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GUIDELINES FOR RETROFIT PERFORMANCE MONITORING

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ABSTRACT

A data specification guideline developed for use in the U.S. Department of Energy (DOE) Single-Family Building Energy Retrofit Research Program is applicable to field monitoring studies of cooling retrofits. The guideline was developed to promote the collection of data (more detailed than billing data) that are needed to fully understand retrofit energy performance. The guideline identifies the important data parameters that should be collected to meet this need and defines the data parameters to ensure that consistent and comparable data are collected. The purpose of this paper is (a) to summarize the data parameters identified in the guideline, and (b) to discuss low-cost instrumentation that can be used to monitor the data parameters identified in a minimum data set.

INTRODUCTION

In recent years there has been increased focus on energy conservation retrofits designed to reduce cooling energy consumption in residential buildings. While continuing laboratory research and development efforts are useful, there is now a need to understand how these retrofits operate in occupied residential buildings. Energy professionals, homeowners, and policymakers need quantitative information on retrofits to make decisions, develop recommendations, and improve program planning. In addition, audit tools to assist in selecting retrofits and optimal sizing techniques based on theoretical considerations must eventually be based on or validated with measured performance results.

A data specification guideline developed for use in the Single-Family Building Retrofit Research Program conducted by the U.S. Department of Energy (DOE) Office of Buildings and Community Systems (1) is applicable to field monitoring studies of cooling (as well as heating) retrofits. The guideline promotes the collection of data (more detailed then billing data) that are needed to more fully understand the energy performance of cooling retrofits. Data that can be collected cost effectively are identified in a minimum data set. These data are sufficient to calculate the true retrofit performance effect.

The primary purpose of this paper is to summarize the details of the data specification guideline to identify the need for this level of monitoring and to facilitate the use of the guideline in future field monitoring studies of cooling retrofits. The referenced document should be consulted for more detailed information. A second purpose is to briefly discuss low-cost monitoring instrumentation and techniques that can be used to collect the data identified in the minimum data set.

GUIDELINE OBJECTIVES

The data specification guideline was developed to meet four general objectives:

1. identify the critical data needed to address a broad range of research questions of concern to DOE regarding the energy performance of single-family building conservation retrofits;
2. identify a minimum data set that should be collected in all DOE-sponsored, single-family retrofit research projects;
3. establish a guideline to assist researchers, in general, in the selection of appropriate data to determine retrofit energy performance; and
4. define the selected data sufficiently to ensure consistency, comparability, and quality among the various experiments following the guideline.

NEED FOR A DATA SPECIFICATION GUIDELINE

The need for a data specification guideline arose from the identification and discussion of three basic technical issues regarding conservation retrofit field monitoring projects:

1. A field monitoring project is composed of four elements: planning and designing the experiment, collecting data, analyzing data, and reporting project results. Many of the problems and shortcomings of past retrofit field monitoring projects have been associated with planning and designing the project. Analysis has been restricted in some past experiments because critical data were not collected. The data specification guideline was developed to perform a portion of the planning needed for DOE-sponsored projects. Eight key project planning activities have been identified that should be followed to ensure the successful completion of a field monitoring project and to assist in the allocation of project personnel and funds (2). These planning activities were followed as appropriate in developing the data specification guideline. The data specification guideline was also developed to be useful to private-sector organizations that have research concerns similar to those of DOE in conducting their own research programs. The guideline identifies data to be considered during the planning process that can enhance the study of retrofit performance in single-family homes.
2. Much has been learned regarding single-family building retrofit performance through the analysis of monthly billing data collected on many homes (primarily for heating-energy savings) and through more detailed data collected from separate experiments on fewer homes. The data collected to date have been insufficient (a) to assess the overall

*Research sponsored by the Office of Buildings and Community Systems, U.S. Dept. of Energy, under Contract No.DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

effectiveness of many conservation measures, (b) to explain fully why deviations between monitored and predicted retrofit energy savings occur, (c) to predict more accurately retrofit performance in individual houses, and (d) to allow the selection of retrofit measures in specific houses. The dispersion in the measured savings of individual houses and differences between predicted and measured values observed in these previous studies have been attributed to many factors, such as changes in occupants' behavior, house characteristics, microclimate effects, variance in the quality of retrofit installations, and inadequate predictive methods. However, the effects of these factors have not been thoroughly quantified. Performance data (more detailed than billing data) collected on a variety of retrofits are needed to address retrofit performance issues and to determine how improvements can be made. The data specification guideline was developed to identify the more detailed data required.

3. Data collected by individual research organizations and DOE must be combined to further the study of conservation retrofits. In fact, establishing a common data base of information would increase the benefits of most data-collecting efforts and allow additional interchange of useful analytical results. Because experiments conducted by various research organizations have research goals that differ in some respects, consistent and comparable data cannot be collected without a guidance document. Moreover, data collected from experiments based on a common set of data specifications will allow easier sharing and communication of the data.

DATA SPECIFICATION GUIDELINE OVERVIEW

The data parameters identified in the guideline are presented in Table 1. The selected data parameters are categorized into a basic data parameter set and optional data parameter sets. Two recording intervals were recommended: weekly and hourly. A minimum data set, defined to be the basic data parameter set monitored weekly, consists of the minimum data that should be collected in all experiments that follow the guideline. The optional data parameter sets and the hourly recording interval should be used with the minimum data set or considered at the user's discretion when more detailed analysis is necessary or desired, depending on the research goals of the specific project.

The output obtained through the implementation of the guideline consists of one-time descriptive information and time-sequential performance measurements. The one-time information represents data collected before, during, or after the experiment through discussions with homeowners, visual observations, and some limited one-time measurements. The time-sequential measurements are continuously monitored with instrumentation throughout the experimental period. All time-sequential measurements within the guideline are defined to be time integrated: a total or average value over the recording period is stored at the end of each recording interval rather than an instantaneous value. A summary of the accuracy, measurement frequency, and expected ranges of each time-sequential data parameter is provided in Table 2.

Table 1. Guideline data specifications

	Recording period	
	Option 1	Option 2
Basic data parameter set		
House descriptive information	*a*	*a*
Space conditioning system descriptive information	*a*	*a*
Entrance interview information	*a*	*a*
Exit interview information	*a*	*a*
Pre- and post-retrofit house infiltration rates	*a*	*a*
Metered space conditioning system performance	*a*	*a*
Retrofit installation quality verification	*a*	*a*
Heating and cooling equipment energy consumption	Weekly	Hourly
Weather station climatic information	Weekly	Hourly
Indoor temperature	Weekly	Hourly
Indoor humidity		Hourly
House gas or oil consumption	Weekly	Hourly
House electricity consumption	Weekly	Hourly
Wood heating utilization		Hourly
Domestic hot water energy consumption	Weekly	Hourly
Optional data parameter sets		
Occupant behavior		
Additional indoor temperatures	Weekly	Hourly
Heating thermostat set point		Hourly
Cooling thermostat set point		Hourly
Indoor humidity	Weekly	
Microclimate		
Outdoor temperature	Weekly	Hourly
Solar radiation	Weekly	Hourly
Outdoor humidity	Weekly	Hourly
Wind speed	Weekly	Hourly
Wind direction	Weekly	Hourly
Shading	*a*	*a*
Shielding	*a*	*a*
Distribution system		
Evaluation of ductwork infiltration	*a*	*a*

[a]One-time measurements.

DATA SPECIFICATION GUIDELINE DETAILS

SCOPE

A residential energy conservation retrofit has been defined as "an alteration of an existing system aimed at the reduction of energy consumption, or at the improvement of thermal comfort in residential buildings, or both" (3). Retrofits that improve only the thermal comfort of the residence were not considered within the guideline. The guideline is primarily applicable to retrofits involving physical changes to the thermal envelope or space conditioning equipment. Domestic hot water and some control-type retrofits are not addressed, because the data and analysis required to study their performance were determined to be dissimilar to the data and analyses required to study the other retrofit categories mentioned.

Table 2. Time-sequential data parameter details for the basic and optional data sets

Data parameter	Accuracy[a]	Range	Stored value per recording period	Scan rate[b]	
				Option 1	Option 2
Basic data parameter set					
Heating and cooling equipment energy consumption	3%		Total consumption	15 s	15 s
Indoor temperature	1.0°F (0.6°C)	50–95°F (10–35°C)	Average temperature	1 h	1 min
Indoor humidity	5% RH	10–95% RH	Average humidity		1 min
House gas or oil consumption	3%		Total consumption	15 s	15 s
House electricity consumption	3%		Total consumption	15 s	15 s
Wood heating utilization	1.0°F (0.6°C)	50–800°F (10–450°C)	Average surface temperature or total use time		1 min 1 min
DHW[c] energy consumption	3%		Total consumption	15 s	15 s
Optional data parameter sets					
Occupant behavior					
Additional indoor temperatures	1.0°F (0.6°C)	50–95°F (10–35°C)	Average temperature	1 h	1 min
Heating thermostat set point	1.0°F (0.6°C)	50–95°F (10–35°C)	Average set point		1 min
Cooling thermostat set point	1.0°F (0.6°C)	50–95°F (10–35°C)	Average set point		1 min
Indoor humidity	5% RH	10–95% RH	Average humidity	1 h	
Microclimate					
Outdoor temperature	1.0°F (0.6°C)	−40–120°F (−40–50°C)	Average temperature	1 h	1 min
Solar radiation	10 Btu/h·ft² (30 W/m²)	0–350 Btu/h·ft² (0–1100 W/m²)	Total horizontal radiation	1 min	1 min
Outdoor humidity	5% RH	10–95% RH	Average humidity	1 h	1 min
Wind speed	0.5 mph (0.2 m/s)	0–20 mph (0–10 m/s)	Average speed	1 min	1 min
Wind direction	5°	0–360°	Average direction	1 min	1 min

[a]All accuracies are ± stated values.
[b]Applicable scan rates if nonintegrating instrumentation is employed.
[c]Domestic hot water.

Particular research goals and specific questions pertain to individual experiments. In an experiment with an attic radiant barrier, for example, the research goals may be to determine the energy savings attributed to the barrier as well as the effect of the barrier on the attic temperatures and structural members. The focus of the data specification guideline was to determine the energy savings resulting from retrofits installed in occupied, single-family homes and the impacts on the energy savings attributable to occupant behavior, the microclimate, and the distribution system (as these are critical and common issues in most retrofit research projects). The guideline does not specifically address non-energy savings issues such as changes in attic temperatures following retrofit installation.

The guideline provides some detail on how sensors should be installed to monitor the identified data parameters. Identifying specific hardware, discussing hardware in general, and providing a complete discussion on sensor installation and installation practices were not considered within the scope of the data specification guideline. Several references address these issues to some extent (3,4,5,6). However, a comprehensive guideline for selecting and installing instrumentation, one that is routinely updated and includes lessons learned from previous monitoring efforts, would be most useful to the monitoring community. A regularly held conference, producing a recommended equipment summary, might also be useful. This paper will discuss briefly some low-cost equipment that can be used to monitor the data parameters on a weekly basis as required of the minimum data set.

MINIMUM DATA SET

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" (3). For the purposes of the data specification guideline, the retrofit effect was considered to be the observed energy savings normalized for outdoor temperature, indoor temperature, and internal load. The effect can be determined by different analytical techniques (1,3,7). The retrofit effect represents the energy savings of the retrofit itself with many occupant-induced savings removed; it allows a cross comparison between the energy savings of different houses to be made on a more equivalent basis. Because determining the retrofit effect was considered to be a basic research problem, it should always be possible to find the retrofit effect with the data collected following the guideline.

The minimum data set was defined to be the basic data parameter set collected weekly. This data set was chosen to represent the data considered essential for determining the retrofit effect. To hold down costs (to make the guideline more attractive and usable to a larger group of potential users), only those data that were absolutely essential to determine the retrofit effect and that could be monitored cost effectively were included in this data set.

RECORDING INTERVALS

The data parameters can be collected at one of two recommended recording intervals: weekly (Option 1) or hourly (Option 2). The proper interval choice for an individual experiment should be based on considerations of the cost and capabilities of existing data acquisition hardware and the different levels of analyses required to meet experimental objectives.

A weekly recording interval is the minimum interval recommended in the guideline. A monthly recording interval was considered but not recommended. Monthly submetered data average out the driving force and response variables over such a long period that it is difficult to determine their effect on performance. In addition, because only a few monthly data points can be collected over a heating or cooling season, experiments can suffer from inadequate data. If experiments last several years, too many changes may occur.

A weekly recording interval was determined to be the least frequent interval sufficient to determine the retrofit effect, while also the most frequent interval that can be performed at low cost. Simple and inexpensive devices can be used to monitor the basic data parameters on a weekly basis. These devices will be discussed in the next section. In addition, recording the basic data parameters weekly does not require a data logging device, as manual recording is possible.

Hourly data recording was recommended as an option because of the expanded analysis that can be performed with hourly data. Many research questions of interest can be addressed by weekly data using appropriate analysis techniques. In general, however, more detailed and complete analysis can be performed using hourly data: parameters that change more frequently than weekly can be better understood; driving forces can be separated; occupant behaviors such as thermostat management and indoor temperature regulation can be analyzed; and, to some degree, peak loads and load profiles can be determined. Two disadvantages of using hourly data are the expense for purchasing and installing an automatic data acquisition system and the increased costs associated with collecting, processing, storing, and analyzing the increased amount of data.

A daily data collection interval was considered as an intermediate time step between hourly and weekly intervals but was not recommended. Because daily data probably need to be collected with a data acquisition system, hourly data could be as easily collected and would be of far greater value.

BASIC DATA PARAMETER SET

A significant amount of one-time information is included in the basic data parameter set. Accurate and complete information on the monitored buildings must be available if the collected data are to be used by others or combined into a data base and analyzed collectively. In addition, a large amount of information is needed to ensure that current or future energy-savings prediction methods and energy-use audits can be verified with the collected data. The following one-time information is required:

1. house descriptive information,
2. space conditioning system descriptive information,
3. entrance interview information,
4. exit interview information,
5. house infiltration measurements,
6. metered performance of space conditioning equipment, and
7. verification of retrofit installation quality.

The descriptive and entrance interview information documents the physical characteristics of the house as well as the behavioral and demographic characteristics of the occupants. The exit interview information identifies changes in these characteristics that may have occurred during the testing program. The house infiltration measurements serve as descriptive variables characterizing the house air exchange rate with and without the retrofit installed. The space conditioning equipment is metered to determine actual operating characteristics such as furnace efficiency and compressor electrical consumption. The quality of the retrofit installation is verified to minimize the influence of improper or inadequate retrofit installations. Audit forms, developed to identify the specific descriptive and interview information to collect, are included in ref. 1.

Submetered heating and cooling measurements should be made by monitoring the energy consumption of the major space conditioning system. This monitoring should include the energy consumption of auxiliary equipment such as fans, blowers, pumps, and controls. Excluding these consumptions from the total would lead to inaccuracies or inconsistencies among experiments because one experimenter might include the auxiliaries while another might not. The energy consumption of small, portable, fossil fuel space heaters used to supply supplemental heat is not included in these measurements. This consumption can be metered, but it would not be practical to do so within the scope of the guideline. The energy consumption of portable electric heaters is defined as an internal load to be included as part of the house energy consumption. In a cooling retrofit study, heating system data collected during the winter may be needed to determine the true retrofit effect. For example, radiant barriers and window treatments, while designed primarily to reduce cooling energy, may also affect heating energy.

The weather station climatic information includes dry-bulb temperature, total horizontal solar radiation, humidity, wind speed, and wind direction. The outdoor temperature is important in the study of retrofit performance; it is required to normalize the measured energy consumptions. The weather station measurement of the outdoor temperature is adequate in many situations and is particulary cost effective. The weather station climatic information includes additional data that should be easily obtained at the same time the outdoor temperature measurements are collected, making the data set more complete and useful to the researcher and other potential users. In analyzing energy consumption during the summer, these additional data may be needed to determine normal cooling season retrofit performance. The weather parameters identified in the optional microclimate data set should be considered if the weather station data are inadequate to describe the climate around the house because of distance or geographical considerations. Summer data are especially likely to be inconsistent. Short-term measurements should be made at the house and compared with the weather station values to help make this determination. (The weather station data should be carefully scrutinized, because their quality is not always high.) If a significant number of houses are being monitored in an area, local weather-monitoring equipment may need to be installed in only a subset of these to adequately characterize the climate for all.

The indoor temperature is defined as the temperature next to the thermostat that controls the space-conditioning equipment. If there are multiple thermostats, the indoor temperature is defined as the temperature at the place where a single thermostat would typically be located. This definition was chosen to ensure consistency. In addition, the temperature at the thermostat affects the operation of the space conditioning equipment. Defining the indoor temperature as the temperature in the main living area of the house was considered but rejected because researchers may choose different locations, creating inconsistencies. Monitoring the indoor temperature weekly was recommended only after reasonably affordable instrumentation (to be discussed in the next section) was identified to collect the data. The cost effectiveness of the minimum data set would be defeated if an expensive data logger was required to collect only the indoor temperature measurement (the remaining time-sequential data parameters can be monitored weekly using billing meters and elapsed-time meters with inexpensive, manual data collection).

The indoor humidity was defined to be the value in the location where the indoor temperature measurement is taken. The indoor humidity measurement need only be collected during the summer, when hourly data are collected. The measurement was not included in the minimum data set (even when studying cooling retrofits during the summer) because an accurate but inexpensive instrument to measure weekly indoor humidity could not be identified. The usefulness of an average weekly indoor humidity value in analysis was also uncertain.

The house fuel consumptions are defined as those indicated by the respective billing meters. These fuel consumptions should be monitored weekly or hourly, depending on the recording interval chosen. Monthly billing data should also be collected as backup for the weekly or hourly data.

If wood heating is used more frequently than one-half day every two weeks, the heating season analysis will certainly require more than the minimum data. This criterion can be relaxed to one day per week if hourly data are collected. In the latter case, the wood heating effect should be quantified. An actual measure of the heat input due to wood is desirable and can be made with a surface temperature measurement, but only for a free-standing wood stove not equipped with a forced convection fan (8,9). For all other cases, the amount of time wood heating is employed should be measured by monitoring the chimney or surface temperature or by sensing the emitted radiation.

The hot water system, one of the largest energy users in the house, contributes to the internal load of the house. The internal load contribution may be small, though, compared with that attributable to lights, stoves, etc. Measuring the consumption of the hot water system was recommended so that these larger, more important internal loads could be determined. For example, the electric consumption of a house may be divided among a heat pump, hot water system, and lights and miscellaneous appliances. Although the internal load due to the lights and other appliances may be greater than that for the hot water system, the electricty consumption of the former cannot be easily metered. However, it can be readily estimated by subtracting the hot water and heat pump consumption from the house total.

OPTIONAL DATA PARAMETER SETS

As analysis needs increase, increased data are also required. The optional data were included to provide a significant "shopping list" that would allow the performance of a retrofit to be more fully explored, either from the data on an individual house or from data assembled into a larger data base. These important data should be combined with the basic data to begin to study the effects of occupant behavior and the microclimate, for example, on retrofit performance. This does not imply that data excluded from the guideline are unimportant. Additional data the researcher deems important can and should always be collected.

The following measurements are included in the occupant behavior data parameter set: additional indoor temperatures, the thermostat setpoints, and the indoor humidity. A temperature measurement for each floor of a house is a highly recommended option, and individual room temperatures may also be monitored. These temperatures can be monitored either weekly or hourly. The setpoints are measured by monitoring the position of the setpoint dial and calibrating this position to correspond to the indicated setpoint temperature. A weekly setpoint measurement is not recommended because its usefulness is expected to be limited. The indoor humidity measurement in the basic data parameter set is only collected hourly because of instrumentation costs. However, a weekly indoor humidity measurement is included as an option in this data set.

Two one-time and five time-sequential measurements are identified under the microclimate data parameter set. The one-time information includes estimating the proportion of unshaded sunlight that strikes the exterior surfaces of the house for both the heating and cooling seasons and determining the appropriate shielding category for the site. Solar viewing devices are commercially available for estimating the proportion of unshaded sunlight striking a south-facing wall. Values for the east, west, and north walls must be based on judgment, because commercial solar viewing devices are not available. The shielding category describes the surrounding site terrain, which can affect the wind velocities at the house. The categories from which to choose correspond to local shielding Classes I, II, III, IV, and V, defined by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (10). This information enhances the solar radiation and wind speed measurements collected under the basic or microclimate data sets by quantifying, to some degree, the effect of the house surroundings on the measurement. The five time-sequential measurements are weather data quantifying the actual on-site outdoor dry-bulb temperature, incident horizontal solar radiation, outdoor humidity, wind speed, and wind direction.

The distribution system data parameter set identifies measurements to describe the tightness of the ductwork and duct connections. The effective leakage area at 0.016 in. H_2O (4 Pa) and the leakage rate at 0.20 in. H_2O (50 Pa), determined by a fan-pressurization test (10,11) should be reported for the following test conditions: (a) the duct outlets and inlets unsealed and the distribution fan off, (b) the duct outlets and inlets sealed and the distribution fan off, and (c) the duct outlets and inlets unsealed and the distribution fan on.

INSTRUMENTATION CONSIDERATIONS

The cost and availability of instrumentation were carefully considered before data were recommended in the guideline. The minimum data set was developed with the assumption that low-cost instrumentation and monitoring techniques were available to collect the identified data parameters. A brief discussion of low-cost instrumentation considered in the development of the minimum data set is provided in this section.

In the previous discussion of the scope of the guideline, references were identified that contain descriptions of appropriate instrumentation used by past researchers that can be used to monitor the identified data parameters. In developing the guideline, new equipment was also identified.

EQUIPMENT SELECTION CRITERIA

Four important selection criteria should be addressed in choosing appropriate instrumentation for field monitoring studies: cost, reliability, accuracy and precision, and installation considerations.

Cost is important if projects are to be performed successfully and within the budget. Unnecessarily expensive equipment can consume a large portion of the funds of a project, limiting the money available to monitor additional data parameters and sites or perform expanded analysis.

Equipment malfunctions have led to the loss of needed data in past experiments. Equipment reliability is very important; accuracy and precision should be sacrificed if necessary in favor of reliability. State-of-the-art or "new" equipment should be employed in field monitoring tests only after its reliability has been thoroughly verified by experienced practitioners.

An instrument measures the intended parameter in varying degrees of accuracy and precision. Instrument accuracy indicates the deviation of the reading from a known input, while precision indicates the instrument's ability to reproduce a certain reading. To reduce costs, instrument accuracy should be sacrificed for instrument precision, because the accuracy of a precise instrument can be subsequently improved through calibration.

Ease of installation needs to be considered before purchasing an instrument. A low-cost instrument is not cost effective if its design requires a costly installation. The instrument must also be capable of operating reliably in the environment in which it will likely be installed. Consideration must be given to ways in which a curious homeowner may interfere with the operation of the instrument.

MULTI-CHANNEL DATA LOGGING EQUIPMENT

Collecting large amounts of data in a single house likely requires using relatively expensive multi-channel data logging equipment to take measurements and record data. Such data logging equipment would be necessary, for instance, if the basic data parameters were monitored hourly or if microclimate data had to be collected instead of using weather station data.

Data logging equipment capable of monitoring 12 or more channels and utilizing a variety of different sensors is often required and typically used. Two such data loggers have been used successfully at the Oak Ridge National Laboratory (ORNL) in field monitoring projects. The hardware cost of these systems ranges from $1500 to $2500, putting them on the "high end" of low-cost instrumentation. Considering the cost of sensors and the time required to install the instrumentation (approximately one-half to one day per site), the cost of instrumenting a single site can be significant. Data loggers designed for long-term, battery-powered operation offer a real advantage in field monitoring studies for several reasons: (a) the location of the equipment is not limited due to power supply considerations, (b) occupants cannot accidentally disrupt power to the device, and (c) problems associated with noise and power surges transmitted through the power line are avoided. Data loggers in this price category can typically store measured data in internal memory or external devices (such as cassette tapes) and are capable of transferring data over telephone lines with modems. The latter feature allows data to be collected remotely at frequent intervals to check on the operation of the experiment. The devices can ususally perform computations using the collected data, allowing the data to be processed into a more usable format on site.

Less expensive data logging equipment, currently available, sacrifices features such as a larger number of channels, sensor compatibility, or programming versatility for reduced cost. This equipment may be suitable for some applications, making collecting detailed data an economically attractive alternative. The cost of this equipment can still be significant, however, ranging from $500 to $1800. Equipment of this type has not been used by ORNL in field tests. A partial listing of data loggers in this price range can be obtained from the author.

TEMPERATURE RECORDING DEVICES

Weekly monitoring of the indoor temperature was included in the minimum data set only after inexpensive instrumentation capable of making this measurement was identified. The data loggers previously described were considered too costly to collect this single measurement, especially if a large number of homes were to be monitored.

Devices including one or two temperature sensors and a recorder in a single package, costing between $200 and $500, were identified during the development of the guideline. A list of the identified devices can be obtained from the author. However, these devices have not been thoroughly tested by ORNL either in the laboratory or in the field. The devices store either average or instantaneous temperature measurements at a preselected time interval (say hourly) or maintain a continuous average temperature since the last instrument reset. In the units that store interval temperature data, hourly data can be stored for approximately two months. Weekly averages can be obtained once the data are transferred to a personal computer either directly, using manufacturer-supplied software, or by using an intermediate storage device. Devices that maintain continuous average temperatures must be inspected and reset weekly to obtain weekly data. The devices are designed so that a person cannot accidentally interfere with the data collection process.

ENERGY CONSUMPTION MEASUREMENTS

Submetered gas consumption can be measured cost effectively by monitoring the on–off state of the equipment under study if the consumption rate is known and is steady when operating and when off. The gas consumption rate of typical gas furnaces and hot water heaters can usually be assumed to be steady and can be measured using the house gas meter. Elapsed-time meters costing approximately $30 and requiring about an hour to install can then be used to measure the operating time of an appliance. A more expensive but possibly more accurate metering option is to use house-type gas meters for submetering. These meters cost approximately $60, but installation may cost an additional $100 to $150.

Submetered electricity consumption measurements can be performed cost effectively in a number of ways. For a majority of residential applications, the amount of inductive or capacitive load is small. In these applications, power factor and reactive power would not typically need to be measured to remain relatively accurate. If the device under study uses a constant amount of power when operating and when off, then electricity consumption can be determined by measuring the operating time of the device using inexpensive elapsed-time meters. If the inductive load is large (as in a heat pump or air conditioner), meters such as home kilowatt-hour meters need to be used to take this into account. These meters cost approximately $80 (meter plus base), and installation might cost an additional $100 to $150.

CONCLUSIONS AND RECOMMENDATIONS

A data specification guideline developed for use in DOE-sponsored single-family retrofit research studies is applicable to both cooling and heating retrofits. The guideline specifies that a minimum data set must be collected in all experiments in order for the true retrofit effect to be calculated and collection data to be used by others to meet a variety of research needs. Use of the guideline is encouraged in non-DOE experiments to help ensure that critical data are collected and that data that can enhance the study of retrofit performance are considered during the experimental planning process.

The minimum data set consists of one-time information and time-sequential sub-metered measurements collected weekly. Weekly data are sufficient to meet many analysis needs. In addition, a weekly collection interval allows inexpensive metering and manual data recording to be employed. Elapsed-time meters and billing meters can be used in most instances to monitor the minimum data parameters. Recently developed devices that can measure and record temperature inexpensively were identified during the development of the guideline to collect the indoor temperature data.

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ACKNOWLEDGMENT

This work was supported by the Assistant Secretary of Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Services Division of the U.S. Department Energy, under contract number DE-ACO5-84OR214OO with Martin Marietta Energy Systems, Inc.