.

As a result of this initial effort, a data specifications protocol for multifamily retrofit performance research was developed under the the Building Services Division of DOE. Such a protocol is consistent with the recommended research items identified in DOE's Multifamily Multiyear Plan.[2] The protocol, if followed by a large variety of research organizations, would serve as a guide in the selection and collection of data required to more fully understand retrofit performance in multifamily housing, allowing for the convenient sharing of the data. The protocol defines the necessary data, both one-time measurements and time-sequential data, that are to be collected for a variety of retrofits in multifamily housing. A companion document which addresses the single-family housing sector has been developed by Oak Ridge National Laboratory.[3]

1.2 Background

A retrofit can be defined as *an alteration of an existing system aimed at the improvement of the performance of its function, but not introducing new uses of the system.* Building retrofits may refer to any of the functions accomplished by the building itself, however, this report is only interested in retrofits that claim to reduce energy consumption and/or improve thermal comfort.

Retrofits can be classified in two general categories:

(1) retrofits that improve the thermal properties of the *building envelope.*

(2) retrofits that improve the performance of space heating or cooling, domestic hot water, lighting, or other *systems* in the building.

Examples of building envelope retrofits are adding wall and attic insulation, weather-stripping, and window improvements. Examples of systems retrofits are furnace/boiler tune-up, temperature control improvements, insulation of the domestic hot water storage tank, and vent dampers. Most buildings that receive any retrofits will have a combination of building envelope and systems retrofits installed at the same time.

Side effects caused by retrofits must also be considered and studied along with the determination of energy savings. Positive side effects may include improved occupant thermal comfort due to reduced radiant surface temperatures or better temperature control. Negative side effects may include water condensation, and subsequent surface stains or long-term structural damage, due to building envelope modifications.

As stated above, a retrofit can produce both energy savings and an improvement in thermal comfort. The effect of the improved thermal comfort on energy savings cannot be defined in a precise manner, as there are many different ways to quantify the indoor climate. The energy savings, which is the main reason for a retrofit, is the variation of energy use due to the retrofit over a specified time interval, such as one heating season.

The retrofit effect can be defined as *the amount of energy saved by a retrofit if all factors are kept constant except for the retrofit itself, which includes occupant behavior changes induced by the retrofit.* The retrofit effect is not the same as the observed energy savings, which is influenced by differences in outdoor climate, indoor climate, occupant behavior changes not due to the retrofit, and changes in occupancy.

Information about occupant reaction to retrofit (and monitoring) activities, and the impact of occupant behavior on building energy use, is very scarce. In addition, the effects of quality of equipment, installation, and maintenance are not well defined. All of these factors can not be fully accounted for in the most sophisticated existing building energy-use models. Yet, experience has shown that these factors are responsible for marked differences between the predicted and measured building energy use. Therefore, accurate estimation of the general impact of multifamily housing retrofits requires the information and insights that can only be gathered from monitoring occupied buildings.

The retrofit effect can be determined by comparing the energy use of retrofited and non-retrofited buildings. Four common experimental designs are discussed in Section 3.0 of this report. Because the comparison is complicated by fact that the energy use is a function of the building thermal features as well as uncontrollable factors (e.g., outdoor climate and occupant behavior), the researchers should consider that:

(1) It will always be difficult to separate the retrofit effect from effects due to other variations.
(2) Field monitoring is expensive and time consuming: consequently superficial or hasty planning could result in a waste of time and money.
(3) The building envelope, the heating system, and the occupants represent a complex and heterogeneous system which will react with different timing and intensity to retrofit changes.
(4) Performing more than one retrofit at a time will introduce additional uncertainties in the evaluation of their individual effects.

1.3 Previous Monitoring Methods

During 1979-1982, the Solar Energy Research Institute (SERI) established a program to evaluate the thermal performance of passive solar buildings at three levels of detail and expense,[4] commonly designated as Class A, B, and C monitoring. Class A refers to a very detailed examination of the thermal processes that make a building function. This type of research-level monitoring is conducted on unoccupied buildings to determine not only energy use, but also to answer questions about why and how individual components of a system operate. The purpose of Class A monitoring is to collect data of high enough quality and sufficient quantity to be used for computer model validation. This level of monitoring is very expensive and therefore limited to a small number of sites.

Although there is a need for some Class A monitoring during development of new retrofit techniques, it is too expensive and provides more detailed information than is necessary for a large-scale monitoring program. Because of the limited number of sites, Class A monitoring does not provide sufficient data about occupant, climactic, or building variations effects.

Large scale building energy use studies have traditionally been conducted using Class C monitoring, which is the collection of utility billing and energy audit information. Although this is the least expensive monitoring technique, it has several limitations. Utility billing occurs at irregular time intervals, which can make it difficult to compare buildings. It is increasingly common for utilities to estimate billing data, which further reduces the accuracy of the data. The number of data points collected during one season is not sufficient for many analysis techniques. In addition, the total utility bill may not provide sufficient detail about the component of the utility bill of interest. A summary of metered energy use studies in the United States is given by Vine.[5]

Class B refers to a middle level of detail and expense. Its principle goal is to provide complete, consistent, and accurate thermal performance and occupancy data for a large sample of retrofits in a variety of buildings and climates. This includes collection of detailed data regarding outdoor climate, indoor climate, and purchased energy. SERI established a large Class B monitoring program for evaluating passive solar residential buildings.[6-10]

These protocols were generally written to obtain data sufficient to analyze the performance of active and passive solar systems or sub-systems in single-family houses. Additional data was also specified to estimate the energy consumption of a similar, non-solar system, in order that energy savings estimates could be made. Since these protocols were written for single-family housing, around a specific data acquisition system and analysis techniques, they are not directly applicable to the general study of retrofit performance. However, they did serve as a guide and background material for the development of this protocol. The multifamily housing retrofit monitoring protocol presented in this report is directed toward Class B monitoring projects.

1.4 Protocol Objectives and User Benefits

A uniform set of monitoring guidelines directed toward retrofit performance analysis needs to address and attempt to standardize a number of issues. These issues, which are shown schematically in Fig. 1.1, include:

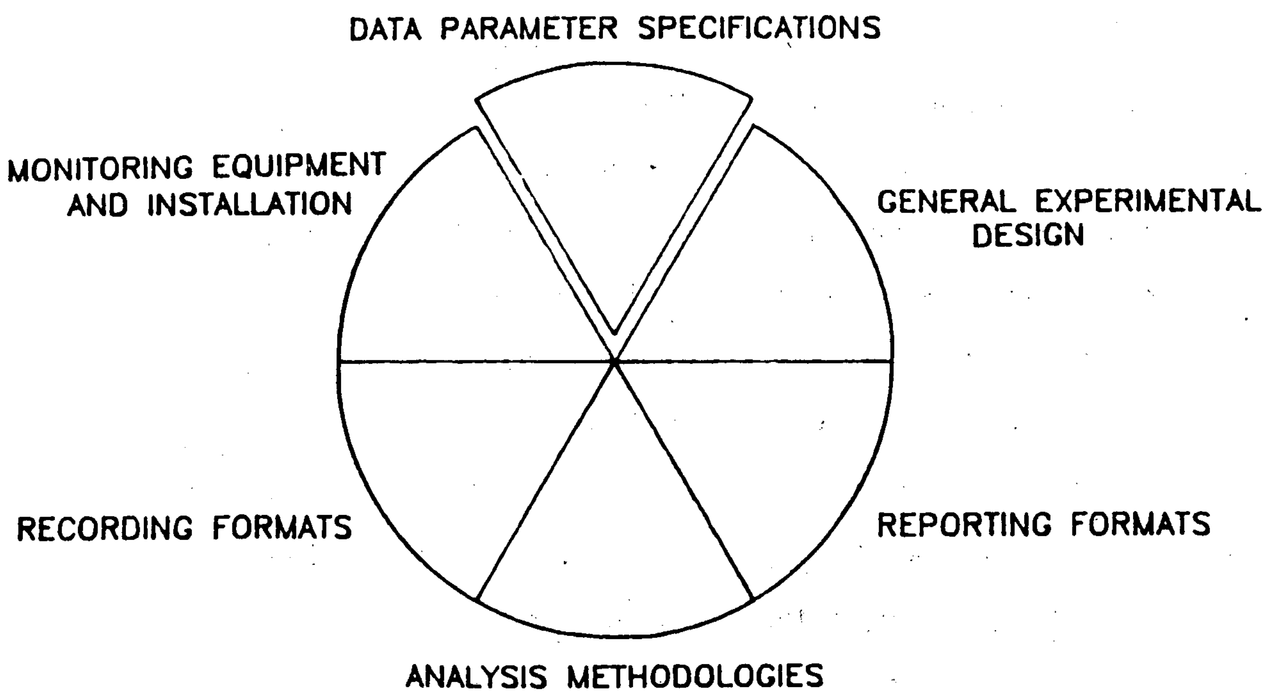

Figure 1.1 A uniform set of guidelines requires the development of a number of individual protocols.

(1) Guidelines on how to organize, plan, and execute a field monitoring research project to ensure its successful completion.

(2) Standardization of the minimum data parameters which should be monitored in all research projects to ensure that sufficient information is collected, with additional guidelines on the selection of additional data parameters to enhance the minimum parameters.

(3) Specification of measurement devices which can be used to monitor the identified data parameters, including a discussion of the selection criteria, mounting specifications and restrictions, accuracy, and acceptable installation practices.

(4) Recording formats for mass storage and data exchange of the collected data.

(5) Standardization of the methodologies to analyze the collected field data.

(6) Reporting formats to present the data and analysis results.

This report presents a data specification protocol (item 2 above) and was written with the expectation that other protocols addressing the remaining issues would be written to complement it.

The objective of this Data Specification Protocol is to establish a standardized experimental research plan (e.g., a set of procedures and specifications) usable by a wide variety of users, identifying the critical data parameters needed to determine the energy performance of multifamily housing energy conservation retrofits. The protocol specifies the data points to be monitored, the frequency at which they should be measured and recorded, and the locations of the sensors.

This protocol will provide a guide for users in the selection of appropriate data parameters to analyze retrofit performance. There are numerous examples of field monitoring projects that failed to collect sufficient information to accurately evaluate the results. The protocol should help this problem by establishing a minimum set of information that should be collected during a field monitoring project, assuring that retrofit researchers collect sufficient information to accurately evaluate a retrofit. Additional optional information which can be collected to perform more detailed analysis is also specified.

In anticipation of a large number of retrofit research programs being conducted simultaneously by a variety of different user groups, a second objective of this protocol is to coordinate the data parameters collected in these programs. Because the information is to be collected in an established format, researchers performing similar monitoring projects will be able to use other data sets with the knowledge that the information collected is complete. This exchange of data will allow all involved researchers to increase their data base, thus providing more accurate results.

1.5 References

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2.0 DATA SPECIFICATION PROTOCOL

2.1 Overview

The data specification protocol is an experimental plan (a set of procedures and specifications) which identifies the critical data parameters needed to evaluate the performance of multifamily housing retrofit measures. The capabilities of existing data acquisition hardware and data analysis techniques were considered in development of the protocol to assure realistic data requirements. By considering a variety of typical analysis techniques it was found that a common set of data applicable to most major retrofits could be tabulated. It is important to note that the data parameters identified in this data specification protocol do not limit the user to one specific data analysis technique. Any one of the existing data analysis techniques can be used to analyze the raw data collected as a result of this protocol.

The selected data parameters have been categorized into a core data set and a specific data set. The core data set represents the minimum data which should be collected in all experiments if the protocol is to be followed. These data have been determined to be essential to assure that a minimum level of analysis can be performed and that the core research questions can be answered. This minimum level of analysis is sufficient to normalize the energy use for factors such as outdoor climate, indoor climate, and internal loads. The minimum data set also represents a significant data set which is easily implemented.

The specific data set represents expanded information allowing for more detailed analysis. These specific data parameters allow the performance of the retrofit to be more fully explored, either on an individual building basis, or after the data has been assembled into a larger data base. These data parameters may require the use of more complicated or costly data collection equipment, or additional expertise on the part of the researcher. The specific data parameters can be monitored at the discretion of the user, depending on the specific retrofit and research goals of the project.

The data specification protocol supports two levels of data recording frequency. The first (lower cost) version specifies weekly data collection for recording parameter averages or totals. In addition to specifying weekly sub-metered energy use, the first version can include weekly average temperatures (indoor and outdoor) and average wind speeds.

The second (higher cost) version specifies hourly data collection for recording parameter averages or totals. The hourly data collection allows for a more detailed data analysis, and also permits study of such things as controls, transient effects, occupant behavior, which may not be apparent in the weekly data set.

These two versions were developed in consideration of the cost and capabilities of existing data acquisition hardware and the different levels of analysis of interest. Weekly data can be collected by relatively simple averaging or totaling sensors and the weekly values manually recorded. Hourly data recording typically requires more sophisticated and costly data acquisition equipment. More detailed and complete analysis can be performed using hourly data than weekly data. Nevertheless, important research questions can be addressed by using weekly data and appropriate analysis techniques.

Figure 2.1 shows a schematic diagram of how the data specification protocol is to be used. Selection of the appropriate weekly or hourly core data is the first step. Because of the differences in data collection requirements for heating, cooling, and domestic hot water retrofits, there is a different core data set for each type of retrofit. The data parameters specified in this core data set must always be collected. Additional data parameters identified in the specific data set can then be added to complement the core data set. Many data parameters in addition to those listed in the data specification protocol can be monitored for any specific project. It is not the intent of the this protocol to exclude any additional data parameters. Rather, the protocol is a guide to identifying the most important parameters which should be measured first, before additional or alternative parameters are considered.

As an example, an experiment following the data specification protocol may use the weekly heating retrofit core data set, specific hourly thermostat set point information for occupant behavior analysis, and attic air temperature, which is in addition to the data specification protocol.

The core data set required by the protocol is presented in Table 2.1. Because of the varied data requirements between the three major types of retrofits, heating, cooling, and domestic hot water, the data parameters required are dependent on the type of retrofit. This allows for customization of the protocol to the retrofit type, preventing unnecessary data collection. The specific data set is presented in Table 2.2.

Both the core and specific data sets are composed of one-time measurements and continuous measurements. The one-time measurements represent information which is collected once, before, during, or after the experiment through discussions with the building owner, building occupants, or visual inspections. In addition, there are some one-time measurements which require appropriate instrumentation, such as heating system efficiency measurements.

Continuous measurements represent data parameters which are monitored as a function of time. All continuous measurements in the protocol are defined to be time-integrated parameters. The appropriate averages or totals over the selected recording interval (i.e., one week or one hour) are recorded. The weekly recording interval may allow the use of mechanical or electronic integrating sensors and manual data recording.

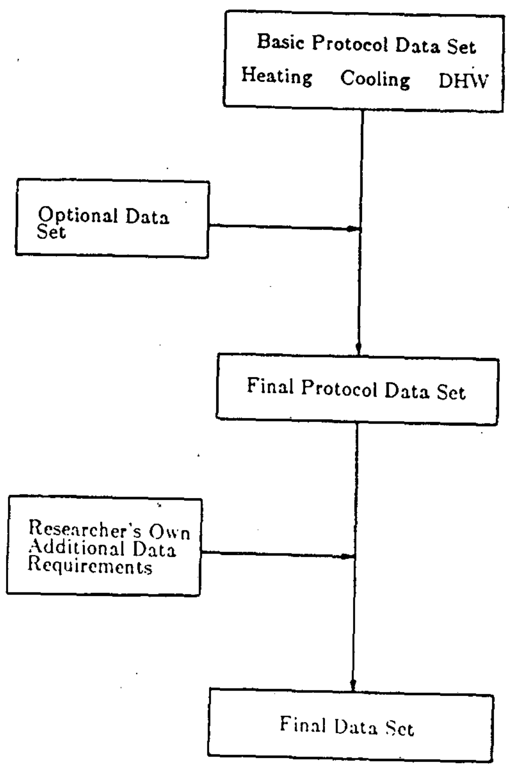

Figure 2.1 A simplified flow diagram indicating the data specification protocol impementaton.

Table 1. CORE DATA SET

	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	•	•	
Burner-fuel flowrate or power consumption	•		
DHW system description			
Equipment			•
Nameplate information			•
Thermostat and controls			•
Burner-fuel flowrate			•
or power consumption			•
Occupant survey			
Number of occupants	•	•	•

Table 2. SPECIFIC DATA SET

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

*Note: "Fenestration management" includes all relevant aspects of the opening and closing of windows and doors.

2.2 Continuous Measurements

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 seasonal periods.

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.

2.2.1 Space Conditioning

The core time-series data set for space conditioning consists of four parameters: 1) the energy consumed for heating by the primary heating source, 2) the energy consumed for cooling by the primary cooling source, 3) the energy consumed for non-space-conditioning purposes (e.g., lighting, appliances, DHW), and 4) the indoor temperature. Auxiliary space-conditioning energy use must also be measured. Indicate whether the air temperature sensor is shielded or unshielded, i.e., 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.

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

2.2.2 Domestic Hot Water System

The core time-series data set consists of four parameters for the DHW system: 1) energy consumption, 2) hot water consumption, 3) cold water temperature, and 4) hot water temperature.

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

2.2.3 Weather Data

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.

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.

2.3 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: 1) the building envelope, 2) the heating, ventilation and air-conditioning (HVAC) system, 3) the domestic hot water (DHW) system, and 4) the building occupants. Collect data by visual inspection, by surveys of building owners and occupants, and by direct measurement.

2.3.1 Building Envelope Description

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 (see ASHRAE *Handbook of Fundamentals* chapter 22 table 16, 1985). Record the age and geographic location of the building using street, city state and ZIP code. List exterior energy uses, e.g., exterior or parking lighting, block heaters.

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. Record the number and layout of apartments and the number and type of windows.

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

2.3.2 HVAC System Description

Describe the HVAC system in the building, giving the fuel type, number and type of equipment, its location, distribution system (location--conditioned vs unconditioned space--insulation characteristics, percent insulated), thermostat controls, and the overall condition of the system. Photograph the main components of the HVAC system.

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 fuel heating value from previous fuel bills for the site or from the utility company. Calculate a yearly average if possible. Record the source of the air to all combustion devices.

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, ceiling or other fans, etc. Determine the use of auxiliary heating and cooling in the occupant surveys.

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

2.3.3 Domestic Hot Water (DHW) System Description

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 (e.g., 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.

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.

2.3.4 Occupant Surveys

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.

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 socio-demographic 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.

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3.0 ADDITIONAL GUIDELINES

3.1 Experimental Design

The data specification protocol presented can not be used effectively until the entire research project is properly organized and directed within the context of a general experimental design. General methodologies to be followed to formulate a successful experimental program have been developed.[1-3] These methodologies recommend an orderly process by which:

(1) the research questions needing to be answered by the experimental program are identified,
(2) the analysis techniques and data parameters required to answer the identified questions are developed or identified,
(3) the budget and manpower limitations are identified to guide the development process.

Additional discussion of analysis techniques, methods of measuring certain data parameters, and/or instrumentation hardware is included in other cited references.[4-6] These references were useful in providing guidance during development of the data specification protocol. More importantly, these reports are useful to individuals and organizations who are just becoming involved in field monitoring studies. The lessons learned by other researchers, as presented in these references, can be very helpful.

Four general experimental designs are commonly employed to conduct field monitoring studies of retrofit performance. The data parameters identified in Section 2.0 are applicable to each. These four experimental designs are 1) on-off, 2) before-after, 3) test-reference and, 4) simulated occupancy. A summary of the advantages and disadvantages are presented in Table 3.1.[7] The experimental design selected for a specific project is dependent on the monitoring/retrofit schedule, number and types of buildings for which there is access, and funding level. Choosing the correct experimental design can simplify the analysis required to evaluate the test results. Often the experimental design can eliminate the need to directly monitor energy flows that are either difficult to measure, or are influenced by uncontrollable variables such as outdoor climate or occupant behavior.

3.1.1 On-Off Experiment

The on-off experimental design can be used whenever the retrofit consists of a system, or a component, that can be turned on and off. When the retrofit is turned off the building operates as if the retrofit did not exist. Examples of applicable retrofits are vent-dampers, outdoor reset, and front-end boilers. The on-off experiment allows the building being retrofitted to be its own reference with regard to the effects of environment of the building and the outdoor climate.

The length of the on-and-off periods can be chosen to satisfy the requirements of the experiment in question, although each period must be greater than the characteristic time constants of the building and systems of the building, and shorter than the time required for a change in the average values of the environmental parameters. For example, the thermal-capacity time constant of uninsulated light construction may be less than one day, whereas the same time constant for insulated heavy construction may be on the order of one week. If the building studied has a one-day time constant, the length of the on-and-off periods should be at least a few days. Even if the period is on the order of one week, it would be possible to go through several on-off cycles of testing during one heating season. In many cases this will reduce the length and cost of the monitoring compared to the before-after test method.

Table 3.1. Advantages and disadvantages of four experimental designs.

Design	Advantages	Disadvantages
On-off	No reference building required	Requires reversible retrofit
	Can be performed multiply in one season	Time constants of building must be considered when length of on-off periods are chosen
	The environment is the same	Outdoor climate during on and off periods may not be the same
	The same model with the same parameter values can be used for most components in on and off states	Requires a model to correct for differences in the outdoor climate
	Long term changes of occupancy less important than in other designs	Short term reactions of occupants may occur when switching from one state to another with unknown effects on consumption
		Dynamic model often required
Before-after	No reference building required	Often more than one heating season required for measurements
	Often less variation in behavior of occupants than in other designs	Running-in and learning period often required to counteract initial change of behavior
	The outdoor environment is the same before and after	The outdoor climate is not the same before and after
	The same model with the same parameter values can be use for most components before and after the retrofit	Requires a model to correct for differences in the outdoor climate
		The measurement equipment may have to be removed during the retrofitting

Table 3.1. Advantages and disadvantages of four experimental designs (cont.).

Design	Advantages	Disadvantages
Test-reference	One heating season suffices for the measurements	Reference building required
	No difference in environment and outdoor climate if test and reference buildings are close	Difficult to verify that occupancy behavior is the same in test and reference buildings
	Difference in energy consumption directly associated with retrofit affect if buildings identical	Difficult to ascertain that test and reference buildings technically identical in all respects
	The same model can be used for most building components	Values of the parameters can be different even if model is the same
		Requires calibration phase if previous difference in energy consumption
		Behavior of occupants in reference building may change if known that they are taking part in an experiment
Simulated Occupancy	Easy to study various occupant behavior effects or to perform parametric studies of its influence on energy use	Loss of information on behavior of real occupants
	Easy monitoring of the occupancy	Expensive and difficult to construct schemes for the simulated occupancy
	One building of a kind often suffices for the experiment	Extra cost for purchase or rent of the building
	Retrofit effect separable from weather and occupancy effects	If only one building of a kind is used variation of outdoor climate may be limited
	Easy to study effects of *standard occupancy schedules*	No information on variation in energy consumption due to varying habits of occupants

If the indoor environment is not significantly different during the on-and-off periods, the occupant behavior should be identical during both periods, resulting in minimal occupant effects on energy use. In cases where the occupant behavior is significantly different during the on-and-off periods (e.g., if the indoor temperature changes enough to affect the number of window openings) the occupant effects must by considered to be part of the natural interaction between occupant, building, and environment.

3.1.2 Before-After Experiment

The before-after experimental design should be used whenever the retrofit consists of a permanent change to the building, or when a system can not be turned on and off without affecting other systems. Examples of applicable retrofits are addition of building insulation, weatherization, or the replacement of the heating or cooling system.

The use of the before-after experiment offers advantages regarding the environment of the building and the exposure to outdoor climate, with the building being its own reference. However, there are no assurances that the average climatic conditions will be the same during the before and after periods, even if the experimental period is very long. The before-after experiments involves comparison of the building energy balance during two periods during which external climatic conditions are different. Therefore, the use of a building model to correct for climatic differences is required to reach any conclusions.

If monitoring data is available for short time periods, it may be possible to directly compare energy use during short time intervals from the before and after periods that experience similar climatic conditions. It is necessary that the number of external parameters influencing the energy use be small, or that the number of such periods be large.

Occupant effects may be of significant importance because of the marked time separation between the before and after periods. The introduction of a retrofit may raise unrealistic expectations about future building performance, which will change the behavior and attitudes of the occupants. There may also be a large occupant population change between the before and after periods.

Occupant adaptation to changes in the indoor climate may require a "running-in and learning period", which is a time before starting measurements of the after-period that is used to avoid the influence of temporary changes in occupant behavior not associated with the retrofit, but only with the introduction of the retrofit. A study of occupant habits and their attitudes towards the retrofit and experiment, before, during, and after the measurement period, should therefore be included in the research program. Such a study does not necessarily need to provide a complete survey of occupant behavior and attitude, but may have the more limited purpose of ascertaining that no large occupant changes have taken place.

3.1.3 Test-Reference Experiment

The test-reference experiment design requires access to at least two buildings, one of which is retrofitted (the test building) and the other which is not (the reference building). The energy consumption of the two buildings will be compared to determine the retrofit energy performance. The two buildings must be as similar as possible in all respects except for the retrofit. In practice this will seldom be possible, which may require the comparison of energy use before the retrofit (calibration phase) and after the retrofit (comparison phase).

The test-reference building set should be as identical as possible, which includes the physical properties, construction type, age, orientation, surroundings, exposure to outdoor climate, and occupant number and behavior. Minor differences between the buildings, such as the internal room distribution, can be accepted if a calibration phase is included in the experiment. If the buildings are situated close to each other there should be similar exposure to the outdoor climate, with the remaining climatic differences due to shading or local shielding differences. These micro-climatic differences will be easier to handle than climatic differences if the buildings are widely separated.

The calibration phase serves to determine the difference in energy consumption between the two buildings before the retrofit. If only two buildings are used, their energy use must be known for sufficient number of years to determine the average difference in energy consumption and deviations. Alternately, the use of sufficiently large building samples will achieve this result.

3.1.4 Simulated Occupancy Experiment

The majority of the energy savings associated with most retrofits is due to improvement of the building envelope or system performance. But, as a second effect, the energy use will be influenced by a possible change in the occupant behavior as a consequence of the retrofit.

As previously described, the comparison of energy use in the test-reference or before-after experiments will not produce the retrofit effect directly. In the before-after experiment the measured energy savings must be corrected for weather variations between heating seasons, although a fairly accurate correction is possible even if a relatively small number of meteorological quantities are measured. In the test-reference experiments deviations from direct retrofit effect measurement are due mainly to occupancy and building similarity differences. However, even if two buildings that had similar energy bills for the past few years are selected for a test-reference experiment, occupancy changes can bias the results.

Using simulated occupancy is a method for avoiding the occupancy problems associated with test-reference experiments. The simulated occupants will reduce the measurement *noise* produced by real occupants' energy related activities. Measurement *noise* would also be eliminated if no occupant simulation was conducted, but the results could not be generalized. The simulated occupancy does not eliminate the influence of occupants on energy use, but will allow its control between buildings. The main disadvantage of this method is that it will not provide any information on second order effects that may be introduced by occupant behavior.

Occupant simulation requires that physiological indices be objectively determined and measured, and that the relationship between stimuli and occupant reactions be modeled. This is the weak point of such a procedure, in addition to its technical feasibility and cost problems.

3.2 Monitoring Equipment and Installation

Instrumentation which can be used to obtain field monitored data have been discussed in detail in several references.[8-11] Principles of various measuring techniques are presented in addition to guidelines which should be followed to meet good installation practices. The theory and application of error analysis to instrumentation are also presented. Since the scope of this data specification protocol does not include a detailed discussion of instrumentation, the cited and other similar references should be consulted for instrumentation selection, installation, and operation guidance.

3.3 Data Analysis Techniques

Usually the data collected during a field monitoring project do not directly answer the research questions posed. The data must be analyzed through the use of algorithms or models to obtain an appropriate answer. The algorithms or models, together with the data, can be used for many purposes, such as:

(1) to calculate performance indicators,
(2) to determine the dependence of a performance indicator on imposed system conditions,
(3) and to interpret why the calculated value of the performance indicator was obtained.

The required algorithms or models can be simple or complicated, depending on the chosen performance indicator and the data collected. For example, a simple algorithm could be used if the observed annual energy savings of a heating system was the performance indicator and the heating energy consumption data were collected for a year before and after the installation of a retrofit. The observed annual energy savings would be defined as the difference in the yearly energy consumption before and after the retrofit, including differences in external climate, indoor climate, and changes in occupancy and occupancy behavior. The pre- and post-retrofit energy consumptions would simply have to be totaled, with their difference being the observed savings.

A more complicated model and additional data would be required if the actual retrofit effect was the performance indicator requested. As previously stated, the retrofit effect has been defined as *the annual amount of energy saved by a retrofit if all factors are kept constant except for the retrofit itself, and changes in the behavior of the occupants induced by the retrofit.* Thus, a more complicated model would normalize the observed energy savings for factors which have changed throughout the testing period, such as outdoor climate, indoor climate, and internal loads.

Regardless of the type of model to be employed, general guidelines for the development of an effective model should be followed. All energy flows within the building may not need to be included in the model, depending upon the effects to be studied. Energy flows that are not affected by the retrofit can often be neglected, as can energy flows which are an order of magnitude smaller than the retrofit effect to be monitored.

Of the issue areas which will need to be covered in other protocols, the area of analysis techniques interacts most strongly with the data specification protocol. The analysis serves as the bridge connecting the research questions with the data collected. This data specification protocol was written to be used with a variety of different types and levels of analysis.

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APPENDIX A

DATA ACQUISITION SYSTEM DESIGN CONSIDERATIONS

By taking into account the issues discussed in this report a properly designed data acquisition system (DAS) can be specified. Although data acquisition hardware, software, and installation are not specified in this report, a brief discussion of DAS design considerations is presented. More complete DAS information is available in the literature.[1-4]

A.1 Sensors and Transducers

The purpose of the sensors and transducers is to produce an output that is detectable and corresponds to the physical quantity being measured. The output of the sensors can be visual, mechanical, or electrical. Electrical sensors can have outputs such as changes in voltage, resistance, current, capacitance, or pulse generation.

One general problem is the ability to interface this wide variety of sensors with a scanning system. The relationship between the physical quantity and output of the sensor can be either linear or nonlinear, with simple relationships preferable. It is important to ascertain whether the relationship between the physical quantity measured and the sensor output is dependent on other external environmental factors. The choice of sensor should be based on:

(1) accuracy
(2) reliability
(3) ability to be interfaced with scanning equipment
(4) initial cost
(5) cost of installation

A.2 Signal Conditioning

Self-excited sensors can usually be interfaced directly with the scanning equipment, however most sensors require some signal conditioning. Amplification to bring the level of a sensor output into a more accurate range of the scanning equipment is the most common signal conditioning, and is usually built into the scanning equipment. Two other common types of signal conditioning are conversion of resistance or current changes to voltage changes. Pulses from a pulse initiating sensor can be converted to a voltage, or read directly by some scanning equipment.

Sensor output integration may reduce the total amount of data that needs to be recorded for physical parameters that vary quickly, but for which only long-term averages or totals are needed (e.g., total furnace ON time or average air temperature). Electronic integration produces an output that is proportional to the time integral of the input signal, but can only be used if the sensor has a linear output. Software integration allows the time averaging/totalization of non-linear signals by applying linearization equations first.

A.3 Scanning and Recording Equipment

Switching the output of each sensor to a data converter is usually accomplished with multiplexers. There are three basic types of multiplexers: reed, FET, or CMOS, each having advantages and disadvantages which should be considered. The manner (i.e., random, periodic, or continuous) and speed in which the channels are accessed, the clock accuracy and stability, and power-failure/power-startup features should also be considered.

The data converter transforms a sensor's signal into a form that can be read by a computer or a human operator. For computer-controlled data acquisition equipment the data converter is an analog-to-digital (ADC) converter. The two most popular ADC are the successive approximation, which can be very fast but requires a sample and hold amplifier, and the dual slope integrating, which has inherent noise rejection qualities. The data rate in most building performance monitoring systems is slow enough to permit the use of dual slope integrating ADC with 4 to 8 conversions per second. Besides, the inherent advantages of automatic zero and noise rejection by selection of integration times equal to an integral number of power-line cycles improves the measurement accuracy.

Considerations for ADC selection include precision, resolution, range, drift, input impedance, bias current, bipolar input capability, differential signal capability, normal and common noise rejection, and the number of significant digits.

Once scanned and converted, the sensor values must be recorded on a storage media, such as paper printout, magnetic tape, magnetic disk, erasable programmable read only memory (EPROM), or random access memory (RAM). When large quantities of data are to be recorded, computer-readable media should always be used to prevent unnecessary manual handling of the data. With battery backed up RAM and telephone modem communication between a field DAS and the research office, temporary storage of data in computer operated RAM with periodic data transfer to a central data management site may be the best choice. This reduces the number of mechanical components in the field, which are a major source of equipment problems.

Site DAS equipment can only be expected to operate correctly within the manufacturer's specified environmental conditions. The most stringent environmental constraints often apply to electronic devices, with typical constraints including:

(1) Most devices will only operate properly within a range of temperatures.
(2) Many devices will not operate when directly exposed to moisture or high humidity.
(3) Many mechanical components will experience early failures when exposed to excessive dust or vibration.
(4) The magnetic media used in many data recording devices will lose currently stored data if exposed to sunlight for extended time periods.

To satisfy these environmental constraints, DAS equipment is usually located in a protective enclosure. If the device is located in a mechanical systems room or residence, the enclosure may prevent access by the unauthorized personnel.

A.4 Data Analysis

The on-site DAS equipment should be capable of converting sensor outputs to engineering units and provide on-site display to facilitate installation debugging and system assessment. In addition, the DAS that records the data may be capable of performing some advanced on-site data analysis. But, for most experiments the ability to readily transfer data from several test sites to a central data management station and perform off-site analysis would be recommended.

A.5 Instrument Security

Monitoring of retrofitted multifamily buildings may involve long-term instrumentation, perhaps over two heating seasons. During this time the equipment is subject to vandalism and theft, and physical deterioration, especially in hot humid spaces.

To guard against vandalism and theft the equipment should be located in limited-access rooms, generally the mechanical room of the building. In addition, the equipment should not be attractive (e.g., use of a nondescript wall-mounted data acquisition system is preferable to using a PC-controlled data acquisition system). There will be some equipment, such as weather towers and individual apartment air temperature sensors, which will remain vulnerable. These can be protected by appropriate installation hardware.

Special precautions may need to be taken to assure that the equipment located in areas such as mechanical rooms does not operate outside of the manufacturer's specifications. Protective dust filters and dehumidifiers may be required to condition the space.

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